Lufthansa Biokerosene Flight Evaluation Results

Dr. Alexander Zschocke, Lufthansa

4th international Conference on Biofuels Stadards

Gaithersburg, 22. October 2012

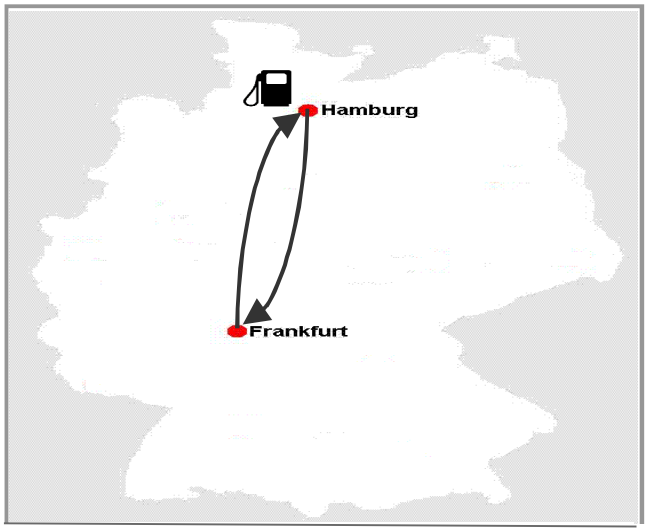
Burn FAIR: A321 in daily operation with HVO Biofuel

- Biofuel on scheduled passenger flights: First „green city pair“ worldwide
- Four daily roundtrips HAM-FRA-HAM with A321 for 6 months
- A/C fuelling in Hamburg only, but within Minimum Ground Time
- Research of engine performance: one engine to operate with 50% blend of HVO kerosene
- Joint research activity of 12 universities and industry partners under Lufthansa leadership
- Partly financed by German Ministry of Economics and Technology

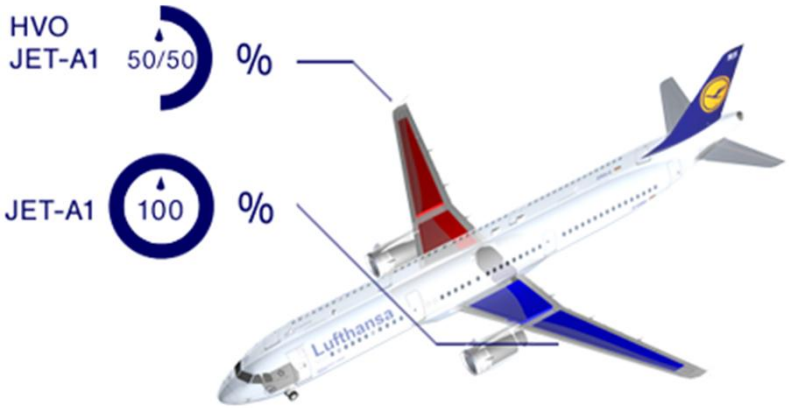
Why do a flight evaluation project?

- ASTM 7566 produced biofuel blends are essentially safe to use
  - Very similiar to conventional kerosene
  - Extensive tests by ASTM members
- However: Minor differences exist, and trouble can lurk in detail
- Safety issues unlikely, but operational issues possible
  - Lab tests cannot perfectly replicate operating conditions
  - Behaviour of large volumes conceivably different from that of small volumes
- Some particular concerns:
  - Potential unmixing of blend due to density difference
  - Microbiological contaminations
- Also, risk of unknown unknowns

Risk analysis



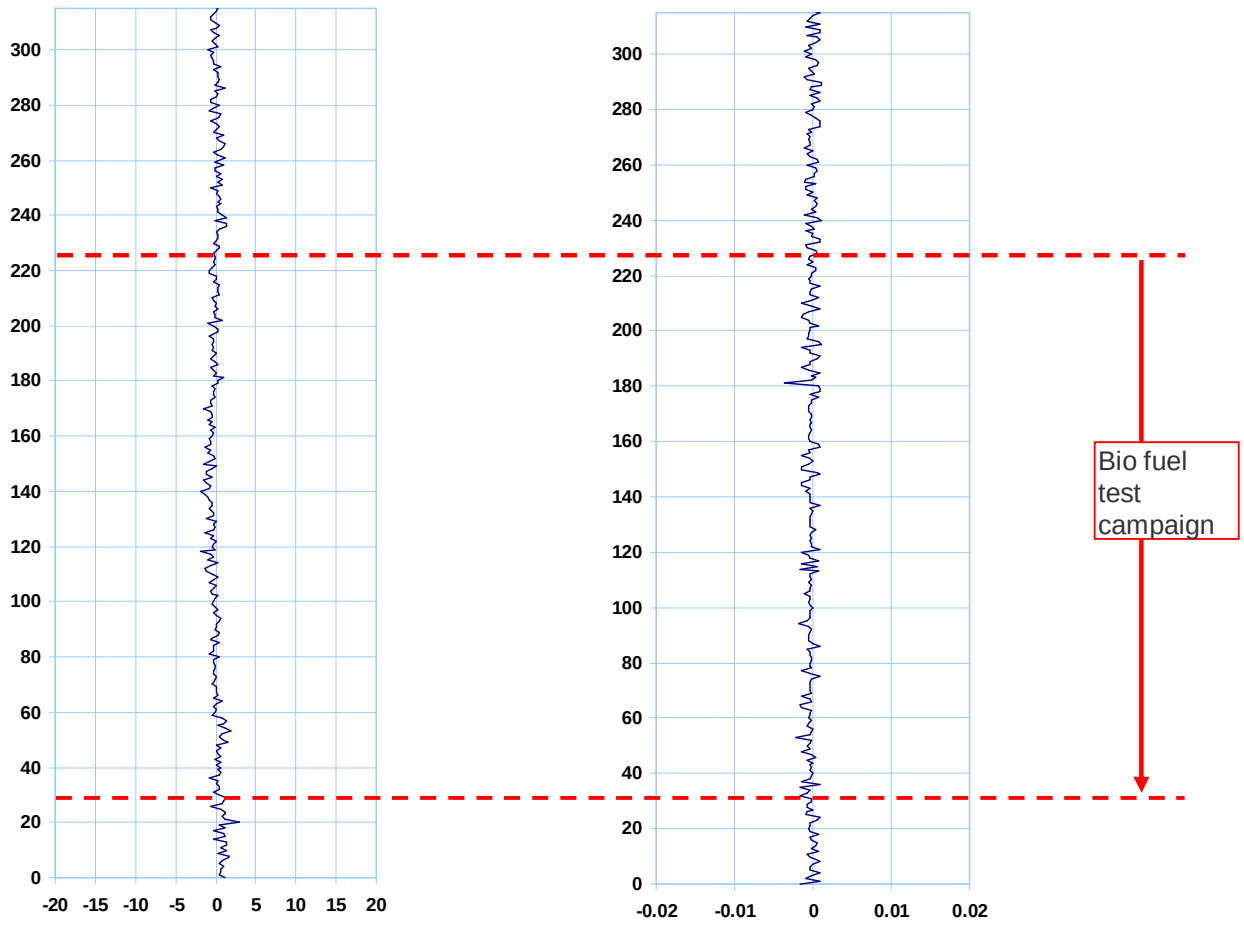
- Inherently safe set-up, as only one engine operated on biofuel blend
- Low-risk route
  - Chosen because FRA and HAM are maintenance bases
  - However, other considerations:
    * No flying over water
    * Severals alternates between FRA and HAM
- First flight with bio kerosene blend without passengers 12. July 2011
- Test of non-normal situations
  - In-flight engine relight
  - Gravity feed
- Smooth flight, no issues observed



In-service evaluation flights

- First commercial flight 15. July 2011
- Last flight 27. December 2011
- Total of 1.187 flights performed
- Fuel consumption 1.557 tonnes bio kerosene blend
- No operational issues reported by flight crews
- Engine parameters monitored during evaluation via ECM
  - Increase in frequency of downlinks
  - Evaluation of messages by MTU using proprietary software
  - Calculation of variances between predicted and actual parameters for both the bio kerosene and the reference engine, then calculations of difference between both engines
  - No significant differences between engines, and no trend

Cruise – EGT and N2 difference trend



Source: MTU

$\Delta EGT_{bio} - \Delta EGT_{conv}$ (K)

$\Delta N2_{bio} - \Delta N2_{conv}$ (%)

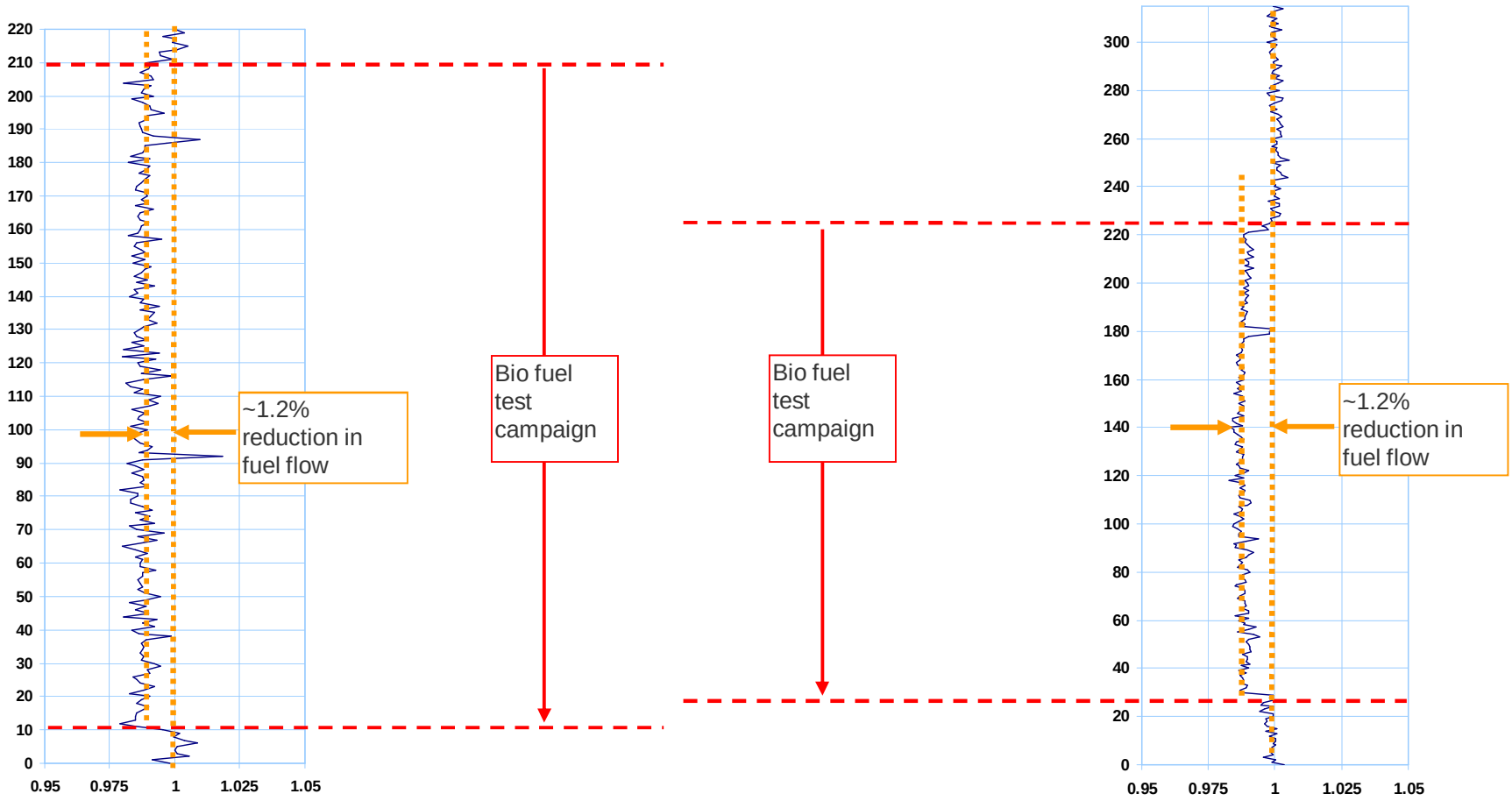
Fuel consumption

- Theoretical expectation before flight evaluation was of slightly lower fuel consumption (in tonnes)
  - Engines are unchanged
    ➡ Energy requirement is the same
  - Biofuel has no aromatics
    ➡ Energy density of biofuel is slightly higher

➡ Slightly less tonnes of biofuel blend should be required for the same thrust

- Energy density of biofuel blend: 43.68 MJ/kg
- Average energy density of conventional fuel at Hamburg airport: 43.27 MJ/kg
- Fuel consumption should be lower by 43.68/43.27 – 1 = ca. 1 per cent

Cruise Fuel Flow – Take-off and Cruise



qFF_{bio} / qFF_{conv} (-) Take-Off

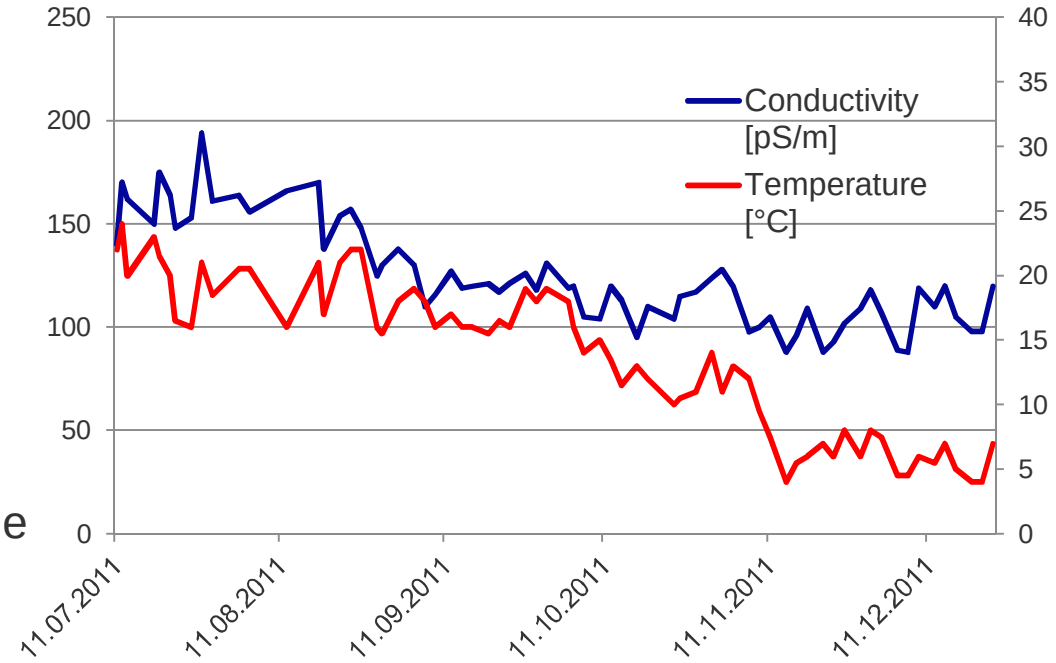
qFF_{bio} / qFF_{conv} (-) Cruise

Source: MTU

Fuel behaviour in tank

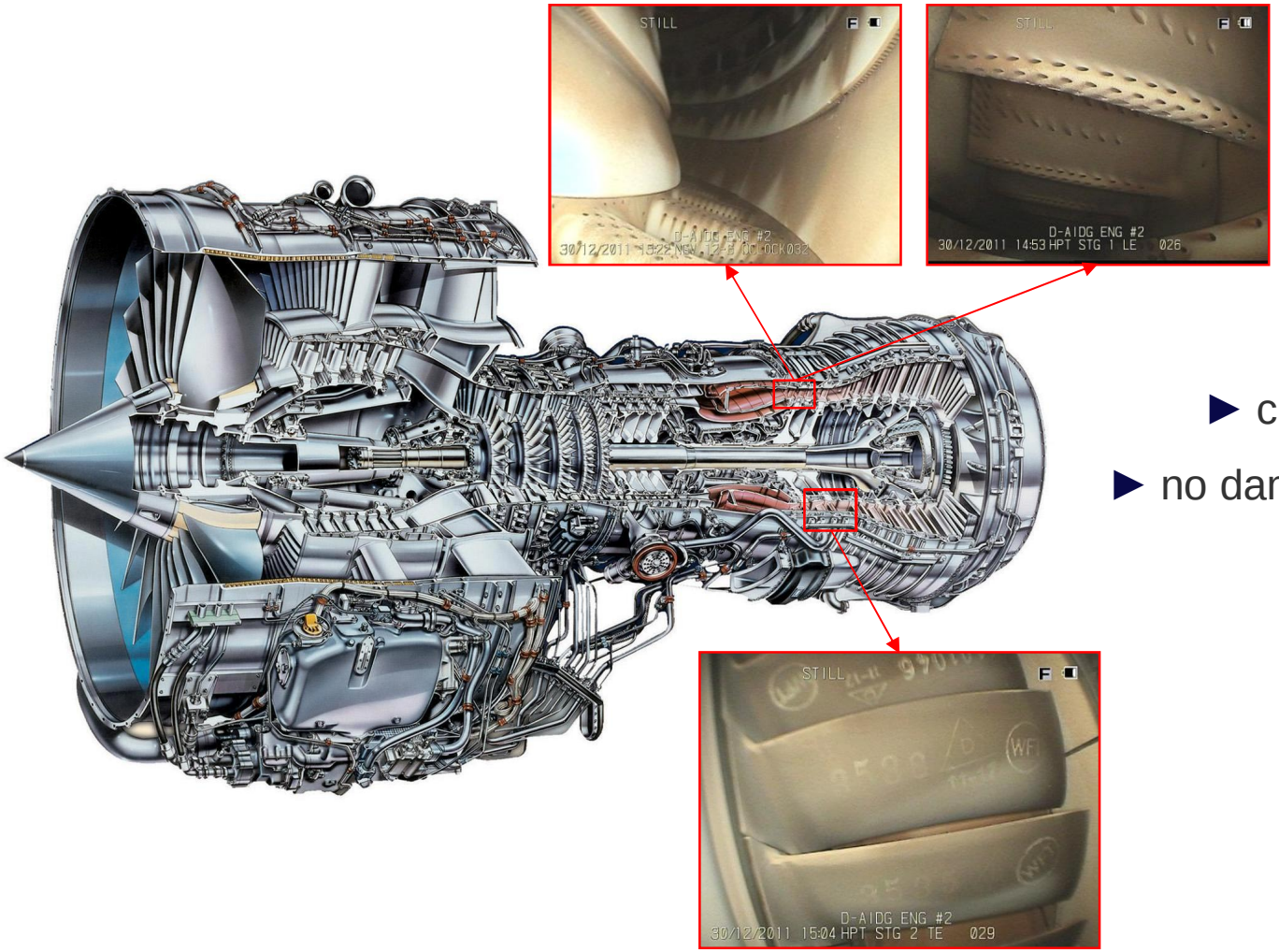
- No unmixing observed
  - Monthly tests of density at top, middle and bottom of tank
  - Density consistently at 0.783 throughout the tank
- No microbiological issues
  - Fuel drained from aircraft and inspected every nine days
  - Full lab analysis for microbial contamination performed 10.10.2011 (four months after product was put into tank)
  - No adverse findings, lab-determined microbial contamination levels at or below detection threshold
- Full ASTM D-1655 analysis performed after end of evaluation, all parameters on-spec

Conductivity behaviour



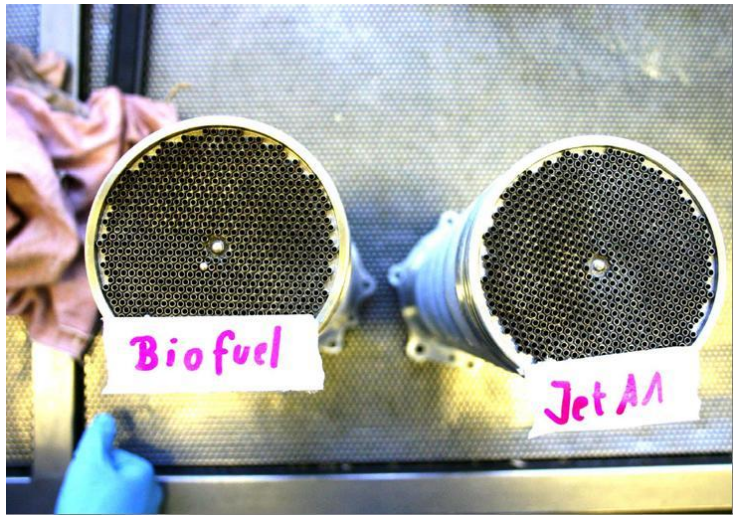
- Running sample conductivity regularly measured
  - Performed when trucking fuel from storage to airport
  - Sample frequency typically every two to three days
- Normal behaviour of running sample
  - Slow decrease of conductivity over time
  - Conductivity rising and falling in parallel with temperature
  - Conductivity always well above limit value of 50 pS/m
- For fuel sampled at bottom, slight rise in conductivity over time observed
  - Different from behaviour of running sample conductivity
  - Conductivity increase traced back to small accumulations of iron at bottom, due to the harbour tank being uncoated - not unusual, and not specific to bio kerosene

Post flight-evaluation boroscope inspection



- clean blades
- no damage to coatings

Post-flight evaluation of tank and fuel-bearing aircraft parts



- Tanks vented and inspected after end of flight evaluation
- No contamination found in inspected area; whole tank in very good conditions with no adverse findings
- Fuel bearing parts removed from aircraft after end of flight evaluation programme for detailed inspection
- Two findings
  - Yellow discolorations on bio kerosene side
  - Less fuel pump cavitations on bio kerosene side
- Removed parts are in good condition. Measured parameters are within limits. Seals and tightness were checked good

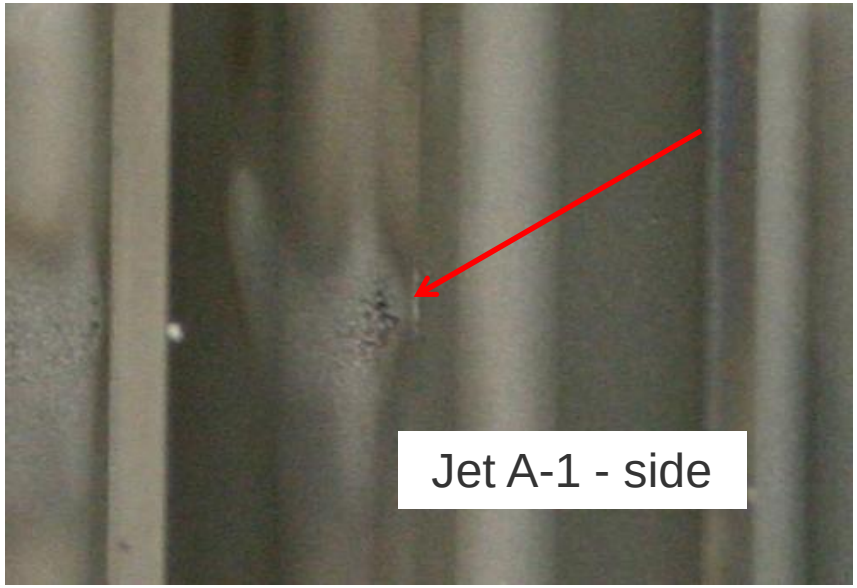
Yellow discoloration

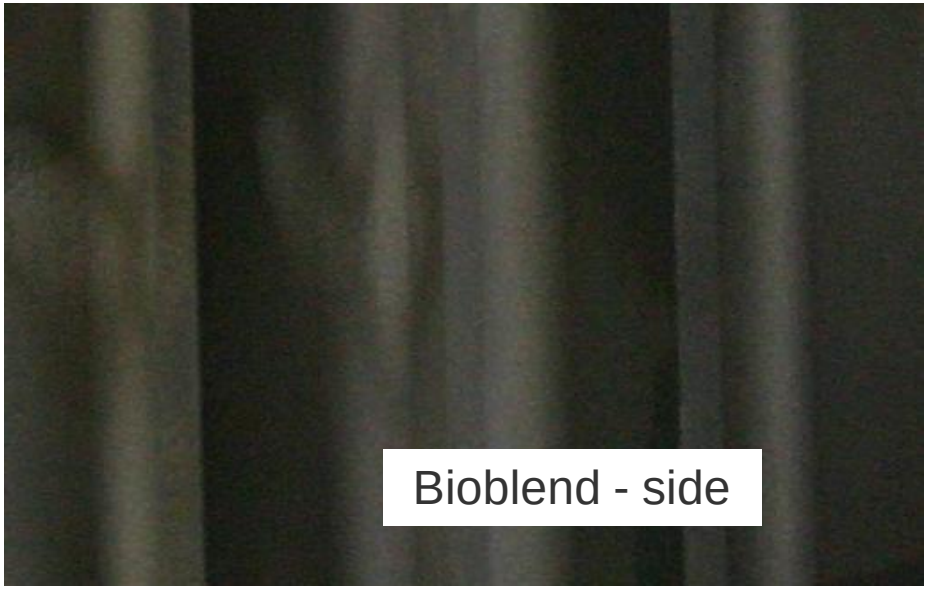
- Yellow discoloration present at bio kerosene engine side only
- Present at all fuel bearing parts between tank and engine where part was exposed to fuel flow
- Could largely be removed by cleaning
- Did not obstruct normal functioning of parts even before cleaning
- Cleaned pump parts analyzed by Airbus after discoloration had been removed by cleaning; no unusual surface impacts found
- Probably due to difference in sulphur content between conventional kerosene used for blending and conventional fuel used at Hamburg airport

Less fuel pump cavitations

- Impellers of fuel pumps powered by conventional kerosene show usual amount of cavitation damage

- Positive surprise on bio kerosene side: Visibly less cavitation impact on impellers of fuel pumps powered by bio kerosene blend, no open-pore damage as yet

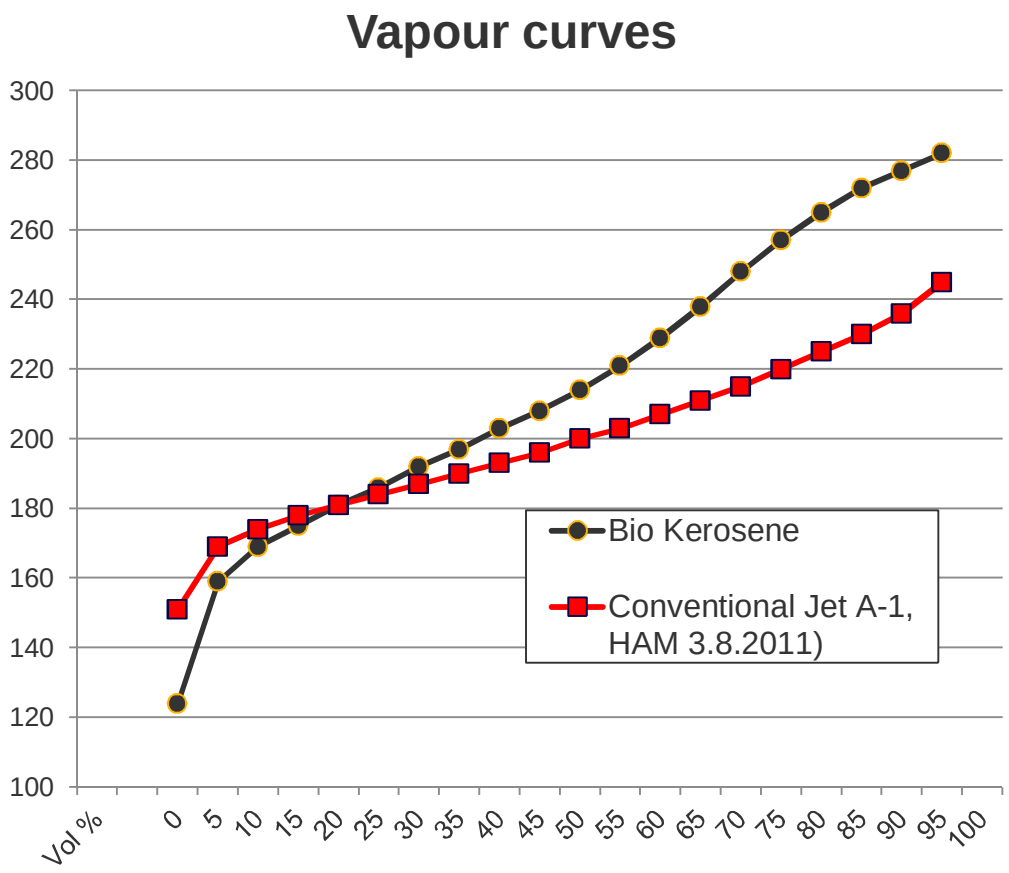




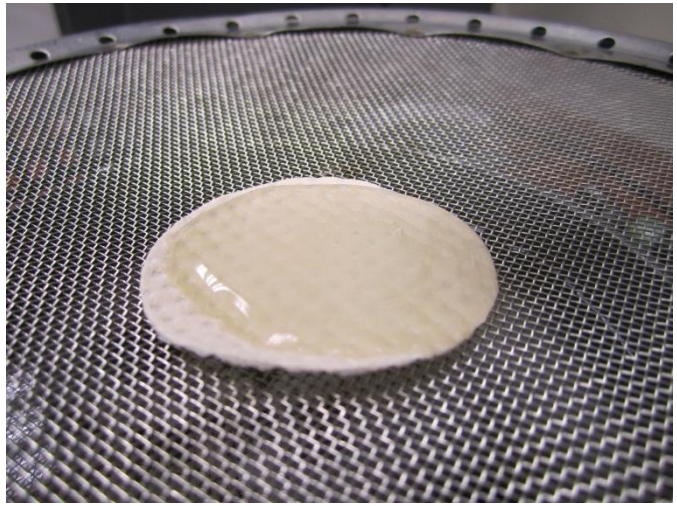
Probable reaon for impeller damage difference

- Lower impeller damage probably due to higher vapour curve of bio kerosene blend

- Caution:
  - Snapshot after less than 2,000 flight hours
  - Only about 10 % of typical flight time before impeller replacement
  - Longer observation time necessary for definite statement
  - Also, may well be batch-specific



Post-flight evaluation of fuelling equipment

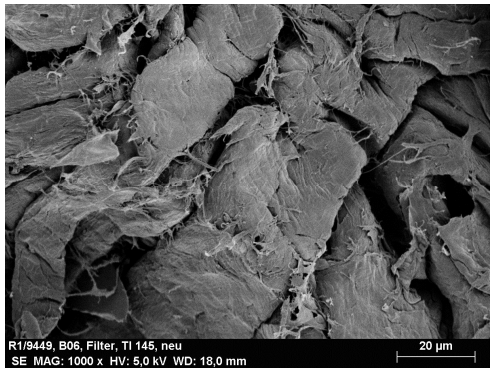


- All fueling of bio fuel blend done from one bowser
- Inspection of fuel monitor elements
  - New elements inserted before start of flight evaluation
  - After end of flight evaluation (total throughput 2.008 cbm), fuel monitor elements replaced and analysed in lab
- Overall performance of fuel monitor elements within specifications: Water Slug Test passed
- Water absorption capacity of individual SAP material
  - On spec behaviour of larger grained T150 material: Test passed
  - Hydrophobic behaviour of fine grained T145 material: Test <u>failed</u>
- Result verified by second lab using different sample of same filter material

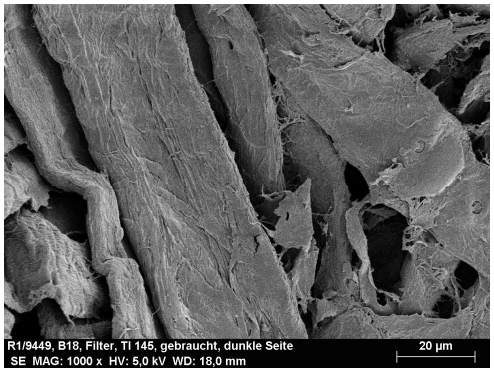
Investigation still ongoing

- No differences to new filter visible using electron microscopy

- No relevant findings using gas chromatography



New Filter



Hydrophobic Filter

- Some candidate findings identified using liquid chromatography

- However, analysis difficult due to lack of reference sample
  - Fuel elements typically only removed and analysed after throughput of tens of thousands of cbm
  - Unknown, how fuel monitor elements normally look like after 2,000 cbm of throughput

- To obtain reference sample, new filter inserted into bowser truck, used for routine fuellings of 2,000 cbm of conventional kerosene, and then removed

- Unfortunately, at time of receipt of reference sample, lab had to undergo unplanned major building work
  - Set back work by some two months
  - Building work now finished
  - Analysis results expected early December

Emission of particles

- Initial approach:
  Measure emissions from bio-blend engine and from reference engine, and compare

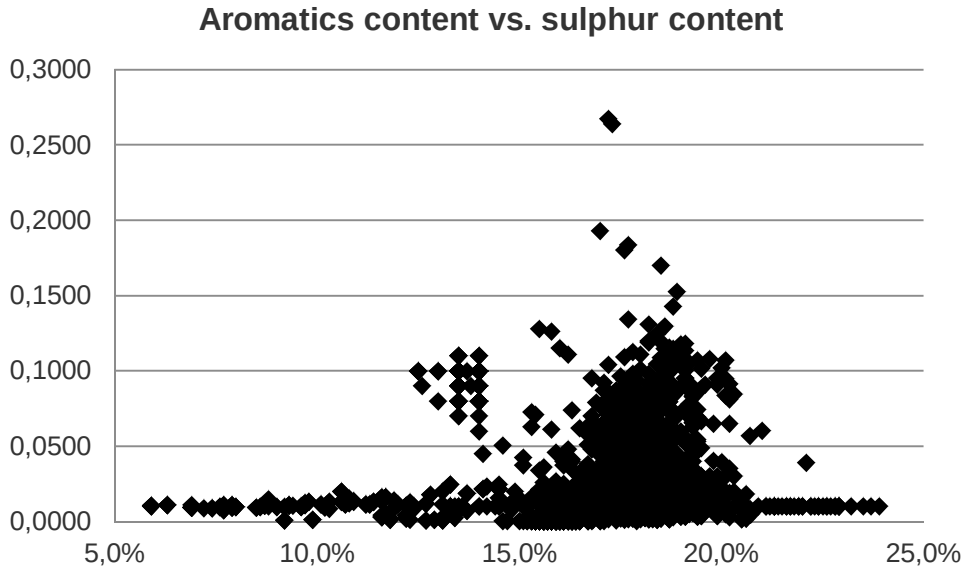
- However:
  - Bio-blend contains conventional fuel blended in Finnland
  - Fuel for reference engine is variable, depending on what fuel is used in Hamburg
  - As Hamburg kerosene was very low in sulphur, SO2-values for bio fuel blend emissions way higher than for reference fuel

- Need for parameters of conventional kerosene available for blending to be known
  - Analysis of actual parameters of kerosene fueled at German airports in 2011 started
  - Based on manual input of data from fuel supply certificates
  - Now in mid-work; some 1.700 certificates for nine airports entered already

Initial results

- Kerosene properties are highly heterogeneous

- There is no single conventional kerosene to compare to bio kerosene



- Using the identical fuel both for as blendstock and reference fuel should give a valid analysis of relative emissions performance. However, that analysis will be valid only for this specific fuel.
  For a different fuel, results may well be different.

- General analysis of bio kerosene emissions impact will require more complex approach

Workability of synthetic kerosene standards

- Production May / June 2011
  - Performed according to draft version of ASTM D 7566 version 11a
  - Identical with final wording
- No clarity on when new version of standard becomes official, permitting use of fuel by airline
  - Date of ASTM acceptance, or date of publication?
  - To play safe,flights only started on day of publication of version 11a
- Standards found workable
- Aromatics content requirements necessitated careful selection of blending kerosene
- Two issues with standards encountered
  - ASTM D-7566 table 2.2 testing too cumbersome for routine production
  - No standard defined for sale or transport of neat bio kerosene

ASTM D-7566 table 2.2 testing

- ASTM D-7566 table 2.2 testing found to be very cumbersome

- Few labs equipped to perform required tests
  ⇨ Need to ships samples to several other countries

- UOP 389 extremely sensitive

➡ Several weeks elapsed between production and final ok from all labs

- Can be done once, but routine performance for each batch not compatible with normal refinery operations

- Currently required to be performed per batch. Ultimate objective of ASTM is to transition to management of change requirement, but transition process and time schedule not defined.

No standard for sale or transport of neat bio kerosene

- ASTM D 7566 defines neat bio kerosene parameters to be met after production
- No issues if blending is performed at production site
- Issue if neat bio kerosene is shipped for blending elsewhere
  - Will typically involve sale of product
  - Recipient needs standard against which to test product on receipt
- ASTM D 7566 is only standard against which recipient can test
- Table 2.2 almost certain not to be met after shipping
  - ASTM D 7566 requires use of same transport infrastructure as for conventional kerosene
  - Will lead to picking up of trace contamination
- Some ASTM D1655 parameters no included in SPK specification
  - Net heat of combustion
  - Lubricity