**Aeronautics Research Introduction**

**Summary:** LARGE performs research and analyses to support the NASA Fundamental Aeronautics goal of reducing aviation impacts on the environment. This work is sponsored by the NASA Fixed Wing Project (Ruben Delrosario, PI) and includes conducting laboratory, test cell/stand, engine-on-wing, airport and in-flight experiments to gain a better understanding of exhaust composition and the links between combustion technologies and engine emissions. We also investigate the evolution of aircraft emissions in the atmosphere, particularly focusing on how fuel and exhaust properties influence the formation and microphysical characteristics of condensation trails (contrails) and cirrus clouds.

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**Some Frequently Asked Questions:**

**LARGE is in the Science Directorate, why does it conduct aeronautics research?**

* In the 1990’s when it became apparent that aviation activities had the potential of impacting both climate and air quality, NASA Aeronautics Mission Directorate (ARMD) collaborated with Science Mission Directorate (SMD) to conduct studies to improve understanding of aircraft emissions and to quantify the atmospheric effects of aviation. LARGE was highly experienced in making airborne measurements and was selected in 1994 under this joint program to collect observations of aircraft wake turbulence and exhaust composition at cruise altitudes.
* Our relationship with aeronautics has continued over the years and has included conducting the highly successful SNIF (1995-1997), SUCCESS (1996), SONEX (1997), EXCAVATE (2001), APEX-1,2&3 (2004-2005), JSF Quick-Look (2007), PW2000 (2008), PW308 (2009), AAFEX-1&2 (2009-2011) and ACCESS (2013-2014) experiments to characterize aircraft engine emissions on the ground and at altitude.

**What type of experimental investigations does LARGE perform?**

Tests run the gamut from evaluating instruments and inlet probes for suitability in sampling aircraft exhaust emissions to conducting flight experiments using chase planes to determine fuel effects on emissions at cruise. Here are descriptions of a few test venues/objectives:

* To advance fundamental understanding of combustion aerosols and their evolution, laboratory tests using a mini-CAST burner are conducted to determine the properties of soot and how these particles become coated with low volatility compounds during the cooling and aging processes. [Moore et al., 2014]
* Advanced combustor concepts are evaluated in flame-tube and sector-rig test facilities at NASA GRC to establish how design characteristics influence emissions. The facilities allow operation of fuel injectors at pressures and temperatures characteristic of modern gas-turbine engines and has sample extraction ports and optical windows for monitoring exhaust composition over a range of P3-T3 conditions. [Peck et al., Magic Probe Article]
* Fundamental studies of exhaust-particle ice nucleation are conducted in the NASA GRC SE-11 high altitude test chamber, which has the capability of simulating atmospheric conditions at flight levels up to 50,000 ft. Exhaust emissions are introduced into the base of the flow-through chamber and ice particle number densities and size distributions are monitored as soot, aerosol precursor, and water vapor concentrations are varied to establish factors that regulate ice particle formation and growth rates [Wong et al., 2013]
* On-wing engine experiments (APEX-1,2,3; PW308; AAFEX-1,2; AAFEX-1,2) are conducted to establish PM emission profiles and investigate how these change with engine type, ambient temperature, thrust level, and fuel properties [e.g., Beyersdorf et al., 2013; Anderson et al., 2011]
* Airport studies are conducted to survey aircraft emission in normal operation, validate plume dispersion models, and develop better algorithms for inferring PM emissions per engine-type from ICAO-archived smoke-number data. (Herndon et al., 2006)
* In-flight exhaust-sampling experiments (SNIF, SUCCESS, ACCESS) provide the only means of determining exhaust composition and contrail-ice properties at cruise altitudes. These involve instrumenting an executive-jet class aircraft (Sabreliner or HU-25C Falcon) with an extensive suite of in situ particle and gas sensors, then performed close formation flights in restricted air space to determine emission factors as a function of ambient conditions, engine operation, and fuel composition [e.g., Anderson et al., 1998a; 1998b]

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**Why do we care about aircraft PM emissions?**

* The latest Inter-governmental Panel on Climate Change (IPCC) report concludes that climate change is real and that it is caused primarily by human activities. European countries are particularly concerned with climate change and have identified aircraft soot emissions and aircraft-induced cirrus clouds as two of its many causes. These concerns have motivated a deal of research over the last 20 years, aimed at gaining an understanding aircraft emissions, characterizing contrail radiative effects, and developing strategies for mitigating aviation environmental effects.
* Air quality is also impacted by aircraft emissions and many European nations have instituted greater restrictions on source emissions than those imposed by the USEPA. The European Union has begun regulating PM number emissions from diesel vehicles and is pressing to institute regulations on other modes of transportation, including aircraft.
* The International Civil Aviation Organization is in the process of instituting quantitative PM mass and number certification standards to replace the qualitative Smoke Number measurement. Emission measurements on a wide range of engines are needed to establish reasonable emission standards.
* The aviation industry operates on a global scale. US airlines and engine and aircraft manufacturers will have to comply with ICAO and European regulations or lose market share.

**What are the benefits of burning alternative jet fuels such as hydro-treated renewable jet (HRJ) as opposed to petroleum-based fuels?**

* Because the fuels are produced from renewable organic carbon feedstocks such as algae, camelina, etc., they produce much lower effective CO2 emissions and thus may mitigate changes in climate caused by build-up of greenhouse gases in the atmosphere
* The fuels can be manufactured here in the U.S., which will stimulate job growth and increase fuel security
* Because the fuels are simple hydrocarbons and do not contain aromatics and sulfur, they produce much lower soot, organic carbon, and sulfate (i.e. PM) emissions and hence may reduce local air quality impacts.
* The lower PM emissions associated with alternative fuels may also reduce contrail formation and hence lower aviation impacts on climate.

**Who is NASA helping with PM emission and alternative fuel research – who is our stakeholder?**

**(Note that the EPA, FAA, Air Force, Navy, Pratt and Whitney, GE Aircraft Engines, Rolls Royce, and Boeing all participated in AAFEX-2)**

* **Policy Makers:** need information on aircraft emissions and how they might be changing as a function of changing fuel supply in order to establish sensible regulations for protecting public health and the environment. At present, the International Civil Aviation Organization is deliberating establishing new number- and mass-based standards for aircraft PM emissions and has asked the SAE E-31 committee to develop detailed protocols for exhaust PM measurements. Emissions data and advanced understanding of aircraft PM sampling gained during the NASA APEX and AAFEX missions are playing prominent roles in establishing these protocols as well as guiding ICAO thinking on what the standards should be for the various classes of aircraft.
* **Climate modelers:** need accurate aviation emission profiles (including detailed information on PM characteristics) and basic understanding of the links between fuels and aircraft emissions to project the environmental impacts of aviation in future scenarios.
* **EPA and state departments of environmental quality**: need accurate aircraft emission profiles as a function of fuel properties for establishing airport PM and criteria pollutant source strengths in models used to produce daily air quality predictions for urban air sheds. These predictions are used to warn the public when air quality could potentially be hazardous for conducting outdoor activities and for curtailing/reducing operations of the most prolific pollution sources.

**Why do we need to do flight tests?  Virgin, Continental, Lufthansa and other operators have already done “green flights”**

* The airline and Air Force test flights simply demonstrate that aircraft operate normally when burning blends of alternative fuels; nothing has been learned about how the fuels influence engine emissions or contrail formation at altitude.
* It is impossible to replicate cruise operating conditions in ground tests in open air venues; full engine tests in something like the NASA Propulsion System Laboratory are hugely expensive, flight tests are cheaper.
* The NASA tests will involve flying an instrumented chase plane to measure trace gas and PM emission in the wake of the “source” aircraft, which will be burning either Jet A or various blends of alternative fuels (probably HRJs or other bio-type fuels). We will determine engine emission factors and establish the links between exhaust particle properties and contrail formation. These data will be used to model aviation effects on atmospheric O3 and PM budgets and contrail formation, all areas of active research by NASA and FAA funded investigators.

**Why do we need to better understand PM issues at altitude?  Is it really a problem**?

* Aircraft soot emissions absorb solar radiation and can heat the atmosphere.
* We do not completely understand the amount and properties of PM emissions produced by aircraft burning standard jet fuel at altitude. We have no information of how alternative fuels affect the quantity and properties of aircraft PM emission at altitude.
* Aircraft PM emissions can also influence the formation and properties of high clouds, which play an important role in regulating climate. Research by Pat Minnis at Langley and by DLR in Germany suggests that contrails have a climate warming effect; other work suggests that sulfur-coated aircraft soot emissions are effective ice-nuclei, which in turn, can cause formation of cirrus clouds in downwind regions which would otherwise be cloud free.
* A variety of studies have been conducted to develop strategies for reducing aviation-cloud effects: flying lower, using contrail formation forecasts to divert aircraft away from cirrus-cloud forming regions, etc.
* Ground tests show that gas turbine engines burning alternative fuels produce much lower soot emissions and, because the fuels are sulfur-free, the soot is insoluble in water, making it less prone to act as ice-nuclei. Since ice formation by homogeneous nucleation (that is, formation without a “seed” particle involved) is very slow, it’s possible that an aircraft burning alternative fuels would be less likely to form contrails and effect cirrus cloud formation under some conditions. A flight experiment which includes detailed measurements of aircraft PM emission and contrail/cloud properties is needed to investigate these possible effects.

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