



**CHARACTERIZATION OF JET FUEL COMBUSTION EMISSIONS DURING A
C-130 AEROMEDICAL EVACUATION ENGINES RUNNING ONLOAD**

THESIS

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AFIT-ENV-MS-17-M-211

**DEPARTMENT OF THE AIR FORCE
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Michelle L. Page

USAF

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Abstract

The purpose of this research was to characterize jet fuel combustion emissions (JFCE) on the ground for potentially hazardous occupational contaminants. JFCE have been extensively characterized due to environmental pollution. Prior research demonstrated that aircraft emit hazardous species, especially at engine start-up and ground idle. Complaints of severe eye, nose, and throat irritation from occupational exposures near aircraft exist. In this study JFCE were tested during an aeromedical evacuation engines running patient onload (ERO) on a C-130 Hercules at the 179th Airlift Wing, Mansfield-Lahm Air National Guard. The following research questions were investigated: 1) do JFCE migrate into occupational breathing zones during engine start-up and ground idle operations such as AE ERO; 2) what are the contaminants and concentrations.

Ultrafine particles, VOC, formaldehyde, carbon monoxide (CO), sulfuric acid, and metals were sampled simultaneously in approximate crew and patient breathing zones. Testing methods were portable condensation particle counters (CPC), polycarbonate filters (PC) and thermophoretic samplers (TPS) for electron microscopy, Multi-gas monitors, EPA methods TO-17 and TO-11, and National Institute of Occupational Safety and Health (NIOSH) methods N0600, N7908, N7300.

Contaminants detected in this study were ultrafine particulate matter, VOC including Environmental Protection Agency hazardous air pollutants (EPA HAP), formaldehyde, CO, and unburned jet fuel. The particles were dominated by soot in

concentrations up to 3.4×10^6 particle/cc. Particle size distributions were varied with most sizes less than 100 nanometers (nm). Particle morphology was highly irregular. Soot elemental composition was predominantly carbonaceous with trace oxygen, sulfur and a few metals. VOC were detected in ppb, and formaldehyde in ppm. Additive or synergistic effects associated with the JFCE mixture may intensify irritation. Health implications from inhaling nano-sized soot particles are inconclusive.

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I. Introduction

General Issue

Many AF personnel are exposed to aircraft exhaust in the course of a normal workday. Jet fuel constituents and combustion products represent the largest chemical exposure of DOD Military and civilian workforce (1). Severe eye, nose and throat irritation from exposure to jet fuel combustion emissions (JFCE) have been reported (2) (3) (4) (5). Increased overall health concerns from occupational exposure to jet fuel since the conversion to kerosene-based jet fuels in the mid – late 1990s led to reduction of the American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour threshold limit value (TLV)-time-weighted average (TWA) from 350 mg/m³ to 200 mg/m³ (1). Occupational exposure guidance exists for jet fuel vapors and aerosols (6), but is lacking for its combustion emissions.

Background

The vast inventory of aircraft in service is essential to the United States Air Force mission to fly, fight, and win in air, space, and cyberspace (7). The current USAF inventory is forecasted to evolve alongside that of the Army and Navy inventories through procurement and modernization efforts necessary to support the Department of Defense's (DOD) growing security challenges (8). The USAF inventory exceeds 5,000 aircraft, and comprises approximately 35% of DOD total inventory (8).

The Air Force Air Mobility Command (AMC) consumes the greatest amount of aviation fuel within the Air Force (9). The AMC fleet alone consumes 28% of DOD aviation fuel. AMC's intensive fuel consumption arises from its varied mission requirements and continuous operational tempo. Its fleet of heavy aircraft provide strategic airlift, aeromedical evacuations, air refueling, and humanitarian aid worldwide.

The primary jet fuel used by the US military since the mid-1990s was Jet Propulsion Fuel number 8 (JP-8) (10). JP-8 replaced JP-4 due to improved safety and operational characteristics. With lower volatility and higher kerosene content, JP-8 greatly reduced the likelihood of post-crash fires and fires arising from maintenance accidents. Operationally, JP-8 provides improved thermal stability and heat sink capability over its JP-4 predecessor (11). Now, the Air Force is converting its primary aviation fuel from JP-8 to commercial Jet A with additives. The conversion significantly reduces extra costs associated with the purchase, transportation, distribution, and storage of JP-8 (12) (13). The major difference between Jet A and JP-8 is the absence of additives such as ice and corrosion inhibitor in the Jet A formulation. Since JP-8 formulations include the additives, segregated transportation and storage has been required, and at high costs to DOD. With Jet A, additives are injected into bulk storage after receipt of the shipment, so that the fuel can be acquired through open markets (12).

The chemical constituents of JP-8 and Jet A + additives are very similar. Both JP-8 and Jet A are kerosene-based fuels, which are complex mixtures of hydrocarbons. Their multicomponent formulations lead to dynamic composition of exhaust species that form under varying conditions. Jet fuel emissions and concentrations also vary in different weather conditions, engine type and engine throttle setting.

Problem Statement

Aircraft emissions have been extensively characterized due to concern for environmental air pollution. Degradation of air quality near airports has been reported. Considering wide acceptance of environmental concern for public health exposure to aviation air pollution, occupational exposure guidance for populations working in close proximity to aircraft exhaust emissions is warranted. Anecdotal accounts of severe eye, nose and throat irritation from exposure to JFCE have been reported in prior studies, AF consults, and interview with AE crew members (2) (3) (4) (5) (14) (15).

JFCE have been found to contain many products, including unburned jet fuel, ultrafine particulate matter, and hazardous air pollutants (HAPs) identified by the US Environmental Protection Agency (EPA) (2) (5) (16) (17) (18) (19). The US EPA has also conducted National Air Toxics Assessments (NATA) as a tool used in efforts to reduce HAPs (20). The 2011 NATA concluded that the pollutants contributing the most to overall cancer risks are formaldehyde, benzene, and acetaldehyde (21). All three were found in JFCE in prior studies.

Research Objectives

Multiple groups are exposed to JFCE on flight lines. Exposure populations include crew chiefs, aircraft maintainers, aircrew members, aeromedical evacuation crews, and patients. Occupationally focused JFCE studies and hazards characterized in those studies are limited. **The goal of this research was to characterize JFCE on the ground during an occupational process to fill testing gaps in prior occupationally focused studies.**

This research characterized the engine start-up and ground idle emissions during an aeromedical evacuation engines running patient onload (AE ERO), an operation necessary for patient extraction in contingency operations or when minimum ground time is required by the mission (22). The hypothesis is that during ERO, emissions from the engine propeller wash migrate into the aircraft because the troop doors and cargo ramp remain open. Exposed personnel include AE crew members, patients, flight crews, loadmaster, spotter, and ground personnel. Of particular concern is exposure to the loadmaster who stands off the foot of the ramp observing for threats and ensuring safety compliance, and spotter who stands 50 feet aft of the ramp directing the flow of patients (22). Figure 1 shows the loadmaster during this study.



Courtesy of the 179th Airlift Wing Public Affairs

Figure 1: Loadmaster during C-130 AE ERO

Research Questions

1. Do JFCE migrate into occupational breathing zones during engine start-up and ground idle operations such as AE ERO?
2. What are the contaminants and concentrations?

Methodology

1. Literature review: The types of literature reviewed include JP-8 fuel and vapor toxicity studies, journal articles characterizing JFCE, USAF consultative letters and guidelines on jet fuel exposure, occupational exposure limits (OEL), and Air Force Instructions (AFI).
2. Sampling Plan: Simultaneous sampling at 5 aircraft locations was conducted on a C-130 Hercules at the 179th Airlift Wing, Mansfield-Lahm Air National Guard Base on two non-consecutive days, 01 June and 09 November 2016.
3. Implications: This research identified JFCE contaminants that are known irritants and some carcinogens, and provided valuable information on emissions migration and particle characteristics. The literature compilation and testing results provide supporting information for mitigation considerations such as alternative fuels conversion and testing suite for future investigations.

II. Literature Review

Background

Much research exists on JFCE from conventional petroleum derived kerosene jet fuels and renewable source derived alternative jet fuels. Prior characterization efforts tested emissions with extractive sampling directly behind the engine and with remote

sampling at downstream locations. Some testing was performed off-wing where the engines were mounted on test stands, while others were conducted on-wing to better represent the exhaust environment on flight lines.

Many prior studies characterizing JFCE were prompted by the 1990 Amendments to the Clean Air Act and the Strategic Environmental Research and Development Program (SERDP). SERDP pursues solutions to the DOD's environmental challenges while sustaining military readiness (23) (24). These prior studies identified a variety of hazardous compounds in petroleum based JFCE. Most of the hazardous species identified are common among different aircraft. Those compounds commonly found in prior JFCE characterizations served as valuable reference in selecting the tests for this study. A consensus drawn from prior studies is that the majority of hazardous species and in highest concentrations are emitted at engine start-up and ground idle (25).

Prior Research

Spicer *et al* (2009) characterized JP-8 exhaust by downstream extractive sampling of both C-130 and F-15 aircraft (19). C-130 emissions were tested at low speed ground idle, high speed idle, flight idle, cruise, and maximum power. F-15 emissions were tested at engine ground idle, low intermediate, high intermediate, military, and afterburner throttle settings. Emission factors were reported for more than 60 hazardous organic gases as well as carbon and nitrogen oxides. They targeted 9 of these compounds for either prevalence in engine ground idle emissions or potential toxicity. Results for the 9 targeted compounds were compared at all 5 throttle settings on both airframes, then between C-130 and F-15 airframes with engines operating at ground idle only. Of the 9

compounds the following prevailed at engine idle on both airframes, and more so in the C-130 emissions: carbon monoxide, ethylene, 1,3-butadiene, benzene, toluene, styrene, formaldehyde, and acrolein. Pleil *et al* (2000) found elevated benzene levels in the exhaust relative to JP-8 fuel benzene content, likely due to alkylbenzene conversion to benzene during incomplete combustion (26).

Corporan *et al* characterized JP-8 combustion emissions from a C-17 Globemaster III in a study comparing JP-8 combustion emissions with those of JP-8/alternative fuel blends for certification of the aircraft on JP-8/AJF blends (17). Gas and particle emissions were measured at engine throttle settings ranging from 4% (idle) to 63% for 15 minutes per throttle setting in high temperature and low humidity weather. The exhaust was sampled 42 centimeters behind the engine using rake-style gas probes and valve box directing the exhaust to various analyzers and active samplers. The testing system was a mobile laboratory, Air Force Research Laboratory – Fuels and Energy Branch Turbine Engine Research Transportable Emissions Laboratory (TERTEL). Particle measurements included particle concentration, mass, and size distribution. Gaseous measurements included HAPs, PAH, carbon monoxide, nitrogen oxides, and sulfur dioxides. The researchers found CO and HAP concentrations from JP-8 combustion emissions highest at engine idle, with formaldehyde dominating the HAP content, followed by acetaldehyde and benzene. Mean particle diameters and particle concentrations increased with increased throttle settings. Combustion emissions particles contained organic carbon (OC) and elemental carbon (EC), with more OC than EC at engine idle. Mean particle diameters for JP-8 and JP-8/alternative fuel blends were less than 100 nanometers. The

researchers reported significant reductions in CO, sulfur oxides, HAP, and particulate matter emissions compared to those from JP-8.

Many other research efforts certifying alternative jet fuel (AJF) blends in civilian and military aviation has been underway due to increased air travel, petroleum fuel costs, environmental air pollution impacts, and energy security concerns. In fact, since March, 2016 United Airlines has been using a 30/70 AJF blend of bio-based/traditional petroleum jet fuel at the Los Angeles airport, reducing emissions by up to 60% (27). An energy and chemical company of Johannesburg, South Africa, Sasol Ltd., developed a jet fuel produced from synthetic coal to liquids (CTL) process that has been approved for use on commercial aircraft (28).

AJF are synthetic paraffinic kerosene (SPK) fuels produced from renewable sources that mimic the chemical properties, safety, and operational performance of petroleum derived jet fuel (29). AJF are often referred to as “drop-in” fuels because they can be used in aircraft with no engine modifications or infrastructure changes. Common types of AJFs and their feedstocks include 1) Fischer-Tropsch (FT) produced from gasification of coal, natural gas, or biomass; 2) hydroprocessed renewable jet (HRJ) produced from bio-oil (also called hydroprocessed esters and fatty acids (HEFA) or synthetic paraffinic kerosene (Bio-SPK); 3) alcohol-to-jet (ATJ), oligomerization of alcohols derived from fermentation of starch and sugar crops; and 4) pyrolysis oil jet fuel produced from biomass (30) (31) (32).

The US Air Force Research Laboratory (AFRL) conducted numerous JFCE characterization campaigns certifying military aircraft for use with alternative jet fuels blended with conventional JP-8 or Jet A fuels. These effort were prompted by concern of

DOD impact on environmental pollution and the DOD Assured Fuels Initiative, whose goal was reducing high fuel costs and dependence on foreign oil (33) (34) (17).

Alternative fuels and JP-8 blended with alternative fuels were tested in parallel with JP-8 on B-52, UH-60 Black Hawk and AH-64 Apache helicopter engines, and C-17 (17) (18) (33) (34). The alternative jet fuels that were tested included coal-derived Fischer-Tropsch (FT) fuel and beef tallow derived hydroprocessed renewable jet (HRJ) fuel blend. Timko et al conducted emissions testing of Jet A, Jet A/FT fuel blends, and biomass fatty acid methyl ester (FAME) fuels on the CFM56 engine, which is the engine used on 737 aircraft (30). A similar effort was conducted on a commercial business class jet engine, PW308 (35). In a series of smog chamber experiments on a T63 engine, Miracolo et al confirmed SOA formation in JP-8 JFCE, and also reported SOA reductions with JP-8/FT fuel blend (36).

JFCE tested in these campaigns include engine smoke number, particle number, mass concentration and size distribution, OC (VOC: HAPs, aromatics, aldehydes, unburned jet fuel), EC, SO_x, NO_x, CO, and PAH. In all campaigns, JFCE were significantly lower with alternative fuels/blends than with pure JP-8 or Jet A (17) (18) (30) (33) (34) (35). Reduced particle count, mass, and sizes were also observed with alternative fuel blends, which is expected due to less OC, aromatics, and SO_x precursors available for particle nucleation and growth. Smoke number and soot reductions were most pronounced at engine idle and lower engine power, which also results from lower aromatic and sulfur content in synthetic jet fuels. EC and OC reductions are in agreement with particle count reductions. In general, the higher the synthetic fuel percentage in the JP-8, Jet A/alternative fuel blends, the greater the JFCE emissions reductions. Also, many

of these “drop in” fuels conform to military and ASTM standards with performance comparable to conventional Jet A and JP-8 fuel (37).

AJFs contain negligible aromatic and sulfur compounds as compared to petroleum based JP-8 and Jet A fuels. Substantial reductions in combustion emissions from use of AJF blends have been reported. National Aeronautics and Space Administration (NASA) reports greater than 50 percent reduction in particle emissions from AJF blended with petroleum based jet fuel (38). Reductions in occupational exposures to combustion emissions from AJF blends would therefore be reasonably anticipated. Although the certification campaigns were successfully completed, the AF is not planning conversion or use of AJFs or blends at the time of this publication.

US Air Force Consults

Part of the literature reviewed were USAF consultative letters associated with complaints of eye, nose, and throat irritation from aircraft exhaust. Exposure assessments have been conducted on crew chiefs during launch and recovery operations for F-15's on Otis Air National Guard Base, MA (39), on KC-135's on Pease Air National Guard Base, NH (40), and on a C-130 AE crew at the 156 AES, Charlotte, NC in (41). The same testing methods were used in all 3 consults: aldehydes (acetaldehyde, acrolein, crotonaldehyde, and formaldehyde), benzene, toluene, ethylbenzene, xylenes (BTEX), JP-8 fuel, and polycyclic aromatic hydrocarbons (PAH) using active sampling methods, and oxide gases measured with direct reading monitors.

The conclusion for all consults was that the personnel were not overexposed to the contaminants measured and no corrective action was needed due to the results being

less than exposure or detection limits. However, the cause of irritation was still unknown. For all above consults, important to note is that ultrafine particles were not tested, and the weather conditions were mild. Extensive environmental campaigns that have characterized JFCE since these consults demonstrated that JFCE contain significant levels of ultrafine particles and higher content of organic hydrocarbon compounds in cold weather. Also, results for the aldehyde samples were not reported for the AE crew consult due to the samples being lost. The author noted possibility of inefficient capture of the contaminants due to speed of the propeller wash. They recommended following the local policy of performing patient onloads with the engines off, and that follow on studies would ensue. Since the 1999 consult from the 156th Aeromedical Evacuation Squadron two other efforts investigated exhaust exposure during ERO (14) (42).

A prior AFIT thesis study investigated C-130 JFCE in response to a request by the Air Force Institute of Environment Safety and Health Risk Analysis (14). The investigator interviewed 12 loadmasters, all whom reported poor air quality in cargo bay after ERO. They reported symptoms of eye, nose, throat irritation, and difficulty breathing. The investigator tested the exhaust for soot-bound PAH, elemental carbon, and carbon monoxide during a mock C-130 ERO cargo onload/offload. The author found that PAH and CO were below OELs. However, EC results periodically exceeded excursion limits of working OELs. He recommended future testing for aldehydes and 2- 3- ring PAH.

Childers *et al* investigated exposures to vapor and particle-bound PAH (42). Particle-bound PAH were measured with photoelectric aerosol sensors (PAS). Vapor phase PAH were collected with XAD-2 filter cartridges and analyzed by gas

chromatography-mass spectrometry (GC-MS). Area samples were collected on the flight line, in a break room, downwind of a four engine run-up, downwind of aerospace ground equipment (AGE), in a hangar, in the cargo bay during a cargo drop exercise, and in a cargo bay during ERO. Total PAH concentrations for all activities/locations were less than 10 $\mu\text{g}/\text{m}^3$. The largest contributor of PAHs on the flight line was from ground support equipment, followed second by ERO. They found that naphthalene and alkyl-substituted naphthalenes dominated the PAH content, but were less than exposure limits.

Another AF inquiry involving JFCE exposure was made in 2013. The 109th Air Lift Wing-Stratton Air National Guard Base, NY requested recommendations for respiratory protection and sampling in extreme cold during LC-130H defueling operations at McMurdo Station, Antarctica (4). Engines running and aircraft movement are required during defueling due to low confidence of engine restart and to keep the plane from sinking into the ice. “Pockets” or “clouds” of contaminated air developing around the rear of plane were reported. They sought respiratory protection effective to -50 °C with communication capability. Only one type mask, Promask 2000, was found certified at -50 °C and was recommended, however, the mask did not meet the communication criteria.

Another study was conducted due to complaints of eye and throat irritation from ground crews and pilots exposed to JFCE at Misawa Air Base, Japan (5). Kobayashi and Kikukawa (2000) investigated formaldehyde content in F-4 aircraft exhaust due frequent accounts of irritation after conversion from JP-4 to JP-8. The irritation was more frequent and severe in winter months. They conducted personal sampling with diffusive samplers and area sampling with active samplers 50 – 75 meters behind the engines where the

personnel normally worked. The researchers sampled in summer and winter, and with varied engine throttle settings. They found high concentrations of formaldehyde with highest concentrations at engine idle and with decreased temperature and humidity. The researchers recommended that personnel avoid working within 75 meters behind the engines, schedule crew activity to avoid the exhaust whenever possible, or use of full face respirators when avoidance was not feasible.

Special consideration should be directed towards exhaust exposures at locations in cold and extreme cold climates where the jet fuel combustion is significantly less efficient and greater content of unburned fuel arises.

Jet Fuel Combustion Emissions Overview (JFCE)

As found in the literature, aircraft engines emit a variety of hazardous species that have potential to adversely impact human health. These emissions include carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and ozone (O₃), volatile and semi-volatile organic compounds (VOC/SVOC) from inefficient combustion of the fuel, unburned jet fuel vapors and aerosols, ultrafine particles, and metals (43) (44). Many of the VOC emissions contain compounds listed as hazardous air pollutants (HAPs) by the US Environmental Protection Agency and in the Agency for Toxic Substances and Disease Registry (ATSDR) (25) (45). HAPs are compounds known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects (46) (47).

Carbon Monoxide (CO)

Carbon Monoxide (CO) concentrations have been found highest at engine start up and ground idle (19) (48) (49). This finding is supported with results from tandem testing of carbon dioxide (CO₂). As the throttle setting increased from idle, carbon dioxide concentration increased, indicative of increasing combustion efficiency with engine power (24). CO is a respiratory health concern because it competes with oxygen to bind with hemoglobin (50). In fact, hemoglobin has such a greater affinity for carbon monoxide that it displaces oxygen in red blood cells, depriving body tissues of oxygen. This action can lead to carbon monoxide-induced hypoxia where symptoms include dizziness, fainting, increased heart rate, headaches, muscular weakness, and nausea. Symptoms of CO exposure generally do not occur below 100 ppm. However, chronic exposure to CO can lead to central nervous system damage, loss of peripheral sensations, poor memory, and general mental deterioration.

Nitrogen Oxides (NO_x)/ Sulfur Oxides (SO_x)

Nitrogen and sulfur oxides arise in the exhaust from oxidation during combustion. The gases adsorb onto soot particles, facilitated by condensation and surface oxygen groups (44). Nitrogen and sulfur oxides found in aircraft exhaust are nitric oxide (NO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), sulfur trioxide (SO₃), and sulfate (SO₄). The sulfur species dominating at engine idle are sulfate, which can react with water in air or on the surface of soot particles to form sulfuric acid (H₂SO₄), especially in humid air (18).

Nitrogen and sulfur oxides have high water solubility, and therefore are absorbed primarily into the upper respiratory tract (50). Nitrogen dioxide odor and taste can be observed at as low as 1 ppm, while sulfur dioxide odor and taste are observed between 3 – 5 ppm. Symptoms of nitrogen and sulfur oxides exposure are eye, upper respiratory tract, and skin irritation that can occur at levels as low as 15 ppm for nitrogen oxides and 8 ppm for sulfur oxides.

Both nitrogen and sulfur oxides were found in the literature to increase with engine throttle setting, with relatively low concentrations emitted at ground idle and highest concentrations at maximum power (19). Due to sulfate tendency to form sulfuric acid, sulfuric acid testing was included in this research. Nitrogen oxides were not tested in this study, but should be considered in follow on work, especially on busy flight lines.

Ozone

Ozone is also a product of JFCE. Reactive alkenes and alkynes hydrocarbons in low power engine emissions are precursors to ozone formation (49). They are highly susceptible to oxidation by hydroxyl radicals also present in the exhaust. Alkenes have the highest affinity for ozone production, but ozone can also form from oxidation of CO. Ozone was not tested in this study but should be included in follow on assessments because of its low regulatory limits. Potential health effects from ozone exposure are eye and mucous membrane irritation. Ozone can also cause pulmonary edema and respiratory disease (51) (52).

VOC

As with all internal combustion engines, combustion efficiency increases with increasing engine power due to higher temperature and pressure. Conversely, combustion at engine start-up and idle is much less efficient. At engine start-up and idle volatile organic compounds (VOCs) from fuel cracking and unburned jet fuel exit the engine (53). Fuel cracking products include alkenes and alkynes ethylene, propylene, and acetylene, single-ring aromatic hydrocarbons such as benzene and substituted benzenes, and intermediate volatility organic compounds (IVOC- C₁₂ to C₂₂ hydrocarbons) (26) (36) (49).

In aging exhaust VOC and IVOC undergo transformations to become different compounds called secondary organic aerosol (SOA) (36). Transformations from which SOA evolve as the exhaust “ages” include oxidation of alkenes by hydroxyl radical ($\bullet\text{OH}$), ozone (O₃), and nitrate radical (NO⁻³), fragmentation induced by photo oxidation, and condensation and adsorption of VOCs onto soot particles upon cooling and dilution with ambient air (43) (49) (36) (54).

Ethylene and formaldehyde are the most abundant VOC at low engine power, and have been used as fuel cracking tracers for scaling hydrocarbons emission indices to compensate for inter-engine variability (49).

Formaldehyde

Formaldehyde is a VOC that is widely used in industry. It is commonly used in the medical laboratories, wood processing industries, building materials, household products, as an industrial disinfectant, and is found in cigarette smoke (55).

Formaldehyde is also a combustion product of automobile and aircraft exhaust, and power plant emissions (5) (56). The majority of formaldehyde entering the environment is from combustion processes.

A substantial amount of literature confirms formaldehyde in JFCE (5) (24) (49) (57) (30) (33). In fact, Formaldehyde dominates the VOC content at engine start-up and idle. It is not contained in jet fuel formulations. Rather, it forms from partial oxidation of ethylene. Cold weather conditions exacerbate formaldehyde formation because of decreased combustion efficiency described earlier.

Formaldehyde is a HAP, toxic and carcinogenic at high levels, and an eye, nose, and throat irritant at low levels (56). Concentrations in air less than 1 ppm can irritate mucous membranes and eyes (50). American Conference of Governmental Industrial Hygienists, ACGIH, report that in the presence of other pollutants formaldehyde can irritate eyes at concentrations between 0.05 – 0.5 ppm (58). The current ACGIH threshold limit value-time weighted average, TLV-TWA, is 0.1 ppm, and the short term exposure limit, TLV-STEL, is 0.3 ppm. The maximum exposure allowed by OSHA during a 15 minute period, OSHA STEL, is 2 ppm (55). OSHA states to “Identify all workers who may be exposed to formaldehyde at or above the action level or STEL through initial monitoring and determine their exposure”. Formaldehyde testing was include in this study.

Unburned Jet fuel

Aircraft exhaust emissions at engine start-up and idle also contain alkanes and aromatics from unburned jet fuel that exit the engine as vapors and aerosols (2) (49). As

with formaldehyde, the amount of unburned jet fuel exiting the engine at start-up and idle increases with decreasing temperatures. Accounts of a visible floating “cloud” or plume of unburned jet fuel emitted at engine start in cold weather climates have been observed (4) (26). Figure 2, “KC-135 Engine Cold Start at Eielson AFB” from the work of Pleil et al illustrates this.



Figure 2: KC-135 Engine Cold Start at Eielson AFB (26)

Particulate Matter/Soot

The evolution of particulate matter (PM) in JFCE is complex. In the combustor, EC and OC are formed from pyrolysis or “cracking”, and combustion of fuel hydrocarbons. The ideal combustion products are carbon dioxide and water. However, inefficient combustion of jet fuel at engine start and idle produces primary PM emissions

consisting of elemental carbon (EC) and organic carbon (OC). OC was described previously as VOC (24) (25). EC are graphitic particles whose surface structures are irregular and readily support condensation and adsorption. EC serve as nuclei or “seeds” for other volatile species in the exhaust (e.g. OC, NO_x, SO_x) to condense or adsorb onto causing soot particle growth.

In addition to carbon, elemental analysis of soot from commercial aircraft has revealed content of nitrogen, sulfur, sodium and trace amounts of metals (53), indicating a hygroscopic nature of the soot particles. Volatile species and water vapor that condense or adsorb onto particles make the particles increasingly hygroscopic, which supports further growth (24). OC and EC both increase with engine throttle setting; however, OC content at engine idle is much higher than that of EC due to lower temperature and pressure (25).

Prior studies demonstrated that the particle mass, number concentrations, and geometric mean diameters increased with increased engine power. Coagulation of primary combustion particles are believed to cause this growth (24) (59). Coagulation occurs as a result of particle collisions in the turbulent post exhaust (59) (60). Nevertheless, particle sizes at all engine throttle settings are only in the nanoparticle range, less than 100 nanometers (nm), which is concerning for respiratory health (24) (48).

For perspective, particulates 5 micrometer (μm) or larger are trapped in the upper respiratory tract (nose) and expelled through nasal discharge (19) (50). Soluble particles however can dissolve and diffuse into the bloodstream. Particles in the 2 – 5 μm size range can get trapped in the tracheal and bronchial regions (back of the throat) where

they are swallowed or coughed and spit out (37). However, particles smaller than 100 nm can lodge into lung capillaries or diffuse into the bloodstream and carried to other body parts.

Health hazards associated with EC and OC diesel engine emissions are well reported. Exposures to high concentrations include headache, dizziness, and eye, nose and throat irritation (61). Chronic exposure can cause cardiovascular, cardiopulmonary and respiratory disease and lung cancer. Diesel exhaust particulate emissions, as with all hydrocarbon fueled engines, are also nano-sized (37). In 2012, diesel exhaust was classified as a known human carcinogen by the International Agency for Cancer Research (IARC) (61).

Nanoparticles may be classified into different types: 1) naturally occurring, which include volcanic ash and forest fire combustion products, 2) incidental, such as welding fumes or diesel exhaust, and 3) engineered (manufactured), such as carbon nanotubes or nano-metals and metals oxides used in ceramics (62). In recent years occupational exposure to nanoparticles have gained much interest due to the health risks associated with the engineered nanoparticle industry (62) (63). Engineered nanoparticles are suspected as more toxic than larger particles because of their increased surface area and surface reactivity, and similarity to biological structures. Combustion emissions have long time been an anthropogenic source of nanoparticles. Properties that combustion emissions share with engineered nanoparticles are increased surface area and surface reactivity. However combustion generated nanoparticles (soot) have irregular shapes. The biological activity of combustion emitted particles once inhaled is unknown. Like engineered nanoparticles, detailed information on the morphology, surface structures and

composition of combustion emitted particles and how these properties may impact worker health should be a topic of interest to occupational safety professionals.

Polycyclic Aromatic Hydrocarbons (PAH)

PAH are a class of SVOC that form in post combustion processes. PAH and soot form from fuel cracking products and unburned fuel precursors in JFCE at low engine power (42) (49). PAHs that dominate in aircraft engine idle exhaust are naphthalene and alkyl-substituted naphthalenes. At high engine power, PAH and soot grow from aromatics formed via the hydrocarbon abstraction acetylene adsorption (HACA) process and coagulation from particle collisions (49). As engine power increases, PAH sizes and concentrations increase.

Naphthalene was tested in this study by TO-17. However, follow on work should characterize PAH in occupational settings on flight lines, especially those with heavy ground aircraft traffic and ground support activities.

Metals

Soot particles containing metals or metal oxides may arise in aircraft exhaust from engine erosion or combustion of fuel additives or lubricants from leaky seals (53). The metals content in exhaust is a function of engine age and maintenance. Transition and heavy metals Aluminum, Strontium, Barium, Sodium, Nickel, Cobalt, Chromium, and Tin, are used in bond coatings, bearings, and underlying alloys. Metals testing was included in this study.

III. Methodology

Sampling Plan Overview

This chapter describes the testing methods and equipment employed and problems encountered. Sampling occurred on two nonconsecutive days- June 1 and November 9, 2016. Additional tests were added to the return visit on November 9, 2016. The sampling strategy was simultaneous sampling at all locations using DRI and traditional active sampling methods. All measurements, including background/pre-run readings, commenced prior to auxiliary power unit (APU) and engine start up, and continued simultaneously for at least 30 minutes, the maximum time it typically takes to load patients during AE ERO. Figure 3, “Summary of Contaminants and Test Methods” summarizes the total testing between both sampling days, June 1 and November 9, 2016.

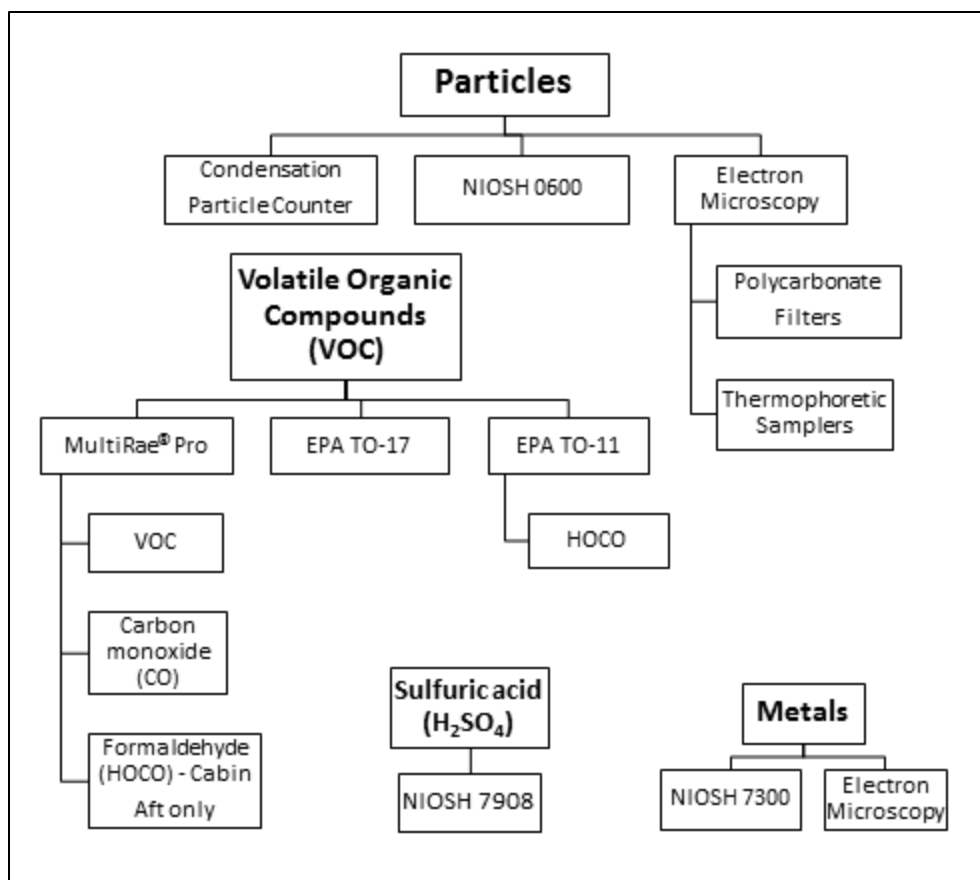


Figure 3: Summary of Contaminants and Test Methods

Ultrafine particles, VOC, CO, and formaldehyde contaminants were tested because of their known content in JFCE. Metals were selected due to limited information in prior studies and potential contribution from engine erosion. Sulfuric acid was added because sulfur oxides are known emissions from which sulfuric acid can form via condensation in aging exhaust. Traditional active sampling methods (NIOSH, EPA) were chosen for specific contaminants because of proven reliability and routine use in occupational exposure assessments.

Consultation with a flight nurse and aeromedical evacuation technician from the US Air Force School of Aerospace Medicine (USAFSAM) provided familiarization with

C-130 AE ERO procedures and aircraft configuration (64). The sampling locations are shown in Figure 4, “C-130 Sampling Locations”.

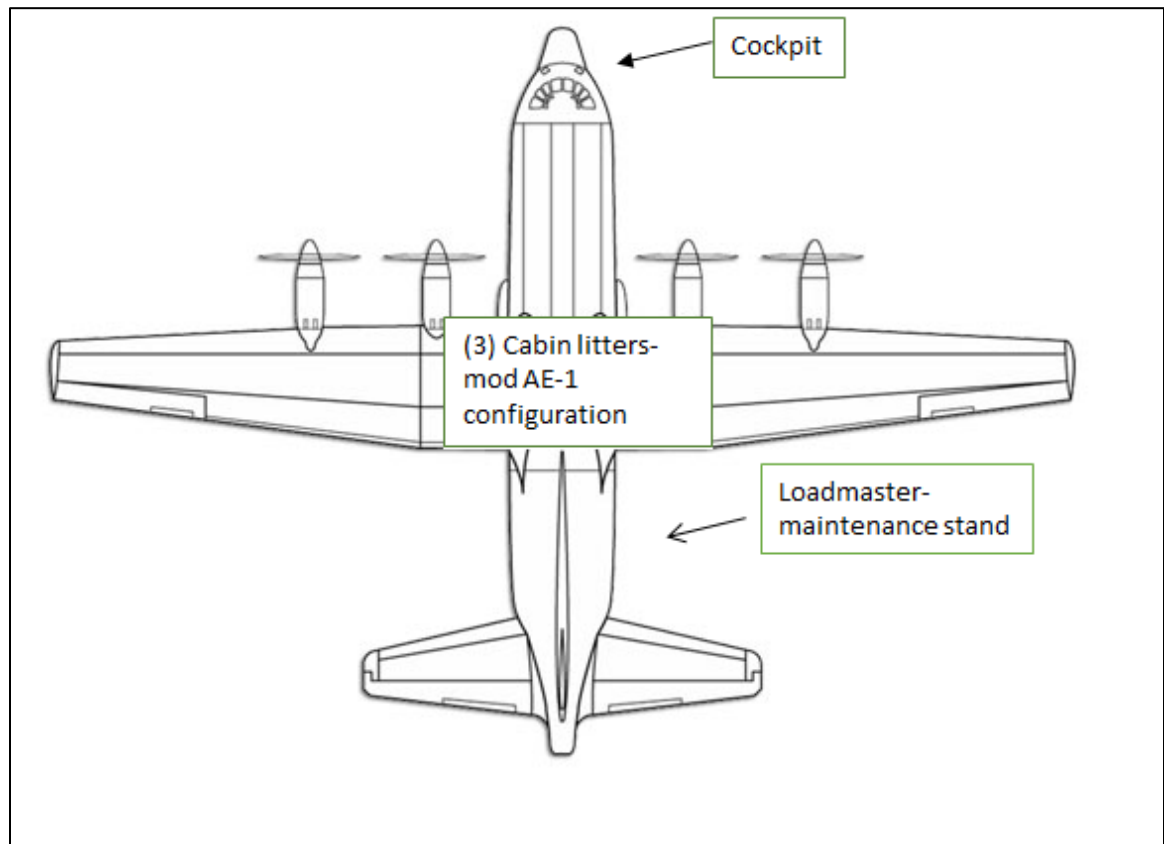
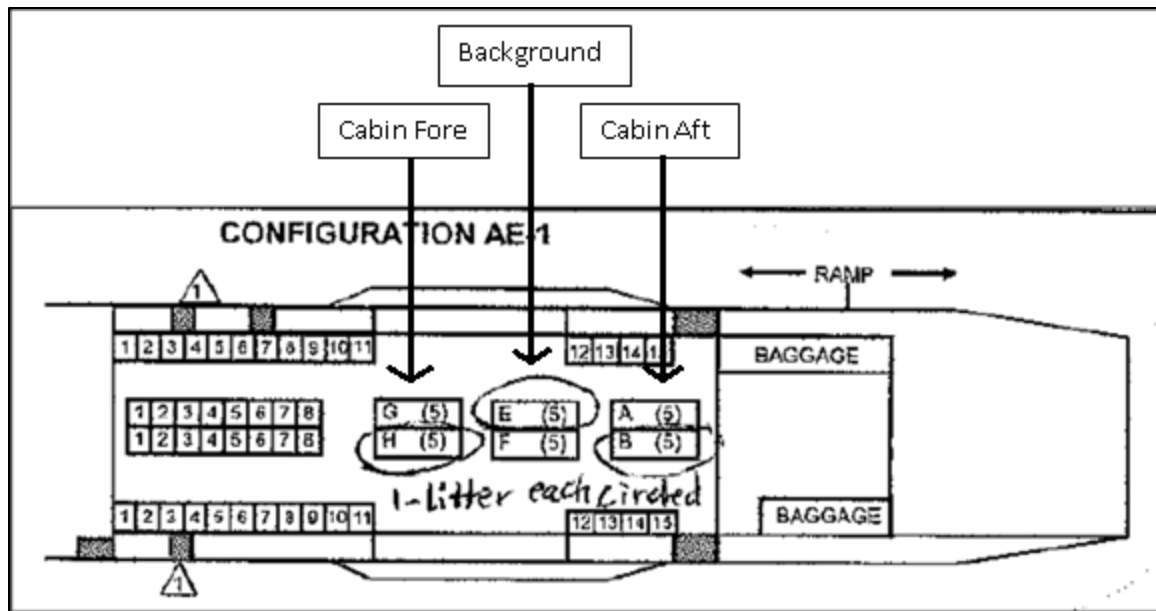


Figure 4: C-130 Sampling Locations

This process was a simulated ERO. This research did not involve human subjects and no patients were involved. Sampling equipment was not placed on personnel. Rather, area sampling was conducted in approximate personal breathing zones. Stanchions and Litters were set-up as a Modified AE-1 configuration. See Figure 5, “Cabin Litter Set-up”. The seats in Figure 5 were not installed.



Whenever possible the sampling equipment was set up to sample in simulated personnel breathing zones. Equipment was attached to the bottom of shallow plastic crates. Figure 6, “Sampling Equipment Set-up”, shows an example of the equipment during set-up at the aircraft.



Courtesy of the 179th Airlift Wing Public Affairs

Figure 6: Sampling Equipment Set-up

Crates were placed on the navigator's table and on the crew rest cot (Nov. 9, 2016 only) inside the cockpit, on three patient litters inside the cabin, and on a maintenance stand at the loadmaster location. See Figures 7 and 8, "Cockpit, Navigator's Table Set-up" and "Cockpit, Crew Rest Cot Set-up (November 9, 2016)", Figure 9, "Cabin Set-up (June 1, 2016)", and Figure 10, "Loadmaster Location Set-up (June 1, 2016)".



Courtesy of the 179th Airlift Wing Public Affairs

Figure 7: Cockpit, Navigator's Table Set-up



Courtesy of the 179th Airlift Wing Public Affairs

Figure 8: Cockpit, Crew Rest Cot Set-up (November 9, 2016)



Courtesy of the 179th Airlift Wing Public Affairs

Figure 9: Cabin Set-up (June 1, 2016)



Courtesy of the 179th Airlift Wing Public Affairs

Figure 10: Loadmaster Location Set-up (June 1, 2016)

Test Methods

Particles/Aerosols

JFCE particles/aerosols were characterized with multiple testing approaches. Condensation particle counters (CPC) were used for particle counts and migration information. NIOSH 0600 method was used for gravimetric testing. Particle size

distribution, count, morphology, and elemental composition were tested with electron microscopy techniques.

Particle Count by TSI® 3007 CPC

Condensation particle counters are ideal for sampling particles in the nano-size range, which are not detectable by optical particle counters or photometers (62). Inside the CPC the stream of particles pass through a region saturated with isopropyl alcohol (IPA) vapors. The IPA vapors condense onto the particles making them “grow” into an optically detectable size. Then the enlarged particles are optically detected when subjected to laser light of which the particles scatter.

TSI® Model 3007 handheld condensation particle counters were used in this study. These models are portable, lightweight, and battery operated. The detectable particle size range of the TSI® Model 3007 is 10 nm to greater than 1 μm with a maximum particle concentration of 10^5 particles/ cm^3 . However CPC are limited to count concentrations, not providing other important particle information such as particle size, distribution, morphology, and chemical composition. For works requiring particle characterization, supplementing CPC with additional equipment/testing that provide this information is ideal.

CPC preparations

All CPCs were prepared per TSI® operating manual. The wicks charged with IPA, and zero checks taken prior to both sampling days.

Due to visual observation of all CPC readings at or above the instruments' maximum range of 10^5 particles/cc during the June 1, 2016 sampling, diluters were

installed onto the CPCs for the November 9, 2016 return visit as in Figure 11, “CPC + Diluter”.



Courtesy of the 179th Airlift Wing Public Affairs

Figure 11: CPC + Diluter

A dilution factor of 10X was chosen based on the results of the TPS units from the June 1, 2016 sampling. Dilution lines made of conductive silicone tubing attached the diluters to the CPCs. Sufficient mixing of the aerosol with filtered air was checked by rotating the diluter and observing no change in concentration other than minor fluctuations normally observed.

Next inter-unit variability checks were conducted on all CPCs using nebulized DI water. The nebulized DI water apparatus is shown in figure 12, “Nebulized Deionized Water Apparatus”.

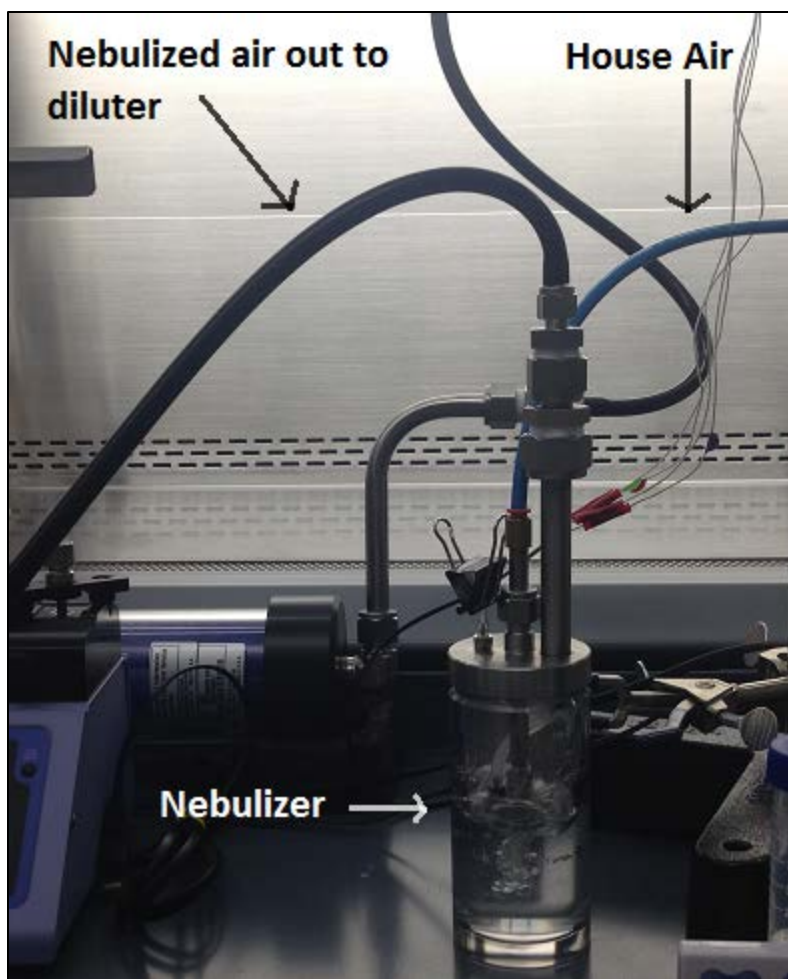


Figure 12: Nebulized Deionized Water Apparatus

One diluter was connected to a manifold, and all CPCs were connected off the manifold, operating simultaneously as in Figure 13, “Inter-unit Variability Checks”.



Figure 13: Inter-unit Variability Checks

Since the manufacturer calibration dates among the units ranged from November 2009 to August 2016, the CPC most recently calibrated (OET ECN 101382) was used as the benchmark for the inter-variability checks. The hoses connecting the manifold to the CPCs were of equal length, 55 in. All units were zero checked simultaneously with a Hepa filter attached to the bottom of the manifold, and completely closing the diluter shutoff valve. All CPC's maintained 0 reading for 1 minute. The inter-unit variability checks were verified at 10,000 pt/cc reading by setting this value on the diluter of the most recently calibrated CPC. The standard deviation among the 5 CPC average readings was 1,224 particles/cc, indicating 12 % variability in readings among the units.

Next the CPCs + diluters were connected to the manifold individually and the diluters set to 10X dilution of the CPC theoretical maximum count of 10^5 particles/cc. This was accomplished by adjusting the diluter valve to read as close to 10,000 particles/cc as possible. Zero checks were conducted again with the individual CPC's. The ability of each unit to read at or above the maximum count was verified by opening the diluter valves completely. To check the dilution factor, the CPCs + diluters were disconnected from the manifold, and the diluted ambient air reading was observed. Then the diluter was removed from the CPC and the undiluted ambient reading was observed. However, the difference observed between the diluted reading and ambient reading was not a 10X difference. So the dilutions were re-set on each CPC based on ambient readings and not nebulized air charging (Ex. CPC + diluter disconnected from the manifold, if ambient reading was 4000 particles/cc, the valve was dialed down to 400 particles/cc).

Once set to 10X dilution with ambient conditions, the diluter valve positions were marked and taped to secure the valve knobs. The ambient readings varied among the CPC's due to variations in the laboratory ambient air. So 10X dilution was set for each CPC based on the individual ambient readings. This was accomplished by logging ambient readings for one-minute, then immediately installing and setting the diluters to 10X of ambient reading, and then logging the dilution readings for one-minute as well. The diluters were post checked the day after the sampling (November 10, 2016).

Particles by TPS100[®] Samplers and PC Filters

The most definitive approach to characterizing ultrafine particles in post combustor emissions is electron microscopy (EM) (62). EM techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), scanning transmission electron microscopy (STEM), and computer controlled scanning electron microscopy (CCSEM) provide comprehensive particle information, including morphology, elemental composition, sizing, and count.

With SEM the particle is subjected to a finely focused electron beam. In interaction with the particle's surface, secondary and backscatter electrons evolve, creating a visible image of the particle (65). With TEM finely focused high energy electrons interact with the particle and either scatter (disappear) into the particle or pass on through to a detection screen (ex. fluorescent) which gives rise to a "shadow" image. The image is described by varied darkness that is dependent on particle density.

In this study EM grids were collected with thermophoretic samplers, TPS100[®], and polycarbonate filters (PC) with conductive cowls, provided by the RJ Lee Group of Monroeville, Pennsylvania. The TPS100[®] and PC filters were analyzed by RJ Lee Group using a 30kV Hitachi[®] S-5500 high resolution field-emission SEM/STEM equipped with a Bruker silicon drift detector for energy dispersive X-ray spectroscopy (EDS). The PC filters were prepared prior to analysis by removing a portion of the filter and placing the filter portion onto a SEM stub (66). A thin layer of carbon was deposited onto the filter with vacuum deposition techniques. The samples were then analyzed by SEM. Bright-field STEM (BF-STEM) images were also acquired for the TPS100[®] samples loadmaster and cockpit (June 1, 2016), and cabin aft (November 9, 2016), which were

further processed using National Institutes of Health (NIH) ImageJ, version 1.45r to obtain particle concentrations.

The TPS100[®] unit is a self-contained handheld sampler equipped with a micro-pump and battery capable of 8 hours of continuous sampling at 5 mL/min (63) (66). Operation of the TPS100[®] is based on thermophoretic force in which a relatively large temperature gradient is applied to a narrow flow channel. The temperature gradient is created between a hot plate and a cold plate. Gas molecules become heated on the hot side of the gradient and gain high kinetic energy, resulting in higher number of collisions. The collisions cause increased momentum propelling the particles in the direction of decreasing temperature and subsequent collection onto the EM grid. The EM grid is a nickel TEM grid coated with a carbon film that the particles are deposited onto. The EM grid sits directly underneath the hot plate, and is in thermal contact with the cold plate, sustaining the thermophoresis zone. Collection efficiency of the TPS100[®] sampler is greater than 90% between 10 and 500 nm equivalent particle diameters.

On June 1, 2016 two TPS100[®] units were sampled, one in the cockpit and the other at the loadmaster location. Also on that day five (plus one field blank) 0.4 µm porosity PC filters with conductive cowls were sampled at a flow rate of 4 L/min using SKC, Inc. AirChek XR5000[®] model personal pumps. The PC filters were sampled at all five locations: Cockpit, Cabin Fore, Background, Cabin Aft, and Loadmaster.

On November 9, 2016 four more TPS100[®] were employed, one each in the cockpit, cabin fore, cabin aft, and loadmaster location. However, there were issues with the TPS sampling on November 9, 2016. The first issue was that the cabin and Loadmaster TPS units were not entering into sampling mode. The cold and hot plate

temperatures were initially set to 31 °C and 105 °C. After lowering the cold plate temperatures to 25 °C, the samplers entered into sampling mode except for the Loadmaster TPS. The cold, windy conditions outside of the cabin may have prevented the Loadmaster TPS from reaching the initial cold plate temperature. The Loadmaster TPS was swapped with that of Cabin Fore, which was sampling. Neither the APU nor engines were started when the TPS units were swapped. The original Loadmaster sampler was then re-assigned as the Background TPS since sampling the background was initially planned but missed in the equipment set-up. The engines were started after all TPS units were sampling. Another issue was that the background TPS sampler (originally the Loadmaster TPS) was mistakenly not turned off until after engine start.

NIOSH 0600, Particulates Not Otherwise Regulated, Respirable/NIOSH 7300, Elements by ICP (Nitric/Perchloric Acid Ashing)

Ultrafine particulates and metals were sampled at all sampling locations (Cockpit, Cabin Forward, Background, Cabin Aft, and Loadmaster) plus a field blank by gravimetric method NIOSH 0600, Particulates Not Otherwise Regulated, Respirable and NIOSH 7300 method, Elements by Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy on June 1, 2016 (67) (68). Both tests were collected on the same cassette using tared 5 µm PVC filter cassettes provided by RJ Lee Group and SKC, Inc. AirChek XR5000® model personal pumps and Aluminum Cyclones. The pumps were calibrated the day before sampling on May 31, 2016 at flow rate of 2.5 mL/min. Post calibrations were conducted the day after sampling on June 2, 2016. This flow rate was selected based on the maximum flow rate recommendation in N0600 and the minimum flow rates

recommended in Table 1 of N7300 method. The samples were analyzed by RJ Lee Group. The N7300 analyses included the following metals: Aluminum, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Molybdenum, Nickel, Strontium, Tin, Titanium, Vanadium, and Zinc.

NIOSH 7908, Non-Volatile Acids (Sulfuric Acid)

Sulfuric acid was also sampled at all locations plus a field blank on June 1, 2016 by NIOSH 7908 method, Non-volatile Acids (69). Quartz fiber filter media provided by RJ Lee Group were sampled using SKC, Inc. AirChek XR5000® personal pumps. Pump pre- and post-calibrations were conducted on May 31, 2016 and June 2, 2016 at the sampling flow rate of 4 mL/min. These samples were also analyzed by RJ Lee Group.

VOC

VOC were characterized with multiple methods. VOC speciation and quantitation were obtained with Compendium Method TO-17 and TO-11 for Formaldehyde. VOC were also sampled with MultiRae Pro® multi-gas meters. Carbon media passive dosimeters were also sampled for VOCs by NIOSH 1501 method for Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) alongside this campaign by another investigator.

Compendium Method TO-17, Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes

VOC were sampled at all locations by Compendium Method TO-17, Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes (70). This analysis and the sorbent tubes, Tenax thermal desorption tubes, were provided by USAFSAM/FHOF. Since the ERO is a short process, the

minimum volume required to collect was calculated using a VOC HAP with a low the short term occupational exposure limit (OEL), Benzene. The laboratory reporting limit (RL) for TO-17 is 2 ppbv. The minimum volume for TO-17 was calculated in Equation 1 using the Cal/OSHA short term exposure limit (STEL) for Benzene, which is 5 ppm (71) (72).

Equation 1

$$V_{min} = \frac{RL}{E * F}$$

Where: RL = Reporting Limit in μg = 2 μg

E = Benzene Exposure Limit = 5 ppm = 15.95 mg/m^3

F = Estimated % exposure limit in the sampling environment = 10% = 0.1

$$V_{min} = \frac{RL}{E * F}$$

$$V_{min} = \frac{2\mu\text{g} * \frac{1\text{mg}}{1000\mu\text{g}}}{15.95\text{mg}/\text{m}^3 * (\frac{1\text{m}^3}{1000\text{L}}) * 0.1} = 1.2 \text{ L}$$

This test was sampled on June 1, 2016 and again on November 9, 2016 due to the pumps shutting down intermittently on June 1, 2016. Pre- and post-calibrations were conducted on May 31 and June 2, 2016 and were noted as difficult, but successful. On June 1, 2016, SKC, Inc. AirChek XR5000® model personal pumps with adjustable low flow tube holders adjusted at a flow rate of 50 mL/min were used. The samples from June 1, 2016 were analyzed, but the data not reliable due to unknown collection volumes.

Realizing unsuitability of the AirChek XR5000[®] pumps, the TO-17 testing was repeated on November 9, 2016 using Gilian GilAir Plus[®] personal pumps at 50 mL/min flow rate. The pumps were pre- and post-calibrated on November 8 and November 10, 2016 with no difficulty.

Compendium Method TO-11A, Determination of Formaldehyde in Ambient Air by High Performance Liquid Chromatography (HPLC)

Formaldehyde was sampled at all locations by Compendium Method TO-11, Determination of Formaldehyde in Ambient Air using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) (66). The analysis and the sorbent tubes, 2,4-dinitrophenylhydrazine treated silica gel with ozone scrubber, were provided by RJ Lee Group. The same personal pumps with an adjustable low flow tube holder used for the TO-17 testing were used with TO-11, but the flow rate was 500 mL/min. The flow rate within the range recommended by the TO-11 method, 100 – 2,000 mL/min, was selected. As with the TO-11 testing, the pumps were intermittently shutting down and the samples from June 1, 2016 were not used. This testing was also repeated on November 9, 2016 using Gilian GilAir Plus[®] personal pumps with pre- and post-calibrations performed on November 8 and November 10, 2016.

VOC by MultiRae[®] Pro Multi-gas Meter

VOC, CO, and Formaldehyde were sampled by Rae Systems, Inc. MultiRae Pro[®] monitors during the November 9, 2016 sampling. Four monitors were sampled, one each in the Cockpit, Cabin Forward, Cabin Aft, and Loadmaster locations. All were equipped

with VOC and CO sensors. However, only Cabin Aft monitor was equipped with a Formaldehyde sensor due to availability of only one sensor.

Weather by TSI® Velocicalc Meter

Weather data was obtained by the Mansfield ANG installation weather office and TSI, Inc. Velocicalc® model 9565-P meters.

Testing Summary

01 June 2016 Sampling

Problems were experienced on the first sampling day. The sampling pumps used for TO-11 and TO-17 collections kept shutting down. As a result the sample volumes collected were unknown for TO-11 and TO-17 and the data was not useable. It was later realized that the model pumps used were not suited for low flow, even with low flow adaptors. These tests were repeated on November 9, 2016 using different pumps suited for low flows. Another problem was that data was not logged on the CPC units. Therefore, particle migration information was not available for the June 1, 2016 testing. However, overall instrument readings were visually observed and noted. Another issue was that less volume was collected on the cockpit TPS than the loadmaster unit. Therefore, the cockpit TPS results may be underestimated. Also, MultiRae® testing was excluded from the June 1, 2016 suite due to time constraints.

During the November 9, 2016 sampling, the TPS units lagged in reaching their temperature set points that were manually entered, which prevented the units from going into sampling mode. TEM grid issues with two of the TPS units (Cockpit and Loadmaster) were observed during laboratory analysis, which resulted in loss of the

electron microscopy data for those TPS units. Another problem on the second testing day was that CPC post dilutor checks were not in agreement with the dilution factors set on the units. Therefore the CPC data were used for qualitative migration information only.

09 November 2016 Sampling:

Each location had the same sampling set up and sampled for the same contaminants simultaneously, with 3 exceptions. 1.) No DRI were placed at the Background location 2.) Formaldehyde was tested by MultiRae® at the Cabin Aft location only due to availability of only one Formaldehyde sensor. 3.) Two CPCs sampled in the cockpit due to availability of an additional unit. One sampled on the navigator's table and one on the crew rest cot.

Figures 14 and 15 summarize the tests, sampling locations, and problems encountered on each day.

June 1, 2016							
Test	CPC*	TPS	SEM PC filters	TO-17**	TO-11**	N7300, N0600	N7908
Hazard	Respirable particulates			VOC	HOCO	Metals, Respirable particulates	H ₂ SO ₄
Sampling Location							
Cockpit (CP)	✓	✓	✓	X	X	✓	✓
Cabin Fore (CF)	✓		✓	X	X	✓	✓
Background (B)			✓	X	X	✓	✓
Cabin Aft (CA)	✓		✓	X	X	✓	✓
Loadmaster (LM)	✓	✓	✓	X	X	✓	✓
* data not logged, visual indication only							
* * Tests excluded due to pumps shutting down							
X = Data not useable							

Figure 14: Test Methods Summary- June 1, 2016

November 9, 2016							
Test	CPC*	TPS **	TO-17	TO-11	MultiRae Pro [®]		
Hazard	Respirable Particulates		VOC	HOCO	VOC****	CO	HOCO
Sampling Location							
Cockpit (CP)	✓	X***	✓	✓	✓	✓	
Cabin Fore (CF)	✓		✓	✓	✓	✓	
Background (B)		✓	✓	✓	✓	✓	✓
Cabin Aft (CA)	✓	✓	✓	✓	✓	✓	✓
Loadmaster (LM)	✓	X***	✓	✓	✓	✓	
* Diluters attached to CPCs, 2 CPCs in cockpit (navigator's table, crew rest cot)							
** TPS units not entering sampling mode, lowered cold plate set points- units went into sampling mode prior to engine start							
***CP and LM not analyzed- TEM grid issues observed during lab analysis							
****Qualitative only- Isopropanol carryover from CPCs							
X = Data not useable							

Figure 15: Test Methods Summary- November 09, 2016

Limitations

Table 1: Test Method Limitations

Tests	Limitations
All	Area sampling is not representative of actual breathing air.
	This research was investigative only. More rigorous follow-on work is required for assessing representative personal exposures.
TSI® 3007 CPC	Manufacturer calibration is only up to 10,000 particles/cc.
	All results were qualitative due to the issues previously described.
	Does not provide particle sizing.
	IPA vapors interfered with VOC multi-gas testing.
N0600	Ultrafine particles have negligible mass, are susceptible to electrical static forces. Volatile particulate matter cannot be determined.
TO-17	Only detects were calibration mix compounds. Library searches identified other chromatography peaks, but only qualitatively.
TPS100®	Equivalent circular diameter calculations are necessary.
	Particle clumping prior to loading can lower the particle count and increase size distribution.
	Low collection efficiency outside 10 – 500 nm particle size range. Does not provide real time data.

See Appendix A, “Equipment List, November 9, 2016” for equipment listing, and Appendix B, “Sampling Information, Methods N0600/N7300/7908, TO-17/TO-11 and SEM PC Filters” for sampling information.

Not all contaminants found in prior studies were sampled in this campaign due to resources and funding limitations. Those contaminants not tested here but are inherent in JFCE are sulfur and nitrogen oxides, ozone and PAH. Including these species in future occupationally focused research would supplement the JFCE exposure information reported in this study and fill testing gaps in the literature.

Suggested Testing Methods for Future Research

Although a single comprehensive personal sampling method is unrealistic for this exposure, one method that may be worth exploring in future investigations is NIOSH 3800, Organic and Inorganic Gases by Infrared Spectrometry (74). This method may be an ideal application for JFCE because it provides analyses for the majority of organic and inorganic gases in JFCE. Sulfur and nitrogen oxides are inherent in the JFCE, but were not tested in this study. NIOSH 3800 can provide analysis of nitrous oxide and sulfur dioxide. An important consideration with this method is minimizing cross-sensitivities. PAH cannot be analyzed with this method, but can be sampled by NIOSH 5506 method, Polynuclear Aromatic Hydrocarbons by HPLC (75).

A method that may be of value in assessing soot exposures from JFCE is NIOSH 5040 method, Diesel Particulate Matter (as Elemental Carbon) (76). This method analyzes total carbon (OC and EC) as well as EC using quartz fiber filters and thermo-

optical analysis. EC results have been used as an exposure marker. Currently there are no regulatory exposure limits for elemental carbon. However, results from this method could provide overall insight into the particle mass concentration exposures.

A suitable method for sampling personal exposures to unburned jet fuel is NIOSH 1550, Naphthas (77). This method analyses various types of hydrocarbon mixtures by Gas Chromatography, Flame Ionization Detector (GC-FID). A limitation of this method is that it does not speciate individual organic compounds in hydrocarbon mixtures. However, NIOSH 1550 can provide quantitative analysis of unburned jet fuel in JFCE. JP-8, Jet A, and total hydrocarbons can be analyzed by N1550 method.

Table 2, “Suggested Methods for JFCE Occupational Exposure Investigations” summarizes a comprehensive testing suite suggested for future JFCE occupational investigations.

Table 2: Suggested Methods for JFCE Occupational Exposure Investigations

Contaminant	Test Methods	Rationale
Formaldehyde	NIOSH 2016/EPA TO-11	Known content in JFCE, occupational carcinogen
Ultrafine soot particles	Direct reading instrument, electron microscopy	Real time particle count, migration indication, soot morphology
Total and Elemental Carbon	N5040	EC as a marker for exposure
Sulfuric Acid	N7908	Suspected in humid conditions
Unburned Jet Fuel	N1550	Found in engine start & ground idle; higher content in cold weather
Volatile organic, Inorganic gases	N3800	One test to provide real-time analyses of multiple hazards
PAH	N5506	Higher concentrations suspected on busy flight lines

IV. Results and Discussion

Particles/Aerosols

Particle Count by TSI® 3007 CPC

CPC particle concentrations from June 01, 2016 sampling exceeded the unit's maximum range, 10^5 particles/cc. Therefore diluters were installed for the return sampling on November 09, 2016. Post dilution checks were conducted on November 10, 2016, which did not match the dilution readings set on November 08, 2016. Figure 16, “CPC Dilution Readings Comparison”, shows comparison between the dilution factors set prior to sampling and post dilution checks. The post dilution factors except for Cabin

Aft CPC deviated considerably from the original 10X dilution factor that was set on the diluters.

		Dilution Setting			Post Dilution Checks		
CPC	Location	11/08/2016 Ambient Readings	11/08/2016 Dilution Readings	Dilution factor (10X)	11/10/2016 Ambient Readings	11/10/2016 Dilution Readings	Dilution factor check
100656	Cabin Aft	7070	711.4	9.9	7670	513	15.0
100657	Cockpit	5500	526.9	10.4	9890	189.5	52.2
101382	Loadmaster	6890	721	9.6	20300	376.5	53.9
RHDJ	Cabin Forward	10100	948.5	10.6	10300	241.8	42.6
RHXBC	Cockpit	3820	381.9	10.0	4030	1010	4.0

Figure 16: CPC Dilution Readings Comparison

A summary of the CPC results from November 09, 2016 are illustrated in Figure 17, “CPC Results, November 09, 2016”.

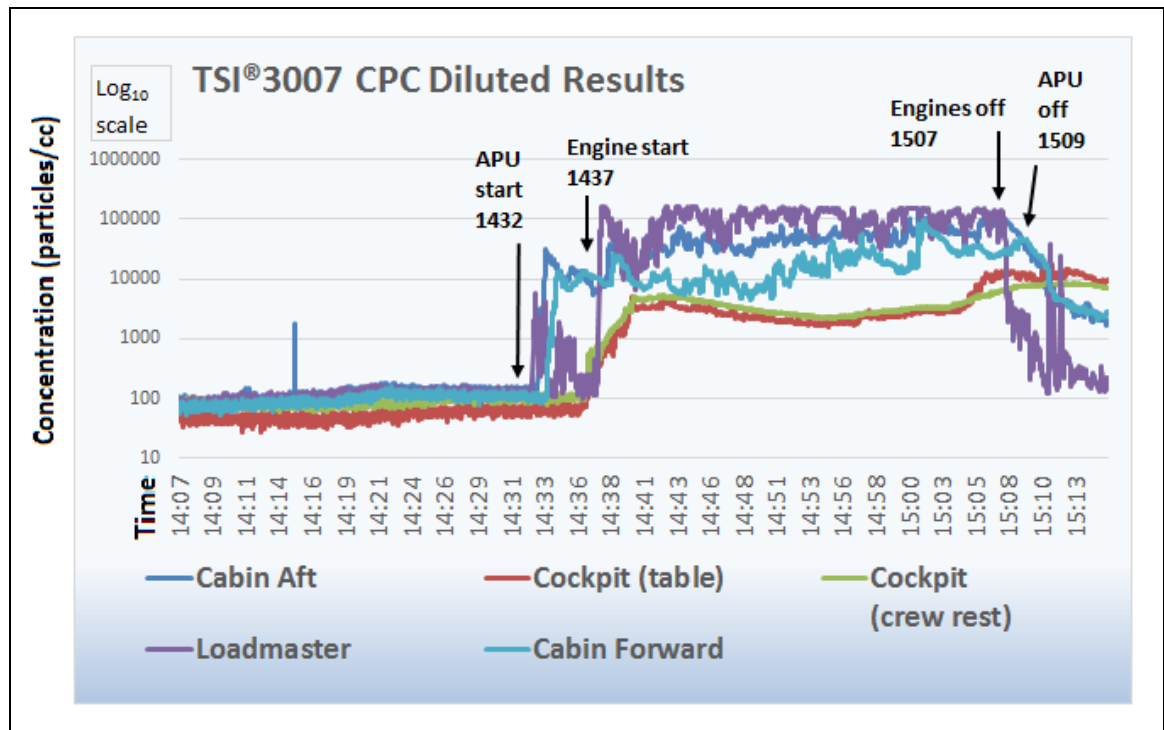


Figure 17: CPC Results, November 09, 2016

The dilutions disparity is not consistent with the CPC results. For example results for both CPCs in the cockpit were expected to deviate considerably from each other based on the dilution factor disparity. However, the data for both Cockpit CPCs follow each other closely throughout the engine run, which was expected based on the duplicate testing in the cockpit. Also all CPC data follow each other tightly in the background readings (prior to APU start). All data with detects follow a trend among the sampling locations similar to TO-11, MultiRae® CO, and TO-17, and EM data during the engine run. The concentrations increased from the cockpit through the cabin and out to the Loadmaster location, where the highest concentrations were observed in all tests. It is possible that the dilutions were consistent when set and remained so during the engine run. The deviations in the post checks may have been due to varying ambient background

particles in the laboratory or CPC overload from the sampling. Nonetheless, the CPC data provided valuable qualitative particle migration information. Also of value are that the actual concentrations are at least some degree higher than the diluted results displayed in Figure 17 (and as visually indicated at the CPC maximum count during the June 01, 2016 sampling).

Particles by TPS100[®] and PC Filters

Overall the TPS and PC filter results were dominated by soot. Results summary of the TPS100[®] and PC filters are displayed in Tables 2 and 3, “Polycarbonate (PC) Filter Results” and “TPS100[®] Results”.

Table 3: Polycarbonate (PC) Filter Results

Sampling Campaign	Collection Date	Location	Duration (min)	Vol. (L)	Observations
First Sampling Campaign	6/1/2016	Load master	31	124	Very heavy particle loading; Primarily soot
	6/1/2016	Cabin AFT	33	132	Moderate particle loading; Primarily soot
	6/1/2016	Cabin Forward	30	120	Moderate/light particle loading; Primarily soot
	6/1/2016	Cockpit	32	129	Low particle loading; Primarily soot
	6/1/2016	Background	44	171	Consistent with a blank
	6/1/2016	Field blank	0	0	Consistent with a blank
<i>Courtesy of RJ Lee Group</i>					

Table 4: TPS100® Results

Sampling Campaign	Collection Date	Location	Duration	Vol. (L)	Hot Plate (°C)	Cold Plate (°C)	Ambient Temp. (°C)	Rel. Humidity	Comments	Concentration (particles/cc) from Offline Sizing
First Sampling Campaign	6/1/2016	Loadmaster	1 hr. 15 min.	0.373	110	25	NA	NA	Good loading. Sizing data provided.	3.40E+06
16-Jun	6/1/2016	Cockpit	20 min.	0.1	110	25	NA	NA	Lighter loading than LM. S-rich volatiles also observed.	1.60E+06
Second Sampling Campaign	11/9/2016	Background (re-assigned from original Loadmaster location)	18 min.	0.089	105	25	7	46	Sparse loading, almost blank; a few soot particles documented	NA
	11/9/2016	Cabin AFT	48 min.	0.238	105	25	8	68	Lightly loaded. Collected during second campaign.	8.60E+05
	11/9/2016	Loadmaster (re-assigned from Cabin Forward)	1 hr. 15 min.	0.373	105	25	8	66	No Grid in Cartridge	NA
	11/9/2016	Cockpit	1 hr. 15 min.	0.373	105	31	11	45	Problem with sample; Grid not analyzed	NA
<i>Courtesy of RJ Lee Group</i>										

The TPS100® samplers analyzed were the Cockpit and Loadmaster samplers from June 1, 2016 and the Background and Cabin Aft samplers from November 9, 2016. The

Loadmaster and Cockpit TPS samplers from the November 9, 2016 sampling were lost due to grid issues discovered during analysis at the laboratory.

The Loadmaster location (June 1, 2016) had the highest loading of soot particles as qualitatively seen in the PC filter and TPS concentration of $3.40\text{E}+06$ particles/cc (66). Particle loading in the Loadmaster TPS sample is displayed in Figure 18, “Loadmaster TPS100® Particle Loading”.

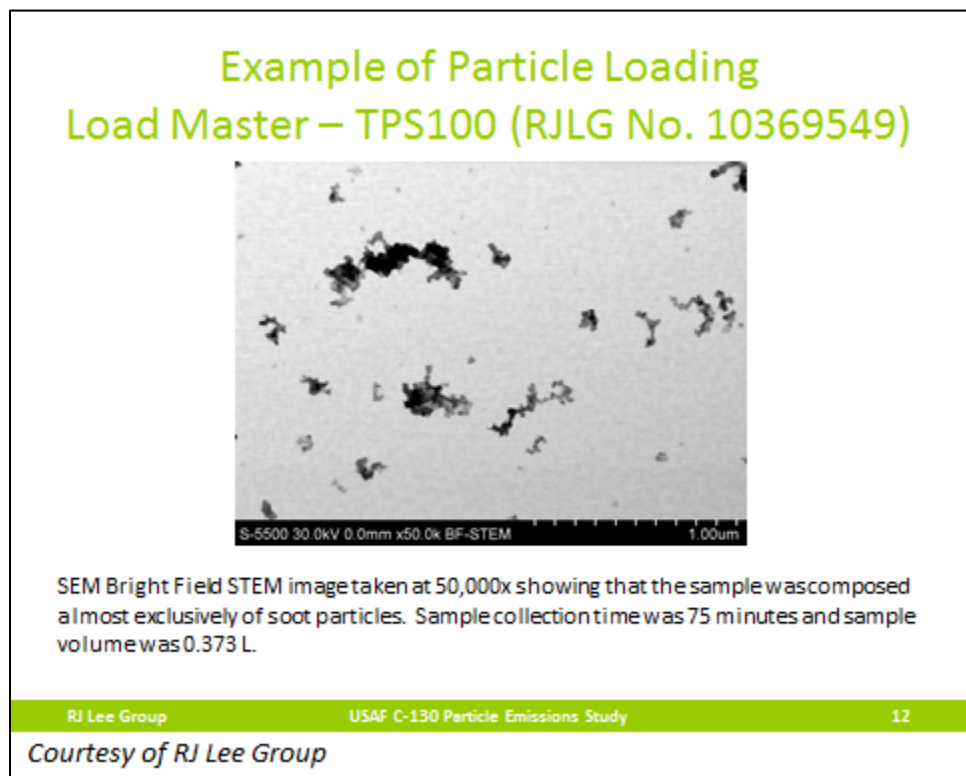


Figure 18: Loadmaster TPS100® Particle Loading

Enlarged view and elemental analysis of a soot particle from the Loadmaster TPS sample reveals primarily carbon content with small amount of oxygen and silicon. See Figure 19, “Elemental Composition of Soot Particle – Loadmaster TPS100®”.

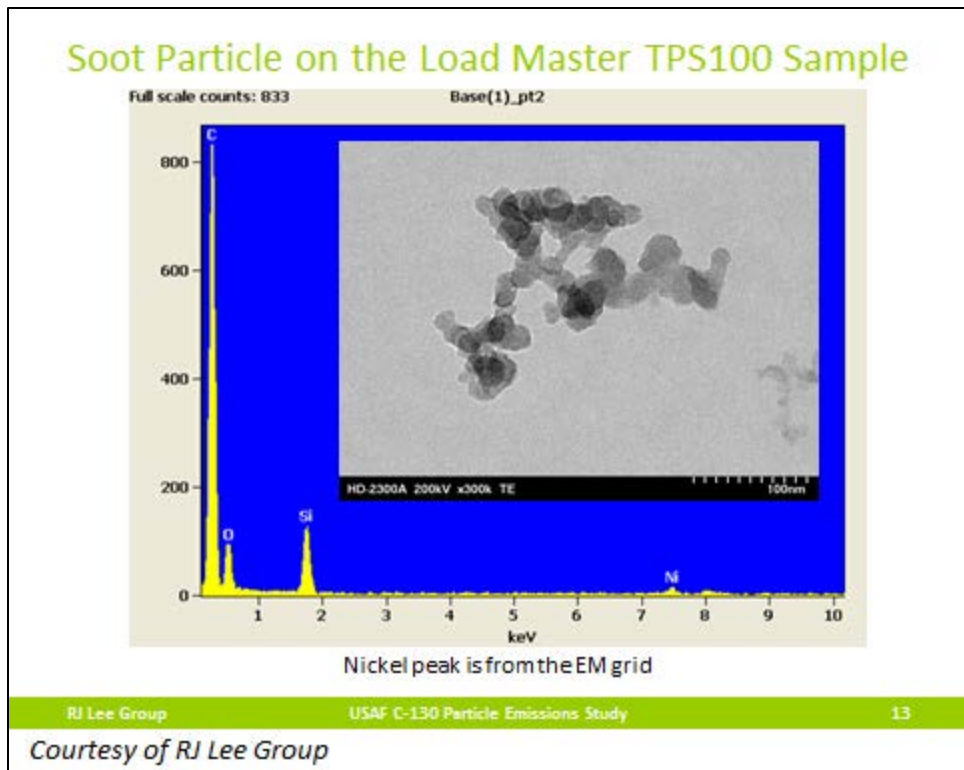


Figure 19: Elemental Composition of Soot Particle – Loadmaster TPS100®

Particle diameter, concentration, and size distribution results for the Loadmaster TPS are summarized in Figure 20, “Loadmaster TPS100® ImageJ Results”.

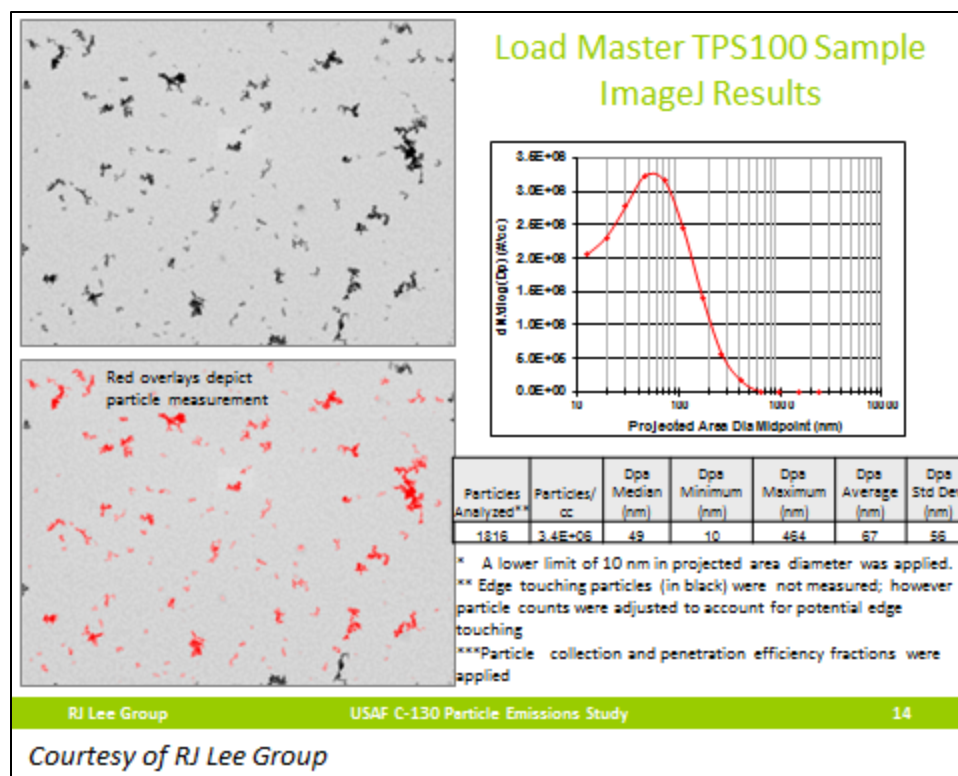
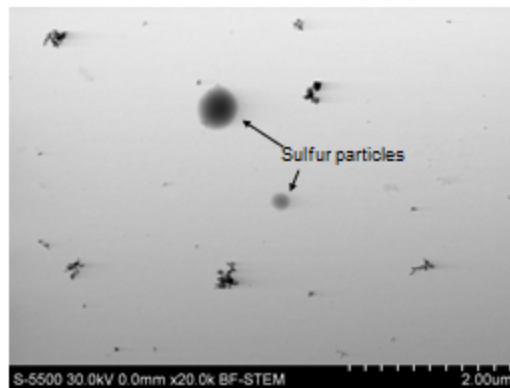


Figure 20: Loadmaster TPS100® ImageJ Results

The particle size range was 10 – 464 nm, with median of 49 nm, and average size of 67 nm. Particle size standard deviation corresponds to the wide size distribution. However, the largest concentrations were of particle sizes less than 100 nm.

Lower concentrations of soot and low numbers of sulfur-containing particles assumed to be secondary organic aerosols (SOA) were observed in the cockpit TPS sample (June 1, 2016). Less volume was recorded in the Cockpit sampler (0.1 L) compared to that of the Loadmaster (0.373 L) on June 1, 2016 due to operator error. Particle loading in the Cockpit TPS sample are shown in Figure 21, “Cockpit TPS100® Particle Loading”.

Example of Particle Loading Cockpit – TPS100 (RJLG No. 10369548)



Bright Field STEM image taken at 20,000x showing that the sample was composed almost exclusively of soot particles. Sulfur containing particles were also present on the sample. Sample collection time was 20 minutes and sample volume was 0.10 L.

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Figure 21: Cockpit TPS100® Particle Loading

Enlarged view and elemental analysis of a soot particle from the Cockpit TPS sample resembles that of the Loadmaster TPS soot particle, as shown in Figure 22, “Elemental Composition of Soot Particle – Cockpit TPS100®”.

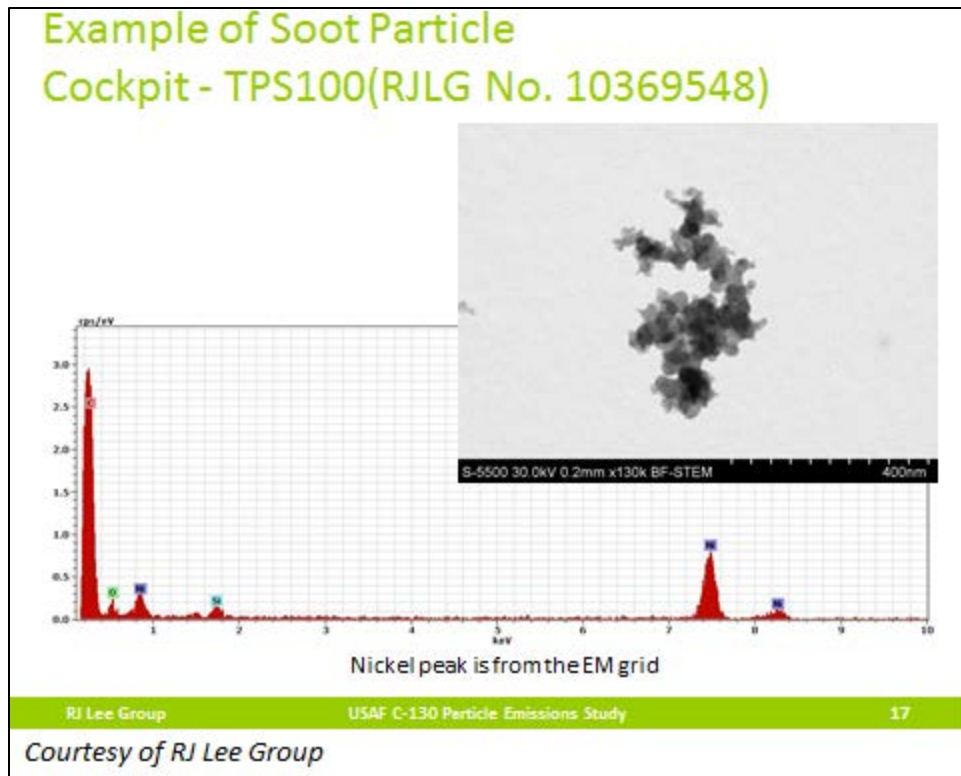


Figure 22: Elemental Composition of Soot Particle – Cockpit TPS100®

Enlarged view and elemental analysis of a sulfur containing soot particle from the Cockpit TPS sample is shown in Figure 23, “Elemental Composition of Sulfur-rich Particle – Cockpit TPS100®”.

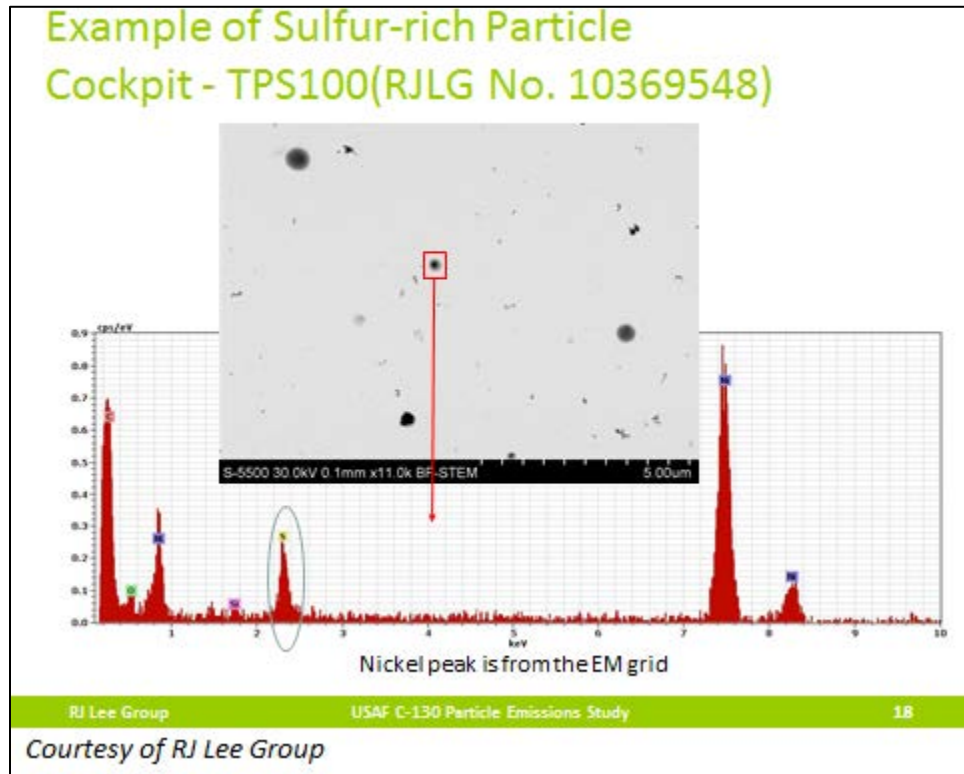


Figure 23: Elemental Composition of Sulfur-rich Particle – Cockpit TPS100®

Particle diameter, concentration, and size distribution results for the Cockpit TPS sample are summarized in Figure 24, “Cockpit TPS100® ImageJ Results”.

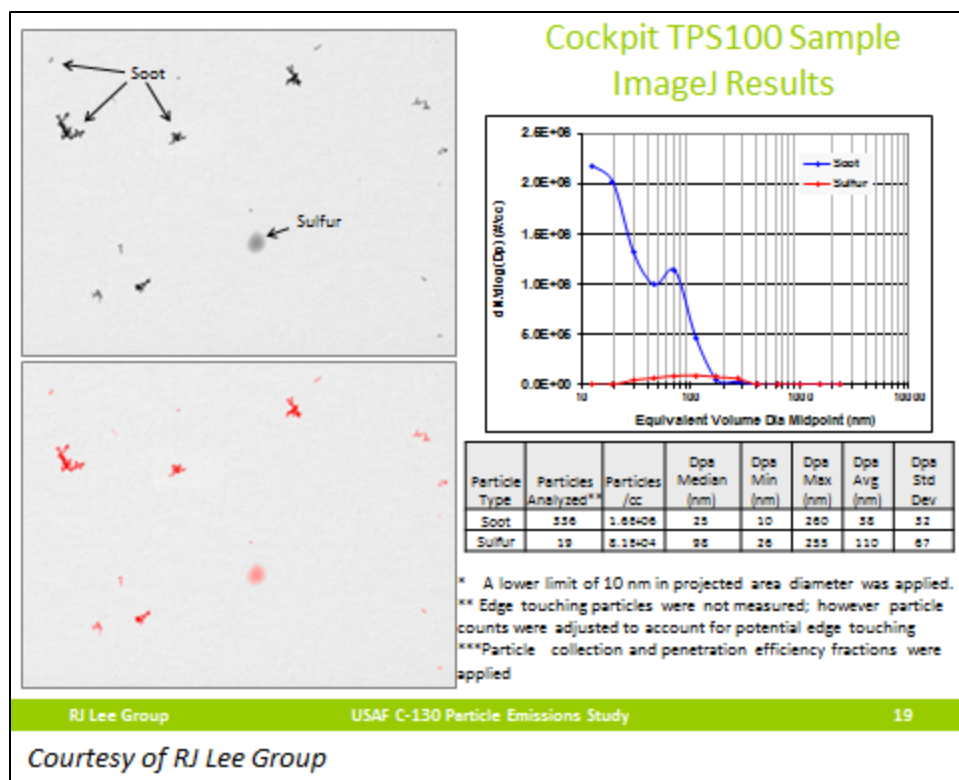


Figure 24: Cockpit TPS100® ImageJ Results

Particle concentrations in the Cockpit TPS sample were $1.6\text{E}+06$ particles/cc of soot and $8.1\text{E}+04$ of sulfur containing particles assumed to be secondary organic aerosols (SOA) (66). The soot particle size range was 10 – 260 nm, with median of 25 nm, and average size of 38 nm. As with the Loadmaster location TPS results, the soot particle size standard deviation of 32 nm corresponds to the wide size distribution, and the largest concentrations were of particle sizes less than 100 nm. The sulfur containing particle size range was comparable to the soot at 26 – 255 nm. However, the median and average sizes are larger than the soot particle at 98 nm (median) and 110 nm (average).

The Cabin Aft TPS sample from November 9, 2016 was lightly loaded with soot particles. Particle loading in the Loadmaster TPS sample is displayed in Figure 25, “Cabin Aft TPS100® Particle Loading”.

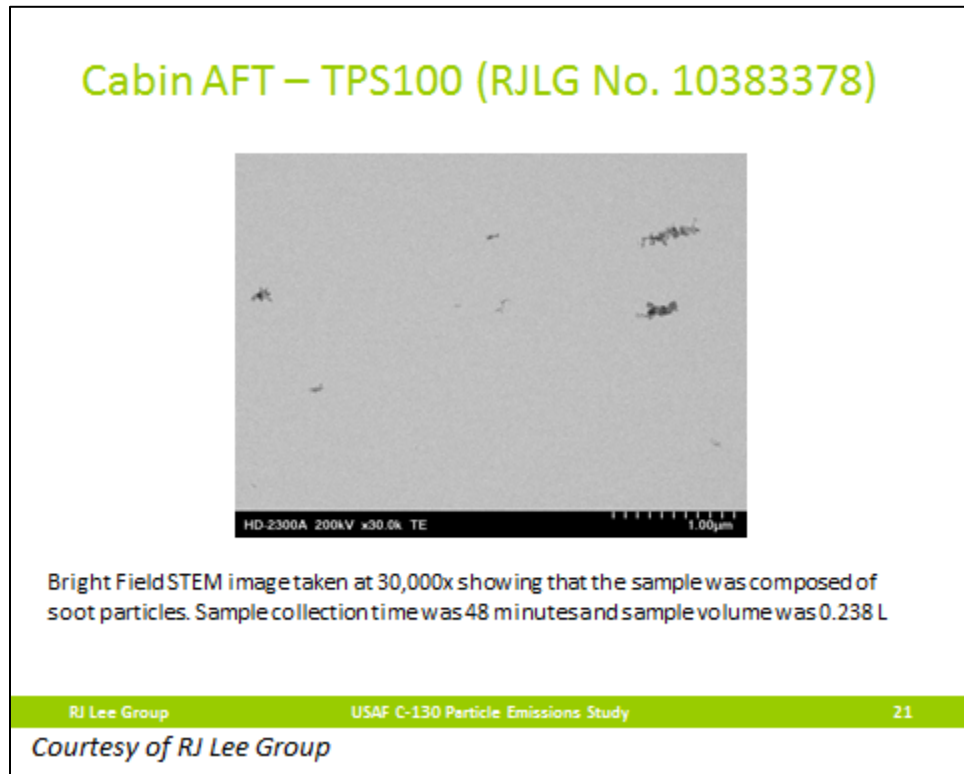


Figure 25: Cabin Aft TPS100® Particle Loading

Enlarged view and elemental analysis of a soot particle from the Cabin Aft TPS sample is shown in Figure 26, “Elemental Composition of Soot Particle – Cabin Aft TPS100®”.

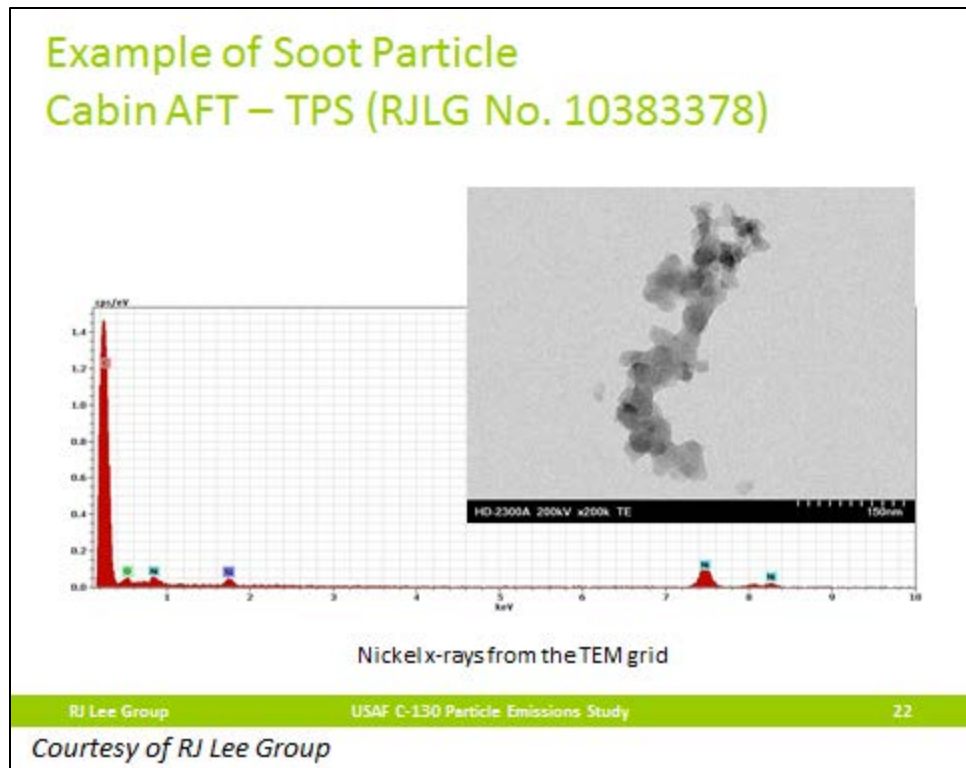


Figure 26: Elemental Composition of Soot Particle – Cabin Aft TPS100®

Particle diameter, concentration, and size distribution results for the Cabin Aft TPS sample are summarized in Figure 27, “Cabin Aft TPS100® ImageJ Results”.

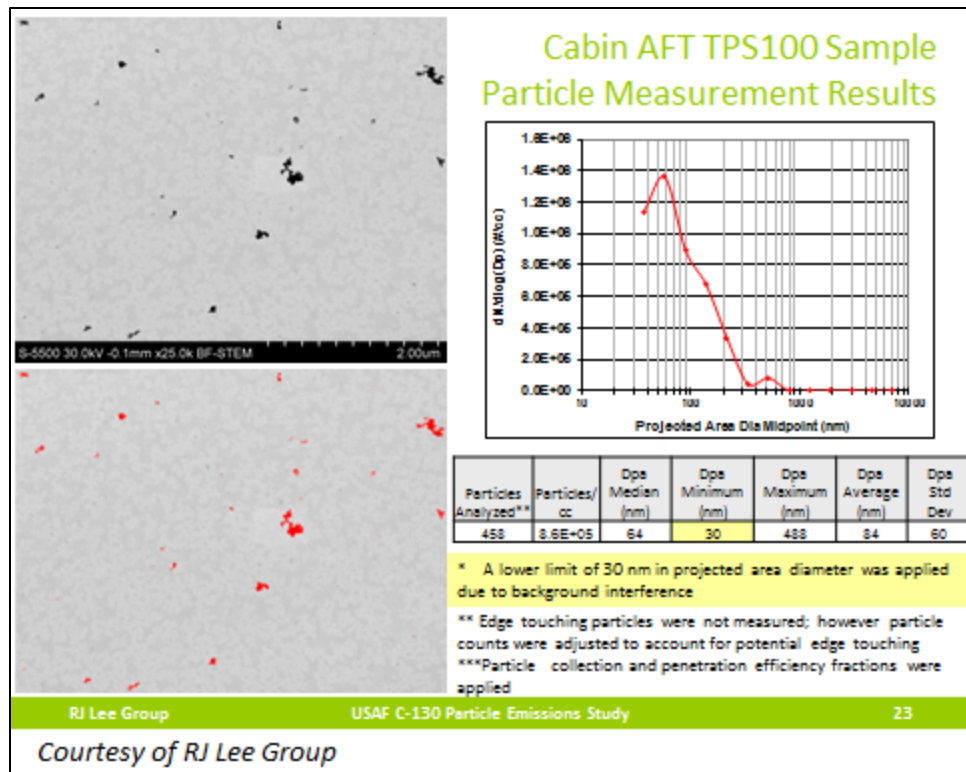


Figure 27: Cabin Aft TPS100® ImageJ Results

Particle concentrations in the Cabin Aft TPS sample were 8.6E+05 particles/cc of soot. The particle sizing was close to that of the Loadmaster location, with a range of 30 – 488 nm (exception is the range low end of 30 nm due to background interference), median of 64 nm, and average size of 84 nm. As with the Loadmaster and Cockpit TPS samples, the highest concentrations were of particle sizes less than 100 nm.

As compared to the TPS sample, results from the PC filters provide qualitative confirmation of soot dominance in the particulate matter. However, these samples were heavily loaded due to the much higher flow rate (4 L/min) than the TPS. Therefore particle separation and count could not be determined. In future investigations, sampling

PC filters with a much lower flow rate would be more suited in high particle environments such as JFCE.

Figures 28, “Loadmaster, TPS100[®] SEM Comparison, 3 μ m Resolution” and Figure 29, “Loadmaster, TPS100[®] SEM Comparison, 1 μ m Resolution” show side by side comparisons of the Loadmaster TPS and PC filter samples.

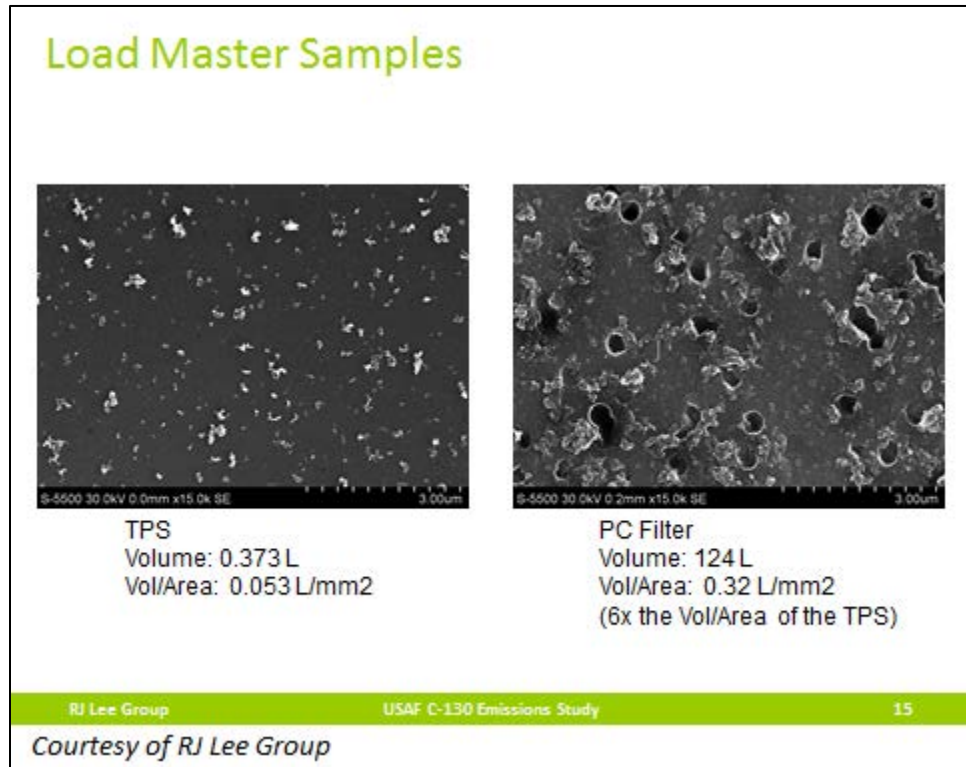
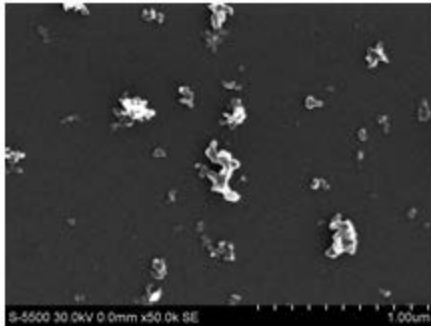
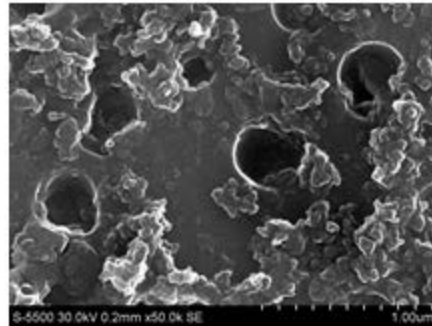


Figure 28: Loadmaster, TPS100[®] SEM Comparison, 3 μ m Resolution

Load Master Samples



TPS
Volume: 0.373 L
Vol/Area: 0.053 L/mm²



PC Filter
Volume: 124 L
Vol/Area: 0.32 L/mm²
(6x the Vol/Area of the TPS)

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Figure 29: Loadmaster, TPS100[®] SEM Comparison, 1 μ m Resolution

PC filter particle loading showed a visible trend of highest to lowest from the Loadmaster-to-Cabin Aft-to-Cabin Fore-to-Cockpit as visible in Figure 30, “PC Filters Particle Loading Trend”.

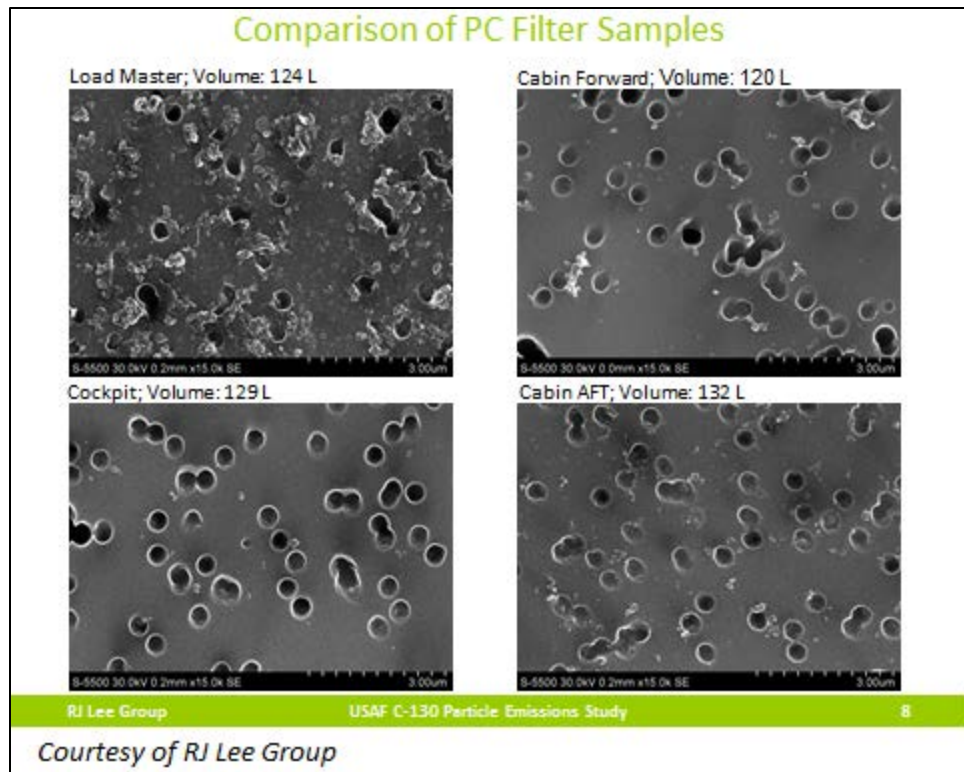


Figure 30: PC Filters Particle Loading Trend

The Cockpit PC filter was less loaded than that of the TPS as shown in Figure 31, “Cockpit PC Filter SEM Images”.

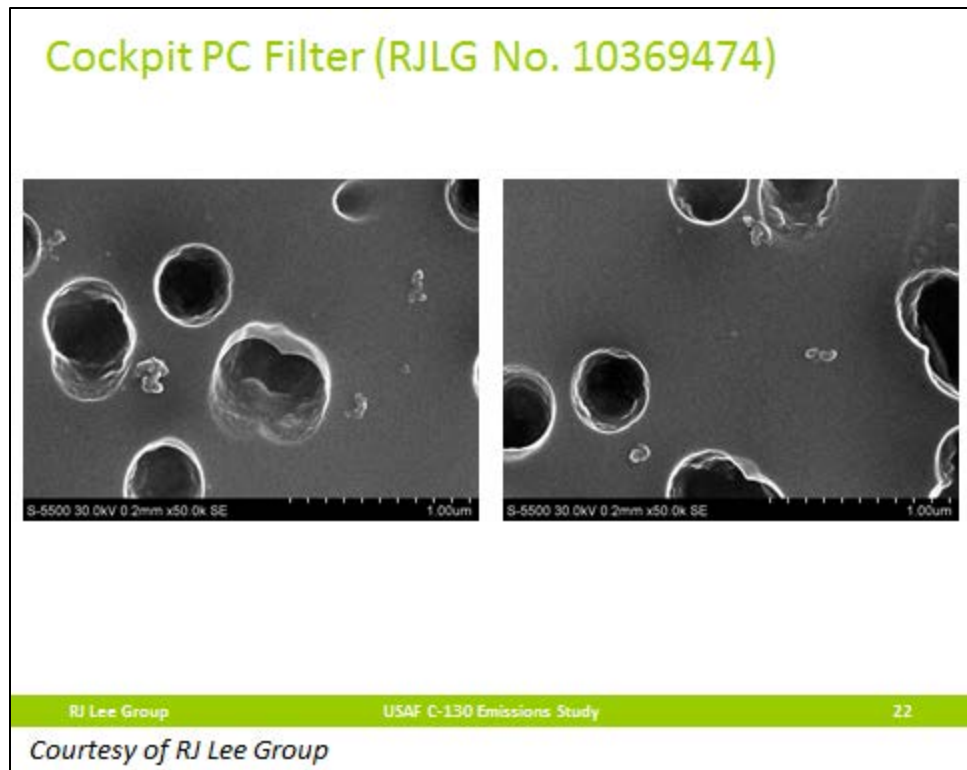
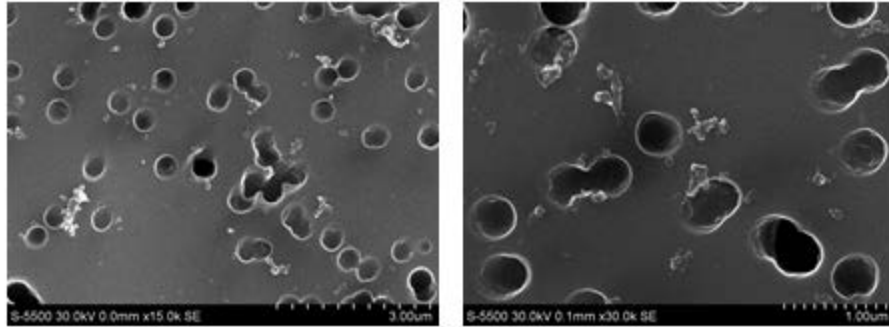


Figure 31: Cockpit PC Filter SEM Images

Irregular shapes and cluster morphology are also observed in the PC filters. Cabin PC Filter SEM Images are shown in Figures 32 – 34.

Cabin Forward PC Filter (RJLG No. 10369475)



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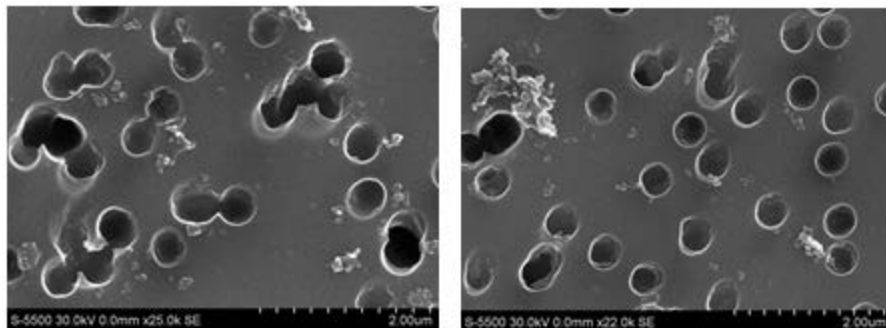
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Figure 32: Cabin Forward PC Filter SEM Image, (1 μ m, 3 μ m Resolution)

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Figure 33: Cabin Forward PC Filter SEM Image, (2 μ m Resolution)

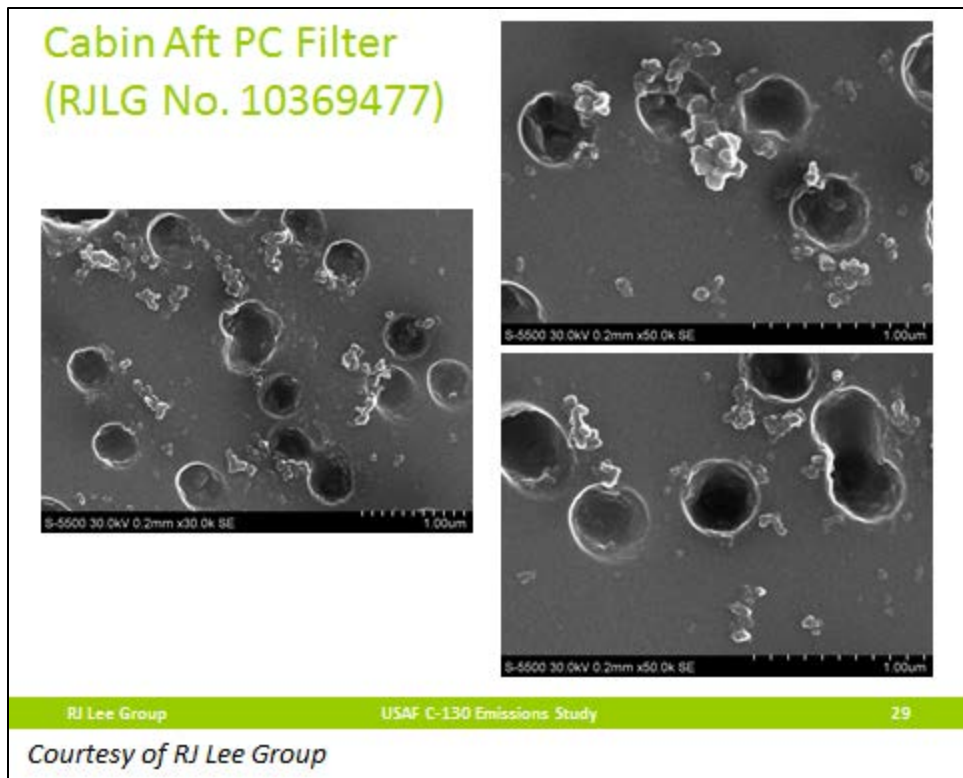


Figure 34: Cabin Aft PC Filter SEM Image, (1 μm Resolution)

As with the TPS samples elemental composition of the PC filters were predominantly carbon with small amounts of oxygen in all samples. The Cabin samples had trace amounts of sulfur, aluminum, and sodium. Aside from the carbon content, the elemental analysis may not absolutely represent all particles because larger clusters from the heavier loading may mask internal particle composition. Elemental analyses results from the PC filters are shown in Figures 35 – 40.

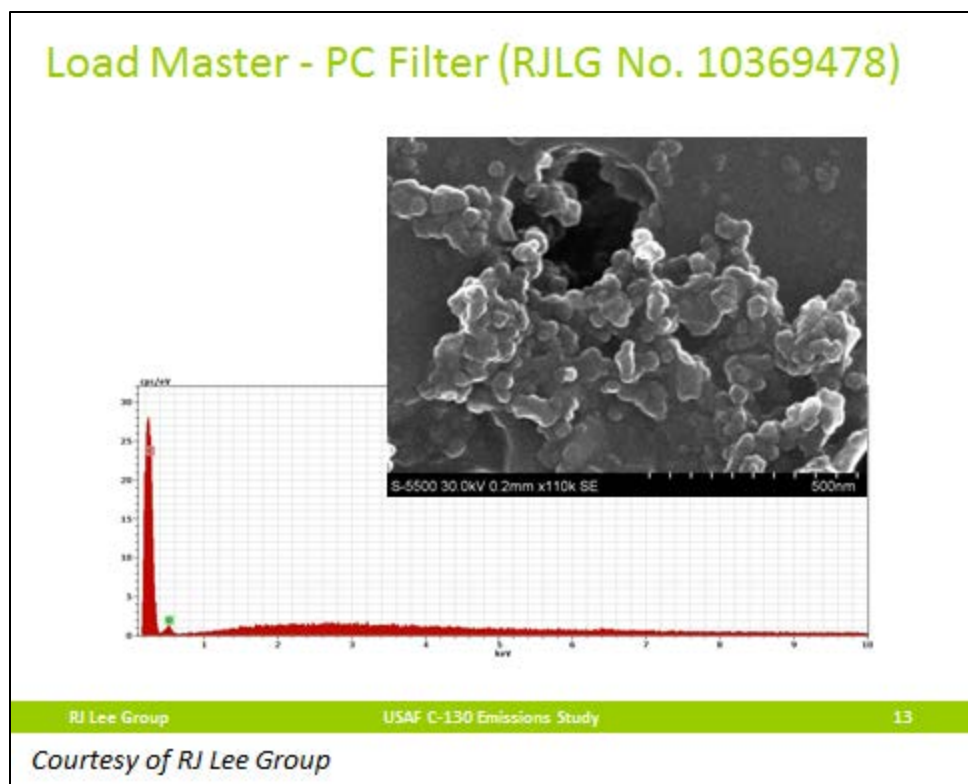


Figure 35: Elemental Composition of Soot Particle – Loadmaster PC Filter (500 nm)

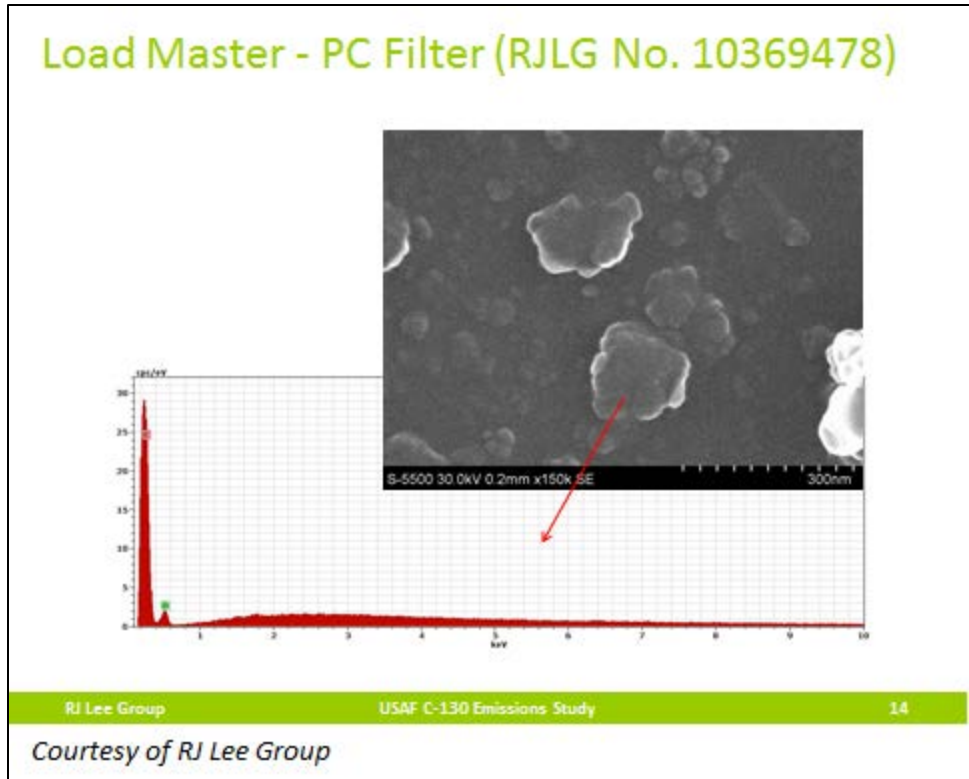


Figure 36: Elemental Composition of Soot Particle – Loadmaster PC Filter (300 nm)

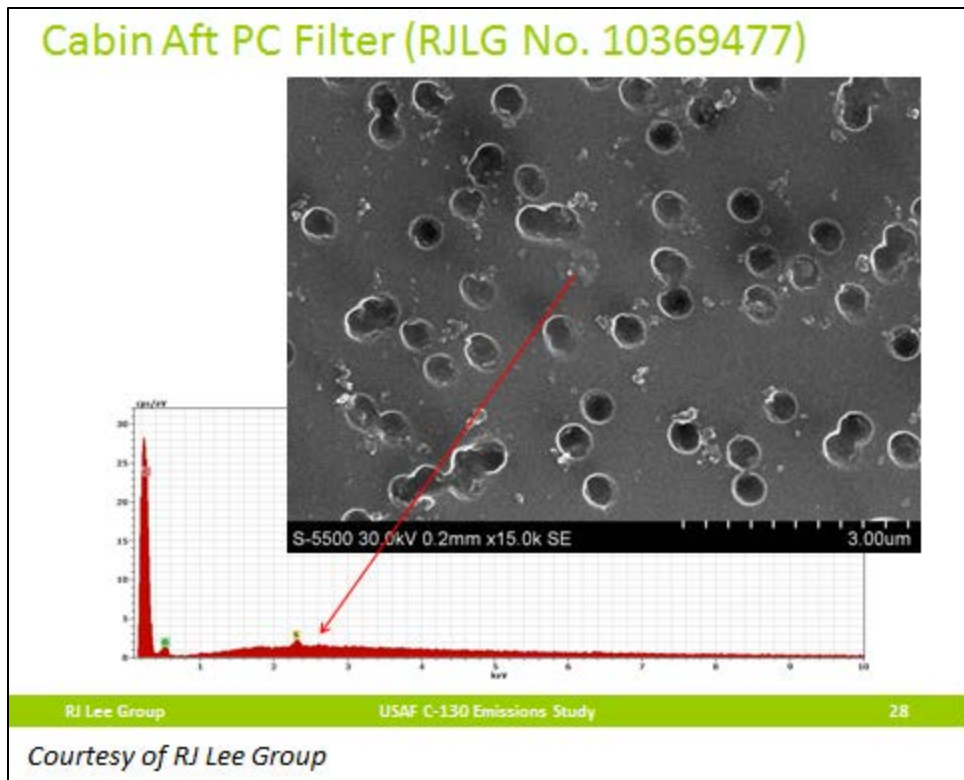
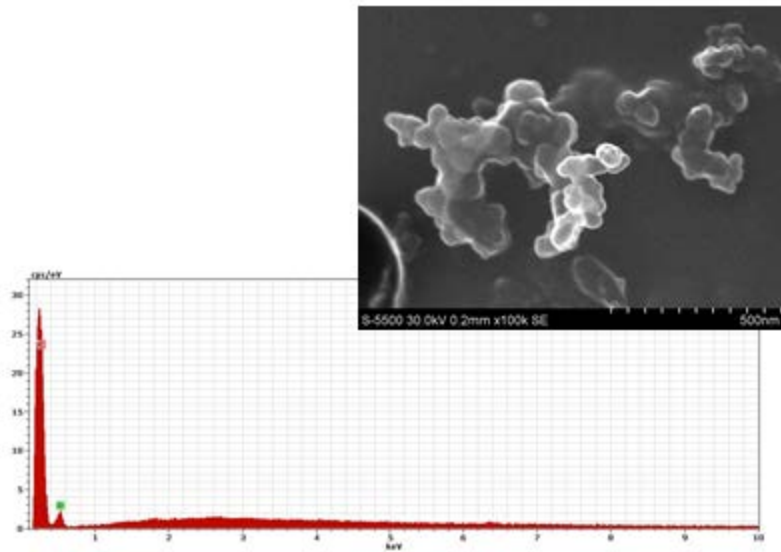


Figure 37: Elemental Composition of Soot Particle – Cabin Aft PC Filter (3 μm)

Cabin Aft PC Filter (RJLG No. 10369477)



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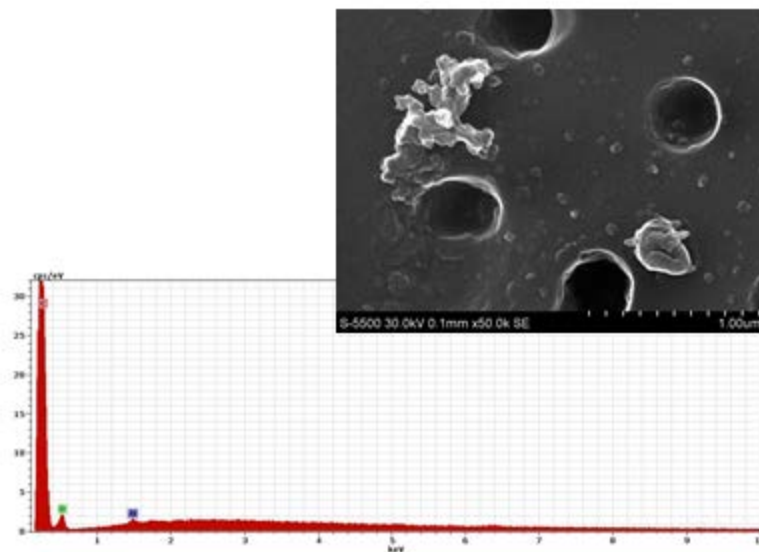
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Figure 38: Elemental Composition of Soot Particle – Cabin Aft PC Filter (500 nm)

Cabin Forward PC Filter (RJLG No. 10369475)



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Figure 39: Elemental Composition of Soot Particle – Cabin Forward PC Filter (1 μm)

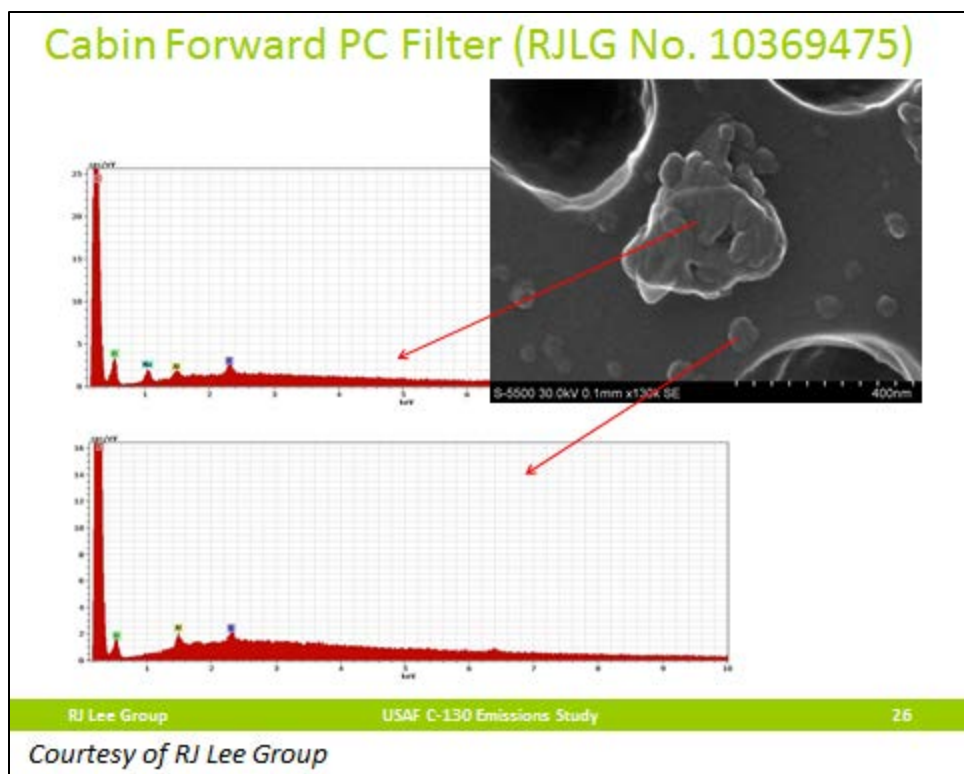


Figure 40: Elemental Composition of Soot Particle – Cabin Forward PC Filter (400 nm)

NIOSH 0600, Particulates Not Otherwise Regulated, Respirable

Results from the N0600 testing were below the reporting limit at all locations. However, gravimetric measurement by N0600 in this exposure environment is challenging since nanoparticles have negligible mass and are susceptible to electrical static forces. Another consideration is that this method is only suitable for non-volatile particulate matter (68). The particles at engine start-up and idle contain more OC than EC. OC cannot be assessed with N0600 method. The limitations of N0600 method most likely accounts for the disparity with the N0600 and CPC and TPS results. This method is therefore not suitable for JFCE application.

NIOSH 7300, Elements by ICP (Nitric/Perchloric Acid Ashing)

All sample results from the NIOSH 7300 testing were below minimum reporting limits. Consistent with findings from prior studies, some trace metals were detected with elemental analysis in the electron microscopy.

NIOSH 7908, Non-Volatile Acids (Sulfuric Acid)

Sulfuric acid results from the NIOSH 7908 testing were below minimum reporting limits. However, sulfuric acid forms from oxidation of sulfur dioxide by water vapor, increasingly more so in humid environments (25). This test is more suited for JFCE testing in humid locations.

Sulfur-containing soot was detected as SOA in the electron microscopy results. Sulfur dioxide was not tested in this effort, but its inclusion in future investigations should be considered.

Compendium Method TO-11A, Determination of Formaldehyde in Ambient Air by High Performance Liquid Chromatography (HPLC)

Formaldehyde was detected above the reporting limit but less than regulatory exposure limits in all sample locations. The Background and blanks results were less than the reporting limit. These results also showed a trend of increasing concentrations from Cockpit to Cabin to Loadmaster locations, indicative of migration into the aircraft. The highest result at the Loadmaster location was above a voluntary exposure limit, NIOSH REL 15-minute ceiling of 0.1 ppm. Formaldehyde is also an occupational carcinogen, and should be closely investigated in follow-on work.

Compendium Method TO-17, Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes

The results were corrected for the instrument calibration volume of 500 mL as in Equation 2, TO-17 Volume Correction Calculation” then Equation 3, “Result Correction Calculation”.

$$V_{\text{corr}} = \frac{V_{\text{samp}}}{V_{\text{cal}}}$$

Equation 2

Where:

V_{corr} = Volume corrected for the instrument calibration volume

V_{samp} = Sampled volume

V_{cal} = Instrument calibration volume = 500 mL

$$\text{ppbv}_{\text{corr}} = \frac{\text{ppbv}_{\text{raw}}}{V_{\text{corr}}}$$

Equation 3

Where:

$\text{ppbv}_{\text{corr}}$ = TO-17 instrument results corrected for calibration volume

ppbv_{raw} = TO-17 raw instrument results

Acetone and methylene chloride were detected in the blanks and samples, including the Background sample. Methylene chloride results are suspected as laboratory contamination since all results are consistent. Acetone results however are higher in the samples than the blanks and Background sample, especially the Cockpit. The

Background acetone result is much less than the samples, but higher than the blanks. This suggests possibility of laboratory carryover as well as contribution from aircraft emissions. The source of Background acetone may be contribution from the plane that taxied and took off as the researchers were setting up equipment.

Small amounts of n-hexane were detected in the blanks but not the samples, which are also suspected as laboratory carryover. Large amounts of isopropyl alcohol (IPA) were detected in all samples and background sample but not the blanks. This was realized to have occurred from IPA vapors from the CPCs, and therefore cannot be assessed in this study.

In the Cockpit, 1,1-dichloroethene (also known as vinylidene chloride) was detected, and had the highest concentration second to acetone (excluding IPA and methylene chloride as they were detected due to carryover). Although detected in the ppbv level, this compound is listed as a carcinogen by the American Conference of Governmental Industrial Hygienists.

In general the number of compounds detected and concentrations show an increasing trend from Cabin to Loadmaster locations, indicative of propeller wash emissions migrating into the cabin. Many of the compounds detected are HAPs, listed on the ATSDR, and most are irritants. Benzene, 1,4-dioxane, and formaldehyde are potential carcinogens (51). The results from the TO-11 and TO-17 sampling are displayed in Table 4, "VOC Results Summary (ppbv)".

Table 5: VOC Results Summary (ppbv)

TO-17 Results (ppbv)	Field Blank	Trip Blank	Background	Cockpit	Cabin Forward	Cabin Aft	Loadmaster
Acetone	7.96	9.04	7.63	144.97	10.84	13.08	10.31
1,1-Dichloroethene				18.93			
MEK				1.84	1.08	1.74	3.70
Benzene				1.00	2.69	4.22	9.96
Toluene				0.39	0.90	1.51	3.88
Cyclohexane					0.62	1.04	2.24
4-Ethyltoluene					0.82	1.19	3.43
Styrene						0.52	1.44
Naphthalene						0.51	1.58
1,4-Dioxane							0.61
2-Hexanone							0.64
m,p-Xylene							1.20
o-Xylene							0.66
1,3,5-Trimethylbenzene							0.48
Formaldehyde (TO-11)				9.00	40.00	73.00	210.00
Results were corrected for instrument calibration volume of 0.550 L							
Compounds are not listed in elution order.							

Table 5, “VOC Health Effects” shows the health hazards associated with the compounds detected by TO-11 and TO-17 analyses. The TO-17 results were in the ppb range and all below the respective OELs (52). However, formaldehyde result at the Loadmaster location as previously stated was above the NIOSH REL 15-minute STEL of 0.1 ppm.

Table 6: VOC Health Effects

Compound	Health Effects	Compound	Health Effects
Benzene (HAP)(ATSDR)	Irritation eyes, skin, nose, respiratory system; dizziness; headache, nausea, staggered gait; anorexia, lassitude (weakness, exhaustion); dermatitis; bone marrow depression; [potential occupational carcinogen]	Acetone	Irritation eyes, nose, throat; headache, dizziness, central nervous system depression; dermatitis
1,4-Dioxane (HAP)(ATSDR)	Irritation eyes, skin, nose, throat; drowsiness, headache; nausea, vomiting; liver damage; kidney failure; [potential occupational carcinogen]	Cyclohexane	Irritation eyes, skin, respiratory system drowsiness; dermatitis; narcosis, coma
Toluene (HAP)(ATSDR)	Irritation eyes, nose; lassitude (weakness, exhaustion), confusion, euphoria, dizziness, headache; dilated pupils, lacrimation (discharge of tears); anxiety, muscle fatigue, insomnia; paresthesia; dermatitis; liver, kidney damage	1,1-Dichloroethene (ATSDR)	Damage to central nervous system, liver, kidney, and lungs
Styrene (HAP)	Nervous system effects	4-Ethyltoluene	No exposure data found
Naphthalene (HAP)(ATSDR)	Irritation eyes; headache, confusion, excitement, malaise (vague feeling of discomfort); nausea, vomiting, abdominal pain; irritation bladder; profuse sweating; jaundice; hematuria (blood in the urine), renal shutdown; dermatitis, optical neuritis, corneal damage	2-Hexanone	Irritation eyes, nose; peripheral neuropathy: lassitude (weakness, exhaustion), paresthesia; dermatitis; headache, drowsiness
m,o, p-Xylene (HAP)(ATSDR)	Irritation eyes, skin, nose, throat; dizziness, excitement, drowsiness, incoordination, staggering gait; corneal vacuolization; anorexia, nausea, vomiting, abdominal pain; dermatitis	MEK (2-Butanone) (ATSDR)	Irritation of the nose, throat, skin, and eyes
Formaldehyde (HAP)(ATSDR)	Irritation eyes, nose, throat, respiratory system; lacrimation (discharge of tears); cough; wheezing; [potential occupational carcinogen]	1,3,5-Trimethylbenzene	Irritation eyes, skin, nose, throat, respiratory system; bronchitis; hypochromic anemia; headache, drowsiness, lassitude (weakness, exhaustion), dizziness, nausea, incoordination; vomiting, confusion; chemical pneumonitis (aspiration liquid)
HAP = Hazardous Air Pollutant			
ATSDR = Agency for Toxic Substances and Disease Registry			

The Loadmaster sample also contained unburned jet fuel visible as a distinct hydrocarbon pattern in the chromatography, which is consistent with literature findings of unburned jet fuel in engine start-up and ground idle emissions in cold weather. A comparison sample was prepared and analyzed to for qualitative confirmation. Thermal desorption tubes were prepared with a pure bulk sample of JP-8 jet fuel and analyzed to compare the jet fuel observed in the Loadmaster and Cabin chromatograms with a known sample. A small amount of the JP-8 bulk sample was spiked into a Tedlar bag filled with ultra-high purity nitrogen and allowed to stabilize for a five minutes. Then thermal desorption (TD) tubes were sampled from the bag using a gastight syringe and then

injecting the JP-8 enriched gas into the TD tubes. Nitrogen carrier gas was plumbed through the TD tubes to establish a carrier gas while the tubes were spiked. Qualitative comparison of the aircraft cabin and Loadmaster samples with the jet fuel test sample GC-MS chromatography is shown in Figure 41, “Unburned Jet Fuel in Cabin, Loadmaster Locations”.

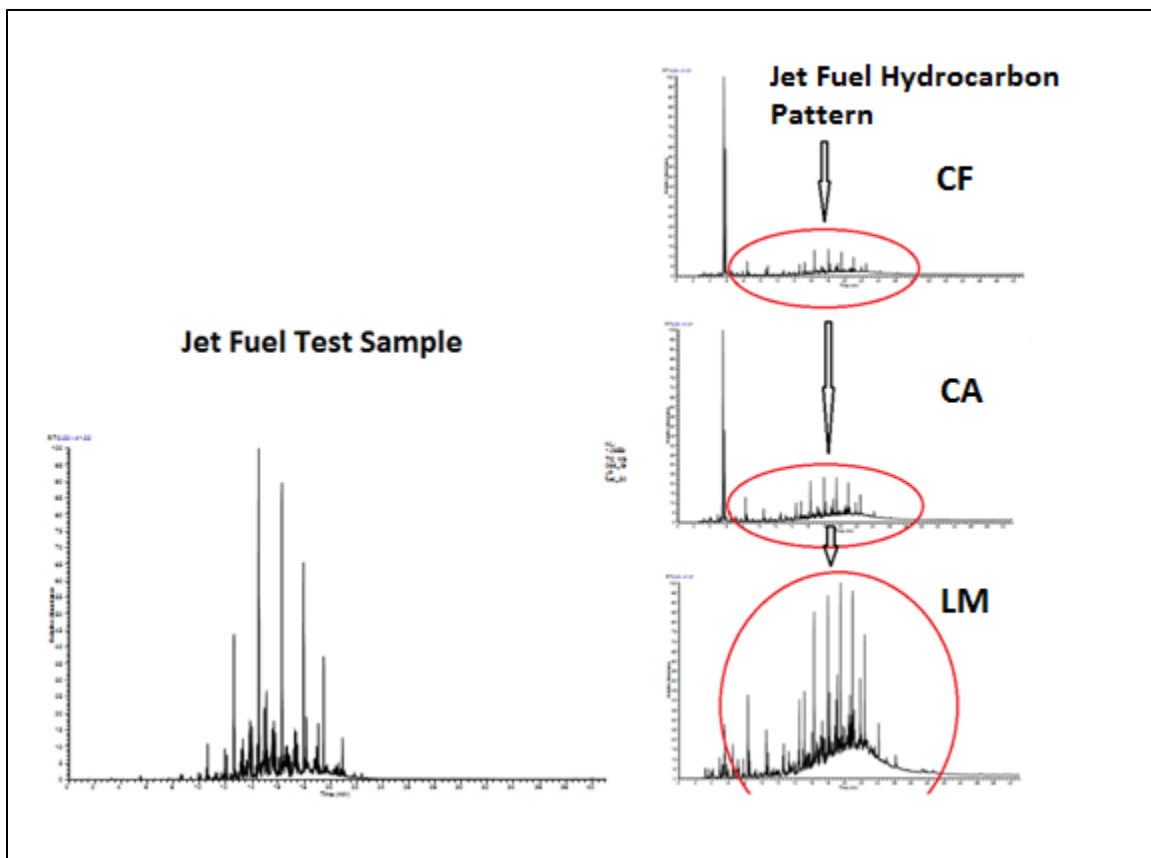


Figure 41: Unburned Jet Fuel in Cabin, Loadmaster Locations

As compared to the compounds detected in the jet fuel test sample, some of the TO-17 compounds detected in the aircraft samples appear to be contributions from unburned fuel while others appear to have formed in the combustion and post-combustion environment as postulated from the literature. Compounds detected in both aircraft and

jet fuel test sample are indicative of unburned jet fuel in the emissions. Those compounds are cyclohexane, toluene, 4-ethyltoluene, naphthalene, ethylbenzene, o-xylene, and 1,3,5-trimethylbenzene, and alkane hydrocarbons nonane, decane, undecane, dodecane, and tetradecane. Compounds detected in only the aircraft samples and postulated as combustion by-products are acetone, 1,1-dichloroethene, methyl ethyl ketone, benzene, styrene, 1,4-dioxane, 2-hexanone, and benzaldehyde. The alkane hydrocarbons nonane, decane, undecane, dodecane, and tetradecane and benzaldehyde peaks were identified by GC-MS library search, and are tentatively qualitative detections because they were not part of the TO-17 calibration mix. Benzaldehyde may be a false positive as it can form from oxidation of the Tenax[®] polymer in ozone rich environments such as jet fuel combustion exhaust (49) (70). Table 6, “Qualitative Comparison of Aircraft and Jet Fuel Test Sample Results” summarizes the comparison.

Table 7: Qualitative Comparison of Aircraft and Jet Fuel Test Sample Results

Qualitative TO-17 Results	Field blank	Trip Blank	Background	Cockpit	Cabin Forward	Cabin Aft	Loadmaster	Jet Fuel Test sample
Compound	X = Detected above RL (2.000 ppbv)							
Acetone	X	X	X	X	X	X	X	
1,1-Dichloroethene				X				
MEK				X	X	X	X	
Benzene				X	X	X	X	
Toluene				X	X	X	X	X
Cyclohexane					X	X	X	X
4-Ethyltoluene					X	X	X	X
Styrene						X	X	
Naphthalene						X	X	X
1,4-Dioxane							X	
2-Hexanone							X	
m,p-Xylene							X	X
Ethylbenzene							X	X
o-Xylene							X	X
1,3,5-Trimethylbenzene							X	X
Methyl Isobutyl Ketone								X
Bromodichloromethane								X
n-Heptane								X
1,2,4-Trimethylbenzene								X
Table lists compounds detected prior to correction for instrument calibration volume.								
GC-MS Library Search Detects	X = Detected							
Benzaldehyde							X	
Nonane								X
Decane					X	X	X	X
Undecane					X	X	X	X
Dodecane					X	X	X	X
Tetradecane					X	X	X	X

VOC by MultiRae® Pro Multi-gas Meter

VOC were detected in all locations. However IPA carryover from the CPCs occurred. The highest VOC were in the Cockpit, which is expected because of the 2 CPCs sampled there and the small area inside the Cockpit. At the Loadmaster location, VOC were not detected until engine start, were fairly continuous throughout the engine run, as with formaldehyde and CO, and dropped off at engine shut down. IPA carryover from the Loadmaster CPC does not appear to have occurred since VOC were not detected

during background sampling prior to engine start. The hot turbulent propeller wash likely dissipated the IPA vapors. The maximum VOC reading at the Loadmaster location was 0.2 ppm, which occurred at engine start. This maximum result is in agreement with the TO-11 formaldehyde result (0.21 ppm) at the Loadmaster location. VOC results at the Loadmaster location are displayed in Figure 42, “MultiRae® VOC Results – Loadmaster (November 9, 2016)”.

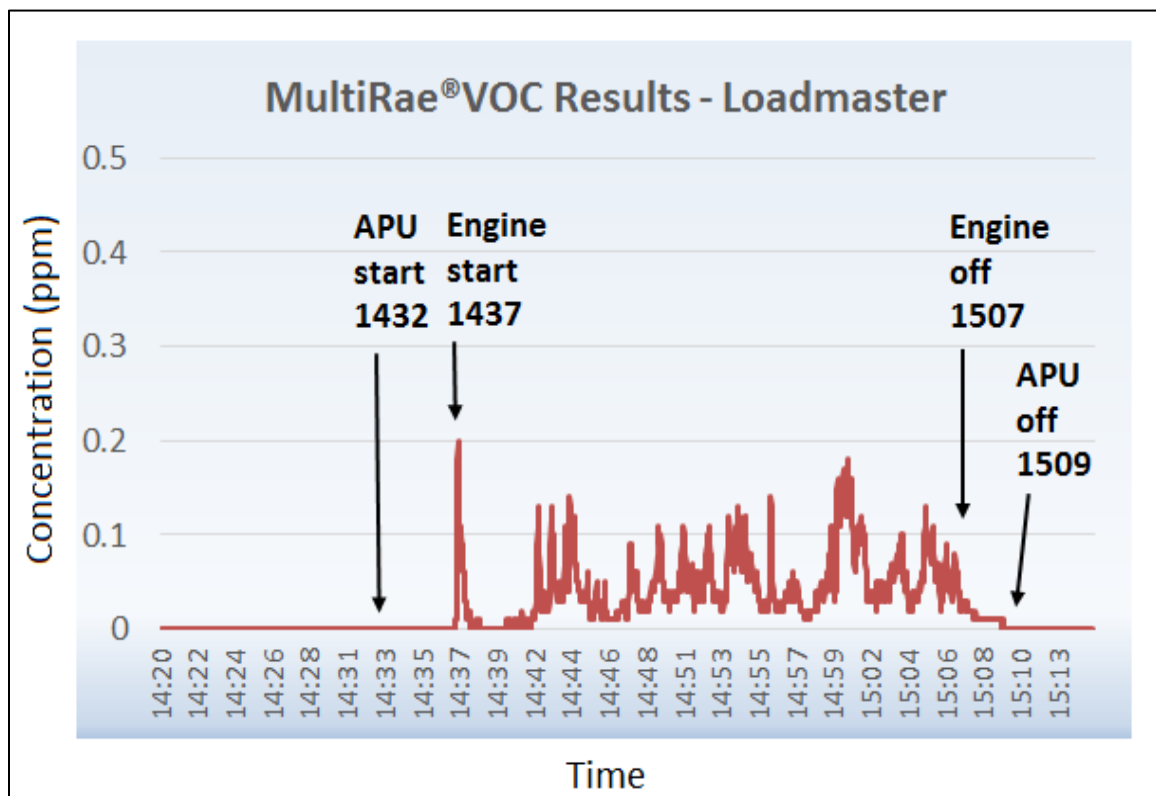


Figure 42: MultiRae® VOC Results – Loadmaster (November 9, 2016)

VOC results at all locations sampled are shown in Figure 42, “MultiRae® VOC Results Summary (November 9, 2016)”. A sensor issue may have occurred with the Cabin Aft VOC test. During the sampling, VOC readings did not appear on the display screen. However, as observed in Figure 43, “MultiRae® VOC Results Summary

(November 9, 2016)”, the Cabin Aft monitor recorded readings that appear irregular as compared to the other sampling locations, and are suspected as erroneous.

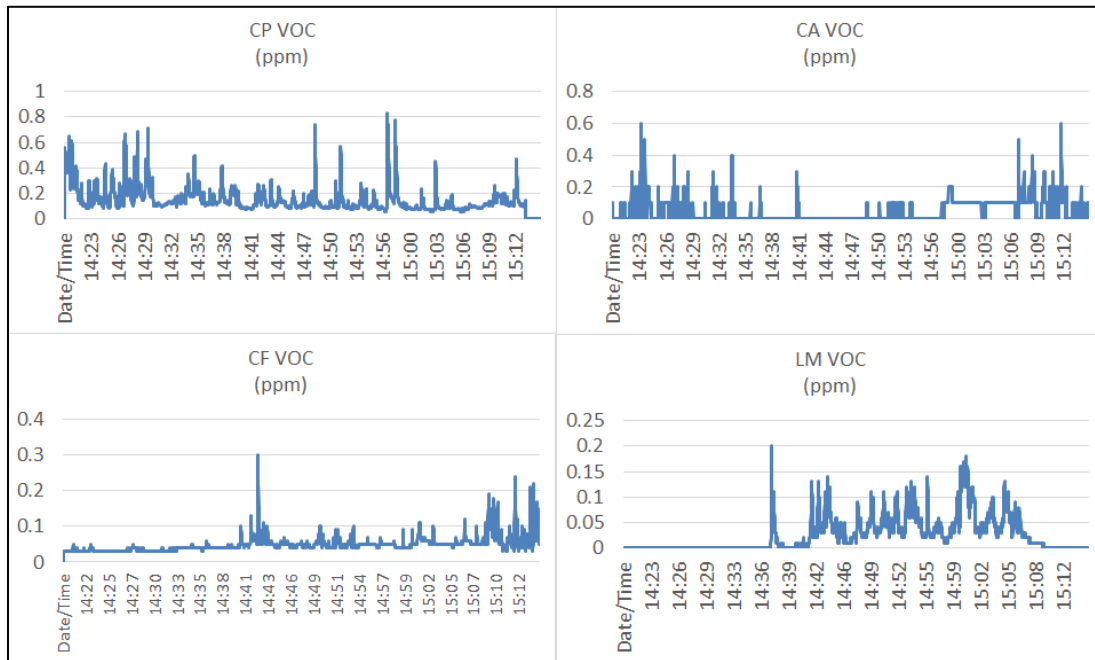


Figure 43: MultiRae® VOC Results Summary (November 9, 2016)

CO was detected in the ppm range at the Cabin and Loadmaster locations. Results show CO detection was fairly continuous throughout the engine run at the Loadmaster location despite the turbulent propeller wash, while readings were not observed in the Cabin until ~20 minutes into the run, indicating migration into the cabin. Loadmaster CO concentrations reached a maximum of 17 ppm, while maximum cabin readings were 7 ppm at Cabin Aft location and 6 ppm at Cabin Forward locations. CO was not detected in the Cockpit. The CO results are displayed in Figure 44, “MultiRae® CO Results (November 9, 2016)”.

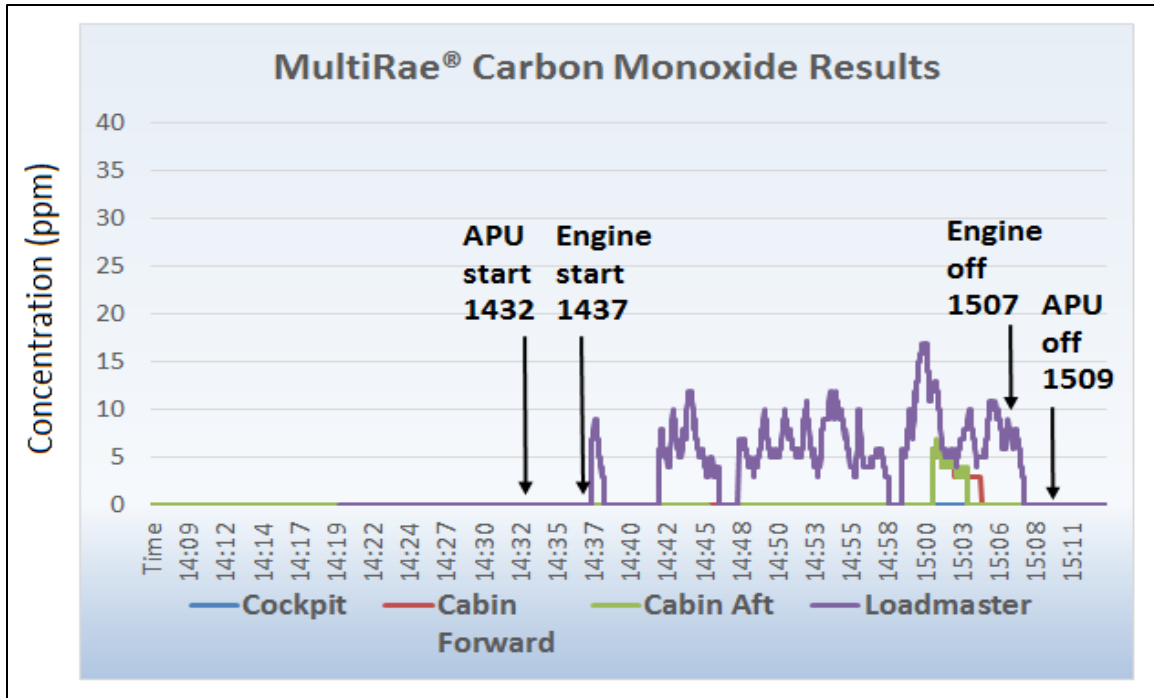


Figure 44: MultiRae® CO Results (November 9, 2016)

Formaldehyde was detected by MultiRae® (Cabin Aft location) at APU start, then throughout the engine run except for a 2 minute lapse due to the meter being turned off then on again. The results are shown in Figure 45, “MultiRae® Formaldehyde Results (November 9, 2016)”. Concentrations steadily increased up to a maximum of 2.86 ppm, then dropped off after engine shutdown.

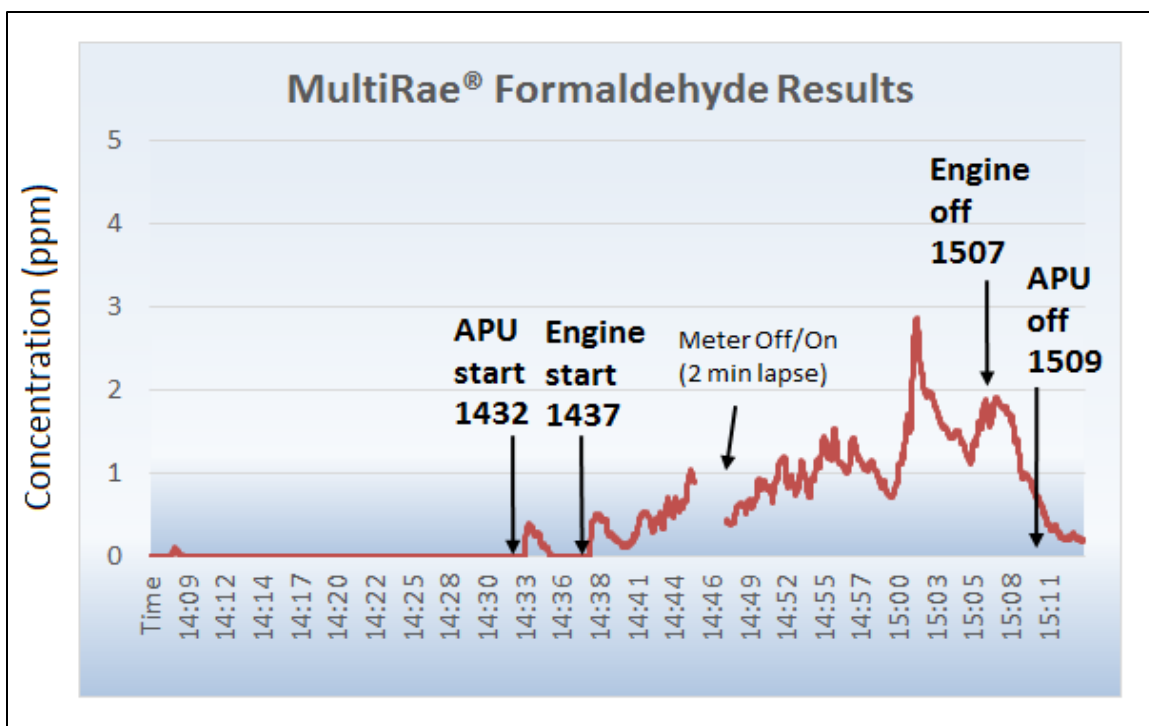


Figure 45: MultiRae® Formaldehyde Results (November 9, 2016)

The MultiRae® formaldehyde results are not in agreement with the TO-11 results, most likely due to cross-sensitivities. Cross-sensitivities are a limitation with MultiRae® in exhaust applications due to the complex mixture. Negative and positive cross sensitivities can occur that underestimate or overestimate the concentrations (78). Sulfur dioxide and nitrogen oxides cause slight positive cross sensitivity with the CO sensor, while CO cause significant positive cross-sensitivity with the formaldehyde sensor (78) (79). Cross-sensitivity most likely explains the disparity between the TO-11 and MultiRae® formaldehyde results. Installing chemical interference scrubbers onto direct reading monitors and using 2,4-DNPH treated silica gel media with potassium iodide ozone scrubbers (employed in this study) for active sampling will prevent cross-sensitivities (80).

Weather by TSI® Velocicalc Meter

Weather conditions on June 1, 2016 were mild with a temperature of 86° F, relative humidity of 36%, barometric pressure of 28.6 inHg, and calm winds. The temperature reached at the Loadmaster location during the engine run was 107°F. Weather conditions on November 9, 2016 were windy and colder with temperature of 45° F, winds at 9 mph with gusts to 17 mph, and 76% relative humidity.

V. Conclusions

All tests with detects reveal a trend of increasing emissions and concentrations from Cockpit to Cabin to Loadmaster locations, which confirms migration of emissions into the cabin. Overall the Loadmaster location contained the highest amounts of all hazards detected. Patient exposure to the emission are also of concern, especially the Critical Care Air Transport (CCAT) patients whom are typically loaded in the aft most litter and stanchion next to the cargo ramp, and whose health is already compromised.

Based on the results of this study the primary contaminants of interest with JFCE exposure during AE ERO, especially at the Loadmaster location, are ultrafine soot particles, formaldehyde, and unburned jet fuel. Although VOC results were below regulatory OELs, those detected are irritants and have health effects associated with chronic exposure. Additive or synergistic effects of the overall mixture of emissions are likely occurring and potentially influencing irritation.

The particle testing in this campaign provided valuable information on soot particles in JFCE. Although there were problems with the CPC testing, the CPC data still provided relevant real-time qualitative information on particle count and migration. The results from June 1, 2016 were visually indicated at or above the CPC maximum count of

10^5 particles/cc. Results from November 9, 2016 actual concentrations were at least some degree higher than the diluted results. With appropriate dilution techniques or models with higher maximum count capacity, CPC proved as valuable tools for assessing JFCE particle concentrations and migration behavior.

The EM results from the TPS and PC filter samples provided valuable information on the morphology, composition, size, and concentration of soot particles in C-130H JFCE at engine ground idle. All particle sizes were in nanometers. Soot concentrations found were $1.6\text{E}+06$ particles/cc in the Cockpit on June 1, 2016 and $3.4\text{E}+06$ particles/cc at the Loadmaster location on November 9, 2016. The thermophoretic nanoparticle samplers were portable, lightweight, and provided impressive particle separation, sizing, concentration, and morphology information that agree with current understanding of soot evolution.

As seen in the EM images JFCE particle composition is dominated by soot of highly irregular shapes, varied equivalent particle diameters, most less than 100 nm. The highest soot concentration was at the Loadmaster location. Soot morphology showed much irregularity, which may have important implications on bioactivity.

The large standard deviation in TPS particle sizes indicates soot particle coagulation/agglomeration in aging exhaust as discussed previously. The smaller particle size distribution in the cockpit may be attributed to the source of air entering the cockpit. Aircraft environmental systems draw engine bleed air from the engine compressor stages, pre-cool and condition the bleed air prior to distribution into the cockpit (and cabin), which may explain the formation of the sulfur containing SOA, 1,1-dichloroethene, and much larger concentration of acetone in the cockpit. At altitude intake air is clean.

However, parked on the ground with the engines running, and nearby aircraft and ground support activity, combustion emissions are likely re-entrained into the engine intake.

The PC filter results could not be compared to those of the TPS. Particle loading on the PC filters was too heavy for effective particle separation because of the high flow rate (4 L/min). However, a significantly lowered flow rate will improve particle separation in high particle environments such as JFCE. This testing application could still provide valuable information in future research efforts.

TPS and PC filter elemental analyses confirmed the dominance of soot in JFCE particles and revealed small amounts of sulfur species in the cockpit (as SOA in the TPS sample) and cabin samples. Trace amounts of aluminum, sodium, and silicon were found in the cabin PC filters. NIOSH 7300 results were below reporting limits, which is in agreement with findings in the literature. Trace amounts of sulfur and oxygen found in the particles support literature discussions of soot hydroscopic quality and propensity to form layers.

Small amounts of sulfur were detected with the TPS, while the NIOSH 7908 results for sulfuric acid were below reporting limits. However, sulfuric acid may be detected in high humidity conditions due to increased likelihood of its formation in ambient air with high water vapor content.

Limitations and Considerations

Assessing occupational exposures to JFCE is challenging. Planned sampling campaigns can be suddenly canceled due to inclement weather or unexpected

unavailability of aircraft. Back-up dates should be included in aircraft scheduling discussions.

Not only are JFCE multi-component mixtures, but the component mixture and concentrations vary as the exhaust ages, in different climates, and with different engine types and airframes. Engine oil, lubricant leaks, aircraft auxiliary power units (APU) and ground support equipment emissions also contribute to the exposure. JFCE from multiple flight line activities occurring at the same time, such as nearby aircraft taxiing and taking-off, are common on busy flight lines and increase emission concentrations. Sampling and mitigation considerations are especially challenging in cold and extreme cold climates due to the high content of unburned fuel aerosol and trouble with sampling equipment (4). Establishing monitoring programs unique to process, location, and airframe will be more effective than a universal approach.

The overall emissions concentrations in this study are considered conservative since only one aircraft was operating at the time of the study, and this project only characterized exhaust emissions on one airframe (C-130H) during one process. On busy flight lines multiple aircraft and ground support equipment often operate simultaneously, increasing emissions concentrations.

Data sets and test selections in this campaign are limited due to the sampling issues experienced and limited resources. Not all contaminants found in prior research were sampled in this campaign. A more rigorous approach that includes a comprehensive testing suite with replicate parallel measurements on multiple days, in different weather conditions, and per airframe will yield statistical confidence in exposure decision making.

In this occupational setting, assessing exposures to particles are challenging because no regulatory limits are established for combustion emission particles. Gravimetric methods are not suitable due to negligible mass and volatile hydrocarbon layers associated with soot nanoparticles. Applying a count based approach to regulatory limits, similar to that used for asbestos OELs, may be more appropriate for combustion particles than mass based approaches (mg/m^3).

Summary

Many of the individual contaminants found in the engine start-up and idle JFCE from this research have known health effects and regulatory limits. However, no occupational exposure limits for combustion particles exist. Health effects from occupational exposure to JFCE are unknown and should be investigated since JFCE are a complex mixture of gases, vapors, and ultrafine particles of which additive or synergistic effects are likely.

Appendix A: Equipment List, November 9, 2016

Location	Equipment	Manuf	Model #	S/N	OET ECN	Vendor Cal date	Start Time	Stop Time
Cockpit	VelociCalc®	TSI, Inc.	9565-P	9565P1625001		Jun-16	1307	1324
	Thermoanemometer probe	TSI, Inc.	964	P16250019		Jul-16		
	Hand-held Condensation Particle	TSI, Inc.	3007	3007-04160001	RHXBC	Apr-16	1322	1524
	Hand-held Condensation Particle	TSI, Inc.	3007	3007-07080002	100657	Dec-09	1322	1523
	MultiRae Pro	Rae Systems					1313	1521
	Thermophoretic sampler	RJ Lee Group	TPS100					
	air sampling pump 1	Sensidyne, LP	Gilian GilAir® Plus				1417	1521
	air sampling pump 2	Sensidyne, LP	Gilian GilAir® Plus				1417	1521
	air sampling pump tubing							
	TD tube							
	SG tube			6441000360/lot10302				
Cabin Background	VelociCalc®	TSI, Inc.	9565-P	9565P1625001		Jun-16	1325	1529
	Thermophoretic sampler	RJ Lee Group	TPS100					
	air sampling pump 1	Sensidyne, LP	Gilian GilAir® Plus				1328	1421
	air sampling pump 2	Sensidyne, LP	Gilian GilAir® Plus				1328	1421
	air sampling pump tubing							
	TD tube							
	SG tube			6441000355/lot10302				
Cabin Fore	Thermoanemometer probe	TSI, Inc.	964	P16250019		Jul-16		
	Hand-held Condensation Particle	TSI, Inc.	3007	3007-02120016	RHDJ	Apr-15	1321:55:00	1517
	MultiRae Pro	Rae Systems					1314	1532
	Thermophoretic sampler	RJ Lee Group	TPS100					
	air sampling pump 1	Sensidyne, LP	Gilian GilAir® Plus				1420	1517
	air sampling pump 2	Sensidyne, LP	Gilian GilAir® Plus				1420	1517
	air sampling pump tubing							
	TD tube							
	SG tube			6441000353/lot10302				
Cabin Aft	Thermoanemometer probe	TSI, Inc.	964	P16250019		Jul-16		
	Hand-held Condensation Particle	TSI, Inc.	3007	3007-07080003	100656	Nov-09	1321	1530
	MultiRae Pro	Rae Systems					1321	1532
	Thermophoretic sampler	RJ Lee Group	TPS100					
	air sampling pump 1	Sensidyne, LP	Gilian GilAir® Plus				1422	1509
	air sampling pump 2	Sensidyne, LP	Gilian GilAir® Plus				1422	1509
	air sampling pump tubing							
	TD tube							
	SG tube			6441000351/lot10302				
Loadmaster	VelociCalc®	TSI, Inc.	9565-P	9565P1625001		Jun-16	1317	1515
	Thermoanemometer probe	TSI, Inc.	964	P16250019		Jul-16		
	Hand-held Condensation Particle	TSI, Inc.	3007	3007-12090003	101382	Aug-16	1321	1515
	MultiRae Pro	Rae Systems					1419	1516
	Thermophoretic sampler	RJ Lee Group	TPS100					
	air sampling pump 1	Sensidyne, LP	Gilian GilAir® Plus				1425	1312
	air sampling pump 2	Sensidyne, LP	Gilian GilAir® Plus				1425	1312
	air sampling pump tubing							
	TD tube							
	SG tube			6441000356/lot10302				
Blanks	SG tube field blank			6441000359/lot10302				
	SG tube trip blank			6441000357/lot10302				
	SG tube lab blank			6441000354/lot10302				

Appendix B: Sampling Information, Methods N0600/N7300/7908.TO-17/TO-11 and

SEM PC Filters

Test	Start Time	Stop Time	Sample Duration (min)	Volume (L)	Sample Date	Media	Flow rate (L/min)	Results (mg/m ³)
CP N7908	1338	1410	32	159.94	June 1, 2016	Quartz fiber filter	4.998	<RL
CF N7908	1342	1412	30	150.81	June 1, 2016	Quartz fiber filter	5.027	<RL
B N7908	1229	1314	45	224.91	June 1, 2016	Quartz fiber filter	4.998	<RL
CA N7908	1342	1415	33	165.89	June 1, 2016	Quartz fiber filter	5.027	<RL
LM N7908	1349	1420	31	153.95	June 1, 2016	Quartz fiber filter	4.966	<RL
FB N7908	*	*	0	0.00	June 1, 2016	Quartz fiber filter	N/A	<RL
CP N7300/N0600	1338	1410	32	78.66	June 1, 2016	PVC filter	2.458	<RL
CF N7300/N0600	1342	1412	30	73.83	June 1, 2016	PVC filter	2.461	<RL
B N7300/N0600	1231	1314	43	106.43	June 1, 2016	PVC filter	2.475	<RL
CA N7300/N0600	1342	1415	30	72.66	June 1, 2016	PVC filter	2.422	<RL
LM N7300/N0600	1349	1420	31	76.35	June 1, 2016	PVC filter	2.463	<RL
FB N7300/N0600	*	*	0	0.00	June 1, 2016	PVC filter	N/A	<RL
CP-SEM	1338	1410	32	128.90	June 1, 2016	Polycarbonate filter, conductive cartridge	4.028	See SEM results
CF-SEM	1342	1412	30	119.79	June 1, 2016	Polycarbonate filter, conductive cartridge	3.993	See SEM results
B-SEM***	1230	1314	44	175.87	June 1, 2016	Polycarbonate filter, conductive cartridge	3.997	See SEM results
CA-SEM	1342	1415	33	131.93	June 1, 2016	Polycarbonate filter, conductive cartridge	3.998	See SEM results
LM-SEM	1349	1420	31	124.50	June 1, 2016	Polycarbonate filter, conductive cartridge	4.016	See SEM results
FB-SEM	*	*	0	0.00	June 1, 2016	Polycarbonate filter, conductive cartridge	N/A	See SEM results
CP TO-11	1417	1521	64	32.00	Nov. 9, 2016	2,4-DNP treated silica gel	0.5	0.01
CF TO-11	1420	1517	57	28.50	Nov. 9, 2016	2,4-DNP treated silica gel	0.5	0.049
B TO-11	1328	1401	33	16.50	Nov. 9, 2016	2,4-DNP treated silica gel	0.5	<RL
CA TO-11	1422	1509	47	23.50	Nov. 9, 2016	2,4-DNP treated silica gel	0.5	0.089
LM TO-11	1425	1512	47	23.50	Nov. 9, 2016	2,4-DNP treated silica gel	0.5	0.26
FB TO-11	*	*	0	0.00	Nov. 9, 2016	2,4-DNP treated silica gel	N/A	ND
CP TO-17	1417	1521	64	3.20	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
CF TO-17	1420	1517	57	2.85	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
B TO-17	1328	1401	33	1.65	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
CA TO-17	1422	1509	47	2.35	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
LM TO-17	1425	1312	47	2.35	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
FB TO-17	*	*	0	0.00	Nov. 9, 2016	Thermal desorption tubes	0.05	See TO-17 Results Table
* Field Blank samples were collected prior to Background sampling								
** Pre- and post- pump calibrations were conducted using a Bios Defender™ calibrator by averaging 10 measurements.								
***B-SEM volume was incorrectly entered on the laboratory analytical request form as 171 L.								

Appendix C: TO-17 Results Summary

TO-17 Results (ppbv)	Field blank	Trip Blank	Background	Cockpit	Cabin Forward	Cabin Aft	Loadmaster
Volume (L)	N/A	N/A	1.65	3.20	2.85	2.35	2.35
Corrected Volume (L)	N/A	N/A	3.00	5.82	5.18	4.27	4.27
Compound	Uncorrected Instrument Results						
Acetone	7.96	9.04	22.89	843.47	56.15	55.87	44.07
1,1-Dichloroethene (Only in ther Cockpit)				110.15			
IPA (Carryover from CPCs)				284.16	1142.04	1399.10	688.95
MEK				10.71	5.59	7.43	15.82
Benzene				5.82	13.96	18.01	42.56
Cyclohexane					3.23	4.46	9.57
Methylene Chloride (Lab Carryover)	19.16	23.77	17.88	14.97	16.63	14.24	14.88
n-Hexane	2.54	4.48					
Toluene				2.26	4.68	6.43	16.58
4-Ethyltoluene					4.22	5.07	14.67
Styrene						2.21	6.17
Naphthalene						2.17	6.73
1,4-Dioxane							2.62
2-Hexanone							2.72
m,p-Xylene							5.13
Ethylbenzene							3.34
o-Xylene							2.82
1,3,5-Trimethylbenzene							2.03
Compound	Results Corrected for Calibration Volume						
Acetone	7.96	9.04	7.63	144.97	10.84	13.08	10.31
1,1-Dichloroethene (Only in ther Cockpit)				18.93			
IPA (Carryover from CPCs)				94.72	196.29	270.00	161.24
MEK				1.84	1.08	1.74	3.70
Benzene				1.00	2.69	4.22	9.96
Cyclohexane					0.62	1.04	2.24
Methylene Chloride (Lab Carryover)	19.16	23.77	5.96	2.57	3.21	3.33	3.48
n-Hexane	2.54	4.48					
Toluene				0.39	0.90	1.51	3.88
4-Ethyltoluene					0.82	1.19	3.43
Styrene						0.52	1.44
Naphthalene						0.51	1.58
1,4-Dioxane							0.61
2-Hexanone							0.64
m,p-Xylene							1.20
Ethylbenzene							
o-Xylene							0.66
1,3,5-Trimethylbenzene							0.48

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14. ABSTRACT The purpose of this research was to characterize jet fuel combustion emissions (JFCE) in an occupational setting. Prior research demonstrated that aircraft emit hazardous species, especially at engine start-up and ground idle. Complaints of eye, nose, and throat irritation from occupational exposures near aircraft exist. In this study JFCE were tested during an aeromedical evacuation engines running patient onload (ERO) on a C-130 Hercules at the 179 th Airlift Wing, Mansfield-Lahm Air National Guard. Ultrafine particles, VOC, formaldehyde, carbon monoxide (CO), sulfuric acid, and metals were sampled simultaneously in approximate crew and patient breathing zones. Testing methods were portable condensation particle counters (CPC), polycarbonate filters (PC) and thermophoretic samplers (TPS) for electron microscopy, MultiRae [®] gas monitors, EPA methods TO-17 and TO-11, and NIOSH methods N0600, N7908, N7300. Ultrafine particulate matter, VOC including EPA HAPs, formaldehyde, CO, and unburned jet fuel were detected. Particles were dominated by soot that was predominantly carbonaceous with trace oxygen, sulfur and few metals in concentrations up to 3.4E+06 particles/cc. Particle size distributions were varied with most sizes less than 100 nanometers (nm). Particle morphology was highly irregular. VOC were detected in ppb, and formaldehyde in ppm. Additive or synergistic effects are suspected and may intensify irritation. Health implications from inhaling nano-sized soot particles are inconclusive.					
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