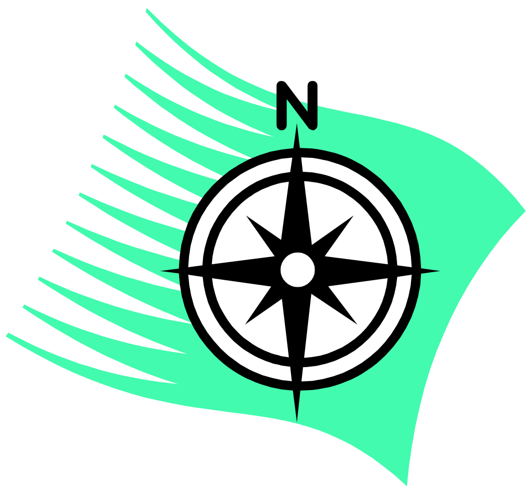
Aviation Emissions Characterization Roadmap

Organizational Plan and Project Reference



December 5, 2008

Table of Contents

1. Executive Summary 1
2. Introduction 1
3. Policy Goals 2
4. Overview of PM and HAP Research 5
5. Description of Programs 8
   - Office of Environment and Energy (AEE) 9
     - First Order Approximation FOA3 and FOA3a 10
     - Hydrocarbon Speciation Profile for Aviation 11
   - Continuous Lower Energy, Emissions, and Noise (CLEEN) Technologies Development 12
   - Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) 13
     - Project 3 – Report to Congress: Aviation and the Environment 14
     - Project 9 – Measurement of Emissions for Research Database and Policy Database 15
     - Project 11 – Health Impacts of Aviation-Related Air Pollutants 16
     - Project 15 – Energy Policy Act Study 17
     - Project 16 – Investigation of Aviation Emissions Air Quality Impacts 18
     - Project 17 – Alternative Fuels 19
     - Project 20 – Emission Characteristics of Alternative Aviation Fuels 20
     - Project 27 – Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels 21
     - Project 28 – Environmental Cost-Benefit Analysis of Alternative Jet Fuels 22
   - Airport Cooperative Research Program (ACRP) 23
     - ACRP 02-03 – Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis 24
     - ACRP 02-03a – Measurement of Gaseous HAP Emissions from Idling Aircraft as a Function of Engine and Ambient Conditions 25
     - ACRP 02-04 – Research Needs Associated with Particulate Emissions at Airports 26
     - ACRP 02-04a – Summarizing and Interpreting Aircraft Gaseous and Particulate Emissions Data 27
     - ACRP 02-08 – Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality 28
   - Aircraft Particle Emissions Experiments (APEX) 29
     - APEX1 – Aircraft Particle Emissions Experiment 1 30
     - Delta Atlanta Hartsfield 31
     - JETS APEX2 32
     - APEX3 33
     - Alternative Aviation Fuels EXperiment (AAFEX) 34
     - APEX4 35
   - Strategic and Environmental Research & Development Program (SERDP) 36

Measurement of Emissions from Military Aircraft 37
Emission Factors for Particulate Matter, Nitrogen Oxides, and Air Toxic Compounds from Military Aircraft..38
Interim PM Test Method for High Performance Gas Turbine Engines 39
Reduced Particulate Matter Emissions for Military Gas Turbine Engines Using Fuel Additives 40
Kinetic Database for PAH Reactions and Soot Particle Inception During Combustion........................41
Predictive Chemical and Statistical Modeling of PM Formation in Turbulent Combustion with Application to Aircraft Engines 42
Aromatic Radicals-Acetylene PM Chemistry 43
Effects of Soot Structure on Oxidation Kinetics...44
Combustion Science to Reduce PM Emissions for Military Platforms 45
Predicting the Effects of Fuel Composition and Flame Structure on Soot Generation in Turbulent Non-Premixed Flames 46
Quantifying Sulfate, Organics, and Lubricating Oil in Particles Emitted from Military Aircraft Engines 47
Measurement and Modeling of Volatile Particle Emissions form Military Aircraft..............................48
Development and Application of Novel Sampling Methodologies for Study of Volatile Particulate Matter in Military Aircraft Engines 49
Extreme Light Diagnostics for Measuring Total Particulate Emissions 50
E-31 Aircraft Exhaust Emissions Measurement Committee (SAE E-31)...51
Omega 52
Characterizing Near-Surface Aircraft Particulate Emissions...53
ALFA: Aircraft Plume Analysis Facility Secondment...54
Understanding Initial Dispersion of Engine Emissions..55
Aviation Emissions and their Impact on Air Quality 56
European Gas Turbine Particulate Emission (PartEmis) Research Project...57
PartEmis Combustor Campaign 58
Hot End Simulator Campaign 59
Aviation Integrated Modeling (AIM) Project 60
Multi-Scale Air Quality Impacts of Aviation..61
Appendix A – Glossary, Acronyms & Abbreviations A-1
Glossary A-1
Acronyms & Abbreviations... A-2
Appendix B - Primer on Aviation PM and HAP emissions B-1
What is PM? B-1
How is PM formed? B-1
How does PM affect health? B-3
How is PM regulated in the U.S.?...B-3

What are the sources of PM at an airport? B-5
Why are aviation-related PM issues so important to airport operators? B-6
What tools are available for evaluating PM emissions at airports? B-7
What about Hazardous Air Pollutants? B-8
Appendix C – Literature Reference C-1
PM Measurements: On-Wing Gas Turbine Engines C-1
PM Measurements: Ground Service Equipment C-1
Soot Properties: Gas Turbine Engines C-2
Soot Properties: Jet Fuel Combustion in ICE's and other Burners C-2
Modeling Air Quality at Airports and in Their Vicinity C-3
Measurements of PM in the Vicinity of Airports C-4
Non-toxicology HAP references C-5
Toxicology HAP References C-7
Appendix D - AEC Roadmap 6th Meeting – Participants and Meeting Minutes D-1
Participants D-1
Meeting Minutes D-2

AEC Roadmap – Organizational Plan and Project Reference

1. Executive Summary

The Aviation Emissions Characterization (AEC) Roadmap is an interagency collaboration to coordinate research activities and communicate research findings among stakeholders and other parties with an interest in PM and HAP emissions from aviation sources. Recent research into air pollutant health effects has confirmed that small particles, typical of those produced in aircraft engines and other combustion sources, can be inhaled deeply into the lungs and even enter the blood stream, with more significant health impacts than larger particles that are trapped in the nasal passages. Analysis has shown that, perhaps even more significant, some pollutants are further transformed in the atmosphere to produce secondary particles that result in greater exposure of the general population. Also, airport operators are faced with employee and community concerns about emissions from airports yet our understanding of emission levels and pollutant characteristics are incomplete. For these reasons, PM and HAP research is significant and increasing in importance.

This document describes the mission and organization of the AEC Roadmap and identifies current knowledge gaps and considerations that are important to guide future research. It summarizes the programs and projects within the purview of the Roadmap that are underway and planned to resolve these knowledge gaps, and provides supporting reference information. The document is intended to serve as a single source for understanding the status and direction of research into PM and HAP emissions from aviation sources.

2. Introduction

The AEC Roadmap was organized from a restructuring of the former National Particulate Matter Roadmap for Aviation during the 5th Meeting of Primary Contributors. The motivation for the change was the addition of hazardous air pollutants (HAP) to the scope of the Roadmap as well as the decision to include all airport emission sources rather than just aircraft engines. As part of the reorganization, the decision was made to shift from discrete Product Groups to a Coordination Council that will guide the organization. After the 5th Meeting, the following Terms of Reference were adopted by the Coordination Council to describe the organization and work activities of the AEC Roadmap.

Mission Statement

The Aviation Emissions Characterization (AEC) Roadmap is a collaboration of parties interested in aviation emissions characterization research and development and regulatory activities of government, industry, academia, and the public with a particular focus on particulate matter (PM) and hazardous air pollutant (HAP) emissions. The objective is to gain the necessary understanding of emissions' formation, composition, and growth and transport mechanisms for assessing aviation's emissions and understanding their impact on human health and the environment. Ultimately, the Roadmap will also guide aviation technology development and, if warranted, other mitigation activities.

Scope

The AEC Roadmap will investigate emissions from aircraft engines, auxiliary power units (APU), ground support equipment (GSE), and other emissions sources that may be unique to the aviation industry or other sources present at airports that may not be adequately understood.

Governance

The AEC Roadmap will be guided by a Coordination Council, made up of representatives of Federal agencies, industrial organizations, academic institutions, and other private organizations with an interest in PM emissions who collectively have subject-matter expertise in all essential areas (as determined by the Council) and who have sufficient authority in their respective organizations to address relevant budget and policy considerations.

The Coordination Council will be supported by a Secretariat that includes necessary technical and administrative support. FAA will supply the chair of the Secretariat and the funds necessary for its operation.

Work Activities

The AEC Roadmap will hold an annual face-to-face meeting, open to all interested participants, usually in the late spring at a convenient location.

The Coordination Council will hold monthly teleconferences, on the second Thursday of the month. The purpose of the calls is to discuss research findings, direction, need for new goals or projects, strategies to secure funding for essential projects, and any other information necessary to achieve the mission of the AEC Roadmap.

Important notices, meeting minutes, and action items will be communicated by the Secretariat or individual Coordination Council members as appropriate via e-mail and will be posted to the Roadmap KSN site.

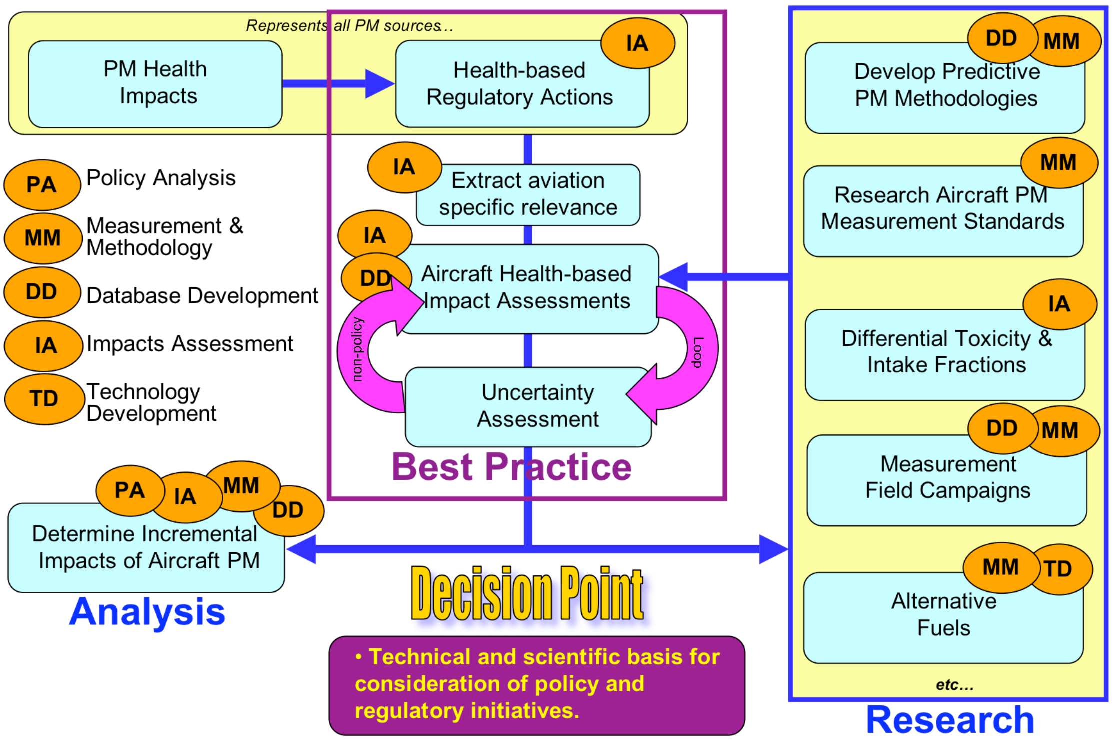
A Roadmap Document will be prepared and updated annually that describes the scope, direction, schedule, and goals of pertinent research and development activity. The document will incorporate other important information related to Roadmap activity or investigations by its participants with a particular focus on evaluating the incremental health impacts attributable to aviation. [This report is the noted Roadmap Document for the current year.]

3. Policy Goals

Information on PM and HAP emissions from aviation sources has been coming from a wide range of research programs over the past several years. As the aviation and environmental communities begin to understand this data, policy issues and considerations are coming into focus. A key role of the AEC Roadmap then is to inform policy makers, ensure policy decisions are based on solid scientific and technical information, and regulatory initiatives are focused and effective.

The figure below illustrates the flow of information that guides activities of the AEC Roadmap. It identifies areas where coordination and linkage are needed. It can be used to identify the need for developing metrics, measurement procedures, and impact analysis methodologies, highlight where databases and forecasts can be used to develop and assess baseline emissions and impacts, and confirm the need for specific information to support policy decisions and assess their impacts.

Roadmap Integration Process



FAA and other federal agencies are working within the structure of ICAO CAEP to consider the need for new regulatory initiatives that address PM and/or HAP emissions from aviation sources and their incremental health impacts. Several topics with significant policy implications that are presently on the horizon include:

- LTO certification standards for volatile and nonvolatile PM emissions
- PM and gaseous emissions interdependencies and secondary effects
- Incremental health impacts
- Removing sulfur from jet fuel
- Cruise emissions that influence climate
- Assessing HAP emissions beyond inventories

These are among the key topics for AEC Roadmap consideration in the coming year.

In addition to these important policy goals, the following research needs and key considerations were identified in the 6th Meeting of Primary Contributors held June 17-18, 2008 at the EPA laboratory in Research Triangle Park, NC:

- Determining incremental health impacts are critical from a policy/regulatory perspective - integration of research efforts is key to facilitate analysis.
- Research is needed to address SAE E-31 issues in response to policy and regulatory needs.
- A sampling system is needed to measure volatile PM emissions at the engine exit.
- Secondary formation of PM emissions has been identified as a predominant influence on health impacts associated with aircraft engine emissions.
- Sulfur oxide and NOx emissions from aircraft engines have been identified as the predominant PM emissions contributor.

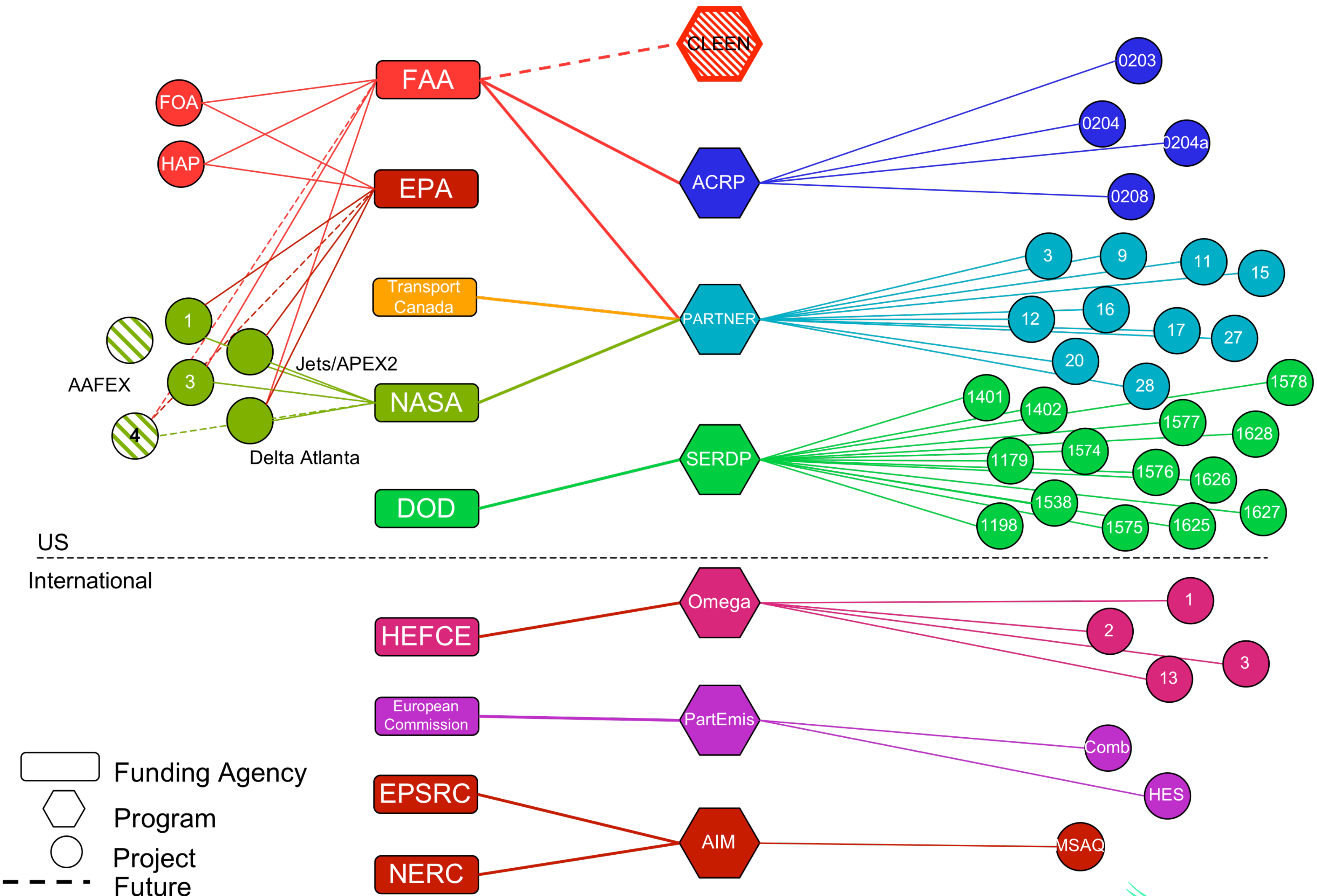
- The impact of climb/cruise emissions (outside of the LTO) on air quality could be significant and warrants more assessment.
- Further research is needed to fully understand evolution and fate of PM emissions from airports sources (e.g. aircraft, GSE and APU).
- Alternative fuels research is gaining sponsorship especially due to rising fuel costs and GHG emissions consequences.
- Pollutant fate and transport modeling has progressed and is a productive area for further research.
- Assess PM emissions at altitude and potential influence on air quality.
- Assess model scale with impact to measure aviation emission impacts from the area around airports to broader regional impacts.
- The development and use of a PM response surface model (RSM) approach is beneficial to analyzing a variety of policy scenarios to estimate apportionment of health impacts. Consider how uncertainties associated with PM RSM might be addressed through further research activities coordinated under the Roadmap.
- Future measurement campaigns should be expanded to cover modeling and exposure aspects that contribute to advancing the impact analyses.
- Additional HAP emissions data is needed to characterize the current commercial aircraft fleet especially with regard to the current estimate of 23% unknown mass and methane.
- Further research is needed to understand HAP emissions due to variations in ambient conditions.
- Future measurement campaigns should address gaps in the gas-phase HAP emissions database to improve the national guidance for assessing HAP emissions inventories.
- SERDP/DOD research projects have many of the same objectives as non-military research projects, thus offering opportunities for filling knowledge gaps. Resources for developing a sampling system leveraging on current and planned SERDP/DOD project efforts should be identified.
- Make use of European PartEmis research program results to advise future measurements and analysis under the Roadmap and as a basis for comparative analysis against results from US projects.
- Engage Roadmap participants in the planned FAA ULS (ultra-low sulfur jet fuel) study as appropriate and brief progress/results at the next annual roadmap meeting.
- Consider combining measurement campaign goals and objectives to maximize resources and leverage for combined effectiveness (e.g. consider use of AAFEX as measurement campaign platform in lieu of APEX4 for the near term).
- Monitor progress of airport monitoring studies, review results as they are made available, and consider how future measurement programs might benefit from lessons learned.
- Consider how future measurement programs and resulting data can be used to improve FOA3 and identify an appropriate version that should serve to suffice as the FOA going forward for use until a database of actual PM emissions exists.
- Extend detailed sampling and analysis to APUs, GSE, and other airport sources.

These should guide current research activity and planned research programs. More complete minutes of the meeting are included in Appendix D.

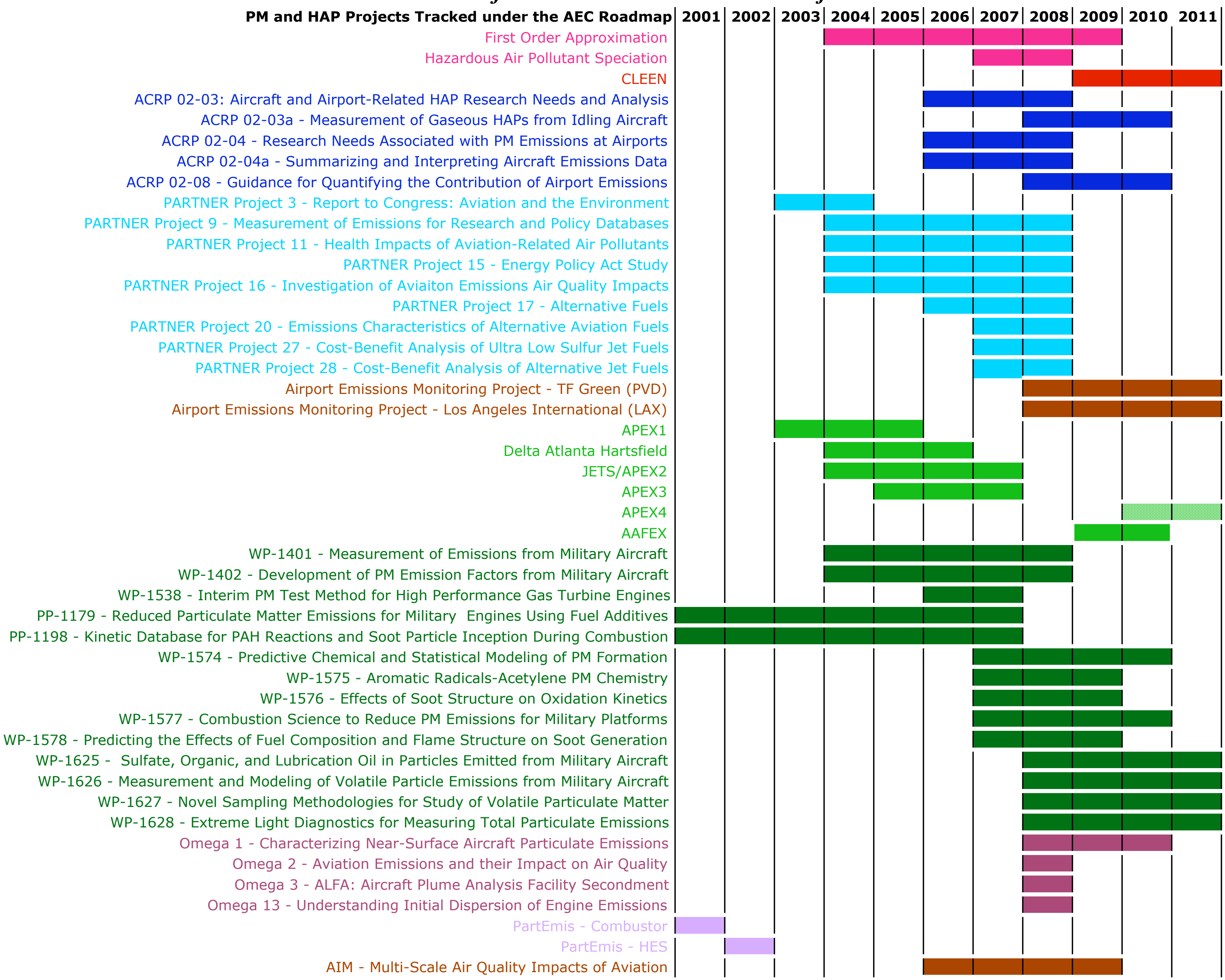
4. Overview of PM and HAP Research

This section provides an overview of resources devoted to PM and HAPs and a timeline for their application. The figure below shows the flow of research funding from the Federal agencies that support scientific research to coordinated research programs and from there to individual projects, including some future programs and projects that are expected, however the funding is not yet authorized. It illustrates the shared funding for many programs, which necessarily requires coordination among the agencies in defining program research goals. Included in the figure are two research programs funded by the international community, which came under the purview of the Roadmap during the past year. Following the figure is a timeline to provide additional context for understanding status and progress of PM and HAP research.

Flow of Funds for PM and HAP Projects



Timeline for Aviation PM and HAP Projects



5. Description of Programs

This section describes research programs that address issues related to PM and HAP emissions from aviation sources. Key projects within the programs are summarized. The following programs or funding agencies are included in this section:

- FAA Office of Environment and Energy
- Continuous Low Energy, Emissions, and Noise (CLEEN) Technologies Development
- Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER)
- Airport Cooperative Research Program (ACRP)
- Aircraft Particle Emissions Experiment (APEX)
- Strategic and Environmental Research & Development Program (SERDP)
- E-31 Aircraft Exhaust Emissions Measurement Committee (SAE E-31)
- Omega
- Measurement and Prediction of Emissions of Aerosols and Gaseous Precursors from Gas Turbine Engines (PartEmis)

Program Title

Office of Environment and Energy (AEE)

Agency Sponsor

Federal Aviation Administration

Description

FAA's Office of Environment and Energy (AEE) develops tools and metrics to effectively characterize, assess, and communicate environmental effects, interrelationships, and economic implications. It facilitates international agreements on standards, recommended practices, and mitigation options; assesses consequences and informs policy; develops and advances operational, technology and policy options to enable a balanced approach to environmental improvements for the NextGen system; and enables development of Environmental Management Systems to dynamically manage Next Gen environmental impacts. AEE funds the AEC Roadmap and supplies its secretariat. In addition to funding a wide range of collaborative, cost-shared programs with other organizations (see PARTNER, ACRP, and CLEEN below as examples), the office also funds individual research activities to support its mission.

The following AEE projects are summarized in this document:

- First Order Approximation FOA3 and FOA3a
- Hydrocarbon Speciation Profile for Aviation

More information (reports, website, project contact):

http://www.faa.gov/airports_airtraffic/environmental_issues/

Project Title			
First Order Approximation FOA3 and FOA3a			
Program	Agency Sponsor	Project ID	
	FAA/AEE		
Start Date	End Date	Status	Funding
2004	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
FAA/AEE, Volpe Center, EPA,			

Description

The First Order Approximation (FOA) was developed to estimate PM for airport planning and regulatory requirements. The FOA is only for estimation of PM emissions from jet turbine aircraft in the vicinity of airports. FOA 1.0 included only the non-volatile fraction of the PM emissions and is based on the ICAO smoke number (SN). Scaling the volatile and non-volatile components was included in FOA 2.0 to make it more complete.

Subsequently a new procedure was needed to improve the fidelity of the approximation and better estimate the volatile fraction, resulting in further methodology development in FOA3. FOA3 uses the ICAO SN to estimate the non-volatile component and the volatile component is estimated by breaking down the total volatile emissions into the most important components: sulfur, organics, and lubrication oil. Nitrates are not considered to be an important contributor based on available information.

FOA3 development is ongoing as it is modified to meet the needs of specific programs. Most recently it was used for the Energy Policy Act aircraft study. Version FOA3a was developed to ensure it is appropriately conservative in its results. Planned developments include coordination with various groups such as SAE for measurement interpretation and continued refinement and additions of independent components as needed to support total PM estimation. A longer term goal for FOA is to quantify lubrication oil contribution to volatile PM.

More information (reports, website, project contact):

CAEP WP, A First Order Approximation (FOA) for Particulate Matter, Prepared by WG2, TG4;

Eyers, C., CAEP/WG3/AEMTG/WP5, Improving the First Order Approximation (FOA) for Characterizing Particulate Matter Emissions from Aircraft Engines, Alternative Emissions Methodology Task Group (AEMTG) Meeting, Rio De Janeiro, Brazil.

Project Title			
Hydrocarbon Speciation Profile for Aviation			
Program	Agency Sponsor	Project ID	
	FAA/AEE, EPA		
Start Date	End Date	Status	Funding
2006	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
FAA/AEE, EPA			
Description			

An improved hydrocarbon speciation profile is needed to assess HAP emissions from aircraft and to convert between alternative measures of hydrocarbon emissions such as unburned hydrocarbons and total organic gases. A new profile has been developed based on a comparison of older profiles and the most recent aircraft engine emissions data from the APEX campaigns (see below). This new hydrocarbon speciation profile, which includes HAPs, will be published in a report and added to SPECIATE-5, EPA's hydrocarbon speciation preference. Data from future research projects will be used to maintain the profile and to resolve the significant remaining uncertainty.

More information (reports, website, project contact):

Program Title

Continuous Lower Energy, Emissions, and Noise (CLEEN) Technologies Development

Agency Sponsor

FAA

Description

The FAA is planning to establish a program to develop continuous lower energy, emissions and noise (CLEEN) technologies for civil subsonic jet airplanes to help achieve the Next Generation Air Transportation System (NextGen) goals to increase airspace system capacity by reducing significant community noise and air quality emissions impacts in absolute terms and limit or reduce aviation greenhouse gas emissions impacts on the global climate. The CLEEN program is focused on reducing current levels of aircraft noise, air quality and greenhouse gas emissions, and energy use, and advancing alternative fuels for aviation use. The focus of this effort is to: (1) mature previously conceived noise, emissions and fuel burn reduction technologies from Technology Readiness Levels (TRLs) of 3-4 to TRLs of 6-7 to enable industry to expedite introduction of these technologies into current and future aircraft and engines, and (2) assess the benefits and advance the development and introduction of alternative "drop in" fuels for aviation, with particular focus on renewable options.

The intentions of the CLEEN Program are (1) development and test validation of airframe and engine technologies that will reduce aircraft noise, NO_x emissions (and limit or reduce other emissions), and fuel burn, and (2) evaluation of the feasibility of use of alternative fuels in aircraft systems, including successful demonstration and quantification of benefits. The CLEEN Program goals are to develop and demonstrate:

1. Certifiable aircraft technology that reduces fuel burn by 33% compared to current technology, reducing energy consumption and greenhouse gas (CO2) emissions;
2. Certifiable engine technology that reduces landing and takeoff cycle (LTO) nitrogen oxide emissions by 60 percent, at a pressure ratio of 30, over the ICAO standard adopted at CAEP 6, with commensurate reductions over the full pressure ratio range, while limiting or reducing other gaseous or particle emissions;
3. Certifiable aircraft technology that reduces noise levels by 32 EPNdB cumulative, relative to Stage 4 standards;
4. The feasibility of use of alternative fuels in aircraft systems, including successful demonstration and quantification of benefits; and
5. Transition strategies that enable "drop in" replacement for petroleum derived turbine engine fuels with no compromise in safety.

More information (reports, website, project contact):

http://www.faa.gov/airports_airtraffic/environmental_issues/

Program Title

Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER)

Agency Sponsor

FAA/NASA/Transport Canada

Description

The Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) is a leading aviation cooperative research organization, and an FAA/NASA/Transport Canada-sponsored Center of Excellence. PARTNER fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. The organization's operational headquarters is at the Massachusetts Institute of Technology.

The following PARTNER projects are summarized in this document:

Project 3 – Report to Congress: Aviation and the Environment

Project 9 – Measurement of Emissions

- Research Database
- Policy Database

Project 11 – Health Impacts of Aviation-Related Air Pollutants

Project 15 – Energy Policy Act Study

Project 16 – Investigation of Aviation Emissions Air Quality Impacts

Project 17 – Alternative Fuels

Project 20 – Emissions Characteristics of Alternative Aviation Fuels

Project 27 – Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels

Project 28 – Environmental Cost-Benefit Analysis of Alternative Jet Fuels

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/

Project Title

Project 3 – Report to Congress: Aviation and the Environment

Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 3**	
Start Date	End Date	Status	Funding
2003	**2004**	**Complete**	**$TBD**

Participating Organizations

MIT, Georgia Tech, University of North Carolina – Chapel Hill

Description

In December 2003, as part of HR 2115 Vision 100-Century of Aviation Reauthorization Act, Congress required the Secretary of Transportation, in consultation with NASA, to study reducing aircraft noise and emissions, and increase fuel efficiency. The study was conducted by PARTNER, the Partnership for AiR Transportation Noise and Emission Reduction.

Presented to Congress in March 2006, the report <http://mit.edu/aeroastro/partner/reports/congrept_aviation_envirn.pdf> recommends that the United States should adopt a national aviation and environmental goal of reducing the significant impacts of aircraft noise and emissions on local communities by the year 2025, notwithstanding anticipated growth in movement of people and goods. The report says that by that date, uncertainties regarding both the contribution of aviation to climate change and the impacts of aviation particulate matter and hazardous air pollutants, will be reduced to levels that enable appropriate action. This action would mitigate restraints on air travel, commerce, and national security. Emphasizing the diversity of the reports' contributors, the report "vision" says that "Through broad inclusion and sustained commitment among all stakeholders, the U.S. aerospace enterprise will be the global leader in researching, developing, and implementing technological, operational and policy initiatives that jointly address mobility and environmental needs."

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project3.html;
http://www.govtrack.us/congress/bill.xpd?bill=h108-2115

Project Title			
Project 9 – Measurement of Emissions for Research Database and Policy Database			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 9**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
MS&T, Boise State University, MIT, University of Central Florida			
Description			

Project 9's objectives are to characterize the emissions (both small particles and condensable gaseous species) from aircraft and airports through measurements, understand and model the microphysical processes associated with particle formation, and determine the health effects of emissions.

The project product will be a research database of PM and HAPS emissions from aircraft plus a policy database of engine PM emission factors. Plume models will also be developed. Data for the databases will come from APEX field campaigns.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project9.html; Delta - Atlanta Hartsfield (UNA-UNA) Study

Project Title			
Project 11 – Health Impacts of Aviation-Related Air Pollutants			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 11**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
Harvard School of Public Health, Harvard University			
Description			

The demand for aviation transport is expected to increase 2-3 times over the next two decades, and that may lead to an increase in some emissions. The FAA recognizes the growing public health concern associated with aviation emissions. In order to quantify the health and human exposure risks with reduced uncertainties, the FAA has initiated this research project through PARTNER. The main science objective of this project is to understand and evaluate the potential incremental health risks due to direct (or primary) and indirect (secondary) aviation emitted air pollutants such as hazardous air pollutants (HAPs or toxics), ozone and particulate matter. Once sufficiently well developed, the research carried out under this project with strong interactions with PARTNER projects 9 and 16, will greatly help airport operators in preparing Environmental Assessment and Environmental Impact Statements in support of National Environmental Policy Act requirements. Additionally, this research project will help to consider potential tradeoffs amongst emissions, and to provide information for comprehensive policy analyses for aviation management pursued under other PARTNER research projects. The product will be spatially resolved, airport-vicinity, emissions exposure data with potency estimates.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project11.html

Project Title			
Project 15 – Energy Policy Act Study			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 15**	
Start Date	End Date	Status	Funding
2006	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
MIT			

Description

The Energy Policy Act of 2005 requires the FAA and EPA to initiate a study to identify:

1. The impact of aircraft emissions on air quality in nonattainment areas;

2. Ways to promote fuel conservation measures for aviation to enhance fuel efficiency and reduce emissions; and

3. Opportunities to reduce air traffic inefficiencies that increase fuel burn and emissions.

The Massachusetts Institute of Technology is assisting the FAA and the EPA in meeting their obligations under the EPACT in each of the above areas. This project requires coordination and partnership with CSSI, Inc. and Metron Aviation, as some of the deliverables are interdependent with deliverables being fulfilled by CSSI and Metron under separate FAA agreements.

The product of the project will be a Report to Congress (EPACT): quantitative estimates of emissions impacts and methods for improved fuel efficiency. The study will be used to identify PARTNER research needs.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project15.html;
http://web.mit.edu/aeroastro/partner/reports/congrept_aviation_envirn.pdf

Project Title			
Project 16 – Investigation of Aviation Emissions Air Quality Impacts			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 16**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
University of North Carolina – Chapel Hill			
Description			

Today, aircraft emissions that impact air quality represent a relatively small contribution to overall regional emissions. With a projected 2-3 times growth in aviation transport sector over the next two decades, some aviation emissions are expected to increase. The National Vision for Aviation and Environment, which forms the basis for the environmental strategy of the Next Generation Air Transportation System, states that the significant environmental and health impacts of air quality caused by aviation emissions will be reduced in absolute terms notwithstanding the anticipated growth in aviation. In order to understand and evaluate the potential role of aviation emissions in air quality, the FAA has initiated this research project through PARTNER. The main science objective of this project is to quantify the potential incremental contribution of aviation emissions to air quality though their interaction with the background air. The research carried out under this project will exchange information with PARTNER projects 9 and 11. The lessons learned under this project will help to develop methodology for air quality analysis to aid airport operators in preparing Environmental Assessment and Environmental Impact Statements in support of National Environmental Policy Act requirements. Additionally, this research project will help to consider potential tradeoffs amongst emissions, and to inform comprehensive policy analyses for aviation management that are being pursued under other PARTNER research projects. The project is expected to lead to an improved understanding of aviation’s impact on air quality.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project16.html

Project Title			
Project 17 – Alternative Fuels			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 17**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
MIT			

Description

Project 17 will explore the potential to reduce aviation environmental impacts via alternative fuels while taking into account the full lifecycle of these fuels. The study will be conducted by MIT researchers from the Department of Aeronautics and Astronautics and the MIT Laboratory for Energy and the Environment, in collaboration with Pratt & Whitney, The Boeing Company, General Electric Aircraft Engines, Airports Council International – North America, and the Aerospace Industries Association.

The project objective is to evaluate the relative environmental impacts of potential alternative aviation fuels. Consideration will be given to kerosene fuels and other hydrocarbon fuels derived from fossil fuels, synthetic liquid fuels manufactured from coal, biomass or natural gas, bio-fuels made from agricultural crops, and hydrogen. The evaluation will include the full chain of use from initial energy harvesting/resource extraction, to production and transportation, to use by the aviation industry, to any end-of-use/disposal issues. Considerations include the full range of health, welfare and ecological impacts including effects related to changes in non-renewable resource use, air quality, community noise, water quality, exposure to hazardous materials, and global climate change.

The product of the project will be a report detailing opportunities and challenges of various alternative fuels for aviation.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project17.html

Project Title			
Project 20 – Emission Characteristics of Alternative Aviation Fuels			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 20**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
Missouri University of Science & Technology (MS&T)			
Description			

In an information paper from the International Civil Aviation Organization's Committee on Aviation Environmental Protection Seventh Meeting in Montreal in February 2007, "The Potential use of Alternate Fuels for Aviation," it is stated that, "Interest in alternative fuels for commercial aviation has grown in tandem with concerns about rising fuel costs, energy supply security and the environmental effects of aviation. At the moment, the largest single driver for industry adoption of alternative fuels is the high cost of petroleum. If oil prices remain high, alternatives will remain attractive. However, energy security and possible environmental benefits are also powerful drivers. And, if oil demand outpaces supplies, jet fuel availability could become a constraint to growth. The United States has determined that it is prudent to explore now the potential move toward alternative fuels."

The objectives of Project 20 are to work with the aviation community to gather accurate data on emissions from candidate alternative fuels and to compare these emission characteristics with those of conventional aviation fuel types being gathered in PARTNER Project 9 – Measurement of Emissions. These data will provide the essential information for PARTNER Project 17 – Alternative Fuels and to the aviation community at large as it charts a course for environmental sustainability in an uncertain energy future. The product of the project will be the creation of a database of particulate matter and hazardous air pollutant emissions from engines burning Jet-A/JP-8, and alternative fuels including biojet and Fischer-Tropsch synthetic fuel.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project20.html

Project Title			
Project 27 – Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 27**	
Start Date	End Date	Status	Funding
2008	**2010**	**Ongoing**	**$TBD**
Participating Organizations			
MIT, Cambridge University, Stanford University, University of Houston, Harvard University			

Description

Since 2006, regulations for highway diesel fuel sold in the United States have specified an ultra low sulfur fuel content standard of 15 parts per million. This value is substantially lower than the previous standard of 500 ppm and is intended to vastly reduce particulate matter pollution from diesel vehicles. However, there currently exists no ultra low sulfur policy for jet fuel, which has an average sulfur content of approximately 600 ppm. Project 27 will perform a detailed environmental cost-benefit assessment of the potential introduction of ultra low sulfur jet fuels in U.S. and worldwide markets.

A proposed simulation will build on previous work with the use of higher-fidelity modeling and broader scenario analyses. Specifically, Project 27 will use advanced simulation methods to assess desulfurization-induced changes in fuel properties and their impacts on the radiative properties of soot and contrails. In addition, Project 27 will include a full life-cycle analysis of ultra low sulfur jet fuel that will account for the increased carbon dioxide production that results from the desulfurization process.

This multi-university project will draw on broad international expertise in air quality and climate modeling. Project 27 will first work with industry to refine the assumptions that support the analysis. Subsequently, research teams will employ different air quality modeling approaches and climate-modeling approaches to assess ultra low sulfur fueled aircraft emissions across all phases of flight. The resulting refined environmental cost-benefit analysis will offer substantial improvements over currently available data.

The project will produce improved tools for assessing and modeling the true environmental and operational impacts of ultra low sulfur jet fuel. Refined environmental cost-benefit analyses that will aid policymakers and refinery operators in determining future direction will also be produced.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project27.html

Project Title			
Project 28 – Environmental Cost-Benefit Analysis of Alternative Jet Fuels			
Program	Agency Sponsor	Project ID	
PARTNER	**FAA**	**Project 28**	
Start Date	End Date	Status	Funding
2008	**2010**	**Ongoing**	**$TBD**
Participating Organizations			
MIT			

Description

Alternative jet fuels hold the promise of energy supply diversification in the face of rising oil prices. In addition, alternative fuels may reduce environmental impact from aviation-related combustion emissions.

To properly account for the environmental costs and benefits of introducing alternative fuels, we must evaluate the environmental impacts. This extends from the fuel origin, as it is produced; to its end, as combustion products enter the environment; what is referred to as a "well-to-wake analysis." The focus of Project 28 is on the creation and use of an aviation-specific life-cycle analysis framework to assess the alternative fuel environmental impacts from well-to-wake. This proposed analysis framework will build on existing well-to-tank and tank-to-wake methodologies.

The broad Project 28 objective is to evaluate the relative environmental impacts of multiple potential alternative aviation fuels that are compatible with existing aircraft and infrastructure. Analyses will include examining traditional kerosene fuels from conventional and unconventional petroleum resources; hydrocarbon fuels derived from fossil fuels such as oil sands and oil shale; synthetic liquid fuels manufactured from coal, biomass, or natural gas; and biojet made from first and second generation biomass. Biojet is an oxygen-free hydrocarbon fuel that is derived from renewable oil resources.

The evaluation will include the full chain of use, from initial energy harvesting / resource extraction, to production and transportation, to use by the aviation industry, to end-of-use and disposal issues. Project 28 will consider health, welfare, and ecological impacts, including effects related to changes in non-renewable resource use, air quality, community noise, and global climate change. This work builds on PARTNER Project 17 (a pending PARTNER-RAND alternative fuels report) that studies the economic and policy aspects of adopting alternative jet fuels.

The project will result in improved tools for assessing and modeling the health, air quality and ecological impacts of alternative jet fuels. Refined environmental cost-benefit analyses that will assess various alternative jet fuels and future changes to fuel specifications will also be produced.

More information (reports, website, project contact):

http://mit.edu/aeroastro/partner/projects/project28.html

Program Title

Airport Cooperative Research Program (ACRP)

Agency Sponsor

National Academy of Engineering/Transportation Research Board/FAA

Description

The Airport Cooperative Research Program (ACRP) was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. In October 2005, the Federal Aviation Administration (FAA) executed a contract with the National Academies, acting through its Transportation Research Board (TRB), to serve as manager of the ACRP. Representatives of airport operating agencies provide program oversight and governance. ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. The ACRP undertakes research and other technical activities in a variety of airport subject areas including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration.

The following ACRP projects are summarized in this document:

ACRP 02-03 – Aircraft and Airport Related HAPs

ACRP 02-03a – Measurement of Gaseous HAP Emissions from Idling Aircraft as a Function of Engine and Ambient Conditions

ACRP 02-04 – Particulate Emissions at Airports

ACRP 02-04a – Gaseous and Particulate Emissions Data for Aircraft

ACRP 02-08: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality

More information (reports, website, project contact):

Airports Cooperative Research Program; Research Needs Associated with Particulate Emissions at Airports;

Project Title			
ACRP 02-03 – Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis			
Program	Agency Sponsor	Project ID	
ACRP	**TRB, FAA**	**ACRP 02-03**	
Start Date	End Date	Status	Funding
2006	**2008**	**Complete**	**$100k**
Participating Organizations			
Aerodyne, Inc.			

Description

This report provides guidance on the most important projects to the airport community for ACRP consideration in the area of hazardous air pollutants (HAPs). It examines the state of the latest research on aviation-related HAP emissions and identifies knowledge gaps that existing research has not yet bridged. These gaps and related research needs are then prioritized based on the ability of research in those areas to provide airports a better understanding of the relationship of the type and amount of HAPs being emitted and their impacts. While the main purpose of this report is to identify key research areas important to the airport community for ACRP consideration, research communities at large will also benefit from this report's comprehensive analysis of aviation-related HAP research needs.

More information (reports, website, project contact):

http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=131

Project Title			
ACRP 02-03a – Measurement of Gaseous HAP Emissions from Idling Aircraft as a Function of Engine and Ambient Conditions			
Program	Agency Sponsor	Project ID	
ACRP	**TRB, FAA**	**ACRP 02-03a**	
Start Date	End Date	Status	Funding
2008	**2010**	**RFP open**	**$500k**
Participating Organizations			
TBD			
Description			

The objective of this project is to design and implement a test program to measure gaseous HAP emissions from in-production jet engines operating at a range of idle settings and ambient temperatures. The primary research objective of this program would encompass measurements of total hydrocarbons and speciated hydrocarbons, including HAPs, within the exhaust plume at a reasonable proximity of the engine nozzle to capture emissions prior to condensation of volatile gasses. The secondary research objective would be to include measurements at a downstream location where the plume has cooled to near-ambient temperatures.

More information (reports, website, project contact):

http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=2424

Project Title			
ACRP 02-04 – Research Needs Associated with Particulate Emissions at Airports			
Program	Agency Sponsor	Project ID	
ACRP	**TRB, FAA**	**ACRP 02-04**	
Start Date	End Date	Status	Funding
2006	**2008**	**Complete**	**$100k**
Participating Organizations			
Environmental Consulting Group, Inc., Aerodyne, Inc., MS&T, CSSI, Inc.			

Description

This report provides guidance on the most important research needed by the airport community in the area of particulate emissions. It examines the state of industry research on aviation-related particulate matter (PM) emissions and identifies knowledge gaps that existing research has not yet bridged. These gaps and related research needs are then prioritized based on the ability of research in those areas to address airports' needs for more thorough and accurate aviation-related PM emissions inventories. While the main purpose of this report is to identify key research areas important to the airport community for ACRP consideration, research communities at large will also benefit from this report's comprehensive analysis of aviation PM emissions-related research needs.

More information (reports, website, project contact):

http://www.trb.org/news/blurb_detail.asp?id=9252

Project Title			
ACRP 02-04a – Summarizing and Interpreting Aircraft Gaseous and Particulate Emissions Data			
Program	Agency Sponsor	Project ID	
ACRP	**TRB, FAA**	**ACRP 02-04a**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$350k**
Participating Organizations			
MS&T, Aerodyne, Inc., ECG, Inc., CSSI, Inc.			
Description			
The objective of this research is to summarize, analyze, and interpret the scientific data available from the Aircraft Particle Emissions Experiment (APEX) 1-3 and the Delta – Atlanta Hartsfield (UNA-UNA) experiment. The results will be presented in a comprehensive report to help the airport community and general public understand the data's ability to contribute to developing better air quality assessments in the airport environment.			
More information (reports, website, project contact):			
http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=133; Delta - Atlanta Hartsfield (UNA-UNA) Study			

Project Title			
ACRP 02-08 – Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality			
Program	Agency Sponsor	Project ID	
ACRP	**TRB, FAA**	**ACRP 02-08**	
Start Date	End Date	Status	Funding
2008	**2010**	**Ongoing**	**$600k**
Participating Organizations			
Wyle Laboratories, Inc., Synergy Consultants, Inc., Ian Waitz			

Description

The objective of this research project is to provide guidance for airport operators on effective tools and techniques for measuring airport contributions to ambient air quality. The research will evaluate existing and potential monitoring strategies and forecasting techniques that airport operators can use to measure airport-related air quality impacts on local jurisdictions that may exceed what is traditionally measured and modeled for National Environmental Policy Act (NEPA) purposes. The evaluation process will require selection of a specific airport as a test case for application of a combination of air quality measurement and state-of-the-art modeling techniques and an evaluation of the results of that application. This research project will identify gaps in existing models and the inputs to those models, future research needed to fill those gaps to improve the predictive capabilities of available models, a set of detailed recommendations for implementing an optimal emissions monitoring and forecasting strategy, and guidance to airport operators on how to select and carry out that strategy.

More information (reports, website, project contact):

http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=2101

Program Title

Aircraft Particle Emissions Experiments (APEX)

Agency Sponsor

NASA, EPA, DOD, FAA, CARB

Description

Over the past decade, the National Aeronautics and Space Administration (NASA) has sponsored a variety of studies to assess the environmental impact of aviation and to gather detailed aircraft emission data for use in guiding development of more efficient and less polluting turbine engine technology. An important recent such series of studies are referred to as the Aircraft Particle Emissions Experiment (APEX) studies. The first APEX project was conducted at NASA Dryden Flight Research Center (DFRC), Edwards Air Force Base, California in April 2004. APEX is a collaborative research effort, sponsored by NASA, the Environmental Protection Agency (EPA), and the Department of Defense (DOD), with additional funding for select projects by Federal Aviation Administration (FAA) and the California Air Resources Board (CARB). The APEX projects have brought together a diverse group of scientists to address its many and diverse objectives.

The following APEX projects are summarized in this document:

APEX 1 – Aircraft Particle Emissions eXperiment 1

UNA-UNA – Delta Atlanta Hartsfield

JETS/APEX 2 – Aircraft Particle Emissions eXperiment 2

APEX 3 – Aircraft Particle Emissions eXperiment 3

More information (reports, website, project contact):

Wey, et al, "Aircraft Particle Emissions eXperiment (APEX)" NASA/TM-2006-214382, ARL-TR-3903, Cleveland, OH, September 2006; *Journal of Propulsion and Power (2007),* Vol. 23, No.5

Project Title			
APEX1 – Aircraft Particle Emissions Experiment 1			
Program	Agency Sponsor	Project ID	
APEX	**NASA, EPA, DOD**	**APEX1**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**Complete**	**$TBD**
Participating Organizations			
MS&T, Aerodyne, Inc.,			

Description

The Aircraft Particle Emissions Experiment (APEX1) was the first ground-based experiment to simultaneously examine gas and particle emissions from a modern commercial aircraft over the complete range of engine power.

APEX1 was conducted at NASA Dryden Flight Research Center (DFRC), Edwards Air Force Base, California, between April 20-29, 2004. Particle and gas emissions from one of the NASA DC-8 aircraft's CFM-56-2C1 engines were measured as functions of engine power, fuel composition, plume age, and local ambient conditions. The specific objectives were: to examine the impact of fuel sulfur and aromatic content on soot and secondary particle formation; to follow the evolution of particle characteristics and chemical composition within the engine exhaust plume as it cooled and mixed with background air; to examine the spatial variation of particle properties across the exhaust plume; to evaluate new measurement and sampling techniques for characterizing aircraft particle and gas emissions; and to provide a data set for use in studies to model the impact of aircraft emissions on local air quality.

During APEX1, particle and gas emissions were measured at 11 engine power settings for each of three different fuels (base, high sulfur, and high aromatic fuels) in samples drawn from probes located 1, 10 and 30 m downstream from the engine exhaust plane. At the 1 m and 10 m sampling locations, multiple probe tips were used to examine the spatial variations of emissions properties across the exhaust plume. This testing matrix provided engine gas and particle emission information for more than 400 test conditions. Ambient conditions as well as engine temperatures, fuel flow rates, fan speeds, were carefully documented for each of the test points examined during the experiment. APEX results represent the first and most extensive set of gas and particle emissions data from an in-service commercial engine wherein multiple instruments were used to quantify important species of interest.

More information (reports, website, project contact):

Wey, et al, "Aircraft Particle Emissions eXperiment (APEX)" NASA/TM-2006-214382, ARL-TR-3903, Cleveland, OH, September 2006; *Journal of Propulsion and Power (2007),* Vol. 23, No.5

Project Title			
Delta Atlanta Hartsfield			
Program	Agency Sponsor	Project ID	
APEX	**NASA, EPA, DOD**	**UNA-UNA**	
Start Date	End Date	Status	Funding
2004	**2006**	**Complete**	**$TBD**
Participating Organizations			
MS&T, Aerodyne, Inc., NOAA			

Description

The second of the APEX series of studies was carried out at Atlanta Hartsfield International Airport in September 2004. Mobile laboratories were deployed to conduct two series of measurements of aircraft engine generated PM emissions. The first series was conducted at the maintenance facilities of Delta Airlines and focused on PM emissions in the vicinity of the exhaust nozzle of several different aircraft whose engines were cycled through a matrix of reproducible engine operating conditions as in APEX1. The second series introduced a novel approach focusing on emissions generated under actual operational conditions. This series was conducted by placing the mobile laboratories adjacent to and downstream of active runways. In these latter measurements advected exhaust plumes generated by a broad mix of commercial transport aircraft taxiing and departing the airport during normal operations were detected and analyzed. The Delta-Atlanta Hartsfield Study was the first opportunity to measure PM and gaseous emissions from in-service commercial transports.

Dedicated engine tests on stationary aircraft took place. The aircraft tested were selected from those scheduled to be overnight at the airport. The exhaust plumes of each aircraft were investigated using both probe sampling at the engine exhaust nozzle exit, and remote sensing using LIDAR at a point in the plume close to the exhaust nozzle exit, thus permitting comparisons of measurement techniques. Another objective was a study of engine-to-engine variation within the same class and where possible, two aircraft with the same engine class were studied.

More information (reports, website, project contact):

Wey, et al, "Aircraft Particle Emissions experiment (APEX)" NASA/TM-2006-214382, ARL-TR-3903, Cleveland, OH, September 2006; *Journal of Propulsion and Power (2007),* Vol. 23, No.5; Herndon, S.C., J.T. Jayne, P. Lobo, T. Onasch, G. Flemming, D.E. Hagen, P.D. Whitefield, R.C. Miake-Lye, "Commercial Aircraft Engine Emissions Characterization of In-Use Aircraft at Hartsfield-Jackson Atlanta International Airport," accepted for publication in *Environmental Science and Technology* (2008); http://web.mit.edu/aeroastro/partner/reports/proj9-deltaatlantaharts-rpt.pdf

Project Title			
JETS APEX2			
Program	Agency Sponsor	Project ID	
APEX	**NASA, EPA, DOD**	**APEX2**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**Complete**	**$TBD**
Participating Organizations			
MS&T, Aerodyne, Inc., UC-R			

Description

JETS APEX 2 consisted of two series of experiments similar to the Delta Atlanta Hartsfield study. The first series focused on PM emissions in the vicinity of the exhaust nozzle of several different aircraft whose engines were cycled through a matrix of reproducible engine operating conditions as in APEX1. The second series focused on emissions generated under actual operational conditions, conducted by placing the mobile laboratories adjacent to and downstream of active runways. In these latter measurements, advected exhaust plumes generated by the mix of commercial transport aircraft taxiing and departing the airport during normal operations were detected and analyzed.

The first series of experiments relied heavily on experience gained in the previous APEX studies where custom-designed probes and extensive support equipment were used to sample jet exhaust in the on-wing position at six thrust settings: 4%, 7%, 30%, 40%, 65% and 85%. In all, both engines of four parked 737 aircraft were tested.

Particle-laden exhaust was extracted directly from the combustor/engine exhaust flow through the probe, transported through a sample train, distributed, and analyzed in each group's suite of instrumentation. Sampling probes were located at different positions downstream of the engine exit plane: 1m, 30m and 50m on the starboard side, and at 1m on the port side of the aircraft. These aircraft engine emissions measurements were performed at the Ground Runup Enclosure (GRE). The engine types were selected to represent both old (-300 series) and new (-700 series) technologies. Real-time PM physical characterization was conducted. Size distributions from 5nm to 1µm were measured for all test points and associated aerosol parameters e.g. geometric mean diameter, geometric standard deviation, total concentration, and mass and number-based emission indices were evaluated.

The second set of measurements sampled jet engine exhaust downwind of an active taxiway and runway at Oakland International Airport while the aircraft performed standard Landing and Take-Off (LTO). The runway tests demonstrated the potential of downwind emissions monitoring adjacent to active taxi- and run- ways as a means to rapidly acquire evolving aircraft PM characteristics from in-service commercial aircraft. Emissions were monitored during a twelve hour period of daylight aircraft operations along a single runway where the downwind exhaust plumes for over 300 aircraft were sampled.

More information (reports, website, project contact):

Wey, et al, "Aircraft Particle Emissions experiment (APEX)" NASA/TM-2006-214382, ARL-TR-3903, Cleveland, OH, September 2006; *Journal of Propulsion and Power (2007),* Vol. 23, No.5; http://www.arb.ca.gov/research/apr/past/04-344.pdf

Project Title			
APEX3			
Program	Agency Sponsor	Project ID	
APEX	**NASA, EPA, DOD, FAA**	**APEX3**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**Complete**	**$TBD**
Participating Organizations			
MS&T, Aerodyne, Inc., AEDC, MSU, DOT			

Description

APEX3 was the fourth campaign in the APEX series. The main objective of APEX3 was to advance the knowledge of aircraft engine particle emissions. APEX 3 was conducted at Cleveland Hopkins International Airport (CLE) from October 26 – November 8, 2005. In APEX3, as in the three previous studies, engine exhaust emissions and plume development were examined by acquiring data from the exhaust nozzle and in the near field plume from a range of stationary commercial aircraft. A complementary study of downwind plumes during normal operations was abandoned because the prevailing winds during the scheduled sampling times did not transport the plumes to the available sampling locations.

PM and gas phase emissions were acquired from a range of current in-service commercial aircraft engines including regional aircraft provided by Express Jet, passenger aircraft provided by Continental Airlines, a freight aircraft provided by FedEx, and the NASA general aviation aircraft. Engine exhaust was sampled at three different locations in the plume, nominally 1m (i.e. exhaust nozzle), 15m, and 30m for the small aircraft (regional jet and general aviation jet), and 1m, 30m, and 45m for the large aircraft.

More information (reports, website, project contact):

Wey, et al, "Aircraft Particle Emissions experiment (APEX)" NASA/TM-2006-214382, ARL-TR-3903, Cleveland, OH, September 2006; *Journal of Propulsion and Power (2007),* Vol. 23, No.5

Project Title			
Alternative Aviation Fuels EXperiment (AAFEX)			
Program	Agency Sponsor	Project ID	
APEX	**NASA, TBD**	**AAFEX**	
Start Date	End Date	Status	Funding
2009	**2010**	**Planned**	**$TBD**
Participating Organizations			
TBD			

Description

Alternative fuels (synthetic or biological) offer a near-term means of meeting the increasing global demand for crude oil-derived fuels that can also be manufactured domestically to enhance US energy security. Alternative fuels can also produce lower emissions to help alleviate aviation impacts on local air quality and climate. For these reasons, NASA is planning the Alternative Aviation Fuels Experiment (AAFEX), which is needed to determine the exact impact of alternative fuels on gas-turbine engine performance and emissions.

The objectives of AAFEX are to examine the effects of alternative fuels on the performance and primary emissions of a commercial jet engine, to investigate the effects of engine power, fuel composition, and ambient conditions on volatile aerosol formation and growth in aging aircraft exhaust plumes, and to establish APU emission characteristics and examine their dependence on fuel composition.

NASA is planning to use government-owned aircraft so there will be no restrictions on data (CFM-56), use standard methods, and follow ICAO certification tests. They will look at the impact of ambient conditions and plan to test both coal and natural gas derived FT fuels. The project is planned for Palmdale, CA (fewer security issues) in January 2009.

More information (reports, website, project contact):

Project Title			
APEX4			
Program	Agency Sponsor	Project ID	
APEX	**FAA, TBD**	**APEX4**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**Planned**	**$TBD**
Participating Organizations			
TBD			
Description			
APEX4 is anticipated as the next aircraft emissions analysis campaign in the APEX series. Key goals for APEX4 will be to identify and address remaining research gaps, leverage funding from other agencies where possible, and define PARTNER (and other program) projects that can leverage the activity of this emissions measurement project.			
More information (reports, website, project contact):			

Program Title

Strategic and Environmental Research & Development Program (SERDP)

Agency Sponsor

US Department of Defense

Description

The Strategic Environmental Research and Development Program (SERDP) is the Department of Defense's (DoD) environmental science and technology program, planned and executed in full partnership with the Department of Energy and the Environmental Protection Agency, with participation by numerous other federal and non-federal organizations. To address the highest priority issues confronting the Army, Navy, Air Force, and Marines, SERDP focuses on cross-service requirements and pursues high-risk/high-payoff solutions to the Department's most intractable environmental problems. The development and application of innovative environmental technologies support the long-term sustainability of DoD's training and testing ranges as well as significantly reduce current and future environmental liabilities.

The following SERDP projects are summarized in this document:

Non-Volatile PM Projects

WP-1401 – Measurement of Emissions from Military Aircraft
WP-1402 – Development of PM Emission Factors from Military Aircraft
WP-1538 – Interim PM Test Method for High Performance Gas Turbine Engines
PP-1179 – Reduced Particulate Matter Emissions for Military Gas Turbine Engines Using Fuel Additives
PP-1198 – Kinetic Database for PAH Reactions and Soot Particle Inception During Combustion
WP-1574 – Predictive Chemical and Statistical Modeling of PM Formation in Turbulent Combustion with Application to Aircraft Engines
WP-1575 – Aromatic Radicals-Acetylene PM Chemistry
WP-1576 – Effects of Soot Structure on Oxidation Kinetics
WP-1577 – Combustion Science to Reduce PM Emissions for Military Platforms
WP-1578 – Predicting the Effects of Fuel Composition and Flame Structure on Soot Generation in Turbulent Non-Premixed Flames

Volatile PM Projects

WP-1625 – Quantifying Sulfate, Organic, and Lubrication Oil in Particles Emitted from Military Aircraft Engines
WP-1626 – Measurement and Modeling of Volatile Particle Emissions from Military Aircraft
WP-1627 – Development and Application of Novel Sampling Methodologies for Study of Volatile Particulate Matter in Military Aircraft Emissions
WP-1628 – Extreme Light Diagnostics for Measuring Total Particulate Emissions

More information (reports, website, project contact):

http://www.serdp.org/

Project Title			
Measurement of Emissions from Military Aircraft			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1401**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
ORNL, ARCADIS, EPA, AFRL			

Description

The objectives of this project are (1) to develop a comprehensive emissions measurement program by employing both conventional and advanced measurement techniques, (2) to develop emission factors for military aircraft of fixed- and rotary-wing configurations, and (3) to investigate the spatial and temporal evolutions of the exhaust plumes.

The combined use of commercial and research-grade measurement techniques will produce reliable, high-quality, aircraft emissions data for the U.S. military. In contrast to emissions measured in an engine test cell, the aircraft emission factors derived from field measurements will be representative of aircraft that are currently in service or are expected to be in service for future decades. The measurements will be conducted at pre-selected distances from the engine exhaust exits, and the data will enable the examination of plume dynamics and direct establishment of source-receptor relationship of the emissions sources. The sampling methodology and monitoring techniques include (1) a tunable diode laser absorption spectroscopy (TDLAS), an ultraviolet differential optical adsorption spectroscopy (UV DOAS), an open-path Fourier transform infrared spectroscopy (OP-FTIR), and time-integrated sampling and analysis methods for carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, and air toxics; (2) a scanning mobility particle spectrometer (SMPS), an aerodynamic particle sizer (APS), several differential mobility analysis (DMA) based systems, a nanometer aerosol size analyzer (nASA), a micro-orifice uniform deposition impactor (MOUDI), and a frequency-modulated coherent microburst laser induced differential absorption radar (LIDAR) for aerosol particle mass concentration, number density, size distribution, and chemical speciation; (3) an aerosol beam focused laser-induced plasma spectrometer (ABFLIPS) and inductively coupled plasma mass spectroscopy (ICP-MS) for measurement of toxic metals and organo-metallic compounds; and (4) standard surface meteorology and auxiliary engine performance data.

This project aims to develop an effective emissions monitoring program for fixed- and rotary-wing military aircraft. The project will yield high-quality and comprehensive emissions data to significantly reduce the uncertainties associated with existing emission estimates. The end products will include (1) state-of-the-art measurement techniques and instruments developed for military aircraft emissions measurement, and (2) high quality aircraft emissions factor data sets, which are expected to fill gaps in the EPA Mobile Source Air Toxics (MSAT) program and for Toxic Release Inventory (TRI) reporting, as well as assist in future decision making and design of cost-effective air pollution control strategies.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP-1401.pdf

Project Title			
Emission Factors for Particulate Matter, Nitrogen Oxides, and Air Toxic Compounds from Military Aircraft			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1402**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
Battelle, ARCADIS, EPA-EMC, AFRL, DOE-PNNL			

Description

The objective of this project is to develop, evaluate and apply a system for rapid real-time measurement of emission factors of particulate matter, nitrogen oxides and trace toxic air pollutants from military aircraft engines, and to do so in such a manner that facilitates regulatory acceptance.

The technical approach involves monitoring exhaust constituents using rapid, sensitive, real-time measurement systems where feasible, together with short-term (i.e., minutes) sampling and analysis methods. Emissions in exhaust from aircraft/engines outdoors will be monitored to facilitate both extractive and remote sensing measurements. The exhaust stream will be sampled at a point 20+ nozzle diameters behind the engine, depending on the power setting, to minimize the chances of sample degradation in the sample probe. Three high-priority engines for the initial emissions measurements have been selected: the F100, F119, and 404. Emissions will be monitored at five power settings corresponding to Idle, Approach, Intermediate, Military, and Afterburner (for afterburner engines). Tests at each power condition will be replicated, and multiple engines of each type will be examined. These replicate tests will provide estimates of the precision of the emission factors. The design also addresses the question of the accuracy of the emissions data. Most of the toxic air pollutants that are the focus of this study can only be measured by extractive sampling (i.e. removing a sample of the exhaust stream for analysis), which can raise concerns about the integrity of the sample that passes through probes and tubing prior to analysis. To address this concern, the exhaust will be monitored by remote sensing at the same position in the exhaust stream where extractive sampling is performed. Several of the target chemicals are amenable to the remote sensing approach so that, for the first time, any influence of extractive sampling on sample integrity can be assessed by comparison with the remotely sensed data.

The result of this effort will serve several purposes: (1) provide input and fill data gaps identified in EPA's MSAT program; (2) provide input and fill data gaps for the UATS; and (3) provide input to mesoscale transport modeling of DoD air emissions, an effort that began in fiscal year 2003. The emissions data will help to maintain military training schedules and to permit planners to consider movements of airborne units from one facility to another. At the conclusion of this project, DoD will possess an extensive database of toxic air pollutant emission factors from high-priority military aircraft, with documented uncertainties, collected in a manner designed to assure regulatory acceptance.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP-1402.pdf

Project Title			
Interim PM Test Method for High Performance Gas Turbine Engines			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1538**	
Start Date	End Date	Status	Funding
2004	**2008**	**Ongoing**	**$TBD**
Participating Organizations			
NAVAIR, MS&T, Aerodyne, AEDC			

Description

Building on SERDP project WP-1536, the objective of this project is to develop an Environmental Protection Agency (EPA)-approved interim PM test method for high performance gas turbine engines that will provide legally defensible emission data required for basing decisions. The interim test protocol will use state-of-the-art particulate emissions testing instrumentation and provide an alternative approach to EPA Test Method 5, which does not measure particulate size, distribution, and chemical species.

This project will develop an EPA-approved PM test method based on results from recent PM testing in the private sector. In addition, this project will gather PM and gaseous emissions data at the exit plane of an F414 engine and may perform an optional test of an F100 engine. Testing will include use of the Mass Aerosol Sampling System (MASS) and Combustion DMS500 Fast Particulate Spectrometer to acquire real-time PM number and size distribution data, an Aerosol Mass Spectrometer to collect real-time chemical composition data, and a Tunable Infrared Laser Differential Absorption Spectrometer (TILDAS) to measure gaseous species. The data will be analyzed and a test plan developed in consultation with EPA for PM testing of the F-135 engine.

The new EPA-approved interim PM test method will provide accurate emissions data required for high performance aircraft basing decisions, while saving DoD time and money as compared to the current approved test method. This project also will help advance the science of PM testing.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP-1538.pdf

Project Title			
Reduced Particulate Matter Emissions for Military Gas Turbine Engines Using Fuel Additives			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**PP-1179**	
Start Date	End Date	Status	Funding
2001	**TBD**	**TBD**	**$TBD**
Participating Organizations			
AFRL, ARL, PSU, UDRI, MS&T, ISSI, UTRC			

Description

The technical objective of this project is to identify and develop one or more additives for JP-8, JP-5, and diesel fuels that will reduce both the mass Emissions Index (mass EI = grams of PM2.5 emissions/kilogram of fuel) and the number density Emissions Index (number density EI = particle number density/kilogram of fuel) of PM2.5 at the exhaust exit of military gas turbine engines by 70 percent. The fuel additive should furthermore be benign to the environment, cost no more than $0.10 per gallon of fuel, and have no impact on the engine life or performance.

The use of fuel additives is a pervasive and cost effective approach that has the potential to reduce PM2.5 emissions in all engines of the fleet. However, the development of a PM2.5 emissions reduction additive poses a major challenge due to the complexity of the particulate formation process in gas turbine combustors. To simplify the problem, different laboratory burners will be used to simulate the soot formation and burnout regions in the gas turbine combustor. These laboratory burners will be used to study and evaluate the PM2.5 emissions reduction potential of additives. Fundamental experiments will be conducted to provide insight into the additive mechanisms so that improved additive formulations can be developed. Additives will be evaluated with the laboratory burners until one or more are found that appear to meet the program objectives. Additive confirmation tests will be performed in practical engines to determine if the final selected additives meet the program goals. The final additives will be evaluated in a T-63 engine, used in helicopters and auxiliary power units, and in an AGT-1500 gas turbine engine, used in the M-1A tank.

The benefit of this project will be significant emissions reduction, which is related directly to the amount of fuel consumed by a gas turbine engine. PM2.5 emissions at some Department of Defense bases could decrease by as much as 40 to 70 percent if all military aircraft were to adopt this technology. The potential benefit would be even greater if it was also adopted by U.S. commercial aircraft, which account for about 88 percent of annual jet fuel consumption.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/PP-1179.pdf

Project Title			
Kinetic Database for PAH Reactions and Soot Particle Inception During Combustion			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**PP-1198**	
Start Date	End Date	Status	Funding
2001	**TBD**	**TBD**	**$TBD**
Participating Organizations			
NIST, Sandia National Laboratry, AFRL			

Description

The purpose of this project is to develop a National Institute of Standards and Technology (NIST)-quality, gas-phase chemical kinetic database describing the transformation of fuel molecules to their desired end products of carbon dioxide and water, as well as to the undesired PAH, and to develop the first quantitative soot particle inception model based on experiments.

Existing data will first be compiled, evaluated, and updated using NIST CHEMRATE, a user friendly reaction rate theory program, to determine which kinetic rates will potentially be measured. Rates will be further identified for fuel cracking and reactions involving PAH with three or fewer rings using a shock tube and for reactions involving early soot or PAH with three or more rings using a well stirred reactor. A particle inception model will be developed based on experiments performed in diffusion flames and in the well stirred reactor. Both atmospheric pressure work involving gaseous fuels and high pressure work involving liquid fuels will be performed. The data base and model will be tested in the Air Force Research Laboratory UNICORN (Unsteady Ignition and Combustion with Reactions) computer code.

The PAH/particle inception model developed in this study will have the potential to streamline the military's particulate mitigation strategies based on computer-based engine design and fuel additive development.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/PP-1198.pdf

Project Title

Predictive Chemical and Statistical Modeling of PM Formation in Turbulent Combustion with Application to Aircraft Engines

Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1574**	
Start Date	End Date	Status	Funding
2007	**2011**	**Ongoing**	**$TBD**

Participating Organizations

Stanford University, University of California – Berkeley, University of Texas – Austin

Description

The objective of this project is to advance the predictive capability of soot models with application to military-type aircraft gas turbine engines. Research will be conducted in coordination with SERDP projects WP-1575, WP-1576, WP-1577, and WP-1578, which are investigating the formation of particulate matter emissions resulting from the combustion of military fuels.

Researchers have identified a set of critical modeling requirements and will undertake a comprehensive program covering three different research areas—chemical modeling, statistical modeling, and soot modeling in turbulent combustion. The chemical modeling aspect of the project includes further improvements of the gas-phase kinetics, the aggregation models, and the heterogeneous reactions on the particle surface leading to further soot mass growth or oxidation. Several models exist for the statistical modeling of particle dynamics, which typically provide some approximation to the particle size distribution function. In this project, researchers will develop a new method that, for the first time, will provide a joint statistical description of particle size and surface coverages. To apply the models to soot formation in turbulent combustion, the chemical and statistical methods will be incorporated into turbulent combustion models for large-eddy simulation. In addition, the complex interactions of molecular and turbulent transport with the flame chemistry and particle formation and oxidation will be studied and quantified in direct numerical simulations, and appropriate models will be developed. In all three areas, models will be validated with experimental data. In particular, the comprehensive soot model will be validated in large-eddy simulations of soot formation in actual aircraft engine combustor geometries.

This project will ultimately lead to the availability of computational methods to predict soot formation in military aircraft engines. Such methods will improve the understanding of pertinent formation and oxidation processes and reduce emissions of soot from future engines.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP-1574.pdf

Project Title			
Aromatic Radicals-Acetylene PM Chemistry			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1575**	
Start Date	End Date	Status	Funding
2007	**2010**	**Ongoing**	**$TBD**
Participating Organizations			
University of Illinois - Chicago			

Description

Military gas turbine engine fuels such as JP-8 are composed of up to 25% aromatics with the principal components being methyl- and alkyl-substituted single- and two-ring aromatics (xylenes, butylbenzene, and methyl naphthalenes), which decompose to form the highly reactive phenyl, phenylic-type radicals, and the benzyl radical. This project will study key reactions involving these primary aromatic radicals with acetylene that lead to the formation of larger polycyclic aromatic hydrocarbons (PAH) and will study the combustion of xylene, a military fuel aromatic surrogate, in view of these reactions. A database of stable species profiles for these poorly characterized aromatic radical reactions will be obtained for the first time. The experimental data will be used to probe and confirm mechanistic pathways and to develop and validate detailed predictive chemical kinetic models under practical turbine conditions.

A unique high-pressure shock tube will be used to perform experiments for the key aromatic radical-acetylene reactions implicated in incipient PM formation over a wide range of high pressures (10-100 atm) and temperatures that encompass typical conditions in military turbines and combustors. The data will (1) test the validity of current mechanistic routes for these key reactions at high pressures, (2) gauge the importance/dominance of addition to reactive phenyl and phenylic radicals in contrast to the more stable benzyl and benyzlic radicals in forming larger PAHs, and (3) confirm and obtain high-pressure limiting rate coefficients. The species profiles from the high-pressure experiments along with other experimental data where available also will be used to develop and validate accurate detailed chemical kinetic models.

The detailed model developed for the incipient stages of PM formation will provide accurate descriptors for the chemical kinetics in large computational engine design codes, thereby aiding combustion engineers in designing efficient combustors. The model also will be a valuable quantitative tool for predicting emissions in order to address regulatory and legislative concerns.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP_FS_1575.pdf

Project Title			
Effects of Soot Structure on Oxidation Kinetics			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1576**	
Start Date	End Date	Status	Funding
2007	**2010**	**Ongoing**	**$TBD**
Participating Organizations			
University of Utah			

Description

The objectives of this project are to (1) determine the effect of the structure of soot, as influenced by the fuel composition and soot temperature history, on the rate of soot oxidation by oxygen gas; (2) quantify the role of internal surface area on soot reactivity; and (3) develop power-law kinetic correlations for soot/O_2 oxidation as a function of temperature, oxygen, and time for soots of different structures and porosity. Research will be conducted in coordination with SERDP projects WP-1574, WP-1575, WP-1577, and WP-1578, which are investigating the formation of particulate matter emissions resulting from the combustion of military fuels.

Experiments will be conducted in a novel two-stage burner. In the first stage, soot is generated, while in the second stage, the soot is oxidized in either a fuel-rich or fuel-lean environment. In this project, experiments will focus on liquid fuels, specifically surrogates and jet fuel, and fuel-lean conditions. The experiments are supported by particle size measurements from a nano-scanning mobility particle sizer (SMPS) and transmission electron microscopy (TEM) of grids used to collect soot samples thermophoretically. The SMPS provides particle mobility diameter while the TEM shows particle morphology.

The literature shows a range of kinetic expressions for the oxidation of soot by oxygen gas. This project will elucidate the kinetics as a function of soot structure and internal surface area. Consequently, this will enable more accurate model predictions of soot formation/oxidation in full-scale systems.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP-1576.pdf

Project Title			
Combustion Science to Reduce PM Emissions for Military Platforms			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1577**	
Start Date	End Date	Status	Funding
2007	**2011**	**Ongoing**	**$TBD**
Participating Organizations			
University of Southern California, University of California – Berkeley, UTRC			
Description			

The objective of this project is to aid DoD in meeting current and future NAAQS PM2.5 regulations by establishing the fundamental science needed to develop and validate soot models for realistic fuels and reducing PM2.5 emissions from GTEs in military platforms. Research will be conducted in coordination with SERDP projects WP-1574, WP-1575, WP-1576, and WP-1578, which are investigating the formation of particulate matter emissions resulting from the combustion of military fuels.

This project involves strongly coupled, mutually supportive experimental and simulation efforts conducted in concert with the other four SERDP projects. Specifically, this project will focus on understanding the fundamental effects of fuel chemistry and pressure on soot production and burnout for hydrocarbon fuels and evaluating soot models and fuel mechanisms provided by the other SERDP projects. In addition, this project will oversee the coordination efforts among the five projects. Working with the SERDP partners, state-of-the-art and baseline soot models will be integrated into a unique simulation code called UNICORN (UNsteady Ignition and COmbustion using ReactioNs) along with “full” chemistry mechanisms for ethylene, a typical JP-8 fuel, JP-8 surrogate fuels, and alternative fuels. UNICORN, with “full” or reduced chemistry mechanisms, will be used to predict the soot characteristics expected from elevated pressure experiments. The experiments will be designed to methodologically progress in complexity in a way that supports systematic data analysis and interpretation.

UNICORN also will be used as a tool to interpret the experimental results in terms of the chemistry and pressure effects on soot production and burnout. The results of the analysis will be provided to the SERDP partners to aid their development of improved soot models. Experiments will be repeated as the SERDP partners provide improved soot models. The soot models and reduced fuel chemistry mechanisms developed by the SERDP partners and validated through this project will be integrated into a Pratt & Whitney combustor code for investigating soot reduction potential of current and future GTEs in military platforms.

This project will provide (1) an extensive experimental database for validation of kinetic and soot models; (2) evaluations of three or more “full” chemistry/soot mechanisms for JP-8 and alternate fuels with identification of the most accurate mechanisms and refinement of the

kinetics models for the best soot mechanism; and (3) two validated research codes, UNICORN for predictions based on “full” chemistry and a design code for predicting soot emissions from combustors burning practical fuels.

More information (reports, website, project contact):
http://www.serdp.org/Research/upload/WP-1577.pdf

Project Title

Predicting the Effects of Fuel Composition and Flame Structure on Soot Generation in Turbulent Non-Premixed Flames

Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1578**	
Start Date	End Date	Status	Funding
2007	**2010**	**Ongoing**	**$TBD**
Participating Organizations			
Sandia National Laboratory			

Description

This project aims to achieve true predictiveness of gas turbine combustor models through an integrated measurement and modeling effort focusing on turbulent, nonpremixed flames relevant to military gas turbine engines. By combining detailed flowfield and soot measurements with high-fidelity turbulent flame modeling, accurate reduced-chemistry models for soot formation and oxidation will be generated.

Researchers at the Combustion Research Facility of Sandia National Laboratories will apply advanced laser diagnostics to develop a unique, well-documented data set of key soot, chemical species, and flowfield properties in a series of nonpremixed turbulent jet flames that are amenable to modeling. Ethylene, JP-8 surrogate, and a blend of JP surrogate and Norpar-13 will be used in these flames. In parallel, researchers at the University of Southern California will use an array of experimental techniques to characterize the kinetics and coalescence properties of incipient and growing soot. This information is needed for accurate interpretation of the laser-based flame measurements and for proper treatment of soot carbonization and aggregation properties in soot models. Large eddy simulations (LES) will be performed on the turbulent flames using a two-moment to multimoment approach to treat soot formation and oxidation. Reduced chemical models describing the effects of fuel chemistry on soot formation and oxidation will be evaluated and tested to yield the best match with experimental results. Experiments also will be conducted on soot formation in liquid spray jet flames of JP-8 surrogate and JP-8/Norpar mixtures at temperatures and pressures appropriate for gas turbine operation.

The reduced chemical and soot models developed will be available and directly usable by engine manufacturers and Department of Defence personnel using standard computational fluid dynamic models to predict emissions from gas turbine engines. In addition, the experimental database generated will be well-documented and posted on an external web site for use by the scientific research community in making comparisons with high-fidelity models.

More information (reports, website, project contact):

http://www.serdp.org/Research/upload/WP_FS_1578.pdf

Project Title			
Quantifying Sulfate, Organics, and Lubricating Oil in Particles Emitted from Military Aircraft Engines			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1625**	
Start Date	End Date	Status	Funding
2008	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
Aerodyne, Inc., UTRC, Pratt & Whitney, MIT			
Description			
The objective of this project is to understand how volatile particle contributions affect the properties of PM emissions and how they evolve. Advanced particle measurement instruments will be used to explore several types of contributions to volatile PM. Fuel sulfur, incompletely combusted fuel organics, and engine lubrication oil contributions will be explored to isolate these individual contributions.			
More information (reports, website, project contact):			

Project Title			
Measurement and Modeling of Volatile Particle Emissions form Military Aircraft			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1626**	
Start Date	End Date	Status	Funding
2008	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
Carnegie Mellon University			

Description

The objective of this project is to obtain fundamental understanding of volatile PM emissions from military GTE.

The project approach will be to investigate principles controlling formation of volatile PM emissions, characterize organic aerosol emissions, and develop theoretical model that accounts for both gas-particle partitioning and photochemical aging on volatile PM emissions.

More information (reports, website, project contact):

Project Title			
Development and Application of Novel Sampling Methodologies for Study of Volatile Particulate Matter in Military Aircraft Engines			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1627**	
Start Date	End Date	Status	Funding
2008	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
ORNL, AFRL, University of Dayton			
Description			
The objective of this project is to investigate the formation and transformation of volatile PM in military aircraft emissions. The project approach will be to evaluate current micro-dilution tunnel technology for characterization of formation and transformation of volatile PM, develop and incorporate advanced thermodenuder-spectroscopic measurement technologies, and conduct research in a GTE in various conditions. The data will be used to prescribe aerosol dynamic model and improve predictive ability.			
More information (reports, website, project contact):			

Project Title			
Extreme Light Diagnostics for Measuring Total Particulate Emissions			
Program	Agency Sponsor	Project ID	
SERDP	**DOD/OSD**	**WP-1628**	
Start Date	End Date	Status	Funding
2008	**TBD**	**Ongoing**	**$TBD**
Participating Organizations			
AFRL, ISSI			

Description

The objective of this project is evaluate novel methods for characterizing volatile PM emissions from military GTE.

The project approach will be to evaluate extreme light, femtosecond - LIBS and conventional nanosecond - LIBS as techniques for making time and spatially resolved, in situ measurements of total mass, composition, number density, and size distribution of solid and volatile aerosol particulates in simulated GTE plume environments..

More information (reports, website, project contact):

Program Title

E-31 Aircraft Exhaust Emissions Measurement Committee (SAE E-31)

Agency Sponsor

SAE International

Description

The SAE E-31 Aircraft Exhaust Emissions Measurement committee addresses all facets of aircraft exhaust emissions measurement – tools, methods, processes, and equipment. It is responsible for standardizing measurement methods of emissions from aircraft, including isolated combustor systems. E-31 Committee was formed to develop and maintain cognizance of standards for measurement of emissions from aircraft power plants and to promote a rational and uniform approach to the measurement of emissions from aircraft engines and combustion systems to support the practical assessment of the industry.

The E-31 Committee, in its operation uses an Executive Committee, Membership Panel, Subcommittees and working technical panels as required to achieve its objectives. Participants in the SAE E-31 committee include OEMs, suppliers, propulsion emissions measurement companies, consulting firms, government and others across the aerospace and defense industries.

Standards development/revision activities

ARP1533B – Procedure for the Analysis and Evaluation of Gaseous Emissions From Aircraft Engines

ARP1179A – Aircraft Gas Turbine Engine Exhaust Smoke Measurement

AIR5917 – Procedures for Measurement of Gaseous Emissions from Gas Turbine Engines Using Fourier Transform Infrared Analysis

Recently published documents

ARP4418A – Procedure for Sampling and Measurement of Engine and APU Generated Contaminants in Bleed Air Supplies from Aircraft Engines

ARP1256C – Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines

AIR5892A – Nonvolatile Exhaust Particle Measurement Techniques

ARP1533A – Procedure for the Analysis and Evaluation of Gaseous Emissions From Aircraft

More information (reports, website, project contact):

E-31 Aircraft Exhaust Emissions Measurement Committee

Program Title

Omega

Agency Sponsor

Higher Education Funding Council for Education (HEFCE)

Description

Omega is a publicly funded partnership that offers impartial, innovative and topical insights into the environmental effects of the air transport industry and sustainability solutions. Omega provides knowledge and tools and acts as a forum for debate and as a catalyst for action by the sector and policy makers - to address this increasingly urgent and high profile issue. This partnership brings together experts from nine UK universities. The Omega partnership draws upon experts in environmental and social sciences, technology, business, economics, environment, politics and global regulation. Omega is led by Manchester Metropolitan University with Cambridge and Cranfield Universities; other University partners are Leeds, Loughborough, Oxford, Reading, Sheffield, and Southampton.

Omega works closely with those at the frontline of the aviation community – ranging from industry, to government through to NGOs – to explore solutions that are practical and deliverable. Omega brings together parties with often divergent views to share and develop knowledge and best practice in a 'neutral forum'. Omega has collaborative arrangements with academics in Europe, the US and China.

The following OMEGA projects are summarized in this document:

Characterizing Near-Surface Aircraft Particulate Emissions

ALFA: Aircraft Plume Analysis Facility Secondment

Understanding Initial Dispersion of Engine Emissions

- Modeling the Dispersion of Aircraft Engine Efflux in Proximity of Airports in an Atmospheric Boundary Layer Wind Tunnel
- Prediction of the Mixing of Engine Exhaust Gases
- Jet Vortex Interaction

Aviation Emissions and their Impact on Air Quality

More information (reports, website, project contact):

http://www.omega.mmu.ac.uk/

Project Title			
Characterizing Near-Surface Aircraft Particulate Emissions			
Program	Agency Sponsor	Project ID	
OMEGA	**HEFCE**	**Omega 1**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**TBD**	**$TBD**
Participating Organizations			
University of Oxford, Cambridge, Cranfield			

Description

This project will enhance knowledge about aircraft PM through development and use of a cheap portable instrument to provide the capability to measure the size, composition and number of particles, in a size range relevant for human health (0.1 to 10 µm), in real time. No such instrument is available commercially. This instrument will be used to characterize aerosol and inform modeling in an airport environment and it will enable a better understanding of the processes in engine emission and plume, which is essential if the actual apportioning of their impact on air quality is to be assessed, and taking measurements to see if enhanced peak aerosol concentrations occur as aircraft induced vortices dissipate near the ground in the areas close to the airport. These measurements are required to verify dispersal models and identify pollution sources.

The Heathrow noise pens used for engine tests provide an opportunity to measure the particulate emission characteristics of a number of different aircraft engines. These tests will give the variation in particulate composition and size with aircraft engine type. Given that the latest research indicates that particle composition, size and number are important parameters for human health, an ability to characterize aircraft particulate matter is needed to assist correct targeting of mitigation.

Apart from providing airport and airline stakeholders with a comprehensive description of particulate emissions, the project links with Omega activity to enhance knowledge of wake and vortex effects on dispersion of emissions. In turn, this will refine modeling capabilities used for current and future predictive assessment of airport air quality.

More information (reports, website, project contact):

http://www.omega.mmu.ac.uk/characterising-near-surface-aircraft-particulate-emissions.htm

Project Title			
ALFA: Aircraft Plume Analysis Facility Secondment			
Program	Agency Sponsor	Project ID	
OMEGA	**HEFCE**	**Omega 3**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**TBD**	**$TBD**
Participating Organizations			
Manchester Metropolitan University, Sheffield			

Description

The facility, being developed at Manchester Metropolitan University (MMU), will develop a plume analysis capability and is the first of its kind in Europe. It will enable improved understanding of plume composition and local dispersion. In particular, it will facilitate building a database of operational aircraft emissions, a better understand the complex physics and chemistry within the plume, and development of insights into the environmental impacts of operational controls such as reduced thrust, and fuel modifications including bio-fuels.

A secondment from the German DLR Institute for Atmospheric Physics to MMU will be funded to draw in key expertise in particle measurement and analysis. This person will provide a bridge between the design of the probe – used to sample engine exhaust emissions – and the measurement equipment using an aerodyne high resolution mass spectrometer to measure particulate matter.

Data derived from ALFA with the expertise through this international support will represent a step forward in understanding available to Omega stakeholders in the critical area of plume dispersion and its effect upon modeled air quality concentrations. The facility will contribute towards more accurate modeling and hence remove uncertainty that is affecting the development potential of the aviation sector at a regional, national and international level.

More information (reports, website, project contact):

http://www.omega.mmu.ac.uk/aircraft-emissions-plume-analysis.htm

Project Title			
Understanding Initial Dispersion of Engine Emissions			
Program	Agency Sponsor	Project ID	
OMEGA	**HEFCE**	**Omega 13**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**TBD**	**$TBD**
Participating Organizations			
Manchester Metropolitan, Oxford, Cambridge, Cranfield, Sheffield, Leeds, Reading, Southamption, Loughborough Universities			
Description			

This project examines the nature of the aircraft engine exhaust, in terms of its gaseous and particle emissions. With three discrete components to the work, it will examine aircraft emissions at all stages of operation – ground idle, taxi, take-off, climb, cruise and landing – in order to analyze and model the way emissions disperse and enable an in-depth analysis of pollutant levels.

To produce accurate models for pollutant dispersal, part of the study will focus on building a precise picture of aircraft plumes during cruise (high altitude pollution) and for landing and take-off cycles (for local air quality assessments). Exhaust from a jet engine is a very complex flow of hot fast gas and cold, slower moving gas. It is non-uniform, highly turbulent and has various velocity scales and chemical reactions. Using computational fluid dynamics (CFD) – a process whereby numerical methods and algorithms are used to calculate and analyze fluid and gas flows – the project will construct an accurate model of the flow immediately down stream of the engine exit and of the mixing process. It will result in a much better understanding of how the exhaust from a jet engine turns into a mixed plume; and of the composition of the plume itself.

During take-off and landing the wings of an aircraft produce lift, which in turn generates powerful trailing vortices. These vortices interact with the exhaust plumes from the engines and the way that jet exhaust disperses is altered as a result. At present there is limited understanding of this phenomenon. Another element of this project will investigate the interaction between vortices and exhaust plumes.

Researchers will develop a CFD model that is able to predict the combined jet/vortex flow field for distances of a kilometer or more behind the aircraft.

The final element of the project will develop a sub-scale model of exhaust dispersion in an atmospheric boundary layer wind tunnel. This simulates the conditions of an aircraft engine in flight so that the plume can be analyzed in the context of atmospheric wind and upwind conditions. Very few data are available relating to the use of this technique for simulating aircraft engine exhaust plumes. This study will make it possible to assess key factors influencing plume trajectory and concentration levels in a number of simulated wind conditions and for a range of aircraft operations.

Understanding the factors that determine pollutant concentration levels around airports is a key objective. The three elements of this study will all contribute to a better understanding of the behavior of aircraft engine exhaust and thus how aircraft technology affects the atmosphere.

More information (reports, website, project contact):

http://www.omega.mmu.ac.uk/understanding-initial-dispersion-of-engine-emissions.htm

Project Title			
Aviation Emissions and their Impact on Air Quality			
Program	Agency Sponsor	Project ID	
OMEGA	**HEFCE**	**Omega 2**	
Start Date	End Date	Status	Funding
TBD	**TBD**	**TBD**	**$TBD**
Participating Organizations			
Manchester Metropolitan University			

Description

Airport emissions come from many sources, including aircraft, airside vehicles, power plants, and road traffic. Aircraft create strong but intermittent emissions, making it difficult to tell how they affect the overall level of pollution in an area. This study includes a series of field measurements on an aircraft at Cranfield Aerodrome, in which engine emissions will be measured using a range of advanced techniques. A complementary series of studies will take place at British Airways Engineering at Heathrow Airport.

Aircraft in maintenance at Heathrow have their engines test run through a range of power settings in a noise-suppressing pen. This standardized environment will allow a set of repeatable air-quality measurements to be obtained over a range of aircraft types. Data collected will complement a large set of physical and chemical measurements on exhaust plumes from aircraft obtained over two years at Heathrow and Manchester airports.

The project will improve ways of characterizing the dispersion of separating out emissions from aircraft engines and help to enhance modeling of impacts in the community. It will harness academic expertise in engine performance, aeronautics, environmental science and atmospheric physics and chemistry to provide data on aviation emissions, as well as improving air quality monitoring techniques.

More information (reports, website, project contact):

http://www.omega.mmu.ac.uk/aviation-emissions-and-their-impact-on-air-quality.htm

Program Title

European Gas Turbine Particulate Emission (PartEmis) Research Project

Agency Sponsor

European Commission, Swiss Federal Office for Education and Science

Description

The objective of PartEmis (Measurement and Prediction of Emissions of Aerosols and Gaseous Precursors from Gas Turbine Engines) was to make comprehensive measurements of the physical and chemical properties of a gas turbine exhaust from combustor to engine exit, specifically looking at the physical and chemical properties of the aerosol emissions and their interaction with each other and gaseous exhaust components. Testing was conducted on a combustor and a unit that simulated a three-shaft turbine section (i.e., hot end simulator (HES)) with operating conditions simulating cruise temperatures (at 30,000 feet). The project measured the chemical composition of the exhaust gases including speciation of the organic and inorganic components, including ions. The fuel sulfur content (FSC) was varied to measure its effect on the exhaust composition and properties.

The following conclusions were drawn from the testing:

- Smoke size and number density unaffected by HES stage FSC and operating conditions.
- Significant aerosol mass with diameters > 1µm.
- Increasing particle shrinkage with FSC and decreasing size.
- Particle surface area unaffected by FSC but increases through HES stages.
- Particle hydroscopicity increases with FSC; small particles are more hydroscopic.
- Cloud condensation nuclei increase with FSC and HES stage.
- Peak number density of volatile aerosol < 4µm.
- Sulfate increases with FSC, measurement sampling system dependent.
- S(IV) to S(VI) conversion varies with power setting, HES stage and FSC.
- The majority of total HC is methane, significant carbonyl and carboxylic acid concentrations present.

More information (reports, website, project contact):

http://www.QinetiQ.com/

Petzold, A. et al, “Particle Emissions fro Aircraft Engines – A Survey of the European Project PartEmis” *Meteorologische Zeitschrift*, Vol. 14, No. 4, 465-476, August 2005.

Wilson, CW, et. al., “Measurement and Prediction of Emissions of Aerosols and Gaseous Precursors from Gas Turbine Engines (PartEmis): An Overview” *Aerospace Science and Technology* 8 (2004), 131-143.

Project Title			
PartEmis Combustor Campaign			
Program	Agency Sponsor	Project ID	
PartEmis	**EC, SBBW**		
Start Date	End Date	Status	Funding
January 2001	**February 2001**	**Complete**	**$TBD**
Participating Organizations			
DLR, QintiQ, Max Planck Inst., Paul Scherrer Inst., Universities of Vienna, Leeds, Louis Pasteur, Duisburg-Essen, and Wuppertal, Vienna University of Technology, Rolls Royce			

Description

The sub-program of the PartEmis project was measuring the exhaust composition at the combustor exit. Measurements were made at two engine cruise conditions characteristic of modern and older engines with fuel at three different sulfur levels (50 ppm, 410 ppm, and 1,270 ppm for the first sub-program and 40 ppm, 400 ppm, and 1,300 ppm for the second). The aerosol properties that were measured include: mass and number concentration, size distribution, mixing state, thermal stability, hygroscopicity, cloud condensation nuclei (CCN) activation potential, and chemical composition

More information (reports, website, project contact):

http://www.QinitiQ.com/

Vancassel, X., et. al., "Volatile Particles Formation During PartEmis: A Modelling Study" *Atmospheric Chemistry and Physics* 4, 2004. 439-447. http://www.atmos-chem-phys.org/acp/4/439

Haverkamp, H., et. al., "Positive and Negative Ion Measurements in Jet Aircraft Engine Exhaust: Concentrations, Sizes, and Implications for Aerosol Formation" *Atmospheric Environment*, 38 (2004), 2879-2884.

Wilhelm, S., et. al., "Detection of Very Large Ions in Aircraft Gas Turbine Engine Combustor Exhaust: Charged Small Soot Particles?" *Atmospheric Environment*, 38 (2004), 4561-4569.

Petzold, A., et. al., "On the Effects of Organic Matter and Sulphur-Containing Compounds on the CCN Activation of Combustion Particles" *Atmospheric Chemistry and Physics*, 5, 2005, 3187-3203.

Gysel, M., et. al., "Properties of Jet Engine Combustion Particles During the PartEmis Experiment: Hygrosopicity at Subsaturated Conditions" *Geophysical Research Letters*, vol. 30, No. 11, 1566, 2003, 20-1 to 20-4.

Petzold, A., et. al., "Properties of Jet Engine Combustion Particles During the PartEmis Experiment: Microphysics and Chemistry" *Geophysical Research Letters*, vol. 30, No. 13, 1719, 2003, 52-1 to 52-4.

Hitzenberger, R., et. al., "Properties of Jet Engine Combustion Particles During the PartEmis Experiment: Hygrosopic Growth at Subsaturated Conditions" *Geophysical Research Letters*, vol. 30, No. 14, 1779, 2003, 15-1 to 15-4.

Nyeki, S., et. al., "Properties of Jet Engine Combustion Particles During the PartEmis Experiment: Particle Size Spectra (d<15 nm) and Volatility" *Geophysical Research Letters*, vol. 31, L18105, 2004, L18105(1)-L18105(4).

Project Title			
Hot End Simulator Campaign			
Program	Agency Sponsor	Project ID	
PartEmis	**EC, SBBW**		
Start Date	End Date	Status	Funding
March 2002	**March 2002**	**Complete**	**$TBD**

Participating Organizations

DLR, QintiQ, Max Planck Inst., Paul Scherrer Inst., Universities of Vienna, Leeds, Louis Pasteur, Duisburg-Essen, and Wuppertal, Vienna University of Technology, Rolls Royce

Description

This sub-program of the PartEmis project included measuring the exhaust composition at the high pressure, intermediate pressure, and low pressure stages of the HES (March 2002). Inter-stage measurements helped characterize particle properties as they pass through an engine's turbine stages. Aerosol composition testing found more than 100 non-methane VOCs and their composition was independent of fuel sulfur content.

More information (reports, website, project contact):

http://www.QinitiQ.com/

Nyeki, S., et. al., "Properties of Jet Engine Combustion Particles During the PartEmis Experiment: Particle Size Spectra (d<15 nm) and Volatility" *Geophysical Research Letters*, vol. 31, L18105, 2004, L18105(1)-L18105(4).

Program Title

Aviation Integrated Modeling (AIM) Project

Agency Sponsor

Engineering and Physical Research Council, Natural Environment Research Council

Description

Managing the global air transportation system to ensure continued economic and social benefits while mitigating environmental impacts is becoming a major challenge. The system is large, complex, multi-disciplinary and involves numerous stakeholders with different agendas. Therefore, sustainable development of the system depends crucially on the delivery to policymakers and stakeholders of robust results incorporating improved understanding of the processes and interactions between the key system elements that determine environmental, societal and economic impacts. There is an urgent need to model the contributions of aviation at local and global levels in order to assess the best aviation policies to be pursued in the future that strike appropriate balances between these key indicators.

This new program initiative is to create such a policy assessment tool: the Aviation Integrated Modelling (AIM) project. Based in the Institute for Aviation and the Environment, this inter-disciplinary project was initiated in October 2006 with approximately £1m funding from UK research councils (primarily EPSRC and NERC) for its initial, 3-year phase. The project is modelling and integrating a wide range of key elements relevant to this goal.

More information (reports, website, project contact):

http://www.arct.cam.ac.uk/aim/index.html

AIM Brochure - Two page executive summary introducing the project.

AIM Introductory Paper - A 10 page conference paper introducing the project and its scope.

Project Title			
Multi-Scale Air Quality Impacts of Aviation			
Program	Agency Sponsor	Project ID	
AIM	**EPSRC, NERC**		
Start Date	End Date	Status	Funding
October 2006	**2009**	**Ongoing**	**$TBD**
Participating Organizations			
Cambridge University, MIT			

Description

The project goal is to identify how many people die (i.e., premature mortality) as a result of aviation globally each year, identifying which flight phases are important, and which segments of the population are most at risk. The proposed modeling framework is intended to predict changes in ground-level pollutant concentrations attributable to aviation globally and to estimate health impacts and regulatory compliance costs.

Global, regional, local, and plume scales are all important ranging from jet mixing and plume chemistry to dispersion, advection, and source effects, to advection, convection, and atmospheric chemistry. A 3D plume modeling approach, which reproduces experimental results from Heathrow, is used.

Initial modeling results showed 7,600 premature deaths worldwide due to aviation - especially impacts due to cruise emissions resulting in surface level pollutant concentrations. 90% of the impact is due to secondary PM. LTO emission impacts reflect aviation activity (e.g., high in eastern US, western Europe, and south east Asia).

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More information (reports, website, project contact):

http://www.arct.cam.ac.uk/aim/index.html

Barrett, S., R. Britter., "A Simple Approach for Rapid Operational Air Quality Modelling at Airports", 11th Interrnational Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatory Purposes, Cambridge, UK, July 2-5, 2007.

Appendix A – Glossary, Acronyms & Abbreviations

Glossary

advected plume – wind-transported exhaust plume, subject to local meteorological conditions

aerosol – aerodynamic suspension of particles in air

aircraft gas turbine engine – any gas turbine engine used for aircraft propulsion or for power generation on an aircraft, including those commonly called turbojet, turbofan, turboprop, or turboshaft type engines

black carbon –non-volatile diesel particulate matter, often used interchangeably with soot or elemental carbon (see below), although it is most often used when discussing optical properties

classical aerodynamic diameter – the diameter of an equivalent unit density sphere with the same settling velocity in still air as the particle in question

coarse particle – particle with a classical aerodynamic diameter between 2.5 and 10 μm

deposition – an airborne pollutant that reaches the ground by force of gravity, rain, or attaching to other particles

EIm – Emission Index (mass), the mass of emissions of a given constituent per thousand mass units of fuel burned (e.g. g/kg fuel) also total mass of particulate emissions in the same units

elemental carbon – often referred to as EC and frequently used interchangeably with black carbon and soot, although it is most often used when referring to chemical properties; the refractory carbon found in combustion-generated particulate matter; the portion of a sample of combustion-generated particulate matter that remains after volatile components have been removed; also known as graphitic carbon

engine exit plane – any point within the area of the engine exhaust nozzle at an axial distance within 0.5 diameters (or equivalent, if not circular) downstream from the outer edge of the nozzle

fine particle – particle with a classical aerodynamic diameter less than 2.5 μm

HAPs – Hazardous Air Pollutants, 188 pollutants that the Clean Air Act Amendments of 1990 required EPA to regulate; also referred to as "air toxics;" the complete list of pollutants can be found in Appendix C – The Clean Air Act Amendments of 1990 List of Hazardous Air Pollutants and on the EPA website: http://www.epa.gov/ttn/atw/orig189.html; for the purpose of this report, particulate matter, while hazardous and potentially toxic, are not included in the definition of HAPs

nonroad – mobile emission sources not commonly operated on public roadways such as airport ground support equipment, lawn mowers, etc.

nonvolatile particles – particles that exist at engine exit plane temperature and pressure conditions

nucleation – the process of initial formation of a particle from vapor; this process is usually facilitated by the presence of small particles called condensation nuclei, which serve as sites for condensation

organic carbon – often referred to as OC, is a major component of particulate carbon and is composed of many compounds most of which partition between the gas and aerosol phases at ambient conditions and are referred to as semi-volatile organic compounds (SVOC)

photochemical – the interaction of atoms, molecules, and light

PM_{10}, $PM_{2.5}$, $PM_{1.0}$ – regulatory designations of particulate matter less than or equal to 10 micrometers, 2.5 micrometers, and 1.0 micrometers, respectively, in diameter; these measures are similar to the terms coarse, fine, and ultrafine, respectively

primary particle – a particle that is emitted directly from the source

secondary particle – a particle that forms as the result of a chemical reaction or other means by combining with other elements after leaving the source

smoke – small gas-borne solid particles, including but not limited to black carbonaceous material from the burning of fuel, which in sufficient concentration create visible opacity

smoke number – (SN) the dimensionless term quantifying smoke emission; SN increases with smoke density and is rated on a scale from 0 to 100; SN is evaluated for a sample size of 16.2 kg of exhaust gas/m^2 (0.0239 lb/in^2) of filter area

soot – non-volatile diesel particulate matter, also referred to as black carbon or elemental carbon (see above)

total carbon – the sum of elemental carbon and organic carbon

ultrafine particles – particles with a classical aerodynamic diameter of less than 0.1μm

volatile particles – particles formed from condensable gases after the exhaust has been cooled to below engine exit conditions

Acronyms & Abbreviations

AAFEX – Alternative Aircraft Fuel Experiment

ACRP – Airports Cooperative Research Program

AEDC – Arnold Engineering Development Center

AEDT – Aviation Environmental Design Tool

AESO – Aviation Environmental Support Office

AFRL – Air Force Research Laboratory

AIR – Aerospace Information Report

APEX – Aircraft Particle Emissions Experiment

APU – Auxiliary Power Unit

ARP – Aerospace Recommended Practices

CAEP – Committee on Aviation Environmental Protection

CLEEN – Continuous Lower Energy, Emissions and Noise

COE – Center of Excellence

ESTCP – Environmental Security Technology Certification Program

FOA – First Order Approximation

GSE – Ground Support Equipment

HAP – Hazardous Air Pollutant

ICAO – International Civil Aviation Organization

NAVAIR – Naval Air Systems Command

NFESC – Naval Facilities Engineering Service Center

PM – Particulate Matter

SAE – Society of Automotive Engineers

UNA-UNA – Unknown Airport Unknown Airline

Appendix B - Primer on Aviation PM and HAP emissions

This appendix presents basic information on particulate matter emissions in general and aviation emissions specifically. This material was originally published by the Transportation Research Board, Airport Cooperative Research Program, in *ACRP Report 6: Research Needs Associated with Particulate Emissions at Airports, ACRP Report 7 Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis*, and *ACRP Report 9: Summarizing and Interpreting Aircraft Gaseous and Particulate Emissions Data*. Research activities are described, as are regulatory requirements. Analytical tools that are used to analyze these emissions are also described. Much of the general information on particulate matter is adapted from U.S. EPA data and information compiled in support of the National Ambient Air Quality Standards (NAAQS) for particulate matter.[1,2,3]

What is PM?

Particle pollution from fuel combustion is a mixture of microscopic solids, liquid droplets, and particles with solid and liquid components suspended in air. Solid particles are referred to as non-volatile particles and liquid droplets are referred to as volatile particles. This pollution, also known as particulate matter, is made up of a number of components, including soot or black carbon particles, inorganic acids (and their corresponding salts, such as nitrates and sulfates), organic chemicals from incomplete fuel combustion or from lubrication oil, abraded metals, as well as PM present in the ambient air due to natural sources, such as soil or dust particles, and allergens (such as fragments of pollen or mold spores).

The diameters of particles in the ambient atmosphere span five orders of magnitude, ranging from 0.001 micrometers (or 1 nm) to 100 micrometers. Larger particles, such as dust, soil, or soot, are often large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. Particle size is important to the health effects they pose since smaller particles can be inhaled more deeply into the lungs, with a more significant potential health impact compared to larger particles. Residence time in the air is also dependent on size. Particle size also is a key determinant of visibility impacts.

Larger particles, those smaller than 10 micrometers[4] but larger than about 2.5 micrometers, are referred to as coarse particles and typically represent most of the mass included in PM_{10}, the mass of particles smaller than 10 micrometers. Particles between 2.5 micrometers and 0.1 micrometers are referred to as fine particles. A particle 2.5 micrometers in diameter is approximately 1/30th the diameter of a human hair. Particles below 0.1 micrometers are considered ultrafine particles. Together, fine and ultrafine particles are represented as $PM_{2.5}$, meaning all particles less than 2.5 micrometers.

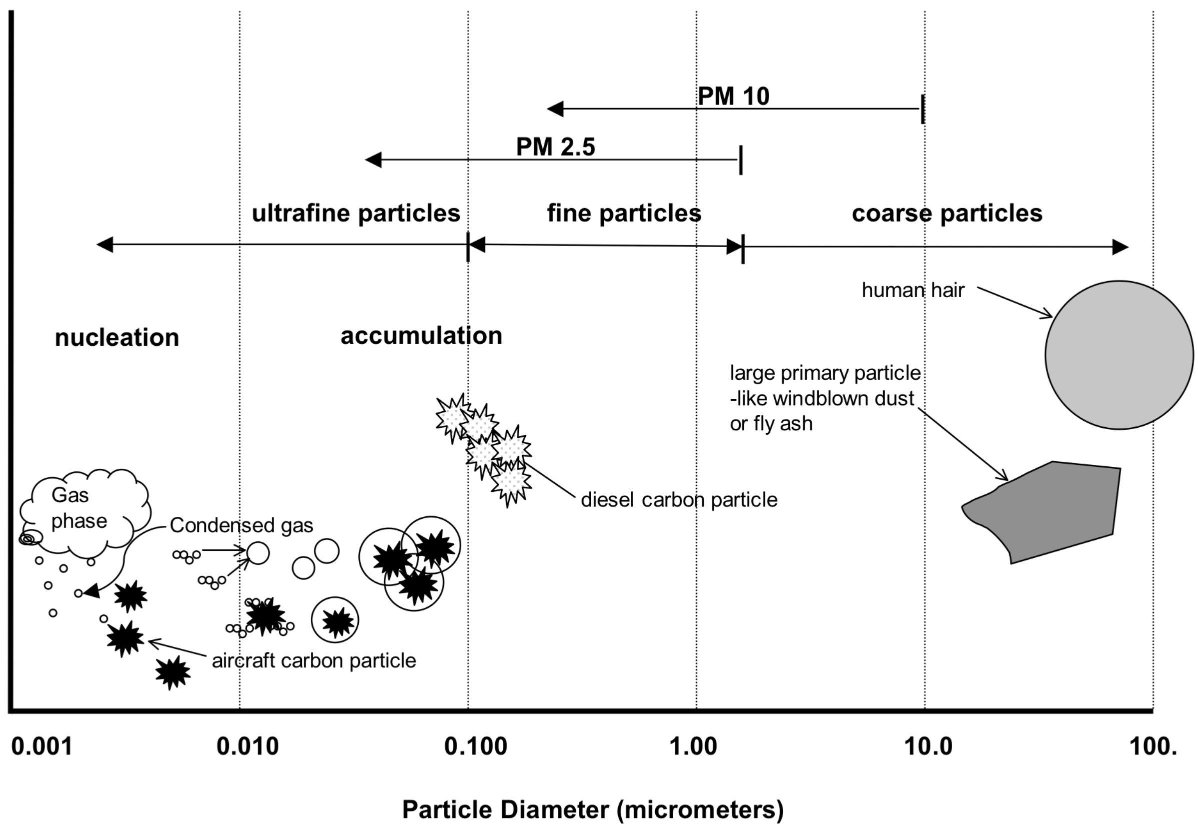
How is PM formed?

Different particle types tend to have different sources and formation mechanisms. Coarse particles around airports are generally primary particles from sources such as: wind-blown dust, sea spray, sand or salt storage piles, construction activity, or crushing or grinding operations (most commonly associated with construction activity). Ultrafine particles can arise from a number of sources as well, including primary PM produced during combustion or newly nucleated (e.g., condensed) particles formed in the atmosphere or in aircraft plumes from condensable gases. Ultrafine particle emission sources at airports include various fuel combustion sources such as aircraft, auxiliary power units (APU), ground support equipment (GSE), power turbines, diesel emergency generators, and vehicle traffic in and around the airport, as well as the atmospheric generation of new volatile particles from condensation. Ultrafine particles in aircraft exhaust include a variety of particle types ranging from those that form in the combustor (carbon particles), to those that nucleate from condensable gases (sulfuric

[1] Fine Particle (PM 2.5) Designations, Basic Information http://www.epa.gov/pmdesignations/basicinfo.htm
[2] Particulate Matter, Basic Information http://www.epa.gov/oar/particlepollution/basic.html
[3] Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, December 2005, http://www.eap.gov/ttn/naaqu/standards/pm/data/pmstaffpaper_20051221.pdf
[4] In this paper, particle size descriptions refer to the aerodynamic diameter (see definition for "classical aerodynamic diameter" in glossary).

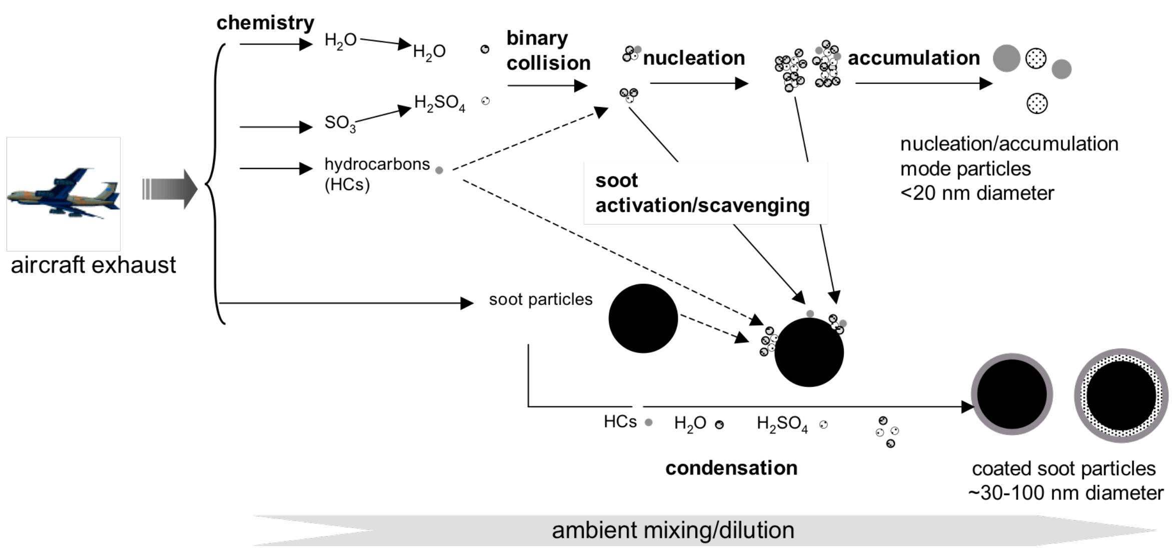
acid, partially burned fuel, and vaporized lubrication oil), and grow larger as a result of coagulation and condensation onto the particle surfaces in the 0.1 to 0.5 micrometer range. Diesel particles from GSE and other ground vehicles tend to be larger than aircraft particles and aggregate into chain particles rather than the more spherical particles seen from aircraft engines. The particles described here, which are emitted directly from a source or form in the immediate vicinity of the source, are referred to as primary particles or primary PM. Exhibit 1 illustrates the range of PM commonly encountered.

Exhibit 1: Particle Size of Airport PM Emission



Secondary particle formation, which results from complex chemical reactions in the atmosphere and/or particle nucleation processes, can produce either new particles or add to pre-existing particles. Examples of secondary particle formation include: (1) the conversion of sulfur dioxide (SO_2), which is produced by oxidation of the sulfur in fossil fuels, to sulfuric acid (H_2SO_4) vapor, which then forms droplets as the sulfuric acid condenses due to its low vapor pressure. The resulting sulfuric acid aerosol can further react with gaseous ammonia (NH_3), for example, in the atmosphere to form various particles of sulfate salts (e.g., ammonium sulfate $(NH_4)_2SO_4$); (2) the conversion of nitrogen dioxide (NO_2) to nitric acid (HNO_3) vapor that interacts with PM in the atmosphere, and reacts further with ammonia to form ammonium nitrate (NH_4NO_3) particles; and (3) reactions involving gaseous volatile organic compounds (VOC), yielding condensable organic compounds that can also contribute to atmospheric particles, forming secondary organic aerosol particles. The complex reactions that take place as a result of nucleation, condensation, accumulation, and reaction illustrate why measuring PM emissions can be so complex. Aircraft engine emission standards apply at the engine exit, yet PM of concern to regulators and the community are not fully formed at that point. Exhibit 2 illustrates the evolution of primary and secondary particles.

Exhibit 2: Evolution of Particulate Matter from Aircraft Engine Exhaust



Aircraft engines emit a mixture of soot and volatile gases. As pictured above, these gases cool to ambient temperature by mixing with ambient air and convert to the particle phase by condensation and nucleation/growth. The nucleation/growth mode particles and soot coatings are complex mixtures of sulfuric acid, water, partially burned hydrocarbons, and engine oil.

Ultrafine, fine, and coarse particles typically exhibit different behaviors in the atmosphere as the ambient residence time of particles varies with size. Ultrafine particles have a relatively short life, on the order of minutes to hours, and generally travel from less than a mile to less than 10 miles since they are likely to grow larger into fine particles. Fine particles remain suspended longer in the atmosphere since they do not grow larger and are too small to readily settle out or impact on stationary surfaces. They can be transported thousands of miles and remain in the atmosphere for days to weeks. Coarse particles can settle rapidly from the atmosphere with lifetimes ranging from minutes to hours (occasionally a few days) depending on their size, atmospheric conditions, and altitude. Large coarse particles are generally too large to follow air streams and tend to settle out gravitationally and by impacting onto stationary surfaces, rarely traveling more than 10 miles.

Fine and ultrafine particles suspended in the atmosphere absorb and reflect light, which is the major cause of reduced visibility (haze) in parts of the United States. Sulfates, nitrates, organic matter, and elemental carbon are primary components of these small particles.

How does PM affect health?

Coarse particles can be inhaled but tend to remain in the nasal passage. Smaller particles are more likely to enter the respiratory system. Health studies have shown a significant association between exposure to fine and ultrafine particles and premature death from heart or lung disease. Fine and ultrafine particles can aggravate heart and lung diseases and have been linked to effects such as: cardiovascular symptoms; cardiac arrhythmias; heart attacks; respiratory symptoms; asthma attacks; and bronchitis. These effects can result in increased hospital admissions, emergency room visits, absences from school or work, and restricted activity days. Individuals that may be particularly sensitive to fine particle exposure include people with heart or lung disease, older adults, and children.

How is PM regulated in the U.S.?

A wide range of regulatory provisions intended for environmental purposes apply to airport activity and equipment. Aircraft engines have certification requirements for smoke emissions, ground access vehicles are subject to tailpipe emission standards, the composition of jet fuel, diesel fuel, and gasoline are all regulated to limit harmful emissions, many operational activities and equipment require operating permits, and airport construction and expansion plans are subject to constraints where the regional air quality does not meet healthy standards. EPA sets most regulatory standards and many are administered by state agencies. FAA is responsible for ensuring these regulations do not pose conflicts with safety and other requirements especially for aircraft operations. This regulatory structure has developed over the past several decades.

As a result of health and visibility concerns from PM, EPA set the first NAAQS for PM in 1971. At the time, standards for "total suspended particles" (TSP) were based on the mass-based concentration of particles between 25 and 45 micrometers, which was the then state-of-the-art for particle samplers. The primary (health-based) standard was set at 260 micrograms per cubic meter of ambient air, 24-hour average, not to be exceeded more than once per year and 75 $\mu g/m^3$ annual average. A secondary (welfare-based) standard of 150 $\mu g/m^3$, 24-hour average, not to be exceeded more than once per year was also established. The standards were revised in 1987 (moving from TSP to PM_{10}), 1997 (adding $PM_{2.5}$), and again in 2006. The 2006 standards set levels for PM_{10} of 150 $\mu g/m^3$ for 24-hour average and $PM_{2.5}$ of 35 $\mu g/m^3$ for 24-hour average and 15 $\mu g/m^3$ annual average. The welfare-based secondary standards were made the same as the primary standard in 2006. EPA no longer regulates particles larger than 10 micrometers (e.g., sand and large dust) since they are not deemed readily inhalable. Recent studies by EPA have shown that $PM_{2.5}$ cannot be used as a surrogate for ultrafine particles, so future regulatory reviews may emphasize smaller particles, possibly using $PM_{1.0}$ as the regulatory standard.

EPA's regulatory approach sets standards for ambient air quality in geographic regions that generally represent metropolitan areas. The local PM concentration is the sum of all regional sources of PM and the regional ambient background. EPA estimates the annual average background for PM_{10} ranges from 4 to 8 $\mu g/m^3$ in the western U.S. and 5 to 11 $\mu g/m^3$ in the eastern U.S.; for $PM_{2.5}$, estimates range from 1 to 4 $\mu g/m^3$ in the west to 2 to 5 $\mu g/m^3$ in the east. PM emissions from airport and other regional sources mix relatively quickly with the ambient background PM. The combination of emissions from airports and other regional sources and ambient concentrations of PM result in a combined atmospheric PM loading that depends on complex, non-linear atmospheric processes, including chemical reactions and pollution transport. This makes it difficult to isolate the contribution of airport activity from all other emissions sources in an area.

In addition to the NAAQS there are other regulations that directly or indirectly effect PM emissions from aviation. For example, the International Civil Aviation Organization (ICAO) has established aircraft engine certification standards[5] that limit smoke emissions, as measured by "smoke number." Since smoke is a component of total PM, these standards indirectly influence aircraft PM emissions.

ICAO has also established international certification limits for oxides of nitrogen (NO_x) from jet engines. These limit the amount of NO_x emitted, which can produce nitrates that condense in the atmosphere hours to days after emissions forming secondary volatile particles. EPA has adopted ICAO's certification standards as national regulations. FAA in turn monitors and enforces engine certification.

Sulfur in jet fuel combines with oxygen from the air during combustion, producing sulfur dioxide (SO_2). This SO_2 is further oxidized to sulfuric acid after leaving the engine, and eventually all of the fuel sulfur becomes sulfate. A small fraction (a few percent or less) of the sulfur converts to sulfate before the engine plume disperses, and is considered part of the primary particulate matter emissions. The remaining sulfur converts to sulfate hours to days after the emission, contributing to secondary particulate matter. Sulfur emissions are directly related to the sulfur content of the fuel. Internationally accepted standards[6] for Jet A, which is the commercial aviation fuel used in the US, limit fuel sulfur content to 0.30% wt. maximum. In practice, however, Jet A sulfur content ranges between 0.04 and 0.06% wt[7].

Nonroad diesel equipment, such as GSE, is not required to have emission controls like diesel vehicles licensed for on-road use. Under new national regulations, EPA is requiring diesel fuel suppliers for nonroad equipment to reduce fuel sulfur content, eventually to the same ultra-low sulfur limits required for on-road diesel. This will allow the nonroad equipment to use advanced emission control technologies, which may be a requirement for these vehicles in the future. These requirements for diesel fuel sulfur limits and engine emission standards are

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[5] International Civil Aviation Organization, International Standards and Recommended Practices, Environmental Protection, Annex 16 to the Convention on International Civil Aviation, Volume II, Aircraft Engine Emissions

[6] ASTM International D 1655-04a, Standard Specification for Aviation Turbine Fuels

[7] Intergovernmental Panel on Climate Change, Aviation and the Global Atmosphere (1999)

being phased in between now and 2014. Reducing the fuel sulfur content and adding emission controls will reduce PM emissions from nonroad equipment by 90%[8]. GSE using alternative fuels such as compressed natural gas, propane, or electricity[9] have very little or no PM emissions.

Stationary emission sources at airports include various facilities and equipment like boilers, emergency generators, incinerators, fire training facilities, and fuel storage tanks. Many of these equipment types require specific operating permits with PM emission limits. Stationary sources typically represent about 1% of PM emissions at airports.

The National Environmental Policy Act of 1969 (NEPA) established a policy to protect the quality of the human environment and requires careful scrutiny of the environmental impacts of Federal actions, which could include grants, loans, leases, permits and other decisions or actions requiring Federal review or approval. For airports, NEPA applies to most major construction projects as a result of FAA funding or approval. One of the most common assessments used to confirm NEPA compliance for airport projects is General Conformity, which seeks to ensure that actions approved by the federal government do not cause increases in emissions that could exceed air quality standards. This serves to indirectly limit increases in ambient PM and other emissions.

What are the sources of PM at an airport?

There are many individual PM emission sources at airports. These include:

- Aircraft engines
- Aircraft auxiliary power units (APU)
- Ground support equipment (GSE)
- Passenger vehicles
- Tire and brake wear
- Stationary power turbines
- Training fires
- Sand and salt piles
- Construction grading and earth moving

PM emissions from each of these sources are different in terms of size, composition, and rate.

Emissions from these sources can be quantified by direct measurement using monitoring equipment or estimated using emission inventory methods. Historically for airport sources, emissions inventory methods have been most prevalent. These methods generally require information about each source's population, size, activity rate, and a PM emission factor or emission index. An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., milligrams of particulate emitted per kilogram of fuel burned). Such factors make it easier to estimate emissions from various sources of air pollution.

In some cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average). EPA maintains a reference[10] of emission factors for many sources. In other cases, specific emission factors are compiled for each emission source. For example, gaseous emission factors specifically for aircraft are included in the ICAO Aircraft Engine Emissions Data Bank[11]. Unfortunately, PM emission factors for aircraft, the largest PM source at airports, are not included in the Emissions Data Bank. Aircraft engine particulate emissions have not been well studied or characterized in the past and are only now being tested.

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[8] Environmental Protection Agency, Office of Transportation and Air Quality, *Final Regulatory Analysis: Control of Emissions from Non-Road Diesel Engines*, EPA420-R-04-007, May 2004.

[9] PM is emitted during electricity generation at the power plant, however, utility power production is well controlled compared to internal combustion engines and the net result is fewer PM emissions.

[10] AP-42, http://www.epa.gov/ttn/chief/ap42/index.html

[11] ICAO Aircraft Engine Emissions Data Bank http://www.caa.co.uk/default.aspx? catid=702&pagetype=90

Smoke Number data are in the ICAO databank, but are only a surrogate for PM emissions via the First Order Approximation (FOA) (see below).

GSE are commonly the second largest PM source at airports, sometimes comparable to aircraft as a PM source. GSE are mostly powered by diesel engines although a smaller percentage have gasoline engines and a smaller percentage still use electric power. The diesel and gasoline engines used by GSE are common engine types found in trucks and other industrial vehicles. PM emissions from these engines are well characterized for mass of emissions, however, in emission factor references GSE are typically lumped into a diverse set of equipment referred to as nonroad vehicles. This also includes lawn and garden equipment, agricultural equipment, commercial marine vessels, recreational equipment, and other vehicle types. This makes it difficult to compute PM inventories that reflect airport-specific emissions.

Why are aviation-related PM issues so important to airport operators?

Today, airports are faced with community, employee, and regulatory concerns about PM emissions, yet airports have very limited data on PM emissions from aircraft engines and APUs, data on other sources varies in quality and availability, and only limited data is available on ambient PM around airports. Newly tightened ambient air quality standards and greater health and environmental concerns present hurdles for airports as they need to modernize and expand to meet the increasing demand for air transportation. Yet airports represent only one PM emission source category among many in a region.

In addition to complying with General Conformity requirements and assisting states in complying with national ambient air quality standards, airports must address complaints from communities and employees who are concerned about health impacts resulting from exposure to airport emissions. Many airports also receive complaints about deposits of soot, grit, and oily residue airport neighbors find on their cars and outdoor furniture, which the complainants believe must come from airport activity.

Several airports have conducted particle deposition studies in nearby and adjacent communities to evaluate whether airport activity is responsible for the deposition of concern to the citizens. Deposition studies have been conducted near Los Angeles International Airport, T.F. Green Airport, Boston Logan International Airport, Charlotte/Douglas International Airport, Detroit Metropolitan Wayne County International Airport, John Wayne-Orange County Airport, Seattle-Tacoma International Airport, Ft. Lauderdale Hollywood International Airport, and Chicago O'Hare International Airport. None of these studies have shown a definitive link between the airports and the deposited material. These studies commonly find the deposits are typical of the material found throughout urban areas that come from diesel trucks, construction activity, wind-blown dust, pollen and mold. This is perhaps not unexpected since the PM from aircraft and APUs is comprised of fine or ultrafine particles, which are too small to settle gravitationally or to be deposited by impacting stationary surfaces and remain suspended in the atmosphere. These studies are not conclusive, however, since they used different methodologies and many only sampled dry deposition and did not collect material deposited through rainfall, which is a primary mechanism for scrubbing suspended particles from the atmosphere. Future deposition studies will be able to build on these findings and new information coming from aircraft PM research to improve our understanding of the contribution of airport emissions to deposited PM.

As noted earlier, little was known about aircraft PM emissions until recently when several federally funded research programs were conducted. To date, a great deal is known about a few engines with no testing done on most of the engine models in the fleet. The research results are still being analyzed to better understand PM formation in aircraft engines and its evolution in the plume. Even for those engines studied, more testing will be required to gain the data needed to develop emission factors with the same level of confidence as for emission factors used for other emission sources, which can relate operating conditions to final state PM emissions.

With regard to GSE, EPA has taken steps to reduce PM emissions from nonroad vehicles. In response to national environmental regulations, refiners will begin producing low-sulfur diesel fuel for use in locomotives, ships, and nonroad equipment, which includes GSE. Low-sulfur diesel fuel must meet a 500 parts per million (ppm) sulfur maximum. This is the first step of EPA's Nonroad Diesel Rule, with an eventual goal of reducing the sulfur level of fuel for these engines to meet an ultra-low standard (15 ppm) to enable new advanced emission-control technologies for engines used in locomotives, ships, and other nonroad equipment. These most recent nonroad engine and fuel regulations complement similarly stringent regulations for diesel highway trucks and buses and highway diesel fuel for 2007.

Beginning June 1, 2006, refiners began producing clean ultra-low sulfur diesel fuel, with a sulfur level at or below 15 parts per million (ppm), for use in highway diesel engines. Low sulfur (500 ppm) diesel fuel for nonroad diesel engines will be required in 2007, followed by ultra-low sulfur diesel fuel for these vehicles in 2010.[12] Stringent emissions standards for new GSE will be phased in between 2008 and 2014 as part of this rule. Whether and when similar reductions in fuel sulfur content will occur in aviation jet fuel has yet to be determined.

What tools are available for evaluating PM emissions at airports?

As noted earlier, airport emissions are analyzed by applying emission factors, drawn from emissions testing data of representative sources, to airport-specific operational data for various emission sources, and then all sources are combined into an "emissions inventory." Inventories are usually represented in mass emissions per unit of time (e.g., lbs/day or tons/year). Inventories are typically compiled for criteria pollutants and their precursors (i.e., NO_x, SO_x, CO, VOC, and PM). Various analytical tools are available to support these complex computations and aid in analyzing the results.

Emissions and Dispersion Modeling System (EDMS)[13]

EDMS is a combined emissions and dispersion model for assessing air quality at civilian airports and military air bases. The model was developed by the Federal Aviation Administration (FAA) in cooperation with the United States Air Force (USAF) and is used to produce an inventory of emissions generated by sources on and around the airport or air base, and to calculate pollutant concentrations in these environments.

PM emissions are computed for aircraft main engines in EDMS version 5.0.2 by applying the First Order Approximation version 3.0a, where smoke number data are available. PM emissions for on-road vehicles are computed using the MOBILE model, described below. Similarly, PM emissions for GSE are computed using the NONROAD model. EDMS also contains a database of PM emission factors for stationary sources that are commonly found at airports. No data currently exist for modeling PM from aircraft auxiliary power units (APU).

MOBILE[14]

As mentioned above, EDMS uses the EPA-developed MOBILE model (version 6.2 is included with EDMS 5.0.2) to compute emission factors for on-road vehicles. MOBILE allows the user to model emission factors for a fleet of vehicle types or an individual vehicle class based on the mix of vehicle types and age, and considers vehicle speed and ambient meteorological conditions as well.

NONROAD[15]

Similar to MOBILE, EPA's NONROAD model provides emission factors for ground support equipment at airports that consider the rated horsepower of the engine, fuel type, and the load factor. The traditional application of the model is to use the embedded database of county-level nonroad fleet information, however, the underlying vehicle data was extracted by the EPA for use in EDMS to allow the emissions for individual vehicles to be computed.

First Order Approximation 3.0a (FOA3a)[16]

First Order Approximation 3.0 (FOA3), is being developed by the ICAO Committee for Aviation Environmental Protection (CAEP) Working Group 3 to estimate PM emissions from commercial aircraft engines in the absence of acceptable data or emission factors. Data from the APEX aircraft engine emission

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[12] Environmental Protection Agency Clean Air Nonroad Diesel – Tier 4 Final Rule, http://www.epa.gov/nonroad-diesel/2004fr.htm
[13] Emissions and Dispersion Modeling System Homepage http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/
[14] MOBILE 6 Homepage http://www.epa.gov/otaq/m6.htm
[15] NONROAD Homepage http://www.epa.gov/otaq/nonrdmdl.htm
[16] Kinsey, J., Wayson, R.L, EPAct PM Methodology Discussion Paper (2007).

tests is being used in its development. FOA3 models three components of PM using the sum of three separate equations: a power and polynomial function of smoke number for non-volatile PM, a constant for SO_4, and a function of HC emission indices for fuel organics. EDMS uses the FOA3a methodology for U.S airports, which includes additional reasonable margins to accommodate uncertainties. FOA3a adapts the FOA3 equations to be more conservative in the calculation of SO_4 and fuel organics while keeping the equations the same for non-volatile PM.

Aviation Environmental Design Tool (AEDT) [17]

AEDT, presently under development and testing, is designed to incorporate and harmonize the existing capabilities of the FAA to model and analyze noise and emissions. Building on current tools, including EDMS, common modules and databases will allow local and global analysis to be completed consistently and with a single tool. With this tool, users will be able to analyze both current and future scenarios to understand how aviation effects the environment through noise and emissions on a local and global scale.

Aviation environmental Portfolio Management Tool (APMT)[18]

APMT is currently being developed by the FAA as a component of AEDT to allow tradeoffs between noise and emissions to be better understood. The tool has three primary capabilities: cost effectiveness analysis, benefit cost analysis, and distributional analysis. The “costs” and “benefits” are computed at a societal level by considering economic and health effects.

Community Multiscale Air Quality model (CMAQ)[19]

CMAQ was developed through a NOAA-EPA partnership and allows the analyst to model a variety of air quality effects, including: tropospheric ozone, toxics, acid deposition, and visibility degradation. This is accomplished by including robust modeling of the atmospheric physics and chemical reactions. The scale of the model is variable with grid sizes ranging from less than 4 km to over 36 km depending on the needs of the analysis.

Microphysical Models

Microphysical models refer to a class of atmospheric models intended to predict cloud formations based on the formation and size of droplets and the nucleation of particles. The same techniques used to predict water-based clouds in the sky can be applied toward predicting the formation of plumes of aerosols and particulate matter. Microphysical modeling has been used to model aviation PM evolution both at altitude and at ground level.

What about Hazardous Air Pollutants?

In addition to PM, measurements during APEX and from older military engines indicate the presence of hazardous air pollutants (HAPs), alternatively referred to as air toxics. HAPs are regulated by the EPA based on the cancer and non-cancer risk they pose with acute or chronic exposure. Volatile organic compounds (e.g., toluene), chlorinated volatile organic compounds (e.g., tetrachloroethylene), and metals (e.g., nickel) are three classes of HAPs. As dictated by the Clean Air Act, the EPA maintains a list of HAPs. Additionally, for mobile source emissions the EPA maintains a “Master List of Compounds Emitted by Mobile Sources”. Measurements of ambient HAP concentrations are not as widespread as those of the criteria pollutants. Descriptions of individual HAPs and their sources and emissions at airports have been provided in recent documents.

In addition to aviation, many sources emit HAPs, including ground transportation, construction, power generation, and dry cleaning. At airports, several sources contribute to HAPs emissions. A partial list of “airside” sources includes baggage tugs, solvent use, and the aircraft themselves. Benzene and formaldehyde

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[17] Federal Aviation Administration, Office of the Environment and Energy *AEDT News,* (1:1), September 2007.
[18] Aviation Environmental Portfolio Management Tool (APMT) Prototype http://www.faa.gov/about/office_org/headquarters_offices/aep/models/history/media/2006-02_CAEP7-WG2-TG2-6_IP02_APMT_Prototype.pdf
[19] CMAQ Homepage http://www.epa.gov/asmdnerl/CMAQ/cmaq_model.html

are two commonly known aircraft-engine HAPs. Airport “road-side” sources include on-road vehicles (cars, buses, shuttles, etc.).

Appendix C – Literature Reference

Recent literature searches on PM and HAP emissions from aviation sources are summarized in this appendix.

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Appendix D - AEC Roadmap 6th Meeting – Participants and Meeting Minutes

Participants

The individuals listed below participated in the most recent AEC Roadmap 6th Meeting of Primary Contributors held June 17-18, 2008 in Durham, NC at EPA's Research Triangle Park offices.

Rich Altman	Commercial Aviation Alternative Fuels Institute (CAAFI)
Stephen Andersen	US Environmental Protection Agency (EPA)
Bruce Anderson	US National Aeronautics & Space Administration (NASA)
Steven Barrett	Cambridge University
Steve Baughcum	Boeing Company
Francis Binkowski	University of North Carolina, Chapel Hill
Bruce Cantrell	BKC Consulting
Meng-Dawn Cheng	Oak Ridge National Laboratory (ORNL)
Edwin Corporan	US Air Force, Air Force Research Laboratory (AFRL)
Will Dodds	GE Aviation
Lawrence Goldstein	Transportation Research Board, Airports Cooperative Research Program (ACRP)
Mohan Gupta	US Federal Aviation Administration, Office of Environment and Energy (FAA/AEE)
Adel Hanna	University of North Carolina, Chapel Hill
Greg Hemighaus	Chevron
Jim Hileman	Massachusetts Institute of Technology (MIT)
Curtis Holsclaw	US Federal Aviation Administration, Office of Environment and Energy (FAA/AEE)
Robert Howard	US Air Force, Arnold Engineering Development Center (AEDC)
Leon Hsu	Harvard School of Public Health (HSPH)
Chris Hurley	QinitiQ
Sabrina Johnson	US Environmental Protection Agency (EPA)
Alan Kao	Environ
John Kinsey	US Environmental Protection Agency (EPA)
Xu Li-Jones	US Navy
David Liscinsky	United Technologies Research Center (UTRC)
Prem Lobo	Missouri University of Science and Technology (MS&T)
Carl Ma	US Federal Aviation Administration, Office of Environment and Energy (FAA/AEE)
Bryan Manning	US Environmental Protection Agency (EPA)
Lourdes Maurice	US Federal Aviation Administration, Office of Environment and Energy (FAA/AEE)
Ed McQueen	US Federal Aviation Administration, Office of Environment and Energy (FAA/AEE)
Rick Miake-Lye	Aerodyne, Inc.
David Nelson	Aerodyne, Inc.
John Pehrson	Camp, Dresser & McKee (CDM)
Mel Roquemore	US Air Force, Air Force Research Laboratory (AFRL)
Bill Sowa	Pratt & Whitney
Kathy Tacina	US National Aeronautics & Space Administration (NASA)
Ian Waitz	Massachusetts Institute of Technology (MIT)
Roger Wayson	Volpe
Sandy Webb	Environmental Consulting Group, Inc. (ECG)
Darcy Zarubiak	Jacobs Consulting

AVIATION EMISSIONS CHARACTERIZATION ROADMAP

Sixth Meeting of Primary Contributors
U.S. Environmental Protection Agency
Research Triangle Park
Durham, NC
June 17-18, 2008

MEETING MINUTES

June 17, 2008

1. Introductions and logistics – John Kinsey [EPA] and Ed McQueen [FAA]

John Kinsey welcomed the attendees to EPA's Research Triangle Park offices and provided logistics information. All meeting attendees introduced themselves.

Ed McQueen described the meeting expectations and identified the following key issues to consider:

- transition from Product Group to Coordination Council
- expansion to include HAPs
- engagement with international community
- identification of knowledge gaps and need for new initiatives
- whether current and forecast research funding is sufficient to support prospective policy decisions on
    - fuel sulfur content
    - NOx stringency
    - ICAO PM certification standards

2. Roadmap Integration Process and Broader Policy Initiatives - Curtis Holsclaw [FAA]

Curtis described the Roadmap integration process as a means to visualize how different groups are coordinated and ensure linkages between groups are confirmed. It is also a means to facilitate development of metrics, measurement procedures, and impact analysis methodology, use databases and forecasts to develop and assess baseline emissions and impacts, implement a framework for evaluating changes in impacts, develop guidance for air quality analysis and compliance with national requirements, and support liaison with ICAO CAEP to promote a basis for regulatory consideration.

With regard to CAEP, **Curtis** noted that FAA is coordinating activities with CAEP. An upcoming meeting will consider increasing NOx stringency; further characterize PM emissions; coordinate with SAE E-31; assess PM emissions certification methodology; and strive to understand health and environmental impacts of PM and HAP.

Also with CAEP working groups, FAA is working to coordinate development of methods, models, and guidance materials for environmental assessment, specifically for further development of FOA , modeling guidance to Task Group 4, and guidelines to SAE A-21 emissions (noise) product work team.

In the coming year, ICAO CAEP is considering NOx stringency assessment; setting goals on NOx technology, fuel burn technology/operational, and environmental performance; and understanding potential use and emissions from alternative fuels, which includes using low sulfur jet fuel. **Curtis** showed LTO NOx emissions and indicated where new stringency may be set (CAEP 6 less 20%).

With EPA and EASA, FAA has worked to provide input to SAE E-31. Guidance was offered to E-31 on the following three issues:

- pursue a test method based on total (volatile and non-volatile) PM mass measured at the engine exit plane
- proceed with work on a test method for PM number
- devote available resources towards research to answer key remaining questions

The agencies requested a draft ARP to address total PM emissions from aircraft engines by end of 2010.

With regard to HAP emissions guidance, a HAP emission methodology for inventory is needed that is nationally consistent, scientifically supported, representative of today's fleet, and something that can be updated regularly. Based on new HAP data and NEPA-driven need to understand HAP emissions, a technical data report has been produced with new profile for aircraft. A new guidance document is being developed and this new information is being incorporated into EDMS 5.1.

Looking ahead, there are several policy implications that may be important:

- LTO certification standards for (volatile and non-volatile) PM
- PM and gaseous emissions interdependencies and secondary effects
- incremental health impacts
- removing sulfur from jet fuel
- cruise emissions that influence climate
- assessing HAP emissions beyond inventories

Curtis summarized by noting there is a clear need for more information on PM and HAP emissions to support complex, significant policy considerations.

ACTION ITEM – **Curtis** to provide the letter from EPA, FAA, and EASA to SAE E-31 for distribution to all attendees. **[NOTE: Letter can be found in a separate file (CAEP8_WG3_CETG4_IP02 [EASA-EPA-FAA Letter to E-31 080509 FINAL]-1).pdf transmitted with the minutes as well as posted to the AEC Roadmap KSN website.]**

3. Energy Policy Act Study - Ian Waitz [MIT]

In the Energy Policy Act (EPAct) of 2005 (Public Law 109-58), Congress required FAA and EPA to conduct a study of the impact of aircraft emissions on air quality, identifying opportunities to promote fuel conservation to enhance fuel efficiency and emissions reductions, and identify ways to reduce air traffic inefficiencies that increase fuel burn and emissions. The EPAct Study was funded under Partner Project 15 (and related work) by FAA and EPA. The focus of the report is on the impact of aircraft emissions on nonattainment regions. A baseline of emissions for 148 airports (increasing ultimately to 325 airports) was developed and emissions were modeled with EDMS, which provided input data to CMAQ, which provided input to BenMAP. The inventory included APU emissions, based on an APU utilization survey. The project used FOA 3a, which is significantly more conservative than FOA 3.

Aviation's contribution to regional $PM_{2.5}$ inventories is below 2.5% in nonattainment areas with a national average of 0.2%. The project used CMAQ to evaluate the impact if aviation emissions were removed from the inventory completely. Primary and secondary emissions, as contributions to ambient air quality in nonattainment areas, show significant impact in certain regional areas – notably Southern California. Similar results were found for ozone impact regionally although the national average is 0.12% aircraft contribution to ozone inventory. Aviation's contribution to ozone health impact is small compared to other sources like power plants and vehicle traffic for ozone health impacts and much less than PM health impacts from aviation sources.

The analysis showed the importance of secondary SOx, secondary NOx, primary PM, and primary organics. The results underscore the importance of secondary aerosols although there are significant uncertainties. Modeling resolution and impacts above 3,000, which were not included in the analysis, may result in an underestimate of impacts by a factor of 2-20.

4. Update on JPDO and NextGen – Lourdes Maurice [FAA]

Lourdes described the JPDO structure and the framework for NextGen, which is to develop the aviation system that we will need to handle 2-3 times capacity by 2025. A key element of the JPDO is the Environment Working Group, which is charged with developing environmental protection strategies to allow sustained aviation growth.

Lourdes noted the challenge is to reduce aviation's environmental footprint, even with projected growth. The way forward is to have an absolute reduction in noise and air quality emissions impacts achieved through:

- better science and modeling
- accelerated air traffic management modernization
- encouraging new aircraft technology
- developing alternative fuels
- market based initiatives and international collaboration

Primary impacts of concern for aviation are from PM (primary and secondary impacts) rather than ozone. Improvement in ATM can reduce delays and hence emissions. Better science is essential, which emphasizes the significance of the AEC Roadmap and similar initiatives.

The way forward comprises the following strategies:

- better science and integrated analysis
- improved ATM
- new aircraft technology (e.g., CLEEN)
- new alternative fuels that will reduce aviation's environmental footprint (ULS fuels – either conventional Jet A or synthetics will reduce PM)
- policy initiatives such as long term environmental targets and a national framework for Environmental Management Systems, and
- international collaboration (e.g., ICAO CAEP)

In summary, Lourdes noted that environmental constraints to aviation growth are real and environmental challenges need to be addressed. R&D is an essential element and the AEC Roadmap is a prime example of an initiative that is critical to the success of NextGen.

5. ACRP 02-04 PM Emissions from Airports – Sandy Webb [ECG]

Sandy reviewed the work on ACRP project 02-04 *Research Needs Associated with Particulate Emissions at Airports.* During the project 80 airports were surveyed to determine their need for information about PM emissions and any concerns they had. Based on that information, select airports representatives were identified for follow up detailed interviews. Several PM researchers were also interviewed in detail and the scientific literature was reviewed for latest data and information on airport PM emissions. From this collection of information, the current state of knowledge on aviation PM emissions was summarized and critical knowledge gaps were identified.

Research needed to fill the current knowledge gaps was described and the project team developed several problem statements for ACRP to consider for future funding. **Sandy** noted that the project report would be published and available in July 2008.

6. ACRP 02-04a PM and Gaseous Emissions Testing – Prem Lobo [MS&T]

Prem reviewed the data collected from engine emissions testing campaigns and reviewed the various findings from an evaluation of that data. As with ACRP 02-04, knowledge gaps related to engine-specific data needs were defined. He listed the engines for which data is needed to effectively characterize today's fleets and particularly noted that the results indicate a mass-based inventory is inadequate to capture the significant volatile PM production observed in the plume.

An extended discussion followed on the need for number-based measures of PM emissions vs. mass-based measures only.

7. ACRP 02-03 HAP Emissions from Airports – David Nelson [Aerodyne]

David presented the project findings and a prioritized research agenda based on the project work activities focused on HAPs and secondary organic PM. The project focused on emissions and toxicology of HAPs.

David noted the need to combine emission rates and toxicology to assess priority of HAP emissions. Taking toxicology into account changes the analyst's perspective of the importance of individual sources and compounds. For example, taking toxicity into account, the significance of aircraft grows from approximately one quarter of the concern to approximately three quarters of the concern and stationary sources practically disappear in significance.

Based on the work of the project team, aircraft at idle are the predominant source of HAPs at a typical airport; emissions and toxicity evaluation yields a new listing of most important HAPs related to aviation; HAPs from non-aircraft sources, notably GSE, can be significant; current speciation profiles are generally accurate; and, atmospheric processing in plumes is important.

In the prioritized research agenda, **David** identified four key activities for information development needed to better understand HAP emissions at airports.

1. Quantify dependence of HAP emissions as a function of ambient conditions and engine technology.
2. Quantify actual thrust levels used by aircraft during low thrust phase of the LTO cycle.
3. Quantify HAP emissions from GA aircraft.
4. Identify emission sources most important to on-airport and off-airport exposure.

8. Alternative PM Testing and Certification – Stephen Andersen [EPA]

Stephen noted that the use of EPA Method 5 for aircraft engine testing came about in a misapplication of procedure, in part because it was readily available. However, it is time consuming and expensive.

Development of the Joint Strike Fighter (JSF) was moving in a way that was inconsistent with using Method 5 and typical procedures so a new approach and method was needed. The project to address the need for JSF testing and certification followed an aggressive timeline with adequate budget. They dismissed Method 5 as obsolete.

EPA was willing to commit to using a new procedure if the interim methods and resulting data were scientifically valid and both volatile and nonvolatile particles were included in the interim method.

Stephen declared the new process is state of the science technology, it relies on real time measurement, and it is informing key policy issues on NextGen.

9. PM Sampling Progress and Open Issues – Robert Howard [AEDC]

Robert reviewed the key findings from the development work on the interim JSF testing method related to PM sampling. Among key findings he noted that line losses were modest in unheated lines, which largely agreed with predictions of empirical models, and would typically lead to a < 10% underestimate of particle mass emissions; line losses in heated lines were larger than predicted and could lead >20% underestimate of particle mass emissions. The military will be running methodology evaluation/validation tests late this summer on an F100 engine at Tinker AFB.

Robert then reported on a new SBIR project awarded to Aerodyne to advance volatile PM sampling.

In summary, **Robert** noted that probe tip effects on PM sampling have not been validated; there is an open question about probe tip dilution versus dilution addition just downstream and probe tip temperature cooling effects; a better understanding of sample line temperature effects is needed. Also, volatile particle processing measurements are needed that are representative of conditions several meters downstream of the exit plane whether in plume or sample line and there is a need for an absolute calibration source.

There followed an extended discussion of line loss issues and alternative means of calibrating and accounting for changes to the particles in the sampling system.

10. Alternative Fuels - Candidate fuels, Production potential and Schedule – Jim Hileman [MIT]

Jim noted that increasing price of fuel and environmental impacts motivates the need for alternative fuels. He described several alternative jet fuels, notably the synthetic paraffinic kerosene. Ultra low sulfur jet fuel, which is an alternative composition not alternative feedstock, is the nearest term candidate for an alternative jet fuel.

Jim presented a wide variety of alternative fuel production projects showing their development status and process, noting that you can get two thirds of production capacity of jet fuel as a maximum, although typical from historical production is more like 20%. He noted that a typical large airport uses approximately 1 million gallons of jet fuel a day, which is comparable to 25 thousand barrels a day of jet fuel production. He then gave an overall assessment of how much alternative jet fuel could be supplied via different fuels over a 10-year horizon.

In conclusion, **Jim** explained that many projects are being pursued but the scale is small and the time frame is long.

11. Combustion Emissions from Alternative Jet Fuels – Edwin Corporan [AFRL]

Edwin summarized engine emission evaluations conducted using alternative fuels. He presented test results and future plans for further testing. AFRL tested a helicopter engine with biodiesel, oxygenates, and a Fisher-Tropsch (FT) fuel in 2003-2004. In 2006-2007, they tested helicopter, B52, and TF33 engines using JP-8 and FT fuel blends. Also in 2007, they tested a CFM-56 engine at GE on FT fuel blends, neat FT fuel, and two biojet fuels. More recently they tested a PW308 at a Pratt& Whitney facility on FT fuel blends and neat FT fuel.

From their testing they found significant benefits from FT fuels on PM emissions – demonstrating both a reduction in particle size, particle number, particle mass, and smoke number. **Edwin** noted the reduction in PM emissions is primarily due to reduced aromatics. Also, AFRL found no compromise on engine performance with neat FT fuel.

CFM-56 testing results showed reduced particle size and number, reduced smoke number, and a significant reduction in PAH compounds in soot. The results also showed reduced CO and sulfur emissions but otherwise negligible impact on other gaseous emissions.

Based on testing to date, AFRL has found there are beneficial impacts on emissions with FT fuel. This was confirmed on all platforms tested to date with the largest benefits at low power. The Air Force is moving forward with certification of weapon systems for a 50/50 FT fuel blend by 2011.

12. Alternative Aviation Fuel Experiment – Bruce Anderson [NASA]

Bruce noted that alternative (synthetic or bio) fuels offer a short-term means of meeting the increasing global demand for crude oil-derived fuels that can also be manufactured domestically, which helps improve our energy security. Alternative fuels can also produce lower emissions to help alleviate aviation impacts on local air quality and climate. For these reasons, NASA is planning the Alternative Aviation Fuels Experiment (AAFEX), which is needed to determine the exact impact of alternative fuels on gas-turbine engine performance and emissions.

The objectives of AAFEX are to examine the effects of alternative fuels on the performance and primary emissions of a commercial jet engine, to investigate the effects of engine power, fuel composition, and ambient conditions on volatile aerosol formation and growth in aging aircraft exhaust plumes, and to establish APU emission characteristics and examine their dependence on fuel composition.

NASA is planning to use government-owned aircraft so there will be no restrictions on data (CFM-56), use standard methods, and follow ICAO certification tests. They will look at the impact of ambient conditions and plan to test both coal and natural gas derived FT fuels. The project is planned for Palmdale (fewer security issues) in January 2009.

Bruce offered an open invitation to other agencies to participate in AAFEX. NASA will pay for aircraft, fuel, operations, etc. and other participants can bring their own instruments.

13. Alternative Fuels Developments – Rich Altman [CAAFI]

Rich noted that CAAFI is striving to demonstrate the aviation industry's intent to become "first mover" into alternative fuels. The initiative's strategy is to certify fuels early, ensure R&D activity to support this intention is in place, to promote discussions between airlines and fuel suppliers, and ensure the greenhouse gas life cycle emissions are significantly beneficial.

Certification targets are for 50% FT blends, including biomass, to be certified by 2008, 100% FT blends, again including biomass, and 50% biojet blends to be certified by 2010, and pure hydrotreated oils and second generation algae fuel to be certified by 2013.

Rich described three plants representing three million gallons per day potential alternative fuels production that are targeting product available for the 2012-2013 time frame.

14. SERDP – Soot Production R&D – Mel Roquemore [AFRL]

A 2006 RFP initiated the SERDP research program into soot production. SERDP selected five programs to participate. The overall program was developed from the five programs that responded to the RFP. The problem focus and program motivation was non-volatile PM2.5, using JP8 and alternative fuels.

Mel described the sequence of steps in combustion activity, with increasing levels of complexity, that organize the program's science.

15. SERDP – Volatile Particle R&D – Rick Miake-Lye [Aerodyne]

Rick noted that the volatile particle work is one year behind soot studies. The objective is to understand the formation and fate of volatile PM. The focus is on composition and properties of the volatile components and a desire to understand the species and particles and their dependence on ambient conditions.

Rick then reviewed the four projects that comprise the volatile particle program. The projects are for four years or less. Among other objectives, they want to understand new volatile particle formation and volatile coating of soot particles.

16. NASA Technology Assessment and Development Plans – Bill Sowa [P&W] & Kathy Tacina [NASA]

Kathy noted that understanding the engineering control of the physics driving PM and volatile PM precursor emissions and how technologies can reduce PM emissions is in its initial stages. The Technology Development Group plans to evaluate measurement methods and conduct parametric studies to develop a fundamental understanding of the formation, destruction, sensitivities, and control of aircraft PM emissions and provide critical tools and information to the development of advanced technologies (combustor, engine, fuels, etc.) for PM emissions reduction.

NASA has research projects on many if not all of the program elements from the (formerly titled) PM Roadmap Technology Development Product Group work plan including the following:

- national combustion code improvements
- model-based design of high temperature, high pressure particle sampling systems
- particulate studies that can simulate conditions up to 45,000 feet
- microstructure, morphology, and nanostructure assessments of particles

Bill described alternative fuels testing with the P&W geared turbofan. They are similar to the tests described above by **Edwin Corporan**. PM emissions were reduced with an alternative fuel/jet fuel blend; other emissions did not change.

17. PartEmis – Chris Hurley [Qinitiq]

The objective of PartEmis (Measurement and Prediction of Emissions of Aerosols and Gaseous Precursors from Gas Turbine Engines) was to make comprehensive measurements of the physical and chemical properties of a gas turbine exhaust from combustor to engine exit, specifically looking at the physical and chemical properties of the aerosol emissions and their interaction with each other and gaseous exhaust components. Testing was conducted on a combustor and a unit that simulated a three-shaft turbine section (i.e., hot end simulator (HES)) with operating conditions simulating cruise temperatures (at 30,000 feet). The project measured the chemical composition of the exhaust gases including speciation of the organic and inorganic components, including ions. The fuel sulfur content was varied to measure its effect on the exhaust composition and properties.

The test program consisted of two sub-programs; measuring the exhaust composition at the combustor exit (January-February 2001) and measuring the exhaust composition at the high pressure, intermediate pressure, and low pressure stages of the HES (March 2002). Measurements were made at two engine cruise conditions characteristic of modern and older engines with fuel at three different sulfur levels (50 ppm, 410 ppm, and 1,270 ppm for the first sub-program and 40 ppm, 400 ppm, and 1,300 ppm for the second). The aerosol properties that were measured include: mass and number concentration, size distribution, mixing state, thermal stability, hygroscopicity, cloud condensation nuclei (CCN) activation potential, and chemical composition. Inter-stage measurements helped characterize particle properties as they pass through an engine's turbine stages. Aerosol composition testing found more than 100 non-methane VOCs and their composition was independent of fuel sulfur content.

Chris reported that the following conclusions were drawn from the testing:

- Smoke size and number density are unaffected by HES stage fuel sulfur content and operating conditions.
- Significant aerosol mass is produced with diameters > 1µm.

- Increasing particle shrinkage with fuel sulfur content and decreasing size.
- Particle surface area is unaffected by fuel sulfur content but increases through HES stages.
- Particle hydroscopicity increases with fuel sulfur content, small particles are more hydroscopic.
- Cloud condensation nuclei increases with fuel sulfur content and HES stage.
- Peak number density of volatile aerosol is < 4μm.
- Sulfate increases with fuel sulfur content, measurement sampling system dependent.
- S(IV) to S(VI) conversion varies with power setting, HES stage and fuel sulfur content.
- The majority of total HC is methane, with significant carbonyl and carboxylic acid concentrations present.

There was extensive discussion regarding the final conclusion with regard to the presence of methane in jet engine exhaust.

Chris reported that potential future work is for use of the HES for comparative measurements involving both the EU and US. He noted the advantages of HES over engine measurements are:

- Low running costs.
- Flexible operating conditions.
- Steady emission levels – long sampling times possible.
- Optical access at LP exit.
- Well-mixed sample is available at each stage and no by-pass flow.
- Direct access at each stage (e.g. direct sampling into a mass spectrometer).
- Diluted and un-diluted heated sample lines.
- Passivated sampling system.
- Dedicated accommodation for participants.
- Inexpensive variation of fuel sulfur content.

18. Multi-scale Air Quality Impacts of Aviation – Steven Barrett [Cambridge/MIT]

The goal of **Steven's** research was to identify how many people die (i.e., premature mortality) as a result of aviation globally each year, identifying which flight phases are important, and which segments of the population are most at risk. His proposed modeling framework is intended to predict changes in ground-level pollutant concentrations attributable to aviation globally and to estimate health impacts and regulatory compliance costs.

Global, regional, local, and plume scales are all important ranging from jet mixing and plume chemistry to dispersion, advection, and source effects, to advection, convection, and atmospheric chemistry. His 3D plume modeling approach, which reproduces experimental results from Heathrow, was described.

His initial modeling results showed 7,600 premature deaths worldwide due to aviation - especially impacts due to cruise emissions resulting in surface level pollutant concentrations. 90% of the impact is due to secondary PM. LTO emission impacts reflect aviation activity (e.g., high in eastern US, western Europe, and south east Asia).

19. PM Monitoring Study at Teterboro Airport – Alan Kao [Environ]

The Teterboro Airport has been the site for an assessment of the impacts of aviation emissions. Extensive monitoring was conducted at two locations off primary runways and two modified monitoring stations. LTOs at Teterboro were slightly bimodal, Saturday was lowest air traffic day; road traffic was bimodal during weekdays and unimodal on weekends with Sunday the lowest traffic day.

Teterboro monitoring showed the highest cancer screening risk for all monitoring sites around the state; the result is dominated by formaldehyde. Similar results were found for non-cancer screening risk. According to **Alan**, it was clear that background emissions were a significant portion of monitored compounds. For the study, a summertime spike in formaldehyde, which is not completely understood, is driving the risk. $PM_{2.5}$ showed slight elevation but may reflect different monitoring equipment. A report on the study is available (http://www.state.nj.us/dep/dsr/teterboro).

20. PVD Airport Monitoring Project – Alan Kao [Environ] (on behalf of Brenda Pope [T.F. Green Airport (PVD)])

The work plan for conducting the monitoring project was approved in October 2007. Four monitoring stations have been established near the ends of runways around the airport. The plan will monitor for VOCs, SVOCs, carbonyls, $PM_{2.5}$ (total mass), black carbon, particulate-bound PAHs, and ultrafine particles. Monitoring will also include Pb monitoring to support the EPA NAAQS review. The monitoring was installed during the first quarter of 2008 and will continue until 2015 (i.e., 7 years).

21. Air Quality and Source Apportionment Study at LAX Airport – Darcy Zarubiak [Jacobs Engineering]

July 10 will be the start of a new monitoring program at LAX planned to run for one year. Air quality hurdles to airport modernization are motivating the project. The study is to determine existing emissions, sources, and LAX contribution, and to provide a data set of monitored pollutants that can be used to apportion LAX emissions. The study is not a health effects or epidemiology study.

Monitoring at LAX has been going on since 1998 but with the new data, **Darcy** notes they hope to be able to apportion emissions to sources. The project will start with a demonstration project to confirm methods and instruments. Eight regulatory agencies are participating in study.

22. PM Response Surface Model - Ian Waitz [MIT]

According to **Ian**, current regional models are too slow for policy comparison. A surrogate model was developed for use with APMT. EPA already has a multi-pollutant PM response surface model (RSM). MIT used that model and made it specific to aviation, using four variables – fuel burn, NOx emission index (EI), fuel sulfur content, and non-volatile PM EI. The model does national level emissions concentrations; predicts typically within 1% of CMAQ with worst case being only within 5% of CMAQ.

Calculated health impacts are about half of those from using intake fraction method and similar to results of the EPACT study. Apportioning health impacts showed an allocation of 30% SO2 and volatile sulfur PM, 28% NOx, 11% non-volatile PM, and 30% VOCs and organic volatile PM. Work is underway to improve and extend this PM RSM component of APMT.

23. FOA Development Update - Roger Wayson [Volpe Center]

Roger described the FOA3.0 structure and recent development activities. He identified several sources of error in FOA's prediction accuracy, largely due to the lack of correlation between smoke number and PM. He showed a proposed new structure that would add several new elements to the methodology. There is also a goal to add an element to capture the effects of lubrication oil.

At the end of the presentation there was an extended discussion of the benefits of continuing support for FOA and the need for a phase out plan, as working on FOA is not a long-term endeavor. Lourdes specifically noted that FOA may be good enough and we should focus efforts on the next steps – not minute enhancements to FOA.

24. Hydrocarbon Speciation Profile for Aviation – John Kinsey [EPA]

John explained the need for improved HAP speciation and the ability to convert between unburned hydrocarbons (THC) and total organic gases (TOG). He reviewed the shortcomings of the current speciation profile.

For the new profile, the APEX HAPs data set was used. He noted that HAPs are predominantly from low power operations (e.g., idle and taxi). There are no gas phase hydrocarbons in engine emissions above 30% power. (P&W noted that their emissions experts agree with this assessment).

All HAPs data tracks the emissions of formaldehyde. Based on this data, a new HC (including HAPs) profile was developed. It will be published in a report and added to SPECIATE-4.2, EPA's HC speciation reference as Profile No. 5565 . Future projects (e.g., APEX-4 campaign) will be a source of data to reduce the unresolved components and the magnitude of uncertainty remaining in the new profile.

25. Update on Researcher's and Policy Databases – Prem Lobo [MS&T]

Prem reported that data from all engine measurement campaigns is being compiled into a database, referred to as the Researcher's Database. It originally was a PM database, but HAPs have recently been added. It is structured along lines of ICAO databank. He demonstrated an Excel file that now includes all available data.

Data from JETS APEX2 and APEX3 has not been added to the database yet because all of the data collected during those campaigns has not been released. He anticipates that it will be incorporated into the researcher's database within the next year.

The Policy Database will be derived from the Researcher's Database and will include verified emission factors for individual engines much as the ICAO databank. No schedule was reported for the availability of a Policy Database.

26. Air Quality Impacts of Aviation Modeling – Adel Hanna [UNC]

Aviation emissions of NOx and $PM_{2.5}$ are small (generally <1%) but future growth and certain areas motivate interest in modeling/analyzing these emissions. The work at UNC has focused on three airports – Atlanta (ATL), O'Hare (ORD), and T.F. Green (PVD). The models used include EDMS, which provides inputs to SMOKE, which in turn provides inputs to CMAQ. This approach allows modeling of a wide range of scales from the airport vicinity to regional US.

The modeling demonstrates airports contribute (i.e., increase) $PM_{2.5}$ and aerosol emissions. **Adel** noted the secondary components of $PM_{2.5}$ contribute about 50-60% of total $PM_{2.5}$ impacts for all three airports studied. Aircraft emissions can have a spatial influence of up to 200 km from the airport.

27. Health Impacts of Aircraft Particulates – Leon Hsu [HSPH]

First order risk assessment of health impacts due to aviation emissions was conducted based on dispersion model emissions. The sequence of study steps was emissions > concentration changes > damage estimation > outcome valuation and aggregation. The study focused on emissions at three airports (PVD, ORD, ATL). Emissions from AERMOD and CMAQ were linked with potency, concentration-response function values, and population patterns to estimate which compounds contribute most to population risks and which uncertainties would be valuable to reduce.

The study found that formaldehyde dominates risk for air toxics but updating risk figures may move it from a cancer risk to non-cancer risk. The study also found that 108 sq km covers most exposure, with much lower rates of exposure found beyond that limit.

Secondary PM is more relevant to population impacts than primary PM. **Leon** noted the study determined that the effects of criteria pollutants are much greater than the effects of air toxics on cancer. It is necessary to model at regional or national scale for PM; smaller-scale modeling may be adequate for air toxics. Standard methods cannot capture non-cancer effects well, especially in the presence of multiple co-exposures.

28. ACRP Update and Upcoming Projects - Larry Goldstein [TRB/ACRP]

Larry reported on several projects that are significant for the AEC Roadmap.

ACRP 02-03a – is a new HAP project. The RFP was just released. The project is to measure gaseous HAP emissions from idling aircraft as a function of engine operations and ambient conditions. The project has a $500k budget and a 24-month schedule. Proposals are due in about 60 days for an expected project start in Fall 2008.

ACRP 02-06: GHG Emissions Inventory Guidebook – is nearing completion.

ACRP 02-08: Quantifying Contribution of Airport Emissions to LAQ – is a project to prepare a guidebook for airports to use to conduct monitoring and modeling. The contract has just been signed and the project will start soon.

ACRP02-09: Development Plan for Multimodal Noise and Emissions Model. This project has a budget of $200k and a project schedule of 13 months. The contract is awaiting approval and the project is expected to start in the summer of 2008.

29. PARTNER Project Planning - Jim Hileman [MIT]

Jim reported on the PARTNER steps to identify new projects and develop a strategic plan for PARTNER:

- Identify research gaps
- Define projects that PARTNER would like to work on
- Focus on FY08 & FY09, but consider longer term as well
- Prioritize projects
- Consider PARTNER competencies

The process is collaborative with participation from PARTNER Investigators and Advisory Board Members. There are four planning groups: Noise, Air Quality, Climate, and Interdependencies. There are over 80 participants within the four groups. Six telecons per group were conducted over two months and 53 potential new projects were identified.

Jim reviewed current projects, new, funded projects, and other proposed but unfunded projects in each of the four planning groups.

30. Planning for APEX4 – Carl Ma [FAA]

Carl reviewed the previous campaigns and emphasized how one campaign builds on all prior campaigns. There will be a new approach to APEX4, with a more focused research agenda. Key goals include:

- measure HAP species for mass balance
- support the needs of E-31 for sampling methodologies

- integrate PARTNER Projects 11 and 16 by modeling near and far field plumes plus exposure and health impact
- minimize measurement duplication
- leverage funding.

There was a discussion of the opportunity to calibrate instruments against each other where duplication may be taking place and possible standardization of instruments.

Planning to date includes telecons, coordination among agencies, refinement of goals, and lists of action items assigned to individual participants. The timeline is undetermined at this point; it depends on test conditions, airline and airport availability, funding level, and demonstration of "compelling" need.

31. AEC Roadmap Document – Sandy Webb [ECG]

Sandy reviewed an outline of the AEC Roadmap Document. The document is envisioned to be a reference document to PM and HAP research activities that may be of interest to AEC Roadmap participants as well as others that may be outside of the immediate Roadmap activities.

The document will include a description of the AEC Roadmap organizational plan, referencing the Roadmap's terms of reference. Key policy goals needing support and information on PM and HAPs will be identified. The interrelationships between the various primary funding agencies will be shown to highlight their connection and support for various research initiatives. Individual project summaries will be included for reference by AEC Roadmap members and others with an interest in aviation PM and HAP emissions. Supporting appendices will include a glossary and list of acronyms, a primer on PM and HAP emissions, a summary of essential literature references, and a participants list and meeting minutes from this meeting.

32. Agency Coordination, Budget Outlook, and Future Direction – Lourdes Maurice [FAA]

Lourdes discussed her perspective on the progress of research that is coordinated under the umbrella of the AEC Roadmap. She noted that much of the research has been very successful and great progress has been made in understanding PM and HAPs emissions from aviation sources. She noted that having an international presence at the meeting was significant and in the future the Roadmap could be improved by getting Omega and ECATS research incorporated into the Roadmap. She also noted the benefit of having a greater presence of DOD in the Coordination Council telecoms and the annual meeting. She also noted that ACRO is critical to progress.

Her expectation is that the FAA budget for PM/HAP will increase next year (if the President's budget request for FY09 is approved), which is very significant. She believes good progress is being made and that is an endorsement for the continuation of the AEC Roadmap.

33. Conclusions and Considerations Going Forward – Sandy Webb [ECG]

Sandy led a review and discussion of key findings, decisions, and future considerations that had been recorded by the FAA/AEE staff during the meeting up to this point.

Key Conclusions and Research Needs:

- Determining incremental health impacts are critical from a policy/regulatory perspective - integration of research efforts is key to facilitate analysis.
- Research is needed to address E-31 issues in response to policy and regulatory needs.
- A sampling system is needed to measure volatile PM emissions at the engine exit.
- Secondary formation of PM emissions has been identified as a predominant influence on health impacts associated with aircraft engine emissions.
- Sulfur oxide and NOx emissions from aircraft engines have been identified as the predominant PM emissions contributor.
- An updated, speciated HC profile for aircraft engines is being developed based upon recent APEX measurement data; a methodology for inventorying HAPs emissions associated with commercial aircraft fleets is also being developed for publication.
- Additional HAPs emissions data is needed to characterize the current commercial aircraft fleet especially with regard to the current estimate of 23% unknown mass and methane.
- Further research is needed to understand HAPs emissions due to variations in ambient conditions.
- The impact of climb/cruise emissions (outside of the LTO) on air quality could be significant and warrants more assessment.
- Further research is needed to fully understand evolution and fate of PM emissions from airports sources (e.g. aircraft, GSE and APU).
- SERDP/DOD research projects have many of the same objectives as non-military research projects, thus offering opportunities for filling knowledge gaps.
- Alternative fuels research is gaining sponsorship especially due to rising fuel costs and GHG emissions consequences.
- Results from the European PartEmis project provide a basis for comparative analysis against results from US projects; published research project papers are being made available for review and contacts

with individual researchers can be arranged through **Chris Hurley**.

- Airport monitoring studies are being carried out to understand emissions sources that contribute to air quality and health impacts.
- The development and use of a PM RSM approach is beneficial to analyzing a variety of policy scenarios to estimate apportionment of health impacts.
- Further analysis of measurement data and model formulation is required to understand areas for improving upon FOA3.
- Pollutant fate and transport modeling has progressed and is a productive area for further research.
- Assess model scale with impact to measure aviation emission impacts from the area around airports to broader regional impacts.

<u>Considerations going forward:</u>

- Continue Coordination Council telecons to promote more integrated research activities.
- Future measurement campaigns should be expanded to cover modeling and exposure aspects that contribute to advancing the impact analyses.
- Coordination Council should assess the E-31 response to agency direction and identify specific actions including research that can be included in current and near term activities.
- Future measurement campaigns should address gaps in the gas-phase HAPs emissions database to improve the national guidance for assessing HAPs emissions inventories.
- Identify resources for developing a sampling system leveraging on current and planned SERDP/DOD project efforts.
- Make better use of linkages with ongoing SERDP projects to advise Roadmap activity.
- Make use of PartEmis research program results to advise future measurements and analysis under the Roadmap.
- Engage Roadmap participants in the planned FAA ULS study as appropriate and brief progress/results at the next annual roadmap meeting.
- Assess PM emissions at altitude and potential influence on air quality.
- Consider combining measurement campaign goals and objectives to maximize resources and leverage for combined effectiveness (e.g. consider use of AAFEX as measurement campaign platform in lieu of APEX4 for the near term).
- Monitor progress of airport monitoring studies, review results as they

are made available, and consider how future measurement programs might benefit from lessons learned.

- Consider how uncertainties associated with PM RSM might be addressed through further research activities coordinated under the Roadmap.
- Consider how future measurement programs and resulting data can be used to improve FOA3 and identify an appropriate version that should serve to suffice as the FOA going forward for use until a database of actual PM emissions exists.
- Extend detailed sampling and analysis to APUs, GSE, and other airport sources.
- Role of the Roadmap needs to be continually updated and redefined.
- Open discussions on annual research projects and schedules are very helpful. A chart (a Gaant Chart for example) to show the schedule for various research programs would be helpful.

AVIATION EMISSIONS CHARACTERIZATION ROADMAP

Sixth Meeting of Primary Contributors

U.S. Environmental Protection Agency
Research Triangle Park
Durham, NC
June 17-18, 2008

FINAL AGENDA

June 17, 2008

08:30am – 08:45am	Welcome and Introductions [Ed McQueen, FAA; John Kinsey, EPA]
08:45am – 09:00am	Meeting Expectations [Ed McQueen, FAA]
09:00am – 09:20am	Roadmap Integration Process Status [Curtis Holsclaw, FAA]
09:20am – 09:50am	Update on the Energy Policy Act Study [Ian Waitz, MIT]
09:50am – 10:15am	Update on JPDO and NextGen [Lourdes Maurice, FAA]
10:15am – 10:30am	*Morning Break*
10:30am – 11:30pm	ACRP PM/HAPs Update • Particulate Emissions at Airports [Sandy Webb, ECG] • Gaseous and Particulate Emissions Data for Aircraft [Prem Lobo, MS&T] • Aircraft and Airport Related HAPs [Scott Herndon, Aerodyne]
11:30am – 12:15pm	Particle Modeling and Measurement Developments • PM Sampling – Progress and Open Issues [Robert Howard, AEDC] • Alternative PM Testing Method [Stephen Andersen, EPA]

12:15pm – 01:30pm	*Lunch Break*

01:30pm – 02:45pm — Alternative Fuels Developments [Rich Altman, CAAFI – Moderator]

- Alternative Jet Fuels – Candidate Fuels, Production Potential, and Production Schedule [Jim Hileman, MIT]
- Emissions from Alternative Jet Fuels [Edwin Corporan, AFRL]
- AAFEX – Alternative Aviation Fuel Experiment [Bruce Anderson, NASA Langley]

02:45pm – 03:45pm — Technology Modeling and Development Projects

- SERDP (Strategic Environmental Research and Development Program) /ESTCP (Environmental Security Technology Certification Program) Projects Update –
  - Non-Volatile [Mel Roquemore, AFRL]
  - Volatile [Rick Miake-Lye, Aerodyne]
- NASA Technology Assessment and Development Plans [Bill Sowa, P&W/Kathleen Tacina, NASA]

03:45pm – 04:00pm — *Afternoon Break*

04:00pm – 05:00pm — EU Research Activities

- Update on Partemis [Chris Hurley, Qinitiq]
- Multi-scale Air Quality Impacts of Aviation [Steven Barrett, University of Cambridge/MIT]

June 18, 2008

08:00am – 9:00am — Airport PM/HAP Monitoring Projects

- PM Monitoring Project at T.F. Green Airport, Providence Rhode Island [Brenda Pope, TF Green]
- PM Monitoring Project at Los Angeles International Airport [Darcy Zarubiak, Jacobs Consulting]
- PM Monitoring Study at Teterboro Airport, NJ [Alan Kao, Environ]

09:00am – 10:45am	Air Quality Modeling and Health Impacts • Response Surface Modeling – Initial Findings [Ian Waitz, MIT] • First Order Approximation Development Update [Roger Wayson, Volpe] • Hydrocarbon Speciation Profile for Aviation [John Kinsey, EPA] • Update on Researchers' and Policy Databases [Prem Lobo, MS&T] • Air Quality Impacts Modeling [Adel Hanna, UNC] • Response Surface Modeling – Initial Findings [Ian Waitz, MIT] • Health Impacts of Aircraft Particulates [Leon Hsu, Harvard School of Public Health]
10:45am – 11:00am	*Morning Break*
11:00am – 12:00pm	Upcoming Projects of Interest to AEC Roadmap Participants • Upcoming ACRP HAP Project and Air Quality Modeling Project [Larry Goldstein, TRB] • New PARTNER Projects [Jim Hileman, MIT] • Planning for APEX 4 [Carl Ma, FAA] • Identification of Research Program Gaps or Other Projects of Interest [Open to Meeting Participants]
12:00pm – 12:15pm	AEC Roadmap Document [Sandy Webb, ECG]
12:15pm – 12:40pm	Agency Coordination, Budget Outlook, and Future Direction [Lourdes Maurice, FAA]
12:40pm – 01:00pm	Conclusions and Considerations Going Forward [Sandy Webb, ECG]

The meeting agenda is designed to allow all participants to catch flights out of Raleigh/Durham International Airport at 4:00 pm.