AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

ACRP

Web-Only Document 41:

Alternative Jet Fuels Emissions

Quantification Methods Creation and Validation Report

Booz Allen Hamilton
McLean, Virginia

In association with:

Environmental Consulting Group
Annapolis, Maryland

Missouri University of Science and Technology
Rolla, Missouri

Csonka Aviation Consultancy, LLC
Lebanon, Ohio

Final Report for ACRP 02-80
Submitted August 2019

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRB
TRANSPORTATION RESEARCH BOARD

ACRP

Web-Only Document 41:

Alternative Jet Fuels Emissions

Quantification Methods Creation and Validation Report

Booz Allen Hamilton
McLean, Virginia

In association with

Environmental Consulting Group
Annapolis, Maryland

Missouri University of Science and Technology
Rolla, Missouri

Csonka Aviation Consultancy, LLC
Lebanon, Ohio

Final Report for ACRP Project 02-80
Submitted August 2019

ACKNOWLEDGMENT

This work was sponsored by the Federal Aviation Administration (FAA). It was conducted through the Airport Cooperative Research Program (ACRP), which is administered by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine.

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRB
TRANSPORTATION RESEARCH BOARD

The National Academies of

SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.national-academies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at **www.TRB.org**.

C O O P E R A T I V E   R E S E A R C H   P R O G R A M S

CRP STAFF FOR ACRP Web-Only Document 41

Christoper J. Hedges, *Director, Cooperative Research Programs*
Lori L. Sundstrom, *Deputy Director, Cooperative Research Programs*
Joe Navarrete, *Senior Program Officer*
Hanna Vagnerova, *Program Associate*
Eileen P. Delaney, *Director of Publications*
Natalie Barnes, *Associate Director of Publications*
Jennifer Correro, *Assistant Editor*

ACRP PROJECT 02-80 PANEL
ACRP 2: Environment

Arlyn Purcell, *Port of Seattle | Seattle-Tacoma International Airport, Seattle, WA* (Chair)
Randolph Rodney Hadley, *City of Atlanta (GA) Department of Aviation, Atlanta, GA*
Leonard A. Krugler, *Los Angeles World Airports, Van Nuys Airport, Van Nuys, CA*
Eric C. Lu, *Ramboll, Irvine, CA*
Aaron G. Stash, *United Airlines, Chicago, IL*
Saadat A. Syed, *, South Windsor, CT*
Thomas Cuddy, *FAA Liaison*
Warren Gillette, *FAA Liaison*
Christine Gerencher, *TRB Liaison*

ACRP 02-80: QUANTIFYING EMISSIONS REDUCTIONS AT AIRPORTS FROM THE USE OF ALTERNATIVE JET FUELS

PHASE 2 – EMISSIONS QUANTIFICATION METHODS CREATION AND VALIDATION

Prepared for:
Airport Cooperative Research Program ACRP 02-80 Transportation Research Board Of The National Academies of Sciences, Engineering and Medicine

Submitted By:

Booz Allen Hamilton,
McLean, VA

In association with:

Environmental Consulting Group

Missouri University of Science and Technology

Csonka Aviation Consultancy, LLC

Table of Contents

List of Figures

List of Tables

1.0 Introduction

One of the most challenging environmental issues facing the aviation industry today is the impact of jet fuel emissions on the global climate. As a result, airlines throughout the world have committed to reducing their emissions-driven climate impacts. The primary means for reducing these impacts over the long term is through use of sustainable alternative jet fuels (SAJF) produced from non-petroleum sources, which reduce life-cycle greenhouse gas (GHG) emissions. Emissions testing conducted to date shows that, in addition to reducing life-cycle GHG emissions, SAJF also impacts emissions of other pollutants. Sulfur oxides (SO_x) and particulate matter (nvPM) emission reductions are particularly significant. Emissions of other air quality pollutants including carbon monoxide (CO), unburned hydrocarbons (UHC), hazardous air pollutants (HAP), and nitrogen oxides (NO_x) are also reduced, to a lesser extent, or at least do not increase. These additional emissions benefits may be highly valued by airports. The air quality emissions reductions from SAJF use could become an important component of airlines' commitment to supporting airports' sustainability goals. These benefits could improve relations with airport workers and the communities near airports that may be concerned with local air quality or could give airports flexibility to grow under State Implementation Plan (SIP) constraints. For these reasons, use of SAJF to reduce aircraft emissions will become significantly more important in coming years. Capturing the air quality benefits in a way that is useful to airports requires understanding how SAJF reduce pollutant emissions, quantifying the reduction, and demonstrating the impact through an easy-to-use tool that airports can apply to their emissions inventories.

PATH TO IMPACT FACTOR QUANTIFICATION

- Primary metrics included engine type, engine operating condition, fuel composition, blend percentages, atmospheric conditions, etc.
- The tabulated data revealed that in many cases the engine specific emissions may be dependent on three primary metrics: fuel composition, engine power, and fuel type.
- There was insufficient data to allow the fuel composition or engine-fuel-power specific dependency to be parameterized with any statistical significance.
- The power complexity was addressed by developing a weighted average impact based on the ICAO LTO cycle fuel burn values.
- The ICAO LTO cycle was designed to capture normal aircraft/airport operations, and hence can be used to normalize typical power usage.
- The fuel-type and engine-type complexities were addressed by incorporating them into the uncertainty analysis accompanying the impact factor quantification.

This document is organized as follows. Section 2 describes the emissions impact quantification methodology. Section 3 summarizes the impact quantification factor, uncertainty functions, sample impact factors, and uncertainties at 50% SAJF blend. Section 4 describes in detail the pollutant-specific analysis used to develop the impact quantification factor and uncertainty functions. Section 5 describes the results of the airport emissions inventory impact analysis which estimates the reduction in pollutant species across airports with different characteristics in terms of size and operations mix. Section 6 provides guidance to use SAJF impact factors for emissions inventory and dispersion modeling at airports. Section 7 summarizes all available emissions data. Section 8 provides instructions to use the Alternative Jet Fuel Assessment Tool

2.0 Emissions Impact Quantification Methodology

The work described in this report is the second phase of ACRP 02-80. The first phase was publication of *State of the Industry Report on Air Quality Emissions from Sustainable Alternative Fuel,* which provides an understanding of how SAJF impacts aircraft emissions. This phase analyzes the data compiled in the report to quantify SAJF emission impacts. Results of this analysis were subsequently used to develop a simplified tool that will allow airports to easily estimate emission reductions from use of SAJF at their airport. The *State of the Industry Report* and the emissions analysis tool are the two key products from ACRP 02-80.

The analysis in this phase validated our expectations of emissions reductions when SAJFs are employed. It also provides the basis upon which the magnitude of these reductions can be estimated. The *State of the Industry Report* compiled data on emissions from the use of SAJF from 51 technical publications. Data from those publications were analyzed to determine, validate, and quantify pollutant-specific impact factors, which quantify the benefits. The impact factor for an emissions species is the change in the species emissions index (EI) caused by use of a SAJF blend; the fractional impact factor is the change in the pollutant emissions index caused by use of a SAJF blend divided by the pollutant's emissions index for the conventional fuel. A pollutant-specific tabulation of all available emissions data associated with SAJF usage was included in Section 3.0.

The aviation industry is in the early phase of developing and employing SAJF and as a result, the extent of emissions testing today is somewhat limited. The earliest tests were conducted using alternative fuels that would not meet today's SAJF specifications. Fuels that would meet present SAJF specification, hydrotreated esters and fatty acid (HEFA) fuels that meet the ASTM1655 Annex 1 specification, have been the predominant fuels tested. The earliest tests often used measurement schemes that are not as accurate as presently certified measurement methods. Some tests were conducted on combustor rigs or auxiliary power units (APU) rather than aircraft main engines and some were conducted on commercial engines while others used military engines. For those tests conducted using aircraft main engines, a single engine design (CFM56) was primarily used. These limitations constrained the range of factors that could be used as independent variables in the analysis. Similarly, limitations on the availability of detailed fuel composition for both conventional jet fuel and the alternative jet fuels in some tests restricted specific fuel components such as hydrogen content or aromatic composition from being used as independent variables. Despite these limitations, the project team developed quantitative relationships that will allow airports to estimate changes in the mass of emissions for all pollutants resulting from use of SAJF.

The methodology for quantifying emissions impacts from SAJF employs six steps:

STEP 1 of the impact plan identifies critical parameters that influence the positive or negative impact of burning SAJFs. Primary metrics include engine type, engine operating condition, fuel composition, blend percentages, atmospheric conditions, etc. Different authors and test campaigns focused attention on different metrics that quantify various emissions and the effects of different alternate fuels. No one study was sufficiently comprehensive to support impact analysis for all pollutant species of interest as a function of all salient metrics. The tabulated data reveals that in many cases the engine specific emissions are engine power and fuel type dependent. However, there is insufficient data to allow the engine-fuel-power, specific dependency to be parameterized with any statistical significance. Furthermore, for airports to address the power dependency, they would have to provide their own fuel burn vs. power profiles for their airport. In order to avoid this complexity, the power dependency has been captured for the impacts analysis by developing a weighted average impact based on the International Civil Aviation Organization (ICAO) LTO cycle fuel burn values. The ICAO LTO cycle is designed to capture normal aircraft/airport operations and hence can be used to normalize typical power usage. A term to capture any baseline EI effect was not included due to the lack of consistent data. In the case of the fuel type dependency, the reported effect is found to be weak and the fuel specific data is insufficient to permit parameterization. As a result, the impacts analysis reported in this study does not specifically address fuel composition. However, by default its impact is incorporated into the uncertainty analysis for the pollutant-specific impact factors developed. This is also the case for engine type to engine type variability. Since all campaign data sets specify blend percent for the fuel blends studied, this parameter has been selected as the critical parameter to define impacts.

STEP 2 of the impact plan devises a pollutant-specific emissions spreadsheet based on the metrics identified in Step 1 and quantifies the observed impacts, typically represented by percent changes in the emission indices.

STEP 3 of the impact plan assesses the pollutant-specific data to determine the viability of performing a functional analysis per metric. A functional analysis depends on the range of data per metric. The greater the range, the greater the confidence in the functional relationship. For example, if the metric is blend percentage, emission data for a minimum of two blends is required for a linear relationship with a limited confidence factor. More than two data points are required to define a non-linear relationship.

STEP 4 of the impact plan develops functional impact relationships for those species identified in Step 3 as viable candidates, i.e., having sufficient data to support the functional analysis.

STEP 5 of the impact plan performs the pollutant-specific functional analysis. This consists of fitting functions that best represent the relationship between the parameters of interest such as blend percentage and impact factor. General linear and non-linear least squares methodologies are used to achieve the fitting.

3.0 Summary of Results

Using the impact factor quantification plan described above, pollutant-specific functions were developed for each of the pollutant species examined in this study i.e., SO_x, NO_x, CO, nvPM (mass), nvPM (number), UHC and HAPs. In each case the critical parameter is blend percent (blend%). The resulting quantification functions and their associated uncertainties are given in Table 1. By way of application, example numerical impact factors are presented for a blend of 50% SAJF, which is a common boundary condition. Definitions of the terms used in Table 1 are given in Table 2.

Table 1: Quantification functions, impact factors and their associated uncertainties

Pollutant Species	Impact Quantification Factor Functions and Estimated Uncertainties	Impact Factor Δf blend%=5	Uncertainty δ blend%=5	Impact Factor Δf blend%=50	Uncertainty δ blend%=50
SO_x	$\Delta fSOx,[S] = \left(\frac{blend\%}{100\%}\right) * \left(\frac{[S_{SAJF}]}{[S_{conv}] - 1}\right).$	-0.037		-0.375	
	$\delta\Delta fSOx,[S] = \Delta fSOx - \left(\frac{blend\%}{100\%}\right) * \left(1 + \delta\left(\frac{blend\%}{100\%}\right)\right) * \left[\left(\frac{[S]_{sajf}-\delta[S]}{[S]_{conv}+\delta[S]}\right) - 1\right]$		0.007		0.072
nvPM (number)	$\Delta f\_EIn\_fit = -1.25E-2 * blend\% + 5.91E-5 * blend\%\hat{}2.$	-0.061		-0.477	
	$\delta\Delta f\_EIn\_fit = \{(5.23E-3 * blend\%)^2 + (7.73E-5 * blend\%2)2\}^{1/2}$		0.026		0.325
nvPM (mass)	$\Delta f\_EIm\_fit = -1.90E-2 * blend\% + 1.20E-4 * blend\%\hat{}2$	-0.092		-0.65	
	$\delta\Delta f\_EIm\_fit = \{(5.31E-3 * blend\%)2 + (6.70E-5 * blend\%\hat{}2)\ 2\}1/2$		0.026		0.314
NO_x	No significant impact; δΔf>Δf. ($\Delta f\_EI_{NOx} = -0.0024 \pm 0.0039$)	-0.002	0.004	-0.002	0.004
CO	$\Delta f\_EI_{CO} = -2.16E-3 * Blend\%$	-0.01		-0.108	
	$\delta\Delta f_{CO,fit} = 9.32E-4 * blend\%$		0.004		0.047
UHC	$\Delta f\_EI_{UHC} = -0.3482 * tanh(0.322 * blend\%).$	-0.321		-0.348	
	$\delta\Delta f\_EI_{UHC} = 0.1234 * tanh(0.2867 * blend\%).$		0.11		0.123
HAPs	No significant impact; δΔf>Δf. ($\Delta f\_EI_{HAPS} = -0.006 \pm 0.046$)	-0.006	0.046	-0.006	0.046

Table 2: Definitions for terms used in Table 1

ΔfSOx, EI = Fractional impact factor for SO_x emission index.
ΔSOx = impact factor for SO_x emission index = Change in SO_x emission index.
EISOx, conv = SO_x emission index for the blending conventional jet fuel.
blend% = Percentage of SAJF blended with conventional jet fuel.
EISOx, SAJF = Emission index for pure SAJF.
ΔfSOx, [S] = Fractional impact factor for SO_x expressed as function of fuel sulfur content.
[SSAJF] = Fuel sulfur content of the SAJF.
[Sconv] = Fuel sulfur content of the conventional jet fuel.
δ... = Uncertainty in a given parameter.
Δf_EIn_fit = The fractional impact factor for number-based EI based on a functional fit to tabulated data.
Δf_EIm_fit = The fractional impact factor for mass-based EI based on a functional fit to tabulated data.
Δf_EI_{NOx} = The fractional impact factor for NO_x.
Δf_EI_{CO} = The fractional impact factor for CO.
Δf_EI_{UHC} = The fractional impact factor for UHC.
Δf_EI_{HAPs} = The fractional impact factor for HAPs.

For comparison, Figure 1 presents the results of the emissions reductions for CO, SO_x, nvPM (number), and nvPM (mass) at 5% and 50% blends. These pollutant species provided the most significant results beyond the uncertainty bounds.

NO_X, HAPS, AND UHC UNCERTAINTY

- For NO_x and HAPs, this study found no statistically significant impact associated with SAJF because the uncertainty in impact factors are greater than the impact factor.
- For UHC, there was extensive scatter in the underlying data driven by one study (Ref 17). As a result, this study did not produce statistically meaningful results for UHC impact factors.

The impact factor uncertainty for NO_x and HAPs is greater than the corresponding impact factor, which implies that there is no statistically significant impact associated with SAJF usage for these species.

The functional fit analysis for UHC impact is confounded by the extensive scatter in the small amount of data available in the literature on UHC emissions (three papers (Refs 6, 17, 21) with 80% of the data coming from Ref 17). The observed scatter appears to be driven by not only blend ratio but also engine operating condition (Ref 17). As a result, the authors caution applying the impact factors for UHC resulting from the above functional analysis. The authors further recommend the pursuit of additional experimental studies on UHC emissions associated with

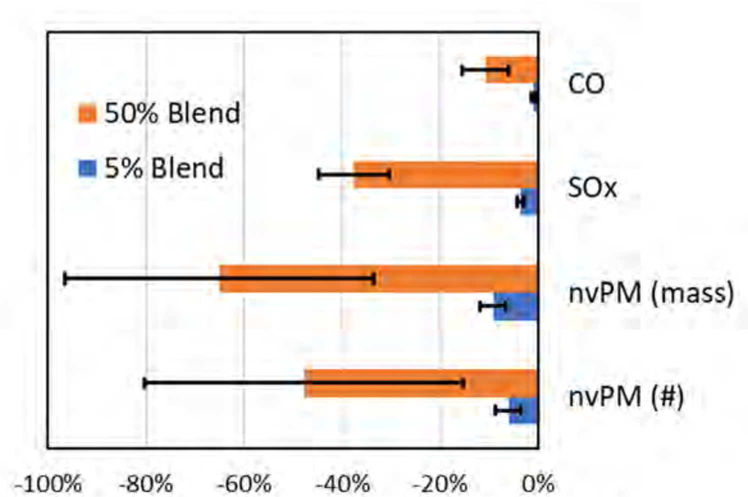


Figure 1: Emissions reductions at 5% and 50% SAJF blends for CO, SO_x, nvPM (mass) and nvPM (#).

blended SAJFs as a function of engine operating condition in order to strengthen confidence in the resulting impact factor analysis.

4.0 Pollutant-Specific Analysis

In the following sections the detailed analysis undertaken to quantify the impacts for the pollutant species SO_x, nvPM N, nvPM Mass, NO_x, CO, UHC, and HAPs is presented.

4.1 SO_x

The SO_x emission indices ($EI_{SOx,\ blend}$) of the conventional/SAJF blends are found to be directly proportional to the amount of sulfur found in the fuel burned, independent of engine type and operating condition, according to the following functional relationship:

$$\mathrm{EI}_{\mathrm{Sox,blend}} = \left(\frac{1-blend\%}{100\%}\right) * \mathrm{EI}_{\mathrm{Sox,conv}} \tag{1}$$

where $EI_{SOx,\ conv}$ denotes the SO_x emission index for the conventional fuel. This relationship assumes that the alternate fuel contains negligible sulfur compared to that of the conventional fuel. This assumption is borne out by the literature. Hence the impact on SO_x of the SAJF can be defined as

$$\Delta_{\mathrm{SOx}} = \mathrm{EI}_{\mathrm{SOx,blend}} - \mathrm{EI}_{\mathrm{SOx,conv}} = -\left(\frac{blend\%}{100\%}\right) * \mathrm{EI}_{\mathrm{SOx,conv}} \tag{2}$$

STEP 1 – Critical metrics are found to be blend% and fuel sulfur content. Based on available data from the State of the Industry Review, $\Delta\ SO_x$ is found to be independent of engine type, engine operating condition, and atmospheric conditions. The only dependency on the alternate fuels was its sulfur content with metrics sulfur concentration ([S] in %wt. sulfur, or ppm) and blend%.

STEP 2 – The SO_x impacts spreadsheet is given in Table 3.

Table 3: The SO_x emissions impact spreadsheet

Alt fuel	Ref fuel	Engine	Impact	Ref #
FT GTL	JP-8	CFM56-2C1	EI_SO_2 ↓ 90% for pure FT, and ↓ intermediately for blends.	6
HEFA/FT	JP-8	F117-PW-100	SO_2 ↓ 50% for 50% blend.	20

STEP 3 – The emissions data indicated a quantifiable presence of sulfur, not only in the conventional fuel, but also in the blended SAJFs. Fuel analyses where available supported this observation. Step 3 concludes that any impact analysis should account for the total sulfur content in the blended fuel.

STEP 4 – The following function was found to represent the impact of sulfur on SO_x emissions.

$$\mathrm{EI}_{\mathrm{SOx,blend}} = \left(\frac{1-blend\%}{100\%}\right) * \mathrm{EI}_{\mathrm{SOx,conv}} + blend\% * \mathrm{EI}_{\mathrm{SOx,\ SAJF}} \tag{3}$$

where $EI_{SOx,\,SAJF}$ denotes the SO_x emission index for the neat SAJF, and

$$\Delta_{SOx} = EI_{SOx,blend} - EI_{SOx,conv} = \left(\frac{blend\%}{100\%}\right) * (EI_{SOx,SAJF} - EI_{SOx,conv}) \tag{4}$$

$$\Delta f_{SOx,EI} = \frac{\Delta_{SOx}}{EI_{SOx,conv}} = \left(\frac{blend\%}{100\%}\right) * \left(\frac{EI_{SOx,SAJF}}{EI_{SOx,conv} - 1}\right), \tag{5}$$

where $\Delta f_{SOx,\,EI}$ denotes the fractional impact factor for SO_x expressed in terms of emission indices.

Using

$$EI_{SOx,SAJF} = EI_{SOx,conv} * \frac{[S_{SAJF}]}{[S_{conv}]}, \tag{6}$$

where $EI_{SOx,\,SAJF}$ denotes the emissions factor for the neat SAJF. Then

$$\Delta_{SOx} = \left(\frac{blend\%}{100\%}\right) * \left(\frac{[S_{SAJF}]}{[S_{conv}] - 1}\right) * EI_{SOx,conv} \tag{7}$$

where $[S_{SAJF}]$ and $[S_{conv}]$ denote the sulfur weight percents for the component fuels, and thus the SO_x fractional impact factor $\Delta f_{SOx,\,[S]}$ can be written in terms of sulfur weight percents as

$$\Delta f_{SOx,[S]} = \left(\frac{blend\%}{100\%}\right) * \left(\frac{[S_{SAJF}]}{[S_{conv}]} - 1\right). \tag{8}$$

There will be measurement uncertainties in blend%, EI_{SOx}, and [S], which will lead to uncertainties in $\Delta f_{SOx,\,EI}$ and $\Delta f_{SOx,\,[S]}$, as given by the expressions:

$$\delta\Delta f_{SOx,EI} = \Delta f_{SOx} - \left(\frac{blend\%}{100\%}\right)\left(1 + \delta\left(\frac{blend\%}{100\%}\right)\right) * \left[\frac{EI_{SOx,sajf} - \delta EI_{SOx}}{EI_{SOx,conv} + \delta EI_{SOx}} - 1\right], \tag{9}$$

and

$$\delta\Delta f_{SOx,[S]} = \Delta f_{SOx} - \left(\frac{blend\%}{100\%}\right) * \left(1 + \delta\left(\frac{blend\%}{100\%}\right)\right) * \left\{\frac{[S_{SAJF}] - \delta[S]}{[S_{conv}] + \delta[S]} - 1\right\}. \tag{10}$$

where δEI_{SOx} and $\delta[S]$ denote uncertainties in measure SO_x emission index and fuel sulfur content.

Here the uncertainties are taken to be the difference between the impact factor calculated using the parameters $EI_{SOx,SAJF}$, and $EI_{SOx,conv}$ shifted by δEI_{SOx} in such a way as to give the largest deviation, for the case of Eq. (5), and calculated using the parameters $[S_{SAJF}]$ and $[S_{conv}]$ shifted by $\delta[S]$ in such a way as to give the largest deviation, for the case of Eq. (8).

STEP 5 – In Reference 6 (Beyersdorf, et al.), a paper describing the results of the Alternative Aviation Fuel Experiment (AAFEX) campaign, the SAJF of interest was Fisher-Tropsch (FT) Gas To Liquid (GTL) and the conventional fuel was JP-8 in a 50% blend. The fuel sulfur content of the JP-8 was reported to be 1148 ppm, and the sulfur content of the FT GTL was assumed to be zero. However, SO_2 was observed in the exhaust of neat FT GTL. A companion report for project AAFEX (ref 22) provided the fuel analyses for all fuels burned in the project and revealed a fuel sulfur content of 19 ppm for the neat FT GTL. The blend% of 50% used in AAFEX applied to Eq. (5) and Eq. (9) thus gives a $\Delta f_{SOx,\,[S]}$ of -0.4917 ± 0.0069, assuming a 0.5% uncertainty in blend% and uncertainties in fuel sulfur content of 10%. Using the Beyersdorf observational EI data ($EI_{SOx,\,conv}$ = 2.3 g/kg; $EI_{SOx,\,SAJF}$ = 0.2 g/kg) in Eq. (5) and (9) gives $\Delta f_{SOx,\,EI}$ = -0.492 ± 0.036, assuming a 0.5% uncertainty in blend% and uncertainties in EI measurements of 0.15 g/kg. These measurement uncertainties are conservative estimates of uncertainty based on measurement experience. To determine if the difference in impact factors between the EI method and the Sulfur content method is significant, the Error Ratio (ER) can be defined as:

$$ER = \frac{|\Delta fSOX,EI - \Delta fSOX,[S]|}{\delta\Delta fSOX,EI + \delta\Delta fSOX,[S]} \tag{11}$$

where ER < 1 implies the error bars in Δf_{SOx} overlap. For the Beyersdorf data, ER=0.83. Hence the impact factor relationship, Eq. (8) and (10), agrees with the measurement data to within experimental error.

In Reference 20 (Corporan, et al.), a paper describing emissions from blends of Hydroprocessed Renewable Jet (HRJ) and FT SAJFs with JP-8, burned in F117-PW-100 engines on a C-17 aircraft. A 50% blend of HRJ with JP-8 was studied. The fuel sulfur content of the JP-8 was reported to be 0.08 wt.%, and 0.02 wt.% for the HRJ. Applying Eq. (8) and (1) gives a $\Delta f_{SOx[S]}$ of -0.375 ± 0.072, assuming a 0.5% uncertainty in blend% and uncertainties in fuel sulfur content of 1%. Using the Corporan normalized observational EI data (EI_{conv} = 1; EI_{SAJF} = 0.55) in Eq. (5) and (9) gives $\Delta f_{SOx,\,EI}$ = -0.225 ± 0.181, assuming a 0.5% uncertainty in blend% and uncertainties in EI measurements of 0.3. For the Corporan data, ER=0.59. Hence the impact factor relationship, Eq. (8) and (10), agrees with the measurement data to within experimental error.

SO_x Findings

The fact that the uncertainty in ΔfSO_x, [S] is smaller than the absolute value of ΔfSO_x, [S] implies that there is a statistically meaningful SO_x impact associated with alternative fuel usage.

$$\Delta fSOx,[S] = \left(\frac{blend\%}{100\%}\right) * \left(\frac{[S_{SAJF}]}{[S_{conv}]} - 1\right).$$

$$\delta\Delta fSOx,[S] = \Delta fSOx - \left(\frac{blend\%}{100\%}\right) * \left(1 + \delta\left(\frac{blend\%}{100\%}\right)\right) * \left[\frac{[S]_{sajf}-\delta[S]}{[S]_{conv}+\delta[S]} - 1\right]$$

Illustrative example:

To illustrate the use of the impact factor, assume an airport has normal SO_x emissions of 1,000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF at a 50% blend (50% blend ➔ Δf_ SO_x = -0.375 and $\delta\Delta f\ SO_x$,[S] = 0.072), and assuming $[S]_{sajf}$ = 0.02 and $[S]_{conv}$=0.08, the SO_x emissions savings would be 45 kg/year (1000*0.12*0.375) with an uncertainty of 8.6 kg/year (1000*0.12*0.072).

4.2 nvPM Number

For nvPM number we anticipated a similar relationship as that for SO_x. At currently approved blend percentages of up to 50%, the reduction in nvPM number emissions is directly related to the amount of SAJF burned, thus the emission index of the blend ($EIn_{PM,\ blend}$), for a given engine and operating condition, can be expressed as follows:

$$\mathrm{EIn}_{\mathrm{PM,blend}} = \alpha * \mathrm{EIn}_{\mathrm{PM,conv}} * (1 - blend\%) + \beta * \mathrm{EIn}_{\mathrm{PM,SAJF}} * blend\%, \tag{12}$$

where $EIn_{PM,\ conv}$ and $EIn_{PM,\ SAJF}$ denote the emission indices for the conventional and alternate fuels, respectively, and α and β are constants. The impact on nvPM number due to the SAJF for specific engines and their operating conditions is

$$\begin{aligned}\Delta\mathrm{f\_EIn} &= \frac{\mathrm{EIn}_{\mathrm{PM,blend}} - \mathrm{EIn}_{\mathrm{PM,conv}}}{\mathrm{EIn}_{\mathrm{PM,conv}}} \\ &= \left[\alpha * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \left(\frac{\mathrm{EIn}_{\mathrm{PM,ASJF}}}{\mathrm{EIn}_{\mathrm{PM,conv}}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1 \\ &= \varphi 0 + \varphi 1 * \left(\frac{blend\%}{100\%}\right) \left(with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{\mathrm{EIn}_{\mathrm{PM,ASJF}}}{\mathrm{EIn}_{\mathrm{PM,conv}}}\right) - \alpha\right).\end{aligned} \tag{13}$$

STEP 1 – Based on the limited available data from the State of the Industry Review, the observational data is found to be dependent on power and blend%. For use in the Aviation Environmental Design Tool (AEDT) model, an average value for impact factor, weighted over LTO cycle fuel burns, is calculated, resulting in impact factors depending on blend% alone.

STEP 2 AND 3 – The nvPM N emissions impact spreadsheet is given in Table 4 below. In the spreadsheet Δf_EIn {LTO EIn} denotes the power dependent nvPM Number impact factors; FF*t denotes the product of fuel flow rate for a given operational mode and the time in mode as defined by the ICAO LTO cycle. This represents the fuel burned in the mode and is used as a weighting function to get an LTO weighted impact factor, Δf_EIn_{weight}. $\Delta f\_EIn_{avg,\ weight}$ is the average of all Δf_EIn_{weight} values recorded for a given blend%. Multiple values were only found for 50% and 100% blend percentages; δ denotes the standard deviation in Δf_EIn_{weight} values and is used as the uncertainty in $\Delta f\_EIn_{avg,\ weight}$.

STEP 4 – Development of functional impact relationships. Table 4 gives the $\Delta f\_EIn_{avg,\ weight}$ for two values of blend%, with associated uncertainty (δ). The published references gave EI values at various measured engine power points. Linear interpolations or extrapolations were performed on these to get EI values at the LTO cycle power points. Line loss was accommodated in this analysis through its implicit inclusion in the published data.

Table 4: nvPM number emissions impact spreadsheet

Species	Engine	Conv fuel	SAJF	blend%	Ref #	LTO pwr	LTO EIn_{blend} (arbitrary units)	LTO EIn_{conv} (arbitrary units)	LTO Δf_EIn	FF*t Wt fct	$Δf\_EIn_{weight}$	$Δf\_EIn_{avg, weight}$	δ
nvPM N	CFM56-2	JP-8	FT GTL	50	6	7	2.32E+14	1.17E+15	-0.80	3.128	-0.66	-0.48	0.10
						30	1.49E+14	9.89E+14	-0.85	1.48			
						85	7.13E+14	1.45E+15	-0.51	2.488			
						100	9.04E+14	1.37E+15	-0.34	0.961			
nvPM N	GE CF700-2-D-2	Jet A1	HEFA-SPK	50	15	7	2.90E+15	7.30E+15	-0.60	3.128	-0.54		
						30	3.09E+15	7.77E+15	-0.60	1.48			
						85	4.37E+15	9.07E+15	-0.52	2.488			
						100	6.97E+15	9.87E+15	-0.29	0.961			
nvPM N	CFM56-7B	Jet A1	FT GTL	50	36	7	2.39E+01	1.00E+02	-0.76	3.128	-0.51		
						30	4.37E+01	1.00E+02	-0.56	1.48			
						85	7.18E+01	1.00E+02	-0.28	2.488			
						100	7.75E+01	1.00E+02	-0.23	0.961			
nvPM N	PW308	JP-8	FT GTL	50	22	7	66.66421	100	-0.33	3.128	-0.26		
						30	7.16E+01	1.00E+02	-0.28	1.48			
						85	81.35593	100	-0.19	2.488			
						100	81.35593	100	-0.19	0.961			
nvPM N	TF33	JP-8	FT GTL	50	22	7	56.96892	100	-0.43	3.128	-0.33		
						30	62.43468	100	-0.38	1.48			
						85	76.19070	100	-0.24	2.488			
						100	79.7	100.0	-0.20	0.961			
nvPM N	CFM56-2	JP-8	HEFA T	50	22	7	19.02036	100	-0.81	3.128	-0.46		
						30	37.76184	100	-0.62	1.48			
						85	84.7	100.0	-0.15	2.488			
						100	116.1782	100	0.16	0.961			
nvPM N	CFM56-7	JP-8	FT GTL	50	22	7	18.25047	100	-0.82	3.128	-0.45		
						30	49.2	100	-0.51	1.48			
						85	87.97677	100.0	-0.12	2.488			
						100	98.3	100	-0.02	0.961			
nvPM N	T63	JP-8	FT GTL_{Shel}	50	22	7	41.09336	100	-0.59	3.128	-0.46		
						30	47.47716	100	-0.53	1.48			

Species	Engine	Conv fuel	SAJF	blend%	Ref #	LTO pwr	LTO EIn_{blend} (arbitrary units)	LTO EIn_{conv} (arbitrary units)	LTO Δf_EIn	FF*t Wt fct	$Δf\_EIn_{weight}$	$Δf\_EIn_{avg, weight}$	δ
						85	67.8	100.0	-0.32	2.488			
						100	71.50738	100	-0.28	0.961			
nvPM N	T63	JP-8	HEFA T_{Dyn}	50	22	7	38.25739	100	-0.62	3.128	-0.48		
						30	47.10700	100	-0.53	1.48			
						85	65.3	100.0	-0.35	2.488			
						100	68.34655	100	-0.32	0.961			
nvPM N	T63	JP-8	FT GTL_{Syn}	50	22	7	35.43809	100	-0.65	3.128	-0.51		
						30	42.68464	100	-0.57	1.48			
						85	62.7	100.0	-0.37	2.488			
						100	67.65956	100	-0.32	0.961			
nvPM N	T63	JP-8	HEFA C	50	22	7	35.78425	100	-0.64	3.128	-0.51		
						30	45.08090	100	-0.55	1.48			
						85	62.7	100.0	-0.37	2.488			
						100	65.18571	100	-0.35	0.961			
nvPM N	T63	JP-8	HEFA T	50	22	7	30.55271	100	-0.69	3.128	-0.53		
						30	41.73004	100	-0.58	1.48			
						85	62.7	100.0	-0.37	2.488			
						100	66.42264	100	-0.34	0.961			
nvPM N	CFM56-2	JP-8	FT GTL	100	6	7	1.05E+14	1.17E+15	-0.91	3.128	**-0.83**	**-0.66**	**0.33**
						30	1.30E+13	9.89E+14	-0.99	1.48			
						85	3.98E+14	1.45E+15	-0.72	2.488			
						100	5.39E+14	1.37E+15	-0.61	0.961			
nvPM N	GE CF700-2-D-2	Jet A1	HEFA-SPK	100	15	7	5.70E+15	7.30E+15	-0.22	3.128	-0.17		
						30	6.08E+15	7.77E+15	-0.22	1.48			
						85	7.63E+15	9.07E+15	-0.16	2.488			
						100	9.83E+15	9.87E+15	0.00	0.961			
nvPM N	GE CF700-2-D-2	Jet A1	FT-SPK	100	15	7	2.00E+14	7.30E+15	-0.97	3.128	-0.90		
						30	2.95E+14	7.77E+15	-0.96	1.48			
						85	1.27E+15	9.07E+15	-0.86	2.488			
						100	3.57E+15	9.87E+15	-0.64	0.961			
nvPM N	CFM56-7B	Jet A1	FT GTL	100	36	7	1.41E+00	1.00E+02	-0.99	3.128	-0.72		
						30	1.27E+01	1.00E+02	-0.87	1.48			
						85	5.77E+01	1.00E+02	-0.42	2.488			
						100	6.06E+01	1.00E+02	-0.39	0.961			

An uncertainty weighted least squares quadratic fit (Δf_EIn vs. blend%) was performed using the data given in Table 5. The resulting values for the fit (Δf_EIn_fit) are given in Table 5. The fit function is:

$$\Delta\text{f\_EIn\_fit} = 2.0E-30 - 1.25E-2 * blend\% + 5.91E-5 * blend\%\text{\^{}}2. \tag{14}$$

A quadratic function was found to work better than the linear expression given above in the introduction.

Table 5: nvPM impact factor analysis

blend%	$\Delta f_{avg,\ weight}$	δ	Δf_EIn
0	0	0	0.00
50	-0.48	0.10	-0.48
100	-0.66	0.33	-0.66

STEP 5 – The original Δf_EIn data (points) and the weighted quadratic function fit (dotted line) are shown in Figure 2. The blue data points represent the original impact factors, the orange data points represent the uncertainty weighted functional fit values.

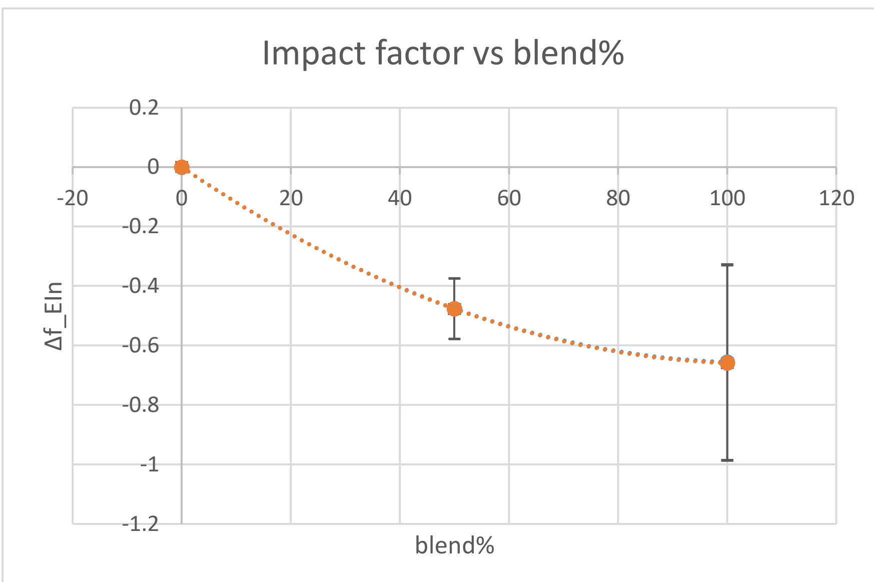


Figure 2: Δf_EIn data and uncertainty weighted quadratic function fit

The original and fitted data along with an impact factor ER is given in

Table 6. The number-based emission index impact factor ER is defined as

$$\mathrm{ER}_{\Delta f\_EIn} = \frac{|\ \Delta f\_EIn\_fit - \Delta f\_EIn\ |}{(2*\delta)} \qquad (15)$$

Table 6: $\Delta f\_EIn_{avg, weight}$, Δf_EIn_{fit}, and associated ER

blend%	$\Delta f_{avg, weight}$	δ	Δf_EIn	ER
0	0	0	0	0
50	-0.48	0.10	-0.48	0.01
100	-0.66	0.33	-0.66	0.01

The fact that the curve in Figure 2 passes through the data and their associated ERs are always less than unity, reveals that the Δf_EInfit function is a good representation for the EIn impact factor data and is thereby validated.

The fit coefficients (constant, linear term, quadratic term) in the uncertainty weighted EIn impact factor equation contain uncertainty. Taking the uncertainty terms to add in quadrature, the uncertainty in the EIn impact factor (given above Table 4) function becomes:

nvPM N Findings

The fact that the uncertainty in Δf_EIn_fit is smaller than the absolute value of Δf_EIn_fit implies that there is a statistically meaningful nvPM N impact associated with alternative fuel usage.

$$\Delta f\_EIn\_fit = -1.25E-2 * blend\% + 5.91E-5 * blend\%\hat{}2.$$

$$\delta\Delta f\_EIn\_fit = \{(5.23E-3 * blend\%)^2 + (7.73E-5 * blend\%2)2\}^{1/2}$$

$$\delta\Delta f\_EIn\_fit = \{(1.0E-8)^2 + (5.23E-3 * blend\%)^2 + (7.73E-5 * blend\%2)2\}^{1/2} \quad (16)$$

Illustrative example:

To illustrate the use of the impact factor for nvPM N, assume an airport has normal particle number emissions of 10^{16}/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend (50% blend ➔ Δf_EIn = -0.48) the nvPM number emissions savings would be 5.73 x 10^{14}/year (10^{16} * 0.12 * 0.48) with an uncertainty of 3.9x10^{14}/year (10^{16}*0.12*δΔf=0.325).

4.3 nvPM Mass

For nvPM mass we anticipate a similar relationship as that for nvPM N. At currently approved blend percentages of up to 50%, the reduction in nvPM mass emissions is directly related to the amount of SAJF burned, thus the emission index of the blend ($EIm_{PM, blend}$), for a given engine and operating condition, can be expressed as follows

$$EIm_{PM,blend} = \alpha * EIm_{PM,conv} * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * EIm_{PM,SAJF} * \left(\frac{blend\%}{100\%}\right), \quad (17)$$

where $EIm_{PM, conv}$ and $EIm_{PM, SAJF}$ denote the mass-based emission indices for the conventional and alternate fuels.

The impact on nvPM mass due to the SAJF for specific engines and their operating conditions is

$$\Delta f\_EIm = \frac{EIm_{PM,blend} - EIm_{PM,conv}}{EIm_{PM,conv}} = \left[\alpha * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \left(\frac{EIm_{PM,ASJF}}{EIm_{PM,conv}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1$$
$$= \varphi 0 + \varphi 1 \left(\frac{blend\%}{100\%}\right)\left(with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{EIm_{PM,ASJF}}{EIm_{PM,conv}}\right) - \alpha\right). \quad (18)$$

STEP 1 – Based on the limited available data from the State of the Industry Report, the observational data is found to be dependent on power and blend%. For use in the AEDT model, an average value for impact factor, weighted over LTO cycle fuel burns, is calculated, resulting in impact factors depending on blend% alone.

STEPS 2 AND 3 – The nvPM Mass emissions impact spreadsheet is given in Table 7 below. In the spreadsheet Δf_EIm denotes the power dependent nvPM Mass impact factors; FF*t denotes the product of fuel flow rate for a given operational mode and the time in mode as defined by the ICAO LTO cycle. This represents the fuel burned in the mode and is used as a weighting function to get an LTO weighted impact factor, Δf_EIm_{weight}. $\Delta f\_EIm_{avg, weight}$ is the average of all Δf_EIm_{weight} values recorded for a given blend%. δ denotes the standard deviation in Δf_EIm_{weight} values and is used as the uncertainty in $\Delta f\_EIm_{avg, weight}$.

Table 7: nvPM mass emissions data

Species	Engine	Conv fuel	SAJF	blend%	Ref #	LTO pwr	LTO EIn_{blend} (arbitrary units)	LTO EIn_{conv} (arbitrary units)	LTO Δf_EIm	FF*t Wt fct	$Δf\_EIm_{weight}$	$Δf\_EIm_{avg, weight}$	δ
nvPM M	CFM56-2C	JP-8	FT GTL	50	6	7	1.91E+00	1.01E+01	-0.81	3.1278	-0.77	-0.65	0.12
						30	1.26E+00	1.40E+01	-0.91	1.48			
						85	2.89E+01	9.14E+01	-0.68	2.4882			
						100	4.46E+01	1.15E+02	-0.61	0.9611			
nvPM M	GE CF700-2-D-2	Jet A1	HEFA-SPK	50	15	7	8.52E+00	1.70E+01	-0.50	3.1278	-0.66		
						30	9.417808	28.68151	-0.67	1.48			
						85	23.67424	114.5833	-0.79	2.4882			
						100	60.60606	296.4015	-0.80	0.9611			
nvPM M	CFM56-7B	Jet A1	FT GTL	50	36	7	3.52E+01	1.00E+02	-0.65	3.1278	-0.53		
						30	3.66E+01	1.00E+02	-0.63	1.48			
						85	6.34E+01	1.00E+02	-0.37	2.4882			
						100	6.06E+01	1.00E+02	-0.39	0.9611			
nvPM M	CFM56-2C	JP-8	FT GTL	100	6	7	5.66E-01	1.01E+01	-0.94	3.1278	-0.93	-0.70	0.24
						30	1.17E-01	1.40E+01	-0.99	1.48			
						85	8.77E+00	9.14E+01	-0.90	2.4882			
						100	1.80E+01	1.15E+02	-0.84	0.9611			
nvPM M	GE CF700-2-D-2	Jet A1	HEFA-SPK	100	15	7	1.14E+01	1.70E+01	-0.33	3.1278	-0.38		
						30	16.73412	28.68151	-0.42	1.48			
						85	67.23485	114.5833	-0.41	2.4882			
						100	183.7121	296.4015	-0.38	0.9611			
nvPM M	GE CF700-2-D-2	Jet A1	FT-SPK	100	15	7	5.68E+00	1.70E+01	-0.67	3.1278	-0.81		
						30	5.681818	28.68151	-0.80	1.48			
						85	7.575758	114.5833	-0.93	2.4882			
						100	13.25758	296.4015	-0.96	0.9611			
nvPM M	CFM56-7B	Jet A1	FT GTL	100	36	7	3.24E+01	1.00E+02	-0.68	3.1278	-0.69		
						30	9.86E+00	1.00E+02	-0.90	1.48			
						85	3.94E+01	1.00E+02	-0.61	2.4882			
						100	3.66E+01	1.00E+02	-0.63	0.9611			

STEP 4 – Table 8 gives $Δf\_EIm_{avg, weight}$ for three values of blend%, with associated uncertainty. Δf_EIm is zero at blend%=0 with zero uncertainty, since the impact of alternate fuel is zero when there is no alternate fuel.

An uncertainty weighted least squares quadratic fit is performed using the uncertainties given in Table 8. The resulting values for the fit (Δf_EIm_fit) are given in Table 8. The fit function is:

$$\Delta f\_EIm\_fit = -7.98E-31 - 1.90E-2 * blend\% + 1.20E-4 * blend\%\hat{}2. \quad (19)$$

A quadratic function was found to work better than the linear expression given above in the introduction.

Table 8: nvPM mass impact factor analysis

blend%	$\Delta f_{avg,\ weight}$	δ	Δf_EIm_{fit}
0	0	0	0.00
50	-0.65	0.12	-0.65
100	-0.70	0.24	-0.70

STEP 5 – The original Δf_EIm data (orange points) and the weighted quadratic function fit (dotted line) are shown in Figure 3.

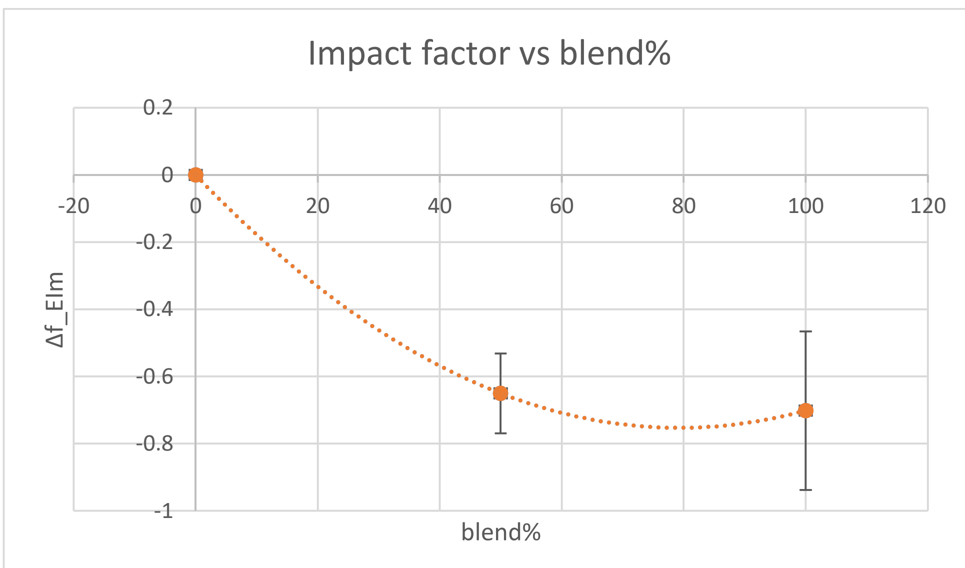


Figure 3: Δf_EIm data and uncertainty weighted quadratic function fit

The original and fitted data along with an impact factor ER is given in Table 9. The ER is defined as

$$ER_{\Delta f\_EIn} = \frac{|\Delta f\_EIn\_fit - \Delta f\_EIn|}{2 * \delta} \quad (20)$$

Table 9: $\Delta f_{avg,\ weight}$, Δf_EIm_{fit}, and associated ER

blend%	$\Delta f_{avg,\ weight}$	δ	Δf_EIm_{fit}	ER
50	-0.65	0.12	-0.65	0.00
100	-0.70	0.24	-0.70	0.00

The fact that the fitted curve passes through the data error bars in Figure 3 and their associated ERs are always less than unity, reveals that the Δf_EIm_{fit} function is a good representation for the EIm impact factor data and is thereby validated.

nvPM Mass Findings

The fact that the uncertainty in Δf_EIm_fit is smaller than the absolute value of Δf_EIm_fit implies that there is a statistically meaningful nvPM M impact associated with alternative fuel usage.

$$\Delta\text{f\_EIm\_fit} = -1.90E-2 * blend\% + 1.20E-4 * blend\%\text{^}2$$

$$\delta\Delta\text{f\_EIm\_fit} = \{(5.31E-3 * blend\%)^2 + (6.70E-5 * blend\%\text{^}2)^2\}^{1/2}$$

The fit coefficients (constant, linear term, quadratic term) in the uncertainty weighted EIm impact factor equation contain uncertainty. Taking the uncertainty terms to add in quadrature, the uncertainty in the EIm impact factor (given above Table 8) function becomes:

$$\delta\Delta f\_EIm\_fit = \{(1.0E-8)^2 + (5.31E-3 * blend\%)^2 + (6.70E-5 * blend\%2)^2\}^{1/2} \quad (21)$$

Illustrative example:

To illustrate the use of the impact factor for nvPM Mass, assume an airport has normal particle mass emissions of 1000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend (50% blend ➔ Δf_EIm = -0.65) the nvPM mass emissions savings would be 78 kg/year (1000 * 0.12 * 0.65) with an uncertainty of 38 kg/year (1000*0.12*δΔf=0.314).

4.4 NO_x

For NO_x we anticipated a small if not negligible impact. At currently approved blend percentages of up to 50%, the reduction in NO_x emissions is directly related to the amount of SAJF burned, thus the emission index of the blend ($EI_{NOx,\ blend}$), for a given engine and operating condition, can be expressed in a similar manner as used for SO_x, nvPM N, and nvPM Mass:

$$\mathrm{EI}_{\mathrm{NOx,blend}} = \alpha * \mathrm{EI}_{\mathrm{NOx,conv}} * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \mathrm{EI}_{\mathrm{NOx,SAJF}} * \left(\frac{blend\%}{100\%}\right), \quad (22)$$

The impact on NO_x emissions due to the SAJF for specific engines and their operating conditions is

$$\Delta f\_EI_{NOx} = \frac{EI_{NOx,blend} - EI_{NOx,conv}}{EI_{NOx,conv}} = \left[\alpha * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \left(\frac{EI_{NOx,ASJF}}{EI_{NOx,conv}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1 = \varphi 0 + \varphi 1 * \left(\frac{blend\%}{100\%}\right) \ (with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{EI_{NOx,ASJF}}{EI_{NOx,conv}}\right) - \alpha). \quad (23)$$

STEP 1 – Based on the limited available data from the *State of the Industry Report*, the observational data is found to be dependent on power and blend%. For use in the AEDT model, an average value for impact factor, weighted over LTO cycle fuel burns, is calculated, resulting in impact factors depending on blend% alone.

STEP 2 AND 3 – The NO_x impact spreadsheet is given in Table 10 below. In the spreadsheet Δf_EI_{NOx} denotes the NO_x impact factors after averaging over the ICAO LTO cycle. $\Delta f\_EI_{NOx,\ avg}$ is the average of all Δf_EI_{NOx} values recorded for a given blend%. δ denotes the standard deviation in Δf_EI_{NOx} values and is used as the uncertainty in $\Delta f\_EI_{NOx,\ avg.}$

Table 10: NO_x emissions impact spreadsheet

Species	Engine type	Conv fuel	SAJF	blend%	Ref #	Δf_EINOx	Δf_EINOx_Avg	δ
NO_x	SaM146	Jet A1	DSHC	10	42	0	-0.0253	0.04376
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	10	17	0		
NO_x	CFM56-5C4	Jet A1	DSHC	10	42	-0.0758		
NO_x	SaM146	Jet A1	DSHC	20	42	0	-0.0783	0.12378
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	20	17	0		
NO_x	CFM56-5C4	Jet A1	DSHC	20	42	-0.0532		
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	25	17	0	-0.0033	0.00577
NO_x	CFM56-7B	Jet A	Bio-SPK	25	51	-0.01		
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	40	17	0	-0.0899	0.1557
NO_x	9 pt. lean direct low emissions combustor	JP-8	AMJ	50	49	0	-0.0047	0.01643
NO_x	AE 3007 combustor	JP-8	ATJH SPK	50	26	0		
NO_x	TFE34	JP-8	ATJH SPK	50	26	0		
NO_x	PW615F	JP-8	ATJH SPK	50	26	0		
NO_x	TPE331-10YGD	JP-8	ATJH SPK	50	26	0		
NO_x	F117-PW-100 = PW2000	JP-8	Beef Tallow	50	20	0		
NO_x	T63-A-701	JP-8	Beef Tallow	50	21	0		
NO_x	TPE331-10	JP-8	Bio-SPK	50	10	0		

Species	Engine type	Conv fuel	SAJF	blend%	Ref #	Δf_EINOx	Δf_EINOx_Avg	δ
NO_x	T63-A-703	JP-8	Fats & Grease	50	21	0		
NO_x	T63-A-700	JP-8	FT GTL	50	21	0		
NO_x	CFM56-7	JP-8	FT GTL	50	22	0		
NO_x	CFM56-2	JP-8	FT GTL	50	22	0		
NO_x	F117	JP-8	FT GTL	50	22	0		
NO_x	TF33	JP-8	FT GTL	50	22	0		
NO_x	PW308	JP-8	FT GTL	50	22	0		
NO_x	T63-A-700	JP-8	HEFA	50	21	0		
NO_x	CFM56-7	JP-8	HEFA	50	22	0		
NO_x	CFM56-2	JP-8	HEFA	50	22	0		
NO_x	F117	JP-8	HEFA	50	22	0		
NO_x	TF33	JP-8	HEFA	50	22	0		
NO_x	PW308	JP-8	HEFA	50	22	0		
NO_x	JT9D-7R4G2	Jet A	HVO	50	51	0		
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	50	17	0		
NO_x	CFM56-7B	Jet A	Bio-SPK	50	51	-0.05		
NO_x	CFM56-7	Jet A1	FT-GTL	50	47	-0.0673		
NO_x	T63-A-701	JP-8	Beef Tallow	100	21	0	-0.032	0.07233
NO_x	T63-A-703	JP-8	Fats & Grease	100	21	0		
NO_x	T63-A-700	JP-8	FT GTL	100	21	0		
NO_x	T63-A-700	JP-8	HEFA	100	21	0		
NO_x	GTCP85 Garret Honeywell APU	Jet A1	UCO SPK	100	17	0		
NO_x	CFM56-7	Jet A1	FT-GTL	100	47	-0.1941		
NO_x	MK113 APU Artouste	Jet A1	FT-GTL	100	34	-0.030		

STEP 4 –Table 11 takes selected parameters from Table 10 for further analysis.

Table 11: NO_x impact factors vs. blend%

blend%	Δf_EINOx_Avg	δ
10	-0.0253	0.04376
20	-0.018	0.031
25	-0.0033	0.00577
40	0	0.006

blend%	Δf_EINOx_Avg	δ
50	-0.0047	0.01643
100	-0.032	0.07233

Figure 4 shows a plot of $\Delta f\_EI_{NOx,\ Avg}$ vs blend% with associated uncertainties. This plot suggests that a constant function is the best fit to the data. An uncertainty weighted least squares fit of a constant to the data was performed yielding a result of

$$\Delta f\_EI_{NOx} = -0.0024 \pm 0.0039 \tag{24}$$

The fact that the uncertainty in Δf_EI_{NOx} (0.0039) is greater than the absolute value of Δf_EI_{NOx} (0.0024) implies that there is no statistically meaningful NO_x impact associated with alternative fuel usage.

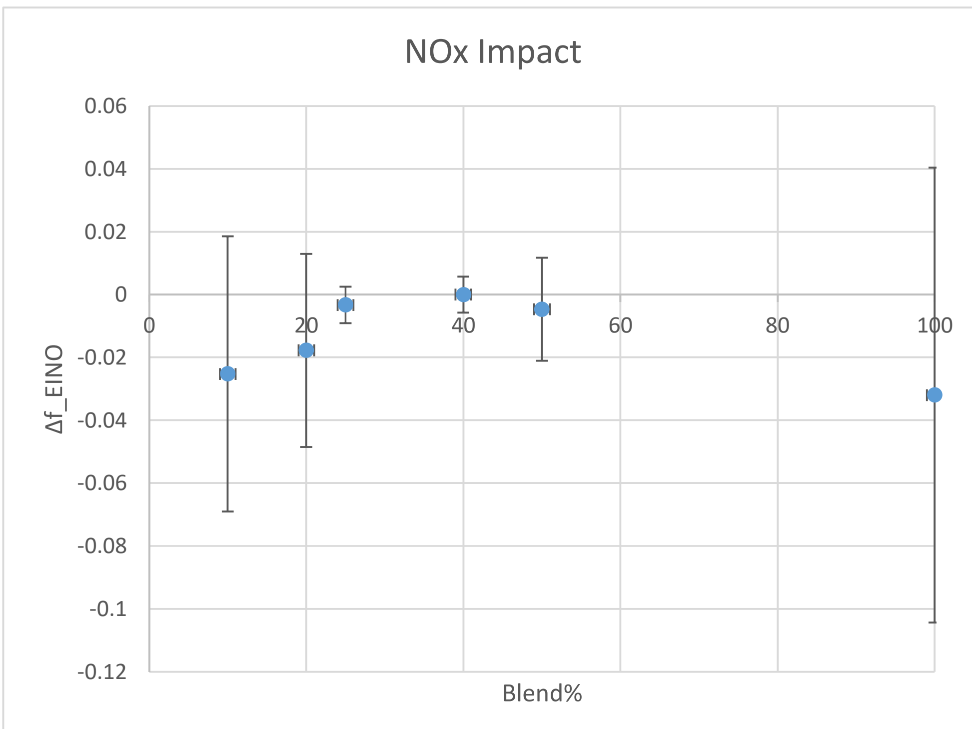


Figure 4: Δf_EINO_x, Avg vs blend% and associated uncertainties

STEP 5 – The original Δf_EI_{NOx} data and the weighted constant function fit values are shown in Figure 5. The blue data points represent the original impact factors, the orange data points represent the uncertainty weighted functional fit values.

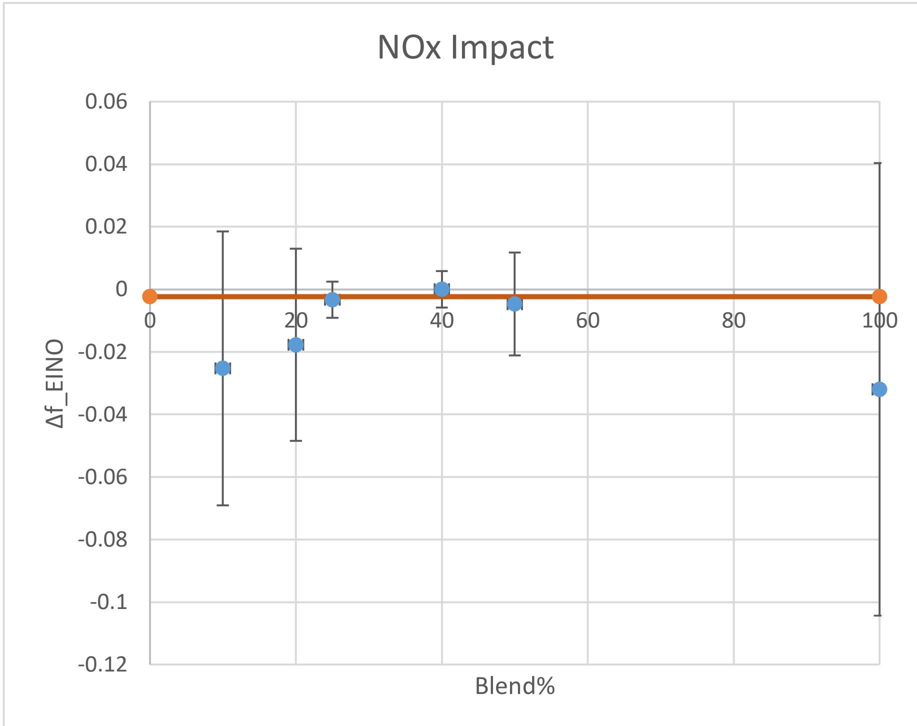


Figure 5: NOx impacts vs. blend%. Blue circles represent original data; orange line gives functional fit.

The original and fitted data along with an impact factor ER is given in Table 12. The ER is defined as

$$ER_{\Delta f\_EINOx} = \frac{\Delta f\_EI_{NOx}\_fit - \Delta f\_EI_{NOx}}{(\delta + \delta_{fit})} \tag{25}$$

with δ_{fit} = 0.0039 denotes the standard deviation in the constant fit.

Table 12: $\Delta f\_EI_{NOx\text{-}Avg}$, $\Delta f\_EI_{NOx,\ fit}$ and associated ER

blend%	Δf_EINOx_Avg	δ	Δf_EINOx_fit	δ_fit	ER
10	-0.0253	0.04376	-0.0024	0.0039	0.48
20	-0.018	0.031	-0.0024	0.0039	0.44
25	-0.0033	0.00577	-0.0024	0.0039	0.10
40	0	0.006	-0.0024	0.0039	-0.25
50	-0.0047	0.01643	-0.0024	0.0039	0.11
100	-0.032	0.07233	-0.0024	0.0039	0.39

The fact that the error bars in Figure 5 overlap and their associated ERs are always less than unity, reveals that the Δf_EI_{NOx} function is a good representation for the EI_{NOx} impact factor data and is thereby validated.

NO_x Findings

The fact that the uncertainty in Δf_EI_{NOx} (0.0039) is greater than the absolute value of Δf_EI_{NOx} (0.0024) implies that there is no statistically meaningful NO_x impact associated with alternative fuel usage.

Illustrative example:

To illustrate the use of the impact factor for NO_x, assume an airport has normal NO_x emissions of 1000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend the NO_x emissions savings would be 0.29 kg/year (with an uncertainty of 0.47 kg/year). The fact that the uncertainty in the NO_x emissions savings (0.47 kg/year) is greater than the absolute value of savings (0.29 kg/year) implies that there is no statistically meaningful NO_x impact associated with alternative fuel usage.

4.5 CO

For CO we anticipated a similar relationship as that for nvPM. At currently approved blend percentages of up to 50%, the reduction in CO emissions is directly related to the amount of SAJF burned, thus the emission index of the blend ($EI_{CO,\ blend}$), for a given engine and operating condition, can be expressed in a similar manner as used for SO_x, nvPM N, and nvPM Mass:

$$\mathrm{EI}_{\mathrm{CO,blend}} = \alpha * \mathrm{Ein}_{\mathrm{CO,conv}} * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \mathrm{Ein}_{\mathrm{CO,SAJF}} * \left(\frac{blend\%}{100\%}\right), \quad (26)$$

The impact on CO emissions due to the SAJF for specific engines and their operating conditions is

$$\begin{aligned}\Delta f\_EI_{CO} &= \frac{(\mathrm{EI}_{\mathrm{CO,blend}} - \mathrm{EI}_{\mathrm{CO,conv}})}{\mathrm{EI}_{\mathrm{CO,conv}}} \\ &= \left[\alpha * \left(1 - \frac{blend\%}{100\%}\right) + \beta * \left(\frac{\mathrm{EI}_{\mathrm{CO,SAJF}}}{\mathrm{EI}_{\mathrm{CO,conv}}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1 \\ &= \varphi 0 + \varphi 1 * \left(\frac{blend\%}{100\%}\right) \left(with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{\mathrm{EI}_{\mathrm{CO,SAJF}}}{\mathrm{EI}_{\mathrm{CO,conv}}}\right) - \alpha\right). \quad (27)\end{aligned}$$

STEP 1 – Based on the limited available data from the State of the Industry Report, all the observational data is found to be dependent on blend%. For those cases where an engine power dependency was reported, a weighted average was used, where the weight function was the fuel burned for the ICAO LTO cycle, similar to the NO_x analysis.

STEP 2 AND 3 – The CO impact spreadsheet is given in Table 13 below. In the spreadsheet Δf_EI_{CO} denotes the CO impact factors, and $\Delta f\_EI_{CO,\ avg}$ is the average of all Δf_EI_{CO} values recorded for a given blend%. δ denotes the standard deviation in Δf_EI_{CO} values and is used as the uncertainty in $\Delta f\_EI_{CO,\ avg.}$

Table 13: CO emissions impact spreadsheet

Species	Engine	Conv fuel	SAJF	blend%	Ref #	Δf_EI CO	Δf_EI CO_Avg	δ
CO	Combustor	JP8	FT	50	44	-0.242	-0.129	0.119
CO	PW2000	JP8	HRJ	50	20	-0.265		
CO	T63	JP8	FT shell	50	21	-0.087		
CO	CFM56-7	Jet A1	FT	50	47	0.007		
CO	T701-C	JP8/JetA1	FT & HEFA	50	22	-0.059		
CO	Combustor	JP8	FT	100	44	-0.402	-0.174	0.106
CO	T63	JP8	FT shell	100	21	-0.258		
CO	T63	JP8	FT Rentech	100	21	-0.111		
CO	T63	JP8	HRJ R8	100	21	-0.129		
CO	T63	JP8	HRJ tallow	100	21	-0.114		
CO	T63	JP8	HRJ Came	100	21	-0.154		
CO	CFM56-7	Jet A1	FT	100	47	-0.085		
CO	T701-C	JP8/JetA1	FT shell	100	22	-0.140		

STEP 4 – Table 14 takes selected parameters from Table 13 for further analysis.

Table 14: CO impact factors for selected blend%, with uncertainty

blend%	Δf EI CO	δ
0	0	0
50	-0.129	0.0660
100	-0.174	0.1319

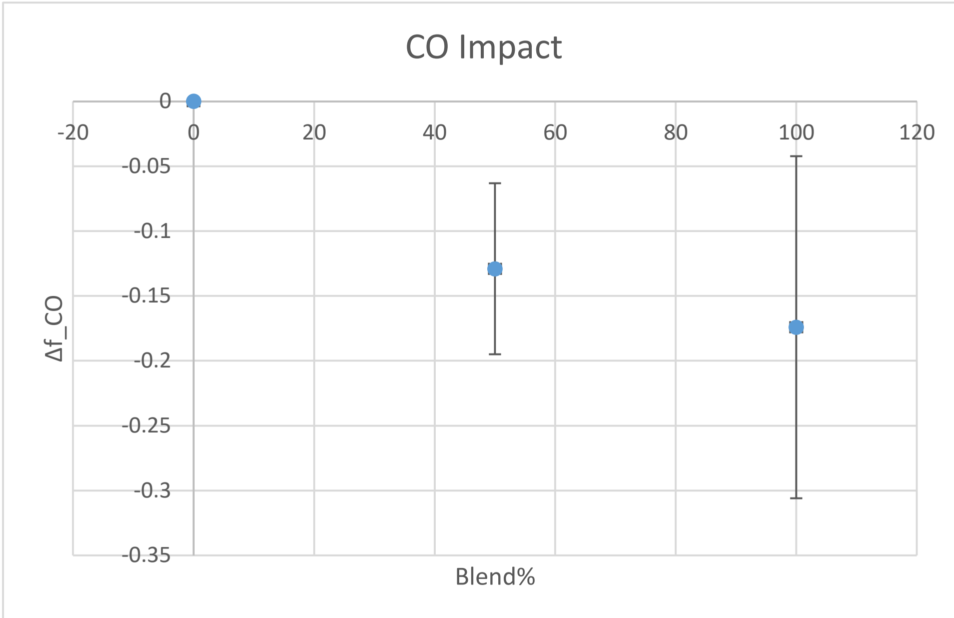


Figure 6: CO impact vs. blend%

Figure 6 shows a plot of $\Delta f\_EI_{CO,\,Avg}$ vs blend% with associated uncertainties. This plot suggests that a linear function is the best fit to the data. An uncertainty weighted linear least squares fit to the data was performed yielding a result of:

$$\Delta f\_EI_{CO} = -2.41E - 16 - 2.16E - 3 * Blend\% \tag{28}$$

STEP 5 – The original Δf_EI_{CO} data and the weighted linear function fit values are shown in Figure 7. The blue data points represent the original impact factors, the orange data points represent the uncertainty weighted functional fit values.

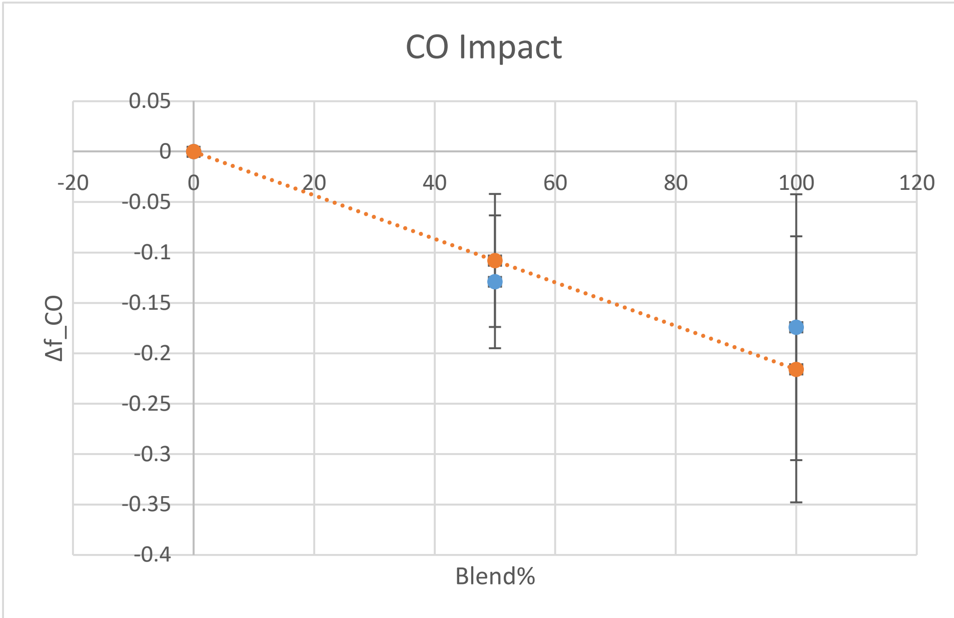


Figure 7: CO impact vs. blend% with linear fit

The original and fitted data along with an impact factor ER is given in Table 15. The ER is defined as

$$\mathrm{ER}_{\Delta f\_EICO} = \frac{|\,\Delta f\_EI_{CO}\_fit - \Delta f\_EI_{CO}\,|}{(2\delta)}\,. \tag{29}$$

Table 15: $\Delta f\_EI_{CO\_Avg}$, $\Delta f\_EI_{CO\_fit}$ and associated ER

blend%	Δf EI CO	δ	Δf EI CO_{Fit}	ER
0	0	0	2.41E-16	0
50	-0.129	0.0660	-0.108	0.16
100	-0.174	0.1319	-0.216	0.16

The fact that the error bars in Figure 7 overlap and their associated ERs are always less than unity, reveals that the Δf_EI_{CO} function is a good representation for the EI_{CO} impact factor data and is thereby validated.

The fit coefficients (constant, linear term) in the uncertainty weighted CO impact factor equation contain uncertainty. Taking the uncertainty terms to add in quadrature, the uncertainty in the CO impact factor function (given above step 5) becomes:

$$\delta\Delta f_{CO,\,fit} = \{(1.0E\text{-}8)^2 + (9.32E\text{-}4*blend\%)^2\}^{1/2} \qquad (30)$$

CO Findings

The fact that the uncertainty in Δf_EI_{CO} is smaller than the absolute value of Δf_EI_{CO} implies that there is a statistically meaningful CO impact associated with alternative fuel usage.

$\Delta f\_EI_{CO} = -\,2.16E\text{-}3*Blend\%$

$\delta\Delta f_{CO,\,fit} = 9.32E\text{-}4*blend\%$

Illustrative example:
To illustrate the use of the impact factor for CO, assume an airport has normal CO emissions of 1000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend (50% blend ➔ Δf = -0.108) the CO emissions savings would be 13 kg/year (1000*0.12*0.108) with an uncertainty of 5.6 kg/year (1000*0.12*δΔf=0.047).

4.6 UHC

For UHC we anticipated a similar relationship as that for CO. At currently approved blend percentages of up to 50%, the reduction in UHC emissions is directly related to the amount of SAJF burned, thus the emission index of the blend ($EI_{UHC,\,blend}$), for a given engine and operating condition, can be expressed in a similar manner as used for SO_x, nvPM N, and nvPM Mass:

$$\mathrm{EI}_{\mathrm{UHC,blend}} = \alpha * EI_{\mathrm{UHC,conv}} * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * EI_{\mathrm{UHC,SAJF}} * \left(\frac{blend\%}{100\%}\right), \qquad (31)$$

The impact on UHC emissions due to the SAJF for specific engines and their operating conditions is

$$\begin{aligned}\Delta f\_EI_{UHC} &= \frac{EI_{\mathrm{UHC,blend}} - EI_{\mathrm{UHC,conv}}}{\mathrm{EI}_{\mathrm{UHC,conv}}}\\ &= \left[\alpha * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \left(\frac{EI_{UHC,SAJF}}{EI_{UHC,conv}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1\\ &= \varphi 0 + \varphi 1 * \left(\frac{blend\%}{100\%}\right)\left(with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{EI_{UHC,SAJF}}{EI_{UHC,conv}}\right) - \alpha\right).\end{aligned} \qquad (32)$$

STEP 1 – Based on the limited available data from the State of the Industry Review, all the observational data is found to be dependent on blend%. For those cases where an engine power dependency was reported, a weighted average was used, where the weight function was the fuel burned for the ICAO LTO cycle, similar to the NO_x and CO analyses.

STEP 2 AND STEP 3 – The UHC impact spreadsheet is given in Table 16 below. In the spreadsheet Δf_EI_{UHC} denotes the UHC impact factors, and $\Delta f\_EI_{UHC, avg}$ is the average of all Δf_EI_{UHC} values recorded for blend%s of 50% and 100%. For 25% blend%, the average is taken over blend%s from 5% to 40%; for 75% blend%, the average is taken over blend%s from 60% to 95%. δ denotes the standard deviation in Δf_EI_{UHC} values over the range of blend% used for the average, and is used as the uncertainty in $\Delta f\_EI_{UHC, avg.}$

Table 16: UHC spreadsheet

Species	Conv fuel	SAJF	blend%	Ref #	Δf_EI UHC	Δf_EI UHC_Avg	δ
UHC	Jet A1	HEFA	5	17	-0.527		
UHC	Jet A1	HEFA	10	17	-0.175		
UHC	Jet A1	HEFA	15	17	-0.438		
UHC	Jet A1	HEFA	20	17	-0.556		
UHC	Jet A1	HEFA	25	17	-0.525	-0.399	0.168
UHC	Jet A1	HEFA	30	17	-0.155		
UHC	Jet A1	HEFA	40	17	-0.417		
UHC	JP-8	FT GTL	50	21	-0.027	-0.140	0.219
UHC	JP-8	FT GTL	50	6	0.000		
UHC	Jet A1	HEFA	50	17	-0.393		
UHC	Jet A1	HEFA	60	17	-0.417		
UHC	Jet A1	HEFA	70	17	-0.382		
UHC	Jet A1	HEFA	75	17	-0.510	-0.447	0.053
UHC	Jet A1	HEFA	80	17	-0.418		
UHC	Jet A1	HEFA	85	17	-0.467		
UHC	Jet A1	HEFA	90	17	-0.413		
UHC	Jet A1	HEFA	95	17	-0.523		
UHC	JP-8	FT GTL	100	21	-0.264	-0.257	0.053
UHC	JP-8	FT GTL	100	21	-0.253		
UHC	JP-8	HRJ R8	100	21	-0.246		
UHC	JP-8	HRJ tallow	100	21	-0.235		
UHC	JP-8	HRJ Came	100	21	-0.348		
UHC	JP-8	FT GTL	100	6	-0.171		
UHC	Jet A1	HEFA	100	17	-0.282		

STEP 4 –

Table 17 takes selected parameters from Table 16 for further analysis.

Table 17: UHC impact factors for selected blend%s, with uncertainty

blend%	Δf_EI UHC_Avg	δ
0	0	0
25	-0.399	0.168
50	-0.140	0.219
75	-0.447	0.053
100	-0.257	0.053

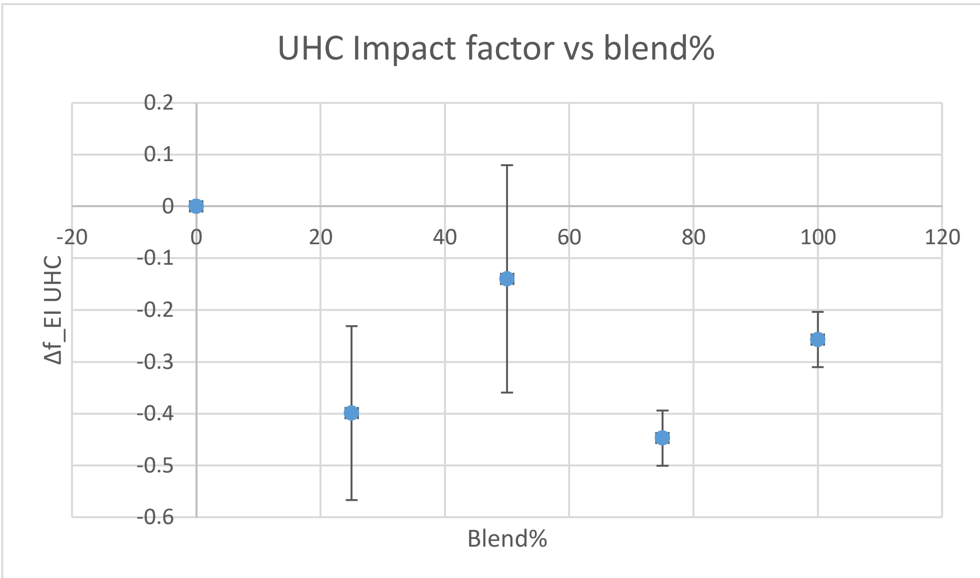


Figure 8: UHC impact vs. blend%

Figure 8 shows a plot of $\Delta f\_EI_{UHC, Avg}$ vs blend% with associated uncertainties. This plot suggests a function that is 0 at 0 blend percent, decreases as blend% increases initially, and asymptotically reaches a constant value at larger blend%s. A best least square fit to this data was done with a hyperbolic tangent function, which has an appropriate shape. The result is given by

$$\Delta f\_EI_{UHC} = -0.3482 * tanh\,(0.322 * blend\%). \qquad (34)$$

A hyperbolic tangent function was also used to fit the uncertainty (δ) in Δf_EI_{UHC} as shown in Figure 9, with the result

$$\delta\Delta f\_EI_{UHC} = 0.1234 * tanh\,(0.2867 * blend\%). \qquad (35)$$

STEP 5 – The original Δf_EI_{UHC} data and the uncertainty weighted function fit values are shown in Figure 9. The blue data points represent the original impact factors, the orange data points represent the uncertainty weighted functional fit values.

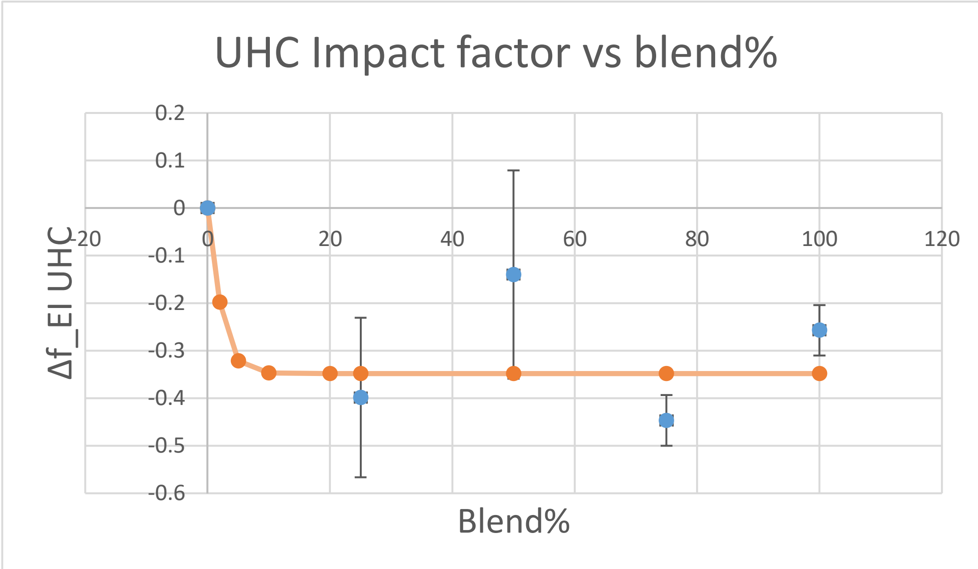


Figure 9: UHC impact vs. blend% with its functional fit

The original and fitted data along with an impact factor ER is given in Table 18. The ER is defined as

$$ER_{\Delta f\_EIUHC} = \frac{|\ \Delta f\_EI_{UHC}\_fit - \Delta f\_EI_{UHC}\ |}{(\delta + \delta\Delta f\_EIUHC)} \tag{36}$$

Table 18: $\Delta f\_EI_{UHC\_Avg}$, $\Delta f\_EI_{UHC\_fit}$ and associated ER

blend%	Δf EI UHC	δ	Δf EI UHC_{fit}	$\delta\Delta f\_EI_{UHC}$	$ER_{\Delta f\_EIUHC}$
0	0	0.0053	0.0000	0.0053	0.00
25	-0.3990	0.1677	-0.3482	0.1234	0.17
50	-0.1400	0.2195	-0.3482	0.1234	-0.61
75	-0.4471	0.0534	-0.3482	0.1234	0.56
100	-0.2570	0.0533	-0.3482	0.1234	-0.52

The fact that the error bars in Figure 9 overlap and their associated ERs are always less than unity, reveals that the Δf_EI_{UHC} function is a good representation for the EI_{UHC} impact factor data and is thereby validated.

UHC Findings

The fact that the uncertainty in Δf_EI_{UHC} is smaller than the absolute value of Δf_EI_{UHC} implies that there may be a statistically meaningful UHC impact associated with alternative fuel usage. Due to the variability of available data, the team was not able to definitively derive a relationship between blend percentage and UHC emissions reduction that can be confidently used to describe UHC emissions.

$\Delta f\_EI_{UHC} = -0.3482 * tanh\,(0.322 * blend\%)$.

$\delta\Delta f\_EI_{UHC} = 0.1234 * tanh\,(0.2867 * blend\%)$.

Illustrative example:

To illustrate the use of the impact factor for UHC, assume an airport has normal UHC emissions of 1000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend (50% blend ➔ Δf = -0.348) the UHC emissions savings would be 41.8 kg/year (1000 * 0.12 * 0.348) with an uncertainty of 14.8 kg/year (1000*0.12*δΔf=0.123).

Note: The functional fit analysis for UHC impact is confounded by the extensive scatter in the small amount of data available in the literature on UHC emissions (three papers (Refs 6, 17, 21) with 80% of the data coming from Ref 17). The observed scatter appears to be driven by not only blend ratio but also engine operating condition (Ref 17). As a result, the authors caution applying the impact factors for UHC resulting from the above functional analysis. The authors further recommend the pursuit of additional experimental studies on UHC emissions associated with blended SAJFs as a function of engine operating condition in order to strengthen confidence in the resulting impact factor analysis.

4.7 HAPs

For HAPs we anticipated a small if not negligible impact. At currently approved blend percentages of up to 50%, the reduction in HAPs emissions is directly related to the amount of SAJF burned, thus the emission index of the blend (EIn_{HAPs}), for a given engine and operating condition, can be expressed in a similar manner as used for SO_x, nvPM N, and nvPM Mass:

$$EI_{\mathrm{HAPs,blend}} = \alpha * EI_{\mathrm{HAPs,conv}} * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * EI_{\mathrm{HAPs,SAJF}} * \left(\frac{blend\%}{100\%}\right), \qquad (37)$$

The impact on HAPs emissions due to the SAJF for specific engines and their operating conditions is

$$\Delta f\_EI_{HAPs} = \frac{\mathrm{EI_{HAPs,blend}} - \mathrm{EI_{HAPs,conv}}}{\mathrm{EI_{HAPs,conv}}}$$
$$= \left[\alpha * \left(1 - \left(\frac{blend\%}{100\%}\right)\right) + \beta * \left(\frac{\mathrm{EI_{HAPs,ASJF}}}{\mathrm{EI_{HAPs,conv}}}\right) * \left(\frac{blend\%}{100\%}\right)\right] - 1$$

$$= \varphi 0 + \varphi 1 * \left(\frac{blend\%}{100\%}\right)\left(with\ \varphi 0 = \alpha - 1, \varphi 1 = \beta * \left(\frac{EI_{HAPs,ASJF}}{EI_{HAPs,conv}}\right) - \alpha\right). \tag{38}$$

STEP 1 – Based on the limited available data from the State of the Industry Report, the observational data is found to be dependent on power and blend%. For use in the AEDT model, an average value for impact factor, weighted over LTO cycle fuel burns, is calculated, resulting in impact factors depending on blend% alone.

STEP 2 AND STEP 3 – The HAPs impact spreadsheet is given in Table 19 below. In the spreadsheet Δf_EI_{HAPs} denotes the HAPs impact factors after averaging over the ICAO LTO cycle. $\Delta f\_EI_{HAPs,\ avg}$ is the average of all Δf_EI_{HAPs} values recorded for a given blend%. δ denotes the standard deviation in Δf_EI_{HAPs} values and is used as the uncertainty in $\Delta f\_EI_{HAPs,\ avg.}$

Table 19: HAPs spreadsheet

Species	Conv fuel	SAJF	blend%	Ref #	Δf_EI HAP	Δf_EI HAP_Avg	δ
HAP HCHO	JP-8	HRJ	50	20	-0.2789	-0.1590	0.2962
HAP CH3CHO	JP-8	HRJ	50	20	-0.4278		
HAP HCHO	JP-8	HRJ+FT	50	20	-0.3823		
HAP CH3CHO	JP-8	HRJ+FT	50	20	-0.4049		
HAP HCHO	Jet A1	HEFA	50	35	0.0039		
HAP CH3CHO	Jet A1	HEFA	50	35	0.4599		
HAP Acrolein	Jet A1	HEFA	50	35	0.1142		
HAP C6H6	JP-8	HRJ.C	50	22	-0.2316		
HAP C7H8	JP-8	HRJ.C	50	22	-0.2831		
HAP HCHO	Jet A1	HEFA	75	35	-0.0115	0.1611	0.1731
HAP CH3CHO	Jet A1	HEFA	75	35	0.3347		
HAP Acrolein	Jet A1	HEFA	75	35	0.1602		
HAP HCHO	Jet A1	FT GTL	100	47	-0.0378	-0.3091	0.2203
HAP HCHO	Jet A1	FT GTL	100	35	-0.1400		
HAP CH3CHO	Jet A1	FT GTL	100	35	0.0254		
HAP Acrolein	Jet A1	FT GTL	100	35	-0.5069		
HAP C6H6	JP-8	HRJ.C	100	22	-0.4124		
HAP C6H6	JP-8	HRJ.T	100	22	-0.4407		
HAP C7H8	JP-8	HRJ.C	100	22	-0.4752		
HAP C7H8	JP-8	HRJ.T	100	22	-0.4853		

STEP 4 – Table 20 takes selected parameters from Table 19 for further analysis.

Table 20: HAPs impact factors vs. blend%

blend%	Δf_EI HAP_Avg	δ
0	0	0
50	-0.159	0.296
75	0.161	0.173
100	-0.309	0.220

Figure 10 shows a plot of $\Delta f\_EI_{HAPs,\ Avg}$ vs blend% with associated uncertainties. This plot suggests that a constant function is the best fit to the data. An uncertainty weighted least squares fit of a constant to the data was performed yielding a result of

$$\Delta f\_EI_{HAP} = -0.006 \pm 0.046 \qquad (39)$$

The fact that the uncertainty in Δf_EI_{HAP} (0.046) is greater than the absolute value of Δf_EI_{HAP} (0.006) implies that there is no statistically meaningful HAP impact associated with alternative fuel usage.

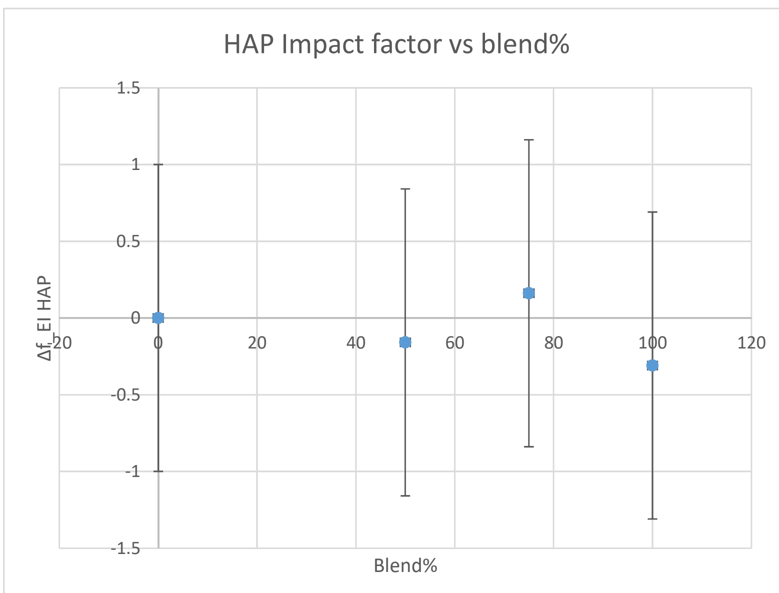


Figure 10: HAPs impact factors vs. blend%

STEP 5 – The original Δf_EI_{HAPs} data and the weighted constant function fit values are shown in Figure 11. The blue data points represent the original impact factors, the orange data points represent the uncertainty weighted functional fit values.

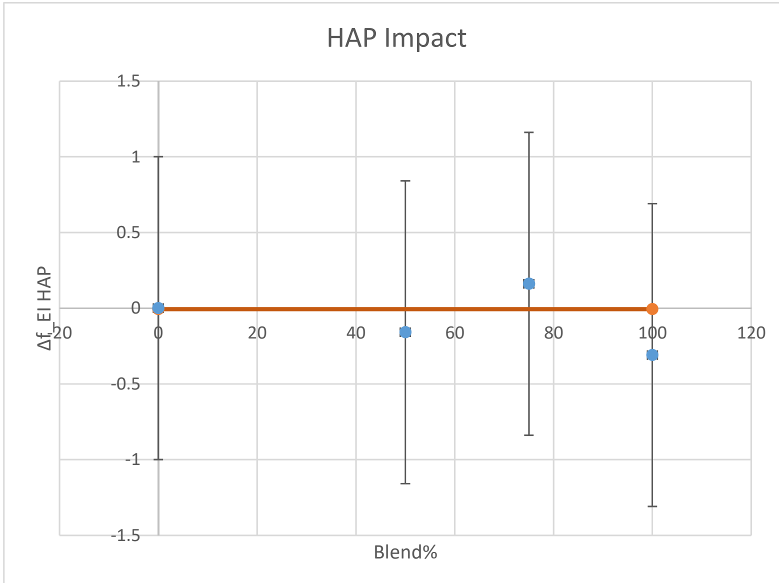


Figure 11: HAPs impact vs. blend%

The original and fitted data along with an impact factor ER is given in Table 21. The ER is defined as

$$ER_{\Delta f\_EIHAPs} = \frac{|\ \Delta f\_EI_{HAPs}\_fit - \Delta f\_EI_{HAPs}\ |}{\delta + \delta_{fit,HAPs}} \quad (40)$$

with $\delta_{fit,\ HAPs}$ = 0.046 denotes the standard deviation in the constant fit.

Table 21: $\Delta f\_EI_{HAPs\_Avg}$, $\Delta f\_EI_{HAPs\_fit}$ and associated ER

blend%	Δf EI HAP	δ	Δf EI HAPfit	ER
0	0	0	-0.0181	0
50	-0.1590	0.2962	-0.006	0.26
75	0.1611	0.1731	-0.006	-0.48
100	-0.3091	0.2203	-0.006	0.69

The fact that the error bars in Figure 11 overlap and their associated ERs are always less than unity, reveals that the Δf_EI_{HAPs} function is a good representation for the EI_{HAPs} impact factor data and is thereby validated.

HAPs Findings

The fact that the uncertainty in Δf_EI_{HAP} (0.046) is greater than the absolute value of Δf_EI_{HAP} (0.006) implies that there is no statistically meaningful HAP impact associated with alternative fuel usage.

Illustrative example:

To illustrate the use of the impact factor for HAPs, assume an airport has normal HAPs emissions of 1000 kg/year. Assuming 12% of the jet fuel used at the airport is blended conventional/SAJF, at a 50% blend the HAPs emissions savings would be 2.2 kg/year (with an uncertainty of 5.3 kg/year). The fact that the uncertainty in the HAPs emissions savings (5.3 kg/year) is greater than the absolute value of savings (2.2 kg/year) implies that there is no statistically meaningful HAP impact associated with alternative fuel usage.

5.0 Airport Emission Inventory Impact Analysis

The impact quantification factor functions described in the previous section are developed for SAJF blends of conventional jet fuel types (i.e., Jet A, Jet A1, JP 8) which are used by jet and turboprop aircraft types (i.e., non-piston operations). The overall reduction in emissions of pollutant species from use of SAJF blended jet fuel at airports would therefore depend the number of non-piston operations relative to piston operations. To understand the variance in the potential overall reduction in emissions of pollutant species for various operations mix (i.e., piston to non-piston ratio) and SAJF blend percentages, emissions inventory impact analysis was conducted at twelve (12) airports using the AEDT. The twelve airports selected are representative of airports in the U.S. in terms of type (i.e., primary, non-primary), size (i.e., large-medium-small hubs, non-hubs, general aviation and reliever), and operational characteristics (piston to non-piston ratio). The results of the analysis for the three-key pollutants (i.e., CO, SO_x and nvPM) are shown in Figure 12. The horizontal axis is the SAJF blend percentages and the vertical axis is the range of the potential reduction in pollutant emissions. The lower range is the reduction expected at airports with significant piston operations and very low non-piston operations. The upper range is the reduction expected at airports with significant non-piston operations and very low piston operations.

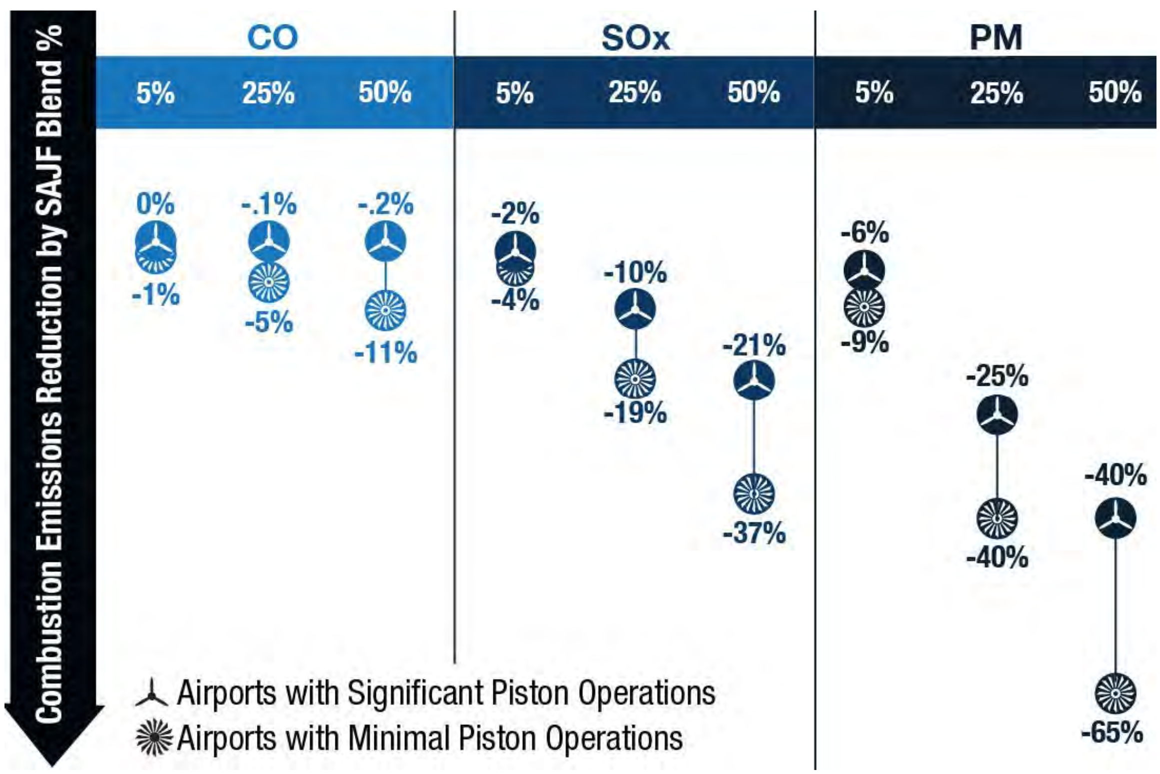


Figure 12: Potential Reduction in Emission of Pollutant Species

6.0 Guidance to Use SAJF Impact Factors for Emissions Inventory and Dispersion Modeling at Airports

6.1 Guidance to Account for SAJF Impacts on Airport Emissions Inventory

This section describes the method to adjust an airport emission inventory using the impact quantification factor functions to estimate the impact of SAJF blend percentages at airports.

The pollutant-specific analysis described in section 4 show SAJF blend percentage as the only critical factor in determining the impact of use of SAJF at airports. Therefore, the impact of SAJF blend percentage on the airport emission inventory can be determined using the impact quantification functions to adjust the total baseline emission inventory as a post-process. The overview of the process to determine the impact of SAJF on airport emissions inventory is shown in Figure 13.

STEP 1 – Determine SAJF blend percentage for which the impact needs to be estimated.

STEP 2 – Compute the impact factors and associated uncertainties for each pollutant by plugging in SAJF blend percentages in the equations in Table 1.

STEP 3 – Output the baseline emission inventory to three distinct datasets:

1) Total emission inventory for non-piston operations (step 3.1)
2) Total emission inventory for piston operations (step 3.2)
3) Total emission inventory for non-piston and piston combined (step 3.3).

STEP 4 – Compute the total adjusted emission inventory for non-piston operations for each pollutant using total baseline emission inventory for non-piston operations (from step 3.1) and the impact factor computed is step 2, as shown below:

$$Adjusted\ Non\_Piston\ Emission\ Inventory_{pollutant} = Baseline\ Non\_Piston\ Emission\ Inventory_{pollutant} * (1 + Impact\ Factor_{pollutant})$$

STEP 5 – Compute the total adjusted emission inventory as the sum of the total baseline emission inventory for piston operations (from step 3.2) and the total adjusted emission inventory for non-piston operations (from step 4).

$$Adjusted\ Emission\ Inventory_{pollutant} = Baseline\ Piston\ Emission\ Inventory_{pollutant} + Adjusted\ Non\_Piston\ Emission\ Inventory_{pollutant}$$

STEP 6 – Compute the impact of SAJF on the total airport emissions inventory using the total adjusted emission inventory (from step 5) and the total baseline inventory emission (step 3.3) as shown below:

$$SAJF\ Impact_{pollutant} = \left(\frac{Adjusted\ Emission\ Inventory_{pollutant}}{Baseline\ Emission\ Inventory_{pollutant}}\right) - 1$$

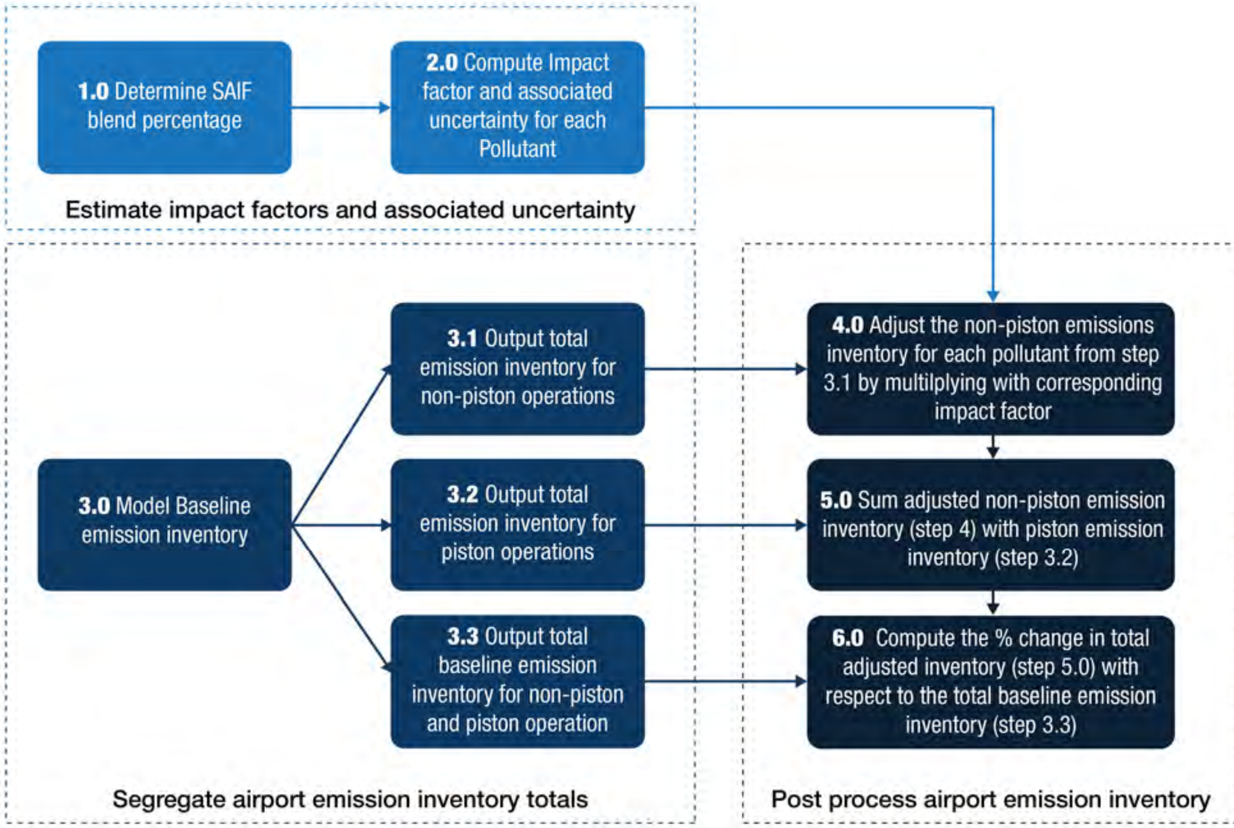


Figure 13: Overview of the process to compute the impact of SAJF on airport emissions inventory

6.2 Instructions to Segregate Piston and Non-Piston Aircraft Operations in AEDT

The impact quantification factors only apply to emissions from non-piston operations, therefore it is recommended to segregate non-piston operations and piston operations before modeling the airport inventory emissions. This section describes the process to segregate non-piston and piston operations into separate groups (i.e. cases as defined in AEDT) in the annualization defined in AEDT.

The non-piston operations can be separated from piston operations by defining them under separate cases in the AEDT standard input file. Alternatively, the AEDT GUI can be used to segregate the piston and non-piston operations into separate groups as described below.
Note: The instructions below are for AEDT version 2D.

The process to create separate groups within the annualization using the AEDT GUI are as follows:

1. Go to the Operations tab and click on the Aircraft button in the Display ribbon to list all the operations defined in the study. Make sure while creating the operations list the "User ID" field has some identifier to tell the non-piston from piston aircraft. In the example below all the piston aircraft have "User ID" starting with a "P" and non-piston with "NP".

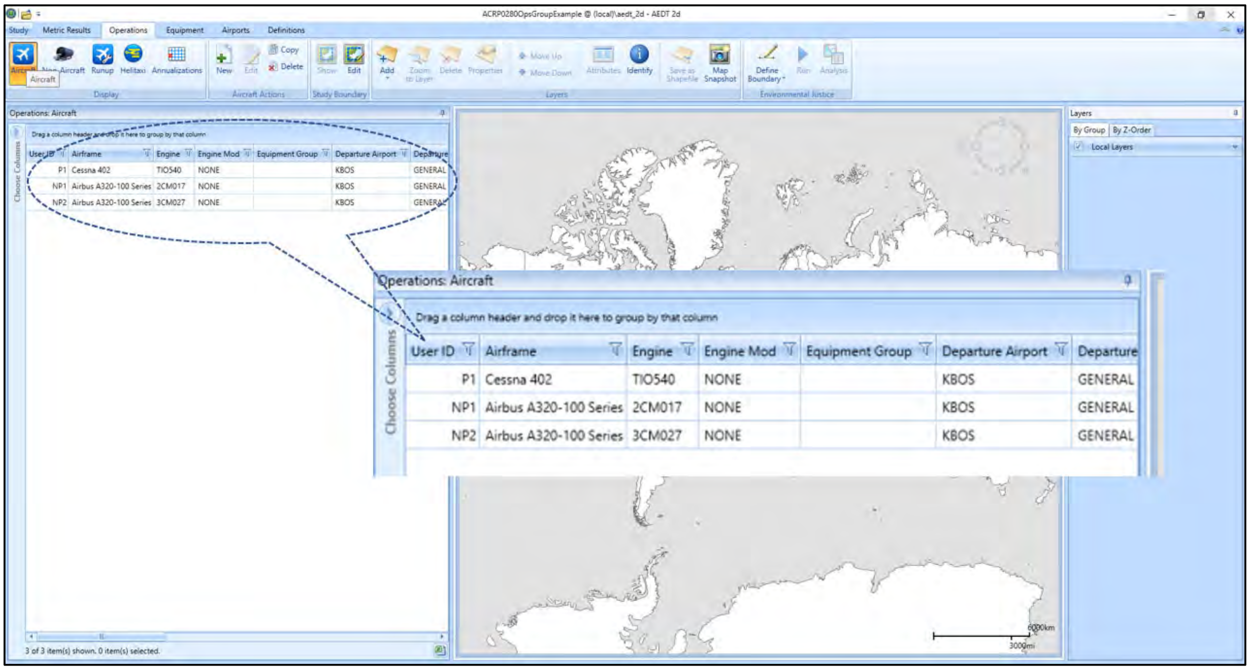


Figure 14: Example of an operations list with piston aircraft have "User ID" starting with a "P" and non-piston with "NP"

2. Click on Annualizations button in the Display ribbon and click on the New button in the Annualization Actions button
3. Select checkbox "Add new aircraft operation group(s)" and click next. The next page will show the list available operations and option to add new operation groups.
4. Type the name of the operations group and click add.
5. Use the "User ID" filter to select all the operations to be added to the operations group and click next. In the example below, non-piston aircraft operations are assigned to a user defined group named Ops_nonpiston using the following steps: First a new operation group called Ops_nonpiston is created, next the "User ID" filter is opened and using the criterion "Starts with" set to "NP" all the non-piston aircraft operations are filtered. Next all the filtered operations are moved to the Ops_nonpiston operation group by selecting and dragging the operations to the operation group as shown below. Note: To select all the filtered operations, select any one operation and then use "Ctrl+A" option.

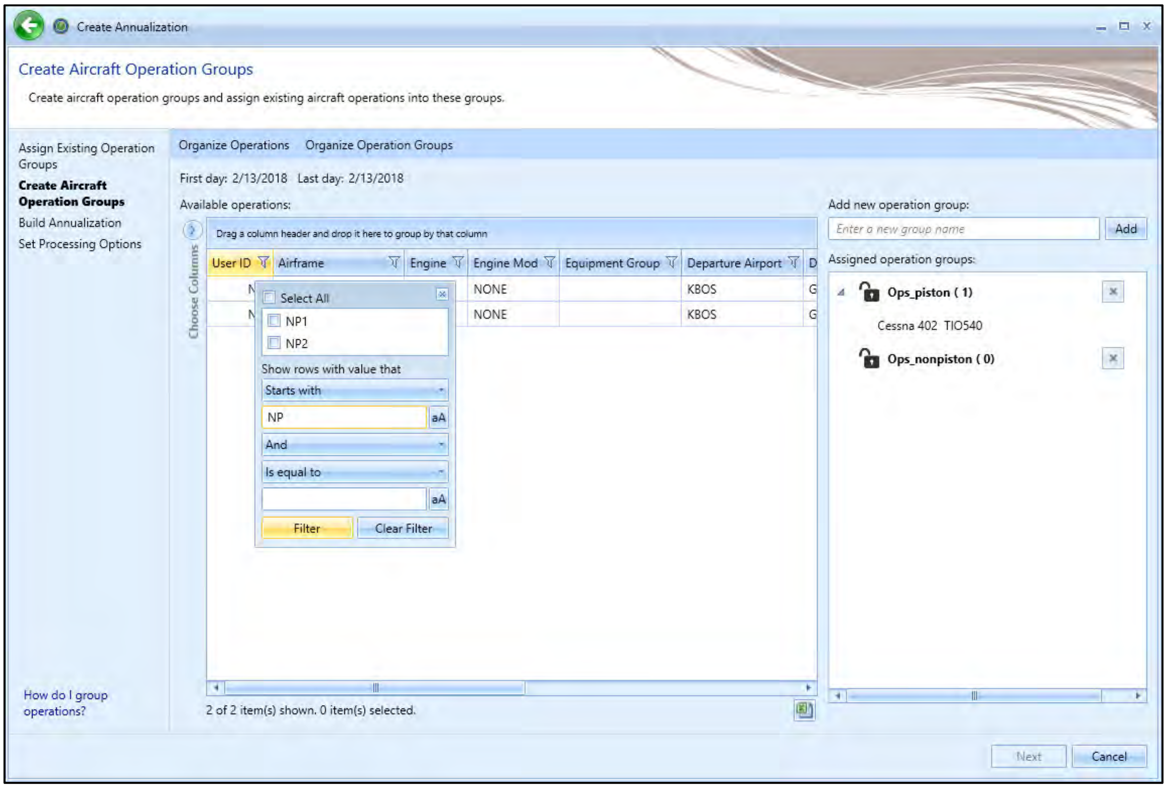


Figure 15: Example showing the use of "User ID" filter to select and group piston and non-piston aircraft operations

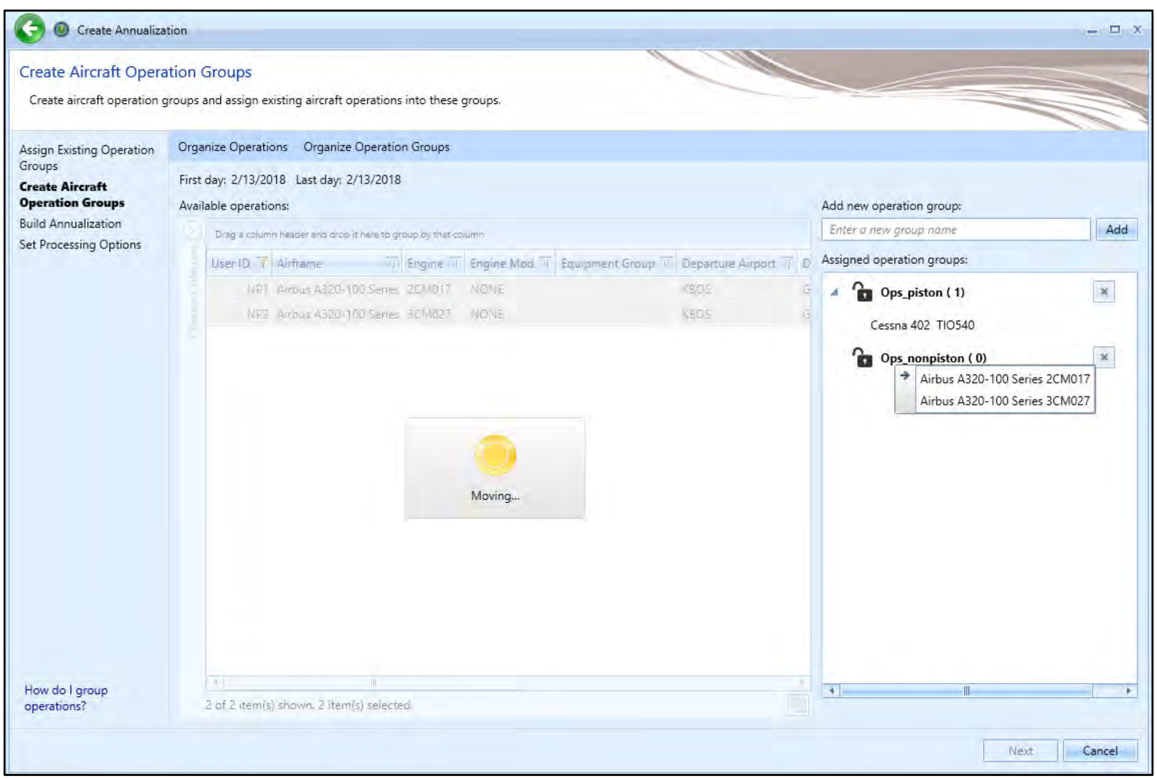


Figure 16: Example showing method to drag selected operations to the corresponding operations group

6. On the next page move the operations groups to "Root" in the "Assigned annualization window" using the select and drag feature and click next.
7. Finally set the processing options or choose the default options and click "Create" to create the annualization.
8. Create the emissions metric using the annualization created using the process described above the run the metric.

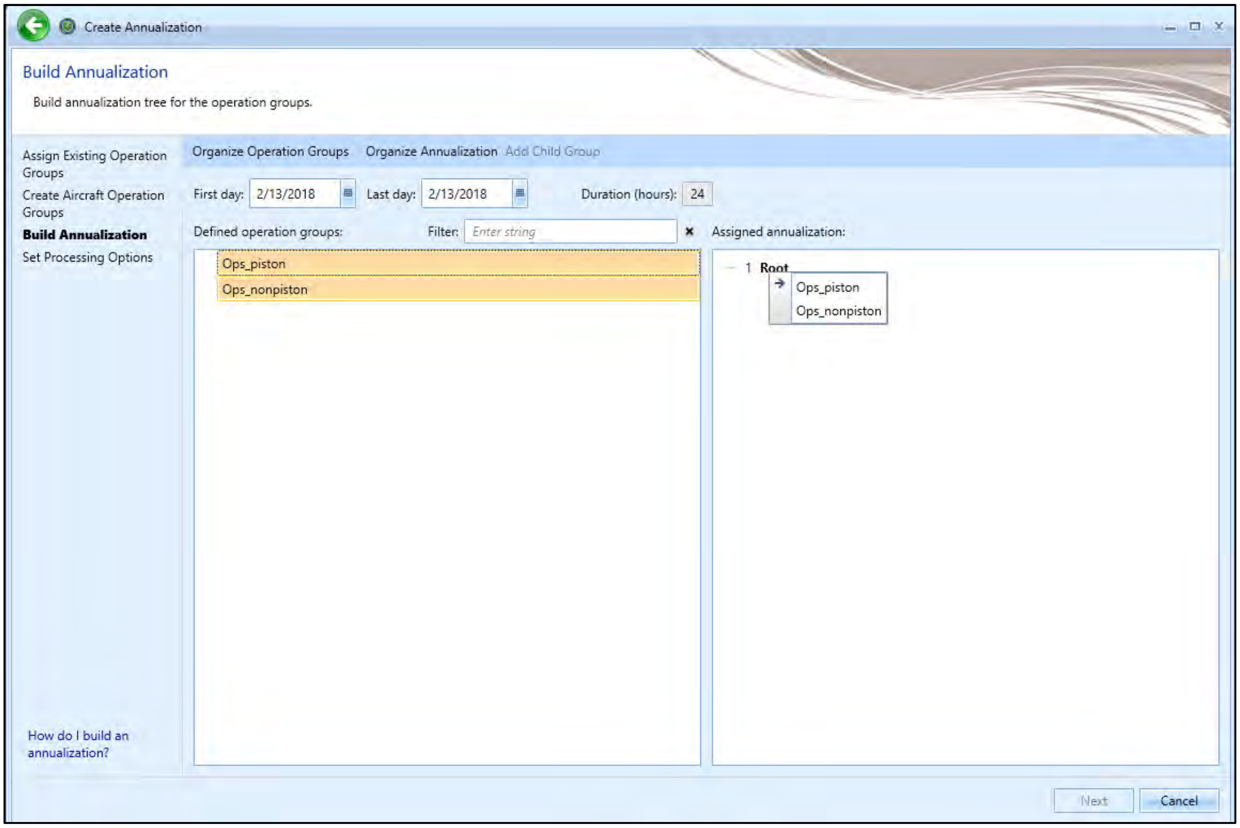


Figure 17: Example showing method to drag operations group to the Root annualization

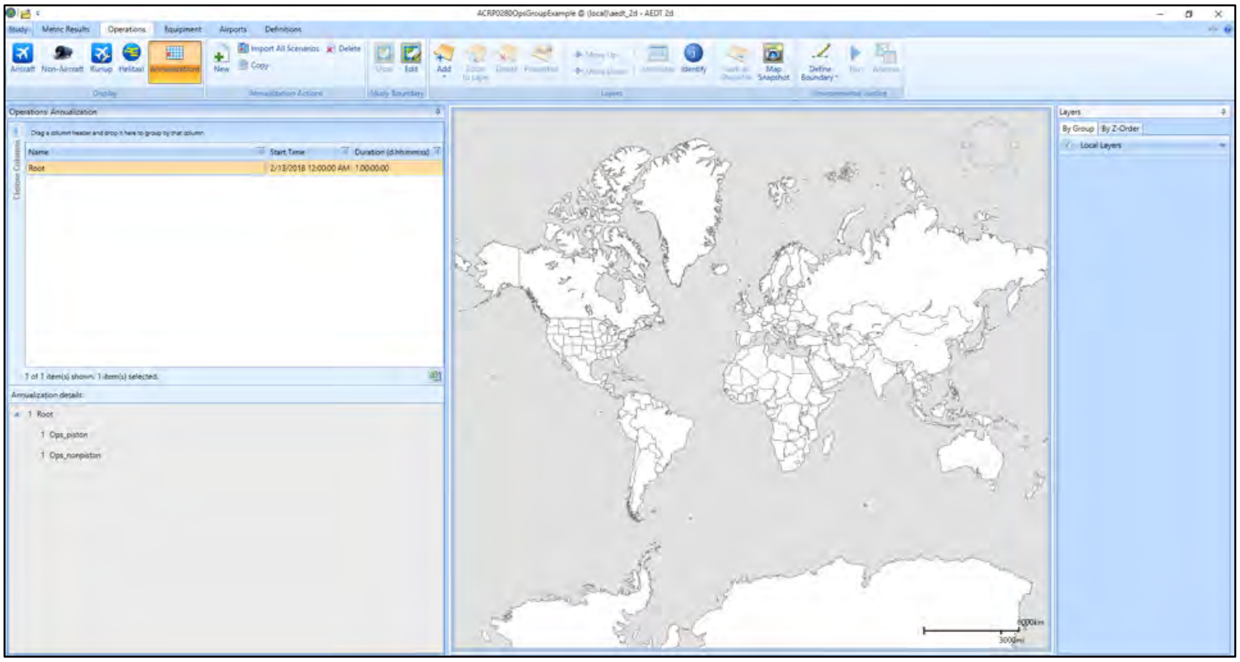


Figure 18: Screenshot showing the annualization created

Once the metric is run, the user can view the results in the Reports tab by selecting the metric and then clicking on Emissions and Fuel button in the Reports ribbon. The user can generate the emission inventory report for each aircraft operations group (piston and non-piston) by selecting the group using the drop-down option show in the figure below and save the results to .csv file, which can then be processed using the approach described in the previous section to compute the adjusted emission inventory.

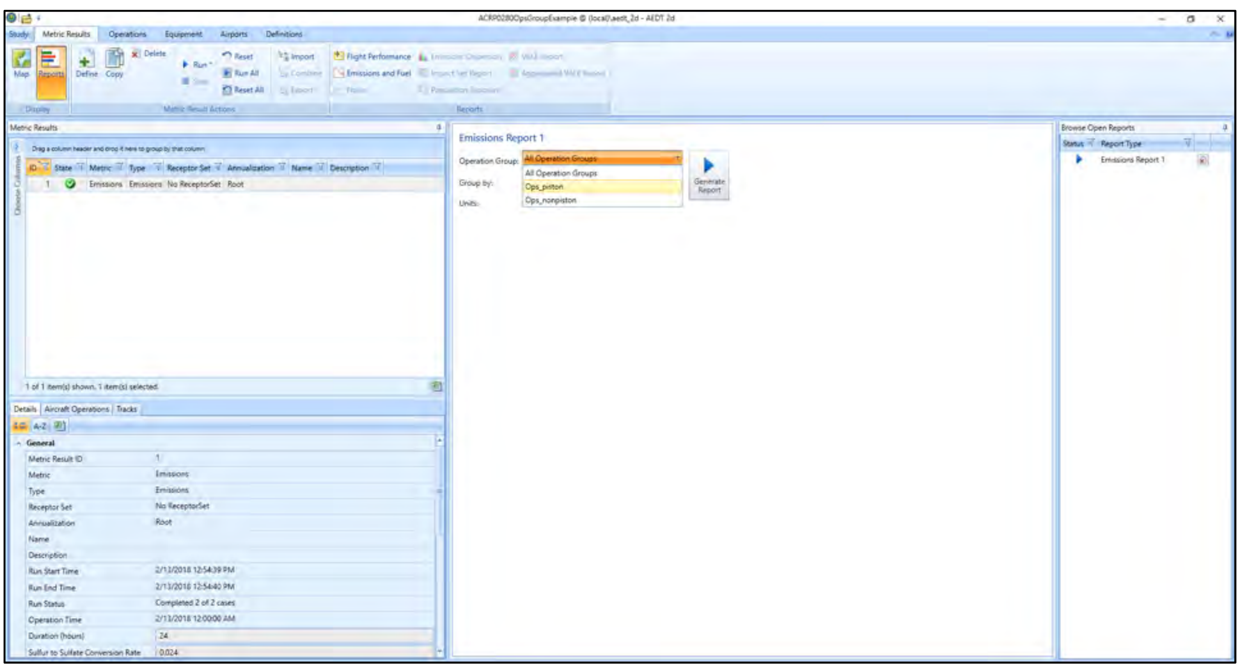


Figure 19: Example showing method to generate emission inventory report for each operations group

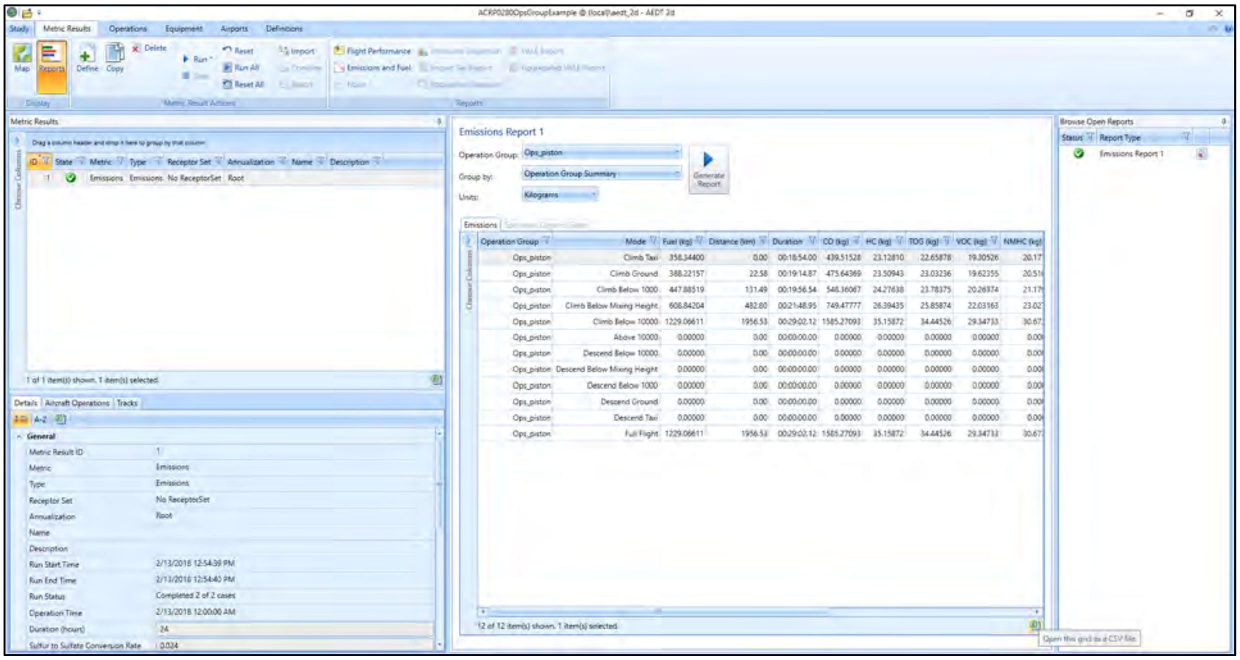


Figure 20: Example showing results for piston aircraft operation group

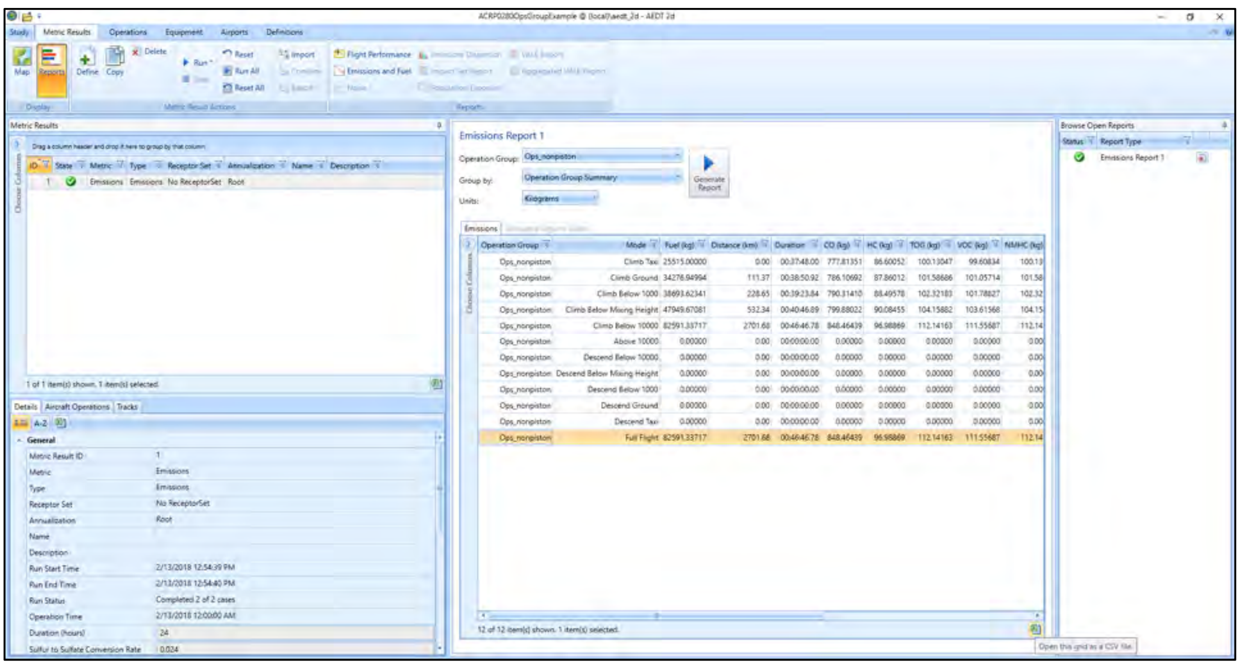


Figure 21: Example showing results for non-piston aircraft operation group

6.3 Guidance to Account for Impact of SAJF on Emission Dispersion at Airports

The SAJF impact factors apply only to non-piston operations and in case of emission inventory, the SAJF impact factors can be applied to non-piston emissions as a post-process. As described in the previous section, the emission inventory can be conducted with piston and non-piston operations as separate cases in the study scenario, which then calculates the total baseline emissions inventory for each case separately to apply the post-process methodology.

Unlike emissions inventory, the emissions dispersion, which is expressed as pollutant concentration (µg/m³) at the receptors, is computed for all the operations in the study scenario and therefore does not produce separate outputs for piston and non-piston operations.

The dispersion analysis for piston and non-piston operations can be modeled as sperate scenarios. However, emission dispersion from separate scenarios cannot always be combined, as emission dispersion is sensitive to operations departure times, the corresponding weather, and the use of the delay and sequencing model. Therefore, for airports with piston and non-piston operations, the post-processing methodology may not yield accurate estimates for impact of SAJF on emission dispersion.

The emissions dispersion tools currently do not model dispersion for nvPM. A method to model nvPM dispersion is proposed, which involves calculating the ratio of the nvPM to PM in the total emission inventory and then adjusting the PM dispersion concentration as a post-process to obtain the emissions dispersion concentration for nvPM.

This section describes methods to account for impact of SAJF on emissions dispersion at 1) airports that only have non-piston operations and 2) airports that have mix of pistons and non-piston operations.

6.3.1 Guidance to Account for Impact of SAJF on Emission Dispersion at Airports with Only Non-Piston Operations

For airports with only non-piston operations, the impact of SAJF on emissions dispersion can be determined as post-process of the baseline emissions dispersion concentrations at the receptor as follows:

STEP 1 – Determine SAJF blend percentage for which the impact needs to be estimated.

STEP 2 – Compute the impact factors and associated uncertainties for each pollutant by plugging in SAJF blend percentages in the equations in Table 1.

STEP 3 – Model and output baseline emissions dispersion concentrations.

STEP 4 – Compute the adjusted emissions dispersion concentration at each receptor using the baseline emissions dispersion concentrations and the impact factor computed is step 2, as shown below:

$$\begin{aligned} &Adjusted\ Non\_Piston\ Emissions\ Dispersion_{pollutant} \\ &\quad = Baseline\ Non\_Piston\ Emissions\ Dispersion_{pollutant} * (1 \\ &\quad + Impact\ Factor_{pollutant}) \end{aligned}$$

For nvPM, before applying the above formula, compute the baseline emissions dispersion concentration at each receptor using the ratio of the total nvPM and PM inventory emissions as follows:

$$\begin{aligned} &Baseline\ Non\_Piston\ Emissions\ Dispersion_{nvPM} \\ &\quad = Baseline\ Non\_Piston\ Emissions\ Dispersion_{PM} * \left(\frac{Total\ nvPM\ Emissions}{Total\ PM\ Emissions}\right) \end{aligned}$$

STEP 5 – Compute the impact of SAJF on the total airport emissions dispersion at each receptor using the total adjusted emissions dispersion and the total baseline emissions dispersion, as shown below:

$$SAJF\ Impact_{pollutant} = \left(\frac{Adjusted\ Emissions\ Dispersion_{pollutant}}{Baseline\ Emissions\ Dispersion_{pollutant}}\right) - 1$$

6.3.2 Guidance to Account for Impact of SAJF on Emission Dispersion at Airports with Piston and Non-Piston Operations

There are two potential methods to account for impact of SAJF in emissions dispersion calculations at airports with both piston and non-piston operations. The first is the post-process method which involves the following steps:

STEP 1 – Determine SAJF blend percentage for which the impact needs to be estimated.

STEP 2 – Compute the impact factors and associated uncertainties for each pollutant by plugging in SAJF blend percentages in the equations in Table 1.

STEP 3 – Group piston and non-piston operations into separate study scenarios.

STEP 4 – Model and output baseline emissions dispersion concentrations for the two scenarios (i.e., piston and non-piston).

STEP 5 – Compute the adjusted emissions dispersion concentration at each receptor for non-piston operations using the corresponding baseline emissions dispersion concentrations and the impact factor computed in step 2, as shown below:

$$\begin{aligned} &Adjusted\ Non\_Piston\ Emissions\ Dispersion_{pollutant} \\ &\qquad = Baseline\ Non\_Piston\ Emissions\ Dispersion_{pollutant} * (1 \\ &\qquad + Impact\ Factor_{pollutant}) \end{aligned}$$

For nvPM, before applying the above formula, compute the baseline emissions dispersion concentration at each receptor using the ratio of the total nvPM and PM inventory emissions as follows:

$$\begin{aligned} &Baseline\ Non\_Piston\ Emissions\ Dispersion_{nvPM} \\ &\qquad = Baseline\ Non\_Piston\ Emissions\ Dispersion_{PM} * \left(\frac{Total\ nvPM\ Emissions}{Total\ PM\ Emissions}\right) \end{aligned}$$

STEP 6 – Compute the total adjusted emissions dispersion concentration at the receptors as the sum of the baseline emissions dispersion concentrations for piston operations and the adjusted emissions dispersion concentration for non-piston operations (from step 4).

$$\begin{aligned} &Total\ Adjusted\ Emissions\ Dispersion_{pollutant} \\ &\qquad = Baseline\ Piston\ Emissions\ Dispersion_{pollutant} \\ &\qquad + Adjusted\ Non_{Piston} Emissions\ Dispersion_{pollutant} \end{aligned}$$

STEP 7 – Compute the total baseline emissions dispersion concentration at the receptors as the sum of the baseline emissions dispersion concentrations for piston operations and the baseline emissions dispersion concentration for non-piston operations (from step 4).

$$\begin{aligned} &Total\ Baseline\ Emissions\ Dispersion_{pollutant} \\ &\qquad = Baseline\ Piston\ Emissions\ Dispersion_{pollutant} \\ &\qquad + Baseline\ Non_{Piston} Emissions\ Dispersion_{pollutant} \end{aligned}$$

STEP 8 – Compute the impact of SAJF on the airport emissions dispersion at each receptor using the total adjusted emissions dispersion and the total baseline emissions dispersion as shown below:

$$SAJF\ Impact_{pollutant} = \left(\frac{Total\ Adjusted\ Emissions\ Dispersion_{pollutant}}{Total\ Baseline\ Emissions\ Dispersion_{pollutant}}\right) - 1$$

As described previously, the post-process methodology may not yield accurate estimates for impact of SAJF on emissions dispersion at airports with both piston and non-piston operations, as emissions dispersion from separate scenarios cannot always be combined; emissions dispersion is sensitive to operations departure times, corresponding weather, and use of the delay and sequencing model.

To compute more accurate estimates of SAJF impacts on emissions dispersion at airport, a second method is proposed, which involves generating a new list of aircraft with the emissions indices (EIs) adjusted to account for the SAJF impact factors.

The method involves the following steps:

STEP 1 – Determine SAJF blend percentage for which the impact needs to be estimated.

STEP 2 – Compute the impact factors and associated uncertainties for each pollutant by plugging in SAJF blend percentages in the equations in Table 1.

STEP 3 – In the modeling tool, create new aircraft types for each of the aircraft types in the baseline scenario and modify the EIs for the landing takeoff (LTO) modes using the impact factors computed in step 2.

$$\begin{aligned} &Adjusted\ Emissions\ Index_{pollutant,\ LTOmode} \\ &\qquad = Emissions\ Index_{pollutant.\ LTOmode} * (1 + Impact\ Factor_{pollutant}) \end{aligned}$$

STEP 4 – Create two scenarios, the baseline scenario with the original the piston and non-piston aircraft, and the modified scenario with the original piston and the modified non-piston aircraft.

STEP 5 – Model and output emissions dispersion concentrations for the two scenarios.

STEP 6 – Compute the impact of SAJF on the total airport emissions dispersion at each receptor using the emissions dispersion from the modified scenario and the emissions dispersion from the baseline scenario as shown below:

$$SAJF\ Impact_{pollutant} = \left(\frac{Modified\ Emissions\ Dispersion_{pollutant}}{Baseline\ Emissions\ Dispersion_{pollutant}}\right) - 1$$

Note: Although SAJF use impacts nvPM emissions, the impact on nvPM emissions dispersion concentrations cannot be computed using the method described above. As mentioned before, the emissions dispersion tool only model emissions dispersion for total PM (10 and 2.5), which constitutes volatile PM components from fuel sulfur content (PMSO) and hydrocarbon (fuel) organics (PMFO) and nvPM. The EI for these pollutants are computed using First Order Approximation 3.0 Method (FOA 3.0) which is hard-coded in the emissions modeling tools and cannot be modified by the user.

7.0 Tabulation of All Available Emissions Data

This section includes tables summarizing the impacts of alternative fuels on the emissions of SO_x, PM2.5, CO, UHC, NO_x, and HAP and their associated references. This is taken from the phase one “State of the Industry Report.”

Table 22: Alternative fuel impact on SO_x emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
FT GTL	JP-8	CFM56-2C1	EI_SO_2 ↓ 90% for pure FT, and ↓ intermediately for blends.	6
HEFA	JP-8	F117-PW-100	SO_2 ↓ 50% for 50% blend.	20

* The engine operating conditions are typically found in the root data upon which impacts are derived.

Table 23: Alternative fuel impact on PM2.5 emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
ATJH SPK	JP-8	PW615F	Smoke # & nvPM no Δ.	26
Beef Tallow	JP-8	F117-PW-100 =	nvPM N ↓ 63% at idle; nvPM GMD ↓ 10-15%; EIm ↓ 50- 70% at 63% power; SN no Δ.	20
Beef Tallow	JP-9	T63-A-701	Soot ↓ significantly.	21
Camelina	Jet A	TFE-109 Honeywell	nvPM EIn ↓ at power settings of 10% and 30%.	44
Camelina	JP-10	T63-A-702	Soot ↓ significantly.	21
CH-SKA	Jet A2	CF-700-2D-2	black carbon (BC) mass ↓ 38-50%.	15
Fats & Grease	JP-11	T63-A-703	Soot ↓ significantly.	21
FT GTL	Jet A1	CFM56-7B	EIn ↓, EIm ↓.	36
FT GTL	Jet A1	CFM56-7	nvPM N & Mass & GMD ↓.	48
FT GTL	JP-8	CFM56-2C1	nvPM Mass ↓ 86% averaged over power for pure FT, ↓.	6
FT GTL	JP-8	CFM-56-2C	EIn ↓ varied monotonically with power: factor 200 at idle, factor 4 at max thrust; EIm ↓ factor 30 at 45-65% power, factor 7 at 85% power.	2
FT GTL	JP-8	T63-A-700	Soot ↓ significantly.	21
FT GTL	JP-8	CFM56-7	EIn ↓ up to 80%.	22
FT GTL	JP-8	CFM56-2	EIn ↓ up to 80%.	22
FT GTL	JP-8	PW308	EIn ↓ up to 35%.	22
FT-AAFEX	JP-8	CFM56-2-C	nvPM ↓.	19

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
FT-SPK	Jet A1	CF-700-2D-2	nvPM N ↓ 70-95%; BC mass ↓ 70-95%.	15
HEFA	JP-8	CFM56-8	EIn ↓ up to 80%.	22
HEFA	JP-8	CFM56-3	EIn ↓ up to 80%.	22
HEFA	JP-8	PW309	EIn ↓ up to 35%.	22
HEFA, SAK	Jet A	TRS-18 Microturbo	nvPM N & Mass ↓ 35-70%.	23
HEFA-SPK	Jet A3	CF-700-2D-2	nvPM N ↓ 40-60%; BC mass ↓58-82%.	15
HRJ-AAFEX	JP-9	CFM56-2-C	nvPM ↓.	19
SPK	JP-8	Allison T63-A-	nvPM N, Mass, and GMD ↓.	12
SPK	JP-8	PW308	Soot ↓ 95% at idle & 50% at 85% power.	25
SPK	JP-8	CFM56	Soot ↓ 98% at idle & 70% at 85% power.	25
UCO–HEFA	Jet A	GTCP85-129 Garrett Honeywell	nvPM N & Mass & GMD ↓.	18

* The engine operating conditions are typically found in the root data upon which impacts are derived.

Table 24: Alternative fuel impact on CO emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
SPK	JP-8	Allison T63-A-700	CO ↓ 10-20% except no Δ for the m-xylene/C12 blend.	12
Sasol FSJF	Jet A		CO ↓ 19% in LTO cycle.	8
FT-SPK	Jet A1		CO ↑ when lean & ↓ when rich.	28
FT-GTL	JP-8	Combustor sector	CO ↓.	45
FT-AAFE X	JP-8	CFM56-2-C	Minor Δ in gaseous emissions.	19
HRJ-AAFEX	JP-9	CFM56-2-C	Minor Δ in gaseous emissions.	19
Bio fuel	RP-3	Combustor rig	CO ↑.	16
Beef Tallow	JP-8	F117-PW-100 = PW2000	CO ↓ 20-40%.	20
FT GTL	JP-8	CFM-56-2C	CO ↓ 9%.	2
ATJH SPK	JP-8	AE 3007	CO ↑ slightly at low power.	26
ATJH SPK	JP-8	TFE34	CO ↑ slightly at low power.	26
ATJH SPK	JP-8	PW615F	0.	26

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
ATJH SPK	JP-8	TPE331-10YGD	CO ↑ slightly at low power	26
Beef Tallow	JP-9	T63-A-701	CO ↓ 10-25%	21
Bio-SPK	Jet A	CFM56-7B	CO ↑ 5-9%	10
Bio-SPK	JP-8	TPE331-10	CO no Δ except slightly ↓ at low power	10
Bio-SPK	JP-8	TFE731-5	CO ↓ ~2% at idle	10
Camelina	JP-10	T63-A-702	CO ↓ 10-25%	21
DSHC	Jet A1	SaM146	0	43
DSHC	Jet A1	CFM56-5C4	0	43
Fats & Grease	JP-11	T63-A-703	CO ↓ 10-25%	21
FT GTL	Jet A1	CFM56-7	Modest changes in CO	48
FT GTL	JP-8	T63-A-700	CO ↓ 10-25%	21
FT GTL	JP-8	CFM56-7	Normalized CO 0.8-1.0.	22
FT GTL	JP-8	CFM56-2	Normalized CO 0.8-1.0.	22
FT GTL	JP-8	F117	Normalized CO 0.8-1.0.	22
FT GTL	JP-8	TF33	Normalized CO 0.8-1.0.	22
FT GTL	JP-8	PW308	Normalized CO 0.8-1.0.	22
HEFA	JP-8	CFM56-8	Normalized CO 0.8-1.0.	22
HEFA	JP-8	CFM56-3	Normalized CO 0.8-1.0.	22
HEFA	JP-8	F118	Normalized CO 0.8-1.0.	22
HEFA	JP-8	TF34	Normalized CO 0.8-1.0.	22
HEFA	JP-8	PW309	Normalized CO 0.8-1.0.	22
SPK			Normalized: CO 0.74-0.87 for 100% alt fuel. Normalized: CO 0.83-0.91 for 50% blend.	13

* The engine operating conditions are typically found in the root data upon which impacts are derived.

Table 25: Alternative fuel impact on UHC emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
ATJH SPK	JP-8	AE 3007	UHC ↑ slightly at low power.	26
ATJH SPK	JP-8	TFE34	UHC ↑ slightly at low power.	26
ATJH SPK	JP-8	TPE331-	UHC ↑ slightly at low power.	26

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
Beef Tallow	JP-9	T63-A-701	UHC ↓ 20-30%.	21
Bio fuel	RP-3 aviation kerosen	Combustor rig	UHC ↓ by up to 61%. Increasing ethanol content ↓ UHC.	16
Bio-SPK	JP-8	TPE331-10	UHC ↓ 5-20% at lowest power.	10
Bio-SPK	JP-8	TFE731-5	UHC ↓ ~2% at idle.	10
Camelina	JP-10	T63-A-702	UHC ↓ 20-30%.	21
Fats & Grease	JP-11	T63-A-703	UHC ↓ 20-30%.	21
FT GTL	JP-8	CFM56-2C1	EI_UHC ↓ 40% for pure FT, and ↓ intermediately for blends.	6
FT GTL	JP-8	CFM-56-2C	THC ↓ 22%.	2
FT GTL	JP-8	T63-A-700	UHC ↓ 20-30%.	21
FT-AAFEX	JP-8	CFM56-2-C	Minor Δ in gaseous emissions.	19
HRJ-AAFEX	JP-9	CFM56-2-C	Minor Δ in gaseous emissions.	19
Sasol FSJF	Jet A		UHC no Δ at idle.	8
SPK			Normalized: UHC 0.68-0.76 for 100% alt fuel. Normalized: UHC 0.76-0.86 for 50% blend.	13
UCO SPK	Jet A1	GTCP85	0	17

* The engine operating conditions are typically found in the root data upon which impacts are derived.

Table 26: Alternative fuel impacts on NO_x emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
AMJ	JP-8	9 pt. lean direct low emissions	0	50
ATJH SPK	JP-8	AE 3007	0	26
ATJH SPK	JP-8	TFE34	0	26
ATJH SPK	JP-8	PW615F	0	26
ATJH SPK	JP-8	TPE331-10YGD	0	26
Beef Tallow	JP-8	F117-PW-100 = PW2000	0	20
Beef Tallow	JP-9	T63-A-701	0	21

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
Bio fuel	RP-3 aviation kerosene	Combustor rig	NO_x ↓ by up to 70%. Increasing ethanol content ↓ NO_x.	16
Bio-SPK	Jet A	CFM56-7B	- (1-5%)	42
Bio-SPK	Jet A	CFM56-7B	NO_x ↓ 1-5%	10
Bio-SPK	JP-8	TPE331-10	0	10
Bio-SPK	JP-8	TFE731-5	NO_x ↑ 3.5% at cruise condition	10
Camelina	JP-10	T63-A-702	0	21
CH-SKA	Jet A2	CF-700-2D-2 General Electric	NO_x ↓ 7-25%	45
DSHC	Jet A1	SaM146	0	43
DSHC	Jet A1	CFM56-5C4	NO_x slightly ↓ except slightly ↑ at cruise	43
DSHC	Jet A1	131-9 APU	NO_x slightly ↓ except slightly ↑ at cruise	43
Fats & Grease	JP-11	T63-A-703	0	21
FT GTL	Jet A1	CFM56-7	NO_x ↓ 10% for 100% FT and ↓ 5% for 50% blend	48
FT GTL	JP-8	CFM-56-2C	NO_x ↓ 5-10% at high power, 10% at idle	2
FT GTL	JP-8	T63-A-700	0	21
FT GTL	JP-8	CFM56-7	0	22
FT GTL	JP-8	CFM56-2	0	22
FT GTL	JP-8	F117	0	22
FT GTL	JP-8	TF33	0	22
FT GTL	JP-8	PW308	0	22
FT GTL (100%)	Jet A	CFM56-7B	-10%	48
FT GTL (50%)	Jet A	CFM56-7B	-5%	48
FT-AAFEX	JP-8	CFM56-2-C	Minor Δ in NO_x	19
FT-GTL	JP-8	Combustor sector	NO_x ↓ when lean & ↑ when rich.	45
FT-SPK	Jet A1	Tubular combustor	NO_x ↑ at low pressure; no Δ at high pressure.	7

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
FT-SPK	Jet A1		NO_x ↓ always except when rich at high inlet air temp.	28
HEFA	Jet A1	MK113 APU	↓ except slightly ↑ at idle	34
HEFA	JP-8	9 pt. lean direct low emissions	0	50
HEFA	JP-8	CFM56-8	0	22
HEFA	JP-8	CFM56-3	0	22
HEFA	JP-8	F118	0	22
HEFA	JP-8	TF34	0	22
HEFA	JP-8	PW309	0	22
HRJ-AAFEX	JP-9	CFM56-2-C	Minor Δ in NO_x	19
HVO	Jet A	JT9D-7R4G2	0	42
Sasol FSJF	Jet A		NO_x ↓ 4% in LTO cycle	8
SPK			Normalized: NO_x 0.91-1.01	13
UCO SPK	Jet A1	GTCP85 Garret Honeywell APU	0	17

* The engine operating conditions are typically found in the root data upon which impacts are derived.

Table 27: Alternative fuel impact on HAP emissions

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
Beef Tallow	JP-8	F117-PW-100 = PW2000	HAP ↓	20
Beef Tallow	JP-9	T63-A-701	Formaldehyde no Δ	21
Camelina	JP-10	T63-A-702	Formaldehyde no Δ	21
Fats & Grease	JP-11	T63-A-703	Formaldehyde no Δ	21
FT GTL	Jet A1	MK113 APU	Formaldehyde ↓ 30% Acrolein ↓ 36-64%	35
FT GTL	Jet A1	CFM56-7	Modest changes in HCHO	48
FT GTL	JP-8	CFM-56-2C	HAPS ↓ significantly, e.g., EI–benzene ↓ factor 5 at idle.	2
FT GTL	JP-8	T63-A-700	Formaldehyde no Δ	21
FT GTL	JP-8	CFM56-7	0	22
FT GTL	JP-8	CFM56-2	0	22

Alt Fuel	Ref Fuel	Engine	Impact	Ref #
FT GTL	JP-8	F117	0	22
FT GTL	JP-8	TF33	0	22
FT GTL	JP-8	PW308	0	22
FT-AAFEX	JP-8	CFM56-2-C	Minor Δ in gaseous emissions	19
HEFA	Jet A2	MK113 APU	No Δ in aldehyde emissions.	35
HEFA	JP-8	CFM56-8	0	22
HEFA	JP-8	CFM56-3	0	22
HEFA	JP-8	F118	0	22
HEFA	JP-8	TF34	0	22
HEFA	JP-8	PW309	0	22
HRJ-AAFEX	JP-9	CFM56-2-C	Minor Δ in gaseous emissions	19
Beef Tallow	JP-8	F117-PW-100 = PW2000	HAP ↓	20
Beef Tallow	JP-9	T63-A-701	Formaldehyde no Δ	21
Camelina	JP-10	T63-A-702	Formaldehyde no Δ	21
Fats & Grease	JP-11	T63-A-703	Formaldehyde no Δ	21

8.0 Instructions to Use the Alternative Jet Fuel Assessment Tool

The Alternative Jet Fuel Assessment Tool is a Microsoft Excel-based tool designed to help airports estimate the reduction in aircraft landing takeoff (LTO) cycle emissions from the use of SAJF. The tool models emissions of SO_x, nvPM, CO, UHC, NO_x, and HAPs. The homepage of the tool shows two options to estimate the percentage reduction in emissions at the specified SAJF blend percentage as shown in Figure 22. Option 1 evaluates emissions reduction based on the airport's annual emissions inventory for each pollutant. Option 2 evaluates emissions reduction based on a description of the airport's operational characteristics.

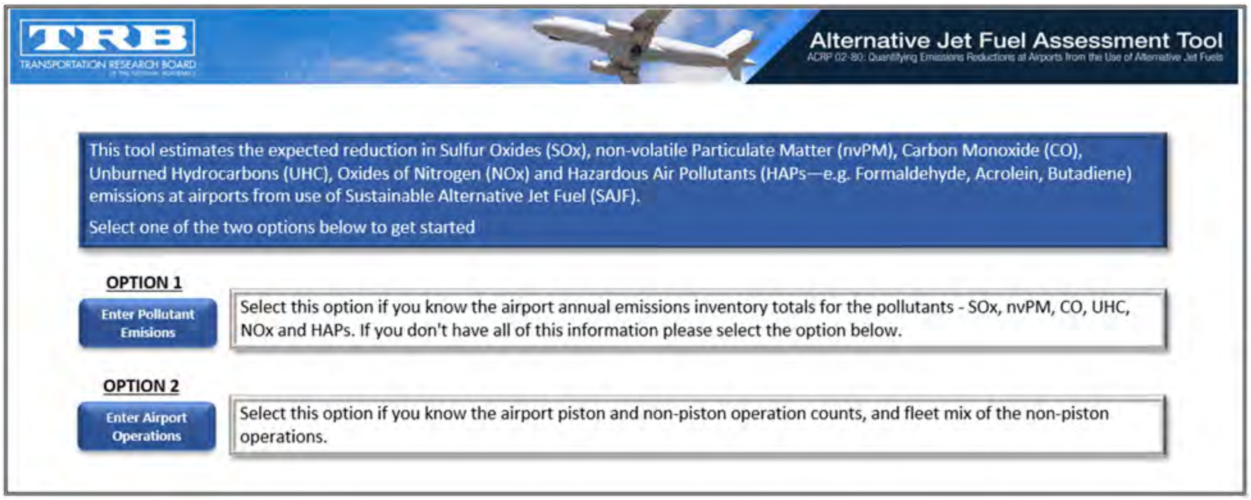


Figure 22: Home page of the Alternative Jet Fuel Assessment Tool

If the user selects Option 1 on the Home page, the tool displays an Inputs page shown in Figure 23. The text box on the left contains instructions for data entry and page navigation.

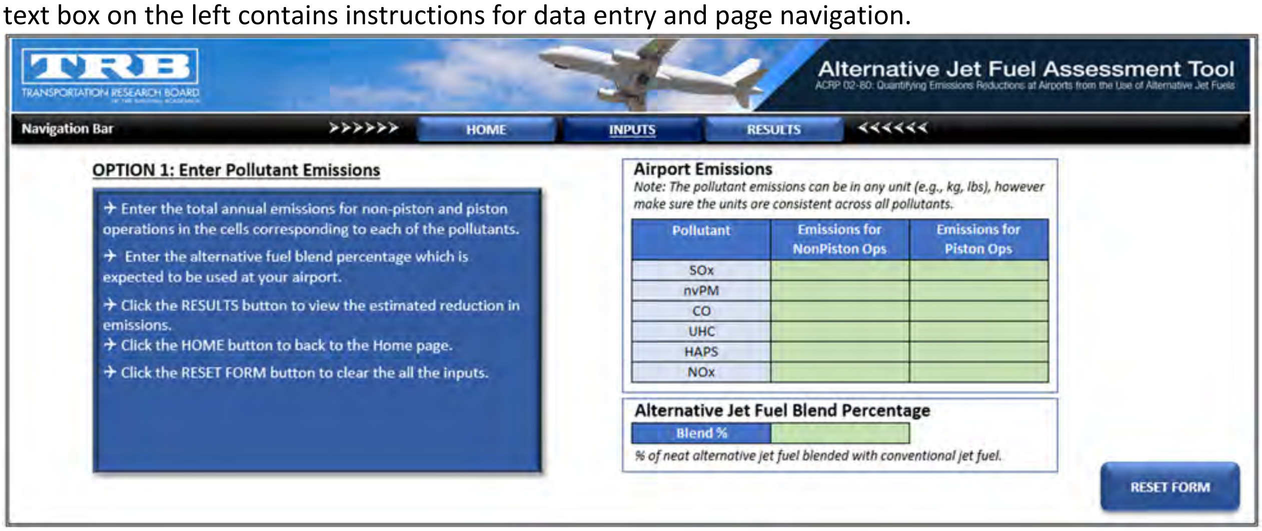


Figure 23: Layout of the Inputs page for Option 1

The user can enter airport emissions information by pollutant and the alternative jet fuel blend percentage, then click on the Results button in the navigation bar to view the analysis. The user can return to the Home page or clear the form using the Reset button. The tool will not display the Results page unless all inputs have been entered; an error message will notify the user of missing inputs as shown in Figure 24.

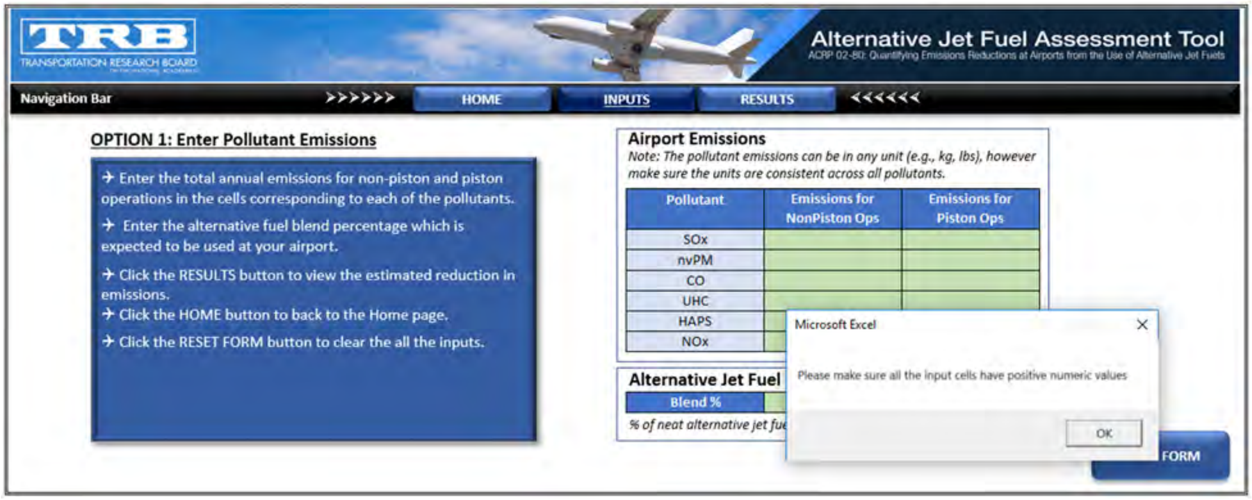


Figure 24: Example of an error message when required input information is missing

If the user selects Option 2 on the Home page, the tool displays an input form shown in Figure 25. The text box on the left contains instructions for data entry and page navigation. The user can enter the number of non-piston and piston operations and alternative jet fuel blend percentage. The user can select the airport category and airport operations description, then click on the Results button in the navigation bar to view the analysis. As with the Option 1 Inputs page, the user can return to the Home page or clear the form using the Reset button. The tool will not display the Results page unless all inputs have been entered; an error message will notify the user of missing inputs.

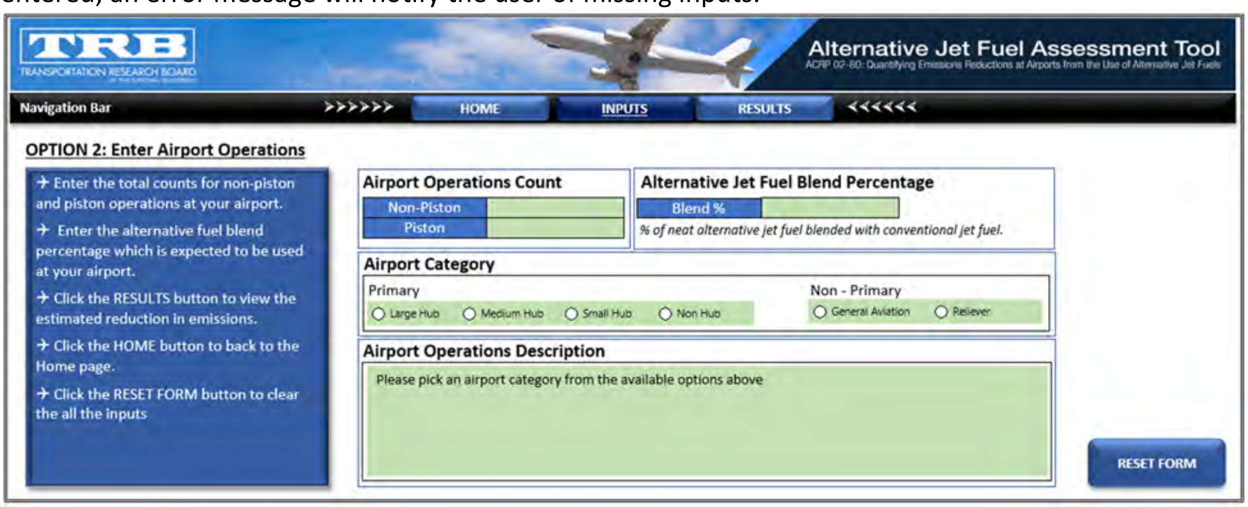


Figure 25: Layout of Inputs page for Option 2

The Results pages for both input options are the same. As shown in Figure 26, the left panel summarizes the user inputs and provides navigation instructions. The center panel displays the expected reduction in each pollutant's emissions along with an uncertainty bound at the specified SAJF blend percentage. The right panel plots the expected reduction in each pollutant's emission at various SAJF blend percentages.

The plot also displays a vertical red line which indicates the SAJF blend percentage the user entered on the Inputs page. The user can return to the Home page or the Inputs page using the navigation bar.

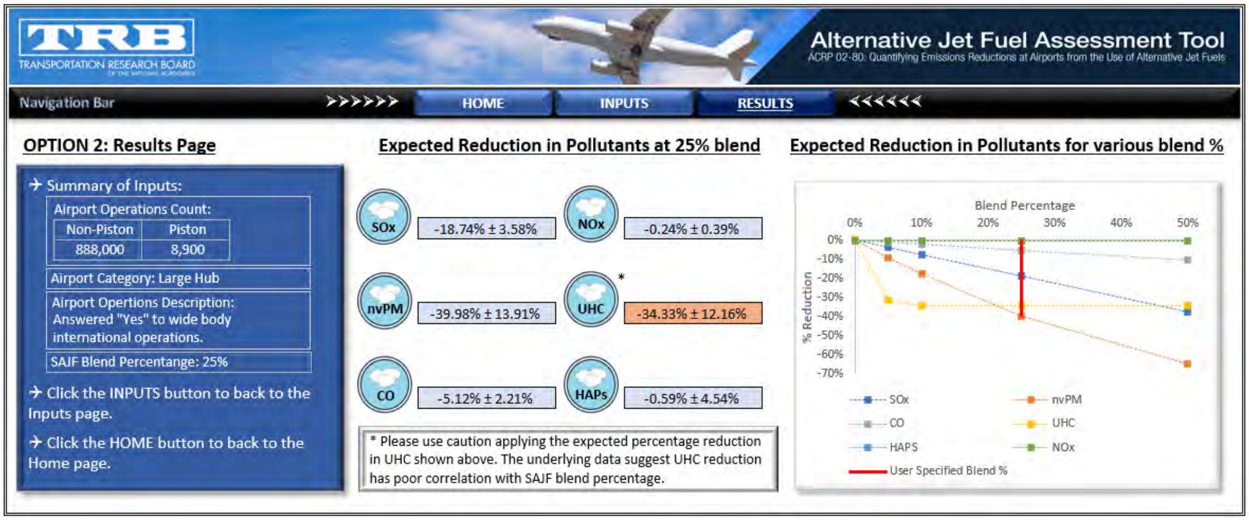


Figure 26: Layout of the Results page

References

Reference 1

PM Characteristics of Low NOx Combustor Burning Biodiesel and its Blends with Kerosene

Authors

Altaher, M.A., Andrews, G.E., and Li, H.

Source

Proceedings of ASME Turbo Expo 2013: Turbine Technical Conference and Exposition GT2013. San Antonio, Texas, USA

Publication Date

June 3-7, 2013

Abstract

PM emissions from gas turbine engines have increasing attention due to their impact on global climate change, human health and local air quality. Most of the existing data for particle size distribution in aero engines is for diffusion or rich/lean type combustors where the rich zones generate solid nano particle carbon emissions. This work investigates well mixed lean low NOx combustion where mixing is good and generation of solid carbon particulate emissions should be very low. This work investigated the particulate number concentrations and size distributions of exhaust gases emitted from a radial swirler based low NOx gas turbine combustor. The tests were conducted using a radial swirler industrial low NOx gas turbine combustor under atmospheric pressure and 600K at reference Mach number of 0.017 and 0.023. A baseline of natural gas combustion was compared with a waste rape seed cooking oil methyl ester biodiesel (WME), its blend with kerosene B20, B50 and pure kerosene. The particulate emissions were compared as a function of the lean well mixed primary zone equivalence ratio. A scanning mobility particle sizer (SMPS) with a Nano-Differential Mobility Analyzer (NDMA) was used to determine the number and concentration and size distribution of aerosols. The results showed that all WME particulates showed unimodal distribution characteristics with peak particle number at around 20nm. Conversion of the number distribution to mass showed very low mass emissions of around 1 mg/kg_{fuel}. Modern low NOx engines such as the Trent 970-84 has carbon mass emissions of 9 mg/kg_{fuel} based on the ICAO FOA-3 procedures. Thus, it is not unreasonable that in much lower NOx combustor designs the solid mass emissions will be lower than in current low NOx engines. Comparison is also made with particulate emissions from a diffusion flame APU gas turbine and much higher particle number emissions were demonstrated.

Reference 2

Alternative Aviation Fuel Experiment (AAFEX)

Authors

Anderson, B.E., et al.

Source

NASA Project Report
NSAS/TMI2011I217059

Publication Date

February 2011

Abstract

The rising cost of oil coupled with the need to reduce pollution and dependence on foreign suppliers has spurred great interest and activity in developing alternative aviation fuels. Although a variety of fuels have been produced that have similar properties to standard Jet A, detailed studies are required to ascertain the exact impacts of the fuels on engine operation and exhaust composition. In response to this need, NASA acquired and burned a variety of alternative aviation fuel mixtures in the Dryden Flight Research Center DC-8 to assess changes in the aircraft s CFM-56 engine performance and emission parameters relative to operation with standard JP-8. This Alternative Aviation Fuel Experiment, or AAFEX, was conducted at NASA Dryden s Aircraft Operations Facility in Palmdale, California, from January 19 to February 3, 2009 and specifically sought to establish fuel matrix effects on: 1) engine and exhaust gas temperatures and compressor speeds; 2) engine and APU gas phase and particle emissions and characteristics; and 3) volatile aerosol formation in aging exhaust plumes.

Reference 3

Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS-2) Flight Experiment

Authors

Anderson, B.

Source

Langley Research Center, ACCESS Science and Implementation Teams

Publication Date

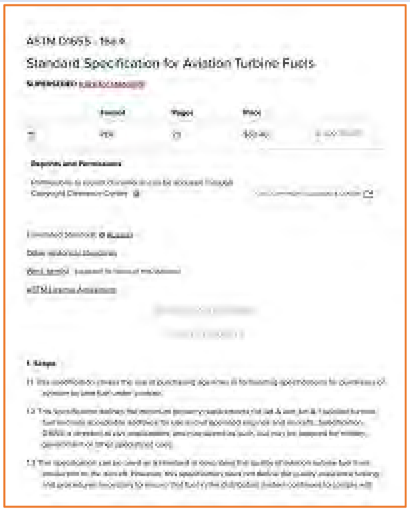
January 9, 2015

Abstract

Although the emission performance of gas turbine engines burning renewable aviation fuels have been thoroughly documented in recent ground-based studies, there is still great uncertainty regarding how the fuels effect aircraft exhaust composition and contrail formation at cruise altitudes. To fill this information gap, the NASA Aeronautics Research Mission Directorate sponsored the ACCESS flight series to make detailed measurements of trace gases, aerosols and ice particles in the near-field behind the NASA DC-8 aircraft as it burned either standard petroleum-based fuel of varying sulfur content or a 50:50 blend of standard fuel and a HEFA jet fuel produced from Camelina plant oil. ACCESS 1, conducted in spring 2013 near Palmdale CA, focused on refining flight plans and sampling techniques and used the instrumented NASA Langley HU-25 aircraft to document DC-8 emissions and contrails on five separate flights of approx.2 hour duration. ACCESS 2, conducted from Palmdale in May 2014, engaged partners from the Deutsches Zentrum fuer Luft- und Raumfahrt and National Research Council-Canada to provide additional scientific expertise and sampling aircraft (Falcon 20 and CT-133, respectively) with more extensive trace gas, particle, or air motion measurement capability. Eight, muliti-aircraft research flights of 2 to 4 hour duration were conducted to document the emissions and contrail properties of the DC-8 as it 1) burned low-sulfur Jet A, high sulfur Jet A or low-sulfur Jet A/HEFA blend, 2) flew at altitudes between 6 and 11 km, and 3) operated its engines at three different fuel flow rates. This presentation further describes the ACCESS flight experiments, examines fuel type and thrust setting impacts on engine emissions, and compares cruise-altitude observations with similar data acquired in ground tests.

Reference 4

[ASTM D1655-16a, Standard Specification for Aviation Turbine Fuels]


ASTM D1655 - 16a
Standard Specification for Aviation Turbine Fuels

Authors

ASTM International

Source

ASTM International. West Conshohocken, PA

Publication Date

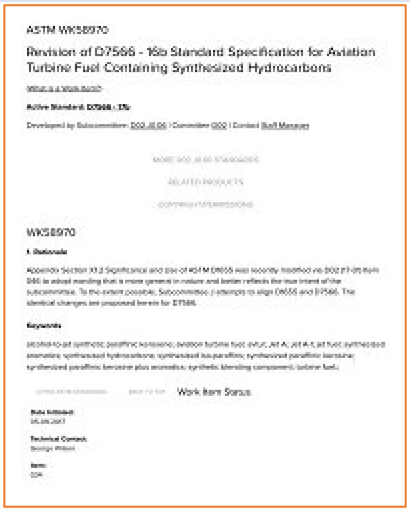
April 1, 2016

Abstract

This specification covers the use of purchasing agencies in formulating specifications for purchases of aviation turbine fuel under contract. This specification defines the minimum property requirements for Jet A and Jet A-1 aviation turbine fuel and lists acceptable additives for use in civil operated engines and aircrafts. Specification D1655 is directed at civil applications, and maintained as such, but may be adopted for military, government or other specialized uses.

Reference 5

ASTM D7566-16b, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons



ASTM WK58970

Revision of D7566 - 16b Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

WK58970

Work Item Status

Abstract

Appendix Section X1.2 Significance and Use of ASTM D1655 was recently modified via D02 (17-01) Item 046 to adopt wording that is more general in nature and better reflects the true intent of the subcommittee. To the extent possible, Subcommittee J attempts to align D1655 and D7566. The identical changes are proposed herein for D7566.

Authors

ASTM International

Source

ASTM International. West Conshohocken, PA

Publication Date

July 1, 2016

Reference 6

Reductions in Aircraft Particulate Emissions due to the use of Fischer–Tropsch Fuels


Reductions in aircraft particulate emissions due to the use of Fischer–Tropsch fuels

Authors

Beyersdorf, A. J., Timko, M. T., Ziemba, L. D., Bulzan, D., Corporan, E., Herndon, S. C., Howard, R., Miake-Lye, R., Thornhill, K. L., Winstead, E., Wey, C., Yu, Z., and Anderson, B. E

Source

Atmos. Chem. Phys., Vol. 14, pp. 11-23.

Publication Date

2014

Abstract

The use of alternative fuels for aviation is likely to increase due to concerns over fuel security, price stability, and the sustainability of fuel sources. Concurrent reductions in particulate emissions from these alternative fuels are expected because of changes in fuel composition including reduced sulfur and aromatic content. The NASA AAFEX was conducted in January-February 2009 to investigate the effects of synthetic fuels on gas-phase and particulate emissions. Standard petroleum JP-8 fuel, pure synthetic fuels produced from natural gas and coal feedstocks using the Fischer–Tropsch (FT) process, and 50% blends of both fuels were tested in the CFM-56 engines on a DC-8 aircraft. To examine plume chemistry and particle evolution with time, samples were drawn from inlet probes positioned 1, 30, and 145 m downstream of the aircraft engines. No significant alteration to engine performance was measured when burning the alternative fuels. However, leaks in the aircraft fuel system were detected when operated with the pure FT fuels as a result of the absence of aromatic compounds in the fuel. Dramatic reductions in soot emissions were measured for both the pure FT fuels (reductions in mass of 86% averaged over all powers) and blended fuels (66%) relative to the JP-8 baseline with the largest reductions at idle conditions. At 7% power, this corresponds to a reduction from 7.6 mg kg-1 for JP-8 to 1.2 mg kg-1 for the natural gas FT fuel. At full power, soot emissions were reduced from 103 to 24 mg kg-1 (JP-8 and natural gas FT, respectively). The alternative fuels also produced smaller soot (e.g., at 85% power, volume mean diameters were reduced from 78 nm for JP-8 to 51 nm for the natural gas FT fuel), which may reduce their ability to act as cloud condensation nuclei. The reductions in particulate emissions are expected for all alternative fuels with similar reductions in fuel sulfur and aromatic content regardless of the feedstock. As the plume cools downwind of the engine, nucleation-mode aerosols form. For the pure FT fuels, reductions (94% averaged over all powers) in downwind particle number emissions were similar to those measured at the exhaust plane (84%). However, the blended fuels had less of a reduction (reductions of 30-44%) than initially measured (64%). The likely explanation is that the reduced soot emissions in the blended fuel exhaust plume results in promotion of new particle formation microphysics, rather than coating on pre-existing soot particles, which is dominant in the JP-8 exhaust plume. Downwind particle volume emissions were reduced for both the pure (79 and 86% reductions) and blended FT fuels (36 and 46%) due to the large reductions in soot emissions. In addition, the alternative fuels had reduced particulate sulfate production (near zero for FT fuels) due to decreased fuel sulfur content. To study the formation of volatile aerosols (defined as any aerosol formed as the plume ages) in more detail, tests were performed at varying ambient temperatures (-4 to 20 C). At idle, particle number and volume emissions were reduced linearly with increasing ambient temperature, with best fit slopes corresponding to-8 × 1014 particles (kg fuel)-1 C-1 for particle number emissions and-10 mm3 (kg fuel)-1 C-1 for particle volume emissions. The temperature dependency of aerosol formation can have large effects

Reductions in Aircraft Particulate Emissions due to the use of Fischer–Tropsch Fuels	
	on local air quality surrounding airports in cold regions. Aircraft-produced aerosols in these regions will be much larger than levels expected based solely on measurements made directly at the engine exit plane. The majority (90% at idle) of the volatile aerosol mass formed as nucleation-mode aerosols, with a smaller fraction as a soot coating. Conversion efficiencies of up to 2.8% were measured for the partitioning of gas-phase precursors (unburned hydrocarbons and SO2) to form volatile aerosols. Highest conversion efficiencies were measured at 45% power.

Reference 7

An Experimental Comparison of the Emissions Characteristics of Standard Jet A-1 and Synthetic Fuels


Springer Link

An Experimental Comparison of the Emissions Characteristics of Standard Jet A-1 and Synthetic Fuels

Abstract

Abstract

Emissions characteristics of lean, turbulent, partially premixed swirled flames of synthetic fuels along with a standard Jet A-1 fuel are studied. The investigated synthetic fuels are (a) Fully synthetic jet fuel (FSJF), (b) Fischer–Tropsch synthetic paraffinic kerosene (FT-SPK), (c) FT-SPK+20 % hexanol, and (d) FT-SPK+50 % naphthenic cut. The measurements are performed in a tubular combustor equipped with a burner based on the principle of air-blast atomization. The exhaust gas compositions are measured using a non-dispersive infrared gas analyzer for carbon dioxide (CO_2) and carbon monoxide (CO), a flame ionization detector for unburned hydrocarbons (UHC), and a chemical luminescence detector for nitric oxides (NO and NO_2). The EI of CO and NOX of the investigated fuels are calculated using guidelines provided by the Society of Automotive Engineers (SAE). Measurements are performed at several combustor pressure levels, i.e., 0.3, 0.54 and 0.8 MPa, to compare the emissions behavior of the investigated fuels at varied operating conditions. At 0.3 MPa of combustor pressure, the order of fuels with their increasing formation of NOX are FSJF, FT-SPK+20 % hexanol, Jet A-1, FT-SPK+50 % naphthenic cut and neat FT-SPK. Differences in the observed NOX formation behavior of the investigated fuels are attributed to their probable different degrees of mixing with air in the combustor. At 0.8 MPa, no significant differences in their emissions characteristics are observed due to very low absolute values; hence we report that at higher pressure conditions which prevail in the aero-engine combustion systems, the emissions characteristics of tested synthetic fuels are very close to that of standard Jet A-1 fuel.

Authors

Bhagwan, R., Habisreuther, P., Zarzalis, N., and Turrini, F.

Source

Flow Turbulence Combustion, Vol. 92, pp.865–884.

Publication Date

2014

Reference 8

Recent developments in studies of alternative jet fuel combustion: Progress, challenges, and opportunities


Renewable and Sustainable Energy Reviews

Recent development in studies of alternative jet fuel combustion: Progress, challenges, and opportunities

Authors

Zhang, C., Hui, X., L. Yuzhen., and Sung, C.

Source

Renewable and Sustainable Energy Reviews

Publication Date

2016

Abstract

With the growing air transport demand and concerns about its environmental impacts, alternative jet fuels derived from non-conventional sources have become an important strategy for achieving a sustainable and green aviation. In the past 10 years, governments around the world along with aviation industry have invested significant efforts into exploring all sorts of alternative jet fuels that can be used to power aircraft engines. Among all the alternative jet fuels explored, the aviation sector has agreed that hydrocarbon-based 'drop-in' replacement fuels, which are fully interchangeable and compatible with current conventional jet fuels, would be the best choice in the near future, as they can be used without any modifications to today's aircraft or fuel infrastructure. This paper reviews the current state of development of 'drop-in' alternative jet fuels including various FT synthetic jet fuels and bio-jet fuels. Recent advances in research activities on alternative jet fuels, including fuel property evaluations, combustor component tests, engine tests, and flight tests, are highlighted. Furthermore, basic research needs for understanding the combustion characteristics of alternative jet fuels are underlined and discussed by reviewing recent fundamental combustion studies on ignition, extinction, flame propagation, emissions. and species evolution of various conventional and alternative jet fuels. Recognizing that the use of 'simpler' surrogate fuels to emulate the behavior of 'complex' alternative jet fuels is of fundamental and practical importance for the development of physics-based models to enable quantitative emissions and performance predictions using combustion modeling, recent studies on surrogate formulation for alternative jet fuels are also reviewed and discussed. This review concludes with a brief discussion of future research directions.

Reference 9

Aviation Gas Turbine Alternative Fuels: A Review


Alternative fuels in aviation

Abstract

Authors

Blakey, S., Rye, L., Wilson, C.W.

Source

Proceedings of the Combustion Institute, Vol. 33, November 9, pp.2863-2885.

Publication Date

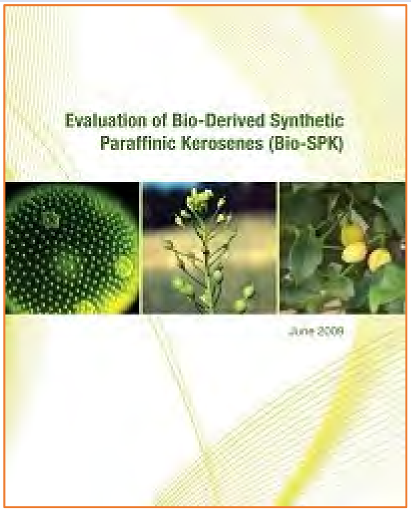
2010

Abstract

During the last years, the aviation sector has been looking into alternatives to kerosene from crude oil, to combat climate change by reduction of greenhouse gas (GHG) emissions and to ensure security of supply at affordable prices. The efforts are also a reaction to commitments and policy packages. Currently, a wide range of possible fuel candidates and fuel blends are discussed in the triple feedstock, process, and product. Any (synthetic) aviation fuel must be certified; hence, a profound knowledge on its properties, in particular thermophysical and chemical, is inevitable. In the present paper, an overview is given on alternative jet fuels, looking into the short-term and long-term perspective. Examples focusing on experimental and modeling work of combustion properties of existing—coal to liquid, gas to liquid (GtL)—and possible alternative fuels—GtL + 20 % 1-hexanol, GtL + 50 % naphthenic cut—are presented. Ignition delay times and laminar flame speeds were measured for different alternative aviation fuels over a range of temperatures, pressures, and fuel–air ratios. The data are used for the validation of a detailed chemical reaction mechanism following the concept of a surrogate. Such validated reaction models able to describe and to predict reliably important combustion properties of jet fuels are needed to further promote the development of even more sophisticated jet engines and to optimize synthetic jet fuel mixtures in practical combustors.

Reference 10

Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPK)



Authors

Boeing Company

Source

UOP, U.S. Air Force Research Laboratory, Report Version 5.0, Committee D02 on Petroleum Products and Lubricants, Subcommittee D02.J0.06 on Emerging Turbine Fuels, Research Report D02-1739. ASTM International, West Conshohocken, PA

Publication Date

June 28, 2011

Abstract

It is of paramount importance that our industry must continue to progressively improve its environmental performance and lessen impacts to the global ecosystem, while continuing to reduce operating costs. Aviation recognizes these challenges must be addressed to ensure industry viability and is actively seeking to provide technologically driven solutions. Bio-derived jet fuel is a key element in the industry strategy to address these challenges. The signatories to this summary and many others have invested significant time and resources to further the research, development and commercialization of bio-derived jet fuel. Virgin Atlantic paved the way with its proof of concept flight powered by biofuel in February 2008. Since that time, a broader range of fuels have become available that more closely replicate the performance characteristics of conventional kerosene jet fuel. Significant progress has been made in verifying the performance of SPK made from sustainable sources of bio-derived oils, that can be used in commercial aircraft at a blend ratio of up to 50 percent with traditional jet fuel (Jet A or Jet A-1). A cross-industry team consisting of Boeing, Honeywell/UOP, Air New Zealand, Continental Airlines (CAL), Japan Airlines (JAL), General Electric, CFM, Pratt & Whitney, and Rolls Royce participated in a series of tests flights with a bio-derived SPK (Bio-SPK) to collect data to support eventual certification of Bio-SPK jet fuels for use in commercial aviation pending the necessary approvals. This document provides a summary of the data collected from the Bio-SPK research and technology program, as well as a discussion about the additional data that is being generated to support fuel approval.

Reference 11

Effects of Fuel Aromatic Content on Nonvolatile Particulate Emissions of an In-Production Aircraft Gas Turbine

Authors

Brem, T.B., et al

Source

Environmental Science & Technology, Vol. 49, Issue 22, pp.13149-13157

Publication Date

October 23, 2015

Abstract

Aircraft engines emit particulate matter (PM) that affects the air quality in the vicinity of airports and contributes to climate change. Nonvolatile PM (nvPM) emissions from aircraft turbine engines depend on fuel aromatic content, which varies globally by several percent. It is uncertain how this variability will affect future nvPM emission regulations and emission inventories. Here we present BC mass and nvPM number EIs as a function of fuel aromatic content and thrust for an in-production aircraft gas turbine engine. The aromatics content was varied from 17.8 % (v/v) in the neat fuel (Jet A-1) to up to 23.6 % (v/v) by injecting two aromatic solvents into the engine fuel supply line. Fuel normalized BC mass and nvPM number EIs increased by up to 60% with increasing fuel aromatics content and decreasing engine thrust. The EIs also increased when fuel naphthalenes were changed from 0.78 % (v/v) to 1.18 % (v/v) while keeping the total aromatics constant. The EIs correlated best with fuel hydrogen mass content, leading to a simple model that could be used for correcting fuel effects in emission inventories and in future aircraft engine nvPM emission standards.

Reference 12

Characterization of Gaseous and Particulate Emissions from a Turboshaft Engine Burning Conventional, Alternative, and Surrogate Fuels

Authors

Cain, J., DeWitt, M.J., Blunck, D., Corporan, E., Striebich, R., Anneken, D., Klingshirn, C., Roquemore, W.M., and Vander Wall, R.

Source

Energy Fuels, Vol. 27, pp.2290−2302

Publication Date

2013

Abstract

The effect of fuel composition on the operability and gaseous and PM emissions of an Allison T63-A-700 turboshaft engine operated at four power settings was investigated in this effort. Testing was performed with a specification JP-8, a SPK, and four two-component surrogate mixtures that comprise compound classes within current and future alternative fuels. Comparable engine operability was observed for all fuels during this study. Major gaseous emissions were only slightly effected, with trends consistent with those expected based on the overall hydrogen content of the fuels. However, minor hydrocarbon and aldehyde emissions were significantly more sensitive to the fuel chemical composition. Linear correlations between speciated hydrocarbon and aldehyde emissions were observed over the full engine operating range for the fuels tested. The corresponding slopes were dependent on the fuel composition, indicating that fuel chemistry affects the selectivity to specific decomposition pathways. Unburned fuel components were observed in the engine exhaust during operation with all fuels, demonstrating that completely unreacted fuel compounds can pass through the high temperature/pressure combustion zone. Nonvolatile PM emissions (soot) were strongly affected by the fuel chemical composition. Paraffinic fuels produced significantly lower PM number and mass emissions relative to aromatic-containing fuels, with the paraffin structure affecting sooting propensity. The observations are consistent with those expected based on simplified soot formation mechanisms, where fuels with direct precursors for polycyclic aromatic hydrocarbon formation have higher PM formation rates. The effect of a specific chemical structure on the relative PM production is important as this would not be evident when comparing sooting tendencies of fuels based on bulk fuel properties. All fuels produced similar single log-normal size distributions of soot, with higher sooting fuels producing larger mean diameter particles. It is hypothesized that the controlling growth and formation mechanisms for PM production are similar for different fuel chemistries in this regime, with composition primarily affecting soot formation rate. This hypothesis was supported by preliminary TEM analyses that showed similar soot microstructures during operation with either conventional JP-8 or alternative fuels. Overall, this study provides additional and improved insight into the effect of fuel chemical composition on complex combustion chemistry and emissions propensity in a gas turbine engine and can assist with the successful development of predictive modeling tools.

Reference 13

Energy and Environmental Viability of Select Alternative Jet Fuel Pathways

Authors

Carter, N. A., Stratton, R.W., Bredehoeft, M.K., and Hileman, J.I

Source

47th AIAA/ASME, SAE, ASEE Joint Propulsion Conference & Exhibit. AIAA 2011-5968. San Diego, CA

Publication Date

July 31 – August 3, 2011

Abstract

This paper analyzes alternative jet fuels in terms of how they could change emissions from military and civil aircraft and in terms of the challenges in meeting future energy goals. Estimations of the continental United States (CONUS) conventional jet fuel energy usage for the civil and military aviation fleets were used to inform the magnitude and logistics of where the fuels would be needed. To adequately meet military goals, the U.S. Air Force (USAF) and U.S. Navy (USN) would need to supply roughly 47,500 bpd and 18,800 barrels per day (bpd) of alternative jet fuels by 2016, respectively. The total amount of fuel for both military and civil goals would reach nearly 132,000 bpd within the next decade if tentative goals become actual policy. Quantifications of the emissions affecting surface air quality from CONUS civil, USAF and USN aircraft, as well as 50% and 100% SPK combustion emissions normalized by conventional jet fuels were also provided. Although a 50% blend of SPK has been permitted, additional testing and analysis is needed for approval of higher blend percentages. It was found that NOX emissions from military aircraft tend be lower while primary PM2.5, CO and UHC emissions tend to be higher than their civilian aircraft counterparts. This is indicative of military aircraft being less efficient at lower power settings than civil aircraft during the LTO cycle. Emissions reductions with 50% and 100% SPK use could provide military and civil aviation planners with more options when locating aircraft in nonattainment areas within the CONUS. For some emissions, the introduction of SPK fuels could allow for additional aircraft for the same environmental impact or decreased overall air quality footprint for a particular location. SPK fuels from Fischer–Tropsch Biomass-to-Liquid (BTL) and HRJ processes were examined for their ability to meet future alternative fuel and environmental goals. BTL facilities were found to have larger capital costs and HRJ required large land area. Life-cycle analysis (LCA) of greenhouse gas (GHG) emissions for select F-T BTL and HRJ were found to potentially meet or exceed organizational goals in the near term. High yield crops like algae could provide the energy and environmental goals, but additional constraints must be considered, such as water and CO_2 requirements; furthermore, these technologies need to be translated from the lab to commercial production. Additional research is required to provide an in-depth geographic analysis of the CONUS commercial and military demand centers and resource constraints to better understand the challenge in meeting future alternative fuel goals.

Reference 14

Environmental and Economic Assessment of Microalgae-Derived Jet Fuel

Authors

Carter, N. A.

Source

Laboratory for Aviation and the Environment. Massachusetts Institute of Technology. Cambridge, MA

Publication Date

June 2012

Abstract

Significant efforts must be undertaken to quantitatively assess various alternative jet fuel pathways when working towards achieving environmental and economic United States commercial and military alternative aviation fuel goals within the next decade. This thesis provides LCAs of the environmental and economic impacts of cultivating and harvesting phototrophic microalgae; extracting, transporting, and processing algal oils to hydrocarbon fuels; and distributing and combusting the processed renewable jet fuel for a pilot scale facility. Specifically, life-cycle greenhouse gas (GHG) emissions, production costs, freshwater consumption, and land use were quantified for four cultivation and two extraction technology sets. For each cultivation and extraction type, low, baseline, and high scenarios were used to assess the variability of each performance metric. Furthermore, sensitivity analyses were used to gain insights as to where efforts towards improving certain technologies could have the largest impact on improving the life-cycle metrics. The four cultivation technologies include open raceway ponds, horizontal serpentine tubular photobioreactors (PBRs), vertical serpentine tubular PBRs, and vertical flat panel PBRs. Open raceway ponds were modeled from previous literature, while the PBRs were modeled, validated and optimized for specific constraints and growth inputs. The algal oil extraction techniques include conventional dewatering, drying, and extraction using hexane in a similar process to seed oil extraction (termed dry extraction in this study) as well as algal cell lysing with steam and potassium hydroxide as well as fluid separation and washing processes (termed wet extraction). Overall, open raceway pond cultivation with wet extraction performed most favorably when compared with the other scenarios for GHG emissions, production costs, freshwater consumption, and areal productivity (including the entire cultivation and extraction facility), yielding 31.3 g-CO2e/MJ_{HEFA-J}, 0.078 \$/MJ_{HEFA-J} (9.86 \$/gal_{HEFA-J}), 0.38 $L_{freshwater}$/MJ_{HEFA-J} and 17,600 L_{TAG}/ha/yr for the baseline cases with brackish water makeup. The life-cycle GHG emissions and production cost metrics for the open raceway pond with wet extraction low scenario were both lower than that of conventional jet fuel baselines. For all cases, the inputs most sensitive to the life-cycle metrics were the cultivation system biomass areal productivity, algal extractable lipid weight fraction, and downstream harvesting system choices.

Reference 15

[Characterization of Emissions from the Use of Alternative Aviation Fuels, Journal of Engineering for Gas Turbines and Power]


Characterization of Emissions From the Use of Alternative Aviation Fuels

Authors

Chan, T.W., Chishty, W. A., Canteenwalla, P., Buote, D., and Davidson, C.R.

Source

Journal of Engineering for Gas Turbines and Power, Vol. 138 / 011506-1

Publication Date

January 2016

Abstract

Alternative fuels for aviation are now a reality. These fuels not only reduce reliance on conventional petroleum-based fuels as the primary propulsion source, but also offer promise for environmental sustainability. While these alternative fuels meet the aviation fuels standards and their overall properties resemble those of the conventional fuel, they are expected to demonstrate different exhaust emissions characteristics because of the inherent variations in their chemical composition resulting from the variations involved in the processing of these fuels. This paper presents the results of back-to-back comparison of emissions characterization tests that were performed using three alternative aviation fuels in a GE CF-700-2D-2 engine core. The fuels used were an unblended synthetic kerosene fuel with aromatics (SKA), an unblended Fischer–Tropsch (FT) SPK and a semi-synthetic 50–50 blend of Jet A-1 and hydroprocessed SPK. Results indicate that while there is little dissimilarity in the gaseous emissions profiles from these alternative fuels, there is however a significant difference in the PM emissions from these fuels. These differences are primarily attributed to the variations in the aromatic and hydrogen contents in the fuels with some contributions from the hydrogen-to-carbon ratio of the fuels.

Reference 16

Experimental Study of the Gaseous and Particulate Matter Emissions from a Gas Turbine Combustor Burning Butyl Butyrate and Ethanol Blends


Applied Energy

Experimental study of the gaseous and particulate matter emissions from a gas turbine combustor burning butyl butyrate and ethanol blends

Highlights

Abstract

Authors

Chen, L. Zhang, Z. Lu, Y., Zhang, C., Zhang, X., Zhang, Cu., Roskilly, A.P.

Source

Applied Energy, Vol.195, pp.693-701

Publication Date

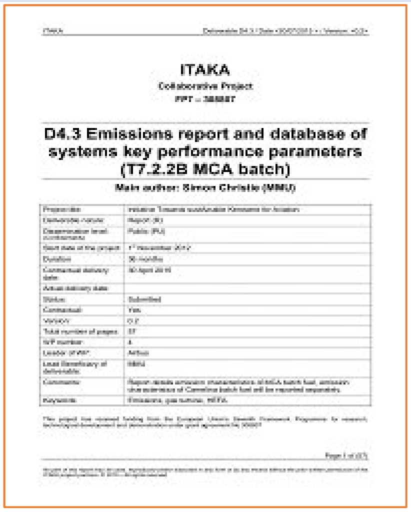
2017

Abstract

This paper reports the gaseous pollutants and PM emissions of a gas turbine combustor burning butyl butyrate and ethanol blends. The gas turbine has been tested under two operational conditions to represent the cruising (condition 1) and idling (condition 2) conditions of aero engines. Aviation kerosene RP-3 and four different biofuels using butyl butyrate (BB) and ethanol blends were tested and compared to evaluate the impact of fuel composition on CO, NOx, unburnt hydrocarbon (UHC) and PM emissions under selected two operational conditions. The PM number (PN) concentration and size distributions were measured by a SMPS. The compositions of filter borne PM were analysed by ion chromatograph technique. The concentrations of CO, NOx and UHC were detected and analysed by a gas analyser. Results indicated that under idling and cruising conditions the CO emissions from BB and ethanol blends were higher than that of RP-3 due to the relatively lower combustion temperature of the biofuels compared with that of RP-3. Results of the NOx emission comparison indicated the biofuels produced less NOx than RP-3 and the increase of ethanol content in the biofuels could reduce the NOx and UHC emissions. The particles smaller than 20 nm played a dominant role in PN emissions at condition 1 with the range from 2 × 106/cm3 to 4 × 107/cm3. There was a peak value of particle number concentration with the particle size ranging from about 25 nm and 40 nm. The PN emission index at condition 1 was higher than that at condition 2 for the biofuels, while the trend was opposite to that of RP-3. The ions analysis indicated Ca2+ and SO42− were the two dominant ions in the PM emissions of biofuels.

Reference 17

D4.3 Emissions Report and Database of Systems Key Performance Parameters



ITAKA

Collaborative Project

D4.3 Emissions report and database of systems key performance parameters (T7.2.2B MCA batch)

Main author: Simon Christie (MMU)

Authors

Christie, S.

Source

ITAKA Collaborative Project, FP7-308807

Publication Date

April 30, 2015

Abstract

In the development of alternative fuels for aviation there have been a number of significant scale research projects within the EU: SWAFEA (2008-2011) investigated the impact and feasibility of using alternative fuels in aviation; Alfabird (2009-2012) evaluated a selection of 'best candidate' alternative fuels; and most recently Initiative Towards sustAinable Kerosene for Aviation (ITAKA) (2012-2015) an intermediate scale 'value chain' project that aims to produce, flight-test and evaluate 4000 tonnes of sustainable biofuels.

The ITAKA project is a collaborative research venture designed to address some of the barriers that challenge the development of sustainable aviation biofuels in the EU. In the following task, the direct emissions from the combustion of the ITAKA MCA batch biofuel in a small gas turbine engine are assessed so that their environmental impact can be placed in context and better understood. This is an important issue since aviation emissions can have a direct impact on atmospheric chemistry and on the radiative balance that extends well beyond the CO_2 effect: Contrails formed by condensation of water vapour onto exhaust PM and aerosols may trigger the formation of induced cirrus clouds, similarly, emissions of NOx may perturb the natural chemical cycles and lead to ozone production or destruction depending on latitude and altitude as well as modifying the time of residence for methane in the atmosphere. Hence, modeling the atmospheric impact of aviation requires the synthesis of aircraft movement data and detailed aircraft emissions data into atmospheric models. And while the combustion of fuel in a gas turbine engine is a highly efficient process, there is no reason to assume that the emissions from HEFA based fuels will be identical to those from the combustion of Jet A-1. Due diligence requires that the emission profile for the combustion of these fuels must come under scientific scrutiny ahead of the large scale introduction of new fuels on climate, security or economic grounds. The ITAKA HEFA based biofuels are produced with properties that are within the specification envelope of ASTM D7566, however there are appreciable chemical and physical differences. The impact of these differences on aircraft emissions is largely unknown, although some consensus and generalized rules are beginning to emerge. The objective of this task has been to collect experimental emission data using a small APU gas turbine engine and consolidate this with structured knowledge from the wider literature. In comparison to full rig testing or on-wing testing, emission testing on an APU has the advantage that a comparatively modest quantity of fuel is required, tests are relatively low cost, and the information gained is comparable since fuel chemistry is the dominant impact parameter. The experimental data capture the important emission characteristics and key features of engine performance when powered by ITAKA MCA HEFA based biofuel. A full range of fuel blend ratios has been considered from 100% Jet A-1 through to 100% biofuel. This is the largest most comprehensive dataset in the literature. It has been extended to cover the range of blends beyond the current ASTM 50% certification limit which may be important in future certification, and

D4.3 Emissions Report and Database of Systems Key Performance Parameters	
	allows performance and emission trends to be assessed with statistically significant confidence. The ITAKA MCA biofuel sourced from SkyNRG was derived from used cooking oil, while a straight run Jet A-1 sourced from within the UK was used as both baseline and blend component fuel. A complete GC x GC analysis of the MCA biofuel and baseline Jet A-1 provided a comprehensive qualitative and quantitative chemical breakdown of the fuel groupings, and showed that the aromatic, alkane and cyclo-paraffinic structures in the two fuels are significantly different.

Reference 18

[Gas Turbine Engine Nonvolatile Particulate Matter Mass Emissions: Correlation with Smoke Number for Conventional and Alternative Fuel Blends]

Authors

Christie, S., Lobo, P., Lee, D., Raper, D.

Source

Science & Technology, Vol. 51, 2017, pp.988-996.

Publication Date

2017

Abstract

This study evaluates the relationship between the emissions parameters of smoke number (SN) and mass concentration of nonvolatile PM (nvPM) in the exhaust of a gas turbine engine for a conventional Jet A-1 and a number of alternative fuel blends. The data demonstrate the significant impact of fuel composition on the emissions and highlight the magnitude of the fuel-induced uncertainty for both SN within the Emissions Data Bank as well as nvPM mass within the new regulatory standard under development. Notwithstanding these substantial differences, the data show that correlation between SN and nvPM mass concentration still adheres to the First Order Approximation (FOA3), and this agreement is maintained over a wide range of fuel compositions. Hence, the data support the supposition that the FOA3 is applicable to engines burning both conventional and alternative fuel blends without adaptation or modification. The chemical composition of the fuel is shown to impact mass and number concentration as well as geometric mean diameter of the emitted nvPM; however, the data do not support assertions that the emissions of BC with small mean diameter will result in significant deviations from FOA3.

Reference 19

An Overview of the National Jet Fuels Combustion Program

Abstract

This paper provides an overview of the National Jet Fuels Combustion Program led by the Federal Aviation Administration, the U.S. Air Force Research Laboratory, and the NASA. The program follows from basic research from the U.S. Air Force Office of Scientific Research and results from the engine-company-led Combustion Rules and Tools program funded by the U.S. Air Force. The overall objective of this fuels program was to develop combustion-related generic test and modeling capabilities that can improve the understanding of the impact of fuel chemical composition and physical properties on combustion, leading to accelerating the approval process of new alternative jet fuels. In this paper, the motivation and objectives for the work, participating universities, gas turbine engine companies, other federal agencies, and international partners are described.

Authors

Colket, M., Heyne, J., Rumizen, M., Gupta, M., Jardines, A., Edwards, T., Roquemore, W. M., Andac, G., Boehm, R., Zelina, J., Lovett, J., Condevaux, J., Bornstein, S., Rizk, N., Turner, D., Graves, C., Anand, M.S.

Source

AIAA SciTech Forum 54th AIAA Aerospace Sciences Meeting, San Diego, CA

Publication Date

January 4-8, 2016

Reference 20

Alternative Fuels Tests on a C-17 Aircraft: Emissions Characteristics


DEFENSE TECHNICAL INFORMATION CENTER

Abstract

Emissions evaluations were conducted on a C-17 Globemaster III F117-PW-100 engine operated with alternative fuels blends. These tests support the USAF goal of 50% domestic fuel consumption using alternative (synthetic) fuels with lower or equal carbon footprint than petroleum fuels by 2016. The tests took place at Edwards Air Force Base on the period of August 16 through 27, 2010 as part of the United States Air Force (USAF) Alternative Fuels Certification Office ground and flight tests to certify the C-17 on a 50/50 by volume JP-8/HRJ fuel blend. Emissions were collected from engine 3 of the parked aircraft operated on conventional JP-8 and 50/50 blends of JP-8 and a beef tallow-derived HRJ, and a 50/25/25 blend of JP-8, HRJ and a coal-derived Fischer–Tropsch (FT) fuel. Gaseous and PM emissions were measured. PM measurements included particle number (concentration), mass and size distribution. In addition, HAPs emissions, SNs and chemical analysis of soot samples were performed for the engine operated with the three fuels. Emissions were collected for five engine operating conditions ranging from 4% (idle) to 63% of rated maximum thrust. Test results show that the alternative fuel blends resulted in no operational anomalies or detrimental impacts on the gaseous or PM emissions of the F117 engine for any of the conditions tested. Moderate reductions in carbon monoxide (CO) emissions (30%) and more significant reductions in sulfur oxides (50%), measured HAPs (60%) and PM emissions (30-60%) relative to operation with JP-8 were observed. The alternative fuels had negligible impact on nitrogen oxides (NOx) emissions.

Authors

Corporan, E., DeWitt, M.J., Klingshirn, C.D., Anneken, D.

Source

Air Force Research Laboratory Interim Report, AFRL-RZ-WP-TR-2011-2004, Wright-Patterson Air Force Base, OH, December 2010

Publication Date

December 2010

Reference 21

Chemical, Thermal Stability, Seal Swell, and Emissions Studies of Alternative Jet Fuels

Abstract

This effort describes laboratory evaluations of six alternative (non-petroleum) jet fuel candidates derived from coal, natural gas, Camelina, and animal fat. Three of the fuels were produced via Fischer−Tropsch (FT) synthesis, while the other three were produced via extensive hydroprocessing. The thermal stability, elastomer swell capability, and combustion emissions of the alternative jet fuels were assessed. In addition, detailed chemical analysis was performed to provide insight into their performance and to infer potential behavior of these fuels if implemented. The fuels were supplied by Sasol, Shell, Rentech, UOP, and Syntroleum Corporation. Chemical analyses show that the alternative fuels were comprised of mostly paraffinic compounds at varying relative concentrations, contained negligible heteroatom species, and were mostly aromatic-free. The six paraffinic fuels demonstrated superior thermal oxidative stability compared to JP-8, and therefore, have increased resistance to carbon formation when heated and can be exposed to higher temperatures when used to cool aircraft systems. Material compatibility tests show that the alternative fuels possess significant seal swelling capability in conditioned nitrile O-rings; however, elastomer swelling was significantly lower than for JP-8, which may likely result in fuel leaks in aircraft systems. Engine tests with the alternative fuels demonstrated no anomalies in engine operation, production of significantly lower nonvolatile PM (soot), and moderately lower unburned hydrocarbons and carbon monoxide emissions compared to baseline JP-8 fuel. Also, no penalty (i.e., increase) in fuel flow requirement for equal engine power output was observed. In general, this study demonstrates that paraffinic fuels derived from different feedstocks and produced via FT synthesis or hydroprocessing can provide fuels with very similar properties to conventional fuels consisting of excellent physical, chemical, and combustion characteristics for use in turbine engines. These types of fuels may be considered as viable drop-in replacement jet fuels if deficiencies such as seal swell, lubricity, and low density can be properly addressed.

Authors

Corporan, E., Edwards, T., Shafer, L., DeWitt, M.J., Klingshirn, C.D., Zabarnick, S., West, Z., Striebich, R., Graham, J., Klein, J.

Source

Energy & Fuels, Vol. 25, pp.955-966

Publication Date

March 2, 2011

Reference 22

Comparison of Emissions Characteristics of Several Turbine Engines Burning Fischer-Tropsch and Hydroprocessed Esters and Fatty Acids Alternative Jet Fuels

Authors

Corporan, E., DeWitt, M.J., Klingshirn, C.D., Anneken, D., Shafer, L., Striebich, R.

Source

Proceedings of ASME Turbo Expo 2012, Copenhagen, Denmark

Publication Date

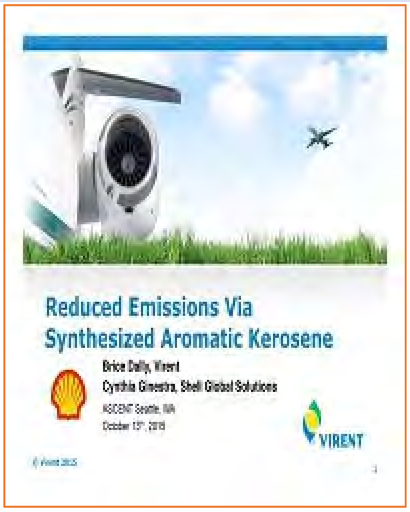
June 11-15, 2012

Abstract

A summary of the impacts of alternative fuel blends on the gaseous and PM (mostly soot) emissions of aircraft turbine engines is presented. Six engines were studied under several U.S. Air Force and NASA sponsored programs to assess the impacts of the alternative (non-petroleum) fuels on emissions and/or to support the certification of military aircraft for the use of 50/50 (by volume) alternative fuel/JP-8 blends. One turboshaft (T63) and five turbofan (CFM56-7, CFM56-2, F117, TF33 and PW308) engines were studied. Fuels derived from coal and natural gas produced via Fischer–Tropsch (FT) synthesis, and fuels from animal fats and plant oils produced via hydroprocessing [hydroprocessed esters and fatty acids] were evaluated. Trends of alternative fuel impacts on emissions compared to conventional fuel for the different engine types are discussed. Results consistently show significant reductions in PM emissions with the alternative fuel blends compared to operation with conventional fuels. These relative reductions were observed to be lower as engine power increased. Engines operated with different alternative fuel blends were found to produce similar slopes of normalized particle number to engine power with only the magnitude of the reductions being a function of the fuel type. These results suggest that it may be plausible to predict particle number emissions from turbine engines operated on alternative fuels based on engine, engine setting, limited PM data and fuel composition. Gaseous emissions measurements show modest reductions of carbon monoxide, unburned hydrocarbons and HAPs with the alternative fuels for several engines; however, no clear dependency of fuel impacts based on engine characteristics were observed.

Reference 23

Reduced Emissions Via Synthesized Aromatic Kerosene



Authors

Daily, B., Ginestra, C

Source

Virent briefing to ASCENT Seattle, WA

Publication Date

October 13, 2015

No link is publicly available for this document. Access must be requested.

Contact Link:
https://ascent.aero/contact/

Abstract

Virent provides a low cost, bio-based route to drop-in products. Its BioForming® Technology is a leading catalytic route that allows feedstocks to direct replacement fuels and chemicals. Virent's technologies provide many competitive advantages, such as a continuous, catalytic process with higher yields of aromatic chemicals and fuels, competitive economics at commercial scale, and feedstock flexibility. As one component of a partnership between Virent and Shell focused on technology and product qualification, this study sought to demonstrate the potential of synthetic aromatic kerosenes (SAKs) in the Alternative Jet Portfolio to provide benefits over conventional jet fuel aromatics. Gaseous and particulate emissions from a turbojet engine burning SAK blends and Jet A blends with equal aromatic levels at different power settings were measured in a simulated altitude chamber. Results showed 35% - 70% reductions in nvPM number and mass due to SAK blends over a range of power and altitude conditions. There was no detectable difference in combustor performance on SAK blends vs. Jet A blends.

Reference 24

[Alternative Aviation Fuel Experiment II (AAFEX II) Overview]

Abstract

Description and results from the Alternative Aviation Fuel Experiment II (AAFEX II). The objective of this experiment was to perform static aircraft engine testing using Hydrotreated Renewable Jet (HRJ) and other fuels to determine effects on engine performance and emissions. Also, examine methodologies for particle sampling to assist the SAE – E-31 Aircraft Particle Measurement Subcommittee in developing a standard particle sampling technique.

Authors

Del Rosario, R., Koudelka, J., Wahls, R., Madavan, N., Bulzan, D.

Source

NASA Presentation, Interagency Working Group – Alternative Fuels

Publication Date

September 19, 2012

Reference 25

Scaling Air Quality Effects from Alternative Jet Fuel in Aircraft and Ground Support Equipment

CORE

Scaling air quality effects from alternative jet fuel in aircraft and ground support equipment

Abstract

Authors

Donohoo, P.

Source

M.Sc. Thesis, Massachusetts Institute of Technology, Cambridge, MA

Publication Date

2010

Abstract

Many of the nation's largest airports, including Los Angeles International Airport, the Hartsfield-Jackson Atlanta International Airport, Chicago O'Hare International Airport and Washington Dulles International Airport are located within areas designated by the EPA as having ambient PM concentrations that exceed National Ambient Air Quality Standards. When inhaled, fine PM can enter the blood stream from the lungs and increase the risk of illness and premature mortality. This thesis examines the potential of two jet fuel types, ultra low-sulfur jet fuel and SPK, to reduce aviation's contribution to ambient PM concentrations. Scaling factors were developed for airport criteria pollutant emissions to model alternative jet fuels in aircraft and ground support equipment. These linear scaling factors were based on currently published studies comparing standard diesel and jet fuels with alternative jet fuels. It was found that alternative jet fuels lower or maintain all air pollutant emissions considered (primary PM, sulfur oxides, nitrous oxides, unburned hydrocarbons and carbon monoxide) for both aircraft and ground support equipment. To quantify the potential benefits of changing fuel composition on ambient PM concentrations, a study of the Atlanta Hartsfield-Jackson International Airport was completed using both emissions inventory analysis and atmospheric modeling. The atmospheric modeling captures both primary PM and other emissions that react in the atmosphere to form secondary PM. It was found that the use of an ultra low-sulfur jet fuel in aircraft gas turbines could reduce the primary PM inventory by 37% and SPK could reduce the primary PM inventory by 64%. The atmospheric modeling predicts that an ultra low-sulfur jet fuel in aircraft could reduce ambient PM concentrations due to aircraft by up to 57% and SPK could reduce PM concentrations due to aircraft by up to 67%. Thus, this study indicates that the majority of air quality benefits at Atlanta Hartsfield-Jackson International Airport that could be derived from the two fuels considered can be captured by removing the sulfur from jet fuel through the use of an ultra low-sulfur jet fuel.

Reference 26

Evaluation of Alcohol to Jet Synthetic Paraffinic Kerosenes (ATK-SPK)

Authors

Edwards, T., Meyer, D., Johnston, G., McCall, M., Rumizen, M., Wright, M.

Source

Report Version (1.10), Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants, Subcommittee D02.J0 on Aviation Fuels, Research Report D02-1828, ASTM International, West Conshohocken, PA

Publication Date

April 1, 2016

No link is publicly available for this document. Access must be requested.

Contact Link: https://www.astm.org/CONTACT/

Abstract

In 2009 a new ASTM specification (D7566-09, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) was developed for aviation turbine fuels. Contained in D7566-09 is a specification for a SPK blend component made from synthesis gas using the Fischer–Tropsch process commonly referred to as FT-SPK. Also contained in D7566-09 is a specification for a blend of FT-SPK with conventional petroleum-based jet fuel. The specification allows for a maximum of a 50% blend of FT-SPK with conventional jet fuel. A new annex, A2, was added which presents a specification for the hydroprocessed esters and fatty acids SPK made from Bio-Oils. Annex A2 specification also allows for a maximum of a 50% (v) blend of HEFA-SPK with conventional jet fuel. It's the intent of this report to demonstrate that a suitable SPK can be produced from an alcohol source (ATJ-SPK) that can satisfy the requirements outlined in D7566-12A and be considered for Annex A4. Further, it's also the intent of this report to demonstrate that a 50% (v) ATJ-SPK fuel blend with conventional petroleum jet fuel is suitable for use in turbine engines for commercial aviation. The report followed the guidelines outlined in the current version of ASTM D4054, "Standard Practice for the qualification and approval of new Aviation Turbine Fuels and Fuels Additives". Samples of ATJ-SPK fuels were provided from 5 different fuel producers (Gevo Inc., LanzaTech, Swedish Biofuels, Cobalt/Navy, and UOP) using a variety of alcohol feedstocks. The 100% and 50% (v) ATJ-SPK fuels were compared to 100% and 50% (v) FT-SPK and HEFA-SPK fuels using the same analytical method and plotted on the same graph whenever possible. FT-SPK fuel samples were produced by Sasol, Syntroleum, Shell and with HEFA-SPK fuels produced by UOP. This report contains an extensive amount of analytical fit-for-purpose testing that was performed on the ATJ-SPK, HEFA-SPK, and FT-SPK neat and 50% fuel blends and this report includes engine ground test data specific for the ATJ-SPK fuel blends conducted by GE/CFM, Rolls Royce, Pratt & Whitney, and Honeywell. The engine ground tests included performance, operability, and emission testing.

Reference 27

Particulate Emissions Hazards Associated with Fueling Heat Engines

Authors

Hendricks, R.C., Bushnell, D

Source

International Journal of Rotating Machinery, Article ID 415296

Publication Date

March 18, 2011

Abstract

All hydrocarbon- (HC-) fueled heat engine exhaust (tailpipe) emissions (<10 to 140 nm) contribute as health hazards, including emissions from transportation vehicles (e.g., aircraft) and other HC-fueled power systems. CO_2 emissions are tracked and, when mapped, show outlines of major transportation routes and cities. Particulate pollution affects living tissue and is found to be detrimental to cardiovascular and respiratory systems where ultrafine particulates directly translocate to promote vascular system diseases potentially detectable as organic vapors. This paper discusses aviation emissions, fueling, and certification issues, including heat engine emissions hazards, detection at low levels and tracking of emissions, and alternate energy sources for general aviation.

Reference 28

[Comparison of Combustion Properties Between a Synthetic Jet Fuel and Conventional Jet A-1]

Authors

Hermann, F.

Source

Proceedings of ASME Turbo Expo, GT2005-68540, Nevada

Publication Date

2005

Abstract

Aviation fuel is a petroleum product that fulfills the Standard Specification for Aviation Turbine Fuels. Crude oil has been the raw material for production of aviation fuels for many years. Since the availability of crude oil is predicted to be limited in the future, alternative raw materials for aviation fuels are highly desirable. A Swedish company, Oroboros AB, has developed a novel clean synthetic jet fuel, LeanJet®. The fuel is produced synthetically from synthesis gas (Syngas) by the Fischer–Tropsch process. A comparative experimental investigation of combustion properties has been performed, comparing the synthetic jet fuel with Jet A1. The following parameters were investigated in an atmospheric combustor, which was originally designed for a Volvo Aero turbine (VT40): • Emissions of NOx, CO and HC; • Ignition and extinction points; • Liner temperatures; • Soot levels in the combustor. The emission measurements showed good combustion efficiency with low HC and CO for both fuels. With very lean mixtures, however, both the CO and the HC levels increased for the synthetic fuel. The nitrous oxides for the synthetic jet fuel were reduced over the operation conditions investigated. Qualitative reduction of soot levels was also seen for the synthetic jet fuel. The fuels showed no difference in material temperature along the combustor wall. Small differences in ignition characteristics were found, but no differences in extinction were observed.

Reference 29

Effect of Soot Structure Evolution from Commercial Jet Engine Burning Petroleum Based JP-8 and Synthetic HRJ and FT Fuels

Abstract

Soot from jet engines is relevant to environmental and health concerns. In this study, JP-8, HRJ (hydrotreated renewable jet), and FT fuels were tested in a CFM56-2C1 engine on a DC-9 aircraft. Comparisons of PM physical structure at length scales spanning aggregate to primary particle to nanostructure, all by TEM, are reported. Petroleum-based JP-8 derived soot shows the nanostructure progression from amorphous to graphitic-like as a function of increasing engine power. Soots from the renewable HRJ and FT fuels exhibit significant nanostructure at each power level. Results are interpreted in terms of different soot formation regions with associated variations in temperature and local equivalence ratio. The driver for such differences is the nascent fuel composition, more specifically the different classes of components therein.

Authors

Huang, C.J., Vander Wal, R.L.

Source

Energy and Fuels, Vol. 27, pp.4946-4958.

Publication Date

July 24, 2013

Reference 30

ICAO Airport Air Quality Manual

Authors

International Civil Aviation Organization (ICAO)

Source

(1st ed.). Montreal, Quebec, CA

Publication Date

2011

Abstract

This manual covers an evolving area of knowledge and represents currently available information that is sufficiently well-established to warrant inclusion in international guidance. This manual covers issues related to the assessment of airport-related air quality that are either specifically within the remit of the ICAO (such as main engine emissions) or where there is an established understanding of other non-aircraft sources (such as boilers, ground support equipment and road traffic) that will contribute, to a greater or lesser extent, to the impact on air quality.

There are potential emissions source issues relevant to but not covered in this manual (e.g. forward speed effects of aircraft, influence of ambient conditions on aircraft emissions, aircraft start-up emissions, aircraft brake and tire wear) that have been identified and are the subject of further investigation by ICAO, Member States, observer organizations or other expert organizations, taking into account practical experience.

This first edition of the manual includes chapters on the regulatory framework and drivers for local air quality measures; emissions inventory practices and emissions temporal and spatial distribution; completed emissions inventory (including a detailed sophisticated aircraft emissions calculation approach); dispersion modeling; airport measurements; mitigation options; and interrelationships associated with methods for mitigating environmental impacts. Throughout the document, additional references are provided for those interested in exploring these topics in further detail.

This is intended to be a living document, and as more knowledge on this subject becomes available, it will be updated accordingly.

Reference 31

[Health Effects of Ambient Air Pollution, How Safe is the Air We Breathe?]

Abstract

Health Effects of Ambient Air Pollution aims to provide the reader with an overview of the health effects of air pollution in human subjects. The majority of the book is devoted to the discussion of the health effects of common wide-spread air pollutants regulated by the U.S. Environmental Protection Agency through National Ambient Air Quality Standards. The book reviews the sources and fate of common air pollutants in ambient air and researches the adverse effects of these outdoor and indoor air pollutants in 'in vivo' cell systems, animals, and humans.

Authors

Koenig, J.Q.

Source

Kluwer Academic

Publication Date

2000

Reference 32

Hazardous Air Pollutants and Asthma

Hazardous air pollutants and asthma

Authors

Leikauf, G. D.

Source

Environmental Health Perspective, Vol. 110, Suppl. 4, pp.505-526.

Publication Date

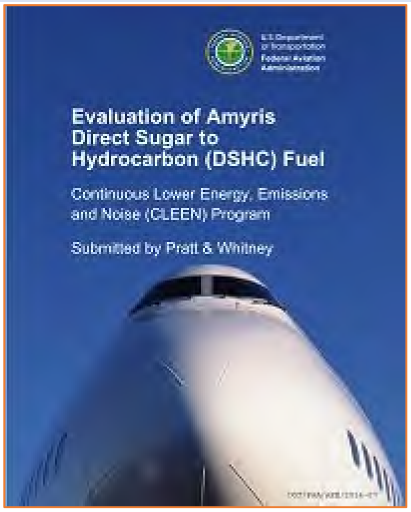
2002

Abstract

Asthma has a high prevalence in the United States, and persons with asthma may be at added risk from the adverse effects of HAPs. Complex mixtures (fine PM and tobacco smoke) have been associated with respiratory symptoms and hospital admissions for asthma. The toxic ingredients of these mixtures are HAPs, but whether ambient HAP exposures can induce asthma remains unclear. Certain HAPs are occupational asthmagens, whereas others may act as adjuncts during sensitization. HAPs may exacerbate asthma because, once sensitized, individuals can respond to remarkably low concentrations, and irritants lower the bronchoconstrictive threshold to respiratory antigens. Adverse responses after ambient exposures to complex mixtures often occur at concentrations below those producing effects in controlled human exposures to a single compound. In addition, certain HAPs that have been associated with asthma in occupational settings may interact with criteria pollutants in ambient air to exacerbate asthma. Based on these observations and past experience with 188 HAPs, a list of 19 compounds that could have the highest impact on the induction or exacerbation of asthma was developed. Nine additional compounds were identified that might exacerbate asthma based on their irritancy, respirability, or ability to react with biological macromolecules. Although the ambient levels of these 28 compounds are largely unknown, estimated exposures from emissions inventories and limited air monitoring suggest that aldehydes (especially acrolein and formaldehyde) and metals (especially nickel and chromium compounds) may have possible health risk indices sufficient for additional attention. Recommendations for research are presented regarding exposure monitoring and evaluation of biologic mechanisms controlling how these substances induce and exacerbate asthma.

Reference 33

Evaluation of Amyris Direct Sugar to Hydrocarbon (DSHC) Fuel



Authors

Lew, L., Biddle, T., United Technologies Corporation

Source

Continuous Energy, Emissions and Noise (CLEEN) Program, East Hartford, CT

Publication Date

April 16, 2014

Abstract

This report documents an engine test and a combustor test performed by Pratt & Whitney (P&W) in the evaluation of a branched C15 farnesane paraffin for use as a jet fuel blending stock. The farnesane was produced by Amyris, Incorporated (Amyris) and Total S.A. (Total) using a direct sugar to hydrocarbon (DSHC) process. The work was performed under the Continuous Lower Energy, Emission, and Noise (CLEEN) program, Contract DTFAWA-10-C-00041. P&W Canada (P&WC) performed a PW615F engine test on a baseline Jet A and a 20%/80% fuel blend of Amyris Farnesane/Jet A. The objective was to determine the impact of Amyris Farnesane on engine performance, operability and emissions. The PW615F is a 1,460 pound thrust, two-spool turbo fan with a reverse-flow combustor and dual-channel full authority digital engine control. The engine tests were performed at the six performance points shown below. Specific Fuel Consumption (SFC), gaseous emissions: carbon monoxide (CO), unburned hydrocarbon (UHC), carbon dioxide (CO_2), oxides of nitrogen (NOx), SN, and PM, through laser induced incandescence were measured at these six points: • Ground idle (GI) • 30 percent power • 50 percent power • 85 percent power • 93 percent power • 100 percent takeoff power (1,460 lbf thrust). No difference was observed in engine operability for the Amyris Farnesane fuel blend compared to that of the baseline Jet A-1 fuel. No negative impact was observed on SFC, gaseous emissions, SN, or PM. Inspection of fuel system components showed no adverse effects from operation on the farnesane fuel blend. Under the direction of P&WC, Université Laval performed tests on a single nozzle can combustor test section. Ground starts at 50, 0, -20, -30, and -40 °F and altitude relights at 15, 20, 25, 30, and 35 kft were performed. No starting differences or altitude relight lean boundary differences were observed. The rich limits were not achieved for the relights due to rig constraints.

Reference 34

Influence of Fuel Composition, Engine Power, and Operation Mode on Exhaust Gas Particulate Size Distribution and Gaseous Emissions from a Gas Turbine Engine

Authors

Li, H, et.al

Source

Proc. ASME Turbo Expo, GT2013-94854

Publication Date

2013

Abstract

The impact of fuel composition, engine power (idle and full power) and operation mode (cold and hot idle) on the gaseous emissions, particle number and mass concentrations and size distributions from an aircraft APU was investigated. A re-commissioned Artouste MK113 APU engine was used. The engine was run at three operational modes: i.e. approximately 6 minutes at idle (cold idle) after stabilized from start, 6 minutes at full power and then returning to idle again (hot idle) for 6 minutes. All operating parameters of the engine were monitored and recorded. The engine exhaust particle measurements and gaseous emissions were taken at three operating modes. Five alternative fuels/blending components were tested and compared to neat conventional JetA1 fuel either in pure or blended forms. These fuels varied in their compositions in terms of H/C ratio, density and other properties. A SMPS with a NDMA was used to determine the number and mass concentration and size distribution of engine exhaust in the size range from 5 nm to 160 nm. The influence of fuel elemental ratio (H/C), engine power and cold/hot operation on particle number and mass size distribution was investigated. The results show that there was a good correlation between fuels H/C ratio and particle concentrations, particle size and distributions characteristics. The engine at hot idle produced ~20% less particles compare to the results at cold idle. The alternative fuel blends produced less particles than JetA1 fuel. The testing fuels produced similar levels of NOx, slight reductions in CO and remarkable reductions in UHC compared to JetA1.

Reference 35

Quantification of Aldehydes Emissions from Alternative and Renewable Aviation Fuels using a Gas Turbine Engine


Atmospheric Environment

Quantification of aldehydes emissions from alternative and renewable aviation fuels using a gas turbine engine

Highlights

Abstract

Abstract

In this research three renewable aviation fuel blends including two HEFA blends and one Fatty Acids Ethyl Ester (FAE) blend with conventional Jet A-1 along with a GTL fuel have been tested for their aldehydes emissions on a small gas turbine engine. Three strong ozone formation precursors: formaldehyde, acetaldehyde and acrolein were measured in the exhaust at different operational modes and compared to neat Jet A-1. The aim is to assess the impact of renewable and alternative aviation fuels on aldehydes emissions from aircraft gas turbine engines so as to provide informed knowledge for the future deployment of new fuels in aviation. The results show that formaldehyde was a major aldehyde species emitted with a fraction of around 60% of total measured aldehydes emissions for all fuels. Acrolein was the second major emitted aldehyde species with a fraction of ~30%. Acetaldehyde emissions were very low for all the fuels and below the detention limit of the instrument. The formaldehyde emissions at cold idle were up to two to threefold higher than that at full power. The fractions of formaldehyde were 6–10% and 20% of total hydrocarbon emissions in ppm at idle and full power respectively and doubled on a g kg−1-fuel basis.

Authors

Li, Hu, Altaher, Mohamed A., Wilson, Chris W., Blakey, Simon, Chung, Winson, Rye, Lucas.

Source

Atmospheric Environment, Vol. 84, pp.373-379

Publication Date

2014

Reference 36

Comparison of PM Emissions from a Commercial Jet Engine Burning Conventional, Biomass, and Fischer-Tropsch Fuels

Authors

Lobo, P., Hagen, D., Whitefield, P.

Source

Environmental Science & Technology, Vol. 45, pp.10744-10749

Publication Date

2011

Abstract

Rising fuel costs, an increasing desire to enhance security of energy supply, and potential environmental benefits have driven research into alternative renewable fuels for commercial aviation applications. This paper reports the results of the first measurements of PM emissions from a CFM56-7B commercial jet engine burning conventional and alternative biomass- and, Fischer–Tropsch (F-T)-based fuels. PM emissions reductions are observed with all fuels and blends when compared to the emissions from a reference conventional fuel, Jet A1, and are attributed to fuel properties associated with the fuels and blends studied. Although the alternative fuel candidates studied in this campaign offer the potential for large PM emissions reductions, with the exception of the 50% blend of F-T fuel, they do not meet current standards for aviation fuel and thus cannot be considered as certified replacement fuels. Over the ICAO Landing Takeoff Cycle, which is intended to simulate aircraft engine operations that affect local air quality, the overall PM number-based emissions for the 50% blend of F-T fuel were reduced by 34 ± 7%, and the mass-based emissions were reduced by 39 ± 7%.

Reference 37

[Evaluation of Non-volatile Particulate Matter Emission Characteristics of an Aircraft Auxiliary Power Unit with Varying Alternative Jet Fuel Blend Ratios. Energy and Fuels]

Authors

Lobo, P., Christie, S., Khandelwal, B., Blakey, S.G., Raper, D.W.

Source

Energy and Fuels, Vol. 29, pp.7705-7711

Publication Date

October 16, 2015

Abstract

The aviation industry is increasingly focused on the development of sustainable alternative fuels to augment and diversify fuel supplies while simultaneously reducing its environmental impact. The impact of airport operations on local air quality and aviation-related greenhouse gas emissions on a life-cycle basis have been shown to be reduced with the use of alternative fuels. However, the evaluation of incremental variations in fuel composition of a single alternative fuel on the production of nonvolatile PM (nvPM) emissions has not been explored. This is critical to understanding the emission profile for aircraft engines burning alternative fuels and the impact of emissions on local air quality and climate change. A systematic evaluation of nvPM emissions from a GTCP85 aircraft APU burning 16 different blends of used cooking oil (UCO)-derived hydroprocessed esters and fatty acids (HEFA) -type alternative fuel with a conventional Jet A-1 baseline fuel was performed. The nvPM number- and mass-based EI for the 16 fuel blends and neat UCO–HEFA fuel were compared against those for the baseline Jet A-1 fuel at three APU operating conditions. The large data set from this study allows for the correlation between fuel composition and nvPM production to be expressed with greater confidence. The reductions in nvPM were found to be greater with increasing fuel hydrogen content (higher proportion of UCO–HEFA in the fuel blend). For a 50:50 blend of UCO–HEFA and Jet A-1, which would meet current ASTM specifications, the average reduction in nvPM number-based emissions was ~35%, while that for mass-based emissions was ~60%. The nvPM size distributions were found to narrow and shift to smaller sizes as the UCO–HEFA component of the fuel blend increased. This shift has a greater impact on the reduction in nvPM mass compared to the overall decrease in the nvPM number when comparing the UCO–HEFA fuel blends to the baseline Jet A-1.

Reference 38

Influence of Jet Fuel Composition on Aircraft Engine Emissions: A Synthesis of Aerosol Emissions Data from the NASA APEX, AAFEX, and ACCESS Missions

Authors

Moore, R.H., Shook, M., Beyersdorf, A., Corr, C., Herndon, S., Knighton, W.B., Miake-Lye, R., Thornhill, K.L., Winstead, E.L., Yu, Z., Ziemba, L.D., Anderson, B.E.

Source

Energy and Fuels, Vol. 29, pp.2591-2600

Publication Date

February 25, 2015

Abstract

We statistically analyze the impact of jet fuel properties on aerosols emitted by the NASA Douglas DC-8 (Tail No. N817NA) CFM56-2-C1 engines burning 15 different aviation fuels. Data were collected for this single engine type during four different, comprehensive ground tests conducted over the past decade, which allow us to clearly link changes in aerosol emissions to fuel compositional changes. It is found that the fuel aromatic and sulfur content most affect the volatile aerosol fraction, which dominates the variability (but not necessarily the magnitude) of the number and volume EIs over all engine powers. Meanwhile, the naphthalenic content of the fuel determines the magnitude of the nonvolatile number and volume EI as well as the BC mass EI. Linear regression coefficients are reported for each aerosol EI in terms of these properties, engine fuel flow rate, and ambient temperature and show that reducing both fuel sulfur content and naphthalenes to near-zero levels would result in roughly a 10-fold decrease in aerosol number emitted per kilogram of fuel burned. This work informs future efforts to model aircraft emissions changes as the aviation fleet gradually begins to transition towards low-aromatic, low-sulfur alternative jet fuels from bio-based or Fischer–Tropsch production pathways.

Reference 39

Biofuel Blending Reduces PM Emissions from Aircraft Engines at Cruise Conditions

Authors

Moore, et al.

Source

Nature 21420, doi:10.1038

Publication Date

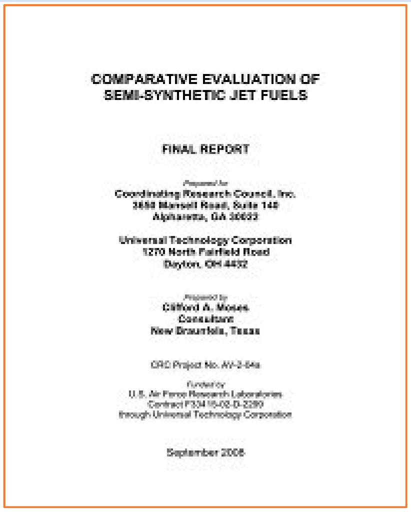
March 16, 2017

Abstract

Aviation-related aerosol emissions contribute to the formation of contrail cirrus clouds that can alter upper tropospheric radiation and water budgets, and therefore climate(1). The magnitude of air-traffic-related aerosol-cloud interactions and the ways in which these interactions might change in the future remain uncertain(1). Modeling studies of the present and future effects of aviation on climate require detailed information about the number of aerosol particles emitted per kilogram of fuel burned and the microphysical properties of those aerosols that are relevant for cloud formation(2). However, previous observational data at cruise altitudes are sparse for engines burning conventional fuels2,3, and no data have previously been reported for biofuel use in-flight. Here we report observations from research aircraft that sampled the exhaust of engines onboard a NASA DC-8 aircraft as they burned conventional Jet A fuel and a 50: 50 (by volume) blend of Jet A fuel and a biofuel derived from Camelina oil. We show that, compared to using conventional fuels, biofuel blending reduces particle number and mass emissions immediately behind the aircraft by 50 to 70 per cent. Our observations quantify the impact of biofuel blending on aerosol emissions at cruise conditions and provide key microphysical parameters, which will be useful to assess the potential of biofuel use in aviation as a viable strategy to mitigate climate change.

Reference 40

Comparative Evaluation of Semi-Synthetic Jet Fuels (FT-SPK)


COMPARATIVE EVALUATION OF
SEMI-SYNTHETIC JET FUELS

FINAL REPORT

Prepared for
Coordinating Research Council, Inc.
3650 Mansell Road, Suite 140
Alpharetta, GA 30022

Universal Technology Corporation
1270 North Fairfield Road
Dayton, OH 4432

Prepared by
Clifford A. Moses
Consultant
New Braunfels, Texas

CRC Project No. AV-2-04a

Funded by
U.S. Air Force Research Laboratories
Contract F33415-02-D-2299
through Universal Technology Corporation

September 2008

Authors

Moses, C.A.

Source

Final Report, Coordinating Research Council, Inc., Universal Technology Corporation, CRC project No. AVI 2I04a, Alpharetta, GA

Publication Date

September 2008

Abstract

This report compares the properties and characteristics of five blends of individual SPKs with petroleum-based Jet A, Jet A-1 or JP-8 fuel to make semi-synthetic jet fuels (SSJF). The study was requested by the aviation fuel community to provide technical support for the acceptance of SPK derived from synthesis gas as blending streams up to 50%(v) in fuel specifications for aviation turbine fuel. The methodology for comparison was to be the properties and characteristics used in the original evaluation of the Sasol SSJF which has experienced 9 years of successful service since it was approved for use as commercial jet fuel by DEF STAN 91-91 in 1998. The SPK used by Sasol in the original SSJF was produced by a Fischer–Tropsch (F-T) process using synthesis gas derived from coal. The synthesis gases for the four new candidates were produced from natural gas. The details of the F-T process conditions and the downstream processing differed among the five SPK fuels. Although all five SPK fuels were comprised almost entirely of saturated hydrocarbons, i.e., normal, iso-, and cyclo-paraffins, there were distinct differences in the ratio of the three families and in the distribution of carbon numbers. Despite these differences, when blended at 50%(v) with conventional jet fuels, these five SPK fuels produced SSJFs that were very similar to each other and had fit-for-purpose properties and characteristics that were very typical of conventional jet fuel. Moreover, all five SPKs met all of the requirements of Table 1 with the exception of density. It is important to realize there are no new chemical compositions involved in SSJF, just a change in the ratios of the aromatics to the saturates, i.e., the paraffin families. It is believed that these five fuels covered a large range of SPK compositions likely to result from F-T catalysis of synthesis gas based on the ratios of the paraffin families and the variation in the range of carbon numbers. It is concluded that semi-synthetic kerosenes produced by blending conventional jet fuels with up to 50%(v) SPK derived from synthesis gas by F-T catalysis and downstream processing and having compositions similar to that described in this report are fit-for-purpose as jet fuel. This conclusion has been validated by nine years of operation on one SSJF and in-depth flight-testing and test experience in ground support systems on another two of the five SSJFs evaluated here. Based on the property data of the five SPKs evaluated, it was possible to develop a composition and performance based definition of SPK derived from synthesis gas through an F-T process that would assure that SSJF with up to 50%(v) such SPK would be fit-for-purpose as jet fuel and certifiable under major fuel specifications. This definition is based on meeting a modification of Table 1 requirements designed to assure that the producer has control over the processes for making SPK and to assure a minimum quality of product, both as an item of commerce and for making SSJF.

Reference 41

Evaluation of Synthesized Aromatics Co-Produced with Iso-Paraffinic Kerosene for the Production of Semi-Synthetic Jet Fuel (SKA)


1 November 2015

Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants
Subcommittee D02.J0 on Aviation Fuels
Section D02.J0.06 on Emerging Turbine Fuels

Research Report: D02-1810

Evaluation of Synthesized Aromatics
Co-Produced with Iso-Paraffinic Kerosene for the Production of Semi-Synthetic Jet Fuel

ASTM D7566 Annex

Authors

Moses, C.

Source

Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants, Subcommittee D02.J0 on Aviation Fuels, Section D02.J0.06 on Emerging Turbine Fuels, Research Report D02-1810, ASTM International, West Conshohocken, PA

Publication Date

November 1, 2015

No link is publicly available for this document. Access must be requested.

Contact Link: https://www.astm.org/CONTACT/

Abstract

This report compares the properties and characteristics of a Synthesized Kerosene containing Aromatics (SKA) with those of approved Synthesized Paraffinic Kerosenes (SPK) and petroleum-based jet fuels. Specifically, the SKA is produced by adding a benzene-rich stream to the UOP Cat-Poly™ reactor that converts C3 and C4 olefins into Sasol's Iso-Paraffinic Kerosene (IPK). The benzene is alkylated to single-ring aromatics along with the production of the IPK. The result is IPK plus 15 to 20% single-ring aromatics and is termed IPK/A, which in turn belongs to the larger class of SKAs. Chemically, IPK/A differs from the original Sasol IPK only by the presence of the aromatics, and IPK/A meets all the requirements of ASTM D7566 Annex A1 defining acceptable SPKs from F-T products with the exception of the presence of the aromatics and a higher density due to those aromatics. Data are presented showing that the aromatics in IPK/A are all single-ring compounds distributed over several carbon numbers and many isomers. Moreover, detailed chemical analysis shows that the specific aromatics present in IPK/A are also in conventional jet fuels, so chemically, IPK/A is typical of conventional fuels. The results of the D4054 fit-for-purpose evaluation demonstrate that IPK/A by itself, i.e., unblended, has properties and characteristics that are typical of conventional jet fuels. The presence of the aromatics is not detrimental to any of the fit-for-purpose properties and characteristics. The density of IPK/A is greater than that of IPK and other SPKs due to the presence of the aromatics, thus making IPK/A more like conventional jet fuel than the F-T SPKs that have been generically approved by D7566. Note: New results are presented for materials compatibility tests on additional elastomers that were requested by the engine and airframe OEMs following the review of the earlier version of this report. Also, new data for specific heat, thermal conductivity, and water solubility have been added, all from improved test procedures. Finally, a 50/50 blend of IPK/A with conventional Jet A-1 meets all the D7566 Table 1 property requirements for turbine fuels containing synthesized hydrocarbons. Sasol IPK/A described in this report is one example of a F-T synthesized paraffinic kerosene to which have been added aromatics synthesized by the alkylation of light mono-aromatics, primarily benzene. Technically the results would be the same if alkylated mono-aromatics were added to any F-T paraffinic kerosene approved by D7566 Annex 1. A new annex is proposed for D7566 for the more general case of F-T kerosenes containing aromatics synthesized by the alkylation of mono-aromatics (FT-SPK/A) rather than limiting the annex to the Sasol IPK/A product. This new annex will follow the precedence of Annex A1 (FT-SPK). FT-SPK/A would be blended up to 50% with conventional jet fuel under the same conditions and restrictions as those of the SPKs already approved in Annex A1. Other restrictions requested by the aviation fuels community are also presented in this report. Suggested wording for the proposed Annex are provided.

Reference 42

Evaluation of Synthesized Iso-Paraffins Produced from Hydroprocessed Fermented Sugars (SIP Fuels)

Authors

Roland, O., Garcia, F., TOTAL New Energies, Amyris, Inc., U.S. Air Force Research Laboratory

Source

Final Version (3.). Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants, Subcommittee D02.J0 on Aviation Fuels, Research Report D02- 1776, ASTM International, West Conshohocken, PA

Publication Date

June 15, 2014

No link is publicly available for this document. Access must be requested.

Contact Link: https://www.astm.org/CONTACT/

Abstract

Total and Amyris are producing, from biomass, a farnesane aviation grade that is a high quality hydrocarbon grade. Data was collected in order to demonstrate the use of farnesane as a renewable component to be blended in jet fuel. This research report proposes a new annex for ASTM D7566, Standard Specifications for Aviation Turbine Fuels Containing Synthesized Hydrocarbons which defines specifications (detailed batch requirements) for the farnesane aviation grade to be used as a blending component in conventional jet fuel at an incorporation rate up to 10 vol. %. In support of the inclusion of this new annex in ASTM D7566, the typical composition and bulk physical and performance properties of farnesane was investigated on the basis of the property tables A1.1 & A2.1 and A1.2 & A.2.2 outlined in ASTM D7566-12, Annexes A1 and A2. In addition, farnesane-containing fuels at an incorporation rate up to 20 vol. % were extensively analyzed on the basis of the property Table 1 outlined in ASTM D7566-12 and the fit-for-purpose property Table 1 outlined in ASTM D4054, standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives. Farnesane-containing fuels are termed “Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars” (SIP fuels) and have been developed under the ASTM Task Force “Direct Sugar to Hydrocarbons” (DSHC). Total and Amyris produce at industrial scale farnesene (branched C15 molecules containing four double bonds) by fermentation of sugars. Through a combination of hydroprocessing and fractionation steps, farnesene is converted into farnesane (branched C15 paraffin) as a high quality hydrocarbon grade composed of nearly 100 wt. % of carbon and hydrogen. Such grade contains more than 98 wt. % of saturated hydrocarbons, less than 0.1 wt. % of aromatics and less than 1.5 wt. % of hexahydrofarnesol, a low polar branched C15 alcohol. Olefins are present in traces (typically less than 0.2 wt. %). Non-hydrocarbon compositions of this grade is in accordance with the maximum concentration limits defined for nitrogen, water, sulfur, metals and halogens in Synthesized Iso- Paraffinic Kerosene grades as per ASTM D7566-12, Annex A1, Table A1.2 and Annex A2, Table A2.2. Bulk physical and performance properties of blends of farnesane from 5 vol. % up to 20 vol. % into fossil Jet A-1 fuel satisfy the requirements outlined in ASTM D7566-12. Fit-for-purpose data from SIP fuels at incorporation rates of 10 vol. % and 20 vol. % are in the typical range of aviation turbine fuels containing synthesized hydrocarbons as defined in ASTM D4054-09. In particular, due to its intrinsic and unique properties (high thermal stability above 355°C, low freezing point below -60°C and high neat heat of combustion above 43.5 MJ/kg), farnesane improves the properties of the jet fuel it is blended with. Complementary data on the impact of the incorporation rate of 10 vol. % of farnesane on various conventional jet fuels representative of the industry as well as of the incorporation rate up to 50 vol. % are also presented. In addition, this research report includes data from engine ground tests conducted by Snecma and Lufthansa and from APU and combustor rig tests conducted by Honeywell using 10 vol. % and 20 vol. % farnesane, and the description of three test flights conducted by Airbus and CFM, and by Etihad and Boeing. In light of the results described in this report, Total

Evaluation of Synthesized Iso-Paraffins Produced from Hydroprocessed Fermented Sugars (SIP Fuels)	
	and Amyris are pursuing the ASTM approval for the use of jet fuel containing farnesane at an incorporation rate up to 10 vol. % and the inclusion of the proposed new annex that defines and controls the farnesane aviation grade.

Reference 43

Estimation and Comparison of Particle Number Emission Factors for Petroleum-based and Camelina Biofuel Blends used in a Honeywell TFE-109 Turbofan Engine

Authors

Shila, Jacob J., and Johnson, Mary E.

Source

AIAA SciTech Forum, 54th AIAA Aerospace Sciences Meeting, San Diego, California

Publication Date

January 4-8, 2016

Abstract

The experiments to estimate the total PM emissions factors for three types of fuels used in a high bypass turbofan engine were conducted at the National Testing Facility for Aerospace Fuels (NaTeF) during April 2014. The purpose of the study was to determine whether the PM emissions factors for biofuel blends would be lower compared to those of traditional Jet A fuel at four different engine power settings. The study investigated the number-based emissions factors (EI_n) of total PM emissions in the exhaust stream out of a Honeywell TFE-109 turbofan engine as functions of engine thrust settings and fuel composition. Three types of fuels were tested on the engine and analyzed. The fuels were 100% Jet A, 75% Jet A-25% Camelina blend, and a 50% Jet A – 50% Camelina blend. The PM emissions, for each type of fuel, were sampled 1 meter from the engine exhaust plane while the engine was being operated. The TFE-109 turbofan engine was operated to run at four (4) engine power settings which were 10%, 30%, 85%, and 100% engine power settings. The study focused on estimating total PM EI_n. The EI_n for the 50% Jet A – 50% Camelina biofuel blend at 10% and 30% engine power settings were significantly lower compared to the PM EI_n of Jet A fuel. The average EI_n for all fuels, at all the observed four engine settings, were estimated to range between $1(10)^{15}$ and 10^{16} particles per kilogram of fuel.

Reference 44

Alternate-fueled Combustor-sector Performance: Part A: Combustor Performance Part B: Combustor Emissions

Abstract

Alternate aviation fuels for military or commercial use are required to satisfy MIL-DTL-83133F or ASTM D 7566 standards, respectively, and are classified as “drop-in’’ fuel replacements. To satisfy legacy issues, blends to 50% alternate fuel with petroleum fuels are acceptable. Adherence to alternate fuels and fuel blends requires “smart fueling systems’’ or advanced fuel-flexible systems, including combustors and engines, without significant sacrifice in performance or emissions requirements. This paper provides preliminary performance and emissions and particulates combustor sector data. The data are for nominal inlet conditions at 225 psia and 800°F (1.551 MPa and 700 K), for SPK -type FT fuel and blends with JP-8+100 relative to JP-8+100 as baseline fueling. Assessments are made of the change in combustor efficiency, wall temperatures, emissions, and luminosity with SPK of 0%, 50%, and 100% fueling composition at 3% combustor pressure drop. The performance results (Part A) indicate no quantifiable differences in combustor efficiency, a general trend to lower liner and higher core flow temperatures with increased FT fuel blends. In general, emissions data (Part B) show little differences, but, with percent increase in FT-SPK-type fueling, particulate emissions and wall temperatures are less than with baseline JP-8. High-speed photography.

Authors

Shouse, D.T., Neuroth, C., Hendricks, R.C., Lynch, A., Frayne, C.W., Stutrud, J.S., Corporan, E., Hankins, T.

Source

ISROMAC13-2010-49

Publication Date

2010

Reference 45

Black Carbon Emissions Reductions from Combustion of Alternative Jet Fuels


Atmospheric Environment

Black carbon emissions reductions from combustion of alternative jet fuels

Highlights

Abstract

Authors

Speth, R.R., Rojo, C., Malina, R., Barrett, S.R.H.

Source

Atmospheric Environment, Vol. 105, pp.37-42

Publication Date

January 19, 2015

Abstract

Recent measurement campaigns for alternative aviation fuels indicate that BC emissions from gas turbines are reduced significantly with the use of alternative jet fuels that are low in aromatic content. This could have significant climate and air quality-related benefits that are currently not accounted for in environmental assessments of alternative jet fuels. There is currently no predictive way of estimating aircraft BC emissions given an alternative jet fuel. We examine the results from available measurement campaigns and propose a first analytical approximation (termed ‘ASAF’) of the BC emissions reduction associated with the use of paraffinic alternative jet fuels. We establish a relationship between the reduction in BC emissions relative to conventional jet fuel for a given aircraft, thrust setting relative to maximum rated thrust, and the aromatic volume fraction of the (blended) alternative fuel. The proposed relationship is constrained to produce physically meaningful results, makes use of only one free parameter and is found to explain a majority of the variability in measurements across the engines and fuels that have been tested.

Reference 46

Impact of Aviation Non-CO2 Combustion Effects on the Environmental Feasibility of Alternative Jet Fuels

Abstract

Alternative fuels represent a potential option for reducing the climate impacts of the aviation sector. The climate impacts of alternatives fuel are traditionally considered as a ratio of life-cycle greenhouse gas (GHG) emissions to those of the displaced petroleum product; however, this ignores the climate impacts of the non-CO_2 combustion effects from aircraft in the upper atmosphere. The results of this study show that including non-CO_2 combustion emissions and effects in the life cycle of a SPK fuel can lead to a decrease in the relative merit of the SPK fuel relative to conventional jet fuel. For example, an SPK fuel option with zero life-cycle GHG emissions would offer a 100% reduction in GHG emissions but only a 48% reduction in actual climate impact using a 100-year time window and the nominal climate modeling assumption set outlined herein. Therefore, climate change mitigation policies for aviation that rely exclusively on relative well-to-wake life-cycle GHG emissions as a proxy for aviation climate impact may overestimate the benefit of alternative fuel use on the global climate system.

Authors

Stratton, R.W., Wolfe, P.J., Hileman, J.I.

Source

Environmental Science & Technology, Vol. 45, Issue 24, pp.10736-10743

Publication Date

November 22, 2011

Reference 47

Combustion Products of Petroleum Jet Fuel, a Fischer-Tropsch Synthetic Fuel, and a Biomass Fatty Acid Methyl Ester Fuel for a Gas Turbine Engine


Combustion Science and Technology

Combustion Products of Petroleum Jet Fuel, a Fischer–Tropsch Synthetic Fuel, and a Biomass Fatty Acid Methyl Ester Fuel for a Gas Turbine Engine

Abstract

Authors

Timko, M.T., Herndon, S.C., de la Rosa Blanco, E., Wood, E.C., Yu, Z., Miake-Lye, R.C., Knighton, W.B., Shafer, L., DeWitt, M.J., Corporan, E.

Source

Combustion Science and Technology, Vol. 183, pp.1039-1068

Publication Date

April 13, 2011

Abstract

We report combustion emissions data for several alternatives to petroleum-based Jet A jet fuel, including a natural gas-derived Fischer–Tropsch (FT) synthetic fuel; a 50/50 blend of the FT synthetic fuel with Jet A-1; a 20/80 blend of a fatty acid methyl ester (FAME) with jet fuel; and a 40/60 blend of FAME with jet fuel. The chief distinguishing features of the alternative fuels are reduced (for blends) or negligible (for pure fuels) aromatic content and increased oxygen content (for FAME blends). A CFM International CFM56-7 gas turbine engine was the test engine, and we measured NOX, CO, speciated volatile organic compounds (including oxygenates, olefins, and aromatic compounds), and nonvolatile particle size distribution, number, and mass emissions. We developed several new methods that account for fuel energy content and used the new methods to evaluate potential fuel effects on emissions performance. Our results are categorized as follows: (1) regulated pollutant emissions, CO, and NOX; (2) volatile organic compound emissions speciation; and (3) particle emissions. Replacing all or part of the petroleum jet fuel with either FAME or FT fuel reduces NOX emissions and may reduce CO emissions. Combustion of FT fuel and fuel blends increases selectivities and in some cases yields of oxygenates and some hydrocarbon volatile organic compound emissions relative to petroleum jet fuel. Combustion of FAME fuel increases propene and butene emissions, but despite its oxygen content does not strongly affect oxygenate emissions. Replacing petroleum jet fuel with zero aromatic alternatives decreases the emissions of aromatic hydrocarbons. The fuel effects become more pronounced as the size of the aromatic molecule increases (e.g., toluene is reduced more strongly than benzene). Particle emissions are decreased in particle size, number density, and total mass when petroleum jet fuel is replaced with the zero aromatic fuels. The effects of fuel composition on particle emissions are most pronounced at lower power conditions, i.e., when combustion temperature and pressure are lower, and less efficient mixing may lead to locally higher fuel/air ratios than are present at higher power.

Reference 48

[Insights into the Combustion Chemistry Within a Gas-Turbine Driven Auxiliary Power Unit as a Function of Fuel Type and Power Level using Soot Nanostructure as a Tracer]


Fuel

Insights into the combustion chemistry within a gas-turbine driven auxiliary power unit as a function of fuel type and power level using soot nanostructure as a tracer

Highlights

Abstract

Abstract

Particulate emissions were collected from an APU directly upon TEM grids for particle characterization by HRTEM. Carbonaceous emissions from two fuels, a coal-based Fischer–Tropsch and standard JP-8 were compared, each at three power levels. Differences in soot nanostructure, specifically fullerenic content reveal changes in the combustion chemistry with engine power level, as do differences in aggregate size between the two fuels. As inferred from the soot nanostructure, comparison between fuels demonstrates the impact of fuel structure upon soot formation chemistry.

Authors

Wal, V., Bryg, R.L., Victoria M., Huang, C-H

Source

Fuel Vol. 115, pp.282–287

Publication Date

2014

Reference 49

Effects of Bio-Derived Fuels on Emissions and Performance Using a 9-Point Lean Direct Injection Low Emissions Concept


Effects of Bio-Derived Fuels on Emissions and Performance Using a 9-Point Lean Direct Injection Low Emissions Concept

Abstract

A 9-Point Lean Direct low emissions combustor concept was utilized to evaluate gaseous emissions performance of two bio-derived alternative jet fuels and a JP-8 fuel for comparison. Gaseous emissions were measured in a flame tube operating at inlet temperatures from 650 up to 1030 F, pressures of 150, 250, and 350 psia, and a range of fuel/air ratios. The alternative fuels consisted of a Hydroprocessed Esters and Fatty Acids Fuel made from tallow and a second bio-derived fuel produced from direct fermentation of sugar.

Authors

Wey, C., and Bulzan, D.

Source

Proc. ASME Turbo Expo, GT2013-94888

Publication Date

2013

Reference 50

The Impact of Advanced Biofuels on Aviation Emissions and Operations in the U.S.


Energy Economics

The impact of advanced biofuels on aviation emissions and operations in the U.S.

Highlights

Abstract

Abstract

We analyze the economic and emissions impacts on U.S. commercial aviation of the Federal Aviation Administration's renewable jet fuel goal when met using advanced fermentation (AF) fuel from perennial grasses. These fuels have recently been certified for use in aircraft and could potentially provide greater environmental benefits than aviation biofuels approved previously. Due to uncertainties in the commercialization of AF technologies, we consider a range of assumptions concerning capital costs, energy conversion efficiencies and product slates. In 2030, estimates of the implicit subsidy required to induce consumption of AF jet fuel range from $0.45 to $20.85 per gallon. These correspond to a reference jet fuel price of $3.23 per gallon and AF jet fuel costs ranging from $4.01 to $24.41 per gallon. In all cases, as renewable jet fuel represents around 1.4% of total fuel consumed by commercial aviation, the goal has a small impact on aviation operations and emissions relative to a case without the renewable jet fuel target, and emissions continue to grow relative to those in 2005. Costs per metric ton of carbon dioxide equivalent abated by using biofuels range from $42 to $652.

Authors

Winchester, N., Malina, R., Staples, M.D., Barrett, S.R.H.

Source

Energy Economics, Vol. 49, pp.482-491

Publication Date

April 8, 2015

Reference 51

Sustainable Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK) Jet Fuel Flights and Engine Tests Program Results

Abstract

This paper describes the results of an industry effort to test Bio-derived Synthetic Paraffinic Kerosene (Bio-SPK) from natural plant oils. The program included the identification and sourcing of sustainable feedstocks, the use of a new fuel processing method, numerous fuel tests, engine operability, performance and emissions tests, and flight testing in three Boeing aircraft models. The Bio-SPK blended fuels have potential to reduce life-cycle CO_2 emissions and be compatible with current aircraft, systems, and infrastructure.

Authors

Rahmes, et.al

Source

AIAA, 2009-7002

Publication Date

September 2009