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Theo Rindlisbacher / Lucien Chabbey

Guidance on the Determination of Helicopter Emissions

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Contact person: Theo Rindlisbacher
Tel. +41 58 465 93 76, Fax +41 58 465 92 12, theo.rindlisbacher@bazl.admin.ch

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Motivation and Summary

The civil aviation emission inventory of Switzerland is a bottom-up emission calculation based on individual aircraft tail numbers, which includes the tail numbers of helicopters. Although helicopters may be considered a minor source of aviation emissions, it is interesting to see that in a small country like Switzerland, more than 1000 individual helicopters have been flying in the last couple of years, some of them doing thousands of cycles or so called rotations. Switzerland therefore needs to include helicopters in the country's aviation emission inventory. However helicopter emissions are extremely difficult to assess because their engine emissions data are usually not publicly available and there is no generally accepted methodology on how to calculate helicopter emissions known by FOCA. In the past, the helicopter emission estimations done by FOCA have been based on two engine data sets only. Assumptions for fuel flow and Nitrogen oxides (NO_x) have been conservative and it has become evident that the share of helicopter emissions in the emission inventory of Switzerland has been significantly overestimated so far, at least for CO_2 and NO_x.

FOCA therefore launched project HELEN (**HEL**icopter **EN**gines) in January 2008 with the main goal to fill significant gaps of knowledge concerning the determination of helicopter emissions and to further improve the quality of the Swiss civil aviation emission inventory. The FOCA activity for engine emission testing is based on Swiss aviation law[1], which states that emissions from all engine powered aircraft have to be evaluated and tested. The legal requirement also incorporates aircraft engines that are currently unregulated and do not have an ICAO[2] emissions certification – like aircraft piston, helicopter, turboprop and small jet engines. Helicopter engine emissions have been measured at the engine test facility of RUAG AEROSPACE, Stans, Switzerland, where turboshaft engines are tested after overhaul. The measured turboshaft engines are owned by the Swiss Government. As turboshaft engine emissions measurements during ordinary engine performance tests are not very costly, the measurements have been extended to incorporate particle emissions, smoke number, carbonyls and to study the influence of different probe designs used for small engine exhaust diameters. These measurements have been performed by DLR INSTITUTE OF COMBUSTION TECHNOLOGY, Stuttgart, Germany.

The results of the measurements as well as confidential helicopter engine manufacturer data are the basis for the suggested mathematical functions for helicopter engine emission factors and fuel flow approximations. In order to make the functions work, only the input of shaft horsepower (SHP) is necessary. The maximum SHP of the engine(s) of a certain helicopter must first be determined and can be found in spec sheets or in flight manuals. Percentages of maximum SHP for different operating modes and times in mode are listed and are differentiated between three categories of helicopters: piston engine powered, single and twin turboshaft powered helicopters. Calculated shaft horsepower for different modes is then entered into approximation formulas which provide fuel flow and emission factors.

Power settings and times in mode for the modelling have been established a first time in 2009 with in-flight measurements, from helicopter flight manuals and with the help of experienced flight instructors. In 2015, the Working Group 3 of the ICAO Committee on Environmental Protection (CAEP) developed a guidance for generating aggregated cycle emissions data for small turbofan, turboprop, helicopter and APU engines. FOCA was interested to compare the guidance of the report with its own guidance (2009). Indeed, the Working Group 3 used the FOCA guidance of 2009 as a basis but adjusted it. Some adaptations have been made and are re-used and implemented in the updated version of the FOCA guidance (2015). The main adaptations are listed below:

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[1] SR 748.0, LFG Art. 58

[2] International Civil Aviation Organisation

- The GI departure (4 minutes) and the GI arrival (1 minute) have been merged into a single GI mode (5 minutes). Furthermore, the power setting of the GI mode has been adjusted to 20%, 13%, 7% and 6% for the piston engine, the single light engine, the twin light engine and the twin heavy engine respectively.

- Concerning the Take-off and Approach mode, the power settings stay unchanged in comparison with the guidance of 2009.

- A number of new helicopter models and engines have been added to the database.

- Finally, a new variable has been added with the 2015 update: The number of PM non-volatile matter is now roughly estimated and taken into account.

In consequence, the FOCA reviewed the 2009 helicopter emissions guidance and provides an update with edition 2. The edition 2 report presents the updated estimation of LTO[3] and one hour emissions for individual helicopter types. It has to be noted that helicopters may fly many cycles (rotations) far away from an airport or heliport, especially for aerial work. To overcome problems with emissions estimation for helicopter rotations, estimations of per hour emissions are suggested to complement the LTO values. In the case of Switzerland, helicopter companies transmit the annual flight-hours of their helicopters to FOCA, which allows applying a flight-hour based emissions calculation in most cases. This guidance suggests using the emission values per hour also for determination of helicopter cruise emissions. Finally, the guidance material offers a summary list of helicopters with estimated LTO and one hour emissions for direct application in emission inventories.

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[3] LTO = Landing and Take-off cycle

1. Classification of Helicopters by Engine Category

1.1 Piston Engine Powered Helicopters

Piston engine powered helicopters are the smallest helicopter category. Most of them are two-seaters used for pilot education and training. Their operation includes a lot of hover exercises. Generally, they are operated at low level and at low altitudes because of their limited high altitude performance. Typical engines have four or six horizontally opposed cylinders and are air cooled. The engine technology goes back to the 1950s. The engines run on gasoline (AVGAS or MOGAS). For operational studies, the **Schweizer 269C** and the **Robinson R22** have been selected as the representative helicopter in this category.

1.2 Single Engine Turboshaft Powered Helicopters

The majority of civil helicopters are powered by a single gas turbine with a shaft for power extraction (“turboshaft engines”). The shaft drives a reduction gear for the main rotor and the tail rotor. Maximum shaft power for this helicopter category is normally in the range of 300 to 1000 kW. Most of the turboshaft engine compressors are single stage and the driving shaft is a free turbine, which means that it is not mechanically connected to the compressor shaft. The engines run on jet fuel. For operational studies, the **Eurocopter AS350B2 Ecureuil** has been selected as the representative helicopter in this category.

1.3 Twin Engine Turboshaft Powered Helicopters

The basic engine design is normally identical to that of the single engine turboshaft helicopters. The reason for making a distinction is the fact that the engines run at significantly lower power during normal operation compared to a single engine powered helicopter. If one engine should fail, the remaining engine is capable of restoring nearly the performance of the helicopter at twin engine operation. This has to be taken into account when doing emissions calculations, as e.g. a doubling of the fuel flow of the single engine for a twin engine helicopter would result in an excessive overestimation of the fuel consumption. For operational studies, the **Agusta A109E** (MTOM 2850 kg) and the **Eurocopter AS332 Super Puma** (MTOM 8600 kg) have been chosen as the representative helicopters in this category.

2. Operational Assumptions for Emissions Modelling

2.1 General Remarks about Helicopter Operations and their Modelling

In contrast to fixed wing aircraft, helicopters usually need a high percentage of the maximum engine power during most of the flight segments. They often fly cycles (or so called rotations) away from an airport or heliport, especially for aerial work. This poses special problems to emissions estimation of helicopters. Airport or heliport movements are usually not consistent with the actual number of rotations flown. This guidance material suggests two ways of how to deal with helicopter emissions:
A practitioner may use one of the three suggested standard LTO cycles below, corresponding to the respective helicopter category and multiply the resulting LTO emissions (see section 3) with the number of LTO (= number of movements divided by 2). This is suggested for airport LTO emissions calculation.
For a country's emission inventory, the practitioner may use the emissions calculation given per flight-hour, if the helicopter operating hours are known. In this case, helicopter rotations and cruise are considered to be included and the final emission calculation is given simply by multiplying the emissions per hour by the number of operating hours.
If helicopter cruise emissions have to be calculated for a given flight distance, it is suggested to start again with the emissions per hour data and divide them by an assumed mean cruising speed for the respective helicopter type.

Example: Estimated fuel consumption for helicopter type XYZ (see section 3) = 133 kg fuel / hour
Mean cruising speed (from spec sheet, flight manual etc.) [4] = 120 kts
→ 133 kg fuel / hour divided by 120 Nautical Miles / hour = 1.11 kg fuel / Nautical Mile
The value of 1.11 kg fuel / Nautical Mile is multiplied by the number of Nautical Miles flown in order to get the number of kg fuel.

2.2 Piston Engine Helicopter Operations

Engine running time on ground shows a great seasonal variability, with a long engine warm up sequence in winter and a long cool down sequence at the end of the flight in summer (air cooled engines). Total engine ground running time has been determined to be approximately 5 minutes. Climb rate has been assumed 750ft/min based on performance tables of the reference helicopter manuals, resulting in more time needed to climb 3000ft (LTO) with piston engine than with turboshaft powered helicopters. However, approach time is considered similar to the other helicopter categories.

Engine percentage power for ground running is higher than for piston engine aircraft. From RPM and Manifold Pressure indications, it is assumed 20% of max. SHP. For hover and climb, nearly full SHP is used. According to information from experienced flight instructors, cruise power is usually set near the maximum continuous power. Therefore, 95% of max. SHP is the suggested cruise value. Approach shows a large variation in power settings, but it is generally relatively high (60% of max. SHP), either for maintaining a comfortable sink rate or for gaining speed in order to reduce flight time.

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[4] Aircraft or helicopter speeds are often given in kts (knots). 1 knot = 1 Nautical Mile per hour

Table 1: Suggested times in mode and % of max. SHP for piston engine helicopters. GI = Ground Idle before departure and after landing, TO = Hover and Climb, AP = Approach. “Mean operating % power per engine” = power setting for determination of emissions per flight-hour.

GI_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI %Power per engine	TO %Power per engine	AP %Power per engine	Mean operating %Power per engine
5	4	5.5	20	95	60	90

2.3 Single Engine Turboshaft Helicopter Operations

The values of table 2 have been generated from flight testing. An example of detailed recording and calculation of weighted averages is given in Appendix A.

Table 2: Suggested times in mode and % of max. SHP for single engine turboshaft helicopters

GI_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI %Power per engine	TO %Power per engine	AP %Power per engine	Mean operating % power per engine
5	3	5.5	13	87	46	80

2.4 Twin Engine Turboshaft Helicopter Operations

For twin engine helicopters, the % power values per engine are normally lower than for single engine helicopters. At 100% rotor torque, the two engines are running at less than their 100% power rating[5]. This has been taken into account in table 3 (see Appendix B). It is suggested to first calculate the emissions of one engine based on the % power and times in mode below, followed by a multiplication of the results by a factor of 2.

Table 3: Suggested times in mode and % of max. SHP per engine for small twin engine turboshaft helicopters (below 3.4 tons MTOM)

GI_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI %Power per engine	TO %Power per engine	AP %Power per engine	Mean operating % power per engine
5	3	5.5	7	78	38	65

For large twin engine turboshaft helicopters it is suggested to further reduce the %power values (see Appendix C)

Table 4: Suggested times in mode and % of max. SHP per engine for large twin engine turboshaft

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[5] Generally, if an engine should fail, the remaining engine can restore nearly the twin engine performance (depending on the helicopter model).

helicopters (above 3.4 tons MTOM)

GI_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI %Power per engine	TO %Power per engine	AP %Power per engine	Mean operating % power per engine
5	3	5.5	6	66	32	62

3. Estimation of Fuel Flow and Emission Factors from Shaft Horsepower

The functions suggested in this section are based on the fitting of FOCA's own engine test data and on confidential engine manufacturer data. Manufacturer data are confidential and can not be published together with a corresponding engine name.

The main concept consists of entering a SHP value into the formulas and getting fuel flow (kg/s) and the emission factors for the standard pollutants (EI NO_x (g/kg), EI HC (g/kg), EI CO (g/kg), EI $PM_{\text{non volatile}}$ (g/kg), and EI PM number)[6]. The following steps are recommended:

- Firstly, the practitioner need to determine the maximum SHP of the engine(s) of the selected helicopter. The information can be found in publicly available helicopter or engine spec sheets or in helicopter operating manuals.
- Secondly, the helicopter category (piston, single turboshaft, twin turboshaft) has to be determined. With the corresponding table in section 2, the estimated SHP for the different operating modes of that helicopter engine are calculated.
- Next, the mode related SHPs are entered into the corresponding approximation functions, suggested in this section. The results are fuel flow and emission factors estimations for all modes of that particular helicopter.
- Finally, fuel flow and emission factors are combined with time in mode (from the appropriate table in section 2) to generate kg of fuel and grams emissions for LTO and one hour operation (see next section 4).

Due to a substantial variability of real measured emissions data between different engine types, the suggested general approximation functions for emissions may still lead to an error of a factor of two or more for a specific engine (see Appendix F). For PM emissions, these are very rough estimations and the error may be one order of magnitude. For fuel flow, the error is assumed +- 15%. The suggested formulas are representing the current state of knowledge. With additional data, a further refinement and improvement of the approximations would be possible.

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[6] NO_x = Nitrogen oxides, HC = unburned hydrocarbons (unburned fuel), CO = Carbon monoxide, PM non volatile = Non volatile ultra fine particles, generally soot

3.1 Piston Engines

- Fuel flow (kg/s):

$$Fuel\ flow \approx 19 * 10^{-12} * SHP^4 - 10^{-9} * SHP^3 + 2.6 * 10^{-7} * SHP^2 + 4 * 10^{-5} * SHP + 0.006$$

- Emission factors for NO_x

Table 5

Mode	GI	TO	AP	CRUISE
% max. SHP	20%	95%	60%	90%
EI Nox (g/kg)	1	1	4	2

- Emission factors for HC:

$$EI\ HC\left(\frac{g}{kg}\right) \approx 80 * (SHP^{-0.35})$$

- Emission factors for CO:

$$EI\ CO\ \left(\frac{g}{kg}\right) \approx 1000\ (for\ all\ SHP)$$

- Emission factors for PM (non volatile particles, soot)

Table 6

Mode	GI	TO	AP	CRUISE
% max. SHP	20%	95%	60%	90%
EI PM (g/kg)	0.05	0.1	0.04	0.07

All data for approximations of fuel flow and emission factors are taken from FOCA project ECERT. A graphical representation of approximation functions can be found in Appendix E.

- PM number:

$$PM\ number \approx \frac{EI\ PM\left(\frac{g}{kg}\right)}{\frac{\pi}{6} * Mean\ Particle\ Size^3(nm^3) * e^{(4.5*1.8^2)}}$$

EI PM (g/kg) and the mean particle size depends on the power settings and are approximated in table 6 and 7 respectively.

Table 7

Estimation of the Mean Particle Size depending on the Power settings.

Piston Engine	Idle/Taxi	Approach	Takeoff	Mean
Power setting	20%	60%	95%	90%
Mean Particle Size nm	18.9	29.2	40.3	39.3

3.2 Turboshaft Engines

- Fuel flow (kg/s) for engines above 1000 SHP

$$Fuel\ flow\ \approx 4.0539 * 10^{-18} * SHP^{5} - 3.16298 * 10^{-14} * SHP^{4} + 9.2087 * 10^{-11} * SHP^{3} - 1.2156 * 10^{-7} * SHP^{2} + 1.1476 * 10^{-4} * SHP + 0.01256$$

- Fuel flow (kg/s) for engines above 600 SHP and maximum 1000 SHP

$$Fuel\ flow \approx 3.3158 * 10^{-16} * SHP^{5} - 1.0175 * 10^{-12} * SHP^{4} + 1.1627 * 10^{-9} * SHP^{3} - 5.9528 * 10^{-7} * SHP^{2} + 1.8168 * 10^{-4} * SHP + 0.0062945$$

- Fuel flow (kg/s) for engines up to 600 SHP

$$Fuel\ flow\ \approx 2.197 * 10^{-15} * SHP^{5} - 4.4441 * 10^{-12} * SHP^{4} + 3.4208 * 10^{-9} * SHP^{3} - 1.2138 * 10^{-6} * SHP^{2} + 2.414 * 10^{-4} * SHP + 0.004583$$

- Emission factors for NO_x

$$EI\ NOx\left(\frac{g}{kg}\right) \approx 0.2113 * (SHP^{0.5677})$$

- Emission factors for HC

$$EI\ HC\left(\frac{g}{kg}\right) \approx 3819 * (SHP^{-1.0801})$$

- Emission factors for CO

$$EI\ CO\left(\frac{g}{kg}\right) \approx 5660 * (SHP^{-1.11})$$

- Emission factors for PM (non volatile particles, soot)

$$EI\ PM\ non\ volatile\left(\frac{g}{kg}\right) \approx -4.8 * 10^{-8} * SHP^2 + 2.3664 * 10^{-4} * SHP + 0.1056$$

- PM number:

$$PM\ number \cong \frac{EI\ PM\left(\frac{g}{kg}\right)}{\frac{\pi}{6} * Mean\ Particle\ Size^3(nm^3) * e^{(4.5*1.8^2)}}$$

EI PM (g/kg) can be obtained by applying the aforementioned equation. An estimation of the mean particle size in function of SHP is found in the table 8.

Table 8

Estimation of the Mean Particle Size depending on the Power settings and on the engine type.

Twin Engine (light)	Idle/Taxi	Approach	Takeoff	Mean
Power setting	7%	38%	78%	65%
Mean Particle nm	20	21.8	35.8	31.1
Single Engine	Idle/Taxi	Approach	Takeoff	Mean
Power setting	13%	46%	87%	80%
Mean Particle nm	19.1	24.2	38.5	36.5
Twin Engine (heavy)	Idle/Taxi	Approach	Takeoff	Mean
Power setting	6%	32%	66%	62%
Mean Particle nm	20.2	20.4	31.5	30

A graphical representation of approximation functions can be found in Appendix F.

4. Final Calculations

4.1 LTO Emissions

$$\text{LTO Fuel} = 60 * \left(\text{GI}_{\text{Time}} * \text{GI}_{\text{Fuel}_{\text{flow}}} + \text{TO}_{\text{Time}} * \text{TO}_{\text{Fuel}_{\text{flow}}} + \text{AP}_{\text{Time}} * \text{AP}_{\text{Fuel}_{\text{flow}}}\right) * \text{number of engines}$$

Remark: The factor of 60 converts minutes to seconds, as the times in the tables of section 2 are given in minutes but the estimated fuel flow values are in kg per second (see sections 2 and 3 of this guidance material)

$$\text{LTO NOx} = 60 * \left(\text{GI}_{\text{Time}} * \text{GI}_{\text{Fuel}_{\text{flow}}} * \text{GI}_{\text{EI}_{\text{NOx}}} + \text{TO}_{\text{Time}} * \text{TO}_{\text{Fuel}_{\text{flow}}} * \text{TO}_{\text{EI}_{\text{NOx}}} + \text{AP}_{\text{Time}} * \text{AP}_{\text{Fuel}_{\text{flow}}} * \text{AP}_{\text{EI}_{\text{NOx}}}\right) * \text{number of engines}$$

LTO HC, CO and PM are calculated accordingly by replacement of EI NO_x by EI HC, EI CO or EI PM.

4.2 Emissions for One Hour Operation

Fuel for one hour operation =

3600 * (fuel flow for mean operating power per engine) * number of engines

NO_x emissions for one hour operation =

3600 * (fuel flow for mean operating power per engine) * (EI NO_x for mean operating power per engine) * number of engines

HC, CO and PM emissions for one hour operation are calculated accordingly.

5. Helicopter Emissions Table

Based on this guidance material, estimated LTO emissions and emissions for one hour operation have been calculated for a variety of helicopters. The table is offered for direct application in emission inventories, for example by matching helicopter tail numbers with the emission results for the corresponding helicopter types contained in the table. The original excel file, containing all input data and calculation formulas can be downloaded from the FOCA Web As far as fuel consumption and emissions for one hour operation (respectively cruise) are concerned, the results have been scaled in a range of about +-15% for some of the helicopters according to information from operators. This procedure allows to more accurately reflecting differences between different helicopter models. With more information expected from operators in the future, the scaling factors will be updated. For details about current one hour operation scaling factors, see Appendix D.

Table 9: Estimated LTO emissions and one hour operation emissions for different helicopter models.

						LTO Emissions						One hour emissions					
Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Max SHP per engine	Number_of_Engines	LTO fuel (kg)	LTO NOx (g)	LTO HC (g)	LTO CO (g)	LTO PM non volatile (g)	LTO PM number	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (g)	One hour PM number
H011	S76	SIKORSKY S76	PT6B-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
H012	A119	AGUSTA A119	PT6B-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
H013	A139	AUGUSTA 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
H013	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
H017	A139	AGUSTA A139	PT6C-67C	1100	2	60.4	377.5	739.7	949.1	11.8	3.939E+16	412.2	3.55	1.37	1.65	101	3.33E+18
H020	EXPL	MD 900	PW206A	621	2	36	127.7	577.5	1158.2	6	3.0591E+16	223.2	1.08	0.87	3.39	43	7.88E+17
H022	A109	AGUSTA A109E	PW206C	550	2	34.6	159.9	629.1	1216.7	5.4	2.9751E+16	194.4	1.01	1	3.73	35.8	1.18E+18
H030	A109	AGUSTA A109	PW207C	650	2	34.9	157.3	632.7	1226.6	5.8	3.084E+16	177.7	0.93	0.9098	3.4	35	1.15E+18
H031	B427	Bell 427	PW207D	572	2	34.9	150.4	243.7	671.7	5.6	3E+16	197.4	1.19	0	1.91	37	1.06E+18
H032	EXPL	MD 902	PW207E	429	2	36.9	125.4	657.6	1227.3	5.4	2.8302E+16	212.8	1.05	0.83	3.22	36	6.53E+17
H101	AS65	AS 365 C1 DAUPHIN	ARRIEL 1A1	641	2	41.6	210.7	761.7	988.5	7.1	3.0735E+16	261	1.7	1.47	1.83	51	1.51E+18
H101	AS65	AS 365 C2 DAUPHIN	ARRIEL 1A2	641	2	41.6	210.7	761.7	988.5	7.1	3.0735E+16	261	1.7	1.47	1.83	51.2	1.51E+18
H102	AS35	AS 350 ECUREUIL	ARRIEL 1B	641	1	23.4	128.2	289.6	370.6	4.2	3.0155E+16	133.2	0.97	0.6	0.75	29	9.39E+17
H103	AS65	AS 365 N DAUPHIN	ARRIEL 1C	660	2	42.2	217.7	753	976.8	7.2	3.0964E+16	265.2	1.75	1.45	1.8	53	1.55E+18
H104	AS65	AS 365 N1 DAUPHIN	ARRIEL 1C1	700	2	43.4	231	724.2	938	7.6	3.143E+16	274.3	1.87	1.41	1.73	56	1.65E+18
H105	AS65	AS 365 DAUPHIN	ARRIEL 1C2	763	2	45.2	253.8	679.1	877.4	8.2	3.2145E+16	289.5	2.08	1.35	1.68	61	1.81E+18
H106	AS35	AS 350B ECUREUIL	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	1.10E+18
H106	AS50	AS 550 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
H107	AS55	AS 555 FENNEC	ARRIEL 1D1	712	2	43.8	235.5	713.8	924.1	7.7	3.1554E+16	277.1	1.91	1.4	1.72	57	1.68E+18
H108	A109	AGUSTA 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
H108	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
H108	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
H110	AS35	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
H110	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
H110	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
H111	AS65	AS 365 N3 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
H111	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
H112	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
H113	AS50	AS 350B3 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
H114	S76	SIKORSKY 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
H115	S76	SIKORSKY 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
H121	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
H122	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
H122	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
H123	EC20	EC 120	ARRIUS 2F	432	1	18.8	81.7	364	469.9	2.9	2.7589E+16	114	0.66	0.79	0.98	21	6.15E+17

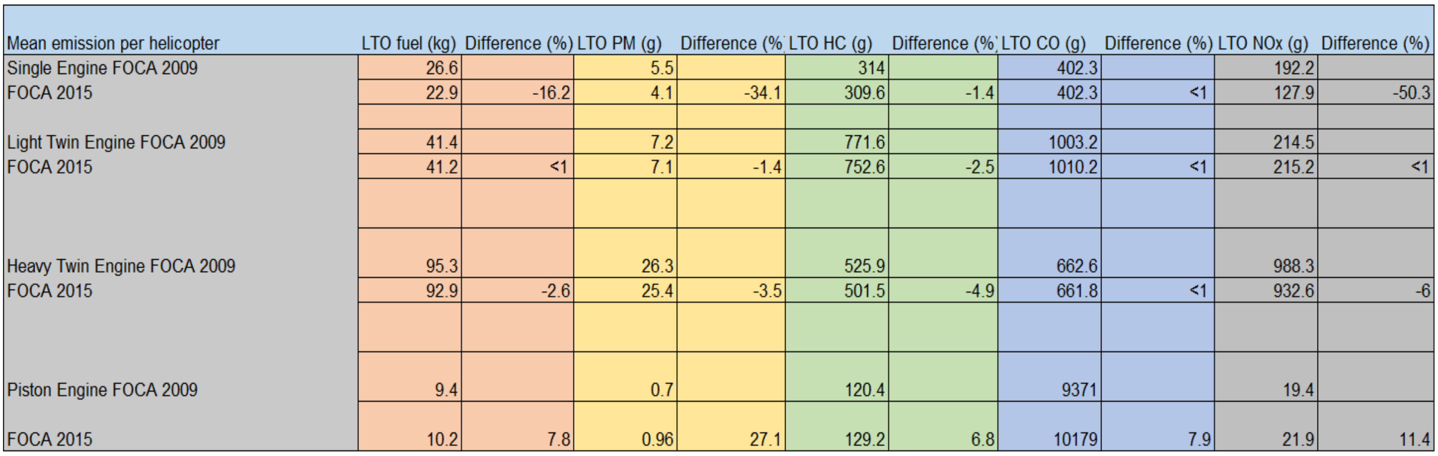
Table 9: (Continued)

						LTO Emissions						One hour emissions					
Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Max SHP per engine	Number_of_Engines	LTO fuel (kg)	LTO NOx (g)	LTO HC (g)	LTO CO (g)	LTO PM non volatile (g)	LTO PM number	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (g)	One hour PM number
H124	A109	AGUSTA A109 Power	ARRIUS 2K	670	2	42.4	220.7	741.8	961.1	7.3	3.1181E+16	240.7	1.61	1.3	1.61	48	1.58E+18
H131	ALO2	ALOUETTE II	ARTOUSTE IIC5	402	1	18.1	75.4	378	489.2	2.7	2.718E+16	109.7	0.61	0.82	1.02	19.4	6.39E+17
H131	ALO2	ALOUETTE II	ARTOUSTE IIC6	402	1	18.1	75.4	378	489.2	2.7	2.718E+16	109.7	0.61	0.82	1.02	19.4	6.39E+17
H132	EC20	EC-120 COLIBRI	ARTOUSTE III B	563	1	21.4	108.9	308.9	395.9	3.6	2.9258E+16	134.9	0.92	0.7	0.86	27	8.04E+17
H132	LAMA	SA315B LAMA	ARTOUSTE IIIB	563	1	21.4	108.9	308.9	395.9	3.6	2.9258E+16	159.2	1.08	0.83	1.02	32.2	5.89E+17
H132	ALO3	SA316B ALOUETTE III	ARTOUSTE IIIB	563	1	21.4	108.9	308.9	395.9	3.6	2.9258E+16	134.9	0.92	0.7	0.86	27.2	8.96E+17
H133	AS55	AS 355 ECUREUIL 21	ARTOUSTE III B	563	2	37.6	175.8	802.1	1046.7	6.1	2.9876E+16	235.7	1.41	1.53	1.91	44	1.29E+18
H141	GAZL	SA341 GAZELLE	ASTAZOU IIIA	644	1	23.5	128.9	288.6	367.6	4.2	3.0155E+16	148.5	1.08	0.67	0.82	32	5.83E+17
H141	GAZL	SA341 GAZELLE	ASTAZOU IIIN2	644	1	23.5	128.9	288.6	367.6	4.2	3.0155E+16	148.5	1.08	0.67	0.82	32	5.83E+17
H142	ALO3	SA316B ALOUETTE III	ASTAZOU XIVB	590	1	21.9	114.5	299.8	384.7	3.8	2.9446E+16	139.4	0.98	0.69	0.85	29	9.52E+17
H142	GAZL	SA342 GAZELLE	ASTAZOU XIVG	590	1	21.9	114.5	299.8	384.7	3.8	2.9446E+16	139.4	0.98	0.69	0.85	28.9	5.28E+17
H142	GAZL	SA342 GAZELLE	ASTAZOU XIVH	590	1	21.9	114.5	299.8	384.7	3.8	2.9446E+16	139.4	0.98	0.69	0.85	28.9	5.28E+17
H151	TIGR	EUROCOPTER 665 TIGER	MTR 390	1450	2	69	507.6	613.6	781	15.2	4.3258E+16	476	4.76	1.17	1.43	133	1.95E+18
H161	2HAC	HAL DHRUV MK.II	TM333-2B2	1219	2	63.4	421.3	688.7	881.4	12.9	4.0814E+16	434.1	3.95	1.29	1.56	112	3.68E+18
H201	H500	HUGHES 500	DDA250-C18	317	1	16.4	59.5	438.2	571.2	2.3	2.5999E+16	98.8	0.48	0.96	1.2	16	2.94E+17
H202	A109	AGUSTA A109A II	DDA250-C20B	420	2	32.8	130.2	960.2	1262	4.9	2.8197E+16	203.5	1.04	1.82	2.28	34	1.12E+18
H202	AS55	AS 355	DDA250-C20F	420	2	32.8	130.2	960.2	1262	4.9	2.8197E+16	203.5	1.04	1.82	2.28	34	1.01E+18
H202	A109	AUGUSTA A109	DDA250-C20B	420	2	32.8	130.2	960.2	1262	4.9	2.8197E+16	203.5	1.04	1.82	2.28	34	1.12E+18
H202	B105	BO 105	DDA250-C20	400	2	32.2	124.3	986.4	1297.6	4.7	2.7856E+16	199.6	1	1.88	2.36	32.7	9.67E+17
H202	B105	BO 105	DDA250-C20B	420	2	32.8	130.2	960.2	1262	4.9	2.8197E+16	203.5	1.04	1.82	2.28	34	1.01E+18
H203	B06	BELL 206B	DDA250-C20	400	1	18.1	75.4	380	491.7	2.7	2.718E+16	109.5	0.61	0.82	1.03	19.3	5.71E+17
H203	B06	BELL 206B	DDA250-C20B	420	1	18.5	78.6	368.2	476.2	2.8	2.7368E+16	101	0.58	0.72	0.9	18	5.38E+17
H203	B06	BELL 206B	DDA250-C20J	420	1	18.5	78.6	368.2	476.2	2.8	2.7368E+16	101	0.58	0.72	0.9	18	5.38E+17
H203	EN48	ENSTROM 480	DDA250-C20W	420	1	18.5	78.6	368.2	476.2	2.8	2.7368E+16	112.3	0.64	0.8	1	20.2	3.69E+17
H203	H500	HUGHES 501	DDA250-C20B	420	1	18.5	78.6	368.2	476.2	2.8	2.7368E+16	112.3	0.64	0.8	1	20.2	3.69E+17
H203	MD 52	MD 520N	DDA250-C20	400	1	18.1	75.4	380	491.7	2.7	2.718E+16	109.5	0.61	0.82	1.03	19.3	3.53E+17
H204	B06	BELL 206B	DDA250-C20R	450	1	19.1	85.1	354.8	457.7	3	2.7762E+16	105	0.63	0.7	0.86	19.4	5.73E+17
H204	B06	BELL 206B	DDA250-C20R/4	450	1	19.1	85.1	354.8	457.7	3	2.7762E+16	105	0.63	0.7	0.86	19.4	5.73E+17
H204	B06	BELL 206L	DDA250-C20R	450	1	19.1	85.1	354.8	457.7	3	2.7762E+16	116.7	0.7	0.77	0.96	22	6.39E+17
H204	H500	MD 500N	DDA250-C20R	450	1	19.1	85.1	354.8	457.7	3	2.7762E+16	116.7	0.7	0.77	0.96	21.6	3.95E+17
H205	A109	AGUSTA A109	DDA250-C20R/1	450	2	34	140	919.6	1206.8	5.2	2.8552E+16	209.7	1.11	1.74	2.18	35.9	1.18E+18
H205	A109	AGUSTA A109C	DDA250-C20R	450	2	34	140	919.6	1206.8	5.2	2.8552E+16	209.7	1.11	1.74	2.18	36	1.18E+18
H205	B06T	BELL Twin Ranger	DDA250-C20R	450	2	34	140	919.6	1206.8	5.2	2.8552E+16	209.7	1.11	1.74	2.18	35.9	1.06E+18
H206	B06	BELL 206L	DDA250-C30	650	1	23.6	130.5	286.5	365.5	4.2	3.0234E+16	149.4	1.11	0.66	0.82	32	9.55E+17
H206	B06	BELL 206L	DDA250-C30P	650	1	23.6	130.5	286.5	365.5	4.2	3.0234E+16	149.4	1.11	0.66	0.82	32	9.55E+17
H207	S76	SIKORSKY S76	DDA250-C30S	650	2	41.6	212.2	750.1	972.9	7.1	3.084E+16	263	1.71	1.46	1.81	52	7.59E+17
H208	B222	BELL 222	DDA250-C40B	715	2	43.8	237.1	710.5	918.7	7.7	3.1574E+16	277.8	1.92	1.39	1.72	57	1.68E+18

Table 9: (Continued). Green shaded lines are piston engine powered helicopters.

						LTO Emissions						One hour emissions					
Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Max SHP per engine	Number_of_Engines	LTO fuel (kg)	LTO NOx (g)	LTO HC (g)	LTO CO (g)	LTO PM non volatile (g)	LTO PM number	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (g)	One hour PM number
H208	B430	Bell 430	DDA250-C40B	715	2	43.8	237.1	710.5	918.7	7.7	3.1574E+16	277.8	1.92	1.39	1.72	57	1.68E+18
H211	LYNX	WESTLAND BATTLEFIELD LYNX	GEM 42-1	1120	2	60.8	385.3	727.3	933.7	11.9	3.9552E+16	415.9	3.62	1.36	1.66	103	1.88E+18
H221	B407	Bell 407	DDA250-C47B	650	1	23.6	130.5	286.5	365.5	4.2	3.0234E+16	149.4	1.11	0.66	0.82	32	9.55E+17
H221	MD60	MD 600N	DDA250-C47M	808	1	26.7	168.7	252.7	319.7	5.2	3.2187E+16	175.7	1.46	0.62	0.76	42	7.68E+17
H222	B06	BELL OH-58A+	RR T63-A-720	420	1	18.5	78.6	368.2	476.2	2.8	2.7368E+16	112.3	0.64	0.8	1	20	5.97E+17
H301	B222	BELL 222	LTS101-750C.1	735	2	44.6	246	704	909.6	8	3.1895E+16	282.6	1.98	1.38	1.7	59	1.74E+18
H301	BK17	BK117B	LTS101-750B.1	727	2	44.2	240.5	700.3	905.5	7.9	3.179E+16	280.7	1.96	1.38	1.71	58.1	1.72E+18
H302	AS50	AS 350 SD2 ASTAR	TL LTS-101-700D2	742	1	25.5	152.5	266.7	338.6	4.8	3.1399E+16	164.5	1.3	0.63	0.77	38	1.11E+18
H303	UH1	BELL UH-1H	T53 L13	1400	1	41.7	359.8	214.7	266.7	10.3	3.8725E+16	271.3	3.09	0.53	0.62	84.1	1.23E+18
H303	KMAX	K-1200	T53 17A-1	1500	1	43.3	388.5	206.5	257.6	11.1	3.9765E+16	283.9	3.35	0.51	0.62	91	1.66E+18
H304	UH1	AGUSTA-BELL AB-204B	T53-09A	1100	1	36.6	273.3	246.5	308.9	8.1	3.5462E+16	235.2	2.33	0.59	0.73	65	9.55E+17
H305	H47	CH-47 Chinook	T55-GA-714A	4800	2	153.8	2380.2	319.6	385.1	51.8	6.6267E+16	1223.6	24.23	0.83	0.98	471	8.60E+18
H401	MI26	MIL MI-2	ISOTOW GTD-350	400	2	30	104.4	1095.3	1448.3	4.2	3.0809E+16	196	0.94	1.94	2.43	32	5.78E+17
H402	MI8	MIL MI-8	TV2-117	1500	2	70.2	525.4	600.8	764.4	15.7	4.3822E+16	485.1	4.95	1.15	1.41	138	2.52E+18
H403	KA27	KA-32A12	TV3-117VMA	2200	2	86.4	816.8	472.6	591.7	23	5.0548E+16	621.2	7.89	0.98	1.18	211	3.85E+18
H501	H53	SIKORSKY CH-53G (S-65)	T 64-GE-7	3925	2	125.6	1688.7	346.5	428.3	41.3	6.2697E+16	977.5	17.3	0.82	0.98	388	7.10E+18
H502	H53S	SIKORSKY MH53E	T64-GE-416	4380	2	138.2	1998.9	330.6	404	46.2	6.4685E+16	1083.4	20.37	0.81	0.98	427	7.81E+18
H503	HUCO	BELL 209 HUEYCOBRA	T700-GE-401	1800	2	77.2	646.8	534.9	677	18.7	4.6879E+16	541.3	6.17	1.06	1.25	168	3.07E+18
H503	H60	SIKORSKY BLACK HAWK	T700-GE-700	1622	2	73	575.3	571	724.9	16.9	4.4976E+16	507.6	5.43	1.11	1.32	15	2.74E+18
H505	2HAC	PLACEHOLDER	GE CT7-6	1920	2	79.8	693.9	514.1	644.8	19.9	4.7976E+16	564.7	6.66	1.03	1.24	180	5.90E+18
H506	S92	SIKORSKY S92A	GE CT7-8A	2740	2	98.8	1066.2	419.1	524.5	28.9	5.506E+16	735.1	10.59	0.91	1.1	271	3.97E+18
H701	MI26	MIL MI-26	LO D-136	11400	2	268.2	2426.4	2885.5	1893.6	95.9	6.1279E+16	142827	4627.6	38.56	42.85	1428	2.61E+19
H801	W3	PZL W-3 SOKOL	PZL-10W	880	2	44.8	247.6	689.3	889.7	8.1	3.6784E+16	309	2.35	1.31	1.61	68	9.96E+17
HF30	AS32	SUPER PUMA	MAKILA 1A1	1820	2	78.7	391.1	46.4	457.6	16.4	3.1774E+16	453.6	3.1	0.19	1.32	151	4.96E+18
HP41	R22	R22 BETA	HO-360	180	1	7	17.2	99.3	6970	0.5	9.7298E+15	72	0.14	0.84	72	6.5	9.52E+16
HP42	HU30	HUGHES 300	HIO-360	190	1	8.7	20.8	121.9	8650	1.2	2.2557E+16	54.6	0.11	0.74	54.58	8	1.17E+17
HP42	EN28	ENSTROM 280C	HIO-360	190	1	8.7	20.8	121.9	8650	1.2	2.2557E+16	54.6	0.11	0.74	54.58	8	1.17E+17
HP42	H269	Schweizer 269C	HIO-360	190	1	8.7	20.8	121.9	8650	1.2	2.2557E+16	54.6	0.11	0.74	54.58	8	1.17E+17
HP43	R44	R44 RAVEN	HIO-540	245	1	8.5	19	110.8	8450	1.2	2.2979E+16	59.9	0.12	0.72	59.86	9.5	1.39E+17
HP44	UH12	HILLER UH-12A	TVO-540-1B	320	1	11.6	24.8	143.2	11600	0.8	9.3726E+15	82.3	0.16	0.91	82.33	5.8	8.50E+16
HP45	B47G	Bell 47G-3B	TVO-435-A1D	220	1	7.3	16	103.4	7300	0.5	9.3726E+15	49.9	0.1	0.63	49.94	3.5	5.13E+16
HP45	B47G	Bell 47G-3B	TVO-435-B1A	266	1	9.2	20	121.1	9200	0.7	9.3726E+15	64.6	0.13	0.76	64.62	4.5	6.59E+16
HP51	SYCA	BRISTOL SYCAMORE	ALVIS LEONIDES	550	1	33.5	62	328.3	33500	2.7	9.3726E+15	276.8	0.55	2.52	276.8	19.4	2.84E+17
HP61	EXEC	ROTORWAY EXEC 90	ROTORWAY RI RW-162	160	1	5	11	77.8	5000	0.4	1.0449E+16	34.5	0.07	0.48	34.5	2.4	3.52E+16
HP62	SCOR	ROTORWAY SCORPION	ROTORWAY RW 133	133	1	4.2	9.3	71.5	4200	0.3	9.3726E+15	28	0.06	0.42	28.04	2	2.93E+16

Table 10: Comparison between the 2009 and 2015 FOCA guidance



Mean emission per helicopter	LTO fuel (kg)	Difference (%)	LTO PM (g)	Difference (%	LTO HC (g)	Difference (%	LTO CO (g)	Difference (%)	LTO NOx (g)	Difference (%)
Single Engine FOCA 2009	26.6		5.5		314		402.3		192.2	
FOCA 2015	22.9	-16.2	4.1	-34.1	309.6	-1.4	402.3	<1	127.9	-50.3
Light Twin Engine FOCA 2009	41.4		7.2		771.6		1003.2		214.5	
FOCA 2015	41.2	<1	7.1	-1.4	752.6	-2.5	1010.2	<1	215.2	<1
Heavy Twin Engine FOCA 2009	95.3		26.3		525.9		662.6		988.3	
FOCA 2015	92.9	-2.6	25.4	-3.5	501.5	-4.9	661.8	<1	932.6	-6
Piston Engine FOCA 2009	9.4		0.7		120.4		9371		19.4	
FOCA 2015	10.2	7.8	0.96	27.1	129.2	6.8	10179	7.9	21.9	11.4

References

1) Rotorcraft Flight Manuals: Robinson R22, Schweizer 300C Helicopter Model 269C, Hughes 500D, Bell 206B, Eurocopter EC120B, EC145 (645), Agusta A109E, Agusta A119, Aerospatiale AS350 B2 Ecureuil, AS532 Cougar

2) FOCA engine database (not publicly available)

3) FOI (Swedish Defence Research Agency) engine database for turboprop and turboshaft engines (not publicly available)

4) Aircraft piston engine emissions , FOCA, 2007

5) Emission indices for gaseous pollutants and non-volatile particles of flight turboshaft engines, FOCA/DLR turboshaft engine measurements, FOCA/DLR, 2009 (not publicly available yet)

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14) Control of air pollution from aircraft and aircraft engines, US Environmental Protection Agency, US federal register, Volume 38, Number 136, July 17, 1973

15) Helicopter Pictures © by B. Baur, FOCA, Switzerland

Appendix A: LTO data, cruise data and estimated emissions for a single engine turboshaft helicopter

SINGLE ENGINE TURBINE HELICOPTER LTO AND CRUISE DATA

HBXVA	19.02.2009		
Type	AS350B2		
Engine	Arriel 1D1		
Ref. Power:			
100%T	732	SHP	
94%T (MCP)	688	SHP	
TOM	2020	kg	(= 90% MTOM)
OM test end	1820	kg	

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	SHP %	Engine N1 %	RoC RoD (ft/min)	Est. SHP	Est. FF (kg/s)	Est. EI NOx (g/kg)	Est. EI HC (g/kg)	Est. EI CO (g(kg)	Est. EI PM (g/kg)
GI	2	2	15	7	70	0	51	0.014	1.974	54.375	71.639	0.118
GR (full rotor RPM)	2	4	23	23	80.2	0	168	0.025	3.879	15.045	19.129	0.144
HOVER IGE	0.3	4.3	65	65	90.3	0	476	0.039	6.996	4.899	6.038	0.207
CL	2.5	6.8	90	90	95.8	1000	659	0.050	8.416	3.447	4.207	0.241

TO 5 NM	3.7	7.7
TO 3000ft	3	7

	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	4.7	14.9	137.3	178.9	0.6
TO	8.1	67.5	29.1	35.5	1.9
Total 1	12.8	82.4	166.4	214.4	2.6

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	SHP %	Engine N1 %	RoC RoD (ft/min)	Est. SHP	Est. FF (kg/s)	Est. EI NOx (g/kg)	Est. EI HC (g/kg)	Est. EI CO (g/kg)	Est. EI PM (g/kg)
DCT	2.5	2.5	60	60		700	439	0.037	6.686	5.341	6.599	0.200
DCT	1	3.5	45	45		500	329	0.032	5.678	7.287	9.081	0.178
AP	0.7	4.2	30	30		500	220	0.028	4.511	11.292	14.243	0.155
FINAL	0.3	4.5	15	15	78	250	110	0.020	3.043	23.872	30.743	0.131
FINAL	0.7	5.2	20	20	80	250	146	0.023	3.583	17.496	22.339	0.139
HOVER IGE	0.3	5.5	60	60	89	0	439	0.037	6.686	5.341	6.599	0.200
GI	1	6.5	15	7	69	0	51	0.014	1.974	54.375	71.639	0.118

L 5NM	4.5	5.5
L 3000ft	5.5	6.5

	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	0.9	1.7	46.3	61.0	0.1
AP	10.7	62.8	86.7	108.8	2.0
Total 2	11.6	64.5	133.0	169.8	2.1
TOTAL LTO	24.4	146.9	299.4	384.2	4.6

CRUISE and LTO MEAN

CR	Cruise	Mean Time (Min.)	Est. SHP	Est. Mean FF (kg/s)	Est. Mean EI NOx (g/kg)	Est. Mean EI HC (g/kg)	Est. Mean EI CO (g/kg)	Est. Mean EI PM (g/kg)
CR	**75%**	60	549	0.043	7.588	4.197	5.151	0.221
CR	**80%**	60	586	0.045	7.872	3.914	4.795	0.228
CR	**85%**	60	622	0.047	8.147	3.666	4.483	0.234
CR	**90%**	60	659	0.050	8.416	3.447	4.207	0.241

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
75%	155	1178	651	799	34
80%	163	1281	637	781	37
85%	171	1389	625	765	40
90%	178	1501	615	751	43

LTO	Mean SHP %	Mean Time (Min.)	Est. SHP	Est. Mean FF (kg/s)	Est. Mean EI NOx (g/kg)	Est. Mean EI HC (g/kg)	Est. Mean EI CO (g/kg)	Est. Mean EI PM (g/kg)
GI	**15**	4	110	0.020	3.043	23.872	30.743	0.131
TO	**87**	2.8	639	0.048	8.273	3.561	4.351	0.237

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
GI	4.9	14.9	117.2	151.0	0.6
TO	8.1	67.2	28.9	35.4	1.9
Total 1	13.0	82.2	146.2	186.3	2.6

LTO	Mean SHP %	Mean Time (Min.)	Est. SHP	Est. Mean FF (kg/s)	Est. Mean EI NOx (g/kg)	Est. Mean EI HC (g/kg)	Est. Mean EI CO (g/kg)	Est. Mean EI PM (g/kg)
AP	**46**	5.5	336	0.033	5.743	7.131	8.882	0.180
GI	**7**	1	51	0.014	1.974	54.375	71.639	0.118

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (k)
AP	10.8	62.0	76.9	95.8	1.9
GI	0.9	1.7	46.3	61.0	0.1
Total 2	11.6	63.6	123.2	156.8	2.0
TOTAL LTO	24.7	145.8	269.4	343.2	4.6

Appendix B: LTO data, measured fuel flow and estimated emissions for a small twin engine turboshaft helicopter (continued on next page)

TWIN ENGINE TURBINE HELICOPTER LTO DATA

HBXQE	12.02.2009	
Type	A109	
Engine	PW206C	
Ref. Power:		
max. one engine	550	SHP
100% Rotor-Torque	900	SHP
MC per engine	450	SHP
TOM	2850	kg (= MTOM)
OM test end	2650	kg

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	Total SHP %	Engine 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC RoD (ft/min)	Est. SHP per engine	Est. FF per engine (kg/s)	Est. EI NOx per engine (g/kg)	Est. EI HC per engine (g/kg)	Est. EI CO per engine (g/kg)	Est. EI PM per engine (g/kg)
GI	3.3	3.3	9	6	61.5	60.3	0.01	0.01	0	27	0.010	1.372	108.626	145.882	0.112
GR (full rotor RPM)	0.7	4	21	21	75.5	74.7	0.01583	0.01583	0	95	0.019	2.795	28.073	36.315	0.128
HOVER IGE	0	4							0	0					
CL	3	7	95	95	90.4	91.4	0.03333	0.03194	1000	428	0.036	6.584	5.499	6.800	0.198

	Time Incr. (Min)	Time sum (Min.)
TO 5 NM	4	8
TO 3000ft	3	7

	Meas. Total fuel (kg)
GI	5.3
TO	11.7
Total 1	17.0

	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	5.7	10.1	487.3	652.2	0.7
TO	13.0	85.7	71.6	88.5	2.6
Total 1	18.7	95.8	558.9	740.7	3.2

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	Total SHP %	Engine 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC RoD (ft/min)	Est. SHP per engine	Est. FF per engine (kg/s)	Est. EI NOx per engine (g/kg)	Est. EI HC per engine (g/kg)	Est. EI CO per engine (g/kg)	Est. EI PM per engine (g/kg)
DCT	2.5	2.5	60	60			0.0257	0.0257	700	270	0.028	5.072	9.033	11.324	0.166
DCT	1	3.5	45	45			0.0222	0.0222	500	203	0.025	4.308	12.325	15.584	0.152
AP	0.7	4.2	30	30			0.0167	0.0167	500	135	0.022	3.422	19.097	24.443	0.137
FINAL	0.3	4.5	15	15			0.0148	0.0148	250	68	0.016	2.309	40.376	52.758	0.121
FINAL	0.7	5.2	20	20			0.0158	0.0158	250	90	0.019	2.718	29.592	38.336	0.127
HOVER IGE	0.3	5.5	70	70			0.0275	0.0275	0	315	0.030	5.536	7.648	9.543	0.175
GI	1	6.5	8	6			0.01	0.01	0	27	0.010	1.372	108.626	145.882	0.112

	Time Incr. (Min)	Time sum (Min.)
L 5NM	4.5	5.5
L 3000ft	5.5	6.5

	Meas. Total fuel (kg)
GI	1.2
TO	14.6
Total 1	15.8
TOTAL LTO	32.9

	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	1.2	1.7	134.0	180.0	0.1
AP	16.6	73.9	227.7	289.9	2.6
Total 2	17.8	75.6	361.7	469.9	2.7
TOTAL LTO	36.5	171.4	920.6	1210.6	6.0

Appendix B: Weighted average LTO data, measured cruise fuel flow and estimated emissions for a small twin engine turboshaft helicopter

CR	Est. Total SHP	Mean Time (Min.)	**Est. SHP % per engine**	Est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (kg/s)	Est. Mean EI HC per engine (kg/s)	Est. Mean EI CO per engine (kg/s)	Est. Mean EI PM per engine (kg/s)
75%	675	60	**61**	338	0.031	5.757	7.098	8.840	0.180
80%	720	60	**65**	360	0.032	5.972	6.620	8.228	0.185
85%	765	60	**70**	383	0.034	6.181	6.201	7.693	0.189
90%	810	60	**74**	405	0.035	6.385	5.830	7.220	0.194

Meas. Fuel (kg)
200

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
75%	225	1296	1598	1990	41
80%	233	1394	1545	1921	43
85%	242	1497	1501	1863	46
90%	251	1603	1464	1813	49

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
GI	9	4	**7**	39	0.012	1.686	73.401	97.512	0.115
TO	95	3	**78**	428	0.036	6.584	5.499	6.800	0.198

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
GI	5.9	10.0	433.9	576.4	0.7
TO	13.0	85.7	71.6	88.5	2.6
Total 1	18.9	95.7	505.4	664.9	3.3

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
AP	46	5.5	**38**	209	0.026	4.386	11.909	15.044	0.153
GI	6	1	**5**	27	0.010	1.372	108.626	145.882	0.112

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
AP	16.9	74.2	201.5	254.6	2.6
GI	1.2	1.7	134.0	180.0	0.1
Total 2	18.2	75.9	335.6	434.6	2.7
TOTAL LTO	37.1	171.6	841.0	1099.4	6.0

CR	Est. Total SHP	Mean Time (Min.)	**Est. SHP % per engine**	Est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (kg/s)	Est. Mean EI HC per engine (kg/s)	Est. Mean EI CO per engine (kg/s)	Est. Mean EI PM per engine (kg/s)
75%	675	60	**61**	338	0.031	5.757	7.098	8.840	0.180
80%	720	60	**65**	360	0.032	5.972	6.620	8.228	0.185
85%	765	60	**70**	383	0.034	6.181	6.201	7.693	0.189
90%	810	60	**74**	405	0.035	6.385	5.830	7.220	0.194

Meas. Fuel (kg)
200

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
75%	225	1296	1598	1990	41
80%	233	1394	1545	1921	43
85%	242	1497	1501	1863	46
90%	251	1603	1464	1813	49

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
GI	9	4	**7**	39	0.012	1.679	74.045	98.391	0.115
TO	92	3	**75**	413	0.035	6.452	5.715	7.075	0.195

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
GI	5.9	9.9	437.7	581.6	0.7
TO	12.7	84.0	74.4	92.1	2.5
Total 1	18.6	93.9	512.0	673.6	3.2

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
AP	43	5.5	**35**	193	0.025	4.186	13.018	16.485	0.149
GI	9	1	**7**	39	0.012	1.679	74.045	98.391	0.115

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
AP	16.5	70.8	220.3	279.0	2.5
GI	1.5	2.1	91.3	121.4	0.1
Total 2	17.9	72.9	311.7	400.4	2.7
TOTAL LTO	36.5	166.8	823.7	1074.0	5.9

Appendix C: LTO data, measured fuel flow and estimated emissions for a large twin engine turboshaft helicopter (continued on next page)

TWIN ENGINE TURBINE HELICOPTER LTO DATA

HBXQE	12.01.2009	
Type	AS32	
Engine	MAKILA 1A1	
Ref. Power:		
max. one engine	1820	SHP
100% Rotor-Torque	2996	SHP
MC per engine	1589	SHP
TOM	7600	kg (= MTOM)
OM test end		kg

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	Total SHP %	Engine 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC RoD (ft/min)	Est. SHP per engine	Est. FF per engine (kg/s)	Est. EI NOx per engine (g/kg)	Est. EI HC per engine (g/kg)	Est. EI CO per engine (g/kg)	Est. EI PM per engine (g/kg)
GI	3.3	3.3	7	5.8	65	65	0.0233	0.0233	0	87	0.022	2.665	30.740	39.865	0.027
GR (full rotor RPM)	0.7	4	15	15	75	75	0.0375	0.0375	0	225	0.033	4.570	11.015	13.885	0.069
HOVER IGE	0.1	4.1	64	64	90	90	0.0653	0.0653	0	959					
CL	3	7.1	81	81	90.3	90.1	0.075	0.075	1000	1213	0.079	11.904	1.782	2.136	0.300
								Meas. Total fuel (kg)			Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
TO 5 NM	4	8					GI	12.4		GI	11.4	35.6	294.5	380.8	0.4
TO 3000ft	3	7					TO	27.8		TO	28.6	340.4	51.0	61.1	8.6
							Total 1	40.2		Total 1	40.0	376.1	345.5	441.9	9.0

LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	Total SHP %	Engine 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC RoD (ft/min)	Est. SHP per engine	Est. FF per engine (kg/s)	Est. EI NOx per engine (g/kg)	Est. EI HC per engine (g/kg)	Est. EI CO per engine (g/kg)	Est. EI PM per engine (g/kg)
DCT	2.5	2.5	45	45	84.2	84.5	0.0542	0.0542	700	674	0.057	8.526	3.362	4.101	0.188
DCT	1	3.5	41	41	83.9	83.2	0.05	0.05	500	614	0.054	8.088	3.718	4.548	0.174
AP	0.7	4.2	30	30			0.047	0.047	500	449	0.047	6.773	5.210	6.433	0.132
FINAL	0.3	4.5	15	15			0.0375	0.0375	250	225	0.033	4.570	11.015	13.885	0.069
FINAL	0.7	5.2	20	20			0.04	0.04	250	300	0.038	5.381	8.073	10.089	0.090
HOVER IGE	0.3	5.5	65	65			0.066	0.066	0	974	0.069	10.506	2.260	2.727	0.255
GI	1	6.5	7	5.8			0.0233	0.0233	0	87	0.022	2.665	30.740	39.865	0.027
								Meas. Total fuel (kg)			Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
L 5NM	4.5	5.5					GI	2.8		GI	2.6	6.9	79.9	103.7	0.1
L 3000ft	5.5	6.5					TO	33.3		AP	34.4	273.9	146.9	180.8	5.9
							Total 1	36.1		Total 2	37.0	280.8	226.8	284.4	5.9
							TOTAL LTO	76.3		TOTAL LTO	77.0	656.9	572.3	726.3	15.0

Appendix C: Weighted average LTO data, measured cruise fuel flow and estimated emissions for a large twin engine turboshaft helicopter

CRUISE and LTO MEAN

CR	Est. Total SHP	Mean Time (Min.)	**Est. SHP % per engine**	Est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)	
75%	2247	60	**62**	1124	0.076	11.395	1.937	2.326	0.284	
80%	2397	60	**66**	1198	0.079	11.820	1.806	2.166	0.297	
85%	2547	60	**70**	1273	0.082	12.234	1.692	2.025	0.310	NOT PRACTICAL
90%	2696	60	**74**	1348	0.086	12.637	1.590	1.900	0.322	

Operating Mass (kg)	Meas. Fuel (kg)
7600 (light)	480

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)	
75%	544	6195	1053	1265	154	
80%	567	6705	1024	1228	169	
85%	591	7234	1000	1197	183	NOT PRACTICAL
90%	616	7784	980	1170	199	

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
GI	7	4	**6**	111	0.024	3.062	23.593	30.374	0.035
TO	80	3.1	**66**	1205	0.079	11.858	1.795	2.152	0.299

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
GI	11.5	35.2	270.9	348.8	0.4
TO	29.4	348.8	52.8	63.3	8.8
Total 1	40.9	384.0	323.7	412.1	9.2

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
AP	39	5.5	**32**	579	0.053	7.819	3.964	4.858	0.165
GI	5.8	1	**5**	87	0.022	2.665	30.740	39.865	0.027

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
AP	34.9	272.6	138.2	169.4	5.8
GI	2.6	6.9	79.9	103.7	0.1
Total 2	37.5	279.6	218.2	273.0	5.8
TOTAL LTO	78.4	663.6	541.9	685.1	15.0

CRUISE and LTO MODEL

CR	Est. Total SHP	Mean Time (Min.)	**Est. SHP % per engine**	Est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
75%	2247	60	**62**	1124	0.076	11.395	1.937	2.326	0.284
80%	2397	60	**66**	1198	0.079	11.820	1.806	2.166	0.297
85%	2547	60	**70**	1273	0.082	12.234	1.692	2.025	0.310
90%	2696	60	**74**	1348	0.086	12.637	1.590	1.900	0.322

Operating Mass (kg)	Meas. Fuel (kg)
7600 (light)	480

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
75%	544	6195	1053	1265	154
80%	567	6705	1024	1228	169
85%	591	7234	1000	1197	183
90%	616	7784	980	1170	199

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
GI	9	4	**7**	127	0.025	3.311	20.331	26.066	0.040
TO	91	3	**75**	1365	0.086	12.727	1.569	1.874	0.325

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
GI	12.2	38.0	233.5	299.3	0.5
TO	31.1	374.4	46.2	55.1	9.6
Total 1	43.3	412.4	279.6	354.4	10.0

LTO	Mean total SHP %	Mean Time (Min.)	**Mean est. SHP % per engine**	Mean est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
AP	43	5.5	**35**	637	0.055	8.257	3.574	4.367	0.179
GI	9	1	**7**	127	0.025	3.311	20.331	26.066	0.040

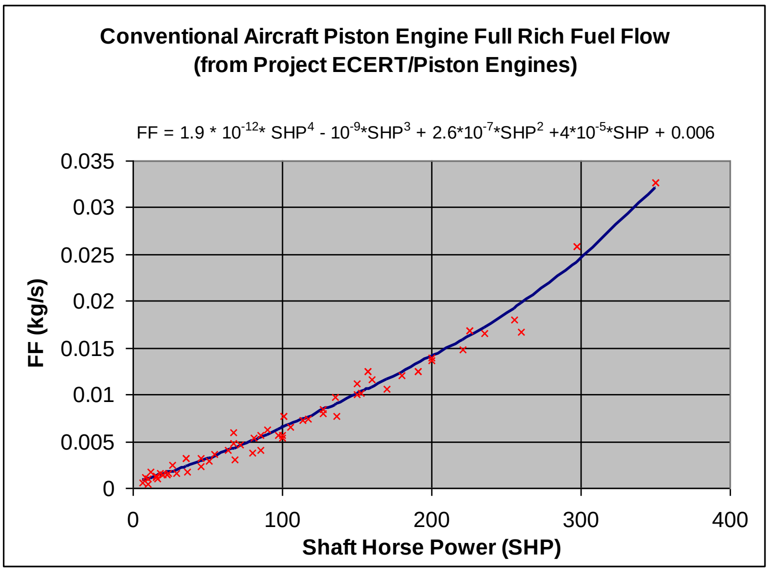
	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
AP	36.5	287.9	124.6	152.3	6.3
GI	3.0	8.6	52.9	67.8	0.1
Total 2	39.6	296.5	177.5	220.1	6.4
TOTAL LTO	82.8	708.9	457.1	574.5	16.4

Appendix D: Estimated one hour operation emissions and indicated scale factors (status March 2009). Example: Scale factor 0.9 means that the estimated one hour fuel and emissions have been multiplied by a factor of 0.9

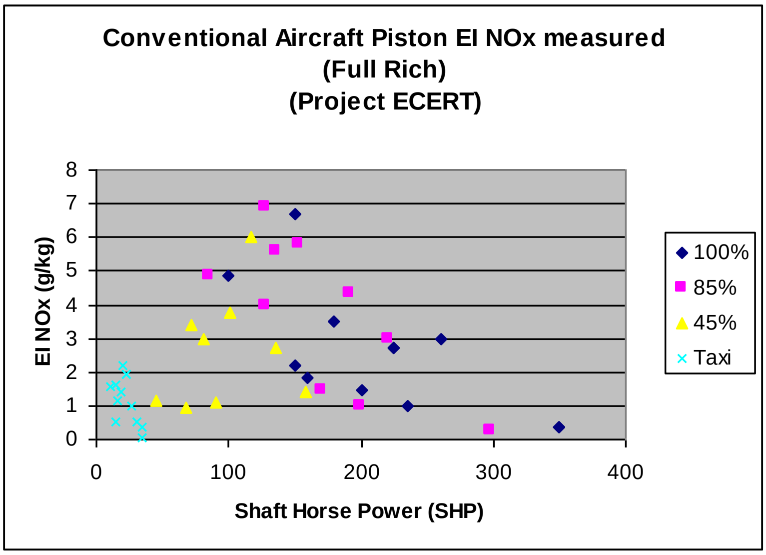
					One hour emissions					
Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Mean operating helicopters specific scale factor	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (g)	One hour PM number
H505	2HAC	PLACEHOLDER	GE CT7-6	1	564.7	6.66	1.03	1.24	180	5.90E+18
H161	2HAC	HAL DHRUV MK.II	TM333-2B2	1	434.1	3.95	1.29	1.56	112	3.68E+18
H205	A109	AGUSTA A109	DDA250-C20R/1	1	209.7	1.11	1.74	2.18	35.9	1.18E+18
H202	A109	AGUSTA A109A II	DDA250-C20B	1	203.5	1.04	1.82	2.28	34	1.12E+18
H108	A109	AGUSTA A109 K2	ARRIEL 1K1	0.9	255	1.79	1.24	1.53	53	1.75E+18
H022	A109	AGUSTA A109E	PW206C	0.9	194.4	1.01	1	3.73	35.8	1.18E+18
H124	A109	AGUSTA A109 Power	ARRIUS 2K	0.9	240.7	1.61	1.3	1.61	48	1.58E+18
H202	A109	AGUSTA A109	ALLISON 250-C20B	1	203.5	1.04	1.82	2.28	34	1.12E+18
H205	A109	AGUSTA A109C	DDA250-C20R	1	209.7	1.11	1.74	2.18	36	1.18E+18
H030	A109	AGUSTA A109	PW207C	0.9	177.7	0.93	0.9098	3.4	35	1.15E+18
H012	A119	AGUSTA A119	PT6B-37	1	216	1.77	0.07	0.78	54	1.78E+18
H015	A139	AUGUSTA A139	PT6T-3D	1	360	2.56	0.26	1.98	112	3.68E+18
H017	A139	AGUSTA A139	PT6C-67C	1	412.2	3.55	1.37	1.65	101	3.33E+18
H131	ALO2	ALOUETTE II	ARTOUSTE IIC5	1	109.7	0.61	0.82	1.02	19.4	6.39E+17
H131	ALO2	ALOUETTE II	ARTOUSTE IIC6	1	109.7	0.61	0.82	1.02	19.4	6.39E+17
H132	ALO3	SA316B ALOUETTE III	ARTOUSTE IIIB	1	134.9	0.92	0.7	0.86	27.2	8.96E+17
H142	ALO3	SA316B ALOUETTE III	ASTAZOU XIVB	1	139.4	0.98	0.69	0.85	29	9.52E+17
HF30	AS32	SUPER PUMA	MAKILA 1A1	0.9	453.6	3.1	0.19	1.32	151	4.96E+18
H102	AS35	AS 350 ECUREUIL	ARRIEL 1B	0.9	133.2	0.97	0.6	0.75	29	9.39E+17
H106	AS35	AS 350B ECUREUIL	ARRIEL 1D1	0.9	146.5	1.16	0.57	0.7	33	1.10E+18
H110	AS35	AS 350 B3	ARRIEL 2B	0.83	151.6	1.3	0.51	0.62	37	1.22E+18
H110	AS35	AS 350 B3	ARRIEL 2B1	0.83	151.6	1.3	0.51	0.62	37	1.22E+18
H113	AS50	AS 350B3 ASTAR	ARRIEL 2D	1	200.3	1.82	0.59	0.72	52	1.53E+18
H302	AS50	AS 350 SD2 ASTAR	LTS-101-700D2	1	164.5	1.3	0.63	0.77	38	1.11E+18
H106	AS50	AS 550 FENNEC	ARRIEL 1D1	0.9	146.5	1.16	0.57	0.7	33.4	9.87E+17
H202	AS55	AS 355	DDA250-C20F	1	203.5	1.04	1.82	2.28	34	1.01E+18
H107	AS55	AS 555 FENNEC	ARRIEL 1D1	1	277.1	1.91	1.4	1.72	57	1.68E+18
H121	AS55	AS 355 N	ARRIUS 1A	1	216.2	1.19	1.67	2.08	38	1.12E+18
H133	AS55	AS 355 ECUREUIL 21	ARTOUSTE III B	1	235.7	1.41	1.53	1.91	44	1.29E+18
H101	AS65	AS 365 C1 DAUPHIN	ARRIEL 1A1	1	261	1.7	1.47	1.83	51	1.51E+18
H101	AS65	AS 365 C2 DAUPHIN	ARRIEL 1A2	1	261	1.7	1.47	1.83	51.2	1.51E+18
H103	AS65	AS 365 N DAUPHIN	ARRIEL 1C	1	265.2	1.75	1.45	1.8	53	1.55E+18
H104	AS65	AS 365 N1 DAUPHIN	ARRIEL 1C1	1	274.3	1.87	1.41	1.73	56	1.65E+18
H105	AS65	AS 365 DAUPHIN	ARRIEL 1C2	1	289.5	2.08	1.35	1.68	61	1.81E+18
H111	AS65	AS 365 N3 DAUPHIN	ARRIEL 2C	1	308.9	2.35	1.31	1.61	68	2.01E+18
H203	B06	BELL 206B	DDA250-C20	1	109.5	0.61	0.82	1.03	19.3	5.71E+17
H203	B06	BELL 206B	DDA250-C20B	0.9	101	0.58	0.72	0.9	18	5.38E+17
H203	B06	BELL 206B	DDA250-C20J	0.9	101	0.58	0.72	0.9	18	5.38E+17
H204	B06	BELL 206B	DDA250-C20R	0.9	105	0.63	0.7	0.86	19.4	5.73E+17
H204	B06	BELL 206B	DDA250-C20R/4	0.9	105	0.63	0.7	0.86	19.4	5.73E+17
H204	B06	BELL 206L	DDA250-C20R	1	116.7	0.7	0.77	0.96	22	6.39E+17
H206	B06	BELL 206L	DDA250-C30	1	149.4	1.11	0.66	0.82	32	9.55E+17
H206	B06	BELL 206L	DDA250-C30P	1	149.4	1.11	0.66	0.82	32	9.55E+17
H222	B06	BELL OH-58A+	RR T63-A-720	1	112.3	0.64	0.8	1	20	5.97E+17
H205	B06T	BELL Twin Ranger	DDA250-C20R	1	209.7	1.11	1.74	2.18	35.9	1.06E+18
H202	B105	BO 105	DDA250-C20	1	199.6	1	1.88	2.36	32.7	9.67E+17
H202	B105	BO 105	DDA250-C20B	1	203.5	1.04	1.82	2.28	34	1.01E+18
H208	B222	BELL 222	DDA250-C40B	1	277.8	1.92	1.39	1.72	57	1.68E+18
H301	B222	BELL 222	LTS101-750C.1	1	282.6	1.98	1.38	1.7	59	1.74E+18
H221	B407	Bell 407	DDA250-C47B	1	149.4	1.11	0.66	0.82	32	9.55E+17
H013	B412	Bell 412	PT6T-3	1	360	4.1	1.76	1.12	112	3.30E+18
H031	B427	Bell 427	PW207D	1	197.4	1.19	0	1.91	37	1.06E+18
H208	B430	Bell 430	DDA250-C40B	1	277.8	1.92	1.39	1.72	57	1.68E+18
H108	BK17	BK117	ARRIEL 1E2	1	283.3	1.98	1.38	1.7	59	1.74E+18

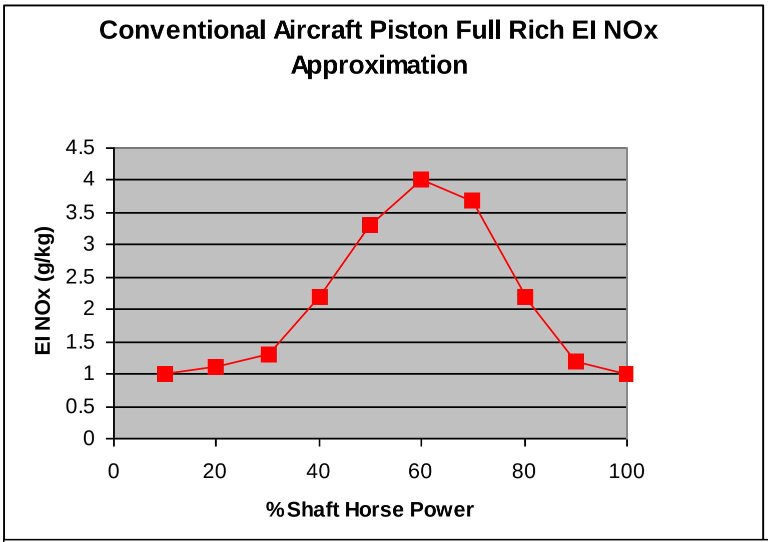
					One hour emissions					
Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Mean operating helicopters specific scale factor	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (g)	One hour PM number
H108	BK17	BK117 C-2	ARRIEL 1E2	1	283.3	1.98	1.38	1.7	59	1.74E+18
H301	BK17	BK117B	LTS101-750B.1	1	280.7	1.96	1.38	1.71	58.1	1.72E+18
H123	EC20	EC 120	ARRIUS 2F	1	114	0.66	0.79	0.98	21	6.15E+17
H132	EC20	EC-120 COLIBRI	ARTOUSTE III B	1	134.9	0.92	0.7	0.86	27	8.04E+17
H110	EC30	EC 130 B4	ARRIEL 2B1	1	182.6	1.57	0.61	0.75	44.6	1.32E+18
H122	EC35	EC 135	ARRIUS 2B1	1	259.3	1.66	1.49	1.84	51	1.50E+18
H122	EC35	EC 135	ARRIUS 2B2	1	259.3	1.66	1.49	1.84	51	1.50E+18
H111	EC55	EC 155 B	ARRIEL 2C1	1	308.9	2.35	1.31	1.61	68	1.24E+18
H112	EC55	EC 155 B1	ARRIEL 2C2	1	337.4	2.73	1.26	1.55	79	1.44E+18
H203	EN48	ENSTROM 480	DDA250-C20W	1	112.3	0.64	0.8	1	20.2	3.69E+17
H020	EXPL	MD 900	PW206A	1	223.2	1.08	0.87	3.39	43	7.88E+17
H032	EXPL	MD 902	PW207E	1	212.8	1.05	0.83	3.22	36	6.53E+17
H141	GAZL	SA341 GAZELLE	ASTAZOU IIIA	1	148.5	1.08	0.67	0.82	32	5.83E+17
H141	GAZL	SA341 GAZELLE	ASTAZOU IIIN2	1	148.5	1.08	0.67	0.82	32	5.83E+17
H142	GAZL	SA342 GAZELLE	ASTAZOU XIVG	1	139.4	0.98	0.69	0.85	28.9	5.28E+17
H142	GAZL	SA342 GAZELLE	ASTAZOU XIVH	1	139.4	0.98	0.69	0.85	28.9	5.28E+17
H305	H47	CH-47 Chinook	T55-GA-714A	1	1223.6	24.23	0.83	0.98	471	8.60E+18
H201	H500	HUGHES 500	DDA250-C18	1	98.8	0.48	0.96	1.2	16	2.94E+17
H203	H500	HUGHES 501	DDA250-C20B	1	112.3	0.64	0.8	1	20.2	3.69E+17
H204	H500	MD 500N	DDA250-C20R	1	159.2	1.08	0.83	1.02	32.2	5.89E+17
H501	H53	SIKORSKY CH-53G (S-65)	T64-GE-7	1	977.5	17.3	0.82	0.98	388	7.10E+18
H502	H53S	SIKORSKY MH53E	T64-GE-416	1	1083.4	20.37	0.81	0.98	427	7.81E+18
H503	H60	SIKORSKY BLACK HAWK	T700-GE-700	1	507.6	5.43	1.11	1.32	15	2.74E+18
H503	HUCO	BELL 209 HUEYCOBRA	T700-GE-401	1	541.3	6.17	1.06	1.25	168	3.07E+18
H403	KA27	KA-32A12	TV3-117VMA	1	621.2	7.89	0.98	1.18	211	3.85E+18
H303	KMAX	K-1200	T53 17A-1	1	283.9	3.35	0.51	0.62	91	1.66E+18
H132	LAMA	SA315B LAMA	ARTOUSTE IIIB	1.18	159.2	1.08	0.83	1.02	32.2	5.89E+17
H211	LYNX	WESTLAND BATTLEFIELD LYNX	GEM 42-1	1	415.9	3.62	1.36	1.66	103	1.88E+18
H203	MD52	MD 520N	DDA250-C20	1	109.5	0.61	0.82	1.03	19.3	3.53E+17
H221	MD60	MD 600N	DDA250-C47M	1	175.7	1.46	0.62	0.76	42	7.68E+17
H401	MI26	MIL MI-2	ISOTOW GTD-350	1	196	0.94	1.94	2.43	32	5.78E+17
H701	MI26	MIL MI-26	LO D-136	1	142827	4627.6	38.56	42.85	1428	2.61E+19
H402	MI8	MIL MI-8	TV2-117	1	485.1	4.95	1.15	1.41	138	2.52E+18
H011	S76	SIKORSKY S76	PT6B-36A	1	360	2.99	1.3	0.79	85	1.25E+18
H114	S76	SIKORSKY S-76 C+	ARRIEL 2S1	1	313.4	2.38	1.3	1.6	70	1.02E+18
H115	S76	SIKORSKY S-76C++	ARRIEL 2S2	1	324.5	2.56	1.28	1.56	74	1.08E+18
H207	S76	SIKORSKY S76	DDA250-C30S	1	263	1.71	1.46	1.81	52	7.59E+17
H506	S92	SIKORSKY S92A	GE CT7-8A	1	735.1	10.59	0.91	1.1	271	3.97E+18
H151	TIGR	EUROCOPTER 665 TIGER	MTR 390	1	476	4.76	1.17	1.43	133	1.95E+18
H303	UH1	BELL UH-1H	T53 L13	1	271.3	3.09	0.53	0.62	84.1	1.23E+18
H304	UH1	AGUSTA-BELL AB-204B	T53-09A	1	235.2	2.33	0.59	0.73	65	9.55E+17
H801	W3	PZL W-3 SOKOL	PZL-10W	1	309	2.35	1.31	1.61	68	9.96E+17
HP45	B47G	Bell 47G-3B	TVO-435-B1A	1	63.4	0.3	0.65	0.82	10	4.60E+17
HP45	B47G	Bell 47G	TVO-435-A1D	1	90.7	0.39	1.14	1.45	13.7	2.01E+17
HP44	UH12	HILLER UH-12A	TVO-540-1B	1	82.3	0.44	0.91	0.86	14	2.05E+17
HP42	HU30	HUGHES 300	HIO-360	1	54.6	0.05	0.74	54.58	8	1.17E+17
HP42	H269	Schweizer 269C	HIO-360	1	54.6	0.05	0.74	54.58	8	1.17E+17
HP62	SCOR	ROTORWAY SCORPION	ROTORWAY RW 133	1	2.4	0.01	0.04	0.07	0.3	4.39E+15
HP42	EN28	ENSTROM 280C	HIO-360	1	54.6	0.05	0.74	54.58	8	1.46E+17
HP43	R44	R44 RAVEN	HIO-540	1	59.9	0.06	0.72	59.86	9	1.74E+17
HP51	SYCA	BRISTOL SYCAMORE	ALVIS LEONIDES	1	144.2	1.04	1.31	0.84	30	4.45E+17
HP41	R22	R22 BETA	HO-360	1	72	0.07	0.84	72	6	1.19E+17
HP61	EXEC	ROTORWAY EXEC 90	ROTORWAY RI RW-162	1	2.4	0.01	0.05	0.06	0.3	5.49E+15

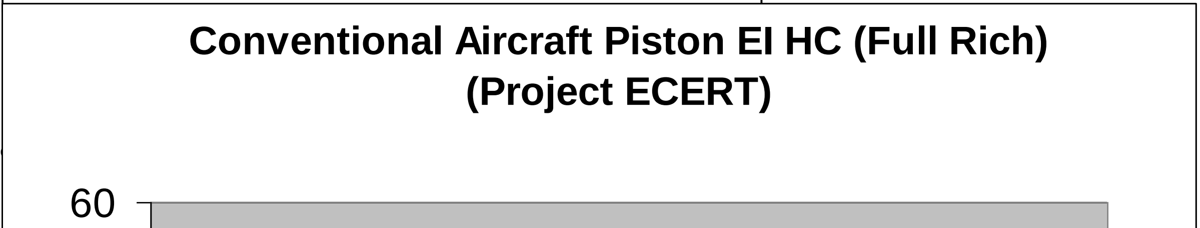
Appendix E: Graphical Representation of Approximation Functions for Piston Engines

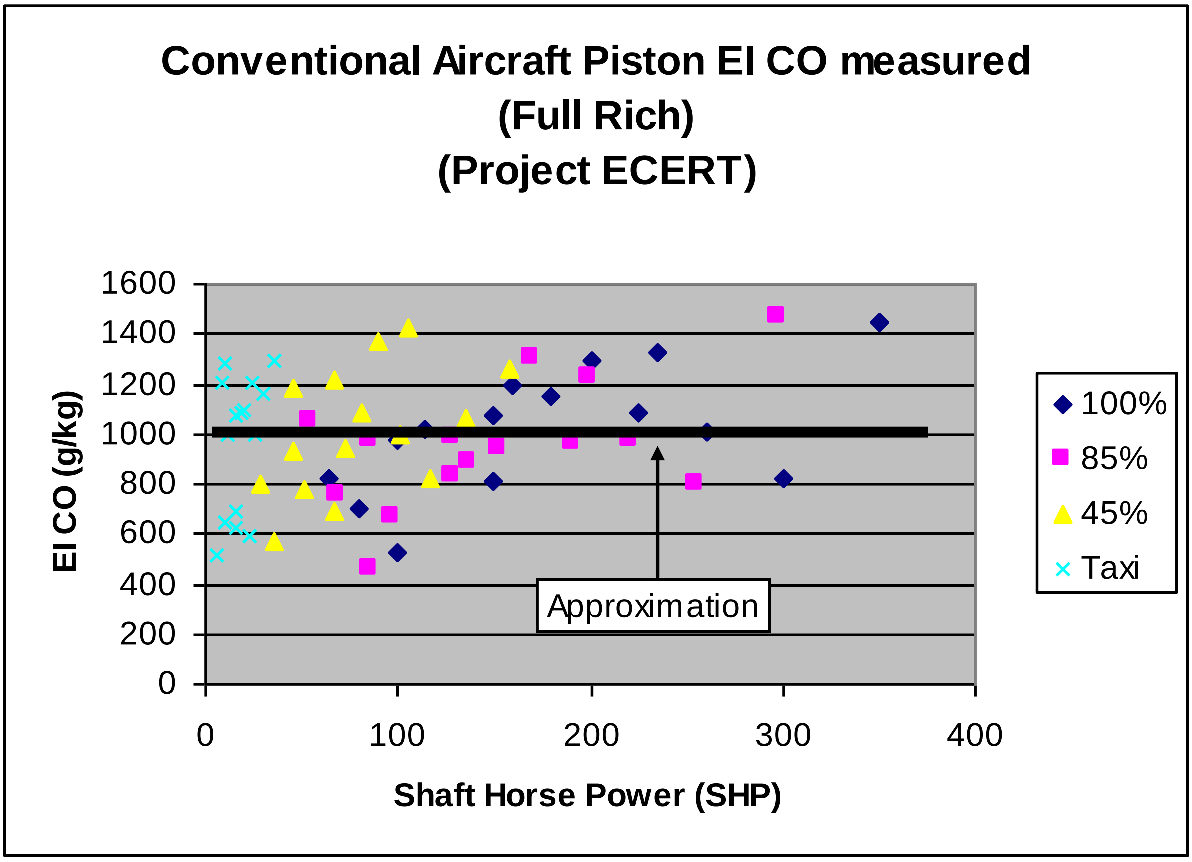

Conventional Aircraft Piston Engine Full Rich Fuel Flow
(from Project ECERT/Piston Engines)

$FF = 1.9 * 10^{-12} * SHP^{4} - 10^{-9} * SHP^{3} + 2.6 * 10^{-7} * SHP^{2} + 4 * 10^{-5} * SHP + 0.006$

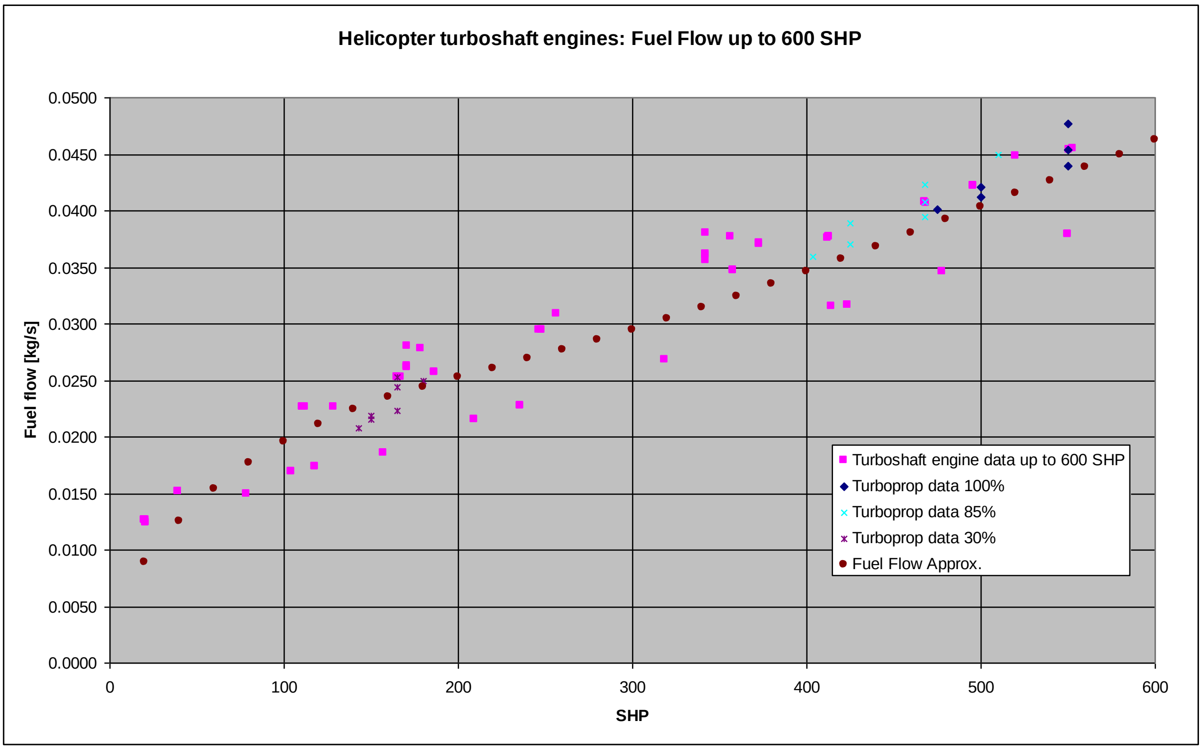

Conventional Aircraft Piston EI NOx measured
(Full Rich)
(Project ECERT)

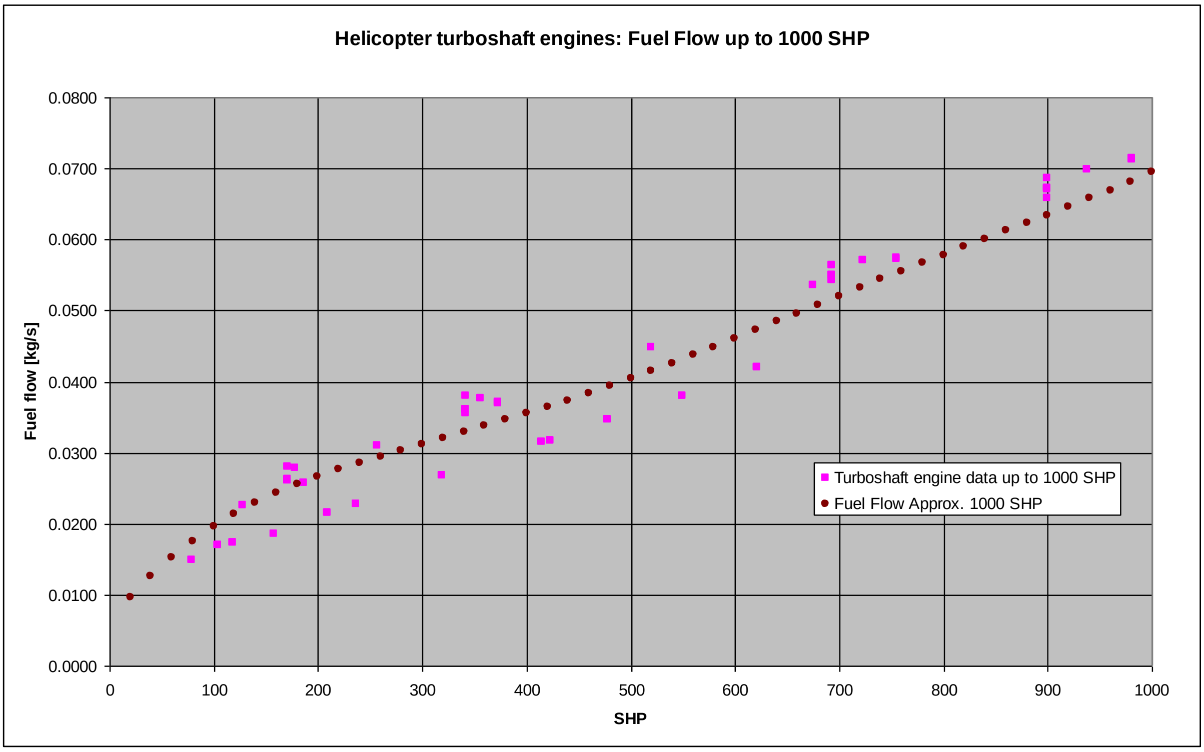

Conventional Aircraft Piston Full Rich EI NOx Approximation

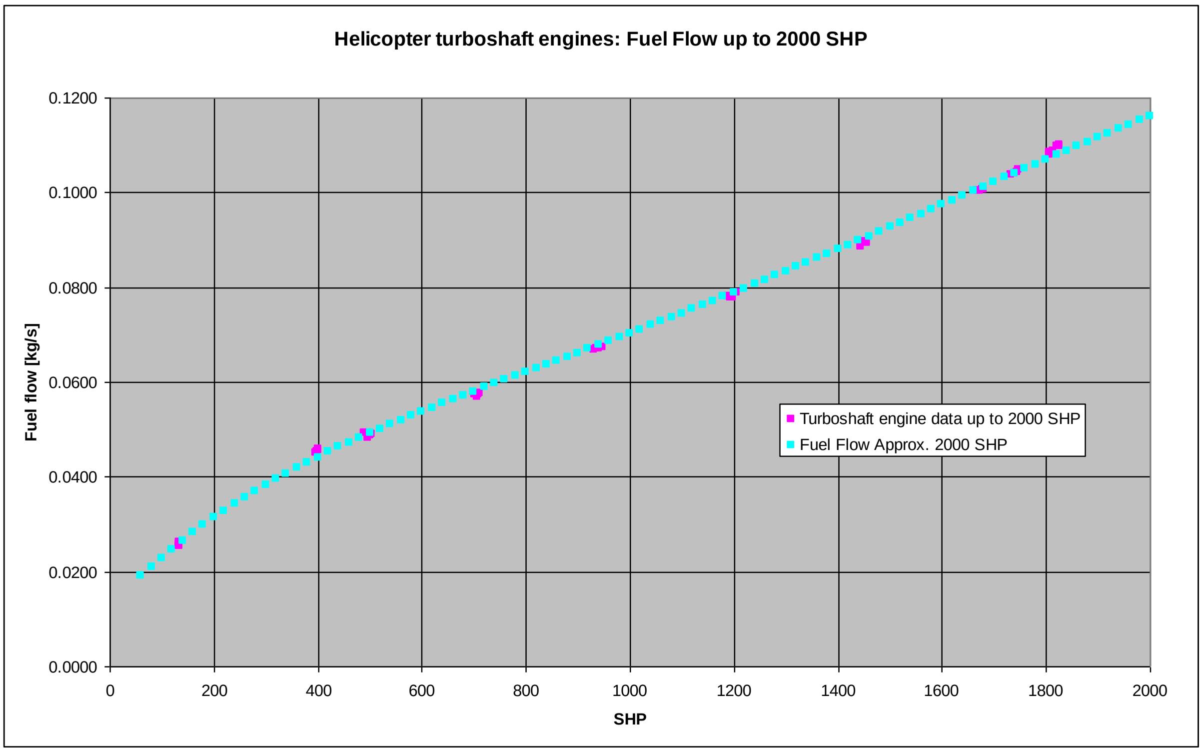

Conventional Aircraft Piston EI HC (Full Rich)
(Project ECERT)

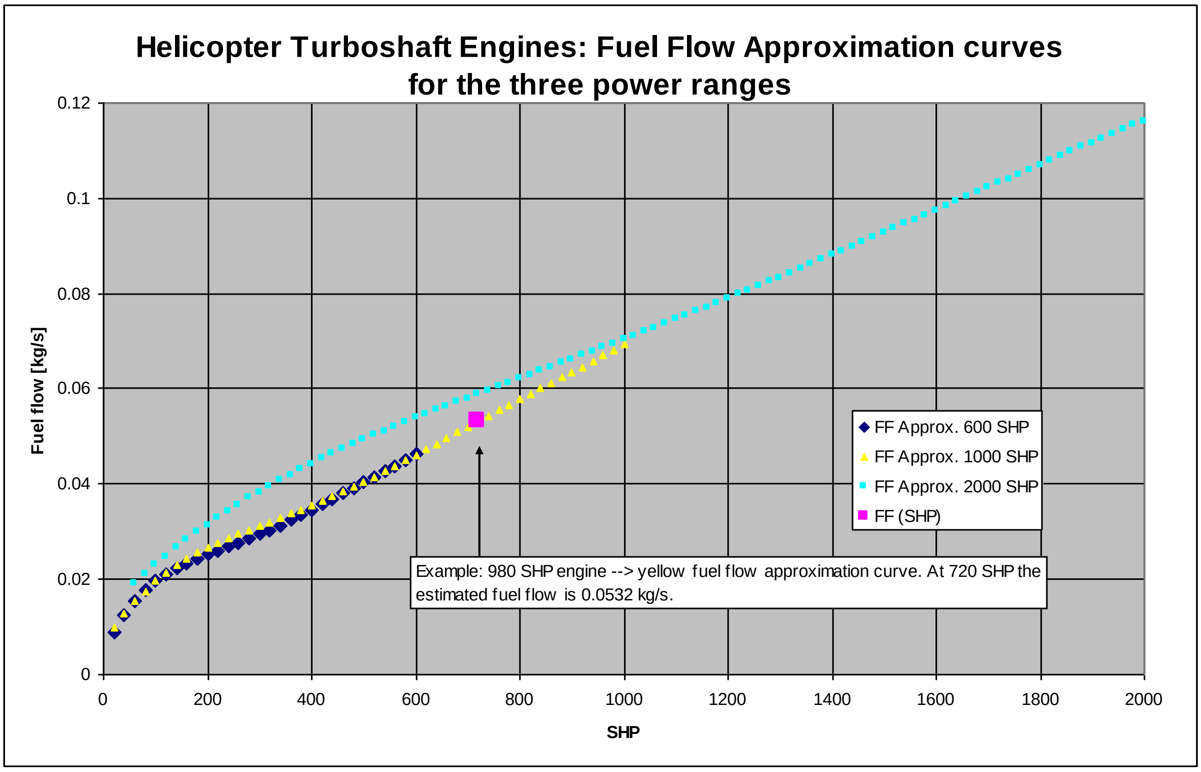

Conventional Aircraft Piston EI CO measured
(Full Rich)
(Project ECERT)
EI CO (g/kg)
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
Shaft Horse Power (SHP)
Approximation
◆ 100%
■ 85%
▲ 45%
× Taxi

Appendix F: Graphical Representation of Approximation Functions for Turboshaft Engines

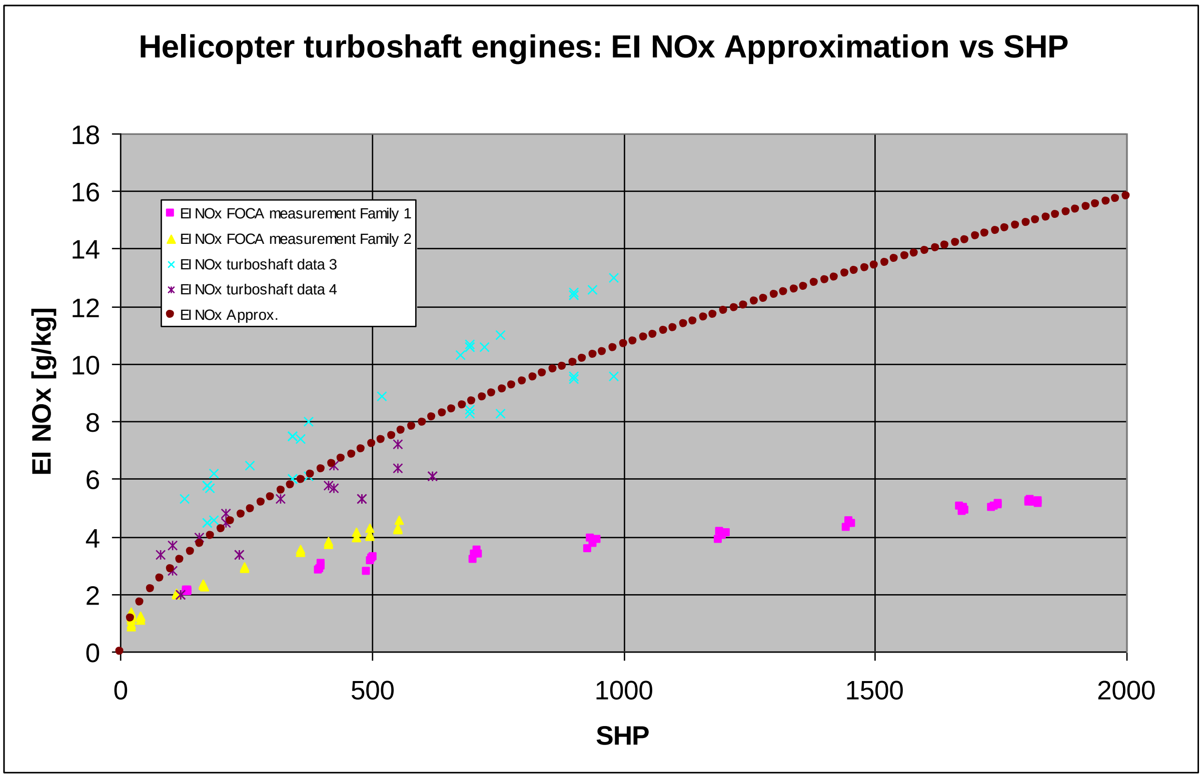


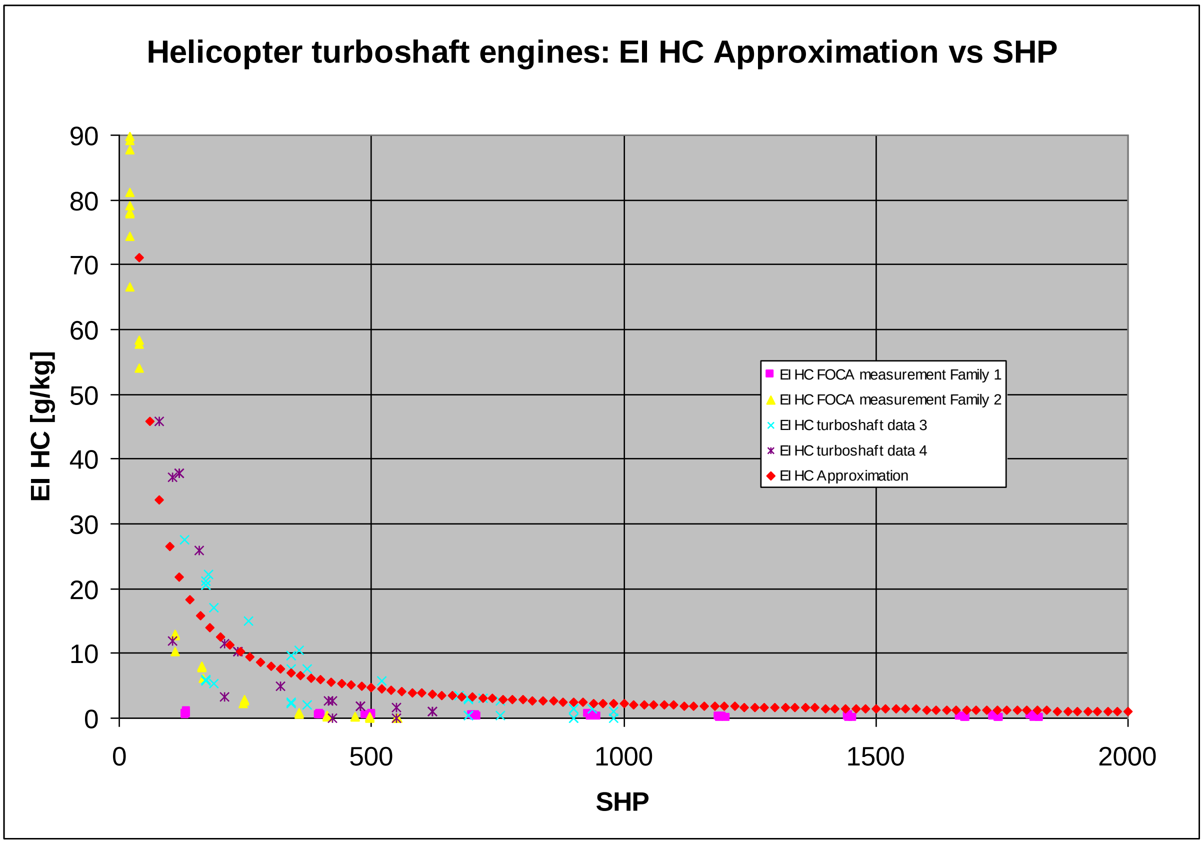


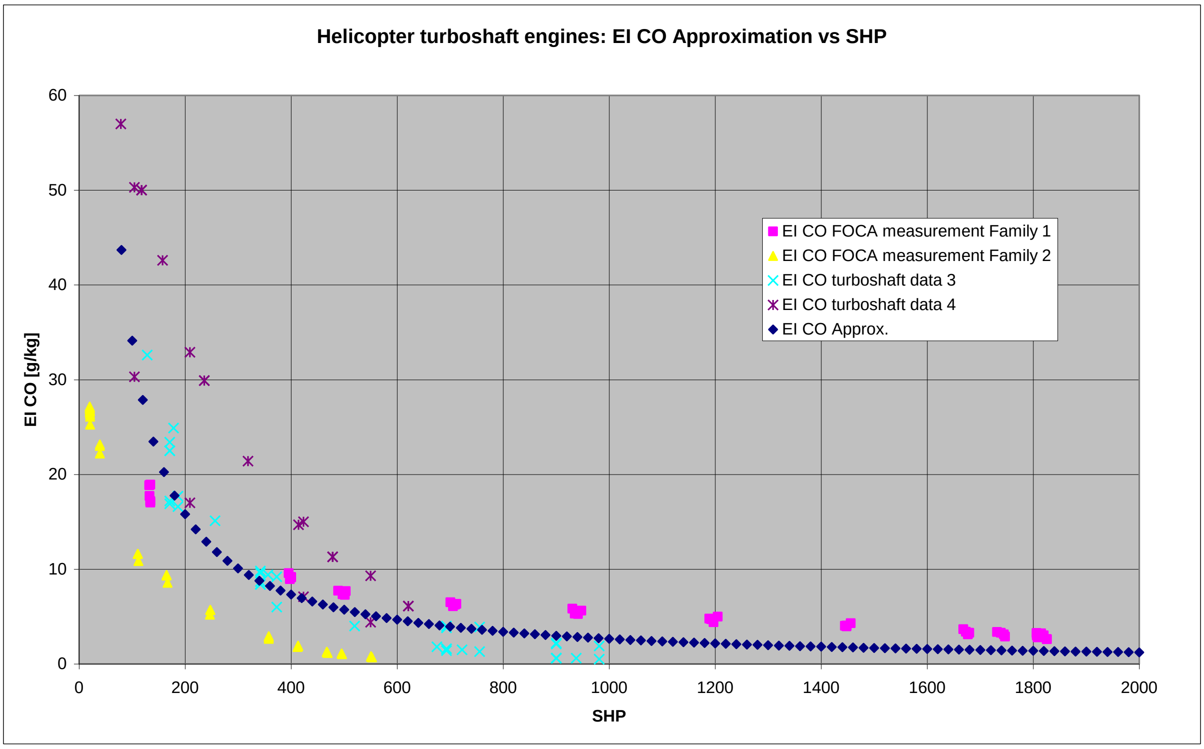


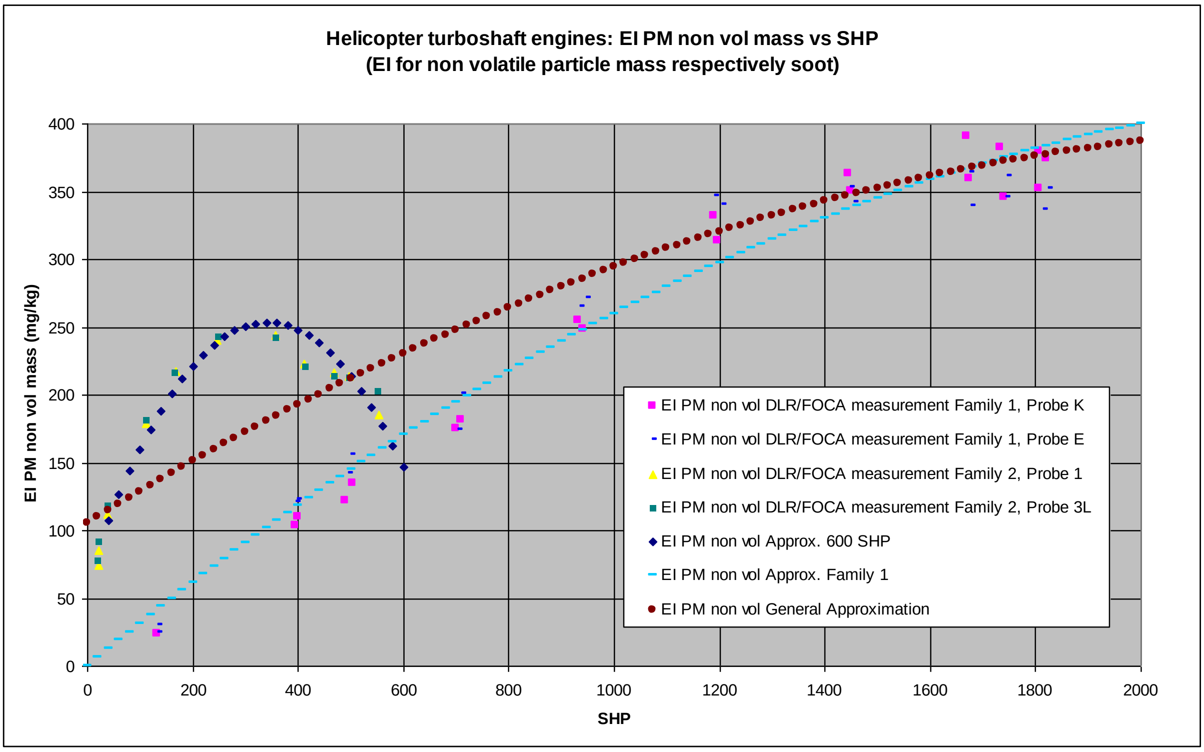


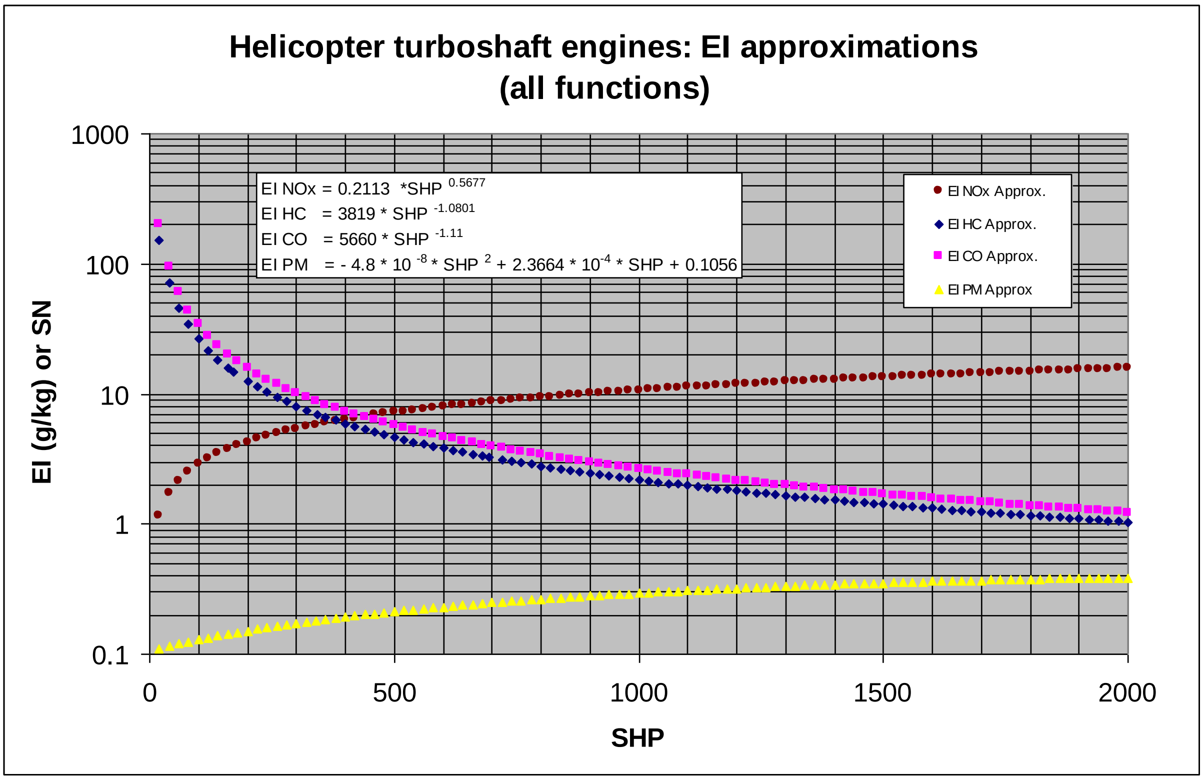
Example: 980 SHP engine --> yellow fuel flow approximation curve. At 720 SHP the estimated fuel flow is 0.0532 kg/s.


Helicopter turboshaft engines: EI NOx Approximation vs SHP
EI NOx [g/kg]
SHP
0
2
4
6
8
10
12
14
16
18
0
500
1000
1500
2000
EI NOx FOCA measurement Family 1
EI NOx FOCA measurement Family 2
EI NOx turboshaft data 3
EI NOx turboshaft data 4
EI NOx Approx.


Helicopter turboshaft engines: EI HC Approximation vs SHP
EI HC [g/kg]
SHP
0
10
20
30
40
50
60
70
80
90
0
500
1000
1500
2000
EI HC FOCA measurement Family 1
EI HC FOCA measurement Family 2
EI HC turboshaft data 3
EI HC turboshaft data 4
EI HC Approximation


Helicopter turboshaft engines: EI CO Approximation vs SHP
EI CO [g/kg]
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
SHP
■ EI CO FOCA measurement Family 1
▲ EI CO FOCA measurement Family 2
× EI CO turboshaft data 3
✳ EI CO turboshaft data 4
◆ EI CO Approx.


Helicopter turboshaft engines: EI PM non vol mass vs SHP
(EI for non volatile particle mass respectively soot)
EI PM non vol mass (mg/kg)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
SHP
■ EI PM non vol DLR/FOCA measurement Family 1, Probe K
- EI PM non vol DLR/FOCA measurement Family 1, Probe E
▲ EI PM non vol DLR/FOCA measurement Family 2, Probe 1
■ EI PM non vol DLR/FOCA measurement Family 2, Probe 3L
◆ EI PM non vol Approx. 600 SHP
— EI PM non vol Approx. Family 1
● EI PM non vol General Approximation


Helicopter turboshaft engines: EI approximations (all functions)
EI (g/kg) or SN
1000
100
10
1
0.1
0
500
1000
1500
2000
SHP
EI NOx = 0.2113 *SHP $^{0.5677}$
EI HC = 3819 * SHP $^{-1.0801}$
EI CO = 5660 * SHP $^{-1.11}$
EI PM = - 4.8 * 10 $^{-8}$ * SHP ^{2} + 2.3664 * 10^{-4} * SHP + 0.1056
● EI NOx Approx.
◆ EI HC Approx.
■ EI CO Approx.
▲ EI PM Approx