Transition to Unleaded Fuels for General Aviation

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NRC Aerospace
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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 only 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

Total Airborne Lead Emissions (2015 data)

- Base metals mining, smelting & refining
  113t (70%)
- Aviation
  27t (17%)
- Iron & Steel (including Iron ore)
  8t (5%)
- Pulp & Paper
  3t (2%)
- Other
  11t (7%)

Source: Environment and Climate Change Canada
<table>
<thead>
<tr>
<th>Powerplant type</th>
<th>Total Civil Fleet</th>
<th>Commercial Fleet *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of a/c</td>
<td>Hrs Flown</td>
</tr>
<tr>
<td>Turbine</td>
<td>5106</td>
<td>3,010,840</td>
</tr>
<tr>
<td>Piston</td>
<td>30103</td>
<td>1,058,671</td>
</tr>
<tr>
<td>Total</td>
<td>35209</td>
<td>4,069,511</td>
</tr>
</tbody>
</table>

- 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
  o “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

**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
A New Unleaded Avgas – Challenges

• 94 octane gasoline (ethanol-free) + TEL = 100LL
• To date, no suitable replacement “additive” has been found
  o New fuels are completely new chemical formulations
• Now it becomes a balancing act:
  • 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.
  o Engine performance (power, knock, etc.)
  o Engine operability (cold starts, altitude relights, transients, etc.)
  o Engine emissions (gaseous and particulates)
  o Test throughout flight envelope (0 – 30,000 ft.; cold/standard/hot days)
  o 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.
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

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
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</thead>
<tbody>
<tr>
<td>Maximum Rated Power</td>
<td>325 HP (242 kW)</td>
</tr>
<tr>
<td>Maximum Rated Speed</td>
<td>2700 RPM</td>
</tr>
<tr>
<td>Maximum Rated Manifold Pressure</td>
<td>40.5 in Hg (137 kPa)</td>
</tr>
<tr>
<td>Bore</td>
<td>5.25 in (133.4 mm)</td>
</tr>
<tr>
<td>Stroke</td>
<td>4.00 in (101.6 mm)</td>
</tr>
<tr>
<td>Displacement</td>
<td>520 in³ (8521 cm³)</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>7.5</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>6</td>
</tr>
</tbody>
</table>
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
• 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
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.
Thank you

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# The Canadian Piston Fleet – Fuel requirements

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

<table>
<thead>
<tr>
<th>Minimum avgas fuel grade required (from TCDS)</th>
<th>Total Civil Piston Fleet</th>
<th>Commercial Piston Fleet *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of a/c</td>
<td>Hrs Flown</td>
</tr>
<tr>
<td>100LL</td>
<td>8833</td>
<td>621,658</td>
</tr>
<tr>
<td>91/96 or lower</td>
<td>14234</td>
<td>431,468</td>
</tr>
<tr>
<td>Unknown + Diesel ***</td>
<td>7036</td>
<td>5545</td>
</tr>
<tr>
<td>Total</td>
<td>30103</td>
<td>1,058,671</td>
</tr>
<tr>
<td>% 100LL</td>
<td>29</td>
<td>59</td>
</tr>
</tbody>
</table>

**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!*