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ORIGINAL PAPER

Towards greener helicopters

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Abstract Environment protection is now considered as a key point by the population and has become a political and economical stake as related in Kyoto protocol signature which defines objectives for greenhouse effect gases reduction. Based on greenhouse effect gases like carbon dioxide (CO_2) and increasing temperature, European Union has implemented an Emission Trading System to give each country emission CO_2 targets and a trade tool to share tons of CO_2. The European Union has fixed specific objectives to aeronautic section via the Advisory Council for Aviation Research and innovation in Europe. Helicopter community is implementing qualitative tools called environmental metrics to measure the achieved progress. Environmental acoustic metrics have been defined based on noise levels and colors, related to ICAO limitation levels and in the frame of European research project Cleansky. Similarly, environmental metrics for CO_2 emission have also been defined based on fuel consumption values and colors. The more the helicopter is environment friendly, the greener the metric. In anticipation of environmental requirements strengthening, some helicopter manufacturers have launched research studies on environmental technologies like Friendcopter project to develop low acoustic level flight procedures based on HELENA computations, or engine manufacturers have invested in technological research projects to improve engine performance and environment impact. In addition, the helicopter product full life cycle is globally considered under the international standard ISO 14001 for environment management as well as human health and environment protection in comparison to REACH European regulation. The reader of the article will certainly notice that the challenge is now: "Towards greener helicopters".

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Abbreviations

ACARE	Advisory Council for Aviation Research and innovation in Europe
CFD	Computational fluid dynamics
CO_2	Carbon dioxide
EU	European Union
EMS	Emergency medical service
ETS	Emission trading system
GHG	Green house effect gases
HAI	Helicopters Association International
ICAO	International Civil Aeronautical Organization
INM	Integrated noise model
NO_x	Nitrogen oxides
R&D	Research and development
REACH	Registration, evaluation and authorization of chemicals
SAR	Search and rescue
SL ISA	Sea level international standard atmosphere (15 °C, 101325 Pa)
VIP	Very important person

1 Introduction

Since the end of 20th century, environment protection has become an increasing demand from the population and has been strengthened among western industrial countries. It has become one of the worldwide political and economical stakes.

In particular, global warming and its consequences have been concerning the different governments of our planet. The first major political action was the Kyoto protocol signature in 1997 which defines the objectives for greenhouse effect gases reduction to limit the earth average temperature rise up to 2 °C maximum, between now and 2100.

This environmental axis, greenhouse effect gases reduction, has been essentially declined in the aeronautical community in a need to reduce fuel consumption. However, beyond this axis of progress, two other major axes need to be mastered as well: the external acoustic level to which population is exposed and the mastering of the product life cycle, from its conception, through the supply of raw materials, the production processes, the product use at the customer's, the maintenance, and the recycling process and end of life.

In this paper, after a high level presentation of regulations and constraints, as well on a worldwide prospect as on a European or local prospect, means, research tools and objectives which have been deployed for the helicopters to cover the three virtuous axes of environmental protection will be addressed: the reduction of external acoustic level to which population is exposed, the fuel consumption reduction, the product life cycle management for respecting the environment.

2 Greenhouse effect and political answers

Greenhouse effect is the consequence of a complex thermo-mechanical interaction between solar radiation which is partially filtered by the atmosphere, partial reflection by the Earth of this formidable energy quantity, and blockage of reflected energy by certain clouds of our sky, which are composed by gases so-called 'greenhouse effect gases' or GHG such as carbon dioxide (CO_2) and nitrogen oxides (NO_x) in particular. The more the clouds of the sky, the warmer the atmosphere (Fig. 1).

Regarding CO_2, the main contributor to this complex phenomenon, its life cycle in the atmosphere under concentrated state, after emission, is of the order of 100 years, and its consequence in terms of atmospheric reflection, captured then stored by the oceans, is of the order of 40 years. In other words, to be efficient in 2100 and to master greenhouse effect, one must act as early as today and continuously during the years to come, if not already very late!

Indeed, measurements performed since the middle of nineteenth century do not leave much doubt regarding CO_2 concentration increase during the industrial era. Moreover, such concentration keeps on increasing at an exponential rate since the second half of twentieth century (Fig. 2).

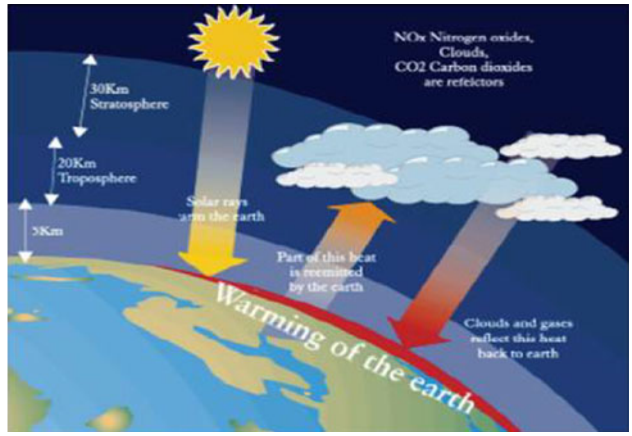

Fig. 1 Green house effect (from [2])

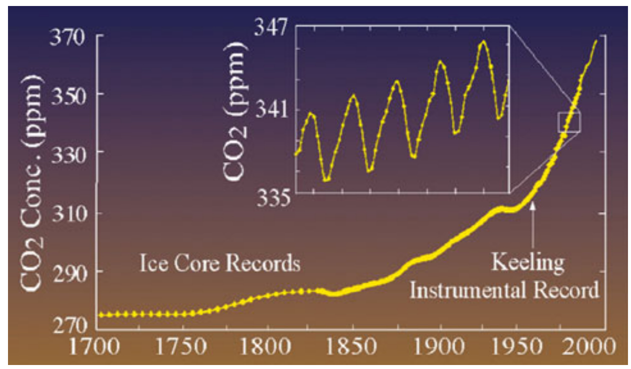

Fig. 2 Evolution of CO_2 concentration with time (from [2])

CO_2 emissions in the world are not equivalent from one country to another, for many reasons: local climatic differences (hot countries, cold countries), different tax policies for the energy, different level of industrial development, etc.

Hence, Kyoto protocol, signed by all countries in 1997 but ratified only from 2005 on by a majority of them, defines an objective of greenhouse effect gases reduction at world level of 5.1 % in equivalent CO_2 for the 2008–2012 period as compared to the situation in 1990.

Thirty seven countries outside European Union (EU) and 27 countries inside EU have been fixed dedicated reduction rate objectives according to their level of industrialisation and to the technologies available for greenhouse effect gases mastering. Global EU reduction rate objective has been fixed to 8 %.

The EU, to answer to Kyoto protocol, has put in place a dedicated system called emission trading system (ETS), composed on the one hand of objectives fixed country by country to account for intra-European differences, and on the other hand of a tool, the trade share ton of CO_2. As an example, Germany, the electricity production is mainly based on fossil energy plants, must reduce its emissions by 21 %, a great more than 8 %, while France must keep status quo, and Portugal, not to impair its necessary economical growth, is allowed to emit in 2012 as much as 27 % more than in 1990.

Beyond 2012, to limit greenhouse effect in 2100 to 2 °C max, objectives are still under discussion. Indeed, the future protocol after-Kyoto is at the heart of strong negotiations between nations and is blocked on two main points:

- Developing countries refuse in majority to accept quantitative objectives for gas reduction rates, as long as a financial and technological support is not rapidly brought by industrial countries.
- The application of current Kyoto protocol in the industrial countries appears to be particularly difficult.

A compromise might be to extend beyond 2012 Kyoto protocol before a convergence between nations is foreseen.

The share ton CO2, or 'right to pollute', has been introduced in 2007 at around 20€ per ton, with a market objective around 25€ per ton in 2012 [1].

Besides, it has to be noted that the introduction of the ETS is progressive, with a first period from 2005 to 2007 which only concerned European countries and energy sector for plants with power higher than 20 MW. The 'rights to pollute' delivered at that time by the EU were numerous and this provoked a collapse of the share ton CO_2 down to 1€. Then, in a second period, between 2008 and 2012, when the ETS has been enlarged to the other associated European countries (such as Switzerland and Norway), as well as to the aeronautical sector, EU has decreased the number of shares by around 10 % leading to a rise of the share CO_2 (20€ in March 2011 [2, 3]).

It is also interesting to underline that Europe not only claims to impose the ETS to aeronautical actors of its member countries as early as 2012 taking into account intra-European flights, but also to invite its major partner and competitor, the USA, to respect this system from 2012 on, as long as any flight departing or arriving on the European ground will be considered eligible for ETS application.

Moreover, last ETS revision has been made in December 2008 and foresees that between 2013 and 2020 a 10 % reduction of greenhouse effect gases be effective for aeronautics.

3 Aeronautics and helicopter industry contribution in greenhouse effect

Looking back to the last 30 years, energy sector is responsible for more than 25 % of greenhouse effect gases emission, while transport sector (all transportation means considered) is responsible for 13 % of these emissions. However, on the only year 2004, transportation sector weights 23 % emissions. Aeronautics, in this sector, experiences a strong economical growth. Even if today, it only represents 1/8 (i.e. 3 % of worldwide emissions), it must pay much attention to this issue and it must propose means to control it.

Hence, all sectors must feel concerned, from industry, through operators and regulators.

The European Union, well aware of the stake, has fixed specific objectives to its aeronautic sector, via the Advisory Council for Aeronautical Research and innovation in Europe (ACARE). In the below table (Fig. 3), among the five main strategic axes for improvement, the environment is in good place. The three environmental virtuous axes have been quantified with challenging objectives.

Helicopter community is now conscious of the stake, political, economical, and societal, even though in the aeronautical sector it only roughly weights 1 %, which means less than 0.03 % of worldwide greenhouse effect gases emissions, as it is illustrated in the graph below (Fig. 4).

This is the reason why, as it will be developed in the forthcoming lines of this paper, the helicopter community is putting in place quantitative tools to measure the progress achieved (environmental metrics), means to propose new technologies for the helicopters, new manufacturing processes and new operational usage. All these actions are part of research and development (R&D) projects.

4 Environmental metrics for the helicopter

In order to provide technical objectives consistent with global objectives, fixed by ETS or ACARE, to measure

Fig. 3 ACARE goals for 2020 [1]

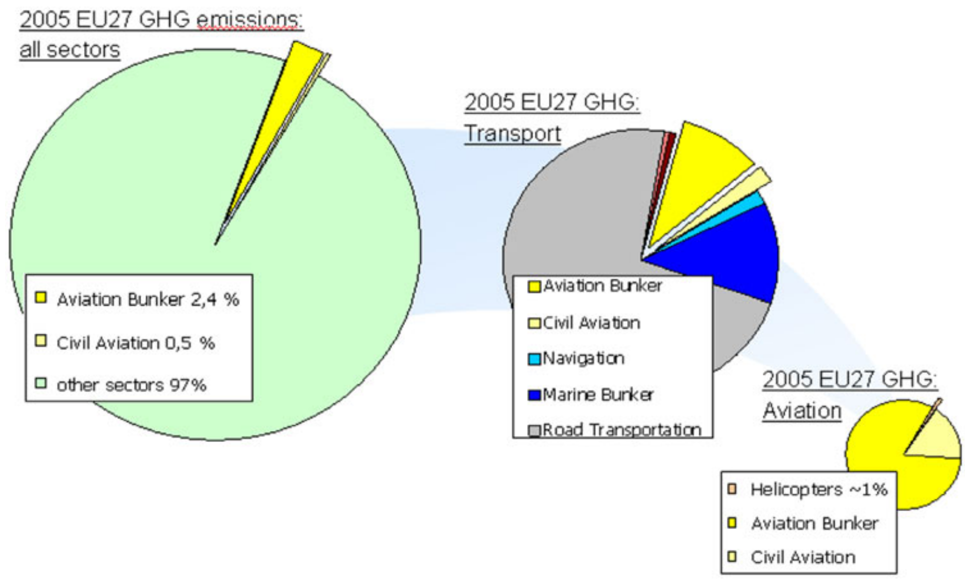

Fig. 4 Distribution of GHG emissions with transport means [3]

progress achieved, and to compare different technologies developed to reach such objectives, metrics as universal as possible should be defined. Moreover, these metrics should be easily measurable, well adapted to helicopter and social missions for which helicopters are operated, all of this for each of the environmental axes.

In particular, each metrics must comply with the following requirements:

- It must be a simple communication tool, which does not only focus on the scientific community.
- It must be easily available and controllable through recognized means.
- It must allow a performance ranking of technologies as far as environmental issues are concerned.

While for the life cycle management, such a metric is hard to define, meantime, worldwide helicopter manufacturers, research centers and associated advisory entities, led by European manufacturers, themselves triggered by the European Union, have joined their efforts to define metrics for external acoustics and CO_2 emissions (or fossil energy consumption). The progress of this work is presented thereafter.

4.1 Environmental acoustic metrics

Since 1985, a helicopter external acoustics regulation scheme has been existing at International Civil Aeronautical Organization (ICAO) level, so-called 'chapter 8'. It has been worldwide recognized. While this scheme has evolved since its birth, nevertheless its basic principles still apply: for each helicopter, measure the acoustic level for three flight conditions representative of its operational usage (high speed fly-over, climb with max take-off rate, approach with moderate slope and velocity); certification acoustic level limits vary with mass and are expressed in EPNdB unit. This unit accounts for time exposure duration, filtering and dissymmetry of acoustic energy spectral distribution, to render the psychoacoustic behavior of the human ear.

Another scheme, for light helicopters only, simplified to limit the cost of the acoustic certification, proposes an alternative to chapter 8, so-called 'chapter 11', but the grounds remain similar.

In a will for simplification and readability for large public, the environmental metric is directly elaborated from an average of differences as compared to ICAO limitation levels for each of the certification scheme flight procedures. The following resulting diagram (Table 1 in Fig. 5) depicts the relative positioning for a majority of helicopters manufactured in Europe or in North America, with reference to ICAO limits—pre 2002:

From these gaps, a label for acoustics environmental quality has been elaborated by Eurocopter [4]. It has then been proposed to European helicopters manufacturers partners in the frame of European research project Cleansky (for Cleansky project presentation, see further below), then to ICAO helicopters manufacturer partners, thanks to an international think-tank animated by American Helicopter Society (AHS) International, and recently supported by HAI. This label is built around the following principles:

- to be a simple and imaging communication tool,
- to comparatively sort out products so that they can be distinguished from each other,
- to present label bands which are centered around averaged today helicopters in operation,
- to leave a significant progress margin which is consistent with ACARE goals (−50 % on perceived energetic

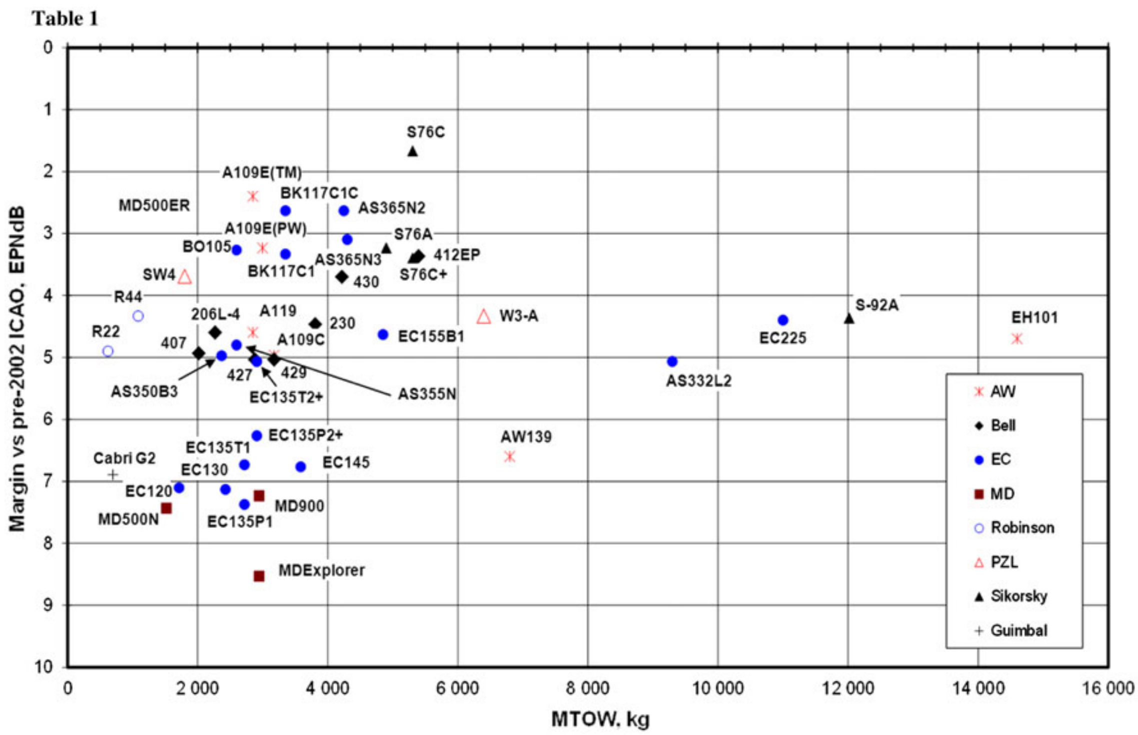

Fig. 5 Acoustic ICAO Annex 16 levels average margins (from database of International Coordinating Council of Aerospace Industries Associations)

acoustic level as compared to 2,000 years fleet distribution), knowing that halving the acoustic energy corresponds to −6 dB.

The table below (Table 2 in Fig. 6) illustrates the definition of this label (dB). Note that it is based on cumulative margins on each of the three flight phases, similar to what is commonly adopted for fixed wings communication. Therefore, a factor of 3 correlates between Figs. 5 and 6.

Hence, an EC130 (the Ecureuil/A-star AS350 with low acoustic level fenestron®) is labeled B+, which rewards the effort made as early as during its design phase to develop a silent product. The majority of aircraft are labeled C or C+ (like the Dolphin EC155B1). No aircraft, the max take-off weight of which is above 1,000 kg, can claim to be labeled A+, which is consistent with ACARE goal (currently: −50 % compared to average fleet 2000). Note, however, that some helicopters which would be labeled A+ may even not fully reach the very demanding ACARE goal by 2020.

It has to be mentioned that ongoing work in the international working group may slightly modify the above presented label.

4.2 Environmental metrics for CO_2 emission

Opposite to acoustics, no certification or regulation scheme already exists for CO_2 emissions.

In the frame of the European research project Cleansky, a task has been given to partners to define a metric. For helicopters, Eurocopter has built a metric based on the following considerations (in addition to general considerations for environmental metrics) [4]:

- The chemical equation of full combustion of kerosene in a turbine leads to a linear relation between emitted CO_2 and consumed fuel. Thus, fuel consumption is a good marker of emitted CO_2.
- The main operational added value of a helicopter is its unique capability to hold a steady hovering flight [emergency medical service (EMS), search and rescue (SAR) operations]. Moreover, operators report and trace their missions in a flight hours' basis on a year long. Hourly consumption, instead of distance consumption (such as liters/km) is thus well adapted.

Fig. 6 Proposed acoustic green label: reference '0' = ICAO limits pre-2002

Table 2

D	D+	C	C+	B	B+	A	A+
0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15	16 17 18 19	20 21 22 23	24 25 26 27	≥ 28

↑ Post-2002 regulations

Table 3

	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

Nota : 1 kilogram of consumed fuel emits 3,11 kilograms of CO2.

Fig. 7 Proposed consumption green label

Fig. 8 EC135 helicopter (copyright Eurocopter photographer)

Fig. 9 AS365N3 Dauphin helicopter (copyright Eurocopter photographer)

- Helicopter missions are diverse, similarly to car operations. Three main operational phases are selected and weighted in average: high speed level flight (very important person (VIP), off-shore), best endurance level flight (police, survey), and hovering flight.
- It is necessary to de-rate the metric by the helicopter weight, to allow comparison between helicopters of different weight range, similarly to the acoustics scheme, and thus to introduce a notion of individual responsibility and limitation to CO_2 emission.

The definition of the metric is then derived, and it is expressed in kilograms fuel per flight hour [conditions "Sea level international standard atmosphere (15 °C, 101,325 Pa)" (SL ISA)] and per 100 kg reference useful load (close to the difference between maximum weight certified for the helicopter and equipped empty weight, including pilot).

In the same way and for the same reason as for the acoustic metric, a label is built around the consumption metric (Table 3 in Fig. 7).

Here below, an illustration of this label is given, for two helicopters of Eurocopter products (Figs. 8, 9):

Today, none of the operated helicopters can claim to be in band A of the label. Moreover, ACARE goal of 50 % reduction for CO_2 emission is representative of the effort to be made on most recent aircraft (label B or C) to bring them up to band A+ of the label.

It should be highlighted that, as well as for the acoustic label, ongoing work in the international working group may slightly modify the above presented label.

5 Research studies on environmental technologies for helicopters

For external acoustic, some manufacturers have anticipated in the 90s the tendency of environmental requirements strengthening.

For example, one can mention Mc Donnell Douglas and its technologies of main rotor fitted with high blades number and reduced rotation speed (MD520N, MD600N, MD explorer), as well as its anti-torque function by NOTAR® system. One can also mention Eurocopter and its quiet fenestron® technology (phase modulation and reduced rotation speed), its main rotor with variable and reduced rotation speed and complex blade tips (EC120, EC130, EC135, EC145).

So, these helicopters are figured between 3 and 6 dB below new standards, in consistency with the trend requested by ACARE.

Europe has supported this change through the Friendcopter research project (2004–2008), which allowed, among other subjects, to develop low acoustic level flight procedures for modern European helicopters (EC 130, EC 135, A109), as well as computing methods of on ground noise impact (HELENA noise footprint model, Fig. 10), more suited to helicopters than the American competitor integrated noise model (INM) derived from fixed wings.

The running Cleansky project (2009–2014) gathers all participants in aeronautical research (fixed and rotating

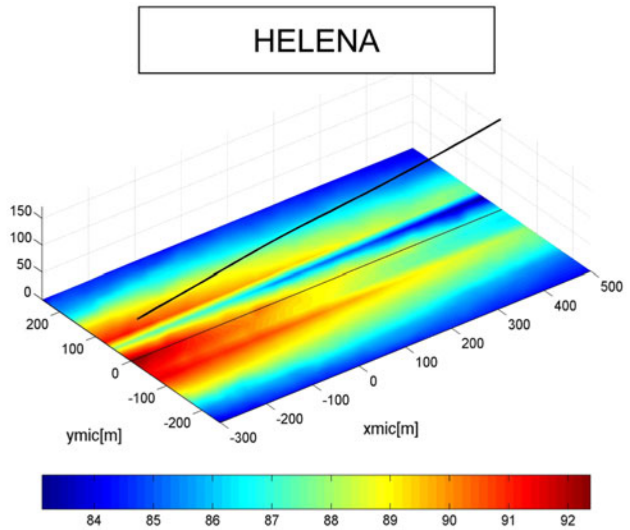

Fig. 10 On ground noise impact of approaching helicopter: HELENA computation (copyright Eurocopter)

wings, engine manufacturers, in-flight operation managers) and addresses each one of the three improvement axes. It sets quantified targets for acoustic and for greenhouse effect gases emissions, and encourages new technologies development to reach them (Fig. 11).

For helicopters, the technological improvement axes studied with Cleansky need to address the following:

- Drag and acoustic level reduction for blades with new shapes and new aerodynamic profiles.
- Fuselage and hub drag reduction by intensive use of computational fluid dynamics (CFD).
- Electrical systems generalization (instead of hydraulic systems) and a step to energy hybridization.
- The development of a diesel cycle engine, to replace turbines which of course have a better weight/power ratio, but a 30 to 40 % higher consumption.
- A materials definition and manufacturing processes favouring recycling and minimizing energy consumption in frameworks manufacturing.
- Flight trajectories minimising, depending on need, ground acoustic impact or consumption and associated flight control system laws.

Beyond European research, engine manufacturers invest in technological research complementary projects, like turbines consumption improvement (thanks to materials more temperature-resistant in high pressure turbine stages (Fig. 12) and flow monitoring in compressor blades to increase their rate) or their NO_x rejection (with vapor injection inside burning chamber to get closer to full burning), the ambitious target being to decrease between 15 and 25 % the consumption.

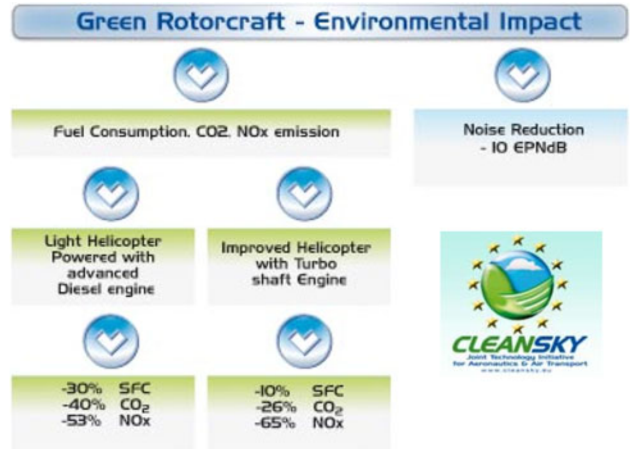

Fig. 11 Cleansky targets of emissions reduction [5]

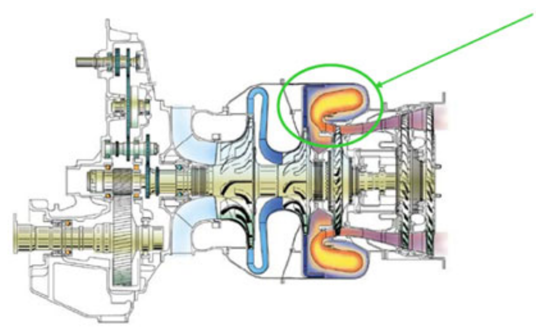

Fig. 12 Helicopter turbine sketch

On the same way, helicopter manufacturers study acoustic level and performance improvement of rotors, by developing smart rotors which adapt to their aerodynamic environment, fitted with active blade trailing edge flaps (Fig. 13), or with blade active twist modified with torsion induced by piezo-electric devices in blade structure.

6 The helicopter product full life cycle management

The above paragraphs have mainly emphasized on two representative axes of helicopter design and operation. These two axes are only a part, of course important, of helicopter full life cycle management. But environment protection also includes choice of cleaner elaboration and recyclable materials, as well as implementation of non-aggressive manufacturing processes with low energy needs. It moreover refers to the use of protecting environment maintenance methods and reduced global environmental impact during normal operational use: not only the helicopter operation itself but also the required ground installations.

In fact, the helicopter has the advantage of requiring small ground installations to operate, due to its flight and

Fig. 13 Blade with active flaps 'blue pulse' (copyright Eurocopter)

landing capability on punctual area: no need of road infrastructure requiring a lot of asphalt and other building materials the manufacturing and use of which are not very green; no need of large ground area that would condemn our green nature and its storing plants which transform and recycle solar energy and CO_2. These aspects must be part of helicopter industry global carbon balance roadmap, through metrics covering all industrial activities and services.

The international standard ISO 14001 for environment management, which European helicopter manufacturers respect, recognizes their efforts by demanding them to demonstrate that:

- They develop products in agreement with environmental rules and answering to customers needs.
- They apply a permanent environmental instinct during complete product life from design to recycling.
- They manufacture through clean processes.
- They encourage the product use for environment protection (for example using environmental procedures described in the flight manual).
- They propose maintenance that take care of environment.
- They estimate their product environmental performance by comparison to targets previously demonstrated to be reached.

Dangerousness and environment protection are assessed in comparison of European regulation "Registration, evaluation and authorization of chemicals" (REACH) which has two targets: protect human health and protect environment.

It draws up a permanently updated list, of chemical products (natural or by combinative processes) that are allowed, dangerous or forbidden.

It forces manufacturers to modify, adapt and transform their products to stay compliant. It relies on the safety-first principle, on transparent information and it has a legal character, so that it becomes mandatory and deterrent whatever being subsequent economical outcomes.

7 Conclusion

The uprising idea to consider sustaining development leads economical players, who want to keep their activity prosperous in the future, to study their impact on environment and combined energy aspects.

The helicopter community follows this tendency. Important efforts are being deployed to make the helicopter more 'friendly' that is to say more acceptable by general public as well as in terms of perceived acoustic levels than in terms of greenhouse effect gases emission.

But the dialog between on the one hand helicopter and regulation specialists and on the other hand general public, not aware of these subjects, is not easy and generates huge misunderstandings if not situations of conflict.

In order to have a better understanding between contributors, specialists and non-specialists, an approach has been launched, consisting in the proposal, at world wide level, to measure, with a six color level scaling label, two key parameters that are characteristic of helicopter activity: acoustic level and carbon dioxide emission.

Similarly to electrical appliances purchased in a supermarket, each one will see by quick glance which helicopter is more environmental friendly, and each one will easily value technological improvements made between a helicopter and another one.

As reported in the previous lines, two accurate metrics are proposed at world wide level for acoustic and carbon dioxide emission, with the hope for a quick convergence in their acceptance.

In addition, standards and regulations are available to partially take into account the product's environmental performance during its full life cycle (manufacturing, operational use, end of life and recycling).

The reader must have certainly noticed that A+, the best proposed level which is green colored, is reached by none among today helicopters and that is of course the challenge to be taken up: 'To greener helicopters'. Some manufacturers have already introduced in their global strategy 'the environmental friendly helicopter' as a new sale axis as well as performance, cost, safety or comfort.

This initiative should be greeted and strongly supported in the coming years.

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