Effects of Alternative Fuels

(Session II: How does fuel affect emissions)

"Beyond CO_2: Bio kerosene, engine emissions and technical constraints"
Flightpath 2020 Workshop

Brussels, 25 April 2013

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Overview

- Alternative fuels and approval
- Aviation emissions in general
- Alternative fuels and alternative emissions
- Examples
- Future options

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ALTERNATIVE FUELS AND APPROVALS

Process and status

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ASTM D4054 approach to approval via ASTM D7566

- Test programme is a four-tier, gated process – developed with Fischer Tropsch (FT) fuels

1. Specification "Table 1"
2. Fitness for Purpose tests
3. Component & rig testing
4. Engine testing

Maintain dialogue with OEMs, to check which tests are needed

- Final Research report – approved by Original Equipment Manufacturers (OEMs) - is basis for approval via new ASTM D7566 annex and then into standard Jet A/Jet A-1 specifications.

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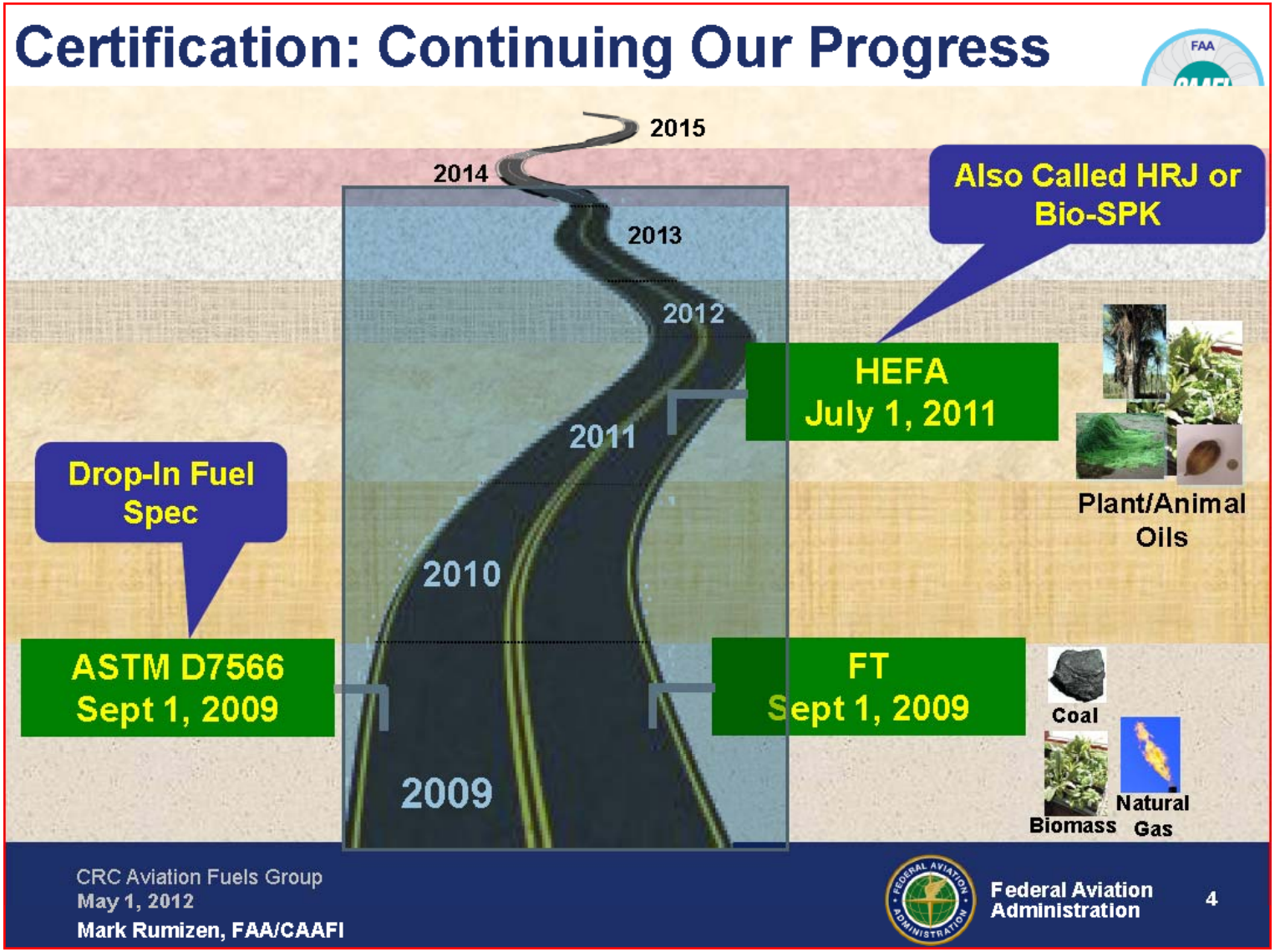
First approvals - FT Synthetic Paraffinic kerosines (SPKs)



HEFA = Hydroprocessed esters & fatty acids

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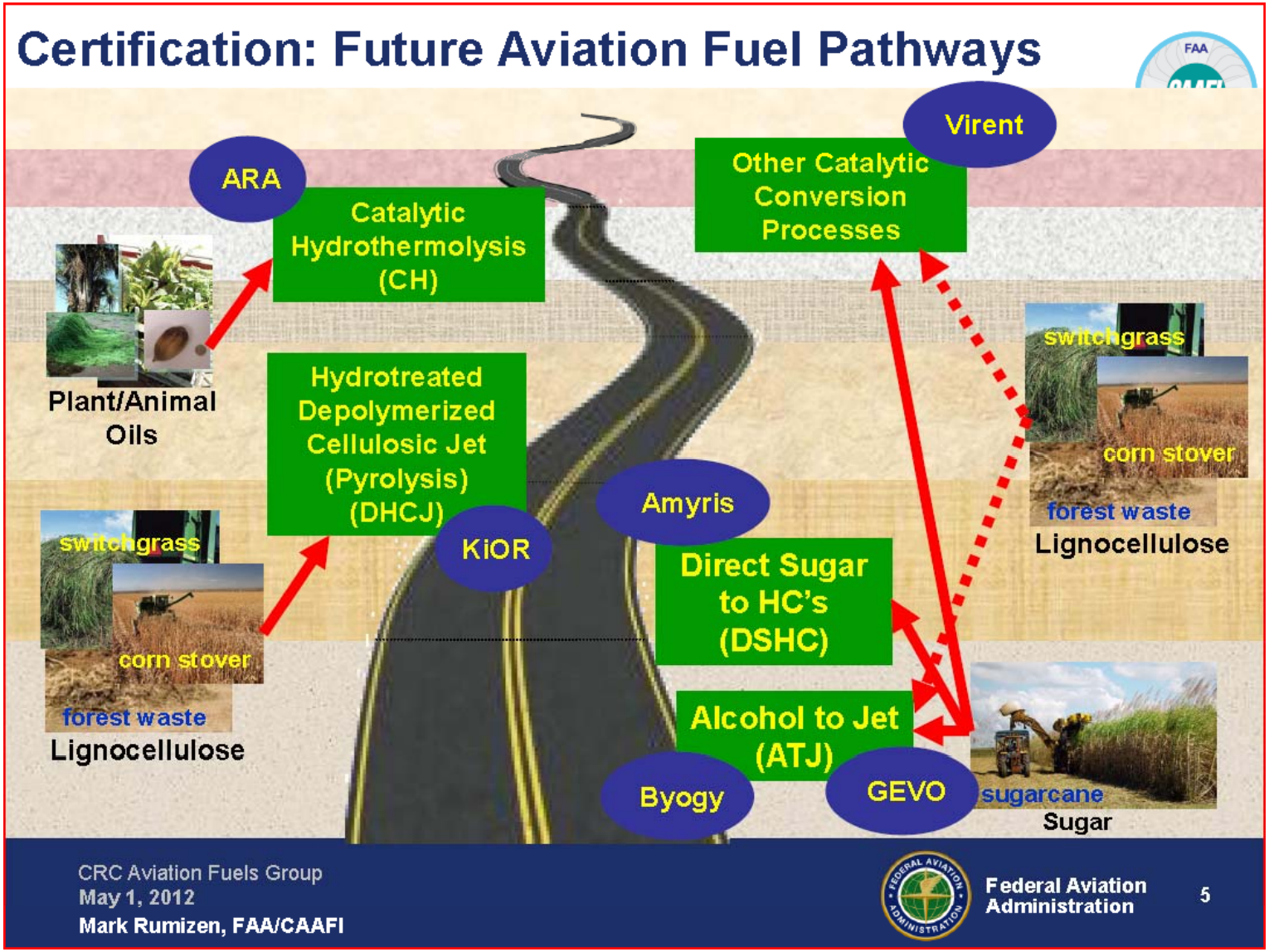
HEFAs approved now other pathways being examined



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ASTM Task Force Comparisons – Indicative only

TF	SPK	Aromatics	Feedstock	Max %	Status
FT	X		Coal, Gas, Bio, X	50	Approved
HEFA	X		Bio-oils	50	Approved
SKA	X	X (Low to normal)	As FT	TBA	Low level RR imminent
ATJ-SPK	X		Carbohydrates	50?	
ATJ-SKA	X	X		TBA	
HDCJ			Lignocellulosic	30	
DSHC	X		Sugars	10%?	
Catalytic thermolysis			Bio oils	???	
Virent SAK Virent SK	X X	X Trace	Sugars or Lignocellulosic	25	FFP testing
Co-processing	X	X	Bio &/or Coal or Biomass Pyrolysis oils	100?	TF being formed
HEFA SKA	X	X	Bio oil	>50?	TF being formed?
SWIFT		X	BioAcetone?	50%?	TF being formed

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AVIATION EMISSIONS IN GENERAL

Engine certification and Fuel contributions

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Aircraft emissions

- Composition depends on
  - Stage of flight (engine load)
  - Engine (design and status)
  - Fuel composition
- Primary emissions - Ranking per kg fuel burned:

Major	Minor
CO_2	CO
Water	NO_x
	SO_x
	Unburned hydrocarbon (UHC)
	Soot

Chemistry happens behind the plume, creating secondary products

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Engines – Regulated emissions and LTO cycles

- New engines have to meet emissions limits for ICAO specified Landing Takeoff cycles (emissions up to 3,000 feet) to be certified
- Current LTO focus is NO_x, UHC, CO, Smoke number
- Total flight emissions will depend on % LTO and % other sectors (cruise)

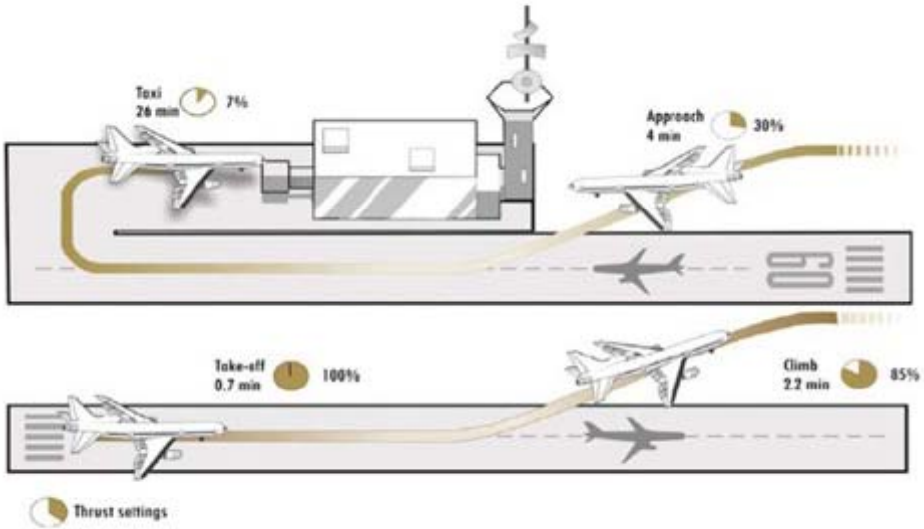

Figure 1 - Illustration of ICAO Emissions Certification Procedure LTO Cycle.
Source: ICAO.

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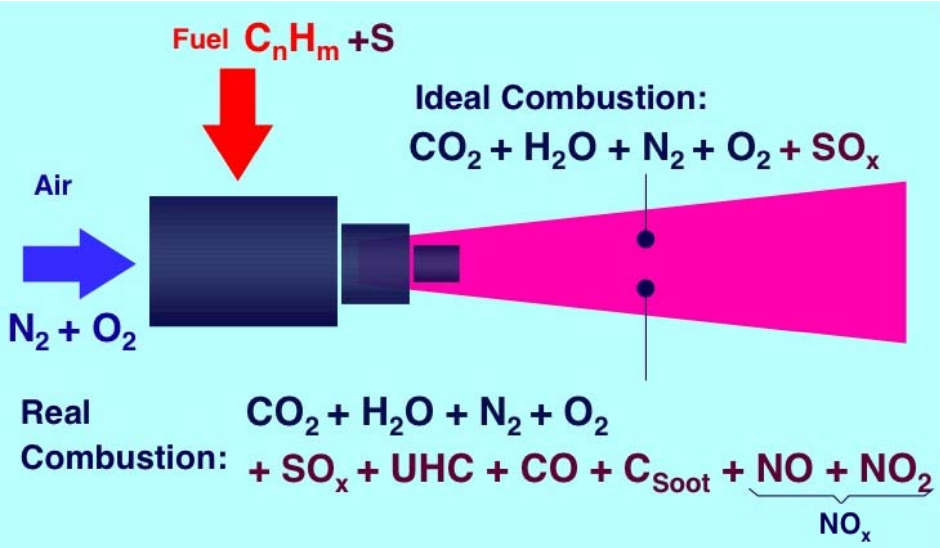
Fuels and how they affect emissions



Lower m/n for aromatics than alkanes

- Total sulphur content
  - Direct link to total SO_x
  - Affects level of Sulphate Particulates
- Total aromatics content
  - Strong impact on Smoke number (and smoke point)
- Total nitrogen content
  - Not linked to NO_x
- Heat content (lower heating value)
  - Amount of total fuel burned

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Alternative fuels and alternative emissions

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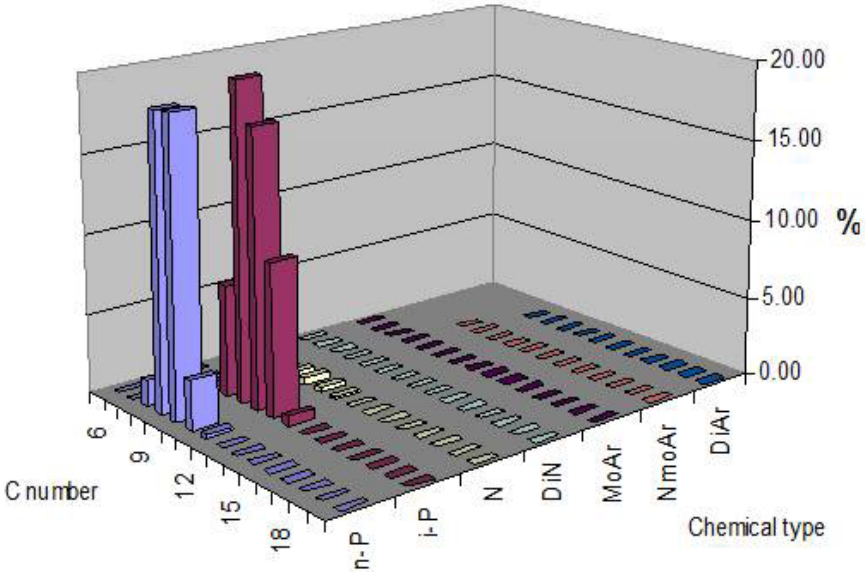
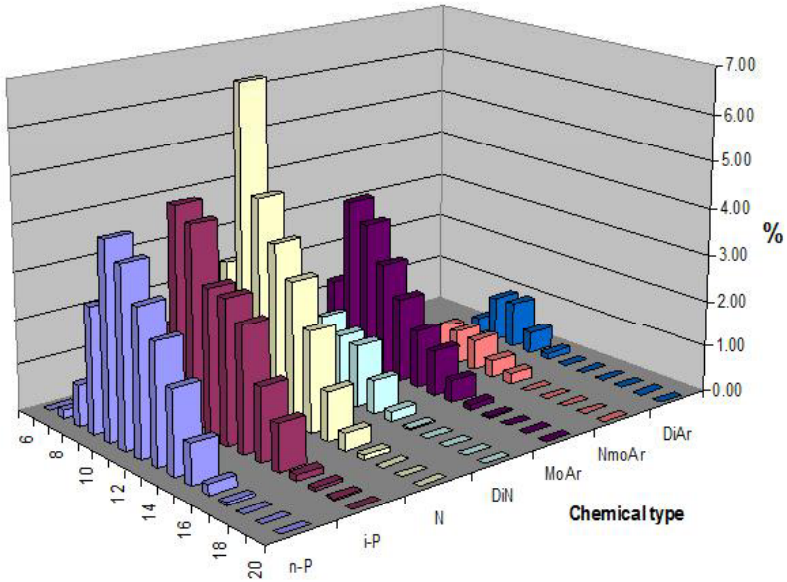
Composition of Jet fuels – Detailed Chemistry by GCxGC

GTL Kerosene



Typical Jet A-1



"Two dimensional" gas chromatography separates fuel components by

- Carbon number
- Molecule type (polarity)

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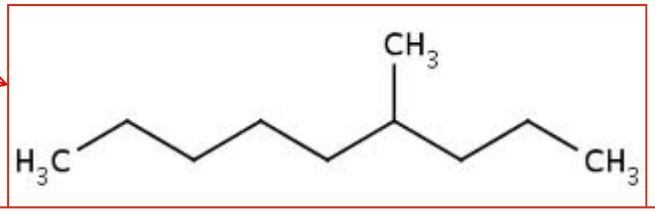
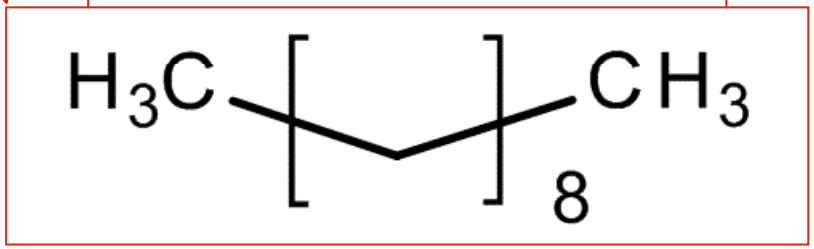
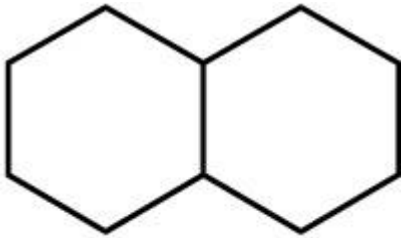
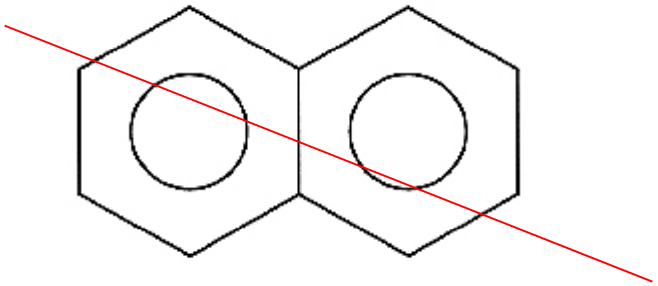
Alternative Fuels – Combustion & emissions differences

- Mostly pure hydrocarbons, e.g.
  - Very low S, O and N
- FTs and HEFAs
  - Neat - very low aromatics & low cyclos
  - Blends- below average aromatics
- Other routes – some will create aromatics
  - Can expect blends with similar total aromatics
  - Can expect lower diaromatics









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Industry Combustion & Emissions testing with Alternatives

- USAF/UDRI during approval stages (2007 onwards, FTs & HEFAs)
  - —T63 helicopter and other engines in US Air Force fleet
  - —Rig tests, On wing tests pre flights, etc.
  - —*Many reports (IASH, CRC, etc.). FTs reduced PMs, SOx, etc.*
- NASA AAFEX II experiments 2011 (FTs & HEFAs)
  - —FT and HEFA SPKs and blends, in DC-8 with CFM-56-2C engines
  - —*"Fuel effects on particulate matter emissions very clear & profound"*
- Royal Military College, Canada (FTs)
  - —GE F404 engine qualification. PMs, SOx reductions.

- A few non-SPKs now being tested, e.g. via FAA/CLEEN projects

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Collaborative work – Overview (*= combustion/emissions)

- TU Delft*
  - Prove & improve payload/range predictions with real flight data
- Qatar Consortium*
  - Getting to know more about Gas-to-Liquids Kerosenes – pathfinders for other synthetic paraffinic kerosene (SPK) fuels.
  - Broadening technology and R&D in Qatar.
  - *Rolls-Royce , DLR and Texas A&M in Qatar focused on C/E aspects.*
- AlfaBird (EU)*
  - GTL Kero "base" fuel for candidates & 1 of 4 final phase fuels
  - Full findings in final AlfaBird report to EC + papers from contributing universities, Aerospace labs, OEMs, etc.
- DREAM (EU)*
  - GTL Kero supplied for "Alternative Fuels" work package of this aircraft/aeroengine design programme

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Examples – with emphasis on GTL Kerosenes

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TUD - Aircraft engine ground performance tests

- Schiphol Airport, Jan 2011, involving:
  - NLR, TUD, DLR, Shell
- 2 sets of blends up to 50% volume GTL kero. Lab and aircraft tests.
- Gaseous & particulates measurements for each LTO condition.
  - Absolute measurements converted to Emissions Indices
- Full details in ANERS and IASH papers (2011)

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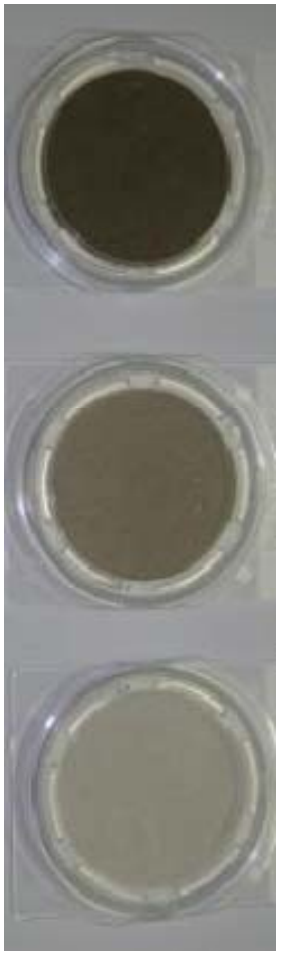
TUD Delft – Preliminary work in 2009

- Performance, particles and emissions data gathered
- Post flight component checks

- Preliminary findings positive
  - No harms to components up to 50% GTL
- Significant soot reduction
  - Soot filters in the exhaust capture line show stepwise reductions in soot as GTL content is increased ➔
  - One Local Air Quality bonus



10% GTL

20% GTL

30% GTL

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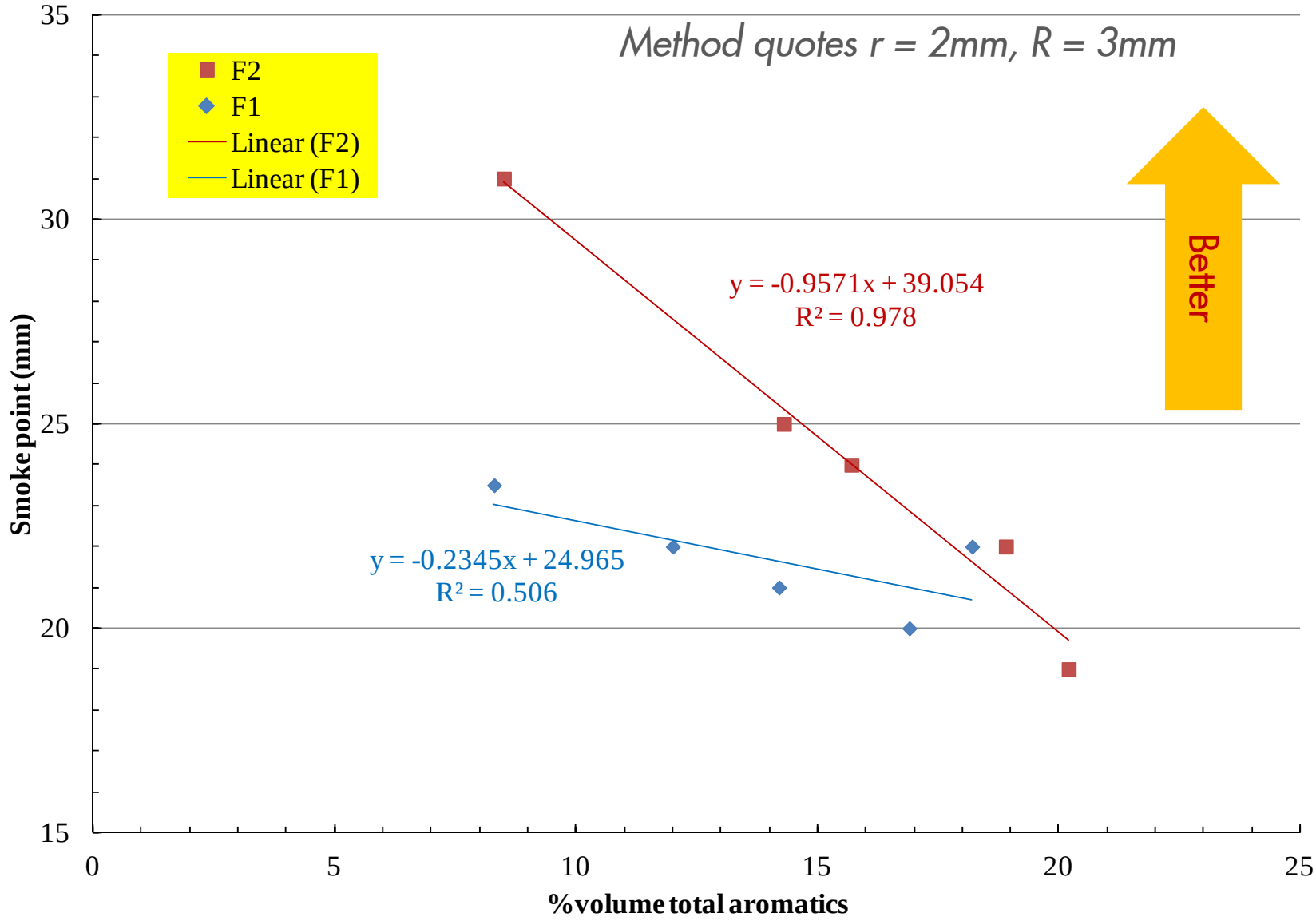
Smoke Point as a function of total aromatics content



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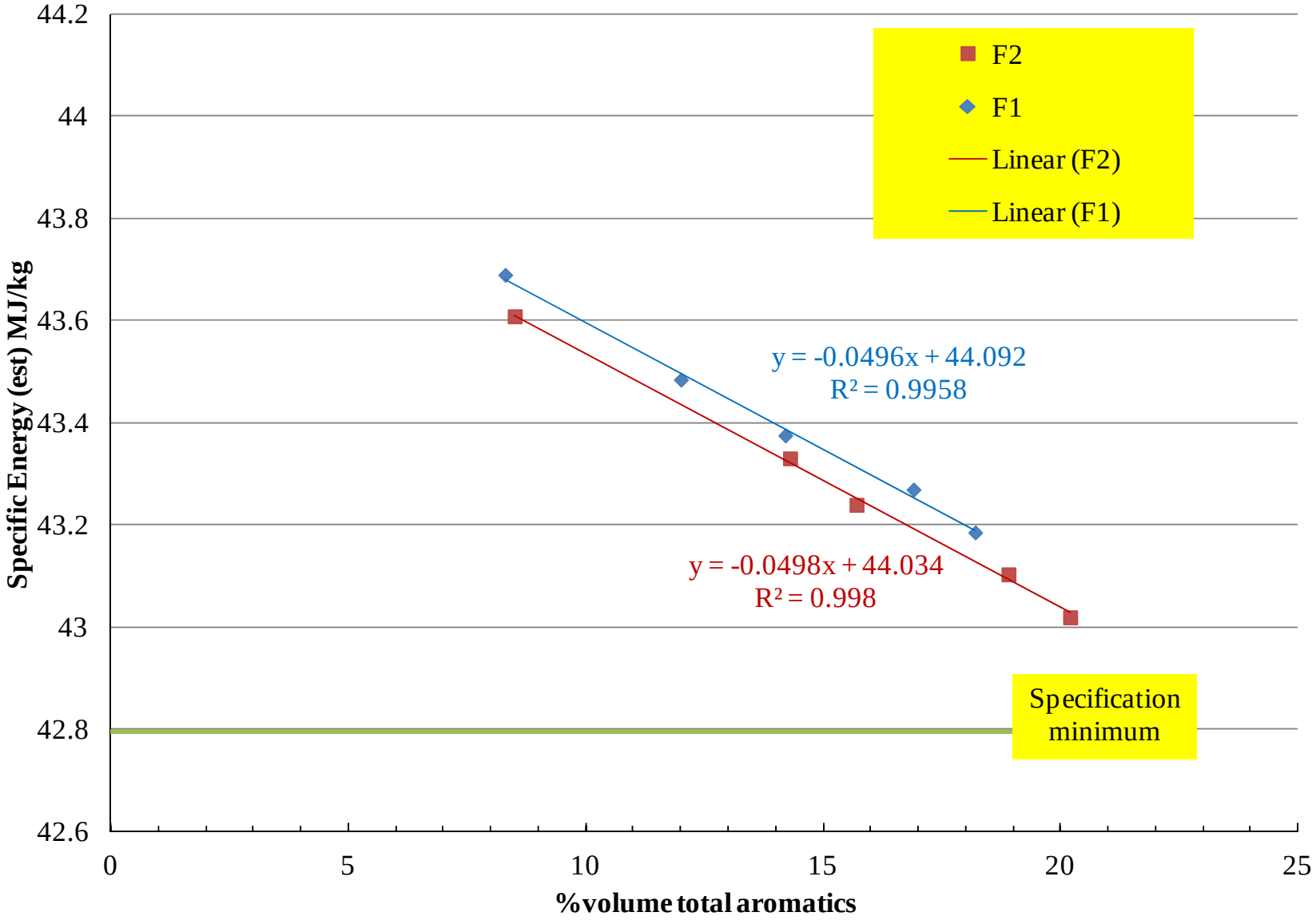
Estimated specific energy as a function of total aromatics



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Ground engine testing – 1 - Overview

- Cessna Citation II
- P&W JT15D-4 engines
- Test fuels to starboard engine
  - On-site fuel change & checks
- Performance data capture & analysis
- Measurements
  - On-board
  - Post test engine inspection

- ICAO LTO cycle
  - 4 engine settings
- One extra setting - cruise

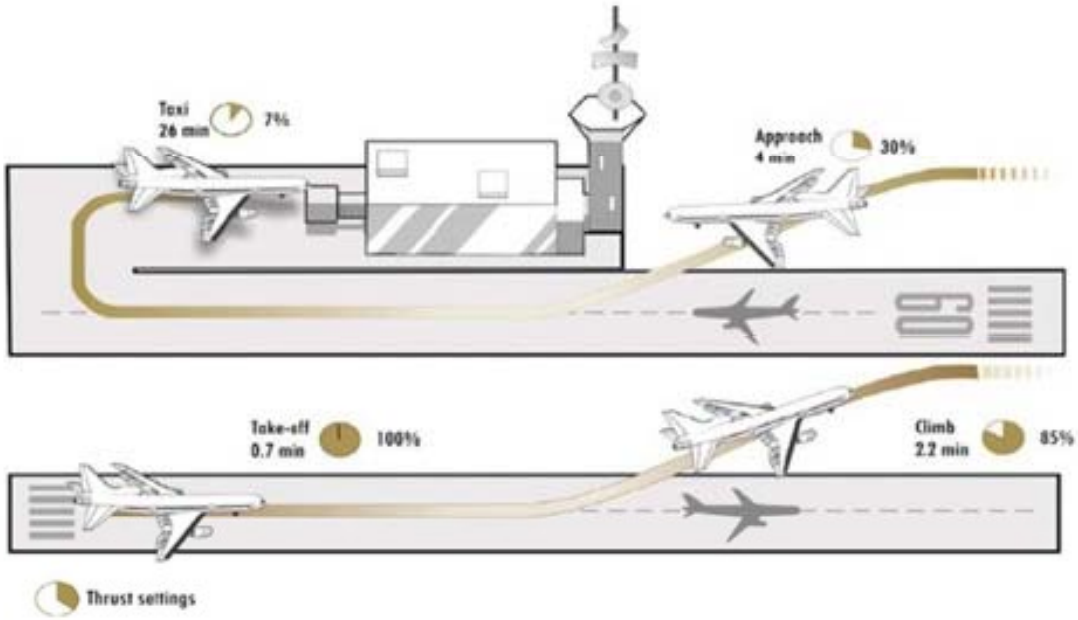

Figure 1 - Illustration of ICAO Emissions Certification Procedure LTO Cycle.
Source: ICAO.

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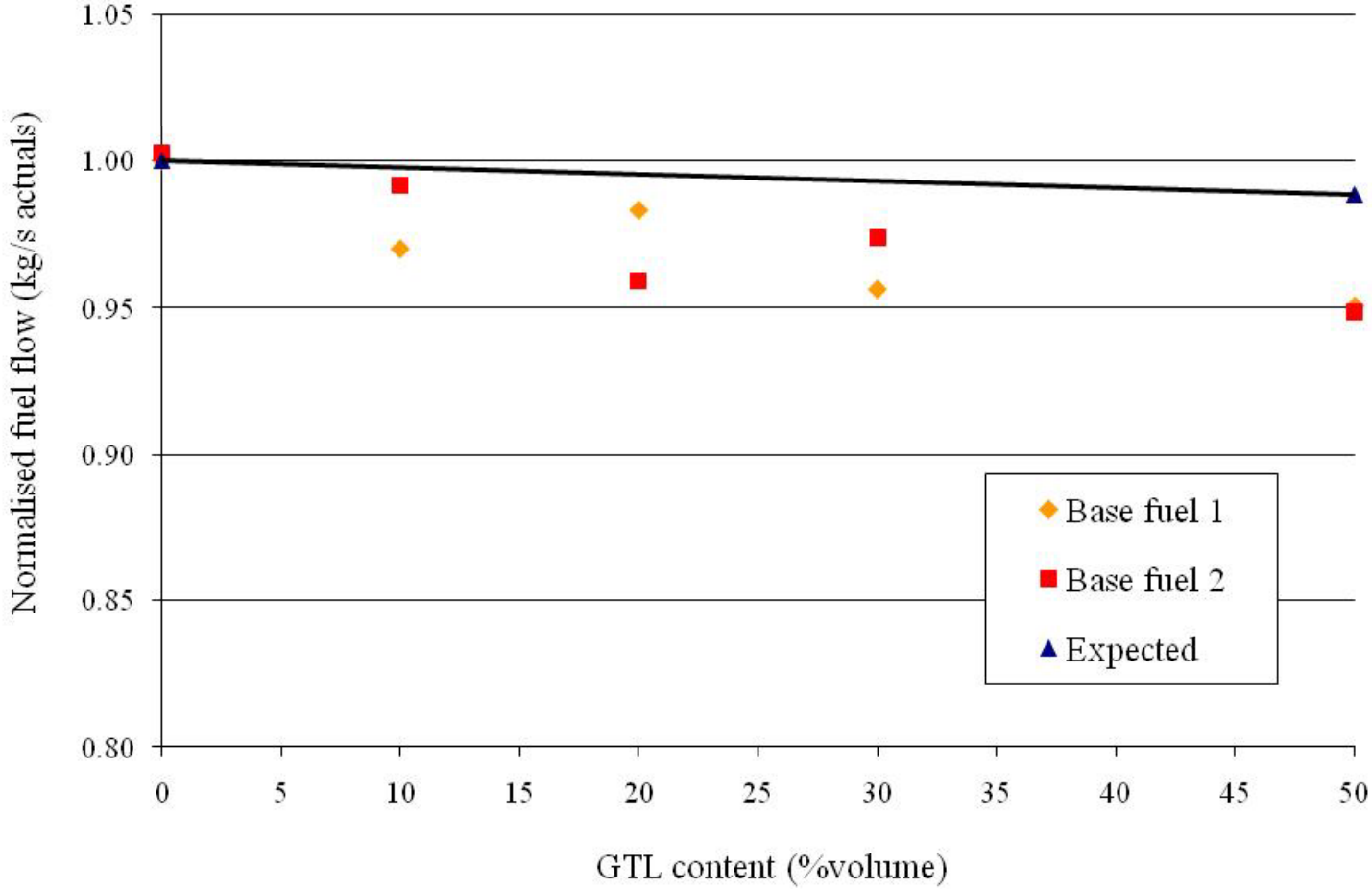
Ground engine testing – 2 – Fuel consumption

- Fuel consumption at constant engine setting
  - Greater fuel flow reduction than expected from fuel LHV, e.g. Cruise:



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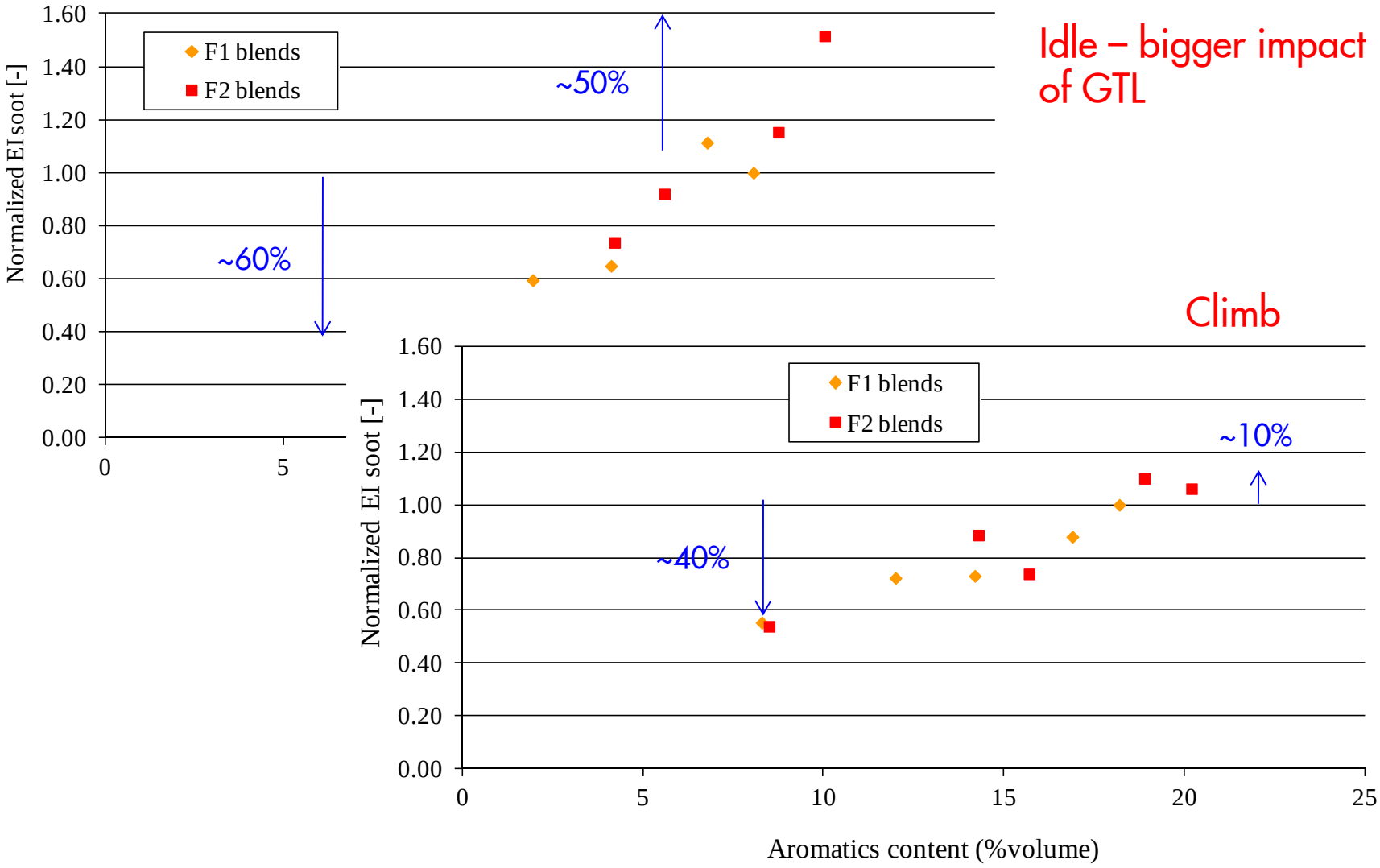
Emissions Testing – Soot at idle and climb



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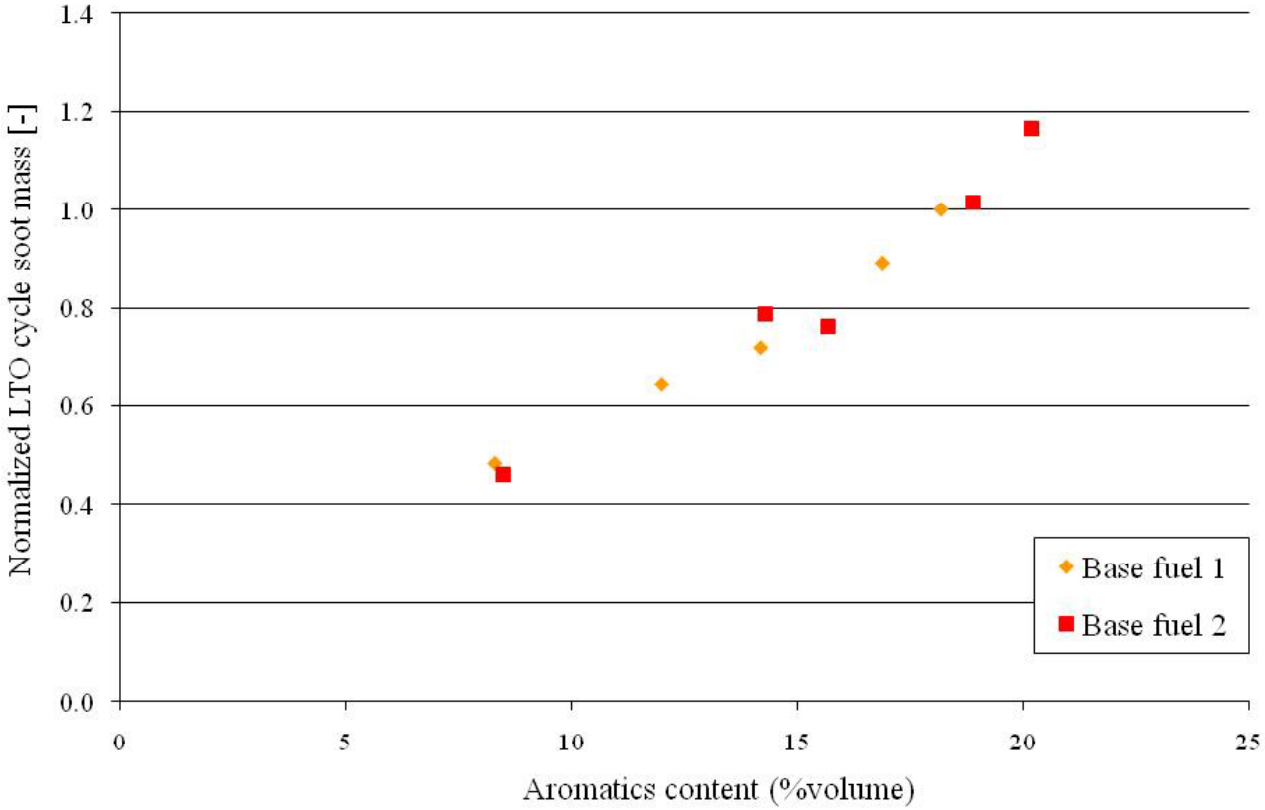
Emissions Testing – 2 – LTO cycle soot

LTO cycle soot emissions versus aromatics content



Also, Particulates – mean diameter, EI(PN) and EI(PM) - all reduce with GTL for both base fuels and across conditions

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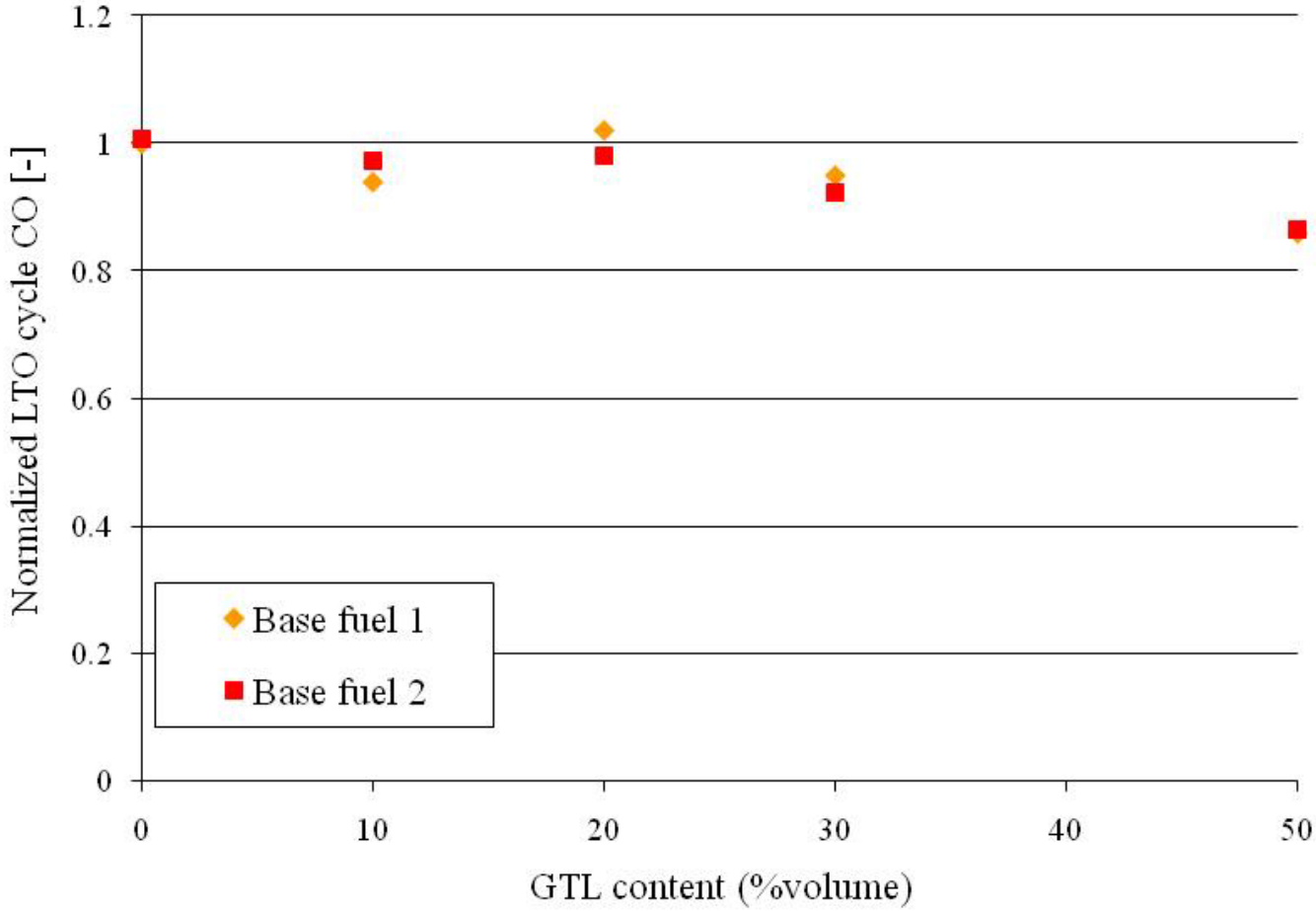
Emissions Testing – 3 - CO

Normalised LTO cycle CO emissions vs GTL content



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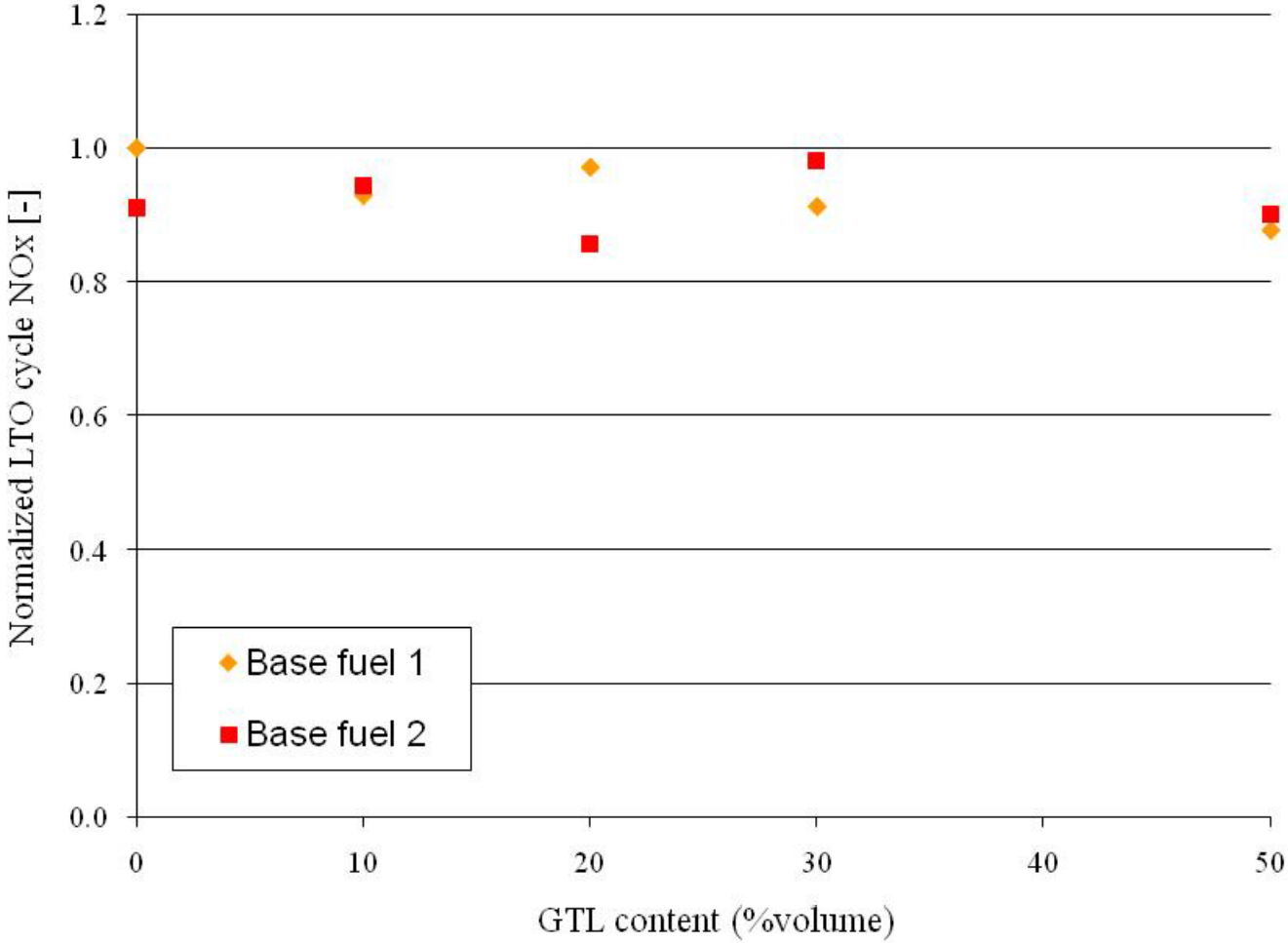
Emissions Testing - 4 - NO_x

LTO cycle NOx emissions vs GTL content



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Emissions Testing – 5 - Learnings and leads

- Increasing GTL content of fuels improves most emissions at one or more power settings of ICAO test protocol
  - EI(m) of particulates trends lower with increasing % GTL, decreasing aromatics content. Minor effect, if any, of aromatics type.
- Improvements can be seen at GTL contents below 50%
  - Gas sampling line particulates taken from gas sampling lines drop off rapidly, with step improvements 10 to 20 to 30%.
  - Improvement increases with reduced power setting.
- Other gaseous improvements more subtle
  - Expected SO_x reductions are seen, though measurement below instrument threshold for ultra-low sulphur fuel.
  - Small NO_x improvements (some fuels), & CO improves at 50% GTL.

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TUD IASH paper conclusions were:

- Models predict payload/range improvements with SPK
  - LHV is linear by volume with composition
  - (LTO Fuel flow to GROUND engine reduced even more)
- Smoke reductions predicted from lab tests, but not simple function of total aromatics content reduction/SPK increase
- GTL kero/Jet A-1 blends (0-50%) improve emissions from aircraft engines compared with Jet A-1 base fuel
  - SO_x as predicted; NO_x and CO less than expected
  - Soot/particulates significantly decreased

Subsequently, Dutch authorities gave permission to fly, and in Q1 2012 blends above 50% were flown. No issues. Results being analysed.

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Future options

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FLITES targets

Penetrate turbine and fuel performance via exhaust plume :

- **Soot imaging :** CW-Laser-Induced Incandescence
- **CO_2 imaging :** Near-IR absorption tomography
- **Unburned HC imaging :** Mid-IR absorption tomography
- **NO measurement :** Line-of-sight through plume
- **Make measurements as function of:**

  - Engine condition

  - Bio-fuel content

References

- Tim A. Snijders, Joris A. Melkert, Joanna M. Bauldreay, Paul F. Bogers, Claus R. M. Wahl and Manfred G. Kapernaum, "Impact of fuel composition on emissions and performance of GTL Kerosine blends in a Cessna Citation II", IASH 2011, the 12th International Conference on Stability, Handling and Use of Liquid Fuels,16-20 October 2011, Sarasota, Florida, USA.
- Joanna M Bauldreay, Paul F Bogers and Ali Al-Sharshani, "Use of surrogate blends to explore combustion-composition links for synthetic paraffinic kerosines", IASH 2011, the 12th International Conference on Stability, Handling and Use of Liquid Fuels,16-20 October 2011, Sarasota, Florida, USA.
- T. Snijders and J.A. Melkert, "Evaluation of safety, performance and emissions of synthetic fuel blends in a Cessna Citation II", given at the 3AF/AIAA Aircraft Noise and Emissions Reduction Symposium (ANERS), Marseilles, France, 25-27 October 2011.

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Q&A

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