Reduced Emissions Via Synthesized Aromatic Kerosene

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ASCENT Seattle, WA

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Biobased feedstocks to direct replacement fuels and chemicals

BIOFORMING

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Virent At a Glance

Leading catalytic route to low carbon 'drop-in' bio-based fuels and chemicals

- **Founded in 2002 and headquartered in Madison, Wisconsin**
- **High quality products , significant validation acceptance**
- **Strategic relationships with industry leaders**
- **Extensive Intellectual Property (IP) portfolio**

Partners & Investors

Cargill

HONDA
The Power of Dreams

The Coca-Cola Company

Capability

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Virent – Shell

Partnership: Technology and Product Qualification

- Joint Development of Technology Platform
- Joint Collaboration on Product Qualification
- Progressing SK and SAK Jet Fuel through ASTM

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Virent's BioForming® Technology

Leading catalytic route to renewable hydrocarbons

"Eagle" Virent's Demonstration Plant- Madison, WI

- **Fast and Robust**
  - Inorganic Catalysts
  - Moderate Conditions
  - Industry Proven Scalability
- **Energy Efficient**
  - Exothermic
  - Low Energy Separation
  - Low Carbon Footprint
- **Premium Drop-in Products**
  - Tunable Platform
  - Infrastructure Compatible
- **Feedstock Flexible**
  - Conventional Sugars
  - Non-Food Sugars

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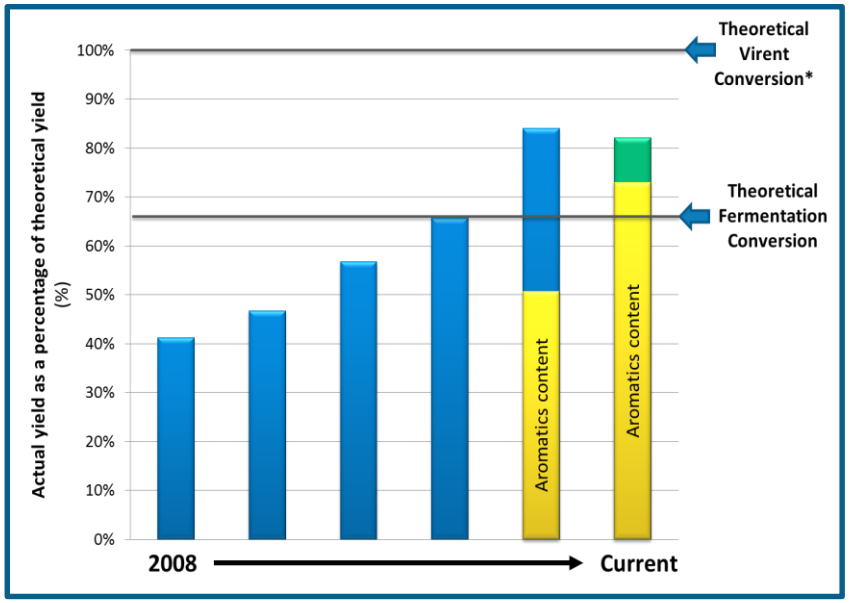
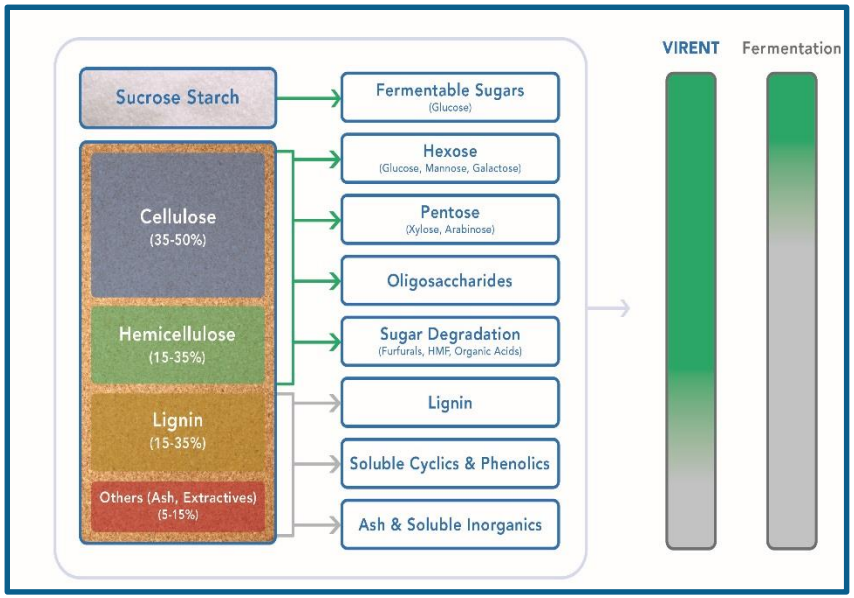
Virent Competitive Advantages

Low cost bio-based route to drop-in products





- *- Virent process with external H_2*

- Continuous, catalytic process
- Higher yields of aromatic chemicals and fuels
- Competitive economics at commercial scale
- Feedstock flexibility: Converts water-soluble oxygenates to drop-in products

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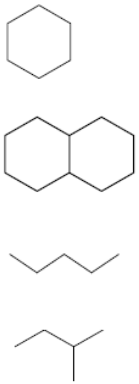
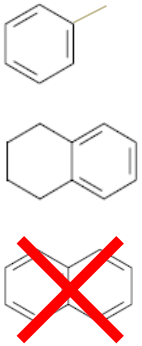
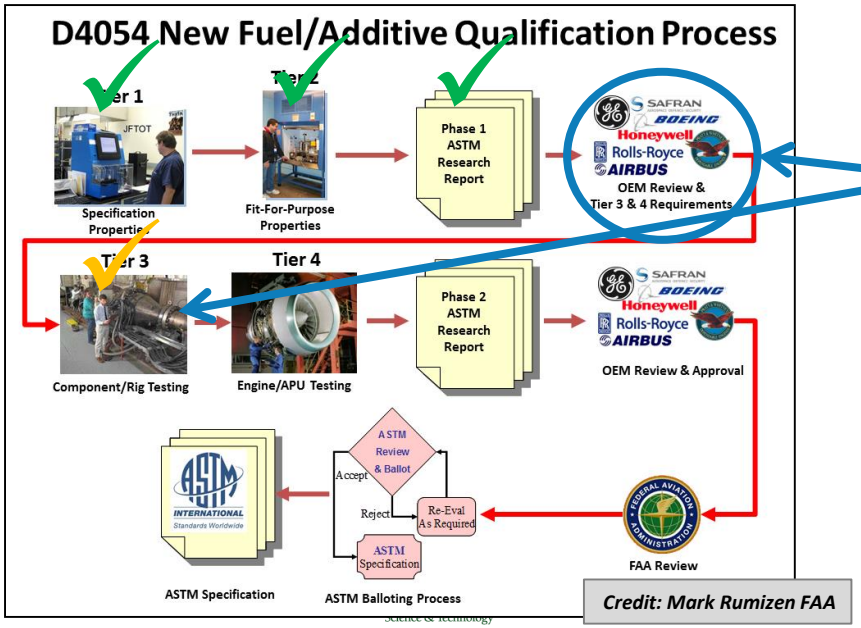
2 Shell/Virent Jet Fuel Products

ASTM Approval Process On-going



Synthetic Kerosene (SK)	Synthetic Aromatic Kerosene (SAK)
100% saturated 80% cycloparaffins 20% paraffins	**100% aromatic** 95% monoaromatics 5% naphthenic-monoaromatics No Naphthalenes
▪ All testing within jet fuel experience ▪ Advantaged ▪ Density ▪ Thermal stability ▪ Freeze point	▪ All testing within jet fuel experience ▪ Advantaged freeze point
ASTM: Seeking 50% blend with conventional jet fuel	**ASTM: Seeking 25% total aromatics blend with alternative or conventional jet fuel (i.e., treat same as conventional aromatics)**





Current status of SK and SAK

Credit: Mark Rumizen FAA

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SAK Role in the Alternative Jet Portfolio

Shell/Virent Testing Collaboration

Background

- Studies have demonstrated the potential of **Synthetic Paraffinic Kerosenes (SPKs)** to reduce emissions both on the ground and in the air
- However, SPKs alone do not make a fit-for-purpose jet fuel – aromatics are required to meet 'drop-in' density and materials compatibility needs
- But not all aromatics are the same – high naphthalenes lead to high soot
- Shell and Virent have developed **Synthetic Aromatic Kerosene (SAK)**, which is 100% aromatic and produced to contain no naphthalenes

What is the effect of synthetic aromatics on jet fuel emissions?

Shell/Virent study to demonstrate:

1. PM emissions benefit of SAK over conventional jet fuel aromatics
2. No negative impact on combustor performance

Additional side opportunities:

1. International collaboration between industry/government/academia
2. Comparison of two PM systems

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SAK Emissions Study

International Collaboration

Parameters investigated

- Fuel composition
- Total aromatics
- Simulated altitudes
- Engine conditions
- Gaseous emissions

CO, CO_2, THC, NO, NO_x

- Particulate emissions

Total PM

nvPM number, mass, and size*

*Measured with the AIR6241 compliant North American nvPM Reference System

Size results not shown for brevity

Fuel		Total Aromatics 17%	Total Aromatics 9%
1	Jet A	■	
2	Jet A/HEFA		■
3	SAK/HEFA	■	
4	SAK/HEFA		■

■ Tested

Engine Speed (RPM)	Simulated Altitude (ft) 5,000	10,000	28,000
27,000 – Idle	■		
29,500		■	
37,000	■	■	■
39,000	■	■	■
40,000	Max EGT	■	■

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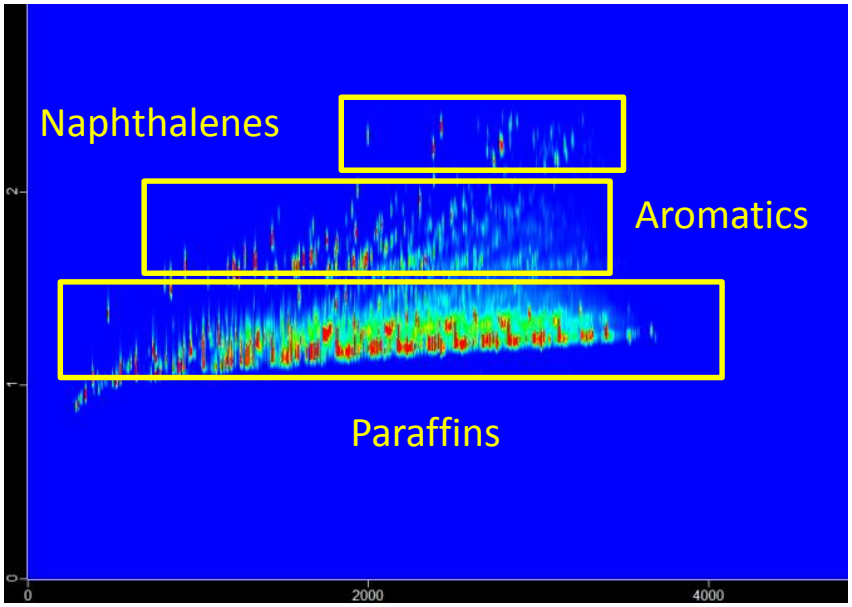
Fuel Composition

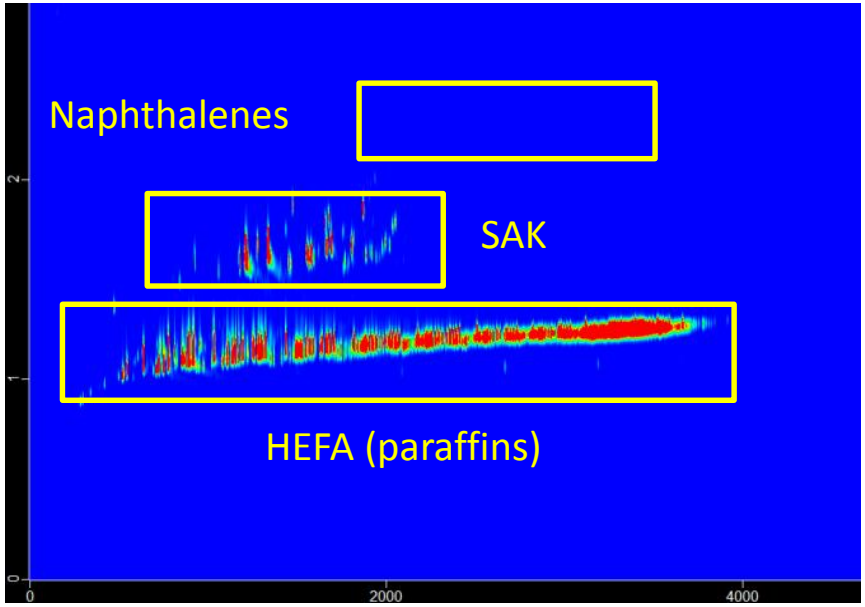
SAK Advantaged – No Naphthalenes

	Fuel	Total Aromatics (wt%)	Naphthalenes (wt%)
1	Jet A	17	2.03
2	Jet A/HEFA	9	1.14
3	SAK/HEFA	17	0
4	SAK/HEFA	9	0

Jet A – 17% aromatics



SAK / HEFA – 17% aromatics



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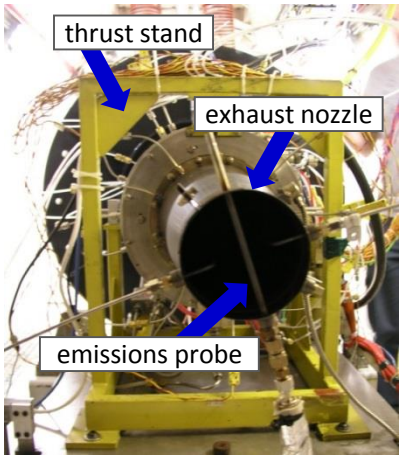
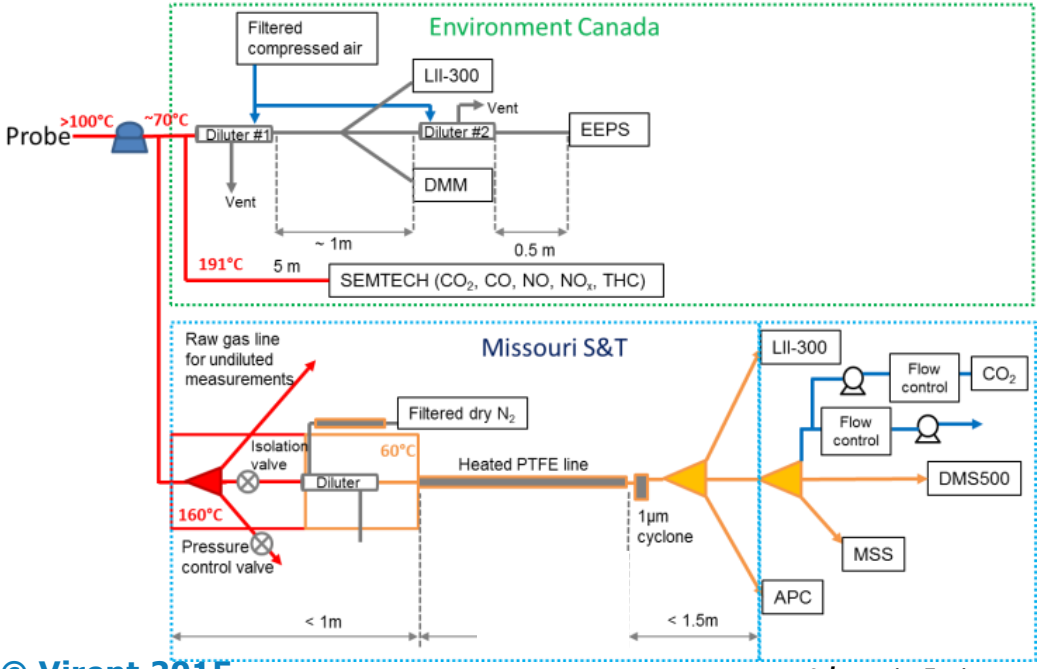
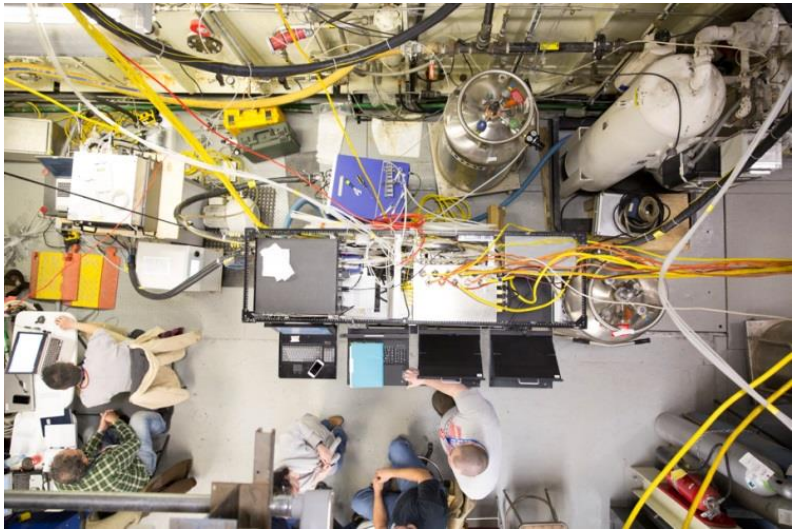
Experimental Setup

Altitude chamber, Engine, Emissions



Microturbo TRS-18 turbojet engine





Schematic: Environment Canada and Missouri S&T

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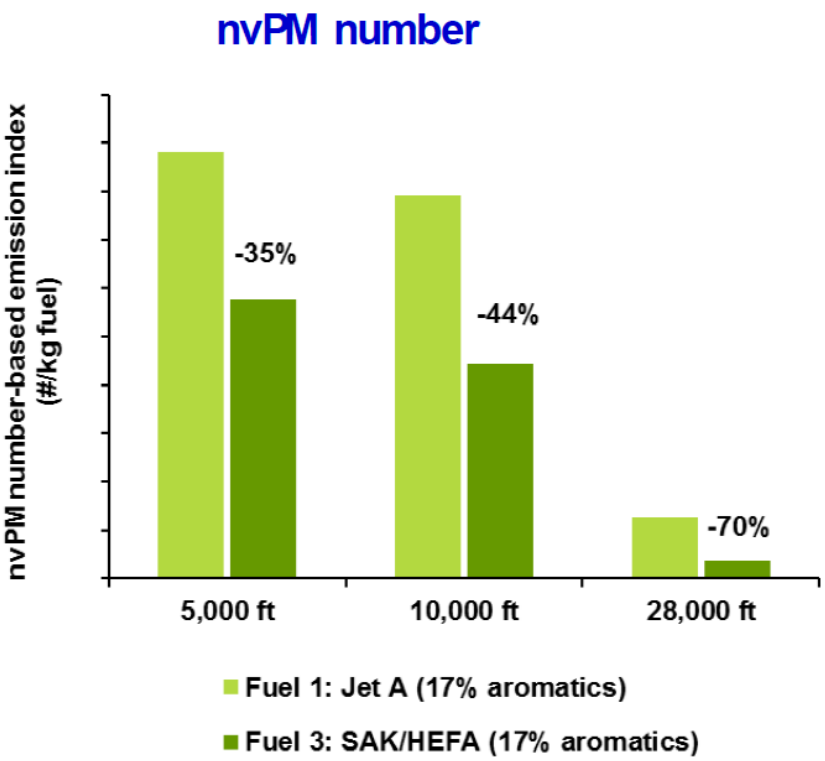
Reductions in Soot

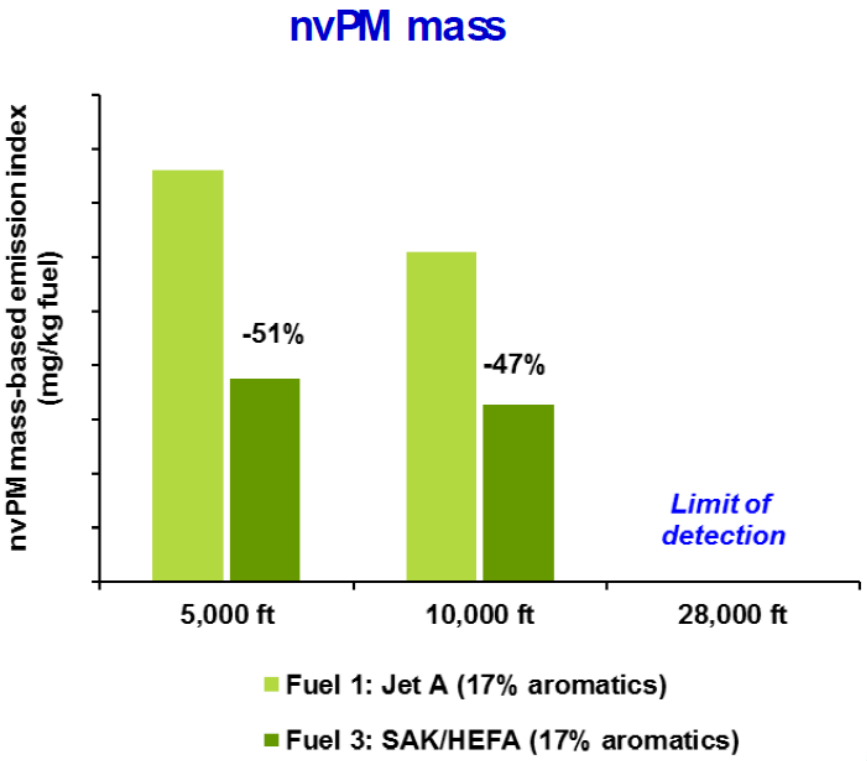
17% Aromatics Emissions

SAK blend vs. Jet A:

Study observed various nvPM reduction levels for all engine settings and altitudes. For example, at 40,000 RPM:

Engine Speed (RPM)	Simulated Altitude (ft) 5,000	10,000	28,000
27,000 – Idle			
29,500			
37,000			
39,000			
40,000	Max EGT		





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Reductions in Soot

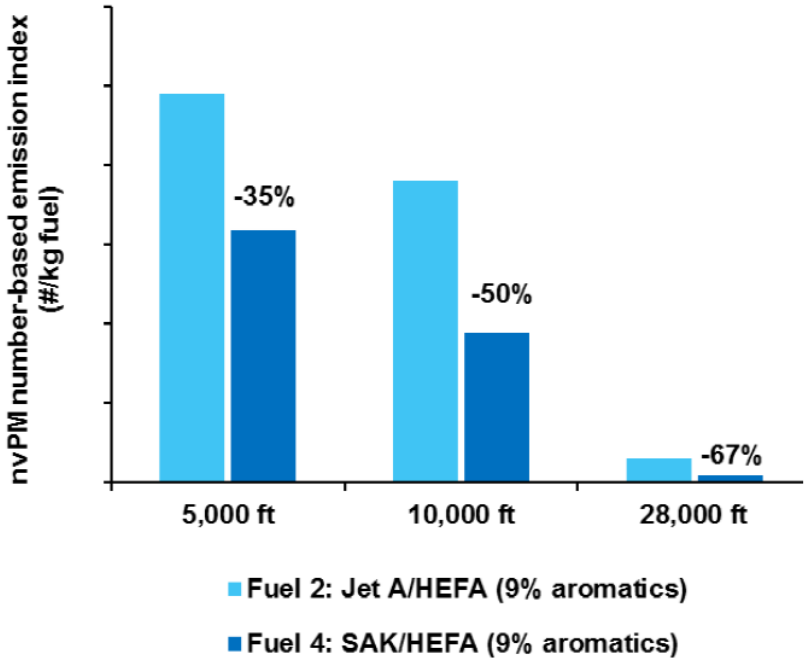
9% Aromatics Emissions

SAK blend vs. Jet A:

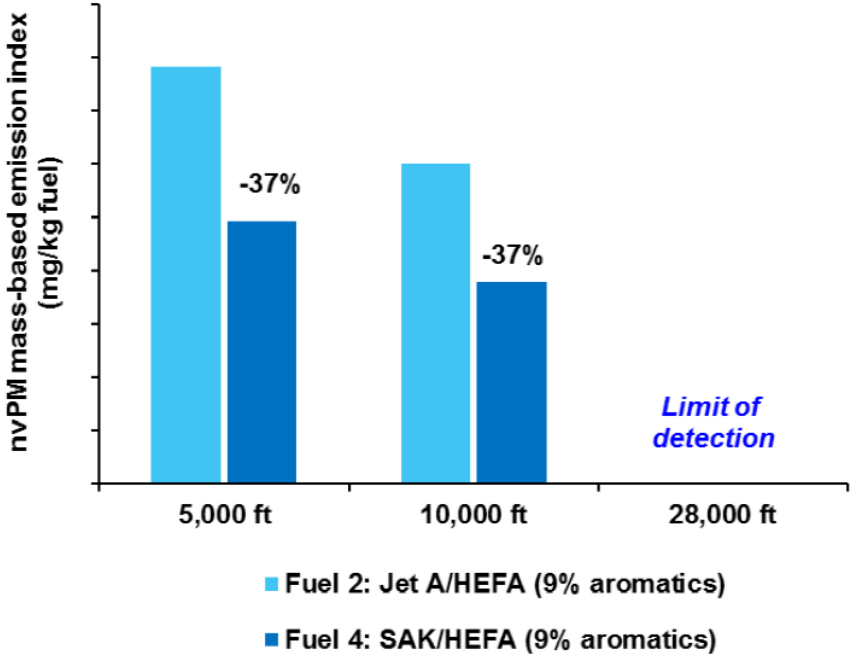
Study observed various nvPM reduction levels for all engine settings and altitudes. For example, at 40,000 RPM:

Engine Speed (RPM) \ Simulated Altitude (ft)	5,000	10,000	28,000
27,000 – Idle			
29,500			
37,000			
39,000			
40,000	Max EGT		

nvPM number



nvPM mass



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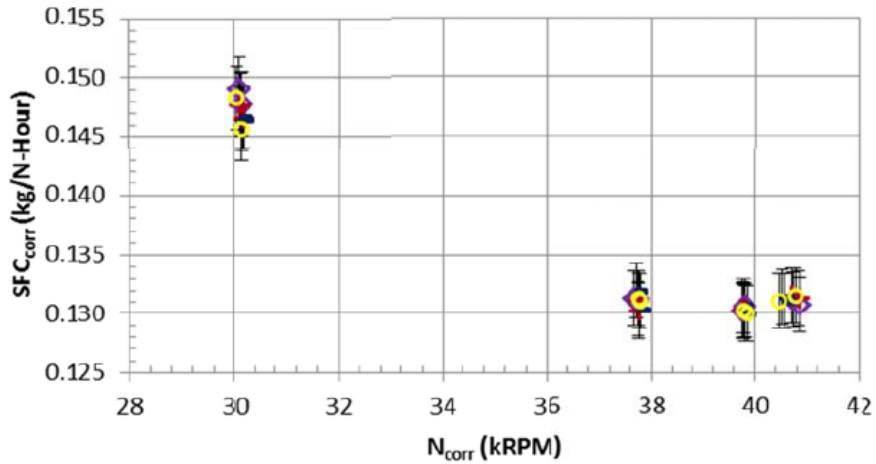
Equivalent Engine Performance

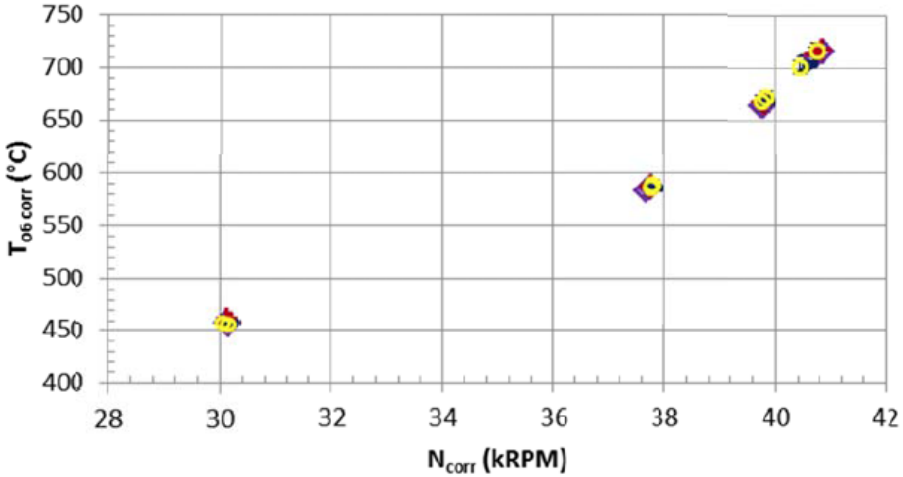
10K Altitude Example

SAK blends vs. Jet A blends: No detectable difference in engine performance

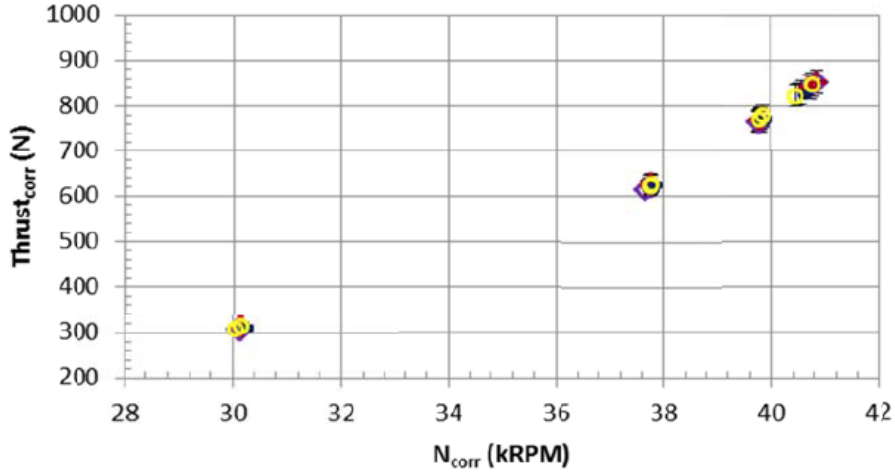
Specific Fuel Consumption



Exhaust Temperature



Thrust



- Fuel 1 – Jet A
- Fuel 2 – Jet A/HEFA
- Fuel 3 – 17% SAK/HEFA
- Fuel 4 – 9% SAK/HEFA

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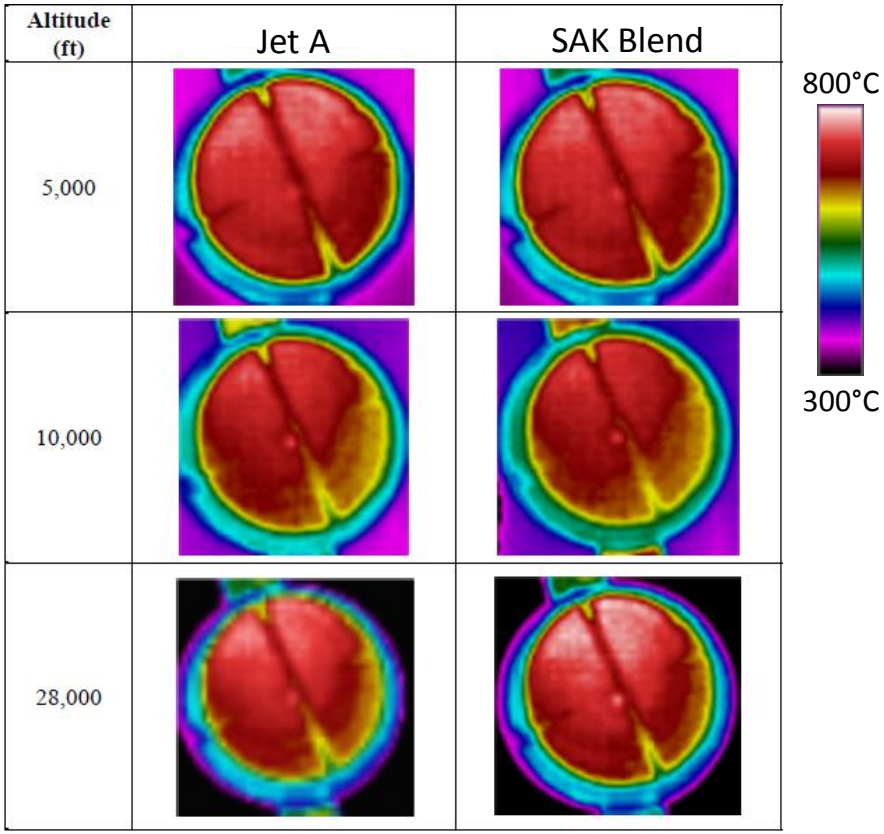
Equivalent Engine Performance

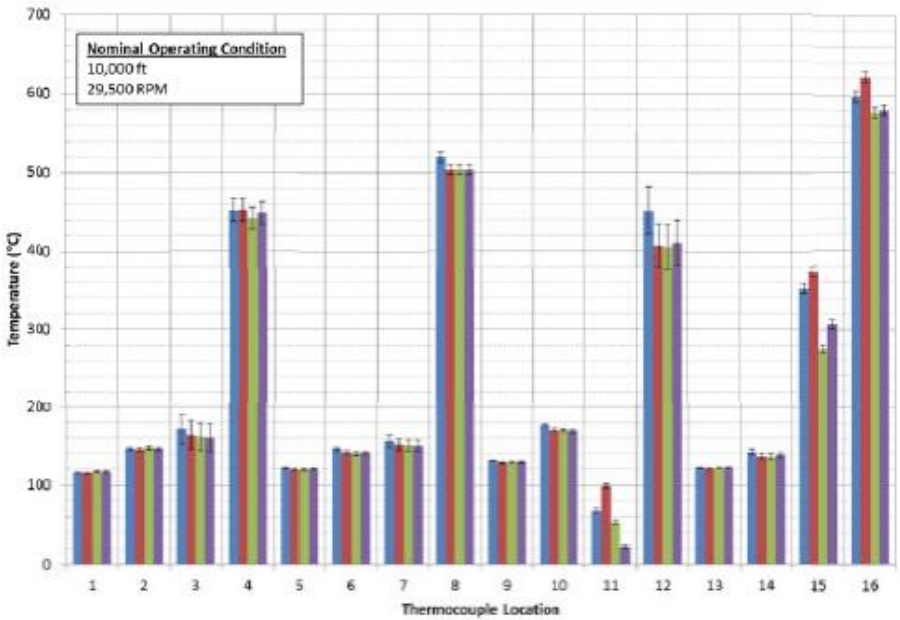
Engine Temperature Results

SAK blends vs. Jet A blends: No detectable difference in temperature profiles

IR Exhaust Temperature Profile



Combustor Metal Temperatures



- Fuel 1 – Jet A
- Fuel 3 – 17% SAK/HEFA
- Fuel 2 – Jet A/HEFA
- Fuel 4 – 9% SAK/HEFA

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Summary

- Measured gaseous and particulate emissions from a turbojet engine burning SAK blends and Jet A blends with equal aromatic levels at different power settings in a simulated altitude chamber
- Observed significant reductions in nvPM number and mass due to SAK blends – approximately 35-70% reductions over range of power and altitude conditions
- No detectable difference in combustor performance from SAK blends vs Jet A blends

Acknowledgements (pictured)
NRC – Pervez Canteenwalla, Wajid Chishty and team
Environment Canada – Tak Chan and team
Missouri S&T – Prem Lobo and team
National Defence Canada – Pierre Poitras
Transport Canada – Ted McDonald

More on this work :
ASTM
IASH
IFAR
ASCENT
ICAO/CAEP/WG3/PMTG
TAC-4
ASTM approval work continues

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Successful SAK Flight Demonstration

Follow-up to Ground Emissions Work

- Test flight on July 17th 2015
- 17% aromatics: **SAK/HEFA** vs **Jet A**
- Emissions measurements at altitude – PM, CO_2, NO_y, N_2O, VOCs, bulk aerosol number, ice particles, water vapor
- Engine performance monitoring

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