# Turbulence Impacts upon Carbonaceous Particulate Size from a Jet Combustor

PennState College of Earth and Mineral Sciences

John and Willie Leone Family Department of Energy and Mineral Engineering

Cindy Choi, Akshay Gharpure, Madhu Singh, Randy Vander Wal

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## BACKGROUND

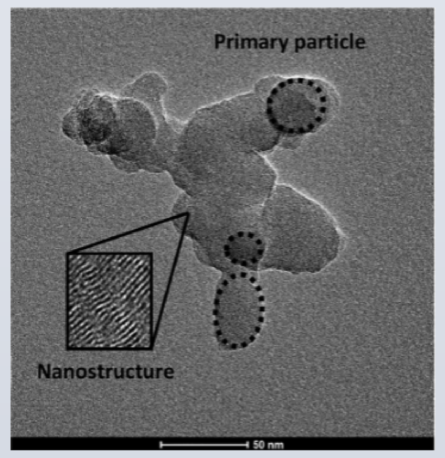
**ND-MAX/ECLIF-II:** (NASA/DLR Multidisciplinary Airborne Experiment – Emission and Climate Impact of Alternative Fuel)

- NASA
- DLR Multidisciplinary Airborne Experiments
- Emission and Climate Impact of Alternative Fuels Second Campaign
- Ground-Level Measurements


## INTRODUCTION

**What is a soot "particle"?**

- Aggregates of soot consist of **primary** particles




**Why does combustion-formed soot matter?**

- Contributes to atmospheric warming
- Cloud condensation nuclei at high altitude
- Respiratory health hazard

**Why does primary particle size vary?**

- ∝ Temperature
- ∝ Phi ($\varphi$) equivalence ratio
- ∝ 1/N1(%)

$$\varphi = \frac{[Mass\ of\ O_2\ + Mass\ of\ N_2]_{air}}{[Mass\ of\ C + Mass\ of\ H]_{fuel}}$$

## OBJECTIVES

- Determine if soot **primary** particle size depends upon thrust
- Identify relationship(s) between thrust and primary particle size
- Analyze the effect of fuel hydrogen content on particle size
- Analyze the effect of fuel aromatic content on particle size
- Compare largest particle size (95th percentile) and smallest particle size (5th percentile) between fuels
- Quantify primary particle size distribution

## MATERIALS & METHODS

**Sampling**

- Parked airbus A320 with V2527-A5 engine
- TEM grid with a carbon film and wire mesh support
- Petroleum-based reference jet fuels with synthetic fuel blends resulting in varying aromatic and hydrogen content: REF3, REF4, SAJF1, SAJF2, and SAJF3
- Different thrusts characterized by compressor fan speed N1 (%): N1=23, 40, 53, 60, 75, and 82

| Test Point | N1 (%) | Thrust (%) |
|---|---|---|
| 1 | 23 | 7 |
| 2 | 82 | 87 |
| 3 | 23 | 7 |
| 4 | 75 | 67 |
| 5 | 60 | 40 |
| 6 | 53 | 25 |
| 7 | 40 | 17 |
| 8 | 60 | 40 |
| 9 | 23 | 7 |

**TEM**

- FEI TALOS 200FX

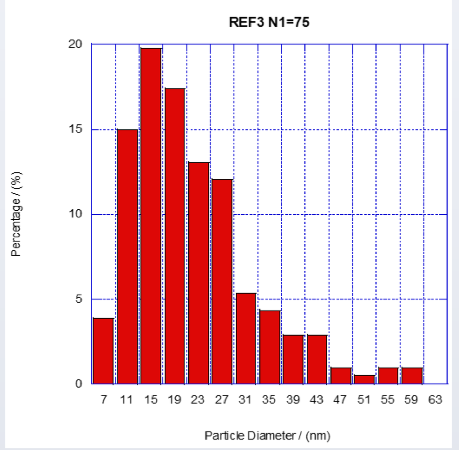
**Software**

- ImageJ
- KaleidaGraph
- Excel

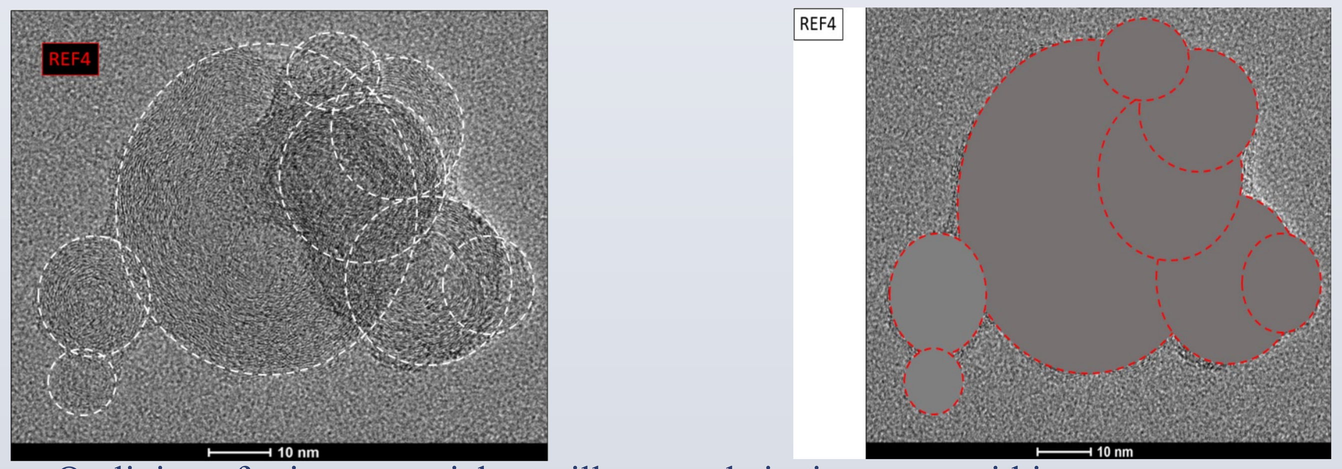
| Fuel Property | REF3 | REF4 | SAJF1 | SAJF2 | SAJF3 |
|---|---|---|---|---|---|
| Aromatics [vol%] (ASTM D1319) PetroLab | 18.6 | 15.4 (ASTM D6379) | 9.6 | 10.8 | 15.2 |
| Hydrogen H [mass%] (NMR ASTM D7171) VT-CHA | 13.65 | 14.08 | 14.40 | 14.51 | 14.04 |

## RESULTS & DISCUSSION

- Partial premixing causes a local $\varphi$ in fuel rich pockets
- High thrust causes wide range of local turbulence levels
- Turbulence creates a broad spectrum in $\varphi$
- Particle growth rate correlates with $\varphi$ (particle size is large for high $\varphi$, small for low $\varphi$)

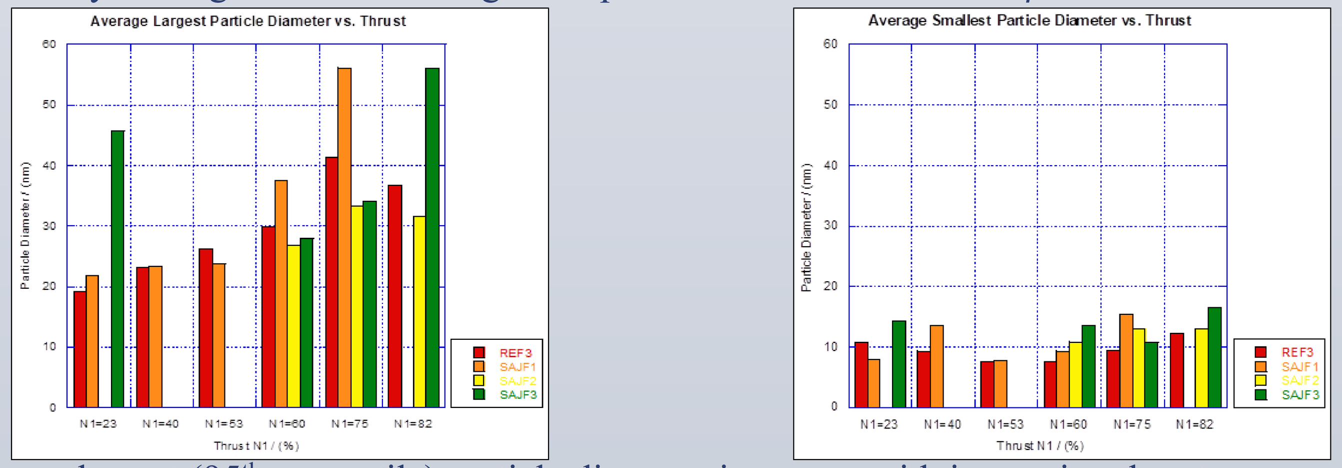



Primary particles exhibit a log-normal size distribution.

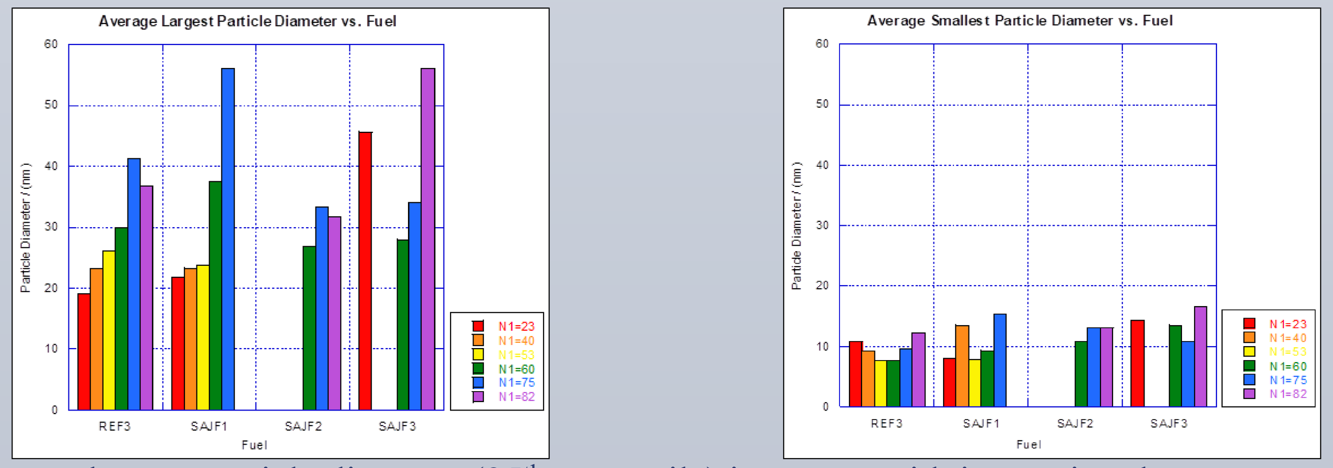



Outlining of primary particles to illustrate their size range within an aggregate.

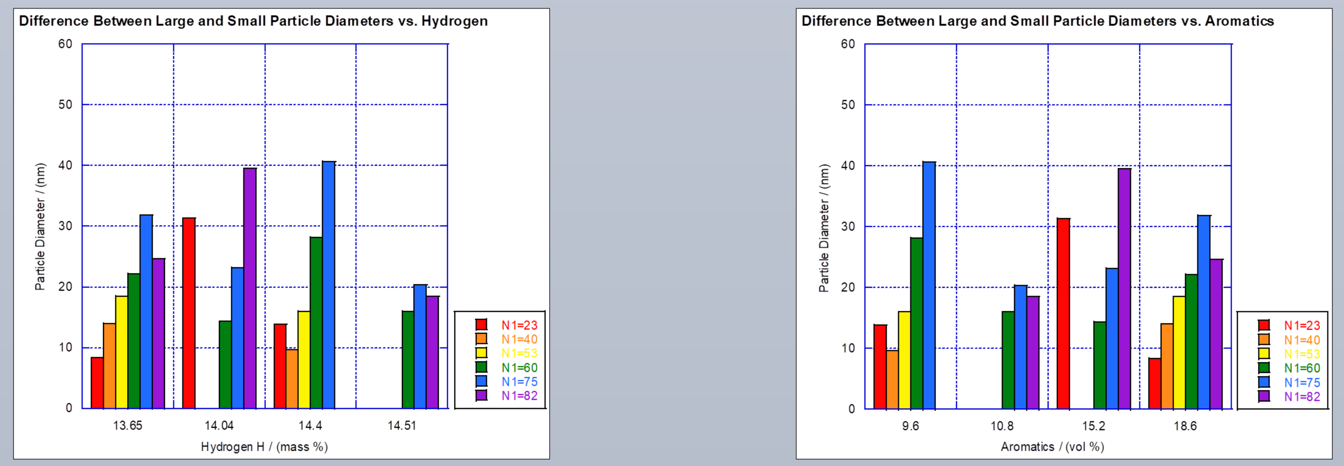
- Wide variation of primary particle size within the same aggregate
- Aggregates form by coalescence of primary particles from multiple fuel rich pockets with different $\varphi$
- Secondary mixing causes the amalgam of particles sizes from varied $\varphi$




- Average largest (95th percentile) particle diameter increases with increasing thrust




- Average largest particle diameter (95th percentile) increases with increasing thrust across all fuels




- No correlation of primary particle size with variation in fuel hydrogen or aromatic content across thrust levels

## CONCLUSIONS

The difference in length of diameters between the largest and smallest particles increased with increasing power. There is no monotonic correlation between primary particle size and fuel hydrogen (mass %) or aromatics (vol. %) content. This study of carbonaceous particulate gives rise to conjecture that soot particles form within the combustor of a jet engine under very different conditions of $\varphi$ and turbulent driven timescales than those formed in laminar laboratory flames.

1. In fuel-rich, soot-forming pockets, primary particle size serves as an alternate measure of local $\varphi$. This is because their size is proportional to the concentration of pyrolyzed fuel molecules.

2. According to the results of electron energy loss spectroscopy (EELS), small primary particles have a lower $sp^2/sp^3$ ratio than large particles. This is consistent with formation at different $\varphi$.

3. Increasing thrust serves to broaden the range of $\varphi$ and correspondingly primary particle sizes.

4. The need to study real systems has become apparent due to the inability of laboratory flames to recreate the range of $\varphi$ and primary particle formation conditions.

5. By defining the range of $\varphi$ for varied thrust levels, the results of this study can be used to calibrate numerical models for particle formation and computational models for turbulent combustion.

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