University of Toronto

# A Critical Assessment of Bio-Fuels for Aviation

Ömer L. Gülder

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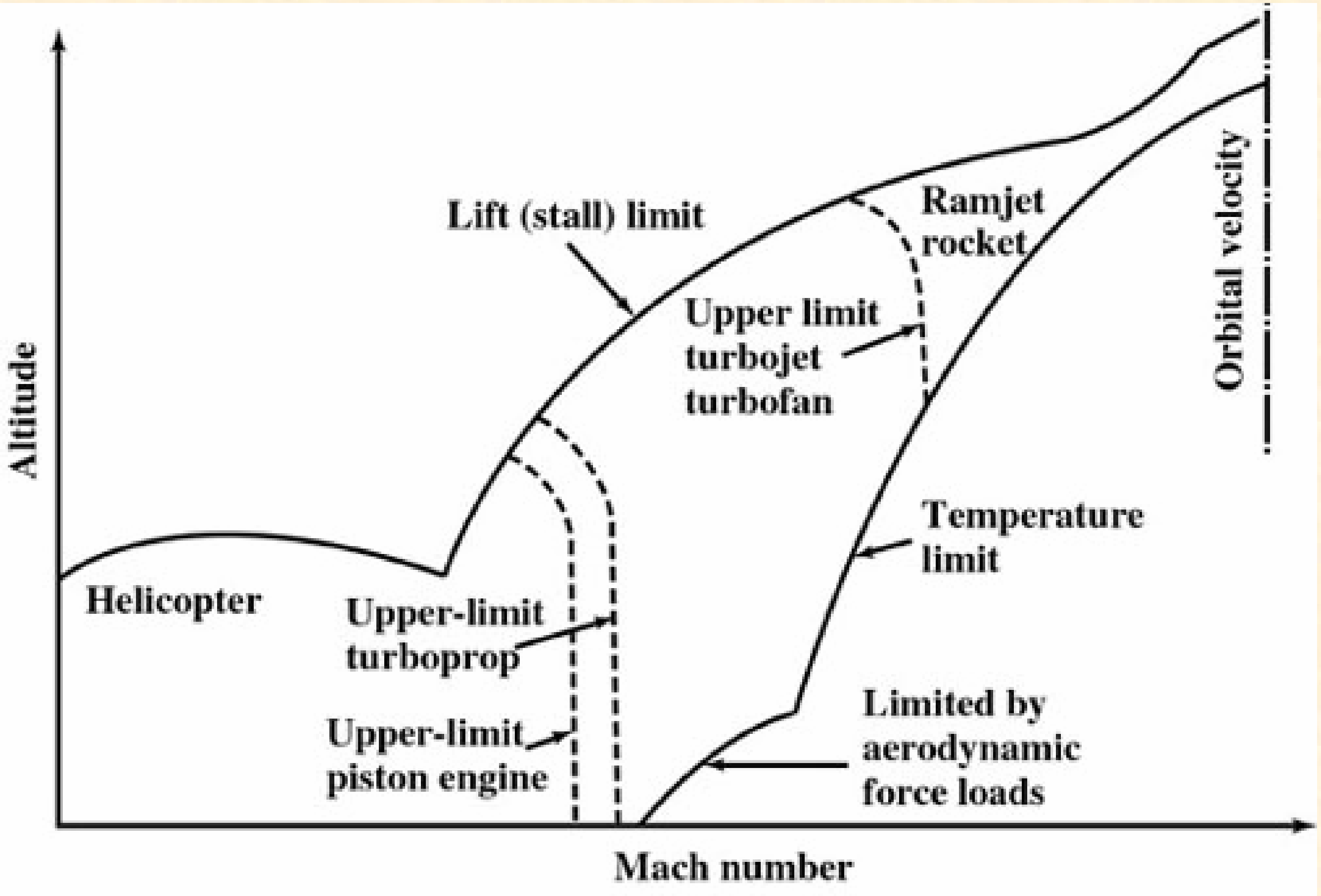
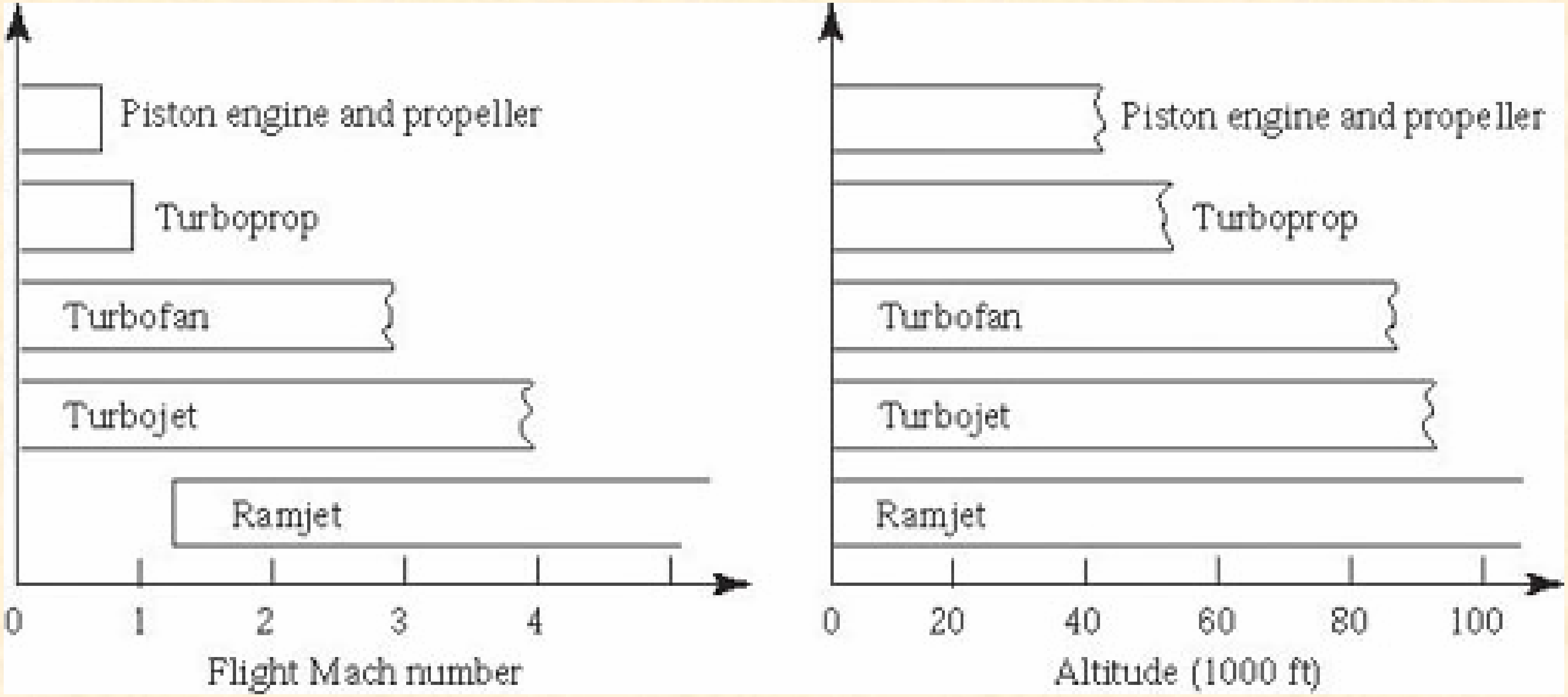
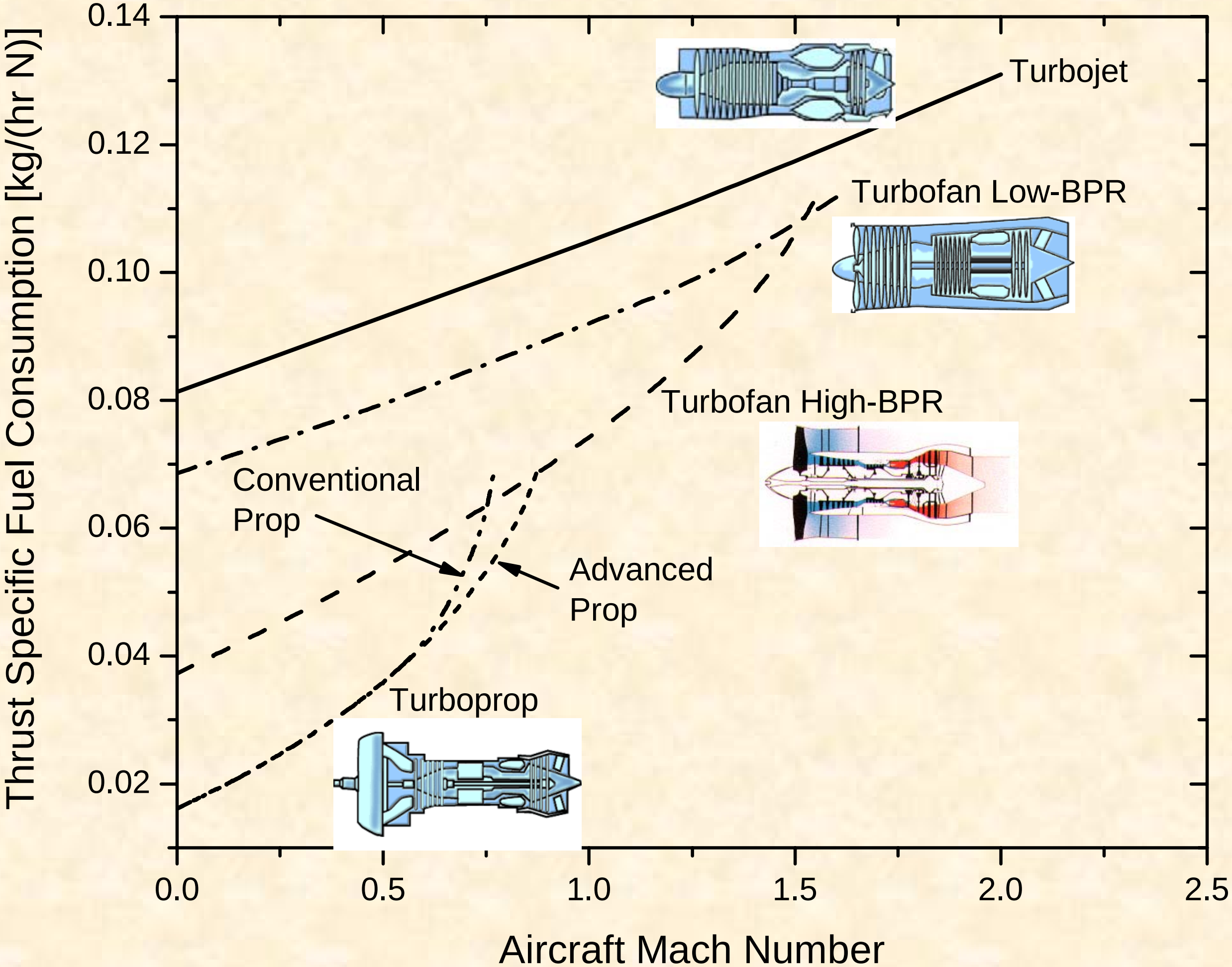
# Flight limits



# Engine limits



# Specific Fuel Consumption of Different Types of Gas Turbine Engines

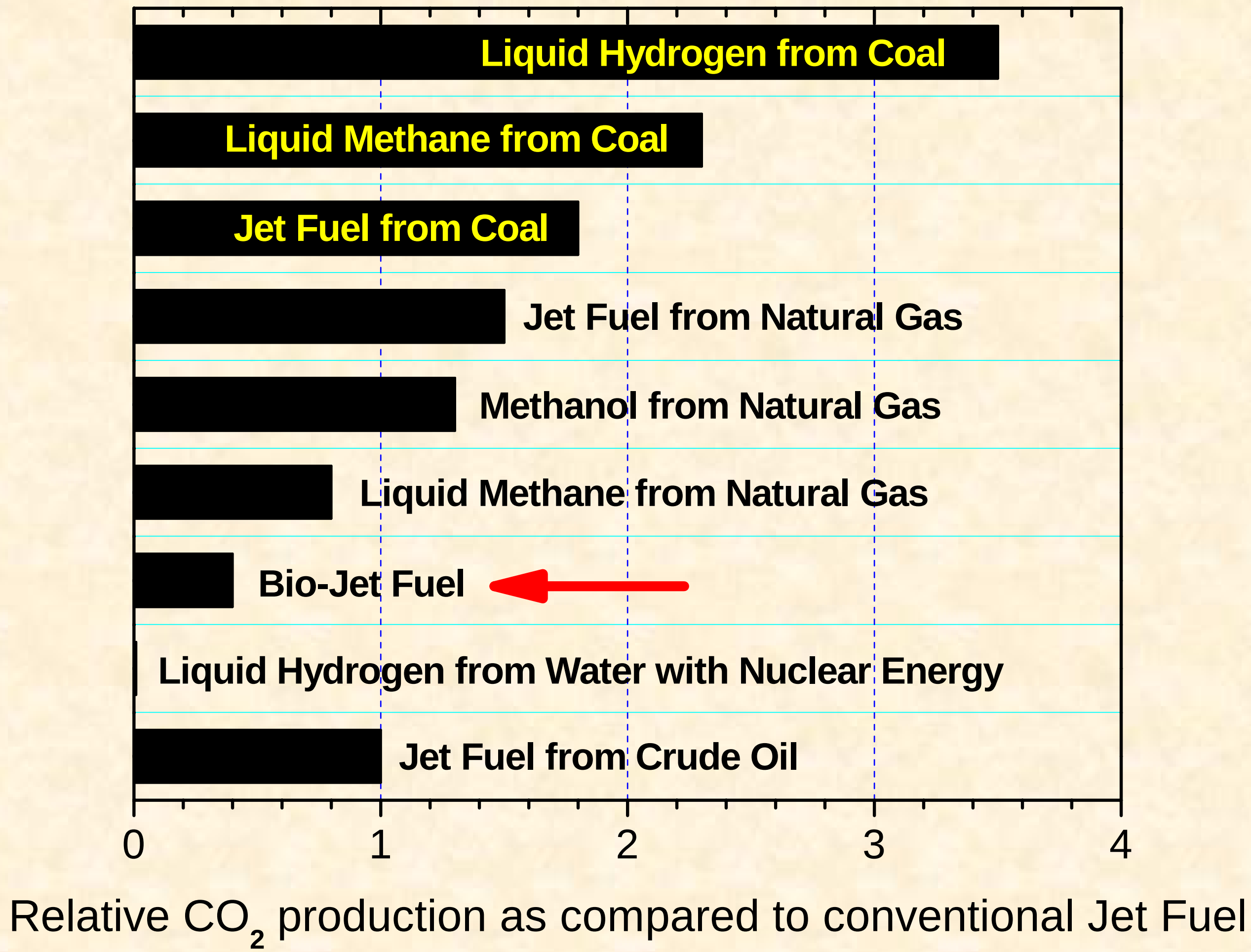


# Bio-fuels

- Biodiesel/FAME (fatty acid methyl ester)
- Ethanol

- Methanol (if produced from biomass)
- Butanol (by fermentation of sugars or starch)

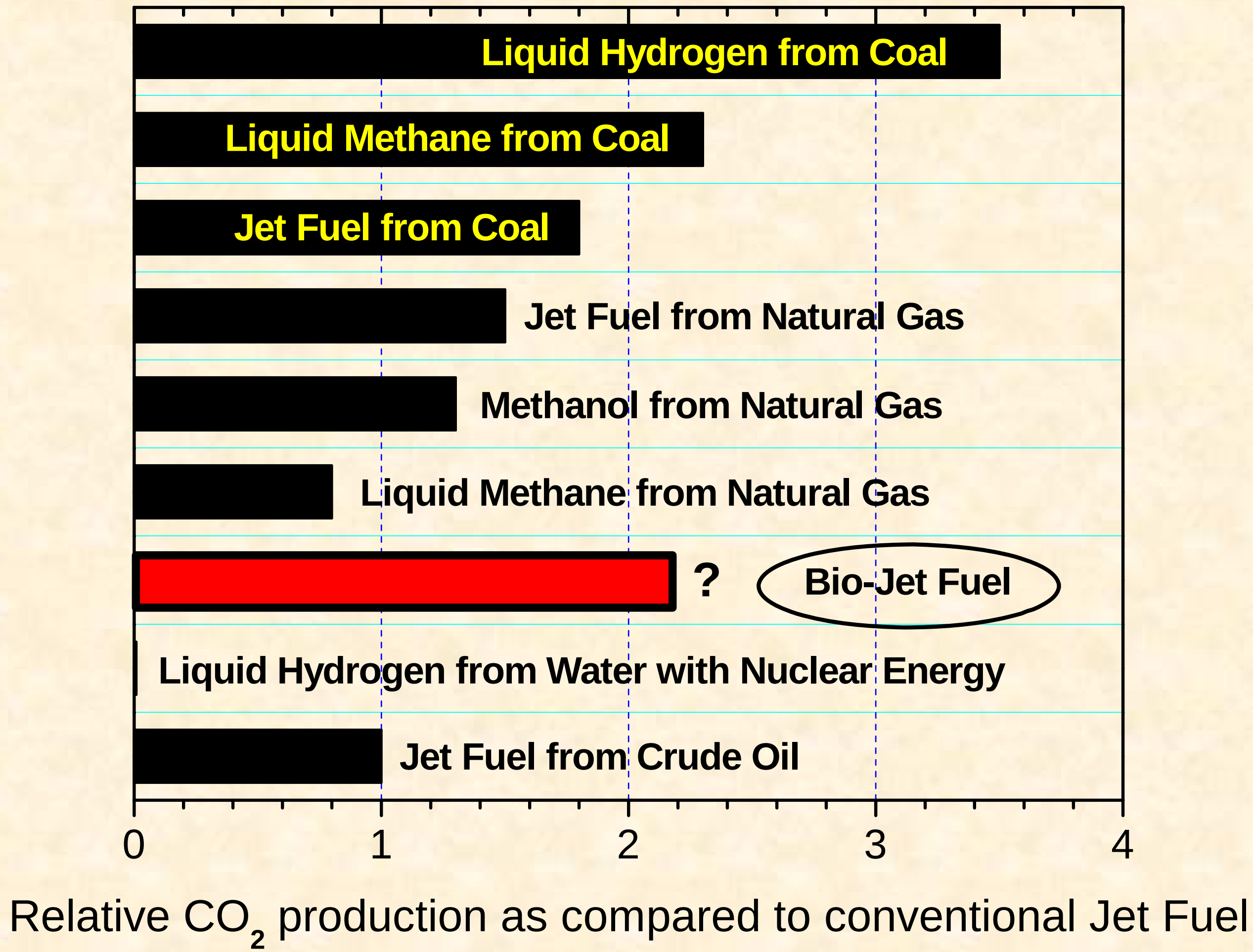
# Relative $CO_2$ production of different liquid fuels



# Contribution of bio-fuels to GHG emissions

- Bio-fuels were believed to reduce GHG emissions through $CO_2$ sequestration by the growth of feedstock
- However, most recent findings imply that carbon savings depend on how bio-fuels are produced
- When land clearance is taken into account, all major bio-fuels cause massive increases in GHG emissions

# Relative $CO_2$ production of different liquid fuels



# General criteria to assess alternative aviation fuels

- Energy economics, production cost and availability
- Ground infrastructure, distribution
- Impact on aircraft (mass, aerodynamics, range,..)
- Fuel handling and thermal stability
- Combustion characteristics and emissions

# Economics, production cost, and availability

- In US, Canada, and EU-15 countries between 30 to 70% of current crop area should be devoted to bio-fuel production to replace 10% of their transport fuels
- Emissions of nitrous oxide, $N_2O$, from nitrogen fertilizers negates all the carbon savings achieved by replacing fossil fuels

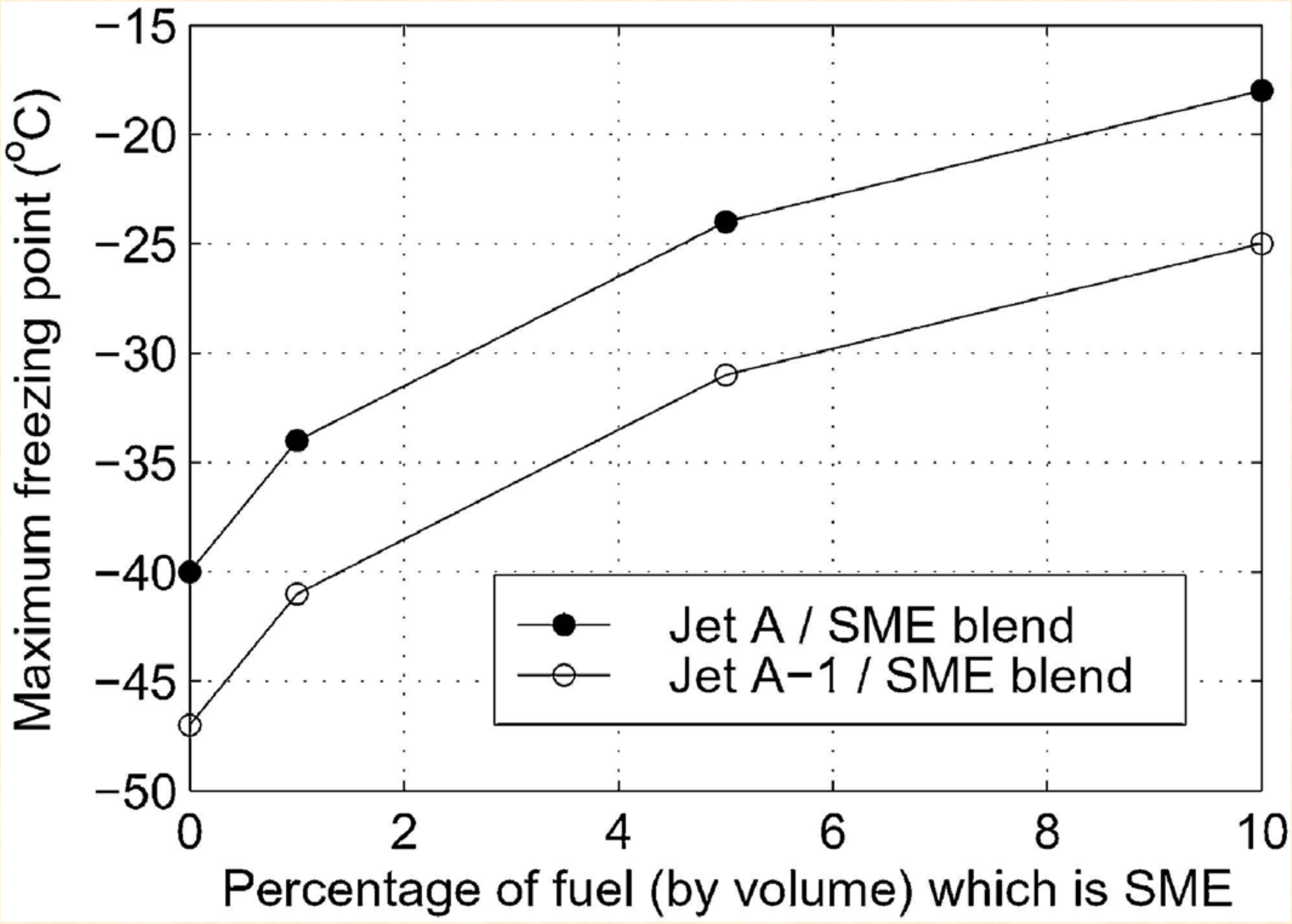
# Ground infrastructure and impact on aircraft

- For liquid bio-fuels blended with jet fuel, the impact on ground infrastructure and on aircraft are not major concerns
- Depending on the bio-fuel content in the blended jet fuel, aircraft range might be slightly reduced for the same fuel tank volume

# Fuel handling and thermal stability

- Freezing point
  - On polar routes, temperature of the fuel can reach freezing point
- Material compatibility
  - Materials used in fuel lines, fuel pumps, seals and hoses
- Thermal stability

# Maximum freezing point of soy methyl ester / jet fuel



# Material compatibility of biodiesel

- Catalytic oxidation due to presence of certain metals can potentially lead to sediments, gels, and salts
- Certain materials used for gaskets and seals degrade
- Holds higher levels of dissolved water than petroleum counterparts
- Microorganisms will degrade biodiesel faster than petroleum fuels and introduce contaminants into the fuel system

# Thermal stability

- Fuel is used as a coolant before it reaches the injectors and burns in combustion chamber
- If fuel temperature exceeds a certain value, fuel starts thermally decomposing and forming deposits
- Deposits can plug the injector passages and cause undesirable carbon deposits
- Assessment of stability of conventional jet fuels is done by a standard test

# Thermal stability of bio-fuels

- Data, if any, on stability of bio-fuel/jet fuel blends are limited
- Biodiesel by itself is known to be less tolerant to heating than jet fuel
- Whether the current stability test is valid for bio-fuel/jet fuel blends is not known
- New procedures to assess the stability of bio-fuel blends might be required

# Combustion characteristics

- Spray and spray combustion are affected by changes in density, viscosity and surface tension
  - Some data available for jet fuel / biodiesel blends
  - Jet fuel / ethanol blends ?
  - Pure biodiesel or ethanol data are not available
- Soot formation

# Emissions

- Engine-out carbon dioxide, nitric oxides, and unburned hydrocarbons emissions are expected to be similar to jet fuel
- Large uncertainties in soot formation and soot aerosol emissions
  - Bio-fuels
  - Biodiesel/jet fuel blends
  - Ethanol/jet fuel blends

# Soot formation and soot aerosol emission

- Combustion chamber life/maintenance
  - Thermal radiation on chamber walls is strongly correlated with soot concentrations in the chamber during combustion
- Impact of soot aerosol on radiation forcing

# Soot formation

- Influence of fuel chemical structure on sooting tendency is predictable for fossil fuels (specifically at atmospheric conditions)
- It is generally believed that atmospheric data can be scaled to engine operating pressures for conventional jet fuels

# Soot formation

- Limited data at atmospheric conditions with biodiesel and ethanol/jet fuel blends
- Since bio-fuels (biodiesel, SME) have relatively different structures, their sooting tendencies are highly variable
- No procedure to assess sooting tendency of bio-fuels yet

# Soot formation

- The pressure sensitivity is expected to be different for bio-fuels
- Scaling atmospheric data to engine conditions is not trivial
- No benchmark data exist on soot formation tendencies of bio-fuels at elevated pressures

# General criteria to assess alternative aviation fuels

- Energy economics, production cost and availability - ??
- Ground infrastructure, distribution
- Impact on aircraft (mass, aerodynamics, range,..)
- Fuel handling and thermal stability
- Combustion characteristics and emissions

# Approval and certification (drop-in alternative fuel)

- Engine and combustor tests to demonstrate that there would be no adverse effects on engine operation:
  - Engine performance and endurance
  - Low temperature atomization
  - Emissions
  - Ignition and altitude relight
  - Lean blowout

# Concluding remarks

- If and when economics/availability issue is resolved, bio-fuel blends can be used for aviation
- If above resolved, use bio-fuels for ground transportation only