Impact of SAFs on particulate formation: a comparative study in laminar premixed flames

F. Picca*, F. Sasso*, M. Commodo, P. Minutolo**, A. D'Anna***
fabio.sasso@unina.it
* DICMaPI - Università di Napoli Federico II, P.le Tecchio 80, 80125, Napoli, Italy
** STEMS-CNR, P.le Tecchio 80, 80125, Napoli, Italy

Abstract
Sustainable Aviation Fuels are gaining attention as viable alternatives to conventional jet fuels in response to the need for reduced aviation emissions. This study uses experimental and modelling approaches to examine their effect on soot formation in terms of particle size distributions in premixed ethylene/air flames. A Sustainable aviation fuel, mainly composed of saturated branched alkanes with low aromatic content, was compared to conventional Jet A-1 fuel under identical conditions. Results show SAF combustion yields consistently smaller particles and reduced soot mass compared to Jet A-1, confirming the capability of SAF to reduce soot formation.

Introduction
In recent years, the need to reduce emissions of atmospheric pollutants to combat climate change and preserve human and environmental health has become increasingly urgent. Sustainable Aviation Fuels (SAFs) represent a valuable alternative to traditional jet fuel in transportation sector. Chemically, SAFs are renewable liquid fuels produced from biomass, organic waste, and direct CO_2 capture from the air [1], primarily composed of branched alkane isomers. Regarding the presence of aromatics, which are important for sealing properties, the aim is to gradually replace them with cycloalkanes. In principle, a SAF is designed to be a safe and effective substitute for conventional jet fuel; its almost identical chemical properties allow it to be blended directly and used interchangeably without modification to aircraft engines or associated equipment [2]. This work investigates the effect of a SAF on particulate formation, focusing on its kinetic aspects and resulting particle size distributions (PSDs), as well as unburned products in premixed flames. A coupled experimental and modelling methodology was employed. Comparative experiments were conducted using both SAF and conventional aviation fuel Jet A-1 under identical operating conditions.

Experimental
Two premixed flames, Ethylene/Air/SAF and Ethylene/Air/Jet A-1, were experimentally analysed. The SAF analysed in this study is mainly composed of branched and linear saturated alkanes, with a low total aromatic content (less than 0.9% w/w based on ASTM D6379 method). Conversely, kerosene Jet A-1 has a total

aromatic content of 21% (based on ASTM D2425 method). Based on these compositional characteristics and experimental measurements, SAF was represented as a surrogate fuel $C_{12}H_{26}$ with an experimentally determined density of 750 kg/m³. Similarly, Jet A-1 was represented as a surrogate $C_{10.5}H_{21.5}$ with a density of 800 kg/m³. The liquid fuels were converted to a vapour phase after pre-evaporation by heating to 400 K. The pre-mixed laminar flames were stabilized on a McKenna burner operating at atmospheric pressure with the amount of carbon fixed at 88.25 mmol/min. The flame parameters are given in Table 1.

Table 1. Flames Parameters

Flame	Flow, l/min (STP)			Gas Velocity, cm/s	Equivalence Ratio
	C_2H_4	Air	C_xH_y		
Et/Air/SAF 30%	1.01	9.66	$5.0*10^{-4}$	6.30	2.16
Et/Air/Jet A-1 30%	1.01	9.60	$4.7*10^{-4}$	6.30	2.16

PSDs were measured along the flame axis using a mobility scanning particle sizer (SMPS), TSI model 3938; stable gas analysis was performed by a TESTO model 350 to check the repeatability of the experiments. Flames were modelled by using [3]. The kinetic mechanism includes the oxidation of a few representative hydrocarbons, which are important components of aviation fuel surrogates. A surrogate for jet fuels is chosen to be comprised of n- and iso-alkanes (n-dodecane and 2,2,4 trimethyl heptane), cycloalkanes, aromatics, including monocyclic and polycyclic aromatic rings . The chemical model is assembled in stages, starting with a base model that accounts for the oxidation and pyrolysis of ethylene and methane and adding sub-mechanisms for the individual components of the surrogate. Benzene and Polycyclic Aromatic Hydrocarbons (PAHs) are responsible for the nucleation and surface growth of particles [3]. The aromatic growth mechanism is followed through a discrete-sectional method that accounts for molecular growth and different H-C ratios for every section. 125 lumped species are considered with a C atoms number ranging from 24 to $4 \cdot 10^8$ and H/C ratios ranging from 0 to 1. The model is modified to consider the morphological nature of the formed carbon agglomerates as suggested by Maricq and Xu [4]. Indeed, the particles' effective density is suggested to be lower than the agglomerate bulk density because of particle aggregation in fractal structures. A primary particle diameter of 10 nm has been chosen for the calculations.

Result and discussion

Figure 1 illustrates the normalized PSDs of particles produced based on residence time, represented here as height above the burner (HAB). A key observation is that particles generated using SAF are consistently smaller than those produced with Jet A-1 under similar conditions. This behaviour is observable throughout the entire flame, as depicted in Fig 1. In both flames, at short residence times (HAB=7mm), the PSDs exhibit an early bimodal characteristic that becomes more pronounced at HAB=8 mm, indicating a slightly advanced stage in flame development. As residence times increase, the bimodal distribution becomes more defined, with the first particle mode remaining relatively stable, while the second and larger mode shifts towards larger particle sizes. The modelled curves that illustrate this behaviour align well with the experimental curves.

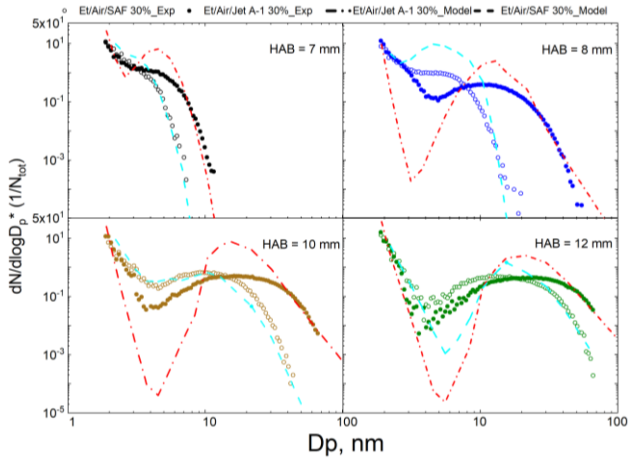

Figure 1 Open circles for SAF and filled circles for Jet A-1; the corresponding model predictions are shown as cyan lines for SAF, red lines for Jet A-1.

Conclusions

In this work, a comparative study between SAF and conventional aviation fuel Jet A-1 was conducted. SAF consistently produces fewer and smaller soot particles than Jet A-1 fuel across all flame heights, supporting its potential to reduce soot emissions in aviation. The modelling results qualitatively follow the experimental trends, validating the approach while suggesting areas for refinement.

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References

[1] Wang, W.C., Tao, L., "Bio-jet fuel conversion technologies" *Renew. Sustain. Energy Rev.* 53:801–22 (2016)
[2] Wang, B., Ting, Z.J., Zhao, M,. "Sustainable aviation fuels: Key opportunities and challenges in lowering carbon emissions for aviation industry" *Carbon Capture Sci. Technol.* 13 (2024).
[3] D'Anna A., Sirignano M., Kent J.," A model of particle nucleation in premixed ethylene flames." *Combust Flame* 157:2106–15 (2010).
[4] Maricq, M.M., Xu, N., "The effective density and fractal dimension of soot particles from premixed flames and motor vehicle exhaust" *J Aerosol Sci* 35:1251–74 (2004).