Overview and Results from the Alternative-Fuel Effects on Contrails & Cruise EmiSSions (ACCESS) Flight Experiment

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ACCESS Sponsored by NASA Fundamental Aeronautics, Fixed-Wing Project

NASA Alternative-Fuel Emissions Research

- **Laboratory tests** to determine alternative fuel combustion and emissions characteristics
  - High-pressure flame-tube experiments on LDI fuel injectors—ongoing
  - High-pressure tests on GE & PW sector rig combustors—2013
- **Ground-based engine tests** to evaluate alternative fuel effects on emissions under real-world conditions
  - PW308—March 2008
  - AAFEX-I—January 2009
  - AAFEX-II—March 2011
  - APU—October 2012
- **Cloud chamber tests** to examine PM effects on contrail formation
  - ACCRI/FW Tests—2010—2015
- **Airborne experiments** to evaluate fuel effects on emissions and contrail formation at cruise
  - **ACCESS-I: Feb-April, 2013**

ACCESS Builds on Previous Airborne Tests

German Aerospace Agency (DLR)

- SULFUR flight series, mid 1990's , Falcon 20 chasing ATTAS, A310, A340, B707, B747, B737, DC8, DC10
- Pollution from aircraft emissions in the North Atlantic (Polinat), Falcon 20, 1990's
  *** Included Near-Field Sampling of NASA DC-8 ***
- CONCERT—Falcon 20, various aircraft, 2009-2011

NASA

- Subsonic-Assessment Near-Field Interactions Flights (SNIF), 1995--1997
  -Sabreliner chased NASA B737, P-3B, and C-130, F16s over east coast
- SUbsonic Assessment Cloud and Contrail Effects Special Study (SUCCESS), Spring 1996
  -Sabreliner chased NASA DC-8 and B757; DC-8 chased B757

NRC Canada

- Aviation Emissions Environmental Measurements (AEEM), 2011-
  -T33 chased Falcon 20 and commercial airliners

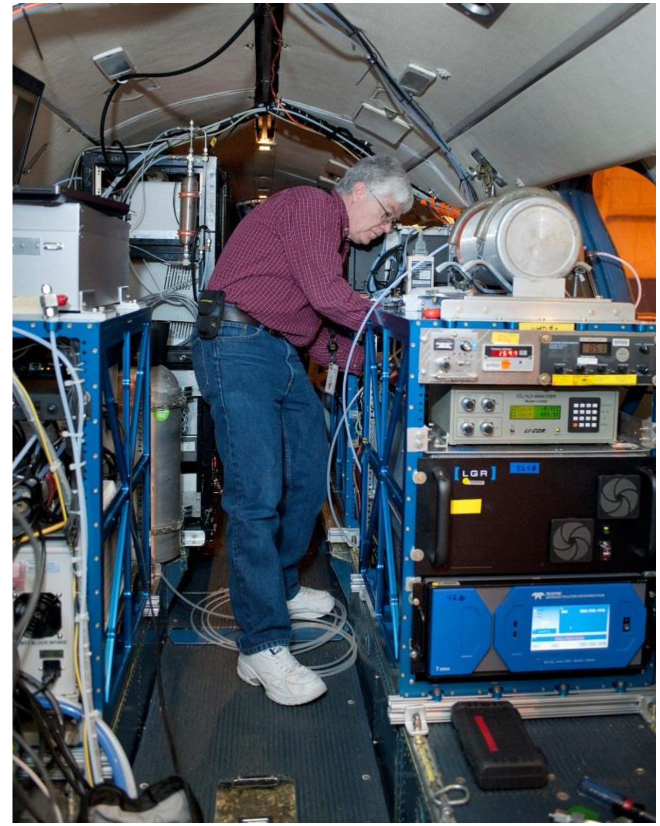
Specific Test Objectives

1. Examine the effects of Alt fuels on aircraft cruise-altitude gas and particle emission indices
2. Characterize the evolution (growth, changes in composition) of exhaust PM how this is impacted by fuel composition
3. Investigate the role of soot concentrations/properties and fuel sulfur in regulating contrail formation and the microphysical properties of the ice particles.
4. Survey soot and gas-phase emissions in commercial aircraft exhaust plumes in air-traffic corridors to provide context for DC-8 measurements

ACCESS Goals

1. Develop and demonstrate safe and effective approaches for obtaining near- and far-field measurements of DC-8 exhaust composition and contrail characteristics. Concerns: engine flame outs, airframe stress, instrument saturation in near-field/lack of sensitivity in far-field, etc.
2. Obtain ground and in-flight data at comparable fuel-flow rates to evaluate possible links in data sets. Motivation: ~75 hours of detailed DC-8 emission data from APEX and AAFEX—do they have any value in predicting cruise emissions?
3. Obtain ground and airborne emissions measurements from a broad range of commercial aircraft using the same ACCESS instrument suite to address question: Are the DC-8's CFM56 engines representative of the broader fleet?
4. Obtain gas, aerosol and cloud particle measurements at nearly the same location on the Falcon airframe to facilitate EI calculations for all parameters, include contrail ice.

Chase Aircraft: NASA Langley Falcon HU25



- Procured in 2011 from U.S. Coastguard to support Airborne Science programs
- Aircraft shown to be highly versatile, used in dozens of studies by DLR
- Was modified for atmospheric sampling and use as a remote-sensor test-bed
- Was outfitted with RVSM to allow operation in flight corridors

Source Aircraft: NASA Dryden DC-8

- Uses CFM56-2-C engines; NASA asset, no restrictions on data use or for burning alt fuels
- Ground-based emissions studied in over 75 hours of tests during APEX, AAFEX-I, and AAFEX-II
- In-flight emissions previously characterized during SUCCESS and POLINAT

Previous Tests Indicate DC-8 PM Emissions Significantly Reduced by Burning Alt Fuels

ACCESS Experiment Activities

- Modified Falcon HU25 with sample inlets and cloud probes
- Mounted extensive instrumentation package in Falcon cabin
- Procured JP-8 and Camelina-based HEFA fuels
- Deployed Falcon and Mobile Lab to Palmdale 2/19/2013
  - Mixed 50:50 JP-8/HEFA and obtained fuel certification
  - Performed "practice" flight with DC-8 to hone techniques
  - Performed 4 exhaust and contrail sampling missions with DC-8 in 32 kft to 37 kft altitude range
  - Conducted extensive ground sampling of DC-8 exhaust to obtain more detailed emissions data
- Transited Home to Langley 4/14/2013

Project went on Hiatus from March 7 to April 2, 2013 for Dryden Safety Stand-Down

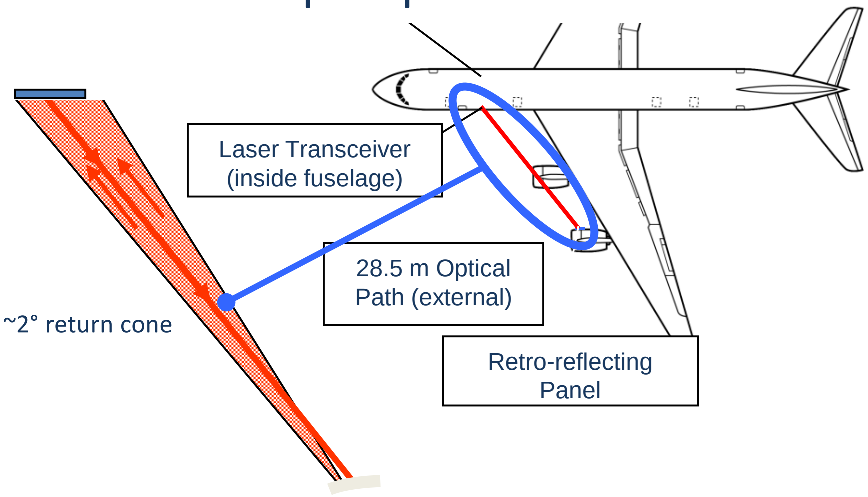
Falcon Modifications

HIMIL Aerosol/Gas Inlet

Cloud Droplet Probe

Wingtip Pylons for Cloud Probes

Open-path DLH

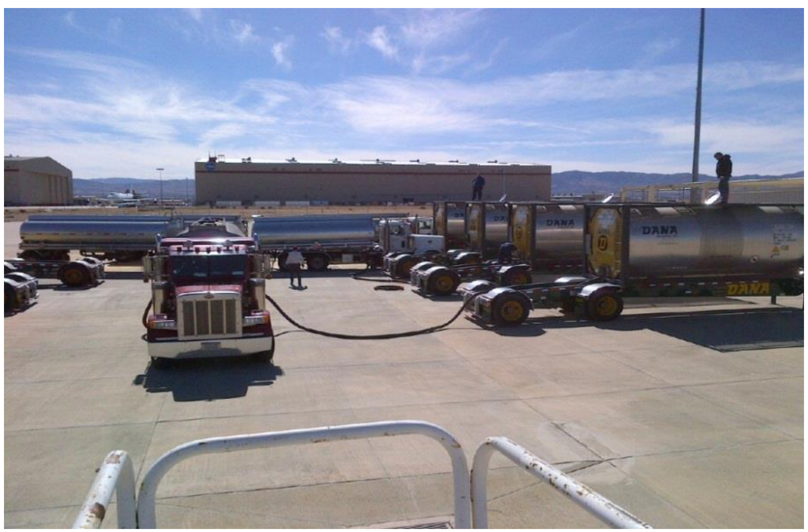


Falcon In Situ Measurements

Parameter	Instrument	Operating Principle
CO_2	LiCor 7000	Non-Dispersive IR Absorption
CO, CO_2, H_2O	Los Gatos Research ICOS Instrument	Cavity Ring-down Absorption
H_2O	LaRC -- DLH	Long-path IR
	Edgetech 137	Chilled Mirror
NO	Teledyne T200UP	Chemiluminescence
NO_2	Los Gatos Research ICOS Instrument	Cavity Ring-down Absorption
O_3	2B Technologies	UV Absorption
Ultrafine Aerosol > 3 nm	TSI3025 CPC	Condensation Growth/Optical
Fine Aerosol >10 nm	TSI3010 CPC	Condensation Growth/Optical
Nonvolatile Aerosol >10 nm	TSI3010 CPC w/thermal denuder	Condensation Growth/Optical
Aerosol Hygroscopicity	TSI 3787 water-based counter	Condensation Growth/Optical
Aerosol Size: 10 to 300 nm	TSI SMPS	Condensation Growth/Optical
Aerosol Size: 80 to 1000 nm	DMT Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Optical Scattering
Soot Mass	Particle Soot Absorption Photometer (PSAP)	Light attenuation through a filter
Soot size/mass	DMT Single Particle Soot Photometer (SP2)	Laser Incandescence
Cloud Particle Size	DMT Cloud Droplet Probe (CDP)	Optical Scattering
Cloud Particle Size/Images	DMT Cloud, Aerosol and Precipitation Spectrometer (CAPS)	Optical Scattering/Imaging
T, P, Altitude, TAS, IAS, etc.	Falcon Air Data Computers/Ballard Interface	Ship's Instruments
Platform Position, Attitude and Accelerations	Applanix INS/GPS	GPS, ring-laser gyro stabilized accelerometers

ACCESS Fuel Properties

Test	JP-8	HEFA Blend	Ratio
Sulfur (ppm)	820	500	0.61
Aromatics (%vol)	18	9.8	0.54
Density (kg/L)	0.81	0.79	0.98
End Point (degC)	275	279	1.01
Heat of Combustion (MJ/kg)	43.1	43.3	1.00
Hydrogen Content (%Mass)	13.9	14.4	1.04
Smoke Point	21.5	27	1.26

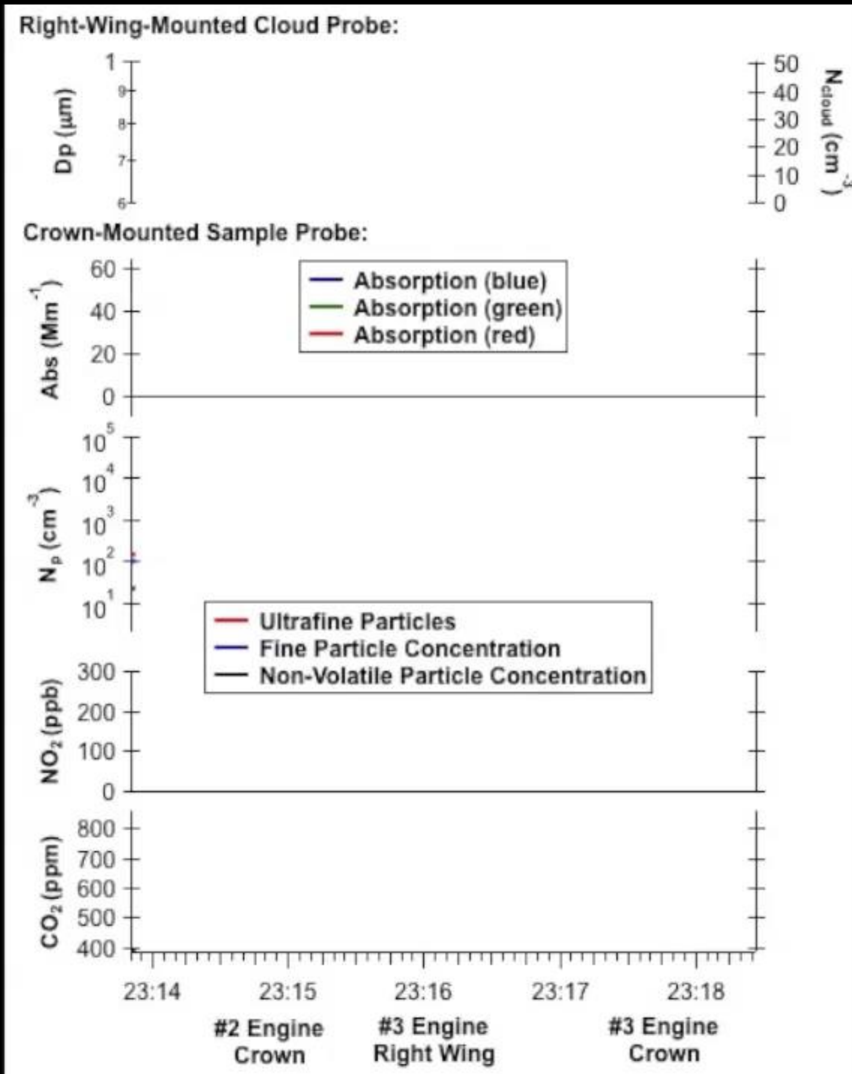


Obtained 36 kgals JP-8, 6 kgals HEFA; Mixed 50:50 blend in 10 kgal tanker

Contrail Sampling Flight Plans

- Falcon took off ~0.5 hours before DC-8, crew performed calibrations while climbing
- Rendezvous with DC-8 at 32 kft over Edwards AFB complex in restricted air space
- Aircraft climbed in tandem to altitudes where persistent contrails formed, typically 34 kft
- Aircraft matched speed and Falcon commenced sampling exhaust and contrails
- Aircraft typically remained on station for 3 hours before Falcon had to RTB

Time Series For Typical Set of Maneuvers

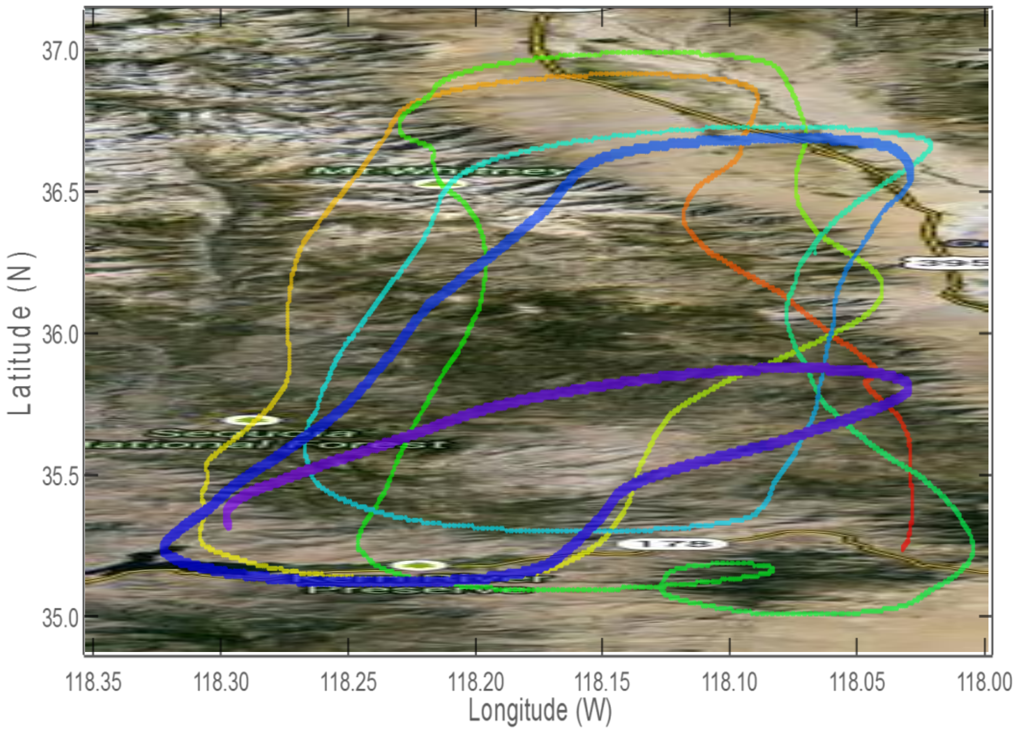


12 April 2013 Flight

1:11 min. duration; Speed is 400% of real time

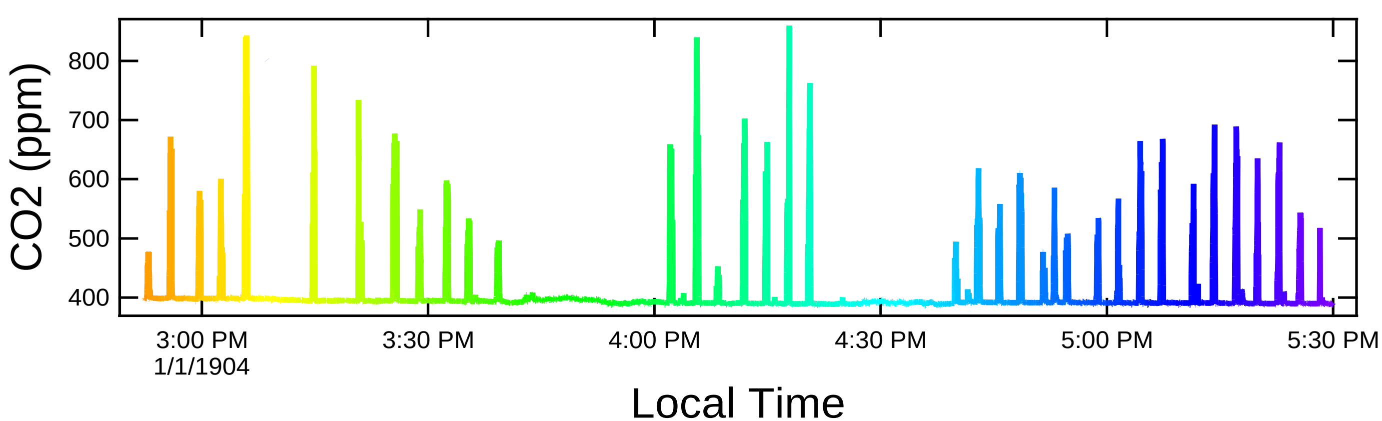
Flights Entailed flying Racetracks over Edwards

Thick Line = HEFA Blend; Thin Line = JP-8



Flight Rules

- Contrails must be visible to outline wingtip vortices
- Falcon to exit plume when wake-vortex roll-up evident
- Far-field measurements restricted to sampling exhaust/ice detraining from top of wake vortices
- Falcon to remain clear of contrail until wake vortices decay
- Must remain < 50 NM from landing strip



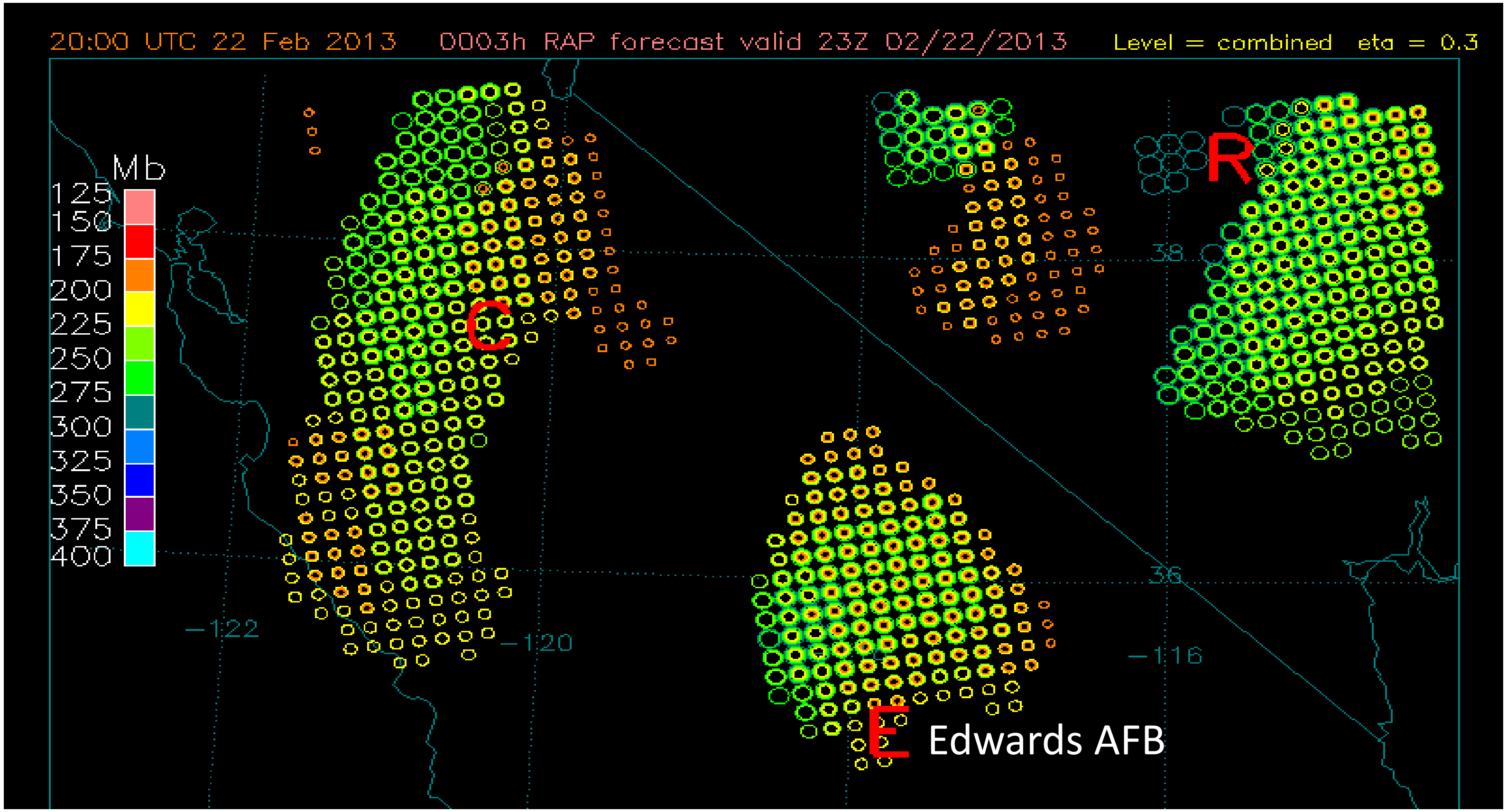
Engine Thrust Varied to Study Power Dependence of Emissions and Contrail

Inboard Engines Idled Back

Outboard Engines Idled Back

Varied Engine FF from ~1000 to 3000 lbs/hr, balancing Inboard/Outboard thrust to maintain constant 200 knots IAS

Contrails Scarce, Used Prediction Model to Plan Flights



Langley Contrail Forecast Model (Pat Minnis, PI)

• http://enso.larc.nasa.gov/sass/contrail_forecast/contrail_prediction.html
• Partly developed under ACCRI program
• Predicts contrail formation probability over CONUS at various flight altitudes based on RUC model temperature and humidity forecast data
• Model yields short (2 hr) and long (2 day) contrail predictions
• Site also included satellite images and a vast assortment of meteorological data products

ACCESS also Included Ground Measurements

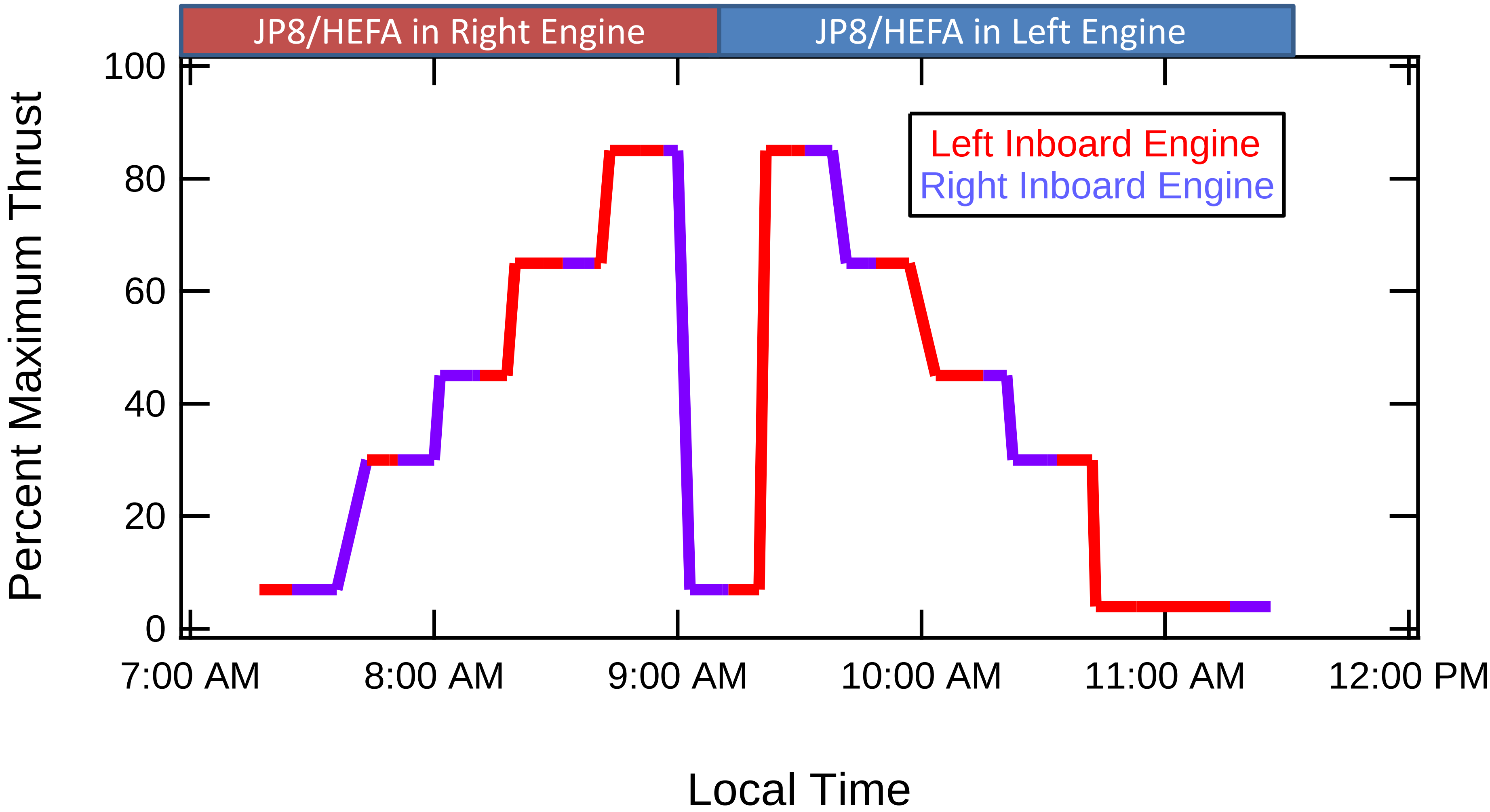
Enabled additional measurements, power settings, and traceability to past results

- Probe stands mounted at 30 m behind both inboard engines
- Falcon instrument payload + the mobile laboratory with additional instruments (shown at right)
- Cycle through fuels, power settings over an approximately 4-hr. experiment

Mobile Laboratory Instruments

Parameter	Instrument	Measurement Type
CO2	LiCor 7000	Non-Dispersive IR
Total Hydrocarbons	California Analytical Instruments	FID
SO2	Thermo Scientific	Pulsed Fluorescence
Ultrafine Aerosol Number Density (Ntot)	TSI3775 particle Counter	Condensation Growth/Optical
Nonvolatile Aerosol Number Density (Nnv)	Thermal Denuder/TSI3022 Particle Counter	Condensation Growth/Optical
Aerosol Size, 10 to 300 nm	TSI Scanning Mobility Particle Sizer (SMPS)/TSI3776	Electical Mobility
Nonvolatile Aerosol Size, 10 to 300 nm	TSI SMPS w/thermal denuder/TSI3772	Electical Mobility
Aerosol size, 6 to 560 nm	TSI Electical Exhaust Particle Sizer	Electrical Mobility
Aerosol Extinction	ARI CAPS Pmex	Cavity-Attenuated Phase-Shift
Aerosol Composition	ARI High-Resolution Time of Flight Aerosol Mass Spectrometer	Aerosol evaporation/Mass Spect Analysis
Aerosol Density	Kanomax Aerosol Mass Analyzer/SMPS	Centrifugal/Electrostatic separation
Size-Resolved Aerosol Solubilty Specta	Scanning flow DMT CCN/DMA	Thermal gradient CCN

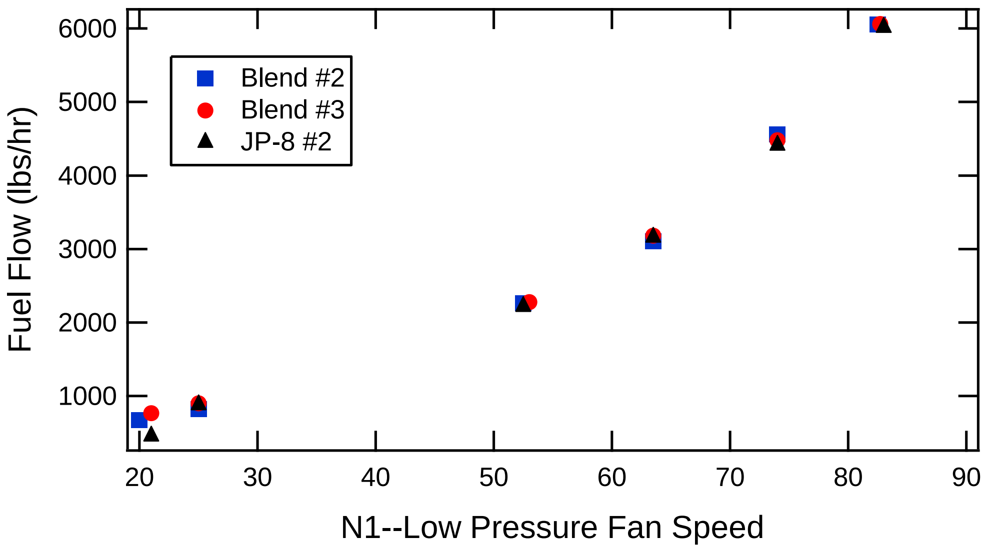
Ground Test Sampling Matrix

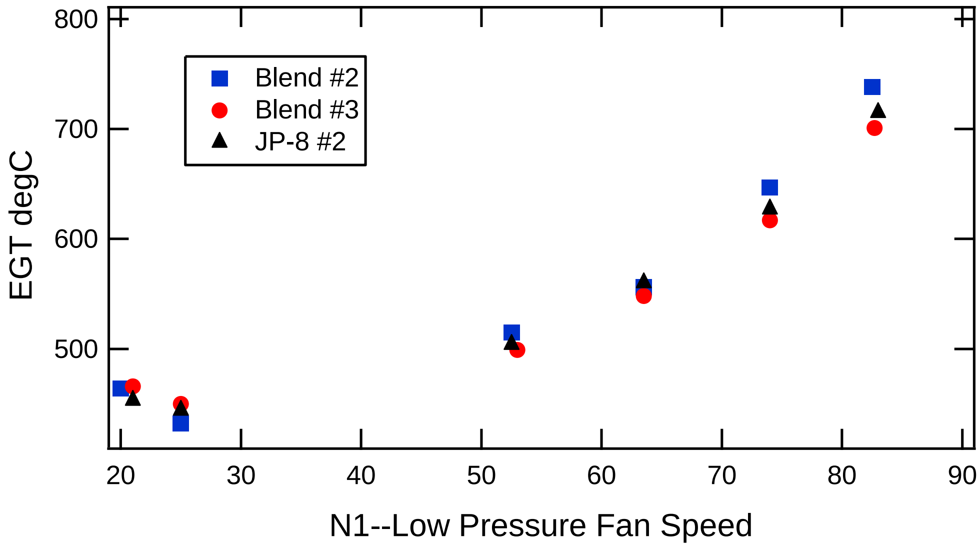


Test was not perfect: Temperature increased 10 F and JP-8 became contaminated with blend over course of experiment

Fuels Yielded Similar Engine Performances

Data from Ground Tests



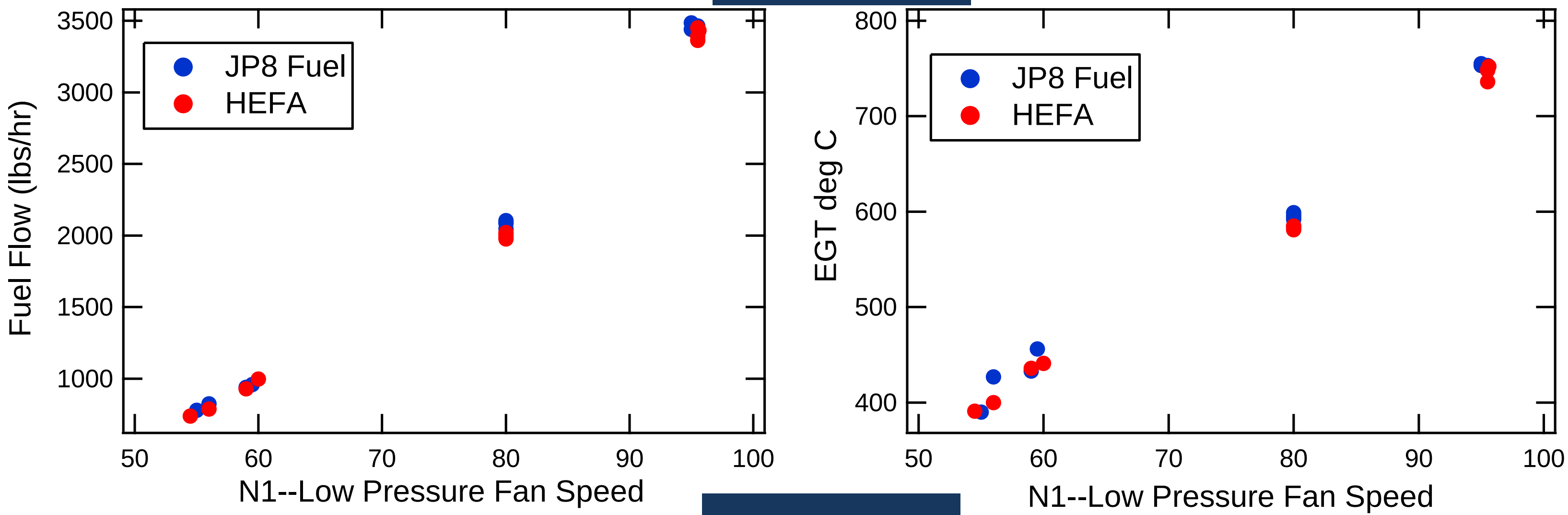


Values not corrected for fuel density, heat of combustion or variations in ambient temperature and humidity

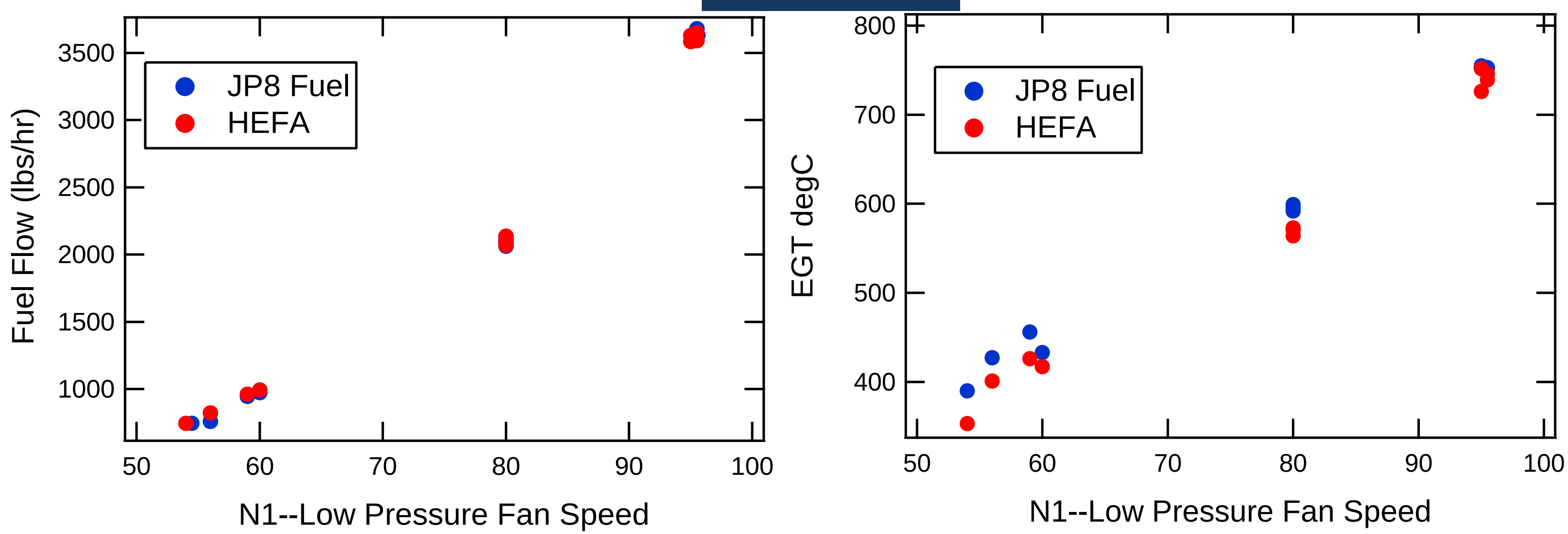
Data read from cockpit displays and hand recorded; values are visual averages

In-Flight Fuel Performance at 34 kft

#2 Engine



#3 Engine



Any Questions to This Point?

Next Up: Rich to Present Measurement Results