NACRE novel aircraft concepts

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NOMENCLATURE

ACARE	Advisory Council for Aeronautical Research in Europe
CO_2	carbon dioxide
EC	European Commission
EU	European Union
EEFAE	Efficient Environmental Friendly Aero Engine (FP5 project)
FP5	Fifth Framework Programme of the European Commission
FP6	Sixth Framework Programme of the European Commission
NACRE	New Aircraft Concepts Research
NEFA	New Empennage for Aircraft (FP5 project)
NEXUS	Unconventional Aerodynamics (UK nationally funded project)
R&T	research and technology
ROSAS	Research On Silent Aircraft concepts (FP5 project)
SILENCE(R)	Significantly Lower Community exposure to aircraft noise (FP5 project)
SFB	Simple Flying Bus
TELFONA	Testing for Laminar Flow on New Aircraft (FP6 2nd Call project)
VELA	Very Efficient and Large Aircraft (FP5 project)
VITAL	enVIronmenTALly friendly aero engine
WP	work package

ABSTRACT

Commercial transport aircraft developed today are defined to balance all requirements foreseen for the short or medium term. Best engineering knowledge as much as minimum business risks consistently lead to the so-called 'classic' aircraft configuration. This balanced approach is efficient but can also inhibit innovative practices.

Ensuring a sustainable growth in the aviation sector may require radical changes in the way we design and operate aircraft. Started in April 2005, NACRE is a four-year European research and technology integrated project, partly funded by the European Community under the Sixth Framework Programme, which aims at integrating and validating technologies that will enable the potential of new aircraft concepts to be assessed.

In order to explore the most relevant capabilities and meet the widest range of challenges, the NACRE R&T project has identified a set of concepts tailored to address specific subsets of design drivers:

- The Pro-Green aircraft concepts putting a major emphasis on the reduction of environmental impact of air travel;
- The Passenger-driven Aircraft concepts aiming at optimised payload and appreciable quality of future aircraft for the end users;
- The Simple Flying Bus, which puts the biggest emphasis on low manufacturing costs and minimum cost of ownership.

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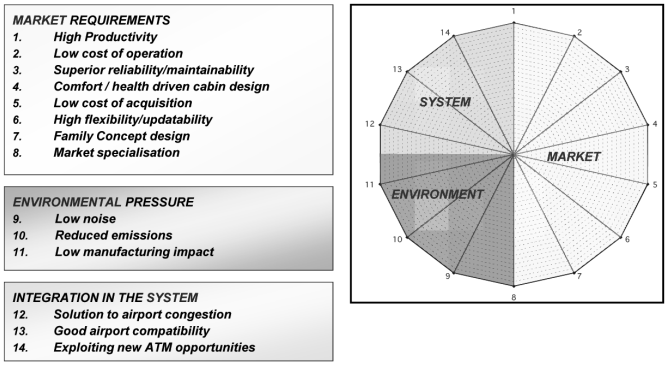


Figure 1. Key driving factors for the future air transport system.

Irrespective of what final future product configurations might ever look like, the NACRE aircraft concepts act as basic vectors, encompassing all the expected capability developments. The general project objectives are thus to use these concepts in order to:

- Explore alternative routes for the major aircraft components (fuselage, wing, engine integration) better suited to their specific targets and which would have been rejected in a balanced approach;
- Provide better answers to the full range of requirements by developing and, in some cases, validating the associated envelope of innovative component designs and associated technologies.

NACRE is by essence a focused multidisciplinary approach. It does not concentrate on one specific aircraft concept, but it is aimed at developing solutions at a generic aircraft component level, which will enable the results to be applicable for a range of new aircraft concepts. For each of the major aircraft components, the multidisciplinary investigations will require an exploration of the different associated aspects of aerodynamics, materials, structure, engines and systems with the goal of setting the standards in future aircraft design, thus ensuring improved quality and affordability, whilst meeting the strengthening environmental constraints (emissions and noise), with a vision towards improving significantly the global efficiency of the air transport system.

1.0 INTRODUCTION

Published in January 2001, the well-known report *European Aeronautics – a vision for 2020*[1] builds upon the achievements of commercial aircraft of past decades to outline five major challenges with associated qualitative and quantitative goals. It thus provides the key drivers for responding to the anticipated society's needs. After careful analysis of the challenges ahead, Airbus has implemented this vision by selecting typical alternatives to the classic aircraft configuration, designed to drive innovation in specific fields of endeavour.

This paper provides a synthesis of the motivation at the origin of the NACRE European integrated project and of the implementation of the project. The NACRE acronym stands for New Aircraft Concepts Research, and this paper also offers a broad outline of the work carried out within the first work package called 'Novel Aircraft Concepts'.

There are three other technical workpackages, which cover the actual detailed aspects of the technologies and concepts that NACRE aims to develop and assess at all levels, ranging from specific discipline levels (aerodynamics, handling qualities, acoustics, structures, systems and cabin, etc.) to individual component level and overall aircraft level.

By thinking outside the box, NACRE aims to develop key technologies, design tools and processes as enablers for novel aircraft concepts and configurations. It addresses three of the ambitious ACARE long-term challenges of quality and affordability, environment, and efficiency of the air transport system:

- Quality/comfort and efficiency: +15/20% volume improvement per passenger at same aircraft efficiency and enhanced services, way we operate aircraft, maintenance and reliability;
- Affordability: –15% of aircraft economics and costs of operation to reduce fares finally for the end-users;
- Environment: Noise: –10dB per operation; Fuel burn: –25% (fuel kg/seat/km); the ACARE challenge of 50% is shared with other stakeholders.

2.0 APPROACH AND IMPLEMENTATION

The focus of this investigation was set on capability development, moving away from usual development constraints and allowing step changes to be considered in many fields. This stands as a major decision to allow broadness of innovation to expand.

Understanding the challenges was the first step in setting up NACRE, long before it even started. The right questions needed to be asked, even before starting, which means that the key driving factors for future aircraft had to be captured and analysed (see Fig. 1), ranging from various market requirements such as productivity, cost of operation, reliability, etc. to environmental criteria and other factors. This activity was perhaps the most important as it sets a frame for the whole project.

Commercial transport aircraft as developed today are indeed defined to balance all requirements foreseen for the short or medium term. Best engineering knowledge as much as minimum business risks lead the efforts to choose the classic aircraft configuration. If all foreseen requirements were to be gathered on a spider chart (Fig. 1), the expected performance of these new conventional aircraft would be represented by a circle. In order to explore the more innovative capabilities and meet the widest range of challenges, NACRE proposed to identify aircraft concepts tailored to address specific subsets of drivers.

Each of these concepts allows exploration of alternative routes better suited to their specific targets / biased scenarios, and which would have been rejected in a balanced approach. It is by nature a focused multi-disciplinary approach. In our spider chart, each alternative concept is represented by an eccentric curve, outperforming the classic configuration for its specific criteria.

The next step was to down-select the concepts. In order to explore the most relevant capabilities and meet the widest range of challenges as per previous analyses, Airbus spent quite some time to define the set of concepts tailored to address specific subsets of design drivers that were the founding base of NACRE. Complementing and challenging the classic configuration, they are the most able to drive innovation in their respective field of difficulty. These are called the champions:

- The Proactive Green ('Pro-Green') aircraft concepts paying major emphasis on eco-efficiency for the reduction of environmental impact of air travel (Fig. 2);
- The Passenger-friendly or Passenger-driven Aircraft concepts aiming at optimised internal space for payload and passengers, hence appreciable quality of future aircraft for the end users (Fig. 3);
- The Simple Flying Bus, which puts the biggest emphasis on low manufacturing and maintenance costs for improved revenue (Fig. 4).

Hence the champions and the technologies they employ aim to

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Figure 2. The Proactive Green aircraft concept.

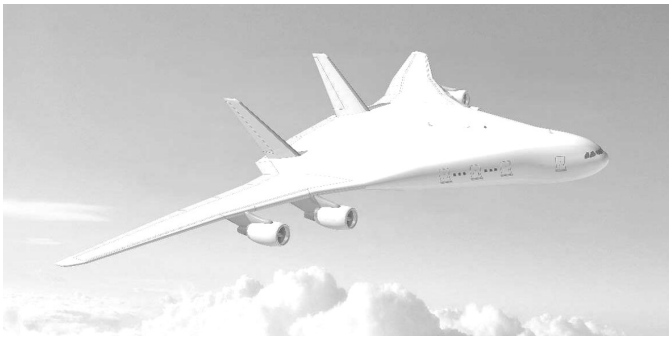


Figure 3. The Passenger-friendly Flying Wing aircraft concept.



Figure 4. An example of the Simple Flying Bus aircraft concept.

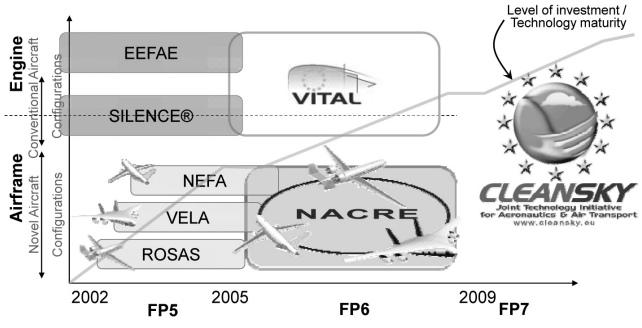


Figure 5. EU R&T Roadmap on New Aircraft Concepts.

address requirements stemming from several stakeholders that are seen as 'customers': industrials' research strategy and policy makers and future aircraft programmes, airlines, planners, societal and political stakeholders.

Irrespective of what final future product configurations might ever look like, these future concept champions simply act as basic vectors, describing and stimulating the whole set of future capability developments.

In order for the champions to play their role, their shapes assemble the most relevant design ideas to fulfil their target. Each of them, even though it may be the best selection of design ideas to tackle its specific challenges, is also faced with potential multi-disciplinary showstoppers. Lifting these barriers, even more so when they are common to several concepts, is to be seen as a major incentive for new technology developments.

The champions eventually develop into families of concepts, which is worth to insist are not aircraft products at all, but can be used as car manufacturers do with concept cars. They have very aggressive architectures, which move away in a radical fashion from the conventional tube-and-wing architecture, and they are packed with innovative concepts and technology features. Yet the technologies that are developed are generic ones, which could find application in many other types of aircraft configurations.

Of course the first mission in NACRE was to exploit the precursory initiatives undertaken in Europe. Most of the NACRE work builds upon the results of previous initiatives from the Fifth Framework Programme. As such, NACRE is the logical follow up of previous upstream research projects on unconventional concepts. The three main FP5 projects, which are relevant to NACRE are:

- ROSAS (Research On Silent Aircraft conceptS), which ended in March 2005 and has explored the so-called low noise aircraft configurations with the prime objective of defining the shielding potential of engine noise by the airframe using innovative engine-to-airframe integration concepts.
- VELA (Very Efficient and Large Aircraft), which has explored until September 2005, the Flying Wing configurations, aiming at improving passenger comfort and capacity, while improving environmental performance.
- NEFA (New Empennage for Aircraft), which explored until January 2006 innovative empennage concepts such as U and V tails, aiming at improved overall efficiency and reduced manufacture costs.

Figure 5 shows the phasing of NACRE with these projects. It also shows in parallel with NACRE the engine-specific European projects of FP5, EEFAE and SILENCE(R), and FP6 VITAL. The VITAL project (enVIronmenTALly friendly aero engine), led by Snecma, aims at providing a quantum leap in low noise and low emission engine components and architectures. Some of the engine concepts developed in VITAL were actually enablers for, and part of the result of, the Pro-Green unconventional aircraft concepts of NACRE.

Both NACRE and VITAL feed into CleanSky, which is the next biggest ever research programme on new aircraft concepts in the 7th Framework Programme. Whereas the order of magnitude of each FP5 project's gross budget was around €5m, NACRE has a €30m budget and CleanSky roughly at €1·6bn. Obviously the level of maturity of the concepts investigated is consistent with the level of investment (Fig. 5).

The NACRE consortium, spearheaded by Airbus, is composed of 36 partners from 13 European countries (including Russia). The team provides an impressive spread of expertise and capability for the aeronautical industry throughout Europe: four among the partners are airframe manufacturers: Airbus, Alenia, Dassault Aviation, Piaggio; three are engine manufacturers: Rolls-Royce, Snecma, MTU Aero Engines; three are key suppliers: Aircelle, Messier-Dowty, Dowty Propellers; ten are national research centres: Aircraft Research Association (UK), CIRA (Italian Research Centre), DLR (German Aerospace Centre), EADS Innovation Works

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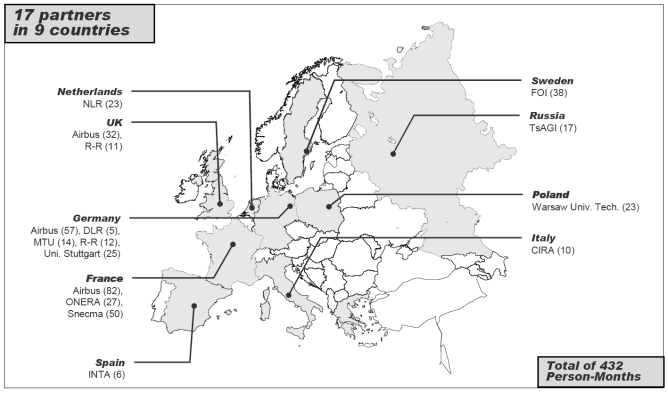


Figure 6. Novel Aircraft Concepts – Partnership.
(Partners' budget in person-months in WP1 are given in parentheses)

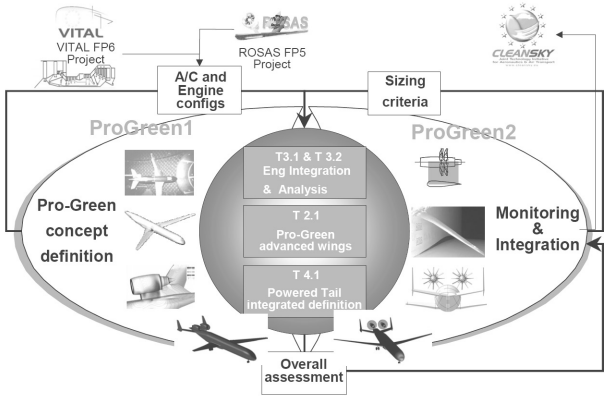


Figure 7. Pro-Green domain.

(Germany), FOI (Swedish Aerospace Centre), INTA (Spain), NLR (Dutch National Aerospace Lab), ONERA (France), TsAGI (Central Aerohydrodynamic Research Centre, Russia), VZLU (Czech Republic); seven universities: Trinity College Dublin, University of Greenwich, Technical University of Munich, University of Stuttgart, Royal University of Technology KTH Stockholm, Warsaw University of Technology, Southampton University; and finally four small and medium enterprises: IBK (Germany), INASCO (Greece), PEDECE (Portugal), ARTTIC (France).

The consortium should receive a total funding from the European Community of around €17m.

Incidentally 'nacre' also means 'mother of pearl' in French, and the first workpackage ('WP1') named 'novel aircraft concepts' really is a shell for all the jewels and pearls that are the innovative technologies developed in the other three workpackages. Indeed the main objective of WP1 is to drive the development of these technologies and associated capabilities. Once concepts are selected in WP1 for both components and aircraft, a baseline configuration needs to be sized for each aircraft concept, while sizing the respective aircraft requires first to define top-level requirements.

WP1 is clearly the backbone of the project, providing focus and bringing together sets of innovative features into the research aircraft platforms for assessment and guidance. However, disciplines and technologies need to be first integrated at major aircraft component level: wing and empennage, powerplant system integration, fuselage and cabin, respectively within work packages 2, 3 and 4, through a typical multi-disciplinary design and optimisation approach. Integration at aircraft level differs from the latter and is indeed conducted in WP1: each aircraft concept's components are integrated to produce the overall aircraft concept assessment.

Within the novel aircraft concepts work package of NACRE, a total of 17 partners from nine countries have been involved as shown in Fig. 6.

3.0 THE PRO-GREEN AIRCRAFT CONCEPTS

The work in response to the eco-efficiency challenge represents 50% of the total budget in NACRE. In order to develop the target requirements and the technology pack for the Pro-Green champions, NACRE relied mainly upon the results of the ROSAS project. Through VITAL, a wealth of knowledge was gathered on engine design and architecture potentials for reduced environmental impact, in terms of noise and CO_2 emissions. This of course induces some constraints already for aircraft architecture and general arrangement. In order to set the foundation of the Pro-Green work across the project, two configurations were produced at the start of NACRE, Pro-Green 1 and Pro-Green 2. There were in fact two families of concepts, with a very flexible set of features and characteristics, so that components' design space and scope of research were as important as the actual aircraft general arrangements. All these Pro-Green concepts were clearly devoted to pulling different sets of technology bricks, all targeting noise-effective configurations (Fig. 7).

Indeed the prime objectives are to develop silent-by-design engine integration concepts and to lift all potential showstoppers, but also to be able to complete a fair assessment of the concepts at aircraft level, with a reasonable degree of confidence. The component concepts need then to be optimised targeting lowest possible fuel burn, hence best CO_2 emission performance.

The detailed component design work and technological solution developments are conducted in the other project workpackages, but WP1 offers a shell for the end integration. The main components investigated are the engine integration, with a complete loop of multidisciplinary design work for the rear fuselage-mounted propulsion systems, and innovative wing systems with low-noise high lift and landing gear systems studies and integration. Part of the role of WP1 in this context is to provide a good framework or design space, with constant monitoring.

The results feed into the next loop, which will be done in CleanSky.

For each of the two Pro-Green eco-concepts, very different challenging propulsion systems were defined: a ducted contra-rotating fan engine by Snecma and a contra-rotating open-rotor system by Rolls-Royce. Detailed definition of these was delivered at the end of the first year for the detailed engine integration design. Synergies with VITAL, on the development of propulsion-systems technologies, were used for the engine concepts produced in NACRE.

Indeed, one of the major objectives of the Pro-Green concepts is to achieve significant shielding of the engine noise propagating to the ground during take-off and landing in order to reduce the community noise exposure in the vicinity of airports. The multidisciplinary investigation studies conducted on the Pro-Green engine integration paved the way to a major experimental task consisting of a wind-tunnel test campaign at a dedicated facility belonging to ONERA for an experimental assessment of the amount of noise shielding from the engine systems.

In parallel, the analysis and risk mitigation for uncontained rotor failure of an engine saw the achievement of a number of milestones in the second year as well, which has consolidated the schedule and set the pace for the investigations to come during the third year. The most promising research paths on this topic have been highlighted and, further, experimental activities were launched to foster progress in the understanding of the physical phenomena of impact and energy absorption and to validate existing numerical-modeling capabilities.

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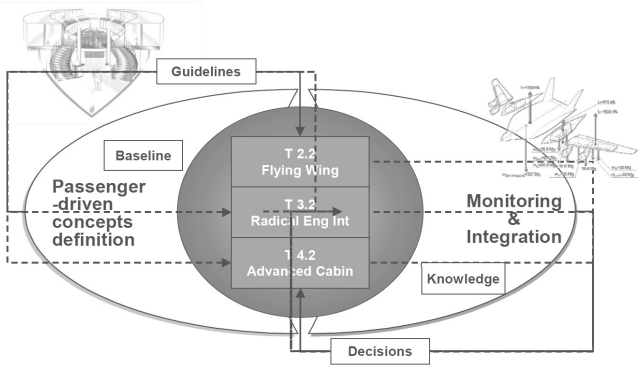


Figure 8. Passenger-driven domain.

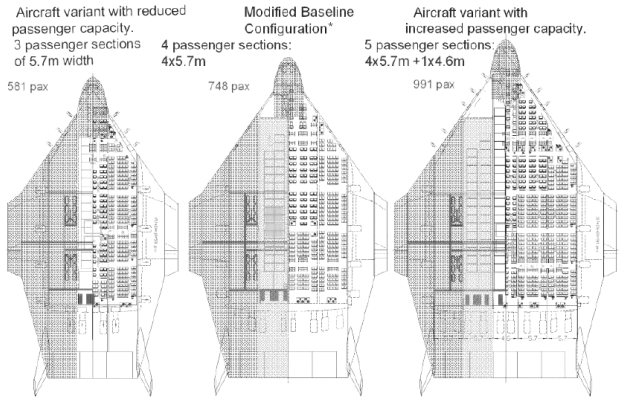


Figure 9. Flying Wing family concept.

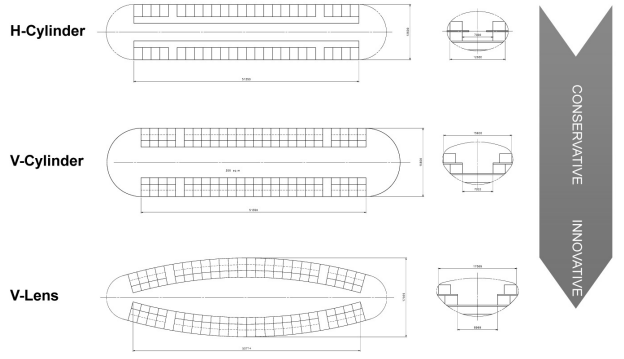


Figure 10. Flying Cruiseliner. – cabin concepts.

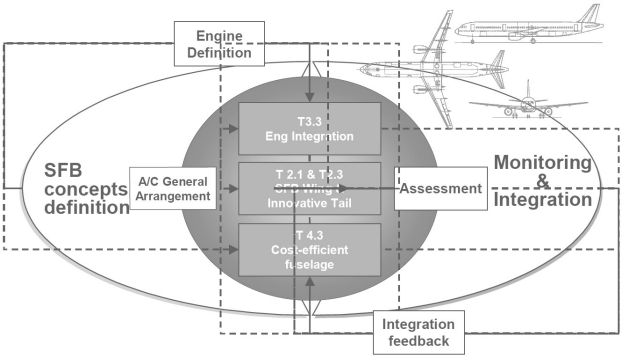


Figure 11. Simple Flying Bus domain.

Finally, those Pro-Green aircraft concepts feature a range of advanced wing concepts, for which a suitable design space had first to be clearly defined. During the second year of the project, the baseline wing configurations were defined and assessed. Dedicated wing planforms for natural laminar flow is one of the key issues of investigation in this area.

Hence, the baseline Pro-Green 1 concept, which is fitted with the contra-fan engines from VITAL, earns a forward-swept, slat-less laminar design. The contra-fan engine is designed for minimum noise using two ducted contra-rotating fan stages, whereas the wing planform arguably provides for improved natural laminar-flow behaviour.

The Pro-Green 2 concept features the open-rotor system by Rolls-Royce with Dowty Propellers and lower Mach number wings with a high aspect ratio and a low sweep supplied by the NEXUS project. In NACRE, the Pro-Green 2 wings have a turbulent boundary layer, as the investigation on laminar design with such a low-sweep high aspect ratio planform is conducted in another project called TELFONA. Together with TELFONA, NACRE will deliver to CleanSky the laminar-flow prediction capabilities, which were further developed and to some extent validated by code-to-code comparison using different physical modelling strategies for different prediction codes.

4.0 THE PASSENGER-FRIENDLY AIRCRAFT CONCEPTS

The Passenger-friendly domain offers two different sets of aircraft designs. The first one is the Flying Wing, sometimes derived into a Blended-wing Body, and so-called Flying Cruiseliners.

The principle of fostering innovation by using extreme concepts is the same as explained before, however the flying wing for one is such an integrated configuration that this is a specific task in its own right in NACRE. The other component tasks are the radical engine integration with buried powerplant systems on the upper side of the vessel, and a real ‘inside-out’ passenger-driven cabin task (Fig. 8).

The initial Flying Wing configuration was developed starting from the FP5 VELA project achievements. This Flying Wing baseline configuration can accommodate as many as 750 passengers, but the concept of ‘family’ has been considered in some depth by TsAGI for a family of aircraft from 580 to 1,000 passengers (see Fig. 9). The idea is certainly not to have the biggest possible aircraft, but to achieve the best understanding of how to accommodate that many people and then how to evacuate all these people quickly in case of emergency.

The definition of the Flying Cruiseliners’ cabins has been carried out throughout the NACRE project (see Fig. 10), for which cabin module concepts were developed in the earliest phase. The overall cabin layout was developed in a range of designs, which have had to be completed from the structural and aerodynamic point of view.

5.0 THE SIMPLE FLYING BUS

The Simple Flying Bus domain (see Fig. 11), with its cost-efficiency objective, is probably the most difficult to illustrate and to present, as most of the cost-effective features are not visible.

In terms of concepts for the SFB components, different planforms for a manufacture-driven wing were investigated, different concepts for empennage reduced wetted surface (which drives actually to a performance improvement too), simple and cost-effective engine integration ideas and composite fuselage structure concepts with systems instal-

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lation. Nevertheless the cost assessment for a new technology or component is the real challenge in this area, and it is amazing how difficult it can be to perform a full cost calculation.

Indeed, a range of innovative low-cost wing concepts and configurations were analysed, and a pre-selection was achieved for thorough analysis.

Aircelle, Snecma and Airbus teamed up to produce the definition of a simple and cost-effective propulsion-system design and to start designing its integration. A number of pylon concepts were developed targeting a strong reduction in manufacturing costs with no penalty on safety and maintenance aspects, while there was minimum impact on performance (weight, drag). The design-to-cost engine study has led to two new engine architectures.

The cost-efficient fuselage activities of SFB started at the beginning of the second year in NACRE.

6.0 SUMMARY

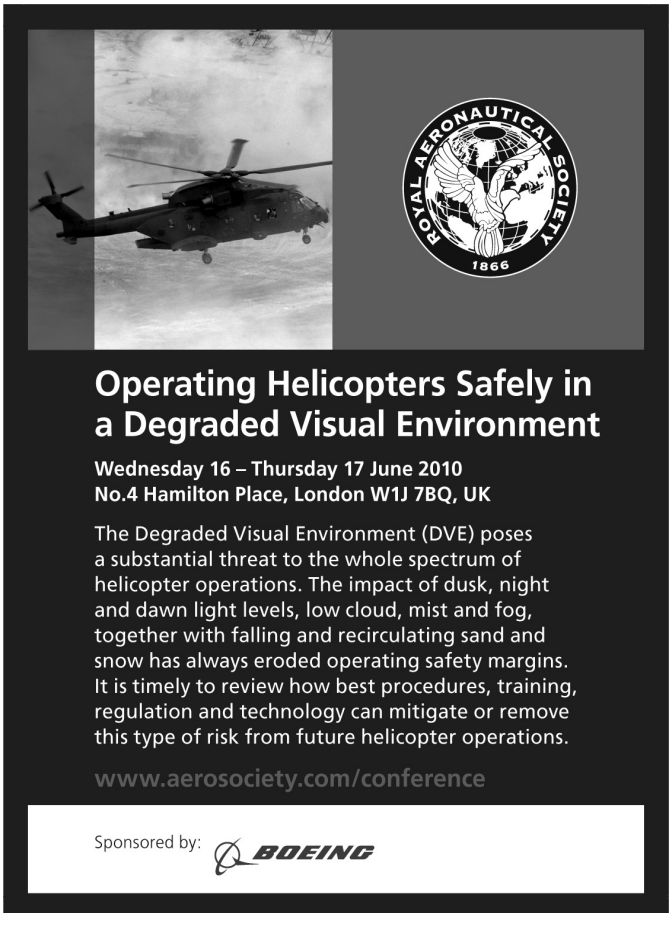
Since it started in April 2005, the activities undertaken in NACRE have fully concentrated not on specific aircraft concepts for the sake of some promising innovative configuration to be pushed into the real aviation market, but on developing integrated technologies on a multidisciplinary multi-component integration level, looking continually at solutions at a generic aircraft component level.

The advantage of such an approach using concept aircraft as technology development platforms will enable the results to be applicable for a range of new aircraft concepts. After three years into the innovation challenge, key results have been produced within the project, motivated by its clear and shared vision and strategy, and fostered via the driving forces of WP1.

Indeed NACRE has delivered already a number of outstanding technology bricks: those on the eco-efficiency area (Pro-Green) are expected to contribute directly to CleanSky, chief among which great progress in laminar-flow prediction and wing design, silent open-rotor system design, rear-fuselage integration and noise-prediction capability for noise shielding. Other outstanding achievements relate to the Flying Wing configuration and cabin evacuation modeling; innovative tail concepts; cost-driven components; and finally Passenger-driven Aircraft concepts.

REFERENCES

1. *European Aeronautics: a vision for 2020 – Meeting society's needs and winning global leadership*, January 2001, Report of the Group of Personalities, European Commission.





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