ALFA-BIRD: Alternative Fuels and Biofuels for Aircraft Development

Overview of main results

prepared by Dr Marina Braun-Unkhoff (DLR) and the Steering Committee based on a collaborative work within Alfa-bird, a FP7 EU project (co-ordinator O. Salvi (EU-VRi) and Airbus)

2nd AirTN Forum
Greening and independence from fossil fuels
8th – 9th October 2012
Frankfurt Airport, Germany
Alfa-bird
Alternative Fuels and Biofuels for Aircraft Development

- Introduction
- Basics – Consortium, Main objectives, Tasks
- Results – achieved (examples)
  - SP 1 Overview of potential alternative fuels
    - Selection of fuels
  - SP 2 Assessment of the suitability
    - 2.1 Exp. tests for injection and combustion laminar flame speed, ignition delay time, species profiles, particles,
    - 2.2 Engine system integration
    - 2.3 Aircraft system integration
    - 2.4 Safety, standards and regulations
- Key Points and Outlook
Aviation Fuels

past

operation

efficient, low emission, safe (specification)
Aviation Fuels 
*nowadays*

**sustainability**

**security of supply**

**price**

**operation**

efficient, low emission, safe (specification)
Aviation Fuels Criteria

operation
- efficient, low emission, safe (specification)

commitments
- available, economic, sustainable

production
- CO₂ reduction by 50%
- NOx reduction by 80%
- Noise reduction by 10dB

policy
- energy policy for Europe
- limit T increase to 2 °C
- renewable energy roadmap
- binding 20% target till 2020
- ETS: aviation included 2012
Alternative Aviation Fuels
Incentives and programmes, Europe

- **JTI CleanSky**
  public-private partnership, 1.6 bil. € (EC: 800 bil. €)
  improvements of aviation & turbine industry
  to achieve ACARE goals

- **Single European Sky ATM Research (SESAR)**
  public-private partnership, 1.9 bil. € (EC: 1.4 bil. €)

- **Alternative Fuels and Biofuels for Aircraft Development (ALFA-BIRD)**
  EU/FP7 co-operation/RTD

- **Biofuels in EU Strategic Energy Technologies (SET-Plan)**
  2010 European Industrial Bioenergy Initiative (EIBI)
  EU Biofuel Flightpath

- **Sustainable Way for Alternative Fuels and Energy for Aviation (SWAFEA)**
  Study, European Commission
Alfa-Bird: basics

Basics

- Alternative fuels and biofuels for aircraft development
- Start July 2008, End June 2012
- 24 main beneficiaries from 8 countries
- European Commission – Directorate General Research
  7th Framework Program, Aeronautics and Air Transport (AAT)
  RTD project, total budget 9.7 MEuro, EU Grant 6.8 MEuro.
Alfa-Bird: main objectives

Basics

- Alternative fuels and biofuels for aircraft development
- Start July 2008, End June 2012
- 24 main beneficiaries from 8 countries
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Main objective

- To develop the use of alternative fuels in aeronautics with a middle / long term perspective.
  - Considering the possibility of revisiting fuel specifications
  - Re-considering the whole aircraft system (fuel, engine and ambience)
Alfa-Bird: workplan

SP1: Overview of potential alternative fuels

SP2: Assessment of the suitability of alternative fuels for aircraft

SP3: Technical analysis and future alternative fuels strategy

SP4: Overall management and support (including Advisory Group & IPR management)

14 WP
44 tasks
52 deliverables
9 Milestones
SP1 Selection of the 4 main promising pathways

Fuel survey and economy: selection of 12 blends

Biomass

Bio-Oil extraction

Hydrolysis / Fermentation

Gasification

Bio-Oils

Ligno-cellulosic Bio-conversion

Pyrolysis / Liquification

Syngas

Esterification

Hydrotreatment

Ethanol / C2+ Alcohols

Methanol synthesis

Shift reaction

Fischer-Tropsch process

Esterification

Hydrotreatment

Naphthen. SynJet

Methanol

Hydrogen

FT SynJet

Certified: SSJF 1999
FSJF 2008
FT-SPK 2009
HEFA-SPK 2011

M. Braun-Unkhoff (DLR) on behalf of ALFA-BIRD team
SP1 Selection of the 4 main promising pathways

Fuel survey and economy: selection of 12 blends

- Blends could be outside Jet fuel specification compositional boundaries

- FRL: Fuel readiness level defined by CAAFI, a measure of the fuel’s progress towards full commercialization

- Fuel matrix built around three axes
  
  - Paraffinic compounds → FRL 7-9  *Short term view*
  - Naphthenic compounds → FRL 3  *Middle term view*
  - Oxygenated compounds → FRL 1  *Long term view*

- Based on standard characterization
  
  ASTM D7566: allowing up to 50% Fischer-Tropsch fuels
  
  "synthetic paraffinic kerosene" SPK in jet fuel blends

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FSJF: Fully Synthetic Jet Fuel
FT-SPK: Fischer-Tropsch Synthetic Paraffinic Kerosene
FAE: Fatty Acid Esters
HRJ: Hydrotreated Renewable Jet fuel
SP1 Selection of the 4 main promising pathways

Alternative Fuels selected

- Two 100% synthetic jet fuels
  - CtL (FSJF)
  - GtL (FT-SPK)

- Two blends
  - GtL + 20% 1-hexanol
  - GtL + 50% naphthenic cut

- FSJF \textit{for relative comparison}
- Jet A-1 \textit{for absolute comparison}

FRL
- 3-6, mid-term view (certified 2008)
- 7-9, short term view (certified 2010)
SP2 Assessement of the suitability

WP2.1 Experimental tests for injection and combustion
  - Existing fuels (CALIN)
  - New alternative fuels

Knowledge on real behaviour of fuels in engine

WP2.2 Engine system integration
  Characterisation of material compatibility

WP2.3 Aircraft system integration
  Characterisation of operational compatibility

Data and knowledge of 3-5 new alternatives fuels for operational use in aircraft

WP2.4 Safety, standards and regulations
  Recommendations New specifications

SP3 Technical analysis and future alternative fuels strategy

TP 2.1.1–2.1.3
ONERA, TU Graz, DLR, ICARE, Toronto KIT (Uni Ka)

TP 2.2.1–2.2.6
RR-UK IFP ONERA USFD Technologica Airbus F

TP 2.3.1–2.3.2
DASSAV Airbus UK Technologica

TP 2.4
INERIS Airbus UK
Focus on selected SP2 / SP3 results

SP 2.1 Injection and Combustion
Atomization – Evaporation under non-reactive conditions

LACOM tests – Main results
- Similar behavior of the AF with respect to:
  - spray geometry, granulometry, velocity distributions @ op. conditions
  - $1 < p < 10 \text{ bar} ; \quad 293 < T < 553 \text{ K} ; \quad \text{industrial injection system}$

![Spray semi-angle](image1)

![Droplet velocity axial](image2)

![Sauter mean diameter](image3)
Focus on selected SP2 / SP3 results

SP 2.1 Injection and Combustion
Detailed investigation of oxidation – species: towards reaction model

JSR tests – Main results
- All 4 fuels studied; initial fuel conc. = 1000 ppm
- $p = 10$ bar, $T = 550-1150$ K, $\tau = 1$ ms; $\varphi = 0.5; 1; 2$.
- Complex kinetic scheme built for each fuel (surrogate)
- Kinetic model used for prediction of laminar flame speed and ignition delay time

Gtl+50% naphthenic cut, $\varphi = 1$; $p = 10$ bar; $t = 1$ ms
Focus on selected SP2 / SP3 results

Combustion Properties

- Laminar flame speed
- Ignition delay time

Alternative fuels compared to Jet A-1
- All tested fuels exhibit quite similar
- No show stoppers, but beware of specs.
Focus on selected SP2 / SP3 results

SP 2.1 Injection and Combustion
Emissions: Laminar coflow flames test rig

Soot formation - Main results

- Gaseous species concentrations, soot volume fraction, temperature
- Sooting tendency: Jet A-1 > FSJF > SPK+nc > SPK >SPK+1-hexanol
- Species concentrations and temperature profiles similar
- FSJF and SPK + naphthenic cut have the same behavior

**Soot Concentration Profiles**

- Averaged over 1 min
- Acquisitions repeated 3-10 times
- Highest soot: Jet-A1
- Lowest soot: SPK+Hexanol

**Smoke Points and TSIs**

- Smoke points by ASTM D1322
- TSI = 3.32 $\left( \frac{MW_{SP}}{SP} \right) - 1.47$

- **Fuel**
  - Jet-A1:
  - FSJF:
  - SPK:
  - SPK+ Naph:
  - SPK+ Hexanol:

- **Aromatics (v%)**
  - Jet-A1: 18.5
  - FSJF: 10.7
  - SPK: < 0.1
  - SPK+ Naph: 4.6
  - SPK+ Hexanol: < 0.1

*measured by ASTM D1310 method
*measured by IP 438 method
Focus on selected SP2 / SP3 results

SP 2.2 Engine system integration
Material compatibility

Stress relaxation tests – Main results
- 3 materials tested: nitrile, fluorosilicon, fluorocarbon
- Best compatibility for fluorocarbon O-rings
- Nitrile O-rings easily affected by fuel's composition (esp. aromatic content)
- Impact of changes of chemical structures on stress relaxation process

Nitrile

Fluorocarbon
Focus on selected SP2 / SP3 results

SP 2.2 Engine system integration
Material compatibility: Performance elastomers/non-metallic materials

Ageing tests – Main results

- Similar behavior of CtL, GtL, GtL + 50% naph. cut with the 3 elastomers
- Hexanol greatly weakens NBR and FVMQ
- FKM is the best elastomer in terms of ageing

Test on polymers: Ageing tests

- Tensile properties and hardness
  - NBR
  - Control = 170%
  - Strong thermal effect
  - (Additives loss up to 7%)
  - Hardness

- Swelling: Amount of sorbed fuel after the test
  - FKM and FVMQ
  - No big differences CtL, GtL and GtL+naph
  - More sensitivity to presence of hexanol

- NBR
  - Fuel sorption depends on the aromatic contents except with alcohol
Focus on selected SP2 / SP3 results

SP 2.2 Engine system integration
Evaluation of the fuel thermal stability

**HIRETS – Main results**
- \( \text{GtL} > \text{GtL} + 20\% \text{ hexanol} > \text{CtL} > \text{GtL} + 50\% \text{ naph. cut} \)
- Concerns about \( \text{GtL} + 50\% \text{ naphthenic cut} \)

CtL

GtL + 50% naphthenic cut
SP 2.3 Aircraft system integration

Operational compatibility (aircraft system): Elastomers

Permeability tests – Main results

- 3 elastomers tested: NBR, FVMQ, FKM,
- Best compatibility for fluorocarbon O-rings
- No large differences for FSJF, FT-SPK, FT-SPK + 50% naphthenic cut
- Increase of permeability for the blend GtI + hexanol (diffusion)
Focus on selected SP2 / SP3 results

SP 2.3 Aircraft system integration
Operational compatibility: Gauging, test on fuels

Gauging issues – Main results

- GtL and, to a minor extent, CtL are close to drop-in fuels
- GtL + 20% hexanol, GtL + 50% naph. cut are not drop-in fuels
Focus on selected SP2 / SP3 results

SP 2.4 Safety, standards, and regulations
Flammability domain: Shifts wrt to altitude

![Graphs showing flammability limits for different altitudes and temperatures for Jet A and Jet A + hexanol.](image)
SP3 Technical analysis and future alternative fuels strategy

WP3.1 Environmental balance
Analysis of emissions (CO₂, NOx, soot...) for the life-cycle of alternative fuels

WP3.2 Economical evaluation
New method for economical evaluation of alternative fuels
Result of the analysis

WP3.3
Future alternative fuels strategy for aircraft and implementation
Focus on selected SP2 / SP3 results

SP3 : LCA, business model and socio-economical analysis

BIOFUEL SUBSTITUTION MODEL

MODEL PARAMETER

- [%] installed capacity Gtl: 30
- [%] installed capacity BTL/CL: 40
- Carbon tax [ct/l]: 0.7

Time period

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Oil price change

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Comment on current run:

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SP2 / SP3 results : synthesis

Synthesizing fuel assessment, to give an alternative fuel ranking

- Reference fuel: FSJF (CtL, 100% from coal), Jet A-1 used as an anchor

- Compared fuels:
  - Alfa-bird fuels: FT-SPK (GtL), GtL+50% NC, GtL+20% 1-hexanol
  - SWAFEA fuels: HEFA, HEFA + 50% NC, HEFA+25% Jet A-1, Jet A-1+10% FAE

- 4 Categories with several criteria:
  - Technical & Technological
  - Regulation
  - Environmental
  - Economical

- 4 possible results for each criteria assessment
  - Better than CtL or Jet A-1
  - As good as CtL or Jet A-1
  - Worse than CtL or Jet A-1
  - Questionable
### SP2 / SP3 results: synthesis

#### Synthesis table (1)

<table>
<thead>
<tr>
<th>Category</th>
<th>FT-SPK (GtL)</th>
<th>FT-SPK + 50% naphthenic cut</th>
<th>FT-SPK + 20% hexanol</th>
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<td>9 X 23 X 3 X</td>
<td>8 X 14 X 10 X</td>
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<td>1 X 2 X 1 X</td>
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<td>4 X</td>
<td>3 X</td>
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<td>X</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>13 X 27 X 3 X</td>
<td>12 X 16 X 11 X</td>
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<td><strong>Assumed Ranking</strong></td>
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</table>

Comparison with CtL (FSJF)
## SP2 / SP3 results: synthesis

### Synthesis table (2)

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<tr>
<th>Category</th>
<th>FT-SPK (CtL)</th>
<th>FT-SPK (GtL)</th>
<th>SPK + 50% NC</th>
<th>FT-SPK + 20% hexanol</th>
<th>HEFA 100% HVO</th>
<th>HEFA + 50% NC</th>
<th>HEFA + 25% Jet A-1</th>
<th>Jet A-1 + 10% FAE</th>
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<td>-</td>
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<tr>
<td>Economical</td>
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<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Total</td>
<td>4 X</td>
<td>1 X</td>
<td>1 X</td>
<td>1 X</td>
<td>2 X</td>
<td>4 X</td>
<td>1 X</td>
<td>5 X</td>
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</tbody>
</table>

*Comparison with Jet A-1*

- NBR, FVMQ, FKM permeability test

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M. Braun-Unkhoff (DLR)
on behalf of ALFA-BIRD team

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Synthesis: Conclusions (1)

→ **Main technical problem in alternative fuel due to %aromatics** (mass density)
  → Need at least 8% aromatics → Assess the optimized aromatic quantity (minimum requirement)

→ **Material compatibility is critical** (stress relaxation, elastomers)
  → e.g. nitrile elastomer, the most used in aeronautics → problem X for all Alfabird fuels
  → Material compatibility tests are separated = weighting more than other criteria

→ **Economical assessment** shows that for the moment alternative fuels studied within Alfabird are not competitive compared to conventional production processes
  → But there are leads to explore to improve the situation (incentives, market based measures...)

→ **GHG emissions**: CtL > GtL + CCS ≥ Jet A1 > HEFA/BTL
  → But measurements and experiences are mandatory to adjust the results and have a better estimation

→ **FSJF (CtL from SASOL) offers a constant and controlled quality reference**
  (compared to Jet A-1 which may be variable in content composition)
Synthesis: Conclusions (2)

- **GtL seems to have better technical performance compared to GtL+NC/hex** (except for stress relaxation of nitrile O-ring) but impact on environment is mitigated and seems to be rather negative (based on LCA, compared to Jet A-1)

- **GtL+ NC is very interesting**, the one that mimic the most Jet A-1 composition
  - Comparable properties with better density than neat GtL (except for stress relaxation of nitrile O-ring)
  - NC might come from sustainable feedstock (liquefaction/pyrolysis), in the future

- **Oxygenated fuels are not “drop in” (GtL + hexanol and GtL + FAE)**
  - But interesting in a long term view because of the improvement of environmental impact and some fuel properties. Technical barrier could be break as for the freezing point for FAE, showing rooms for improvement for the future
  - Other tests could be done with other ratios? other alcohols? Other paraffinic cut?
  - Improvement of oxygenated fuel properties might be compromised - too challenging concerning the aircraft/engine architecture

- **For “non drop-in” fuels**
  - Need to find an adequacy (doing compromises) between fuels, airframe/engine architectures, operations and logistics (fuelling infrastructures)
Synthesis: Conclusions (3)

- Biomass feedstock could improve environmental impact
  - HEFA/BtL are the most interesting fuels
  - HEFA and XtLs have been certified with a blend of 50% with Jet A-1
  - Blends outside of certification range from SWAFAEA compared to Jet A-1
    - No test failures for the moment except for Jet A-1 + 10% FAE
    - 100% HEFA should have the same behaviour than 100% XtLs

- 100% BtL supposed to have same behaviour & characteristics than XtLs
  - We cannot verify and test because BtL is not available

- From Alfa Bird WTT analysis and from SWAFAEA LCA analysis:
  - LCA better for 100% BtL and 100% HEFA than all other alternative fuels tested due to sustainable biomass (if available!)
  - BUT Land Use Change is not taken into account
    - LUC has an important impact according to the geographical location
    - iLUC and LUC need to be assessed in the frame of a global agreed methodology (RSB standards) (e.g. EU-VRi and R-Tech innovative tool)
Alfa-bird: Alternative Fuels and Biofuels for Aircraft Development

Conclusions and prospects

- **Alfa-bird** is a R&D project with the objective of looking forward

- next steps envisaged on sustainable alternative fuels
- need for follow-up & additional research
- Certification (e.g. minimum of aromatics, new protocol)
- Industrials (e.g. think about the evolution of the engine and fuel adequacy)

- FT-SPK + hexanol (20%) → FRL 1
- End of the programme: June 2012
- Final workshop: June 13th and 14th in Toulouse
The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° ACP7-GA-213266
Thank you for your attention!

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