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NRC Alternative Fuels Initiative: Experiences and Future Plans

Pervez Canteenwalla and Sean Yun

National Research Council Canada

IFAR Alternative Fuels Virtual Conference
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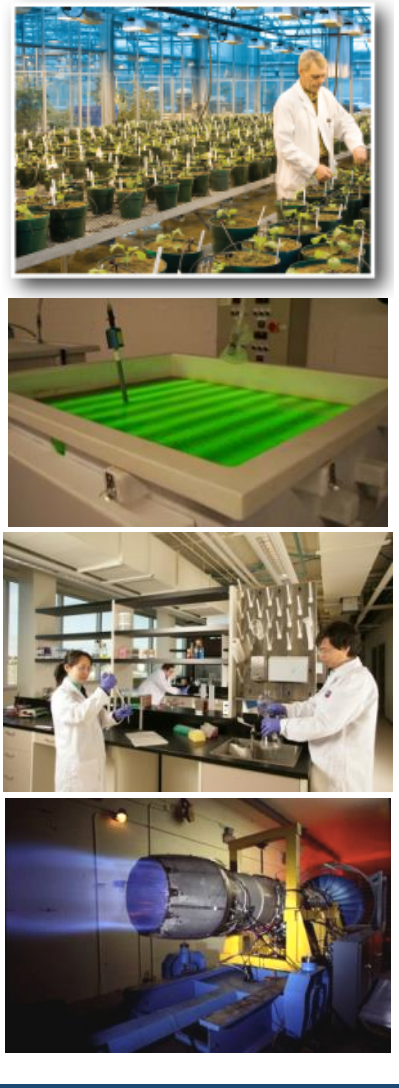
NRC – Aerospace

- Agency of Government of Canada
- Serves as primary aerospace research division for other Canadian government departments:
  - Transport Canada
  - Department of National Defence
- Provides industry with large-scale infrastructure and technology foresight through strategic R&D and technical services

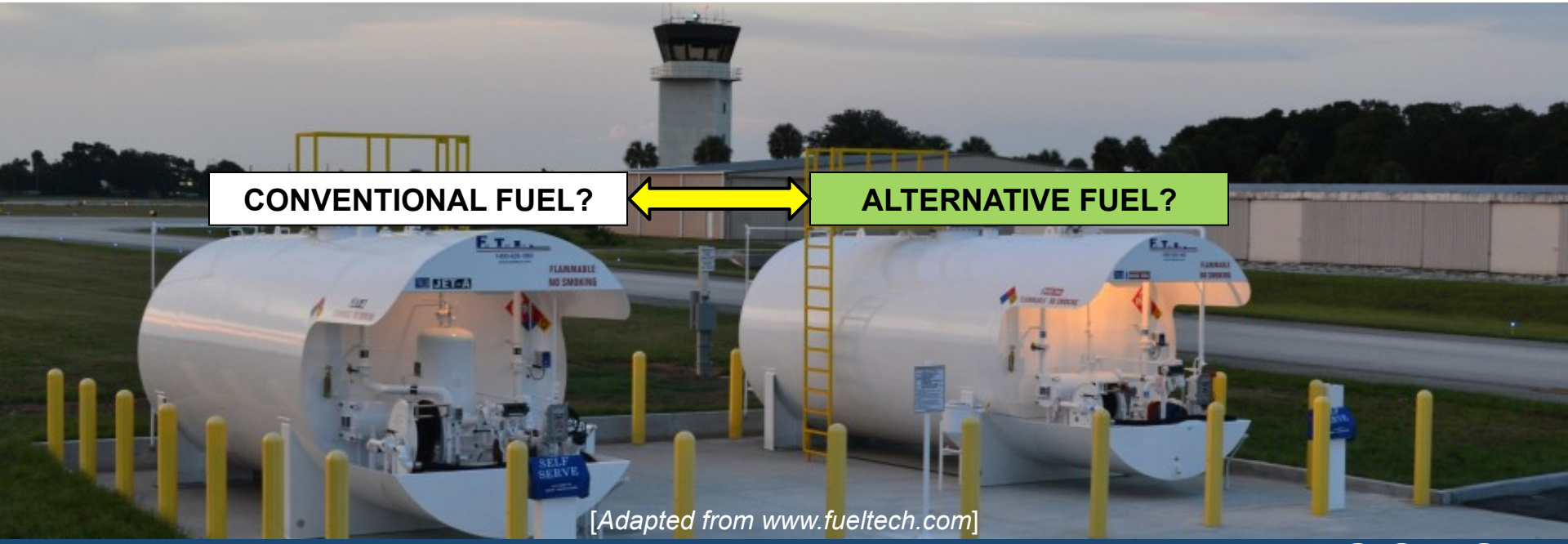
Bringing together NRC and Canada wide Competencies in Aviation Alternative Fuels

- **Microbiology**
  - Identification of high yield algae strains
  - Development of algae harvesting technologies
  - Identification and demonstration of scalable technologies
  - Development of high yielding GM crops
- **Biotechnology**
  - Development of bio chemicals and high-value bio products
  - Development of alternative bio oil pathways
- **Conversion of Biomass**
  - Development of efficient bio-reactors
  - Development of efficient methodologies for dewatering, drying and lipid extraction
- **Alternative Fuel Performance Testing**
  - Engine qualification testing
  - Components and fuel system modification
  - Material and coating compatibility assessment
  - Emissions assessments



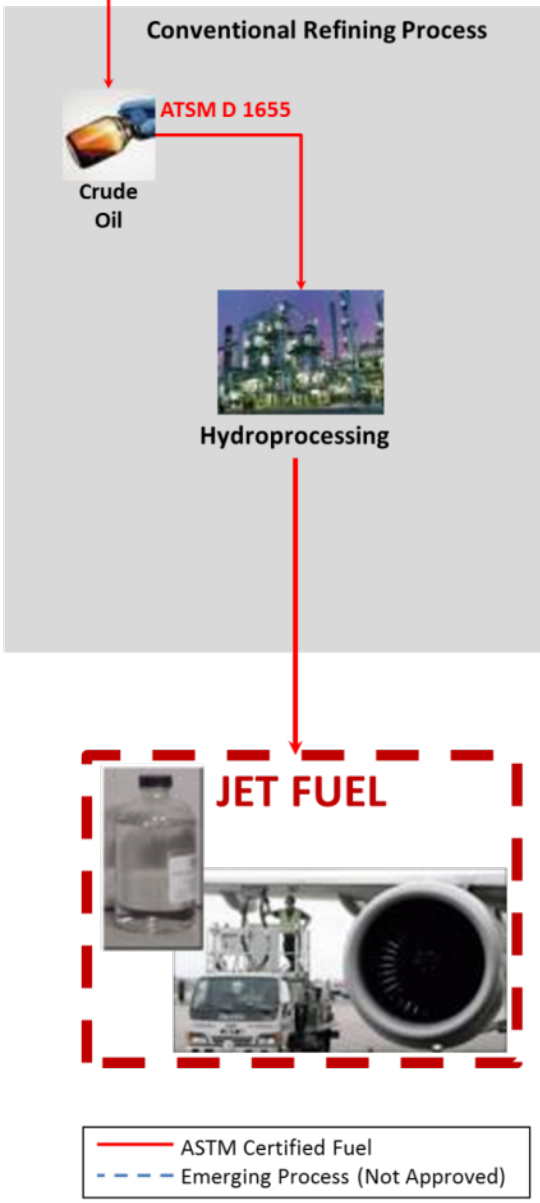
Alternative Fuels

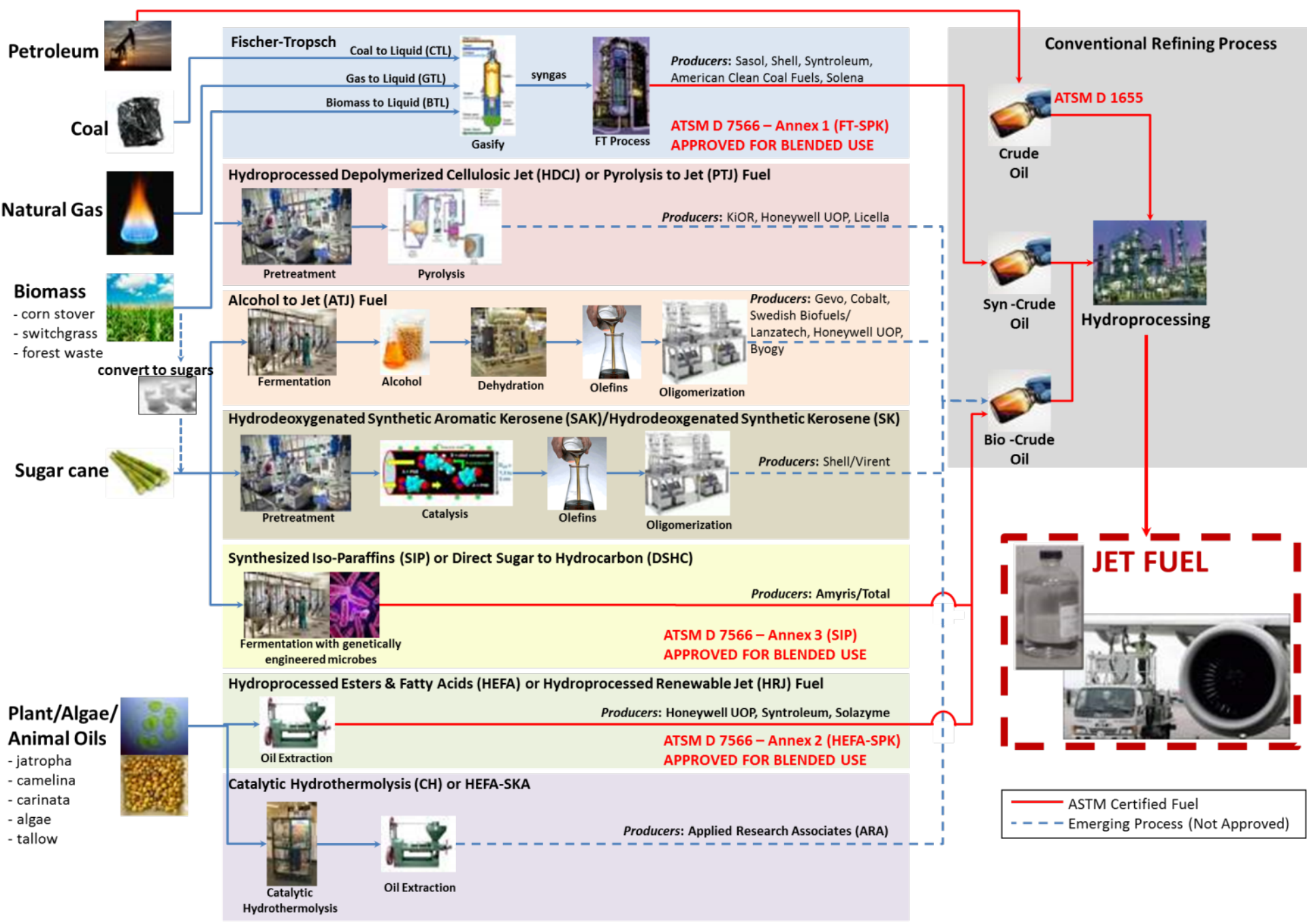
- Focus of this presentation is on “drop-in” aviation turbine fuels (i.e. jet fuel)
  - Drop-in fuels require no modification to existing aircraft/engines and fuel distribution infrastructure
  - Interchangeable with conventional petroleum based fuel



[*Adapted from www.fueltech.com*]

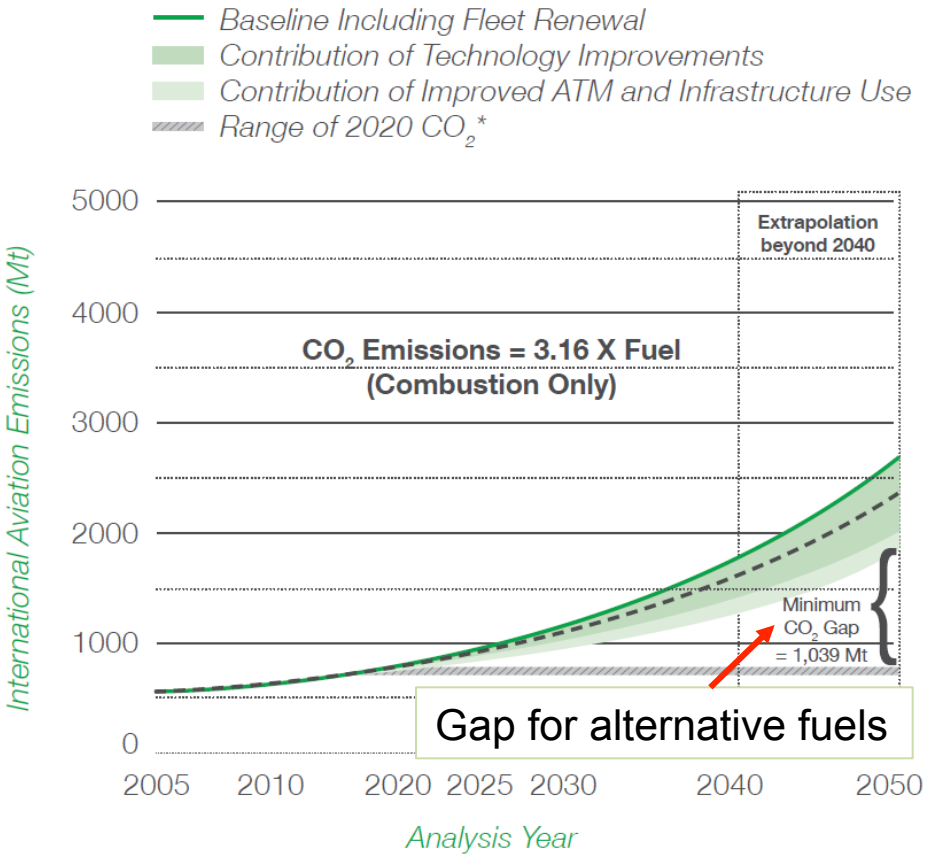
Conventional fuel pathway




Petroleum
Coal
Natural Gas
Biomass
- corn stover
- switchgrass
- forest waste
convert to sugars
Sugar cane
Plant/Algae/
Animal Oils
- jatropha
- camelina
- carinata
- algae
- tallow
Fischer-Tropsch
Coal to Liquid (CTL)
Gas to Liquid (GTL)
Biomass to Liquid (BTL)
Gasify
syngas
FT Process
Producers: Sasol, Shell, Syntroleum, American Clean Coal Fuels, Solena
ATSM D 7566 – Annex 1 (FT-SPK)
APPROVED FOR BLENDED USE
Hydroprocessed Depolymerized Cellulosic Jet (HDCJ) or Pyrolysis to Jet (PTJ) Fuel
Pretreatment
Pyrolysis
Producers: KiOR, Honeywell UOP, Licella
Alcohol to Jet (ATJ) Fuel
Fermentation
Alcohol
Dehydration
Olefins
Oligomerization
Producers: Gevo, Cobalt, Swedish Biofuels/ Lanzatech, Honeywell UOP, Byogy
Hydrodeoxygenated Synthetic Aromatic Kerosene (SAK)/Hydrodeoxgenated Synthetic Kerosene (SK)
Pretreatment
Catalysis
Olefins
Oligomerization
Producers: Shell/Virent
Synthesized Iso-Paraffins (SIP) or Direct Sugar to Hydrocarbon (DSHC)
Fermentation with genetically engineered microbes
Producers: Amyris/Total
ATSM D 7566 – Annex 3 (SIP)
APPROVED FOR BLENDED USE
Hydroprocessed Esters & Fatty Acids (HEFA) or Hydroprocessed Renewable Jet (HRJ) Fuel
Oil Extraction
Producers: Honeywell UOP, Syntroleum, Solazyme
ATSM D 7566 – Annex 2 (HEFA-SPK)
APPROVED FOR BLENDED USE
Catalytic Hydrothermolysis (CH) or HEFA-SKA
Catalytic Hydrothermolysis
Oil Extraction
Producers: Applied Research Associates (ARA)
Conventional Refining Process
Crude Oil
ATSM D 1655
Syn -Crude Oil
Bio -Crude Oil
Hydroprocessing
JET FUEL
ASTM Certified Fuel
Emerging Process (Not Approved)

Drivers for Alternative Fuels?

Civil



[*adapted from ICAO 2013 Environmental Report*]

(Environment)

Military

(Energy Security)

US Department of Defense Targets:

Air Force	50% of aviation fuel from alternative fuel blends by 2016
Navy	50% from alternative fuel sources by 2020
Army	Increase use of renewable energy

[*http://www.fas.org/sgp/crs/natsec/R42859.pdf*]

Aviation Emissions

- CO_2, CO, NO_x…only part of the story for emissions
- The other part is non-volatile Particulate Matter (i.e. soot)
  - $PM_{2.5}$ linked to serious health effects such as cancer and heart disease
  - Global warming potential of PM as high as 2,240 (x CO_2)
  - Some argue that reducing PM emissions is better strategy for countering global warming than reducing CO_2 emissions

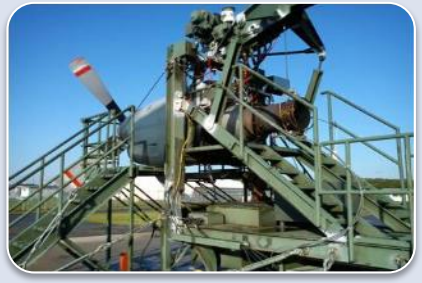
- But how can you reduce if you can't measure?
  - SAE/ICAO in process of developing standards for measuring nvPM → regulation limits to follow

- Link to alternative fuels? Discuss later.

Past and Current Initiatives: Engine Qualification & Emissions Characterization

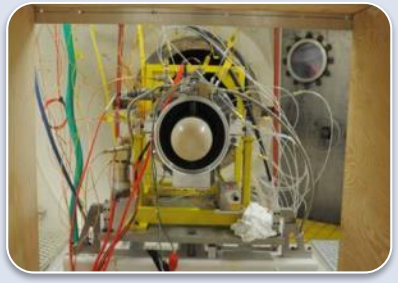
GE F404:

- Fleet qualification for RCAF CF18 aircraft
- Performance, durability & emissions testing
- Semi-synthetic FT fuel



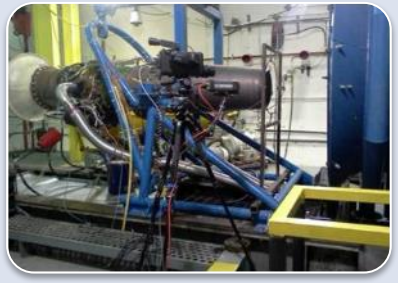
RR-Allison T56:

- Fleet qualification for RCAF CC130 aircraft
- Performance, durability & emissions testing
- Semi-synthetic HEFA



Microturbo TRS18:

- SAFE
- Simulated altitude performance & emission testing
- Fully- & semi-synthetic alternative fuels



GE CF700:

- Qualification testing for unblended 100% biofuel flight
- Performance & emissions testing
- Fully- & semi-synthetic alternative fuels

Past and Current Initiatives: In-flight Operability & Emissions Evaluation

Falcon 20:

- 50-50 Camelina-based HEFA (UOP)
- 50-50 Carinata-based HEFA (UOP)
- 60-40 Carinata-based HEFA (UOP)
- 100% Carinata-based HEFA (ARA CH-SKA)

CT-133:

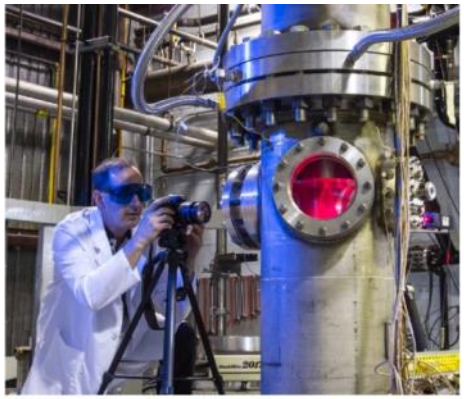
- 50-50 Camelina-based HEFA (UOP)
- 50-50 Carinata-based HEFA (UOP)
- 60-40 Carinata-based HEFA (UOP)
- 100% Carinata-based HEFA (ARA CH-SKA)
- ACCESS-II, the NASA-NRC-DLR collaboration
- Enroute jet transport wake emissions (B767, B777, A340, A380)

Future Initiatives & Plans – NJFCP

NJFCP – FAA's National Jet Fuels Combustion Program

- Expedite and accelerate current ASTM approval process
- Reduces cost of qualification testing
- Reduce fuel quantities required for approval
- Reduce technical risks for engine OEMs
- Additional benefits:
  - Broader fuel specification leading to wider pool of approved fuel alternatives
  - Availability of enhanced modeling and design tools for industry
  - Revised specifications leading to wider operational regimes for engines

NJFCP



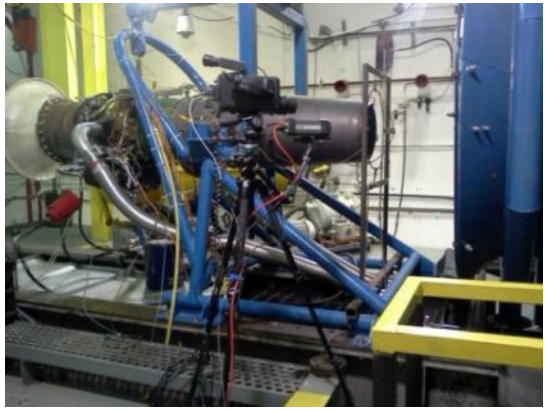
Area #5: Atomization and Spray

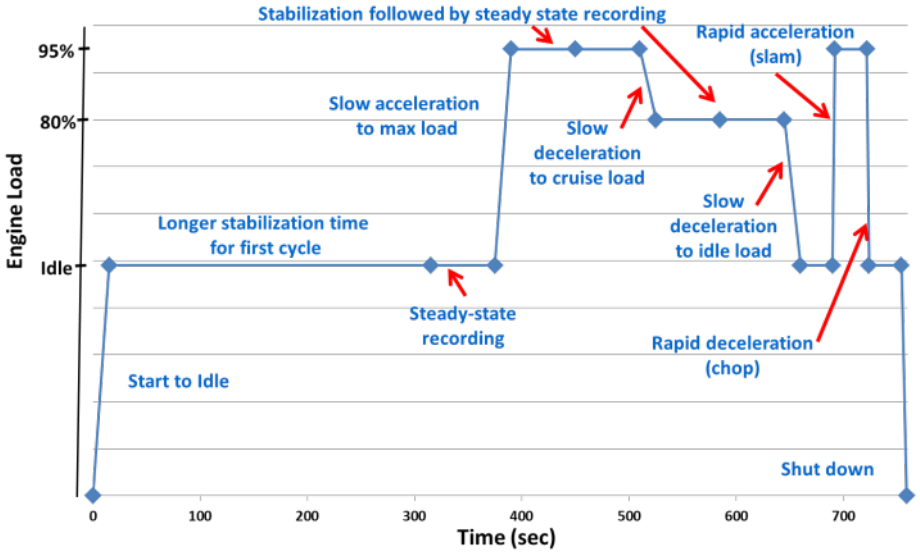
- Two independent facilities (Purdue and NRC) conducting spray testing with same fuel nozzle to provide verification
- Coordinating on providing additional data through different test conditions and diagnostic techniques

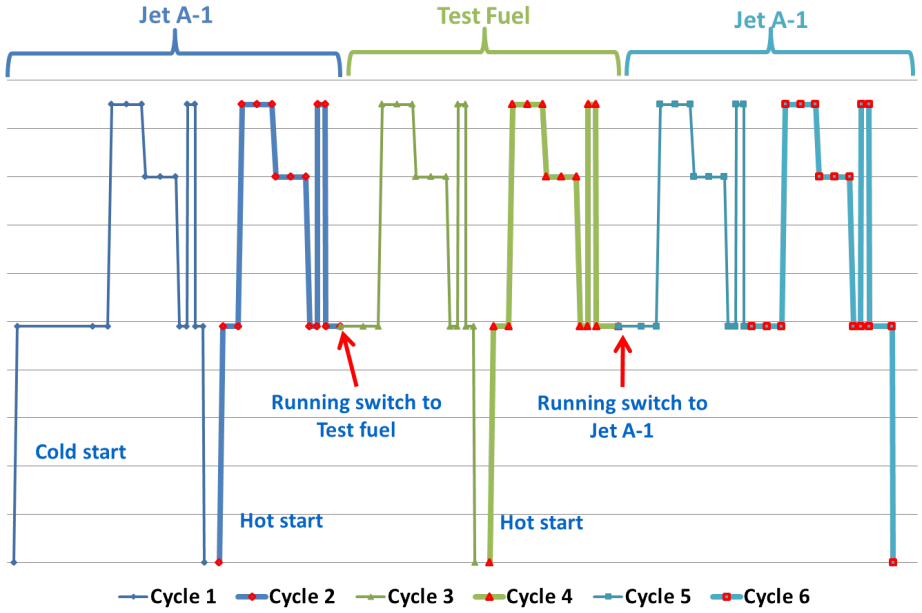
Altitude Engine Testing

- Up to 52,000-ft test cell simulated altitude (independent control of pressure, temperature and humidity)
- Engine performance and operability including LBO, relights, cold starts and transients
- Emission (NOx, CO, CO2, UHC, PM, BC)

Sample Results of Interest – Sea Level Static Engine Testing







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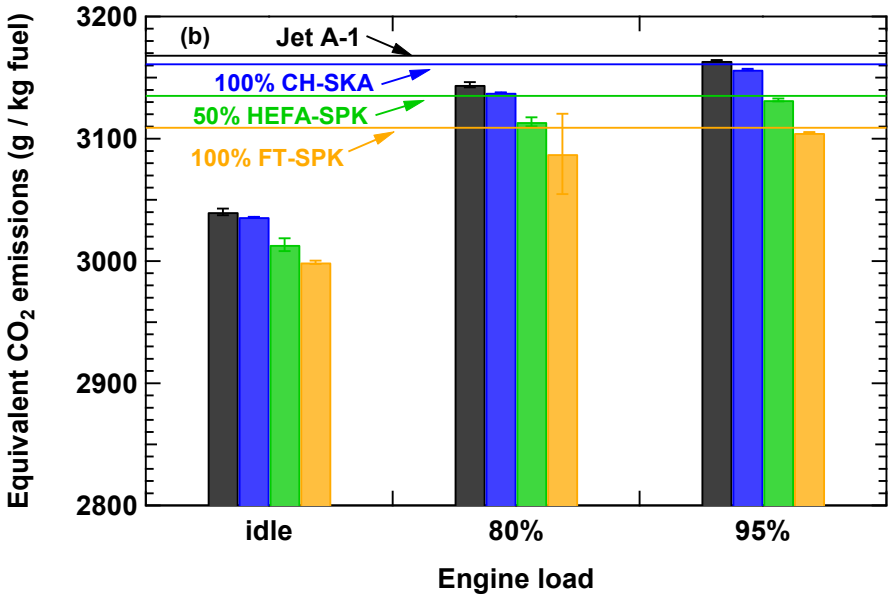
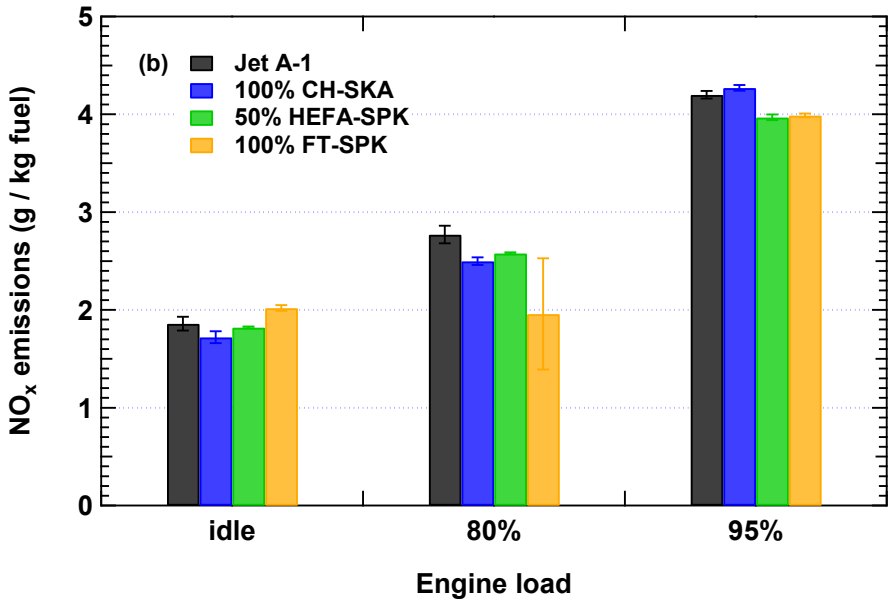
Static Engine Testing: Gaseous Emissions

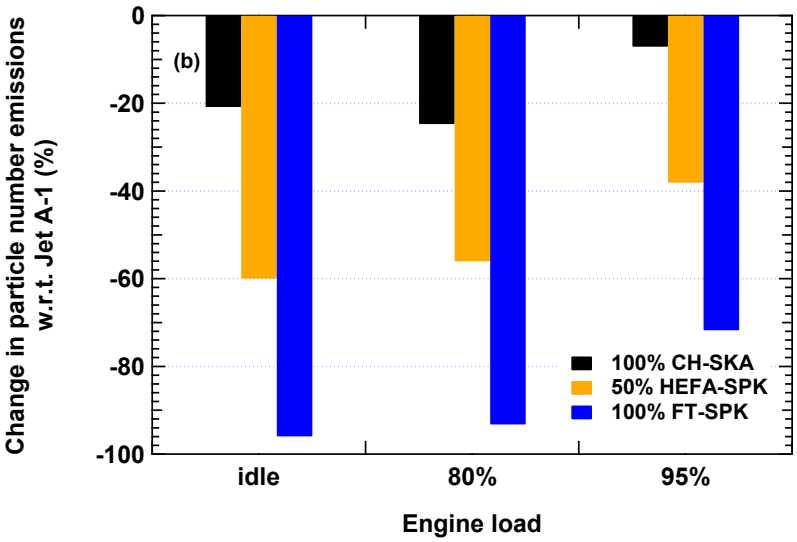


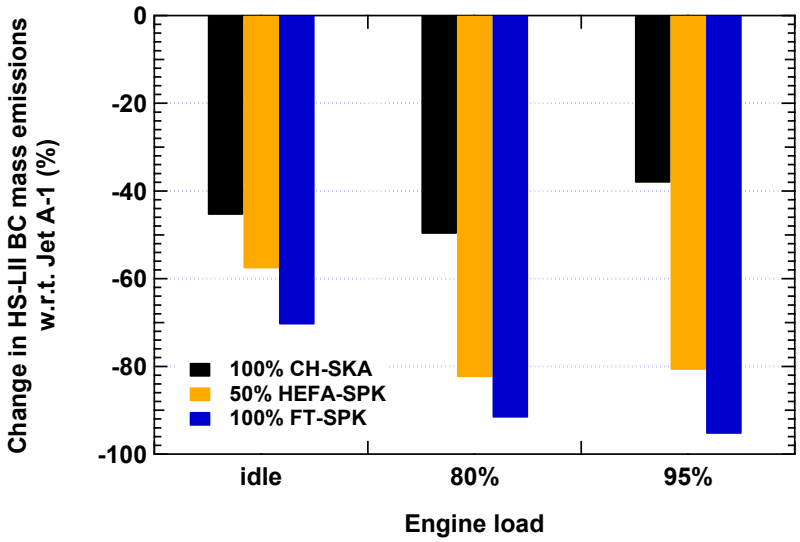


Jet A-1
100% CH-SKA
50% HEFA-SPK
100% FT-SPK

- Emissions measurement conducted by Environment Canada

Static Engine Testing: Particulate Matter Emissions



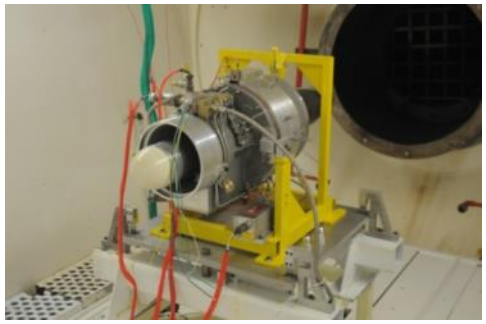


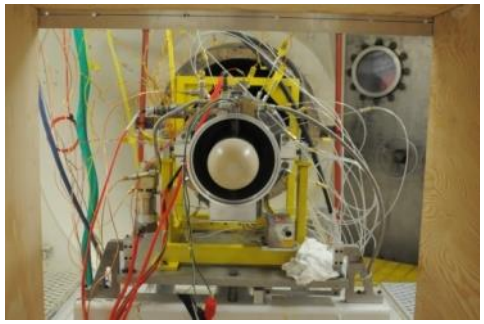
100% CH-SKA
50% HEFA-SPK
100% FT-SPK

- Emissions measurement conducted by Environment Canada

Sample Results of Interest – Simulated Altitude Tests

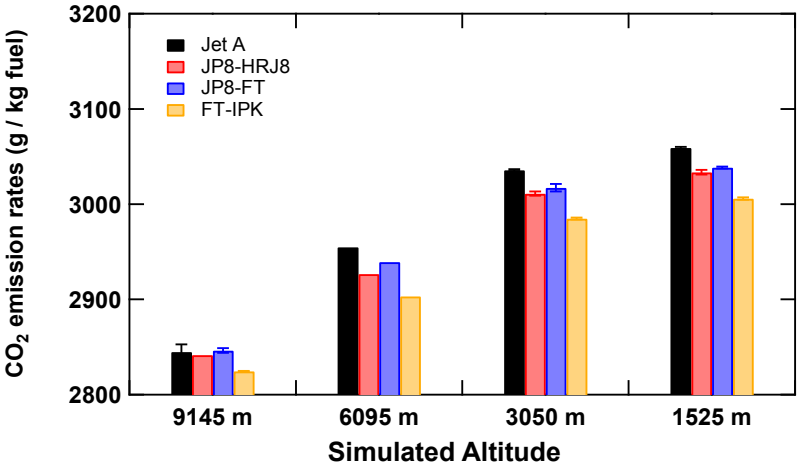
- 1000 N thrust turbojet engine (Microturbo TRS18)
- Tests conducted at NRC's Research Altitude Test Facility
  - 35 ft long x 10 ft internal diameter
  - Simulate altitudes up to 52,000 ft
  - Independent control of pressure and temperature altitudes
- Engine instrumented to gather P and T at all engine stations

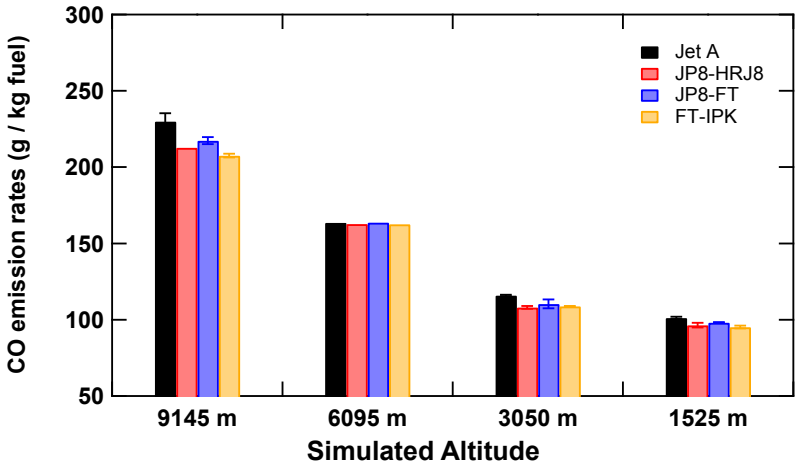


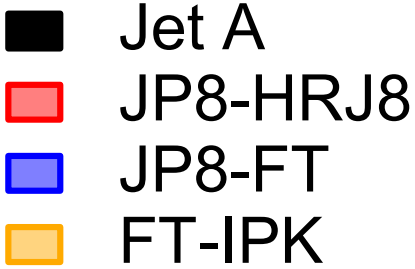


Nominal Altitude [m]	Nominal Uncorrected Engine Speed [RPM]						
	Idle	31,000	35,000	37,000	39,000	41,000	Max. EGT Limited
1525							
3050							
6095							
9145							
11280							

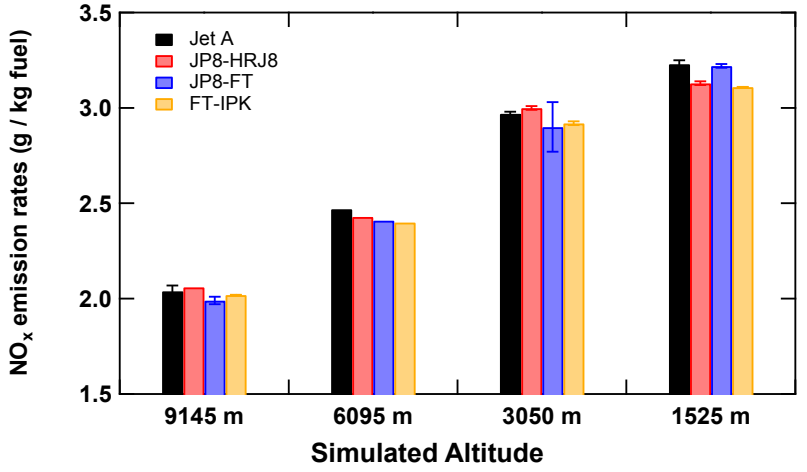
Simulated Altitude Tests: Gaseous Emissions – Fuel Effects





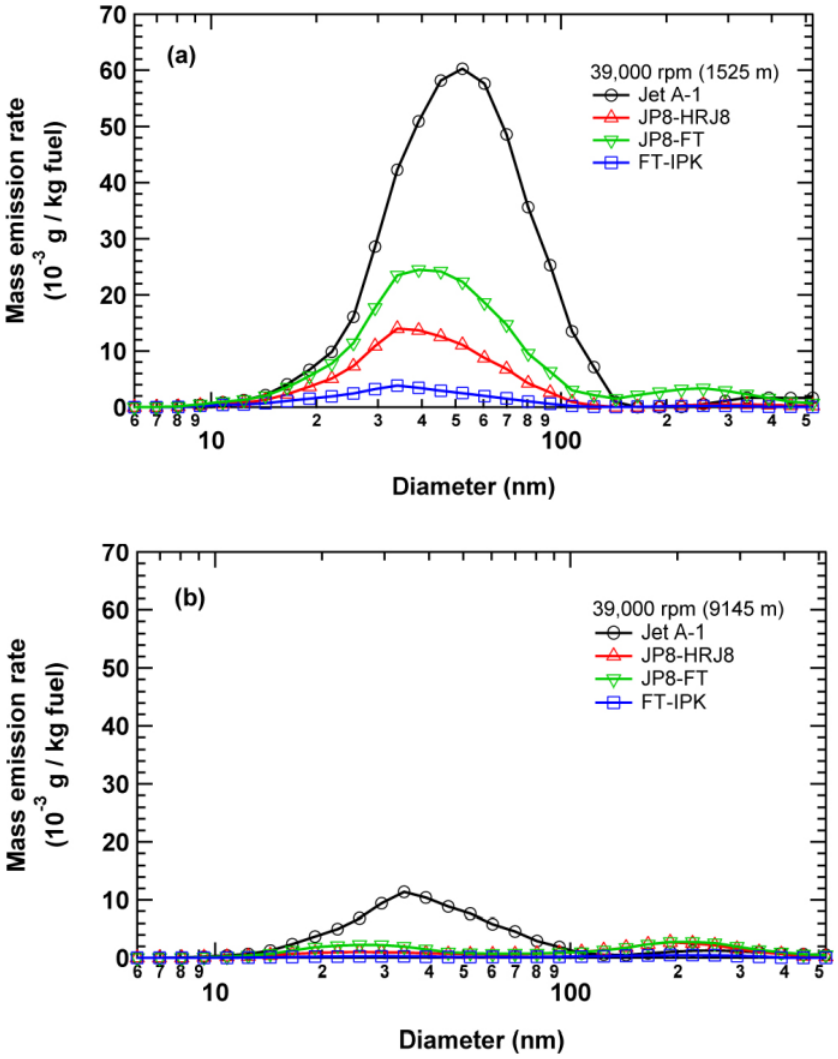


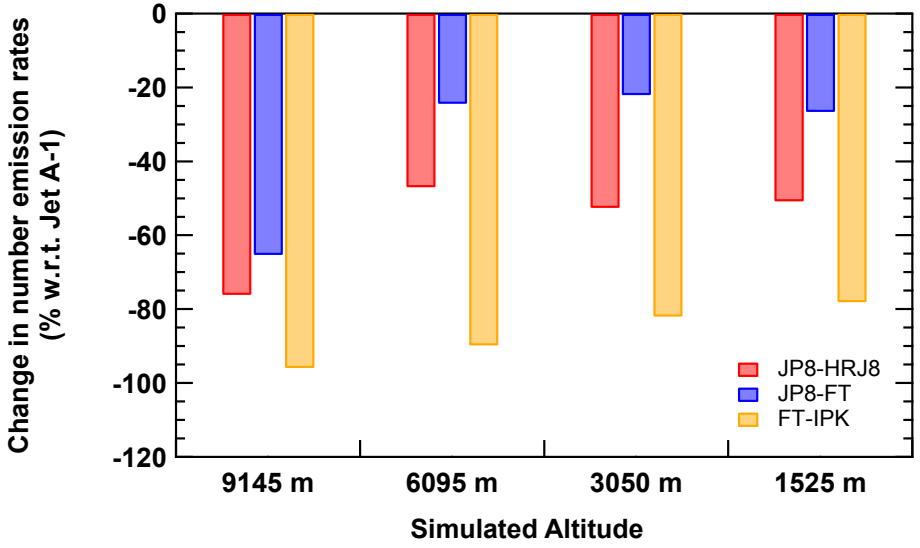
@ 42,000 rpm corrected speed



- Emissions measurement conducted by Environment Canada

Simulated Altitude Tests: Particulate Matter Mass Emissions





@ 39,000 rpm corrected speed

- Emissions measurement conducted by Environment Canada

Sample Results of Interest – In-Flight Operability & Emissions Evaluation

Dassault Falcon 20

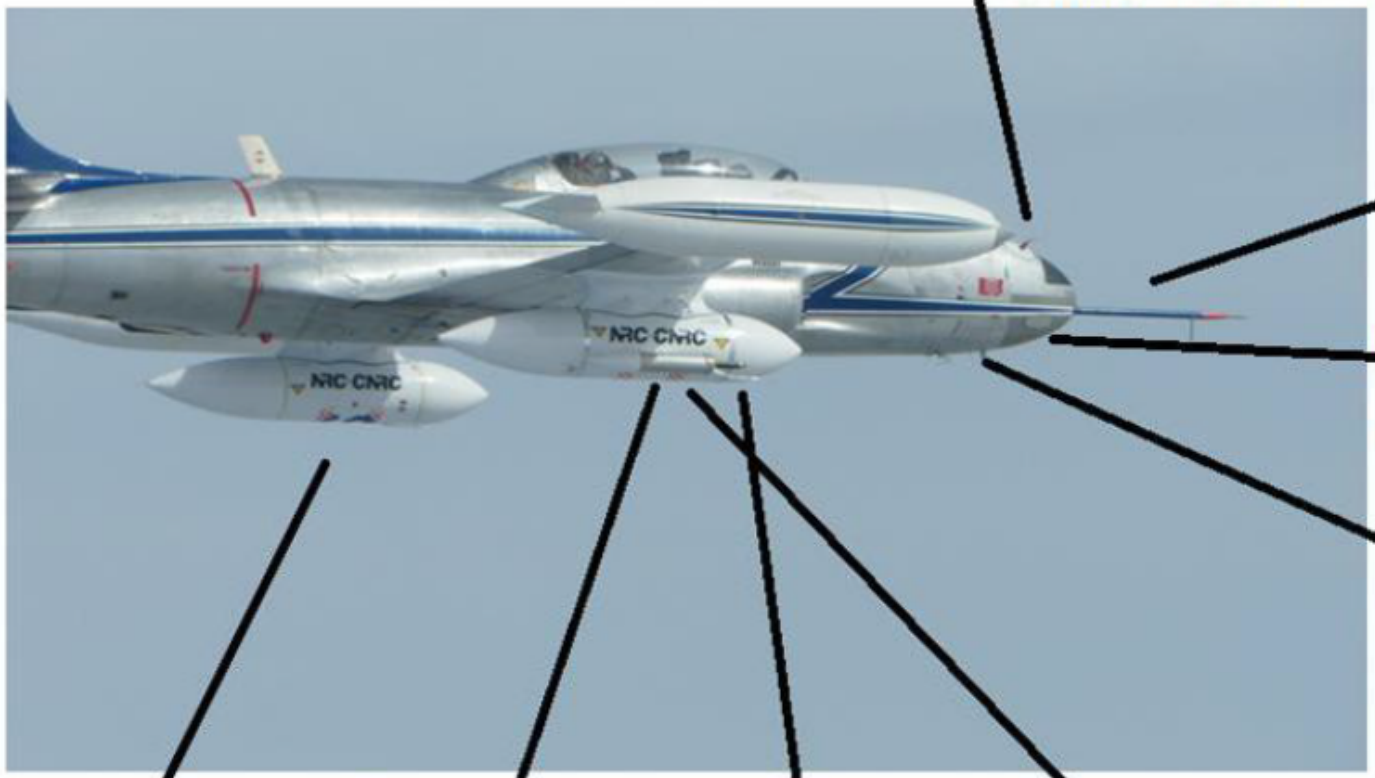
- Twin-engine Business Jet with segregated fuel system for experimental fuel flight operations

Canadair CT-133 (T-33)

- High performance, high G aircraft for emissions research
- In- flight measurements of Black Carbon, NOy, Aerosols (CN), ice/water

NRC aircraft operate under Flight Permits, allowing NRC to modify and operate under experimental configurations

NRC T-33 Emissions Instrumentation



CO2 (LICOR 840A) plus WVap
providing Total Water Content
2 Hz

airdata
600 Hz

NRC Particle
Detector Probe
600 Hz

IMU
600 Hz

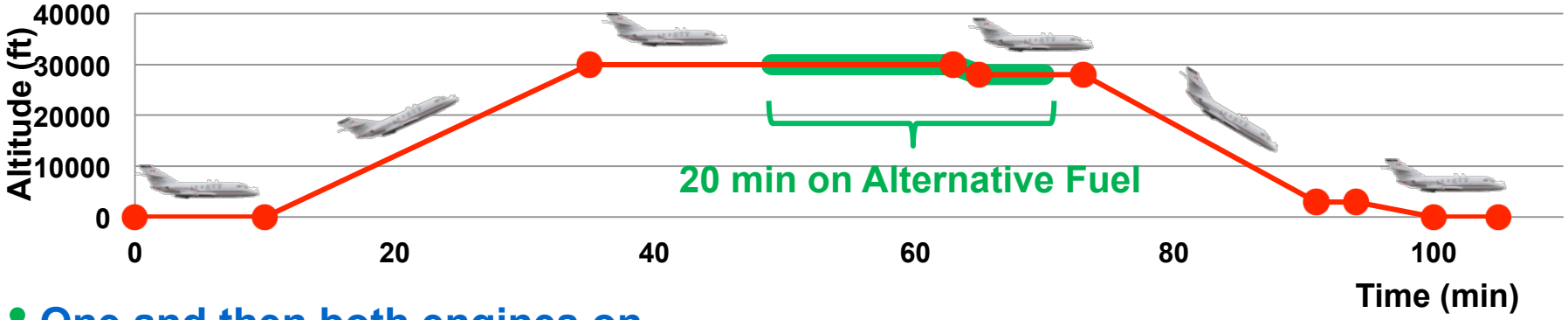
LII200 (operated sub-isokinetic)
20 Hz, but sparse data
(Upgraded to LII300)

FSSP-100
>0.5 μm

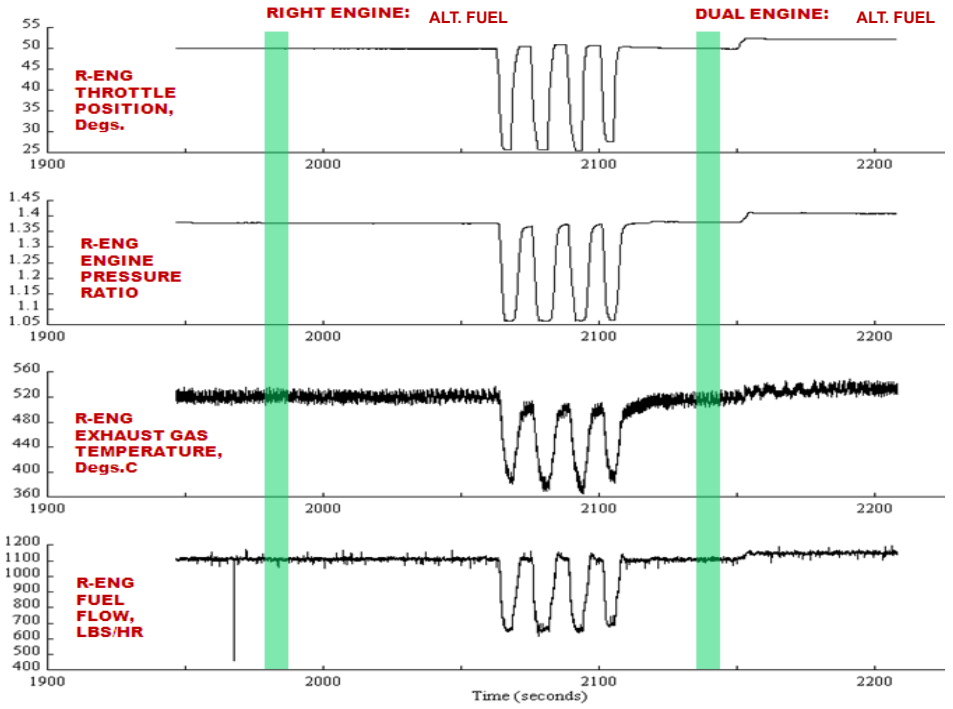
isokinetic inlet for 7610 CNC
> 10 nm

gaseous inlet for NO_y (1 Hz)
and VOC flask system (2 min)

Falcon20 In-Flight Operability Data



- One and then both engines on alternative fuels
- Rapid throttle operations – single engine
- In-flight shutdown & relight – single engine
- In-flight & ground based emissions measurements
- Transparent transition to test fuel
- Comparable engine performance



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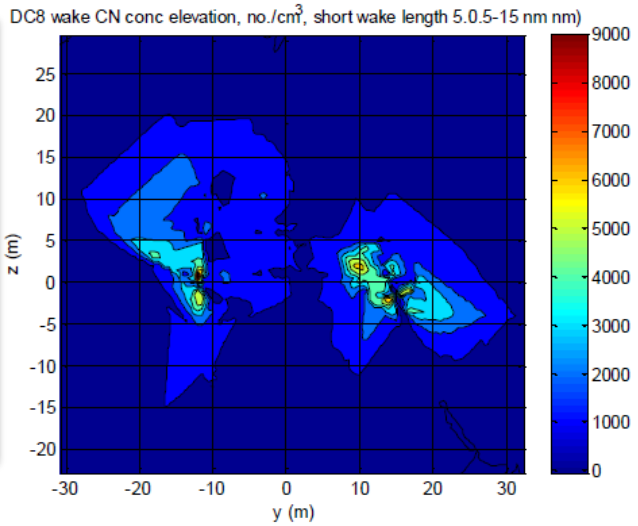
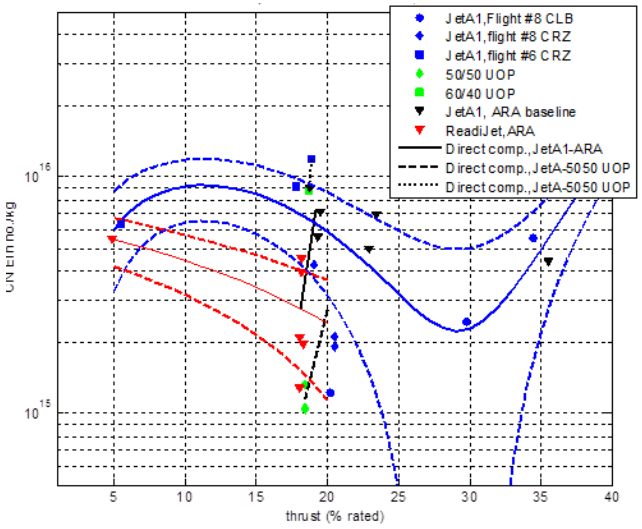
CT-133 Measured Emissions – Airborne Condensation Nuclei

- 9610 CNC Sensor on board
- Measurements @ 30,000 ft cruise
- 25% ~ 60% reduction in CN number when using alternative fuels compared to Jet A1





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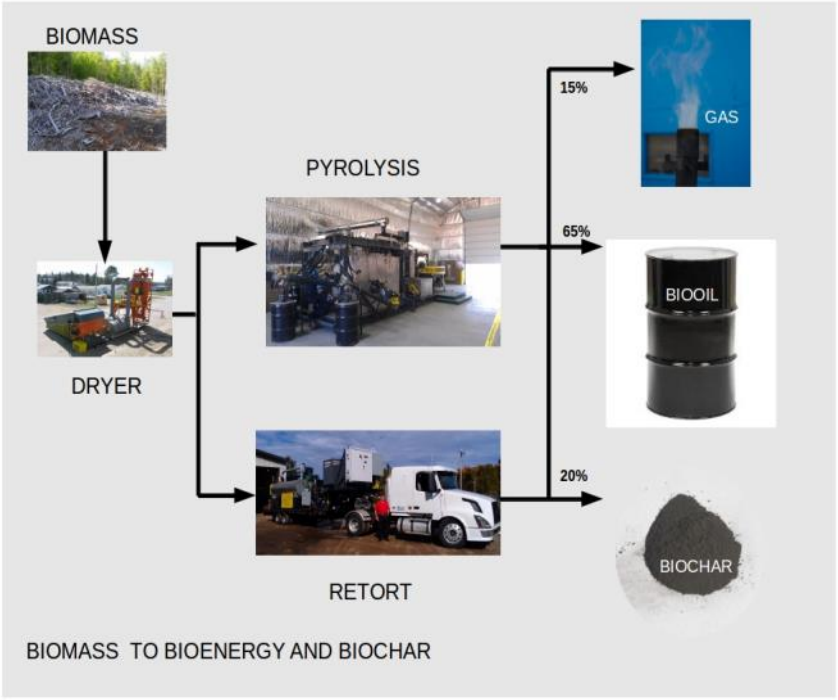
Non-aviation Biofuels

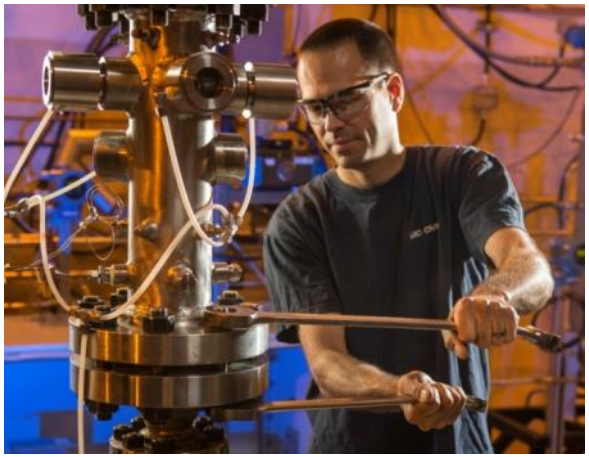
- Working with Canadian bio-oil producers such as pyrolysis oil, bioethanol, etc.
- NRC's effort in the areas of:
  - Characterization of physical and chemical fuel properties
  - Improving the fuel qualities through process change, blending with other fuels
  - Performance evaluation in spray and combustion facility

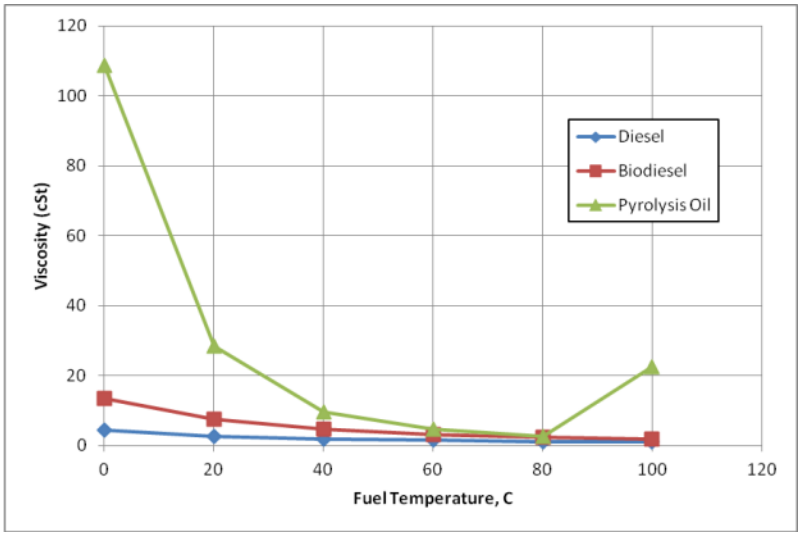


Picture from www.arbitechinc.com

Fuel Properties

- Extremely high viscosity compared other fuels
- Viscosity decreases as fuel temperature rises
- Upper temperature limit exists due to polymerization
- Conduct spray testing and evaluate spray characteristics





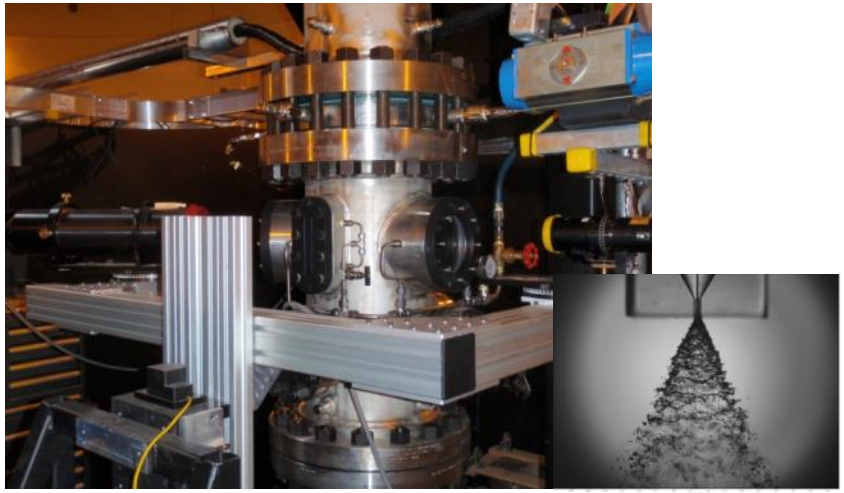
High Pressure Spray Facility

Facility Specification:

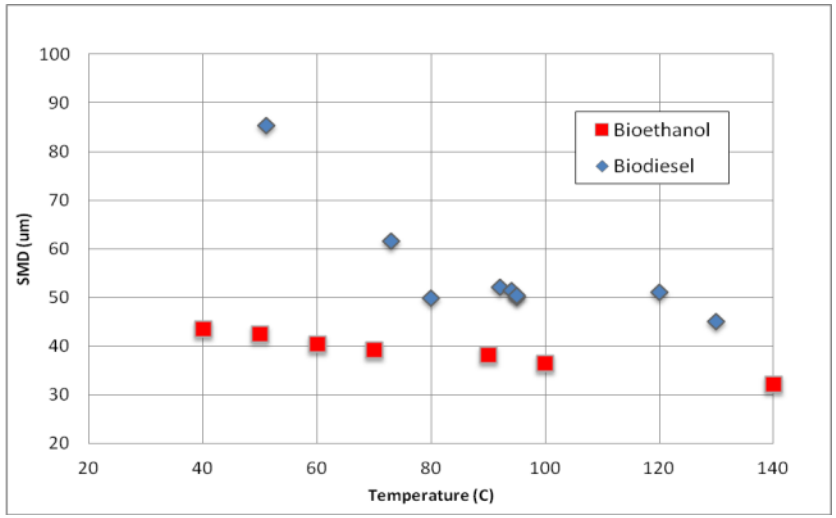
- Spray testing at high pressure conditions
- 4 Ways Optical Accessibility
- Air Box enclosing fuel injector w/t swirler
- Compressed air or nitrogen can be supplied

Measurement:

- Temperature, pressure, mass flow rates
- Laser based diagnostics:
  - Phase Doppler Particle Analyzer (PDPA)
  - Particle Image Velocimetry (PIV)
  - Malvern Laser Diffraction Particle Size Analyzer



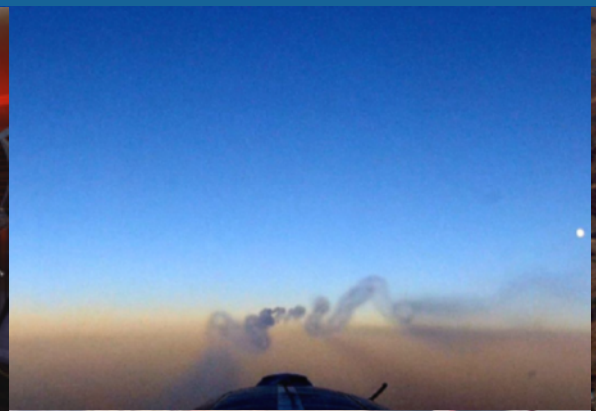
	Press.(psia)	Temp.(K)	Flow Rate (lb/sec)
Air	25 ~ 120	Ambient	0.01 ~ 0.3
Fuel	30 ~ 550	Ambient ~ 600	5 ~150 (lb/hr)



Thank you

Pervez Canteenwalla
Research Officer – Propulsion
Tel: 613-990-0652
pervez.canteenwalla@nrc-cnrc.gc.ca
www.nrc-cnrc.gc.ca

Sean Yun
Research Officer – Combustion and Sprays
Tel: 613-998-1544
sean.yun@nrc-cnrc.gc.ca
www.nrc-cnrc.gc.ca



References

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- McEnally, C.S. et al. “Studies of aromatic hydrocarbon formation mechanisms in flames: Progress towards closing the fuel gap”, Progress in Energy and Combustion Science, 32, pp. 247-294, 2006
- ICAO, “Environmental Report 2013 – Aviation and Climate Change”, http://cfapp.icao.int/Environmental-Report-2013/, 2013

Fuels Evaluated to Date

- Jet A-1 (baseline)
- 50/50 blend of JP8 and Camelina-based Hydroprocessed Renewable Jet (JP8-HEFA)
- Fully synthetic FT-IPK (CTL/GTL)
- 50/50 blend of JP8 and FT-IPK
- 50/50 blend of JP8 and Carinata-based HEFA-SPK
- Fully Synthetic Carinata-based HEFA-SKA (ARA CH-SKA)
- Multiple-ratio blends of catalytic upgraded HDO-SAK (Shell/Virent)