Aircraft Fuel Metering
Purpose of metering

• To adequately mix the proper amount of fuel with the combustion air entering into an engine, during all phases of engine operation.
Section Outline

• Terms

• Fuel metering concepts
  – Characteristics of fuels
  – Characteristics of air
  – Engine operational needs
  – Basic system outline
Section Outline

• Carburetion Principles
  – Air metering
  – Fuel metering
  – Enrichment / derichment
  – Acceleration systems
Section Outline

• Float Carburetors
• Pressure Carburetors
• Fuel Injection Systems
• Diagnostic and troubleshooting
  – Basic strategy development
  – Common failure areas
Terms

• Take-off power = maximum power allowed for take-off operations.
  – usually limited to 1 - 5 minutes

• Rated Power = highest power Mfg. will guaranty the engine to produce continuously at a given altitude.
Terms

• Absolute altitude = highest altitude which the engine will run.

• Friction horsepower = the horsepower required to overcome friction and accessories.
Terms

• Mechanical efficiency = \frac{\text{BHP}}{\text{IHP}}
• Brake horse power = the power available to perform work.
• Indicated horse power = \frac{\text{P.L.A.N.K}}{33,000 \text{ ft.lbs/min}}
Terms

- \( P \) = mean effective pressure
- \( L \) = length of stroke in Ft.
- \( A \) = area of bore in sq/in
- \( N \) = \# of power strokes per min-rpm/2
- \( K \) = \# of cylinders
Terms

- MEP = mean effective pressure
Terms

- Otto cycle = the four stroke cycle
  - Intake
  - Compression
    - ignition (event only)
  - Power
  - Exhaust
Terms

- Otto pressure cycle
Terms

• Density altitude = the effective altitude of prevailing conditions presented in terms of standard conditions.

• Carburetor = a device that meters air and fuel into the intake system.

• Metering = to provide in measured quantities (Websters)
Terms

• Fuel injection = similar to carburetion but fuel distribution occurs at a different location from air metering, usually just behind the intake valve.
Terms

• Octane rating
  – determined by the percentage of iso-octane that must be mixed with normal heptanes to reduce detonation.
  – more iso-octanes reduce detonation to a point.
Terms

• Air metering force
  – Those forces created by air being drawn into the engine because of pressure differential.

• Fuel metering force
  – Air metering forces that are used to determine the air mass entering the engine for fuel metering.
Terms

• Fuel distribution forces
  – Those forces used to distribute and atomize the fuel into the intake air stream.

• Fuel metering and distribution forces may or may not be the same force.
Terms

• Full rich:
  – mixture control setting that provides the maximum fuel flow for any given throttle setting.

• Rich best power:
  – the richest mixture control setting that does not reduce RPM.
Terms

• Lean best power:
  – The leanest mixture control setting that does not cause a lower RPM.

• Best economy:
  – The leanest mixture control setting that will not damage the engine.
Terms

• Best power:
  – The mixture control setting that produces the best overall power without damaging the engine.
Terms

SECTION END
Fuel metering concepts
fuel characteristics

- Aviation gasoline = hydrocarbon fuel
  - C5H12 - C8H18 = common fuel range
  - 2 C5H12 + 16 O2 => 10 CO2 + 13 H2O
  - 2 C5H12 + 16 O2 => 6 CO2 + 13 H2O + 2 NOx + 4 CO = incomplete burn
  - NOx = the brown stuff of smog
  - CO = the most toxic part of smog
Fuel metering concepts
fuel characteristics

• Aviation gasoline has a high rate of vaporization.
• Volatile = readily vaporizeable at a relatively low temperature.
• Has come in a number of different grades.
• Most common grade available = 100LL
Fuel metering concepts
fuel characteristics

• Avgas is made up of many differing molecules of similar structure.

• All gasoline's are composed of many grades of fuel oils.

• This causes them to have boiling points that vary within a range.

• Typical boiling point will range from 100°f - 250°f
Fuel metering concepts

fuel characteristics

• Octane rating is a rating of resistance to detonation. Higher is better.

• Octane calculated by three methods
  – RON = Research Octane Number
  – MON = Motor Octane Number
  – \((\text{RON} + \text{MON})/2\) = average of both
  – Latter is the most common rating.
Fuel metering concepts
fuel characteristics

• Octane rating may be achieved by mixing high octane iso-octanes with lower octane heptanes.
• The iso-octanes reduce detonation
• The heptanes provide more Btu's
• Today many different blends and additives are used in gasoline's.
Fuel metering concepts

fuel characteristics

• Dual octane ratings indicate the lean octane value and the rich octane value.

• 100 octane would have the anti-knock qualities of 100% iso-octane.

• TEL is used to achieve higher than 100% iso-octane ratings.
Fuel metering concepts
fuel characteristics

- T.E.L. Tetraethyl Lead
- Anti-detonation compound
  - stabilizes the rate of burning under extreme conditions.
  - reduces metal adhesion on exhaust valve to seat contact.
- Ethylene dibromide scavenges the lead deposits by forming lead bromide.
Fuel metering concepts
fuel characteristics

• Ethylene dibromide boils around 250°F
• T.E.L. boils around 360°F
• Lead bromide boils between these.
• This causes the TEL to distribute unevenly from the others.
• Some cylinders will get over leaded, others will get over scavenged.
• as much as 96ml/gl from 5.5ml/gl gas.
Fuel metering concepts
fuel characteristics

- Scouring additives such as Tricresyl phosphate, or triphenol phosphate in the oil or fuel may help scavenging lead deposits as well.

- They produce lead phosphate instead of lead bromide, which has an even lower boiling point and mixes better.
## Fuel metering concepts

### fuel characteristics

<table>
<thead>
<tr>
<th>Color</th>
<th>Octane</th>
<th>BTU's</th>
<th>lead ml/gl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>80/87</td>
<td>18,000</td>
<td>.3</td>
</tr>
<tr>
<td>Blue</td>
<td>100LL</td>
<td>18,000</td>
<td>.5 - 2.0</td>
</tr>
<tr>
<td>Green</td>
<td>100/130</td>
<td>19,000</td>
<td>2.9</td>
</tr>
<tr>
<td>Purple</td>
<td>115/145</td>
<td>19,000</td>
<td>4.9</td>
</tr>
</tbody>
</table>
Fuel metering concepts

fuel characteristics

• Avgas has a relatively high heat value in BTU’s.

• BTU = British Thermal Unit

• = energy required to raise one gallon of water 1°f.

• Heat energy does not directly relate to burn rate or temperature generated.
Fuel metering concepts
fuel characteristics

• Ignition temperatures of fuels.
  – Natural gas 1,100°f
  – Gasoline's 600-800°f
  – Diesels 300-400°f
  – Jet fuels 300-450°f
  – Spark plug arc 500-1800°f
  – Best arc temp 900-1300°f
Fuel metering concepts
fuel characteristics

• Lower atmospheric pressures will increase rate of vaporization
• will also lower boiling temperatures
• Fuel must be vaporized to oxidize or burn.
• Fuel must be liquid to be pumped.
• The primary purpose of a fuel distribution device is to administer fuel in an atomized state that is close to vapor.
• Heat energy must then complete the vaporizing process.
• Excess fuel causes excess vaporizing which cools the combustion process.
Fuel metering concepts
fuel characteristics

• Fuel can vaporize in warm engine compartment fuel lines.
• Worse on hot soaked engine being restarted.
• Any turbulence generators in fuel delivery system can accelerate “vapor lock” conditions
Fuel metering concepts
fuel characteristics

- Vapor lock areas
  - sharp bends
  - high rise areas
  - routing close to hot components
  - pump inlets
  - carburetor inlets
Fuel metering concepts
fuel characteristics

• Booster pumps will reduce possibility of vapor lock.
• Gravity feed systems not likely to vapor lock.
• Higher volatility fuels more likely to vapor lock.
Fuel metering concepts

fuel characteristics

• Typical method to “repair” vapor lock
  – Mixture full rich
  – Throttle cracked - slightly open
  – Magnetos on
  – Start engine
  – If it quickly dies then it was probably vapor locked
Fuel metering concepts
fuel characteristics

• Bleed the systems with aux pump.
  – Mixture full lean or at idle cutoff - prevents flooding
  – Throttle full open - activates pump
  – Electric pump on
  – Wait twenty seconds to purge vapor.
  – Start normally.
Fuel metering concepts

fuel characteristics

• Automotive fuels
  – Several STCs exist for the use of auto gas.
  – May only require an identifier hose clamp on a push rod tube.
  – Generally only good for low compression engines.
Fuel metering concepts
fuel characteristics

– won’t have a loss of power but may have reduced high power duration.

– Auto fuel has many additives that are unknown or proven incompatible with aviation systems.

– Some auto gas blends have higher a volatility than avgas and are more likely to vapor lock.
Fuel metering concepts
fuel characteristics

• Methyl tertiary butyl ether
  – can attack rubber causing swelling
  – can make humans sick

• Methyl Alcohol
  – can attack rubber causing swelling
  – can make humans sick
  – can rust components
Fuel metering concepts
fuel characteristics

SECTION END
Fuel metering concepts
air characteristics

- Air is a compound of several gasses
  - 76% nitrogen
  - 21% oxygen
  - 2.1% carbon dioxide and rising
  - the rest is the remaining heavier gasses.
  - lighter gasses tend to rise away.
Fuel metering concepts
air characteristics

• All of these gasses are displaced by moisture.
• Since moisture content varies from none to complete saturation it is not considered to be a part of air.
Fuel metering concepts

air characteristics

• Fuel requires the oxygen for combustion which releases large amounts of heat.

• Elements other than the moisture and oxygen, resist involvement in the combustion process.
Fuel metering concepts
air characteristics

- Nitrogen = N
  - molecular weight of 14
  - forms in molecules of two or more
  - very resistant to molecular interaction with fuel or oxygen
  - will bond with hydrogen to form ammonia's
Fuel metering concepts
air characteristics

- **Oxygen = O**
  - molecular weight of 8
  - forms molecules of two commonly
  - easily interacts with many substances.
  - interaction will consume or release energy
Fuel metering concepts
air characteristics

- Water vapor = H$_2$O
  - molecular weight of 18
  - will weakly bond with itself
  - releases high amounts of energy when forming.
  - displaces heavier N$_2$ and O$_2$ molecules.
Fuel metering concepts
air characteristics

• Avogadro’s law
  – molecules of any gas demand the same space for a given temperature.
• A water molecule will demand the same space as a nitrogen or oxygen molecule.
• This reduces the overall density.
Fuel metering concepts

air characteristics

• Low pressure areas do not attract humidity.
• They are created by humidity.
• Low pressure will reduce the lifting capacity of the wing.
• It will reduce the power output of the engine by decreasing air mass.
Fuel metering concepts
air characteristics

• This will reduce the fuel metering force that measures air mass entering the engine.
• It will reduce the rate of fuel vaporization in the engine due to saturation levels of the air.
• It can reduce detonation.
Fuel metering concepts
engine operational needs

• The primary operational need for an engine is 14.97 parts of air to 1 part of vaporized fuel, by weight.
• This is known as the stochiometric ratio.
• This is the best power to fuel ratio.
  – \( \text{C}_5\text{H}_{12} + 8 \text{O}_2 \rightarrow 5 \text{CO}_2 + 6 \text{H}_2\text{O} \)
Fuel metering concepts
engine operational needs

• Engines can run at
  – 26:1 (super lean)
  – 5:1 (super rich)

• Common ranges for aviation engines are:
  – 16:1 to 12:1 for normal ops
  – 8:1 to 10:1 for enrichment cooling
Fuel metering concepts  
engine operational needs

• There are several differing phases of operation during the typical running cycle of an engine.

• Each phase, or mode of operation requires distinctly different fuel metering needs.

• Some different operating modes are:
Fuel metering concepts

- Starting
- Cold operations
- Warm operations
- Idle operations
- Cruise operations
- High power operations
- Shut down operations
- Differing altitudes and pressures
Fuel metering concepts
engine operational needs

- Starting operations:
- calls for fuel to be delivered to the cylinders with a minimum of cranking.
- fuel metering and atomization forces will be at their weakest.
- compression and ignition will be at their weakest.
Fuel metering concepts

engine operational needs

• Starting and cold operations:
• engine will be at its coldest operating condition
• because vaporization is poor when cold, extra fuel is needed to make up for the lean “vapor” condition. 10%
• fuel distribution will be very uneven.
Fuel metering concepts
engine operational needs

• Idle operation, normal or cold:
• the intake is at its least efficient phase.
• compression efficiency is lowest.
• fuel metering forces are the least stable.
• fuel vaporization and distribution can be very poor.
Fuel metering concepts
engine operational needs

- Transitional operations:
- engine will be trying to accelerate
- may be operating partially on several fuel metering systems
- air fuel ratios may need to cycle between lean and rich as throttle and RPM are transitioned.
Fuel metering concepts
engine operational needs

- Cruise operations:
- power demand is low to medium.
- best fuel economy is desired.
- highest portion of flight time.
- vaporization is good.
- cooling demands are low.
- most likely to develop icing
Fuel metering concepts
engine operational needs

• High power settings:
• for take off and climb.
• may have duration limits.
• most cooling needed.
• best vaporization condition.
• most likely detonation phase.
• compression and ignition at their best.
Fuel metering concepts
engine operational needs

- Shut down operations:
- post metering fuel system needs to be scavenged of burnable mixture.
- combustion chamber needs to be vented of varnish developing gasses.
- engine needs to be safely shut down and defused, pending magneto switch failures and or hot spots.
Fuel metering concepts
engine operational needs

• Altitude - pressure compensation:
• appropriate air:fuel ratios must be maintained at any altitude or pressure.
• can be manual, automatic or both.
• air:fuel ratios may need manual compensation for unusual operations.
  – such as starting, stopping, hot, cold, emergencies, vapor lock, etc.
Fuel metering concepts
engine operational needs
Fuel metering concepts
basic system outline

• Fuel storage and delivery systems must store fuel until needed, then deliver fuel to the fuel metering system, as needed.

• Fuel storage is either in wings, fuselage, or both.
Fuel metering concepts
basic system outline

• Fuel storage systems regulated by FAR 23, covered in AMT 100.

• Common source of fuel contaminants

• Materials compatibility is critical
  – Rubber, sealants, seals, composites
Fuel metering concepts

basic system outline

• Must have
  – Debris / moisture sumps w/ drains
  – Sealed Fuel caps w/ labeling
  – Fuel quantity indicator
  – Fuel outlet screen
  – Pre-firewall off/on/selector valve w/ detent for each engine.
Fuel metering concepts
basic system outline

– valve can’t pass through “OFF”

• Fuel outlet screen must be 8 - 15 mesh.
• must have surface area 5 times the outlet cross-sectional area.
• Gascolater mesh 25 - 1
• Carb strainer mesh 40 - 1
Fuel metering concepts

basic system outline

• Venting systems must be present and functional.
• It must prevent negative pressure differential.
• Cannot allow fuel to be siphoned.
• Must vent overboard safely.
Fuel metering concepts
basic system outline

- Delivery systems can be gravity feed or pump systems.
- Gravity feed systems must provide 150% of maximum fuel demand.
- Pump systems must provide 125% maximum fuel demand.
Fuel metering concepts
basic system outline

• No fuel delivery system device can cause stoppage of fuel flow for any reason or during any failure mode.
Fuel metering concepts
basic system outline

• Mechanical engine powered pump is the most common delivery system.

• Pump systems can be single or dual pump systems.
  – Non-positive displacement centrifugal pumps are used for fuel sump pick-up when line head pressure is too low.
Fuel metering concepts

basic system outline

– Positive displacement pumps are usually an engine driven primary pump.

– They can be geared, pulsed, stroked, vaned, wobble or gerotor.
Fuel metering concepts
basic system outline

• Tubing, hoses, fire sleeve, and filtration as per FAR 23, 33, and 34.
• Fire sleeve forward of the firewall.
• Main filtration at the lowest point.
• Firewall sealed and fuel flow shut off required.
• Alternate or hot air source required.
Fuel metering concepts
basic system outline

• Air metering system
  – must be able to vary air volume entering the engine
  – is primary power/rpm control

• Fuel metering system
  – must have a means to determine approximate air mass entering into combustion chamber.
Fuel metering concepts
basic system outline

• Fuel distribution system
  – must have a means to atomize fuel evenly into the combustion air stream. (complete fuel vaporization is the ideal situation)

• Air / air-fuel compressor system.
  – Pre or post fuel metering/distribution
Fuel metering concepts
basic system outline

• Fuel metering/distribution systems must have a means to accommodate differing engine/flight conditions or requirements.

• Combustion chamber intake valve
  – regulates air/fuel charge into combustion chamber
  – is the end of fuel metering/induction