Joint Planning & Development Office
Environmental Integrated Product Team

Partnership for AiR Transportation
Noise and Emissions Reduction

Workshop on the Impacts of Aviation on Climate Change: A Report of Findings and Recommendations

June 7-9, 2006, Cambridge, MA

Executive Summary

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Contents

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Acknowledgement

I first want to acknowledge the effort of the Next Generation Air Transportation System/Joint Planning and Development Office (NGATS/JPDO) Environmental Integrated Product Team (EIPT) and the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) in getting the Workshop established and to thank the FAA Office of Environment and Energy and NASA Science Mission Directorate's Applied Science Program for providing the support for setting up the actual Workshop. Given that there were no special travel funds provided for attending the Workshop, I also thank the many organizations that contributed this to the participants. The Subgroup leaders, Anne Douglass, Bernd Kärcher, and Wei-Chyung Wang, did a wonderful job of chairing their sessions and organizing the writing for the Workshop report. A special thank you to Mohan Gupta and Malcolm Ko for their extensive help with the meeting preparations and in reviewing this report. I also greatly appreciate the additional reviews of the report we received from David Fahey, Mark Jacobson, and Brian Toon. Finally, I want to also express a big thank you to all of the speakers and participants for their time and efforts. The community interest and participation in this Workshop was exemplary, particularly given the short-lead time for the Workshop. It is this community interest and involvement in establishing the relevance of the issues and in laying the groundwork for the research associated with aviation and climate change that will lead to the successful new research efforts we all hope will result from this Workshop.

Workshop Chair

Don Wuebbles

Executive Summary

The effects of aircraft emissions on the current and projected climate of our planet may be the most serious long-term environmental issue facing the aviation industry [IPCC, 1999; Aviation and the Environment – Report to the United States Congress, 2004]. However, there are large uncertainties in our present understanding of the magnitude of climate impacts due to aviation emissions. With extensive growth in demand expected in aviation over the next few decades, it is imperative that timely action is taken to understand and quantify the potential impacts of aviation emissions to help policymakers address climate and other potential environmental impacts associated with aviation.

The climatic impacts of aviation emissions include the direct climate effects from carbon dioxide (CO_2) and water vapor emissions, the indirect forcing on climate resulting from changes in the distributions and concentrations of ozone and methane as a consequence of aircraft nitrogen oxide (NOx) emissions, the direct effects (and indirect effects on clouds) from emitted aerosols and aerosol precursors, and the climate effects associated with contrails and cirrus cloud formation. To enable the development of the best strategy to mitigate these climatic impacts scientists must quantify these impacts and reduce current uncertainties to enable appropriate action. The only way to ensure that policymakers fully understand trade-offs from actions resulting from implementing engine and fuel technological advances, airspace operational management practices, and policy actions imposed by national and international bodies is to provide them with metrics that correctly capture the climate impacts of aviation emissions.

As a first step in response to the need to address these issues, the Next Generation Air Transportation System/Joint Planning and Development Office (NGATS/JPDO) Environmental Integrated Product Team (EIPT)[1] *and the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER)*[2] *convened a panel of experts from around the world to participate in a "Workshop on the Impacts of Aviation on Climate Change" during June 7-9, 2006 in Boston, MA.* The stated goals of the workshop were to assess and document the present state of knowledge of climatic impacts of aviation; to identify the key underlying uncertainties and gaps in scientific knowledge; to identify ongoing and further research needed and to make prioritized recommendations as to how additional funding may be leveraged to take advantage of other on-going funded research programs; to explore the development of metrics for aviation climate-related trade-off issues; and to help focus the scientific community on the aviation-climate change research needs.

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[1] The EIPT is one of eight integrated product teams of the NGATS/JPDO charged with the role of formulating a strategy that allows aviation growth consistent with the environmental-related goals of NGATS. The JPDO, jointly managed by FAA and NASA, serves as a focal point for coordinating the research related to air transportation for all of the participating agencies (Federal Aviation Administration, NASA, the Departments of Commerce, Defense, Homeland Security, Transportation, and the White House Office of Science and Technology Policy).

[2] PARTNER is a Center of Excellence supported by the Federal Aviation Administration, the National Aeronautics and Space Administration, and Transport Canada.

This report documents the findings and recommendations of the Workshop. While the report does not represent a peer reviewed assessment, the intention is to use the results to provide guidance for the agencies and private sector stakeholders participating in the EIPT to develop and implement an aviation climate research plan to reduce uncertainties to "levels that enable appropriate actions" [Next Generation Air Transportation System-Integrated Plan, 2004].

A major internationally coordinated effort to assess the impacts of aviation on the global atmosphere was sponsored by the U.N.'s Intergovernmental Panel on Climate Change (IPCC, 1999). Since then, while new information has become available, there has been no comprehensive attempt to update the assessment of the science and the associated uncertainties. During this time period, there have also been discussions of how to define the best metrics to account for the wide range of spatial and temporal scales of aviation-induced climate impacts. This workshop agreed with IPCC (1999) that the three most important ways that aviation affects climate are (1) direct emissions of greenhouse gases including CO_2 and water vapor, (2) emissions of NOx that interact with ozone, methane, and other greenhouse gases, and (3) persistent contrails and their effects on cirrus cloud distribution. For this workshop, our focus was on the impacts of subsonic aviation emissions at cruise altitudes in the upper troposphere and lower stratosphere (UT/LS) and on the potential response of the climate system to these emissions. However, it is also recognized that all aircraft emissions must be considered.

Although current fuel use from aviation is only a few percent of all combustion sources of carbon dioxide, the expectation is that this percentage will increase because of projected increase in aviation and the likely decrease in other combustion sources as the world moves away from fossil fuels towards renewable energy sources. In addition, aircraft nitrogen oxides released in the upper troposphere and lower stratosphere generally have a larger climate impact than those emitted at the surface, although some of the much larger surface emissions from energy and transportation sources also reach the upper troposphere.

The workshop participants acknowledged the need for focused research efforts in the United States specifically to address the uncertainties and gaps in our understanding of current and projected impacts of aviation on climate and to develop metrics to characterize these impacts. This could be done through co-ordination and/or expansion of existing and planned climate research programs or may entail new activities. Such efforts should include strong and continuing interactions between the science community, aviation system operators and policy developers to ensure that the most up-to-date science is readily available for policy considerations and that scientists are aware of the questions and challenges faced by operators and policy developers. Participants were asked to provide both short-term (three to five years) and long-term prioritized research needs with achievable goals and objectives that can help to address the uncertainties and gaps associated with key questions on aviation induced climate impacts. These research priorities also include the need to identify, develop and evaluate metrics to characterize the climate impacts of aviation to aid the policy-making process.

Research into the environmental effects of aircraft emissions cannot be decoupled from basic atmospheric research, such as fundamental understanding of the physics and chemistry in the UT/LS region and aerosol-cloud interactions in the context of global climate modeling. The overall science focus of this workshop was divided into three particular Subgroups: (1) Emissions in the UT/LS and resulting chemistry effects, (2) Effects of water and particle emissions on contrails and on cirrus clouds, and (3) Determining the resulting impacts on climate from aircraft emissions and defining metrics to measure these impacts.

Key Findings

A. Emissions in the UT/LS and Resulting Chemistry Effects

State of the Science

The potential importance of aircraft emissions of nitrogen oxides (NOx) (and also from hydrogen oxides (HOx) from water vapor emissions into the stratosphere) on tropospheric and stratospheric ozone has been recognized for several decades. The effects on ozone (O_3) can also affect the production of tropospheric OH and thus affect levels of methane (CH_4). There have been substantial improvements in the chemistry-transport modeling tools used to evaluate the impacts of aviation NOx emissions on O_3 and CH_4 since the 1999 IPCC assessment. The database of observations in the UT/LS has been greatly expanded, and data from the European MOZAIC program (instruments on commercial aircraft) and focused field campaigns are commonly being used to evaluate the global model background state, emphasizing the composition of the upper troposphere and the transition from the troposphere to the lowermost stratosphere. Improvements to the representation of the atmospheric circulation have resulted in better models for the composition and fluxes of ozone and other species in this region. The magnitude of this flux and its spatial and seasonal variability are similar to quantities derived from observations in some models, and uncertainties have been reduced. These improvements should help to better assess the aviation impacts. There are continuing efforts that compare simulations with observations that will likely lead to development of observation-based performance metrics for atmospheric models.

Uncertainties and Gaps

One family of uncertainties in evaluating aviation effects on climate derives from specific model formulation errors and can be addressed by laboratory, numerical, or atmospheric studies that focus on the specific process.

- *Aircraft emissions of gases and particles*. Remaining uncertainties in the emissions, both from uncertainties in how much is emitted (e.g., soot, sulfates) from each aircraft and from uncertainties in the global distribution of these emissions with altitude, latitude, and longitude, need further consideration.
- *The fundamental NOx and HOx chemistry of the upper troposphere*. Large disagreements between the modeled and measured abundances of HOx and NOx gases in the upper troposphere point to errors in either the measurements or in the tropospheric chemical mechanisms and rates. This

discrepancy is not found in the lower stratosphere.

- *Lightning NOx.* Better understanding of lightning NOx in terms of sources and their relationship to convection is needed to evaluate the aircraft perturbation, especially for future climates.
- *Plume processing of aircraft NOx in the first 24 hours*. Better understanding of the possible conversion of NOx to nitric acid (HNO_3) in the aircraft plume needs to be attained.

A second type of uncertainty involves coupling across different Earth system components, and possible non-linear responses to perturbations and/or feedbacks within the chemical system.

- *The coupling and feedbacks of tropospheric CH_4-CO-OH-O_3.* There is no single test (based on observations) that gives confidence that any model accurately responds to a NO_x perturbation.
- *Climate change.* Analyses of future aircraft fleets need to be considered relative to the climate expected. Most model studies and all observations of the meteorology and background chemistry are derived from today's climate.
- *Scavenging.* The process whereby gaseous HNO_3 (and thus NOx) is removed from the atmosphere involves large-scale transport, convection, cloud processes and precipitation. This coupling is a major uncertainty in current chemistry-transport models.
- *Transport and Mixing.* Aircraft emissions will accumulate in atmospheric regions of relatively slow, or stagnant mixing. The seasonality of these regions, the apparent barriers to mixing, and the rapid mixing through convection or other breakdowns in atmospheric stability are a major uncertainty in evaluating aviation impacts today.

Research Recommendations and Priorities

- *Models and Measurements Intercomparison*. A Models and Measurements Intercomparison, emphasizing the UT/LS and free troposphere, should be conducted. This process should lead to model improvements and reduction of uncertainty in model predictions.
- *Vertical transport processes between 2 and 10 km*. Additional measurements and data analyses, along with modeling analyses, are needed to reduce uncertainties in treatment of convection and other transport processes, and in the treatment of lightning effects.
- *Data analysis and modeling*. Expand the analysis of the wealth of data being obtained in the UT/LS by different aircraft and satellite platforms to further constrain the magnitude and seasonality of turnover rates and mixing processes.
- *Re*-examine the impacts of aviation in the UT/LS using several of the improved models.

In the longer-term, field campaigns may be needed to address issues with HOx-NOx chemistry in the UT and to better understand background processes. Further improvements are needed in laboratory studies of heterogeneous processes and low-temperature kinetics.

B. Contrails and Cirrus

State of the Science

Contrails form if ambient air along the flight track is colder and moister than a threshold based on known thermodynamic parameters. Contrails initially contain more but smaller ice crystals than most cirrus clouds. Early contrail evolution depends, in not well understood ways, on aircraft and engine emission parameters. At times contrails organize themselves in long-lived, regional-scale clusters in ice supersaturated air masses. The radiative effect of contrails is different during the day than at night. Aircraft-induced contrail-cirrus add significantly to the natural high cloud cover and have the potential, albeit with large uncertainties, for a relatively large positive radiative forcing (direct effect). Line-shaped contrails are only a portion of the total climate impact of aviation on the cloudiness.

Recent correlation analyses between real-time regional-scale air traffic movements and the occurrence of contrail structures detectable with satellites, suggest the global coverage of persistent, spreading contrails (contrail-cirrus) and inferred radiative forcing might be underestimated by an order of magnitude or more, but large uncertainties remain.

Homogeneous freezing of supercooled aqueous solution droplets initiated by rapid mesoscale temperature fluctuations is a ubiquitous pathway to form cirrus clouds in-situ globally. A global impact of aircraft soot particles processed in dispersing plumes on cirrus (indirect effect) cannot be excluded. By number, aviation might double the background black carbon loading in the UT/LS. The indirect effect depends, along with details of plume processing, on the ability of background aerosol particles to act as ice-forming nuclei. The potential of soot particles emitted by aircraft jet engines to modify high cloudiness in the absence of contrails is affected by the frequent observation of high supersaturations with respect to the ice phase, the relatively small number of heterogeneous ice nuclei (IN) in cirrus conditions, and the ever-presence of mesoscale temperature fluctuations inducing large cooling rates and setting the stage for cirrus formation.

Uncertainties and Gaps

A number of uncertainties and gaps were identified in contrail-cirrus and other aircraft-induced effects on cirrus clouds:

- *Plume particle processing*. It is not well understood how properties (number concentration, surface area, composition, and mixing state) of ambient aerosols are perturbed in the presence of jet engine emissions under various atmospheric conditions and aircraft configurations. Detailed investigations of the microphysical and chemical processes governing the evolution of aviation aerosols in the time scale of days after emission is required.
- *Optical properties of contrails, contrail-cirrus, and cirrus*. Factors controlling the radiative properties of cirrus clouds and contrail-cirrus (ice crystal habit, vertical profiles of ice water content, effective radius) are poorly constrained by observations. The balance between cooling from reflection of sunlight and warming from trapping of heat radiation is also poorly understood.
- *Detection and prediction of ice supersaturation*. Contrails and the expansion of contrails into cirrus clouds occur in an ice supersaturated environment. However, the global distribution of supersaturation in the upper troposphere is not adequately known.

- *In-situ measurements of aerosol chemistry and small ice crystals*. Cirrus ice crystals can range from a few to hundreds of μm or more in size. Measuring this large range requires several instruments and improved agreement between instruments. Existing instrumentation also cannot easily measure the shape of the numerous very small crystals that have been found in contrails and cirrus clouds.
- *Properties of heterogeneous ice nuclei from natural and anthropogenic sources*. The atmospheric effects of ice formation from aviation particles depend on the ice nucleation properties of particles from other anthropogenic and natural sources. However, concentration and chemical composition of IN in the upper troposphere are not well known and are difficult to predict with models.
- *Interactions between heterogeneous ice nuclei and cirrus clouds*. Ice nucleation processes occur within short time scales and are rather localized. Hence it is difficult to determine their relative importance using in-situ measurements. Ice nucleation pathways can be isolated in the laboratory, but the question arises whether the employed IN particles are representative. This issue is particularly important for aircraft because real engine soot and its processing cannot easily be represented in laboratory measurements.
- *Incorporation of effects of aviation-induced particles and cirrus into global models.* Accurate knowledge of ice supersaturation is crucial for quantifying direct and indirect effects of aviation on cirrus cloudiness. Most current models do not adequately represent ice supersaturation, and treat cirrus as a single class of clouds in terms of their radiative properties; thus they are not capable of predicting contrail-cirrus cloud fraction from first principles.
- *Representation of aerosols and contrails in global atmospheric models*. Both models and satellite datasets lack the horizontal and vertical resolution to address many contrail issues. Data useful for validation of aerosol modules is lacking, especially for carbonaceous aerosol. Global models and contrail/cirrus studies need to establish the essential parameters for properly incorporating aviation aerosols and their effects into atmospheric calculations.
- *Long-term trends in contrail-cirrus and cirrus*. Long-term trends can only be ascertained from consistent measurements over extensive periods, but the current satellite record has many uncertainties, limiting the ability to examine past trends. Special care is needed to ensure homogeneous datasets for estimation of future trends in cirrus measurements.

Research Recommendation and Priorities

- *In-situ probing and remote sensing of aging contrail-cirrus and aircraft plumes.* A series of coordinated regional-scale campaigns should be designed and executed to measure the appropriate variables using in-situ and remote sensing measurements with the aim to characterize the growth, decay and trajectories of contrail ice particle populations. Such measurements are also needed to define the abundance and properties of ambient aerosols as well as gaseous aerosol precursor concentrations in the troposphere.

- *Regional studies of supersaturation and contrails using weather forecast models have the potential to include our best physics and the high resolution needed to more accurately predict supersaturation*. Development of these models and associated observational datasets may be the best approach for developing our knowledge in the near term, supporting development of more accurate tools for use in global models.
- *Global model studies addressing direct and indirect effects.* Enhance the treatment of relevant processes, including appropriate parameterizations, in global climate models (GCMs) to improve analyses of contrails and cirrus associated with aircraft.
- *Use of existing or upcoming information from space-borne sensors.* Investigate the optical and microphysical properties of contrail and contrail-cirrus, e.g., optical thickness and effective particle sizes (parameters that are essential to the study of the radiative forcing of these clouds) from space-borne sensors.
- *Process studies of plume and contrail development.* Studies that explore the role of emitted aerosol particles, and how volatile aerosols interact with each other and with background aerosols, are required to understand the indirect effect. Studies that investigate contrail development as a function of emissions and aircraft design and how contrails evolve into cirrus-like clouds would better quantify the direct effect.
- *Laboratory measurements of ice nucleation.* Laboratory data are urgently needed to develop aerosol-related parameterisations of heterogeneous ice nucleation for use in models. It is also recommended to compare different approaches and methods of IN measurements.

Long-term research needs include: (1) development or improvement of instruments that help establish background concentrations and characteristics of heterogeneous ice nuclei and measure supersaturation accurately, and (2) the development and implementation of new concepts for ice phase-related microphysics, supersaturation, radiation, and cloud fraction in climate models enabling a consistent treatment of global aviation effects.

The current suite of satellite instruments is inadequate for evaluating supersaturation. Higher resolution (both horizontally and vertically) is required for the observations. Very accurate measurements of temperatures as well as water vapour mixing ratio are required to derive high quality fields of relative humidity.

C. Climate Impacts and Climate Metrics

State of the Science

In assessing the overall impact of aviation on climate, and to quantify the potential trade-offs on the climate impact of changes in aircraft technology or operations, metrics for climate change are needed to place these different climate forcings on some kind of common scale. Radiative forcing (RF) has been used as a proxy for climate impact for well-mixed greenhouse gases. However, recent analyses have demonstrated that a unit radiative forcing from different climate change mechanisms does not necessarily lead to the same global mean temperature change (or to the same regional climate impacts). The concept of efficacy (E) has been introduced to account for this (i.e., E depends on the specific perturbation to the climate system, such as changes in ozone or aerosol distributions related to aircraft emissions). Hence, it is the product of E and RF that should be evaluated and intercompared for the various climate impacts from aviation. However, RF is not an emissions metric capable of comparing the future impact of different aviation emissions. The applicability of emission metrics, such as Global Warming Potentials (GWPs), have not been adequately tested and evaluated. In addition, changes in precipitation and other climate variables besides temperature are of interest. Climate metrics for aviation need to be done in the context of climate metrics for other short-lived perturbations from other sectors.

An update of the IPCC (1999) radiative forcing (RF) from aviation for the "current" time period finds that, with one exception, the IPCC findings have not significantly changed, apart from the increase in air traffic from 1992 to 2000 (Sausen et al., 2005). The exception is RF from linear contrails, which appear to be at least a factor of three smaller. There is still no reliable estimate of RF from aviation-induced cirrus clouds. Based on recent correlation analyses some authors suggest that this RF might be dominating all other aircraft effects. It is critical that appropriate metrics be established before assuming relative climate impacts for various contributions based on potentially inappropriate metrics.

Uncertainties and Gaps

- *Climate impacts are highly uncertain*. There remain significant uncertainties on almost all aspects of aircraft environmental effects on climate, with the exception of the radiative forcing from the CO_2 emissions. The ozone and methane RFs from NOx emissions are opposite in sign, so the extent to which they offset each other is an important uncertainty. Estimates for contrails and cirrus are particularly highly uncertain.
- *Optical properties of contrails, contrail-cirrus, and cirrus*. As discussed in previous section.
- *Defining metrics for trade-offs*. The scientific community may be able to define useful metrics for the climate change and climate impacts associated with aviation, but further study and consensus building is needed.

Recommended Research and Priorities

- *Radiative effects on climate from contrails and cirrus.* In addition to previously mentioned studies, specific studies aimed at better understanding the climate impacts from contrails and cirrus. Intercomparisons (model to model) and evaluations (compare model to observations) of climate and radiative transfer models.
- *Systematic model intercomparison of efficacy studies*. Evaluate inhomogeneous vertically and horizontally distributed forcing agents. Analyze cirrus changes, ozone changes, CH_4, and direct particle effects, and effects of changes in climate state.
- *Identify, develop and evaluate metrics for climate impact assessment and examine their scientific basis.*
- Quantify the uncertainty in proposed metrics and how it propagates (both parametric input uncertainties and model uncertainties).

D. Studies for Trade-offs Amongst Aviation Emissions Impacting Climate

Along with furthering scientific understanding, there are policy-related needs for sensitivity analyses of the net effects of trade-offs between various interventions in aircraft operations and emissions including:

- NOx reduction technology versus fuel efficiency (i.e., CO_2 emissions)
- flight altitude effects (e.g., effects on ozone and contrail formation)
- changing future geographical distributions of the fleet
- differential impact of day/night operations
- routings to avoid certain regions with specialized chemistry (e.g. supersaturated air, cirrus, or polar)
- studies of the co-dependence of physical impacts, e.g. how future climate change may alter the ozone response

Climate change metrics are expected to play an important role in these analyses. The IPCC report provided instantaneous forcing due to the cumulative impacts of aviation. While this is a measure of how the atmosphere has changed due to historical aviation activities, such estimates of radiative forcing for aviation may not provide an appropriate basis for making policy or operational decisions (time-dependent effects likely necessary), nor are they an appropriate basis for fully evaluating the relative impacts of various aviation effects. This argument is not new; indeed, it is widely understood and accepted, and a variety of alternative integral measures have been pursued.

There is currently no study in the peer reviewed literature that can be cited to justify, based on the scientific understanding of the impact of aviation emissions, the possible choices of metrics suitable for trade-off application. Research is needed to examine the effect of different metrics, and the choices within each metric (e.g. time horizon), on evaluating the relative importance of different aviation emissions. Such studies would need to explore the potential of existing metrics and the possibility of designing new metrics. It must be stressed that even if there is a philosophical agreement on an acceptable metric, current atmospheric models may not be able to calculate these metrics with acceptable accuracy.

Appendices

Appendix 1

Workshop Agenda

Workshop on the Impacts of Aviation on Climate Change

June 7-9, 2006

Boston, MA

June 7

8:00 - 9:00 a.m.	Registration and Breakfast*
9:00 - 9:10 a.m.	Mohan Gupta – Welcome and logistics
9:10 - 9:25 a.m.	Lourdes Maurice – Motivation and Vision for the Workshop: JPDO/NGATS/FAA Context
9:25 - 9:40 a.m.	Malcolm Ko – The EIPT-S/M Panel charge to the workshop
9:40 - 10:15 a.m.	Don Wuebbles – Science overview, workshop goals & objectives, expected outcomes and format
10:15 - 10:30 a.m.	Break
10:30 - Noon	Charge to subgroup leaders: Key questions by the subgroup leaders and general discussion Don Wuebbles – Discussion leader
10:30 - 11:00 a.m.	Anne Douglass – UT/LS and Chemistry Effects
11:00 - 11:30 a.m.	Bernd Kärcher – Contrails and Cirrus Clouds
11:30 - Noon	W.-C. Wang – Climate Impacts and Climate Metrics
Noon - 1:00 p.m.	Lunch
1:00 - 3:00 p.m.	Parallel subgroup meetings **Focus:** Review the present state of scientific knowledge and key underlying uncertainties
3:00 - 3:15 p.m.	Break
3:15 - 5:15 p.m.	Plenary session: Updates from each subgroup with discussions, (approx. 40 minutes each) Don Wuebbles – Discussion leader
5:15 - 5:30 p.m.	Don Wuebbles – Summary and charge for the next session

June 8

- 8:00 a.m.	Breakfast*
8:00 - 10:00 a.m.	Parallel subgroup meetings **Focus:** Explore the metrics of aviation emissions relative to other emissions. Discuss the aviation-related trade-off issues. Identify the gaps in aviation-related research needs.
10:00 - 10:15 a.m.	Break
10:15 - 11:45 a.m.	Plenary session: Updates from each subgroup with discussions, (approx. 30 minutes each) Don Wuebbles – Discussion leader
11:45 - Noon	Don Wuebbles – Summary and charge for the next session
Noon - 1:00 p.m.	Lunch
1:00 - 3:00 p.m.	Parallel subgroup meetings
	Focus: Identify short- and long-term priorities of aviation needs. Identify the ongoing and already planned future research programs and make recommendations on how to leverage upon them to meet aviation needs.
3.00 - 3.15 p.m.	Break
3:15 - 4:45 p.m.	Plenary session: Updates from each subgroup with discussions, (approx. 30 minutes each) Don Wuebbles – Discussion leader
4:45 - 5:00 p.m.	Don Wuebbles – Summary and charge for the next session

June 9

- 8.00 a.m.	Breakfast*
8:00 - 10:00 a.m.	Parallel subgroup meetings
	Focus: Develop final consensus on all issues.
10:00 - 10:15 a.m.	Break
10:15 - 12:30 p.m.	Plenary session: Updates from each subgroup with discussions, (approx. 45 minutes each) Don Wuebbles – Discussion leader
12:30 - 12:55 p.m.	Discussion on publication of the final report, involvement of attendees, review and overall schedule. Don Wuebbles – Discussion leader
12:55 - 1:00 p.m.	Concluding remarks – Mohan Gupta, Malcolm Ko, Don Wuebbles
1:00 p.m.	Adjourn

Appendix 2

Workshop Participants/Authors for Each Subgroup

Workshop Chair: Don Wuebbles, Univ. Illinois - Urbana Champaign

Subgroup 1: Emissions in the UT/LS and Resulting Chemistry Effects

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Jose Rodriguez, GSFC NASA

Subgroup 2: Contrails and Cirrus

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Subgroup 3: Climate Impacts and Climate Metrics

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Appendix 3

Other Attendees at the Workshop

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