



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of the
Environment, Transport, Energy and Communications DETEC

Federal Office of Civil Aviation FOCA
Division Aviation Policy and Strategy

Theo Rindlisbacher

Guidance on the Determination of Helicopter Emissions

Reference: 0 / 3/33/33-05-20



Edition 1 - March 2009

Contents

Motivation and Summary

1. Classification of Helicopters by Engine Category

1.1 Piston Engine Powered Helicopters

1.2 Single Engine Turboshift Powered Helicopters

1.3 Twin Engine Turboshift Powered Helicopters

2. Operational Assumptions for Emissions Modelling

2.1 General Remarks about Helicopter Operations and their Modelling

2.2 Piston Engine Helicopter Operations

2.3 Single Turboshift Engine Helicopter Operations

2.4 Twin Turboshift Engine Helicopter Operations

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

3.1 Piston Engines

3.2 Turboshift Engines

4. Final Calculations

4.1 LTO Emissions

4.2 Emissions for One Hour Operation

5. Helicopter Emissions Table

References

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

Appendix B: LTO data, measured fuel flow and estimated emissions for a small twin engine turboshift helicopter

Appendix C: LTO data, measured fuel flow and estimated emissions for a large twin engine turboshift helicopter

Appendix D: Estimated one hour operation emissions and indicated scale factors

Appendix E: Graphical Representation of Approximation Functions for Piston Engines

Appendix F: Graphical Representation of Approximation Functions for Turboshift Engines

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 CO₂ 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 law¹, 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 ICAO² 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 LTO³ 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.

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



(AVGAS or MOGAS). For operational studies, the **Schweizer 269C** and the **Robinson R22** have been selected as the representative helicopter in this category.

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

1.2 Single Engine Turboshaft Powered Helicopters



AS350B2 Ecureuil has been selected as the representative helicopter in this category.

The majority of civil helicopters are powered by a single gas turbine with a shaft for power extraction ("turboshift 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 turboshift 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**

1.3 Twin Engine Turboshift Powered Helicopters



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.

The basic engine design is normally identical to that of the single engine turboshift 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

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

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

2.3 Single Engine Turboshift 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 turboshift 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 Turboshift 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 rating⁵. 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 turboshift 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 turboshift 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 turboshift 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:

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) \approx

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

- Emission factors for NO_x

Table 5

Mode	GI1	TO	AP	GI2	CRUISE
% max. SHP	20%	95%	60%	20%	90%
EI NO _x (g/kg)	1	1	4	1	2

- Emission factors for HC

$$\text{EI HC (g/kg)} \approx 80 \cdot \text{SHP}^{-0.35}$$

- Emission factors for CO

$$\text{EI CO (g/kg)} \approx 1000 \text{ (for all SHP)}$$

- 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 Turboshift Engines

- Fuel flow for engines above 1000 SHP

Fuel flow (kg/s) \approx

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

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

Fuel flow (kg/s) \approx

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

- Fuel flow for engines up to 600 SHP

Fuel flow (kg/s) \approx

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

- Emission factors for NO_x

$$\text{EI NO}_x \text{ (g/kg)} \approx 0.2113 * (\text{SHP})^{0.5677}$$

- Emission factors for HC

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

- Emission factors for CO

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

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

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

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

4. Final Calculations

4.1 LTO Emissions

$$\text{LTO fuel} = 60 * (\text{GI1_Time} * \text{GI1 fuel flow} + \text{TO_Time} * \text{TO fuel flow} + \text{AP_Time} * \text{AP fuel flow} + \text{GI2_Time} * \text{GI2 fuel flow}) * \text{number of engines}$$

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)

$$\text{LTO NO}_x = 60 * (\text{GI1_Time} * \text{GI1 fuel flow} * \text{GI1_EI NO}_x + \text{TO_Time} * \text{TO fuel flow} * \text{TO EI NO}_x + \text{AP_Time} * \text{AP fuel flow} * \text{AP EI NO}_x + \text{GI2_Time} * \text{GI2 fuel flow} * \text{GI2 EI NO}_x) * \text{number of engines}$$

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 =

$$3600 * (\text{fuel flow for mean operating power per engine}) * \text{number of engines}$$

NO_x emissions for one hour operation =

$$3600 * (\text{fuel flow for mean operating power per engine}) * (\text{EI NO}_x \text{ for mean operating power per engine}) * \text{number of engines}$$

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	
A102	ALOUETTE II	ARTOUSTE IIC5	402	1	18.2	76	384	498	3	110	0.61	0.82	1.02	0.019	
A102	ALOUETTE II	ARTOUSTE IIC6	402	1	18.2	76	384	498	3	110	0.61	0.82	1.02	0.019	
A103	SA316B ALOUETTE III	ARTOUSTE IIIB	563	1	21.4	109	312	401	4	135	0.91	0.70	0.87	0.027	
A103	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.

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	
M8	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 CT17-8A	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	HIO-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	

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)
- 3) [Aircraft piston engine emissions](#), FOCA, 2007
- 4) 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)
- 5) Helicopter performance test results, written communication to FOCA, Swiss Air Force Operations and Aircraft Evaluation, 2009
- 6) Helicopter performance test results, FOCA test flights, FOCA, 2009
- 7) Civil and military turboshaft specifications, www.jet-engine.net
- 8) Turboshaft specifications [Turbomeca](#)
- 9) Turboshaft specifications [Pratt & Whitney Canada](#)
- 10) Turboshaft specifications [Honeywell](#)
- 11) Turboshaft specifications [Rolls-Royce](#)
- 12) Engine specifications [GE Aviation](#)
- 13) Control of air pollution from aircraft and aircraft engines, US Environmental Protection Agency, US federal register, Volume 38, Number 136, July 17, 1973
- 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															CRUISE and LTO MEAN									
HBXVA		19.02.2009													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)	
Type	AS350B2														75%	60	549	0.043	7.588	4.197	5.151	0.221		
Engine	Arriel 1D1														80%	60	586	0.045	7.872	3.914	4.728	0.228		
Ref. Power:															85%	60	622	0.047	8.147	3.666	4.483	0.234		
100%T															90%	60	659	0.050	8.416	3.447	4.207	0.241		
94%T (MCP)															Est. Mean Fuel (kg)									
															75%	155	1178	651	798	34				
TOM															80%	163	1281	637	781	37				
OM test end															85%	171	1389	625	765	40				
															90%	178	1501	615	751	43				
LTO MODE		Time Incr. (Min)	Time sum (Min.)	Rotor torque %	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	70	0	51	0.014	1.974	54.375	71.639	0.118												
GR (full rotor RPM)		2	4	23	80.2	0	168	0.025	3.879	15.045	19.129	0.144												
HOVER IGE		0.3	4.3	65	90.3	0	476	0.039	6.996	4.899	6.038	0.207												
CL		2.5	6.8	90	95.8	1000	659	0.050	8.416	3.447	4.207	0.241												
								Est. Fuel (kg)	Est. NOx (g/kg)	Est. HC (g/kg)	Est. CO (g/kg)	Est. PM (g/kg)												
TO 5 NM		3.7	7.7					GI	4.7	14.9	137.3	178.9	0.6											
TO 3000ft		3	7					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.)	Rotor torque %	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)												
DCCT		2.5	2.5	60	60	700	439	0.037	6.686	5.341	6.599	0.200												
DDCT		1	3.5	45	45	500	329	0.032	5.678	7.287	9.081	0.178												
AP		4.2	4.2	30	30	500	220	0.028	4.511	11.292	14.243	0.155												
FINAL		0.3	4.5	15	78	250	110	0.020	3.043	23.872	30.743	0.131												
FINAL		0.7	5.2	20	80	250	148	0.023	3.593	17.496	22.339	0.139												
HOVER IGE		0.3	5.5	60	89	0	439	0.037	6.686	5.341	6.599	0.200												
GI		1	6.5	15	69	0	51	0.014	1.974	54.375	71.639	0.118												
								Est. Fuel (kg)	Est. NOx (g/kg)	Est. HC (g/kg)	Est. CO (g/kg)	Est. PM (g/kg)												
GI		4.5	5.5					GI	0.9	17.7	46.3	61.0	0.1											
L 3000ft		5.5	6.5					AP	10.7	62.8	86.7	108.8	2.0											
								Total 2	11.6	64.5	135.0	169.8	2.1											
								TOTAL	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	4.728	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)
			155	1178	651	798	34		
	75%		163	1281	637	781	37		
	80%		171	1389	625	765	40		
	90%		178	1501	615	751	43		
									Est. Mean HC (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								
	80%								
	90%								
									Est. Mean CO (g)
	75%								
	80%								
	90%								
									Est. Mean PM (g)
	75%								
	80%								
	90%								
									Est. Mean NO (g)
	75%								

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

HBXOE		12.02.2009												
Type	A109													
Engine	PW206C													
Ref. Power:														
max. one engine	550 SHP													
100% Rotor-Torque	900 SHP													
IMC per engine	450 SHP													
(= MTOM)														
TOM	2850 kg													
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)	RoD (ft/min)	Est. SHP per engine	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	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	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	6.584	5.499	6.800	0.198
Meas.														
Total fuel (kg)														
GI	5.3													
TO	11.7													
Total 1	17.0													
TO 5 NM	4	8												
TO 3000ft	3	7												
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. 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	5.072	9.033	11.324	0.166
DCT	1	3.5	45	45			0.0222	0.0222	500	203	4.308	12.325	15.584	0.152
AP	0.7	4.2	30	30			0.0167	0.0167	500	135	3.422	19.097	24.443	0.137
FINAL	0.3	4.5	15	15			0.0148	0.0148	250	68	2.309	40.376	52.758	0.121
FINAL	0.7	5.2	20	20			0.0158	0.0158	250	90	2.718	29.592	38.336	0.127
HOVER IGE	0.3	5.5	70	70			0.0275	0.0275	0	315	5.536	7.648	9.543	0.175
GI	1	6.5	8	6			0.01	0.01	0	27	1.372	108.626	145.882	0.112
Meas.														
Total fuel (kg)														
GI	1.2													
TO	14.6													
Total 1	15.8													
L 5NM	4.5	5.5												
L 3000ft	5.5	6.5												
TOTAL LTO 32.9														
TOTAL LTO 36.5 171.4 920.6 1210.6 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															
LTO MODE	Time Incr. (Min)	Time sum (Min.)	Rotortorque %	Total SHP %	Engine 1 N1 %	Engine 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC (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	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	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	90	0.0653	0.0653	0	959					
CL	3	7.1	81	81	90.3	90.3	90.1	0.075	0.075	1000	1213	0.079	11.904	1.782	2.136	0.300
Meas. Total fuel (kg)																
TO 5 NM	4	8	GI 11.4 35.6 294.5 380.8 0.4													
TO 3000ft	3	7	TO 28.6 340.4 51.0 61.1 8.6													
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 1 N1 %	Engine 2 N1 %	Engine 1 FF (kg/s)	Engine 2 FF (kg/s)	RoC (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	84.2	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	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)																
L 5NM	4.5	5.5	GI 2.6 6.9 79.9 103.7 0.1													
L 3000ft	5.5	6.5	AP 34.4 273.9 146.9 180.8 5.9													
Total 2 37.0 280.8 226.8 284.4 5.9																
TOTAL LTO 77.0 656.9 572.3 726.3 15.0																

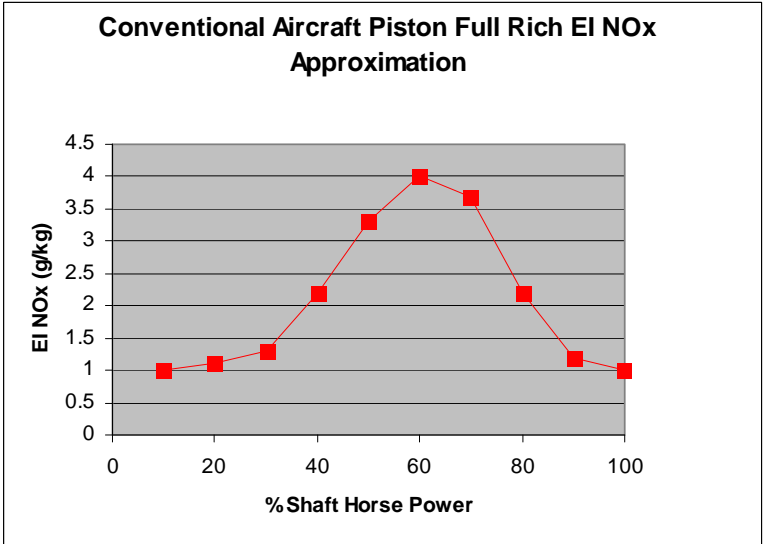
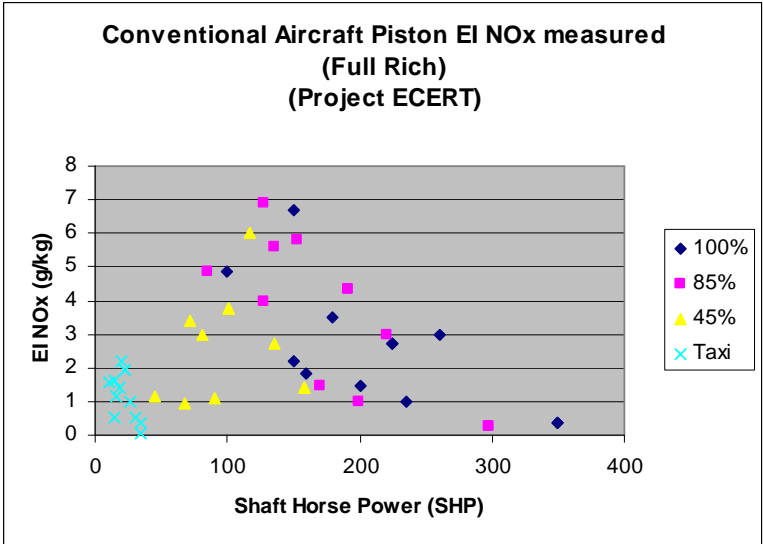
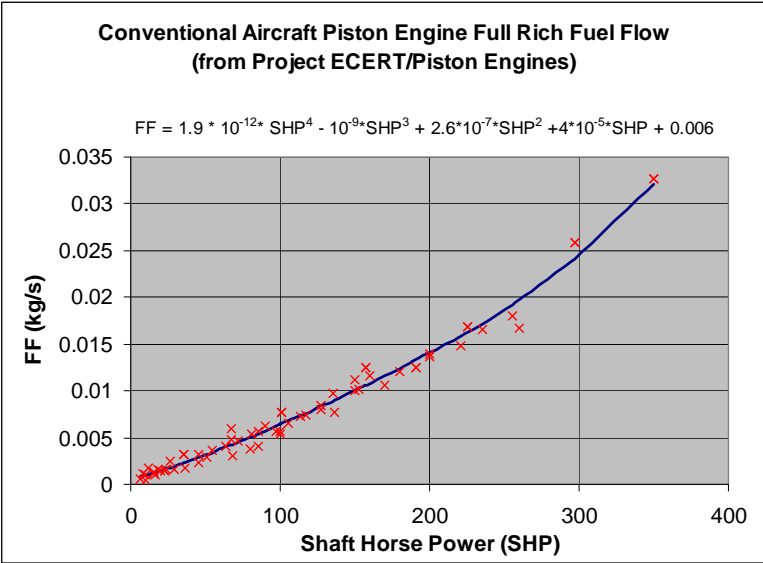
Appendix C: Weighted average LTO data, measured cruise fuel flow and estimated emissions for a large twin engine turboshaft helicopter

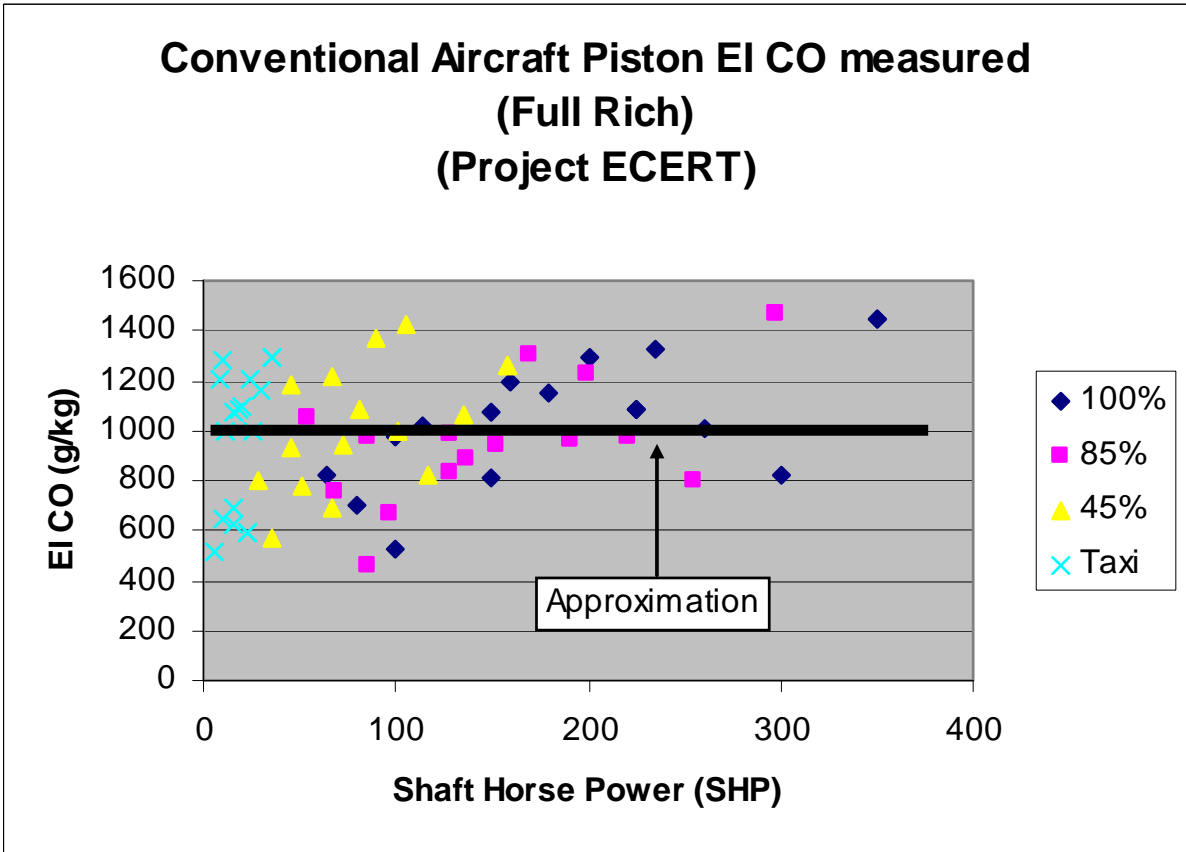
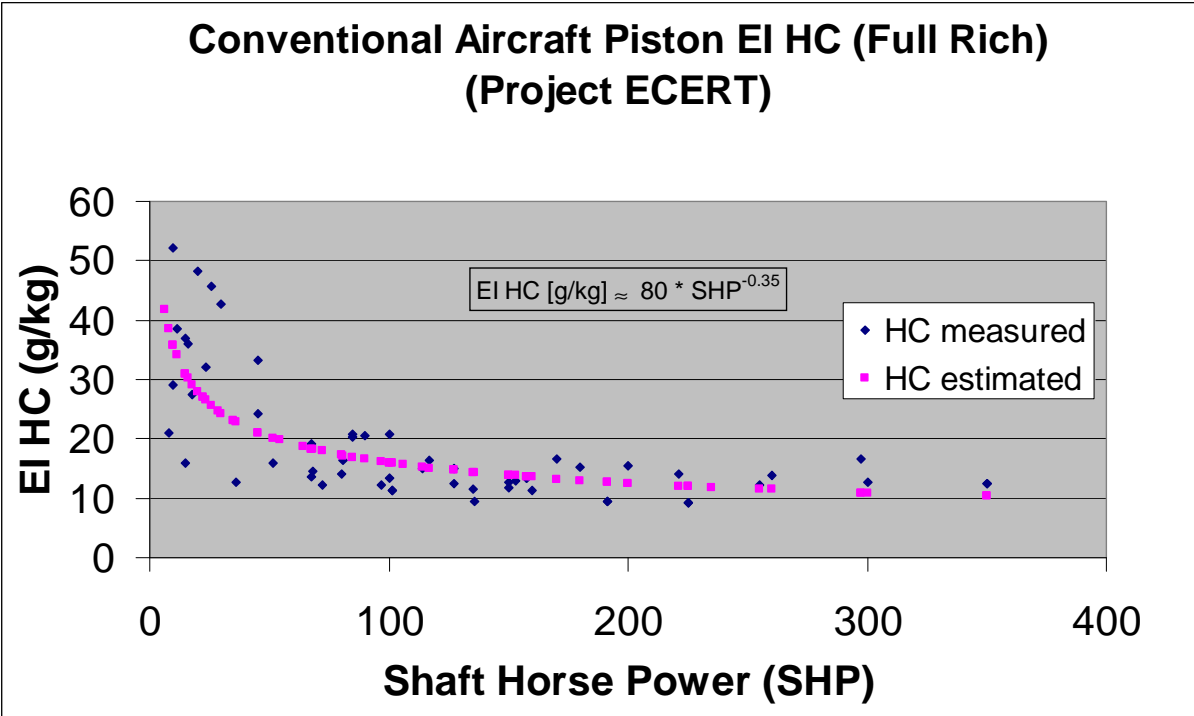
CRUISE and LTO MEAN									
	Est. Total SHP	Mean Time (Min.)	Est. SHP % per engine	Est. SHP per engine	Est. Mean FF per engine (kg/s)	Est. Mean EI NOx per engine (g/kg)	Est. Mean EI HC per engine (g/kg)	Est. Mean EI CO per engine (g/kg)	Est. Mean EI PM per engine (g/kg)
CR									
75%	2247	60	62	1124	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
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
					80%	567	6705	1024	1228
					85%	591	7234	1000	1197
					90%	616	7784	980	1170
	7600 (light)	480							
	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)
LTO									
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
					TO	29.4	348.8	52.8	63.3
					Total 1	40.9	384.0	323.7	412.1

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_I CAO	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	M18	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





Appendix F: Graphical Representation of Approximation Functions for Turboshaft Engines

