HBBA Study: Effects on emissions

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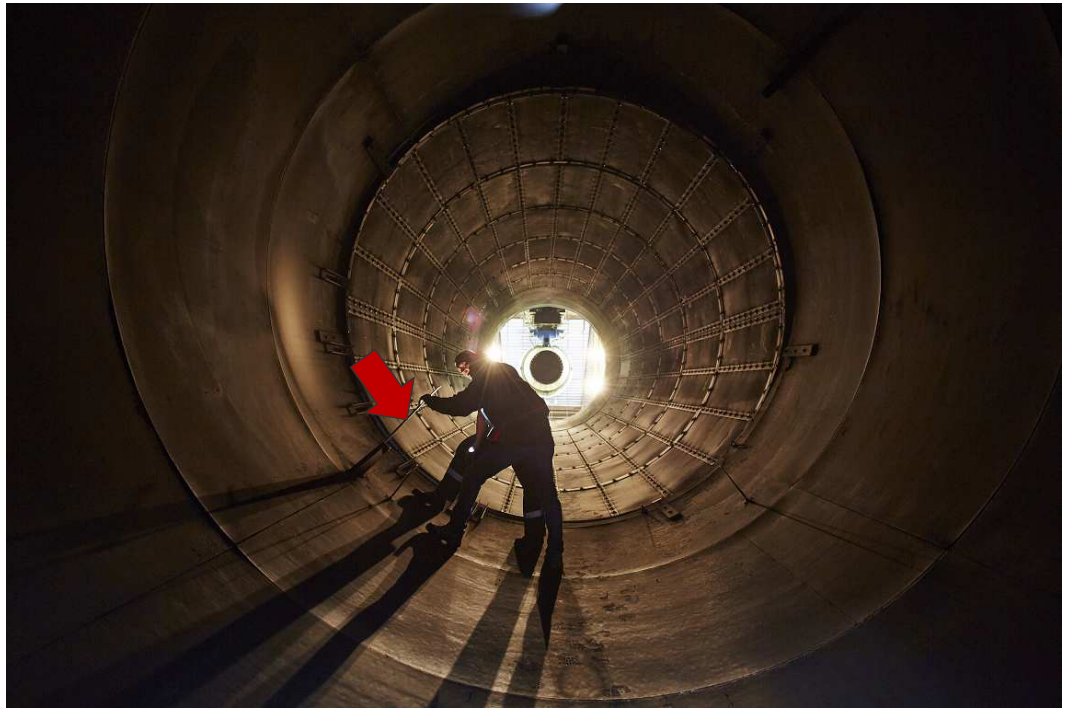
Emissions test using SIP fuel (farnesane)

- Conducted 15th November 2013 at Lufthansa Technik rig test cell in Hamburg

- Test cell fed
  - first with reference convential kerosene
  - then with same conventional kerosene with 10% SIP added
  - then with same conventional kerosene with 20% SIP added

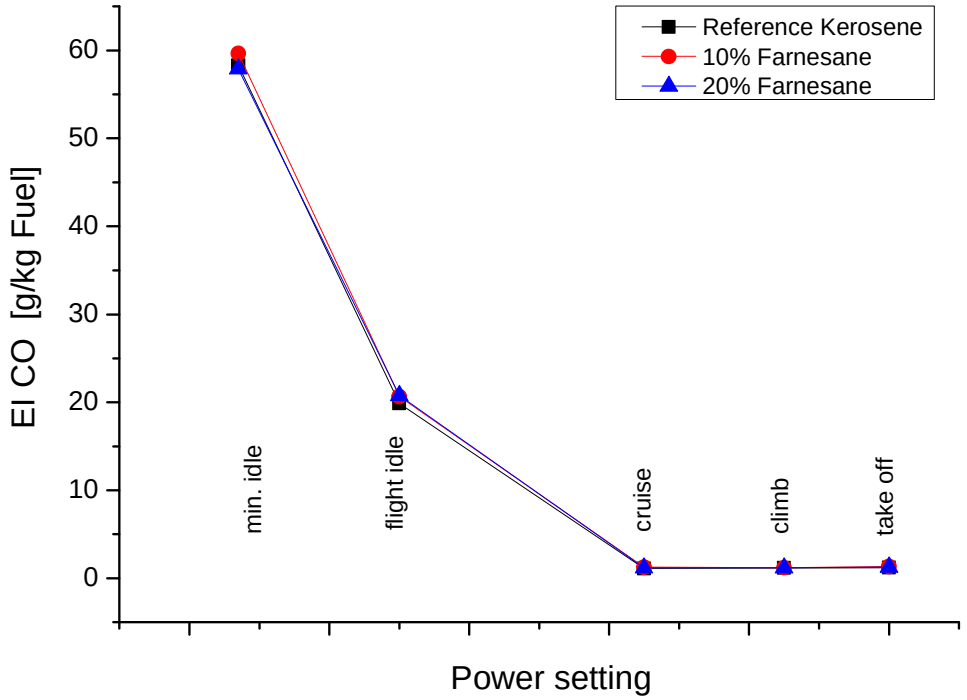
- For conventional kerosene, product from Leuna refinery selected as kerosene with middle of the range properties

Data measurement



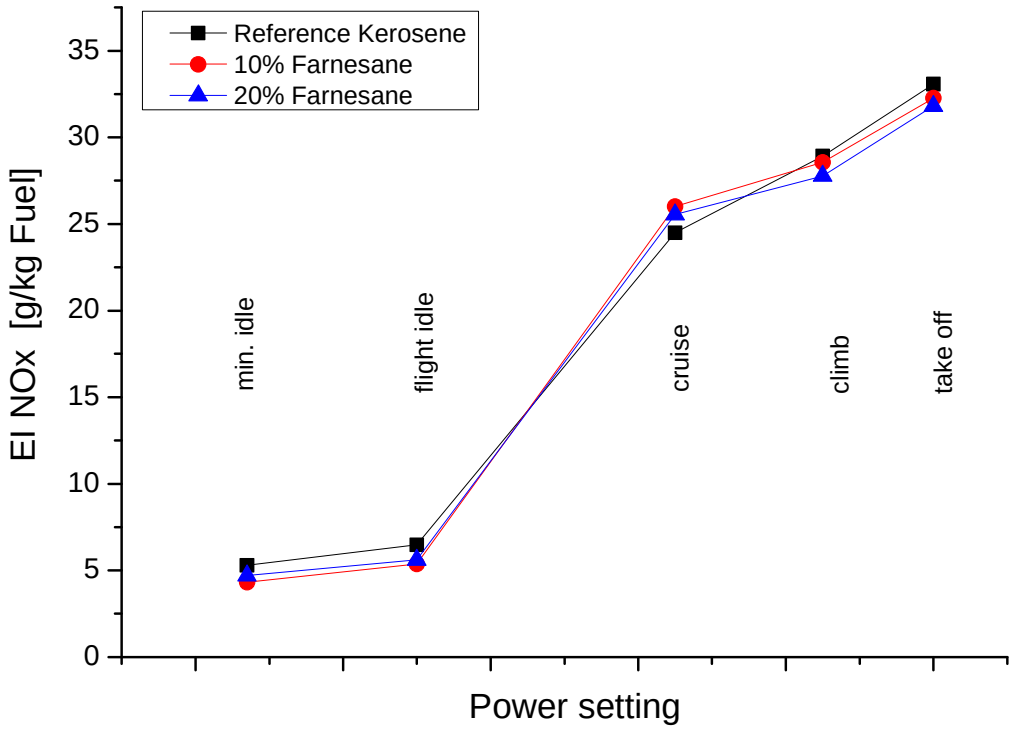
- Engine performance data recorded by Lufthansa test cell equipment
- Exhaust gases and particles measured via probe in exhaust tunnel.
- Emissions measurement and analysis performed by DLR (German Aerospace Center)
- For each test run, engine operated
  - 10 minutes at Minimum Idle
  - 5 minutes at Flight Idle
  - 5 minutes at Cruise Power
  - 3 minutes at Climb Power
  - 1 minute at Take Off Power
- Power settings not corresponding to ICAO cycle, but the same for all three runs

Results: CO emissions



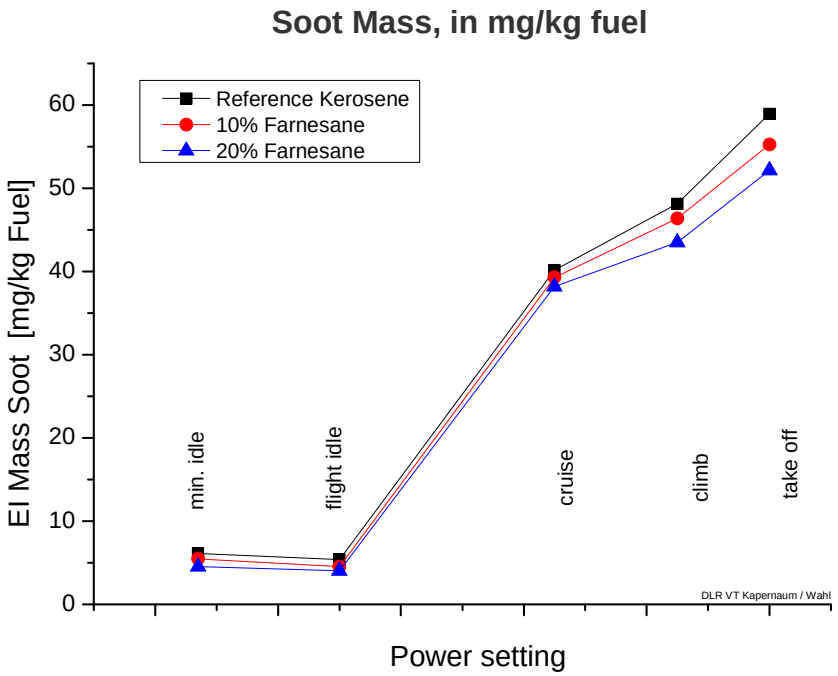
No discernible effect of SIP fuel on CO emissions

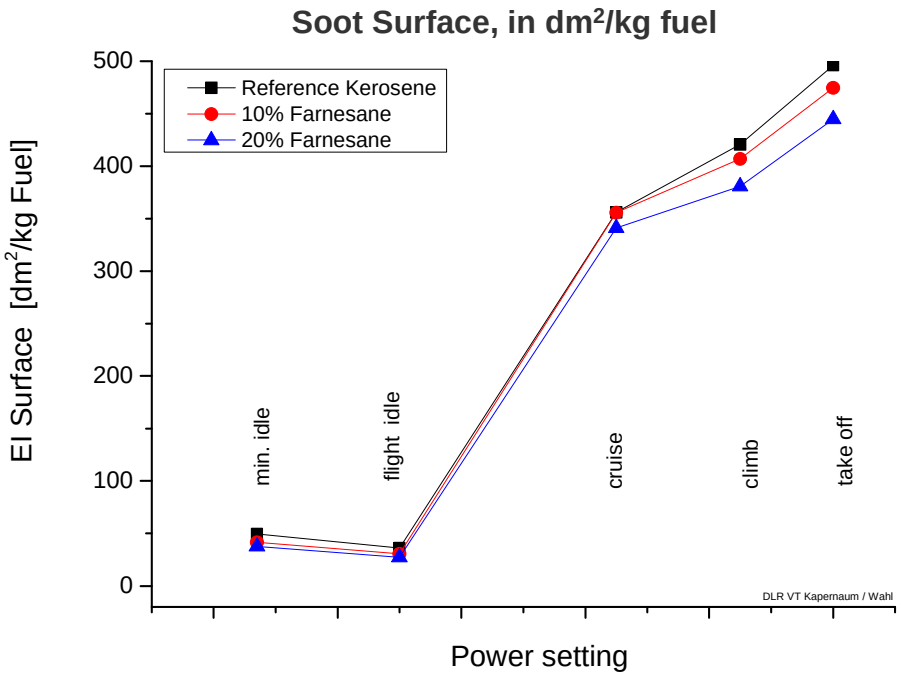
Results: NO_x emissions



- For most power settings, reduction of NO_x by addition of SIP
- However, effect is weak and not completely consistent

Results: Soot emissions – mass and surface

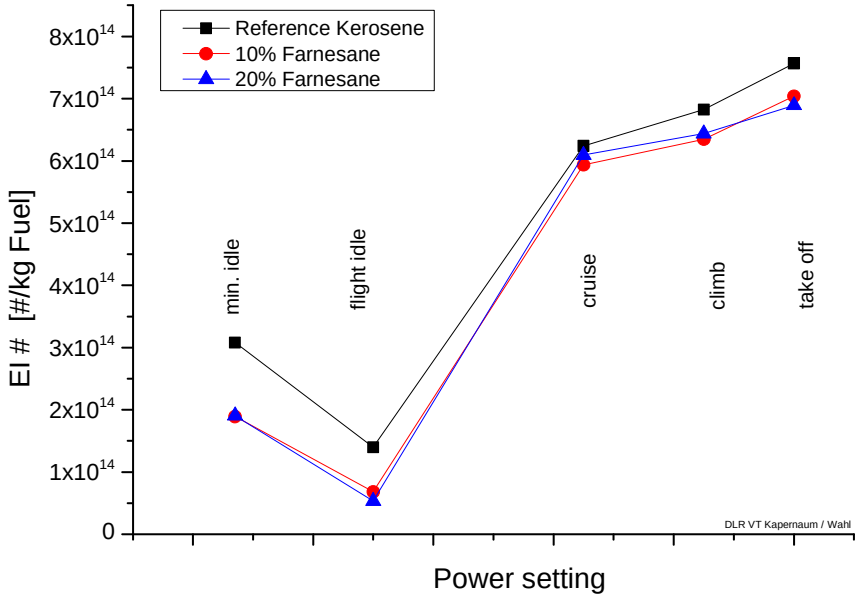




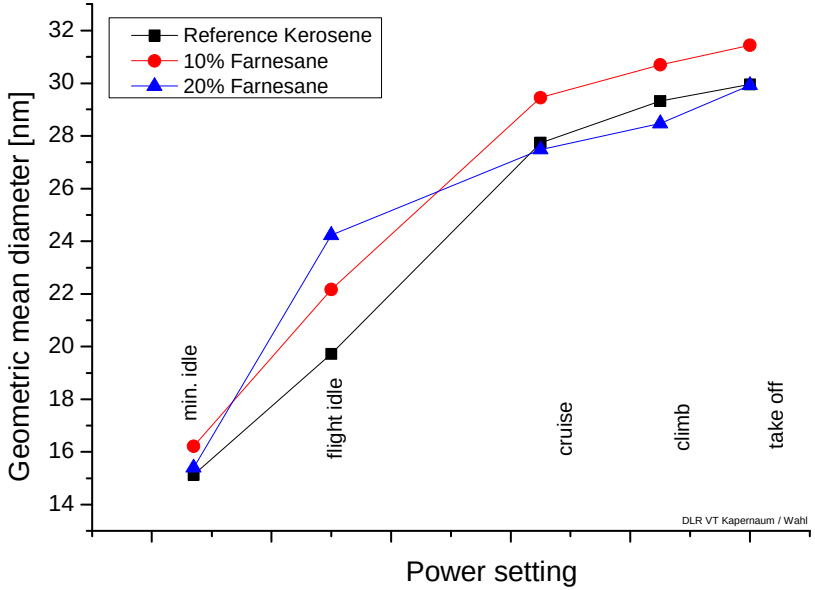
- At all power settings, reduction of soot mass and soot surface by addition of SIP
- Consistent results
- Fairly large reduction at high power settings

Results: Soot emissions – number and diameter of particles

Number of particles per kg fuel



Geometric mean diameter of particles, in mm



- Number of particles reduced by addition of SIP, but little difference between 10% and 20%
- No consistent effect on mean diameter
- Results possibly affected by agglomeration of particles, due to long hoses used

Conclusions

- No adverse emissions effects from SIP fuel
- CO and NO_x unaffected or better
- Clear improvement for soot particle emissions
  - Had been expected due to absence of aromatics in SIP fuel, and was confirmed
  - Mass and surface reduced by addition of SIP
  - Particle numbers also reduced, but data less consistent
  - Soot important due to its triggering role in contrail and cirrus cloud formation
    - Contrail effects considered factor for global warming
    - How big a factor still subject to considerable scientific debate
- No Tendency for average particle diameter to decrease
  - Relevant with view to health effects of ultrafine particles
  - Airport ground operations issue