CONFERENCE ON AVIATION AND ALTERNATIVE FUELS

Rio de Janeiro, Brazil, 16 to 18 November 2009

Agenda Item 1: Environmental sustainability and interdependencies

IMPACT OF ALTERNATIVE FUELS ON AIRCRAFT ENGINE EMISSIONS

(Presented by the International Coordinating Council
of Aerospace Industries Associations)

SUMMARY

Engine and aircraft manufacturers along with the supporting governments have conducted tests to assess the impact of alternative fuels on engine performance and emissions. Engine emissions and performance measurements have been made on several aircraft engines with 100% pure and blended alternative “drop-in” fuels. While having little impact on engine performance and gaseous emissions, alternative fuels use leads to large reduction in particulate matter emissions.

1. INTRODUCTION

1.1 Find attached test results from the tests conducted at GE, P&W and RR.

2. RESULTS

2.1 GE testing: To summarize the emissions results, the addition of the Bio-SPK to the conventional jet fuel was found to have insignificant effects on emissions. The resulting emissions values for the test blends meet the current regulatory requirements. There was a slight reduction in NOx (~1-5%), and an increase in the CO (~5-9%) and UHC emissions (~20-45%). While some parts of the observed changes to emissions are due to measurement variability, they are primarily explained by the anticipated reduction in the peak flame temperature due to the change in hydrocarbon to carbon ratio in the fuel compared to the conventional kerosene tested. Additionally, the impact on spray quality and flame location is also expected to play a major role for emissions levels, especially for CO (carbon monoxide) and UHC (unburned hydrocarbon), and it has to be observed that the changes in these emissions are in absolute terms very small as the datum emissions are very small. Lower smoke emissions (~13-30%) were observed, and this is understood to be as a result of the reduction in the aromatic content of the blends compared to the conventional jet fuel. The emissions may vary among various Bio-SPKs and the current results should be taken to be specific to the Bio-SPK tested. The results from the tests are shown in figures 1 and 2.

2.2 Rolls Royce testing: A series of engine ground runs were conducted on an Air New Zealand Boeing 747-400 aircraft equipped with Rolls-Royce RB 211-524G2-T engines prior to the test flight including a switch of fuel at various progressions of Engine Pressure Ratio (EPR) settings. The engine showed no change in behavior from the operational perspective. A small subset of the Digital Flight Data Recorder/Quick Access Recorder (DFDR/QAR) data from the 1.4 EPR condition, representative of the steady state performance results, is shown in Figure 3.

2.3 The ANOVA (analysis of variance) method was used to correctly establish if there was a statistical difference between the engine measurement data. ANOVA plainly looks at the data presented and therefore generally accounts for all the possible factors present within the dataset; in this case variations in EPR, EGT, throttle angle and measurement variations.

2.4 During the 1.4 EPR power setting condition, a 1.07% lower fuel flow was observed on the engine run of the Bio-SPK blend which is consistent with the 1.08% higher energy density per unit mass of the Bio-SPK fuel blend, which was determined experimentally. This engine-to-lab results comparison gives a 'practical difference' of 1% (1.08/1.07) by mass which when compared to the 95% confidence limits (from ANOVA) of 1.0-1.13% confirms the fuel flow effect seen is real and accurate.

2.5 RR also conducted a test program to assess the impact of Syntroleum Fischer-Tropsch fully synthetic aviation kerosene on performance and material compatibility of aircraft gas turbine engines by evaluating combustion characteristics in a production annular combustor and fuel nozzle assembly and effect on oxidation of turbine blade and vane alloys in a cyclic oxidation rig. Shown in figure 4 are some of the fuel properties that can impact different combustion characteristics. Tests were conducted to determine lean blowout and ignition characteristic of the alternative fuel, emissions and combustor exit temperatures in an annular rig (figure 5). Details of this test program were presented by Rolls Royce at the ICAO organized Alternative Fuels Workshop in Montreal, 2009. Some of the observations made from the tests were:

- Alternative fuel exhibits similar stability and ignition characteristics at low and higher operating conditions to those for JP-8 fuel within experimental error;
- CO, NOx (figure 6), and UHC emissions are similar for both fuels;
- Full annular AE3007 combustor behaves like engine in producing extremely low smoke and remains nearly smoke free for both alternative fuel and JP-8; and
- No measurable differences are observed in pattern factor and radial profiles between JP-8 and FSJF fuels suggesting no adverse impact on turbine vanes durability.

2.6 Pratt & Whitney testing: No engine degradation was evident via control, operability and performance or hardware inspection at the conclusion of the test. The emissions tests of the regulated species were compared for the jet fuel, 50%, and 100% ratios used, and showed no significant change in hydrocarbon (HC), Carbon Monoxide (CO), or Nitrogen Oxides (NOx). While the test setup is shown in Figure 7, figure 8 and 9 show fuel characteristics. Some of the test observations (shown in Table 1 and figure 10 for gaseous species and figures 10, 11 and 12 for PM emissions):

- Negligible Thrust and Fuel Flow impact of alternative fuel as compared to JP8

- No significant difference in Gaseous emissions for the different fuels;
- Lower volatile PM emissions (measured at 50m) for synthetic fuels than for JP8:
    1) EIm sulphate depends linearly on fuel sulphur content; and
    2) At 50 m, plume generated by alternative fuel contain “less” particle sulphate than even ambient air.
- Particulate Matter (PM) emissions for the different fuels:
    1) For pure alternative fuel, PM EI values are orders of magnitude lower in both number & mass at idle relative to JP8. Differences between the fuels diminish with increasing power;
    2) Changes in observed Number EIs largely independent of instrument; “mass” EIs sensitive to measurement technique;
    3) Emission reductions not proportional to the fraction of alternative fuel;
    4) Alternative fuel suppresses volatile aerosol formation in plume as the fuel contains “0” Sulphur; and
    5) At the 50 meter probe, JP8 idle Number EIs were 45 times higher that alternative fuel.
- Powering the engine with the alternative fuel also did not result in any engine performance deterioration, as evidenced by a comparison of the initial and post-test data with JP8 fuel. Upon completion of the testing, the engine was stripped and inspected. No engine hardware deterioration as a result of testing with the alternative fuel was noted. Also, no unusual odors were noted as a result of the use of the alternative fuel, during both handling (i.e., filling of tanks, mixing of fuel blend, etc.), and engine running.

Figure 1. Emissions set-up: (a) Emissions trailer, (b) Emissions installation, (c) Emissions probes

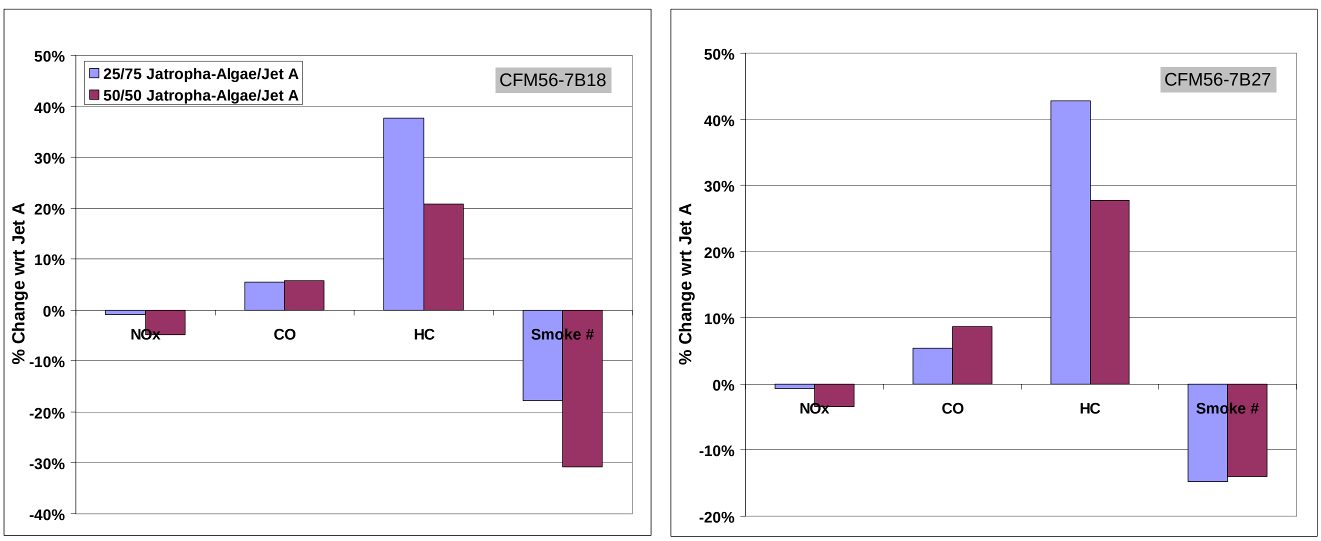

Figure 2. LTO emissions and maximum smoke number for test blends as % difference from Jet A for lowest (18K) and highest (27K) CFM56-7B engine ratings.

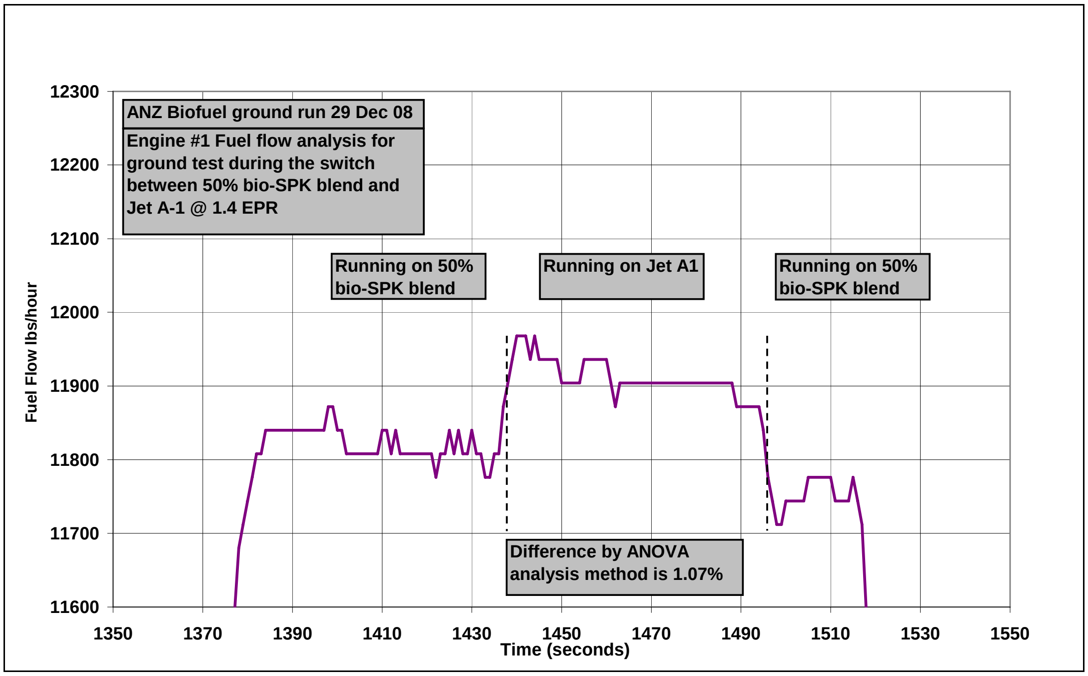

Figure 3. Engine ground-run data is shown from a RR RB211-524G2-T engine taken at Auckland on Dec 30, 2008. The data shows a reduction in fuel flow, due to the higher heat of combustion of the 50% Bio-SPK blend.

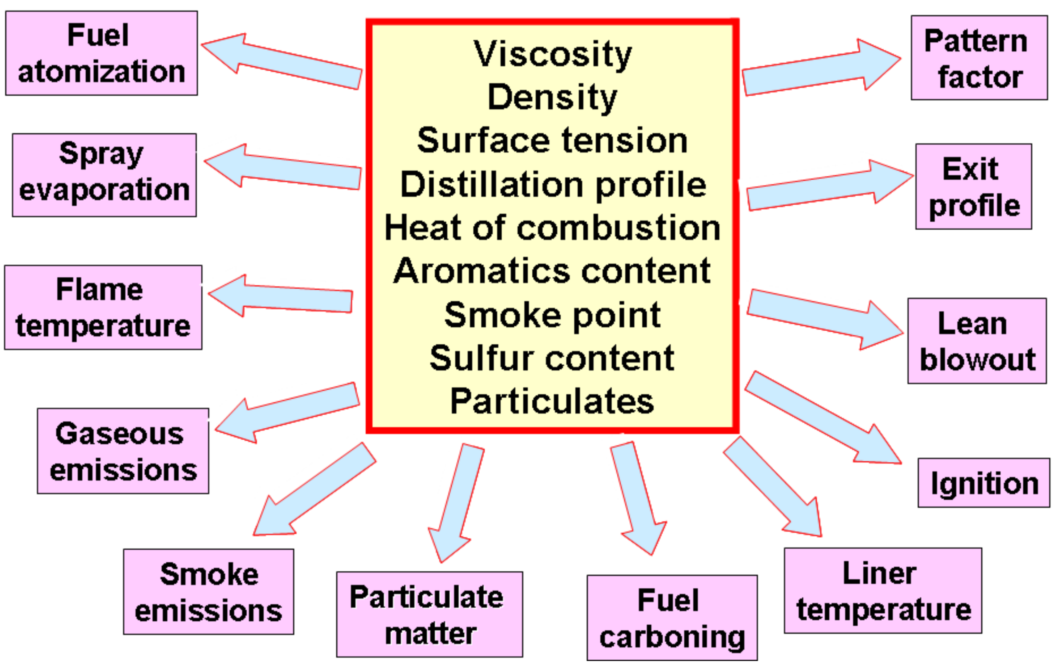

Figure 4. Fuel properties that can impact different combustor performance characteristics

Figure 5: A schematic of the annular rig at Rolls Royce used for testing Alternative fuels.

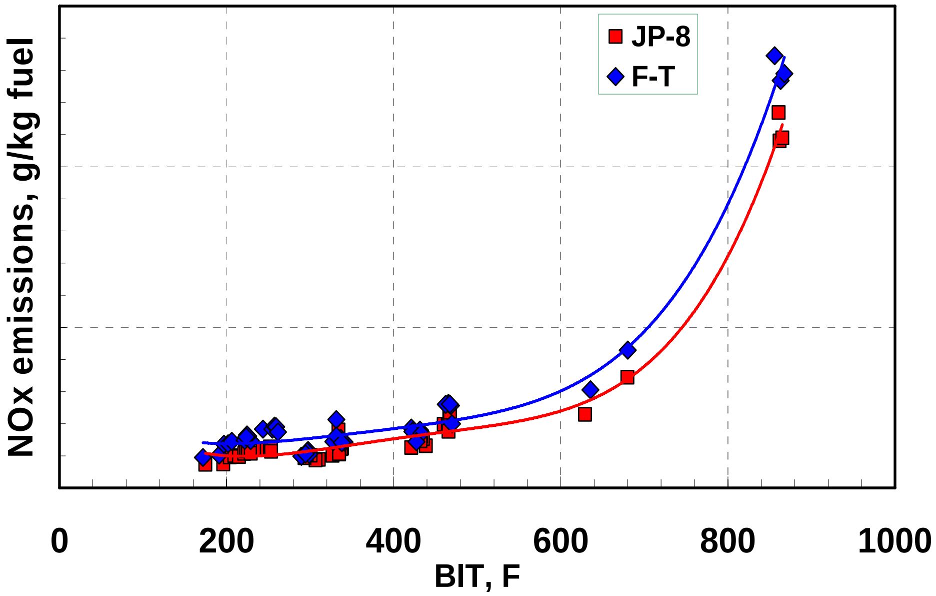

Figure 6. NOx emissions for FT Fuel are in general higher than for JP-8

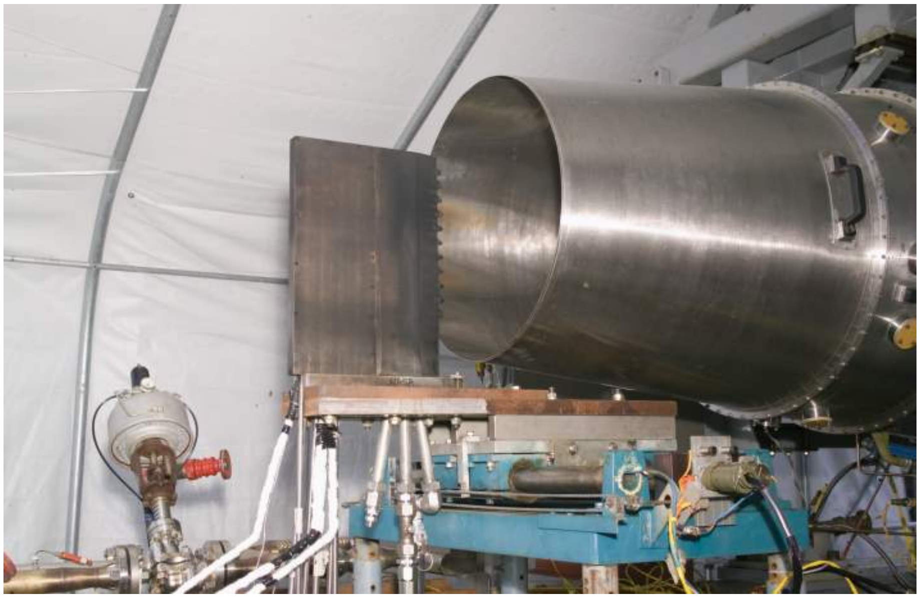

Figure 7. Engine Test setup used at P&W facility to test engine performance and emission characteristics with alternative fuels

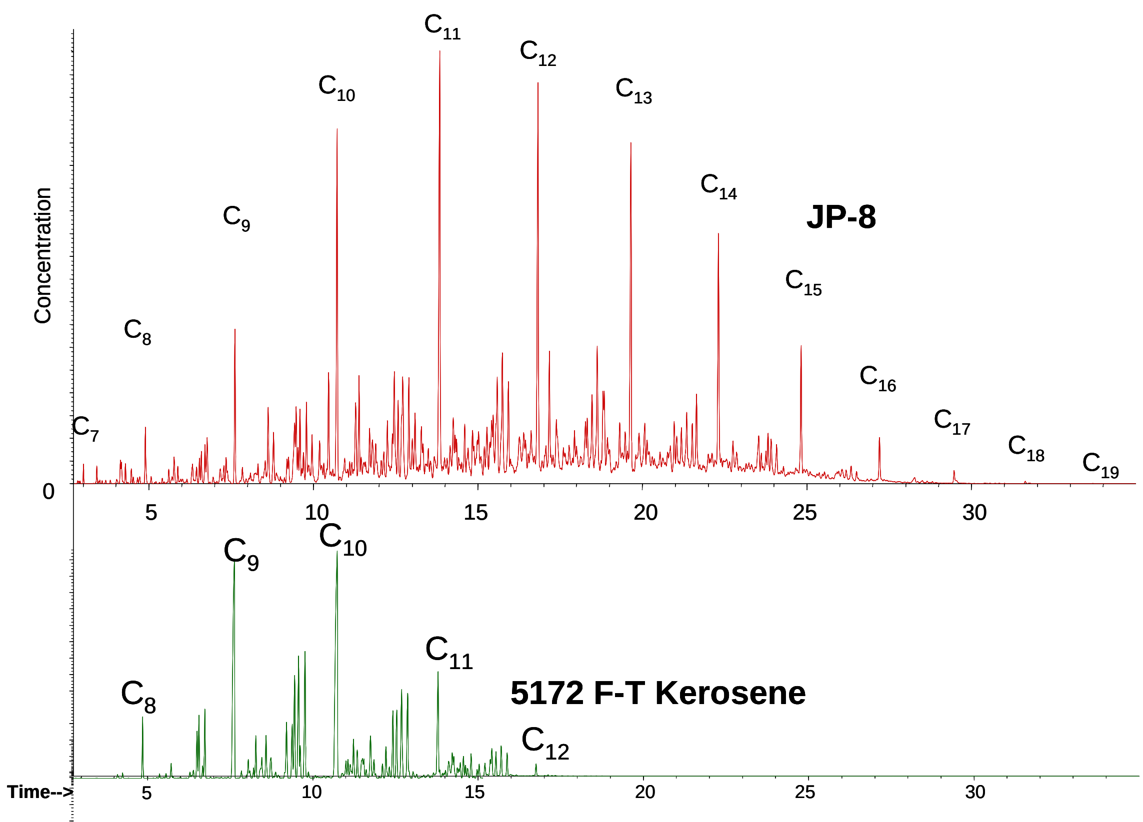

Figure 8. Spectra of fuel used in the tests.

Property	JP-8	Blend	Synthetic
Viscosity (cSt)	1.38	1.14	0.96
Specific Gravity	0.8050	0.7734	0.7377
Net Heat of Combustion (Btu/lb)	18,533	18,735	18,960
Hydrogen % mass	13.95	14.78	15.71
Particulate contamination (mg/L)	0.71	0.21	0.11
Sulphur content (%)	0.123	0.065	0.003
Aromatic content (%)	19	10.1	0.17

Figure 9. Fuel properties of the alternative fuels

	RATIO - Blend/JP8				RATIO – FT100%/JP8			
Thrust (Rotor Speed N1)	Fuel flow	NOx	CO	SO_2	Fuel flow	NOx	CO	SO_2
LOW	0.999	0.97	0.95	0.5	0.98	0.97	0.90	0.0
INTERMEDIATE	1.00	0.98	NA	0.54	0.98	0.97	NA	0.
HIGH	0.995	1.0	NA	0.54	0.97	0.98	NA	0.1

Table1. Gaseous emissions and performance characteristics of an engine with alternative fuel as compared to JP8

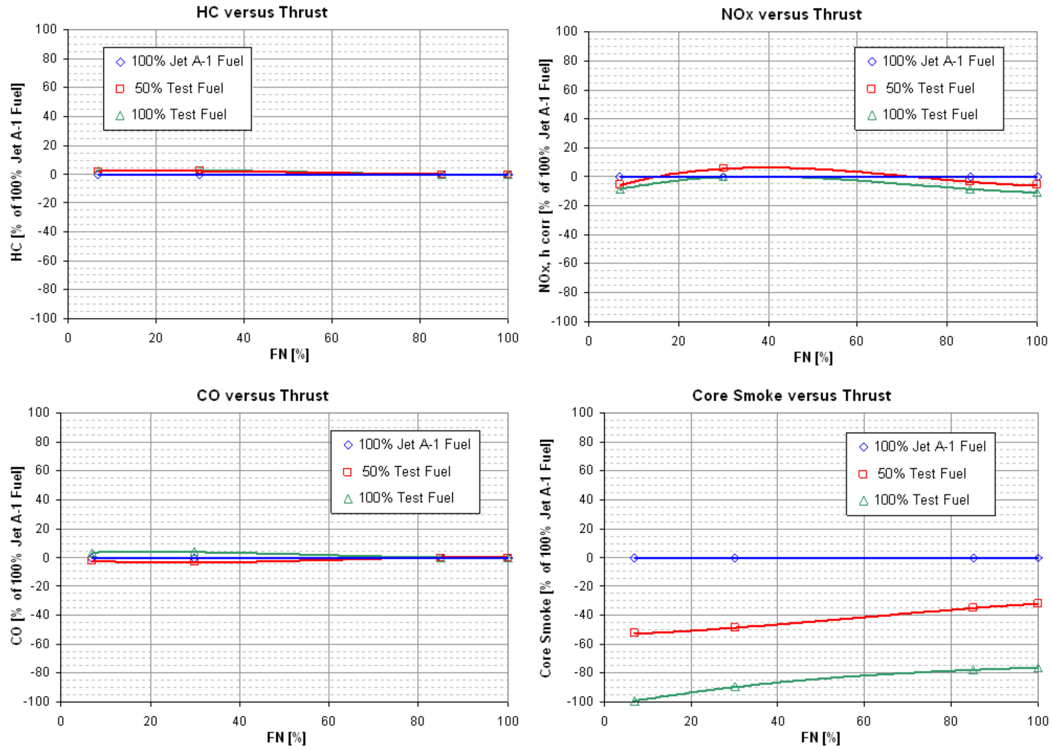

Figure 10. Emission data collected for Jet A-1, blend of 50% Jet A-1 and 50% Neste Oil and 100% Neste Oil in a Pratt and Whitney Canada small turbofan engine.

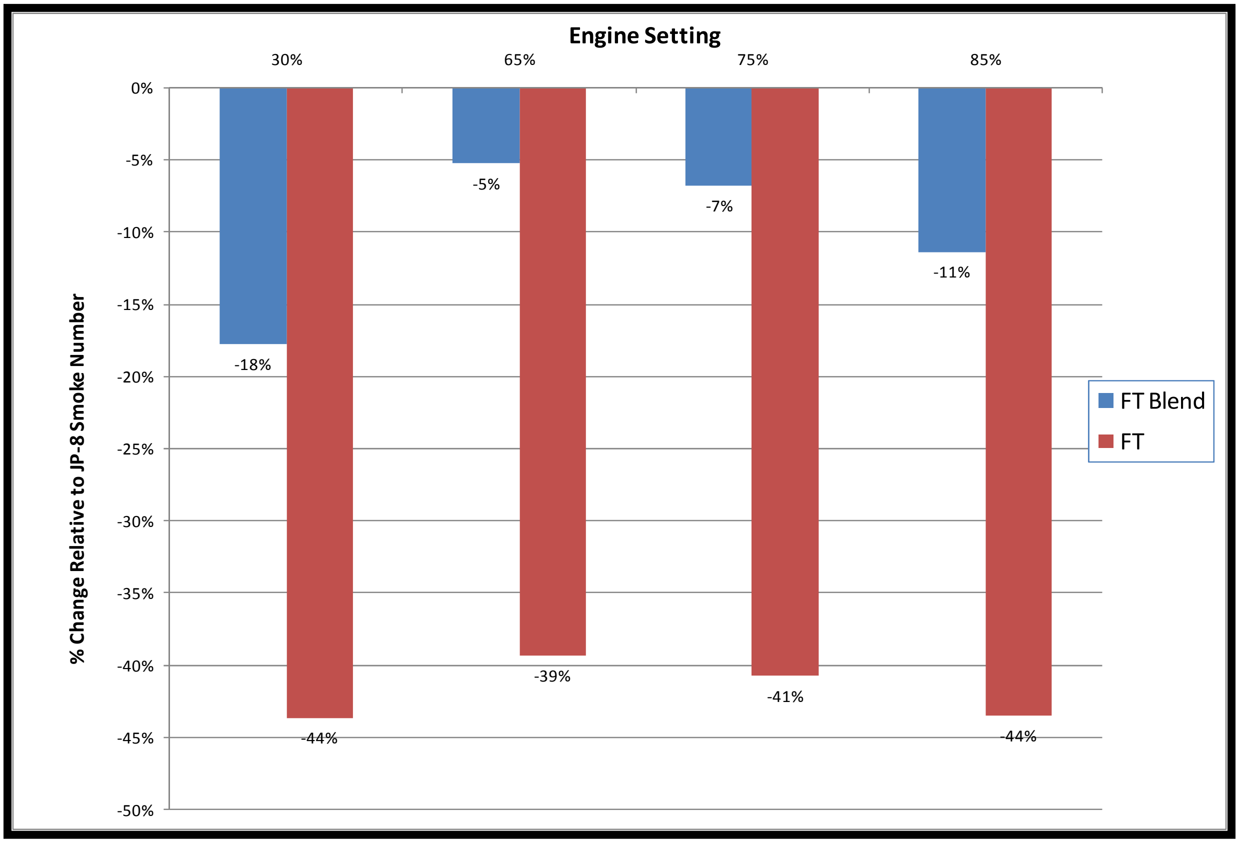

Figure 11. SN reduction seen with alternative fuels

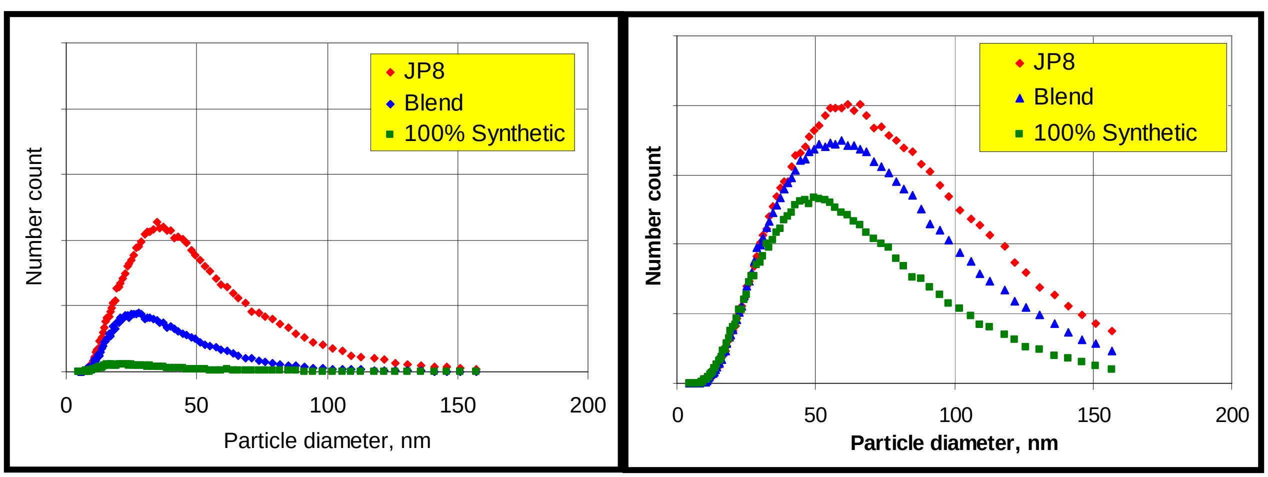

Figure 12. Large reductions in PM with alternative fuels at idle than at higher powers

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