



Project 069 Transitioning a Research nvPM Mass Calibration Procedure to Operations

Missouri University of Science and Technology, Aerodyne Research Inc., & U.S. Air Force Arnold Engineering Development Center

Project Lead Investigator

Philip D. Whitefield
Professor Emeritus of Chemistry
Department of Chemistry
Missouri University of Science and Technology
400 W 11th Street, Rolla, MO 65409
573-465-7876
pwhite@mst.edu

University Participants

Missouri University of Science and Technology (MS&T)

- P.I.: Prof. Philip D. Whitefield
- FAA Award Number: 13-C-AJFE-MST, Amendments 014, 020, and 023
- Period of Performance: June 5, 2020, to January 31, 2026
- Task:
 1. Investigate the validity of the centrifugal particle mass analyzer mass calibration research approach for non-volatile particulate matter certification measurement systems

Project Funding Level

Project	Funding	Matching	Source
13-C-AJFE-MST; Amendment 014	\$846,707.00	\$846,707.00	EMPA letter
13-C-AJFE-MST; Amendment 020	\$100,853.00	\$100,853.00	FOCA letter
13-C-AJFE-MST; Amendment 023	\$99,999.00	\$99,999.00	GE letter

Investigation Team

Missouri University of Science and Technology

Prof. Philip Whitefield, (P.I.)
Steven Achterberg, (research technician)
William Satterfield, research technician

Aerodyne Research, Inc. (ARI)

Dr. Richard Miake-Lye, (subcontractor)

Arnold Engineering Development Center (AEDC)

Dr. Robert Howard, (subcontractor)

Project Overview

This project is designed to investigate the validity of the centrifugal particle mass analyzer (CPMA) mass calibration research approach. The assessment will extend across all non-volatile particulate matter (nvPM) mass ranges encountered during certification tests. The primary goal will be the successful transitioning of the research methods to operations. The project will begin with a laboratory assessment leading to dedicated turbine engines as the test sources at the United





States (U.S.) Air Force (USAF) AEDC. The challenge mass devices for calibration (micro-soot sensor [MSS], laser-induced incandescence monitor, and cavity attenuated phase shift monitor) will be provided by the North American Reference nvPM Measurement System, together with the CPMA and other necessary instruments, such as a DMS500 particulate analyzer, and aerosol mass spectrometer.

Task 1 – Investigate the Validity of the Centrifugal Particle Mass Analyzer Mass Calibration Research Approach for Non-volatile Particulate Matter Certification Measurement Systems

Missouri University of Science and Technology

Objectives

The objectives of this task are to acquire the components of a CPMA-based mass calibration system similar to that described in Society of Automotive Engineers (SAE) E31 discussion paper DP-32 (presented by Dr. G. Smallwood) from the annual SAE E31 committee meeting on June 17-21, 2019, in Saclay, France, assemble the system, and evaluate its performance.

Research Approach

Subtask 1.1 (Completed)

Acquire the components of a CPMA-based mass calibration system similar to that described in SAE E31 discussion paper DP-32 (presented by Dr. G. Smallwood) from the annual committee meeting on June 17-21, 2019, in Saclay, France. The CPMA-based system has also been referred to as the CPMA-Electrometer Reference Mass Standard (CERMS).

Subtask 1.2 (Completed)

Assemble and test the CPMA-based mass calibration system's performance at MS&T's laboratories, by using a miniature combustion aerosol standard (Minicast) as the nvPM generation source (Figure 1). Compare the laboratory performance of the MS&T CPMA-based mass calibration system with that of two highly similar systems owned and operated by the University of Alberta and the Canadian National Research Council (NRC).

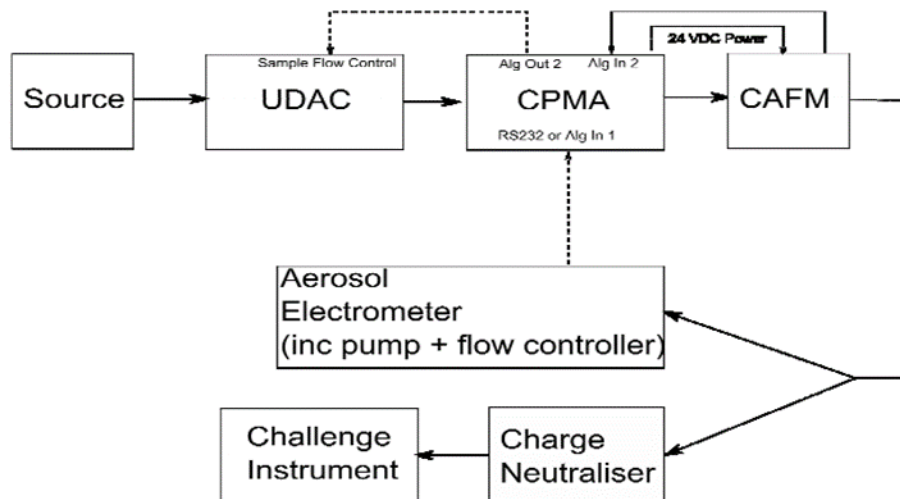


Figure 1. Schematic diagram of the CPMA-based mass calibration system.

Subtask 1.3 (Completed)

Investigate the validity of the CPMA mass calibration research approach across all nvPM mass ranges encountered during certification tests, to successfully transition the methods to operations.

**Subtask 1.3a (Completed)**

Deploy (transport and install) the North American Reference System, including the CPMA-based mass calibration system and ancillary diagnostic suite, with the USAF's AVL® nvPM measurement system and the two Canadian CPMA systems, at engine testing facilities at Arnold Air Force Base in Tennessee, which will include the J85 turbojet and a gas-turbine-based "start cart" as nvPM sources.

Subtask 1.3b (Completed)

Evaluate the performance of the three CPMA-based mass calibration systems, surveying across all mass ranges by using the start cart as the nvPM source; compare these results with concomitant mass calibration data acquired with SAE E-31 elemental carbon/organic carbon (EC/OC)-based mass calibration methods.

Subtask 1.3c (Completed)

Demonstrate the performance with an nvPM emissions test on the J85 engine, with calibration including standard EC/OC analysis, as well as the CPMA-based calibration system described in DP-32.

Subtask 1.3d (Completed)

Decouple the diagnostic suites from the Arnold Air Force Base engine facilities and transport them back to Missouri and Massachusetts.

Subtask 1.4 (Completed)

Analyze and interpret the data gathered in Subtasks 1.2 and 1.3.

Subtask 1.5 (Completed in 2025)

Prepare and deliver a final report.

Milestone

Published a comprehensive paper in the peer-reviewed literature describing (1) the assessment and (2) the conclusions and recommendations arising from the assessment.

Major Accomplishments

Published a comprehensive paper in *Aerosol Science and Technology*, "Quantification of the repeatability and reproducibility of the CPMA-electrometer reference mass standard for in-situ calibration of mass concentration aerosol instruments."

Publications**Peer Reviewed Journal Publication**

Mehri, R., Nishida, R. T., Sipkens, T. A., Smallwood, G. J., Corbin, J. C., Whitefield, P., Achterberg, S., Miake-Lye, R. C., Nault, B. A., Howard, R., & Olfert, J. S. (2025). Quantification of the repeatability and reproducibility of the CPMA-electrometer reference mass standard for in-situ calibration of mass concentration aerosol instruments. *Aerosol Science and Technology*, 60(3), 230-244. <https://doi.org/10.1080/02786826.2025.2568694>

Outreach Efforts

Comprehensive peer-reviewed paper published.

Awards

None.

Student Involvement

None.

Plans for Next Period

There are no plans for the next period. The project ended in 2025.

® AVL is a registered trademark of AVL List GMBH, Graz, Austria.



ASCENT Project 069 Draft Final Report

The final report for ASCENT Project 069 is comprised of two parts, first a comprehensive publication describing the assessment study (see above) and second a list of conclusions and recommendations for future assessment studies developed by the ASCENT Project 069 research team and summarized as follows:

The ASCENT Project 069 team is comprised of the following team members:

- The ASCENT Project 069-funded research was led by P.I. Phil Whitefield (MS&T), and Co P.I.s Rick Miake Lye (ARI) and Robert Howard (AEDC). They were supported by Klaus Woelk, Steven Achterberg, Max Trueblood, Dave Satterfield (MS&T), and Ben Naught (ARI)
- The NRC Canada team was led by P.I. Greg Smallwood, supported by Rym Mehri and Brett Smith
- The University of Alberta team was led by P.I. Jason Olfert, supported by Robert Nishida
- The U.S. Environmental Protection Agency (EPA) team was led by Robert Giannelli, supported by John Kinsey, Jeff Stevens, Samuel Johnson, and David Kittelson.

An anticipated outcome of this study, “Transitioning A Research nvPM Mass Calibration Procedure to Operations,” was to demonstrate that the CERMS system was a field-deployable, user-friendly, low-cost mass calibration system for nvPM measurements during engine emissions certifications. Based on the CERMS in its current state of development and in consideration of the results of this study, the ASCENT Project 069 team believes the CERMS has demonstrated potential to reduce the uncertainty associated with the current reference for mass concentration instruments (EC) but does not fully satisfy the desired operational criteria due to some issues that were observed. Additionally, calibration with a CERMS should be done by a competent laboratory. As a result, the team recommends that a follow-on evaluation study is justified in addressing the unresolved issues described in this report.

It is important to note that using the CERMS is fundamentally different from the traditional calibration method. In the CERMS, the principle is to provide a stream of particles of known mass concentration. Whereas the traditional calibration requires a concurrent measurement of EC to establish the concentration of particles from the calibration source.

In terms of assessing the reproducibility of CERMS, the uncertainties in this study indicate that it may be capable of lowering the uncertainty associated with the calibration of the mass concentration instruments. This uncertainty could be significantly reduced if the recommendations to minimize the bias between CPMA are investigated.

Future experiments should include using different particulate matter measurement techniques in similar configurations (including the aerosol mass spectrometer [AMS]), to investigate if the CERMS system, dilution, and/or other aspects not considered here, lead to the losses of the volatile particulate matter.

Although some of the issues encountered by the ASCENT Project 069 team are a result of instrument limitations (penetration through the instruments and hence low concentration), further studies are recommended to address the issues encountered during this study. These recommended future studies would have the following objectives.

- Objective 1: Reduce the reproducibility uncertainty. The reproducibility for CERMS was largely attributed to the CPMA reproducibility, such that reducing the CPMA uncertainty will have a direct impact on reducing the CERMS uncertainty. The CPMA response could be potentially traceably calibrated using certified reference material (CRM) particles of a known narrow mass distribution.
- Objective 2: Understand the impact of particle conditioning on CERMS. Simultaneous characterization of the particles (using different laboratory and engine sources) upstream and downstream of the CPMA would be informative to understand the effect of the CPMA classification (in time) on the particle composition, with and without the use of a catalytic stripper.
- Objective 3: Increase the CERMS output mass concentration. Determine the influence of the CPMA model (Mk I or Mk II) on the classified particles and penetration through the instrument. Investigate the use of high transmission efficiency chargers in place of the Unipolar Diffusion Aerosol Charger (UDAC).
- Objective 4: Optimize CERMS set point determination. Address the shift in the UDAC charging efficiency in time or changes in the experimental setup.
- Objective 5: Determine performance of CERMS under realistic calibration conditions. Compare CERMS and thermal-optical analysis in the context of a calibration as intended with a gas turbine source across a representative concentration range. This will require a direct comparison of the EC to the electrometer, without any other



instruments, and may result in low concentrations on the filter used for EC analysis due to shorter acquisition periods.

It is recommended that future experiments should use low sulfur jet fuel to avoid poisoning of the catalytic stripper.