Understanding Changes in Aviation Emissions due to AAF with New Combustor Engine Technology. Project 002

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October 16, 2025
Alexandria, VA

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 002 through FAA Award Number 13-C-AJFE-MST under the supervision of Demi Tighe. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

ASCENT Project 002

Understanding Changes in Aviation Emissions due to SAF with New Combustor Engine Technology.

Missouri University of Science and Technology

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PM: Demi Tighe with Nicole Didyk-Wells

Cost Share Partners:

Boeing, Gulfstream, P&W & Airbus Americas

Objective:

Understanding Changes in Aviation Emissions due to SAF with New Combustor Engine Technology.

Project Benefits:

1.) Characterize the volatile and non-volatile particulate matter from engines some not currently in the ICAO emissions databank for nvPM emissions.
2.) Quantify the effects of fuel composition on those emissions by making measurements using a range of SAFs and low sulfur fuels.
3.) Compare results obtained from the instruments of other campaign participants (e.g. NASA) with those from the MS&T team instrumentation
4.) Compare results with the data from prior emissions research campaigns to characterize how the particle emissions vary as engine combustor technology has evolved.
5.) Provide much needed input for improving contrail modeling.
6.) Provide the opportunity to acquire in situ monitoring of contrails and the ambient atmosphere.
7.) Provide real measurement input for CAEP decision making.

Research Approach:

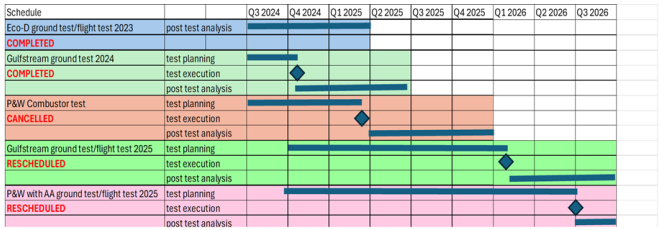
The ASCENT MS&T team with the guidance of emissions specialists at various OEMs propose to make high priority ground-based field measurement campaigns of nvPM and combustion gas emissions from engines on commercial widebody transports, regional a business jet aircraft, and a new technology combustor burning both conventional fuels, low sulfur fuels and candidate sustainable aviation fuels (SAF). These measurements are scheduled to take place in multiple campaigns spanning FY2023 through FY2027 with analysis and results reported through 2027. Where possible each ground based study will be accompanied by a complementary airborne study Each campaign will be preceded by test design, planning and preparation. The cost to ASCENT will be to support the MS&T team to participate in and manage the emission studies,and,to defray some of the costs incurred for the fuels to conduct both ground-based and in flight emissions testing.

Major Accomplishments (to date):

- Ground-based SAF emissions testing opportunities identified
- Funding for emissions testing at EcoD, Gulfstream and P&W awarded
- Emissions testing at Eco-D 2023 and Gulfstream completed

Future Work / Schedule:

- Flight test + Ground Test planning, execution and post analysis
- Test specific data analysis and interpretation



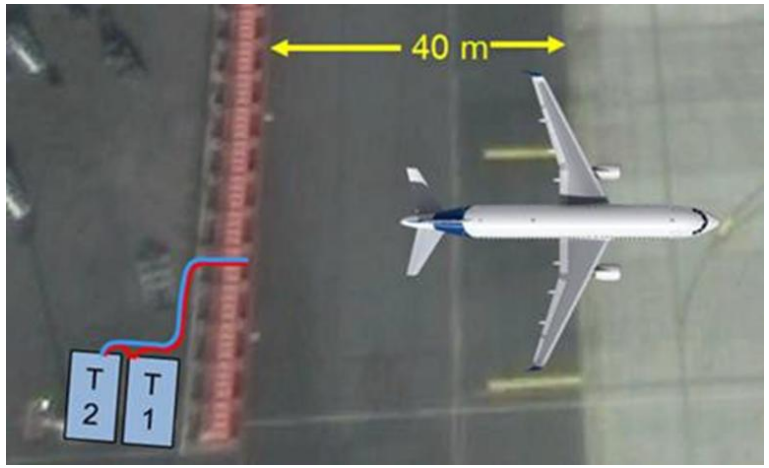
P&W with Embraer (E2) ground test Q4 2026
P&W with Airbus (A320) ground test Q4 2026

This research is funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 069 through FAA Award Number 13-C-AJFE-MST-014 under the supervision of Daniel Jacob. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

Research Objectives

- The ASCENT MS&T team with the guidance of exhaust specialists at various OEMs are making high priority ground-based field measurement campaigns of nvPM and combustion gas exhaust from engines on commercial widebody transports, a regional commercial transport, a business jet aircraft, and a new technology combustor burning both conventional fuels, low sulfur fuels and candidate alternative aviation fuels (AAF).
- These measurements are scheduled to take place in multiple campaigns spanning FY2023 through FY2027 with analysis and results reported through 2027.
- Where possible each ground-based study will be accompanied by a complementary airborne study.
- Each ground-based and airborne campaign will be preceded by test design, planning and preparation.
- The cost to ASCENT will be to support the MS&T team to participate in and manage the exhaust studies, and to defray some of the costs incurred for the fuels to conduct both ground-based and in-flight exhaust testing.

Typical Ground-based Sampling Schematic



Sample line from manifold to NARS = 25m

NRC
Quartz filter sampler

DLR
- CPC
- SMPS
- EEPS
- OPC
- FTIR
- NO_x

NASA
- (TD-)SMPS
- CAPS PMex
- MAAP
- PSAP
- TAP
- CO_2
- Teflon filter sampler

MST (NARS)
- APC
- MSS Plus
- LII 300
- DMS500
- CO_2

ARI
- CAPS PMssa
- cTOF-AMS

Probe

43 m

20m heated line (60°C, 137 L/min)

Sampling manifold (33 °C)

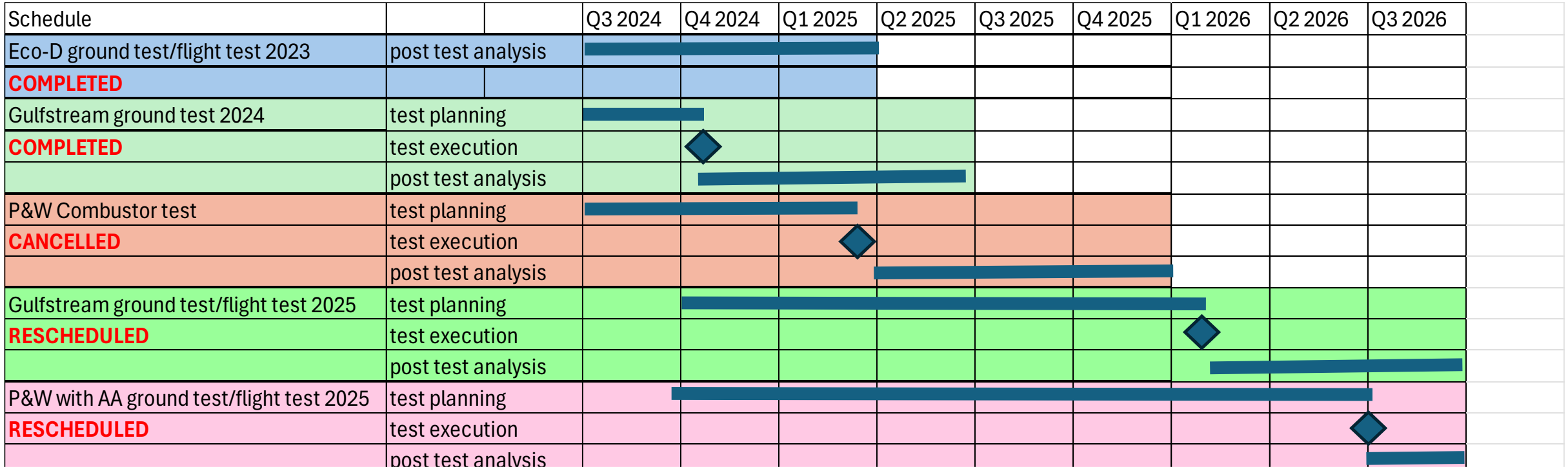
Heated Teflon line (60°C)

NRC LII 300 | NRC LII 300 | NRC PAX | NRC CAPS PMssa | NRC CS-SMPS | NRC TEM sampler | UIBK PTR-ToF-MS

Goals for ASCENT 002 Studies

- Characterize the volatile and non-volatile particulate matter from engines some of which are not currently in the ICAO emissions databank for nvPM emissions.
- Compare AAF exhaust with those from conventional Jet A including low sulfur and blends
- Deconvolve the exhaust issues potentially encountered through lube oil contamination.
- Quantify the effects of fuel composition on exhaust by making measurements using a range of AAFs and low sulfur fuels.
- Compare results obtained from the instruments of other campaign participants (e.g. NASA and DLR) with those from the MS&T team instrumentation
- Compare results with the data from prior exhaust research campaigns to characterize how the particles vary as engine combustor technology has evolved.
- Provide much needed input for improving contrail modeling.
- Provide the opportunity to acquire in situ monitoring of contrails and the ambient atmosphere.
- Provide real measurement input for ICAO - CAEP decision making.

Current and Future Anticipated Schedule



P&W with Embraer (E2) ground test Q4 2026
P&W with Airbus (A320) ground test Q4 2026

Fuels

- The OEMs with the assistance of the FAA, through this proposed effort will coordinate the procurement, fuel properties analysis, delivery, handling, and loading logistics for various fuels in support of the proposed Emissions Testing.
- This includes the fuel volume required to support testing of the source and chase aircraft for the flight tests.
- Fuels used in the eco-D and Gulfstream ground-based studies

❑ ecoD Fuel 1 - Low Sulfur Jet-A max total sulfur target of 1 ppm·

❑ ecoD Fuel 2 - 100% HEFA-SPK

❑ GAC Fuel 1 – 100% HEFA SPK

❑ GAC Fuel 2 – 30%-70% HEFA JETA Blend

❑ GAC Fuel 3 - Conventional JET A

*** Fuels for future ground and flight tests under discussion

ecoD 2023

•Boeing has added a United Airlines 737 MAX 10 aircraft to its ecoDemonstrator fleet and has tested the effects of Sustainable Aviation Fuel (SAF) on contrails and emissions, as well as to reduce the fuel's climate impact.

• The program involved NASA's DC-8 aircraft, which measured and compared the emissions and contrail ice particles of SAF and conventional jet fuel. NASA satellites were also used to capture contrail formation during the campaign .

• Boeing is partnering with various organizations, including NASA, World Energy, FAA, GE Aerospace, and DLR, to analyze how SAF can reduce emissions and achieve environmental benefits.

Boeing, NASA, United Airlines To Test SAF Benefits With Air-To-Air Flights - Oct 12, 2023 (newsroom.com)

Gulfstream SAF Ground Test 2024

Over the week of October 7, researchers, in part funded through ASCENT 02, conducted engine emission sampling on a G700 with Pearl700 engines. The team conducted (six) 6 test runs using 100% HEFA (SAF), a 30/70 Blend of SAF and Jet A, and 100% conventional Jet A.

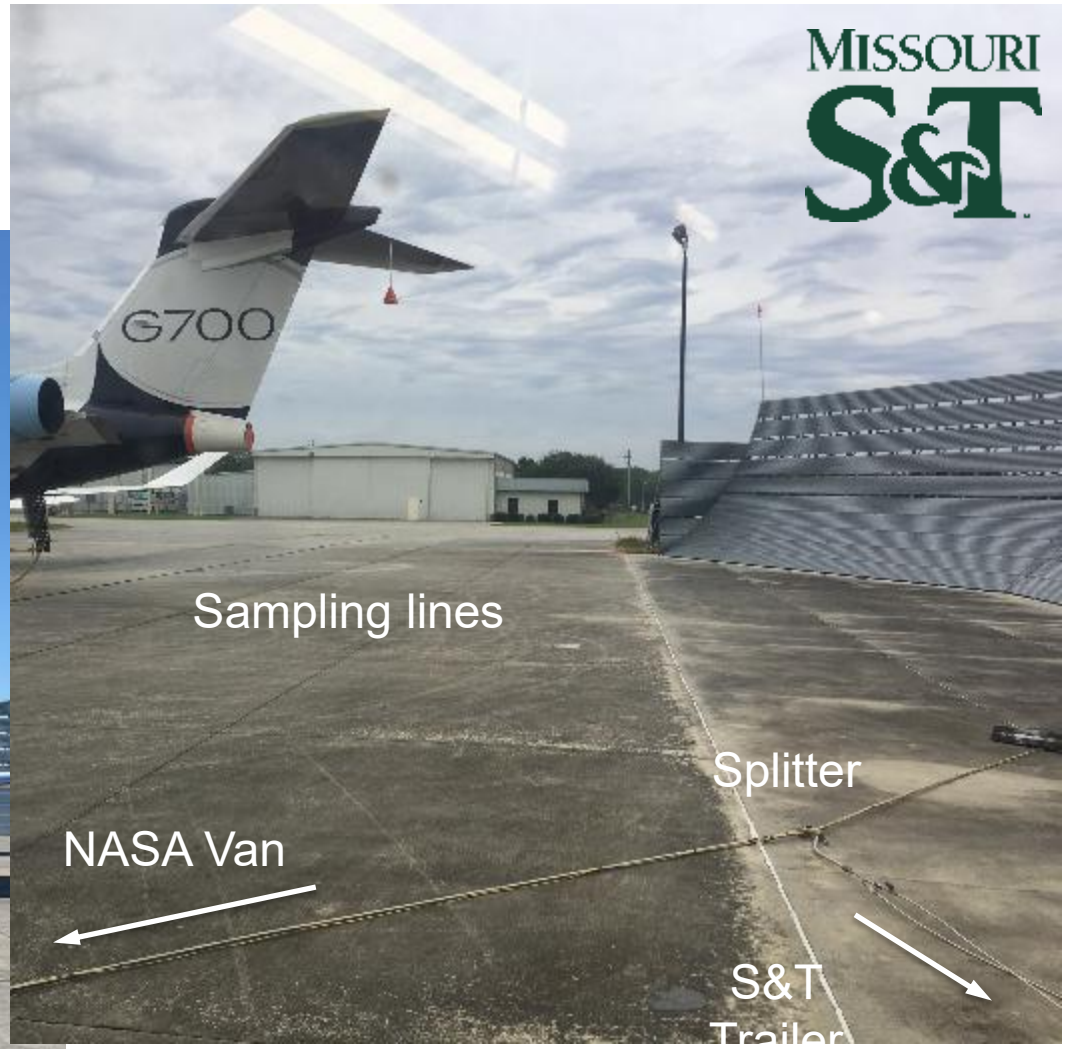
The effects of essentially zero sulfur fuel may have been observed for the first time with the SAF fuel.

For the first time ever, engineers from RR isolated the oil system during the measurements.

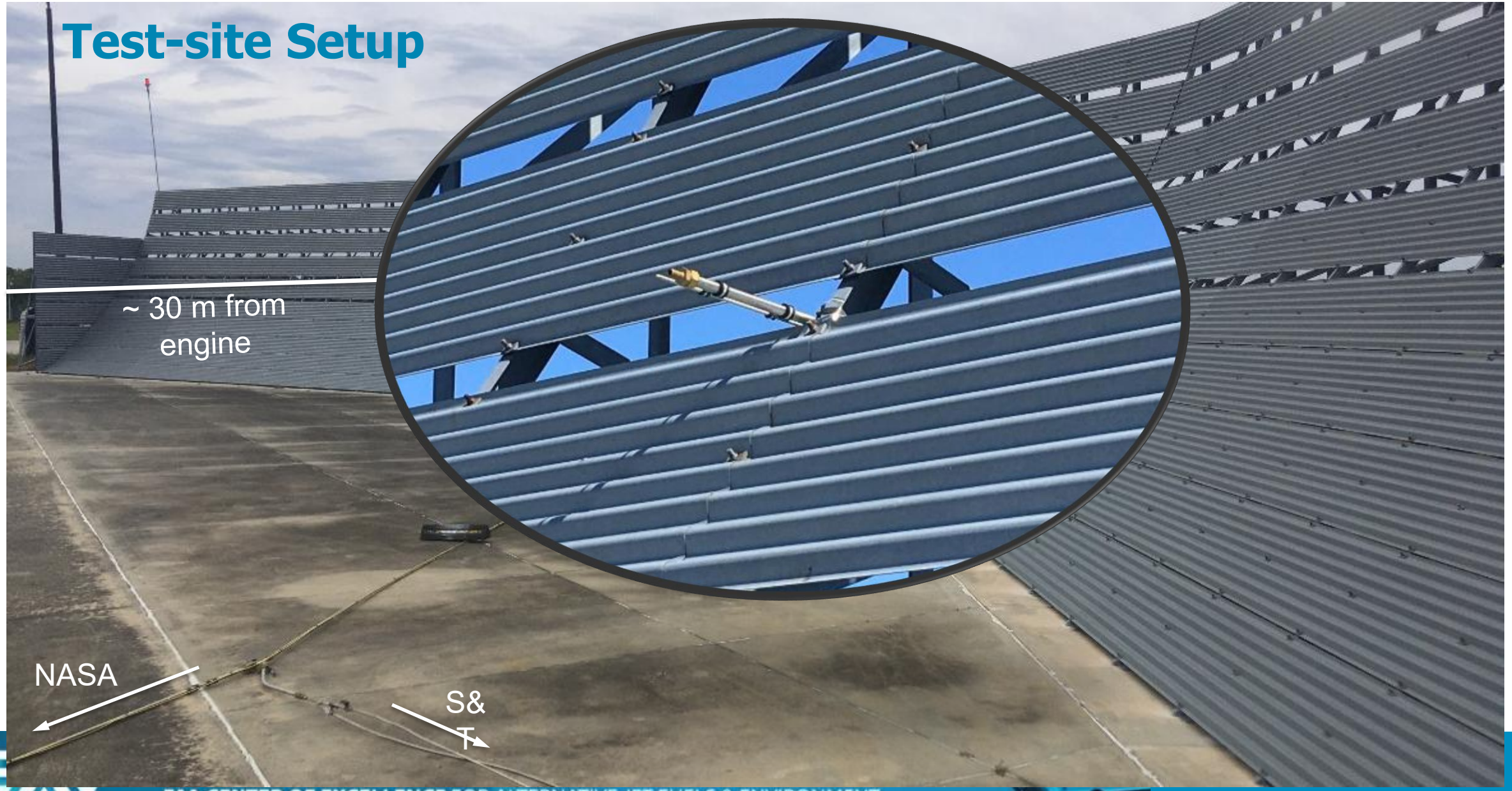
Initial review of the data suggests that the efforts of Gulfstream to provide the experiment with negligible Fuel Sulfur Content (FSC) in the fuel were completely successful. The Sulfur signal was undetectable by the AMS (Aerosol Mass Spectrometer) instrument and this is a significant indication that the sulfur in the fuel was essentially zero.

There was conclusive physical evidence that, in the absence of sulfur, no “nucleation mode” particles were formed.

Test-site Setup
Gulfstream, Savannah GA



Test-site Setup



Missouri S&T Instrumentation

Instruments

- CPC 3775
- APC with built-in VPR
- LII-300 and MSSPlus
- DMS 500
- CAI 600 gas bench
- Li-Cor 480

— tPM number
— nvPM number
— nvPM mass
— particle-size distribution (tPM)
— gas-species (THC, CO_2, CO, O_2, NO_x)
— CO_2

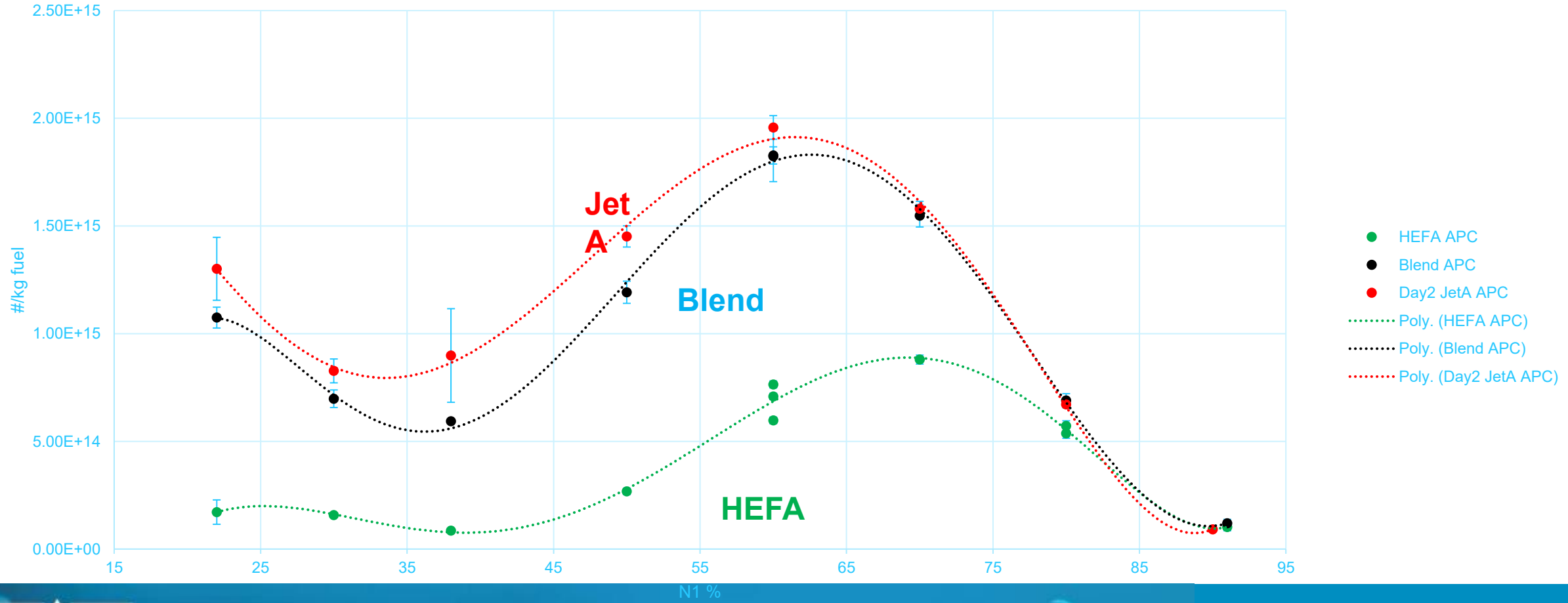
Gas information

- Elevated THC backgrounds were observed on all three days (3.5 -7.0 ppm)
- NO_x and CO_2 levels increased with power (N1) across all fuels

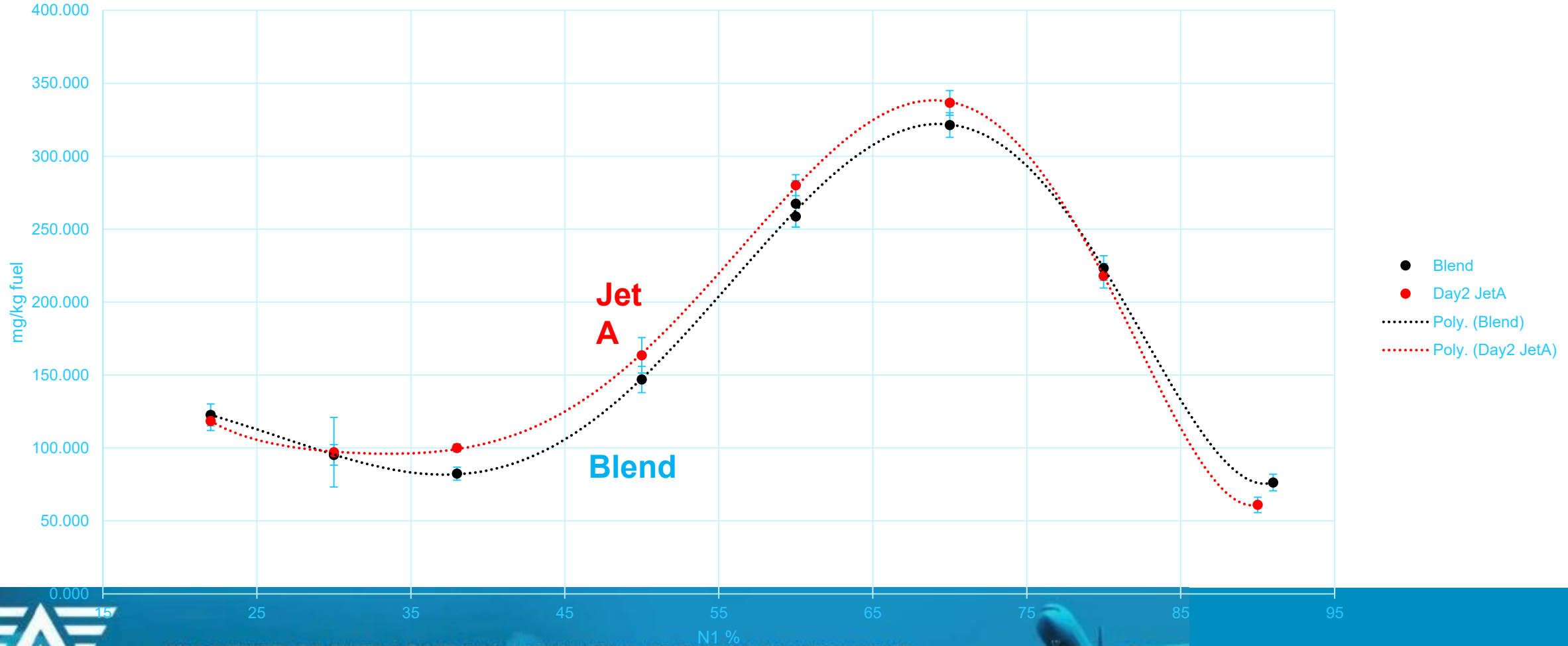
Fuel Effects Summary

- **HEFA** shows a large reduction in
  - nvPM number
  - tPM number
  - nvPM mass
- **HEFA** reduces particles below 10 nm in size, which are typically considered volatile (nucleation mode)
- **HEFA Blend (30/70)** shows a smaller reduction in nvPM compared to pure **HEFA**
  - The reduction is not proportional to the Jet A to HEFA ratio
- **A nucleation mode** is present at all power conditions when **Jet A** is used
  - Its contribution to tPM varies with power (N1%)

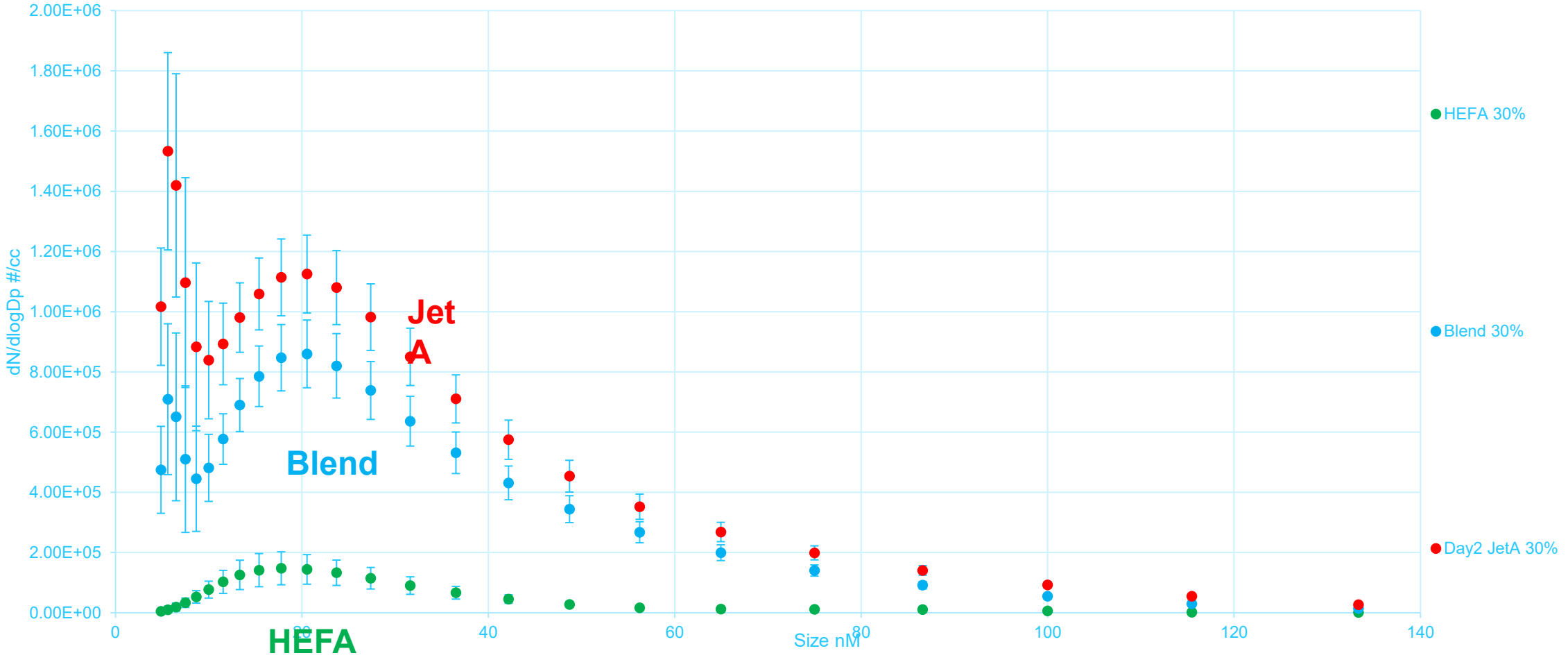
nvPM Number vs. N1% (APC with VPR)



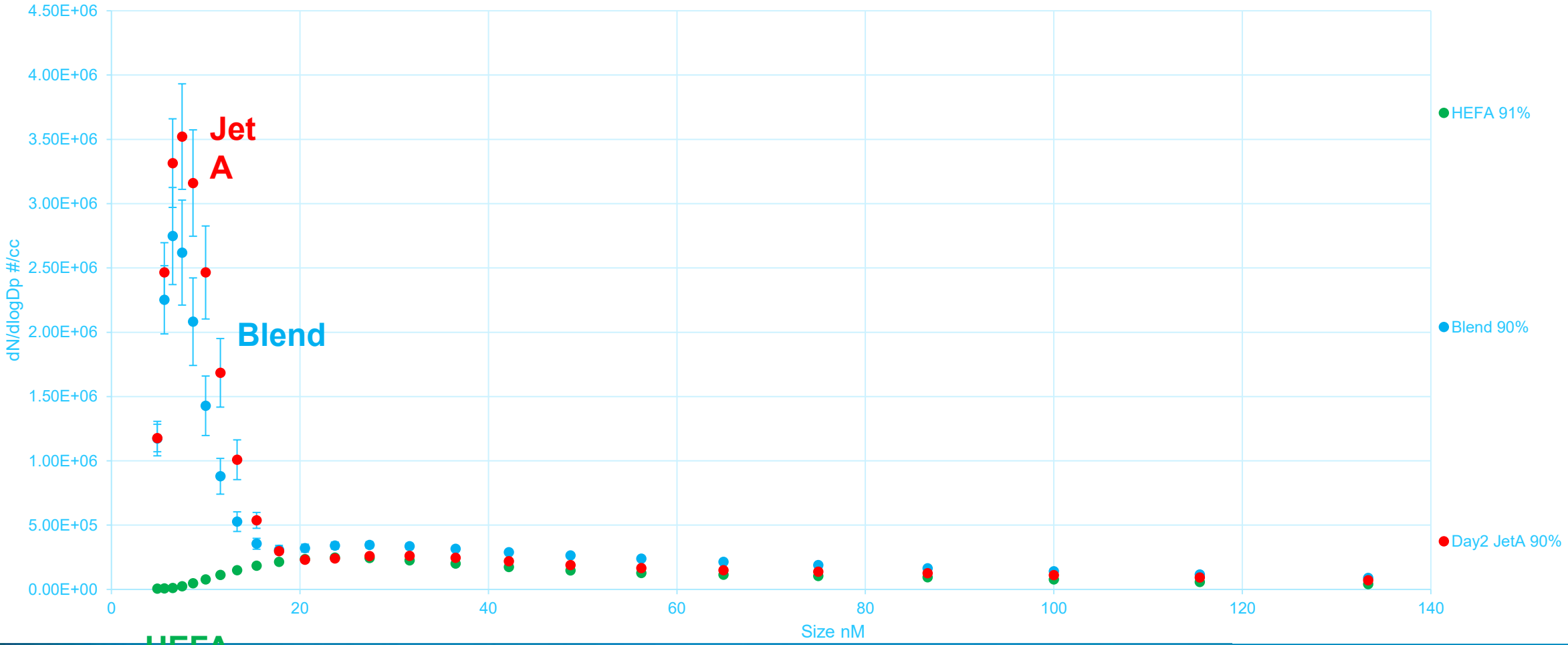
nvPM Mass (MSSPlus, not functioning on Day 1)



Size Distribution (tPM) at N1 30% (DMS 500)



Size Distribution (tPM) at N1 90/91% (DMS 500)



nvPM and tPM Number EI Reduction Trends

- **HEFA / Jet A**
  - nvPM Number
    - **~90%** reduction at low power
    - **~20%** reduction at N1 91%
  - tPM Number
    - **~90%** reduction at low power
    - **~50%** at N1 80%
    - **~65%** at N1 90%

- **Blend / Jet A**
  - nvPM Number
    - **~20%** reduction at low power
    - Decreases with increasing power
  - tPM Number
    - Follows a similar trend to pure HEFA
    - Maximum reduction of **35%**

- **Mass EI Reductions**
  - Relationship with N1 is **more complex**

Major Accomplishments (to date):

- Flight and Ground-based SAF emissions testing opportunities identified
- Funding for emissions testing at EcoD, Gulfstream ground and P&W awarded
- Funding for CRYSTAL, Gulfstream follow-on, Embraer and Airbus A320 proposals in review
- Emissions testing at Eco-D 2023 and Gulfstream ground completed

Future Work / Schedule:

- Fuel sources identified, fuel procured and delivered
- Test planning. Test deployment. Data acquisition
- Test specific data analysis and interpretation
- Publications in preparation for ecoD and Gulfstream

Summary

- Summary statement:
  - ASCENT 002 is becoming a comprehensive project focusing on sustainable emissions characterization, elucidating the sustainability effects of combining novel AAFs and their blends with new engine combustor technology.
  - Next steps for ASCENT 002 include:
    expanding measurement capabilities and model development to address the role of the volatile aerosol component of emissions
    broadening the range of AAF and combustor technology investigated
- Key challenges/barriers
  - Availability of suitable volumes of novel AAFs
  - Access to new combustor technology emissions

Acknowledgements

- The ASCENT 002 team would like to acknowledge the following list of OEMs without whom this work would not be possible:
  - Boeing, United Airlines, Gulfstream, Pratt and Whitney, Airbus and Airbus America, and Embraer.

Participants

- MS&T Steven Achterberg, Lauren Kehoe, William Satterfield, Klaus Woelk and Philip Whitefield
- ARI Rick Miake-Lye
- P&W Tim Snyder