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Guidance on the Determination of Helicopter Emissions

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Contents

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 documentation of the measurements is currently in preparation for publication.

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 with in-flight measurements, from helicopter flight manuals and with the help of experienced flight instructors. The result is an 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 activity data, 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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[1] SR 748.0, LFG Art. 58
[2] International Civil Aviation Organisation
[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 between 6 and 10 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, 90% 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.

Table 1: Suggested times in mode and % of max. SHP for piston engine helicopters. GI1 = Ground Idle before departure, GI2 = Ground Idle after landing. TO = Hover and Climb, AP = Approach. "Mean operating % power per engine" = power setting for determination of emissions per flight-hour.

GI1_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI2_Time (Min.)	GI1 %Power per engine	TO %Power per engine	AP % Power per engine	GI2 %Power per engine	Mean operating % power per engine
4.0	4.0	5.5	4.0	20	95	60	20	90

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

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

GI1_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI2_Time (Min.)	GI1 %Power per engine	TO %Power per engine	AP % Power per engine	GI2 %Power per engine	Mean operating % power per engine
4.0	3.0	5.5	1.0	15	87	46	7	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)

GI1_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI2_Time (Min.)	GI1 %Power per engine	TO %Power per engine	AP % Power per engine	GI2 %Power per engine	Mean operating % power per engine
4.0	3.0	5.5	1.0	7	78	38	5	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 helicopters (above 3.4 tons MTOM)

GI1_Time (Min.)	TO_Time (Min.)	AP_Time (Min.)	GI2_Time (Min.)	GI1 %Power per engine	TO %Power per engine	AP % Power per engine	GI2 %Power per engine	Mean operating % power per engine
4.0	3.0	5.5	1.0	6	66	32	5	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. The documentation of this particular engine tests is not part of the current guidance, but will be referenced as soon as it is published. 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) and EI PM $_{non\ volatile}$ (g/kg))[6]. The following steps are recommended:

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

- 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 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.

3.1 Piston Engines

- Fuel flow (kg/s) ≈

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

- Emission factors for NO_x

Table 5

Mode	GI1	TO	AP	GI2	CRUISE
% max. SHP	20%	95%	60%	20%	90%
EI NOx (g/kg)	1	1	4	1	2

- Emission factors for HC

EI HC (g/kg) ≈ $80 * SHP^{-0.35}$

- Emission factors for CO

EI CO (g/kg) ≈ 1000 (for all SHP)

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

Table 6

Mode	GI1	TO	AP	GI2	CRUISE
% max. SHP	20%	95%	60%	20%	90%
EI PM (g/kg)	0.05	0.1	0.04	0.05	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.

3.2 Turboshaft Engines

- Fuel flow for engines above 1000 SHP

  Fuel flow (kg/s) $\approx$

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

- Fuel flow for engines above 600 SHP and maximum 1000 SHP

  Fuel flow (kg/s) $\approx$

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

- Fuel flow for engines up to 600 SHP

  Fuel flow (kg/s) $\approx$

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

- Emission factors for NO_x

  EI NO_x (g/kg) $\approx 0.2113 * (SHP)^{0.5677}$

- Emission factors for HC

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

- Emission factors for CO

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

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

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

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

4. Final Calculations

4.1 LTO Emissions

LTO fuel =   60 * (GI1_Time * GI1 fuel flow + TO_Time * TO fuel flow + AP_Time * AP fuel flow + GI2_Time * GI2 fuel flow) * 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)

LTO NO_x =   60 * (GI1_Time * GI1 fuel flow * GI1_EI NO_x + TO_Time * TO fuel flow * TO EI NO_x + AP_Time * AP fuel flow * AP EI NO_x + GI2_Time * GI2 fuel flow * GI2 EI NO_x) * 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 page from May 2009 (www.bazl.admin.ch → for specialists → environment → aircraft engine emissions).

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

Aircraft_ICAO	Aircraft_Name	Engine_Name	Max SHP per engine	Number_of_Engines	LTO Emissions					One hour emissions				
					LTO fuel (kg)	LTO NOx (g)	LTO HC (g)	LTO CO (g)	LTO PM non volatile (g)	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (kg)
A109	AGUSTA A109	DDA250-C20R/1	450	2	33.8	139	952	1252	5	210	1.11	1.74	2.17	0.036
A109	AGUSTA A109E	PW206C	550	2	37.1	172	841	1100	6	209	1.24	1.40	1.74	0.039
A109	AGUSTA A109	PW207C	650	2	41.6	212	779	1013	7	237	1.55	1.32	1.63	0.047
A109	AGUSTA A109 K2	ARRIEL1K1	738	2	44.4	245	720	933	8	255	1.79	1.24	1.53	0.053
A109	AGUSTA A109 Power	ARRIUS 2K	670	2	42.2	220	765	993	7	241	1.60	1.30	1.60	0.048
A109	AGUSTA A109A II	DDA250-C20B	420	2	32.8	130	994	1310	5	204	1.04	1.82	2.28	0.034
A109	AGUSTA A109C	DDA250-C20R	450	2	33.8	139	952	1252	5	210	1.11	1.74	2.17	0.036
A119	AGUSTA A119	PT6B-37	900	1	28.5	193	241	305	6	192	1.70	0.60	0.73	0.048
A139	AGUSTA A139	PT6C-67C	1100	2	60.3	376	753	968	12	412	3.54	1.37	1.67	0.101
ALO2	ALOUETTE II	ARTOUSTE IIC5	402	1	18.2	76	384	498	3	110	0.61	0.82	1.02	0.019
ALO2	ALOUETTE II	ARTOUSTE IIC6	402	1	18.2	76	384	498	3	110	0.61	0.82	1.02	0.019
ALO3	SA316B ALOUETTE III	ARTOUSTE IIIB	563	1	21.4	109	312	401	4	135	0.91	0.70	0.87	0.027
ALO3	SA316B ALOUETTE III	ASTAZOU XIVB	590	1	21.9	115	303	389	4	139	0.97	0.69	0.85	0.029
AS32	SUPER PUMA	MAKILA 1A1	1820	2	77.4	652	540	683	19	491	5.60	0.95	1.14	0.153
AS35	AS 350 B3	ARRIEL 2B	848	1	27.5	179	249	316	6	152	1.30	0.51	0.62	0.037
AS35	AS 350 B3	ARRIEL 2B1	848	1	27.5	179	249	316	6	152	1.30	0.51	0.62	0.037
AS35	AS 350 ECUREUIL	ARRIEL 1B	641	1	23.5	129	294	375	4	133	0.97	0.60	0.74	0.029
AS35	AS 350B ECUREUIL	ARRIEL 1D1	732	1	25.2	150	271	346	5	147	1.15	0.57	0.70	0.033
AS50	AS 550 FENNEC	ARRIEL 1D1	732	1	25.2	150	271	346	5	147	1.15	0.57	0.70	0.033
AS55	AS 355	DDA250-C20F	420	2	32.8	130	994	1310	5	204	1.04	1.82	2.28	0.034
AS55	AS 355 N	ARRIUS 1A	480	2	34.8	149	914	1200	5	216	1.19	1.67	2.08	0.038
AS55	AS 555 FENNEC	ARRIEL 1D1	712	2	43.6	235	736	955	8	277	1.91	1.40	1.73	0.057
AS65	AS 365 C1 DAUPHIN	ARRIEL 1A1	641	2	41.3	209	786	1023	7	261	1.69	1.48	1.83	0.051
AS65	AS 365 C2 DAUPHIN	ARRIEL 1A2	641	2	41.3	209	786	1023	7	261	1.69	1.48	1.83	0.051
AS65	AS 365 N DAUPHIN	ARRIEL 1C	660	2	41.9	216	772	1003	7	265	1.75	1.45	1.80	0.053
AS65	AS 365 N1 DAUPHIN	ARRIEL 1C1	700	2	43.2	231	744	965	8	274	1.87	1.41	1.74	0.056
AS65	AS 365 N3 DAUPHIN	ARRIEL 2C	839	2	47.7	285	667	860	9	309	2.34	1.31	1.60	0.068
B06	BELL 206B	DDA250-C20	400	1	18.2	75	385	499	3	109	0.61	0.82	1.03	0.019
B06	BELL 206B	DDA250-C20B	420	1	18.6	79	373	484	3	101	0.58	0.72	0.90	0.018
B06	BELL 206B	DDA250-C20J	420	1	18.6	79	373	484	3	101	0.58	0.72	0.90	0.018
B06	BELL 206B	DDA250-C20R	450	1	19.2	85	358	463	3	105	0.63	0.70	0.86	0.019
B06	BELL 206B	DDA250-C20R/4	450	1	19.2	85	358	463	3	105	0.63	0.70	0.86	0.019
B06	BELL 206L	DDA250-C20R	450	1	19.2	85	358	463	3	117	0.70	0.77	0.96	0.022
B06	BELL 206L	DDA250-C30	650	1	23.7	131	291	372	4	149	1.10	0.66	0.82	0.032
B06	BELL 206L	DDA250-C30P	650	1	23.7	131	291	372	4	149	1.10	0.66	0.82	0.032
B06T	Bell TWIN RANGER	DDA250-C20R	450	2	33.8	139	952	1252	5	210	1.11	1.74	2.17	0.036
B105	BO 105	DDA250-C20	400	2	32.1	123	1025	1353	5	200	0.99	1.88	2.36	0.033
B105	BO 105	DDA250-C20B	420	2	32.8	130	994	1310	5	204	1.04	1.82	2.28	0.034
B222	BELL 222	DDA250-C40B	715	2	43.7	236	734	952	8	278	1.92	1.40	1.72	0.057
B222	BELL 222	LTS101-750C.1	735	2	44.3	244	722	935	8	283	1.98	1.38	1.70	0.059

Table 7: (Continued). Green shaded lines are piston engine powered helicopters.

Aircraft_ICAO	Aircraft_Name	Engine_Name	Max SHP per engine	Number_of_Engines	LTO Emissions					One hour emissions				
					LTO fuel (kg)	LTO NOx (g)	LTO HC (g)	LTO CO (g)	LTO PM non volatile (g)	One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (kg)
B407	Bell 407	DDA250-C47B	650	1	23.7	131	291	372	4	149	1.10	0.66	0.82	0.032
B412	Bell 412	PT6T-3	1800	2	77.0	644	544	688	19	541	6.14	1.06	1.27	0.168
B430	Bell 430	DDA250-C40B	715	2	43.7	236	734	952	8	278	1.92	1.40	1.72	0.057
BK17	BK117	ARRIEL 1E2	738	2	44.4	245	720	933	8	283	1.99	1.38	1.70	0.059
BK17	BK117 C-2	ARRIEL 1E2	738	2	44.4	245	720	933	8	283	1.99	1.38	1.70	0.059
BK17	BK117B	LTS101-750B.1	727	2	44.1	241	727	942	8	281	1.96	1.39	1.71	0.058
EC20	EC 120	ARRIUS 2F	432	1	18.8	82	367	475	3	114	0.67	0.79	0.98	0.021
EC30	EC 130 B4	ARRIEL 2B1	848	1	27.5	179	249	316	6	183	1.56	0.61	0.74	0.045
EC35	EC 135	ARRIUS 2B1	633	2	41.1	206	792	1031	7	259	1.67	1.49	1.84	0.051
EC35	EC 135	ARRIUS 2B2	633	2	41.1	206	792	1031	7	259	1.67	1.49	1.84	0.051
EC55	EC 155 B	ARRIEL 2C1	839	2	47.7	285	667	860	9	309	2.34	1.31	1.60	0.068
EC55	EC 155 B1	ARRIEL 2C2	944	2	51.0	328	622	800	10	337	2.73	1.26	1.54	0.079
EN48	ENSTROM 480	DDA250-C20W	420	1	18.6	79	373	484	3	112	0.64	0.80	1.00	0.020
EXPL	MD 900	PW206A	621	2	40.7	202	802	1045	7	257	1.64	1.50	1.86	0.050
GAZL	SA341 GAZELLE	ASTAZOU IIIA	644	1	23.5	130	293	374	4	148	1.09	0.67	0.82	0.032
GAZL	SA341 GAZELLE	ASTAZOU IIIN2	644	1	23.5	130	293	374	4	148	1.09	0.67	0.82	0.032
GAZL	SA342 GAZELLE	ASTAZOU XIVG	590	1	21.9	115	303	389	4	139	0.97	0.69	0.85	0.029
GAZL	SA342 GAZELLE	ASTAZOU XIVH	590	1	21.9	115	303	389	4	139	0.97	0.69	0.85	0.029
H500	HUGHES 500	DDA250-C18	317	1	16.4	60	446	582	2	99	0.48	0.96	1.20	0.016
H500	HUGHES 501	DDA250-C20B	420	1	18.6	79	373	484	3	112	0.64	0.80	1.00	0.020
H500	MD 500N	DDA250-C20R	450	1	19.2	85	358	463	3	117	0.70	0.77	0.96	0.022
H53	SIKORSKY CH-53G (S-65)	T 64-GE-7	3925	2	125.4	1690	351	433	41	977	17.27	0.82	0.96	0.388
H53S	SIKORSKY SUPER STALLION	T 64-GE-7	3925	3	188.0	2535	526	649	62	1332	21.99	1.27	1.50	0.523
H60	SIKORSKY BLACK HAWK	T700-GE-700	1622	2	72.8	573	581	737	17	508	5.43	1.11	1.34	0.150
KA27	KA-32A12	TV3-117VMA	2200	2	86.2	815	481	605	23	621	7.90	0.98	1.17	0.211
KMAX	K-1200	T53 17A-1	1500	1	43.4	391	210	261	11	284	3.36	0.51	0.61	0.091
LAMA	SA315B LAMA	ARTOUSTE IIIB	563	1	21.4	109	312	401	4	159	1.08	0.83	1.02	0.032
MD52	MD 520N	DDA250-C20	400	1	18.2	75	385	499	3	109	0.61	0.82	1.03	0.019
MD60	MD 600N	DDA250-C47M	650	1	23.7	131	291	372	4	149	1.10	0.66	0.82	0.032
MI8	MIL MI-8	TV2-117	1500	2	70.0	525	611	778	16	485	4.97	1.15	1.39	0.138
S76	SIKORSKY S76	DDA250-C30S	650	2	41.6	212	779	1013	7	263	1.72	1.46	1.81	0.052
S76	SIKORSKY S76	PT6B-36A	981	2	52.2	343	609	782	11	348	2.87	1.24	1.52	0.082
S76	SIKORSKY S-76 C+	ARRIEL 2S1	856	2	48.2	291	659	850	9	313	2.40	1.30	1.59	0.070
S92	SIKORSKY S92A	GE CT7-8A	2740	2	98.5	1066	424	529	29	735	10.59	0.91	1.08	0.271
UH1	BELL UH-1H	T53 L13	1400	1	41.8	361	218	273	10	271	3.09	0.53	0.63	0.084
UH12	HILLER UH-12A	VO-540-1B	320	1	12.3	26	157	12310	1	82	0.16	0.91	82.33	0.006
B47G	Bell 47G	LYC TVO-435-B1A	270	1	9.9	21	134	9873	1	65	0.13	0.76	64.62	0.005
B47G	Bell 47G-3B	LYC VO-435-A1D	220	1	7.8	16	114	7759	1	50	0.10	0.63	49.94	0.003
EN28	ENSTROM 280C	HIO-360	190	1	6.6	14	102	6591	0	42	0.08	0.56	42.00	0.003
EXEC	ROTORWAY EXEC 90	ROTORWAY RI-162	150	1	5.1	11	87	5118	0	32	0.06	0.46	32.07	0.002
H269	SCHWEIZER 269C	HIO-360	190	1	6.6	14	102	6591	0	42	0.08	0.56	42.00	0.003
HU30	HUGHES 300	HIO-360	190	1	6.6	14	102	6591	0	42	0.08	0.56	42.00	0.003
R22	R22 BETA	HO-360	180	1	6.2	13	98	6214	0	39	0.08	0.53	39.46	0.003
R44	R44 RAVEN	HIO-540	245	1	8.8	18	124	8785	1	57	0.11	0.69	57.00	0.004
SCOR	ROTORWAY SCORPION	ROTORWAY RW 133	133	1	4.5	9	80	4519	0	28	0.06	0.42	28.04	0.002
SYCA	BRISTOL SYCAMORE	ALVIS LEONIDES	550	1	34.8	63	349	34826	3	277	0.55	2.52	276.80	0.019

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14) 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

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 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

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (k)
TOTAL LTO	24.7	145.8	269.4	343.2	4.6

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)
GI	2	2	15	7	70	0	51	0.014	1.974	54.375	71.639	0.118
GR (full rotor RPM)	2		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

	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
TOTAL LTO	24.4	146.9	299.4	384.2	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

				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	5.3	5.7	10.1	487.3	652.2	0.7
TO 3000ft	3	7	TO	11.7	13.0	85.7	71.6	88.5	2.6
			Total 1	17.0	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

				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	1.2	1.2	1.7	134.0	180.0	0.1
L 3000ft	5.5	6.5	AP	14.6	16.6	73.9	227.7	289.9	2.6
			Total 2	15.8	17.8	75.6	361.7	469.9	2.7

	TOTAL LTO					
	32.9	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

Cruise (CR)

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

	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

Meas. Fuel (kg): 200

LTO (Total 1)

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 (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)
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 (Total 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 (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)
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

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
TOTAL LTO	36.5	166.8	823.7	1074.0	5.9

Cruise (CR)

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

	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

Meas. Fuel (kg): 200

LTO (Total 1)

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 (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)
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 (Total 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 (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)
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

	Est. Mean Fuel (kg)	Est. Mean NOx (g)	Est. Mean HC (g)	Est. Mean CO (g)	Est. Mean PM (g)
TOTAL LTO	37.1	171.6	841.0	1099.4	6.0

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

Upper table

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

TO 5 NM	4	8
TO 3000ft	3	7

	Meas. Total fuel (kg)	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	12.4	11.4	35.6	294.5	380.8	0.4
TO	27.8	28.6	340.4	51.0	61.1	8.6
Total 1	40.2	40.0	376.1	345.5	441.9	9.0

Lower table

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

L 5NM	4.5	5.5
L 3000ft	5.5	6.5

	Meas. Total fuel (kg)	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
GI	2.8	2.6	6.9	79.9	103.7	0.1
AP	33.3	34.4	273.9	146.9	180.8	5.9
Total 2	36.1	37.0	280.8	226.8	284.4	5.9

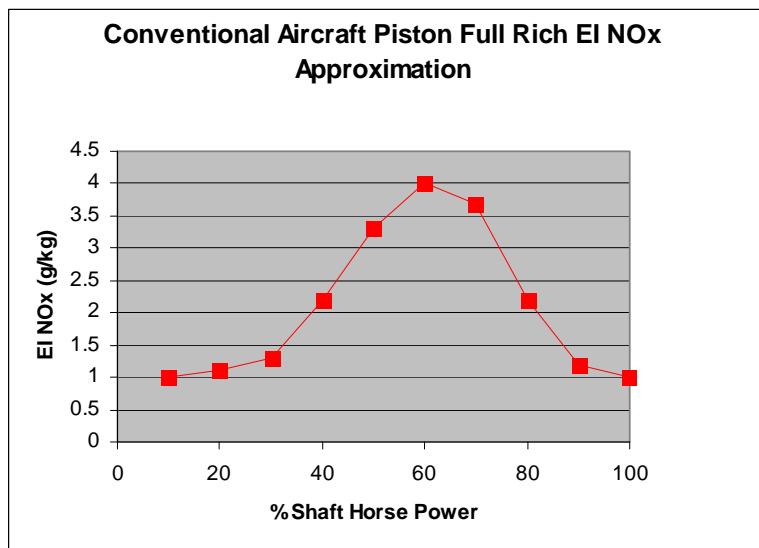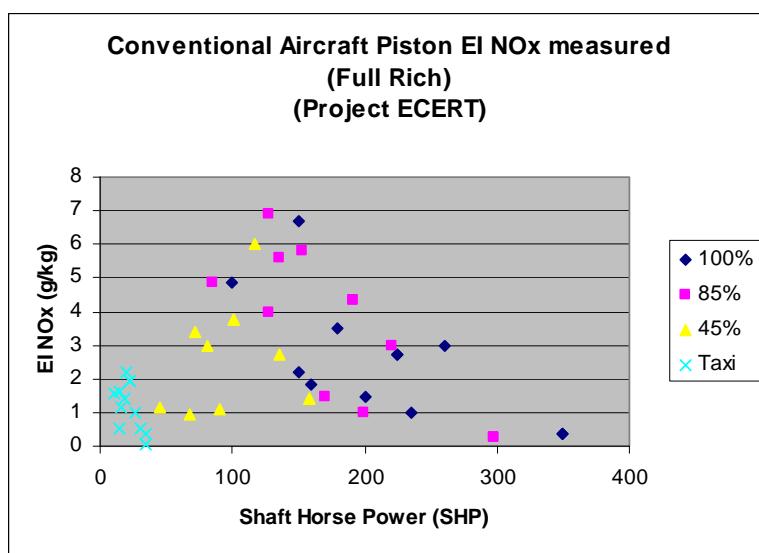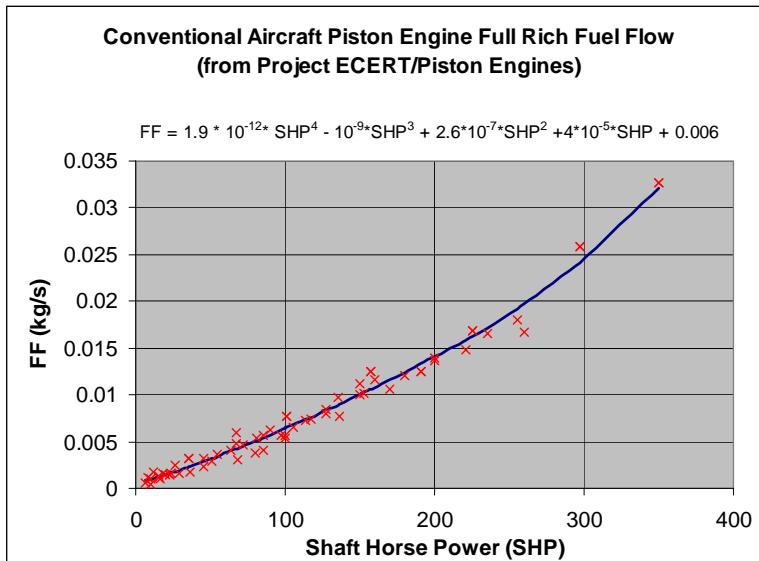|	Meas. Total fuel (kg)	Est. Fuel (kg)	Est NOx (g)	Est. HC (g)	Est. CO (g)	Est. PM (g)
TOTAL LTO	76.3	77.0	656.9	572.3	726.3	15.0

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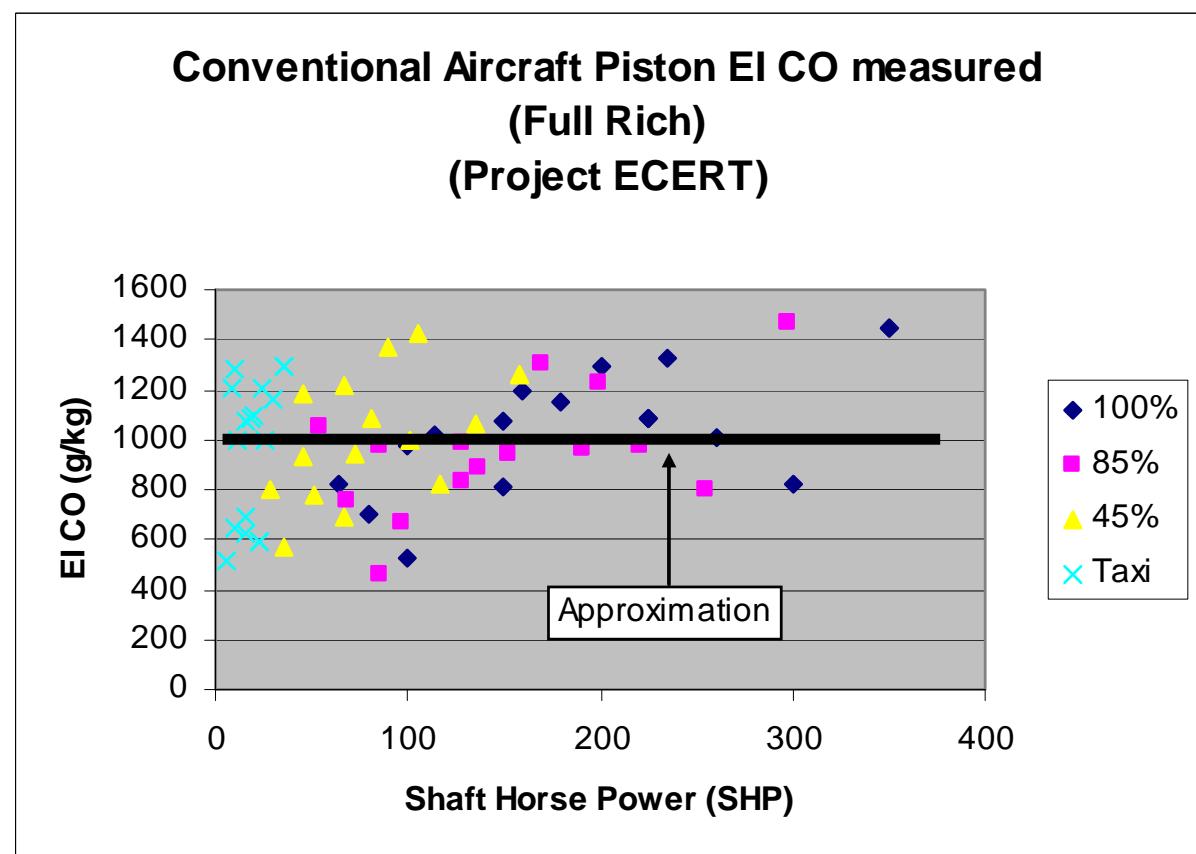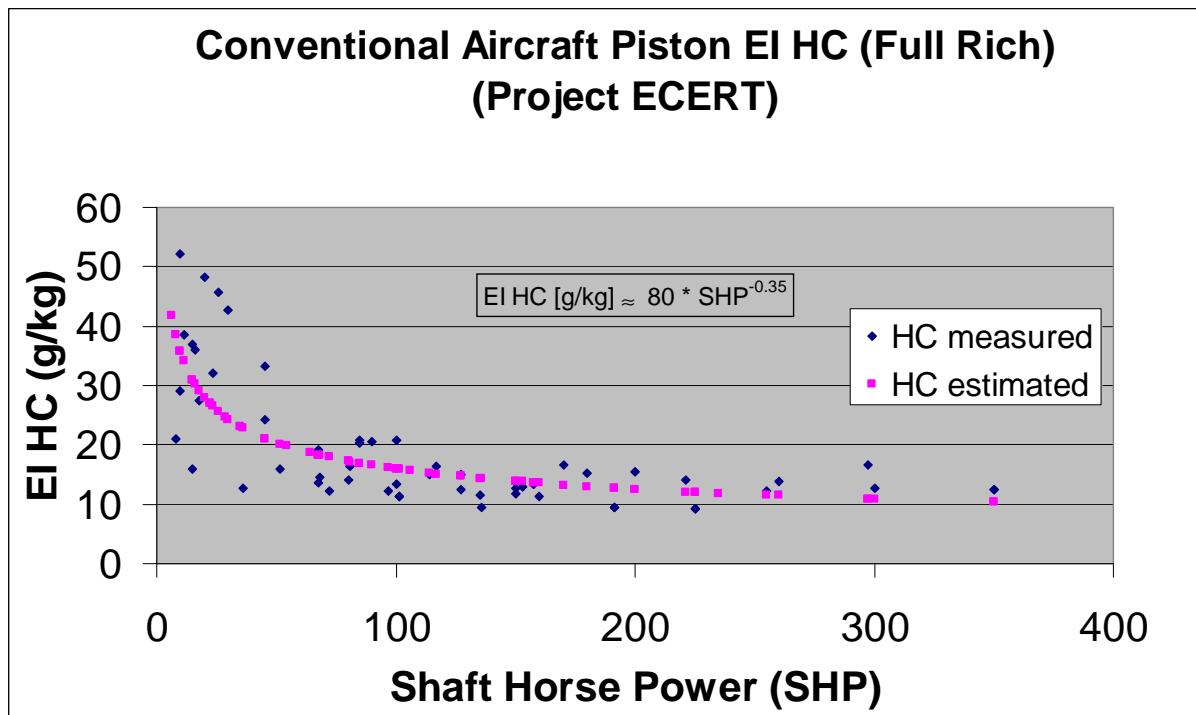
CRUISE and LTO MEAN

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 — NOT PRACTICAL

	Operating Mass (kg)	Meas. Fuel (kg)	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	198 — NOT PRACTICAL
	7600 (light)	480					

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 — NOT PRACTICAL
90%	2696	60	74	1348	0.086	12.637	1.590	1.900	0.322 — NOT PRACTICAL

	Operating Mass (kg)	Meas. Fuel (kg)	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	198 — NOT PRACTICAL
	7600 (light)	480					

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

Code	Aircraft_ICAO	Aircraft_Name	Engine_Name	Mean operating helicopter specific scale factor	One hour emissions				
					One hour fuel (kg)	One hour NOx (kg)	One hour HC (kg)	One hour CO (kg)	One hour PM non vol. (kg)
H001	A109	AGUSTA A109	DDA250-C20R/1	1	210	1.11	1.74	2.17	0.036
H021	A109	AGUSTA A109E	PW206C	0.9	209	1.24	1.40	1.74	0.039
H001	A109	AGUSTA A109	PW207C	0.9	237	1.55	1.32	1.63	0.047
H001	A109	AGUSTA A109 K2	ARRIEL1K1	0.9	255	1.79	1.24	1.53	0.053
H001	A109	AGUSTA A109 Power	ARRIUS 2K	0.9	241	1.60	1.30	1.60	0.048
H001	A109	AGUSTA A109A II	DDA250-C20B	1	204	1.04	1.82	2.28	0.034
H001	A109	AGUSTA A109C	DDA250-C20R	1	210	1.11	1.74	2.17	0.036
H013	A119	AGUSTA A119	PT6B-37	1	192	1.70	0.60	0.73	0.048
H002	A139	AGUSTA A139	PT6C-67C	1	412	3.54	1.37	1.67	0.101
H001	ALO2	ALOUETTE II	ARTOUSTE IIC5	1	110	0.61	0.82	1.02	0.019
H001	ALO2	ALOUETTE II	ARTOUSTE IIC6	1	110	0.61	0.82	1.02	0.019
H001	ALO3	SA316B ALOUETTE III	ARTOUSTE IIIB	1	135	0.91	0.70	0.87	0.027
H001	ALO3	SA316B ALOUETTE III	ASTAZOU XIVB	1	139	0.97	0.69	0.85	0.029
HF30	AS32	SUPER PUMA	MAKILA 1A1	0.9	491	5.60	0.95	1.14	0.153
H001	AS35	AS 350 B3	ARRIEL 2B	0.83	152	1.30	0.51	0.62	0.037
H001	AS35	AS 350 B3	ARRIEL 2B1	0.83	152	1.30	0.51	0.62	0.037
H001	AS35	AS 350 ECUREUIL	ARRIEL 1B	0.9	133	0.97	0.60	0.74	0.029
H001	AS35	AS 350B ECUREUIL	ARRIEL 1D1	0.9	147	1.15	0.57	0.70	0.033
H001	AS50	AS 550 FENNEC	ARRIEL 1D1	0.9	147	1.15	0.57	0.70	0.033
H001	AS55	AS 355	DDA250-C20F	1	204	1.04	1.82	2.28	0.034
H001	AS55	AS 355 N	ARRIUS 1A	1	216	1.19	1.67	2.08	0.038
H001	AS55	AS 555 FENNEC	ARRIEL 1D1	1	277	1.91	1.40	1.73	0.057
H001	AS65	AS 365 C1 DAUPHIN	ARRIEL 1A1	1	261	1.69	1.48	1.83	0.051
H001	AS65	AS 365 C2 DAUPHIN	ARRIEL 1A2	1	261	1.69	1.48	1.83	0.051
H001	AS65	AS 365 N DAUPHIN	ARRIEL 1C	1	265	1.75	1.45	1.80	0.053
H001	AS65	AS 365 N1 DAUPHIN	ARRIEL 1C1	1	274	1.87	1.41	1.74	0.056
H001	AS65	AS 365 N3 DAUPHIN	ARRIEL 2C	1	309	2.34	1.31	1.60	0.068
H001	B06	BELL 206B	DDA250-C20	1	109	0.61	0.82	1.03	0.019
H001	B06	BELL 206B	DDA250-C20B	0.9	101	0.58	0.72	0.90	0.018
H001	B06	BELL 206B	DDA250-C20J	0.9	101	0.58	0.72	0.90	0.018
H001	B06	BELL 206B	DDA250-C20R	0.9	105	0.63	0.70	0.86	0.019
H001	B06	BELL 206B	DDA250-C20R/4	0.9	105	0.63	0.70	0.86	0.019
H001	B06	BELL 206L	DDA250-C20R	1	117	0.70	0.77	0.96	0.022
H001	B06	BELL 206L	DDA250-C30	1	149	1.10	0.66	0.82	0.032
H001	B06	BELL 206L	DDA250-C30P	1	149	1.10	0.66	0.82	0.032
H001	B06T	Bell TWIN RANGER	DDA250-C20R	1	210	1.11	1.74	2.17	0.036
H001	B105	BO 105	DDA250-C20	1	200	0.99	1.88	2.36	0.033
H001	B105	BO 105	DDA250-C20B	1	204	1.04	1.82	2.28	0.034
H001	B222	BELL 222	DDA250-C40B	1	278	1.92	1.40	1.72	0.057
H001	B222	BELL 222	LTS101-750C.1	1	283	1.98	1.38	1.70	0.059
H001	B407	Bell 407	DDA250-C47B	1	149	1.10	0.66	0.82	0.032
H014	B412	Bell 412	PT6T-3	1	541	6.14	1.06	1.27	0.168
H001	B430	Bell 430	DDA250-C40B	1	278	1.92	1.40	1.72	0.057
H001	BK17	BK117	ARRIEL 1E2	1	283	1.99	1.38	1.70	0.059
H001	BK17	BK117 C-2	ARRIEL 1E2	1	283	1.99	1.38	1.70	0.059
H001	BK17	BK117B	LTS101-750B.1	1	281	1.96	1.39	1.71	0.058
H001	EC20	EC 120	ARRIUS 2F	1	114	0.67	0.79	0.98	0.021
H001	EC30	EC 130 B4	ARRIEL 2B1	1	183	1.56	0.61	0.74	0.045
H001	EC35	EC 135	ARRIUS 2B1	1	259	1.67	1.49	1.84	0.051
H001	EC35	EC 135	ARRIUS 2B2	1	259	1.67	1.49	1.84	0.051
H001	EC55	EC 155 B	ARRIEL 2C1	1	309	2.34	1.31	1.60	0.068
H001	EC55	EC 155 B1	ARRIEL 2C2	1	337	2.73	1.26	1.54	0.079
H001	EN48	ENSTROM 480	DDA250-C20W	1	112	0.64	0.80	1.00	0.020
H019	EXPL	MD 900	PW206A	1	257	1.64	1.50	1.86	0.050
H001	GAZL	SA341 GAZELLE	ASTAZOU IIIA	1	148	1.09	0.67	0.82	0.032
H001	GAZL	SA341 GAZELLE	ASTAZOU IIIN2	1	148	1.09	0.67	0.82	0.032
H001	GAZL	SA342 GAZELLE	ASTAZOU XIVG	1	139	0.97	0.69	0.85	0.029
H001	GAZL	SA342 GAZELLE	ASTAZOU XIVH	1	139	0.97	0.69	0.85	0.029
H001	H500	HUGHES 500	DDA250-C18	1	99	0.48	0.96	1.20	0.016
H001	H500	HUGHES 501	DDA250-C20B	1	112	0.64	0.80	1.00	0.020
H001	H500	MD 500N	DDA250-C20R	1	117	0.70	0.77	0.96	0.022
H002	H53	SIKORSKY CH-53G (S-65)	T 64-GE-7	1	977	17.27	0.82	0.96	0.388
H002	H53S	SIKORSKY SUPER STALLION	T 64-GE-7	1	1332	21.99	1.27	1.50	0.523
H002	H60	SIKORSKY BLACK HAWK	T700-GE-700	1	508	5.43	1.11	1.34	0.150
H001	KA27	KA-32A12	TV3-117VMA	1	621	7.90	0.98	1.17	0.211
H001	KMAX	K-1200	T53 17A-1	1	284	3.36	0.51	0.61	0.091
H001	LAMA	SA315B LAMA	ARTOUSTE IIIB	1.18	159	1.08	0.83	1.02	0.032
H001	MD52	MD 520N	DDA250-C20	1	109	0.61	0.82	1.03	0.019
H001	MD60	MD 600N	DDA250-C47M	1	149	1.10	0.66	0.82	0.032
H002	MI8	MIL MI-8	TV2-117	1	485	4.97	1.15	1.39	0.138
H001	S76	SIKORSKY S76	DDA250-C30S	1	263	1.72	1.46	1.81	0.052
H011	S76	SIKORSKY S76	PT6B-36A	1	348	2.87	1.24	1.52	0.082
H001	S76	SIKORSKY S-76 C+	ARRIEL 2S1	1	313	2.40	1.30	1.59	0.070
H002	S92	SIKORSKY S92A	GE CT7-8A	1	735	10.59	0.91	1.08	0.271
H002	UH1	BELL UH-1H	T53 L13	1	271	3.09	0.53	0.63	0.084
HP..	UH12	HILLER UH-12A	VO-540-1B	1	82	0.16	0.91	82.33	0.006
HP..	B47G	Bell 47G	LYC TVO-435-B1A	1	65	0.13	0.76	64.62	0.005
HP..	B47G	Bell 47G-3B	LYC VO-435-A1D	1	50	0.10	0.63	49.94	0.003
HP42	EN28	ENSTROM 280C	HIO-360	1	42	0.08	0.56	42.00	0.003
H001	EXEC	ROTORWAY EXEC 90	ROTORWAY RI-162	1	32	0.06	0.46	32.07	0.002
HP42	H269	SCHWEIZER 269C	HIO-360	1	42	0.08	0.56	42.00	0.003
HP42	HU30	HUGHES 300	HIO-360	1	42	0.08	0.56	42.00	0.003
HP41	R22	R22 BETA	HO-360	1	39	0.08	0.53	39.46	0.003
HP44	R44	R44 RAVEN	HIO-540	1	57	0.11	0.69	57.00	0.004
HP..	SCOR	ROTORWAY SCORPION	ROTORWAY RW 133	1	28	0.06	0.42	28.04	0.002
HP..	SYCA	BRISTOL SYCAMORE	ALVIS LEONIDES	1	277	0.55	2.52	276.80	0.019

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)

$$EI\ HC\ [g/kg] \approx 80 * SHP^{-0.35}$$

- ◆ HC measured
- ■ HC estimated

EI HC (g/kg)

Shaft Horse Power (SHP)

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

EI CO (g/kg)

Approximation

- ◆ 100%
- ■ 85%
- ▲ 45%
- ✕ Taxi

Shaft Horse Power (SHP)

Appendix F: Graphical Representation of Approximation Functions for Turboshaft Engines

Helicopter turboshaft engines: Fuel Flow up to 600 SHP

Helicopter turboshaft engines: Fuel Flow up to 1000 SHP

Helicopter turboshaft engines: Fuel Flow up to 2000 SHP

Helicopter Turboshaft Engines: Fuel Flow Approximation curves for the three power ranges

Helicopter turboshaft engines: EI NOx Approximation vs SHP

Legend:
- 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.

Axes: EI NOx [g/kg] vs SHP

Helicopter turboshaft engines: EI HC Approximation vs SHP

Legend:
- 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

Axes: EI HC [g/kg] vs SHP

Helicopter turboshaft engines: EI CO Approximation vs SHP

Helicopter turboshaft engines: EI PM non vol mass vs SHP
(EI for non volatile particle mass respectively soot)

Helicopter turboshaft engines: EI approximations (all functions)

$EI\ NOx = 0.2113\ *SHP^{0.5677}$

$EI\ HC\ = 3819 * SHP^{-1.0801}$

$EI\ CO\ = 5660 * SHP^{-1.11}$

$EI\ PM\ = -4.8 * 10^{-8} * SHP^2 + 2.3664 * 10^{-4} * SHP + 0.1056$