



# Project 002 Ambient Conditions Corrections for Non-volatile PM Emissions Measurements

**Missouri University of Science and Technology, Aerodyne Research Inc., and Honeywell**

## Project Lead Investigator

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## University Participants

### Missouri University of Science and Technology

- PI: Philip D. Whitefield, Chancellor's Professor of Chemistry
- FAA Award Number: 13-C-AJFE-MST Amendments: 002, 003, 005, 008, 010, and 012
- Period of Performance: September 18, 2014, to February 28, 2021
- Tasks:
  - Task 1. Engine-to-engine variability at Honeywell (completed and reported in the ASCENT 2018-19 annual report).
  - Task 2. Ground-based non-volatile particulate matter (nvPM) emissions from an IAE V2527-A5 engine burning four different fuel types (completed and reported in the 2018-19 annual report).
  - Task 3. Re-examination of engine-to-engine particulate matter (PM) emissions' variability using an Aerospace Recommended Practice (ARP) reference sampling and measurement system (being executed).

## Project Funding Level

PROJECT	FUNDING	MATCHING	SOURCE
13-C-AJFE-MST-002	\$1,288,836.34	\$1,288,836.34	EMPA LETTER
	\$284,613.66	\$284,613.66	TRANSPORT CANADA
13-C-AJFE-MST-003	\$500,000.00	\$500,000.00	EMPA LETTER
13-C-AJFE-MST 005	\$500,000.00	\$500,000.00	EMPA LETTER
13-C-AJFE-MST-008	\$579,234.00	\$579,234.00	EMPA LETTER
13-C-AJFE-MST-010	\$725,500.00	\$725,500.00	EMPA LETTER
13-C-AJFE-MST-012	\$1,217,221.00	\$1,217,221.00	EMPA LETTER

## Investigation Team

- Professor Philip Whitefield, Missouri University of Science and Technology
- Steven Achterberg, research technician, Missouri University of Science and Technology
- Max Trueblood, research technician, Missouri University of Science and Technology
- Dr. Richard Miake-Lye, subcontractor, Aerodyne Research Inc.
- Rudy Dubebout, subcontractor, Honeywell Aerospace
- Paul Yankowich, subcontractor, Honeywell Aerospace



## Project Overview

The International Civil Aviation Organization (ICAO) has published the revised ICAO Annex 16 Vol. II specifying a standardized sampling system for the measurement of non-volatile particulate matter (nvPM) from aircraft engines for use in certification. The Missouri University of Science and Technology (MS&T) owns and operates the ICAO Annex 16 Vol. II compliant North American mobile reference system (NARS) to measure nvPM emissions from the exhaust of aircraft engines. The work under this project exploits the use of the NARS to address issues associated with ambient condition corrections, engine-to-engine variability, and fuel formulation sensitivity. Under ASCENT Project 2, work has been performed on three major Tasks:

### Task 1

Testing has taken place at Honeywell as part of a series of measurements to acquire certification-like data on a set of engines identified by ICAO Committee on Aviation Environmental Protection (CAEP) Working Group 3 (Emissions Technical) Particulate Matter Task Group (CAEP/WG3/PMTG) to be representative of the commercial fleet for entry into the nvPM values database. The engine-to-engine variability of nvPM emissions data from a sample of a large number of engines is required in order to assess the characteristic variability of these engines, which is critical in establishing a regulatory limit for nvPM number- and mass-based emissions. The measurement activity in this Task has been undertaken by Honeywell personnel under subcontract to MS&T. Technical oversight was provided by the MS&T team. This Task was completed in 2019 and reported upon in the 2018–19 annual report.

### Task 2

The NARS and its ancillary equipment have been used to characterize ground-based nvPM emissions from an IAE V2527-A5 engine burning four different fuel types. This work was conducted as part of the NASA/DLR Multidisciplinary Airborne Experiment (ND-MAX) campaign. This Task was completed in 2019 and the results of this study have been described in the 2018–19 annual report. In 2019–20 the data has been uploaded to NASA-DLR database for the ECLIF/ND-MAX and discussions leading to a publication are currently underway.

### Task 3

The NARS and its ancillary equipment are being prepared to quantify the impact of changing conditions on nvPM emissions from a combustor rig and to develop methods for the use of inventory modeling. This Task has been the primary focus of Project 2 in the period October 2019 through September 2020. The preparation has included the recalibration of the mass instruments (LII and MSS+) and the number (APC) and the size instrument (DMS500). The NARS has been operated in its entirety using a minicast as a surrogate source to ensure its continued operability during the pandemic waiting period.

## Task 1 – Engine-to-Engine Variability at Honeywell

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Completed and reported in 2018–19 annual report.

## Task 2 – Ground-Based non-volatile Particulate Matter (nvPM) Emissions from an IAE V2527-A5 Engine Burning Four Different Fuel Types

Missouri University of Science and Technology

In 2019–20, the data was uploaded to NASA-DLR database for the ECLIF/ND-MAX and discussions leading to a publication are currently underway.



## Task 3 – Re-Examination of Engine-to-Engine Particulate Matter (PM) Emissions Variability Using an Aerospace Recommended Practice (ARP) Reference Sampling and Measurement System

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This Task has been the primary focus of Project 2 in the period October 2019 through September 2020.

### Objectives

Changing inlet conditions affect nvPM emissions from aircraft engines. A combustor rig test provides the most flexibility to quantify the impact of changing conditions on nvPM emissions and to develop methods for use in inventory modeling. The MS&T/Aerodyne team will work with Honeywell to conduct combustor rig tests, collect nvPM mass and number emissions data, and analyze data to determine nvPM ambient corrections.

### Research Approach

- Define and assemble a standardized nvPM measurement system that will include the same mass measurement system that was used to sample nvPM from 25 Honeywell HTF7350 production engines in 2017.
- Design and fabricate nvPM emissions rakes and combustor rig adaptive hardware required to enable nvPM and gaseous emissions data to be acquired from Honeywell's existing HTF7000 Combustor Test Rig.
- Perform four combustor rig tests with Jet A and three alternative fuels.
- Vary combustor test conditions (derived from engine cycle performance analysis, covering a range of engine ambient inlet conditions on the ground and at altitude) and measure nvPM emissions.
- Analyze data to inform performance-based nvPM emissions modeling for all altitudes.

### Milestone

The funding for the Honeywell and Aerodyne sub awards is in place and work is underway to prepare for testing at Honeywell's combustor rig facilities in Phoenix, AZ.

### Major Accomplishments

- Honeywell and the MS&T/Aerodyne team have assembled two standardized nvPM emissions measurement systems. Key components are in the process of being recalibrated.
- Honeywell has completed design and fabrication of rakes and adaptive rig hardware required to enable nvPM emissions measurements in the HTF7000 Combustor Test Rig.
- Honeywell has completed the initial set up of the sampling system and performed the shakedown test.
- Honeywell found some hardware interferences in the shakedown tests and these have been corrected.
- Honeywell has conducted a second shakedown test and the sampling system was deemed ready for testing.
- It was anticipated that testing would start in March 2020, however, the onset and continuation of the COVID-19 pandemic throughout the remainder of this reporting period has thwarted all attempts to initiate the testing phase of this Task. This is mainly due to the fact that the initial testing phase required the MS&T team (i.e., MS&T and Aerodyne) to deploy instrumentation and personnel from Missouri and Massachusetts, respectively.
- The Honeywell team, MS&T team, and the FAA have conducted bi-weekly planning teleconferences, but these have largely focused on potential alternative deployment strategies should things improve with travel restrictions driven by the pandemic.
- During the pandemic delay, the calibrations required for the Honeywell and NARS nvPM measurement systems expired. These instruments are currently undergoing recalibration with the hope that the testing can be resumed in early 2021.

### Publications

N/A

### Outreach Efforts

Presentations on the project plan to date have been made at:

- ASCENT virtual advisory board meetings held in April and September 2020.



- AEC Roadmap virtual meeting held in May 2020.

### **Awards**

None

### **Student Involvement**

Three undergraduate research assistants (Christian Hurst, Nicholas Altese, and Susan Donaldson) were employed in pre-test activities, including individual component testing and calibration and data reduction and interpretation. None of these students have graduated.

### **Plans for Next Period**

- Re-install and shakedown of nvPM combustor rig measurement system with rig in test cell.
- Conduct initial rig test with Jet A (Phase I).
- Conduct rig test with three sustainable aviation fuel blends (Phase II).