NRC Alternative Fuels Initiative: Past and Current Experiences and Future Plans

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NASA ACCESS-II Data Workshop

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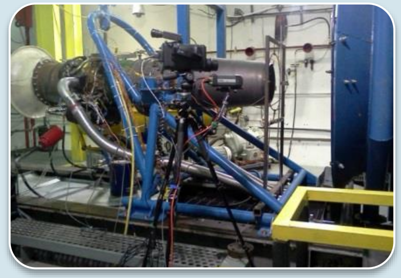
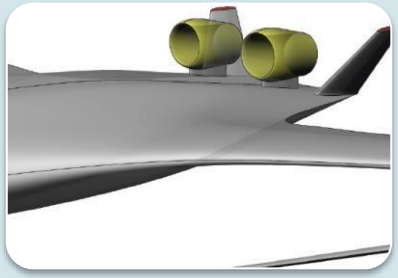
Aeronautics for the 21st Century (Aero21) – NRC's Program on Sustainable Aviation





Manufacturing Efficiency
- Material waste reduction
- Labour intensity reduction
- Cycle time reduction

Fuel Efficiency
- Specific fuel consumption reduction
- Drag reduction
- Aircraft weight reduction

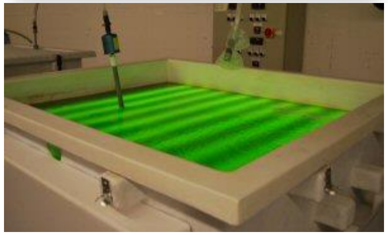
Emissions Control
- Noise reduction
- Air pollution reduction
- **Alt. fuels integration**

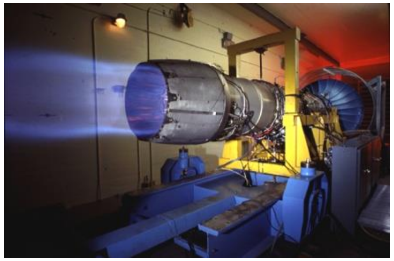
Emerging Concepts
- New aircraft configurations
- Alternative propulsion & power

Demonstration and qualification on major platforms

Bringing together NRC and Canada wide Competencies in Aviation Biofuels

- 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
- Bio-Fuels' Performance Testing
  - Engine qualification testing
  - Components and fuel system modification
  - Material and coating compatibility assessment
  - Emissions assessments





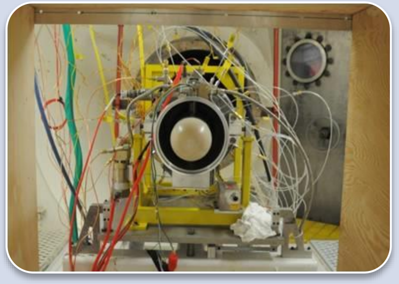
Past and Current Initiatives: Engine Qualification & Emissions Characterization

GE F404:

- Fleet qualification for RCAF F18 aircraft
- Performance, durability & emissions testing
- Semi-synthetic FT fuel

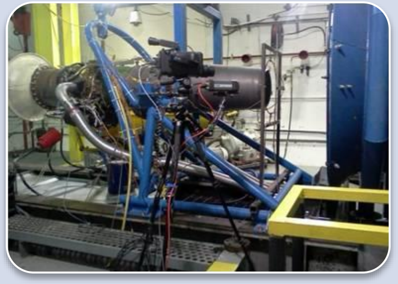
RR-Allison T56:

- 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:

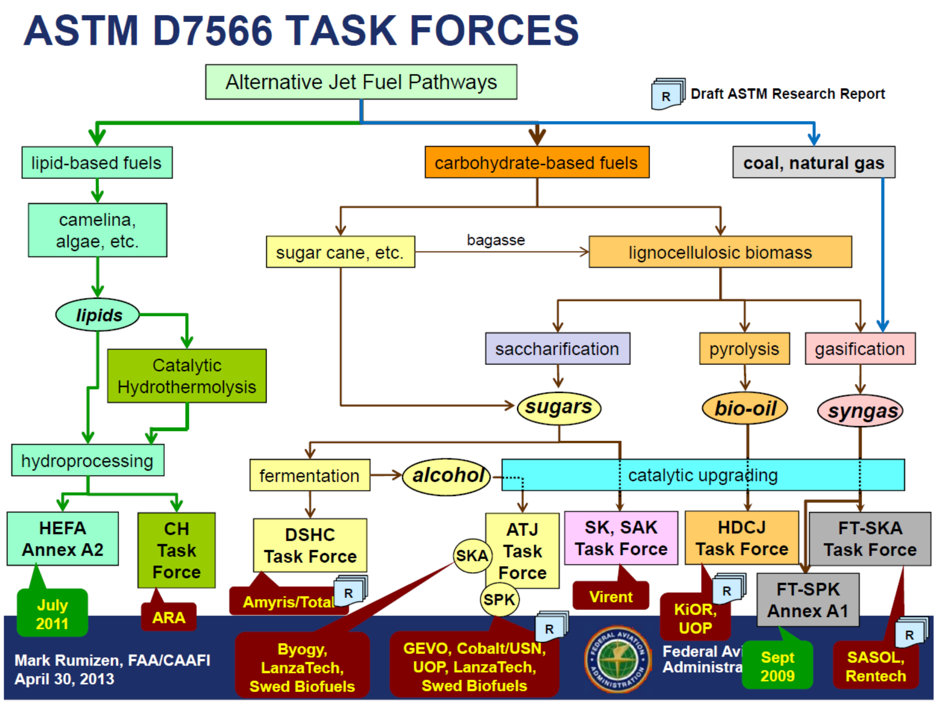
- 50-50 Camelina-based HEFA (UOP)
- 50-50 Carinata-based HEFA (UOP)
- 60-40 Carinata-based HEFA (UOP)
- 100% Carinata-based HEFA (ARA CH-SKA)

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

Fuels Evaluated to Date

- Jet A-1 (baseline)
- 50/50 blend of JP8 and Camelina-based Hydroprocessed Renewable Jet (JP8-HRJ8)
- 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

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Future Initiatives & Plans – NJFCP

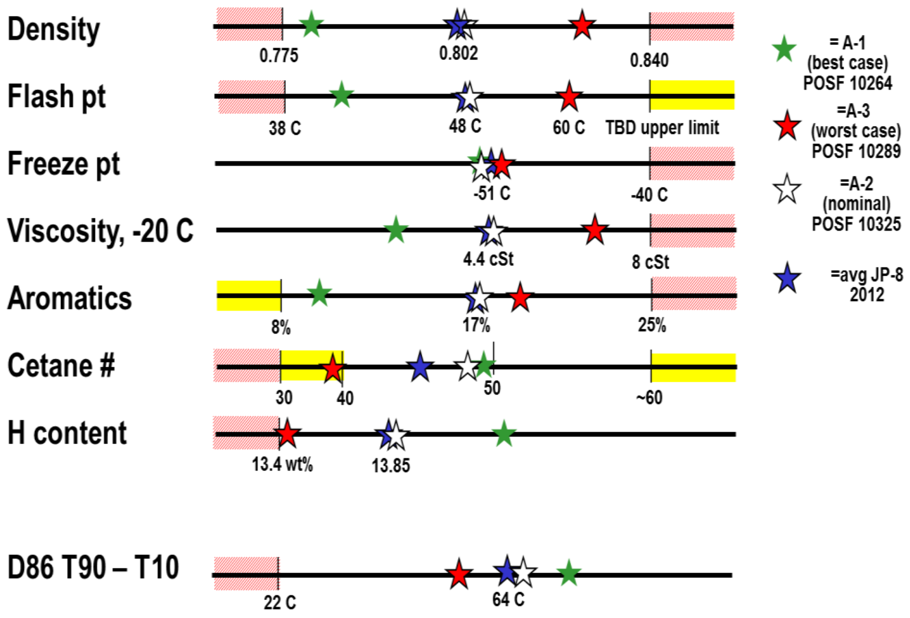
- NJFCP – FAA's National Jet Fuels Combustion Program
- Expedite and accelerate current ASTM approval process
- Reduces cost of qualification testing
- Reduce fuel quantities required for approval
- Reduce technical risks for engine OEMs
- Additional benefits:
  - Broader fuel specification leading to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

NRC's Role & Support for NJFCP

Work Packages
Atomization & Sprays
WP1 – Heated fuels (450 ºF)
WP2 – Chilled fuels (-40 ºF)
Combustion and Emissions
WP3 – Low pressure; Heated fuels (450 ºF)
WP4 – Low pressure; Chilled fuels (-40 ºF)
WP5 – High pressure (20 bar); Heated fuels (450 ºF)
High Altitude Relights
WP6 – Engine performance; up to 15km altitude conditions
WP7 – Combustor rig relights and LBO up to 15km altitude conditions

Fuels to be Evaluated for NJFCP

- Category A fuels derived from petroleum
- Category C fuels developed to explore relevant fringes of composition space
  - Highly branched iso-paraffins only (e.g. Gevo's ATJ)
  - Single component fuels (e.g. Amyris' DSHC/SIP)
  - Predominantly single-ring cyclo-paraffins (e.g. Virent's HDO SK)



Honeywell Rolls-Royce Williams International ASCENT AVIATION SUSTAINABILITY CENTER

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Other Initiatives and Support – SAFE

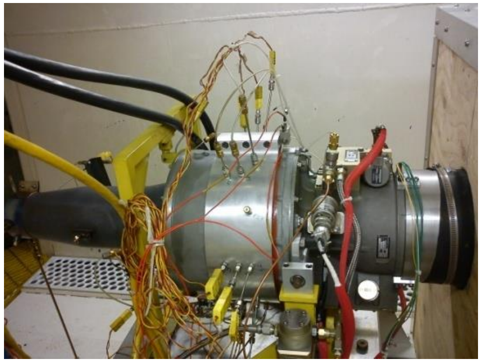
- **SAFE – Sustainable Alternative Fuels Evaluation**
- **Public Partnership: Sponsored by TC, EC, DND and NRC; Additional voluntary engagement from Canadian AAFC, industry and academia**
- **Activity: Broad range of activities targeted at research, development, demonstration and deployment of alternative jet fuel , including development of the entire supply chain**
- **Goals: Facilitate and promote introduction and commercialization of sustainable alternative fuels without bias with respect to feedstock and conversion methodology. Special emphasis on emissions evaluation and reduction**
- **NRC's Role: Co-funding; Conducting research and testing; Coordinating activities**

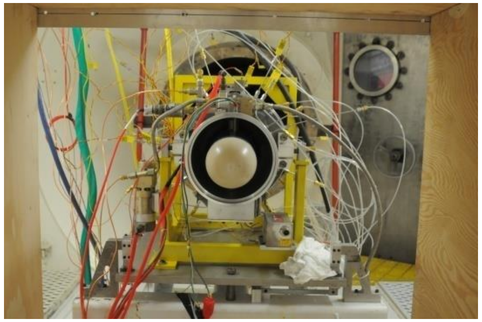
Other Initiatives and Support – BioFuel Net

- **BioFuel Net – Network of Centers of Excellence**
- **Public-Private Funded: Sponsored by Natural Sciences & Engineering Research Council of Canada; co-funded by OGD and industry**
- **Activity: Academic research in the areas of feedstock, conversion, utilization and techno-socio-economics of advanced biofuels for transportation and energy**
- **Goals: Support the growth of Canada's advanced biofuels industry through coordinated research, innovation, effective education, smart policy and strategic partnerships**
- **NRC's Role: Co-funding; Conducting research and testing; Providing guidance on aviation renewable fuels research**

Sample Results of Interest – Simulated Altitude Tests

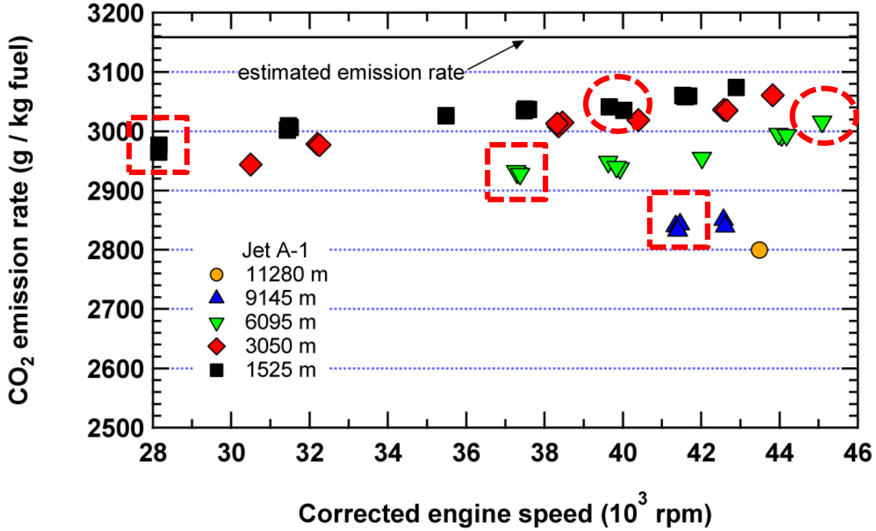
- 1000 N thrust turbojet engine
- Tests conducted at NRC's Research Altitude Test Facility
  - 10 m long x 3 m internal diameter
  - Simulate altitudes up to 12 km
  - Maximum air flow rate of 4.5 kg/s
  - Independent control of pressure and temperature altitudes
- Engine instrumented to gather P and T at all engine stations

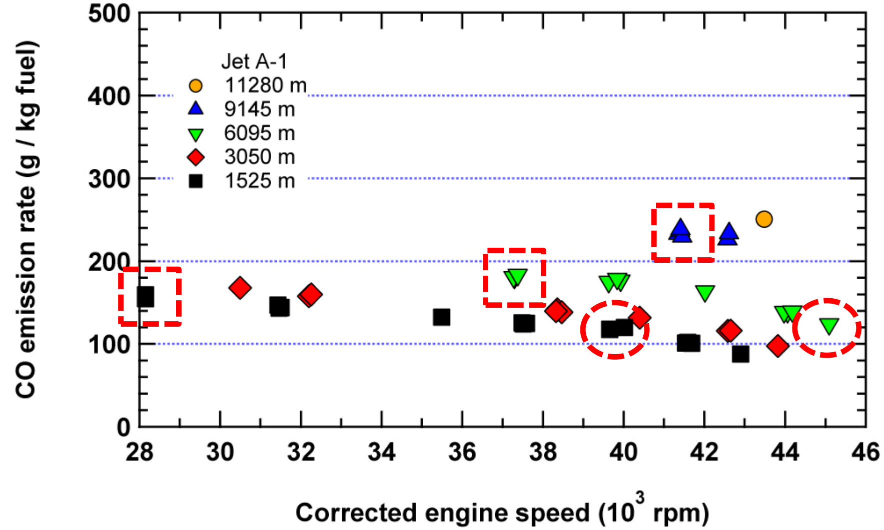




Nominal Altitude [m]	Nominal Uncorrected Engine Speed [RPM]						
	Idle	31,000	35,000	37,000	39,000	41,000	Max. EGT Limited
1525							
3050							
6095							
9145							
11280							

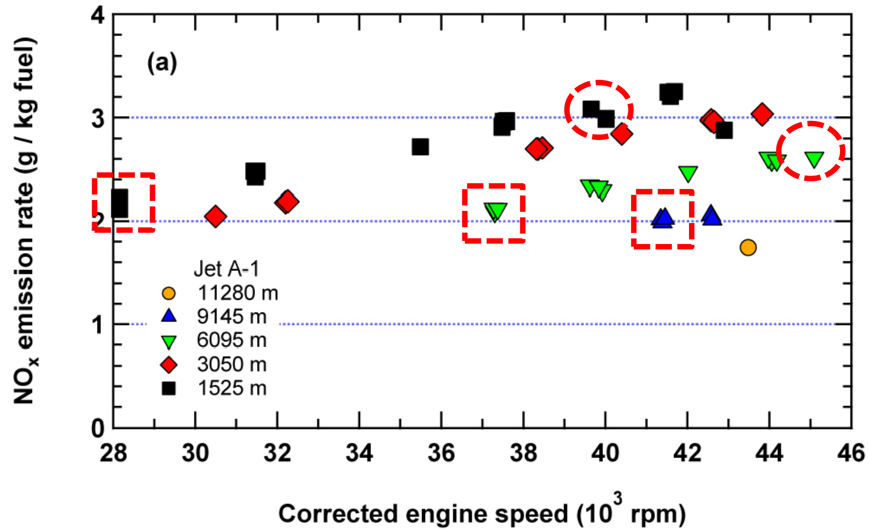
Simulated Altitude Tests: Gaseous Emissions – Altitude Effects



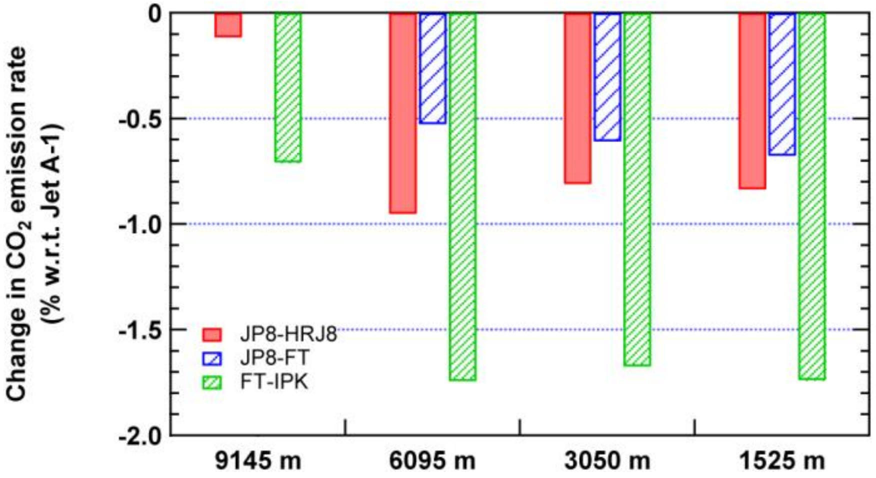


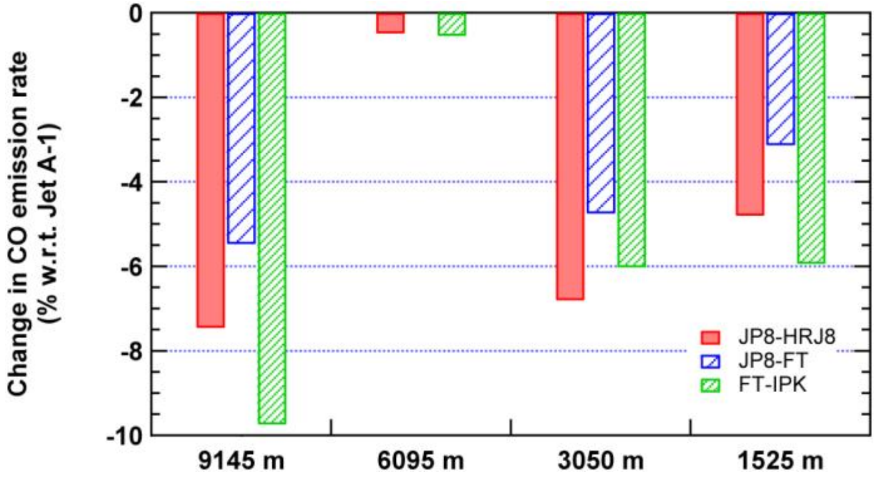
Idle engine load

Cruise engine load

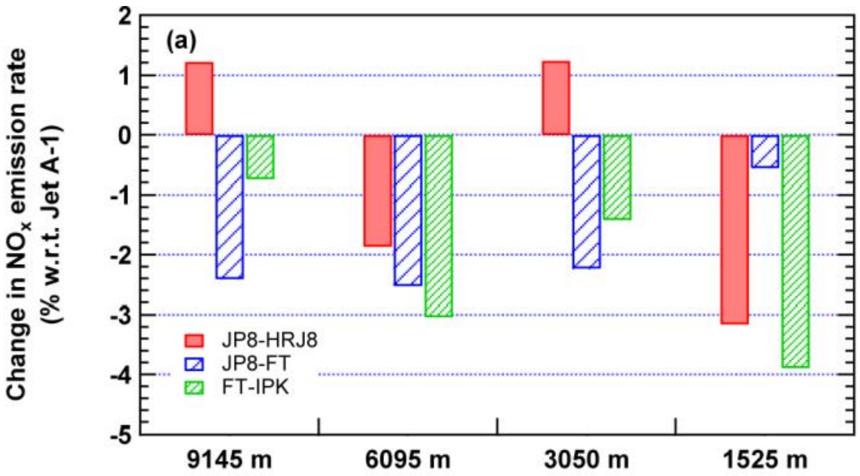


Simulated Altitude Tests: Gaseous Emissions – Fuel Effects

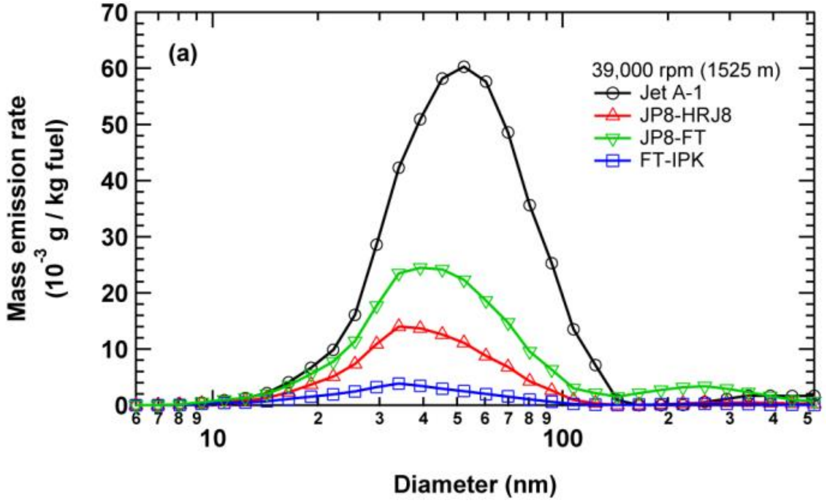


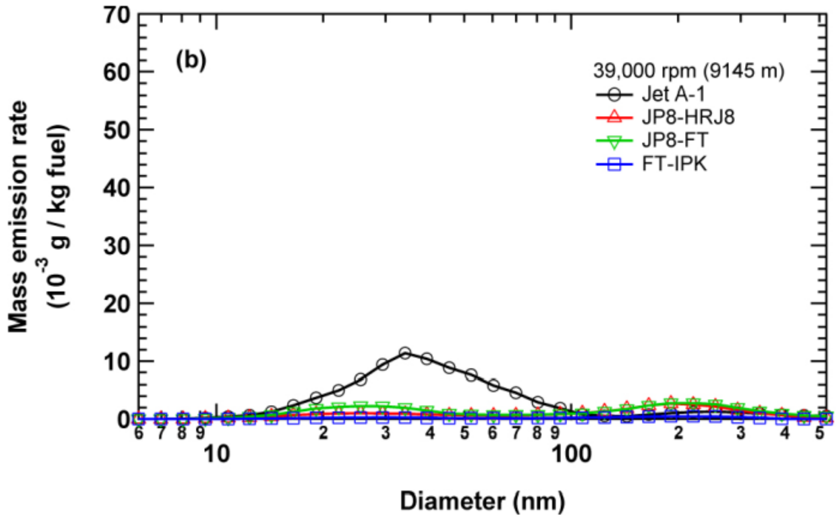


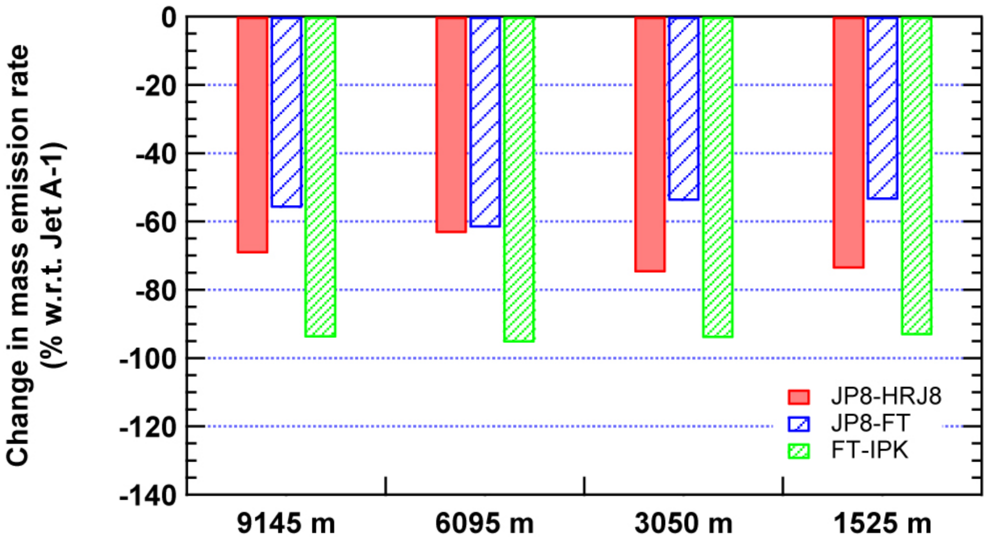
@ 42,000 rpm corrected speed



Simulated Altitude Tests: Particulate Matter Mass Emissions







@ 39,000 rpm corrected speed

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

<u>Dassault Falcon 20</u>

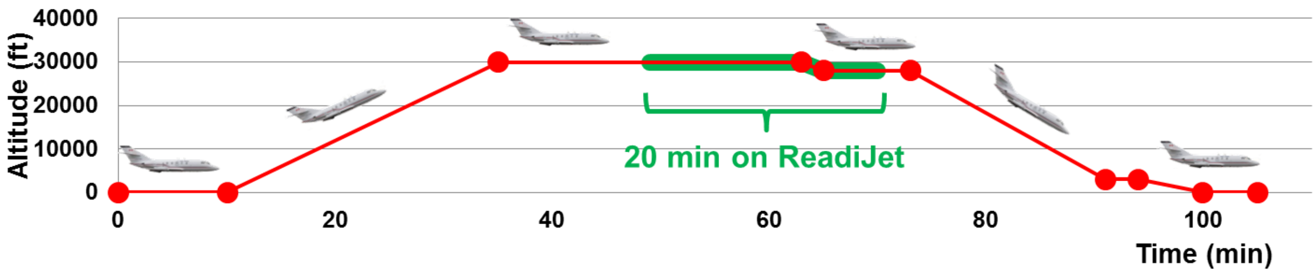
- Twin engine Business Jet with segregated fuel system for experimental fuel flight operations

<u>Canadair CT-133 (T-33)</u>

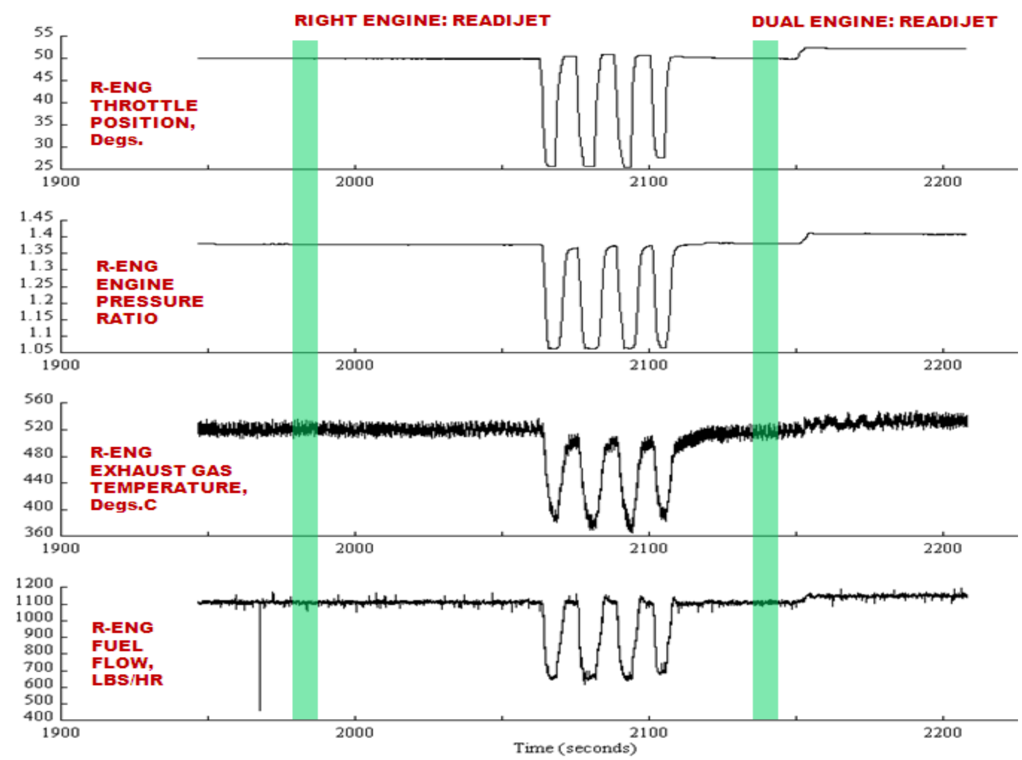
- High performance, high G aircraft for emissions research
- In- flight measurements of Black Carbon, NOy, Aerosols (CN)

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

Falcon20 In-Flight Operability Data

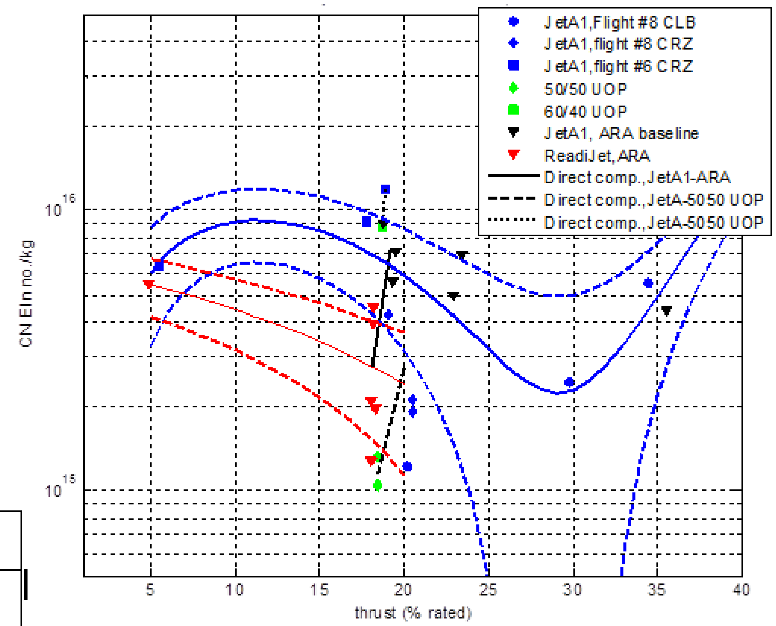


- One and then both engines on alternative fuels
- Rapid throttle operations – single engine
- In-flight shutdown & relight – single engine
- In-flight & ground based emissions measurements
- Transparent transition to test fuel
- Comparable engine performance



CT-133 Measured Emissions – Airborne Condensation Nuclei

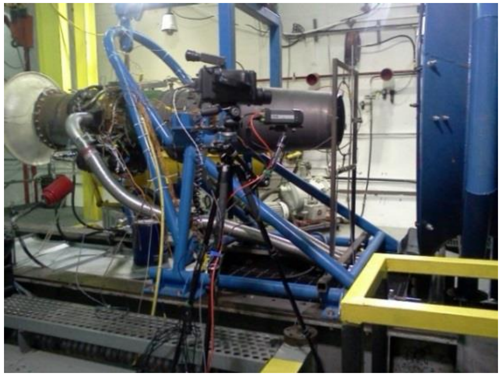
- 9610 CNC Sensor on board
- Measurements @ 30,000 ft cruise

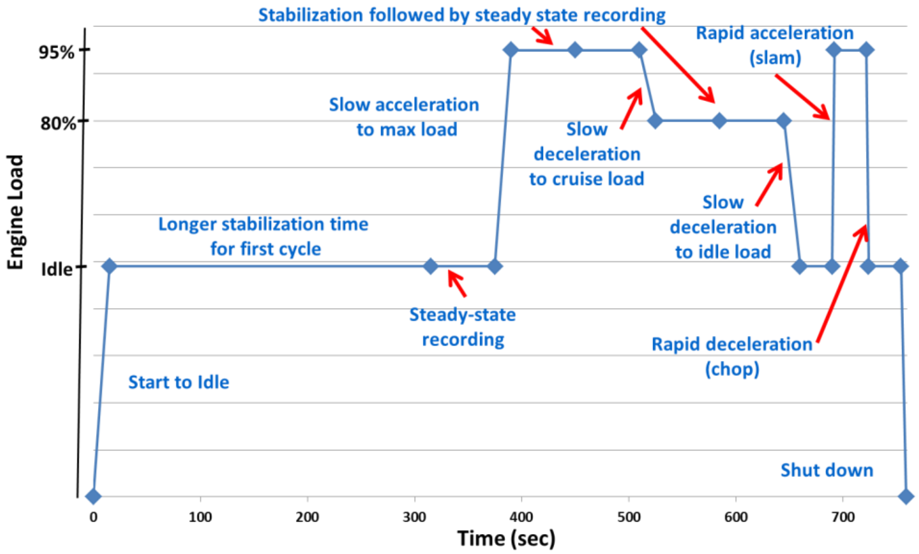


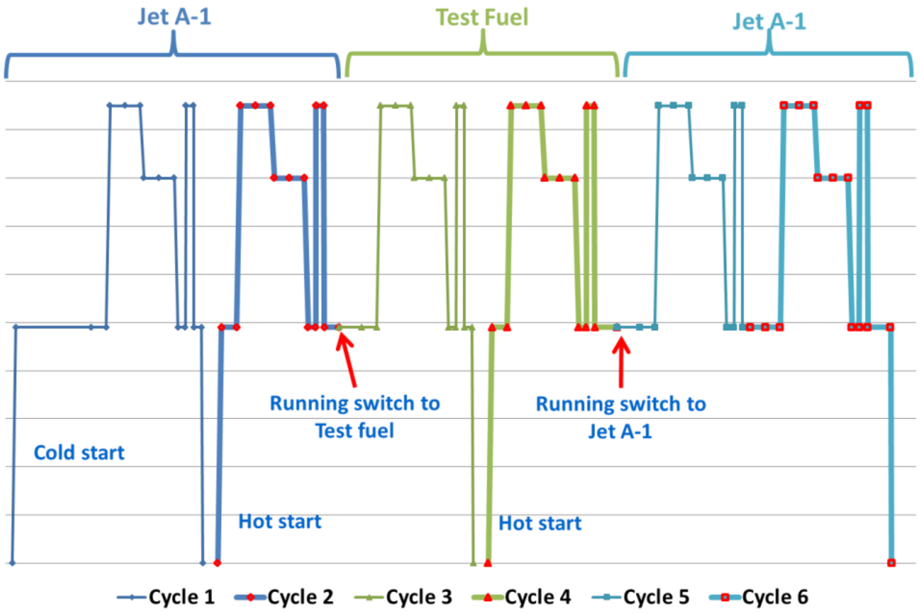
Fuel	CN EIn JetA1 baseline linear regression with %thrust		CN EIn, various comparisons			
			Comparison with JetA1 baseline regression		Direct comparison, back-to-back points, JetA1-to-biofuel	
	Mean, at 30,000 feet (g/kg)	Overall σ about the regression line, (#/kg)	Mean difference (#/kg) (% of JetA1 at 30,000ft)	σ (#/kg) (% of JetA1 at 30,000ft)	Mean difference (#/kg) (% of JetA1 at 30,000ft)	σ (#/kg) (% of JetA1 at 30,000ft)
JetA1	$6.60\,10^{15}$	$2.74\,10^{15}$				
UOP blends (single point), 60/40 & 50/50			$-3.20\,10^{15}$ (-51.4%)	$3.80\,10^{15}$ (60.9%)	$-2.04\,10^{15}$ (-27.6%)	$0.85\,10^{15}$ (11.5%)
ARA ReadiJet, 100%, @ 18% rated thrust			$-3.30\,10^{15}$ (-61.0%)	$1.39\,10^{15}$ (22.2%)	$-4.48\,10^{15}$ (-61.7%)	$1.40\,10^{15}$ (19.3%)

25% ~ 60% reduction in CN number when using biofuels compared to Jet A1

Sample Results of Interest – Sea Level Static Engine Testing







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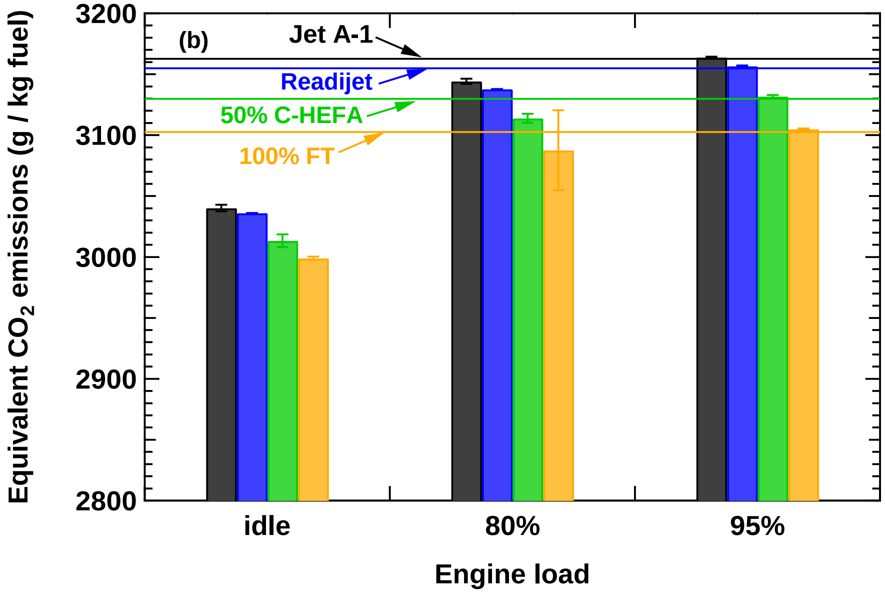
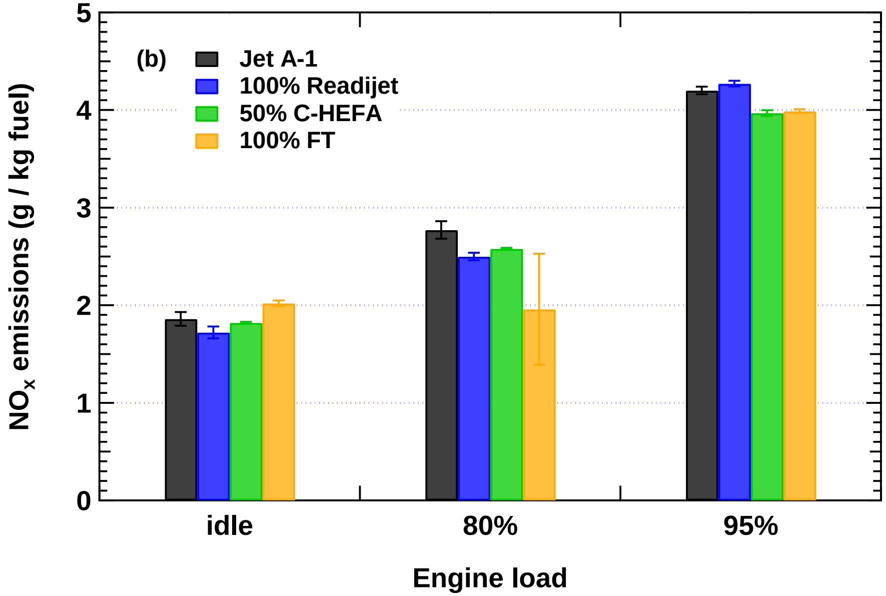
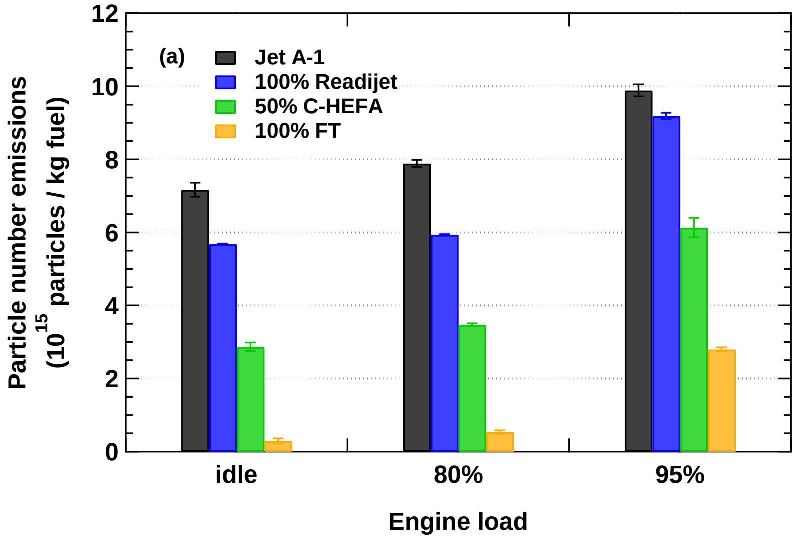
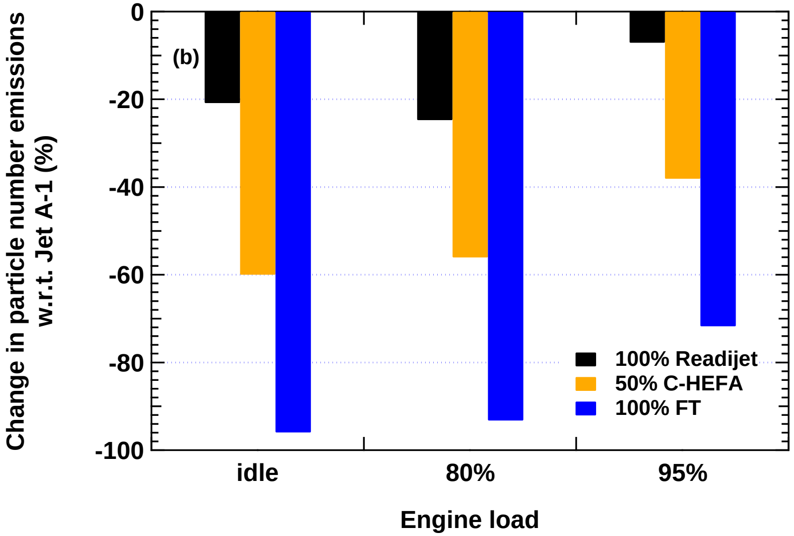
Static Engine Testing – Gaseous Emissions

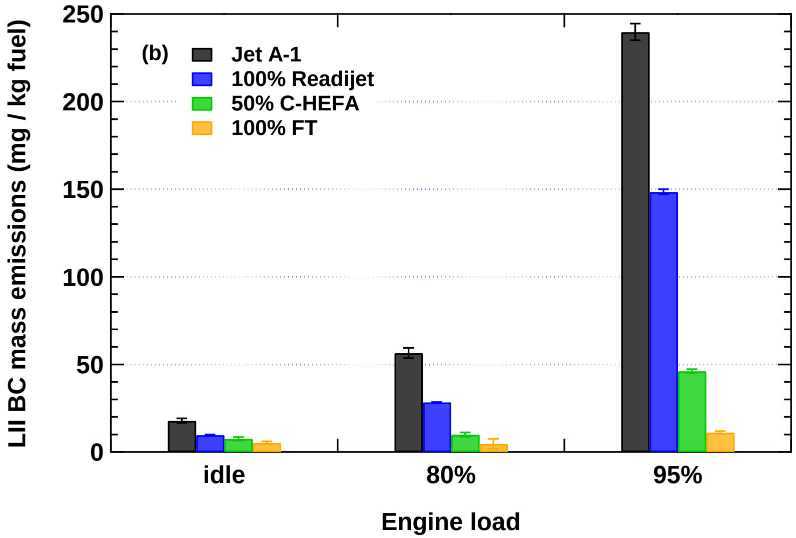


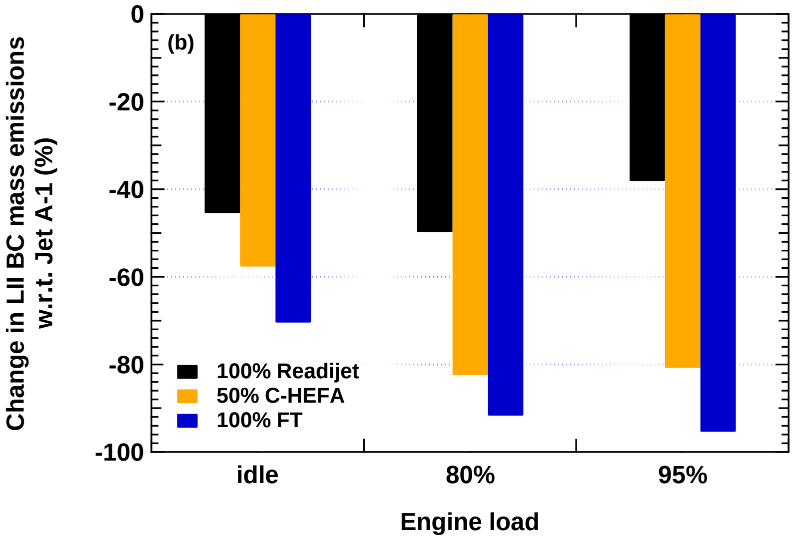


Static Engine Testing – Particulate Matter Emissions









Thank You

For more information on the presented material, please contact:

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