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CLEAN SKY - The GREEN ROTORCRAFT Integrated Technology Demonstrator - STATE OF PLAY THREE YEARS AFTER KICK-OFF

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ABSTRACT

The "greening" of Air Traffic System is one of the main goals of the European Commission 7th Framework Programme for collaborative research in which a dedicate Joint Technology Initiative (JTI) has been launched. The Clean Sky JTI is focused on technology breakthroughs validation contributing to the achievement of the ACARE environmental goals i.e. 50% reduction of CO_2, 80% reduction of NO_x, 50% reduction of external noise within 2020 with respect to 2000. The "Clean Sky" JTI consists of six Integrated Technology Demonstrators, out of which one dedicated to rotorcraft. The Green RotorCraft ITD will deliver innovative rotor blades and engine installation for noise reduction, lower airframe drag, integration of diesel engine technology and advanced electrical systems for elimination of noxious hydraulic fluids and fuel consumption reduction. The programme has been launched mid 2008 and will extend until 2015. The paper aims to present the content of the technology research activities and to show the state of play after the completion of the third period (2010) in terms of technology selection and first preliminary results.

NOTATIONS

ACARE	Advisory Council for Aeronautical Research in Europe
ASD	Aeronautics, Space and Defence European Industries
ATM	Air Traffic Management
CFD	Computational Fluid Dynamics
CFP	Call For Proposals, from which new Partners are selected
CSJU	Clean Sky Joint Undertaking
ED	Eco-Design ITD
GRC	Green RotorCraft ITD
HITS	Highway In The Sky
ITD	Integrated Technology Demonstrator
JTI	Joint Technology Initiative
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances, Directive EC 1907/2006 entered into force on June 1st, 2007.
SAGE	Sustainable And Green Engines ITD
SESAR	Single European Sky ATM Research
SGO	Smart and Green Operations ITD
SRA	ACARE Strategic Research Agenda
TE	Technology Evaluator
TRL	Technology Readiness Level

BACKGROUND

The use of helicopters has been concentrated until now on activities such as medical evacuation, rescue, civil protection, aerial work and law enforcement and such operations are expected to grow sharply in the near future.
In addition, the rotorcraft traffic for passenger transport representing today only a marginal activity is expected to develop rapidly (2 to 3 fold increase in 2015-20 period). For example, helicopter shuttle operations from city heliports to airports, or even between cities without airports or connecting islands to mainland with limited ground infrastructure. In the meantime, thanks to their capability to operate independently from runways and higher speed compared to helicopters, tilt rotors are expected to play a key role as complement of turboprop airplanes feeding major airports with passengers starting from secondary ones.
As a consequence of such traffic growth, the rotorcraft contribution to environmental impact, negligible today, would become more significant in next decade unless a major initiative succeeds in keeping it under control. The

Green Rotorcraft ITD, a component of the Clean Sky initiative, together with other already launched technology programmes at European or national levels responds to the challenge of halving the specific impact of any rotorcraft operation on the environment. Among them it is worth mentioning some European programme launched in the 6th Framework Programme (FP6) the results of which will be raised to a higher maturity level within Clean Sky. In particular:

- FRIENDCOPTER, addressing noise abatement procedures, improved engine integration, active rotor blades with distributed actuation for lower noise and reduced power loss;
- OPTIMAL, addressing airport approach procedures specific to rotorcraft which are compatible with noise abatement and with integration in the general ATM;
- NICETRIP, addressing aerodynamic and aero-acoustic optimisation of the novel ERICA tilt rotor aircraft architecture to reduce noise impact and power demand in take-off and cruise configurations.

THE CLEAN SKY JTI

Joint Technology Initiatives are specific large scale research projects created by the European Commission within the 7th Framework Programme (FP7) in order to allow the achievement of ambitious and complex research goals. The Clean Sky Joint Technology Initiative (JTI) aims to develop and mature breakthrough 'clean technologies' for Air Transport. A Public Private Partnership between European Commission and aeronautical industry has been set up to pull together research and technology resources of the European Union in a coherent 7-year, 1.6 B€ programme contributing significantly to the 'greening' of aviation. The Clean Sky goal is to identify, develop and validate key technologies necessary to achieve major steps towards the ACARE environmental goals for 2020. Clean Sky activities are performed within six "Integrated Technology Demonstrators" (ITDs) and a "Technology Evaluator". The organisation is shown in Fig.1.
Three vehicle-based ITDs (vertically) will develop, deliver and integrate technologies into dedicated aircraft configurations.

The three other ITDs focus respectively on 'ecolonomic' life-cycle, propulsion, and systems. They will deliver technologies which can be integrated in various aircraft configurations by the vehicle ITDs.

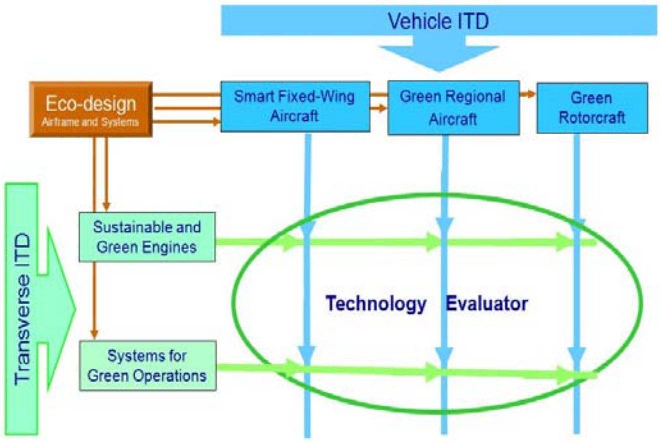

Fig. 1 – The Clean Sky JTI Organisation

THE GREEN ROTORCRAFT ITD

Objectives

The Green RotorCraft ITD (GRC-ITD) gathers and structures all activities concerned specifically with the integration of technologies and demonstration on rotorcraft platforms (helicopters, tilt-rotor aircraft) which can not be performed in platform-generic ITDs.

In line with the ACARE environmental objectives for 2020 (SRA2 addendum 2008) and the general Clean Sky objectives [1], the GRC top-level objectives are to:

- reduce CO_2 emission by 25 to 40% per mission (for rotorcraft powered respectively by turboshaft or diesel engines);
- reduce the noise perceived on ground by 10 EPNdB or halving the noise footprint area by 50%;
- ensure full compliance with the REACH directive which protects human health and environment from harmful chemical substances.

The status of the global helicopter fleet in the year 2000 constitutes the baseline against which achievements will be assessed. Progress toward these goals will result not only from GRC internal activities but also from the collaboration with the relevant cross-cutting activities in SAGE (turboshaft engine), SGO (electrical systems), and ED (eco-design).

Membership, partnership

The GRC activities are conducted by the ITD co-leaders AgustaWestland and Eurocopter, the Polish manufacturer PZL-Swidnik, the research institutes ONERA, DLR, CIRA, the equipment manufacturer SELEX S.I, and the cluster

IGOR constituted by SMEs, universities and laboratories: Airborne Composites B.V., Eurocarbon B.V., LMS International N.V., Microflown Technologies B.V., Micromega Dynamics s.a., Stichting Nationaal Lucht- en Ruimtevaart laboratorium, Technische Universiteit Delft and Universiteit Twente. GRC activities concerning integration of electrical systems are linked with SGO projects and also involve three SGO members: Liebherr-Aerospace Lindenberg GmbH; Thales Avionics Electrical Systems and Hispano-Suiza SA. Since 2010, numerous additional partners (currently more than 40) who perform specific work packages are supporting GRC after being selected through open CFPs.

GRC organisation

The design of all components and systems which directly or indirectly impact the helicopter CO_2 and/or noise emissions needs to be reconsidered in order to reach the ambitious GRC goals. Il is reminded here that emitted CO_2 and burnt fuel are quantities rigidly linked by a constant stoichiometric ratio of 3.15 kg of CO_2 per kg of kerosene. For all practical purpose, reducing the CO_2 emission consequently boils down to minimising the fuel burn.

The GRC upper level work packages or 'subprojects' address respectively: the main rotor blades (GRC1), the airframe aerodynamic drag (GRC2), the on-board electrical systems (GRC3), installation of a diesel engine (GRC4), flight trajectories (GRC5), specific eco-design demonstrators (GRC6). In the last subproject (GRC7), all technical results are synthesized and integrated into conceptual rotorcraft models delivered to TE for assessment of overall environmental benefits.

Rough orders of magnitude of gains expected from individual components along with the rationale for their combination in overall environmental benefits are shown in Fig. 2. Beside the direct effects, particular attention is devoted to weight changes which impact dramatically both fuel consumption and noise emission.

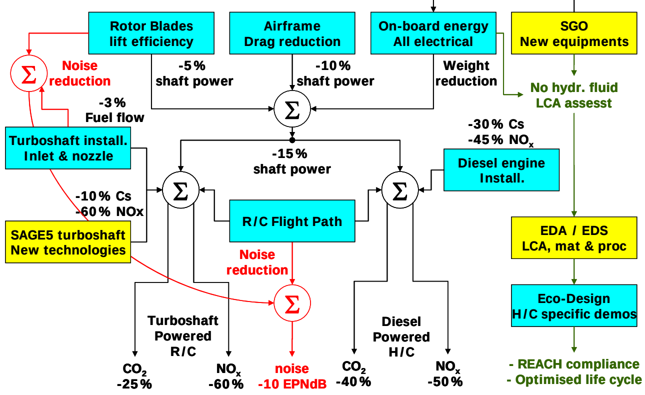

Fig. 2 - Contribution to environmental benefits

Time line

All subprojects (except GRC6) started mid 2008 with background reviews and a first down selection of candidate technologies. The preliminary studies and selection phase are being closed with concept design reviews and some preliminary design reviews held in 2011. The development of critical components or downscaled models is initiated and will be completed mostly by 2013. The manufacturing and assembly of demonstrators and final tests are scheduled from 2014 to 2015.

The technology developments are monitored in terms of risk management and of technology readiness level, with a TRL [2] ranging from 2 to 4 at GRC start up to 5 or 6 targeted at demonstration completion.

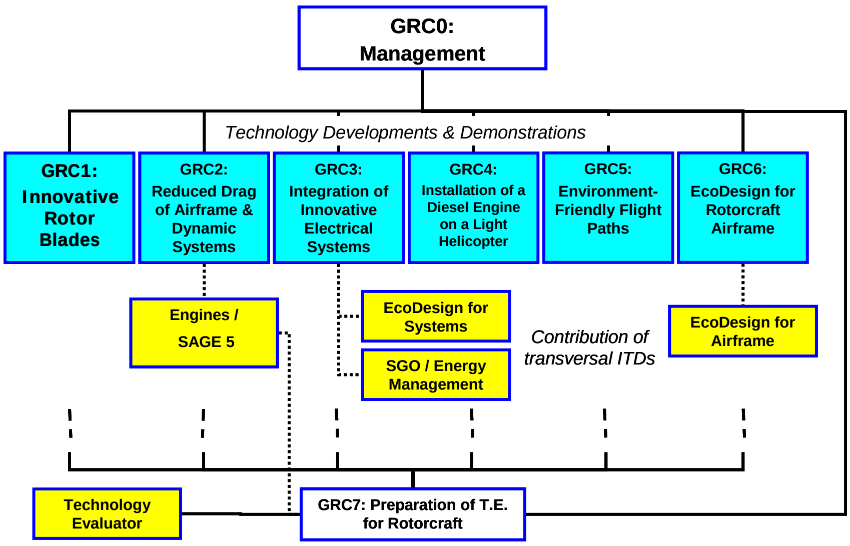

Fig. 3 - GRC top level Work Breakdown Structure

INNOVATIVE ROTOR BLADES (GRC1)

Challenges

The main rotor of a helicopter is both the main user of power (and hence fuel), and the main source of intrusive noise. Working directly to improve the efficiency and reduce the noise of the main rotor is a highly effective way of reducing fuel usage, CO_2 and NO_x emissions, and rotorcraft generated noise levels.

Technology streams

The scope of this subproject is the development and assessment of active and passive technologies based on a two streams strategy. The first one concerns the continuation of the research activities performed within the framework of the FP6 FRIENDCOPTER Integrated Project on active twist technology and the second one based on variation of rotor speed, optimum planform and active rotor system preserving rotor aerodynamic performance and dynamic attributes to maintain stall envelope and reduce vibration.

Active Twist

It concerns the development of a full scale, active twist blade segment based on integrated piezoelectric actuators (Fig. 4) to allow the blade shape to be changed in flight to improve performance and/or reduce rotor generated noise. Analysis will be performed to assess future exploitation challenges, benefits in line with GRC1 objectives and airworthiness / safety evaluation. The expected TRL level at the end is planned to be 4.

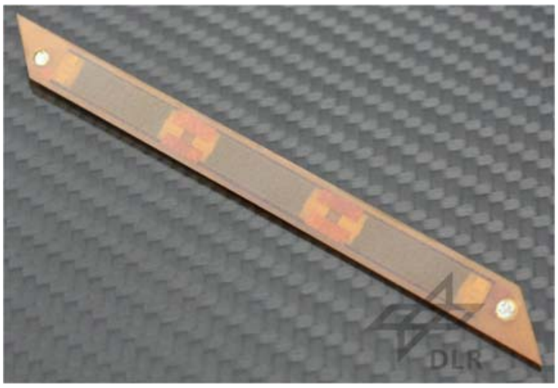

Fig. 4 - Piezoelectric actuators for blade twist

Active Gurney Flap

This dynamic blade control surface implements the same aerodynamic concept as steady Gurney flaps used on non rotating parts of some helicopters and airplanes [3]. It will be thoroughly tested in 2D wind tunnel and new CFD modelling techniques have been developed to study the operation and performance (see Fig. 5). An active Gurney flap system is under development for a full scale main rotor blade and additional partners have been selected to design, manufacture and supply the actuation systems required for model testing and at full scale on a whirl tower [4].

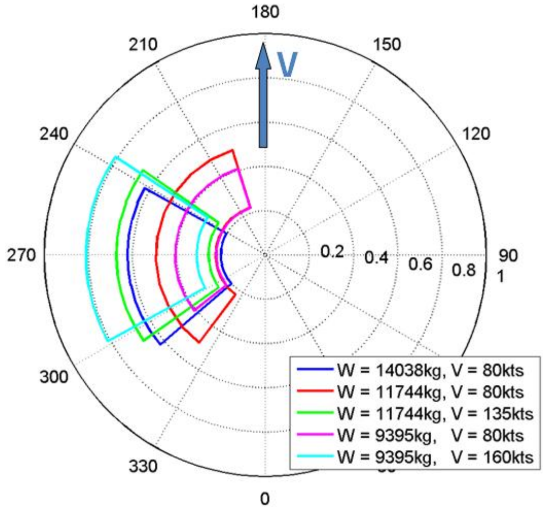

Fig. 5 - Active Gurney Flap – example of performance assessment

At the end of the program TRL 5 is expected to be achieved.

Passive Rotor Optimisation

This development is based on the use of state of the art, multi-objective, genetic algorithms to assess all possible combinations of blade chord and twist distribution and additional blade features e.g. anhedral (Fig. 6). An optimised full-scale blade aiming to maximise performance and minimise noise will be tested on a whirl tower.

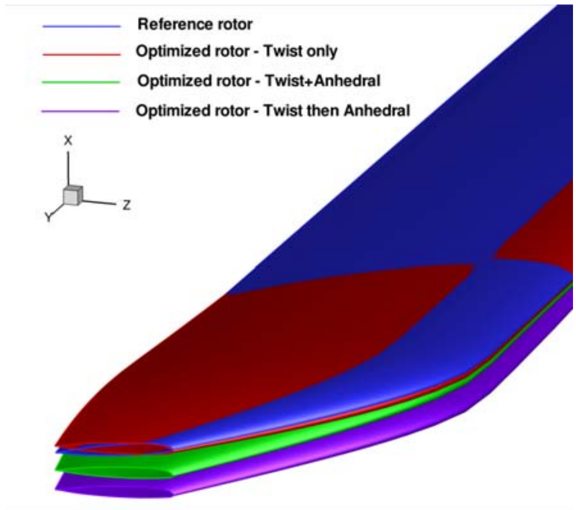

Fig. 6 - Passive Rotor Optimisation (example)

Expected benefits

Current gain targets for rotor blades are -8% power in hover condition, -3% power in cruise, and -6dB in approach.

REDUCED DRAG OF AIRFRAME & NON LIFTING ROTATING PARTS (GRC2)

Challenges

The power required to fly a helicopter in forward flight, and consequently the fuel burn and CO_2 emissions are strongly dependent on the design of its airframe and of non-lifting rotating parts such as the main and tail rotor shaft, control system and hub. These components determine the aerodynamic drag and also the download in the nose-down flight attitude typical for helicopers in cruise flight. A preliminary review confirmed that significant aerodynamic gains could possibly be obtained by:

- Reducing the main rotor hub drag e.g. by means of optimised hub caps and pylon fairings;
- Delaying flow separation on the aft part of blunt fuselage for helicopters equipped with rear access doors, by means of passive or active flow control devices;
- Reducing the tail unit size thanks to optimised design and additional control surfaces.

In addition to conventional helicopter configurations, similar design challenges are adressing tilt-rotor aircraft, especially the ERICA concept investigated in earlier FP5 and FP6 projects including NICETRIP.

The fuel consumption of turboshaft engines depends not only on the output power but also on the aerodynamic performance of air inlets and to a lesser extent, of exhaust nozzles. Engine performance loss as compared to the ground bench reference may be quite substantial, in the order of 5% or more on some helicopters. Some earlier research on the subject was conducted as part of the FP6 Friendcopter which included a re-design of EC135 air inlets. The engine noise could be reduced by 10 dB but the installation loss remained high. Within the GRC2 subproject, this research is further pursued for the twin engine light helicopter and extended to heavy helicopters which feature a different architecture with engines located ahead of the main gearbox. Engine integration in a tilt rotor nacelle is also addressed.

Technology streams

Several complementary technology streams were selected after the initial technology review and corresponding technologies are under development, as described here after.

Rotor hub cap optimisation

The hub cap covering the rotor head allows significantly reducing the drag of hub mechanical parts and mitigate tail shake problems.

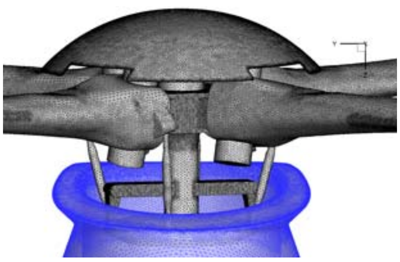

Fig. 7 - Unstructured grid for EC135 main rotor hub

Current optimisation studies which rely on most recent CFD tools focus on three different hub configurations, each of them relevant to a specific weight class. Impact on the full aircraft behaviour and performance benefits will be checked with wind tunnel tests and flight demonstrators (target: TRL 6). The complexity of aerodynamic grids for hub mechanical parts is illustrated on. Two consortia of partners (CARD led by University of Glasgow; HELIDES led by CFD software GmbH) contribute to this work.

Passive and active flow control devices

Passive and active vortex generators are investigated as means to delay the flow separation on the aft part of blunt fuselages. Testing is planned using wind tunnel models (target: TRL 4).

Separation on blunt fuselages can alternatively be controlled by air jets (synthetic or pulsed jets). This advanced technology is investigated by numerical simulation and wind tunnel tests (target: TRL 4).

Active empennage

The specifications are derived from full helicopter dynamic simulation and system performance will be checked in the wind tunnel on a 1:4 scale GOAHEAD project tail unit.

Optimised helicopter geometry

The possibility of combining drag reduction technologies to produce a range of optimised helicopter fuselages tailored for different aircraft sizes and architectures is addressed using CFD (three configurations). The validation is performed in the wind tunnel for a light helicopter - the ADHeRo partner University of Munich contributes to this work – and for a heavy helicopter platform whose baseline design is close to the GOAHEAD model (target: TRL 4).

Optimised geometry for tilt rotor A/C

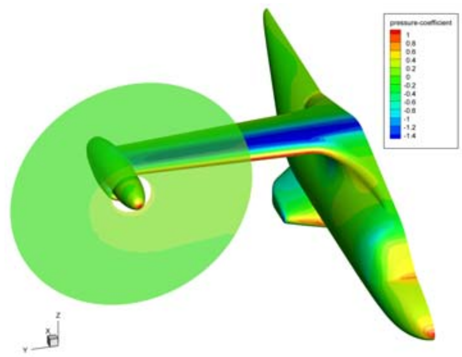

Fig. 8 - ERICA cruise flight CFD computation (CODE-Tilt)

Similar work is planned for the ERICA tilt rotor based on the NICETRIP reference (targeting TRL 4). The CODE-Tilt Partner Consortium led by University of Padova contributes to this work.

Optimised engine inlet & exhaust for helicopters

Enhanced engine installations for improved performance and lower noise are designed for two configurations: light and heavy helicopters. Both wind tunnel and flight tests will validate the solutions (target: TRL 6). The Partner

Consortium HEAVYcOPTeR led by University of Padova contributes to this work.

Optimised engine inlet and exhaust for tilt rotor

A similar effort is conducted in collaboration with the TILTOp Partner Consortium (led by University of Padova) addressing the integration of the engine in the ERICA nacelle, leading to validation by wind tunnel tests (target: TRL 4).

Expected benefits

Depending on the rotorcraft configuration and weight class the aerodynamic cumulated drag benefits are currently estimated in the range 10-15% which would translate into a 4 to 5% fuel consumption reduction for the same payload and mission. The activity performed in GRC2 is supporting the derivation of conceptual rotorcraft helicopter models that will be used by TE for environmental assessment. The airframe aerodynamic data included in these models will be regularly updated by using test results in order to reduce the uncertainty range.

INTEGRATION OF INNOVATIVE ELECTRICAL SYSTEMS (GRC3)

Challenges

The eventual elimination of noxious hydraulic fluids and the reduction of CO_2 emission through efficiency and weight optimisation of on-board energy systems constitute the two crucial objectives pursued in this subproject. The emerging high performance electrical systems and equipements enable a range of new solutions but need to be adapted to the specific helicopter constraints.

Technology streams

Electrical system architecture, electrical network, power management

The required functions and load profiles are established at vehicle level for different helicopter classes. The technology reference for these classes is defined in line with the baseline helicopter models required by the TE.

The key architectural options including the corresponding electrical network are selected according to performance metrics e.g. weight and engine power off-takes which depend on the combination of individual subsystems performance and on power management strategy. These studies are progressing together with the development of subsystems that are reviewed here below. However some clear conclusions have already been reached such as the selection of the 270 VDC standard for medium and heavy helicopters as exemplified on Fig.8.

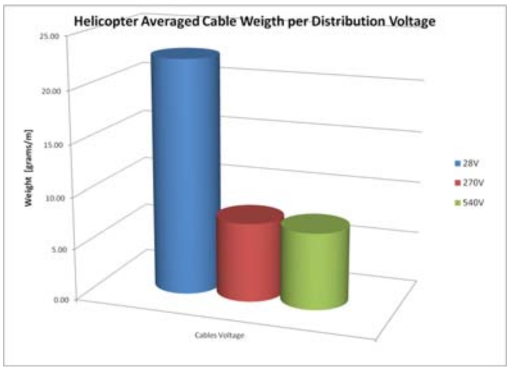

Fig. 8 - Cable weight reduction with 270 & 540 VDC network standards

Brushless starter/generator for turboshaft engine

For small engines, the 28 VDC S/G will remain a good option combined with low voltage batteries but current S/Gs feature poor energy efficiency and require substantial maintenance. A prototype brushless machine with the converter to match a high voltage network for helicopters was specified in GRC3 and is under development and test in the SGO ITD .

Energy recovery, conversion and storage systems

Prototype systems allowing waste energy recovery from several sources are developed in close collaboration with Partners selected from CFPs:

- Heat recovery from engine nozzles (Partner PARS MAKINA) ;
- Energy storage system (partnership being established).

These systems will be tested on ground rigs. Fig.9 illustrates the integration of recovery systems and conversion and storage systems in the electrical architecture.

Electro Mechanical Actuation for landing gear

This system is aimed at providing an alternative solution for taxiing a helicopter without rotor spinning (safety, fuel saving) and without hydraulic power. To be developed and tested in close collaboration with Partners being selected through a CFP.

Electro Mechanical Actuation for primary flight control

The eventual removal of hydraulic systems requires replacement of rotor boosters with all electric actuators. Two actuators are under development with different specifications: one for the light helicopter segment, the other for the heavy/medium. The first one will be tested on a helicopter on ground. The second one developed in the SGO ITD will be tested on the common Electrical Iron Bird (Eco Design for Systems, part of the ED-ITD),.

Power Supply

Some rotor active control systems include piezoceramic actuators that require a dedicated power supply owing to their peculiar high voltage and reactive impedance characteristics. The development of a flight-worthy and compact supply equipment aims at enabling the usage of future active control systems. The PPSMPAB Partner Consortium led by CEDRAT Technologies contributes to this work.

Electric Tail Rotor

This will replace mechanical tail rotor drive shafts, gearboxes and couplings. Key potential advantages include reduced drive train vibration, fatigue and noise, and overall weight savings and improved through-life maintenance. A motor for a conventional tail rotor is developed for ground demonstration whilst the adaptation to Fenestron antitorque systems is limited to pre-project studies.

Expected benefits

The benefits in terms of weight and energy savings can be evaluated only at whole vehicle and mission levels. They can be estimated only after a first round of complete simulations that will be performed by the TE with conceptual helicopter models. The electrical system performance data gathered from individual equipment and subsystem tests will be used to refine models. The final integration and demonstration tests performed on the common EDS Electrical Iron Bird, combining many prototype subsystems, are essential to establish reliable system level performance data.

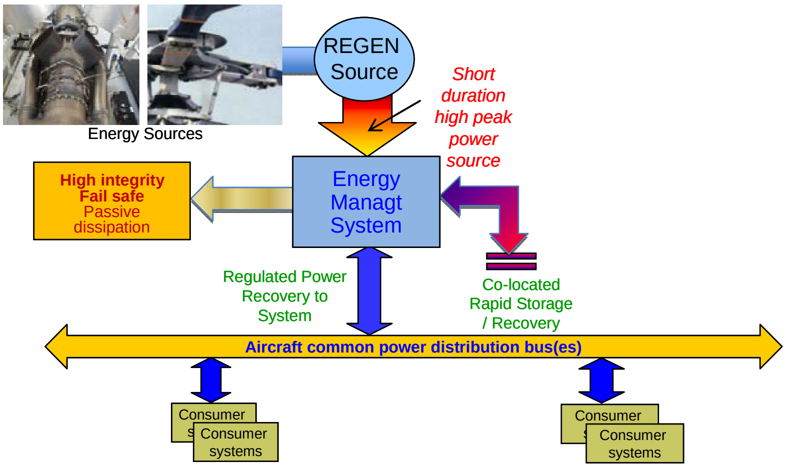

Fig. 9 - Architecture of energy recovery systems

INSTALLATION OF A DIESEL ENGINE ON A LIGHT HELICOPTER

Challenges

Modern diesel engines for automobiles and trucks feature very low fuel consumption and gas emissions. High compression ratio with turbocharging and intercooling, high pressure direct injection with common rail, pilot injection with digital control unit are essential enabling technologies implemented in order to obtain such excellent performance improvements. Moreover, the power-to-weight ratio of diesel engines is steadily increasing with the development of those news technologies.

This triggered successful research and development efforts that lead to substituting modern diesel engines to obsolescent gasoline fueled engines on some general aviation aircraft. However, the current performance and power-to-weight ratio of current EASA certified diesel engines still fall short of what is needed for efficient helicopter flight.

In this context, the GRC4 project is pursuing a two fold objective: firstly to modify, assemble and test a flight-worthy helicopter with a light diesel engine in order to explore the technical difficulties and validate the foreseen benefits in terms of gas emissions; secondly to define further breakthroughs and innovations for the next helicopter generation which would feature very advanced diesel engine along with a vehicle fully optimised for that type of powerplant. Fig. 10 shows the maturity path of such complementary streams.

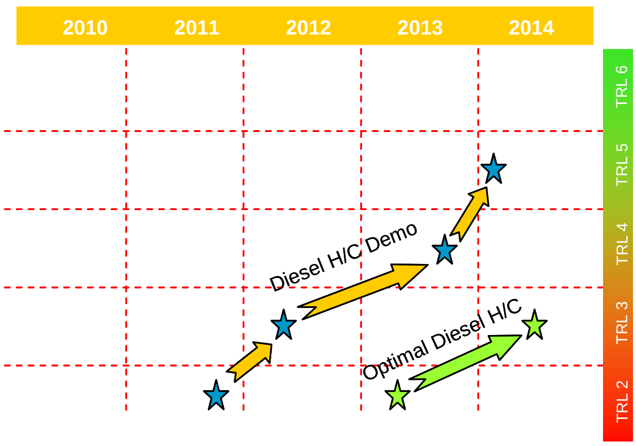

Fig. 10 – TRL Path for the two diesel Technology Streams.

Technology streams

Optimal diesel powered helicopter

The engine for the optimal helicopter architecture is required to feature low specific fuel consumption and very low weight-to-power ratio which only breakthrough technologies will permit to reach. Different advanced engine concept and architectures are considered and compared.

Concept and feasibility assessments are based on analysis and validation of engine integration studies concerning cooling, vibration reduction, mechanical installation, controls and avionics, etc.

This work is conducted in close collaboration with the DELILAH Partner Consortium led by the Lublin University of Technology.

Diesel powered helicopter demonstrator

In order to test a flight-worthy prototype in 2014, an existing helicopter has to be adapted with only limited modifications. The EC120 airframe was chosen since its light weight requires a 330 kW rated engine only.

Preliminary performance studies indicated that the payload-range domain is enlarged w.r.t. the turbine powered reference version provided that the weight-to-power ratio (including power off-takes for cooling and auxiliary engine functions) does not exceed 0.8 kg/kW and specific fuel consumption is less than 240 g/kWh. No diesel engine in this power range currently offers the required combination of low fuel consumption, high power density and reliability matching helicopter specifications [5].

The HIPE-AE440 Partner Consortium (AustroEngine, TEOS) is tasked with the design and prototyping of the engine meeting these specifications, based on their respective experience with general aviation and racing car engines.

Fig. 11 depicts the preliminary engine architecture and shows how it matches the required volume and interfaces with the EC120 airframe.

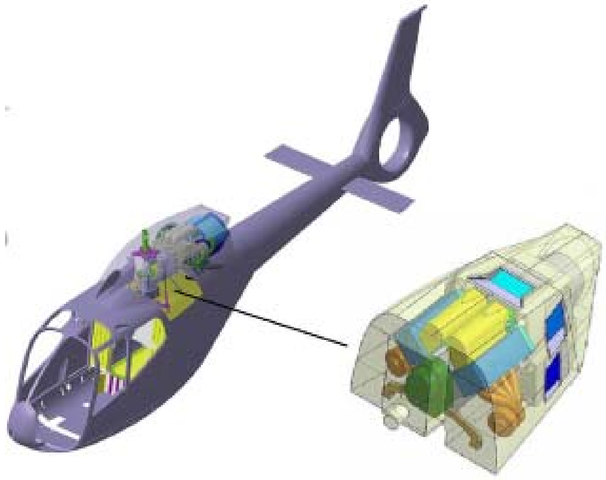

Fig.11- Preliminary demonstrator engine EC120 installation layout

Expected benefits

With the demonstrator engine implementing mature technologies installed on an existing helicopter, the fuel consumption will be reduced by at least 30% over complete missions.

With helicopters of the next generation specifically optimised for advanced diesel engine technologies incorporating exhaust depolluting systems, the gain in fuel consumption and CO_2 emission is foreseen to exceed 40% whilst reducing NO_x emissions by 50%.

ENVIRONMENT FRIENDLY FLIGHT PATH

Challenges

Fast growth of rotorcraft operations to and from airports will generate an increase in gas emissions and footprint noise with helicopters following departure/approach routes designed for fixed wing aircraft. A significant fuel consumption reduction can be achieved with shorter IFR routes not interfering with aircraft traffic and taking advantage of the rotorcraft intrinsic agility. Based on activities already performed in the OPTIMAL and FRIENDCOPTER Integrated Projects, such flight procedures will be further developed.

Technology streams

GRC5 addresses the areas of polluting gaseous emissions (NO_x, CO_2) produced by fuel combustion and of noise generated mainly by rotor blades, engines and transmission gears.

Gaseous emissions

Fuel consumption, and consequently CO_2 and NO_x production, is strongly dependent on flight conditions (altitude, speed, air temperature). For such reason, the flight path is a key parameter for reducing emissions. In order to identify the optimal mission profiles minimising pollutants an appropriate database collecting all the significant flight parameters (speed, engine torque, RPM vs. NO_x and CO_2 emissions) will be created.

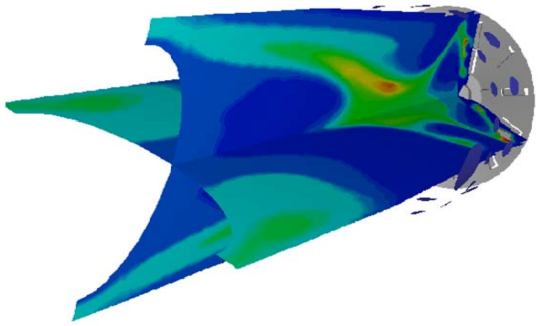

Fig. 12 - Example of numerical evaluation of pollutants

Partners Politecnico di Milano and Centro Combustione Ambiente have been selected to support activities respectively on predictive numerical methodologies (Fig. 12) and experimental measurements. A dedicated flight test campaign to collect pollutant data is scheduled end of 2011.

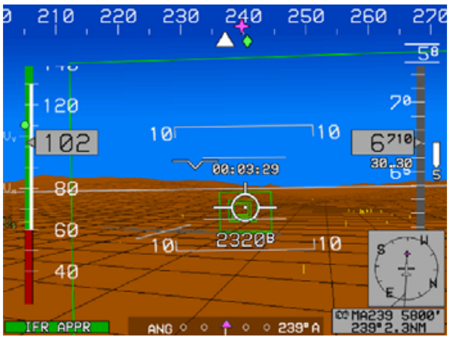

Fig. 13 – HITS Runway Depiction

Noise footprint

Operations within densely populated areas (hospitals, vertiports) require the development of new low-noise procedures, to minimise noise perceived on ground during departure, low level flight and approach with variable airspeed and rate of climb/descent profiles. High vertical precision satellite navigation (EGNOS, Galileo) enables such new procedures. Furthermore dedicated software tools like HELENA code developed in the FRIENDCOPTER project and other specific software developed within GRC5 will support the prediction of noise footprint and allow the optimisation of flight procedures. On-board system will be developed to reduce pilot workload for managing low-noise flight paths (an example is depicted in Fig. 13). The GARDEN partner consortium has been selected to define and deliver air navigation requirements for the design of low noise helicopter-specific IFR procedures, ensuring compliance with ICAO criteria on heliports design. A measurement campaign was performed in 2010 for the noise characterisation of the EC155 to develop low-noise procedures (Fig. 14). The new flight procedures resulting from GRC5 will consider the ATM concepts developed in SESAR.

Expected benefits

The target for pollution reduction based on the GRC5 optimised flight paths is 6% of fuel consumption, while the new low-noise procedures developed in GRC5 contribute to reducing noise perceived by 5 EPN dB.

Fig. 14 - EC155 Flight Test for Noise Measurement

ECO-DESIGN DEMONSTRATORS FOR ROTORCRAFT

Challenges

Eco-Design technological objectives directly derive from the ACARE goal: "To make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products". More specifically the goal is twofold:

- Designing equipped airframe with a minimum of inputs (raw materials, energy, water,…), outputs and nuisances (energy /warming, liquid and gaseous effluents, solid waste, etc) all along the life cycle;
- Suppressing non-renewable and/or noxious substances during operations and maintenance, while keeping the aircraft at the appropriate level of quality and performance.

In the EDA (Eco-Design for Airframe) subproject of the ED-ITD, Life Cycle Analysis (LCA) tools suited to aeronautical industry are developed and a whole range of new materials and manufacturing processes are screened and experimented. EDA also integrate some demonstrators submitted to tests in all phases of the life cycle: manufacturing, maintenance and disposal. Nevertheless these EDA demonstrators address only conventional turbojet airframes. In order to investigate the difficulties associated with helicopter specific components, the GRC6 subproject provides for additional demonstrators, as briefly outlined here after.

Demonstrators

Composite thermoplastic structures

Two demonstrators will be elaborated and tested:

- A helicopter door;
- A tail cone.

Helicopter doors which equip non pressurized cabins feature very large windows and need to match conflicting requirements of very light construction, high stiffness, and low acoustic transmissivity. The tail cone is a load carrying structure which transfers tail forces to the central fuselage and supports the tail rotor transmission shaft.

Both demonstrators are to be designed and manufactured by using 'ecolonomic' materials and processes to achieve cost and weight savings. Fibre reinforced thermoplastic materials are considered most appropriate to reach these objectives. The engineering approach relies on integrated design, reduced number of manufacturing steps, fully recyclable products and ease to dismantle for recycling.

The door demonstrator will be developed in close collaboration with the DEfcodoor Partner Consortium led by the University of Munich. On the other hand, the Partner Centro di Progettazione, Design & Tecnologie dei materiali (ECO-Fairs project) will provide design and technological support for the structural components development.

Mechanical & transmission components

The demonstrators to be elaborated and tested incorporate the following parts:

- Gear box housings (MGB, IGB, TGB);
- Transmission shafts (main rotor, intermediate).

These demonstrators will ban the use of materials and processes appearing in the ASD list of "Priority Declarable Substances" (PDSL, implementing the REACH regulation) e.g. Cadmium/CrVI for protection of alloy steel components, strontium, barium, etc. The envisaged solutions are based on: Keronite, Microarc, and HAE for magnesium protection, CrVI free chemical surface treatment for oil duct protection inside gearboxes, CrVI free temporary protection for intermediate mechanical operations. Zinc-Nickel (with CrVI free post treatments) plating for steel parts and studs, carburizing reserve to replace copper, new anodizing process for aluminium (or sulphuric acid anodising) , new "green" paints (chromate free primer), replacement of "Mastinox " by "Molycote DX " and replacement of some metallic parts by long fibre thermoplastic composites. Production and repair technologies should feature a low energy consumption and low emission of Volatile Organic Components (VOC).

Status

The GRC6 subproject was launched beginning 2011. The technical materials and processes and LCA tools will be based on those developed in the EDA subproject and on substantial background gained in other projects beside Clean Sky. The technology developments aim at a TRL5 maturity level in 2014, to be reach through the followings steps:

- Design modifications, including LCA ;
- Testing of selected components (coupons) ;
- Prototype manufacturing and protection ;
- Testing of prototype in a representative environment
- Dismantling and recycling demonstration on samples
- Evaluation of results and conclusion

All end-of-life demonstrations will be carried out by Partners to be selected from CFPs. Feedback from GRC6 to EDA will support evaluation of EcoDesign results by the TE.

ROTORCRAFT INPUTS FOR THE TECHNOLOGY EVALUATOR

Challenges

The "Technology Evaluator for Rotorcraft", GRC7, provides the interface between the Green RotorCraft and the Technology Evaluator. Its main goal is to deliver to the TE all information, advice and data needed to calculate the rotorcraft environmental impact and to assess the benefits obtained through the technologies developed. In this supporting role, GRC7 endeavours to ensure that the uniqueness of rotorcraft operations is duly taken into account in the comprehensive TE picture.

Modelling activities

GRC7 activities are focused on the preparation of the rotorcraft simulation framework integrating several mathematical models. The following areas have been considered (with the selected software codes in brackets): flight mechanics (EUROPA), noise (HELENA), engine fuel

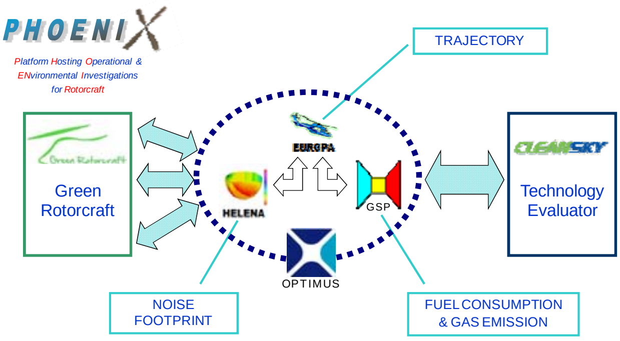

Fig. 15 - The Phoenix Platform

consumption and gas emissions (GSP). In a second step, it is planned to integrate turboshaft engine benefits as resulting from the SAGE5 project. All software components have been federated by using the OPTIMUS toolkit (provided by LMS), in a global simulation platform dubbed PHOENIX (Fig. 15) that is coupled to the TE ones.

Mathematical models representing generic rotorcraft for the following weight classes are prepared: Single Engine Light (SEL ≤ 4 tons), Twin Engine Light (TEL ≤ 4 tons), Twin Engine Medium (4 to 8 tons), Twin Engine Heavy (TEH > 8 tons), Tiltrotor A/C, Diesel-powered Light Helicopter. Typical helicopter missions are modelling the full range of actual operations. Two worldwide rotorcraft fleets are specified, one for the year 2000 and the other for 2020 and beyond (based on commercial forecast). Environmental benefits for the future fleet will be assessed using such conceptual rotorcraft models that integrate the new systems and technologies developed in Clean Sky.

Status

A first example of the PHOENIX application, coupled with the IESTA simulation platform (ONERA) has been performed for typical police missions on Amsterdam, based on preliminany models. Figure 16 shows simulated noise footprints comparing a baseline TEL (year 2000) and the conceptual 2020+ one.

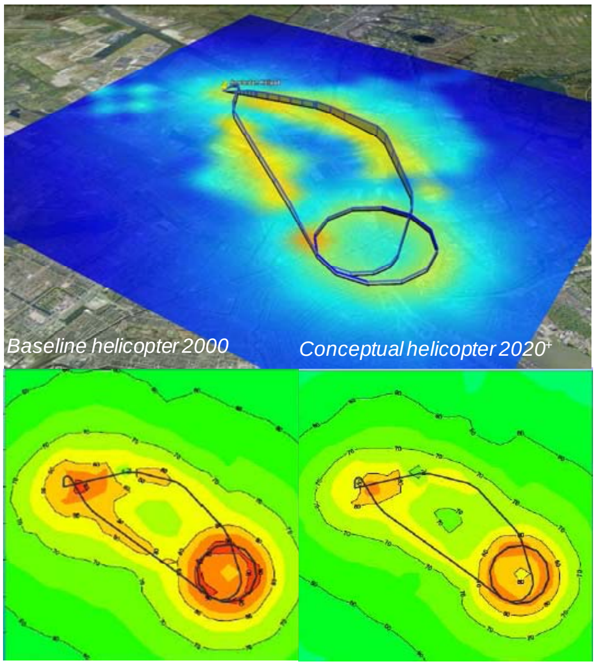

Figure 16 - Mission profiles simulation performed with coupled PHOENIX-IESTA platforms – noise footprint

CONCLUDING REMARKS, PERSPECTIVES

The Green RotorCraft Integrated Technology Demonstrator, part of the FP7 Clean Sky Joint Technology Initiative, is contributing to the reduction of environmental impact of aviation by developing breakthrough 'clean technologies' that will produce crucial benefits as compared to the ambitious ACARE objectives for 2020. At the end of the third period (2010) the GRC technology streams have been identified together with a measure of their potential benefits, for all the six technological areas addressed. Demonstration plan has been consolidated and TRL targets defined, ranging from 4 to 6.

Besides, the simulation PHOENIX platform has been setup and preliminary tests performed in conjunction with the TE aiming to evaluate the environmental benefits produced by technologies relevant to rotorcraft.

The conceptual models elaborated for the TE by European helicopter manufacturers are meant to prefigure the potential exploitation of Clean Sky results on future helicopter and tiltrotor products in a mid term perspective.

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REFERENCES

[1] CSJU publication: Clean Sky at a Glance - Bringing Sustainable Air Transport Closer, www.cleansky.eu, June 2011

[2] Mankins, John C.: Technology Readiness Levels - A White Paper, NASA Office of Space Access and Technology, April 1995

[3] Liebeck, Robert H.: Design of Subsonic Airfoils for High Lift. J. Aircr., vol. 15, no. 9, Sept. 1978, pp. 547-561

[4] J. Wang, Innovative Rotor Blades, Clean Sky Airframers Round Table, Int'l Paris Air Show, www.cleansky.eu, June 2011

[5] Y. Favennec, Light Helicopter Powered with a Diesel Engine, Clean Sky Airframers Round Table, Int'l Paris Air Show, www.cleansky.eu, June 2011