DEFINITION BY EUROCOPTER OF A GREEN METRIC TO ASSESS GAS EMITTED BY HELICOPTERS IN OPERATION

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ABSTRACT

As the global Earth warming and the air pollution became reality over the last decades, the industrial and individual awareness for environmental issues is nowadays a first priority. Whereas it currently contributes only to a marginal fraction of global gas emissions, the aeronautical world strongly reacts to counter its growing contribution. Research programs are launched to develop new technologies and new processes reducing the effect of aviation on global climate change. Among the overall environmental rationale which comprises the whole product life, from raw substances extraction to end life recycling phase, the impacts of the aircraft usage phase on the air pollution need to be measured by accurate and representative environmental metrics. Yet the helicopter operations show versatility with very diverse and dedicated missions, mostly unscheduled, which are only achievable by rotorcrafts. Therefore the impact of helicopters operations on gas emissions is even more difficult to assess than for other transportation means.

This paper presents the methodology to define a metric for assessing the gas emitted by the helicopters in operation. The resulting metric, derived from volume of consumed fuel, or mass of emitted CO_2, differs however from current metrics promoted in the transportation industry, in order to reproduce the very specificity of rotorcraft operational aspects. Based on certified data which is accessible through published documents, it will allow monitoring of environmental behaviour improvement and fulfilment of ACARE goals by providing reliable information. Inspired by aeronautics and automotive worlds, the parameters used to build up the metric calculation are discussed and a sensitivity analysis is performed. The defined metric intends to quantify green benefits of new technologies and new products, and to set the standards for the future.

ABBREVIATIONS

Ch	Hourly Fuel Consumption
Ck	Kilometric Fuel Consumption
EMS	Emergence Medical Service
ETS	Emissions Trading System
EW	Empty Weight
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organisation
ISA	International Standard Atmosphere
MTOW	Maximum Take-Off Weight
mAGW	Minimum Approved Gross Weight
SAR	Search and Rescue
SL	Sea Level
Vbr	Best Range Speed
Vreco	Recommended Speed
GHG	Green House Gases

INTRODUCTION

Why a Green Metric?

In a global world where every stakeholder is responsible for the gas emitted in the atmosphere, it is important to first know how much each one is emitting before taking measures to reduce the emissions rate.
Current figures are making obvious that helicopters have a marginal contribution to global gas emissions (Figure 1).

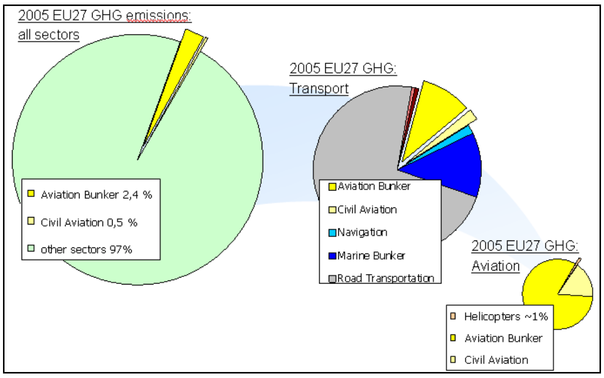

Figure 1: Helicopters Contribution to EU GHG Emissions in 2005

Nevertheless concern is raised by the coming evolution of the general aviation contribution since its growth is in conflict with emission reduction target (Figure 2).

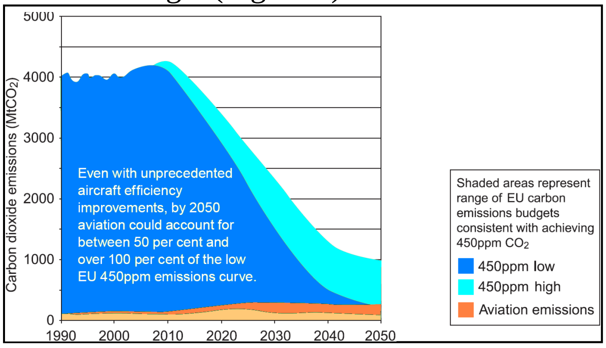

Figure 2: Aviation Growth Contribution to EU Carbon Emissions (reference: Tyndal – Aviation in a Low Carbon EU, 2007)

This statement associated to Kyoto protocol agreement signing has led to several actions in Europe, such as ACARE goals and ETS (Emission Trading Scheme) which impacts aviation (Figure 3).

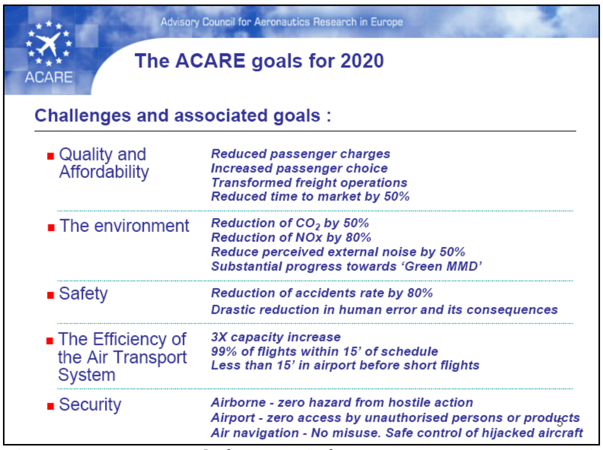

Figure 3: ACARE Goals for 2020 (refence: www.acare4europe.com)

In parallel, European research programs such as Cleansky have been initiated in order to help developing aviation new technologies leading to a lower carbon footprint (Figure 4).

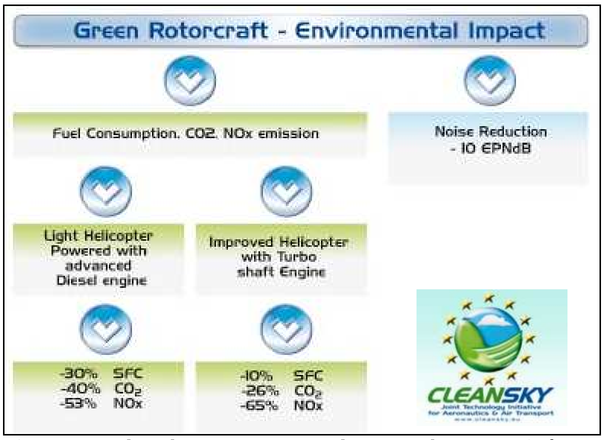

Figure 4: Cleansky Emissions Reduction Objectives (refence: www.cleansky.eu)

The metric presented in this paper has been investigated by Eurocopter and proposed then among Cleansky consortium, whose participants granted main principles. For helicopters, the phase of operation is here the target. Therefore the first step is to establish how emissions in operation will be measured. The Green Metric being established, the current status can be drawn, then the improvements brought by each reduction feature can be assessed. Without an appropriate metric, no current status and no improvement measure can be stated. The stakes of a Green Metric can be seen in three points:

- to provide tools with reliable data to the operators to answer to ACARE goals,
- to provide equitable comparisons among the helicopter world,
- to encourage, promote and quantify new green technologies.

Why Defining a new Metric?

Operational environmental impacts can be seen from two points of view: gas emissions and acoustics. In the acoustics domain, Eurocopter has put efforts for years with international industry leaders, research centres and certification groups. The outcome is the now existing measurement procedures and certification scheme which is accepted internationally. With a combined metric mixing acoustics and emissions, the risk was to make the features unclear. With two complementary metrics, the acoustics metric, directly deduced from existing scheme, is completed by a new emission metric, for which up to now no process exists.

In the automotive industry, a clear process to measure gas emissions already exists. The operations are divided into three representative phases, indeed the drive on highway, the drive on a land street and the drive in the city. The conditions are well described and a time cycle is defined, as shown in Figure 5.

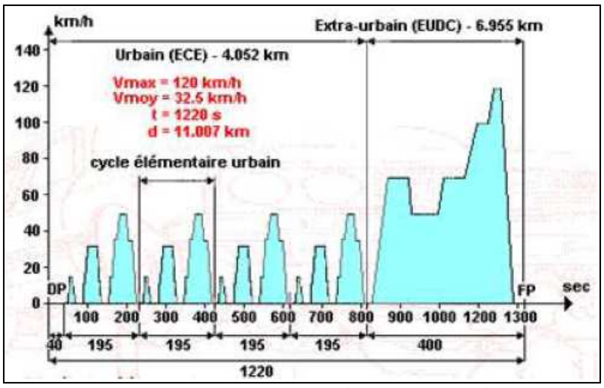

Figure 5: Automotive European Reference Cycle for Emission Evaluation

In the aeronautical world, fixed-wings have begun to derive the automotive metric to their own needs, which is to fly a given distance from point A to point B with a given number of passengers. Therefore the metric in terms of kilogram of fuel per kilometre per transported passenger is for fixed-wings meaningful. General aviation has also begun to set a metric based on fuel burned per capability, the capability being a combination of useful load, maximum range and speed.

For helicopters the situation is totally different: the versatility of the helicopter is such that the existing metrics, as well the automotive one as the fixed-wing one, cannot be applied one to one and must be adapted. Therefore a green metric for measuring emissions in helicopters operations must be new defined.

Definition of a Mean to Assess CO_2 Emissions

The CO_2 emission rate is not given in public data up to now, neither by motorists nor by helicopters manufacturers. This is not part of the certification process.

From the chemical equations of fuel burn, the quantity of CO_2 emission can be deduced. Kerosine is a mixture of hydrocarbons (alkanes C_nH_{2n+2}). For example following formula describes the combustion of dodecane:

dodecane + oxygen ➔ carbon dioxide + water

$$2\ C_{12}H_{26} + 37\ O_2 \rightarrow 24\ CO_2 + 26\ H_2O$$

The molar mass of $C_{12}H_{26}$ molecule is:

$$M = 12 * 12 + 26 * 1 = 170\ g.mol^{-1}$$

The molar mass of CO_2 molecule is:

$$M = 1 * 12 + 2 * 16 = 44\ g.mol^{-1}$$

Using the chemical formula, taking into account stochiometry and the fact that on turboshafts combustion can be considered as complete, from one gram of burnt fuel, the quantity of emitted carbon dioxide can be deduced.

For one g fuel, $\frac{24 * 44}{2 * 170} \approx 3.11$g CO_2 is emitted.

Conclusion: CO_2 emissions can be measured by consumed fuel.

The Interest of the Hourly Fuel Consumption

The use of the hourly fuel consumption can be justified in three points.

First, the helicopter is characterized by its capability to hover. For some operations, as Search And Rescue (SAR) or Emergency Medical Service (EMS), the amount of time spent in hover is non negligible. Therefore a kilometric metric is for these missions non appropriate.

Secondly, helicopters operators usually count in flight hours, not in flown distances, so that a metric based on hourly fuel consumption makes more sense than a metric based on kilometric fuel consumption.

Finally, since operators report their activities using annual flight hours, it is easier for them to translate this data into annual CO_2 emissions if the CO_2 metric is based on hourly fuel consumption, in order to report to emissions control organisms, as it is foreseen in the frame of ETS.

Choice of the Atmospheric Conditions

In order to give the hourly fuel consumption, the atmospheric conditions need to be determined. For that purpose, a sensitivity study has been conducted. Figure 6 shows the hourly fuel consumption with three different atmospheric conditions (SL ISA, SL ISA+20, 1500m ISA+20) based on the example of four helicopters, taken at their MTOW: one Light Single, one Light Twins, one Medium Twins and one Heavy Twins helicopter. All values are given comparatively to the Light Single-engine ones. It shows that, comparing helicopters among them at a given atmospheric condition, their hourly fuel consumption values are ranked in the same way and in similar proportions: it is illustrated by the Medium Twins consuming around 1.5 times more than the Light Single whatever the atmospheric condition is.

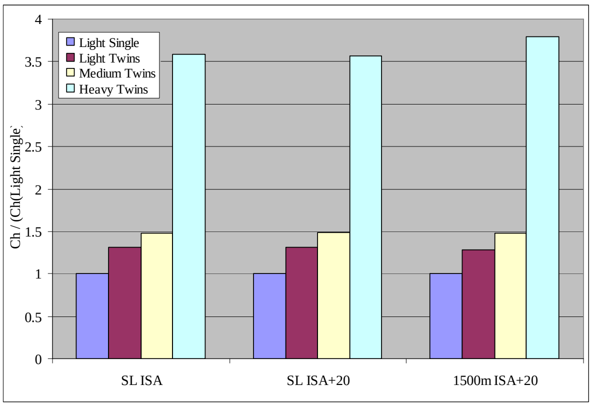

Figure 6: Relative Hourly Fuel Consumption of Four Example Helicopters, at their MTOW at 120kts, for Different Atmospheric Conditions, normalized with Light Single values

Thus the relative positioning of helicopters in terms of pure fuel consumption is similar whatever the atmospheric condition is. Since we want to keep in general as much as possible independent criteria for assessing helicopters (like maximal speed, hover ceiling, fuel consumption…), it is recommended to figure the fuel consumption metric in standard conditions.

All speeds and fuel consumption data are therefore given at SL ISA.

Choice of the Mission Phases

The atmospheric condition being defined, the flight condition in which the fuel consumption is taken needs to be determined. As for the automotive industry, a spectrum defined by three flight conditions is representative of the majority of the operations.

Hover: the Essence of the Helicopter

The helicopter is characterized by its ability to hover, so that the hover must be contained among the three phases to insist on this unique advantage, compared to other road or air transportation means.

Best Endurance Speed (Vbe), Characterizing the Ability to Observe from above

Then, two forward flight conditions can be defined: one being representative of searching and loitering while the other one corresponds to an inbound / outbound level flight. Best endurance speed is used typically in the first case.

Classical inbound / outbound Level Flight Phase: the Choice of the Speed

The choice to define a given speed for the last phase is driven by three main concerns. First, the phase should be representative of high speed flight but in the same time the speed should be flyable by all helicopters, as well the heaviest as the lightest ones. And finally the speed should not introduce any bias between helicopters which would depend on their specific design. One candidate is the recommended speed (Vreco) or the best range speed (Vbr). However, giving the hourly fuel consumption at Vreco or Vbr is not logical, since the goal by flying at Vreco or Vbr is to make a certain distance, not a certain time. To be logical, the fuel consumption at Vreco or Vbr should be expressed in kilogram per kilometer, which is not consistent with the unit of both other phases. Expressing the fuel consumption at Vreco in hour would also penalize fast helicopter which fly a given distance with less time. Vreco can vary much between helicopters, for example from 110kts with BO105 to 142kts with EC225, so that hourly fuel consumptions with so different speed values are not comparable. Figure 7 illustrates a comparison of hourly fuel consumption at 120kts and kilometric fuel consumption at Vreco, both at SL ISA, for four helicopters examples at their MTOW. All values are relative to the Light Single-engine ones.

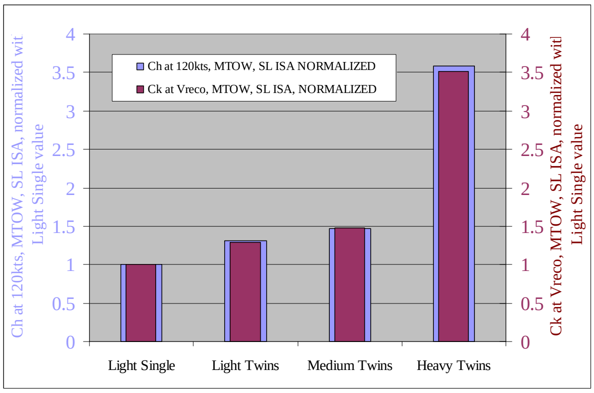

Figure 7: Comparison of Hourly Fuel Consumption at 120kts and Kilometric Fuel Consumption at Vreco

Figure 7 shows that the relative positioning of helicopters does not change significantly by taking Ch at 120kts or Ck at Vreco. Some minor differences can be observed, for example by comparing the Heavy Twins to the Light Single: The ratio of the Heavy Twins Ch at 120kts to the Light Single one is about 2% higher than the ratio of its Ck at Vreco to the Light Single one. On these four examples the difference between these ratios remains however under 2%.

Time Distribution among Three Representative Phases

Having defined the three representative flight phases, an average hourly fuel consumption needs to be computed in order to have only one value instead of three and to keep it simple for operational use. A time distribution, in terms of percentage of time spent in each flight case, has to be found.

In most flight usage spectra, the hover part is under 20%. Then the best endurance speed part is between 15% and 30%, and the 120kts part, accordingly, between 50% and 65%. Figure 8 shows the results of a sensitivity study on the time distribution for four example helicopters (Light Single, Light Twins, Medium Twins, Heavy Twins). The average fuel consumption has been computed taking into account varying distribution: hover 10% and 20%, Vbe from 30% to 40%, and 120kts from 50% to 60%. All values are relative to the Light Single-engine ones.

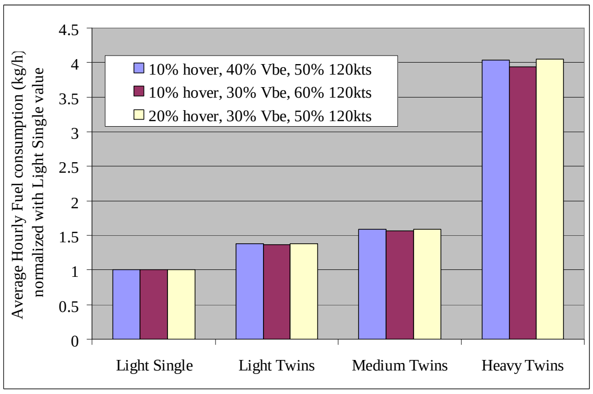

Figure 8: Impact of Time Distribution in an Average Mission Spectrum

On Figure 8 it can be observed that the relative position of the helicopters does not change significantly by changing the weighing of phases. The mission spectrum with the highest amount of time spent at 120kts provides the lowest average fuel consumption for helicopters compared to the Light Single. The mission spectrum with the highest amount of time spent at Vbe (and consequently less time in hover and at 120kts) provides the highest average fuel consumption for helicopters compared to the Light Single. This can be explained by the choice of 120kts: it does not represent the same effort for a Light Single than for a Heavy Twins to fly at this speed. Nevertheless, the variation between highest and lowest average fuel consumption values depending on time distribution is less than 2.5%, and relative positioning of the different helicopters considered is not affected at all.

Since sensitivity has been demonstrated as very low, for internal helicopters classification purposes the following weighing is used inside EUROCOPTER:

- 10% in hover
- 30% at Vbe
- 60% at 120kts

CHOICE OF ADIMENSIONING

In the automotive world, the kilometric emission value is usually given ad hoc, without considering any maximum transport capability or passengers number. Nevertheless

for comparison to other road transportation means, as the train or the bus, the metric per transported passenger is sometimes used.
In the fixed-wing world, some use the maximum cabin capacity, some others the average cabin load. For helicopters, alternatives with respective pros and cons have been investigated. Using an adimensioning factor is in line with the idea of a “climate impact” for a given service, either a transported kilogram or a transported person.
Taking into account the maximum transported passengers in the cabin reduces the helicopter versatile use to a banal transportation mean. This is forgetting all the useful missions as EMS, SAR or aerial work. Therefore, in order to be as general as possible, dividing by a generic kilogram capacity is more meaningful. Two options can be investigated: the payload and the useful load. Since the computation of the payload is extremely dependent on the consumed fuel for a given mission, this cannot be generalized to a unique value. On the contrary, the fuel consumption values can be divided by the useful load, so that the final metric is expressed in kilogram fuel per hour per kilogram useful load. The useful load has the advantage to represent most missions. The useful load needs to be defined carefully, especially with respect to empty weight, which is difficult to assess on comparable configurations. It has been proposed to use following expression:

$$\boxed{Useful\ Load = Minimum\,(MTOW - EW - Pilot;\, MTOW - mAGW)}$$

where:

- MTOW is the Maximum Take-Off Weight given in the flight manual,
- EW is the Empty Weight standard given mostly in the Tech Data,
- mAGW is the Minimum Approved Gross Weight given in the flight manual.

Taking the minimum of two definitions of useful load ensures on one hand the maximum useful load authorized to fly and on the other hand prevents from empty weight definitions with dissimilar configurations.

In order to be fully comparable in the future, it would be necessary to define among the whole helicopter world a common standard empty weight which would be published in the flight manual.

SYNTHESIS: NECESSARY PARAMETERS

Figure 9 summarizes the different parameters used to define the proposed metric and their respective origin from published data.

Parameter	Origin
MTOW	Flight Manual, Chapter 2 (Limitations)
mAGW	Flight Manual, Chapter 2 (Limitations)
EW	Tech Data
Ch at HOGE, SL ISA, MTOW	Complementary Flight Manual
Ch at Vbe, SL, ISA, MTOW	Complementary Flight Manual
Ch at 120kts, SL ISA, MTOW	Complementary Flight Manual

Figure 9: Synthesis of Required Parameters to establish the Emissions Metric

DEFINITION OF A LABEL

With reference to the defined metric, an emissions scale can be defined to rank current helicopters and set objectives for the future.
Each helicopter emission level is labelled by a letter on a scale from A+, which represents long-term objectives, to E. The different levels are equally spaced. Proposed levels limits have been set in accordance with official objectives for the future, as well ACARE (Figure 3) as Cleansky (Figure 4) ones. The proposed scale is shown in Figure 10 in two ways: the second column represents the burnt fuel, the third column shows the emitted CO_2. As shown before, both values are proportional.

	Green Metric (kg fuel / h / 100kg UL)	Green Metric (kg CO_2 / h / 100kg UL), *approximate*
A+	**≤ 9**	**≤ 28**
A	**]9; 12]**	**]28; 37]**
B	**]12; 15]**	**]37; 47]**
C	**]15; 18]**	**]47; 56]**
D	**]18; 21]**	**]56; 65]**
E	**> 21**	**> 65**

Figure 10: Levels Defined for Emissions Green Labels

Based on this scale, Eurocopter helicopters have been labelled as shown in Figure 11.

Model	Emissions Label
EC120	**C**
AS350 B2	**B**
AS350 B3	**B**
EC130 B4	**C**
AS355NP	**D**
BO105 CB-5	**C**
EC135 P2i	**B**
EC135 T2i	**B**
EC145	**B**
AS365 N2	**B**
AS365 N3	**C**
EC155 B1	**C**
EC225	**B**

Figure 11: Emissions Green Labels

If one helicopter is at the upper end of one level, the effort in average fuel consumption to come to the next lower level, keeping the same reference useful load, is shown in Figure 12.

A to A+	-33%
B to A	-25%
C to B	-20%
D to C	-17%
E to D	-14%

Figure 12: Effort on Average Fuel Consumption Reduction to pass from one Upper Level to the Lower Level (keeping unchanged reference Useful Load)

The growing figures on the effort to come from E to A+ illustrates the well-known phenomenon that the last steps are always the most difficult to reach.

CONCLUSION

The green metric for emissions enables giving the operational environmental impact of helicopters for CO_2 emissions. It has been specifically designed for helicopters.

Based on published technical data, the green metric for emissions allows technical comparisons based on three representative generic flight phases: hover, best endurance speed and 120kts.

This green metric for emissions can be completed by a green metric for acoustics, which is already well represented by official ICAO and FAA certification schemes.

Having the global green metric, the current status for current fleet can be drawn before assessing the impact of each improvement feature to reach a more environmental-friendly fleet in the future.

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