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FIELD STUDY ON THE IMPACT OF SUSTAINABLE AVIATION FUELS ON HELICOPTER ENGINE EMISSIONS

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Emission data of helicopter engines

In the second second

Theo Rindlisbacher / Lucien Chabbey

Guidance on the Determination of **Helicopter Emissions**

Reference: COO.2207.111.2.2015750







DLR-Project: ELK (emission map)

-> Engine emission inventory

https://verkehrsforschung.dlr.de/de/ projekte/elk

| Aircraft ICA | | | 1 I I I I I I I I I I I I I I I I I I I | | LTO Emissions | | | | | | One hour emissions | | | | | | |
|--------------|--------------|--------------|---|-------------|---------------|---------------|-------------|----------------|------------|--------------|--------------------|-----------|----------|-------------|-------------|--------------|-------------|
| | Aircraft ICA | Aircraft Nam | Engine Nam | Max SHP per | Number of | | | | | TO PM non | I TO PM | One hour | One hour | One hour HC | One hour CO | One hour PM | One hour PM |
| | 0 | е | e | engine | Engines | LTO fuel (kg) | LTO NOx (g) | LTO HC (g) | LTO CO (g) | volatile (g) | number | fuel (kg) | NOx (kg) | (kg) | (kg) | non vol. (g) | number |
| | | SIKORSKY | | | | | | | | | | | | | | | |
| | S76 | S76 | PT68-36A | 981 | 2 | 59 | 499.9 | 573.6 | 547.2 | 11.6 | 3.463E+16 | 360 | 2.99 | 1.3 | 0.79 | 85 | 1.25E+18 |
| | | AGUSTA | | | | | | | | | | | | | | | |
| | A119 | A119 | PT68-37 | 900 | 1 | 31.5 | 210.5 | 87.3 | 288.8 | 6.4 | 3.3274E+16 | 216 | 1.77 | 0.07 | 0.78 | 54 | 1.78E+18 |
| | | AUGUSTA | | | | | | | | | | | | | | | |
| | A139 | A139 | PT6T-3D | 1800 | 2 | 55 | 312.8 | 250.1 | 689.6 | 12.7 | 4.6879E+16 | 360 | 2.56 | 0.26 | 1.98 | 112 | 3.68E+18 |
| | B412 | Bell 412 | PT6T-3 | 1800 | 2 | 55 | 419.5 | 797.4 | 873 | 12.7 | 4.6879E+16 | 360 | 4.1 | 1.76 | 1.12 | 112 | 3.30E+18 |
| | | AGUSTA | | 1000 | 1000 | | | | | | | | | | | | |
| | A139 | A139 | P16C-67C | 1100 | 2 | 60.4 | 377.5 | 739.7 | 949.1 | 11.8 | 3.939E+16 | 412.2 | 3.55 | 1.3/ | 1.65 | 101 | 3.33E+18 |
| | EXPL | MD 900 | PW206A | 621 | 2 | 30 | 127.7 | 5//.5 | 1158.2 | 6 | 3.0591E+16 | 223.2 | 1.08 | 0.8/ | 3.39 | 43 | 7.88E+17 |
| | | AGUSTA | - | | | | | | 1010 7 | | | | | | | | |
| A109 | A109 | A109E | PW206C | 550 | 2 | 34.0 | 159.9 | 629.1 | 1216.7 | 5.4 | 2.9/51E+16 | 194.4 | 1.01 | 1 | 3.13 | 35.8 | 1.18E+18 |
| | 4400 | AGUSTA | The second | 250 | | 24.0 | 457.2 | 6399 T | 1000 0 | | 20045.40 | | 0.00 | 0.0000 | | | 4 455.40 |
| | A109 | Roll 427 | PW2070 | 670 | 2 | 34.9 | 157.3 | 032.7 | 1220.0 | 5.8 | 3.004E+10 | 107.4 | 0.93 | 0.9098 | 3.4 | 30 | 1.10E+18 |
| | EVDI | LIGE 921 | DIA/2070 | 420 | 2 | 34.9 | 100.4 | £43.1 657.0 | 1227.2 | 5.0 | 2 8302E+40 | 212.0 | 1.19 | 0.00 | 1.91 | 3/ | 6.53E+17 |
| | EAFL | AS 365 C4 | TWZUIE | 469 | 6 | 30.9 | 120.4 | 0.100 | 12213 | 0.4 | 2.0.JUZE * 10 | 212.0 | 1.00 | 0.83 | 311 | 30 | 0.000-17 |
| | 4585 | DALIPHIN | ADDIEL 1A4 | 641 | 2 | 110 | 210.7 | 764 7 | 000 6 | 74 | 3 07355+40 | 024 | 4.7 | 1.47 | 1 02 | | 1.515+10 |
| | n303 | AS 365 C2 | PRINCE IAI | Out. | 2 | 41.0 | 210.7 | 101.7 | 500.0 | 1.1 | 5.0133E 10 | 201 | 1.7 | 1.97 | 1.05 | 51 | 1.512.710 |
| | 4985 | DALIPHIN | APPIEL 1A2 | 641 | 2 | 41.6 | 210.7 | 761.7 | 088.5 | 7.1 | 3.0735E+16 | 261 | 17 | 1.47 | 1.83 | 51.2 | 1.51E+18 |
| - | 1600 | AS 350 | PRIVILL INC | 011 | | 41.0 | 210.1 | 101.1 | 000.3 | | 3.0733L-10 | 201 | | 1.40 | 1.05 | 51.2 | 1.512-10 |
| | 4535 | ECUDEUII | ADDIEL 18 | 641 | | 23.4 | 128.2 | 289.6 | 370.6 | 42 | 3 01555+16 | 133.2 | 0.07 | 0.6 | 0.75 | 20 | 0 30E+17 |
| - | 1000 | AS 365 N | PROLE ID | 041 | | 23.4 | 120.2 | 205.0 | 370.0 | | 3.0133E 110 | 130.2 | 0.37 | 0.0 | 0.75 | | 2.326.11 |
| | 4985 | DALIPHIN | ARRIEL 1C | 660 | 2 | 42.2 | 217.7 | 753 | 076.8 | 72 | 3 0984E+18 | 265.2 | 1.75 | 1.45 | 18 | 53 | 1 55E+18 |
| | 1000 | AS 365 N1 | FEGULETO | 000 | - | 76.6 | | 100 | 010.0 | 1.6 | 0.00012.10 | 200.2 | 1.30 | 1.40 | | | 1.006 10 |
| 4565 | ASES | DAUPHIN | ARRIEL 1C1 | 700 | 2 | 43.4 | 231 | 724.2 | 938 | 7.6 | 3 143E+16 | 274 3 | 1.87 | 1.41 | 173 | 56 | 1.65E+18 |
| - | 16003 | AS 365 | FUTULE IOT | 100 | - | | | 167.6 | | 1.0 | 5.1452.110 | 114.0 | 1.07 | 1.41 | 1.15 | | 1.000-10 |
| | 4585 | DAUPHIN | ARRIEL 1C2 | 763 | 2 | 45.2 | 253.8 | 879 1 | 877.4 | 82 | 3 2145E+16 | 289.5 | 2.08 | 1 35 | 168 | 61 | 1.81E+18 |
| _ | 1000 | AS 350B | TRUCCE TOE | 100 | - | | | 010.1 | 017.1 | | OLTIOL IO | 200.0 | 2.00 | | | | 1.012 10 |
| | A\$35 | ECUREUIL | ARRIEL 1D1 | 732 | 1 | 25.2 | 149.7 | 266.8 | 339.6 | 47 | 3.1321E+16 | 146.5 | 1.16 | 0.57 | 0.7 | 33 | 1.10E+18 |
| - | | AS 550 | | | | | | | | | | | | | | | |
| | AS50 | FENNEC | ARRIEL 1D1 | 732 | 1 | 25.2 | 149.7 | 266.8 | 339.6 | 4.7 | 3.1321E+16 | 146.5 | 1.16 | 0.57 | 0.7 | 33.4 | 9.87E+17 |
| | | AS 555 | | | | | | | | | | | | | | | |
| AS55 | A\$55 | FENNEC | ARRIEL 1D1 | 712 | 2 | 43.8 | 235.5 | 713.8 | 924.1 | 77 | 3.1554E+16 | 277.1 | 1.91 | 1.4 | 1.72 | 57 | 1.68E+18 |
| | | AGUSTA | | | | | - | | | | | | | | | | |
| | A109 | A109 K2 | ARRIEL 1K1 | 738 | 2 | 44.6 | 246 | 700.8 | 907 | 8 | 3.1915E+16 | 255 | 1,79 | 1.24 | 1.53 | 53 | 1.75E+18 |
| | BK17 | BK117 | ARRIEL 1E2 | 738 | 2 | 44.6 | 246 | 700.8 | 907 | 8 | 3.1915E+16 | 283.3 | 1.98 | 1.38 | 1.7 | 59 | 1.74E+18 |
| | BK17 | BK117 C-2 | ARRIEL 1E2 | 738 | 2 | 44.6 | 246 | 700.8 | 907 | 8 | 3.1915E+16 | 283.3 | 1,98 | 1.38 | 1.7 | 59 | 1.74E+18 |
| | A\$35 | AS 350 B3 | ARRIEL 2B | 848 | 1 | 27.6 | 180.5 | 247.7 | 313 | 5.5 | 3.2659E+16 | 151.6 | 1.3 | 0.51 | 0.62 | 37 | 1.22E+18 |
| | AS35 | AS 350 B3 | ARRIEL 2B1 | 848 | 1 | 27.6 | 180.5 | 247.7 | 313 | 5.5 | 3.2659E+16 | 151.6 | 1.3 | 0.51 | 0.62 | 37 | 1.22E+18 |
| | EC30 | EC 130 B4 | ARRIEL 2B1 | 848 | 1 | 27.6 | 180.5 | 247.7 | 313 | 5.5 | 3.2659E+16 | 182.6 | 1.57 | 0.61 | 0.75 | 44.6 | 1.32E+18 |
| | | AS 365 N3 | | | | | | | | | | | | | | | |
| | AS65 | DAUPHIN | ARRIEL 2C | 839 | 2 | 47.8 | 286 | 642.6 | 826.6 | 9 | 3.2984E+16 | 308.9 | 2.35 | 1.31 | 1.61 | 68 | 2.01E+18 |
| | EC55 | EC 155 B | ARRIEL 2C1 | 839 | 2 | 47.8 | 286 | 642.6 | 826.6 | 9 | 3.2984E+16 | 308.9 | 2.35 | 1.31 | 1.61 | 68 | 1.24E+18 |
| | EC55 | EC 155 B1 | ARRIEL 2C2 | 944 | 2 | 51.2 | 329.9 | 603.6 | 774.4 | 10.2 | 3.4164E+16 | 337.4 | 2.73 | 1.26 | 1.55 | 79 | 1.44E+18 |
| | | AS 350B3 | | | | | | | | | | | | | | | |
| AS50 | AS50 | ASTAR | ARRIEL 2D | 952 | :1 | 29.5 | 206.6 | 231.1 | 291.3 | 6.2 | 3.384E+16 | 200.3 | 1.82 | 0.59 | 0.72 | 52 | 1.53E+18 |
| | 200 | SIKORSKY | Second S | 1000 | 200 | | 1.000 | 2000 | 1000 | | 20000 | 1 22202 | 2.82 | | | | |
| | S76 | S-76 C+ | ARRIEL 2S1 | 856 | 2 | 48.4 | 292 | 640.3 | 822.7 | 9.2 | 3.322E+16 | 313.4 | 2.38 | 1.3 | 1.6 | 70 | 1.02E+18 |
| | 1000 | SIKORSKY | | | 2222 | | 0.000.00 | | | | | 2000 | 7.00 | | | | |
| | S76 | S-76C++ | ARRIEL 2S2 | 897 | 2 | 50 | 310.7 | 624.2 | 800.7 | 9.7 | 3.3679E+16 | 324.5 | 2.56 | 1.28 | 1.56 | 74 | 1.08E+18 |
| | AS55 | AS 355 N | ARRIUS 1A | 480 | 2 | 35 | 150.5 | 883 | 1156.2 | 5.4 | 2.8801E+16 | 216.2 | 1.19 | 1.67 | 2.08 | 38 | 1.12E+18 |
| | EC35 | EC 135 | ARRIUS 2B1 | 633 | 2 | 41.2 | 206.9 | 769.1 | 999.6 | 7 | 3.0715E+16 | 259.3 | 1.66 | 1.49 | 1.84 | 51 | 1.50E+18 |
| | EC35 | EC 135 | ARRIUS 2B2 | 633 | 2 | 41.2 | 206.9 | 769.1 | 999.6 | 7 | 3.0715E+16 | 259.3 | 1.66 | 1.49 | 1.84 | 51 | 1.50E+18 |

Fuel-related emission indices are **not** available.





Experimental Overview



Emission measurements at ADAC hangar in Hangelar 03.11.2022 – Reference measurement, Jet A-1 09.11.2022 – SAF blend measurement

https://luftrettung.adac.de/first-rescuehelicopter-flies-on-sustainableaviation-fuel/







Fuel Properties



Regular Jet A-1 & Jet A-1/HEFA blend

- GCxGC analysis
- Hydrogen content (ASTM D7171)
 - Jet A-1 13.79 m%
 - SAF Blend 14.34 m%





Parameter and Instruments

- DMS500 (+ CS), 1 Hz Particle number, -size distribution (total/nv) SMPS (+ CS), 75 s Particle number, -size distribution (total/nv)
- Ecophysics CLD64/700, 1 Hz
- MKS Multigas FT-IR, 1 Hz
- LI-7200RS/LI-850, 1 Hz
- TSI 3776 CPC (ambient)



NOx CO2, CO, NOx CO2, H2O Particle number



Sampling challenges



Requirements

- Safe for the aircraft
- Fast removal
- No contact to helicopter
- Should not be affected by high power runs

Drawbacks

- No heated inlet
- No probe-tip dilution
- "Long" sampling line (20 m)









Experimental Setup – Test Matrix

- Three different power settings (FF 66 kg/h, FF 125 kg/h, FF 150 kg/h)
- Ground run for 10 min, 5 min and 5 min
- Similar fuel flow and torque conditions between reference and SAF experiment Comparable ambient conditions (cold, humid)





Comparability between reference and SAF measurement





- Both runs were repeated in an excellent manner
- The probe alignment was comparable between both runs
- The weather conditions of the reference run could have been better (variation at higher power settings)



NO_x Emission Index





- NOx emission between the two different runs deviate by approx. 5% (9% max.)
- The ambient temperature was not very different (approx. 2°C) but the reference run was accompanied by rain
- The difference is not significant to account for a possible fuel effect
- -> Comparable engine conditions

Particle Volume Size Distribution (nvPM)





Summary and Outlook

- Successful in-field measurement of a helicopter engine with good interday reproducibility
 Shift in particle number size distribution (agglomeration) allows no direct comparison of
- Shift in particle number size distribution emission indices
- Reduction in nvPM particle volume emission when switching from fossil Jet A-1 to SAF blend has been observed
- The reduction in emitted particle volume is quite stable over power settings ("cruise" reference elevated/drifting)
- No other trade-off effects (e.g. NOx) have been observed
- These results are relevant for improving local air quality at/near airports
- Future experiments need to cover oil emissions from the engine







THANK YOU FOR YOUR ATTENTION

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Impressum

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Field Study on the Impact of Sustainable Aviation Fuels on Helicopter Engine Emissions 20.06.2023 Dr. Tobias Schripp DLR Institut für Verbrennungstechnik, Stuttgart DLR, Google Maps

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