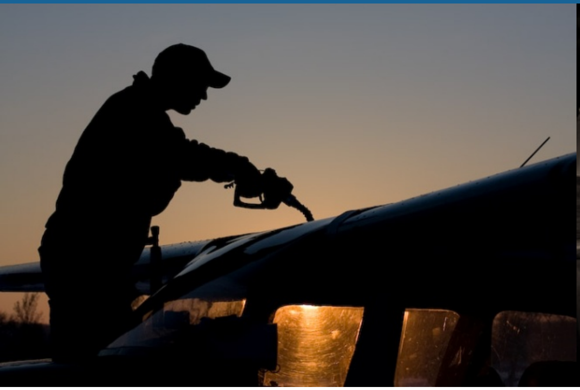
NRC·CNRC

Transition to Unleaded Fuels for General Aviation

Pervez Canteenwalla, Malcolm Imray, Peter Earle, and Wajid Chishty
NRC Aerospace

UTIAS National Colloquium on Sustainable Aviation
June 21-23, 2017

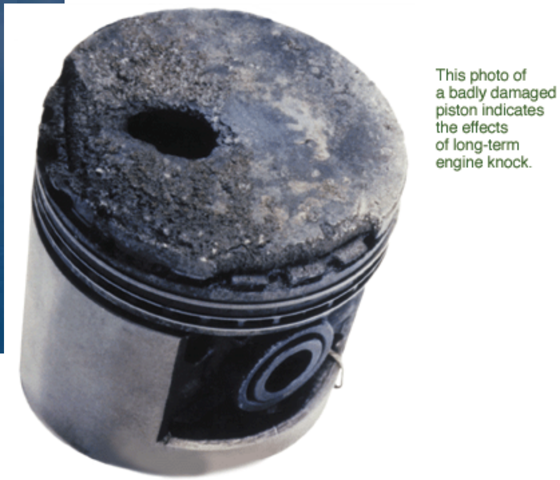


National Research Council Canada   Conseil national de recherches Canada

Canada

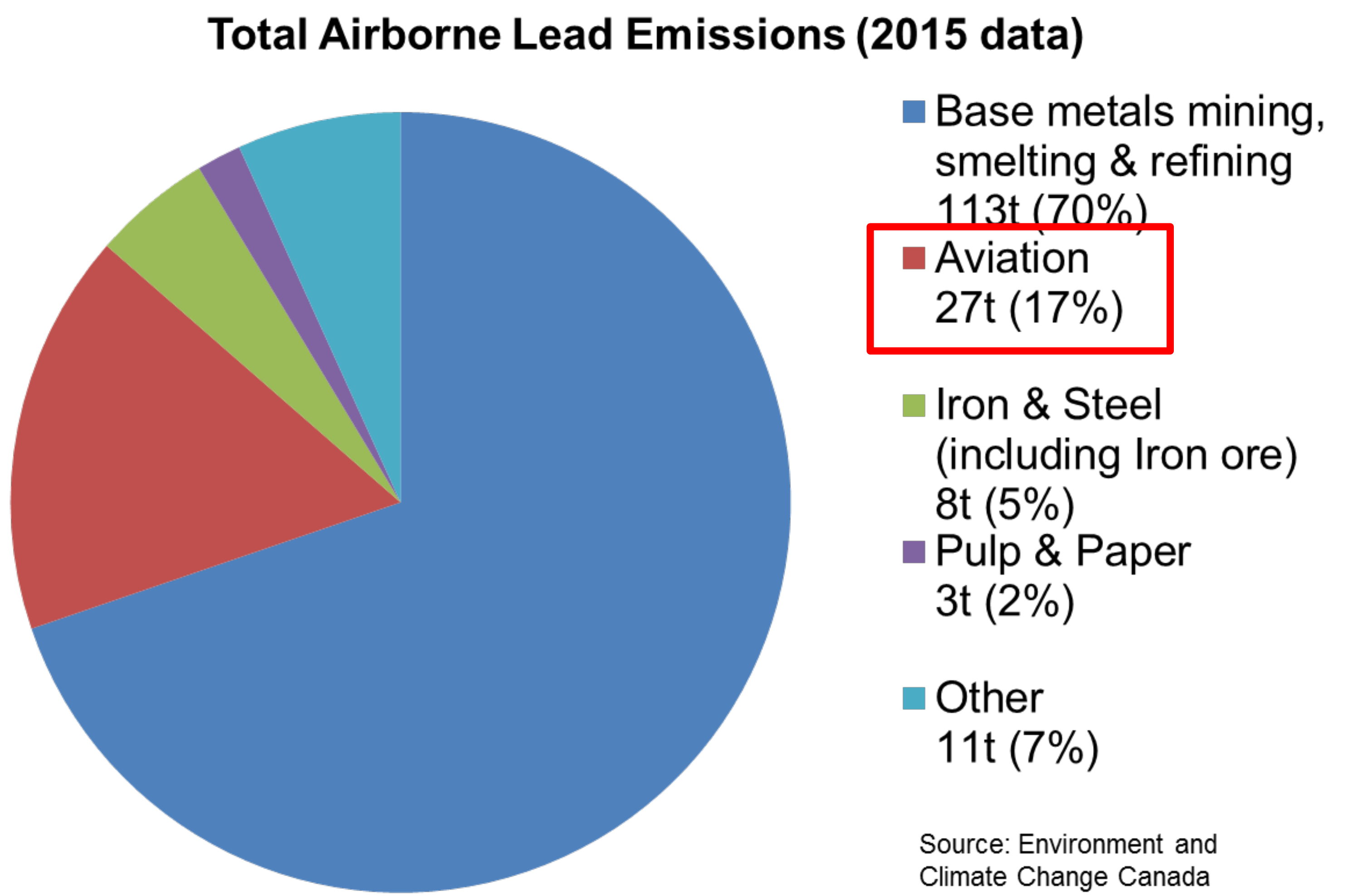
Current AVGAS Situation

- Majority of aviation piston engines use leaded fuel known as 100 low-lead (100LL) aviation gasoline (AVGAS)
- 100LL AVGAS uses tetraethyl lead (TEL) to boost octane and prevent detonation (knock) in high performance piston aero engines;
- 100LL AVGAS is the <u>*only*</u> leaded fuel still mass produced; second leading contributor in Canada to airborne lead in the environment



Source: https://str.llnl.gov/str/Westbrook.html

Airborne Lead Emissions in Canada



The Canadian Civil Aviation Fleet

(Transport Canada Preliminary study: based on CAWIS as of June, 2015 ; hours flown 2013)

Powerplant type	Total Civil Fleet		Commercial Fleet *	
	# of a/c	Hrs Flown	# of a/c	Hrs Flown
Turbine	5106	3,010,840	3820	2,844,343
Piston	30103	***1,058,671***	3120	***602,344***
Total	35209	4,069,511	6940	3,446,687
% Piston	85	***26***	45	***18***

- ***Canadian Piston fleet of 30,000+ aircraft accounts for over 1 million flight hours per year or 26% of total hours flown***
- ***Piston aircraft account for nearly half the commercial fleet and fly nearly 20% of the total hours***

* Commercial fleet excludes Private and State registered aircraft

"Get the lead out" – the push for Unleaded Avgas

- Aviation has an ongoing exemption, for safety reasons, to continue to use 100LL until a suitable replacement is found (same in US).
- Health Canada (HC) and Environment and Climate Change Canada (ECCC) mandate: reduce lead usage to absolute minimum levels consistent with safety
  - *"aviation fuels were identified as high priorities for action"*
- FAA and US industry have established a **Piston Aviation Fuels Initiative** (PAFI) to develop and qualify a new unleaded aviation gasoline
- Transport Canada seeks harmonized approach to fuel qualification and aircraft/engine certification with FAA / EASA

Environment and Climate Change Canada
www.ec.gc.ca

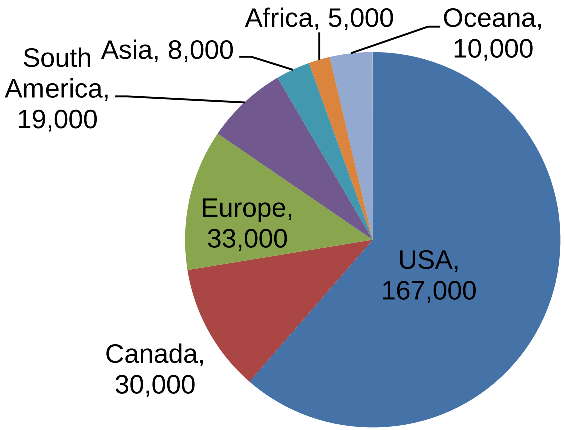
Health Canada
www.hc-sc.gc.ca

US EPA endangerment finding expected some time after 2018; this may make production and use of 100LL illegal

Canadian Problem

World leading contributor to aviation lead emissions

- Canada operates ~15% of the world fleet of piston powered aircraft



Unique Canadian Requirement

- Many small and/or northern communities lack alternative transportation

Safety

- Canadian environment is uniquely hostile – safety concerns regarding alternate fuels

Market Dynamics

- Fuel producers will discontinue leaded avgas (100LL) after US finds and certifies replacements
- No guarantees that US process will provide a fuel that meets Canadian needs

NRC·CNRC

A New Unleaded Avgas – Challenges

- 94 octane gasoline (ethanol-free) + TEL = 100LL
- To date, no suitable replacement "additive" has been found
  - New fuels are completely new chemical formulations
- Now it becomes a balancing act:

- **Octane**

- **Net heat of combustion**
- **Vapor pressure**
- **Freeze point**
- **Viscosity**
- **Material compatibility**
- **Lubricity**
- **etc…**

All fit-for-purpose properties should be met

How to switch to a new fuel?

- Aircraft Flight Manual (AFM) states which fuels the aircraft is approved to use
  - o *Fuel must meet ASTM fuel specifications listed in the AFM*
  - o *Illegal to operate aircraft outside of the specified limitations*
- To change the fuel, you need to conduct testing to make sure the aircraft won't be affected (e.g. engine performance, range, take-off distance, weight and balance, etc.)
- Thousands of different engine / aircraft types
  - o Prohibitively expensive and time consuming to try to test new fuel on each of these.
- USA & Canada taking a different approach through PAFI

Piston Aviation Fuel Initiative (PAFI)

- Test program to qualify fuels with subset of engine/aircraft that are representative of the fleet
- Goal is for fleet-wide approval
- Need to test many things:
  - Physical fuel properties
  - Material compatibility (hoses, seals, bladders, paint, pumps etc.)
  - Storage stability
  - Fuel system effects
  - Carburetor icing
  - Engine / Aircraft Testing ← Canada supporting this

Piston Engine & Aircraft Categories

Type: Fixed Wing
Rotary Wing

Engines: 1 – 6

Cylinders: 1 – 36 cylinders
Low – high compression

Induction: Naturally aspirated
Turbocharged
Supercharged
Intercooled

Fuel System: Carburetor
Fuel Injected
Low wing (fuel boost pump)
High wing (fuel gravity fed)

Cylinder cooling: Air-cooled
Liquid-cooled

Configuration: In-line
Radial
Horizontally opposed

PAFI testing 15 different engine and 11 different aircraft types
"Representative of the current fleet"



Alternative Fuels to 100LL Project

- Government of Canada Clean Air Agenda:

  "*…find ways to reduce airborne pollutants as a result of air transportation*" (NRC, TC, ECCC, HC are all signatories to this policy)

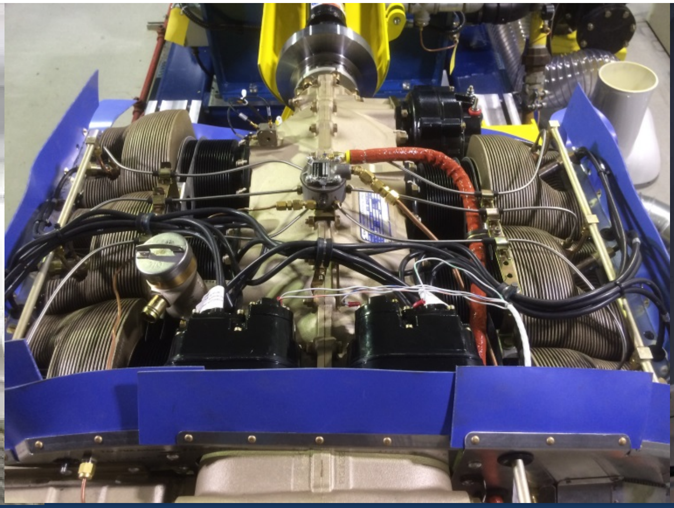
- Joint funded project between Transport Canada (TC), Environment Climate Change Canada (ECCC), Canadian Owners and Pilots Association (COPA), and NRC

- Project objective is to develop aircraft piston engine test beds (ground and flight) to gather experimental data to assist in qualifying 100LL avgas replacement fuels

- Coordinate with FAA and PAFI

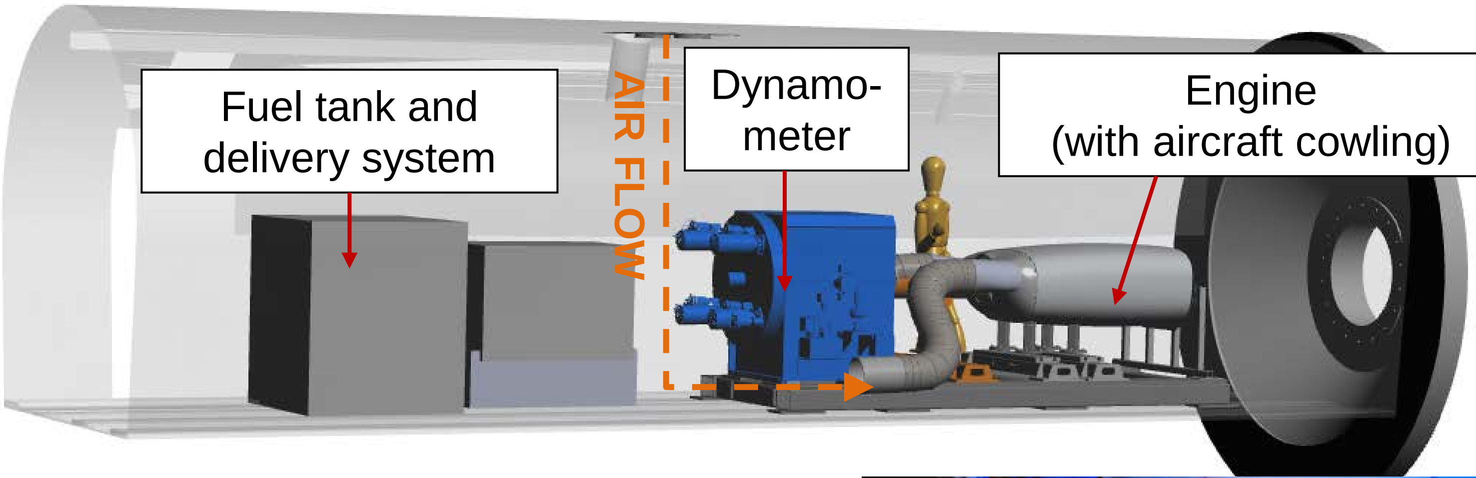
Static Engine Test Rig

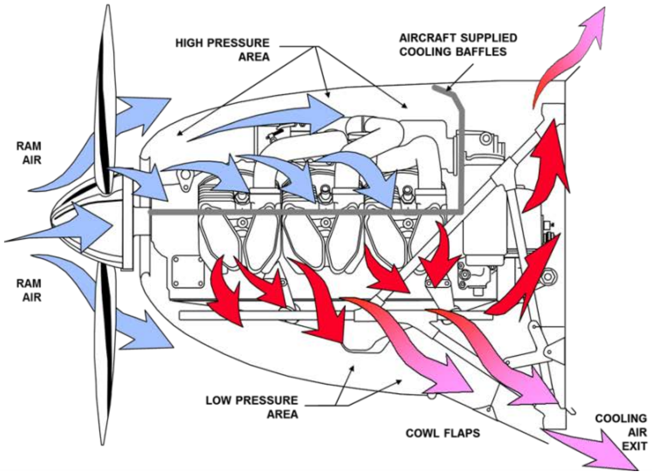
- Develop Testbed for Aviation Piston Engine Research (TAPER)
- Use TAPER in NRC's Research Altitude Test Facility
- Test experimental alternative fuels to 100LL in controlled simulated altitude environment.
    - Engine performance (power, knock, etc.)
    - Engine operability (cold starts, altitude relights, transients, etc.)
    - Engine emissions (gaseous and particulates)
    - Test throughout flight envelope (0 – 30,000 ft.; cold/standard/hot days)
    - Heavily instrumented engine



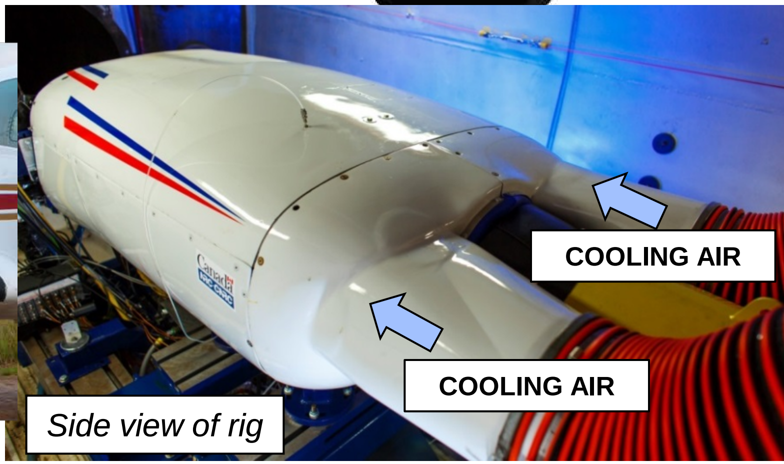
TAPER in NRC Altitude Chamber

- Altitude chamber provides conditioned air (pressure, temperature, and humidity) to simulate altitudes up to 52,000 ft.





Cessna 402C Engine



Side view of rig

Test Engine

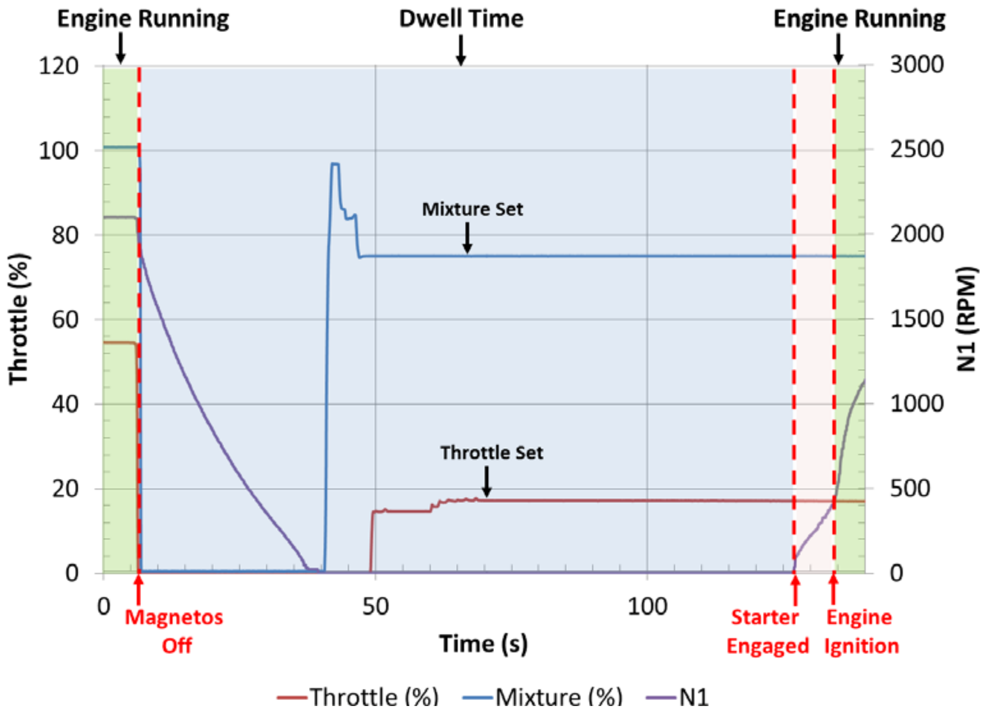
- Continental TSIO-520VB Engine
- Representative of engines used on many GA aircraft
- Six Air-cooled cylinders
- Fuel injection, turbocharged (no intercooler)

One of the “worst-case” engines for detonation at altitude

Maximum Rated Power	325 HP (242 kW)
Maximum Rated Speed	2700 RPM
Maximum Rated Manifold Pressure	40.5 in Hg (137 kPa)
Bore	5.25 in (133.4 mm)
Stroke	4.00 in (101.6 mm)
Displacement	520 in^3 (8521 cm^3)
Compression Ratio	7.5
Number of Cylinders	6

Results – Baseline 100LL

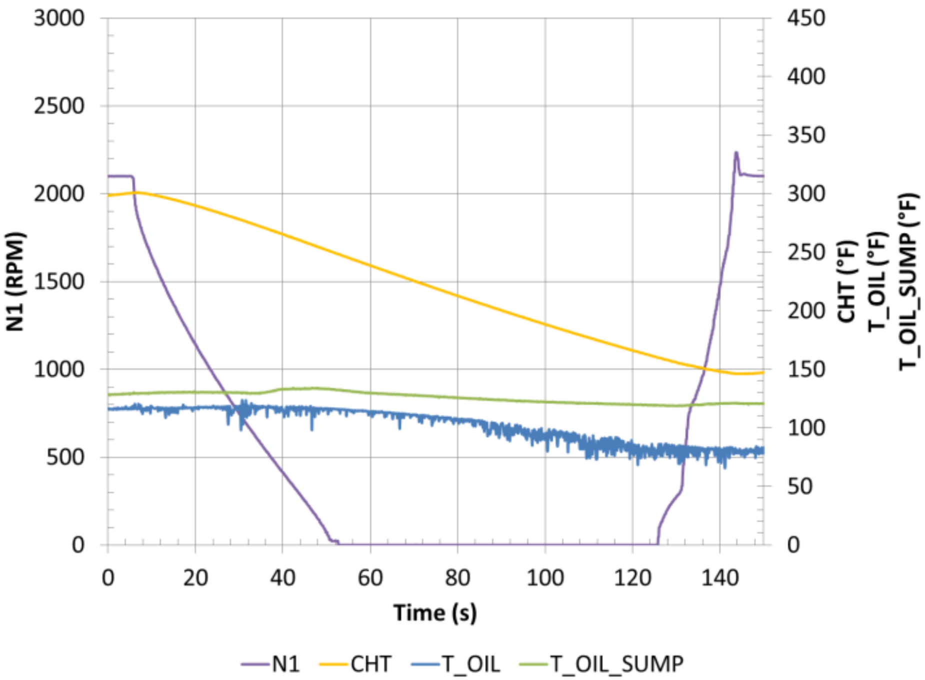
- Altitude Relight
  - o Simulate engine in-flight shutdown
  - o Engine cylinders, oil, and fuel are all cooling during shutdown (30s – 2 min)
    - ▪ Cold fuel harder to atomize and vaporize
  - o Attempt restart

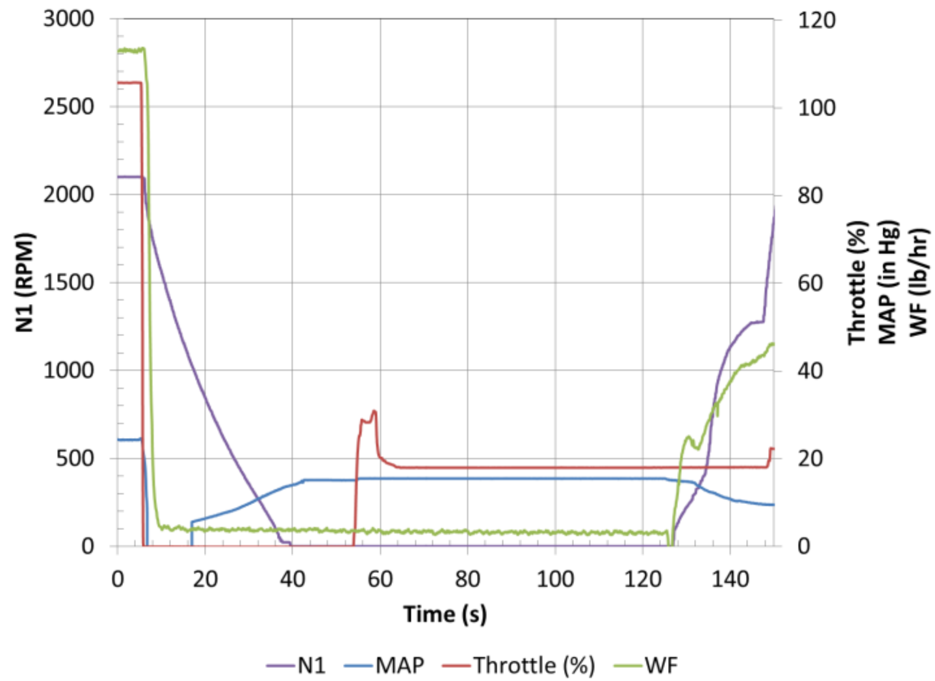


NRC·CNRC

Results – Baseline 100LL

Altitude restart at 20,000 ft



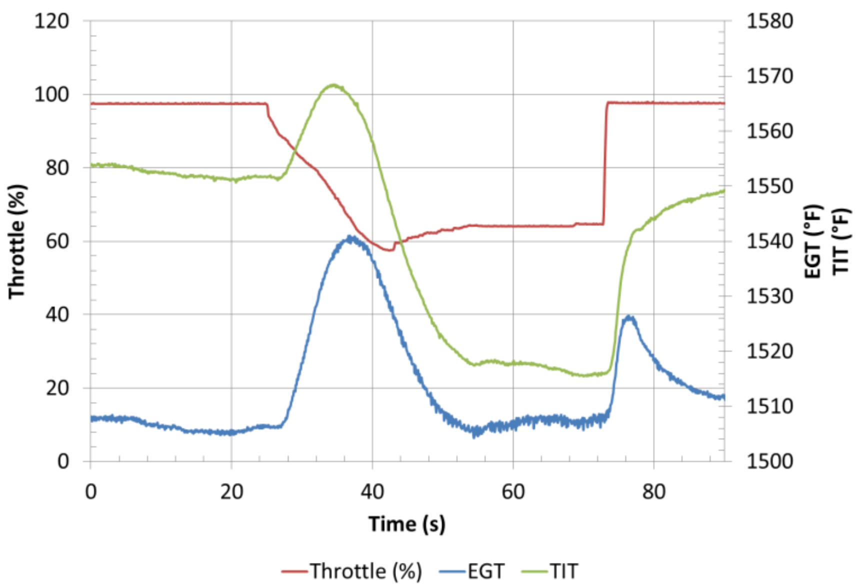


- Monitor how engine oil and cylinders are cooling
- Monitor response of engine during start (accel to idle, fuel flow, turbocharger response, etc.)

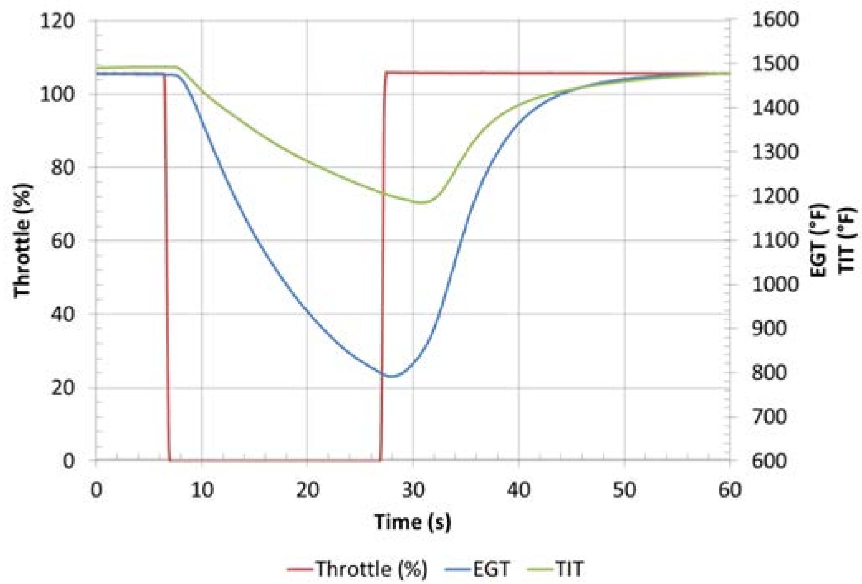
Results – Baseline 100LL

- Transient
  - o Perform slow and fast throttle movements
  - o Changes in combustion characteristics can affect engine response
  - o Monitoring all engine parameters at 20 Hz rate

Altitude: 5,000 ft
Slow decel / fast accel



Altitude: 10,000 ft
Fast decel / fast accel



PAFI Flight Testing: NRC Harvard Mk IV – C-FPTP

- Test experimental alternative fuels to 100LL in actual flight conditions
- Built in 1951
- Canadian variant of T6 Texan
- Max AUW 5750 lbs
- Pratt and Whitney R1340-S3H1 Wasp air-cooled, nine cylinder Supercharged Radial Engine
- 550 BHP (600 at T/O Power)
- Limited OEM Performance Data
- Heavily instrumented by NRC

Instrumentation

- Onboard Data Acquisition System (DAS)
  - Records engine (EGT,CHT, Manifold pressure, rpm, fuel flow, carb/oil/inlet air temps) and non-engine parameters (air data, IMU, control positions, etc.)
- Insight Electronics G-9 Radial Engine Monitor
  - Provides pilot with complete engine status; data also recorded on DAS

Rear Cockpit
DAS Screen

Summary and Future Work

- The transition to unleaded aviation gasoline is becoming a reality.
- US and Canada working toward qualifying a suitable replacement fuel.
- NRC plans to conduct engine testing and flight testing on replacement fuels in 2017-18.

NRC·CNRC

Thank you

Malcolm Imray
Airworthiness Engineer
Tel: 613-990-4484
malcolm.imray@nrc.ca

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

Peter Earle
Research Flight Test Engineer
Tel: 613-998-5524
peter.earle@nrc.ca

Wajid Chishty
Technology Leader
Tel: 613-993-2731
wajid.chishty@nrc.ca

The Canadian Piston Fleet – Fuel requirements

(Transport Canada Preliminary study: based on CAWIS as of June, 2015 ; hours flown 2013)

Minimum avgas fuel grade required (from TCDS)	Total Civil Piston Fleet		Commercial Piston Fleet *	
	# of a/c	Hrs Flown	# of a/c	Hrs Flown
100LL	8833	621,658	N/R **	384,056
91/96 or lower	14234	431,468	N/R **	217,803
Unknown + Diesel ***	7036	5545	N/R **	485
Total	30103	1,058,671	3120	602,344
% 100LL	***29***	***59***	N/R **	***64***

Aircraft requiring 100LL (30% of fleet) fly 60% of the total hours

* Commercial fleet excludes Private and State registered aircraft

** N/R = not reported in the preliminary study

*** Believed to be largely inactive and/or specialty/vintage aircraft; note low hours flown

A New Unleaded Avgas – Challenges

- Removing lead from 100LL would result in 94UL avgas
  - probably usable in at least half of the fleet ***BUT…***
- The existing commercial fleet flying most of the hours (>60%) needs 100 octane to safely deliver rated power
- Fuel distribution infrastructure will only accommodate one avgas
  - Old days of multiple fuel choices (80/87 & 100/130 or 100LL) are not supported by the market size except for special cases – (i.e. mogas at flying clubs)
- New fuel needs to be acceptable for mixing with 100LL to allow for transition
- Besides octane, need to understand other effects of lead removal on engines and fuel systems

The industry needs a new 100UL fuel

- Ideally, fleetwide approval with no STC or engine/aircraft design changes required

If 94UL is the only option, then lots of aircraft will be grounded!