Description and Implementation Plan

for the

Alternative Aviation Fuel Experiment (AAFEX)

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I. PROJECT SUMMARY

The rising cost of oil coupled with the need to reduce pollution and dependence on foreign suppliers has spurred great interest and activity in developing alternative aviation fuels. Although a variety of fuels have been produced that meet the rather broad ICAO specifications for gas turbine engines, detailed studies are required to ascertain the exact impacts of the fuels on engine operation and exhaust composition. In response to this need, NASA has acquired candidate alternative fuels from a variety of sources and will burn the fuels in the Dryden Flight Research Center DC-8 to access changes in the aircraft’s CFM-56 engine performance and emission parameters relative to operation with standard JP-8. This Alternative Aviation Fuel Experiment, or AAFEX, will be conducted at NASA’s Palmdale, CA aircraft facility during January 2009 and will specifically seek to establish fuel matrix effects on: 1) engine and exhaust gas temperatures and compressor speeds and pressures; 2) engine and auxiliary power unit (APU) gas phase and particle emissions and characteristics; and 3) volatile aerosol formation in aging exhaust plumes. A secondary goal of the study will be to evaluate the role of ambient conditions in regulating volatile aerosol emissions. Gas phase measurements will include the standard certification species (CO2, CO, NOx, and THC) along with hydrocarbons, hazardous air pollutants (HAPS), and oxygenated compounds. Measured particle parameters will include smoke number; number density, size distribution and total mass; black carbon morphology, composition and total mass; volatile aerosol speciation and mass; and particle mixing state. Participation by NASA, DOD, FAA and EPA sponsored investigators will facilitate an inter-comparison of particle number, size, and mass measurements made by the different groups, which, in turn, will allow an assessment of the relative differences in particle emission data sets collected in previous test venues.

During AAFEX, the aircraft will be parked in an open-air run-up facility and complete sets of gas and particle emission measurements will be made as a function of thrust as the engine alternately burns JP-8 or one of the alternative fuels. To date, two fuels have been procured for the tests: a Fischer/Tropsch (FT) fuel prepared from natural gas and an FT fuel made from coal. To delineate fuel-matrix related changes in emissions from those caused by changes in ambient conditions, samples will alternately be drawn from the exhaust of an engine on the opposite wing, which will simultaneously be burning JP-8. To examine plume chemistry and particle evolution in time, samples will be drawn from inlet probes positioned 1, and 30 m downstream of the aircraft’s inboard engines; instruments will also placed in a trailer parked ~200 meters behind the aircraft to measure aerosol and gaseous properties in the more aged plume. In addition, the 1 m rake will include multiple gas and aerosol inlet tips so that during initial tests, emissions can be mapped across the breadth of the engine exhaust plane to establish the extent of the core-flow region within the near-field plume. Taking advantage of the broad diurnal variation in air temperature in the Mojave Desert, tests will be conducted in the early morning and at mid-day to examine the effect of ambient conditions on gas phase and volatile aerosol emissions. We anticipate that the project will require 14 days of on-site work involving: instrument and sampling system installation; pre-test instrument calibrations and sampling system efficiency assessments; and data collection during approximately 10 days of engine runs. A data workshop will be held 6 months after mission completion to discuss results. Data will be archived on a publically-accessible web site and findings will be published in a NASA Technical
Memorandum, presented at appropriate meetings and workshops, and published within a journal of international circulation.

II. BACKGROUND AND MOTIVATION

Since 1970, the U.S. has had to import oil from other countries to meet its energy production needs. This situation often places our country in a weak position when negotiating political and diplomatic agreements and forces us to do business with unstable or totalitarian regimes. It leaves us economically vulnerable to fluctuations in supply and open to the threat of embargoes. Shortages of oil may also constrain the growth of some economic sectors, with the aviation industry being a case in point. These factors, coupled with recent oil price increases and the heightened awareness that global fossil fuel production may be at or near its peak has spurred significant interest in developing alternative, domestically-produced fuels for the nation’s transportation sector. A wide variety of alternative liquid fuels are now being tested or used for powering internal combustion engines, with ethanol being the most popular and, because of the food vs. fuel debate, the most controversial.

For the aviation industry, the options for “drop-in” replacement fuels are more limited because of the narrow energy density (i.e. Joules/Liter), viscosity, thermal stability and corrosion property standards that must be met for economically powering the existing aircraft fleet. Alcohol-based fuels are unsuitable for aviation because of their low energy density and potential for corroding fuel system components. Research and development is presently focusing on converting hydrocarbon feedstocks into kerosene using the Fischer-Tropsch (FT) process, which is the basis for the Sasol fuels produced in South Africa. Plants are now operating that convert either natural gas or coal into synthetic fuels that meet Jet A standards, but have improved viscosity and thermal stabilities. These properties extend the fuels’ use to lower temperatures, result in lower fuel system deposits, and allow them to be stored for long periods of time. In addition, FT fuels are essentially aromatic-hydrocarbon and sulfur free, which means their use results in much lower soot and sulfate aerosols emissions, making them particularly attractive for use in mitigating aircraft impacts on local air quality and climate. The downside to these fuels is that they are not sustainable in the long term (natural gas and coal deposits are limited) and their manufacture produces significant amounts of CO₂ (about 1.8 times more than standard jet fuels), which must be captured or permanently sequestered to circumvent possible climate impacts. Also, there are presently no U.S.-based manufacturers that produce these fuels.

The search for renewable aviation fuels that have essentially no direct impact on atmospheric CO₂ levels has focused on bio-oils such as those produced naturally by palm trees, soybeans, corn, and algae. These products are already being used to power diesel vehicles, but they have a number of drawbacks for use in aircraft engines, including a tendency to gel at relatively high temperatures, poor thermal stability, and the fact that they are grown in competition with food crops (i.e., recent increases in ethanol fuel production within the U.S. has caused corn prices to more than double in the last two years). Researchers have found that hydro-treated bio-fuels or 80:20 blends of Jet A and biofuel meet current fuel standards (a Virgin Airlines aircraft recently made a well-publicized flight fueled by such a mixture), but Daggett et al. () and others warn that sufficient land is not available to support large-scale biofuel production from standard farm crops and that an efforts to increase acreage may come at the sacrifice of rainforests and other
ecosystems that are critical in maintaining the earth’s climate system. This factor has led the European Union to abandon programs to develop “fuels from food” and for U.S. to place more emphasis on bio-fuels that can be produced from saltwater plants. Supporting this effort, NASA Glenn Research Center in Cleveland has initiated a pilot program to investigate/refine/optimize techniques for growing saltwater algae and halocytes and to work with commercial partners on procedures to efficiently convert these plants into biostocks suitable for jet fuel production. Researchers estimate that large-scale production of algae-based bio-jet fuels may commence within the next 10 years.

In tandem with research on sources and manufacturing of alternative aviation fuels, engine and aircraft manufacturers along with the federal government have conducted tests to assess the impact of alternative fuels on engine performance and emissions. Because of its interest in gaining fuel security, stable sources of supply, and emission reductions at bases located within EPA non-attainment areas, the U.S. Department of Defense (DOD) has taken a lead this work, conducting ground-based and in-flight tests on stand- and wing-mounted military aircraft engines. However, the bulk of these tests have been conducted on older engine technologies such as those that power helicopters and the B-52 bomber (Corporan et al., 2007) and the results may not be particularly applicable to modern commercial engines. And while engine manufacturers have investigated the effects of alternative fuels on performance and emissions of selected engines, results of the tests are proprietary and thus not available for public use. Clearly, additional alternative fuel tests on modern commercial engines are required to produce an open-access data set that can be used, for example, to guide technology development, refine fuel specifications, and assess environmental impacts.

In addition to uncertainties in alternative fuel impacts, other important questions related to commercial aircraft emissions and their effect on air quality and climate remain unanswered. Through tests conducted during EXCAVATE (Anderson, 2003), the APEX series (i.e., Wey et al., 2007), and UNA-UNA (Lobo, 2008), a fairly good understanding of gas-turbine soot emissions and how they vary with combustor design and thrust setting has been gained. Data gathered in these studies also suggest that sulfurous and organic compounds condense very rapidly within aging exhaust plumes to form volatile aerosols or coatings on soot particle surfaces and that the formation of new particles can be suppressed by reducing fuel-sulfur content. However, the fraction of fuel sulfur that is oxidized to sulfuric acid and the exact source and composition of the volatile organic species are highly uncertain. Data detailing how ambient conditions influence volatile aerosol formation as well as primary pollutant (i.e., soot, hydrocarbons, CO, and NOx) emissions is also in scarce. In addition, a recent study shows that airports may be significant sources of hazardous gas-phase air pollutants, such as benzene, formaldehyde, and naphthalene—very few data are available to assess the aircraft contribution to this potential problem.

The knowledge gap regarding aircraft particle emissions may inhibit expansion and construction of airport facilities in EPA non-attainment areas because the impacts of these activities on local PM2.5 levels cannot be accurately assessed. In an attempt to bridge this gap, the FAA correlated available soot emission data with engine-specific smoke numbers from the ICAO archives to develop a “First Order Approximation” (FOA, Wayson et al. 2007), which provides an estimate of aircraft soot mass emissions at standard engine thrust settings. Terms to estimate
the mass of volatile emissions arising from fuel sulfur, unburned hydrocarbons and engine oil have been incorporated in recent FOA versions, but the magnitudes of these contributions are highly speculative, possibly over-conservative, and certainly need to be verified through comparison with careful measurements of aged exhaust plumes sampled under a variety of ambient conditions.

III. OBJECTIVES AND FUNDAMENTAL QUESTIONS TO BE ADDRESSED

To address the needs outlined above, NASA will conduct an Alternative Aviation Fuel Experiment (AAFEX) to ascertain the impacts of fuels and ambient conditions on aircraft primary and secondary emissions. AAFEX will take place at NASA Dryden Flight Research Center Aircraft Operations Facility (DAOF) in Palmdale, CA during January 2009 and will use the center’s DC-8 to test the effects of coal- and natural gas-derived FT fuels and ambient conditions on its CFM56 engines’ emissions and performance. The tests will focus on the aircraft’s right inboard engine, which was sampled extensively during the spring 2004, NASA-sponsored Aircraft Particle Emission Experiment (APEX-1; see Wey et al., 2007 for details) and thus has a well-documented performance and emission profile. Although the CFM56 is of somewhat older vintage, it is the most widely used engine within the current commercial fleet (almost all B737 use some versions of this engine) and is likely representative of the combustor technology that will be used for at least the next decade. We thus anticipate that the acquired data set will have broad relevance to current studies of air quality and engine technology. The AAFEX test plan will be designed to achieve the following specific objectives:

1) Evaluate whether and how the alternative fuels effect engine performance or produce any notable degradation of engine or fuel system components
2) Determine the effects of alternative fuels and ambient conditions on black carbon and gas phase emission indices (EIs) and characteristics as measured within 1 m of the engine’s exhaust plane.
3) Establish the composition, origin and temperature-dependent concentrations and formation rates of the volatile aerosols that condense in the engine’s exhaust plume as it ages and mixes with background air; determine how fuel composition influences these processes.
4) Establish emission factors for the aircraft’s auxiliary power unit (APU) and determine how these factors change with ambient conditions and fuel composition
5) Evaluate the performance of new black carbon-measuring instruments relative to that of more proven techniques.
6) Compare particle number, size, and mass emission measurements made by separate groups to ascertain the expected range of relative uncertainty in EI values in data sets collected in previous test venues.

Within these broad objectives, some of the specific questions we plan to address include:

A. Aircraft Engine and Operation
1) At specific fuel flow rates, how do engine temperatures, pressure ratios, and fan speeds, exhaust temperatures, etc. compare between the baseline (JP-8) and alternative fuels?
2) Do the pre- and post-mission engine bore-scopes reveal any changes in combustor appearance that might be related to burning the alternative fuels?  
3) Are there any noticeable changes in the fuel system components that might be caused by the alternative fuels?  
4) Do the alternative fuels require any special handling or create any maintenance issues whatsoever?  

B. Baseline Fuel Emissions at 1 m Behind Engine  
1) Are there variations in normalized emissions across the engine exhaust plane and if so, where are the best locations to extract exhaust samples?  
2) What are the CO, THC, and NOx EIs along with SN at the standard ICAO power settings; how do these compare with ICAO archived data and with APEX-1 values? Is the engine operating normally?  
3) What are the EIs of selected hydrocarbon species (including hazardous air pollutants or HAPS)--particularly at low power--and how do these vary with fuel-air-ratio and ambient temperature? What fraction of the total HC emissions can be identified and measured as these selected HCs, and what fraction is unidentified and not measured individually?  
4) What are the black carbon (BC) and total aerosol number and mass EIs and how do these change with power and ambient temperature?  
5) What are the size distribution, morphology, density and PAH content of the soot and how do these change with power and ambient conditions?  
6) Do the BC particles have volatile components or coatings or are volatile aerosols present and if so, how do these vary with sample dilution, power setting and ambient temperatures?  

C. Alternative vs. Baseline (JP-8) Fuels at 1 m Behind Engine  
1) What are the differences in the certification species EIs as a function of power (or selected engine operating conditions) and ambient temperature?  
2) What are the differences in hydrocarbon (and HAPS) EIs as a function of power and temperature?  
3) What are the differences in particle EIs and how do these change with power and temperature?  
4) What are the differences in the BC characteristics (number, size distribution, morphology, mass-to-volume ratio, PAH, etc.) and how do these change with power and ambient conditions?  

D. Fundamental Emissions at 30 m Behind Engine  
1) What fraction of the fuel sulfur gets oxidized to form sulfate aerosols in the plume? Does this vary with engine power or fuel sulfur content?  
2) What is the composition of the volatile organic aerosols in the plume and what are their sources (engine oil, unburned fuel, etc.)  
3) What propensity do the aged particles have to form cloud or ice condensation nuclei? Does this change with fuel sulfur content or engine power?  
4) What factors determine whether low-volatility species condense onto soot or form new particles?
5) Do background gas and aerosol species play roles in the plume chemistry, i.e., are volatile components condensing on ambient aerosols?

E. Alternative vs. Baseline Fuel at 30 m Behind Engine
1) Are the differences in gas phase and black carbon EIs observed at 1 m replicated in the downstream data?
2) What are the differences in volatile aerosol EIs? Are there differences in organic aerosol composition?
3) Does the absence of fuel sulfur suppress the formation of new particles? Do ambient sulfate aerosols and SO$_2$ that are vaporized/oxidized in the combustor condense to form additional aerosols or soot coatings?
4) Are there differences in the faction of particles that are active as CCN?

F. Auxiliary Power Unit Emissions
1) What are the APU EIs for particles and gas phase species, including HAPS?
2) How do the EIs change with fuel, ambient temperature, and plume age?
3) What are the physical characteristics (size, morphology, density, etc.) of the APU BC emissions and how do they vary with fuel, ambient conditions, etc?
4) How do the EIs change over the APU start and warm-up period?
5) How do the total particle mass emissions from the APU compare with those from the engines at idle? Are APUs a significant source of pollution?

G. Sampling Related Issues
1) Are BC, CO, NOy, and THC EIs the same at 30 m as measured at 1 m for each of the fuels and if not, are there issues with the inlet probes and sample transport systems that can account for the differences? Are CO, NO and other reduced species catalytically oxidized during transport through the hot, stainless steel, inlet tips used on the 1-m rakes?
2) What are the size dependent transmission efficiencies of the 1 and 30 m sampling lines? Do the losses vary with ambient temperature? How do they affect the observed aerosol EIs? Does application of line-loss corrections introduce more uncertainty than they eliminate?
3) Does a significant fraction of the observed volatile aerosol condensation occur within the sampling lines?
4) Is there a significant difference between BC mass EIs as measured on the gas and aerosol sampling lines?
5) At high engine powers/exhaust velocities, does BC mass EI vary significantly with sample dilution? Taking flow velocity-dependent line losses into consideration, are large BC particle concentrations artificially enhanced within the dilute samples or depleted within the concentrated samples? Is isokinetic sampling important?

H. Instrument Efficacy
1) How well do BC mass EIs determined by filter techniques (gravimetric, thermo-optical, TEOM) compare with values obtained using the Multi-Angle Aerosol Photometer (MAAP), Laser-Induced Incandescence (Atrium), Single Particle Soot Photometer (SP2), Photo-acoustic Absorption Spectrometer (PASS-3) instruments? How do measured BC
mass compare to nonvolatile particle volume measurements made by SMPS-type systems?

2) Are the instrument performances affected by volatile coatings or do they vary with particle morphology and PAH content?

I. Overall Measurement Harmony

1) During pre-experiment tests using black carbon generated by a Combustion Aerosol Standard (CAST), what are the relative differences in the particle number density, size distribution, and black-carbon mass measurements made using similar instruments operated by the participating groups? Are the differences magnified when sampling at reduced pressures (ambient – 150 mb)?

2) What are the relative differences in CO₂ values measured by the participating groups when sampling NIST-traceable standards of ~0.1, 0.5 and 1% concentration? Does this vary with sample pressure?

3) When given an identical set of particle and CO₂ measurements, are there differences in the number and mass EI values calculated by the different groups? If so, what are the sources of the differences?

4) Using the instruments/techniques defined in the “Interim Test Method”, what are the relative differences in particle number, size, and mass measurements provided by each group when drawing samples from the 1 m aerosol line? Can the differences be accounted for by varying line lengths and the differences in instrument performance as established in the initial inter-comparison tests?

IV. PROJECT DESCRIPTION

A. Experiment Site

AAFEX will be conducted at the Dryden Aircraft Operations Facility (DAOF), which is operated by NASA’s Dryden Flight Research Center, and is located in Palmdale, Calif., about 70 miles northeast of downtown Los Angeles (Figure 1). The leased facility is adjacent to the Palmdale Regional Airport and consists of 210,000 square feet of hanger space and an equivalent amount of space for offices, labs, conference rooms and storage for spare equipment, flammables, and hazardous chemicals. Experiment participants will have access to the hanger round-the-clock during the test period and will be allocated desk and work space in either of the two large experimenter labs that are located adjacent to the hanger area where the DC-8 is typically parked. Internet access will be provided via a secure wireless system, to which participants will be provided IDs and passwords. For badging purposes, participants will be asked to submit visitor request forms several weeks prior to arriving on site. Foreign nationals from “friendly” countries will be allowed escorted access to the hanger and experiment facilities, provided they submit the required visitor request forms at least 6 weeks prior to arrival.
Actual engine test runs will be performed in the run-up area located just north of DOAF near a seldom-used taxiway (Figure 2). The site is at least 300 m and typically cross-wind from the access road and parking lot, so automobile pollution should not be a problem. Equipment vehicles will be driven to the area across active runways and staging areas by properly-licensed operators. Participants and visitors will be transported to the site onboard NASA vehicles,
or can walk or ride a bicycles from the hanger area, if conditions permit. Three-phase power is available at the site and will be used in conjunction with an EPA-provided break-out box to provide single-phase power to each of the experimenter vehicles. Water and portable restroom facilities are also available.

The experiment will be conducted during January, 2009. At this time of year, weather is Palmdale can be fairly cold, with occasional periods of light rain and snow. However, being located near the Mojave Desert, the humidity is usually quite low, which results in wide temperature variations between night and day (see Figure 3). In January, winds are typically light and from the west. Urban pollution is generally not a problem although under certain conditions, air can be transported to the region from LA or the central valley.

![Figure 3. Average monthly temperatures and precipitation at the Palmdale Airport.](image)

**B. Aircraft and Engine Type**

The NASA Dryden, DC-8 will be used as the AAFEX emissions source. This aircraft was originally built by McDonell Douglas and was purchased by NASA from Eastern Airlines in the mid-1980s to be used as a flying laboratory to support earth science research and satellite validation activities. The aircraft is typically flown < 1000 hrs/year, which means it has relatively low number of hours on the engines and airframe. The DC-8 is equipped with four, CFM56-2C1 gas-turbine engines, which are certified at 22,000 pounds thrust; the nominal operating characteristics of selected CFM56 engines are provided in Table 1.

The DC-8’s engines were totally re-built in 2000 when turbine damage was detected after the aircraft flew through a thick cloud of volcanic dust during the SOLVE mission, which was based in Kiruna, Sweden.
Emissions from the DC-8’s right inboard engine were documented in detail during the spring 2004, NASA Aircraft Particle Emission Experiment (APEX; Wey et al., 2006). Gas phase EIs recorded at 7, 30, 85, and 100% of maximum thrust during APEX were consistent with those archived by ICAO from certification tests, suggesting that the DC-8 engines were operating within the manufacturers specifications and also that ground based tests of this nature can provide broadly representative results.

Table 1. Operating Characteristics of CFM56 Engines

<table>
<thead>
<tr>
<th>Engine Parameters</th>
<th>CFM56 engine models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2-C1</td>
</tr>
<tr>
<td>TAKEOFF CONDITIONS (sea level)</td>
<td></td>
</tr>
<tr>
<td>Max. takeoff (lb)</td>
<td>22,000</td>
</tr>
<tr>
<td>Airflow (lb/sec)</td>
<td>788</td>
</tr>
<tr>
<td>Bypass ratio</td>
<td>6.0</td>
</tr>
<tr>
<td>IN-FLIGHT PERFORMANCE (installed)</td>
<td></td>
</tr>
<tr>
<td>(35,000 ft-Mach = 0.80-ISA)</td>
<td></td>
</tr>
<tr>
<td>Max. climb thrust (lb)</td>
<td>5,400</td>
</tr>
<tr>
<td>Overall pressure ratio at max. climb</td>
<td>31.3</td>
</tr>
<tr>
<td>Max. cruise thrust (lb)</td>
<td>4,980</td>
</tr>
<tr>
<td>Cruise SFC (Bucket)(lb/lb hr).</td>
<td>0.671</td>
</tr>
</tbody>
</table>

During APEX, the DC-8 engines were run for over 30 hours while the aircraft was in a parked/chocked position without encountering any significant problems. However to prevent undue stress on the aircraft wings and brakes, runtimes at 85 and 100% thrust were restricted to about 4 and 2 minutes, respectively, and to avoid compressor stalls, power levels were maintained below 40% when winds exceeded 5 mph from directions 90 to 270 degrees off the aircraft heading. These same limitations will be in effect during AAFEX.

C. Fuels

As noted above, an overarching objective of AAFEX is to establish the effects of alternative fuels on the performance and emissions of a representative aircraft engine. The present plan is to run the DC-8 with three different pure fuels—JP8, FT-coal and FT-gas—and 50:50 blends of the test fuels with JP-8. The “baseline” JP-8 will be obtained from Edwards Air Force Base in sufficient quantity to cover all the required engine runs. Ideally, the fuel will have a relatively high sulfur content (>400 ppm) so that questions related to sulfur oxidation and new particle formation can be addressed. Sulfur-doping of the fuel will be considered if sulfur impurity levels are extremely low. The FT test fuels have already been obtained (see Figure 4 for a comparative analysis of the FT—natural gas fuel) from suppliers and will be kept in separate tanker trucks at the site; local fuel trucks will be cleaned and used to mix the 50:50 fuel blends. To avoid contamination, the aircraft tanks and pumps will be cleaned and flushed before fuel transfer. Even so, it is likely that a few gallons of residual fuel will remain within each tank and
be mixed with the test fuels, slightly altering their properties. To determine the extent of this problem and the exact fuel properties, samples will be drawn from the right inboard-engine drain line before and after each test run; these will subsequently be analyzed for a variety of properties, including sulfur and aromatic content, by the Wright-Patterson fuels lab.

D. Fueling Plan

Figure 5 shows a diagram of the DC-8 fuel system. The fuel capacities for the tanks are: 1 and 4 mains, 3100 gals each; 1 and 4 alternates, 1740 gals; 2 and 3 mains, 4700 gals; center auxiliary, 4400 gals; and forward auxiliary, 2100 gals. Valves isolate the tanks from one another so that it is possible to run each engine from a separate fuel tank. The plan is thus to load JP-8 in the center- and number 2 main tanks and the test fuel in the number 3 main tanks, which will allow us to burn JP-8 in the #2 engine and alternative fuel in #3. We can thus contrast the emissions from the two engines to more accurately delineate ambient- from fuel-related changes in emission characteristics.
Aircraft fueling will be accomplished using the following available fuel tanker assets:

FT1 tank truck (Air Force)
FT2 tank truck (Air Force)
Truck A – Fueling capable – 5,000 gal volume with 4,500 usable (NASA – K&A)
Truck B – Fuel/defuel capable – 5,000 gal volume with 4,500 usable (NASA – K&A)
Truck C – Fuel/defuel capable – 5,000 gal volume with 4,500 usable (NASA – K&A)
8,000 gallon Tanker (NASA – K&A)
1,000 gallon Fuel Bowser (NASA – K&A) – all fuel in Bowser handled as waste fuel
4,000 gallon Waste Fuel Truck (NASA – Health & Safety)

Pre-test preparations will follow the steps outlined below:

1. Air Force FT1 & FT2 tankers arrive at site and remain for duration of tests
2. Dryden will arrange for 20,000 gallon JP-8 fuel purchase from Air Force Plant 42
   a. Place fuel in 8,000 gallon tanker truck for reuse post test.
4. Fuel Truck A
   a. Drain and purge tank of fuel
b. Replace all fuel filters

5. Fuel aircraft with JP-8
   a. Use Fuel Truck A to pick up Air Force JP-8 Fuel @ Plant 42 (1 trip of 5,000 gallons + 3 trips of 4,500 gallons each + 1 trip to pick up 1,500 gallons
   b. Place 15,500 gallons on aircraft

6. Fuel truck B (5,000 gallon truck)
   a. Drain and purge tank of fuel
   b. Replace all filters
   c. Fill with 3500 gallons of FT1 fuel from FT1 tanker truck

7. Fuel truck C (5,000 gallon truck)
   a. Drain and purge tank of fuel
   b. Replace all filters
   c. Fill with 3500 gallons of FT2 fuel from FT2 tanker truck

For JP-8 Emissions Tests (Test days 1 & 2):

1. Collect fuel sample from #3 main
2. Run JP-8 emissions tests
3. Collect fuel sample from #3 main

For FT1 Emissions Tests (Test days 3 & 4):

1. Transfer fuel remaining main tank #3 to other tanks on aircraft
2. Point drain residual fuel in main tank #3 into bowser
3. Transfer fuel bowser contents into waste fuel truck
4. Use fuel truck B to place 3000 gallons FT1 fuel in main tank #3
5. Collect fuel sample from #3 main
6. Run day 3 FT1 tests (1 morning, 1 afternoon)
7. Collect fuel sample from #3 main
8. Point drain residual fuel in main tank #3 into bowser
9. Transfer contents of bowser into waste fuel truck
10. Fill truck B with 800 gallons of FT1 fuel from FT1 tanker truck
11. Fill truck B with 1300 gallons of JP-8 fuel from truck A (this will provide a 50/50 mix since there is now 1300 gal., 800 + 500 unusable FT1 in Truck B)
12. Circulate fuel in truck B for 15 minutes
13. Fuel aircraft main tank #3 with 1600 gallons from truck B
14. Collect fuel sample from #3 main
15. Run day 4 FT1/JP-8 blend tests
16. Collect fuel sample from #3 main
17. Point drain residual fuel in main tank #3 into bowser
18. Transfer contents of bowser into waste fuel truck

For FT2 Emissions Tests (Test days 5 & 6):

1. Use fuel truck C to place 3000 gallons FT2 fuel in main tank #3
2. Collect fuel sample from #3 main
3. Run day 5 FT2 tests (1 morning, 1 afternoon)
4. Collect fuel sample from #3 main
5. Point drain residual fuel in main tank #3 into bowser
6. Transfer contents of bowser into waste fuel truck
7. Fill truck C with 800 gallons of FT2 fuel from FT2 tanker truck
8. Fill truck C with 1300 gallons of JP-8 fuel from truck A (this will provide a 50/50 mix since there is now 1300 gal., 800 + 500 unusable FT2 in Truck C)
9. Circulate fuel in truck C for 15 minutes
10. Fuel aircraft main tank #3 with 1600 gallons from truck C
11. Collect fuel sample from #3 main
12. Run day 6 FT2/JP-8 blend tests
13. Collect fuel sample from #3 main
14. Point drain residual fuel in main tank #3 into bowser
15. Transfer contents of bowser into waste fuel truck

For JP-8 Exhaust Chemistry Test (Test day 7):

1. Fuel aircraft main tank #3 with 1500 gals JP-8 (approximately 1400 gallons from truck A and the balance transfer from within aircraft)
2. Collect fuel sample from #3 main
3. Run JP-8 emissions tests (1 morning)
4. Collect fuel sample from #3 main

Post Test Clean-up:
1. Drain & purge contents of truck B & C into waste fuel truck (Approx. 1000 gallons)
2. Replace filters on truck B & C
3. Transfer any remaining JP-8 fuel in truck A on to aircraft
4. Balance fuel load on aircraft
5. Run engine #3 at idle for 15 minutes to purge systems of FT fuels
6. Final balance fuel load on aircraft

E. Participants

AAFEX will be a collaborative effort with sponsorship by NASA, FAA, DOD, EPA, Boeing, GE commercial engines, and UTC. Groups/individuals supported by these organizations that have agreed to participate are listed in Table 2.

Table 2. Potential AAFEX Participants

<table>
<thead>
<tr>
<th>Organization</th>
<th>POC</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEDC</td>
<td>Robert Howard <a href="mailto:Robert.Howard@arnold.af.mil">Robert.Howard@arnold.af.mil</a></td>
<td>Project Engineer, Sampling probes and heated lines</td>
</tr>
<tr>
<td>ARI</td>
<td>Rick Miake-Lye <a href="mailto:rick@aerodyne.com">rick@aerodyne.com</a></td>
<td>NOx, CO, Hydrocarbons, aerosol composition, BC mass</td>
</tr>
<tr>
<td>Boeing</td>
<td>Steve Baughcum</td>
<td>Science advisor, observer</td>
</tr>
<tr>
<td>-----------------</td>
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</tr>
<tr>
<td></td>
<td><a href="mailto:Steven.L.Baughcum@boeing.com">Steven.L.Baughcum@boeing.com</a></td>
<td></td>
</tr>
<tr>
<td>EPA</td>
<td>John Kinsey</td>
<td>Aerosol Mass and Composition</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:kinsey.john@epamail.epa.gov">kinsey.john@epamail.epa.gov</a></td>
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<tr>
<td>GE</td>
<td>Willard Dodds</td>
<td>Engine Performance/Operation Advisor</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:Willard.Dodds@ae.ge.com">Willard.Dodds@ae.ge.com</a></td>
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<tr>
<td>Missouri S&amp;T</td>
<td>Phil Whitefield</td>
<td>Aerosol Physical Properties</td>
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<tr>
<td></td>
<td><a href="mailto:pwhite@mst.edu">pwhite@mst.edu</a></td>
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<tr>
<td>Navy</td>
<td>Xu Li-Jones</td>
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<td><a href="mailto:xu.li-jones@navy.mil">xu.li-jones@navy.mil</a></td>
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<tr>
<td>NASA DFRC</td>
<td>Frank Cutler</td>
<td>Aircraft Operations</td>
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<tr>
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<td><a href="mailto:frank.w.cutler@nasa.gov">frank.w.cutler@nasa.gov</a></td>
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<tr>
<td>NASA GRC</td>
<td>Changlie Wey</td>
<td>Certification gases, SO2, O2, H2O, NMHCs</td>
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<tr>
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<td><a href="mailto:changlie.wey@nasa.gov">changlie.wey@nasa.gov</a></td>
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<tr>
<td>NASA GRC</td>
<td>Dan Bulzan</td>
<td>Project Manager, Test Conductor</td>
</tr>
<tr>
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<tr>
<td>NASA LaRC</td>
<td>Bruce Anderson</td>
<td>Project Scientist, Bulk Aerosol Composition/Physical Properties, Black Carbon Mass</td>
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<tr>
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<tr>
<td>Pratt and Whitney</td>
<td>Anuj Bhargava</td>
<td>Science advisor, instrument/group inter-comparison lead</td>
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<tr>
<td>UTRC</td>
<td>David Liscinsky</td>
<td>Aerosol Physical Properties</td>
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<tr>
<td>WPAFB</td>
<td>Edwin Corporan</td>
<td>Aerosol Physical Properties, BC Mass, Smoke Number, PAH</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:edwin.coporan@wpafb.af.mil">edwin.coporan@wpafb.af.mil</a></td>
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</table>

Primary project leadership will be provided by Bruce Anderson (science), Robert Howard (engineering), Dan Bulzan (management), and Frank Cutler (aircraft operations). However, the final objectives, experiment plan, and operational procedures will be established in consultation with science team members, project stakeholders, and the aircraft support team. Input from GE and Boeing is also critical, as these companies can provide proprietary information on engine, fuel, and airframe issues and can help define engine operating parameters for the alternative fuels and for changing ambient conditions.

The Table 2 list includes principle investigators and consultants that participated in the APEX test series as well as a variety of other aircraft emissions tests conducted by the AAFEX sponsoring agencies. Note that AFRL, MST, NASA LaRC, the Navy, and UTRC provide similar measurements of particle number and size, while ARI, LaRC, and UTRC use the same techniques to measure BC mass. This overlap will provide an opportunity to inter-compare measurement results and help establish the expected range of uncertainty between data sets collected by the individual investigators in separate test programs.

**F. Measurements**

Table 3 lists the minimum set of measurements that are needed to fully address the questions outlined above. Included are a variety of plume and background measurements, which will be used to determine plume age and dispersion characteristics and to establish ambient conditions for engine operation as well for data interpretation purposes. Measurements of ambient O3 and
light level are included to facilitate an examination the time-dependent partitioning of NOy species within the aging exhaust plume. The placement of a ruggedized sonic anemometer on the 30 m inlet should provide data for turbulent plume dispersion modeling, but may not be practical since plume velocities will potentially exceed 50 ms\(^{-1}\) at that location.

The specified suite of aerosol measurements includes many that have not been made in previous venues, but will provide valuable information for determining particle physical properties and composition. For example, to determine whether the volatile aerosols and soot particles are internally or externally mixed, output from a scanning differential mobility analyzer will be sampled by second sizing instrument either directly or after passing through a 350°C heater; if a particular size particle has a solid core (internally mixed), the total count will remain unchanged after heating, but the size will shift to smaller diameters. Conversely, if the number density changes while the size diameter is unaffected, then the volatiles are present as pure aerosol droplets. The new Single Particle Soot Photometer instrument will also allow us to determine whether particles with diameters >100 nm have volatile coatings, as it measures both black carbon mass and optical size (Kondo et al., 2008). Inclusion of CCN and IN measurements will allow us to assess the potential role of aircraft particle emissions in seeding liquid and ice clouds and to determine whether the absence of fuel sulfur mitigates this potential.

Several BC sensing instruments will be deployed, mainly to determine whether they are straightforward to use; provide reliable and consistent data; and are insensitive to changes in soot morphology and coatings. The Multi-Angle Aerosol Absorption Photometer (MAAP) instrument was specified for use in characterizing BC emission from Joint-Stike Fighter engines (PW135) by the “Interim Test Method”, which has subsequently been approved by the EPA as a substitute for “Method 5” determinations of aircraft particle emissions. However, the MAAP calibration is not well-established for aircraft emissions and its response is known to vary as particles accumulate surface coatings. AAFEX tests will allow us to determine the severity of this problem and to evaluate whether any of the new instruments yield better results.

A variety of instruments will be deployed to quantitatively determine the composition of volatile aerosols within the engine exhaust plume. The ARI Aerosol Mass Spectrometer (AMS) is the center-piece of this effort as it provides detailed compositional information on single, non-refractory particles having aerodynamic diameters >30 nm. Bulk soluble organic carbon concentrations will be provided by a Particle Into Liquid Sampler (PILS) coupled to a Total Organic Carbon analyzer. Another PILS will collect soluble aerosol samples for offline analysis for selected inorganic and organic cation and anion species. Aerosol samples collected on quartz-fiber filters will also be analyzed offline for elemental carbon, PAH content, and total organic carbon.
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<td>NASA</td>
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Gas phase measurements will include determinations of CO2, CO, NOx, and THC using ICAO accepted sampling techniques and instruments; these are important for evaluating engine operation and establishing how emissions change with fuel composition and ambient conditions. The Sulfur dioxide and O2 measurements are included to allow real-time fuel sulfur content and fuel-air-ratio determinations. Hazardous Air Pollutant (HAPS) and selected hydrocarbon concentrations will be measured in real-time by a combination of sensors including a Tunable
Diode Laser Differential Absorption Spectrometer (TILDAS), a Proton Reaction Mass Spectrometer (PTRMS) and a Fourier Transform Infrared Spectrometer-based Multi-Gas Analyzer (MGA). Canister samples will also be collected periodically and analyzed offline to determine concentrations of additional species and to verify the assignment of PTRMS mass peaks.

G. Site Layout

Figure 6 is a crude schematic of the experiment site layout, showing the placement of equipment trailers/trucks relative to the aircraft. As noted above the aircraft will be parked and chocked, facing into the prevailing wind, in a run-up area north of the

Figure 5. Layout of equipment trailers at the experiment site. Inlet probe will be placed at 1 and 30 m behind each of the inboard engines.

DAOF. Equipment vehicles will then be parked just off the aircraft’s right wing and sampling rakes/probes will be installed 1 and 30 m behind engines #2 and #3. The aerosol line valve box and sample dilution controls will be located in the MST trailers, hence it is positioned on a line extending perpendicular from the inboard engine exhaust planes and the other trailers are arranged to either side of it. AEDC will operate the gas sampling systems and most of the gas-
phase monitoring instruments will be housed in its trailer, thus their trailer is situated so as to minimize sample line lengths.

Power will be supplied to the trailers from 440 VAC, 3-phase outlets and a bank of 120 VAC outlets located on the test pad (see Figure 6). A wireless weather station will be erected upwind of the site to monitor wind direction and other meteorological parameters. For convenience, portable toilets will be installed behind the row of vehicles. Light will be provided by a row of “stadium” lights located along the north edge of the test area. Communications between the equipment shelters will be provided by a wired, centrally located intercom system provided by Missouri University for Science and Technology. One person in each group will be required to wear a headset during the tests so that changes in the test plan or notification of emergency situations can be quickly communicated. We will also attempt to establish a local area network so that data, notes, and runtime information can be transmitted between groups in real time.

H. Sample Probes

To prevent placing excessive torque on the DC-8 airframe, both inboard engines must be run at approximately the same fuel flow rates when either engine is operated at high-thrust. Assuming
the left engine is supplied with baseline fuel and the two inboard engines exhibit approximately
the same emission characteristics, the left engine can thus be sampled periodically to assess the
effects of changing ambient conditions on emissions characteristics and to provide a
“calibration” standard for judging alternative fuel impacts on exhaust composition. To facilitate
these measurements, multi-probed, “1-m” sample inlet rakes (see for example, Figure 7) will be
positioned behind each of the two inboard engines, just off the center lines (to avoid drawing
sample from the crankcase vent) and within 1 exhaust diameter downstream of the exit planes.

![Figure 7. APEX-1, 1 meter sampling rake (left) and 30 meter inlet probe.](image)

These rakes will contain vertical arrays of gas and aerosol probes mounted in alternate slots on
1.25 inch spacing. The current plan is to use water-cooled, APEX-style sampling probes to
populate the 1-m rakes. These probes were designed by Robert Hiers and Robert Howard of
the Air Force’s Arnold Engineering Development Center (AEDC) for use in sampling emissions
from military aircraft engines. As shown in Figure 8, the probes have an outer jacket through
which water is circulated to prevent overheating of the tip in high temperature conditions. The
mounting rakes

![Figure 8. Diagram of AEDC dilution probe (left) and photo of APEX-1 style probes (right).](image)

also have cooling water channels to protect the o-ring seals on the probes and provide water flow
to the inlet tips. The aerosol probes have an additional, inner jacket to deliver a concentric flow
of dilution gas to the probe tip to prevent water and volatile aerosol condensation and suppress
particle coagulation processes within the sample flow. The “gas” probes have 0.06” diameter
tip openings, which rapidly expands to the internal diameter of 0.25” thin-walled tubing. The aerosol probes have 0.04” inlet diameters and the flow is gradually expanded into 5/16” or 3/8” O.D. tubing downstream of the dilution zone. The probes and rakes are constructed from 316 Stainless Steel and were found to maintain integrity throughout the many hours of testing conducted during APEX1. Subsequent tests have shown that the aerosol probes transmit particles with 80% or better efficiency over the size range (10 to 300 nm) typically associated with aircraft particle emissions (Anderson, 2007; Liscinsky, 2008).

Led by the efforts at AEDC, sample rake designs have evolved over the last several years to facilitate easier deployment and installation of sampling systems. AAFEX will capitalize on this work and use the new “Tinker” rake (T1) that was developed under an Air Force Strategic Environmental Research and Development Program (SERDP) for sampling emissions from the primary test engine (#3). Pictured in Figure 9, this rake has a very small frontal profile (i.e., drag) and is mounted on a traversing table, which will make it possible to move the rake horizontally across the engine exhaust to explore emissions emanating from the crank-case vent tube. An APEX-1 style rake (A1) will be used to sample engine #2; it will be mounted at a 45° angle on an APEX-2 rake stand in order to provide adequate clearance below the engine mounting pilon.

Figure 9. The “Tinker” sampling rake that will be used at 1 m behind Engine #3; note the “button-hook” inlet mounted a few inches to the left of the vertical rake—this will be used to supply sample air to AESO instruments.
Thermocouples will be affixed to the outside of the rakes to record exhaust gas temperatures and impact pressure measurements will be made on the individual gas probes when they are valved-off from the sample flow line. These data will be combined to estimate plume mach number and velocity. They, along with CO₂ measurements from the gas probes, will also be used to determine which of the probes are located within the core flow of the exhaust.

Figure 10 shows a diagram of T1 as it will be installed during AAFEX. The mounting heights are based on the observation that the engine centerline remained at 72⁺² inches above ground level throughout APEX-1, regardless of the fuel loading in the wing and center tanks.

Figure 10. The dimensions and placement of Rake T1. The diagram in the upper right indicates how sample from each of the gas (G-) and particle (P-) probes will be distributed.

The T1 traversing stand will be bolted to the tarmac such that the probe tips are 36 inches behind the center-body of the engine—this gives more than 12 inches clearance between the top of the rake and the lowest point of the engine mounting pylon. A button-hook type inlet probe will also be mounted on the stand and will supply both gas and aerosol samples to AESO instruments 1) mounted within an environmental closure positioned just behind the wing, about 5 m from the engine and 2) operated within an equipment container parked adjacent to the MST trailer. T1
will support 6 dilution probes and 8 gas probes. All 6 dilution probes will be connected to a single valve box (Particle Valve Box 1 or PVB1), which will in turn be connected to a common sampling manifold located in the MST trailer; AFRL, ARI, LaRC and MST will draw samples from the manifold. Of the gas probes, 3 will connect to NASA GRC instruments, 2 to AEDC and 3 to AFRL. AEDC will provide gas flow to ARI, UCSD and Carnegie Melon U. for their sampling needs. AEDC will also collect quartz-filter samples from the gas lines for EC/OC analysis by LaRC. An additional gas probe will be mounted in the lowest rake position and will be used to monitor impact pressure within the engine exhaust stream. An effort will also be made to adapt a thermocouple to fit within a probe holder to measure exhaust gas temperature.

As shown in Figure 11, A1 will be on a 45° angle behind engine #2 and will contain 4 dilution probes, 5 gas probes, 2 thermocouples, and an impact-pressure port. All 4 dilution probes will
be plumbed to a valve box located at the rake-stand base; sample air from the box will be transported through ¾” tubing to the common sample manifold in the MST trailer.

Figure 12. Diagram and sample line specifications for the 1 m rakes.

A more detailed drawing of connections between gas (G-) and particle (P-) probes, gas and particle valve boxes (GVB and PVB, respectively) and participant trailers is provided in Figure 12. Rough dimensions of the system are shown at the bottom of the figure. Note that lines connecting T1 probes to the MST sampling manifold will be a minimum of 70’ long, whereas those from A1 will be > 124’. The types of tubing that will be used to span these distances are described in the lower left-hand region of the diagram. For example, sample from the top particle probe on A1 will pass through ¼” OD tubing to the rake base; 3/8” from the base to the valve box, PBV1; and ¾” from PBV1 to the MST sampling manifold. Design criteria call for using the largest tube diameter possible to reduce pressure drops and particle losses due to inertial impaction. We anticipate total flows of 40 to 150 lpm from the particle probes, depending on engine power, dilution ratios, and sample demands; this yields flow Reynolds Numbers of >10,000 through all tube sections.

The 30 m inlet probe used during APEX-1 is depicted in the right-hand portion of Figure 7. EPA will deploy a pair of these inlets to extract 30-m plume samples from behind each of the DC-8’s
inboard engines. The inlets are composed of 2” sanitary tubing and will be supported by tripod-legs that will be bolted to the concrete pad. Pitot tubes and thermocouples will be affixed to the side of each probe to facilitate exhaust plume velocity and temperature measurements at the corresponding sampling distances. Inlets fashioned from ¾” tubing will be attached with hose clamps to the side of the EPA probes and used to deliver 30-m samples to the MST manifold for distribution to various investigators. A port for introduction of dry N2 dilution gas will be plumbed into these inlets to facilitate an investigation of sample line chemistry, i.e., to address the question of whether a majority of the freshly nucleated.

Figure 13. Diagram of the aerosol sampling system—NOT ACCURATE.

I. Sampling Systems

Design of the gas transport system will be guided by ARP5XX, which establishes the characteristics of sampling systems used in ICAO engine emission certification tests. Consistent with these standards, the ~2 m long lengths of ¼” sample lines that connect the inlet probes to the heated valve box will be wrapped in heat tape and maintained at 160°C using thermocouples and temperature control units. Flow from the valve boxes and individual probes will pass
through heated lines to instruments located in the AEDC and AFRL trailers. The total lengths of sampling line will be kept to a minimum. Purge gas will be piped out each non-selected inlet tip to prevent contamination of the inlet walls and tubing by exhaust components during engine start and at times when flow would otherwise be stagnant within the sampling lines.

AAFEX will place a high priority on incorporating efficient transport lines/components in the aerosol sample delivery system and conducting in-the-field experiments to establish the system’s size-dependent particle losses. Design criteria will include using smooth, seamless, large-bore tubing to reduce turbulent diffusion and inertial particle losses; a minimum of connections and bends to reduce inertial impaction losses; and relatively high sample flow rates to suppress particle coagulation. And, because recent tests show that heated lines induce higher particle losses, all sampling lines will be maintained at ambient temperature. They will also be composed of stainless steel, copper, or carbon-loaded PTFE; conductive silicone tubing (the black tubing sold by TSI) will be specifically avoided in the main trunk lines as it is suspected of out-gassing organic compounds that deposit on the surface of soot particles thereby confusing assessments of engine organic aerosol emissions.

Figure 13 provides a diagram of the aerosol sample system as currently envisioned. At the 1-m rakes, approximately 1 m of thin-walled 3/8” O.D. stainless tubing will bring sample flow from the inlet probes to the 6-port valve boxes. This box has 3/8” Swagelok fittings on the inlet and outlet sides and has an array of 3/8” pneumatically-actuated ball valves that can be remotely operated to select sample/deliver dilution from/to the desired inlet tip(s). Similar to the gas valve box, ~3 lpm of purge gas will be blown out each line that is not selected for sampling to prevent unnecessary contamination of the tips and tube walls. A manifold will be attached to the valve box outlet connectors to converge flow from the 6, 3/8” lines into a single ¾” line. Approximately 20 m of electro-polished ¾” stainless tubing will then be used to transport flow from the VB2 to a sample selection/distribution manifold located in the MST equipment trailer; 40 m of line will be needed for transmission of sample from VB1. Dilution gas (N₂) flow rates will be adjusted using a mass flow control valve and will be set to yield a sample CO₂ mixing ratio of about 2000 ppm.

Samples from the 30 m locations will be drawn through minimum lengths of ¾” tubing to the MST trailer. Within the truck, the ¾” lines from the various probes/rakes will be plumbed to pneumatically-actuated ball valves that will in turn be used to select the desired sample stream. The valve box is designed to pull about 30 lpm bypass flow through the unused lines to prevent deposition of volatile aerosol and gases from stagnant exhaust samples onto the tube walls. Since the aircraft APU cannot be run during engine operation, sampling of its emissions will take place in separate tests and will involve drawing exhaust samples through a ¾” stainless tubing inlet directly into the sample manifold for distribution to participants.

All lines, valves, and inlet probes will be thoroughly cleaned and inspected prior to use. Pressure and vacuum leak checks will be performed on both the gas and aerosol systems with the goal of reducing the leakage rate to < 0.1% of total flow. In addition, integrity of the aerosol transport system will be checked by placing Hepa filters on the inlet probes and counting the number of particles in flow drawn from the downstream manifold; values < 10 cm⁻³ are generally acceptable,
assuming ambient counts are on the order of $10^4 \, \text{cm}^{-3}$. These checks will be performed periodically throughout the emissions tests to verify that the systems remain leak-free.

**J. Line Loss Assessments**

Wall losses due to Brownian and turbulent diffusion and turbulent and inertial impaction are a problem in all aerosol sampling systems that require high sample flow rates and incorporate bends and long lengths of transport tubing. The severity of this problem was investigated during a series of experiments conducted at NASA facilities during 2006 and several techniques were developed for making quick, in-the-field assessments of sample transport efficiency (Liscinsky et al., 2008). Figure 8 shows the simple test apparatus that will likely be used during AAFEX to determine size dependent particle penetration though the sampling lines and valve boxes. Simply stated, the test procedure is to generate a series of mono-disperse particles and measure their concentrations up- and downstream of the test article; the ratio of the two measurements at each size diameter yields the particle penetration function (see Figure 15.) For AAFEX, a Combustion Aerosol Standard (CAST, **references**) will be used to generate a flow of polydisperse soot particles, which will in turn be fed into a Differential Mobility Analyzer (DMA) operating in the “over-pressure” mode for selection of discrete particle sizes over the 10 to 300 nm size range. Using a 15:1 sheath air to sample air ratio, the DMA mono-disperse output will have a size resolution of $\leq 10\%$ of the peak particle diameter. The DMA output stream will be diluted with filtered air or $N_2$ to provide adequate flow to simulate conditions encountered in actual emissions sampling. A matched pair of TSI3010 condensation particle counters (CPC) will be used to measure particle concentrations at the inlet and exhaust ends of the sampling train and a high capacity vacuum pump coupled to a metering valve will be used to adjust system flow to values commonly used during the emissions tests. CPC sample pressures will be recorded and used to correct the particle measurements to standard flow conditions. Loss assessments of the 1 and 30 m sampling systems will be conducted prior to the commencement of emissions testing and will involve measuring particle penetration ratios for 10, 15, 20, 30, 40, 50, 75, 100, 150, 200, 250, and 300 nm diameter particles. A similar evaluation will be made of the gas sampling system to determine how the smoke number, TEOM, PAH, and EC/OC measurements made on that line might be effected by loss processes. To verify that contamination is not altering the system’s
transmission efficiency, the penetration efficiency of each line will be checked periodically by measuring the ratio of ambient particle concentrations between the aerosol inlets and sampling manifold. Drastic drops in efficiency will prompt an inspection and possible cleaning or replacement of suspect system components.

Figure 15. Measured and modeled transmission efficiency for the APEX-3, 30 m sampling line (left) and modeled transmission efficiencies for various sampling system configurations (right) assuming 100 lpm flow (calculations courtesy of David Liscinsky, UTRC.)

K. Initial Instrument Comparisons

Many groups participating in AAFEX will deploy the same or similar instruments to measure particle number, size, and black-carbon mass as well as CO2 mixing ratio. To ensure that any differences between emission profiles measured by the groups are not instrument related, AAFEX will include tests to evaluate the relative performance of participant particle counters, scanning mobility particle sizers, aethelometers (MAAP), and CO2 analyzers. For the particle tests and where practical, participant instruments will be set up in a common area and fed particles produced by a CAST soot generator. Particle size and concentration will be varied by adjusting the CAST fuel to air ratio and varying the amount of dilution flow. Instrument sensitivity to ultrafine particles will be tested by alternately passing the sample flow through a diffusion filter to remove particles <20 nm. Concentrations will be varied in half-decade steps from \(~10^3\) to \(~10^7\) cm\(^{-3}\) to test counter linearity and the ability of the SMPS systems to efficiently place charges on high concentrations of particles. Sample pressure will be varied from \(~550\) Torr to ambient to evaluate its effect on instrument performance. Data from the MAAP instruments will be reduced using the “Onasch” procedure to eliminate any uncertainties due to processing differences. Output from the systems will be plotted on relative scales and used to identify any obvious problems with instrument performance or data recording/processing.

To inter-compare carbon dioxide analyzers that draw from aerosol sample stream, calibration standards will be plumbed the aerosol sampling manifold and distributed to the individual equipment trucks/trailers for mixing ratio determinations. Ideally, standards with mixing ratios
about 0, 0.05%, 0.2%, 0.5%, and 1% will be tested. Measurement results will be shared and a common correction scheme will be developed to ensure that subsequent CO\textsubscript{2} mixing ratios used by the groups in calculating emission ratios are consistent.

To monitor aerosol instrument performance during emission testing, the CAST soot generator will be attached to the aerosol sample manifold and used to produce a known size range and concentration of particles. Groups can compare measurement results from one day to the next to evaluate whether their instruments are operating within specification or to identify any degradation in sample line transmission. To monitor CO\textsubscript{2} analyzer calibration, the aerosol sampling manifold will be flushed with a ~2000 ppm (0.2%) CO\textsubscript{2} standard for approximately 2 minutes during each test run. Instrument zero checks will be performed several times per engine run by flooding the aerosol manifold with dry N\textsubscript{2} gas.

L. Test Matrices

Table 3 lists the planned engine runs and gives estimates of the time and fuel required to accomplish test objectives. Fuel consumption is based on burning JP-8 in engine #2 during all tests and only supplying #3 with the more costly alternative fuels during fuel-specific emission tests. Note that three types of tests are envisioned: 1) an initial equipment shakedown, 2) a comprehensive exhaust mapping/sample dilution experiment (see Table 4), and 3) detailed tests to establish exhaust composition as a function of power and plume age (Table 5). To examine the effects of fuel and ambient conditions on engine emissions, the standard “emissions” test will be repeated with JP-8 and the pure FT fuels in early morning and at midday. Because of its limited supply, only a single engine run can be conducted using the biofuel; we may however, split the test into two parts, performing each half several hours apart to delineate any changes that might be related to ambient temperature and humidity variations.

Table 4. Summary of Engine Test Runs

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Test Objective</th>
<th>Duration (hrs)</th>
<th>Repetitions</th>
<th>JP-8 (gals)</th>
<th>Alt Fuel (gals)</th>
<th>Total Hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP-8</td>
<td>Shake Down</td>
<td>0.5</td>
<td>1</td>
<td>400</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>JP-8</td>
<td>Exhaust Mapping</td>
<td>2.5</td>
<td>1</td>
<td>2400</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>JP-8</td>
<td>Emission Characterization</td>
<td>3</td>
<td>2</td>
<td>5300</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>FT1</td>
<td>Emission Characterization</td>
<td>3</td>
<td>2</td>
<td>2500</td>
<td>2800</td>
<td>6</td>
</tr>
<tr>
<td>FT1 blend</td>
<td>Emission Characterization</td>
<td>3</td>
<td>1</td>
<td>2000</td>
<td>700</td>
<td>3</td>
</tr>
<tr>
<td>FT2</td>
<td>Emission Characterization</td>
<td>3</td>
<td>2</td>
<td>2450</td>
<td>2800</td>
<td>6</td>
</tr>
<tr>
<td>FT2 blend</td>
<td>Emission Characterization</td>
<td>3</td>
<td>1</td>
<td>2000</td>
<td>700</td>
<td>3</td>
</tr>
<tr>
<td>JP-8</td>
<td>Exhaust Characterization</td>
<td>2</td>
<td>2</td>
<td>4000</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Total JP-8=</td>
<td></td>
<td></td>
<td>21050</td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>

31
Goals of the initial “shakedown” test will be to 1) identify any lines or test equipment that might come lose during high-power engine runs and 2) evaluate sample collection and distribution system flows, valving, etc. We anticipate running the inboard engines for about 5 minutes each at power settings of 7, 30, 45, 65, 85% thrust and for 2 minutes at 100% for a total run duration of ~30 minutes. During this and all subsequent tests, observers will be stationed at strategic locations to quickly identify and communicate to the aircraft operators any problems that might arise with either the engines or sampling system installation. Video cameras will also be used to monitor the integrity of the rakes and inlet probes from within the AEDC equipment truck. Anytime lose or vibrating equipment are spotted, the engine will be shutdown as quickly as possible and potential remedies will be discussed and implemented.

Table 5. Exhaust Mapping Test Matrix; values in sample inlet columns are in minutes

<table>
<thead>
<tr>
<th>Engine Power</th>
<th>Fuel Flow Gals/Min</th>
<th>Fuel Gals*</th>
<th>Right Rake Tip</th>
<th>Left Rake Tip</th>
<th>Left 30 m</th>
<th>Right 30 m</th>
<th>Total Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4%</td>
<td>1.75</td>
<td>112</td>
<td>2 2 10 2 2 2 2 2 3 3 32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7%</td>
<td>2.52</td>
<td>91</td>
<td>2 2 10 2 2 2 2 2 3 3 18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>6.15</td>
<td>394</td>
<td>2 2 10 2 2 2 2 2 3 3 32</td>
<td></td>
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<tr>
<td>45%</td>
<td>8.99</td>
<td>324</td>
<td>2 2 10 2 2 2 2 2 3 3 18</td>
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<tr>
<td>65%</td>
<td>13.23</td>
<td>847</td>
<td>2 2 10 2 2 2 2 2 3 3 32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85%</td>
<td>17.63</td>
<td>564</td>
<td>2 2 10 2 2 2 2 2 3 3 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>21.56</td>
<td>86</td>
<td>2 2 10 2 2 2 2 2 3 3 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Gallons= 2417

* Assumes engines #2 and #3 operated at same power
** Assumes probe tip 3 is in core flow

When the experiment and aircraft support teams are satisfied with the integrity and functionality of the sampling equipment, a comprehensive exhaust experiment will be conducted to verify the 1 m probe positioning and determine the optimum sample dilution ratio at each power setting through climb. Table 4 summarizes the power and sampling patterns that will be employed. On engine startup, aerosol samples will be drawn from one 30 m inlet probes while purge air is expelled out each of the 1 m rake tips. Once stable power is reached, for exhaust mapping purposes, sample will alternately be drawn for a period of 2 minutes from each of the 1 m rake tips while employing a constant sample dilution ratio of ~10:1. Next, to examine the effects of dilution and an-isokinetic sampling on volatile aerosol formation and soot particle collection efficiency, emission measurements will be recorded on samples drawn from one of the probes positioned in the core flow as the dilution is systematically varied from ~4:1 to 32:1 in a series of 4, 2-minute-long steps. Finally, to examine plume chemistry and evaluate particle and gaseous species losses in the 1 m rake, samples will be draw for ~3 minutes each from each of the 30 m inlet probes. The process will be repeated at all power settings up to 85% of maximum. If initial results suggest that the rake is not optimally placed within the core flow, the engine will be shutdown, the rake moved, and the mapping re-initiated. The objective will be to ensure that as many aerosol and gas probes are positioned within the core flow (and outside the turbine vent flow) as possible. Because only a limited amount of sample flow is available from each of the 1
m inlet tips, participation in these tests may be restricted to one or two groups or to a select set of instrumentation from each group.

Table 6. Standard Fuel Test Matrix

<table>
<thead>
<tr>
<th>Engine Power</th>
<th>Fuel Flow Gals/min</th>
<th>JP-8 Gals*</th>
<th>Alt-Fuel Gals</th>
<th>Sampling Inlet Dwell Time (mins)</th>
<th>Total Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 m</td>
<td>1 m left</td>
</tr>
<tr>
<td>4%</td>
<td>1.75</td>
<td>11</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7%</td>
<td>2.52</td>
<td>15</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>30%</td>
<td>6.15</td>
<td>74</td>
<td></td>
<td>3</td>
<td>3</td>
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<tr>
<td>45%</td>
<td>8.99</td>
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<td>108</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>65%</td>
<td>13.23</td>
<td>159</td>
<td>159</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
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<td>17.63</td>
<td>212</td>
<td>212</td>
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<td>3</td>
</tr>
<tr>
<td>100%</td>
<td>21.56</td>
<td>43</td>
<td>43</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7%</td>
<td>2.52</td>
<td>30</td>
<td>30</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>100%</td>
<td>21.56</td>
<td>43</td>
<td>43</td>
<td></td>
<td></td>
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<tr>
<td>85%</td>
<td>17.63</td>
<td>212</td>
<td>212</td>
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<tr>
<td>65%</td>
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<tr>
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<td>3</td>
<td>3</td>
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<tr>
<td>30%</td>
<td>6.15</td>
<td>86</td>
<td>86</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7%</td>
<td>2.52</td>
<td>23</td>
<td>23</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4%</td>
<td>1.75</td>
<td>28</td>
<td>28</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4%</td>
<td>1.75</td>
<td>16</td>
<td>16</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
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<tr>
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<td>1.75</td>
<td>11</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Gallons= 1233  1388  Total Minutes= 181

*To prevent cross-mixing of plumes, engine #2 will only be operated 30% power or above; ARI van will be moved to 200 m sample location during 16-minute long, 4% power run*

Table 6 summarizes the test matrix that will be used in the emissions studies. The power settings follow an up and down stair-step pattern with 7% runs at the start, middle and end to assess variations in the engine’s emission characteristics over time and with changing ambient conditions. At engine startup and shutdown, sample air will be drawn from a downstream inlet while purge air is blown out each of the 1 m inlet tips. Except for the 100% power setting, sample will be drawn for about 3 minutes from the individual inlet probes at each power setting; this will allow about 1 minute to open/close valves and to adjust dilution and 2 minutes to collect emission data. Time saved in not having to adjust the downstream sample dilutions will be used to change and stabilize engine power. If wind conditions are optimal, an extended period at the end of each run will be devoted to characterizing plume chemistry at low engine thrust levels. The plan will be to decouple the ARI van from the MST sample manifold and move it downstream to the 200 m sampling location after completing the last step in the power ramp. Once reconfigured, the engine will be operated for an additional 30 minutes at low power to characterize volatile aerosol and hydrocarbon concentrations in the aged plume.
As noted above, the #2 engine must be operated at the higher engine powers to counter-balance the force applied on the right wing by the #3 engine. To reduce alternative fuel consumption and allow for its emissions to be measured as a transfer standard, this engine will burn JP-8 fuel from the aircraft’s fuselage and left wing tanks. If possible, to prevent contaminating the 30 and 200 m exhaust samples with advected exhaust, this engine will only be operated at 30% power levels or above; an extra 2 minutes is included during the initial and final 30% power runs to allow for the startup/shutdown and stabilization of this engine.

Experiments to characterize the aircraft’s APU emissions will be conducted before or after the individual engine fuel tests and will involve drawing sample through a sample-manifold-connected, ¾” tube positioned a few meters downstream of the unit’s exhaust port. The probe position will be varied in real-time to sample the exhaust plume at different ages/stages of dilution. The tests will require about 15 minutes of APU run time and no more than 10 gallons of fuel.

M. Test Procedures

For a typical engine run, the experiment team will arrive on site 1 to 2 hours before engine start to warm-up instruments. About 30 minutes before start, a short briefing will be held between the aircraft operators and the experiment team to review the test objectives, test cards and safety procedures. The test conductor (Dan Bulzan) will then board the plane and establish communications with the distributed investigators via headset. After engine start, the test conductor will announce when power is stable and record engine fuel flows, temperatures, fan speeds, etc. Within the experiment shelters, gas and aerosol sampling system operators will announce when sample concentrations have stabilized, start the clock on the individual test point, and poll the investigators to determine when their sampling requirements have been satisfied. When all have agreed, a new power setting will be requested and the process described above repeated. If at any time a safety issues arises, testing will be halted and the engines shut down as quickly as possible.

N. Engine Power Settings (From Will Dodds at GE)

Test points - If the test setup is generally the same as APEX I, the test points need to be set based on cockpit instrumentation, which seems to limit the options to fuel flow and fan speed. If PM are primarily formed in the combustor, the objective should be to set exactly the same combustor pressure, inlet temperature, fuel air ratio, airflow and humidity each time we want to measure or replicate emissions at a certain test point. If ambient temperature, pressure and humidity were always the same, either fuel flow or fan speed would be equally effective to set the points, however, I expect there will be big swings in ambient temperature during the test. Combustor inlet conditions (pressure, temperature, fuel flow and fuel air ratio) cannot be exactly replicated as ambient temperature changes. As temperature increases, the air is less dense, so more airflow, pumped to a higher pressure and temperature, is needed to achieve a given level of thrust. These effects are not huge, but experience from fuels tests here at GE indicate that changes in emissions due to variation in ambient temperature can be of the same magnitude as changes due to fuel properties.
Figure 16. Power settings as implemented during APEX-1.

My suggestion is to set test points using fan speed, as we did in APEX 1. APEX 1 test points are defined in Figure 16. On a warm day, if we set fuel flow, combustor inlet pressure and fuel flow be close to ISA levels, but combustor inlet temperature and fuel air ratio will be higher than ISA levels. If we set fan speed, fuel flow and combustor inlet pressure will be low, but combustor inlet temperature and fuel air ratio will be closer to ISA levels. We picked fan speed for the first APEX tests because the cockpit gauge could be read more accurately and it came closest to replicating combustor inlet temperature and fuel air ratio, which I guessed were the most important factors in PM emissions formation. For the more recent tests at GE, where we had a full range of instrumentation, we set combustor inlet temperature. There is not a perfect way to do it, and it is important to record all the engine parameters so the emissions data can be analyzed against fan speed, fuel flow or any other engine operating parameter.

Correcting data - No matter how we set points, it just isn't possible to exactly replicate combustor inlet conditions when temperature changes. For gaseous emissions, we have data on how emissions are affected by small changes in pressure, temperature, humidity and fuel air ratio, and that data can be used to correct to ISA conditions. Unfortunately, such data are not available for PM. I believe the best approach to sort out the fuel effects will be to take a lot of
data with the baseline (Jet A) fuel over a wide range of ambient temperatures on at least two different days. This data set could be used to develop an empirical correction for ambient temperature and also give an idea of data repeatability. MST developed an ambient temperature correction for the GE data after the test. It was a good effort, but during that test series, we didn't get enough temperature variation data on any single fuel to make a straightforward correlation.

**Fuel Changeovers** - For fuel tests at GE we calculated the amount of fuel that would be required to completely purge the pumps lines between the fuel tanks and the engine to give an idea how much of a new test fuel would have to be used before it was safe to take data. We monitored fuel flow and specific gravity during the changeover to confirm that the old fuel had been purged out. In past combustor rig tests on different fuels, I have also monitored emissions levels to monitor the fuel changeover.

**O. Test Schedule**

A straw-man schedule of activities for the January, 2009 AFFEX campaign is in shown in the figure below. Teams responsible for installing sampling systems and other equipment (AEDC, NASA, and possibly MST) should arrive prior to the morning of January 20\textsuperscript{th}. At that time, the DC-8 will be towed to run-up area and the NASA and AEDC trucks will be moved into place off the aircraft’s right wing and work to install plumbing, wiring, etc. will commence. The remaining vehicle fleet should be on site and ready to be moved into place by the morning of the 21\textsuperscript{st}. A comprehensive safety and security briefing will be held in the hanger prior to releasing participants to work at the experiment site. Setup should be complete to the point that sampling system checks, line loss experiments and instrument comparisons can begin on Friday the 23\textsuperscript{rd}. A NASA photographer will visit the site that afternoon to take a group picture and document the installation. These activities will continue through the weekend and culminate in a science team meeting on Sunday night to discuss findings and to fine-tune test plans for the following week. Engine testing will commence on Monday the 26\textsuperscript{th} with the initial shakedown and exhaust mapping experiment (see Table 4). Emission sampling will begin Tuesday the 27\textsuperscript{th} and continue until all the fuels have been successfully tested under the desired ambient conditions. Approximately 8 days of testing will be required to address project objectives.

Daily schedules will vary depending on work objectives. During the installation and setup phase work hours will likely extend from 7 am until 7 pm, but may be longer or shorter depending on the level of supervision that is required from the aircraft operations group. On days when two engine runs are scheduled, participants should be on site and ready to take measurements around 5 am. Single run test days will probably include engine operations around noon, which will allow time beforehand and afterward to change fuels and inspect and service the aircraft engines. Access to equipment vehicles before or after standard work hours will be allowed, since NASA science team members will be granted permission to supervise non-aircraft related activities at the experiment site.
# AAFEX DC-8 Test Schedule

**January/February 2009**

<table>
<thead>
<tr>
<th>Sunday</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
</tr>
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<tbody>
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<td>4</td>
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<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

**January**

- **Start Shipping Equipment to Palmdale This Week**
- **Bulk of Equipment to Arrive at Palmdale This Week**
- **Federal Holiday**

![](image)

**February**

- **Test Equipment Pack / Ship**
- **AAFEX Tests Teardown**
- **DC-8 AAFEX Tests**
- **DC-8 AAFEX Tests Margie**
- **Science Team Meeting**
- **Test Day 7**
- **Test Day 8**
- **Test Day 9**
- **Test Day 10**
- **Test Day 11**
- **Test Day 12**
- **Test Day 13**
- **Test Day 14**

**Setup Margin**

**DC-8 AAFEX Engine Running Tests**

- **Complete Line Loss and Instrument Tests**
- **Science Team Meeting**
- **Test Day 1**
- **Test Day 2**
- **Test Day 3**
- **Test Day 4**
- **Test Day 5**
- **Test Day 6**

**AAFEX Tech Brief**

- **Continue Setup**
- **Continue Line Loss Experiments Instrument Comparisons**

**Test Setup / Experimenters Arrive**

- **Begin moving equipment and vehicles to site**
- **Begin Plumbing Setup**

**Setup Margin**

- **Continue Setup**
- **Continue Line Loss Experiments Instrument Comparisons**
V. DATA EXCHANGE, ARCHIVING AND REPORTING

It is NASA’s intention that AAFEX test results be shared with the public as soon as possible. To set the ground rules for the process, a science team meeting will be held at the experiment’s conclusion to review the project documentation, agree on a common test-point numbering scheme, and to discuss data corrections, protocols, archiving and reporting. The following ideas will be put forth:

- All data will be shared openly between team members and deposited on the password accessible “particle measurement” website maintained by NASA GRC.
- Run notes, photographs, system diagrams and documentation, weather observations, engine operational data (fuel flows, temperatures), sampling system data (valve settings, CO2 mixing ratios, etc.) will be loaded onto the website by February 15, 2009 to aid investigators in reducing and analyzing their data sets.
- Taking input from all investigative groups, an executive summary and short power point briefing will be assembled by March 15th, 2009 and made available to participants to share with project sponsors and other stakeholders.
- During May 2009, one or more abstracts will be submitted to AAAR for presentations to be given at the annual fall meeting.
- Preliminary data sets should be submitted to the archive by July 1st, 2009. A 2-3 day science team meeting will be held shortly thereafter in either Hampton (or Virginia Beach) or Cleveland to discuss findings, establish archive formats, and outline paper and report titles.
- Final archive files will be due September 1st, 2009 and transferred to the public side of the NASA website shortly thereafter. Files should be in submitted in EXCEL format and should contain data structures organized around the run date and test point number; APEX-1 file formats provide an acceptable example. A “Readme” file should be included with the data that describes how the measurements were made and discusses any caveats or restrictions.
- Short reports from each group detailing their contributions to AAFEX will be due by December 15th. These will be bundled with an overview report by the project scientist and submitted for publication as a NASA TM by February 1st, 2010.
- An article that describes AAFEX and summarizes its important findings will be prepared and submitted to a suitable journal (Atmospheric Environment?) by mid 2010. For this and articles to follow, authors that make significant use of data from other investigators should offer co-authorship on the paper to those investigators.

VI. PROJECT SAFETY AND SECURITY

It is inherently dangerous to be in the vicinity of an operating aircraft engine as a significant vacuum exists near its inlet and its exhaust gas velocities and temperatures can approach mach 1 and 400°C, respectively, under high thrust conditions. The engines are also susceptible to catastrophic damage if they ingest foreign objects or debris (FOD). In addition to safety issues, aircraft are attractive targets for vandals and international terrorists. To avoid unnecessary delays or harm to participants or equipment, a high priority will be placed on maintaining a safe
and secure work environment during the AAFEX campaign. Specific policies include the following.

- To avoid overcrowding, participating groups should deploy the minimum staff required to operate and maintain their equipment.
- Access to the experiment site by outside observers will be limited and must be approved by project and aircraft management.
- All participants must wear badges while working outside their equipment vehicles and the use of safety glasses will be highly encouraged.
- Participants must not walk across active runways or enter restricted access areas without permission.
- Participants must have permission from aircraft operations to walk/ride bicycles between the experiment site and hanger.
- Flammable liquids must be kept in appropriate containers and stored in the “Flammables” cabinet while in the hanger area.
- MSDS sheets must be readily available for all hazardous compounds.
- Gas cylinders must be appropriately handled and secured.
- Electrical line connections should be wrapped/taped and raised above ground level to reduce hazard due to condensation or precipitation.
- Groups should keep their areas properly policed to reduce trip hazards and promote a more “picturesque” environment.
- Participants should double check to make certain that all tools and loose equipment are removed from the engine operation area before engine runs.
- Participants must remain within their equipment shelters during engine runs; requests to leave the shelters must be approved and coordinated by the test conductor.
- Personnel stationed outside shelters to observe engine, APU, or sampling system operation must wear hearing protection and be in visual or electronic contact with the aircraft ground crew.
- Each trailer/truck must have a least one representative on headset at all times during engine runs.
- Fires or other emergency situations must be quickly communicated to aircraft ground crew so that appropriate actions can be taken.
- After engine runs, participants must remain clear of exhaust-mounted sampling equipment until the test engineer has ascertained that the equipment has cooled to near ambient temperature.

VII. LOGISTICS

A. Travel

If freeway traffic is flowing freely, Palmdale is little over an hour’s drive north of Los Angeles International Airport (LAX). Burbank Airport is about 20 miles closer to Palmdale and is served by most major airlines, but it does not have direct connections to any city east of the Mississippi River. Indeed most flights arrive from/depart to San Francisco, Portland, Seattle or Denver. Palmdale Regional Airport is served by United Express, which conducts two roundtrip flights to San Francisco on weekdays and one each on Saturdays and Sundays.
As for ground transportation, LAX and Burbank are served by all major rental car companies and also provide bus and shuttle service to some locations. From LAX, travelers may catch the Antelope Valley Express, which runs busses at 2 hour intervals throughout the day between the airport and the Palmdale/Lancaster region (see http://www.avairportexpress.com/ for more information). For information on companies that provide ground transportation in Burbank see: www.burbankairport.com/location/documents/GrndTransContactInfoforWEBSITE8-4-08.pdf Avis, Budget, Dollar, Enterprise and Hertz all have local offices in the Palmdale area.

B. Lodging

Palmdale is a city with over 100,000 residents, so a variety of motels and hotels are available. During recent NASA airborne science missions based out of Palmdale, participants raved over the Residence Inn and Holiday Inn, and were generally satisfied with the Hampton Inn. Participants that stayed at the Courtyard by Marriott Motel (not listed, but next door to the Residence Inn) gave mixed reviews—most were satisfied with the accommodations, but complained of the lack of free breakfast and in-room refrigerators. High speed internet is available at all the listed motels. Negotiated AERO Institute rates for visiting DFRC partners or government per diem rates are available at all the listed motels.

Residence Inn by Marriott  
514 W Rancho Vista Blvd  
Palmdale, CA 93551  
Contact – Zarlyn Hidalgo, Sales Manager  
Email – PalmdaleRISales@tharaldson.com  
Quoted Discount Rate – $118.00 (Normally $169.99-184.99)  
(661) 947-4204  
www.marriott.com

Holiday Inn  
38630 5th Street West  
Palmdale, CA 93551  
(661) 947-8055  
www.Holidayinn.com

Hampton Inn and Suites  
39428 Trade Center Drive  
Palmdale, CA 93551  
Contact – Susan Brooks  
661-265-7400  
email – Pdlca_hampton_suites@hilton.com  
Agreement Rate $109.00-129.00 (Normally $159.00-179.00)  
www.hamptoninn.com

Oxford Inn and Suites  
***Lodged APEX-I Participants and includes lots of
1651 W Avenue K   ***amenities, but is 5 miles further from work site than
Lancaster, CA 93534   ***Palmdale Motels
(661) 949-3423
Contact – Patrick Miller, Director Of Sales
Email – patrickm@oxfordsuites.com
Quotes Discount Rate – $110.00
www.Oxfordsuites.com

Hilton Garden Inn, Palmdale
1309 Rancho Vista Blvd
Palmdale, CA  93551
310-259-3088, x540
661-274-2510 FAX
Contact – Ms. Merlin Wan, Director of Sales
merlin
Quoted discount rate -- $139.00
C. Emergency Contacts

In case of fire or injury, call 661-276-5504 from your cell phone or 911 from a land line. DAOF security can be reached at 661-947-4803 and 661-947-4985.

For emergency care or serious illness:

**Antelope Valley Hospital**
1600 W. Avenue J
Lancaster, CA 93534
Operator - (661) 949-5000 (Say Operator)

**Driving Directions**

**North on I-14**, take the Avenue K off ramp. Go straight across the intersection (Avenue K) and continue North on 15th Street West to the corner of Avenue J. The Hospital is on the South-West corner of Avenue J and 15th Street West.

**South on I-14**, take the Avenue K off ramp, turn LEFT on Avenue K, go to 15th Street West. Turn LEFT onto 15th Street West and proceed North to Avenue J. The Hospital is on the South-West corner of Avenue J and 15th Street West.

For less serious problems:

**Palmdale Primary Care Center – South Valley Urgent Care Clinic**
(661) 272-5050 – appointment desk
3830 40th Street East, Suite 100
Palmdale
**Hours:** 7 days a week: 8am-Midnight
*No appointment necessary*

D. Shipping

The following is adapted from information provided to airborne science investigators by Bob Curry: Experimenters should ship all freight (private trucks or commercial shippers, including FedEx or UPS freight) directly to the Palmdale facility (DAOF) using the following address:

DC-8 AAFEX Payload
Dryden Aircraft Operations Facility
2825 East Avenue P
Palmdale, CA 93550

The point of contact for shipping and receiving at the DAOF:
Bob Davis
(661) 212-0155
Letter mail and small packages coming via the U.S. Postal Service should be sent to our Dryden address:

Sandra Morgan - DC-8 AAFEX  
Mail Stop 2332  
NASA Dryden Flight Research Center  
P.O. Box 273  
Edwards, CA 93523

If you are sending letter mail and small packages via express mail (e.g., FedEx, UPS, or any other carrier that will not accept an address with a P. O. Box), please use the following Dryden address:

Sandra Morgan - DC-8 AAFEX  
Mail Stop 2332  
NASA Dryden Flight Research Center  
Bldg. 4876 Warehouse #6  
Lilly Drive  
Edwards, CA 93524

Hazardous materials should be sent with all appropriate DOT labeling. If your shipment includes radioactive material, please notify Bette Davis (661-276-3438) when your equipment begins transit, and provide the expected arrival date and time.
TO: Distribution

FROM: Alternative Aviation Fuel EXperiment DC-8 Mission Manager

SUBJECT: AAFEX test planning and preparation

The DC-8 will participate in the Alternative Aviation Fuel EXperiment (AAFEX) during January 2009. The tests will be conducted at the Dryden Aircraft Operations Facility (DAOF) in Palmdale, CA.

The DAOF is conveniently located in the city of Palmdale, California which offers a variety of hotel, restaurant and car rental options. Los Angeles International, Burbank and Ontario airports are all within 2 hours drive. A limited number of commercial jet flights also arrive and depart from the Palmdale Air Terminal (just 3 miles from the DAOF). Directions to the DAOF can be found at: http://www.nasa.gov/centers/dryden/daof/directions.html

Equipment should be shipped to arrive at the DAOF during the week of January 5, 2009. The test setup will start January 12, 2009 and experiment teams should plan to arrive that same week. See attached schedule for additional details.

The remainder of this e-mail includes instructions regarding the Instrument Questionnaire, Visitor Badging, Shipping and other general information.
Yes, there are also some forms to fill out. Follow the submittal instructions provided with each form. The following information will be helpful regarding a contact if you need assistance or if you need to ship items to the DAOF:

<table>
<thead>
<tr>
<th></th>
<th>E-Mail</th>
</tr>
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<tbody>
<tr>
<td>Fax</td>
<td><a href="mailto:karen.l.richards@nasa.gov">karen.l.richards@nasa.gov</a></td>
</tr>
<tr>
<td></td>
<td>(661) 276-2541</td>
</tr>
<tr>
<td></td>
<td>(661) 276-3675 (please provide a cover that denotes 'Karen Richards, DC-8 AAFEX')</td>
</tr>
<tr>
<td>Phone</td>
<td>(661) 276-2541</td>
</tr>
<tr>
<td></td>
<td>(661) 209-6569 cell</td>
</tr>
<tr>
<td>Mail / Express Mail / Small Packages (FEDEX, UPS, DHL)</td>
<td>NASA Dryden Flight Research Center</td>
</tr>
<tr>
<td></td>
<td>Your Name/Karen Richards/AAFEX</td>
</tr>
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<td></td>
<td>Mail Stop DAOF</td>
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<tr>
<td></td>
<td>P.O. Box 273</td>
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<tr>
<td></td>
<td>Edwards, CA 93523</td>
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<tr>
<td>Freight (FEDEX, UPS, DHL)</td>
<td>NASA Dryden Aircraft Operations Facility</td>
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<tr>
<td></td>
<td>DAOOF</td>
</tr>
<tr>
<td></td>
<td>Attn: Your Name/Karen/AAFEX</td>
</tr>
<tr>
<td></td>
<td>2825 E. Ave. P</td>
</tr>
<tr>
<td></td>
<td>Palmdale, CA 93550</td>
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</tbody>
</table>

Visitor Badging and Background Information Requirements

All visitors to the DOAF must complete the ‘Experimenter Worksheet’ (Appendix A) which will be used for badging and access key cards. The information will be purged from our files within (1) year after completion of the mission. Only your name, business affiliation, address, and phone number will be kept in our DFRC Airborne Science Controlled Customer List.

Please complete all information requested and provide copies of the required documents to Anne Odenthal as noted in the instructions.

This information should be received by us no later than 30 days in advance of the visit. Individuals who are holders of valid "green cards" will be considered on the same basis as other "U.S. persons". The Experimenter Worksheets for Foreign Nationals from countries on the 'Designated Countries' list should be received no later than 70 days in advance of the visit. Failure to receive the request in a timely manner could result in denial of the request.

Instrument Questionnaire

Please complete the ‘Instrument Questionnaire’ (Appendix B) which will be used to help us understand your test setup/support requirements. Please ignore the fact that this questionnaire was designed to address instruments to be installed on the aircraft. WE
will understand that this is a ground test setup with off aircraft facilities requirements. I’ve attempted to ‘N/A” a number of items in the Questionnaire that you need not consider.

Shipping Instructions

Experimenters may ship freight (including FEDEX, UPS, and DHL cargo) directly to the DAOF using the following address:

NASA Dryden Aircraft Operations Facility (DAOF)
Attn: Your Name/Karen/DC-8 AAFEX
2825 East Avenue P
Palmdale, CA 93550

Special shipping instructions will be provided to the experiment teams that may be bringing radioactive material to the DAOF. Please contact Karen Richards at the phone noted in this instruction to make arrangements.

Additional Information

Test teardown: At the conclusion of the AAFEX tests, the teardown of instruments setup will commence (approximately the last week of January).

Return shipping: All DC-8 Experimenters utilizing DC-8 supplied equipment, including racks and blue boxes, are expected to leave that equipment at DFRC upon their final departure from the DAOF. DFRC will assist experimenters with the shipping of their equipment from DFRC to home laboratories by providing normal dunnage (heavy weight cardboard, bubble wrap, and other packaging). Payment for shipments from DFRC must be managed directly between the Experimenter and shipping company.

Proper Attire: Sandals and open-toed or high heel shoes are not allowed in the DAOF or the DC-8. Please be prepared for this when you arrive for the test setup.

Summary

A quick review of the required paperwork:

<table>
<thead>
<tr>
<th>Required forms</th>
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<tbody>
<tr>
<td>Each Visitor to the DAOF</td>
</tr>
<tr>
<td>Experimenter’s Worksheet</td>
</tr>
<tr>
<td>Each Principal Investigator</td>
</tr>
<tr>
<td>Instrument Questionnaire</td>
</tr>
</tbody>
</table>
We look forward to working with all of you on the AAFEX test. Please feel free to call anytime if you have questions about these topics.

Frank Cutler
NASA DC-8 Project manager
NASA Dryden Flight Research Center
(661) 810-6944 cell