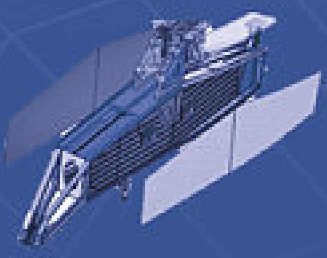
NACRE

Final Activity Report
2005 – 2010



New Aircraft Concepts Research

NACRE

NEW AIRCRAFT CONCEPTS RESEARCH

Final Activity Report
2005 – 2010

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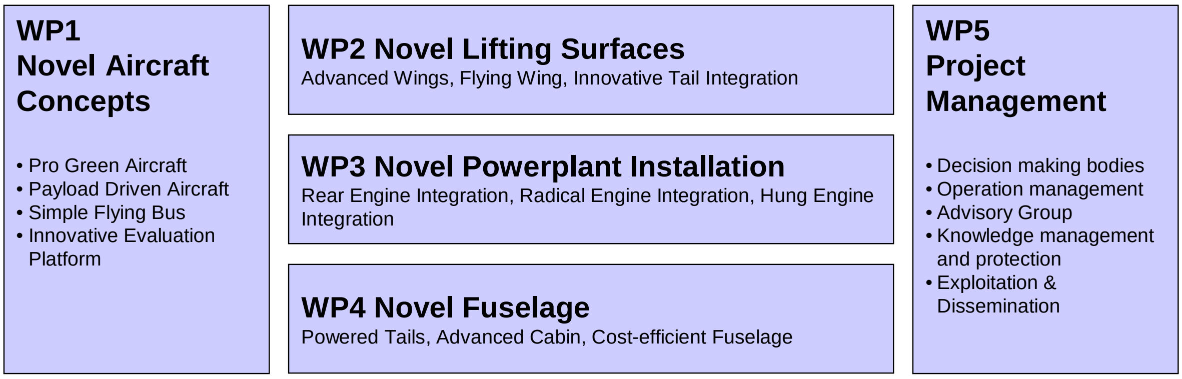
EXECUTIVE SUMMARY

The NACRE Integrated Project was aimed at integrating and validating technologies that enabled New Aircraft Concepts to be assessed. As such, it did not concentrate on one specific aircraft concept, but it developed solutions at a generic aircraft component level (cabin, wing, powerplant system, fuselage…), which allows the results to be applicable to a range of new aircraft concepts. For each of the major aircraft components, the multidisciplinary investigations have explored the different associated aspects of aerodynamics, materials, structure, engines and systems with the goal of setting new standards, together, for the future of aircraft design, thereby ensuring improved quality and affordability, whilst meeting the strengthened environmental constraints (emissions and noise), with a vision of global efficiency of the Air Transport System.

Started in April 2005, NACRE has taken full benefit of the preliminary activities initiated in Europe on Novel Aircraft Concepts in the frame of several FP5 projects such as ROSAS, VELA, NEFA and many others. In order to reach these goals, the NACRE project was organized into five strongly inter-connected workpackages as shown below.



WP1 Novel Aircraft Concepts

- Pro Green Aircraft
- Payload Driven Aircraft
- Simple Flying Bus
- Innovative Evaluation Platform

WP2 Novel Lifting Surfaces

Advanced Wings, Flying Wing, Innovative Tail Integration

WP3 Novel Powerplant Installation

Rear Engine Integration, Radical Engine Integration, Hung Engine Integration

WP4 Novel Fuselage

Powered Tails, Advanced Cabin, Cost-efficient Fuselage

WP5 Project Management

- Decision making bodies
- Operation management
- Advisory Group
- Knowledge management and protection
- Exploitation & Dissemination

Figure 1: NACRE Work Packages

The NACRE consortium, led by Airbus, was composed of 36 partners from 13 European countries (including Russia), providing an impressive spread of expertise and capability for this industry throughout the EU and constituting the complete aeronautical supply chain (Airbus, Alenia, Dassault Aviation, Piaggio Aero, Rolls-Royce, Snecma, MTU Aero Engines, Aircelle, Messier-Dowty, Dowty Propellers (GE), ARA, CIRA, DLR, EADS IW, FOI, INTA, NLR, Onera, VZLU, TsAGI, Trinity College Dublin, Univ. Greenwich, TU München, Univ. Stuttgart, KTH, Warsaw Univ. of Technology, ISVR, PEDECE, INASCO, IBK) and ARTTIC.

During the first year of the project, the NACRE partners undertook to jointly define a set of concepts tailored to address specific subsets of design drivers:

- Two Pro-Green (PG) aircraft concepts put a major emphasis on the reduction of environmental impact of air travel;
- The passenger-driven Flying Wing (FW) concept was developed using the final result of the VELA project, with a view to maximize efficiency for passenger transport and for low fuel consumption;
- The “inside-out” designs of Payload Driven Aircraft (PDA) cabin concepts aiming at optimised payload and appreciable quality of future aircraft for the end users;
- The Simple Flying Bus (SFB) puts the biggest emphasis on low manufacturing costs and minimum cost of ownership.

In order to size the respective aircraft in WP1, whenever required for the component workpackages WP2, 3 and 4, top-level operational objectives were defined by Airbus during the project’s first year for each of the proposed aircraft concepts.

The main interactions between WP1 domains (overall aircraft) and the major aircraft component activities (WP2, 3 and 4) are shown in Figure 2.

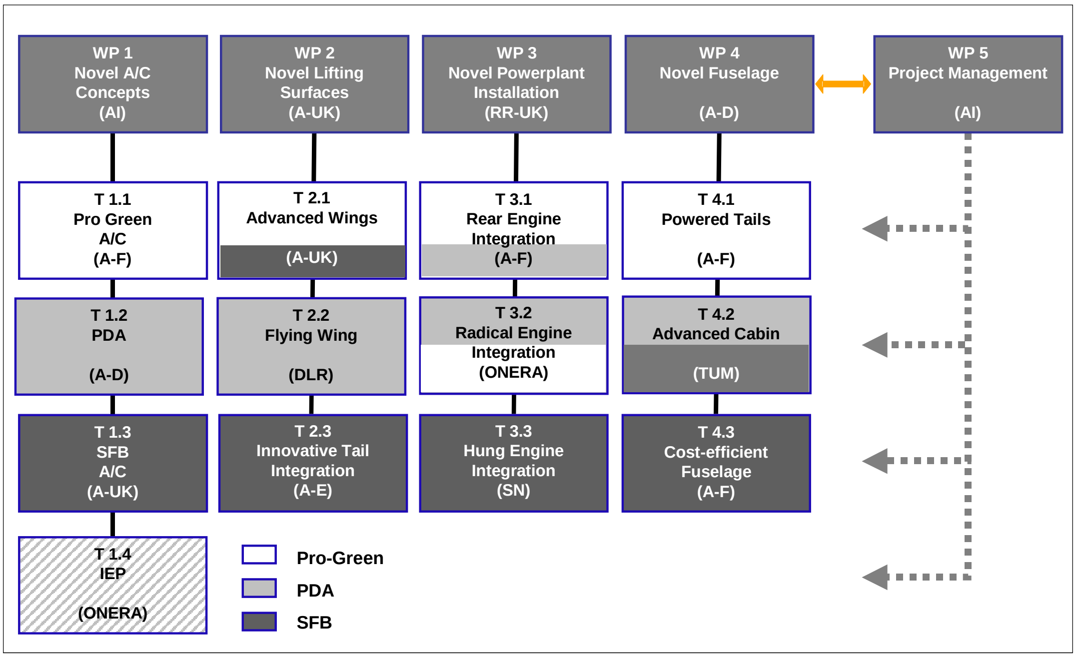


Figure 2: Relationship between WP1 strategic domains and WP2, 3 and 4 activities

For the two Pro-Green aircraft concepts, Snecma on one hand, and Rolls-Royce with Dowty Propellers on the other hand, developed or adapted challenging propulsion systems, respectively a low-noise contra-rotating fan engine (designed within the VITAL FP6 project) for the Pro-Green 1 aircraft and a gear-less contra-rotating open rotor system with a contra-rotating LP turbine for the Pro-Green 2 aircraft. Detailed definition of these was delivered by WP1 to partners in WP3 and 4 at the end of the first year of NACRE. Design studies were subsequently conducted in Task 4.1 and Task 3.1 on the engine integration. Task 4.1 ended in July 2007 when it successfully delivered the final Powered Tail designs to Task 3.1, which signalled the start of the detailed high-speed aerodynamic and acoustic assessments. On the acoustics side, preparation of a "generic" noise shielding wind-tunnel test campaign was undertaken during the first two years of NACRE. The Acoustic WTT Critical Design Review (project milestone M3.1-8) at the end of June 2006 enabled the **Jet noise tests on the SILENCE® BPR-9 nozzle to be performed at CEPrA19 in July 2007.** After a series of setbacks, including a major failure of the CEPrA19 wind tunnel fan in July 2008, which took until September 2008 to be repaired, the **fan noise tests were successfully accomplished well into Year 4 in December 2008, confirming the potential benefit of noise shielding of around 10 dB.** On the aerodynamic analysis side, after an early PDR in July 2006 (M3.1-1), the High-speed Aerodynamic WTT CDR was finally held in February 2008 (M3.1-3) and the **engine installation aerodynamic performance tests were successfully performed at ARA in March 2008.** Year 4 was fully devoted to the exploitation of the wind tunnel test results and comparison with the numerical simulations, which showed a **very good correlation. No strong aerodynamic issue was found that could not be overcome with a proper design.**

However, a strong potential showstopper for Powered-Tail and Flying-Wing aircraft concepts with over-the-body mounted engines could be the Uncontained Engine Rotor Failure (UERF) cases. Mitigation of this failure risk in NACRE comes via high-energy absorption material tests, up to 150 kJ, which aim at validating numerical FEM simulation of an engine rotor fragment (third-of-disc) impacting onto a typical structure part. In addition, the effect of rotation of the fragment before and during impact was unknown and was seen as a great challenge for the numerical models. After a very long and detailed discussion over the key objectives for tests and potential test setup concepts within budget, the first CDR for the impact tests (M3.2-2) was held in December 2006 at the GkNIPAS facility near Moscow, resulting in a partly successful first trial of the rotation device set-up, which took place as part of the event (Step 1.1 L1). The main achievement then was the **validation of the selected test set-up concept and especially of the very innovative device for the rotation.** The second PDR and CDR were held respectively in Stockholm in May 2007 and Moscow in October 2007 (Year 3). The aim was to perform the second series of launches at GkNIPAS in November 2007. All the hardware was ready in time for the tests, but the weather conditions did not permit to go ahead – hence the tests had to be postponed until April 2008. Finally **one launch (Step 1.3 L1) was successfully conducted in April 2008, achieving a 153-kJ energy level absorption. The FEM simulation using the actual test conditions did match the test results very well.** After some more investigation on the measurement and calculation of the speed accuracy, and additional weather constraints, the **second launch was performed in September 2008**. During the one-year project extension the last test series without rotation were successfully performed in May and June 2009 and the non-linear FEM simulation capability was validated taking into account fragment orientation and mass. Finally, the rotation device was again tested for further development (April and July 2009) up to the optimum fragment rotation / translation ratio, and **one test with rotation was achieved on 8th December 2009**. In order to assess the effect of rotation, one last test, with the same conditions but without rotation, was finally performed on 18th March 2010, just one week before the NACRE Final Meeting.

Besides the advanced propulsion designs and integration concepts, the Pro-Green aircraft concepts feature innovative wing designs: the High Aspect-Ratio Low Sweep wings (HARLS) and the Forward Swept Wings (FSW). First a suitable design space was defined during the first year of the project. During the second year, the baseline wing configurations were defined and assessed (M2.1-2), with all adequate tools being established in anticipation. Two phases of detailed analysis were conducted during the third year [D2.1-3] [D2.1-4]. Valuable parametric studies for the HARLS wing include thickness and sweep effect on performance, high-lift device trade studies for minimum noise and the assessment of various landing gear concepts, with the development of a new LG noise analysis process. **For the first time**, high fidelity methods have been used for the prediction of noise emanating from different flap configurations. The final phase to perform the wing systems integration, with trades at aircraft level, was achieved during Year 4 [D2.1-7]. Despite a number of initiatives and concept studies, the structural issue of thin wing (HARLS) issues could not really be overcome in a satisfactory way although no showstopper was actually identified. For the FSW wing, **the assumptions of natural laminar flow prediction were agreed upon between the major stakeholders, DLR and Onera**, which is a major outcome of NACRE and allows smooth introduction of computational prediction capability into Clean Sky. The baseline FSW concept does not carry any leading edge high-lift device (HLD), however during Year 4, a study on novel HLD was performed and identification of main advantages and drawbacks was done. It was shown that a forward swept natural laminar flow wing for a Mach number of 0.76 could be designed with a wide extent of laminar flow, resulting in a **significant reduction of drag potentially up to approximately 38 drag counts**. No particular showstoppers could be identified for this concept; however careful design (low and high speed) must consider the likely high impact on performance of wing/fuselage junction and belly fairing for any future project.

Concerning the Payload Driven Aircraft, the initial specifications from WP1 had been revised during the second year, and cabin module concepts developed by EADS IW, TU München and Airbus to fit the passenger requirements developed within Task 4.2. The overall cabin layout was developed in a range of designs, which started to be wrapped up from the structure point of view. The Phase 2 of the work on the cabin concepts extended until October 2007. During the third year, the structure concepts (triple/quadruple bubble and elliptical cross-sections; single or double strut) and aerodynamic formulas (nose and rear fuselage) were analysed in some detail [D4.2-3] [D4.2-4]. These results were subsequently used in order to refine and adapt the cabin concepts in the last phase.

The initial Flying Wing configuration was developed starting from the FP5 VELA project achievements, and the foundation documentation finally delivered officially in October 2006 ([D1.2-2], [D1.2-3], [D1.2-5]). An advanced engine concept was developed by MTU with consistent specifications during Year 2 ([D1.2-4], formally delivered in January 2007). The Flying Wing detailed analysis (Structure, Handling Qualities) was substantially progressed in Year 3, with a number of FEM models derived for different purposes and a **low speed wind-tunnel test successfully achieved at DNW-NWB Braunschweig in October 2007 for the analysis of different control devices** [D2.2-6]. The cabin evacuation analysis has seen the acceleration in Year 3 of the definition, preparation, and finally the **successful performance of the full-scale partial cabin mock-up [D2.2-10] evacuation tests [D2.2-13], led by University of Greenwich the at Cranfield University facility, in February 2008.** One of the major results of the cabin simulation work by UoG is the assessment of a **minimum 600s flash-over time after start of fire** which, being much higher than for a conventional cabin configuration, provides a significant advantage for the Flying Wing [D2.2-12]. Integration of the Flying Wing results into an intermediate (Phase 1) new status configuration [D1.2-7] was finally completed just in time for the 3rd Annual Review in April 2008. Work continued immediately thereafter on the next status **[D1.2-9]**, which was actually a major change in concept, integrating initial knowledge of engine “close” integration, with **three very large engines semi-buried on the top of the centre body**. This of course does not mean that the under-wing-engined configuration is abandoned, but NACRE was compelled to producing an alternative configuration for more detailed analysis in follow-up projects that could encompass potentially good ideas that cannot simply be discarded – and the design challenges that go along.

As for the Simple Flying Bus domain, the baseline configuration was made available to partners at the end of Year 1, leading to a small delay of activities in the other Workpackages, especially for the Wing. As for Pro-Green, the baseline wing was assessed and innovative wing configurations were thoroughly discussed, and concepts were selected for analysis during the third period.

After a complete re-definition of the scope at the end of Year 1, the SFB innovative tail work started during Year 2. It was decided to perform the investigation of innovative features and concepts on a conventional arrangement empennage, with a concept down-selection achieved end of September 2006 (M2.3-1). The main topics finally investigated are: double-hinged elevator and rudder, and morphing. **Encouraging results, especially for the double-hinged rudder, show a clear interest to pursue the effort in this direction**, and to continue to challenge sizing cases and strategies.

Aircelle, Snecma and Airbus teamed up in Year 2 for the definition of a simple and cost-effective propulsion system design and integration. Trade studies were identified and performed at aircraft level to provide orientation for this activity. A number of pylon concepts were developed targeting a strong reduction in manufacturing costs with no penalty on safety and maintenance aspects, and minimum impact on performance (weight, drag). The design-to-cost engine study has led to two new engine architectures during the second year of the project, and trade-off studies were further performed during the third year leading to the selection of the optimum design. Engine positioning analysis and optimisation has been achieved by INASCO with strong support from Airbus. Finally **innovative thrust reversers** concepts targeting low cost, low weight and low maintenance were investigated, among which the most promising is the **blocker door-less cascade thrust reverser**, leading to a 10% reduction in recurring costs compared to a standard cascade thrust reverser.

The cost-efficient fuselage activities of SFB started at the beginning of Year 2. The work performed was essentially building a matrix of concepts for down-selection, which was achieved in November 2006. Actual design work on first concepts started in February 2007. Structural details were analysed for the centre-fuselage section, as well as the **impact of the wing-to-fuselage junction**. The global configuration was finally frozen in December 2007 (M4.3-3). Several other paths to **simplify the fuselage structure** were investigated, such as removing orbital joints, and system studies were performed, such as **Electrical Structure Network (ESN)**. Furthermore, the manufacturing and assembly studies were formally launched in October 2007, for work within the topics of assembly schemes and specific parts manufacturing (stringers). In addition to the centre-fuselage section, a second barrel, a rear double-curvature part, was analysed from the assembly point of view. Although initially entailing higher costs, there are opportunities for improvement in future research.

Finally, the assessment of the interest of a flying scale aircraft model (IEP) as an innovative alternative to existing experimental tools towards the efficient development of unconventional aircraft concepts was finalized. The Critical Project Review (M1.4-1) was held on schedule (October 2006) at INTA's drone test range close to Seville (CEDEA). However, the specification phase was longer than anticipated and early design choices had to be performed. In order to avoid huge delays, manufacturing (moulds, structure and electronics) had to be run to some extent in parallel to the actual design. The IEP specification and design document [D1.4-3] was finally issued in March 2008.

During 2008, the design and manufacturing of the various parts were completed, and a number of **"acceptance" tests were conducted to mitigate technical risk before actual flight**: static structure loading tests, low-speed aerodynamic and handling wind tunnel tests, landing gear systems tests. Other tests were performed to achieve the required confidence on elements such as powerplant piloting and performance, engine noise radiation in static conditions. Finally, the systems integration started first in Warsaw with the landing gear, then from May 2009 at Stuttgart for all remaining systems. This phase proved also much longer than planned, lasting until early 2010. So-called hardware-in-the-loop tests, or "iron-bird", were conducted to simulate the systems control and in-flight behaviour. Numerous additional validation tests were conducted for all integrated systems, including landing gear retraction tests in October 2009, fuel system in November 2009, a flight test of the Flight Management and Control System and the Autopilot on 25th November 2009. **On 20th January 2010, the IEP was rolled out at Hahnweide airport near Stuttgart**.

It was shipped to Warsaw on 11th February 2010 for the flight test campaign. As the preparation work for the flight tests progressed, formal First Flight Preparation meetings were held both at Stuttgart (01-02 February 2010), to validate the systems and integration, and at Warsaw (22-23 February 2010), to validate the flight test management and procedure, including all aspects of safety and responsibility. These important reviews raised again numerous issues. The first ground runs were tried nevertheless on 25th February 2010 at Modlin airport near Warsaw. Unfortunately the testing conditions and the overall preparation were not adequate and the model was damaged following a runway overrun. Although the model could be quickly repaired, it was decided to suspend the test campaign until proper preparation could be evidenced. The experience in ground testing has shown that **the responsibility for flight testing must be established within the organisation for a chief engineer who carries the technical responsibility of the IEP and a test flight director who is in charge of all of the activities of testing the IEP including the direction of the piloting.** They of course must operate within the framework of a civil or military authority. The flight authorization should be asked for each country where the tests will be performed.

Some of the features of the IEP are unique for this type of "light" UAV (<150kg): autopilot, retractable landing gear, altitude laser sensor. They were designed to enable the model to serve as a testing platform in particular for noise measurements, but also for flight dynamics and even recovery from hazardous conditions. **These capabilities must be exploited in a follow-up project in order to better understand the potential of the modular IEP testing platform concept**. After the NACRE project the consortium will need to define the budget to maintain the IEP in operation and sponsorship as appropriate.

From April 2005 to March 2010, the research work undertaken in NACRE was fully focused 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 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 five years into this 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 during its five-year lifetime, with a forward-looking approach, NACRE has delivered 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, low-noise 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 modelling; innovative tail concepts; cost-driven components; and finally passenger-driven aircraft concepts.

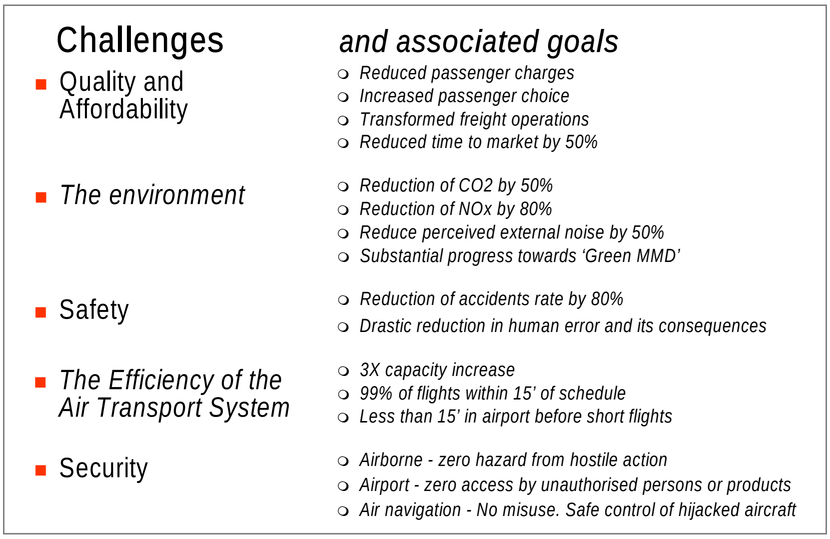
Part 1.

INTRODUCTION AND PROJECT OBJECTIVES

Introduction

The past hundred years have seen the air transport flying with enthusiasm from shaky hops to a mature industry. This revolution in the means of transportation has seen as well a major shift in the driving forces for new aircraft developments. The engineering freedom of the pioneers has now been focused by market needs. Such a trend is irreversible: the next century of flight will not allow the commercial aircraft industry to escape its responsibility, which is to provide answers to the world demand and propose means for transportation and growth acceptable to all the citizens of this planet.

In their 2001 report "European Aeronautics – a vision for 2020", a Group of Personalities has given their view for the future of air transport over the medium to long term. In order to reach sustainable growth, five major challenges are identified associated with qualitative and quantitative goals, Figure 3.



Challenges	*and associated goals*
■ Quality and Affordability	❍ *Reduced passenger charges* ❍ *Increased passenger choice* ❍ *Transformed freight operations* ❍ *Reduced time to market by 50%*
■ *The environment*	❍ *Reduction of CO2 by 50%* ❍ *Reduction of NOx by 80%* ❍ *Reduce perceived external noise by 50%* ❍ *Substantial progress towards 'Green MMD'*
■ Safety	❍ *Reduction of accidents rate by 80%* ❍ *Drastic reduction in human error and its consequences*
■ *The Efficiency of the Air Transport System*	❍ *3X capacity increase* ❍ *99% of flights within 15' of schedule* ❍ *Less than 15' in airport before short flights*
■ Security	❍ *Airborne - zero hazard from hostile action* ❍ *Airport - zero access by unauthorised persons or products* ❍ *Air navigation - No misuse. Safe control of hijacked aircraft*

Figure 3: European Aeronautics – A Vision for 2020

"Vision 2020" [1] gives the key drivers for responding to society's needs. Opposite to inhibiting constraints, these perspective and responsibility have to be seen as powerful stimulations for the innovative engineering spirit, which has prevailed in the aircraft industry since the Wright brothers. Having this in mind and seeing these challenges as new opportunities, the NACRE project developed and implemented a systematic approach to think out of the box and investigate ideas to push further the current state of the art.

Nowadays, commercial transport aircraft 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.

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

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

Irrespective of what final future product configurations might ever look like, these concepts act as basic vectors, describing and stimulating the whole of future capability developments. More than the intrinsic value of any of them, what is of importance is the consistent capability enhancement that they prepare.

The general project objectives were 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 (Fuselage, Wing, Engine Integration) and associated technologies.

NACRE was then by essence a focused multi-disciplinary approach. This Integrated Project aimed at integrating and validating technologies that will enable those New Aircraft Concepts to be assessed and potentially developed. As such, it did not concentrate on specific aircraft configurations, but it was aimed at developing solutions at a generic aircraft component level (cabin, wing, powerplant system, fuselage…), 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 have explored 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 (emission and noise), with a vision of global efficiency of the Air Transport System.

Overview of project objectives

The main objective of NACRE was to break the barriers that prevent the efficient design of Novel Aircraft Configurations to provide quantum steps in Air Travel Affordability, Environmental Performance and Air Transport Efficiency with the following objectives:

Efficiency:	-15% of A/C economics;
Noise reduction target:	-10 dB per operation;
Fuel Consumption:	-25% (fuel burn kg/seat/km);
Volume improvement:	+15/20% per pax at same A/C efficiency and enhanced services.

Many of the technologies considered in this Integrated Project, either within a given area or across areas, may potentially interact, in either a positive or negative way. Therefore it was essential that the research undertaken within the different area be highly integrated, in terms of their deliverables, objectives and timing.

Therefore an overall approach was proposed within NACRE, based upon a subtle mix of a broad spectrum of fundamental and applied research activities grouped in 3 technology areas each exploring new technology options for major aircraft components (Fuselage, Wing, Engine Integration) aiming at developing new aircraft concepts:

- WP2: Novel Lifting Surfaces;
- WP3: Novel Powerplant Installation;
- WP4: Novel Fuselage.

As shown in Figure 4, these 3 technology areas were strongly integrated and coordinated through two additional activities; one technical dealing with definition, integration and appraisal of mutual interaction between individual technology components at overall aircraft level, which includes scale model aircraft flight assessment; the second addressing the overall management and inter-partner / area interactions, training, exploitation and dissemination aspects of the programme:

- WP1: Novel Aircraft Concepts;
- WP5: Project Management.

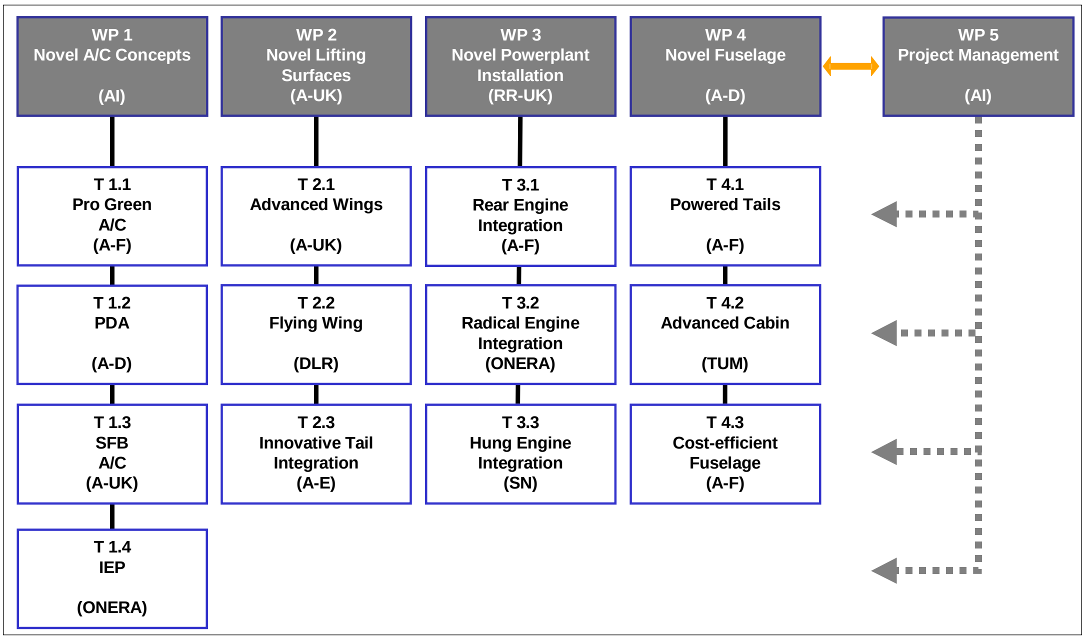


Figure 4: Matrix approach in NACRE

The structure and strategic objectives defined at the beginning of the project for the four technical workpackages are described next.

WP1 – Novel Aircraft Concepts

WP1 aimed to propose to the other work packages a set of challenging unconventional aircraft concepts featuring advanced aircraft components or systems which were studied at aircraft component level through a complete multidisciplinary process (Aerodynamics, Acoustic, Structure and Systems) within WP2, 3 and 4.

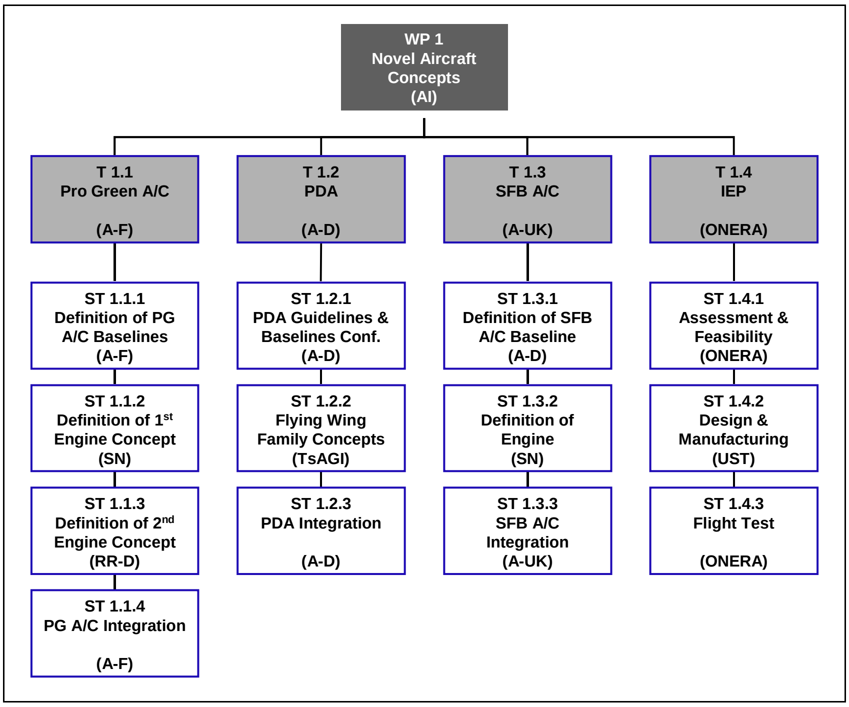


Figure 5: WP1 Structure

WP1 was tailored to provide continuous monitoring for all project activities giving the overall aircraft perspective and to integrate major outcomes at overall aircraft level to challenge the specifics and conflicting objectives of each of the proposed applications.

A dedicated integration exercise was proposed in Task 1.4 through the assessment of the interest, and the potential development, of a flying scale aircraft model as an innovative alternative to the existing experimental tools in view of the efficient development of unconventional aircraft concepts.

WP2 – Novel Lifting Surfaces

The objective of WP2 was to perform multidisciplinary research on unconventional wings and control surfaces, driven by the requirements provided by WP1, and to integrate at wing component level some of the major systems (e.g. landing gear, fuel system).

Three advanced wing concepts were preliminarily defined and sized in WP1 that required in-depth analysis for aerodynamic performance, flight mechanics, structure, aeroelastics, and noise assessment for Pro-Green and SFB application.

Highly innovative cabin concepts developed in PDA were also to be evaluated against the challenging requirements to be issued in WP1 and relying on VELA results for configuration aspects.

Finally, a new type of empennage would be deeply investigated, as far as Stability and Control and Systems integration and Simulation, and relying on WP1 for configuration aspects and mostly on existing NEFA results for aerodynamics.

WP 2 would in return trade information to enable further development of the innovative aircraft concepts and provide some design solutions that would take advantage of the integrated nature of the work or provide specific enabling technology for concept showstoppers.

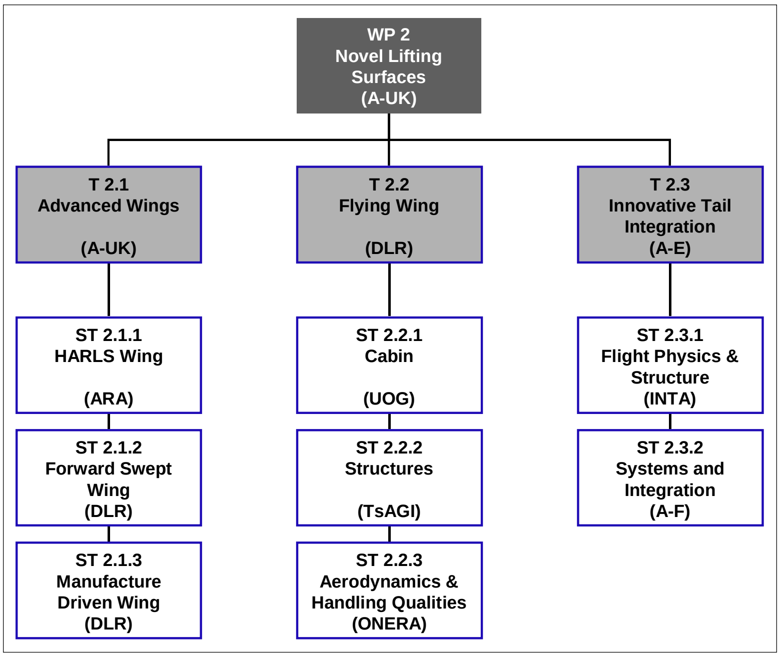


Figure 6: WP2 Structure

WP3 – Novel Powerplant Installation

WP3 addressed the specifics of the integration of advanced engines on the unconventional aircraft concepts as developed in WP1 for Pro-Green, SFB and PDA domain.

The integration of engine over the rear fuselage for maximum shielding of engine noise sources and best achievable fuel burn performance initiated in the FP5 ROSAS project would be complemented through the multidisciplinary evaluation in terms of Aerodynamics and Noise performance as well as through the assessment of energy absorption for engine burst risk mitigation.

One of the key points of the overall definition of the Novel Aircraft Concepts in WP1 would lead to non typical engine installations, up to partially or totally bury the powerplant system into the airframe structure; in order to prepare this radical engine/airframe integration, the proposed activity aimed to put in place the preliminary set of numerical and experimental techniques to better understand and simulate the complete integration of the powerplant into the airframe structure for the key aerodynamics, acoustic and structural issues.

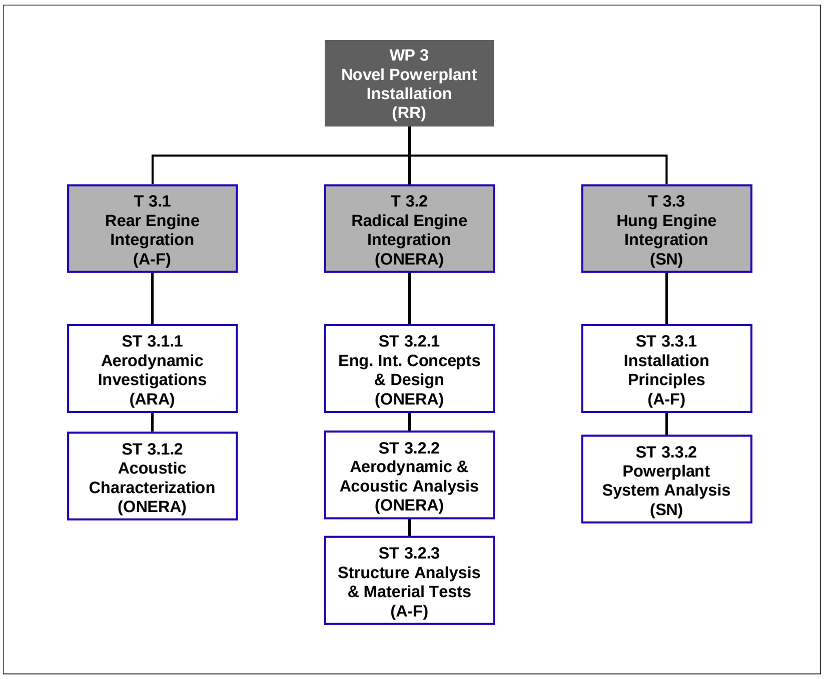


Figure 7: WP3 Structure

Energy absorption for engine burst issue was addressed through a comprehensive material test campaign, and passive (placement of key engine auxiliaries) and active (containment) technologies to mitigate engine burst risk for engine-close-to-engine type of configuration (Pro-Green).

Finally, integration of advanced and affordable engine for a low-cost application was addressed through the specifics of structural (Pylon, Nacelle) and system analysis.

WP4 – Novel Fuselage

WP4 aimed to address through multidisciplinary investigations some innovative fuselage architectures and design principles for Pro-Green, SFB and PDA domains. The objectives of WP4 were:

- To define Powered Tail concepts and design principles;
- To address issues related to innovative wide fuselage concepts as defined in WP1 for a payload driven aircraft fuselage. WP2, which would also provide cabin requirements to WP1, would retrieve wide fuselage constraints from WP4 for the cabin assessment Tasks;
- To define design principles for an advanced low-cost fuselage in line with requirements developed in WP1 and provide WP1 back with the fuselage multidisciplinary tailoring.

In particular, the Pro Green Aircraft concepts required the structural investigation of engine integration concepts onto the rear fuselage, together with innovative shielding empennage, under consideration of multidisciplinary requirements deriving from shielding of engine noise sources; fuel burn efficiency and engine burst risk mitigation (Task 4.1 Powered Tails).

On the other hand, the Simple Flying Bus and Payload Driven Aircraft concepts required major development efforts with regard to typical fuselage architecture. This was also reflected in the work package structure, which further originated in the two Tasks, 4.2 Advanced Cabin (Payload Driven Aircraft) and 4.3 Cost Efficient Fuselage (Simple Flying Bus).

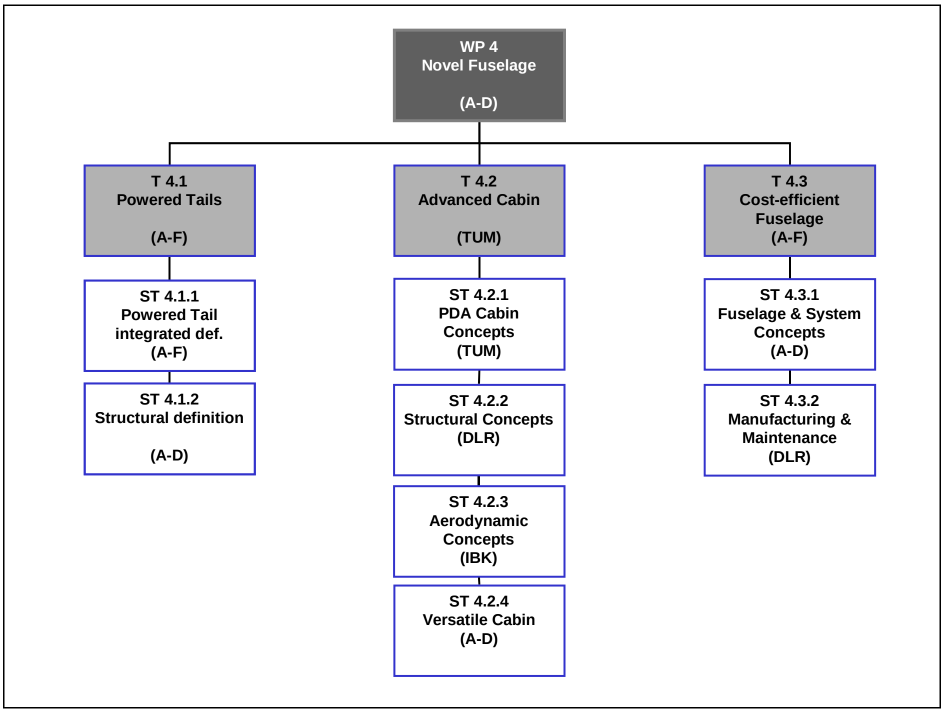


Figure 8: WP4 Structure

Part 2.

TECHNICAL ACHIEVEMENTS AND FINAL RESULTS

WP 1 – Novel Aircraft Concepts

Task 1.1 – Pro-Green A/C

Task objectives at beginning of the project

At the beginning of the project, Task 1.1 primary objective was to define two preliminary innovative aircraft concepts aiming at the maximum environmental performance in both CO2 emissions (fuel burn) and external noise level through the mastering of the key areas related to advanced wing design and unconventional engine integration; those innovative aircraft concepts would feature both advanced engines integrated on top of fuselage for maximum noise shielding and advanced wings designed for best achievable fuel burn performance.

Task 1.1 would deliver preliminary aircraft concepts to Tasks 2.1, 3.1, 3.2 and 4.1 for deeper multidisciplinary analysis in terms of aerodynamics, noise, structure and systems (engine integration related activities to be developed from the FP5 ROSAS), and would provide a continuous monitoring of the Pro-Green domain activities, integrating outcomes at overall aircraft concept level for final assessment in terms of global environmental performance.

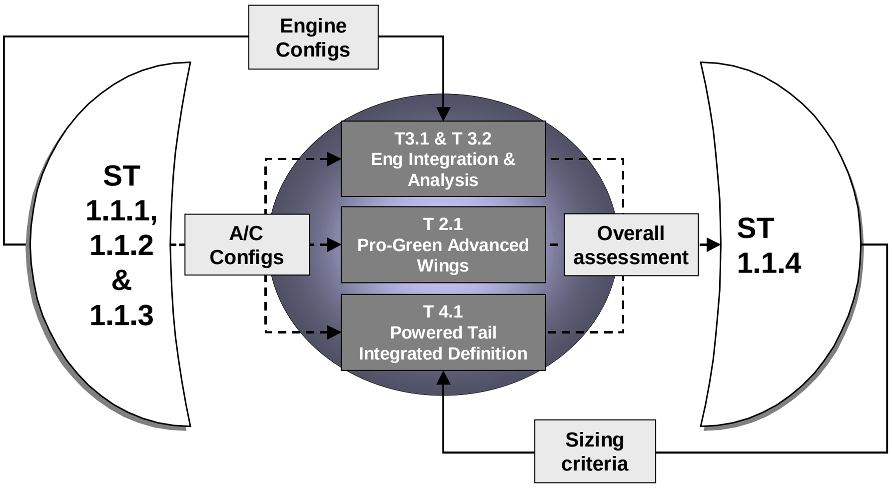


Figure 9: Task 1.1 – Pro-Green domain flowchart

After having defined the baseline aircraft and engine configurations in Year 1, Task 1.1 controlled and monitored the Pro-Green-related activities performed in the other work packages at component level. The integration phase at overall aircraft level started when the first results from other workpackages were delivered.

Subtask 1.1.1 Definition of Pro-Green Aircraft Baselines

This Subtask aimed to define a conventional under wing engine Short/Medium range 200-pax aircraft to be used in the course of the project as the baseline Pro-Green reference aircraft (RPG).

Building on ROSAS final recommendations for engine integration aspects, two innovative Pro-Green Aircraft Concepts (PG) featuring engines installed over the rear fuselage part (2 installation concepts) and advanced wing concept (2 wing concepts) were to be preliminary defined and sized.

Each of the innovative aircraft concepts would then be fitted with the Pro-Green Advanced Engine concepts (PGAE) to be defined in Subtask 1.1.2 and 1.1.3:

- Powered Tail 1 and Wing 1 (PG1) equipped with the PGAE1 engine defined by Snecma;
- Powered Tail 2 and Wing 2 (PG2) equipped with the PGAE2 engine defined by Rolls-Royce.

For each of the PG aircraft concepts, 3 view drawings for WP2, WP3 and WP4 detailed component investigations were to be produced together with the complete set of data (weight, performances, noise…) required to challenge the specific design objectives of the domain.

Subtask 1.1.2 Definition of Engine Concept N°1

Based on thrust level requirements provided by Airbus, Snecma would define a revolutionary Pro-Green Engine Concept N°1 (PGAE1) to be installed on top of fuselage targeting maximum SFC performance and allowing maximum noise sources shielding by the PG1 aircraft airframe.

Studies would consist in defining a performance cycle answering the objectives of the Pro-Green. From this cycle, a cross section of the powerplant system (PPS) would be realized, containing the technological definition of the engine, the nacelle as well as the installation of equipments and EBU. These studies would allow supplying the weight of the powerplant system and the main geometrical characteristics. These studies would be completed by calculations of prediction of both Fuel burn and noise emission; the aspects of maintenance were to be also taken into account during this definition phase.

Subtask 1.1.3 Definition of Engine Concept N°2

Based on thrust level requirements provided by Airbus, RR-UK, RR-D and Dowty Propellers had the objective to define a Pro-Green Advanced Engine Concept N°2 (PGAE2) to be installed on top of the fuselage.

This Pro-Green Advanced Engine concept targeted a maximum SFC performance together with an architecture allowing the maximum noise sources shielding by the PG2 aircraft airframe. The engine should feature a two-stage contra-rotating open rotor architecture. The first engine definition would consider a reduction gearbox for realising the contra-rotation, while the second definition would be based on a contra-rotating LPT driving the propeller stages. The data associated with the second definition was to be traded on aircraft level in Subtask 1.1.4.

Subtask 1.1.4 Pro-Green Aircraft Integration

Airbus, together with Rolls-Royce and Snecma for the engine aspects, aimed to provide a continuous technical monitoring and would integrate all of WP2, WP3 and WP4 outcomes at overall aircraft level. Based on this integration, Airbus would then propose a performance assessment at overall aircraft level, with prime focus on CO2 (fuel burn) and external noise reduction, for the PG1 and PG2 concepts.

Recommendations would be prepared for further development of out-performer environmental aircraft.

Globally from Year 2 onwards, the main objectives of this Task have been:

- Monitor the activities performed in Task 1.4, Task 2.1, Task 3.1, Task 3.2 and Task 4.1.
    - Check their consistency with the Pro-Green objectives;
    - Provide intermediate status on the Pro-Green Aircraft configurations when needed in WPs 2, 3 and 4;
    - Propose an update of PGAE2 engine;
    - Provide engine data for noise assessment;
    - Assess the performance of the Pro-Green Aircraft concepts with respect to the NACRE Pro-Green objectives.
- Gather the information required for completion of final integration and assessment.

Technical achievements

Initially, a discussion between the airframe manufacturer (Airbus) and the engine manufacturers (Rolls-Royce and Snecma) involved in the Pro-Green part of the project led to the refinement of the objectives for Pro-Green Aircraft. Using the promising outcomes from ROSAS, the global noise reduction target seemed achievable. Therefore, it was decided that the focus in NACRE would be:

- Orientations for acoustic engine design (directivity, noise source breakdown);
- Fuel burn reduction.

Snecma decided to work on a Contra-Rotating TurboFan (CRTF) engine for PGAE1 and proposed a first-pass engine with associated data package for PG1 aircraft sizing.

Figure 10: Engine for PGAE1

Rolls-Royce and Dowty Propellers proposed to design a Contra-Rotating Open Rotor (CROR) for PGAE2 (see Figure 11 below) and delivered a preliminary data pack for PG2 sizing.

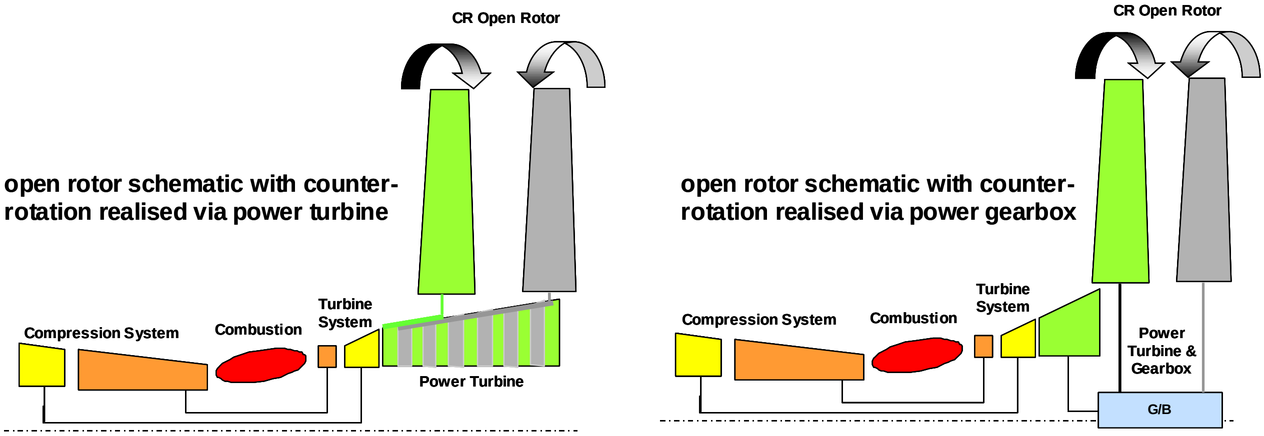


Figure 11: Engine for PGAE2

Airbus defined the two initial baseline aircraft PG1 and PG2, delivering top level requirements, new engine specifications for PGAE1 and PGAE2 engines, 3-view general arrangements, wing planforms in [D1.1-1] and [D1.1-2].

- PG1 features the CRTF engine designed by Snecma, in a Rear Fuselage Nacelle (RFN) position, an H-Tail and a forward-swept wing.
- PG2 features the CROR engine defined by Rolls-Royce/Dowty Propellers, in a RFN position, an H-Tail and a high aspect ratio low sweep wing.

Figure 12: Initial baseline PG1 and PG2 aircraft

Airbus delivered some recommendations, constraints and design space for wings and powered tails designs (Task 2.1 and Task 4.1) in [D1.1-1a], [D1.1-1b], [D1.1-2a] and [D1.1-2b]. Snecma delivered PGAE1 engine data from January to March 2006 in [D1.1-3]. Rolls-Royce and Dowty Propellers delivered PGAE2 data in March 2006 in [D1.1-4].

Continuous support and monitoring towards “Pro-Green-related tasks” (Task 1.4, ST2.1.1, ST2.1.2, Task 3.1, ST3.2.3, Task 4.1) was provided to meet the Pro-Green objectives (low-noise, low-fuel burn). Airbus participated in wings selection for Task 2.1 (with an assessment of several wings at aircraft level) and proposed some specifications for an Innovative Evaluation Platform (IEP) in Task 1.4. Rolls-Royce provided refinement of PGAE2 engine and Snecma delivered the acoustic data pack for final noise assessment at aircraft level.

Most results from Task 4.1 and Task 3.1 were integrated into PG1 and PG2 tail concepts (installation drag target, weight, acoustics).

The baseline FS wing was updated for PG1 with results from Task 2.1 (laminar wing, with droop nose devices):

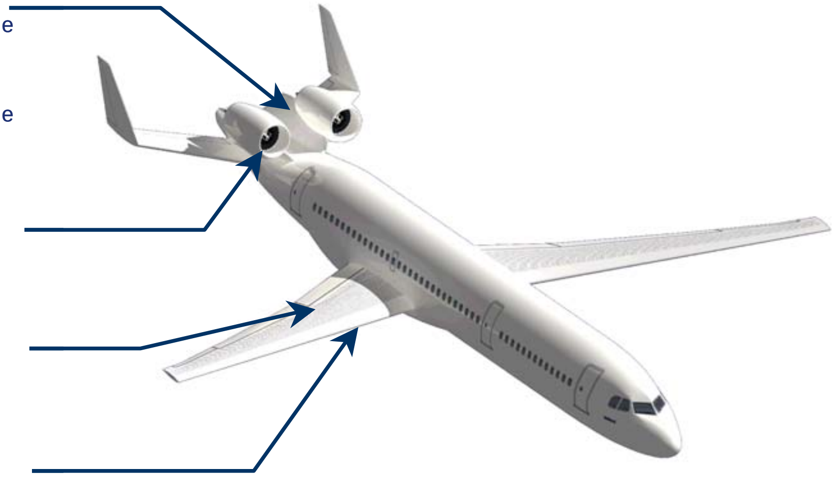
- The trajectories for noise assessment were produced;
- The aircraft optimisation was performed.

The baseline HARLS wing was updated for PG2 with latest results from Task 2.1 (wing C selected):

- Two high-lift systems were investigated for best balance between noise and block fuel;
- The landing gear systems were studied: wing - body - centre landing gear and outriggers;
- The trajectories for noise assessment were produced for the HLD.

The PGAE2 revised engine definition by Rolls-Royce was presented in July 2008. The corresponding deliverable [D1.1-5] was published in March 2009. The integration into the PG2 aircraft and the final assessment was performed.

The main features of the two concepts named PG1 and PG2 are described below in Figure 13 and Figure 14.



Integrated powered tail concept:

Noise shielding empennage and fuselage

Damage tolerant structure (fuselage and pylons)

Low installation drag

Solutions for ‘RFN’ engine maintenance and systems

Contrafan architecture:

Low fan-noise architecture

Compact engine for easier integration

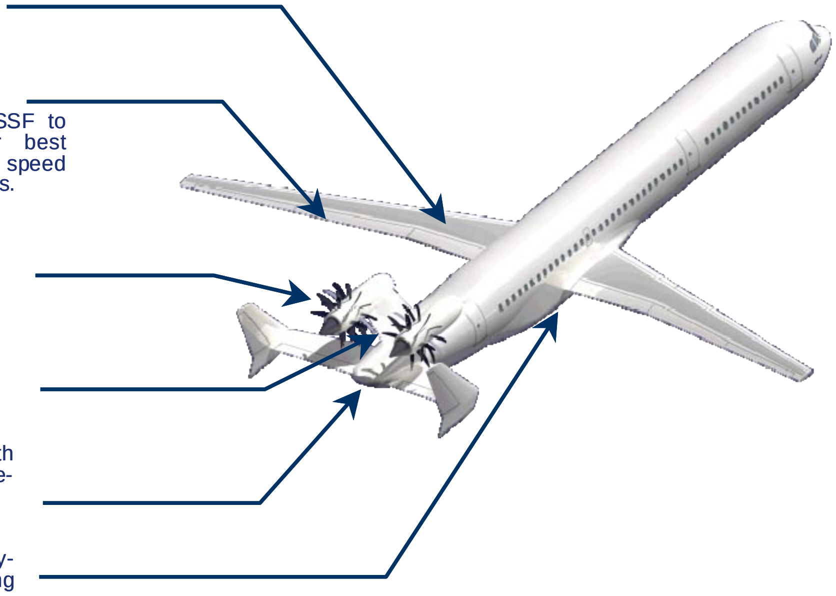
FS wing:

Optimum planform for M0.76 as defined with T2.1, assessment of the best wing among 2 detailed proposals

High lift devices:

Innovative DND + flaps (ensuring full laminarity) *vs.* “low-risk” Krueger slats (with a loss of laminarity on lower surface)

Figure 13: PG1 concept



HARLS wing:

Optimum wing for M0.74 as defined with T2.1

High lift devices:

Several systems from slats + SSF to DND + DSF considered for best compromise between low speed performance, weight and acoustics.

Open Rotor engine architecture:

Geared architecture *vs.* gearless architecture with counter-rotating turbines

Pylons:

Radial pylon *vs.* tangential pylon
Additional cross-link?

Tails:

Noise shielding empennage with forward sweep with damage-tolerant structure

Landing gear:

Wing-mounted- *vs.* twin body-mounted- *vs.* mono centre landing gears for wide-track low-noise solutions

Figure 14: PG2 concept

Both configurations were compared to a reference aircraft (RPG) in the form of a ‘conventional’ aircraft with underwing BPR 9 conventional turbofans.

The diagram in Figure 15 displays a summary comparison of all the concepts considered during the integration exercise.

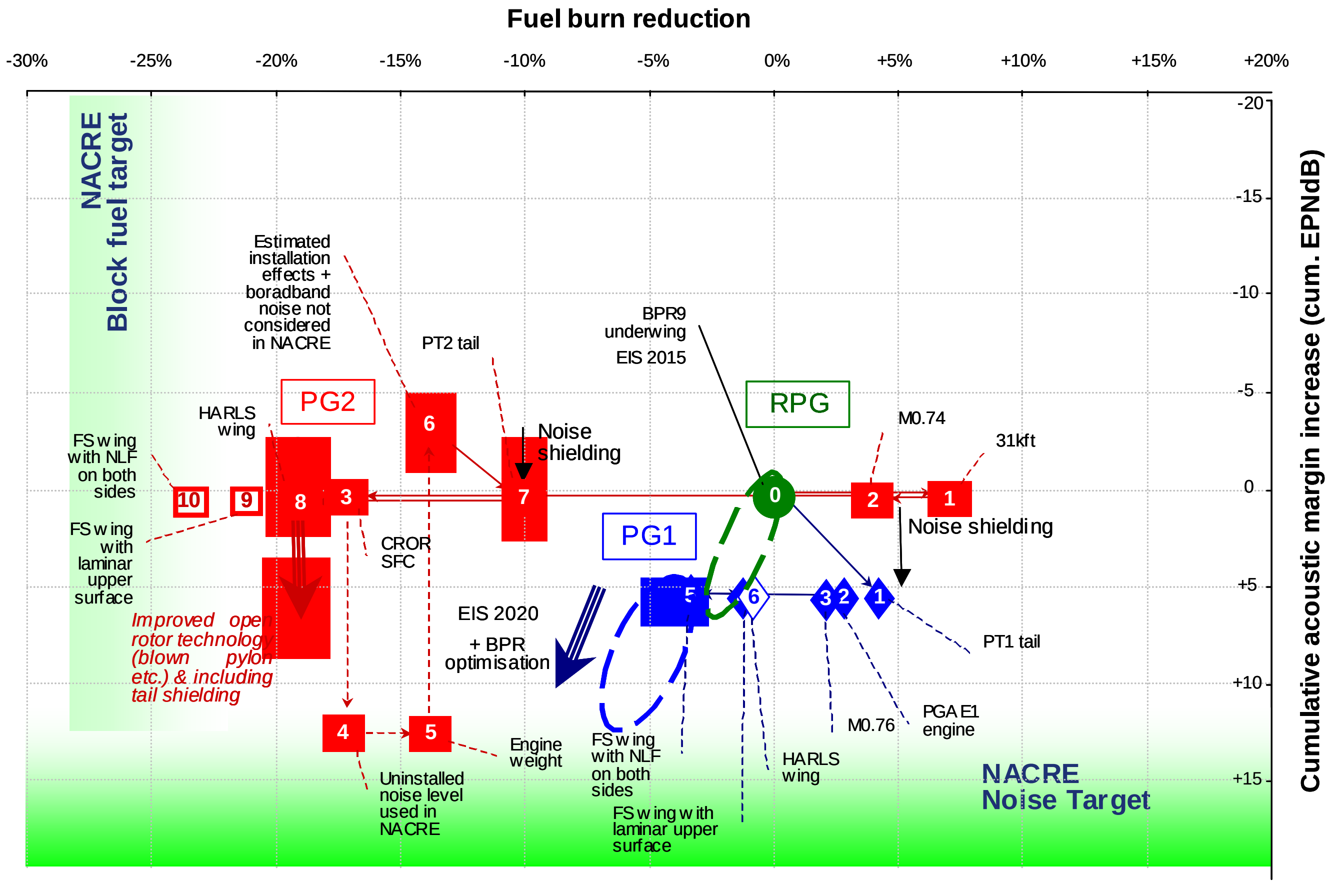


Figure 15: Comparison of the aircraft concepts – block fuel / 3000nm vs. acoustic cumulative margin

The general trends are the following:

- **Contrafan engine for a rear fuselage installation (PGAE1)**: it is a light and compact engine architecture that optimises the installation on top of a noise-shielding tail.
- **Turbofan engine noise shielding configuration (PT1)**: shielding the engine noise by fuselage and empennage can be efficient. With PGAE1 contrafan, it brings around 4 EPNdB cumulative noise reduction for a ~2% block fuel increase.
- **Contra-rotating open rotor (PGAE2)**: it is a fuel-efficient engine architecture, up to 15% SFC reduction. But a ~4% block fuel penalty due to additional weight should be added on top. Additional snowball effects on advanced wing configurations lead to ~16% to 20% block fuel improvement.
- **Open rotor noise shielding by the airframe (PT2)**: although the methods are not mature yet, some preliminary investigations were performed to reduce external noise of aircraft equipped with such engines. A validation exercise including wind tunnel tests would be required. A (more) accurate definition of the engine noise sources is also mandatory.
- **High Aspect Ratio Low Sweep wing (HARLS)**: with a turbulent design and associated to a fuel-efficient engine, this wing brings ~6% block fuel benefit but the associated OWE increase is significant.
- **Natural Laminar Flow Forward Swept wing (FS)**: it brings significant potential benefits (especially for long missions), but it is associated to high risks of losing laminarity, what would increase fuel consumption by 15% to 20% (and increase fuel burnt on 500nm mission by 10% to 15%). This risk and its management have to be further investigated, as well as low speed performance (including take-off) and landing gear arrangement.

Final Conclusions

Conclusions for each Pro-Green component concept can be summarised as follows.

A Contra-Rotating TurboFan (CRTF) with low-diameter fan enables a compact nacelle, thus optimising the installation and integration on top of fuselage, has a low fan noise, is light-weight, but its balance between the noise sources may not be optimum for RFN installation.

For the Turbofan noise shielding configuration (RFN installation), the noise reduction potential is proven, for a reduced aerodynamic and weight penalty, with mature methods validated on tests. Solutions do exist for an integrated powered tail design with a challenging engine installation, and the engine cycle and architecture also have to be adapted to this shield geometry (all noise sources but jet…)

Contra-rotating Open Rotors (CROR) provide a good solution for fuel burn reduction, the geared architecture seeming the most efficient; however, the noise characteristics could not be defined with a high level of accuracy.

For the Open Rotor noise-shielding configuration, an efficient noise attenuation has been computed, but the methods are not mature yet (to be validated in tests), and some noise sources were not modelled. The installation seems challenging (pylon design), but the behaviour of the engine once installed is satisfactory. The target for entry into service was set at 2013-2015 at the beginning of the project, but, due to the lower maturity of the open rotors engine concept, the entry into service of such a technology is not envisaged earlier than 2020.

High aspect ratio low sweep wings (turbulent design) show an interesting block fuel reduction potential, to the expense of increased weight (that penalizes larger wing areas and fuel-volume limited aircraft). The landing gear arrangement is quite challenging (need for a wide-track landing gear on a large-span thin wing): a mono centre landing gear + outriggers could be the best solution. Some airframe noise reduction potential was identified with a low-noise gear and a low-noise high lift system. Aircraft noise can all the more benefit from this airframe noise reduction as the engine noise is efficiently reduced with a noise-shielding empennage.

Forward swept wing (with natural laminar flow) also shows interesting block fuel reduction potential, but loss of laminarity would lead to a large penalty (the configuration required an efficient monitoring of defects and deteriorations all along the aircraft life). The wing weight is seen to penalize short missions, but a deeper investigation of low speed performances (including take-off) is required. The landing gear position and arrangement would require a deeper investigation…

Finally, beyond the main innovative components that we wanted to study from the very beginning of the project (CRTF / CROR, HARLS wing / FS wing…), the Pro-Green configurations did their job as **vectors for innovation** with extra unconventional concepts being developed as enablers for these configurations:

- Engine systems re-localization,
- Engine hoisting system for tail-mounted engine,
- Nacelle openings,
- Centre landing gear + outriggers
- Damage-tolerant structure

Task 1.2 – Payload Driven Aircraft

Task objectives at beginning of the project

Task 1.2 covered a single Payload-driven or Passenger-driven (PDA) domain, but it was actually divided into two separate activities, with two totally different approaches:

- A real passenger-driven design approach, from the inside out, starting from cabin requirements and design followed by structure then aerodynamic assessment. The specification of this configuration would be centred on the needs and packaging of the aircraft payload, with a strong focus on driving alternative cabin designs (Task 4.2 Advanced Cabin).
- Providing guidance and requirements, and integration feedback to a follow-on project of VELA for the Flying Wing activities (Task 2.2), aiming at developing and improving a baseline configuration upon which key technical achievements are assessed. Guidelines on the scope of the research studies were to be prepared in order to enable effectively updating the baseline configurations.

This Task would also provide a decision process to identify which evaluation and validation activities should be considered during the second phase of the project. The flow diagram in Figure 16 below explains the interactions between the workpackages.

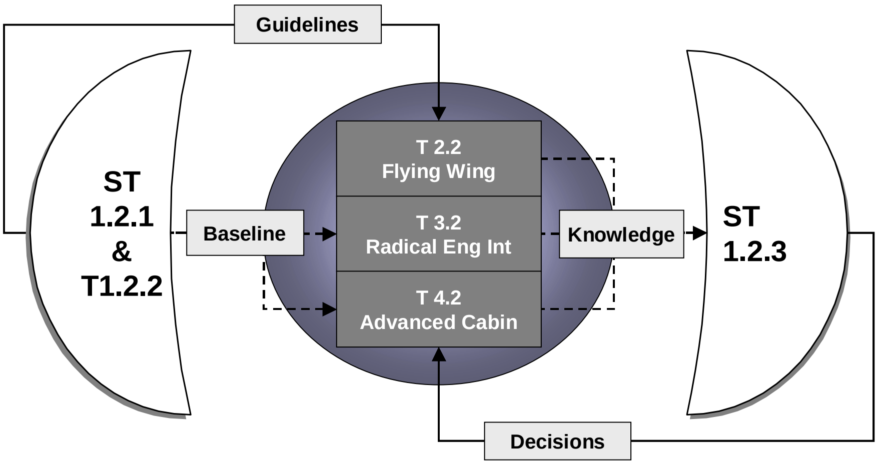


Figure 16: Task 1.2 – PDA domain flowchart

Subtask 1.2.1 Development of PDA Guidelines and Baseline Configurations

This Subtask was devoted to identifying:

- The Flying Wing configuration requirements for the baseline configuration needed for Task 2.2 (Flying Wing) and Task 3.2 (Radical Engine Integration);
- The parameters to be studied in Tasks 2.2, 3.2 and 4.2, and the depth and details of the studies:
    - Guiding parameters could include for example the payload volume for Tasks in Task 4.2 or the pylon height considerations of Task 3.2.
    - The advanced cabin activity should be very broad in scope at the beginning of the study because this is the start of a new approach to cabin design whereas the Flying Wing studies are a follow-on of VELA and hence more detail is expected.

This Task would use these specifications to define a baseline flying wing configuration required for Tasks 2.2 and 3.2. This baseline configuration was expected to be a variant of the configuration developed at the end of VELA (to be referred to as VELA3).

This Task would also define the characteristics of a baseline engine to be used for all configurations and for Task 3.2. A generic advanced engine concept was to be proposed and developed by MTU, based on general requirements supplied by Airbus. Potential concepts for radical engine integration required for Task 3.2 would also be identified.

Subtask 1.2.2 Flying Wing (FW) Family Concepts

The purpose of this Subtask was to concentrate on how to effectively increase or decrease the capacity of a FW configuration based on the guidelines developed in ST1.2.1. This Subtask would develop preliminary options for a family of FW aircraft configurations. The concepts developed would then be delivered to ST1.2.3 to influence an updated FW configuration.

The aim of ST1.2.2 was to outline three FW aircraft configurations that can be regarded as a family for the capacities of 600, 750 and 900pax. The initial configuration from ST1.2.1 is the central one housing 750pax. This configuration would be fine-tuned before the development of the other two. Opportunities for commonality in the family and the global consequences for the three members were to be highlighted for main disciplines such as weight, flight physics and performance.

Subtask 1.2.3 Integration of PDA Domain

The integration Subtask should decide which activities would be studied in further detail in the second phase for the FW studies and the true inside-out PDA activities, and the third phase for true PDA, based upon the results of studies. These decisions would include recommendations for validation testing, in particular for FW (cabin evacuation, handling qualities). This activity would also integrate the lessons learnt and technical results:

- From Tasks 2.2, 3.2 to develop an updated FW configuration in order to demonstrate the changes in configuration directly related to studies performed in NACRE.
- From Task 4.2: at the end of phase 2, a down-selection based on JPDM evaluation was to be made for detailed investigations including concept evaluations of ST4.2.2 and 4.2.3 in phase 3.

Iterative development of FW cabin layouts was intended to improve emergency evacuation. Development of a full scale FW cabin mock-up for emergency evacuation trials in order to validate simulated results of ST2.2.1 was to be accompanied.

During the course of the project it was clarified that an interim FW configuration update (*FW1bis*) needed to be introduced and specified to serve as a clear basis for the quantification of intermediate progress in Task 2.2.

Technical achievements

The first step in Task 1.2 on the true PDA part, linked to the so-called “Flying Cruiseliner” concepts, was to provide in [D1.2-1] the guidelines and the key parameters needed in Task 4.2 for it to develop the PDA cabin concepts and their associated structure and aerodynamic concepts, and the criteria for their evaluation back in Task 1.2. Part of this activity is described in the Task 4.2 section.

Concerning the FW part, thanks to proper phasing between the two projects, the results from VELA were further analyzed until October 2005 before feeding into NACRE. VELA integration results showed recommendations for the cabin, the stability and control as well as for the structural layout.

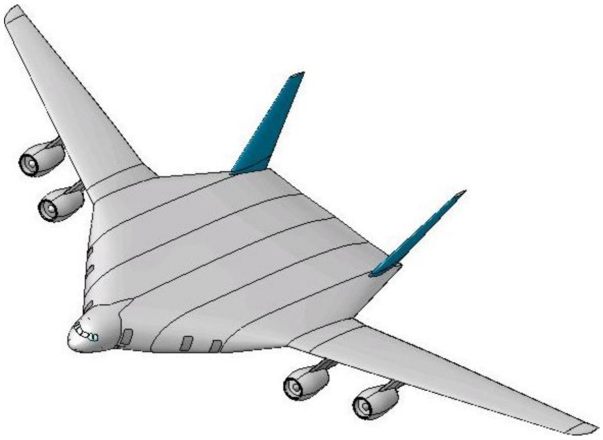


Figure 17: Flying Wing from VELA project

ST1.2.1 delivered all the input data required to the relevant partners of Tasks 2.2 and 3.2. The “NACRE FW1” configuration was defined, together with the research scope for Tasks 2.2 and 3.2. Generally, the objective of a FW configuration is the potential of saving in wetted surface and to compensate payload weight at the same location where lift is generated. The structure reinforcement due to requirements from wing-root bending moments can be reduced, hence potentially weight. Additionally, aerodynamics could be improved by designing smooth surfaces without a dedicated fuselage.

The NACRE-FW1 is a long-range aircraft offering a passenger capacity of 750 seats in a three-class layout. The wing span is fixed to 100 m and the maximum take-off weight is set to 700 tons. The centre body was designed with a single shell concept to account for the inner pressurisation, with two fins mounted at the rear end. Four engines are mounted under the wings.

Similarly to a conventional aircraft, the centre section contains the passenger cabin on the upper deck and the cargo compartment on the lower deck. The cabin is subdivided into four longitudinal bays each offering a twin-aisle long-range standard comfort cabin. Between these bays, structural ribs support the flat pressurised structure of floor and ceiling.

The outer wing shows conventional high lift devices on leading and trailing edge, the centre section is designed with a large elevator on the rear end. The NACRE-FW1 is designed for high subsonic cruise speed. Compared to VELA3, the airfoils of the centre body are modified and the outer wing is twisted to achieve a lift distribution that satisfies both requirements, for overall lift, drag and stability and control.

In ST 1.2.2 the initial work performed by TsAGI concentrated on cabin/cargo-bay layout but also provided principles for structures. Compared with the initial concept, the key feature was the change in Main Landing Gear (MLG) kinematics from sidewise to longitudinal retraction and the position beside instead of behind the cargo bay, thus allowing a longitudinal positioning of MLG according to Handling Qualities (HQ) requirements. As only the variation in cabin width allowed modularity to fulfil the requirements for the FW family concept, the variation of cabin length was not further investigated.

In ST1.2.3, continuous monitoring of technical work and support with technical advice was provided to Tasks 2.2, 3.2 and 4.2 from April 2006 until the end of the Tasks.

One of the most effective methods to improve FW cabin layouts regarding emergency evacuation time was proved to vary aisle widths, positions, alignments and shapes. Because position and size of cabin monuments as galleys and lavatories affect the seat distribution and thus the exit usage ratio, the effects of aisle variations could be clearly identified based on the baseline configuration cabin. Therefore, it was decided to create a new baseline cabin layout in which all cabin monuments in the centre of the cabin layout were removed and replaced by seats, with increased widths of the 3rd and 6th longitudinal aisle between exits 3 and 6 by eliminating one seat per row (+34 seats vs. initial cabin layout). The average evacuation time established by University of Greenwich was 84 seconds. The first variation is the implementation of four diagonal aisles leading from the widened longitudinal aisles to exits 3 and 7. Simulations with this cabin layout are further documented in detail in deliverables [D2.2-11] and [D2.2-13].

In preparation for the Flying Wing redesign in ST1.2.3, the partners in the aforementioned Tasks were asked to extract lessons learnt from their results, which were directly applicable for ST1.2.3 without further post-processing. This is highly important for the aerodynamic database from Task 2.2.

FW1bis interim configuration

The FW1bis interim configuration was intended to maintain the outer shape of FW1 for the sake of better comparability with the initial baseline. This made integration of the 32” wider cabin rather challenging and caused unexpected additional configuration, aerodynamics and structures work. The final planform and all related references remained unchanged. The thickness of the transition area was slightly increased. This modification was however not critical for aerodynamics and could be neglected. The aero database from Task 2.2 was used for the HQ study.

The relocation of the cargo door for FW1bis was the precondition for the chance to relocate the main landing gear as required by the HQ and Stability and Control (S&C) criteria. Many positions for a forward or rearward side-door for cargo were investigated. Only a few of them looked feasible and the one at x=16.2m was selected.

Starting from TsAGI's proposal for the main landing gear [D1.2-8] some Airbus variants of the principle were worked out and one was selected [D1.2-7]. It reasonably satisfied the requirements of cargo bay, structure (with continuous lateral shearwall) and HQ (longitudinal position). Despite that the general arrangement (GA) of FW1bis may look similar to FW1 at first sight, small details like the split ailerons have a significant impact on HQ and S&C.

The FW weight results obtained by TsAGI and Onera were cross-checked and harmonized. However some discrepancy remained in the structure weight estimations, which could not be explained.

The HQ / S&C study demonstrated a good progress in the project. It fully utilises the aero database created in Task 2.2 and provided a method with a specified set of criteria and flight cases that is applicable for the whole class of FW configurations. It allowed in particular adjusting the position of the main landing gear for FW1bis. The configuration obtained was a big improvement already compared with VELA in terms of HQ / S&C, in particular for its take-off capability, but further fine tuning would be needed.

A lot of CFD analysis was performed on the FW1 in Task 2.2. Early Onera results qualitatively confirmed the initial trends from [D1.2-5], as did the TsAGI re-engineering in [D1.2-8]. Hence, in ST1.2.3 the initial data were regarded as robust and only a small check for consequences of the shape modification aside the cabin was done for FW1bis. Drag in cruise was higher in calculations by FOI and Onera, but Onera suspected that this may have resulted from unsuitable meshing in the CFD run. Low speed data calculated by DLR for the database (up to about Mach 0.7) and the data provided by TsAGI [D1.2-8] were used to synthesize polars for the HQ needs.

FW2 final updated configuration

The main effort focused on the collection of component information to achieve a real step update in the configuration layout over FW1 as the heritage from VELA3 and also over FW1bis. Task 3.2 provided the most significant new configuration feature with the over-wing engine installation.

The planform proposal was initially driven by aero and HQ and engine integration space requirements. The area reduction from 2050m^2 to 2000m^2 decreases wetted area and increases aspect ratio. The smooth trailing edge allows partially compensate the loss of control surfaces on the centre-body by surfaces beside the cabin. Control surfaces beside the cabin get more lever arm for better longitudinal effectiveness. Reduction of area and centre body length should be beneficial for overall structure mass, CG and performance.

The consequences for Aerodynamics were:

- A thickness-distribution with a max t/c of about 17% on the centre-body was realised and is challenging for compressibility.
- The overall CM0 is positive as aerofoils on the centre body are designed to have slightly negative camber and no rear loading.
- The cabin floor slope limit of 3° does not allow higher angle of attack for desirable higher lift on centre body.
- The resulting outboard loaded lift-distribution penalizes induced drag.
- An intended low loading on the upper rear part of the centre-body avoids shocks near engine inlets and should ease integration of nacelles.

For OAD and engine arrangement that means:

- The cabin and cargo bay shape is taken over from FW1bis.
- The layout principle of landing gear is taken over from FW1bis.
- The fins from FW1bis were reduced in size by 25%, according to lower lever-arm of outer engine in the on top arrangement.

- The fins were positioned more outboard to reduce aerodynamic interference with outer nacelle.
- The structure layout of the transition area centre body/outer-wing was designed new.
- The structure layout for engine integration was adapted from [D3.2-6] to a curved trailing edge in FW2 instead of the straight one in FW1.

The cargo door arrangement was redesigned to the following guidelines:

- Minimum cargo loading/unloading time;
- Minimum complexity and weight of cargo loading system;
- Minimum clearance of ground vehicles;
- Sufficient ground clearance of cargo door;
- Minimum number of frames between cargo door and other structure cut-outs.

From an operational point of view the optimum cargo door position was found to be between door 3 and door 4. Design is for loading/unloading direction perpendicular to cargo hold‘s longitudinal axis. A slight relocation of two doors and related cross-aisles in the cabin was introduced to fulfil structural constraints from OAD.

The flap layout for HQ was integrated into the given planform. Flap chord limits were set to about 5m or 25% chord whichever is less. With the conventional rudders for lateral control, no winglets were envisaged, as efficiency was expected to be low. They could have been reasonably integrated only if together with the split-flap ailerons they had allowed to remove the fins and thus an inboard extension of TE flaps.

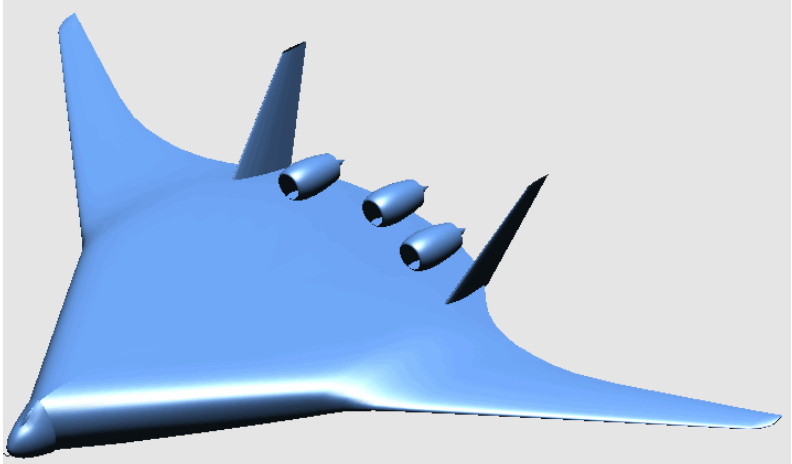


Figure 18: Starting point for the FW2 configuration

The FW2 final updated configuration is documented in [D1.2-9], comprising:

- Assessment of weight, performance and HQ;
- A summary of the work done in Tasks 2.2 and 3.2;
- A comparative collection of characteristic data for Flying Wing versus Conventional Reference Aircraft.

Flying Wing results	**VRef100***	**VELA3**	**FW2**
Area per pax (m^2)	0.983	0.967	1.13 (**+15%**)
L/D	22.4	22.1	23.4
MWE (t)	330	327 (-0.9%)	309 (-6.4%)
MTOW (t)	704	700 (-0.6%)	630 (-9.9%)
Block fuel (t)	239	236 (-1.2%)	194 **(-18.9%)**

*VRef100: conventional architecture, 750-pax double-decker, 100-m span, design range 7650 nm

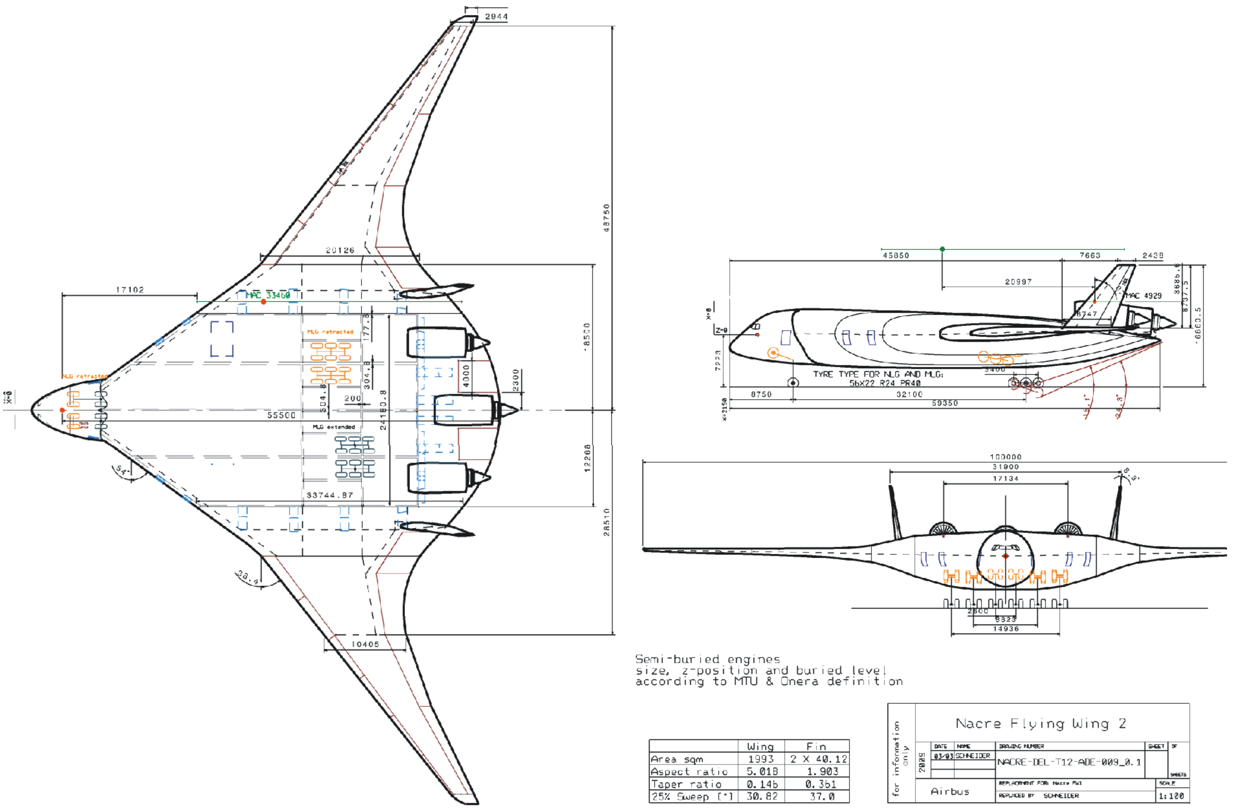


Figure 19: FW2 final updated Flying Wing configuration

True Passenger-driven “Flying Cruiseliner”

On the “True PDA” part, further to the guidelines and key parameters provided in [D1.2-1] to Task 4.2, the Task 1.2 Leader monitored the work on the cabin concepts to ensure proper evaluation back in ST1.2.3. In this frame, three cabin concepts (H-Cylinder, V-Cylinder and V-Lens) were integrated into aerodynamic shapes, which were delivered by partners. Modifications of positions of forward and rear cabin compartments and staircases during the course of the studies led to length reduction, thus reduced wetted area. From these studies performed on optimisation of aero shapes, the conclusion was drawn that H-Cylinder requires the least wetted surface whereas V-Lens and V-Cylinder require the same larger surface.

It was decided to investigate three structural concepts for phase 3 within Subtask 4.2.2:

- Oval cross section without struts
- Oval cross section with one centre row of struts
- Quadruple bubble cross section with two lateral rows of struts

A procedure was defined for Subtask 4.2.2:

- Use 11 frame cylindrical fuselage section (only feasible for H- and V-Cylinder)
- Load it with internal pressure, bending moment, torsion
- Design the centre (i.e. the 6th) frame and assess structure (with cross-check by TsAGI)
- Compare results

The required cargo hold volume was determined: For a capacity of 200 passengers, a baggage weight per passenger of 40kg (first class standard), an assumed baggage density of 160kg/m^3, volume of LD3 container of 4.53m^3, load factor for LD3 container of 0.85, the resulting number of required LD3 containers is 14. For a container length of 1.54m the resulting required cargo hold length for double row configuration is less than 12m.

Final Conclusion

Based on VELA, NACRE extended the Flying Wing investigations in many fields. Despite that the wide scope of somewhat independent detailed component studies (e.g. in Task 3.2) added to a complex integration of the results into a single aircraft configuration, the intermediate FW1bis reflected already the steady progress in configuration knowledge and design skills for Flying Wing development. A lot of the value added by the NACRE studies, in particular Task 2.2, which went into much more detail than VELA, is that many of the assumptions made or expectations raised in VELA could be evidenced and confirmed in NACRE.

The over-wing engine arrangement investigated in Task 3.2 and integrated into the FW2 final updated configuration offered new challenges for the integration, where no experience from previous projects was available. More importantly Task 3.2 delivered valuable results on semi-buried engine positioning concepts.

The FW2 final configuration update required more geometry modifications than expected and design iterations between the disciplines (cabin, structures, aerodynamic design, OAD). As a result of multiple OAD loops and higher maturity of the configuration, the MTOW assessment of the latest version could be reduced by 10% versus its FW predecessors VELA3 and FW1 or the conventional VRef100 reference configuration. The aerodynamic efficiency (L/D) increases from 22 for VRef100 / VELA3 / FW1 / to more than 23 for FW2, in spite of increased passenger comfort, cabin volume and subsequent wetted surface. Altogether this translates to an impressive 19% block fuel reduction for FW2 versus the conventional VRef100 reference configuration.

The results of the true PDA part of Task 1.2, which was in strong interaction with Task 4.2 for all cabin, structural and aerodynamic detailed design activities, are described in Task 4.2 section.

Task 1.3 – Simple Flying Bus A/C (SFB)

Task objectives at beginning of the project

The primary objective of Task 1.3 was to drive the research on innovative aircraft component concepts with the following targets:

- to reduce the cost of acquisition, operation, and maintenance from the aircraft operator perspective;
- to reduce the cost of manufacturing, customisation, and support from the aircraft manufacturer's perspective.

The key aircraft SFB components to be addressed are: advanced fuselage, efficient manufacture-driven wing, innovative empennage, powerplant systems concept (engine and integration). Baseline aircraft concept and engine are defined in Task 1.3 to serve the multidisciplinary investigations per component in WP2, WP3 and WP4. Overall aircraft integration of viable concepts is performed for the challenging assessment of overall aircraft economics.

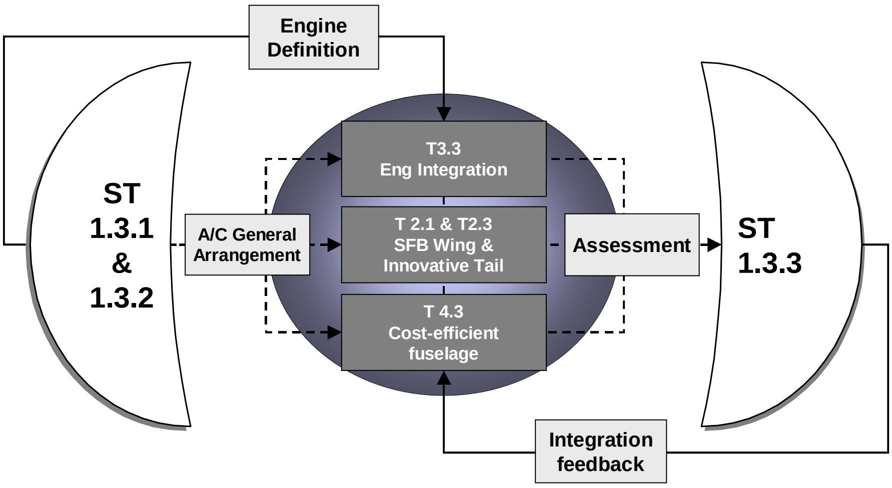


Figure 20: Task 1.3 – SFB domain flowchart

Subtask 1.3.1 Definition of Simple Flying Bus Aircraft baseline

Airbus was in charge of defining a conventional under-wing engine medium-range 200-250 pax reference aircraft to be used in the course of the project as the baseline SFB reference aircraft (RSFB).
Preliminary definition of a challenging SFB aircraft was then to be proposed and sized by Airbus, featuring basic requirements and orientations for the low-cost targeted aircraft concept, in terms of:

- Systems and system location and space provisioning (e.g. cockpit, landing gear, doors and windows, windshield…);
- Structure and manufacturing simplification;
- Economics analysis (recurring, non-recurring costs).

Three-view drawings for WP2, WP3 and WP4 detailed component investigations would be produced for this SFB aircraft concept together with the complete set of data (weight, performances, economics…) required to challenge the specific design objectives of the domain.

Subtask 1.3.2 Definition of engine

Based on thrust level requirements provided by Airbus, Snecma would define an advanced affordable engine concept to be conventionally installed under the wings, targeted at low acquisition and low maintenance cost.

Studies would consist in defining a performance cycle answering the objectives of the SFB aircraft. From this cycle, a cross section of the powerplant system would be realized. It would contain the technological definition of the engine, the nacelle as well as the installation of equipments and EBU. These studies would allow supplying the weight of the powerplant system and the main geometrical characteristics. These studies would be completed by the prediction of fuel burn and of noise emission. The aspects of maintenance cost and low acquisition were to be taken into account.

Subtask 1.3.3 Simple Flying Bus Aircraft Integration

The objective of ST1.3.3 was to ensure proper monitoring and Integration of WP2, 3 and 4 outcomes and refinement of SFB concept for the assessment at overall aircraft level focused on lowest cost for end user:

- Concept component viability assessment for use in future affordable aircraft;
- Performance assessment;
- Economics assessment;
- Cost mitigation analysis;
- Recommendations for the development of missing design capability.

Technical achievements

In Year 1, discussions regarding the definition of preliminary basic requirements were held. Due to needs of the various “task customers” ST2.1.3, Task 2.3, Task 3.3 and Task 4.3, a set of requirements for the baseline SFB aircraft took a lot more effort to define than expected. The requirements allowed making the best use of the component works in those “customer tasks”. After several meetings, it was decided to use the following top-level requirements, based around the scenario of a single-aisle short-range aircraft with a high production rate:

- Design payload: 180 passengers in a 2-class short-range layout
- Design range: 3000 nm
- Cruise speed: Mach 0.78
- Initial cruise altitude: 35000 ft
- Take-off field length: 2000 ft
- Time to climb (to ICA): <25 mins.
- Approach speed: <135 kts
- Nominal entry into service: 2013

One of the reasons for the choice of these requirements was for nominal commonality with NACRE Pro-Green, who also used a single-aisle, short-range aircraft for their studies (albeit with some variations, e.g. cruise speed). Although there was no intention for direct comparison of the results of SFB and Pro-Green, the common requirements allowed some synergies, such as a common fuselage cross-section and cabin layout.

Working from the above requirements, attempts were made to develop a “low-cost” SFB configuration. After significant effort, the conclusion was reached that all “low-cost” configurations studied resulted in excessive performance penalties. In addition, the previous research project “NEFA” had concluded that although a V-tail had performance benefits (less wetted area), the additional systems complexity resulted in no cost benefits over a conventional empennage. Based on these conclusions, a conventional configuration was developed as the SFB Baseline, with the following design features:

- A conventional aft-swept wing with a kinked trailing edge and wing-mounted main landing gear and underwing engines, but of assumed CFR construction, to allow useful research by ST2.1.3.
- A empennage of conventional HTP and VTP, with a target of 20% area reduction (achieved in NEFA by a V-tail), giving Task 2.3 a performance recovery objective.
- A conventional underwing powerplant configuration, giving Task 3.3 the objective of reduced DMC (Direct Maintenance Cost) engine, and reduced manufacturing cost pylon and reduced complexity nacelle.
- A conventional fuselage of circular cross-section and with a low-mounted wing to allow useful research by Task 4.3

On 27 June 2006, a handover meeting was held to transfer Task leadership from Werner Tesch to Keith Macgregor. This involved explanation of all work carried out up to that date within A-D and transfer of all documentation and working files to A-UK.

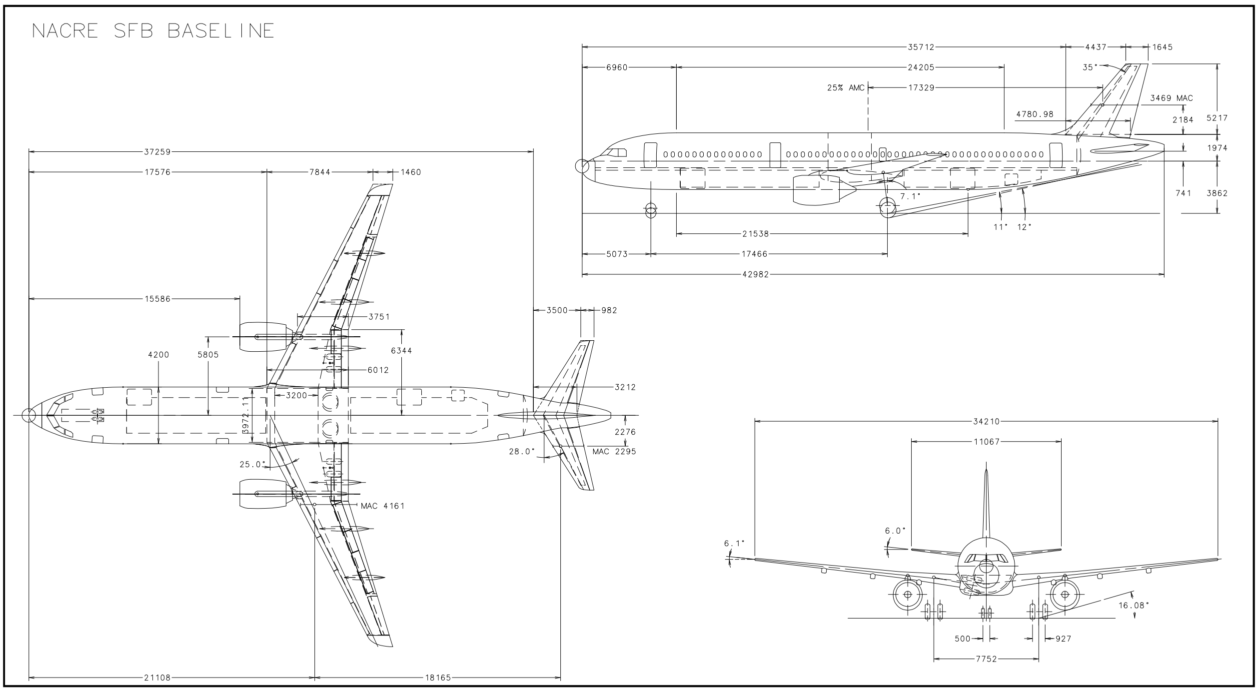


Figure 21: General arrangement of SFB Baseline configuration

The deliverables [D1.3-1] and [D1.3-2] were issued and distributed to relevant Task leaders and all WP leaders on 18 August 2006. The document was officially withdrawn the following day following some of the information contained within it. At the meeting held with Geoff Thomas (EU Expert Reviewer for SFB) on 21 August, it was decided to re-format and re-issue [D1.3-1]/[D1.3-2] deliverable into two separate documents, a "mini-DBD" (Data Basis for Design) of the Baseline configuration and a "Design Space" document containing recommendations and guidelines for component studies. The first of these, the [D1.3-1]/[D1.3-2] "Mini-DBD" were completed and issued on 4 December 2006.

Regular "SFB Workshops" were identified as an important way of improving and encouraging communication between the SFB component tasks. These were not intended to be management meetings, but to provide the opportunity for SFB Task leaders to discuss technical issues in a trans-component environment.

SFB Workshop #1 was held at Airbus in Toulouse on 26th April 2007, attended by representatives from each SFB component Task. The main objective of this meeting was for each component Task to openly discuss a range of relevant issues (i.e. definition of component "boundaries", definition of how the components fit together, information needed and results to be produced).

Following this meeting, a draft version of the SFB "Design Space document" was produced, incorporating the component input at Workshop #1. The purpose of this document was to provide consistent overall-aircraft-level guidance and targets for the NACRE SFB component tasks. It is not a formal NACRE deliverable, but complements the Concept Definition document [D1.3-2] and was updated throughout the project with additional information as it became available.

SFB Workshop #2 was held on 11th July 2007 at Airbus in Toulouse. The main objective was to review the content of the draft version of the Design Space document, followed by open discussion of any topics of relevance to the cross-component attendees (i.e. empennage sizing criteria). The first version of the Design Space document (ref. NACRE-REP-T13-AUK_001_1.0) was issued on 20 August 2007.

SFB Workshop #3 was held at Airbus in Toulouse on 30th October 2007. The main objective of this meeting was a discussion about costing issues and guidance by A-D. This then led to the development of the costing model and baseline for use in providing cost guidance for the SFB component tasks and the final economic evaluation task to be performed by Task 1.3.

SFB Workshop #4 was held at Airbus in Toulouse on 6th March 2008. The main item for discussion at the meeting was the SFB Costing Baseline, which had been developed; with time allocated for relevant cross-component discussions.

Year 4 and the extension phase were useful in consolidating the SFB component Task work, leading towards the final Task 1.3 milestone (M1.3-3) and deliverable [D1.3-4], the evaluation of the SFB component research carried within NACRE at overall-aircraft level.

In the middle years of NACRE, the key roles of Task 1.3 have been to facilitate communication between the SFB component tasks and provide overall-aircraft level support as necessary. This role had continued in year 4 and during the extension, particularly focusing on the fuselage and wing tasks as the powerplant and empennage tasks move towards closure. Technical support to Task 4.3 has included drag assessments of different fuselage geometries. Technical support to Subtask 2.1.3 has included derivation of a number of different wing planforms.

Slow definition of the NACRE SFB Baseline configuration early in NACRE had caused many of the SFB component tasks to run to revised work plans. Although the original Task 1.3 schedule planned for M1.3-3 to be completed by Month 42 (September 2008) and [D1.3-4] to be completed by Month 45 (December 2008), it was decided that some slippage could be planned to allow more time for the component studies to work, as this is arguably where the real benefit of the NACRE SFB research activities lies.

The final technical evaluation task (M1.3-3) was deliberately delayed to allow the SFB component tasks as long as possible to complete useful research work. A request for technical and cost information about the final SFB component concepts was finally sent to the SFB component tasks in Month 47 (February 2009) and relevant information about the final components (e.g. geometry, weights, aerodynamics, materials, manufacturing concepts) was collated by Task 1.3 during Month 48 (March 2009).

It had previously been discussed and agreed that to gain the most benefit from the final SFB evaluation task, each component concept would be evaluated separately and the results compared against the SFB Baseline to show the benefits of each component research at overall-aircraft level. This decision results in a total of five final configurations needing evaluation:

- A “wing configuration” with the final wing concept applied to the SFB Baseline
- An “empennage configuration” with the final empennage sizing applied to the SFB Baseline
- A “powerplant configuration” with the final engine, pylon and nacelle concepts applied to the SFB Baseline
- A “fuselage configuration” with the final fuselage and wing-fuselage interface concept applied to the SFB Baseline
- A “complete configuration” incorporating all the final components together

Each of these evaluations required technical and economic assessment as follows:

1. Modify SFB Baseline to incorporate final component characteristics
    - Geometry, Mass, Drag, etc.
2. Resize modified aircraft as necessary to meet aircraft requirements
    - Technical characteristics of resized aircraft compared with SFB Baseline
3. Evaluate Recurring Cost (RC) of resized aircraft
    - Results presented relative to SFB Baseline
4. Evaluate Direct Operating Cost (DOC) and Manufacturer’s and Operator’s Internal Rate of Return (IRR) of resized aircraft
    - Results presented relative to SFB Baseline

The results of the evaluation of each SFB component Task at overall-aircraft level are as follows:

- Wing: The final wing concept developed by ST2.1.3 featured a simplified planform with centreline joint, straight spars, unkinked trailing edge, 1 flap and 3 flap tracks.
  - Perceived benefits: Lower wing cost due to reduced complexity and part count
  - Penalty: Increased area due to large falsework between rear spar and flap L.E. caused by main landing gear
  - Technical assessment at aircraft level showed that the increased drag caused by the larger wing resulting in a resized aircraft with larger engines, increased fuel burn, increased design weights, slightly increased wing area and component weights.
  - Economic assessment showed that any benefit from the simplified wing concept was outweighed by the larger, heavier aircraft, resulting in a 2.4% RC increase compared to the SFB Baseline, equating to a 1% decrease in manufacturer's IRR. This, combined with the higher fuel burn resulted in a 3.7% DOC increase compared to the SFB Baseline, equating to a 2.77% reduction in operator's IRR. Converting the manufacturer's IRR into operator's IRR results in a decrease of 3.4% in operator's IRR.

- Empennage: Task 2.3 work achieved 9% HTP and 15.3% VTP area reductions relative to a conventionally sized empennage using double-hinged control surfaces. For fairness this was evaluated against an "Alternative SFB Baseline" incorporating an unscaled empennage.
  - Perceived benefits: Reduced drag, reduced material
  - Penalty: Increased system complexity due to double-hinged control surfaces
  - Technical assessment at aircraft level showed that the reduced drag of the smaller empennage resulted in a resized aircraft with marginally lower design weights, engines and fuel burn. A key result is that the significant reduction in empennage size only resulted in a marginal benefit at aircraft level due to the relatively small influence of the empennage.
  - Economic assessment showed that the smaller aircraft resulted in a negligible reduction in RC and in manufacturer's IRR. This, combined with the lower fuel burn resulted in a marginal 0.3% DOC improvement compared to the SFB Alternative Baseline, equating to a 0.2% improvement in operator's IRR. Converting the manufacturer's IRR into operator's IRR results in a decrease of 0.2% in operator's IRR. A key result is that the marginal reduction in aircraft size could easily be outweighed if the double-hinged rudder an elevator increased system costs.

- Powerplant: Task 3.3 developed an engine with reduced DMC and improved SFC, a low cost pylon and a simplified nacelle design.
  - Perceived benefits: Reduced DMC, reduced fuel burn, lower part count, and simplified maintenance.
  - Penalty: None.
  - Technical assessment at aircraft level resulted in a resized aircraft with a smaller wing, lower design weights, engines and fuel burn.
  - Economic assessment showed that the smaller aircraft resulted in a 1.6% reduction in RC, equating to a 0.6% increase in manufacturer's IRR. This, combined with the lower fuel burn resulted in a 0.7% DOC improvement, equating to a 0.5% improvement in operator's IRR. Converting the manufacturer's IRR into operator's IRR results in an increase of 0.9% in operator's IRR.

- Fuselage: Task 4.3 developed a CFRP fuselage made of fewer sections and large panels with simplified tailcone geometry. In addition, a novel wing-fuselage join-up concept was developed where the entire tip-to-tip wing is inserted into a large unpressurised cut-out and fixed using a small number of pin-joints.
  - Perceived benefits: Reduced part count, reduced joints, much simplified wing-fuselage join-up on the FAL.
  - Penalty: A slight weight penalty was reported, although that was later disputed, marginal drag increase due to simplified tailcone geometry.
  - Technical assessment at aircraft level showed that the increased fuselage weight resulted in a resized aircraft with a larger wing, higher design weights, larger engines and higher fuel burn. If the disputed fuselage weight increase were proved to be incorrect then the aircraft would probably remain its original size and weight.

  - Economic assessment showed that any benefits from the simplified fuselage construction and wing-fuselage concept were outweighed by the larger, heavier aircraft, resulting in a 1.3% RC increase compared to the SFB Baseline, equating to a 0.6% decrease in manufacturer's IRR. This, combined with the higher fuel burn resulted in a 0.6% DOC increase compared to the SFB Baseline, equating to a 0.5% reduction in operator's IRR. Converting the manufacturer's IRR into operator's IRR results in a decrease of 0.8% in operator's IRR.

- Complete configuration: Incorporating all the final component concepts
  - Technical assessment at aircraft level showed that beneficial effects of the powerplant and empennage were outweighed by the penalising wing and fuselage, resulting in a resized aircraft with a larger wing, higher design weights, larger engines and higher fuel burn.
  - Economic assessment showed that any benefits from the simplified component concepts concept were outweighed by the larger, heavier aircraft, resulting in a 5.1% RC increase compared to the SFB Alternative Baseline, equating to a 1.5% decrease in manufacturer's IRR. This, combined with the higher fuel burn resulted in a 4.2% DOC increase compared to the SFB Alternative Baseline, equating to a 3.2% reduction in operator's IRR. Converting the manufacturer's IRR into operator's IRR results in a decrease of 4.1% in operator's IRR.

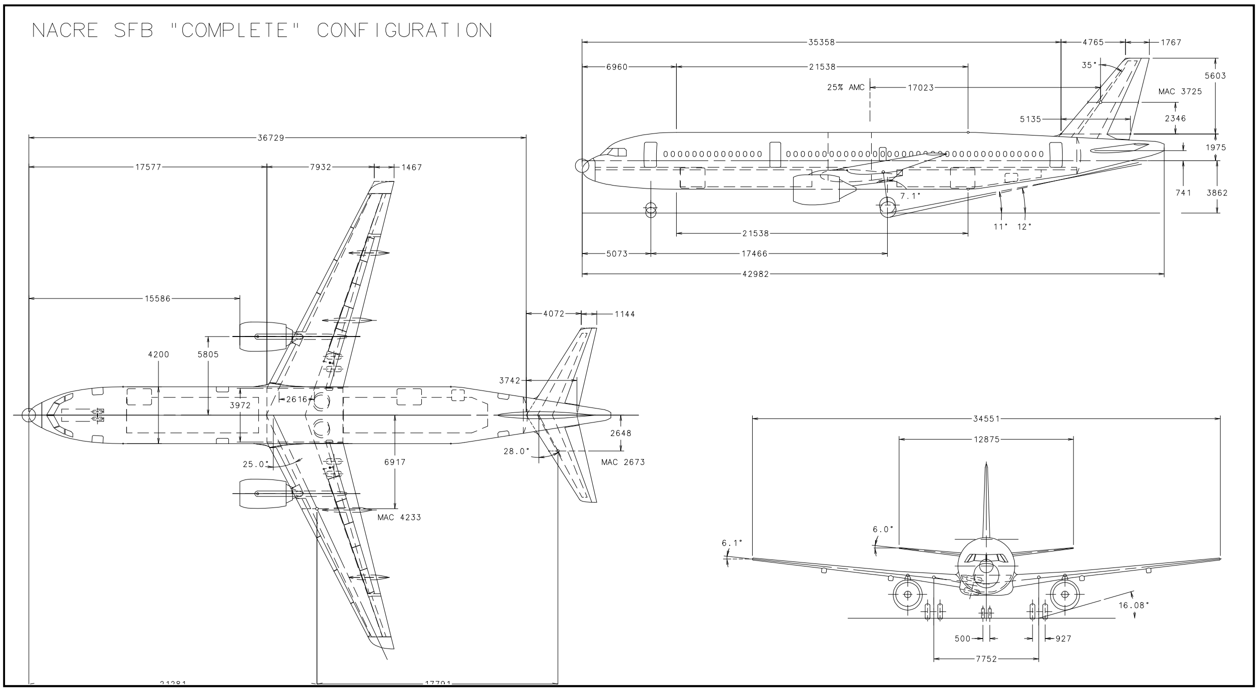


Figure 22: General arrangement of resized SFB Complete configuration incorporating all final component concepts

The final SFB component concepts, technical evaluation, economic evaluation, results, conclusions and various recommendations are comprehensively documented in the final Task 1.3 deliverable [D1.3-4], which was completed and issued in December 2009.

Final Conclusion

Conclusions for each SFB component concept can be summarised as follows:

- Wing (ST2.1.3):
    - Simplified unkinked planform resulted in a significantly larger wing area. Resulting resized aircraft was larger, heavier and less efficient
    - Component-level cost benefits of simplified wing were outweighed by larger aircraft, resulting in higher costs overall for both manufacturer and operator
- Empennage (Task 2.3):
    - Reduced area HTP and VTP achieved using double-hinged control surfaces. Resulting resized aircraft was marginally smaller lighter and more efficient.
    - Effectively no cost change for manufacturer or operator, but could easily become a penalty if double-hinged controls increased system costs
- Powerplant (Task 3.3):
    - Reduced engine DMCs and fuel burn, low-cost pylon and simplified nacelle system. Resulting resized aircraft was smaller, lighter and more efficient
    - Smaller aircraft and more efficient engine resulted in lower costs overall for both manufacturer and operator.
- Fuselage (Task 4.3):
    - Simplified fuselage construction, novel fuselage-wing join-up concept. Resulting resized aircraft was larger, heavier and less efficient
    - Component-level cost benefits of simplified fuselage and wing-fuselage join-up were outweighed by larger aircraft, resulting in higher costs overall for both manufacturer and operator.
- Final “Complete” configuration:
    - Benefits from powerplant and empennage were outweighed by penalties from wing and fuselage. Resulting resized aircraft was larger, heavier and less efficient
    - Component-level cost benefits were outweighed by larger aircraft, resulting in higher costs overall for both manufacturer and operator

Beyond the component-level conclusions, a number of wider conclusions can be drawn:

- The wing and fuselage tasks focused on reducing component cost by reducing complexity, but each incurred a technical penalty (i.e. increased drag or weight). In aircraft-level evaluation it was found that these minor local penalties resulted in a worse aircraft, the costs of which outweighed any local level benefits from component simplification. It was clear that the negative effect of component growth was underestimated during NACRE.
- Task 2.3 achieved good empennage area reductions. NACRE SFB did not show any meaningful cost saving from this work when applied to NACRE SFB, but this technology may show more benefit when applied to a more fuel burn-driven scenario such as NACRE Pro-Green or a long-range aircraft design.

The previously developed “Design Space” document had continued to evolve during the whole project. The final evolution of this document was included as appendix to the final Task 1.3 deliverable, [D1.3-4]. Collation of various “end-of-NACRE” component concepts, technical re-evaluation of the aircraft to ensure that the aircraft “works” and economic comparison of the “start-of-NACRE” and “end-of-NACRE” configurations were provided at a top-level.

Task 1.4 – Innovative Evaluation Platform

Task objectives at beginning of the project

The goal of Task 1.4 was to study an alternative to existing test practices by assessing and showing the benefits of an Innovative Evaluation Platform (IEP). The IEP should be considered as an additional test facility, which in some cases could be competitive with the existing test facilities not only in terms of cost, but also by providing new capabilities and/or more availability or flexibility. If the critical design review after 18 months of the project clearly showed the added value of a IEP (Subtask 1.4.1) a decision would be made whether to proceed or not with the design and manufacturing/modification of a model (Subtask 1.4.2). This IEP was intended to be evaluated in flight (Subtask 1.4.3) to challenge the expected added value compared to the existing experimental tools. The initially limited knowledge of the potential and benefits of this type of experimental platform called upon studies to gain more experience in this field.

The work in Task 1.4 was divided into three Subtasks. The first Subtask covered the first 18 months of the project. A Critical Design Review (CDR) would then take place to decide on further development. Based on the outcome of Tasks 1.1, 1.2 and 1.3 it would here be decided whether an IEP should be built or not and if so, which novel aircraft concept to select.

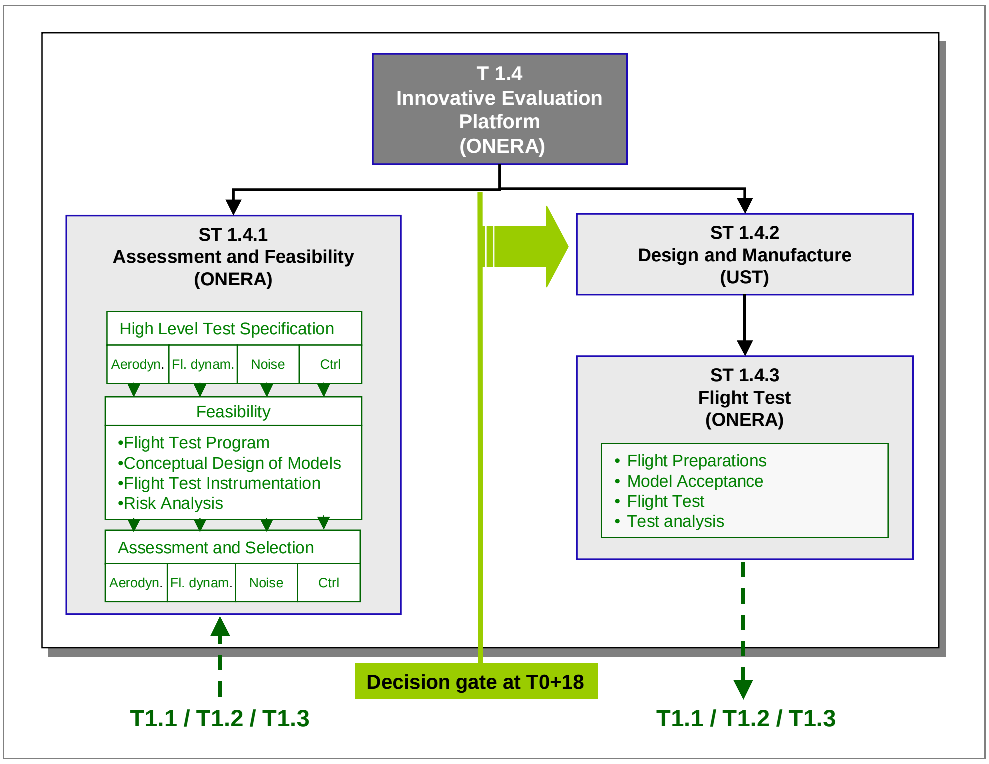


Figure 23: Task 1.4 Flowchart

Subtask 1.4.1 Assessment and Feasibility

The activity in this Subtask should be general enough to be applied to several cases, the objective being to provide a decision method for the most appropriate solution for the concept and the type of problem to be studied. The activity included a high-level test specification where initial aspects of aerodynamics, flight dynamics, noise, controllability etc would be investigated. Feasibility studies would be performed for a flight test programme, flight test instrumentation, conceptual design of models, risk analysis, cost etc. Methodologies and tools for assessing the feasibility of a FSM in comparison with traditional and non-traditional test facilities (e.g. Onera's B20 and SACSO) would be developed. An assessment and selection phase would be carried out towards the end of these Subtasks, based on the studies of aspects of aerodynamics, flight dynamics, noise, controllability etc. The work in this Subtask would not follow a strict time line and the work in different aspects was to be strongly interrelated and coupled. The results from these studies would be applied to the configuration(s) selected by Tasks 1.1, 1.2 and 1.3.

Subtask 1.4.2 Design and Manufacture

Following the outcomes of the Critical Design Review, Subtask 1.4.2 would enter into the design and manufacture of the flying scale model, based on the selection made towards the end of Subtask 1.4.1. Definitions of the 3D geometry etc. would be input from Tasks 1.1, 1.2 and 1.3. Scaling from aircraft to model geometry would be evaluated and performed. A preliminary design needed to be done with a survey of materials, construction principles and definition of systems. Assumptions of loads were to be done as well as structural design and stress calculations and thereafter the design would be frozen and the drawings prepared.

The potential use of existing hardware available in Europe should be considered to make best use of available budget.

Both airborne and ground based test equipment would be needed, however exactly which equipment depended on the kind of tests that were to be performed. Some of the equipment was available beforehand and some needed to be designed and manufactured. The model and its systems would be manufactured by the workshop of one or two partners. This needed to be preceded by definition and manufacture of tooling.

Subtask 1.4.3 Flight Test

The test preparation phase would start in parallel with Subtask 1.4.2. The availability and selection of test range needed to be done. The procedure of gaining an airworthiness certificate was coupled to this choice as well as the model properties. A flight test procedure needed to be defined based on the type of tests that would be carried out. The partner who was to perform the flight tests would perform a model acceptance procedure where the model geometry, structural integrity and dynamics would be tested against the specifications. Also the systems (propulsion, control/navigation, data acquisition) would be tested for both the airborne and the ground based equipment.

Technical Achievements

Design Process

With the objective of being a new tool to investigate certain disciplines, the IEP can be considered as a test facility. Simultaneously, the research is based around the idea of a flying test bed. The IEP is then both a flying platform and a test facility. Because of complex interactions between these characteristics, the IEP team had set up up a thorough design process to define a system of systems meeting stringent specifications.

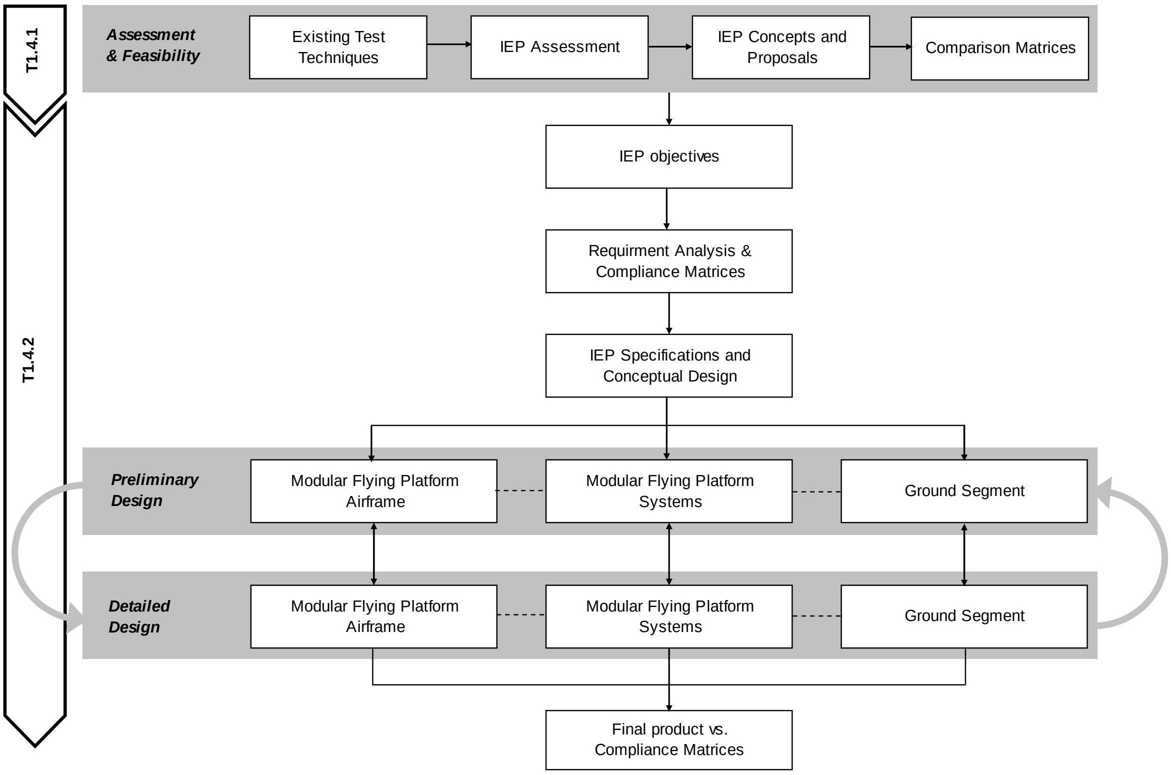


Figure 24: IEP Design Process

As an initial step, the design team starts by analyzing the studies associated with the modularity requirement. A modular airframe involves indeed a structural analysis as well as a stability and control assessment for all possible configurations. This long and complex design loop is even more complex in the case of Blended Wing Body arrangement. Because of the schedule and budget constraints of the NACRE project, the design team decides to aim a reduced modularity enabling the study of advanced evolution of the current transport aircraft. NACRE references in this case for the configuration are the Simple Flying Bus and the Pro Green Aircraft (PGA). Since a key feature of this latest concept is its low noise characteristics and the IEP targets to investigate noise aspects, the design team decides to base the reference configuration of the IEP on the PGA.

The modularity is then validated by offering the possibility to test a different empennage solution on the same aircraft. Always in order to limit the complexity (and thus costs) of the internal systems, it is decided that the second aircraft arrangement must also have the engines in an aft position. After a qualitative assessment of the possible alternatives, a T-Tail solution is chosen. The selected configurations labelled IEP-15 and IEP-21 are illustrated in Figure 25 below.

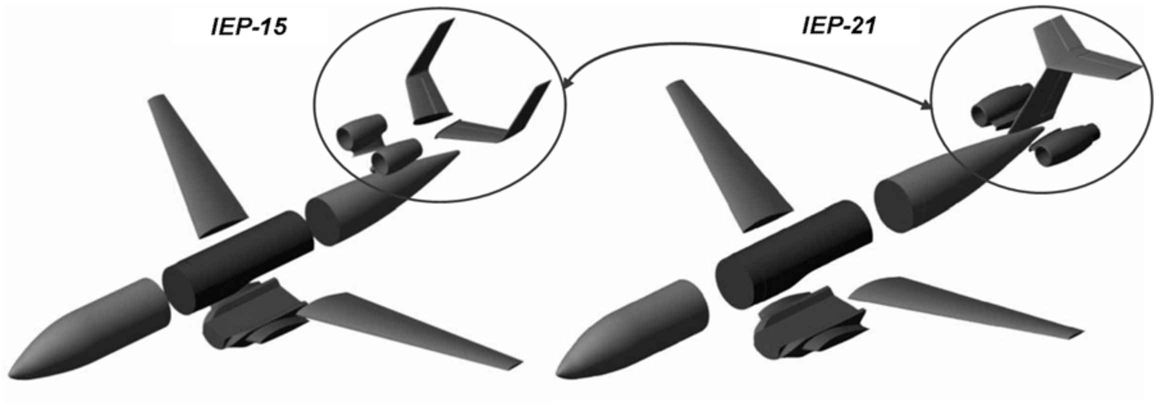


Figure 25: Conceptual 3D models of the Modular Flying Platform

IEP sizing

The key requirement to be met by the flying platform is the Froude similarity with a full scale reference aircraft. In addition to this element, the design team had to consider various constraints:

- Operational constraints (the platform must fly at low altitude to enable visual contact with the external pilot
- Geometrical constraints (the platform size must be limited to avoid logistic issues during operations
- Available engines on the market

In the end, the flying platform has a reference surface of about 1.8 m², a wing span and total length of 4.2m, a take-off gross weight of 145 kg and two turbojet engines (usually used on model aircraft).

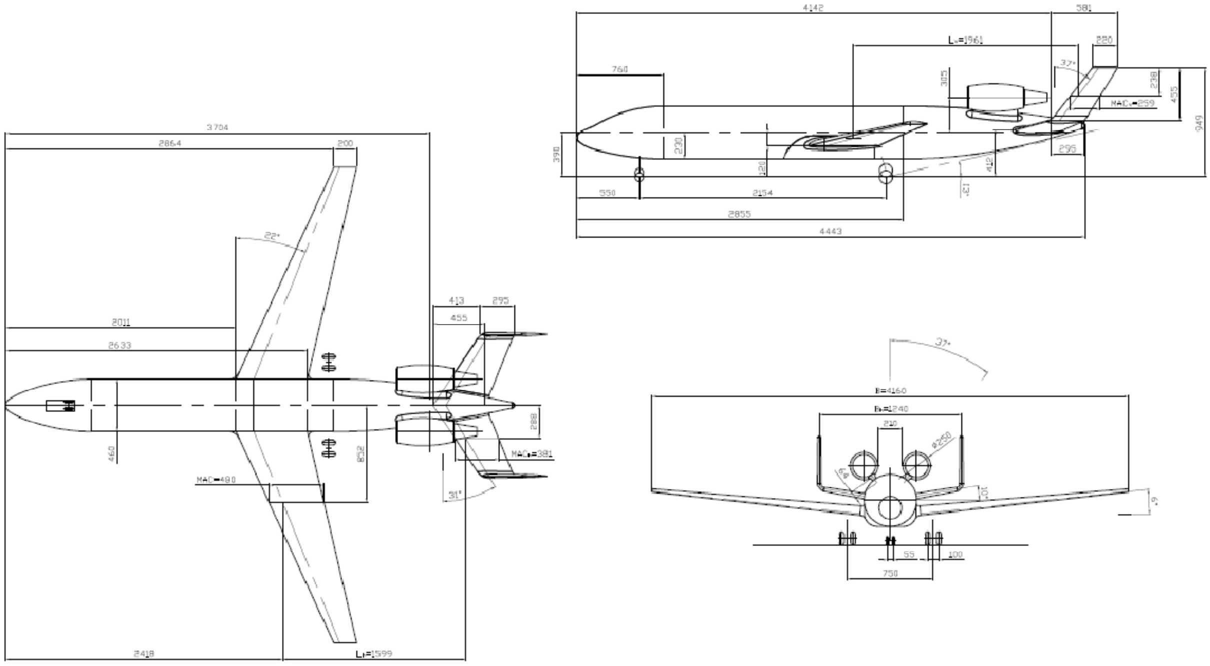


Figure 26: IEP 15 preliminary sizing

Engine

Onera developed a model for take-off performance analysis that was used to define the engine power requirements. Following the engine selection, Onera has proposed a specific shape for the nacelle. After the manufacturing of the nacelle, the engine noise characteristics have been recorded during anechoic wind tunnel tests in the Netherlands. Such tests enabled the Task 1.4 team to have a noise reference to be used during the flight test campaign.

Figure 27: Engine noise characterisation

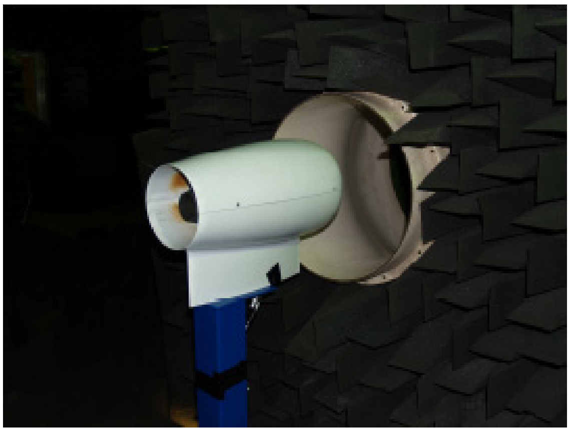


Figure 28: Assessment of nacelle's effects on noise emission

Aerodynamics and Stability and control

CIRA provided aerodynamic data about the airfoils to be used on such an aircraft. Following this initial step, PW and Onera used general rules used in aircraft design to freeze the configuration. Subsequently, NLR made some CFD calculations of IEP 15 and IEP 21 in order to build an aerodynamic dataset. In the end, this database has been integrated in a simulator to verify the flying qualities of both IEP configurations.

Structure design and manufacturing

The 3D internal structure of the fuselage, wing and tailplane (including two ailerons, flaps in six pieces and elevators in three pieces) was defined by PW. The model mould material was purchased by UST and delivered to Onera (Lille) where the model moulds were manufactured. These were shipped to PW where preparations to manufacture the model fuselage was completed. The wing and the tail section (mould and structure) were manufactured when the final findings of the stability and control assessments by NLR was available.

Regarding the manufacturing, the initial step had been the manufacturing of the moulds for the fuselage and the wing. With these moulds, it was possible to manufacture the entire fuselage and to initiate works on the wing. To complete the Wing + Body section of the aircraft, the following tasks were completed by PW:

- Assembling of the cables and actuators inside the wing;
- Closing the wing structure;
- Mould Manufacturing of the central part of the wing;
- Manufacturing of central part of the wing;
- Manufacturing and assembling of the wing-joiners.

In order to verify the integrity of the Wing and Body assembly, PW performed static load tests to assess the wing deformation. The positive results (small elastic deformation) have been subsequently presented in a specific report, which was integrated in [D1.4-7] (Model acceptance report).

Recovery system

Different solutions for the recovery system presented by PW in cooperation with Onera have been discussed. PW analysed how the different parachute compartment locations would influence on reliability and safety in emergency situations. The recovery system design was frozen. The position on the IEP is fixed and the parachute system will be the same as for the VELA Model with different modifications in terms of redundancy. Various tests have been carried out to verify the reliability of the recovery system opening, depending on airspeed and angle of sideslip.

Figure 29: Recovery system tests at University of Stuttgart

Landing gear

Given the intermediate size of the IEP, there was no Commercial-Off-The-Shelf (COTS) solution for a retractable landing gear to be installed. STZAFL decided then to purchase an especially design landing gear from the Institute of Aviation (IoA) in Poland. The provided solution required an important design time and the set-up of the absorbers has been made after a large series of tests. During the integration phase, several changes have been made to the structure to allow a proper fitting and further modification to the on-board systems have been carried out to lock the landing gear in its extreme positions.

Systems design

The system design was done by UST in cooperation with electronics specialists from the subcontractor STZAFL. Actuator tests were performed by UST and it was found that additional tests were necessary. An actuator test device was planned to verify the actuator performance under real flight conditions. The “Iron Bird” built functioned as a test platform and be equipped with the system components.

Regarding the systems development, important studies on the IEP autopilot have been completed by NLR and UST. In particular, the implemented algorithms have been tested through a series of simulations. These studies have been also reported in a document integrated in [D1.4-3].

UST developed the software to control the movable surfaces of the IEP. A series of test on the Iron Bird were conducted to validate some of the design decisions. UST completed the following tasks in order to have a reliable IEP control system:

- Manufacturing of CSM Modules for Wind tunnel test;
- Redesign of Iron Bird actuator integration to latest design;
- Testing of Electronic test equipment for WTT on the Iron Bird;
- Further development of WTT test software;
- Testing of the software on the Iron Bird;
- Hardware supports manufacturing for the electronic integration in IEP (integration scheme applicable to WTT only).

Figure 30: Iron Bird tests of the IEP

Noise equipment

In addition to the on-board systems dedicated to the control and navigation of the IEP, NLR team designed a specific unit for noise measurements. This unit stores the measurements made by the two flush mounted microphones on the fuselage and generates a known noise to be used during flight tests to better assess the shielding effects of the configuration of interest. The electrical and mechanical interface with the IEP avionics has been agreed with UST and PW.

Wind Tunnel Tests

The specific equipment for WT Tests had been subsequently integrated within the IEP airframe by PW and UST through an efficient collaboration. After the integration, it was possible to test and calibrate all actuators, flap deflections and flap force sensors. Figure 31 and Figure 32 below illustrate the completed airframe for both IEP configurations in the test section [D1.4-7]. These tests have been very valuable because they not only allowed the design team to get more accurate data on the aircraft aerodynamics but also tested the on-board systems for an extended period.

Figure 31: IEP15 Tested in the Wind Tunnel

Figure 32: IEP21 Tested in the Wind Tunnel

Vibration tests and flutter analysis

Following information gathered during the wind tunnel tests, PW performed vibration tests in order to accurately calculate the flutter speed of the flying platform. During these tests, the IEP was suspended to avoid ground loads and the internal systems were replaced by local masses in order to simulate the real inertial properties of the aerial vehicle. Then, specific exciters generated a movement with a given frequency and the response of the aircraft was measured through an important number of accelerometers. The recorded measurements enabled to validate a high fidelity structural model used to determine flutter speed.

Figure 33: IEP 21 during vibration tests

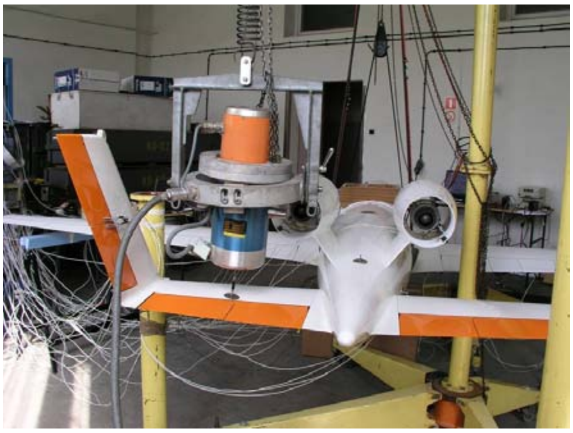


Figure 34: Exciter installed on IEP 15

Ground Tests

The ground tests of the IEP have been performed in two steps. First, UST verified the complete system through Hardware-In-the-Loop simulations (HIL). In this case, the entire IEP is connected to a simulator and critical cases are assessed. In a second phase, outdoor tests have been made during which the team tested the range of the link system, engine and fuel system, and procedures. Following all these verifications, the first taxi tests have been carried out at Hahnweide Airfield near Stuttgart. After all these tests (results are available in the model acceptance report [D1.4-7]), the team decided to send the IEP to Poland to start the experimental campaign.

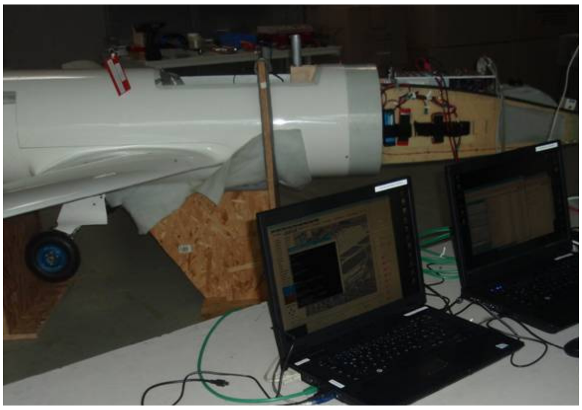


Figure 35: HIL tests of the IEP

Figure 36: IEP 15 Taxi test

Flight Test Preparation

The procedure and details are described in the deliverable [D1.4-6]. All partners involved in ST1.4.3 heavily participated in the completion of the document by providing information on team organization, noise measurement, recovery from hazardous situations, flight dynamics and general procedures on free flight tests based on previous experience.

At the end of the IEP integration, the team decided to hold two First Flight Readiness reviews:
- the first one dedicated to the system validation (FFR1);
- the second one dedicated to the flight test campaign organization (FFR2).

The objective of FFR1 (1-2 February 2010) was to review all the systems verifications and validations performed by UST. The review focused at first on the subsystems of the IEP. For all of them, UST presented the various tests that have been performed, their outcomes and the conclusions. Then the meeting concentrated on the High level tests including the integrated IEP. These validations performed under the form of HIL tests and ground tests in an airfield enabled to verify the system compliance and to identify its limitations.

The results of this FFR1 have been subsequently presented to EC reviewers during a debrief held at Airbus, Toulouse. Questions were raised on some IEP systems and answers were provided by the partners.

The FFR2 (22-23 February 2010) took place in PW with the objective of preparing the Flight Test campaign. During the meeting, the partners discussed about technical aspects (performance and dynamic behaviour of the IEP) as well as safety aspects for flight testing at the selected FTR Modlin Airport. The main conclusions for FFR2 were:
- Verification of performance and flight dynamics models must be completed before the flight tests;
- Safety and responsibility aspects associated with the flight test range must still be clarified.

Despite the fact that preparation was unfinished, the testing team gathered again at Modlin airport on 25 February 2010 and first ground runs were tried nevertheless. Unfortunately the testing conditions and the overall preparation were not adequate and the model was damaged following a runway overrun. The event is documented in [D1.4-9].

Although the model could be quickly repaired, it was decided to suspend the test campaign until proper preparation could be evidenced.

The experience in ground testing has shown that the responsibility for flight testing must be established within the organisation for a chief engineer who carries the technical responsibility of the IEP and a test flight director who is in charge of all of the activities of testing the IEP including the direction of the piloting. They of course must operate within the framework of a civil or military authority.

[D1.4-10] provides a General Report on the whole project encompassing all the other reports stating lessons learnt and the conclusions of the project.

Final Conclusion

In Task 1.4, a team of research centres, universities and members of industry, with extensive experience in test facilities and flying scale models has been assembled with the objective of developing an Innovative Evaluation Platform (IEP). This system, under the form of an unmanned flying platform is intended to be used to help investigations at industrial level in various fields towards the design of future aircraft concepts.

In ST1.4.1 "IEP assessment and feasibility", the consortium gathered information about existing test techniques for the disciplines of interest from both technical and economical point of view. Subsequently, the study focused on the requirements of a flying platform enabling valuable measurements for disciplinary experts. Based on these requirements, the consortium proposed in the end a modular concept of an unmanned flying platform showing potential benefits in comparison to current test facilities. Given this positive outcome, it was decided to design and manufacture the IEP.

After completing a complex phase dedicated to the design of the IEP using know-how of the different members, the design team started the manufacturing and integration of the various components. In order to minimize risks, several tests were carried out all along ST1.4.2 to verify the soundness of the complete system: structural tests on wings and fuselage, wind tunnel tests to assess the aerodynamics, avionics control through the use of a especially built Iron Bird and also vibration tests to assess the critical flutter speed. At the end of this two-year long task, final outdoor tests were carried out to validate the system before delivery for the flight test phase.

The flight test phase (ST1.4.3) started with the definition of the overall strategy for the experimental campaign. Subsequently, flight missions aiming at first at the system assessment and then at data acquisition for disciplinary investigations were characterized. During the same period, partners discussed with authorities to obtain a permit to fly in a closed area. In February 2010, the test team initiated the taxi tests to assess the behaviour of the platform on the runway. Because of adverse conditions and incomplete preparation, an incident occurred during a run and the landing gear and other parts were damaged. It was decided not to resume the tests until all aspects of preparation could be addressed. The re-planning of the preparation activities showed that it was not possible for the team to perform the first flight within a reasonable timeframe within the NACRE project.

During the course of the entire project, European members of the consortium heavily participated to the development of a flying test facility demonstrator meeting stringent requirements. Since all phases of the development have been completed, partners increased their skills and know-how regarding the design, the manufacturing, the integration and the operational aspects of such a complex system. This valuable knowledge in the domain of free flight tests with an unmanned modular platform is rare and any future project in this field will clearly benefit from the advances made in NACRE.

Task 1.4 has been thus an important first step in the development of a new test facility based on flights in real atmosphere in Europe. Because of the achievements and the know-how gained by the consortium in the development of the IEP, the overall Task can be considered a success.

At the end of the project, team members identified key lessons learned that would pave the way for a future European project based on the IEP or its evolution. Today, the system is available and flight tests can be planned after a preparation phase. To manage future use of the IEP, a co-ownership agreement between the various partners has been defined.

WP 2 – Novel Lifting Surfaces

Task 2.1 – Advanced Wings

Task objectives at beginning of the project

The Advanced Wings Task aimed at exploring the integration of wing engineering disciplines to establish the potential of a range of novel wing concepts. Three Subtasks focused on selected baseline wing concepts and TLAR's from WP1 based on alternative design drivers. A range of key multidisciplinary trades and innovative integration solutions were to be identified for each concept for further investigation within the Task. Configuration trade studies would be performed around each wing concept leading to a preliminary integrated wing solution focused on the given design driver. Whilst each concept would be studied in independent Subtasks, maximum opportunity would be taken to feed lessons learnt across the activities during common review periods, enabling some appreciation of the higher level trades between concepts.

Each Subtask had a similar approach to work flow, including an initial activity agreeing the theoretical methods to be used and a common assessment activity where a relatively conventional manufacture driven wing baseline was to be used as the Task 2.1 reference. The main investigation of each Subtask was divided into two phases allowing a broad initial study followed by more detailed integrated activities on selected wing concepts. Following this, integrated wing solutions would be proposed.

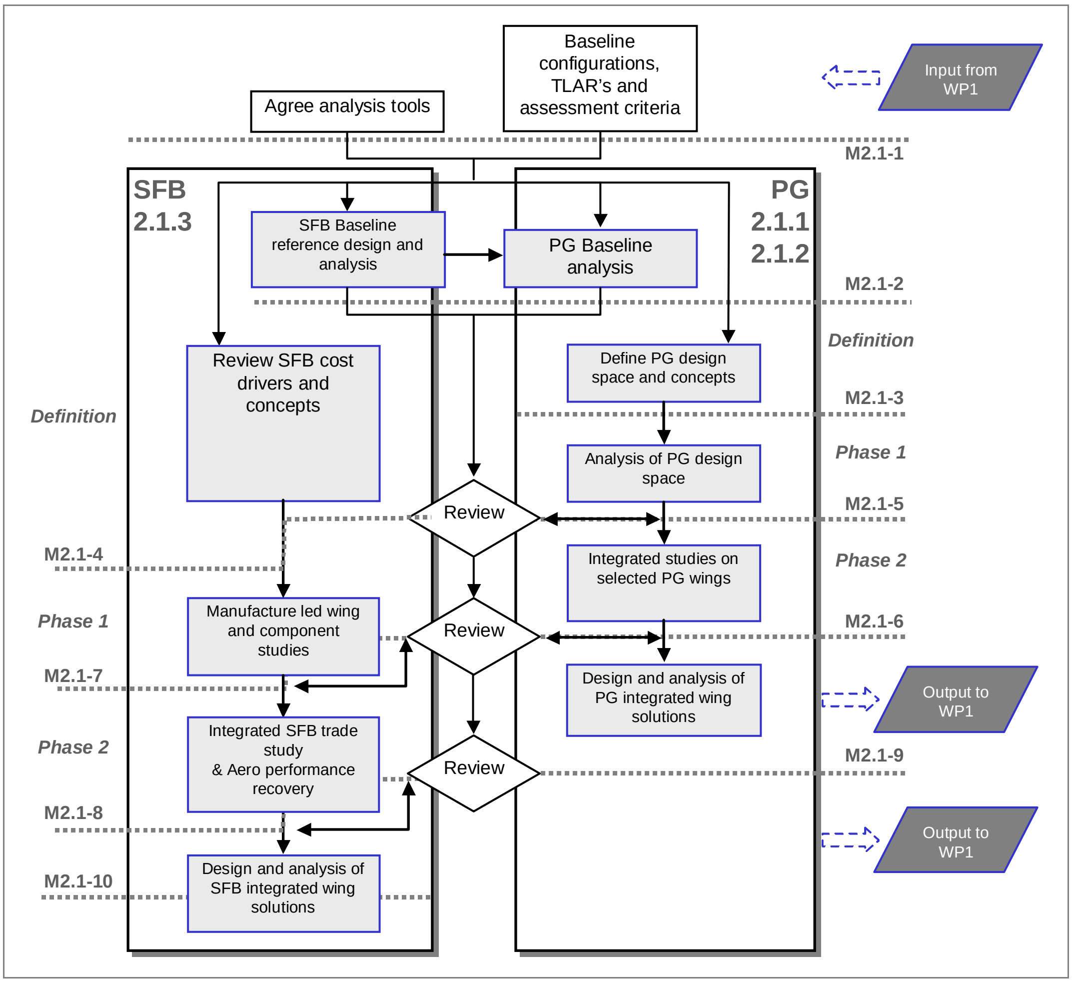


Figure 37: Task 2.1 Flowchart

The Advanced Wings Task was split into three Subtasks, the first two of which addressing the Pro-Green concept and the last the SFB concept.

Subtask 2.1.1 High Aspect Ratio Low Sweep (HARLS) Wing

A **high aspect ratio low sweep wing** concept was to be investigated in Subtask 2.1.1, with particular attention to the associated problems of structures and systems integration. Potential improvements to airframe noise associated with the high lift systems and undercarriage were also planned to be studied. The Subtask would include studies in aeroacoustics, which is another key driver for a Pro-Green configuration. It would deliver trade information relevant for a Pro-Green HARLS wing as well as an integrated wing solution based on the trades.

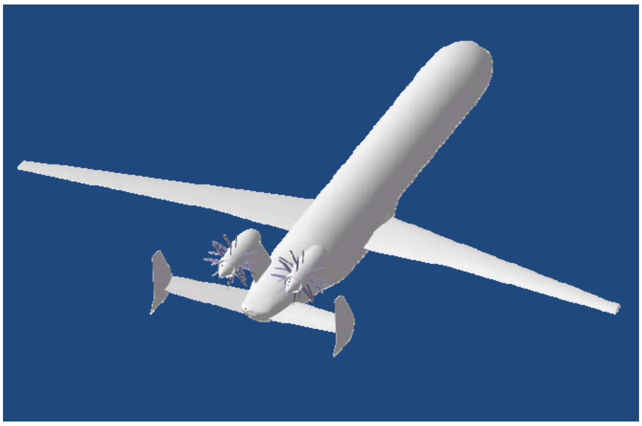


Figure 38: Baseline concept of HARLS Wing on PG2

Subtask 2.1.2 Forward Swept (FS) Wing

The objective of Subtask 2.1.2 was to prove the technologies required to exploit the potential suggested for a Forward Swept Wing as part of a Pro-Green aircraft concept. It was expected that a FS wing concept could incorporate a wide extent of Natural Laminar Flow (NLF) at current high Mach cruise speeds, thus offering a Pro-Green aircraft a significant reduction in drag.
Forward Swept Wing could also provide noise shielding potential for engine installed over the rear fuselage thanks to the forward wing root location.

This Subtask would incorporate aeroelastic analysis considering the specific aeroelastic problems of such wings, as well as the aerodynamic integration of low speed high lift devices. It would deliver two FS wing solutions embodying the NLF, high lift and aeroelastic technology developed.

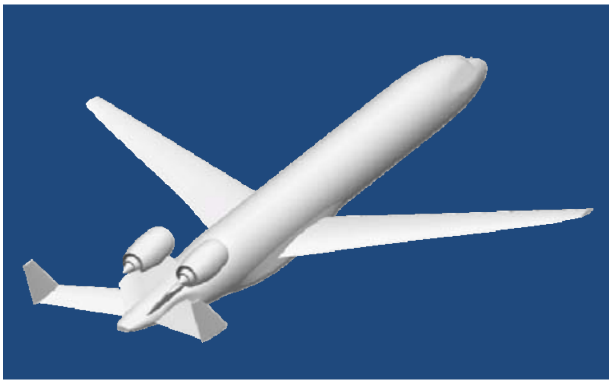


Figure 39: Baseline concept of Forward Swept Wing on PG1

Subtask 2.1.3 Manufacture Driven (SFB) Wing

Subtask 2.1.3 aimed at turning the usual wing design process around, beginning with manufacturing and structural design and finishing with exercises to establish acceptable aerodynamics. The extent of the multidisciplinary integration would effectively cover the entire design-and-make process and enable a genuine investigation of how to minimize aircraft costs.

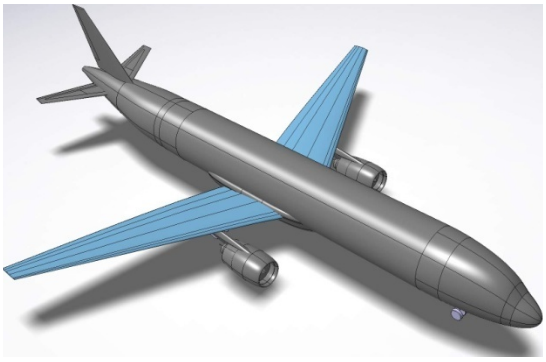


Figure 40: SFB Manufacture Driven Wing concept

Technical Achievements

Subtask 2.1.1 High Aspect Ratio Low Sweep (HARLS) Wing

The study of the High Aspect Ratio Low Sweep (HARLS) wing concept has covered the following aspects: the exploration of the design space, in terms of Mach number, sweep and wing thickness/chord ratio; the optimisation of the most promising parametric wing; the aerodynamic performance assessment of the final optimised wings; the weight assessment of the wings studied, including full aircraft integration aspects; the investigation of various possible high lift device concepts, both aerodynamically and acoustically; the analysis of low noise and novel landing gear concepts; and overall acoustic assessment of the aircraft concept. The study has addressed the main drivers for this wing concept, namely reduced fuel burn and reduced noise levels.

Parametric and Wing Optimisation Studies
In addition to the baseline wing, four wing configurations (Wings A, B, C and D) were defined for aerodynamic and structural trade-off design studies in Phase 1. These configurations were obtained based on a parametric study of the trade-off between thickness, sweep and Mach number. From these studies Wing C, the wing with the lowest fuel burn at the baseline Mach number, was down selected for detailed analysis and integration studies during Phase 2. Potential integration difficulties due to the thinness of this wing resulted in the need to select a wing with a lower cruise Mach number and a thicker wing section. A number of lower Mach number wings were assessed for this purpose in Phase 2 to study the trade-off between structural weight and aerodynamic performance (Wings E, F and G).

Both FOI and CIRA performed re-optimised Wing C and a comparison of the results showed that the FOI design (Wing C FOI) is the best performing wing at M0.74. It was also shown that Wing E is the best performing wing at the lower Mach number of M0.72, potentially offering significant advantages. It was recommended that WP1 re-size Wing E to compare against Wing C FOI.

An alternative optimisation of Wing C was undertaken by NLR, which considered the full aircraft and used different constraints – maintaining the wing sectional geometry and allowing the wing planform to change. This resulted in a wing, which has higher sweep and reduced thickness relative to Wing C and, hence, has different aerodynamic characteristics.

Weights analysis and comparison of wings

The wing weights of the down selected wings were combined with the results of the aerodynamic analysis and then compared, in terms of equivalent drag sensitivities, related to both fuel burn and DOC objectives. This confirmed that Wing C was the best original wing and that Wing C FOI is the best optimised wing for M0.74. The NLR wing was shown to be better on fuel burn but not DOC relative to Wing C FOI. Regarding the lower Mach number wings, Wing E (M0.72) may have significant benefits but reducing cruise speed further Wing G (M0.7) showed no benefit relative to Wing E. These findings should be confirmed by work in WP1 to include the effects of engine performance. However, Wing C FOI was the recommended wing for the subsequent sizing and integration studies in WP1.

Structures study

The study addressed more general issues arising from the concept of the HARLS wing with its reduced thickness and increased span, rather than producing detailed structural analysis of any particular wing.

A new methodology currently under development within Airbus was used in the study. Within the limitations of this new methodology, a full optimisation was not possible; however, a number of options were studied in some detail and it was shown that Option 6, where the stringers are aligned parallel to the mean chord and the ribs perpendicular to the front spar, is the most promising solution. It is noted that there may be a possible requirement to strengthen spars locally at stringer termination points and that this need further investigation. Regarding maintenance issues, HARLS wings may require the use of large removable skin panels to allow access, rather than conventional ‘manholes’, akin to the procedure used on business jets and similar sized aircraft.

High Lift Studies

Airbus performed a far field noise assessment for five different high lift systems. DLR performed a slat gap and overlap variation study on the aerodynamically optimised baseline high-lift system as well as estimating the source noise of alternative high-lift systems (droop nose device (DND) and DND plus double slotted flap). Airbus supplied the Fixed Nose Droop (FND) geometry to VZLU for CFD analysis. All results were passed on to WP1 for further analysis, the results of which showed that for the fuel burn objective, the baseline high-lift system (baseline slats + single slotted flaps (SSF)) performs the best, while for noise considerations, the DND + adapted single slotted flaps is the quietest. All the configurations assessed achieved the CLmax target, within the tolerance of the prediction tool used, with some allowance for increasing the size of the SSF. In the final phase, an additional requirement for CLmax = 3.0 was added to cover potential changes due to wing re-sizing. More complex configurations were studied which all achieved the original CLmax requirement. To achieve the increased target, however, the FND option required a significant increase in the chord of the DSF to 42% chord. The DND + adapted DSF was also shown to achieve this enhanced requirement.

To provide a better approximation of the aerodynamic performance, the baseline and FND + DSF configurations were analysed using CFD. This analysis predicted a significant reduction in CLmax relative to the predictions given by the semi-empirical AeroLSP, for the FND + DSF configuration. Some improvement may be possible from optimising the leading edge shape and the flap, but the results indicate that this configuration is not as promising as first thought.

Due to the increased aspect ratio of the HARLS wing and hence the flaps, consideration has been given to the number of supports required for the flaps, with emphasis on the outboard flap. It was concluded from studying the flap deformation, that the inboard flap layout (2 supports – end-field supported) would be feasible if the flap was sufficiently reinforced and the gap tolerances were quite large. For the outboard flap, it was shown that a triple (field-field-field) support layout would be required to keep the flap deformation and the aerodynamic gap within limits.

All the information obtained for the most promising high-lift devices were used to assess the impact on the performance of a re-sized aircraft. All the alternative devices had either a significant weight penalty compared to the baseline or a CLmax below 3. For the re-sized aircraft, it was shown that those devices that met the CLmax target of 3.0 gave the best overall performance at aircraft level, despite their weight penalty because they avoided a significant increase in wing area. However, they all incurred a fuel burn penalty of between 0.9% (DND+DSF) and 2.9% (DND+SSF).

Landing Gear Concept Studies

Although two concepts were proposed in [D2.1-3], Wing C assumed a novel concept, the centre body-mounted landing gear, as the HARLS wing is too thin to reasonably accommodate a wing-mounted gear. To accompany the body gear, M-D supplied outrigger designs and technical information and drawings to WP1 as requested. M-D supplied landing gear weight estimates and Airbus estimated the impact of the landing gears on the wing weight. Airbus used the information to derive the total landing gear system weight at aircraft level including landing gear, impact on wing and fuselage weight, belly fairings and outrigger fairings. All proposed gears have a weight penalty compared with the baseline (the centre landing gear plus outriggers is 100kg heavier than a wing mounted solution).

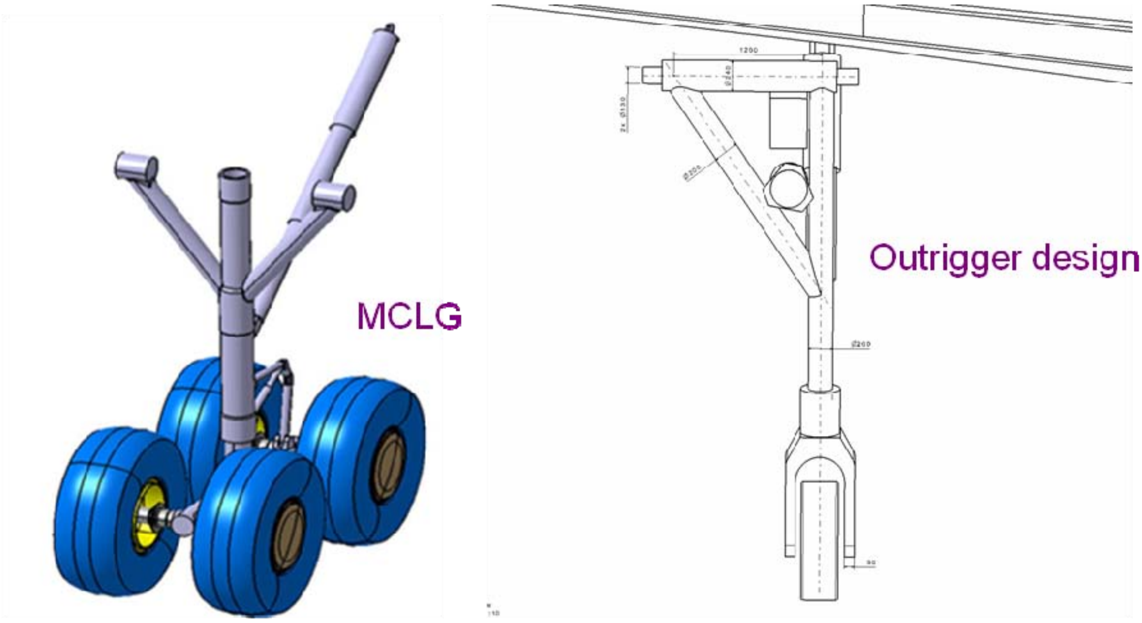


Figure 41: Single body landing gear, or “mono” centre landing gear (MCLG)
and outrigger on the wing

The advantages and disadvantages of the baseline and centre-mounted gears have been considered in comparison with studies carried out for the SFB configuration, which have included twin body-mounted landing gears. There are lateral stability problems associated with both the twin body-mounted gear and the single centre-mounted gear, not necessarily solved by the addition of outriggers for the latter configuration.

Acoustic analysis of both the baseline and centre mounted gear configurations has shown a significant reduction in noise levels (between 2.7 and 5.7 dBA) relative to an A320 main gear, with a further small improvement for the novel gear. It is noted there may be some additional advantages for the single centre gear due to the absence of gear/flap interactions, which may be significant for wing-mounted gears. Also, there is greater freedom in the axial positioning of the gear to obtain the optimum location and for the addition of shielding devices or fairings. Overall, however, it is difficult to draw a final conclusion on the best landing gear configuration for the HARLS aircraft, and further work is required to study the different options in more depth.

Overall aircraft noise assessment

A noise study was carried out on the NACRE PG2 aircraft, which used the baseline wing in an initial phase [D2.1-3] and Wing C in a second phase [D2.1-4]. In Phase 1, airframe noise levels predicted for six high lift device (HLD) configurations were compared without including engine noise data, which were not available for the study. In terms of airframe noise levels, the best HLD configurations for acoustic performance were the DND + adapted DSF, which was the quietest for approach, and the DND + adapted SSF, which was the quietest for take-off (without engine noise or impact of resized aircraft performance, it was difficult to conclude on noise at this stage, but the information could be combined with the block fuel performance to allow a down selection).

In the second phase, two of these HLD configurations, selected using a block fuel criterion (“best balance” between block fuel and noise, as defined by Task 1.1), were studied; namely, the baseline slat + SSF and the DND + DSF configurations. Repeating the analysis for Wing C, and including engine noise data, the DND + adapted DSF was globally quieter than the baseline slat + SSF with an overall aircraft noise delta of -0.3 EPNdB for sideline and -1.8 EPNdB at approach. However, this has to be traded against the almost 1% block fuel penalty incurred by the aircraft.

On the baseline HLD configuration, reducing approach speed by 2% through an increase of Sref by 4% allows a noise reduction of 0.4 EPNdB on airframe noise and 0.3 EPNdB on overall aircraft noise, assuming that trajectory parameters, except the airspeed, are the same (in particular the engine thrust). However, an Sref increase is expected to induce an increase in engine thrust and thus in engine noise. A further study, considering the initial and resized geometries of Wing C with the baseline slat + SSF and using appropriate engine thrusts, should be carried out in order to confirm the trend observed in this study.

On including the landing gear in the analysis, it was shown that the body-mounted CLG produces better acoustic performance than the baseline wing-mounted MLG, with a reduction of -0.2/-0.3 EPNdB on overall aircraft noise for aircraft with either HLD configuration.

Subtask 2.1.2 Forward Swept (FS) Wing

Parametric Analysis and Optimisation
Starting from the PG1 Baseline wing, CIRA, Onera and PW performed preliminary design optimisations. CIRA’s was performed using Euler computations with boundary layer and a database method for transition prediction. The resulting optimised wings were the PG1-CIRA-1 wing, with lower sweep and higher aspect ratio than the baseline and the PG1-CIRA-2 wing which was obtained by performing a pure airfoil shape optimisation of the baseline wing. Using RANS calculations for aerodynamics and transition prediction by a 3D database method, as well as linear stability computations, airfoil twists and wing sweep were optimised by Onera, resulting in the PG1-Onera-1 wing.

PW performed a third optimisation study where a 3D full potential method, coupled with 2D boundary layer computations and an algebraic transition criterion were used to model the aerodynamics. PW chose three wings from their studies: PG1-PW-A with the best lift to drag ratio, PG1-BW-C with the best lift to weight ratio, and PG1-PW-B as a compromise, balancing both ratios. Later, a fourth wing called PG1-PW-S was added. This wing came from a new optimisation without the restriction to a fixed planform area and span.

Although the PG1-CIRA-1 wing appeared to have the widest laminar flow extension, the aeroelastic analysis showed that this wing did not satisfy the requirement for static divergence. Finally, PG1-PW-A was down-selected as the next best wing going forward because it had the best lift to drag ratio. The details of these studies are reported in [D2.1-3].

Integrated Design
Early on in Phase 2 it became apparent that there were deviations in terms of predicted transition locations. Original analysis of Natural Laminar Flow (NLF) extent for a given wing showed large discrepancies between partners (DLR, Onera, KTH, CIRA). In order to keep the results comparable, a detailed comparison study for the different transition prediction methods was performed before the Phase 2 detailed integrated work began, in order to calibrate N-factors (Fokker 100 reference case) and agree on the NLF assumptions. These assumptions could finally be harmonized across partners, which will lead to reliable results for NLF in NACRE and future projects. Once this comparison was completed and assumptions harmonized, a detailed design / optimisation of the PG1-PW-A wing was performed by DLR and Onera. The details of the comparison studies are reported in [D2.1-4].

For their optimised wing design tasks in Phase 3, Onera optimised the PG1-PW-A wing in twist, while DLR re-designed the PG1-PW-A wing to achieve better pressure distribution. Both designs mostly demonstrate improved turbulent design through wave drag reduction. A sensitivity to mesh refinement was highlighted for the NLF performance of Onera’s wing design, so camber design modifications were made to their wing leading edge. This solved the problem of the flow separation on the upper surface in that region.

In addition, Onera performed a study to examine the influence of surface defects such as steps, gaps and isolated roughness, on cruise flight laminarity. A complete set of theoretical criteria was applied to their optimised wing 3D flow data and a minimum defect height was predicted for triggering laminar separation.

KTH has completed a comparison study of both the Onera and DLR designs.

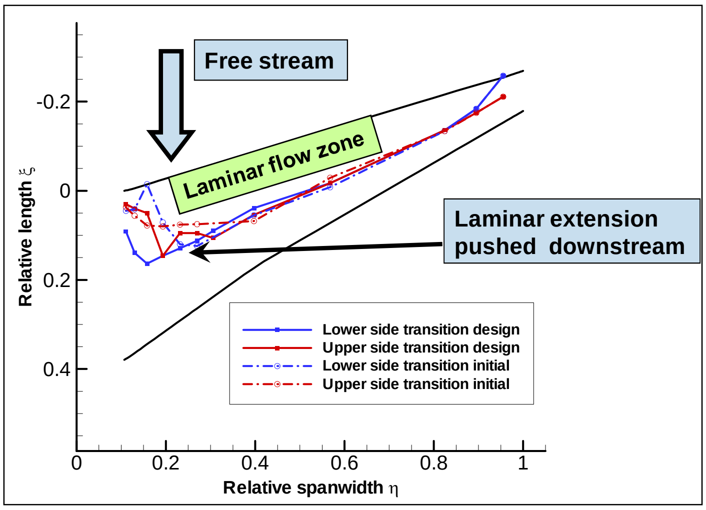


Figure 42: Design improvement of PG1-PW-A wing

Off-design wing studies were completed by CIRA. A test matrix covering a range of Mach numbers and lift coefficients was considered over which the laminar boundary layer stability and buffet margin were assessed. Transition prediction, pressure distribution analysis and laminar performance studies were completed for off-design and climb conditions for both wings, the results of which favoured the DLR wing design.

High Lift Devices Studies

During Phase 2, FOI completed their high-lift system design for integration into the DLR and Onera wing designs. An investigation of the influence of front spar position (15%c versus 20%c) was carried out, as well as the potential effect of Krueger flaps and the inclusion of vortex generators on Fowler flaps.

DLR carried out a performance analysis which showed that the FOI system is sufficient for low speed operation after slight modifications of the flap setting but it only just meets the high-lift requirements with a 152m^2 wing compared to 125m^2 on the SFB. DLR also found that flow separation in the wing-fuselage junction could be delayed to higher angles of attack with the addition of a strake fillet with a high backward sweep angle.

The parasitic drag study performed by Onera showed that even very small steps (≈ 0.2 mm) on the surface would suffice to trigger laminar/turbulent transition under cruise conditions. Hence, a conventional slat would prevent natural cruise flight laminarity, even if retracted very accurately. On the other hand, a wing without any leading edge device would have to be much bigger, thus compensating the laminar benefits again very rapidly.
During the final phase of the Subtask, two leading edge concepts were investigated: a future technology droop nose with a flexible skin to allow for a clean surface in retracted state and a current technology Krueger flap, which only disturbs the lower side of the wing and so permits more than 60% of the laminar gain (compared to laminar upper and lower side). The perceived maximum lift of the droop nose still requires more than 30% of additional wing area, due to separation problems on the inner wing. The Krueger flap seems to show quite similar performance. It turned out that the wing/fuselage junction and the belly fairing have a high impact on the achievable performance and should be designed very carefully (considering both low- and high-speed performance) in future projects.

Structural Design and Aeroelastic Studies

IBK has completed their loads calculations for the two wing designs and passed their results onto DLR as inputs into the structural and aeroelastic studies. For the final wing design from DLR the structural model was set up and sized and the weight of primary structure of the wing was calculated. An overall wing weight comparison between Piaggio, DLR and Airbus shows reasonably consistent results at ~8900kg for a wing with a fixed leading edge. The weight and divergence analysis carried out by DLR showed that variation of the front spar position has an impact on weight and divergence speed. Static divergence was shown to be a problem during the studies. This aeroelastic effect occurs when the tip twist increases with increasing angle of attack, leading to an unstable behaviour, which, because of the geometry, is a common effect in forward swept wings. The static divergence for the wings studied in this Subtask can be controlled by restricting wing thickness distribution to keep the dynamic pressure for static divergence above the limit required by the authorities. It can usually be expected that a forward swept wing is heavier than a backward swept one.

Subtask 2.1.3 Manufacture Driven (SFB) Wing

Phase 1 Wing Down-selection
During Phase 1 weight and cost assessments were performed for three metallic and five CFRP wing concepts. Quantitative cost and weight assessments were not possible for the different configurations so many of the investigations were made on a qualitative basis by comparing the different configurations relative to each other. This also meant it was not possible to compare the metallic and composite configurations.

The metallic wing studies on wing box components (machined ribs and panels with integrated stringers) demonstrated savings of around 10% of the wing box cost. Ultimately it was agreed that due to the greater potential cost and weight savings of the composite concepts, it was decided not to continue with the metallic wing studies. The CFRP assessments continued for the five concepts. In addition to these wing assessments, studies on different low cost engine and landing gear attachments and high lift configurations were performed. This enabled a down selection to be made by eliminating any unfeasible configurations (e.g. extended rib for engine attachment) or by applying engineering based considerations (e.g. Advanced vs. Ultimate Wing).

Finally two CFRP configurations were selected for further study in Phase 2: The Advanced Unkinked Wing concept (with centre line joint and unkinked wing box and planform) and the Extended Centre Wing Box Wing concept (with metallic interface between the centre wing box and the outer wing serving as the landing gear attachment). Both concepts assumed dual wheel, single side stay, wing-mounted, sponson-stowed main landing gear attached to a gear rib.

Phase 2 Detailed Studies
Wing Interfaces – DLR used FEM simulations to model and evaluate the loads at the wing root with the introduction of the innovative discrete fuselage interface proposed by Task 4.3. This was then compared to a conventional wing-fuselage interface. At the current design stage it is not feasible to make a full sizing of the novel interface, so a global assessment from the wing point of view was made in order to provide a recommendation for the design at aircraft level. A comparative structural assessment of the overall weight impact of the novel interface was made showing a global weight increase of 13% for the discrete interface and centreline joint combined compared to a conventional configuration.

High-lift systems – Airbus performed detailed assessments of high lift devices for an un-kinked trailing edge in terms of weights, number of flap supports and gap deformations for different numbers of flap.

Recommendations – A number of recommendations for the low cost wing were made based on the studies completed during Phase 2:

- Centre-line joint to take advantage of new fuselage attachment concept
- The front and rear spars should be straight with no kinks and no centre-box
- Un-kinked planform with single TE flap with triple supports
- The high-lift devices should be Krueger flaps on the LE and dropped hinge flaps on the TE
- Both wing-mounted and body-mounted landing gear should be investigated, although Task 1.3 will assume the wing mounted landing gear option only

Phase 3

Using the assumptions described above, Airbus defined two new wing planforms for study in Phase 3: Wing Y which has space for a wing-mounted landing gear and Wing Z which has no provision for a wing-mounted gear. The completed analysis indicated that although both wings meet the high-lift requirements, Wing Z is undersized for fuel volume. The high-lift assessment confirmed that fuel volume would be the driving constraint for this wing.

Both wings Y and Z have a significant weight penalty compared to an un-kinked wing, and while it was seen that a single flap was possible for un-kinked wings, only a small weight saving was found for three field supports. The wing weight analysis confirmed the expected penalty in removing the planform kink. Wing Z had a significant box weight penalty compared to the baseline of 300kg, probably due to the much smaller root chord for the planform. The trailing-edge weights reflect the size of the fixed TE area, with wing Z being the most efficient having minimum wasted space.

The cruise aerodynamic analysis of Wing Y only showed a big penalty due to the differences in flow development with a double shock being present. However, it was believed that this was more an effect of a non-aerodynamically optimised wing than being a characteristic of a trapezoidal wing and these results were not used within the overall aircraft design within WP1.

The selected SFB high-lift configuration with Krueger flaps on the leading edge and single slotted flaps on the trailing edge was aerodynamically reassessed for Wings Y and Z, showing a sufficient high-lift performance. Since the Krueger flap was believed to be weight and cost neutral with a slat, even including the removal of the front spar penetration, no further weight and cost analysis was performed.

The deformation analysis of the triple supported flap confirmed the feasibility but only if all three supports were on the wing. This meant the inboard support could not be part of the fuselage and hence removed the chance of a significant cost and weight saving.

A relative cost comparison of the different wings was also completed showing a 5% cost reduction for Wing Y and a 16% cost reduction for Wing Z. Hence, this justified the low cost configuration down selection that was made. Both wings gained from the removal of the separate centre-wing box (8%) and reduction of joints (2%). Wing Y suffered from having larger TE areas but Wing Z further gained from having no landing gear attachment (5%) and in minimizing the wasted fixed TE space (2%). The cost impact on the fuselage of having a body-mounted landing gear has not been investigated but the analysis does show the benefits for the wing component alone.

A low cost landing gear was proposed which minimizes the number of expensive folding items, minimizes the structural material and reduces the number of ancillary items through a functional analysis approach. The result is a 19% reduction in landing gear cost coupled with a significant weight reduction.

All results were provided to WP1 for inclusion in the final integration work.

Final Conclusion

Subtask 2.1.1 High Aspect Ratio Low Sweep (HARLS) Wing

The study has addressed the main drivers for this wing concept, namely reduced fuel burn and reduced noise levels. All results have been passed to WP1 to allow integration at overall aircraft level. In terms of overall technical achievements at the wing component level, it can be concluded that there were no showstoppers identified for the HARLS wing. However, further work should be recommended to expand on some of the integration studies, as detailed studies were not possible for many topics, e.g.:

- Indeed one important aspect was the landing gear integration where the studies highlighted potential novel landing gear solutions. Further work is required to study more in depth all aspects of the different options to be able to determine which one is the best solution at overall aircraft level.
- In order to confirm the trend observed in HLD study, further work should be carried out, considering the initial and resized geometries of Wing C with the baseline slat + SSF and using appropriate engine thrusts.

The process of noise analysis of different landing gear configurations has been set-up between different partners and improved. For the first time, high fidelity methods have been used for the prediction of noise emanating from different flap configurations, which provides very useful results for conceptual studies.

The impact on both aircraft performance and noise of using alternative low noise high-lift devices has been shown. Clearly on the specific PG2 design, there is a trade-off between noise benefit and fuel burn penalty.

Finally, the importance of multi-disciplinary studies at component level including understanding the impact at aircraft level has been highlighted throughout the studies. The definition of the integrated design process for the HARLS wing (high speed and low speed) taking into account aerodynamics (including usage of adjoint solvers), structures, acoustics and landing gear installation is a key milestone in integrated wing design.

Subtask 2.1.2 Forward Swept (FS) Wing

In this Subtask, the assumptions for the laminar / turbulent transition prediction methods were calibrated and harmonized across partners, which is a major achievement for future laminar design and collaboration work.

It was shown that a forward swept natural laminar flow wing for a Mach number of 0.76 could be designed with a wide extent of laminar flow, resulting in a significant reduction of drag potentially up to approximately 38 drag counts. For this application, the forward swept wing shows a couple of advantages compared to the backward swept one, permitting natural laminar flow even for Mach numbers above 0.76. On the other hand, such a wing has to be significantly bigger to permit for low approach speeds; hence, an overall assessment of the potential benefit of such a wing has to be made on aircraft level in WP 1.

Overall, despite some critical issues and problems to be overcome (for example on inner wing design and high lift integration) for this FSW, no particular showstoppers could be identified for this concept. For future projects, it might be interesting to look deeper into this concept to further assess its potential and usability. Indeed, the impact of the wing/fuselage junction and the belly fairing on achievable performance requires careful design both for low and high speed.

Subtask 2.1.3 Manufacture Driven (SFB) Wing

The local wing cost reductions were confirmed but overall performance penalties from a bigger and heavier wing significantly impacted the size of the more expensive engine. The economic evaluation at aircraft level calculated that the penalty of the heavier, less efficient, aircraft exceeded any local component level cost savings. This conclusion is a very valuable result when considering low cost wings at the configuration level. However, care should also be taken in that the performance penalties may be specific to the case investigated, whereas the local component savings may be used in a number of different wing design scenarios.

Task 2.2 – Flying Wing

Task objectives at beginning of the project

The aim of this Task was to research innovative solutions for the most important issues of passenger carrying flying wing aircraft, which have not been addressed sufficiently in previous research programs such as VELA and MOB. These are mainly in the areas of:

- Cabin layout and passenger safety;
- Structural solutions;
- Control and aerodynamic performance.

Work would build on the specifications and the baseline flying wing configurations developed in Task 1.2. Initially, different concepts in the three interlinked key areas needed to be examined independently to enrich the results of the VELA project by new and innovative solutions. After a first phase of 18 months, the most promising concepts would be identified and investigated in more depth during the remainder of the programme. Results were to be fed back to Task 1.2 for integration and assessment.

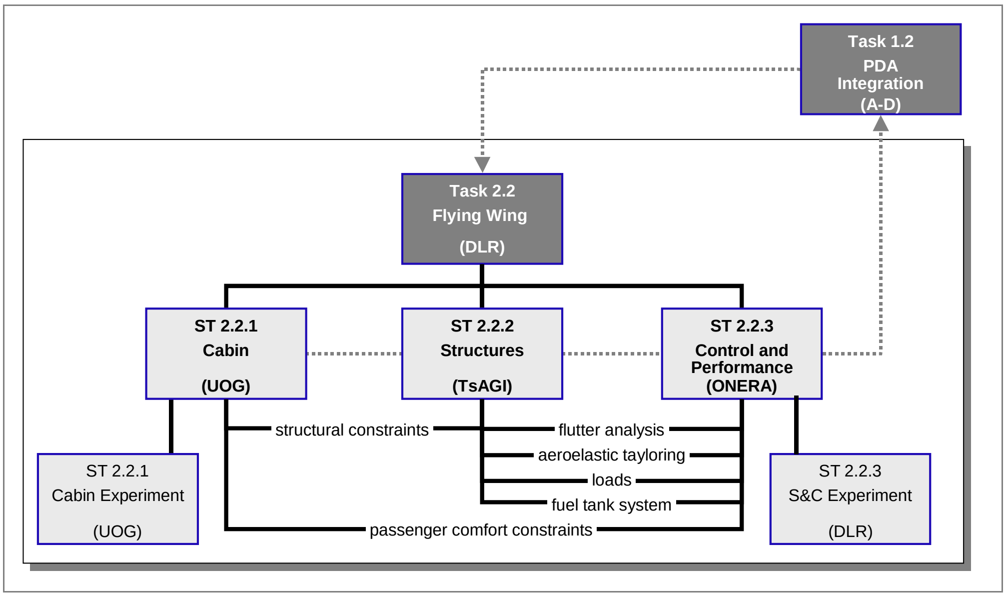


Figure 43: Task 2.2 Flowchart

Subtask 2.2.1 Cabin

The objective of this Subtask was to develop cabin layouts starting from requirements for passenger comfort and safety. These first, creative layouts would define ideal requirements for cabin architecture including shape, volume, exit location and aisle areas. Numerical evacuation simulations performed using the enhanced simulation tools developed in VELA, and fire hazard simulations would be used to assess and optimise the cabin layouts. Compatibility with structural concepts developed in Subtask 2.2.2 would be checked and depending on the structural solutions, these layouts would be adapted in an iterative manner. Evacuation procedures would be developed as required by the new cabin configuration concepts.

A feasibility study for a full size cabin mock-up would be produced to compare possible solutions for such a mock-up (having different sizes and hence economics) and the trials to be performed. As a result of this study, it would then be decided, through a CDR, whether to manufacture a cabin mock-up to be used to verify the predictive capabilities of the numerical model. Based on the experience gained from this simulator, the evacuation model would be fine tuned to improve its predictive capabilities in novel flying wing configurations.

Evacuation Test: As part of the VELA project, the behaviour sub-model within the evacuation model was adapted to cope with the novel configurations offered by flying wing aircraft. The purpose of the test was to observe – for the first time – the evacuation behaviour and performance of passengers and crew in novel flying wing configurations and quantify this behaviour. This information would be used to verify the assumptions used in the behaviour sub-model, to fine-tune the model and to improve its predictive capabilities in flying wing configurations.

Subtask 2.2.2 Structures

The partners involved in this Subtask would expand the suite of structural concepts developed in VELA with new solutions. Therefore, global architectural ideas and local solution concepts would be studied. Additionally, a detailed parametric Finite-Element (FE) model for one structural concept would be developed and made available to Subtask 2.2.3. These models would then be used to perform a combined aerodynamic-structural analysis and to examine control devices exploiting aero-servoelastic effects. These effects would also be taken into account to develop control laws for the elastic aircraft.

Aerodynamic loads delivered by Subtask 2.2.3 would be used for structural dimensioning and the calculation of weights. Also the impact on structural weight of having fins on the centre body versus winglets at the wing tips would be evaluated. The ditching behaviour of potential flying wing configurations would be compared to a conventional aircraft. Simplified models would be derived to study the flutter behaviour. Here, under-wing engines and engines mounted on top of the rear centre body as well as a variation of vertical surfaces with respect to flutter characteristics would be assessed. The results of this Subtask would finally be used in Task 1.2 to assess and improve the baseline flying wing configuration.

Subtask 2.2.3 Control and Aerodynamic Performance

This Subtask contained elements of aerodynamics and control with a strong emphasis on controllability, stability and handling qualities as well as low speed performance. On a flying wing various alternative control devices are likely to be used for control. Therefore a selection of control devices was to be analysed aerodynamically to determine their control characteristics. Low speed flap systems respecting requirements for trim and control would be developed, also taking ground effect into account.

Multidisciplinary design work would be based on the structural models produced in Subtask 2.2.2. These would also be used to optimise control behaviour and to exploit aero-servoelastic effects for control augmentation.

Initially, control efficiencies for various control concepts would be computed. In the second phase, adapted flight control systems would be developed. Here, control laws and flap allocation schemes would be implemented and compared in numerical simulations. Six degrees of freedom would be modelled to implement all coupling effects. The effect of different engine positions on stability would be studied numerically. A selected implementation of a Flight Control System would be embedded in a cockpit simulator and assessed in terms of HQ with a pilot in the loop.

The results of the numerical studies in Subtask 2.2.3 were to be compared against the wind tunnel test results. These results would then be added to the aerodynamic database for the flight control systems.

Technical achievements

Subtask 2.2.1 Cabin

This Subtask started with the development of cabin layouts based on requirements for passenger comfort and safety. These first, creative layouts represented ideal requirements for the cabin architecture including shape, volume, location of exits and aisle areas. The application of numerical evacuation simulations performed with the enhanced simulation tools developed in the VELA project, and of improved fire hazard simulations allowed then to assess and optimise these cabin layouts. Evacuation and crew procedures have been developed as required by the new cabin configuration concepts.

Generation and Refinement of Cabin Layouts

Airbus has worked on a variation of aisle widths, positions, alignments and shapes to improve the cabin layouts regarding emergency evacuation time. Because position and size of cabin monuments as galleys and lavatories affect the seat distribution and thus the exit usage ratio, the effects of aisle variations cannot be clearly identified. Therefore, it was decided to create a new baseline cabin layout in which all cabin monuments in the centre of the cabin layout are eliminated and replaced by seats instead, with increased widths of the 3rd and 6th longitudinal aisle between exits 3 and 6 by eliminating one seat per row each (+34 seats regarding initial cabin layout). The average evacuation time established by UoG was 84 seconds. The first variation is the implementation of four diagonal aisles leading from the widened longitudinal aisles to exits 3 and 7.

Simulations with the best cabin layout have been run by UoG and were complemented by a coupled fire and evacuation analysis. Here the passenger behaviour model was coupled to the environment provided by fire simulation. The results have been extensively documented in [D2.2-12].

Figure 44 below shows a typical cabin layout with 10 usable exits while Figure 45 depicts the associated results of a series of simulation runs. It can be clearly seen that the exits in the rear corner of the cabin, especially the corner exit 7, are not fully used. Improvements have been achieved by rearranging aisles and by improved guidance by additional cabin attendants.

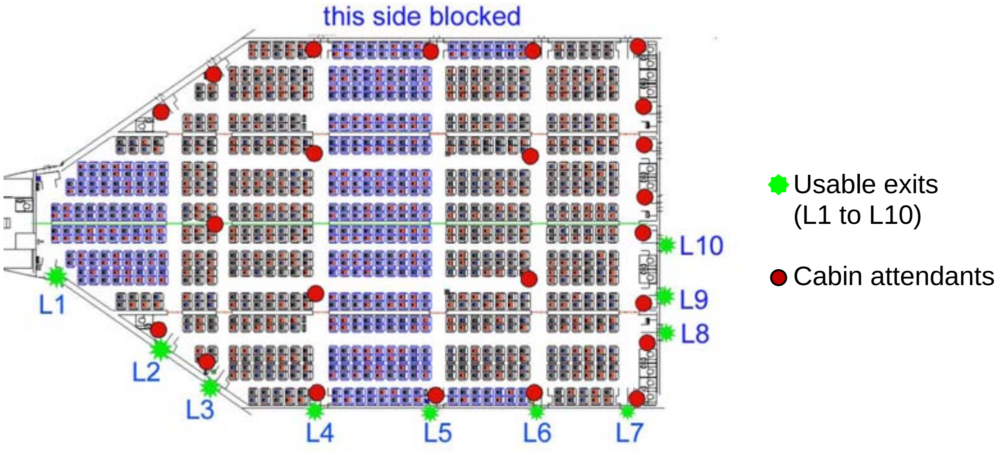


Figure 44: Cabin layout for “Case 10”

A major result of this work was that the flying wing cabin does not suffer from rapid flash-over during the first 480 seconds of the fire. For the cabin layout under consideration, flash-over occurred not earlier than 600 seconds after the start of the fire. This is in contrast to conventional cabin configurations, where flash-over occurs much earlier and is in fact responsible for the well known “90-seconds-rule”. This means that the flying wing cabin has an advantage in terms of safety in case of a cabin fire. An additional conclusion from these results would be that the current 90-seconds rule may (for novel aircraft configurations with very different cabin layouts) have to be replaced by a new rule, based on actual evacuation performance.

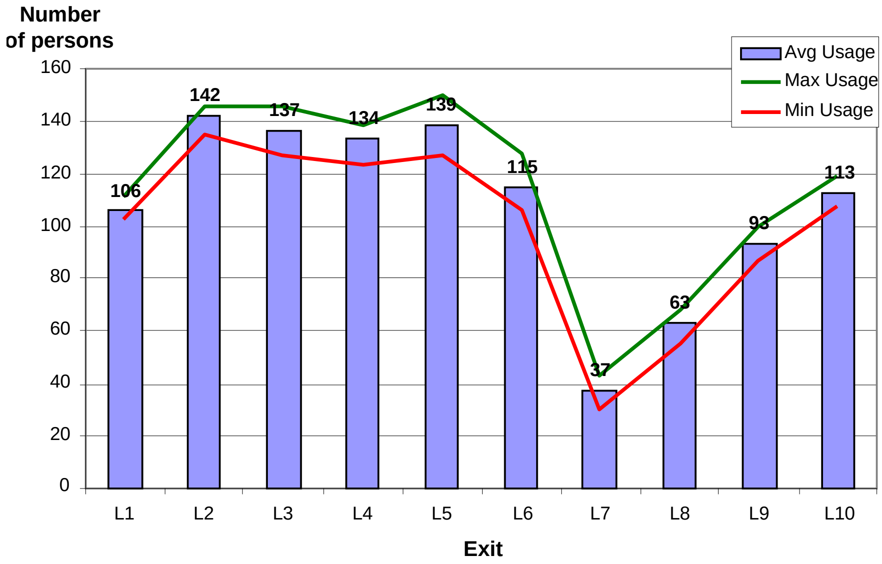


Figure 45: Exit usage for "Case 10"

Experimental Activity

As part of the VELA project, the behaviour sub-model within the evacuation model had been adapted to cope with the novel configurations offered by flying wing aircraft. It was, however, not clear whether the numerical tools were really suitable for the new cabin proportions of flying wing aircraft. Also the simulation results showed a clear under-utilization of the exits in the rear corners of the cabin, which made a validation of such cabin configurations very desirable.

For such an experiment, several options in terms of cabin size, number of trials and environment would have been possible. The consortium as well as external experts were not able to easily estimate the effort required to conduct a large flying wing cabin evacuation trial. Therefore a feasibility study for a full size cabin mock-up was produced to compare possible solutions for such a mock-up (having different sizes and hence economics) and the trials to be performed. As a result of this study, it was decided through a CDR, that a static cabin mock-up of reduced size would be sufficient to verify the predictive capabilities of the numerical model. The purpose of the test was to observe for the first time - the evacuation behaviour and performance of passengers and crew in novel flying wing configurations and to quantify this behaviour. This information was then used to verify the assumptions contained in the behaviour sub-model, to fine-tune the model and to improve its predictive capabilities for flying wing configurations.

The preparation of the test started with numerical simulations by UoG to define a section of the flying wing cabin which would represent the features to be validated and would allow for manufacturing an affordable setup within the budget of the project. These numerical simulations formed the basis for defining the geometry of the cabin mock-up and the experiments to be conducted.

All partners involved in this experimental activity (Airbus, UoG, and TUM) combined their efforts during preparation and execution of the cabin trials as well as the subsequent analysis of the test results. Because the NACRE partners lacked a suitable facility and practical experience, the actual experiments were subcontracted to Cranfield University. The team of Cranfield University had to apply considerable modification to their cabin simulator to represent the features of the flying wing cabin. Figure 46 presents a floor plan of the cabin mock-up developed for the trials.

Besides these mechanical preparations, Cranfield organized the trials including recruitment of the participants. UoG and TUM supported the preparation phase and the trials by supplying and operating recording equipment, personnel and questionnaires.

Finally, the tests were executed in February 2008. Following a smaller "pilot test" two larger trial days with about 400 participants each have been successfully conducted. All desired data had been collected in form of video footage as well as questionnaires filled out by the participants.

After the tests a detailed analysis took place at UoG with students from TUM being involved. The team performed an analysis of evacuation data and a comparison with the numerical predictions. As can be seen in Figure 47, the predicted exit usage matches the actual results of the trials quite well. The critical under-utilization of the corner exit L7 is clearly visible.

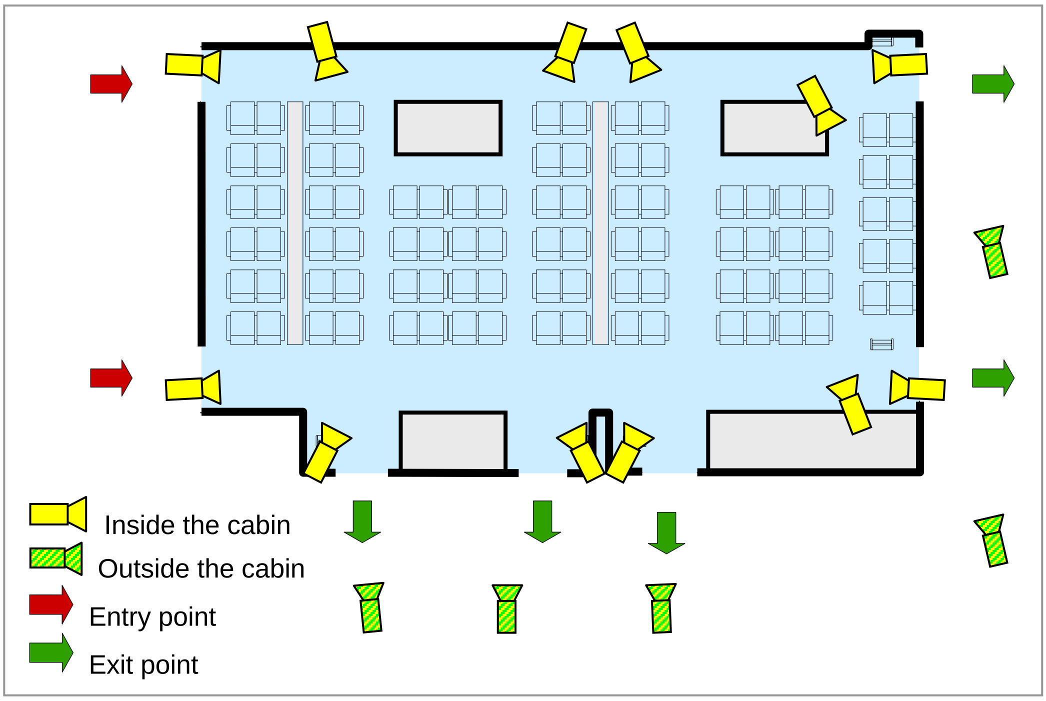


Figure 46: Layout of experimental cabin with location of cameras

Another aspect of the analysis was on path finding in wide fuselage cabins. For this purpose, the questionnaires of selected participants were cross-checked with video material. The influences on the choice of path were analyzed (exit awareness, external influences like crowded aisles or unusual cabin layout.

Further analyses of the video footage concerned the decision time and decision changes for way path through the cabin, the crossing of seat rows and its dependence on cabin conditions like crowds, cabin crew action etc.

Furthermore, the effect of additional cabin crew and crew instructions on passenger's path choice was examined. The experimental results have been studied in context of the problem of re-using participants (learning effect). The test data was analyzed with focus on overall exit usage, leading to hypotheses influencing exit usage behaviour. This analysis also included exit usage rates depending on socio-demographic properties.

The comparison of the experimental results with the predictions demonstrated good agreement and thus confirmed the validity of the numerical simulation. Details of this assessment can be found in [D2.2-13].

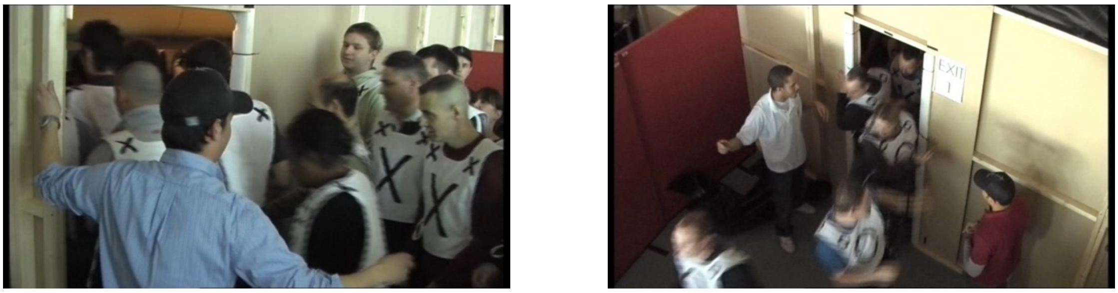


Figure 47: Cabin Trial pictures taken at Entrance 'X' and Exit 1.

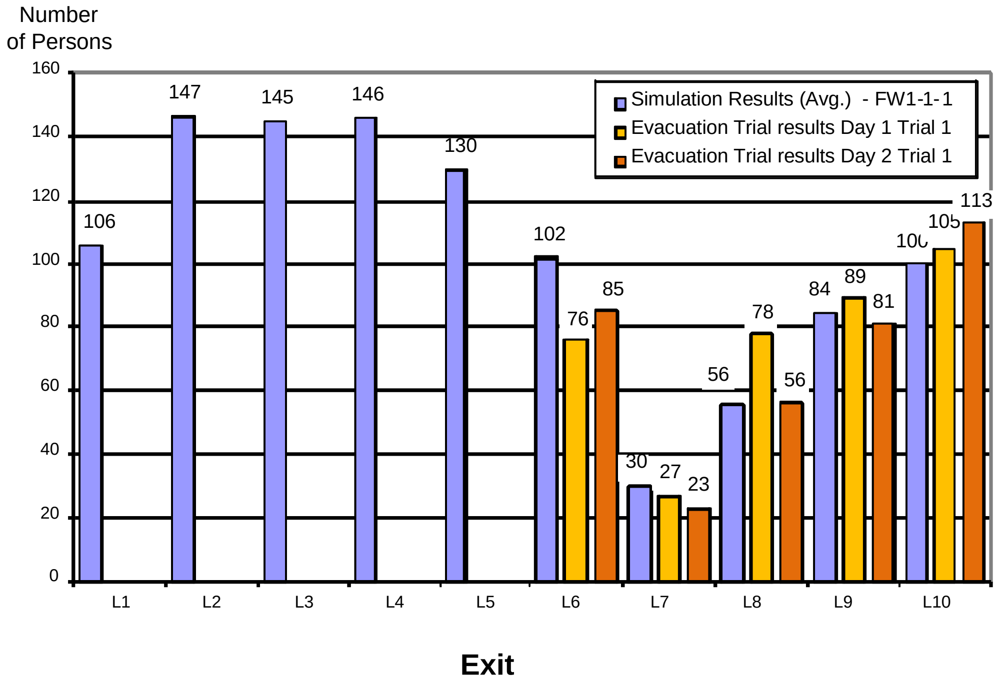


Figure 48: Exit usage comparison between predictions and evacuation trial data

Subtask 2.2.2 Structures

Until today no flying wing transport aircraft of the size of the NACRE configuration has been built. This means that no experience concerning the mass of the structure exists; this is especially true for the flat and pressurized centre body. Therefore considerable effort was directed into the estimation of the structural mass of the vehicle.

The partners involved in this Subtask started with the suite of structural concepts developed in VELA. Global architectural ideas and local solution concepts were studied and a detailed parametric Finite-Element (FE) model for one structural concept was developed. This model has been made available for all partners to study crash and ditching behaviour as well as aeroelastic effects. Initially it was planned to use the elastic model in Subtask 2.2.3 to derive flight control laws for the elastic aircraft, but this proved infeasible within the time and resource constraints of the Task.

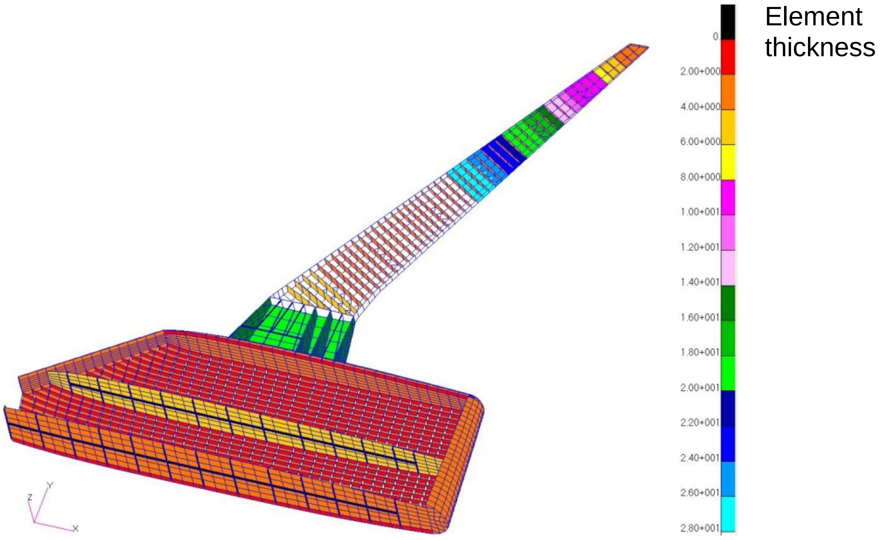


Figure 49: View of the finite-element model of the primary structure

Mass Prediction

On the one hand side TsAGI exercised its preliminary design and sizing tools which use finite element models of varying fidelity as well as empirical assumptions. Unfortunately the result was a breakdown of the structural mass for the almost conventional outboard wing only.

Additionally, Onera refined and adapted its finite element model generator so that simplified but sufficiently realistic structural models could be generated and sized. This structural model also represents the centre body of the aircraft. Only a limited number of load cases could be considered (cabin pressure, 2.5 g flight, and fatigue).

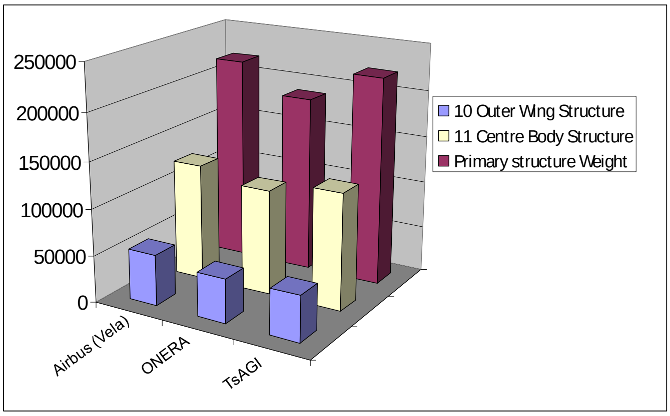


Figure 50: Comparison of FW structure weight estimates

The resulting masses produced by TsAGI and Onera, although stemming from very different models with different construction assumptions, were comparable with the estimates provided by Airbus and could be used in Task 1.2.

Structural Concepts

The centre body of the flying wing configuration houses a flat, pressurized cabin. Onera checked their structural concept for the pressurized central part of the NACRE-FW1 configuration for the two most penalizing loading cases – internal pressure and buckling due to bending loads introduced by the outboard wings.

For this purpose, the coarse finite-element model used for the mass prediction work was refined. It was found that the risk of buckling due to bending loads made it necessary to introduce additional local reinforcements extending across the cabin. The weight penalty associated with these reinforcements has been determined and documented.

The attachment of the classical outboard wings to the flying wing centre body offers many possible solutions. This region requires particular care, since large loads are to be carried through the main body, without compromising passengers’ comfort within the cabin.

DLR has performed a study to develop, compare and assess several concepts for the junction region in terms of mass and complexity of assembly. These concepts were submitted to a detailed analysis and resulting mass trends were recorded. The most promising structural concept proposed as a result of this study makes use of framework truss structure. This concept yielded a lower mass than the more classical frame and web concepts. Since the shear load carrying structure was designed to cross the cabin, trusses are more advantageous than shear webs with regards to passenger comfort.

Aeroelastic Analysis

The dynamic aeroelastic behaviour (flutter characteristics) of several variants of the NACRE flying wing configuration has been examined by DLR. These included engines mounted below the wings as well as above the centre body and two variants of vertical surfaces (centre body fins versus wing tip winglets). All configurations were examined with empty as well as full fuel tanks. The overall result was that none of the configurations led to premature flutter at speeds below dive speed. Therefore it can be concluded that flutter is no issue for the NACRE configuration.

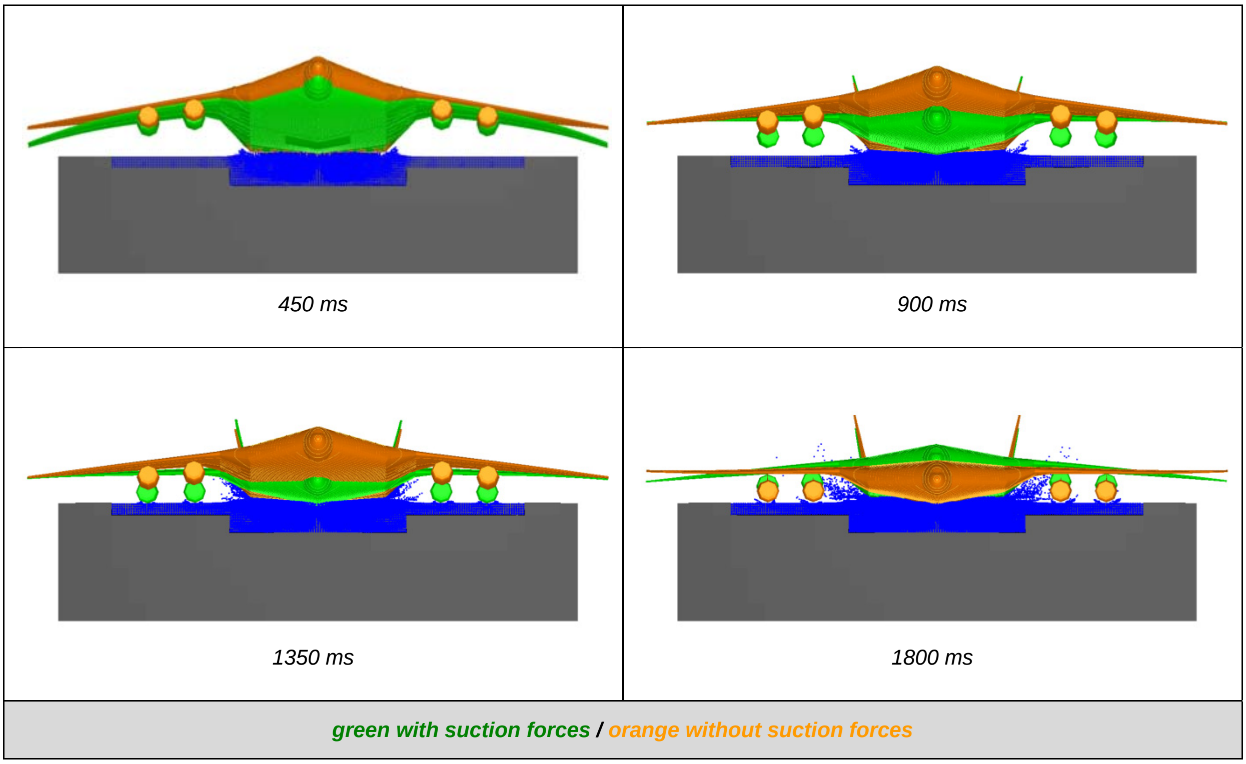
Crash and Ditching Behaviour

The flat centre body of a flying wing aircraft differs considerably from conventional aircraft in its shape as well as internal structure. Therefore it was of interest to study its characteristics during a crash. For NACRE a “ditching in water” scenario was selected as an even more challenging topic. An additional difficulty arises from the interaction of the body with the water, which can create high suction forces due to the large difference in density of the media (air vs. water). Therefore the analysis method was calibrated by using some NACA data from water tank experiments related to flying boats. In the simulation it is possible to switch these suction forces off to study their effect.

Based on the finite element model produced by Onera, a refined model was created by DLR in cooperation with Onera. This more detailed model with smaller element sizes was necessary to model the nonlinear deformations occurring during crash and ditching of the aircraft.

After some initial studies using a rigid model the analysis of a deformable aircraft model was performed using the calibrated external force functions and the static properties as defined by Onera. These deformable simulations are able to approximate the structural loadings and the structural response of the Blended Wing Body aircraft during water impact. To perform impact simulations of a deformable aircraft on a water surface a new multi – model coupling capability of the simulation software was used to keep the calculation time in an acceptable timeframe. Typical results as shown in Figure 51 below highlight the necessity to include the suction forces; otherwise a rather different motion after contact with the water would be predicted.

The results indicate that the accelerations acting on a passenger are within the usual limits and not critical. Design guidelines to improve the crash behaviour have been developed from the simulation results.


450 ms

900 ms

1350 ms

1800 ms

Figure 51: Comparison of rigid and elastic aircraft during ditching

Allowable Deformation Study

The flat surfaces of the pressurized cabin in the centre body of the flying wing will deflect under internal cabin pressure. A study was conducted by TsAGI in cooperation with DLR to find out the relations between the structural mass of these cabin panels and the aerodynamic impact of such deformations. TsAGI performed a large number of analyses of a range of panel designs sized for prescribed maximum deflections. DLR supplied feasible deformation limits, based on simple aerodynamic analyses.

As a result of this analytical work, Pareto front graphs of structural mass versus allowed deformation have been developed for different parts of the centre body. These graphs make it possible to select a maximum deformation limit which is a compromise between mass and aerodynamic performance.

Fuel Tank Optimisation Study
Due to the smaller lever arms, the allowable centre of gravity travel of a flying wing aircraft is smaller than that of a comparable conventional aircraft. PW performed a study to optimise the fuel tank system considering trim, stability and bending moment constraints. Analyses were conducted with different fuel load scenarios, including the usage of trim tanks. This analysis demonstrated that a trim tank offers a lower trimming moment to be generated by wing flaps. Thus the trim drag could be reduced, in extreme cases the drag could be decreased by 4.6 %.

Subtask 2.2.3 Control and Aerodynamic Performance

Due to the time constraints of the project it was decided to model the rigid airplane only. The initially planned extension to the flexible aircraft was not performed. Only a limited study of the control surface derivatives of the outboard wing flap using a modal representation of the aircraft structure was performed at FOI. Correlated to this study TsAGI performed the analysis of novel control devices which exploited aeroelastic effects of the outboard wings.

Shape Optimisation for Performance
FOI was concerned with a purely aerodynamic shape optimisation of the NACRE configuration. The motivation was to provide an optimum shape which could be compared with the shapes optimised within the previous VELA project. Unfortunately this work, involving new implementations and optimisation strategies, did not bring useful improvements. The optimisation relied on the application of a new parameterization of deformations – defined by a radial basis function (RBF) – of the baseline shape. The gradient based optimisation algorithm then adjusted the coefficients in the RBF – similar to a finite element representation - with the objective to achieve a higher lift over drag ratio. In case of the flying wing configuration, this approach was not able to produce any improvements – the application to conventional wings (e.g. the HARLS planform) was more successful. The difficulty may have been caused by the large variation in chord length from root to tip of the flying wing configuration. Here a large number of control points, the variables being optimised, are distributed over the centre body practically wasting degrees of freedom in this region and unnecessarily increasing the optimisation problem. It may be more promising to map the planform first to unit chord length, which would result in a more evenly parameter space. Unfortunately this approach could not be implemented within the available budget and resources.

Flight Simulation and Handling Qualities
In order to develop flight simulations with associated flight control systems, a database of the aerodynamic characteristics of the NACRE configuration was needed. Because the simulation should cover a fairly large range of conditions, the generation of the database was split between several partners:

- Static Derivatives (Polars)
  - Low Speed – DLR
  - High Speed – Onera
- Control Surface Derivatives
  - Low Speed – DLR
  - High Speed – Onera, FOI
- Dynamic Derivatives
  - Low Speed – DLR
  - High Speed – DLR
- Ground Effect Derivatives
  - Low Speed – VZLU

Onera was in charge of collecting the contributions into single database. For this purpose a common database format was defined and used by the partners to deliver their results. Nevertheless, the consolidation of the database proved to be more time consuming than initially planned. But due to the common file formats it was possible to provide updates to the database without hindering the setup of the flight simulation tools.

Three different flight simulation models have been implemented by the following partners:

- Onera – simulation within the “FlightGear” simulator,
- DLR – simulation using Matlab/Simulink and implementation in the Cockpit simulator,
- PW – simulation using Matlab/Simulink.

The DLR approach also allows for the transfer of the flight simulation model with its flight control system implementation to the “ATTAS” flying simulator of DLR. This in-flight simulation method allows for the most realistic assessment of the developed flight control system and handling qualities by pilots. A flight campaign is outside the scope of NACRE, but planned for 2010.

Experimental Activity

Previous research work had indicated that the lateral control power of flying wing transport aircraft can be a limiting factor. Especially in critical conditions, like “engine out during takeoff”, the control power provided by vertical fins can be too small due to their small lever arms. This was the reason to test “new” control devices in NACRE using an existing low speed wind tunnel model of the VELA 2 configuration.

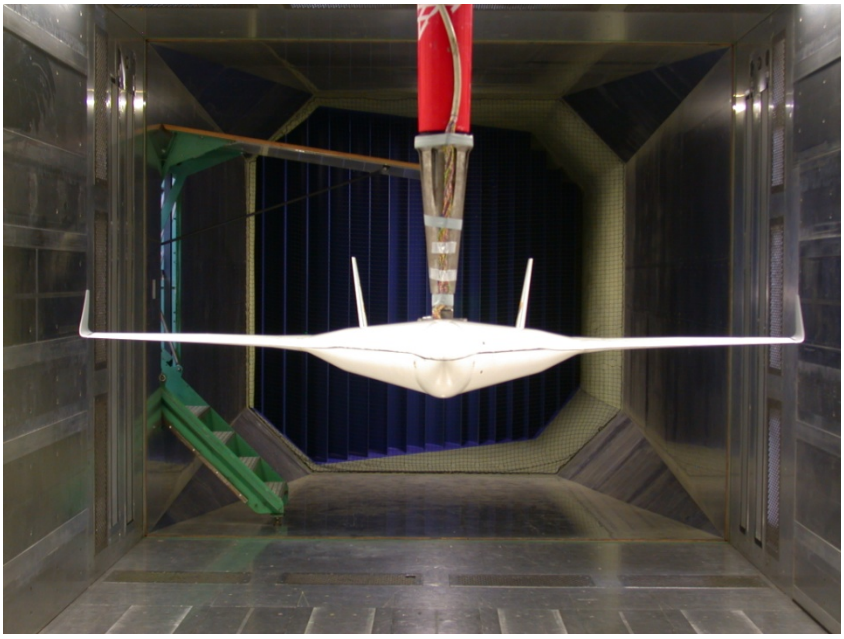


Figure 52: VELA2 model with winglets in the DNW-NWB wind tunnel

Two control devices had been selected and manufactured:

- split ailerons, manufactured by VZLU, and
- large winglets with optional split flaps, provided by Onera.

The wind tunnel model was provided by DLR and modified so that the new winglets could be attached. Tests were conducted to deliver static polars as well as dynamic damping derivatives of the configurations.

A large number of split aileron configurations (symmetrical as well as asymmetrical up-down deflection combinations) have been tested. Based on these results a simplified model was developed to be implemented the split aileron function in the flight simulations. The split ailerons proved to be very efficient for yaw control and drag generation during steep descent.

The winglets proved to be less efficient, mainly due to their narrow chord and the VELA 2 wing planform, which placed the vertical surfaces relatively far forward, thus having little effect on directional stability. They may be better suited for wing shapes with higher sweep angles, locating the wing tips more aft.

Optimum Control Allocation

A flying wing typically has a larger number of trailing edge flaps which can be used to achieve optimised trim settings for various flight conditions. These include cruise conditions (maintain trim and at the same time maximize the lift over drag ratio) as well as low speed cases (maximization of control power at low speeds, maximize drag during descent).

PEDECE implemented a numerical method to find the best application of systems of multiple flaps with respect to various objectives under several constraints. With this method it is possible to find optimum flap settings for e.g. minimum drag in climb or maximum drag in approach while maintaining trim constraints. Eight different pitch trim strategies have been examined. The aerodynamic data required for this work have been taken from the aerodynamic low speed database provided by DLR. The results demonstrate that the flexible and optimised usage of all control surfaces instead of single predetermined allocation yields les trim drag and better control authority. An additional benefit of such a multi-function system is inherent redundancy which could lead to less stringent requirements concerning e.g. actuator failures. These findings apply also to conventional aircraft.

Aeroelastic control devices

As noted above, control power is a critical issue on flying wing airplanes. For any airplane configuration aeroelastic effects at high total pressures become relevant and may lead to reduced or even reversed control power. A conceptual study was performed by TsAGI using an elastic model of the outboard wing in combination with various novel aileron devices.

Results as shown in Figure 54 below in the form of rolling moment versus total pressure (proportional to the square of the flight speed) confirmed that it is possible to delay the reversal effect. The proposed devices have only been regarded at conceptual level, but some of the proposed devices look interesting and should be subjected more detailed analysis in the future. Such concepts could also be applied to other configurations, like forward swept wings.

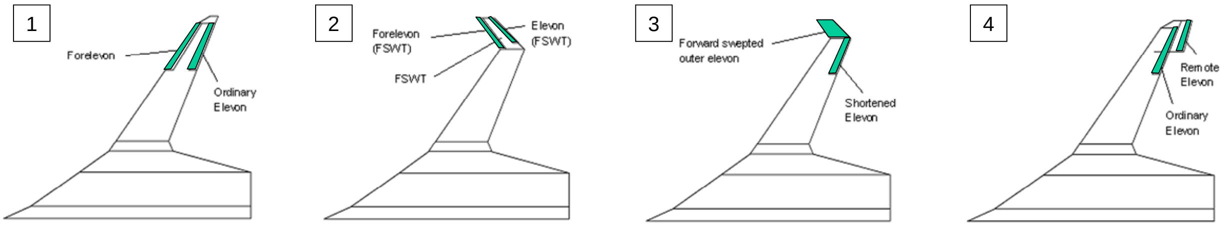


Figure 53: Devices studied to affect the control characteristics of the elastic outboard wing.

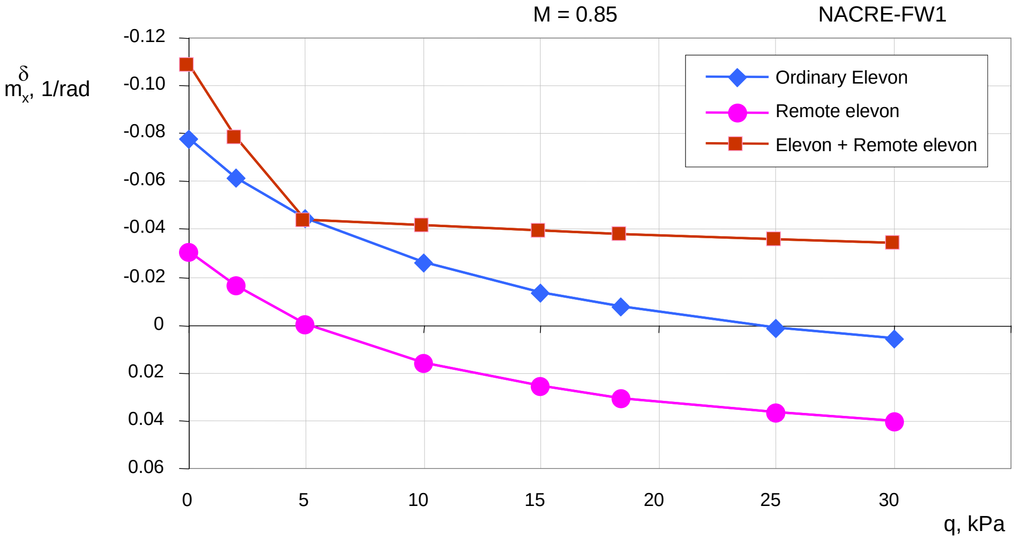


Figure 54: Rolling moment coefficient due to aileron deflection vs. total pressure for device number 4.

Final Conclusion

No global showstoppers for this type of configuration have been identified. The major uncertainties seem to be in the area of mass prediction, whereas the other disciplines are able to handle the flying wing configuration with sufficient confidence. The following list summarizes briefly the main findings per Task.

Subtask 2.2.1 Cabin

- Various cabin layouts have been developed and assessed. The simulation results demonstrate that egress times in accordance with FAR rules can be achieved.
- The Evacuation trials confirmed the predicted performance and hence the validity of the simulation models.
- The egress simulation combined with fire simulation demonstrated a better survivability in a flying wing cabin compared to a conventional tubular fuselage. Flash-over was predicted at 600 s, to be compared to 480 s for a conventional tubular fuselage layout.
- Future work should include cabin layout and evacuation considering the ditched airplane.

Subtask 2.2.2 Structures

- The application and comparison of mass prediction methods demonstrated that it is still rather difficult to make trustworthy mass predictions for novel configurations.
- Various concepts for the integration of outboard wing and centre body have been developed and compared. These concepts should be integrated into future design studies.
- The aeroelastic analysis of several flying wing configurations showed no problems with the static and the dynamic aeroelastic characteristics.
- The analysis of the ditching and crash behaviour showed no worse results than for conventional aircraft and produced useful design guidelines.
- The allowable deformation of the flat cabin structure was assessed in terms of deformation and mass. The results allow for the selection of a suitable compromise between aerodynamic performance and mass.
- Future work should strive to refine the mass estimation methods for the centre body part of the configuration, including more relevant load cases. It may be necessary to perform a more detailed structural design of a centre body cross section (“barrel”) to decrease the mass uncertainties, which are still considered to be too high.

Subtask 2.2.3 Control and Aerodynamic Performance

- A complete aerodynamic database has been generated and can be used for steady as well as dynamic simulations. Considerable effort was needed to define exchange formats and to consolidate the individual contributions of the partners into a single database.
- The wind tunnel experiments supplied data for modelling novel control surfaces like split ailerons. Previously no data for this type of control surfaces was available for research purposes. This gap has now been closed and results will be used, e.g. for validation of numerical tools.
- While the development of a multi-functional control system with a flexible, optimised control allocation scheme is difficult, it offers many benefits in terms of performance as well as reliability.
- The developed flight control systems have been demonstrated in screen and cockpit simulators. Results show that the configuration is flyable, but hampered by control power limits in the engine out case or during takeoff rotation (this is depending on the position of the propulsion system, which was not a major topic of this Task).
- Future work should seek to increase the control power by optimising the (possibly dynamic) allocation of control surfaces and the arrangement of engines under consideration of the engine out condition. Furthermore the stall, spin and tumble behaviour of these configurations with unusual distribution of moments of inertia should be explored.

Summary

This Task dealt with selected topics related to transonic flying wing aircraft for passenger transport. The baseline configuration NACRE-FW1 provided by Task 1.2 was used for all non-generic work.

The Task was divided into three main work areas, namely Cabin, Structures, as well as Control and Performance. The contributions of the individual partners were focused on specific questions which had not yet been answered in previous European and National projects related to flying wing aircraft.

A major effort was directed into the Subtask “Cabin”, which provided for the first time in Europe experimental data for the validation of numerical prediction tools for passenger egress (evacuation) from a flying type wing cabin. Additional important results of this Task were that neither evacuation time nor the dangers of a cabin fire can be considered showstoppers for flying wing cabin layouts.

In the Subtask “Structures”, several topics were of interest. One of the major interests was on mass prediction methods for the primary structure of the cabin centre body. Here mostly finite element based methods were applied, but the results required several consolidations among the partners to achieve an agreement. It must be concluded, that the mass prediction is still suffering from larger uncertainties than desirable.

Results concerning the flutter as well as the crash and ditching behaviour of flying wing structures showed that the associated problems can be solved by applying state of the art engineering knowledge. The question of the impact of structural deformation of the flat pressurized cabin on aerodynamic performance was also addressed and it could be demonstrated that an acceptable compromise between the two disciplines can be found.

Aerodynamics and flight mechanics were the focus of Subtask “Control and Performance”, which required the build-up of an aerodynamic database to construct simulation models, develop flight control systems and finally assess the handling qualities of the flying wing configuration. A wind tunnel experiment was conducted to find the control derivatives of double split ailerons (“crocodile flaps”), which have been integrated into the aerodynamic database. The development of the flight control systems showed that the flying wing can be controlled in normal flight conditions and normal handling qualities can be provided by the system. Specific conditions, mainly the operation with one engine inoperative during takeoff require careful design of the control surfaces and especially of any vertical fins or winglets. In case of the baseline configuration the double split ailerons proved to be essential to maintain control under these conditions. An improvement in this respect can be achieved by moving the engines closer to the centre line, e.g. by placing the engines above the centre body, albeit at a cost of a rather difficult aerodynamic integration.

In retrospect the Task provided many new insights and produced interesting results which filled gaps in the existing knowledge base. One of the initial areas of interest, to build up a simulation of the elastic aircraft could not be achieved however, mainly due to the rather wide range of capabilities and resources provided by each partner.

Nevertheless, the Task can be considered successful. Questions about egress times and survivability in case of an accident of a flying wing aircraft have been satisfactorily answered. A better understanding of structural concepts, mass prediction and aerodynamic control was developed. Results and lessons learned have been transferred to a related follow-on project named “ACFA 2020”, which for example uses the same methodology to produce the aerodynamic database for its aircraft configuration.

Task 2.3 – Innovative Tail Integration

Task objectives at beginning of the project

Task 2.3 aimed at exploring the feasibility of a novel Tail design for a civil aircraft configuration. The results of Task 2.3 would be assessed at overall aircraft level in WP 1, Task 1.3, by comparing with a datum conventional empennage bearing the same functionalities. This would be achieved through a multidisciplinary investigation and assessment. The research in Task 2.3 was initially planned to be undertaken on the V-Tail concept as a follow-up of the FP5 Project NEFA.

The NEFA project aimed at an empennage surface reduction of 20% by the use of a V-Tail leading to a reduction in fuel consumption. Despite the surface reduction, the following facts, related to the handling qualities, degraded the situation:

- Emergence of “new” sizing Handing Qualities criteria as take-off rotation in a One Engine Inoperative situation;
- Degradation of the preliminary aerodynamic model due to coupled α / β effect on V-Tail;
- Poor interaction between left and right arms of the V-Tail.

As a result, a comparison between a classical tail configuration and the V-tail showed that, although the comparison was almost neutral in terms of block fuel, disadvantages for the V-Tails on MWE and MTOW were identified: the benefit in wetted area was compensated by higher trim drag and the V-tail empennage and the rear fuselage section 19 remained heavier than the classic layout.

Due to the NEFA outcomes, a V-tail concept would provide little or no gains at aircraft level and it was consequently decided not to use this concept in NACRE. After top-level discussions about the future of Task 2.3, the activities focused then on innovative tails concepts in conventional tail architecture. The morphing technology was also selected for feasibility studies.

As Task 2.3 was initially structured to work mainly on the flight control system of the V-tails, Subtasks 2.3.1 and 2.3.2 were completely rearranged. On the basis of studying innovative concepts for conventional tail configurations, Task 2.3 members worked together to define their participation in the Task. As result, Subtask 2.3.1 targeted flight physics and structures analyses and Subtask 2.3.2 focused on systems and integration activities.

In terms of the innovative concepts to be studied, Double-Hinged control surfaces for the elevator and rudder were selected due to their potential in terms of empennage size reduction. On the other hand, the Morphing Technology showed a potential at aircraft level worth to be considered. For this reason, this technology was studied within Task 2.3 as a feasibility study for future aircraft designs, but not included in the final Task 1.3 evaluation.

Subtask 2.3.1 Flight physics and structure

The objective of Subtask 2.3.1 was to understand the Flight Physics potential of Double-Hinged concepts and also their impact in terms of Structural definition, by means of a multi-disciplinary analysis. In this way, the influence of the Tail with double-hinged concepts would be analysed from aerodynamics, loads, structural and weights point of view.

Subtask 2.3.2 Systems and Integration

The primary objective of this Subtask was to ensure that the Simple Flying Bus (SFB) aircraft in Task 1.3 would be certifiable as far as stability and control are concerned. Within this framework, this Subtask was to be used to perform HQ investigations of the innovative tail concepts and to define the Flight Control System (FCS) requirements for the SFB aircraft.

For the double hinge work, the goal was to achieve the empennage size reduction target (20%) without degrading the aircraft’s handling qualities or reducing the aircraft’s operational centre of gravity (CG) range.

The Morphing work intended to build upon the initial findings from the early feasibility study, pushing the innovative tail investigation towards more futuristic concepts. The morphing work would be conducted as a feasibility study, based upon the initial handling qualities targets of the double-hinged work and the same SFB aircraft.

Technical Achievements

The original plan for the Innovative Tail Integration Task 2.3 was built upon the work of the NEFA V-Tail project. The V-tail concept was chosen as it was conceived possible to reduce the empennage wetted are and thus the fuel consumption, a major objective for Task 2.3 and the Simple Flying Bus (Task 1.3). Unfortunately, the results of the NEFA project showed that the V-tail concept would provide little or no gains at aircraft level, and it was consequently decided not to use this concept in NACRE.

Task 2.3 focused then on innovative tails concepts in conventional tail architecture. Initially, all the Task members suggested a number of empennage concepts as replacement for the V-tail, consisting of Droop Nose, Trimmable H/VTP, Double-Hinged Rudder/Elevator, Variable Sized H/VTP and Morphing. In order to down-select the most promising concept to be studied in the Task, preliminary analyses were carried out to evaluate the potential of each of the mentioned concepts at aircraft level.

Airbus worked on the one hand on the aerodynamic behaviour of the droop nose device for the HTP and double-hinged concepts. On the other hand, Airbus carried out also a preliminary HQ analysis to evaluate the impact of the mentioned concepts in terms of empennage size reduction. INTA analyzed the ice accretion effect on the droop nose aerodynamic performances. NLR studied several VTP concepts from aerodynamic point of view.

After a rigorous down-selection stage, the Double-Hinged concepts for the elevator and rudder showed the possibility of significant empennage size reductions (~11% for the Horizontal Tail Plane and ~14% for the Vertical Tail Plane). Double-hinged concepts for the empennage were then chosen for the NACRE study. A complete multidisciplinary analysis was decided to carry out in order to evaluate the potential of this concept at aircraft level and its contribution to the Simple Flying Bus aircraft.

In parallel, DLR, Onera and NLR, compiled the state of the art of the Morphing technology and possible applications to improve the empennage performances. This exercise led to investigate the feasibility of a morphing empennage concept for a transport aircraft. This study was foreseen to complement the double-hinged studies, while providing the involved parties the means to investigate some more revolutionary concepts.

The analysis carried out during this first phase of Task 2.3 as well as the outcomes of the concepts down-selection were documented in the deliverable [D2.3-1]. Before starting with the multidisciplinary investigation, the reference aircraft to be used for the Task was chosen. The SFB reference aircraft presented by Task 1.3 has a 20% reduced size empennage according to the target defined for Task 2.3 to achieve. Since for the development of the double-hinged control surfaces, to consider a non-reduced empennage was decided, a new reference aircraft to be used for all the studies and the way to use it were defined.

Two multidisciplinary investigations were planned to be carried out in parallel to study double-hinged concepts for the Horizontal and the Vertical Tail Plane respectively.

Double-Hinged Rudder

Handling qualities analysis

NLR performed a handling qualities investigation to evaluate the empennage area reduction effect due to the implementation of a double-hinged control surface on a VTP. For this analysis, an NLR internal simulator was used, which firstly was set up to represent the performances of Task 2.3 baseline aircraft.

The engine failure at 1.1 VMCa was identified as the sizing manoeuvre for the vertical tail plane of the baseline aircraft. At this condition, the VTP demands an increase of rudder control power to counteract the loss of side force due to the engine out condition. Assuming 20% of DHR control power increase (coming from a preliminary aero optimisation), the study concluded that in all cases, DHR on a 20% reduced size VTP configuration obtains the SHR baseline performance.

The lateral analysis showed that there are generally 2-3 degrees higher sideslip excursions due to 20% VTP surface reduction for bare aircraft (direct law) and also that the stability is still guaranteed.

The complete handling qualities analysis for the VTP with double-hinged rudder is documented in the deliverable [D2.3-2]. A description of the remaining multidisciplinary activities can be found in deliverables [D2.3-3a]/[D2.3-4a]/[D2.3-5a]/[D2.3-6a].

Aerodynamic optimisation

The next step in the multidisciplinary analysis led to perform an aerodynamic optimisation in order to select the best combination of double-hinged parameters that give the maximum rudder control power at the sizing manoeuvre condition. This activity was carried out in parallel by Airbus and NLR.

A preliminary aerodynamic optimisation of the double-hinged rudder installed in an isolated VTP showed that the most promising case was that with configuration “70-95, K=1” (first hinge line position at 70% chord, second at 95% chord, and ratio of deflections of the second versus the first rudder segment of 1). Forces and moments at VMC condition (maximum side force coefficient, drag coefficient and hinge moments and servo forces) and forces at cruise condition were considered as criteria for this optimisation.

The aerodynamic optimisation analysis carried out with installed VTP (model with fuselage, HTP and VTP) by Airbus and NLR confirmed the double-hinged rudder with configuration 70-95, K=1 as the best selection. The final quantification of VTP potential reduction showed an increase of rudder maximum control power of about 15%. With this configuration, the VTP area could be reduced at least by 15%.

As part of the aerodynamic calculations, NLR also developed the actuator principle for the double-hinged rudder. It was assumed that the first rudder segment was driven by a linear hydraulic servo. A passive "push-bar" solution was selected to drive the second rudder segment. A relatively far aft location of the second rudder segment hinge line, $x_{h2}/c = 0.95$, provided an interesting increase in VTP maximum side force capability at a relative low increment of the servo actuation force and push-bar force. For this particular solution, an external push-bar solution may be required.

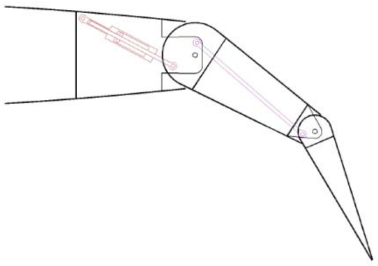


Figure 55: VTP second rudder mechanism principle by means of a push-bar solution

Loads assessment

Following with the multidisciplinary analysis of the double-hinged rudder concept, NLR performed a loads assessment on the VTP with DHR. The overswing sideslip manoeuvre was identified as the critical load case according to the FAR 25.351. The analysis was carried out with the philosophy of keeping the same performances as the SHR.

The flight simulation setup with adapted values for the aerodynamic derivatives was used to evaluate the tail loads manoeuvre. CFD was applied to the isolated-VTP setup to compute the corresponding surface pressure loading.

Structural assessment and weight estimation

NLR used the critical load case to size the structure of the VTP with double-hinged rudder. Three configurations were considered:

- Non-reduced size VTP with single hinged rudder (reference)
- Non-reduced size VTP with double-hinged rudder (configuration 70-85)
- 20% reduced size VTP with double-hinged rudder (configuration 70-85)

A comparison study between a metal (Aluminium) and a composite configuration was also carried out. The final structural assessment demonstrated that the selected critical load case was not adequate to size the structure

Concerning the weight evaluation, two VTP candidates were analysed by NLR: the full-scale single-hinged rudder VTP, serving as a reference, and a 20% reduced area ($x_{h2}/c = 0.85$, $\delta_2/\delta_1 = 1.0$) double-hinged rudder VTP. Weight figures interpolated linearly to the 1/1.153 area reduction of the selected ($x_{h2}/c = 0.95$, $\delta_2/\delta_1 = 1.0$) double-hinged rudder candidate, resulted in a negligible VTP mass change relative to the full-scale single-hinged rudder VTP

Double-Hinged Elevator

Handling qualities analysis

As for the rudder, Airbus carried out a handling qualities investigation to evaluate the empennage area reduction effect due to the implementation of a double-hinged elevator on an HTP. The longitudinal HQ analysis concluded that the CEV (*Centre d'Essais en Vol*) manoeuvre was the HTP sizing case and the necessity of defining requirements for relaxed stability. The investigation also demonstrated that the reduced size HTP demands an increase of elevator control power to keep the same HTP performances as the reference.

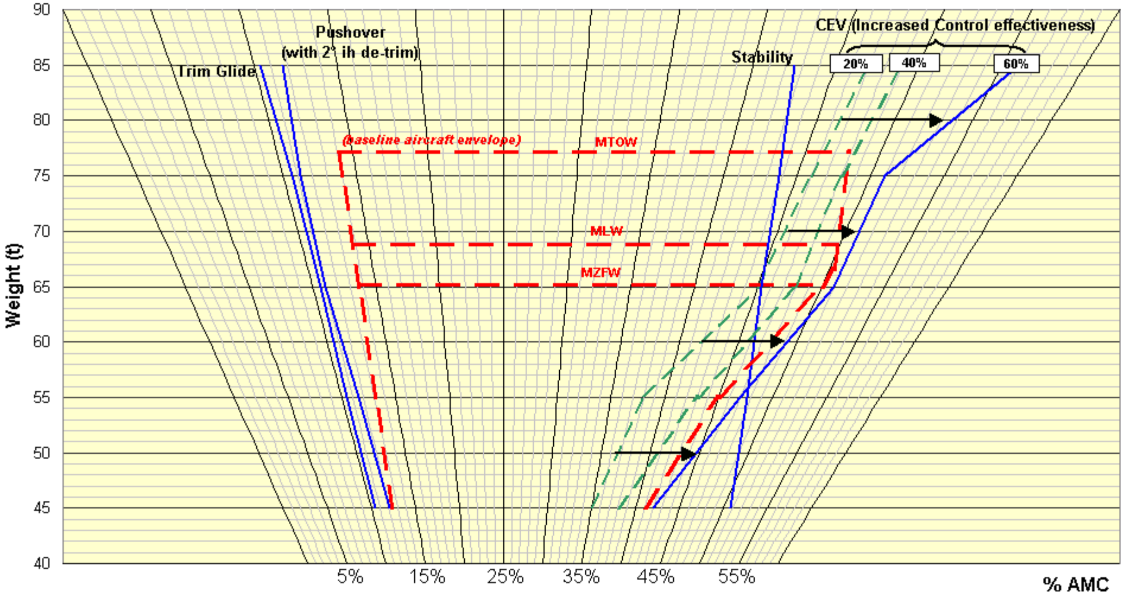


Figure 56: Longitudinal Handling Qualities analysis – CEV manoeuvre

Furthermore, Airbus carried out handling qualities activities trade studies of HTP size versus elevator control power increase, in the line of relaxing the CEV manoeuvre as HTP sizing/limiting criteria – gradually increasing TOGA thrust, and optimisation of longitudinal CG range (by gaining on forward CG with limited minimum HTP setting angle or by moving the wing back slightly). This study was used, after the aerodynamic optimisation, to evaluate the final achievable HTP size.

Together with the work on the rudder, the handling qualities analysis for the HTP with double-hinged elevator is described in [D2.3-2].

Aerodynamic optimisation

The aim of this aerodynamic optimisation was to select the best combination of double-hinged elevator parameters, which provide the maximum control power increase with respect to the reference (single-hinged configuration). 3D RANS calculations performed by INTA showed the configuration 70-80, K=1.4 (first hinge line at 70% of the local chord, second hinge line at 80% of local chord, and ratio between the second and first elevator deflection of 1.4) as the most promising, with a maximum lift coefficient increase of about 13%. The cost however in terms of hinge moments is 50% regarding the single-hinged configuration.

Based on the aerodynamic results and the trade-off between the elevator control power and the HTP size reduction (carried out during the HQ analysis), the Simple Flying Bus' HTP can be reduced by around 9%. Just 4.5% of this reduction was due to the use of the DHE, with the remaining 4.5% gained through an additional control technique (TOGA thrust) adopted for the critical manoeuvre.

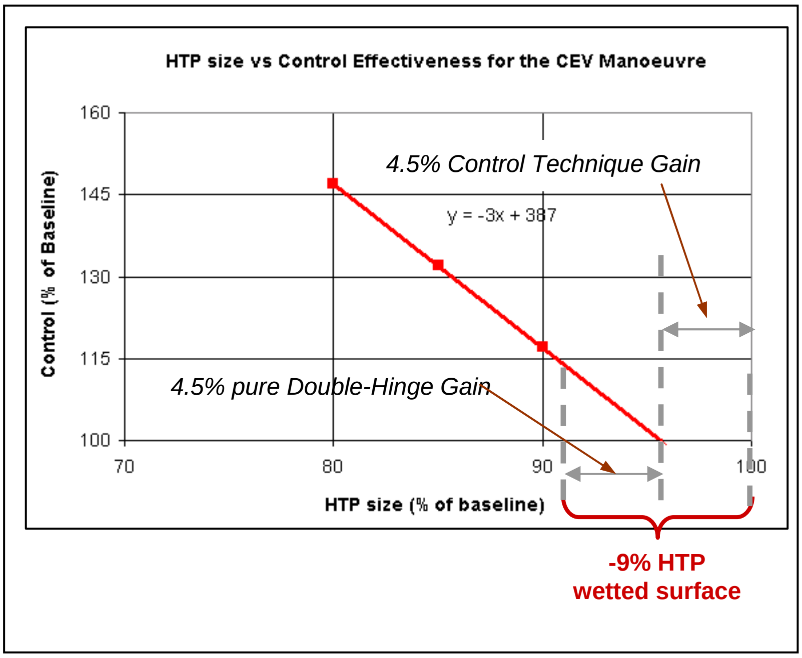


Figure 57: DHE – Elevator control power vs. HTP size reduction

Loads assessment

In order to contribute to the generation of the HTP loads envelope, 3D RANS calculations were carried out by Airbus on the aero optimised configuration.

For the load assessment as well as for the weight estimation of the double-hinged elevator, the following configurations were considered:

- HTP with reference surface and SHE
- HTP with reference surface and DHE
- HTP with 9% surface reduction and DHE (configuration resulting from the aero optimisation)
- HTP with 20% surface reduction and DHE (as initially targeted for Task 2.3)

Airbus studied the aerodynamic loads impact of double-hinged elevator instead of single-hinged elevator, according to aerodynamic conclusions. New correlated load cases were generated, based on original existing Airbus database and modified according to new aerodynamic incremental loads. These cases were used to provide the sensitivity of HTP weight regarding only aerodynamic effects produced by the double-hinged elevator.

The aerodynamic optimisation, aerodynamic data for loads generation as well as the load assessment on the HTP are the object of [D2.3-3b].

Structural and aeroelastic analysis

In parallel with the previous activities, Airbus carried out the structure and actuation analysis of the double-hinged elevator [D2.3-4b].

The mechanism generated for a double-hinged elevator is similar to that designed for the rudder, with a linear hydraulic servo that drives the first element and a passive push-bar that connects the second element to the first one. Airbus demonstrated that this mechanism could be tuned to get a variable gear ratio.

The structural evaluation carried out by Airbus with finite elements methodology showed a lack of stiffness of the secondary elevator towards the tip, leading to a loss of control efficiency and possible aeroelastic instabilities. In order to reduce aeroelastic instabilities of the DHE, a new actuator was designed, which protrudes from the aerodynamic loft (shown in Figure 58 below). An associated aerodynamic drag penalty should be considered at A/C level.

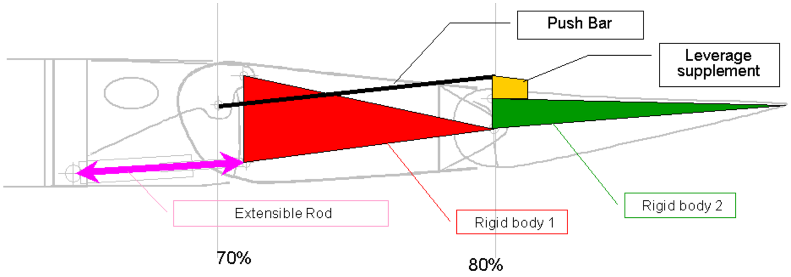


Figure 58: Actuator Mechanism for a DHE

Prompted by the aeroelastic instabilities caused by the lack of stiffness of a full span double-hinged elevator, Airbus proposed a new configuration where the secondary elevator element extends to a fraction of the span of the primary element, which in turn is actuated from inside the fuselage by a torque bar, hence increasing the elevator chord and drastically improving the flutter behaviour. This configuration was patented.

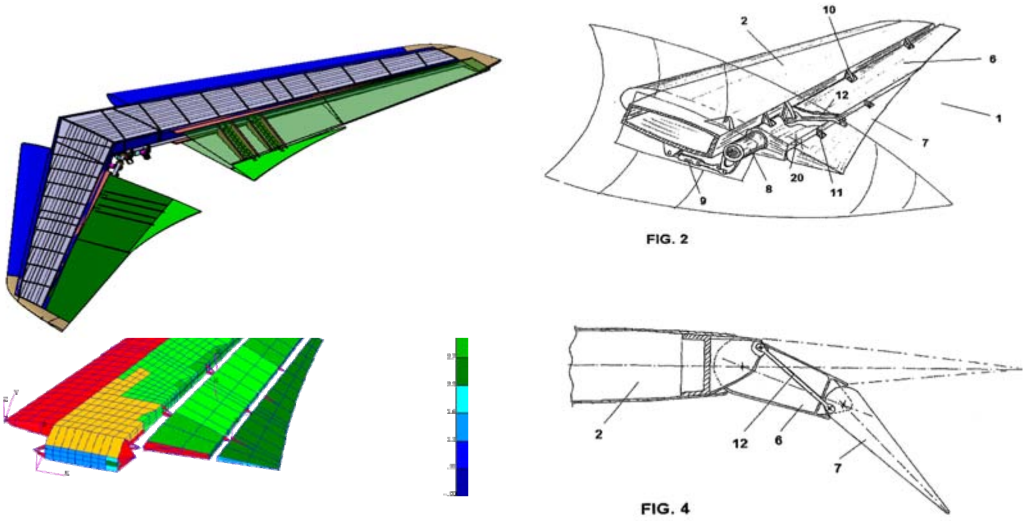


Figure 59: Torque-actuated partial-span double-hinged elevator concept

Flight control system analysis
Onera studied the effect of having double-hinged elevator instead of a single device on the Flight Control laws [D2.3-6b]. The study concluded that the loss of stability caused by the HTP size reduction is not critical for the HTP sizing because it can be restored by a pitch damper. This confirmed that the gain in maximum lift coefficient with elevator deflection determines the HTP size reduction potential. On the other side, Onera demonstrated that, despite the actuator lower activity, the actuator fatigue is higher than with the single configuration as the increment in hinge moments is more important than the reduction of actuator activity (by a factor of 2).

Weight estimation
Taking into account the outcomes of the load assessment and the structural considerations previously given, Airbus carried out the weight impact estimation of the four HTP + Elevator configurations previously mentioned. This analysis based on Airbus weight estimation tools and procedures. Results show that a 9% size reduced HTP with configuration (70-80, K=1.4) is neutral in weight with respect to the SHE. However, there is a weight opportunity for surface reductions higher than 9%. This study is reported in [D2.3-5b].

In order to evaluate the gain in terms of drag saving due to the HTP surface reduction, Airbus carried out an aerodynamic evaluation of both configurations, the reference and the one reduced by 9%, obtaining a drag saving of 1dc. The translation into weight saving at overall aircraft level must be done by Task 1.3.

Morphing Technology

For the analysis of new HTP concepts, which adapt their shape to each flight phase, Onera and DLR worked together on two different approaches for the design of this “morphing” HTP: Variable surface HTP and Morphing airfoil HTP.

The study on the morphing HTP has been documented in [D2.3-8].

Variable Surface HTP

The main idea of a Variable Surface HTP is to have different HTP configurations depending on the flight condition. For the variation of the HTP area a mechatronic approach was chosen, i.e. rigid components driven by mechanical actuating mechanisms.

A work plan for the Variable Surface HTP investigations was proposed by DLR and Onera: after the development of initial structural concepts a pre-selection is done on a qualitative basis. The selected concept was delivered for a sensitivity analysis to estimate the effectiveness of different HTP movements. In parallel the concept was evaluated regarding the maximum possible deflections before the target HTP movement is defined. After a structural pre-design the achievable HTP movement was provided for a final performance evaluation.

In the first phase of the Morphing Empennage task some initial structural concepts were proposed: inside/outside fuselage HTP concepts, single pivot concepts, slide-in concepts and parallel guidance concepts. Due to the flexibility that the ‘Parallel Guidance concept’ presented for the HTP movement, this was the concept selected for a detailed analysis.

As a next step, DLR evaluated the pre-selected “Parallel Guidance Concept” to identify the maximum possible changes in sweep angle φ and surface S_H of the HTP regardless of any technical feasibility. The rear cone and HTP of an A320 type of aircraft were considered as reference for the evaluation.

From an optimised HTP for cruise, the A/C performances must be ensured at Low Speed (LS) condition, which leads to a HTP lift increase. From this idea, Onera carried out a sensitivity analysis aiming at defining the HTP movement from cruise to LS condition to ensure the LS performances.

According to the different HTP sizing criteria, the sensitivity analysis was done at cruise as well as low speed conditions.

At cruise condition, the stability criterion and the cruise trim were checked over the whole mass and centre of gravity range. The stability loss caused by the HTP size reduction can be completely recovered by an active stabilising system. In terms of the trimmed equilibrium in cruise, the following sensitivity analyses were investigated:

- Sensitivity with respect to the HTP surface
- Sensitivity with respect to the HTP lever arm
- Sensitivity with respect to the HTP sweep angle
- Mixed sensitivity with respect to the HTP surface and the lever arm
- Mixed sensitivity with respect to the HTP surface and the sweep angle

At low speed condition, the following three criteria were checked: Trim glide, Pushover manœuvre and CEV manœuvre. In terms of the Trim glide equilibrium, the same sensitivity analyses as for the cruise condition were investigated.

The sensitivity analysis concluded then that the movement of the Variable Surface HTP from cruise to take-off and landing could be defined as follows:

- an increased HTP area,
- a decreased HTP sweep angle and
- the HTP moved backwards.

Based on the pre-selected “Parallel Guidance Concept” DLR generated a structural pre-design, especially considering the issue of transferring the loads from the central hinge mechanism to the movable HTP structure. Finally three concepts were developed: Joint, Telescope and Notch concepts.

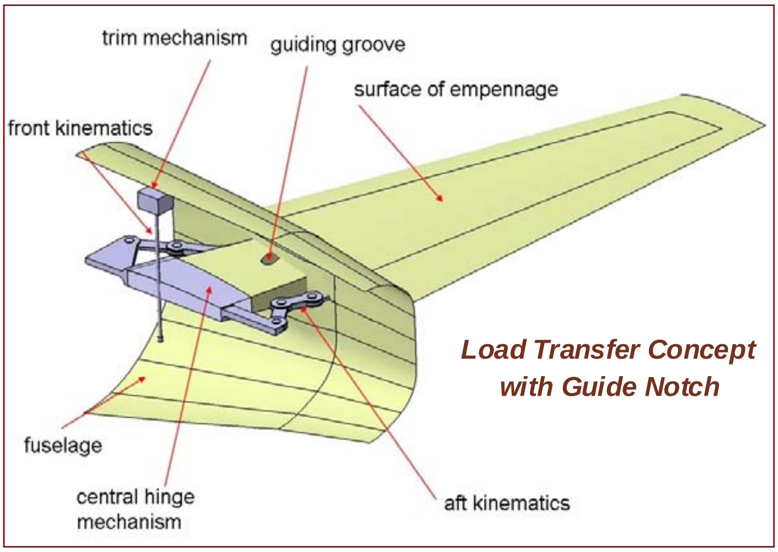


Figure 60: HTP Kinematic pre-design of Notch concept

With the concepts providing this load transfer (Joint Concept, Telescope Concept, Notch Concept) the HTP surface can be reduced by 8 to 10% during cruise flight while increasing the sweep angle by about 20 to 30% depending on the concept. The Notch Concept also allows a 2% increase in the HTP lever arm.

In general, all concepts showed a significant weight penalty due to the additional kinematics and actuating mechanisms. DLR performed however a rough estimate for the weight penalty, derived from military aircraft with a moveable wing, where the total aircraft weight is increased by 4-6%. Considering the structural weight of the HTP being about 8% of the wing structural weight, the Manufacturer's Weight Empty of the SFB aircraft would increase by about 0.4% or 150kg.

From a flight mechanical point of view, the feasibility of a Variable Surface HTP using the Notch Concept can be summarized as follows:

- The low speed criteria concerning the pushover and CEV manoeuvre can be satisfied as the nominal HTP surface can be achieved.
- For trim glide, it is possible to reduce the minimum HTP setting by 0.6^{o} by combining a 19% HTP sweep angle reduction and a 2% HTP lever arm increase.

An 8% cruise tail drag reduction (corresponding to a 10% surface reduction) corresponds to a reduction of global cruise drag by 1 drag count. The Variable Surface HTP seems therefore to be an interesting solution despite its weight penalty at component level.

At aircraft level, the Variable Surface HTP would only be cost neutral in terms of Fuel Burn for a short range aircraft. For a long range aircraft, it could become even interesting in terms of DOC.

Morphing airfoil HTP

As alternative to variable-sweep technologies, airfoil morphing could be used to reduce the HTP surface area. This activity aimed then at developing a morphing HTP device, which is capable of providing the necessary positive and/or negative lift with decreased HTP area.

A work plan for the Morphing HTP investigations was proposed by DLR and Onera: starting from a pre-selection of concepts, the aerodynamic performance of an initial structural shape is evaluated by flight physics. Afterwards guidelines and/or target shapes can be considered in a structural pre-design of a morphing HTP device. Finally a performance evaluation is planned.

Starting from the general approach of a fixed rear spar and untouched elevator, DLR and Onera considered various concepts with differing complexity. In one of the concepts proposed, the HTP box structure and the front spar remain unchanged, and only the airfoil leading edge can be deflected/deformed (Smart Droop Nose). This is therefore the concept with the lowest level of complexity and the one selected for detailed analysis within this Task.

In the preliminary concept evaluation, DLR identified that the key challenge in the design of morphing devices is to meet the adverse requirements of flexibility and stiffness for carrying the aerodynamic forces and at the same time provide a morphing droop angle sufficient for HTP application. To overcome this problem, DLR conducted investigations on corrugated substructures for morphing skin applications.

On the basis of these pre-investigated stringer and skin structures as well as on the identified requirements of morphing skins regarding large strains, DLR developed a pre-design of a leading edge section.

Before the structural pre-design, Onera defined a target shape for the airfoil with the smart droop nose deflected based on the requirement on lift/alpha stall needed for a specific manoeuvre (push-over). The hinge line was considered located at 20% of the local chord.

For the structural pre-design, DLR created a 2D finite element model to calculate the loads introduction points to reach the target shape. The 2D results were transferred to 3D and parametric studies were performed related to: number of actuators spanwise, skin thickness optimisation, fibre lay-up, and assessment of surface quality.

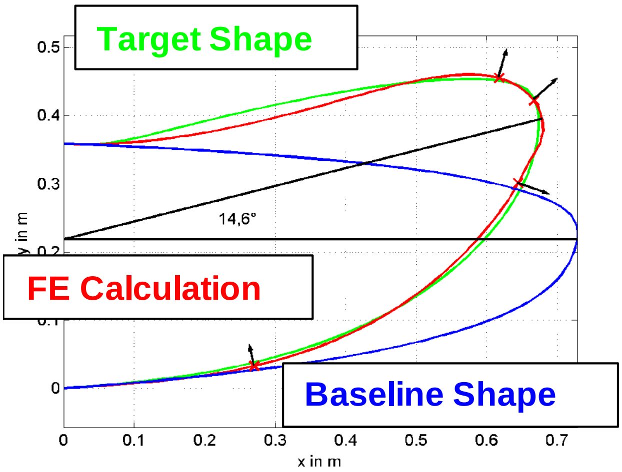


Figure 61: Optimisation results for best-fit shape. Loads introduction points

A droop angle of 6º was achieved for a monolithic skin structure. The targeted deflection of 15° could not be achieved due to large strains resulting even from pure bending deformation. The necessary number of kinematical frameworks leads to high complexity and weight of the system. Furthermore, the achievable surface quality under cruise condition is poor because of the necessarily thin skin.

The performance evaluation carried out by Onera was done upon the 2D aerodynamic analysis and results performed in the early stages of Task 2.3 [D2.3-1]. Following this, the feasibility of a Morphing Airfoil HTP using the smart droop nose concept can be summarized as follows:

- The low speed criteria as the pushover (and in some extent the CEV manoeuvre) can be satisfied as the negative and positive HTP stall angles can be increased by $\pm 1.8^{o}$;
- Trim glide becomes now a sizing criterion together with the rotation at take-off with an increase in the minimum HTP setting angle of about -1^{o};
- The HTP surface can be reduced by 3.5%;
- The global drag can be reduced at the best by 0.35 drag counts.

In general, because of the complexity of the kinematics and mechanisms, the concept shows a significant weight penalty. However, DLR identified that other projects (e.g. SADE) dealing with a smart droop nose for an aircraft wing show that the weight of such a smart droop nose device is approximately the same as for a slat. Following this, DLR estimated that the weight of an HTP with a smart droop nose device would be at least 8.5% higher than for an HTP with a fixed LE.

Having an HTP structural weight of about 630kg for the SFB aircraft, this leads to a weight increase of at least 55kg or 0.15% for the Manufacturer's Weight Empty of the SFB aircraft.

For a short range aircraft, this concept seems to be cost neutral in terms of Fuel Burn (FB), even with a weight increase of 55 kg when the surface quality problems are neglected. In terms of Direct Operational Costs (DOC), there is finally a drag increase of 0.3 drag counts. For the short range aircraft, the Morphing Airfoil HTP seems hence worse than the Variable Surface HTP in FB terms, but better in DOC terms. For a long range aircraft, these results should however be better. An overall aircraft design loop needs however to be performed in order to check its interest at aircraft level.

Final Conclusion

Double-Hinged Concepts

This Task has demonstrated the potential of double-hinged concepts for the empennage surface reduction:

- DHR enables a 15% size reduction for the VTP, leading to a weight saving;
- DHE enables a 9% size reduction of the HTP, with a marginal weight impact.

The comparison between double-hinged rudder and elevator concepts showed that the empennage size reduction strongly depends on the sizing manoeuvre. Hence the application of double-hinged concepts on new aircraft configurations calls upon a new handling qualities analysis to evaluate the tail sizing.

Taking the SFB configuration as the reference aircraft, handling qualities analysis demonstrated that the maximum control power of the control surface is the requirement needed to achieve the maximum tail reduction. CFD calculations were performed to obtain the locus of maximum force coefficient due to the control surface deflection. Flow separation phenomena, occurring at high deflections, can lead to an unsteady behaviour, for which CFD is less reliable. For this reason, wind tunnel tests would be needed to reliably capture the non-linear effects of the flow onto the empennage.

In the light of this, within the ICARO project (Spanish funded project), experimental studies are planned in order to analyse the potential of double-hinged elevators and droop nose devices for a conventional HTP architecture.

The handling qualities analysis also highlighted the need for a Back-up Control Module (BCM) – a pitch or yaw damper mechanism – in order to guarantee the stability lost due to the tail reduction. Since the aim of the Task is to provide a cost benefit at overall aircraft level, the cost/complexity of the BCM systems should be part of the overall integration work.

Considerations on mechanism reliability (actuator and push bar failure modes), an analysis of actuator fatigue and of actuator static and dynamic stiffness is required for a complete understanding of the aeroelastic, weight and cost implications associated with a double-hinged rudder/elevator.

In particular, for the HTP, the following aspects should be taken into account for a future application:

- Flexibility effects were calculated in this study with doublet lattice linear aerodynamics. A full structure/CFD coupling would be required to assess maximum control power including flexible effects as this involves flow separation phenomena;
- A detailed Multidisciplinary Optimisation of the torque-actuated partial-span DHE concept would be required to refine the design and explore its merits. Questions remain as to whether the higher taper ratio and effective spanwise camber variation are consistent with the required aerodynamic characteristics of the tailplane.
- The aerodynamic penalty incurred by the probable protrusion of the push bar attachment needs to be quantified.

The study on the VTP showed the importance of including forces and moments as part of the initial optimisation process. Advantages can be found in terms of hinge moments alleviation and the final actuator sizing.

Morphing HTP

Two approaches for the Morphing HTP were investigated, a Variable Surface HTP and a Morphing Airfoil HTP.

For the **Variable Surface HTP** a couple of initial structural concepts were developed and evaluated, from which the “Parallel Guidance Concept” was pre-selected. This concept allows all reasonable HTP movement (HTP moving in and out, HTP moving forward and backward, sweep angle increasing and decreasing) and was initially evaluated regarding the maximum possible changes in sweep angle and surface area regardless of any technical feasibility.

During the following structural pre-design phase the “Parallel Guidance Concept” was enhanced by implementing different solutions for the load transfer from the centre hinge mechanism inside the fuselage to the moveable HTP structure. With the resulting concepts (Joint Concept, Telescope Concept, Notch Concept) the HTP surface could be reduced by 8 to 10% during cruise flight while the sweep angle is increased by about 20 to 30% depending on the concept. However, all mentioned concepts require a much larger cut-out in the fuselage and show a significant weight penalty due to the additional kinematics and actuating mechanisms.

A detailed weight and cost assessment for the Variable Surface HTP was not possible due to the lack of knowledge of the exact dimensions of the empennage and rear fuselage and the structural and aerodynamic loads.

From a flight mechanical point of view, the Variable Surface HTP seems to be an interesting solution at component level despite its weight penalty, as the movements allow HTP size reduction and HTP sweep angle increase for cruise and additionally HTP lever arm increase for low speed. The pushover and CEV manoeuvre can be satisfied while reducing the minimum HTP setting by 0.6^{o} and while reducing the cruise tail drag by 2-22% depending on the HTP movement.

From the experience gained in Task 2.3, it can be said that an 8% cruise tail drag reduction (corresponding to about a 10% surface reduction) corresponds to a reduction of global cruise drag by 1 drag count, for an A320 type of aircraft. The Variable Surface HTP seems therefore to be an interesting solution despite its weight penalty at component level. An overall aircraft design loop should then be performed in order to check its interest at aircraft level.

Concerning the **Morphing Airfoil HTP** the concept of a morphing leading edge device for HTP application was chosen as the most promising approach regarding the benefit in recovered lift, system complexity and system weight. In the evaluation of the concept the adverse requirements of flexibility and stiffness of the morphing skin turned out to be the key issues in the design of such a device. To overcome this, substructures for the improvement of the out-of-plane stiffness of the skin were investigated.

While the targeted deflection of 15° of the HTP leading edge part could not be achieved due to large strains resulting even from pure bending deformation, a droop angle of about 6° is possible for a monolithic skin structure. However, the necessary number of kinematical frameworks leads to high complexity and weight of the system. Furthermore, the achievable surface quality under cruise condition is poor because of the necessarily thin skin.

As for the Variable Surface HTP, a detailed weight and cost assessment for the Morphing Airfoil HTP was not possible without knowledge of the exact dimensions of the optimised HTP and the structural and aerodynamic loads.

From a flight mechanical point of view, the Morphing Airfoil HTP allows to satisfy the pushover manoeuvre as the negative HTP stall angle can still be increased by -1.8^{o} with a corresponding HTP surface reduction of 9% and a global drag reduction of 0.35 drag counts. It seems however to be less interesting than a classical droop nose device as the targeted deflection of 15^{o} cannot be achieved.

WP 3 – Novel Powerplant Installation

Task 3.1 – Rear Engine Integration

Task objectives at beginning of the project

Task 3.1 aimed at assessing the two Powered Tail concepts, defined for maximum shielding of engine noise sources and best achievable fuel burn. This would be achieved through a detailed analysis in terms of aerodynamics and acoustics. The two concepts would be addressed through numerical computations to assess their aerodynamic performance, to identify possible critical phenomena at take-off/landing conditions and to predict engine installation effects on noise generation and propagation and therefore on noise shielding potential. Aerodynamic concept performance and tail characteristics at cruise flight conditions for one concept and acoustic characteristics of jet and fan noise on a generic configuration would be evaluated by wind tunnel tests.

The synthesis of all these results would serve as a basis for overall aircraft performance assessment of PG1 and PG2 concepts to be performed in Subtask 1.1.4.

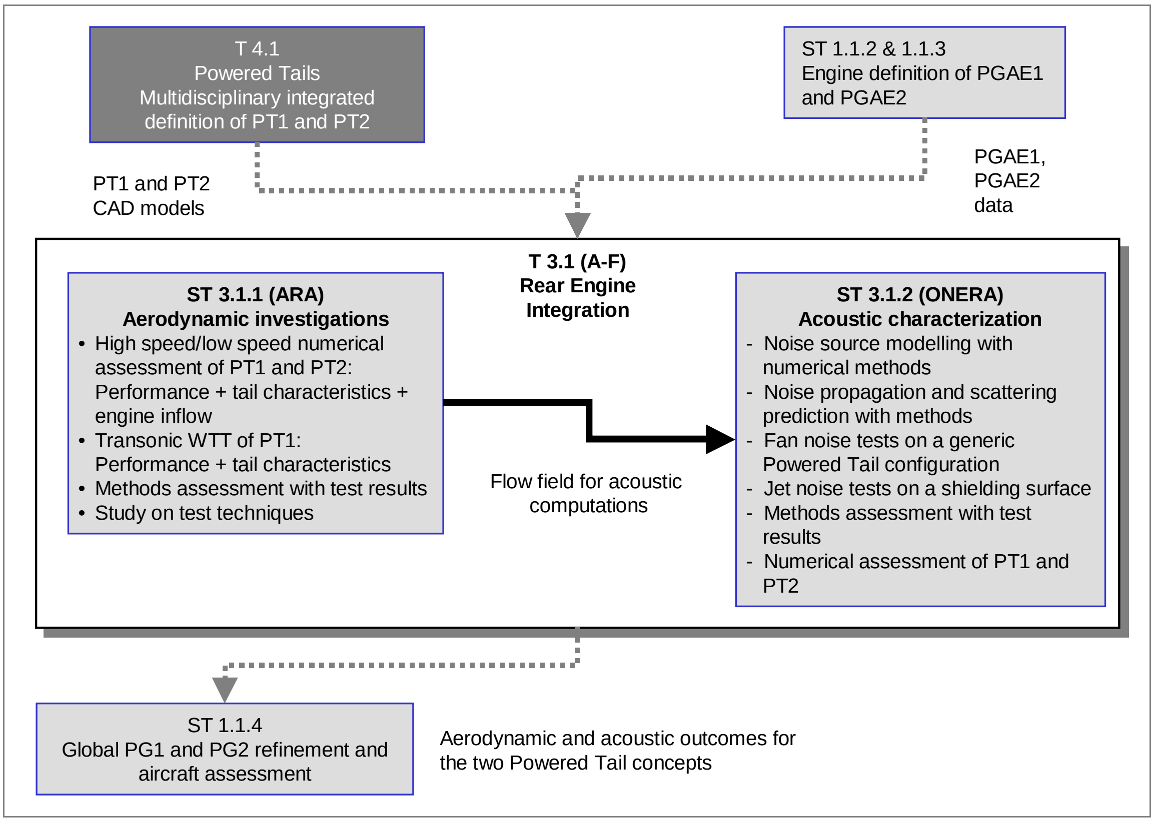


Figure 62: Task 3.1 Flowchart

Subtask 3.1.1 Aerodynamic investigations

The objectives of Subtask 3.1.1 were to assess the aerodynamic performance of the two Powered Tail configurations, PT1 and PT2, defined in Subtask 4.1.1, at cruise flight conditions, and to identify possible critical flow phenomena at cruise and take-off/landing conditions, by using Computational Fluid Dynamics (CFD) and experiments.

Such an unconventional configuration might induce much unexpected phenomena and an assessment of the flight envelope compatible with this powerplant size and location should be conducted:

- At cruise conditions, initial computations would be performed during the PT1/PT2 concepts definition/optimisation task (ST4.1.1). Subtask 3.1.1 would handle the final accurate assessment of engine installation drag and stability aspects. Low and flight Reynolds number CFD computations would be performed to determine the Reynolds effects on flow behaviour;
- For take-off and landing conditions, the interaction of pylon, nacelle and jet with the tails would be investigated: a determination of Horizontal Tail Plane and Vertical Tail Plane efficiency including presence of powerplant, as well as of HTP/VTP stall would be done. Additionally, the influence of the fuselage and the wing on the engine inflow and therefore on engine functioning would be checked.

A transonic Wind Tunnel Test (WTT) was planned to be conducted for the more mature concept, that is PT1 concept derived from the ROSAS RFN concept, to verify flow phenomena in this area, to determine the Powered Tail concept performance as well as tails aerodynamic characteristics, and to get a validation of numerical estimates.

Subtask 3.1.2 Acoustic characterization

Subtask 3.1.2 was devoted to the experimental and theoretical assessment of the Powered Tail concepts noise shielding benefit. The aim was to improve the modelling capability and make use of improved methods so as to assess not only the actual noise reduction potential but to assess and improve also the noise shielding prediction accuracy.

Preliminary studies on noise shielding concepts were successfully conducted within the ROSAS project. Several prediction methods, both analytical and numerical, were developed to estimate the noise shielding effect associated to the scattering of the acoustic waves by the airframe components:

- For uniform external flow cases in 2D and 3D
- To check the importance of the non-homogeneous flow in 2D.

In addition to the encouraging experimental assessment already conducted in ROSAS at CEPrA19, a number of important phenomena were still not captured with those methods that were needed to adequately assess the noise reduction potential of the proposed A/C concepts.

Two new wind tunnel test campaigns, respectively for jet and fan noise shielding effects simulation and measurement, were proposed at Onera CEPrA19 within NACRE, using the same aircraft model developed and manufactured in ROSAS, with some additional features, and held with the wing-support developed in ROSAS, which was fully dedicated for engine noise shielding investigations on aircraft tails.

- For the fan noise test campaign, the same TPS as for ROSAS would be used to simulate a realistic fan noise; a new nacelle would be required for improved support of the TPS, featuring specific monitoring instrumentation also to characterise the fan noise source;
- For the jet noise test campaign, a high bypass ratio nozzle would be used to generate the jet noise and a generic surface would simulate the shielding effect. A specific instrumentation needed to be implemented to adequately characterise the jet sources.

Technical Achievements

Subtask 3.1.1 Aerodynamic investigations

PT1 configuration Assessment

PT1 design has been achieved in Subtask 4.1.1 and delivered to Subtask 3.1.1 for detailed aerodynamic assessment. In this respect, CFD computations have been performed at high and low speed to verify that no unexpected phenomenon occurs, to determine rear end performance, powerplant impact HTP/VTP characteristics, verify engine functioning in cross wind conditions and provide inputs for acoustic computations. Detailed results are documented in [D3.1-3]. A high speed test at ARA has also been performed to characterize PT1 design. Model manufacture characteristics and tests details can be found in [D3.1-5] and [D3.1-7]. A comparison of the results with CFD computations can be found in [D3.1-8].

The main results of the high speed assessment are summarized below:

- In terms of flow features on rear end, a proper flow quality on tails, powerplant and rear fuselage for cruise conditions was shown in CFD and confirmed by WTT.
- A small nacelle/pylon interaction was observed, easily controllable through aerodynamic design work.
- Globally, a very good correlation between CFD and WTT results was obtained.
- A specific CFD study on the configuration with and without twin sting demonstrated that the support had almost no effect on the rear end.

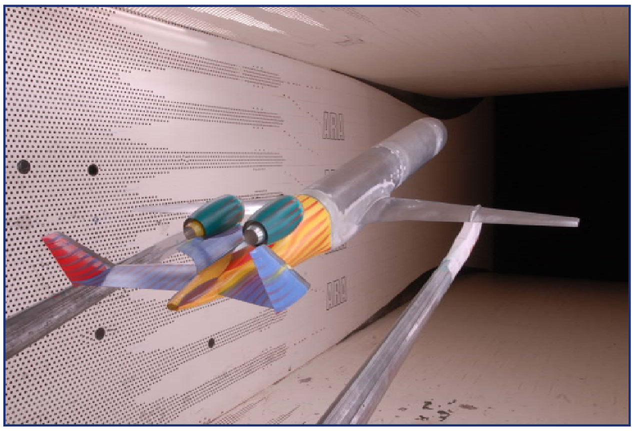
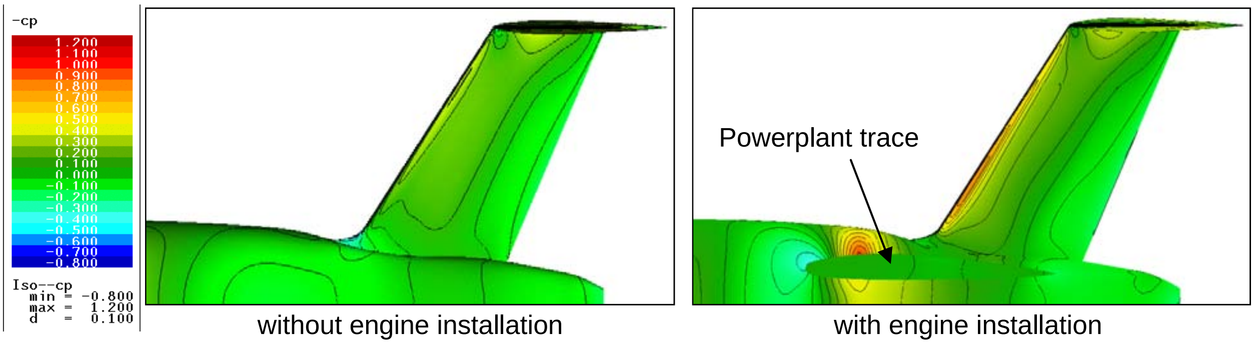


Figure 63: Oil flow on rear end at cruise

The powerplant interaction with the other components has been characterized:

- Powerplant/wing interaction: the wing is hardly impacted by the powerplant presence;
- Powerplant/HTP interaction: HTP lift is increased due to an increase of HTP AoA;
- Powerplant/VTP interaction: there is less contribution of the leeward VTP to the side-force, in sideslip conditions, due to a straightening of the onset flow.



without engine installation

with engine installation

Figure 64: Impact of engine installation on pressure contours on HTP upper surface, M=0.77

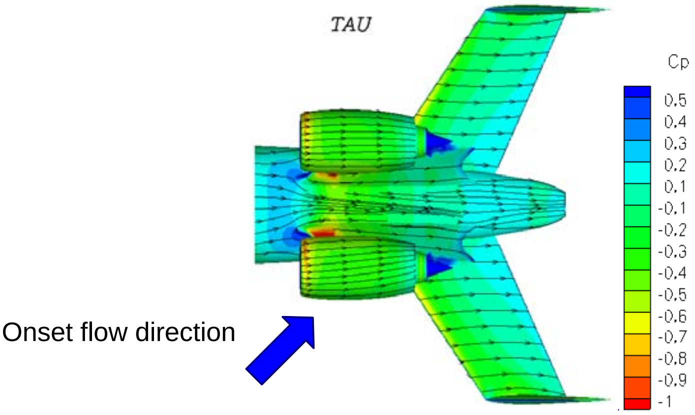


Figure 65: Pressure contours and friction lines, M=0.77, β=2°, Cl=0.5

Test results analysis indicated that best performance is obtained at cruise where the impact of RFN installation on drag is limited and contained. For a consolidated assessment of PT1 performance, a proper nacelle calibration should be achieved in further study.

There is almost no compressibility in rear end area and no separation, but pylon and nacelle flow field is very sensitive to AoA: flow separation occurs on pylon outer side at low incidences, and on pylon inner side above cruise and will require some robust design work.

The powerplant presence influences tail characteristics at high speed:

- Longitudinal assessment: There is a Powerplant impact on HTP efficiency, which will have an impact on HQ. Spanwise lift distribution over HTP is also affected.
- Lateral assessment: Engine installation leads to a decrease of VTP efficiency, due to a decrease of effective sideslip angle seen by the leeward VTP.

In the low speed assessment, no critical phenomenon has been identified on the computations performed: flow remains attached on the rear end for symmetrical flow conditions.

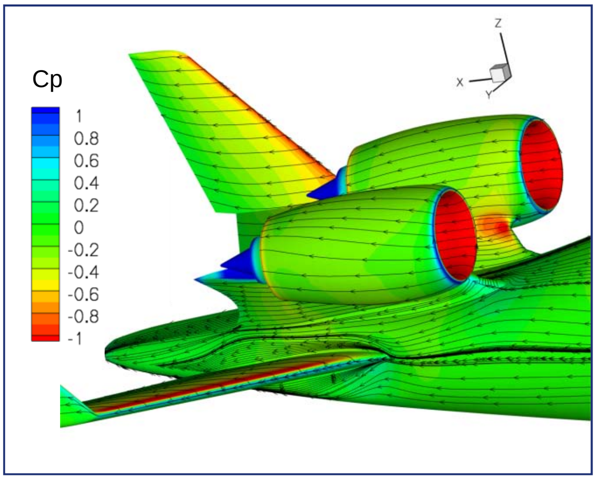


Figure 66: Pressure contours and friction lines, M=0.25, α=8°

As for high speed conditions, the powerplant system influences the tail characteristics at low speed:

- Longitudinal assessment: Nacelles provide a positive lift which is not negligible and their presence decreases the HTP efficiency. Nacelles also have an effect on the lift distribution along the HTP span.
- Lateral assessment: Side force is the highest for the complete rear end (wing/body/tails/nacelle) and engine contribution to the efficiency is in the same order as the tails. VTP efficiency is reduced in presence of the powerplant. Stall occurs first in the outward spanwise locations and on the windward VTP. Engine effect on stall angle is negligible.

Engine functioning in cross-wind conditions has been checked and showed that the leeward nacelle is never critical because the windward nacelle contributes to straighten the flow that will supply the leeward engine. The flow on the windward nacelle is more sensitive, but it should be overcome with some classical design work.

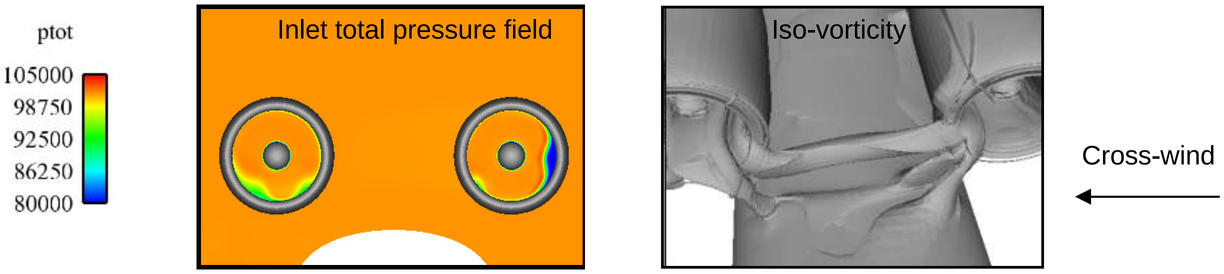


Figure 67: W2AR=465 kg/s, Cross-wind 20 kts

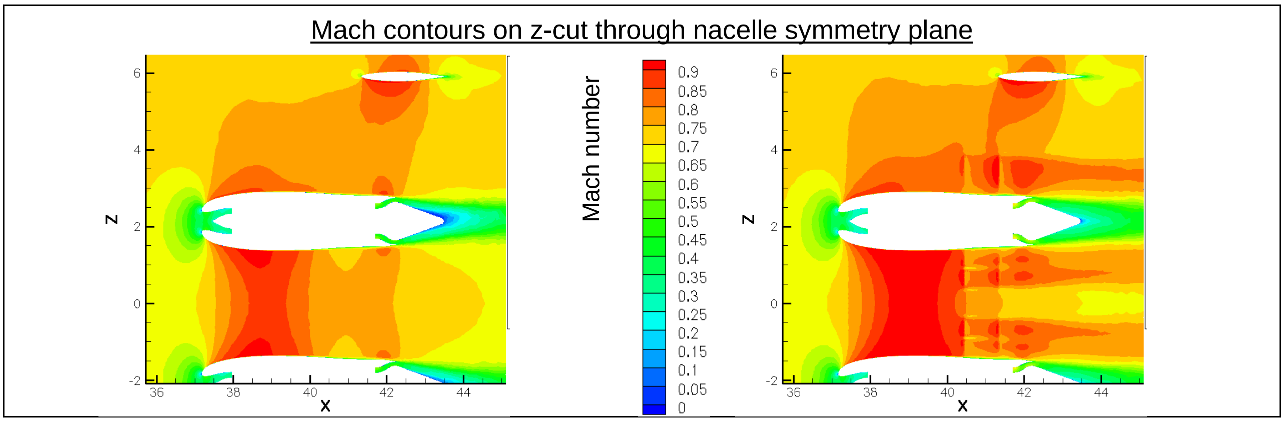
It highlighted the flow complexity in the rear end area: vortices arise from the fuselage and between the nacelles, not impacting the distortion level, but this may excite fan blades in a random way. Overall, this configuration looks feasible in terms of take-off in cross-wind conditions, and does not present a showstopper.

PT2 configuration Assessment

High and low speed computations have been performed on the final PT2 design (Open Rotor configuration) coming from Subtask 4.1.1, using an Actuator Disk. A comparison of different Actuator Disk settings was done, as well as a Drag/Lift polar of the final PT2 configuration [D3.1-4].

The main results can be summarized as follows:

- CFD flow field investigations at high speed, on power-off and power-on configurations, showed a proper flow quality on tails, powerplant and rear fuselage for cruise conditions.
- A channel flow occurs between the two pylons, nacelles and fuselage, but it is not critical.
- Further acceleration on the pylon due to rotors (power-on) is observed.



Power off (Core on)

Power on (Full power)

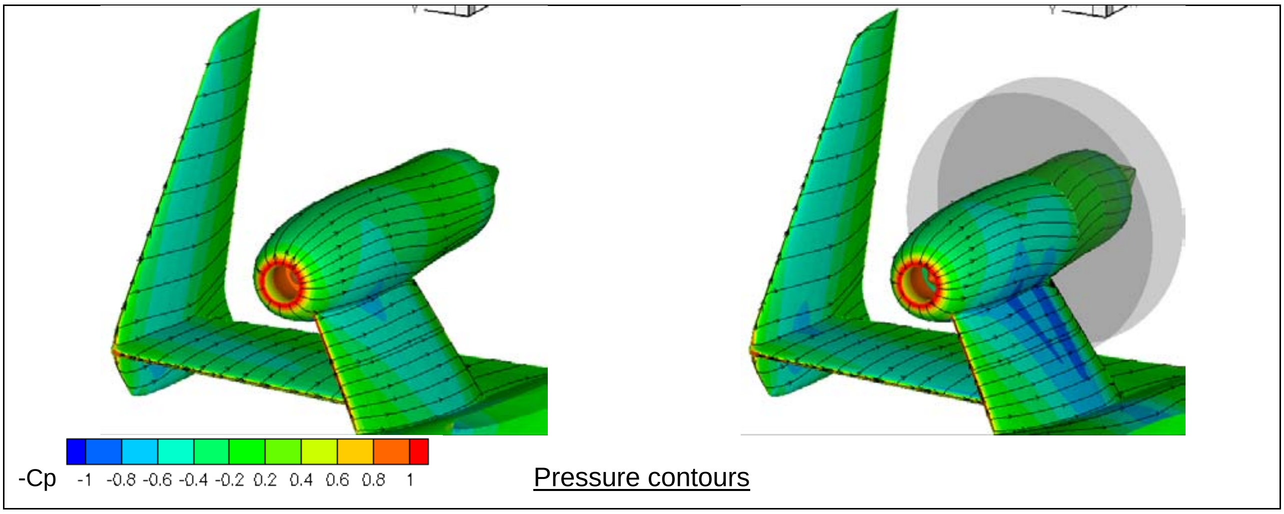


Figure 68: PT2 comparison power off / power on, M=0.74, α=1.75°

The powerplant interaction with other components has been characterized:

- Powerplant/wing interaction: no influence on wing.
- Powerplant/HTP interaction: force on tail changes from down force to lift for fully powered engine.

The A/C influence on propeller inflow: Installation effects produce an inhomogeneous flow field, which will have an impact on propeller performance and noise and indicates that propeller needs to be designed installed.

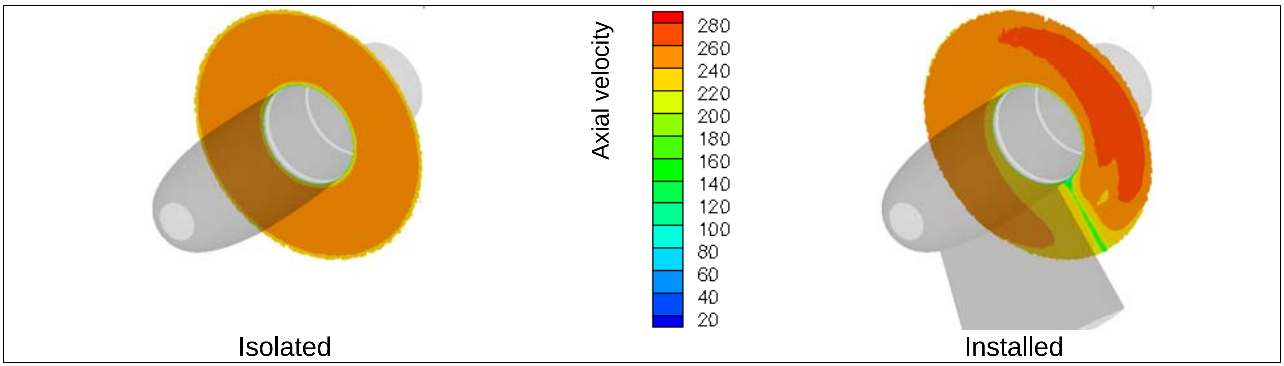


Figure 69: Axial velocity in front of rotors, M=0.74

At low speed, flow field investigation shows that, in symmetrical conditions, the flow remains attached on tail planes, pylon, nacelle, and engine intake for the operational range of tailplane settings. There is a significant impact of power effect on HTP: HTP lift is increased.

In sideslip conditions, flow separation at starboard-side pylon and engine intake (should be overcome by design work).

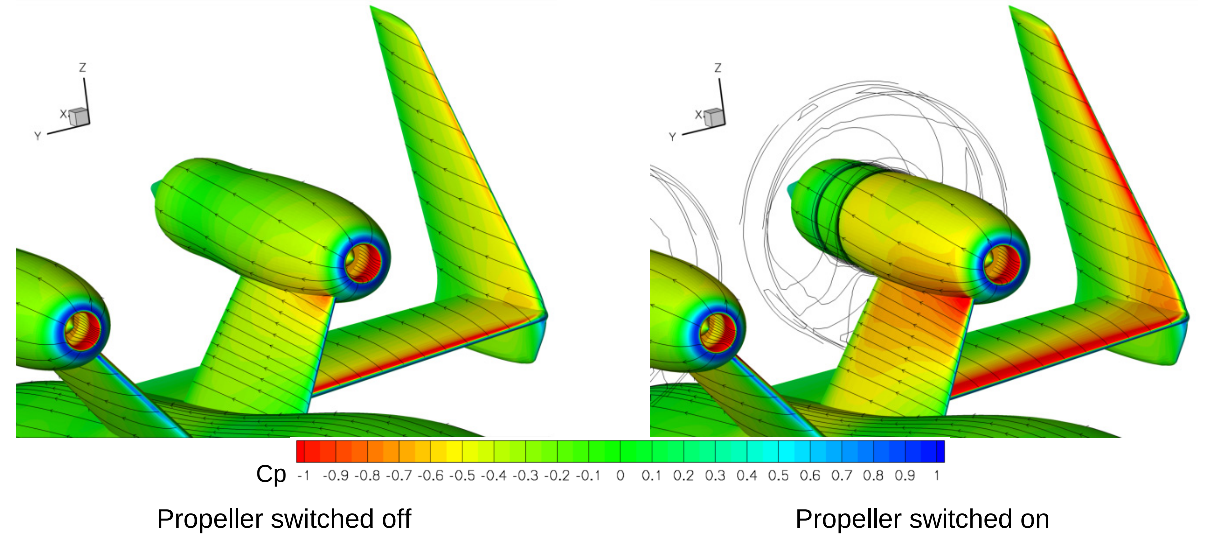


Figure 70: Cp distribution and limiting streamlines, M=0.25, α=8°

The influence on concept performance at high speed can be summarised as follows:

- Power-on increases the lift
- Main penalty in L/D is caused by nacelle/pylon installation
- The propeller stream causes a further drag increase

And for concept performance at low speed:

- Power plant installation reduces lift
- Power-on increases the lift significantly
- Main penalty in L/D is caused by nacelle/pylon installation

Test techniques

Besides, some studies have been conducted to propose several support arrangements aiming at enabling an accurate measurement of the forces acting on the whole aircraft, while ensuring a good prediction of the flow over the rear part of the model. Six alternative configurations have been studied, taking into account TPS air supply constraint. Straight sting and z sting supports have been investigated more deeply (mechanical design and aerodynamic investigation), to determine the one causing the less interference [D3.1-1] [D3.1-2]. Front z sting support was selected as the best candidate.

Subtask 3.1.2 Acoustic characterization

Jet noise wind tunnel tests

The ST3.1.2 jet noise test campaign dedicated to installation effects on turbofan engine jet noise has been performed at Onera's CEPrA19 open-section low-speed acoustic wind tunnel from 26th April until 4th May 2007 for the isolated configuration and from 23rd to 25th July 2007 for the installed configuration.

The test conditions were defined for both the SILENCE(R) baseline and low noise nozzles delivered by Snecma. A EUROPIV wing model was used as a shielding surface, which is a 0.5-m chord 2D high-lift wing with no sweep. A far-field microphone array was used, made of a fly-over and a sideline arc, each of 6 m radius centred on the intersection of the nozzle reference plane and its reference axis and featuring 12 Brüel & Kjær ¼" type 4139 microphones, distributed from 40° to 150° every 10°.

All configurations originally planned in the test matrix have been performed successfully:

- Jet power effect: 3 jet conditions;
- Flight effect: M=0 and M=0.18 for all jet power plus M=0.27 for high power conditions;
- Nozzle effect: baseline nozzle and low noise nozzle;
- Pylon effect: 2 positions, vertical and 45°;
- Installation effects: with and without the wing.

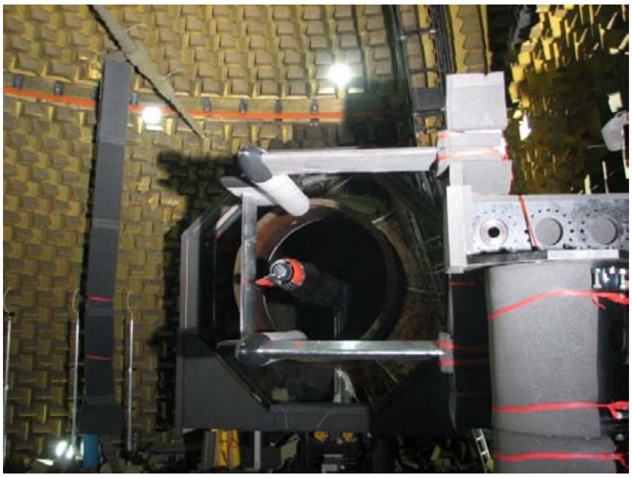


Figure 71: SILENCE(R) BPR9 nozzle installed over EUROPIV wing model at CEPrA19

The far field noise database including third octave band and narrow band analysis was delivered in September 2007 [D3.1-11].

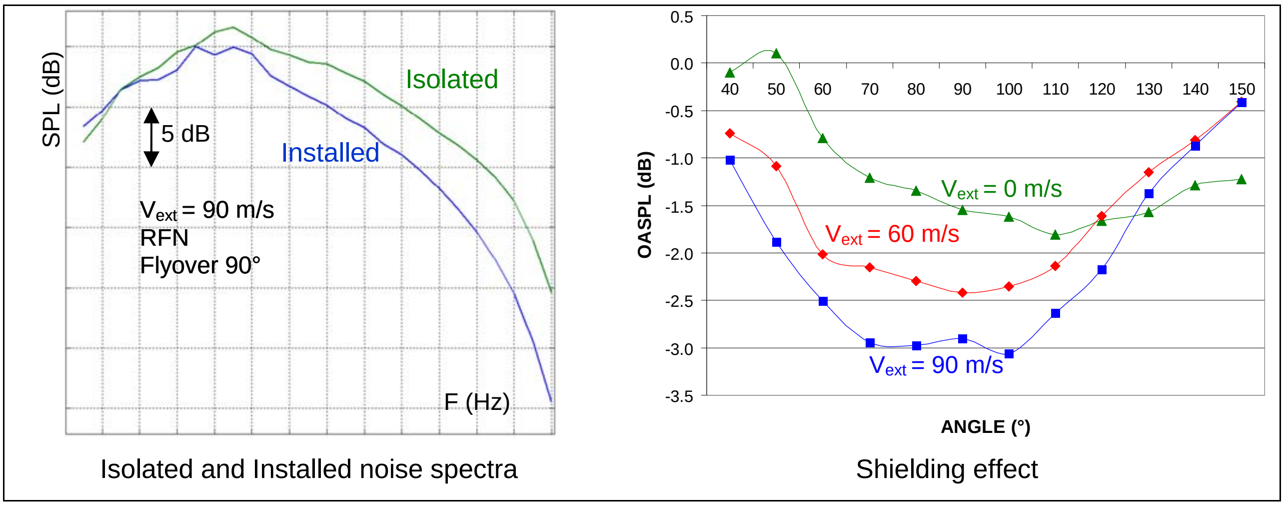


Figure 72: Shielding effect for baseline nozzle

The wing was found to decrease the noise levels radiated on the flyover and sideline observer positions. The measured shielding effects are stronger in the lateral direction and increase with the frequency. The noise attenuation induced by the profile remains however moderate, except at high frequency.

The external flow velocity tends to amplify the installation effects and an increase of the power conditions induces a lowering of the shielding. Measurements also show that the pylon position has only a very weak impact on installation effects. Finally, on the flyover path the shielding is stronger in the downstream direction than on the sideline trajectory, and it is lower at the other angles.

The NACRE jet noise wind tunnel test campaign has provided a very complete experimental database on jet noise installation effects. Its interest is twofold:

- An experimental characterization of jet noise shielding effects in a realistic configuration is supplied, with the impact of various parameters. This is required to investigate and quantify the interest of installation effects for jet noise reduction, and to find the relevant parameters of the shielding;
- The present measurements will be very useful to validate numerical tools aiming at predicting jet noise installation effects.

The tested configuration with the baseline nozzle at the sideline power conditions and without external flow has thus been chosen as the working case of the jet noise numerical activity, and the computational results are compared to the measurements later in this report.

The detailed analysis of the results can be found in [D3.1-12A] and [D3.1-13A].

Fan noise wind tunnel tests

The fan noise tests were started in November 2007. However a serious incident causing damage to the TPS led to delay the tests, which were finally performed at CEPrA19 between 6th October and 11th December 2008.

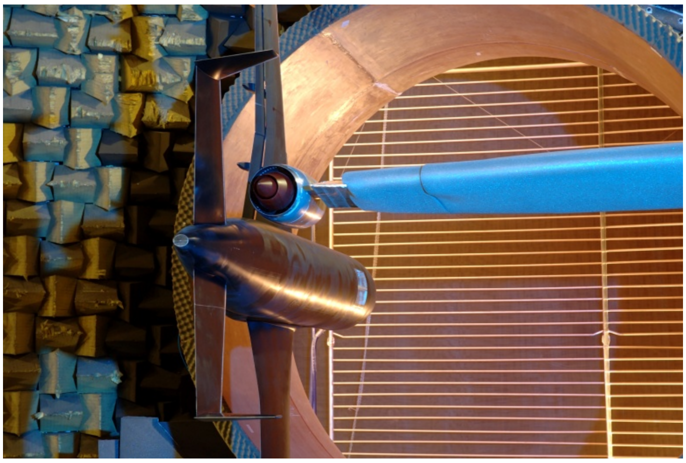


Figure 73: Installed TPS fan noise test at CEPrA19

The tests were performed on a short-range aircraft model provided by Airbus, fitted with a U-tail and mounted vertically on a wing support designed and manufactured within the ROSAS project. The fan noise was simulated by a TPS provided by Airbus. The objectives of this test were to provide the input data required for the propagation codes to model near field and shielding effects. A lot of configurations were tested, firstly isolated TPS and then installed configurations from the complete aircraft up to fuselage only configuration by removing the different parts step by step. Several TPS rotation speeds (3 installed, 6 isolated) and positions (4) relative to the aircraft were tested:

- Component effect
  - TPS on right and left-hand side for complete aircraft model;
  - TPS on left-hand side:
    - Aircraft mock-up without VTP;
    - Aircraft mock-up without VTP, without HTP;
    - Fuselage only;

- Source position effects:
  - Rear-Fuselage Nacelle (RFN) and Side-Fuselage Nacelle (SFN) positions;
  - Several forward positions;
- Engine/flow condition effects:
  - RPM effect;
  - External Mach effect;
- High lift (slat/flap) settings effect
  - 0°/0°
  - 18°/10°
  - 22°/20° with forward nacelle position

The same far-field microphone array as for the jet noise tests were used. Extra measurements were made since ROSAS had pointed out the necessity to better control the fan noise source. The database was delivered in January 2009.

Several trends observed during the ROSAS fan noise test in CEPrA19 were reproduced and confirmed. The main outcomes of the NACRE fan noise wind tunnel tests are:

- Modal content measurement: the outlet modal content has been checked versus the expected theoretical decomposition. It appears that in subsonic regime the real modal content is dominated by the interaction mode more than the broadband content expected. In sonic regime this expected interaction mode is confirmed by the measurements but the rotor-alone mode anticipated does not emerge. In supersonic condition the expected modal content is similar to the sonic one. Experimentally the rotor-alone mode level is increasing but without significant emergence, and the modal content can be considered as broadband.

- “Bifurcation effect”: The TPS outlet was instrumented in order to characterise the fan noise source at the exhaust. Numerical simulations highlighted the influence of the bifurcation that could explain the behaviour of some of the measurements. Actually the measurements in the outlet show that the fan noise source does not vary significantly from one configuration to another. As a consequence, the tonal noise changes identified for different configurations are due only to installation effects. The axial position of the TPS has a strong influence on the far-field noise, for both flyover and sideline arcs, and for the three rotation regimes.

- Shielding: The main conclusion is that the empennage shielding has a strong impact when the TPS is in the reference position near the U-tail, at an azimuthal angle from +50° to -50° around the flyover plane [D3.1-12B]. Moving the TPS forward removes the shielding benefit of the empennage, leading to a major increase of up to 12 dB of the tone levels between 70° and 120°.

  In removing the aircraft parts one by one down to the fuselage-only configuration, it was found that the horizontal tailplane was responsible for most of the noise shielding. Surprisingly, no significant shielding by the wing was measured in the forward arc. In this region, the TPS regime has a notable influence: moderate at the higher regimes, the installation effect becomes strong for the lowest regime. One could argue that the fan noise radiating downstream from the exhaust may have a significant contribution to the upstream noise field as well.

  The ambient flow appears also to have an important impact on both observer arcs: the flyover shielding is increased at upstream directions and the sideline installation effects are attenuated. The slat/flap settings are shown to have small installation effects. Only a slight attenuation is measured downstream in the flyover arc when the flaps are deployed probably associated with the propagation throughout the non-uniform wake of the high-lift wing.

As a conclusion, the wind tunnel test has provided a high-quality extensive database that will be used to validate the numerical simulation methods. Significant improvement has been achieved in comparison with ROSAS wind tunnel tests, in particular in controlling the noise sources and the 3D measurements. These results are detailed in [D3.1-12B] and [D3.1-13B].

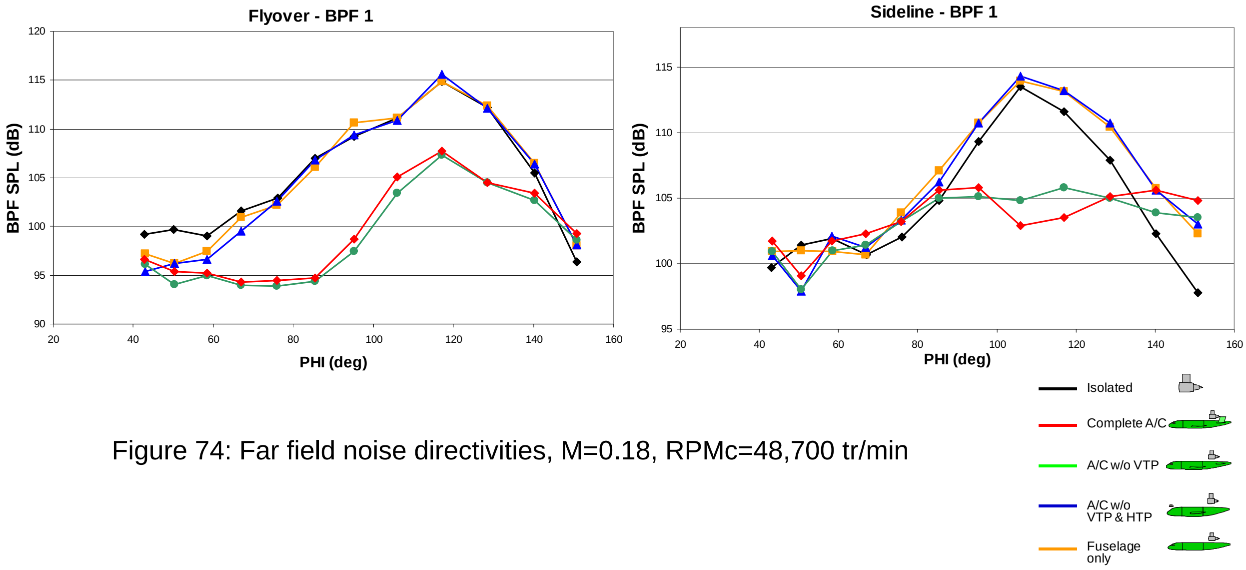


Figure 74: Far field noise directivities, M=0.18, RPMc=48,700 tr/min

Jet noise numerical simulation

Firstly, a benchmarking activity on the mean flow prediction by means of RANS computations was conducted based on the ROSAS results, as the first step in validating the jet noise source prediction methods. Then the NACRE nozzle cases were computed as input for the acoustic predictions.

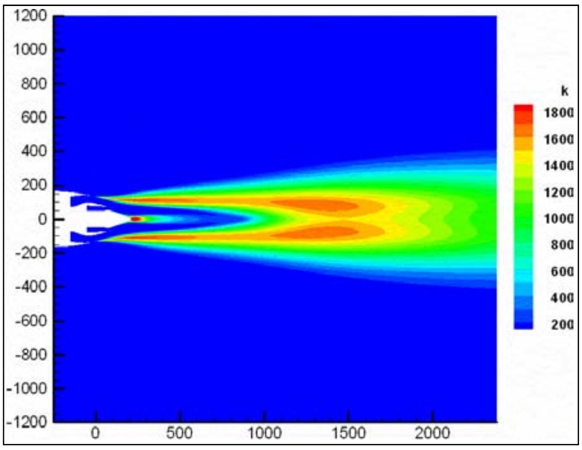


Figure 75: Turbulent kinetic energy from RANS computations on the NACRE case (Dassault Aviation)

The non-uniform flow field was then used with the following methods in order to model the noise sources:

- Goldstein acoustic analogy (TCD, Snecma, RR-D)
- Tam and Auriault in the frequency domain (NLR, Dassault Aviation)
- Random Particle-Mesh (RPM) based on Tam and Auriault in the time domain (DLR)
- Calibrated from RANS and axial beamforming

In particular near-field noise calculations for the NACRE nozzle were delivered by TCD as a multipole input on a Kirchhoff surface, which were then used to calculate the noise propagation into far field and the shielding effects for the installed conditions using a Green's function in different computation strategies. The RPM method used by DLR also provided time-dependent source data on an interface surface. Finally NLR used a method based on Linearized Euler Equations (LEE).

One of the key findings [D3.1-14] was that, the jet directivity being mainly the result of the convection of noise producing eddies and the refraction of the emitted sound by the mean jet flow, the inclusion of the source convection in the amplitude of the source by means of multipole definition gives a reasonable approximation of the jet directivity; however, this approach alone underestimates the directivity. Inclusion of the mean jet flow in the sound propagation can predict the observed refraction effect.

Amongst the most promising results, Dassault Aviation developed a semi-empirical approach to predict installation effects on jet noise based on Tam and Auriault. It first aimed at calculating the far-field noise radiated by isolated coaxial jets and was subsequently extended to installed nozzle configurations. Two test cases were investigated:

- A nozzle installed above an A318 model wing, as tested in ROSAS;
- A nozzle installed above the EUROPIV wing, as tested in NACRE.

The computed acoustic fields were compared with the measurements in order to validate the numerical approach. For the isolated case the prediction was found to be in good agreement with the measurements, for the whole noise frequency range (Figure 76).

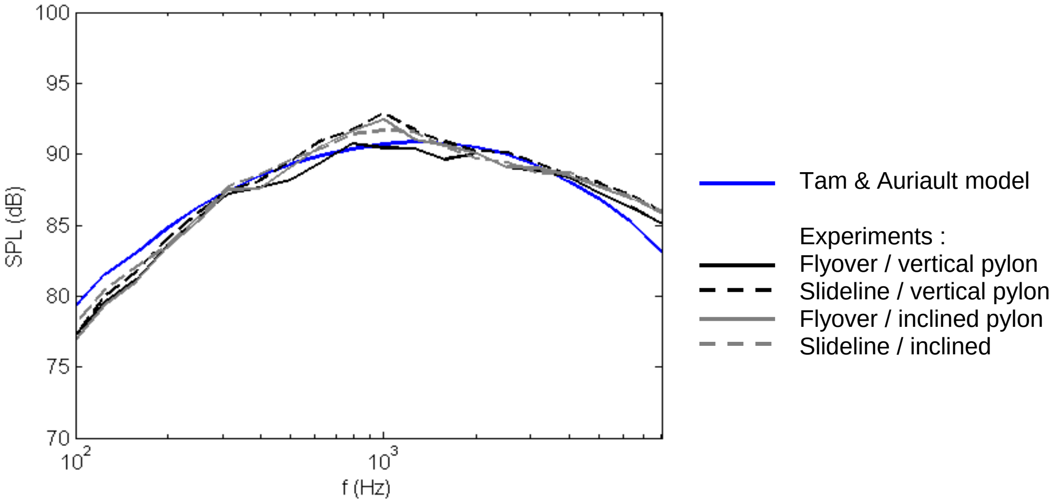


Figure 76: Sound pressure levels at Θ=90° (isolated case)

The installation effects were also well predicted by the model as shown in Figure 77 below.

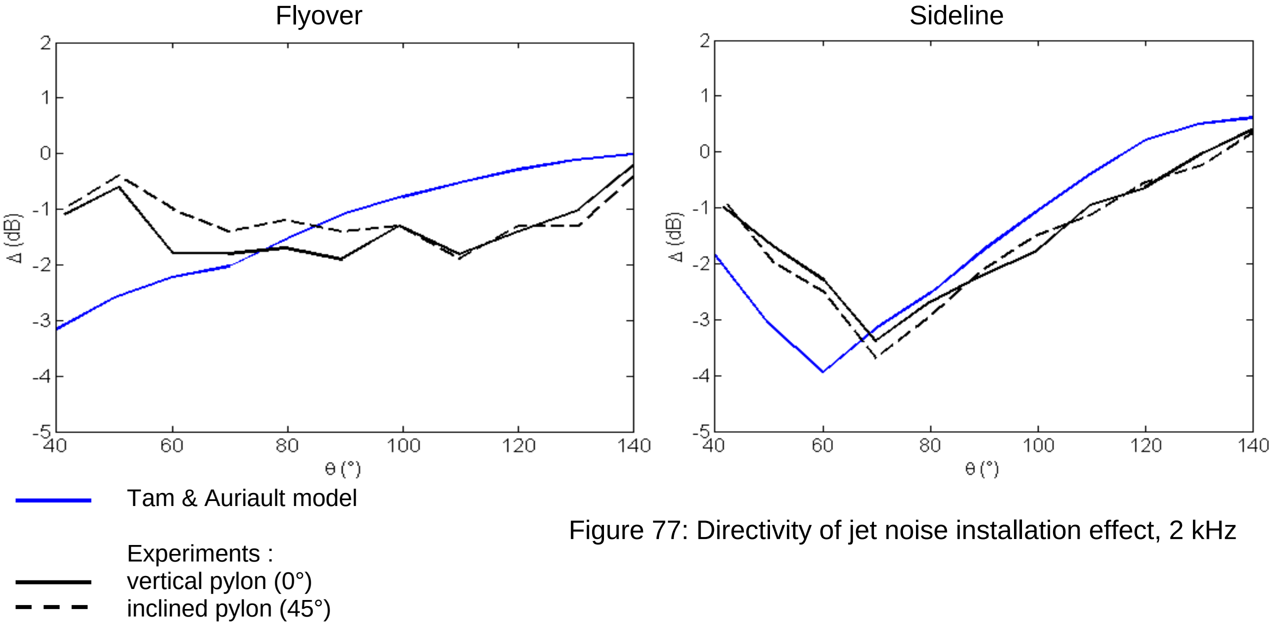


Figure 77: Directivity of jet noise installation effect, 2 kHz

The approach was considered to be a powerful tool to evaluate installation effects on jet noise. However, it appeared important to extend it to full 3D nozzle configurations. Indeed the ROSAS and NACRE experimental results showed that installation effects are impacted by 3D phenomena (internal wakes, pylon, chevrons…), which would enable the methods to be applicable to aircraft configurations with 3D noise reduction devices (chevrons, mixers…).

Similarly adapted to RANS calculations from other partners, the acoustic numerical method developed by Snecma allowed matching the measurements; it describes well the source mechanisms responsible for jet noise and can be used to predict jet noise and to classify different noise reduction technologies. However, the shielding results that are not completely satisfactory, most probably because of the positioning assumptions of the monopole sources, which needed to be changed in order to better take into account the spatial distribution and the directivity of the jet noise sources.

Finally the Fresnel shielding method was proved useful for preliminary estimates of shielding effects, but appears to be inadequate for jet noise problems.

Generally, there is still a large dispersion of predictions. Whilst the experimental results showed unexpectedly low shielding effects, the probability is high that the wing has an important impact on the jet aerodynamics.

Fan noise numerical simulation

The forward fan noise prediction was performed by Dassault Aviation with supporting analysis from by DLR to account for flow effects. The fan noise propagation has been evaluated using the Dassault Aviation in-house BEM/FMM solver SPECTRE. This model has enabled calculations over a substantial portion of the aircraft structure at the 1st BPF (Blade Passing Frequency) for various modes.

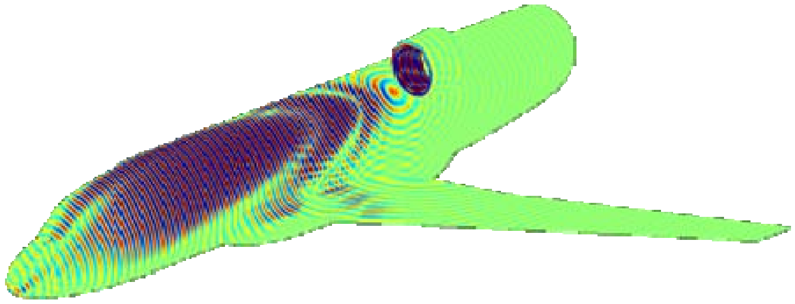


Figure 78: 1st BPF, Mode 1,1 – Engine in Forward Position

The numerical results obtained for the isolated nacelle at M=0 and M=0.18 showed that a uniform ambient mean flow had a minor impact on far field noise. They were in excellent agreement with the experimental results, particularly for the tonal mode modelling (Figure 79).

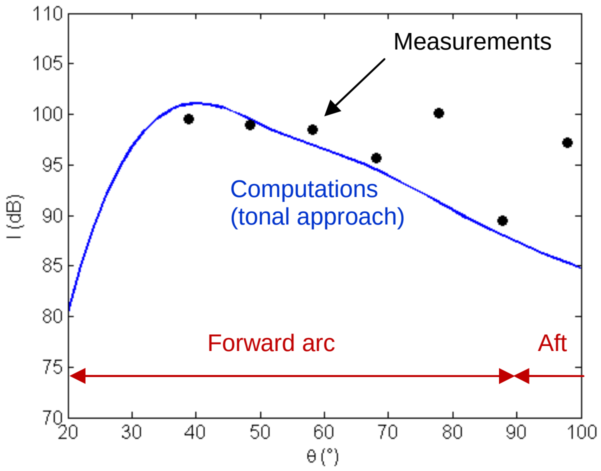


Figure 79: Isolated nacelle directivity for 1st BPF on Sideline (no ambient flow)

For installed configurations, strong shielding effects of higher than 10dB were predicted that also in good agreement with the NACRE tests for both sideline and flyover observer arcs, in particular for the no-flow test (Figure 80 below for the flyover).

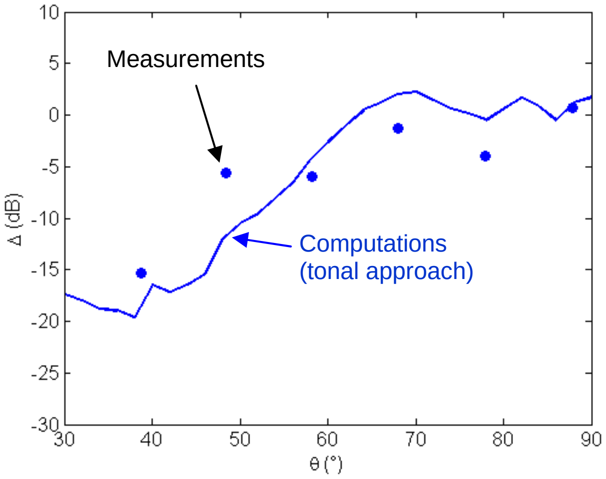


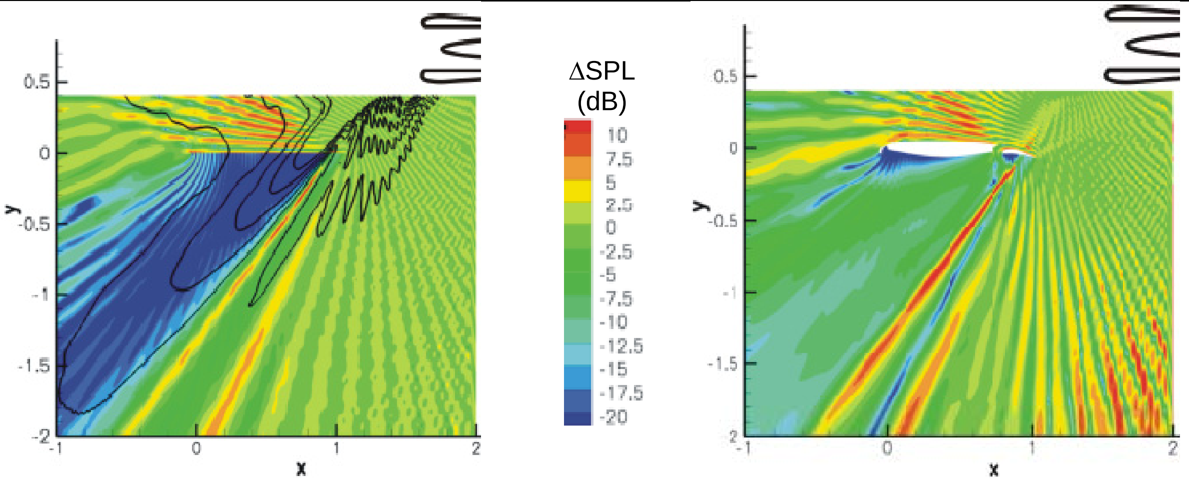
Figure 80: Installation (shielding) effect for 1st BPF on Flyover (“forward 1” position)

Two axial positions of the TPS vs. the aircraft mock-up were tested and simulated (“forward 1” and ‘forward 2”), which showed that:

- The closer the intake to the wing trailing edge, the broader and stronger the shielding region;
- This trend is observed for both flyover and sideline arcs, but the shielding is reduced on sideline observer positions because of fuselage reflections.

For the flow cases again there is a good agreement; however, the experimental results do not show sensitivity to axial engine positioning returning an average shielding effect between the numerical predictions for the two positions. Some discrepancies did arise due to flow effects in the installed cases. Further modelling of the influence of wake and other flow effects should be pursued with a view to integration in the BEM/FMM scattering approach.

In Figure 81 the shielding / installation effects are depicted for a slice at z = 0 (through the engine axis). The black lines in the left picture are iso-SPL lines for the engine sound radiation without obstacles, i.e. the free field (isolated) fan noise directivity. This is an important element to avoid misinterpretation of the shielding levels, because it is possible that, by diffraction, part of the sound energy is radiated into regions which in the free field case are not reached by sound waves. In that case ΔSPL would be positive, but the original SPL at that point is very small. Hence, the overall sum of original SPL and ΔSPL is tolerably small, even if positive ΔSPL values are encountered.



Shielding effect by a flat plate,
in uniform flow M=0.3

Shielding effect by a 2-element high-lift wing,
in viscous RANS mean flow

Figure 81: Installation effects for azimuthal fan mode 0 and radial fan modes 1-4

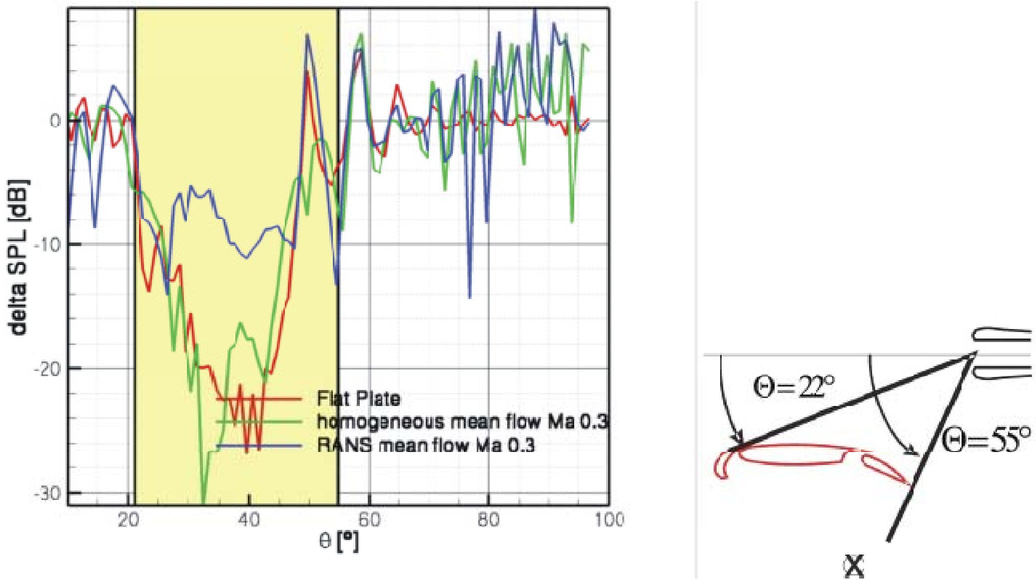


Figure 82: Comparison of installation effects for flat plate
and wing with constant mean flow & RANS mean flow

The effects of wing geometry and flow are shown in Figure 82 above. The yellow rectangle is where the wing lies in the line of sight. The main conclusions which stem from this comparison are as follows:

- Flat plate vs. high-lift geometry: for a constant mean flow, the size of the shield is the most important parameter, not the detailed shape.
- Neglecting the mean flow gradients leads to considerably overestimating the shielding potential.

The aft fan calculations required a two-stage process:

- Propagation of participating annular modes to the immediate exterior through the non-uniform flow field (performed by Onera with TCD support) to the weakly coupled interface.
- Propagation to the far field using a BEM/FMM code. The methodology was numerically validated on engine-alone configuration comparing full Onera's sAbrinA free-field computation to sAbrinA/ACTIPOLE coupling results. A supplemental work plan was defined to apply the methodology to the NACRE installed cases.
- Some comparisons with the far field experimental values were also performed.

The LEE code sAbrinA was run on a large 3D mesh (containing about 11 million nodes) with periodic boundary conditions matched to the mode under investigation. This was run using background flow parameters calculated by Airbus. The propagating modes were then propagated to the Kirchoff surface in order to interface them to the ACTIPOLE code for propagation to the far field (under uniform flow conditions at present).

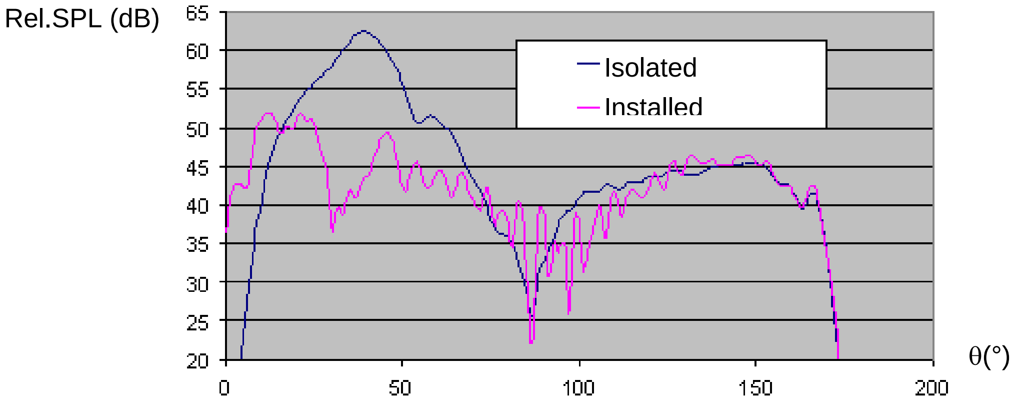


Figure 83: Comparison between isolated and installed directivities, Flyover, m=-4, n=0

As a conclusion, most of the CAA methods implemented provide good comparison with experimental data in isolated conditions, despite the noise field radiated by the TPS is obviously not axisymmetrical (bifurcation/pylon). For the installed conditions, the results based on BEM are quite promising. This work has confirmed the ROSAS result that the rear engine installation concept of PT1 would bring significant acoustic benefit, particularly for the fan noise source, compared with a classic installation.

Numerical simulation of CROR noise source and shielding effects

The objective here was to evaluate the acoustic shielding potential of the PG2 aircraft concept featuring the PT2 Powered Tail equipped with PGAE2 Contra Rotating Open Rotors. The numerical evaluation of the installation effects for this configuration were supplied to Task 1.1 as an input for the overall aircraft noise level assessment and are detailed in [D3.1-18].

Rolls-Royce provided CROR far-field noise levels to DLR and NLR.

- DLR performed a multipole description of the noise sources and noise shielding calculations using a ray tracing code (limited to high frequencies).
- NLR reconstructed the far-field directivity provided by Rolls-Royce thanks to a near-field approximation, and used an LEE method in time domain (limited to low frequencies).

The noise shielding obtained by the two methods is different, and the comparison of the results cannot be done easily, as the frequency domain is not the same, and the source modelling is very different. With both methods, shielding effect is obtained for observers in the flyover arc, and for observers on the sideline arc opposite to the engine. The amplitude of the shielding effect is stronger with the DLR evaluation, probably due to the source modelling, which does not take into account the directivity phenomenon.

Computations performed by NLR with a monopole source at 205.5 Hz (Figure 84) show a shielding effect around 10 dB, which is in line with DLR results at 400Hz. For a spatially distributed source, the shielding potential is less obvious.

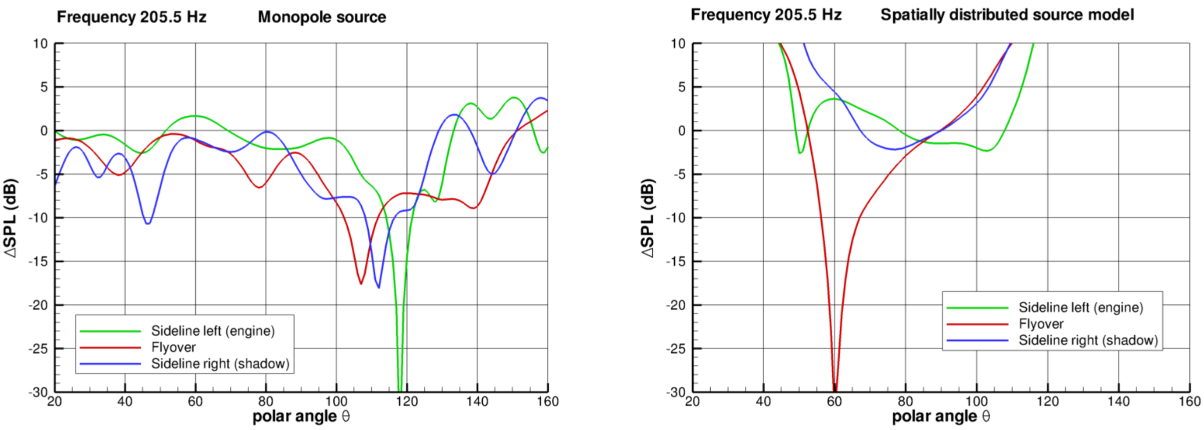


Figure 84: Noise shielding computations by NLR at 205.5 Hz (rotor alone tone)

Indeed, the shielding computations seem to be very sensitive to the source model, and particularly the spatial distribution of the source. Developing an appropriate source model seems crucial to reach definitive conclusions about the shielding, and it needs to be kept in mind for future work on this type of aircraft concept.

Final Conclusion

Subtask 3.1.1 Aerodynamic investigations

For the PT1 configuration, CFD and WTT campaigns have allowed to:

- Identify the main interactions between components:
    - Tails aerodynamic characteristics significantly affected by the presence of the engines: tails efficiency is decreased when adding the engine installation (impact on HQ).
    - Rear end lift increases when adding the engine installation: mainly due to nacelle/pylon interaction on HTP (increase of αHTP).
    - Pylon and nacelle flow field is very sensitive to AoA: flow separation occurs on pylon outer side at low incidences, and on pylon inner side above cruise.
    - Inlet functioning is not impacted in cross wind conditions.
- Validate PT1 design – Overall, flow field is safe on pylon and nacelle at cruise conditions, and this is where there are the best performances. At low speed, no critical interaction phenomena appear at considered conditions.
- Demonstrates good consistency of CFD with respect to Wind Tunnel Tests: most of the phenomena and tendencies are captured, but absolute levels need to be improved.

In conclusion, the performed analysis does not show strong showstoppers for this configuration, from a design point of view. It highlights that specific features (HQ impact) will have to be taken into account from the beginning of A/C sizing and design, and that the HQ behaviour of such a configuration should be characterized.

For further studies, more investigations should be made, for example:

- At high speed:
    - Perform a nacelle calibration, for a consolidated assessment of PT1 performance.
    - Set-up an appropriate methodology to allow a proper comparison to a classical aircraft.
    - Improve the predictions in terms of absolute level and understand the best approach to be adopted for the CFD assessment, especially with regards to the turbulence model choice.
- At low speed, continue with CFD computations on this configuration to understand:
    - Jet effect and thrust rate effect;
    - powerplant effect on A/C manoeuvrability;
    - check fan blade excitation impact in crosswind conditions
    - and confirm CFD results by low speed powered WTT.

For the PT2 configuration, CFD campaigns have allowed to identify the main interactions between components, which are very similar to PT1.

The studies have also allowed validating PT2 design. Specific features (HQ impact thrust dependent) will have to be taken into account from the beginning of A/C sizing and design. Interaction effects of propeller installations are more complex than for turbofans due to the large stream tube interacting with A/C and nacelle.

Further work on the following disciplines could be interesting for any upcoming projects:

- Handling qualities: complete study on impact of propellers on tails characteristics, and especially the effect on the A/C of propeller forces at sideslip and angle of attack (1 P loads)
- Performance: review low speed performance results, to understand the tendencies; calculations at trimmed stationary flight conditions and determination of a Thrust Drag bookkeeping compatible with wind tunnel testing and CFD
- Engine functioning in crosswind operation
- Design: Further optimisation of the rear end to reduce as much as possible the impact of channel flow and parametric study of propeller/pylon distance to minimize pylon effects.

Subtask 3.1.2 Acoustic characterization

The NACRE jet and fan noise wind tunnel tests have provided a high-quality extensive database on installation and shielding effects. Compared with the ROSAS project, significant improvement has been achieved within ST3.1.2 with the wind tunnel test campaign and results, in particular in the way to monitor and control the noise sources as well as with the new 3D measurements.

The interest of the NACRE jet noise wind tunnel test campaign is twofold:

- It provides an experimental characterization of jet noise shielding effects in a realistic configuration, with the impact of various parameters. This is required to investigate and quantify the interest of installation effects for jet noise reduction, and to find the relevant parameters of the shielding;
- The measurements will be very useful to validate numerical tools aiming at predicting jet noise installation effects.

The key findings from the jet noise tests are as follows:

- The presence of the wing reduced the noise levels on the flyover and sideline observer arcs.
- The measured shielding effects appeared to be stronger in the lateral direction and increase with the frequency.
- The noise attenuation induced by the profile remains moderate, except at high frequency.
- The external flow velocity tends to strengthen the installation effects.
- An increase of the power conditions induces a lowering of the shielding.
- The pylon position has only a very weak impact on installation effects.
- Finally, on the flyover path the shielding is stronger in the downstream direction than on the sideline trajectory, and it is lower at the other angles.

From the fan noise tests the following conclusions were made:

- The fan noise source measurements in the TPS outlet showed that the fan noise source does not vary significantly from one configuration to another, which means that the tonal noise changes are due only to the installation effects, not to configuration changes.
- The axial position of the TPS has a strong influence on the far-field noise, for both flyover and sideline arcs, and for all rotation regimes.
- The horizontal tailplane was seen to be responsible for most of the noise shielding. No significant shielding by the wing was measured in the forward arc. In this region, the TPS regime had a notable influence: moderate at the higher regimes, the installation effect becomes strong for the lowest regime.

However, there were strong difficulties linked to the wind tunnel operation (several incidents occurred during the tests) and schedule (conflict between customers had to be managed), which has to be enhanced in the future.

The numerical methods implemented for the prediction of jet and fan noise installation effects for unconventional aircraft concepts have been strongly improved, and most of them have been validated by comparison with the wind tunnel test measurements.

For the jet noise numerical simulations:

- In isolated conditions: most of the prediction methods provide good comparison with experimental data;
- In installed conditions: there is a larger dispersion of predictions and the experimental results show unexpectedly low shielding effects, but the wing probably modifies the jet aerodynamics, which was not considered here and needs to be taken into account in the future.

For the fan noise numerical simulations:

- In isolated conditions, most of the CAA methods implemented provide good comparison with experimental data despite the noise field radiated by the TPS is obviously not axisymmetrical (bifurcation/pylon);
- For the installed conditions, the results based on BEM are quite promising.

Further work was shown to be needed on the numerical simulation capability:

- Isolated engine noise prediction:
  - For aft fan noise, to improve the noise source description (Onera), accounting for:
    - the exact 3D geometry of the nacelle (pylon/bifurcation);
    - the measurement of modal emission in the duct.
  - For CROR, to compute the noise source from CFD (blade pressure fluctuations, single rotor / interaction tones) up to a bounding surface (NLR).
- Installed engine noise prediction:
  - To include the influence of mean flow non-uniformities:
    - for forward fan noise through BEM/FMM with a potential ambient flow;
    - for aft fan and jet, by coupling LEE (RANS flow) and BEM/FMM (Dassault-Aviation).
  - To develop a wave based methodology based on acoustic enthalpy rather than acoustic potential (TCD).
  - For aft fan noise, to improve the hybrid CAA-BEM method (Onera-Airbus) and use BEM solver *BEMUSE* (Onera), to be then validated against experimental data.

Finally, in general the results obtained through this work do confirm the promising potential for the design of advanced aircraft configurations: significant reduction can be obtained by shielding both turbofan and open rotor noise. The results at aircraft level are presented in Task 1.1.

Task 3.2 – Radical Engine Integration

Task objectives at beginning of the project

The objective of Task 3.2 was to investigate the problems raised by a radical integration of the engines on the aircraft airframe. For instance, for a Payload Driven Aircraft (PDA) type configuration, there is an interest to install the engine close or partly buried inside the airframe: the pitching moment due to the engine thrust is reduced and the trimming is obtained with less penalties, the aircraft weight is reduced without any pylon, the engine noise radiated is also reduced due to a masking effect of the airframe. For a Pro-Green Aircraft (PG) type configuration, there is an interest to install the engines on the rear part of the fuselage and relatively close to it to reduce noise emissions and to improve the aerodynamic performances of the wing, without the negative effect of the engine installation. But major issues can occur for the engine due to a bad aerodynamic quality of the intake flow due to the proximity of the airframe, and even for extreme configurations the possible ingestion of the thick airframe boundary layer. In addition, the certification issues can be critical for the case of engine burst event and, for this purpose, material and energy absorption analysis must be considered.

Within Task 3.2, different generic engine installation concepts were planned to be designed, taking into account the baseline configuration characteristics defined within WP1. Then these concepts would be assessed, considering the aerodynamic, acoustic and structural problems: this analysis would be performed with advanced numerical tools. This Task also aimed at identifying and investigating key materials and energy absorption analysis for the challenging certification of such engine installation. The objective was to provide elements in these different disciplines on the advantages and the drawbacks of different radical engine integration concepts.

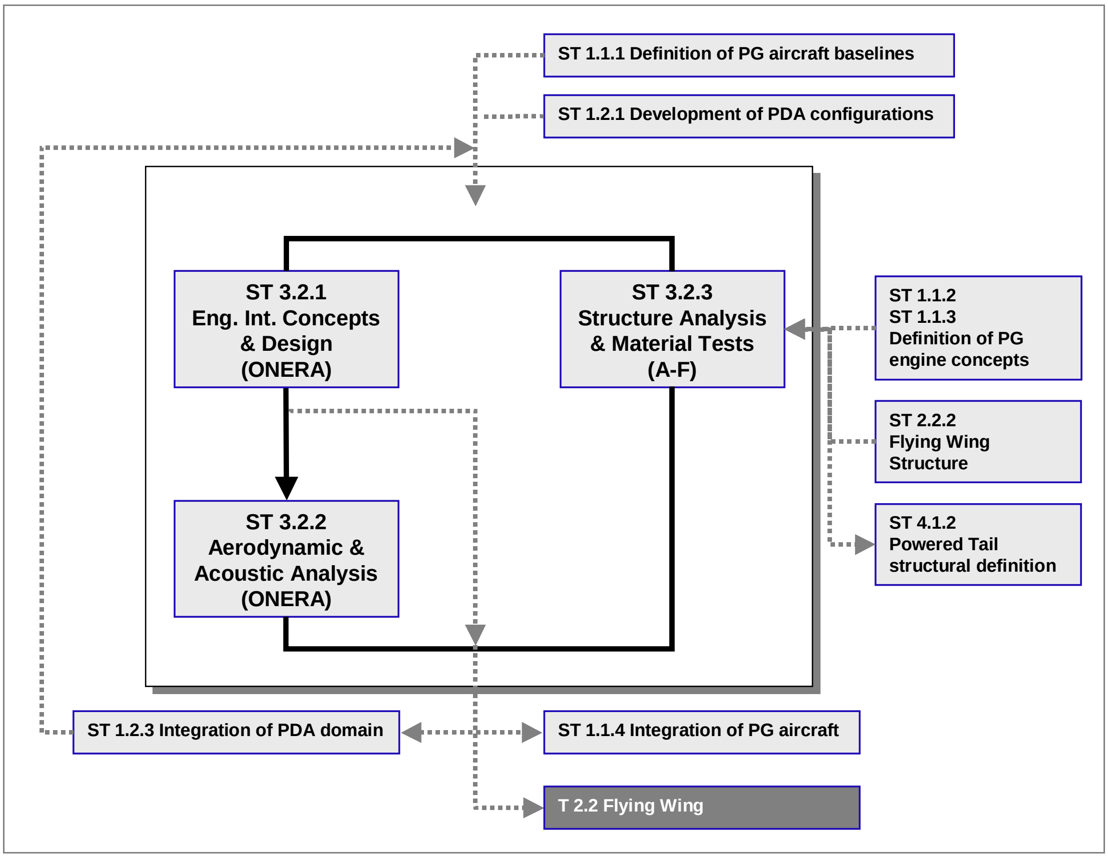


Figure 85: Task 3.2 Flowchart

Subtask 3.2.1 Engine Integration Concepts and Design

Taking into account the general aircraft baseline characteristics delivered by Subtasks 1.1.1 and 1.2.1, different radical engine integration concepts would be designed. A preliminary assessment of these concepts would be done numerically, considering at this stage of the study only the aerodynamic phenomena. From this activity, different concepts would be selected for a detailed analysis within Subtask 3.2.2.

Subtask 3.2.2 Aerodynamic and Acoustic analysis

The most promising engine integration concepts defined within Subtask 3.2.1 would be analysed in detail within this Subtask. The analysis would be done with advanced numerical codes. The aerodynamic and acoustic phenomena would be considered. In particular, the interactions between the engine inlet and the airframe would be analysed, and its consequences on the flow ingested by the engine or on the propagation of the engine noise.

More in detail, the activities would be the following ones:

- Aerodynamic computations would be performed with RANS codes on the different engine installation concepts for a selected number of aerodynamic flow conditions. The flow solutions and the phenomena would be analysed in detail for an assessment of the different concepts. In addition, the capabilities of improvement with flow control techniques would be assessed;
- Acoustic computations would be done with advanced methods on the same configurations to investigate the propagation of an engine fan tone noise for different aerodynamic conditions;
- Additional acoustic activities on engine noise propagation would be done with more simplified methods to assess inlet shape modifications influence or the influence of acoustic liners.

Subtask 3.2.3 Structure Analysis and Material Tests

This Subtask includes investigations of the structural aspects related to a radical engine installation and investigations related to the certification of such configurations.

Structural aspects: would take into account the general aircraft and engine baseline configurations characteristics defined in Tasks 1.1 and 1.2, different structural concepts would be defined for the engine attachments to the airframe (Airbus, Onera, MTU). The investigation would address the overall layout of the powerplant system, and propose “preferred” load paths and design choices. The assessment of the concepts would be done with structural finite element computations. In addition, structural computations of the inlet part would be done to assess the unsteady behaviour (vibrations) due to aerodynamic or acoustic excitations (CIRA).

The main objective was to minimize the weight of these structures, while covering relevant design constraints such as space allocation, maintenance (access to engine) and certification issues. The output of this Task would be the identification of optimal design choices for these radical engine installations, and recommendations for addressing the major design constraints encountered.

Certification aspects: The engine integration specific to the Powered Tail concepts, as developed in Task 4.1, features two engines mounted close to each other. This configuration raises a challenging issue for Certificability in case of engine burst event (Airworthiness Authorities Advisory AMJ 20-128A).

Building on some preliminary recommendations from the ROSAS project, Subtask 3.2.3 would propose to address some design solutions that were identified to overcome this potential showstopper. The proposed activities would focus on defining risks and solutions stemming from a rotor disc burst (high energy fragments) according to the engine installation on the Pro-Green aircraft as defined in Task 4.1.
Both engine and aircraft perspectives would be considered:

- Engine passive (positioning of key systems) and active (containment) concepts;
- Aircraft passive (shielding) concepts.

The investigation on airframe shielding concepts would be based on ambitious energy-absorption material tests to be performed at TsAGI for two types of shields; these tests would include measurement of the dynamic strength of the protection shield samples under small non-localised engine fragment penetration, verification of the engineering methods for loading, determination and estimation of the strength characteristics of the structure elements affected by engine debris. Two types of tests would be performed: one using a rocket-trolley track, the other with a power-catapult system; measurements would register main parameters as debris weight, velocity, angle between the debris penetration trajectory and the shield, and the accuracy of debris concentration in the specified shield area.

Technical Achievements

The activities in Task 3.2 were performed in two steps:

- Firstly, the architecture of the semi-buried engine installation was defined at preliminary design level within Subtask 3.2.1.
- Then, more detailed design activities, including assessment, were performed at discipline level, Subtask 3.2.1 investigating aerodynamics, Subtask 3.2.2 investigating aerodynamics and aeroacoustics, and Subtask 3.2.3 investigating structures and certification aspects.

Subtask 3.2.1 Preliminary aerodynamic design

The general architecture of the radical engine installation was defined by the aircraft manufacturer, considering the NACRE PDA aircraft and the different engine configurations delivered by WP1. The selection of the architecture is the consequence of the constraints in terms of geometry, certification (in particular the fan burst aspect) or maintenance and the result of a pre-design investigation considering aerodynamics, acoustics, structures and flight mechanics. In fact, the selection has been mainly driven by the geometrical and certification constraints.

The main outcomes for the architecture are the following:

- An engine installation corresponding to a PDA configuration with 3 engines is preferred to a configuration with 4 smaller engines;
- The engines are installed over the centre body, in the rear part of the PDA, mainly due to certification aspects. The engines are positioned backward of the pressure bulkhead and the central engine is backward of the lateral ones;
- Due to the engine positions, a PDA configuration without vertical tail plane is proposed with crocodile ailerons.

After the selection of the architecture, the detailed aerodynamic design of different semi-buried intake installations was performed using RANS codes. Two reference shapes, corresponding to burying the engines by 8% and 15% of the fan diameter, have been designed. The objective of the aerodynamic investigation was to assess the engine intake performance (Recovery coefficient, distortion coefficient DC60) for an intake ingesting the airframe boundary layer, this phenomenon being typical of semi-buried configurations. The reference shapes were compared for different aerodynamic conditions (take-off, climb, cruise, …). These shapes were then delivered to Subtask 3.2.2 for improvement in aerodynamics and for assessment in aeroacoustics.

The main outcomes in aerodynamics are the following:

- An acceptable aerodynamic performance for the engine intake was defined by the engine manufacturer and corresponds to a loss of efficiency by 0.5% or a distortion coefficient DC60 equal to 0.36 in cruise conditions;
- The cruise conditions are much more critical for the intake performance (For 8% burying, Recovery=0.974, DC60=0.34) than the low speed ones (Recovery > 0.99, DC60 < 0.03);
- The thickness of the boundary layer ingested by the intake is the most important parameter influencing the intake performance, with the loss of total pressure or the distortion nearly proportional to it. This strong influence is also due to the important fuselage boundary layer (BL) thickness in the rear part of a flying wing;
- The increase of the burying level leads to a loss of performance, but has less influence than the boundary layer thickness:
    - For 8% burying: Recovery=0.974 and DC60=0.34:
    - For 15% burying: Recovery=0.969 and DC60=0.38.
- Although these values of recovery and DC60 are unusual for civil aircraft, the reference configurations fulfil the requirements on performance whatever the aerodynamic condition considered.

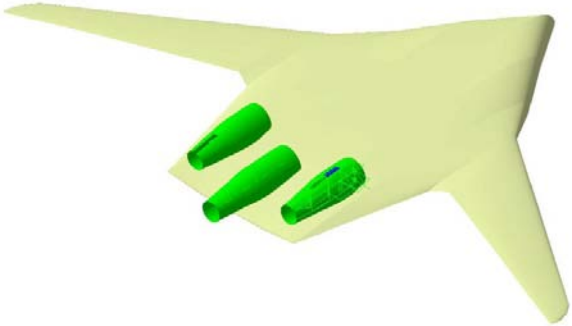
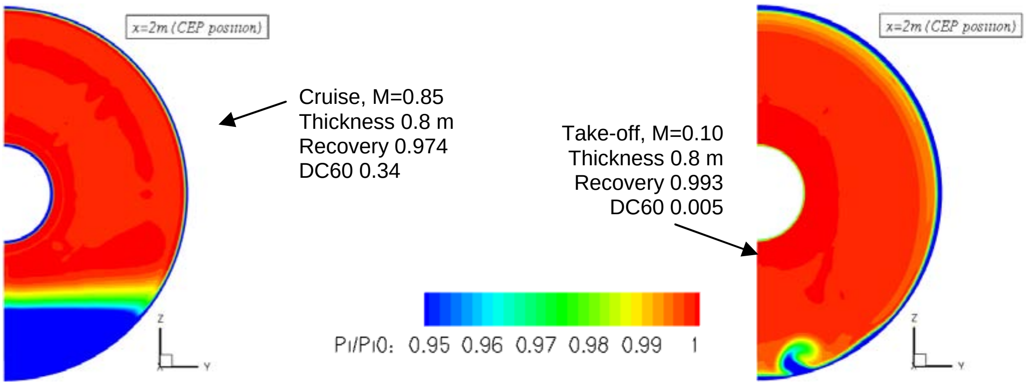


Figure 86: Engine installation architecture selected



Cruise, M=0.85
Thickness 0.8 m
Recovery 0.974
DC60 0.34

Take-off, M=0.10
Thickness 0.8 m
Recovery 0.993
DC60 0.005

Figure 87: Total pressure contours in engine fan plane for BL thickness 0.8m and 8% inlet burying

Subtask 3.2.2 Aerodynamic and acoustic analysis

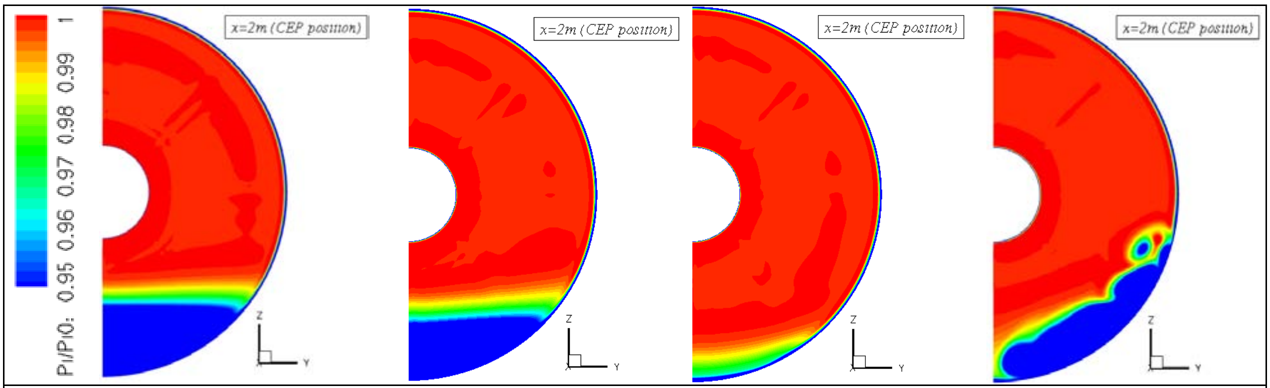
In aerodynamics, the main objective of this Subtask was to improve the performance of the semi-buried engine intake because the values determined in Subtask 3.2.1 were quite unusual for civil aircraft, although considered acceptable. Two different methods were investigated:

- Alenia defined and assessed modified shapes with elliptical cross-sections, derived from the reference shapes delivered by Subtask 3.2.1;
- Onera determined the capabilities of flow control techniques (suction, boundary layer trap, vortex generators) to improve the performance of one shape in cruise conditions. The objective was to reduce the importance of boundary layer ingested but also to obtain a flow more homogeneous in the engine fan plane.

These computations were carried out using RANS codes.

The main outcomes of the aerodynamic investigation were that:

- The intake shape modifications with elliptical cross-sections showed limited benefit for intake performance. No improvement is observed on the recovery coefficient, and the maximum reduction achieved for the distortion coefficient DC60 was 0.06 (16%);
- The flow control techniques can improve significantly the performance.
    - For the 8% buried intake at cruise (Recovery=0.974, DC60=0.34), the highest improvement was obtained with a boundary layer trap as high as half the boundary layer thickness (Recovery=0.996, DC60=0.02).
    - A suction at the wall upstream of the intake leads to a Recovery coefficient of 0.983 and a DC60 of 0.24.
    - The introduction of vortex generators upstream of the intake and inside it leads to a Recovery coefficient of 0.982 and DC60 0.12.
    - Nevertheless, the selection of such technique can only be the result of a global balance at aircraft level, considering all the advantages and drawbacks of it, in particular the energy necessary to drive the system, the weight penalty, the maintenance aspects, the costs.



	No flow control	Boundary layer suction	Boundary layer trap	VGs on fuselage and inside inlet
Recovery	0.974	0.9825	0.996	0.982
DC60	0.34	0.24	0.02	0.12
Massflow sucked	0.	13. kg/s	52. kg/s	0.

Figure 88: Total pressure contours in engine fan plane with flow control techniques (cruise condition)

In aeroacoustics, the objective of the investigation was to evaluate the reduction of engine noise propagation with semi-buried intakes. The following activities were carried out:

- Dassault Aviation determined the noise propagation with a simplified BEM numerical method for the two reference semi-buried intake shapes, as well as the two Alenia shapes, with the objective of comparing the different configurations. The method does not take into account the aerodynamic flow;
- Dassault Aviation, KTH and Onera performed computations with advanced codes, taking into account the aerodynamic flow, with the objective of obtaining a more precise evaluation. A comparison between configurations was also possible thanks to computations by Onera for the two reference shapes;
- Dassault Aviation assessed with a simplified method the possible gain with different positions of acoustic liners inside the engine intake.

All these activities were supported by MTU who delivered the characteristics of engine noise sources.

The main outcomes of the aeroacoustic investigation were that:

- The comparison of the reference shapes with a simplified method showed a reduction in external noise for the deepest buried configuration, but this reduction is moderate. The results with advanced methods, taking into account the aerodynamic flow, confirmed this conclusion but the differences between the two reference shapes are much higher;
- The analysis of Alenia intakes with elliptical sections, by comparison to the reference shape, showed no effect on the flyover noise and a moderate effect on the sideline noise;
- The comparison of simplified and advanced methods, taking into account the aerodynamic flow, showed a significant effect of the flow on noise propagation, with a deviation of the noise to the top direction and a masking effect of a local supersonic region;
- The analysis of acoustic liners influence, when installed inside the intake, by comparing different positions for the same area, showed that the most efficient installation corresponds to liners near the intake lips and on the upper part of the intake.

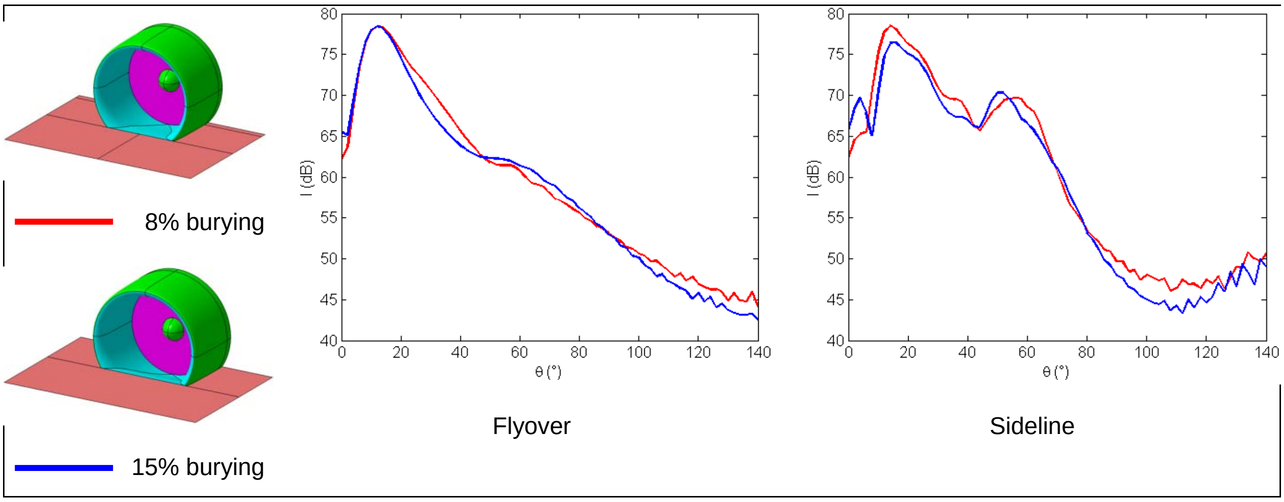
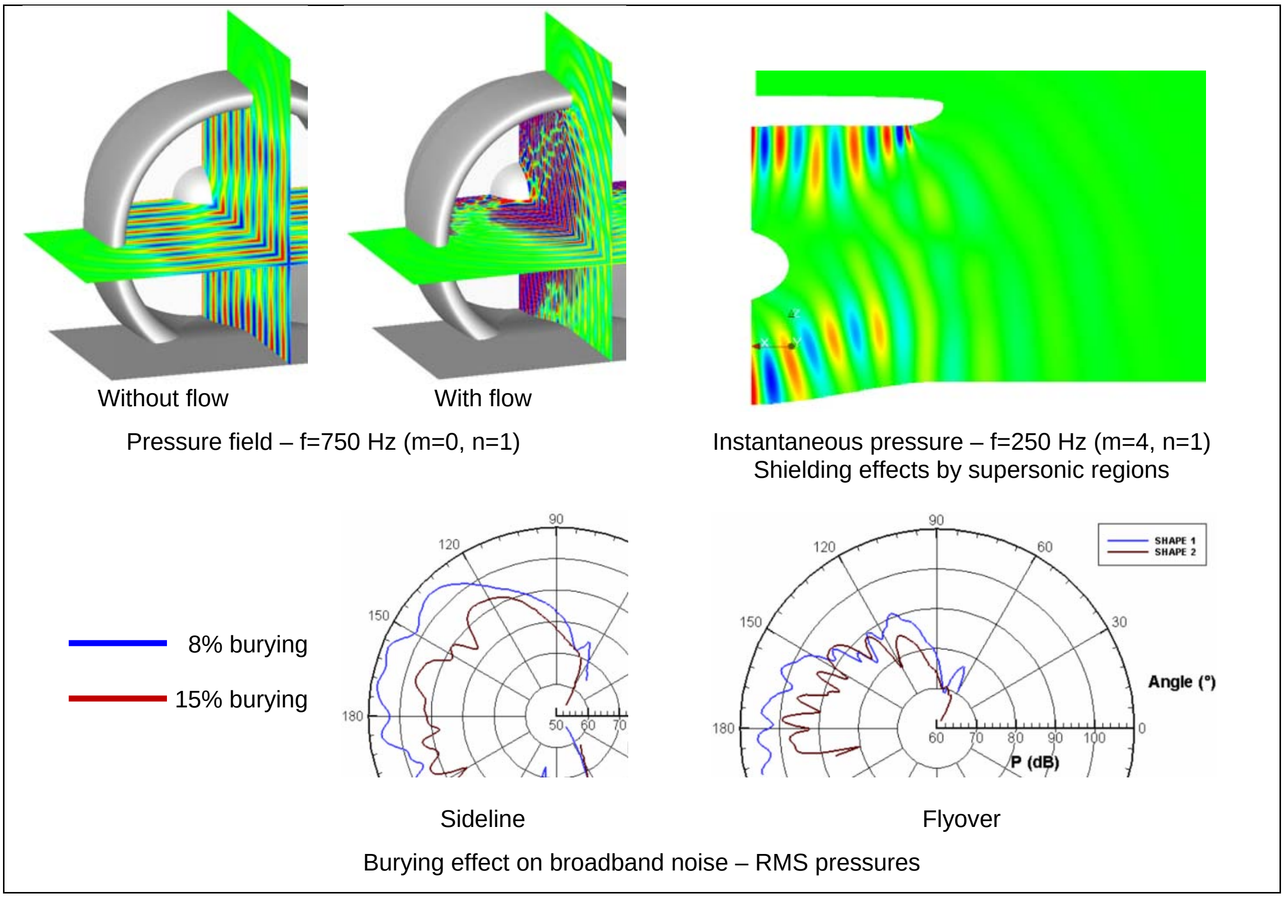


Figure 89: Influence of intake burying level on engine fan tonal noise directivity



Pressure field – f=750 Hz (m=0, n=1)

Instantaneous pressure – f=250 Hz (m=4, n=1)
Shielding effects by supersonic regions

Burying effect on broadband noise – RMS pressures

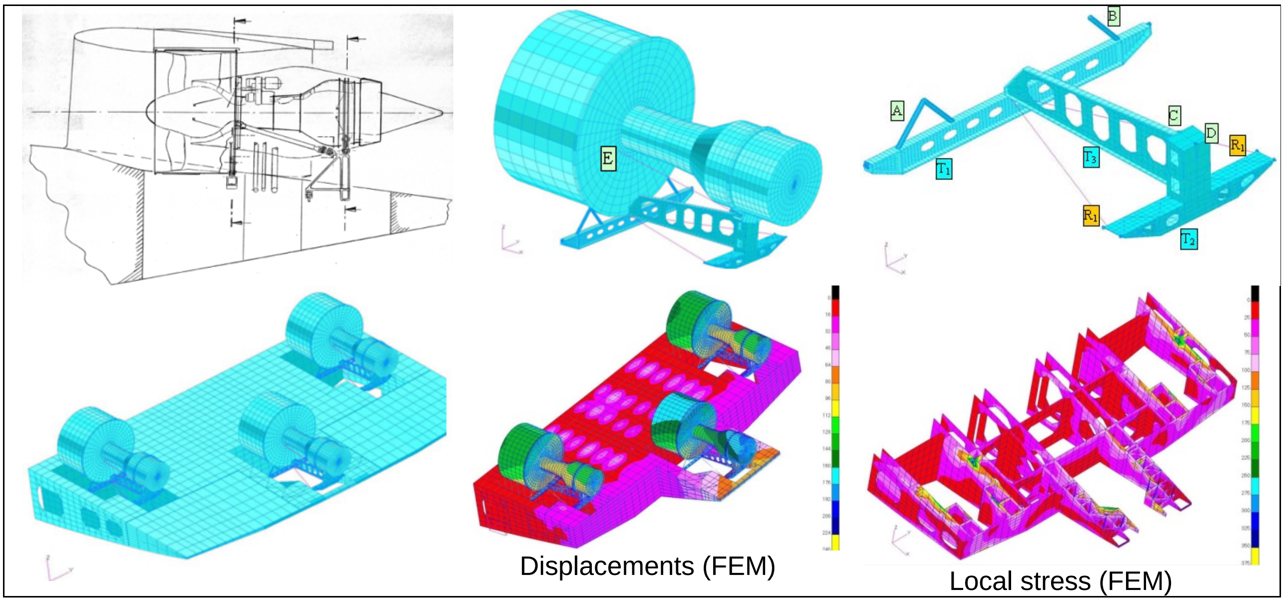
Figure 90: Influence of aerodynamic flow on fan noise propagation

Subtask 3.2.3 Structure analysis and material tests

For the structure activities of the radical engine integration Task, the first step was the definition by Airbus, MTU and Onera of an architecture for the attachment of the engine on the aircraft structure. Then, MTU defined different variants of this architecture and made a comparison and an assessment at pre-design level of the drag, noise, weight and pitching moment. Then, Onera performed a detailed structural design of one concept including weight assessment, followed by FEM analysis to determine the deformations and local stresses for different flight conditions. Finally, a similar assessment was done on a conventional aircraft configuration with under-wing engines, for comparison between the semi-buried and the conventional engine installation. In parallel, CIRA performed trade-off studies on the intake behaviour under static and dynamic loads due to aerodynamic and aeroacoustic forces.

The main outcomes of the structural investigation are the following:

- An engine installation architecture was proposed for the PDA configuration with three semi-buried engines installed over the wing. It appeared that the pitching moment due to the engine thrust is an important parameter to be considered. This architecture is characterised by an inclined engine along the wing surface, a boundary layer separation device under the inlet, and a thrust vector nozzle;
- The detailed design of the attachment structure was done by Onera. FEM computations were performed to check that local displacements and stresses do not exceed the maximum acceptable values. For each engine, the attachment structure weight is 846 kg;
- A similar exercise was achieved for a PDA configuration with a conventional engine installation with four engines under the wing. The global weight balance includes the attachment structure weight and the airframe reinforcement due to engine installation. The total weight is 9,100 kg for three engines over the wing, and 12,700 kg for four engines under the wing, illustrating the important weight saving obtained with a semi-buried installation;
- CIRA assessed the static and dynamic behaviour of the engine intake. Different flight conditions, levels of burying the engine inside the airframe, materials and skin thickness were considered. The static analysis showed that the low speed conditions are more critical than the high speed ones. In addition, composite material was found to be the best choice, compared to titanium or aluminium. The dynamic analysis showed a very high modal density for aluminium and a lower one for the composite material.



Displacements (FEM)

Local stress (FEM)

Figure 91: Structural concept for over-wing engine installation with engine removal from bottom and FEM analysis

The second part of this Subtask addressed the issue of energy absorption by a structure part from a high-energy fragment of an engine rotor, typically a third of a disc, in the event of an engine rotor failure and the release of debris. For each new aircraft model type certification, the aircraft manufacturer is requested to demonstrate that precautions have been taken to minimize the hazards to the aircraft in such (otherwise unlikely) events. This requirement has to draw special attention in the context of innovative aircraft configurations with engines close to one another. This certification exercise is usually done using infinite energy associated to the debris. The regulation allows using possible energy absorption considerations provided methods are supported by tests.

The general aim of the NACRE work was to investigate finite engine debris energy, either in view of demonstrating that the debris are in fact contained after having crossed some aircraft parts, or to size and design shields to contain or to deviate them.

Some methods have been developed and validated in the past to predict the part of the debris kinetic energy that is absorbed by a typical structure of aircraft at the impact, when the initial debris kinetic energy is lower than 20 kJ, or 30 kJ in some specific cases (small fragments). But there was no documented testing available for high energy cases such as large energy debris above 30kJ.

These methods have allowed developing numerical models for metallic structures. The aim in NACRE was to collect sufficient experimental data in order to validate those numerical models for higher energy fragments.

Initially a broader test programme was established, part of which was integrated into NACRE. For the studies covered by the NACRE test programme, the key objectives were:

- To gather experimental data in view of validating the numerical models for 1/3rd disc fragment impact on metallic structures (engine case or aircraft part).
- To evaluate experimentally the effect of rotation of a 1/3rd disc fragment on the aircraft damage, represented by fragment penetration into a thick metallic panel;

The first series of tests (Step 1.3) was devoted to translation velocity only, with energies up to 150 kJ. The aim of this series of tests was to study the influence of the parameters involved in the hard debris impacts, in order to validate the finite element models for metallic structures impacts.

FE methods have been developed and validated for some specific cases of small hard debris (engine blade) impacts onto shields where the translation energy level was lower than 30kJ, no rotational energy was present, the mass was 1.5kg and the velocity was in the region of 200m/s. The Step 1.3 tests intended to collect data in view of validating an extension of the application of this FE method to translation energy levels of 150kJ, with and without rotational energy, where the fragment has a mass of up to 25kg and a velocity of up to 250m/s.

Velocity is important as it affects duration of impact and how much time the structure has to react to the loading. At high speeds the local area affected by the impact may mean surrounding structure and boundary conditions are not important whereas at lower velocity they could absorb a lot of energy. The projectile shape can affect the shield material's failure mechanism, pointed projectiles piercing the shield while blunt ended ones could cause plugging. The angle of impact is also important, for normal impacts the shield failure mechanism would be like a punching/blanking operation while impacts making a small angle to the shield are more like machine tool cutting operations. The shield's failure mechanism may be dependent on its thickness; thin sheets could result in petaling while thick plates could result in plugging and/or spalling. The final thickness for the target plates selected was as high as 40 mm.

For this experimental investigation conducted at the GkNIPAS facility outside Moscow, the development of experimental equipment involved putting together a complete system of high speed video cameras, a gauging system for strain measurements on the shield itself, an alternative means to measure the fragment residual speed as well as the trolley speed. In our case, the shield attached to a test bench was moving on a carriage, while the fragment was held static at a predefined position on the trajectory of the carriage.

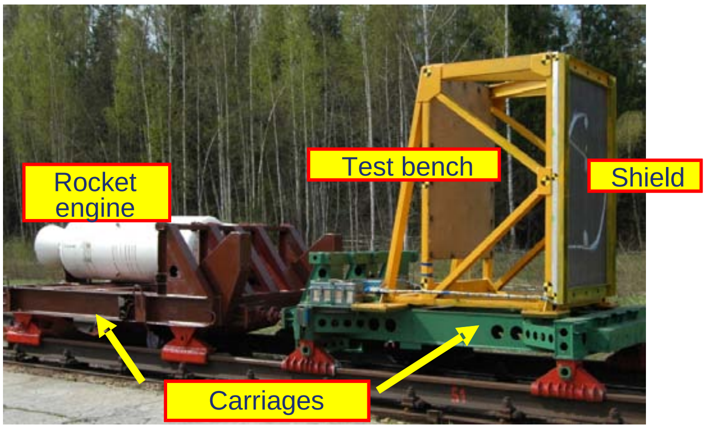


Figure 92: General view of the experimental test bench for trolley speed 200-250 m/s

Figure 93: Step1.3 Launch 1 impact (back side of target)

Figure 94: General view of the test bench with inclined screen for trolley speed 200-250 m/s

A rebound of the fragment was observed.

Impact on target

Figure 95: Step 1.3, Launch 3 with inclined screen – trolley speed 212 m/s, screen angle 60°

Concerning the influence of the rotation on the impact damage (Step 1.2), a key outcome of this experimental activity was the development of the testing facility itself, in particular for the rotation devices and their capability to generate the right ratio of rotation speed vs. translation speed of the fragment relative to the shield.

An experimental investigation with intermediate validation tests (“demonstration” launches and “technological” launches) was conducted for rotation devices with capability of generating the rotation of a model fragment of up to 20.5kg at the right speeds, with several iterations in particular on the material characteristics of the device (Figure 98).

The table below provides a complete view on the tests successfully achieved:

№		Date	Objective of launch	with/without shield	Speed of trolley	Results
1	**Step 1.1 Launch1**	**14.12.2006**	**First launch with rotation**	**+**	**89 m/s**	**Perforation of the shield and damage of clamps. Fragment rebounded.**
2	**unofficial L1**	**11.04.2007**	**DEMO**	**-**	**203 m/s**	**Rotation of the fragment only.**
3	**unofficial L2**	**19.04.2007**	**DEMO**	**-**	**140 m/s**	**Rotation of the fragment only.**
4	**Step 1.3 Launch 1**	**23.04.2008**	**Launch with translation only**	**+**	**214 m/s**	**Fragment stuck in the shield.**
5	**Step 1.3 Launch 3**	**22.09.2008**	**Launch with translation only**	**+**	**219 m/s**	**Perforation of the shield and fragment rebound.**
6	**Launch 1'**	**22.04.2009**	**Technological**	**-**	**193 m/s**	**Rotation of fragment only.**
7	**Step 1.3 Launch 2**	**06.05.2009**	**Launch with translation only**	**+**	**219 m/s**	**Full penetration of the fragment throw the shield.**
8	**Step 1.3 Launch 4**	**14.05.2009**	**Launch with translation only**	**+**	**176 m/s**	**Fragment stuck in the shield.**
9	**Step 1.3 Launch 5**	**04.06.2009**	**Launch with translation only**	**+**	**118 m/s**	**Perforation of the shield and fragment rebound.**
10	**Launch 2'**	**15.06.2009**	**Technological**	**-**	**139 m/s**	**Rotation of fragment only.**
11	**Step 1.2 Launch 1**	**08.12.2009**	**Launch with translation and rotation**	**+**	**134 m/s**	**Perforation of the shield and fragment rebound.**
12	**Step 1.2 Launch 2**	**03.2010**	**Launch with translation only**	**+**	**-**	**-**

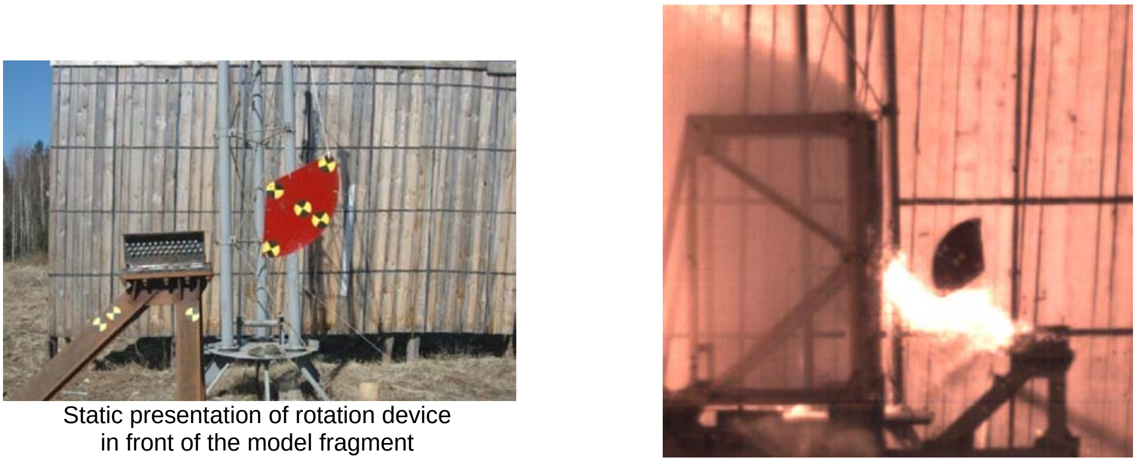
The design of the rotation device was patented and its capability was validated by means of real tests.

- Rotation speed up to 405 rad/s in technological launch 1’ (trolley speed 193 m/s);
- Rotation speed up to 353 rad/s in technological launch 2’ (trolley speed 139 m/s);
- Rotation speed up to 313 rad/s in customer launch 1 Step 1.2 (trolley speed 134 m/s).

Concerning the numerical simulation methods, a technique was created, based on the MSC.Dytran code (commercial-off-the-shelf), to simulate and analyse the dynamic strength of isotropic metallic shields under the impact of model fragments and of the test benches and trolley attachment structures, and to model the interaction between the rotation device tubes and the model fragments.

Good comparison was achieved between predictions and experiments for Step 1.1 launch 1 and Step 1.3 launches 1, 2. Fairly good numerical simulations were also achieved for Step 1.3 launches 3, 4, 5 and Step 1.2 launch 1, compared with the experimental results. The interaction between the rotation device and model fragments however raised a number of difficulties that need yet to be overcome before actually being able to simulate this dynamic process using the COTS code MSC.Dytran.

Figure 96: General view of the test bench with rotation device for trolley speed 100-150 m/s



Static presentation of rotation device
in front of the model fragment

Frame of high speed video camera
about 1/200 s before hitting the shield

Figure 97: Model fragment before and after strike with rotation device

Lay out of rotation device with steel tubes

Structure of rotation device after the test

Figure 98: Details of rotation device

Final Conclusion

Within Task 3.2 of the project NACRE, different investigations were performed on configurations with engines partly buried inside the airframe. Different disciplines have been considered and in particular aerodynamics, aeroacoustics, structures, certification aspects. Specific concerns have been identified for such configurations. Nevertheless, some technical solutions have been identified to overcome these concerns. Some of the most significant conclusions are presented here after:

- Concerning the general architecture of the aircraft with semi-buried engines, it was necessary to install the engines downstream of the pressurised region of the fuselage for certification constraints. In addition, a configuration without tail planes has to be envisaged;
- In aerodynamics, the main problem is the overall aerodynamics on the upper side of the inner wing. The key issue for this type of configuration, with over-wing engines installation, is to avoid strong shocks and separation, which might occur given the supercritical or even near sonic flow field.
- The specific problem investigated here was the significant loss of engine intake performance due to the ingestion of the boundary layer developing over the airframe. Nevertheless, it seems that flow control techniques such as suction or vortex generators can be applied to solve this concern;
- In acoustics, an installation over the airframe and partly buried inside it has a highly beneficial effect on the reduction of external noise. In addition, acoustic liners can improve this reduction;
- In structures, an engine installation partly buried in the airframe leads to a reduction of mass, in particular due to the absence of pylon;
- Concerning the certification aspects, the proximity of the engine to the aircraft cabin is a critical point for semi-buried configurations.

Concerning the high-energy impact material tests for energy absorption investigation, the methodology to perform high-energy tests for experimental dynamic strength investigation was successfully defined and implemented, and unique experimental results were obtained at the GkNIPAS facility. The rotation device structure designed and manufactured in GkNIPAS allowed to get rotation speeds in the range of 350-400 rad/s for high kinetic energy of model fragment with trolley speeds ~130-220 m/s.

Overall, 4 structures of test benches, 3 structures of trolley, 5 structures for the rocket attachments were designed and manufactured, including the test benches themselves with engines and rotation device attachments as required. 12 launches were successfully performed, out of which 8 “customer launches”, 2 “demonstration launches” and 2 “technological launches” for the development of the rotation device. 8 test reports plus 8 simulation reports were delivered by TsAGI and GkNIPAS.

The technique for computer modelling in the frame of the MSC.Dytran code was created to calculate dynamic strength of protective shield under the impact of a model fragment and analysis showed the good correlation of calculated and experimental results. It was not possible however in the frame of MSC.Dytran code to achieve a suitable technique for the computer modelling of the interaction between model fragments and the rotation device.

Task 3.3 – Hung Engine Integration

Task objectives at beginning of the project

The main objective of Task 3.3 was to provide the engine integration perspective for the Simple Flying Bus as far as the complete propulsion system architecture (Engine, Pylon, Nacelle and systems) is concerned. The integration of this activity with the other components of the SFB concept was monitored via Task 1.3 and in particular strong links with the Manufacture Driven Wing investigations in Subtask 2.1.3 would be ensured.

Task 3.3 would receive preliminary aircraft concepts from Task 1.3 in order to contribute to a deeper multidisciplinary analysis in terms of propulsion system positioning, structure and systems. In this frame, it would address both:

- A parametric study on the propulsion system positioning under the wing (Subtask 3.3.1), by considering the constraints of the Manufacture Driven Wing and contributing back to Subtask 2.1.3 for the integrated definition of that wing, by providing engine loads application points, in an overall multidisciplinary approach;
- The problematic of “economic aspects vs. engine design” for the SFB aircraft architecture throughout the integration design, in Subtask 3.3.2. This activity should ensure compatibility of the propulsion system definition with the objectives defined in Task 1.3 and provide concrete recommendations for future design towards these objectives, to be derived in other frames.

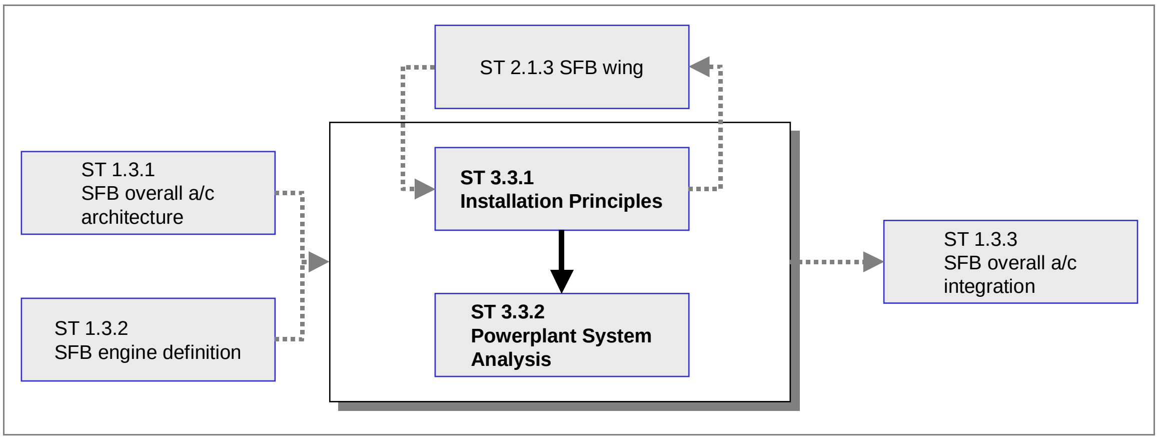


Figure 99: Task 3.3 Flowchart

Subtask 3.3.1 Installation Principles

This Subtask aimed at conducting parametric studies mainly for an integrated design of the engine positioning. In order to support this exercise, innovative engine installation principles for conventional under-wing integration would be developed, such as symmetrical pylons. The goal was to respond to the SFB top-level requirements defined in Task 1.3. Improving economics being the key driver, both manufacturing and maintenance cost efficiency improvements would be targeted.

Thus the engine integration characteristics would basically be as simple as possible, both from the structure and systems standpoint, e.g. symmetrical pylons, which would be the same on both sides of the aircraft.

Efforts/loads towards the wing and geometric constraints would be analysed in strong relation with Subtask 2.1.3 (Manufacture-Driven Wing). This would particularly contribute to the final integration and assessment of the SFB concept aircraft in Task 1.3 and would ensure that this is managed not only by a top-down approach (overall aircraft requirements down to components) but also bottom-up (components up to overall aircraft).

Regarding systems, the envisaged parametric studies would lead to certain assumptions on the complete powerplant. For instance, the engine, which is to be defined in Subtask 1.3.2, would be subsequently assumed to have no thrust-reverse devices.

Subtask 3.3.2 Powerplant System Analysis

Derived from Task 1.3 (SFB top level requirements), for an additional weight saving target, this Subtask would tackle more in detail the powerplant systems and maintenance aspects. It would especially concentrate on establishing exchange rates with respect to economics, reliability and functionality, for various bypass ratio values, which would lead to recommendations on systems/equipment architecture. Innovative systems' architectures would be selected and the systems design and systems' architecture tailored for the SFB requirements (for example, recurring costs for maintenance).

Technical Achievements

In order to define a cost-reduced powerplant system (and its components) suitable for the SFB aircraft concept, a set of basic assumptions was established at the beginning of this Task:

- More electric engine;
- No acoustic 'goodies' (to decrease costs);
- Thrust reverser (T/R) policy:
    - SFB Baseline aircraft had T/R;
    - Solutions without T/R were investigated by Airbus, but no viable substitution solution was found.

In general, several paths were investigated, either by trying to identify new promising concepts or by relaxing the design constraints.

Nacelle and Thrust Reverser concepts

On the nacelle studies conducted by Aircelle, concepts and manufacturing processes were investigated to reduce acquisition and maintenance costs. As the T/R is the main contributor to nacelle cost, most efforts were focused on that part. The main opportunities identified were:

- Lower reverse efficiency requirement vs. current T/R due to BPR (20-25% for BPR of 8 to 9 vs. 40% for BPR of 5);
- Simpler T/R architecture with potential simpler actuation system.

Other trade-off studies were performed on the exhaust system material, such as Inconel vs. high-temperature Titanium alloy.

blocker door-less cascade thrust reverser

A low-cost, low-weight, low-maintenance blocker door-less cascade thrust reverser was further defined with the following main features:

- Removal of blocker doors to reduce manufacturing, assembly cost and maintenance cost:
- Change in aerolines to achieve natural blockage of fan duct in reverse mode;
- Same nacelle length, to keep same material and manufacturing cost as other nacelle and pylon parts;
- Transcowl stroke as short as possible to save weight, cost and complexity.

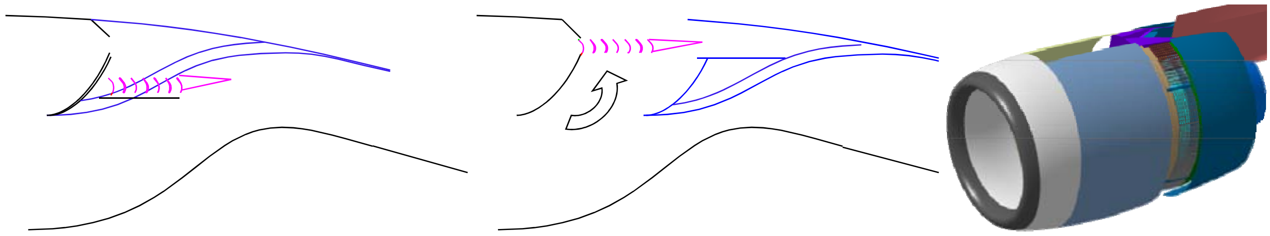


Figure 100: Aircelle blocker door-less cascade thrust reverser

The concept was assessed in terms of weight, acoustic-treated area and performance:

- Weight was reduced by removing drag links and blocker doors;
- No detrimental impact on acoustics, the smaller treated area being compensated by the fan duct shape;
- No significant aerodynamic impact on performance either, as the increase in fan-duct loss and core-cowl scrubing drag is outweighed by drag link deletion and external nacelle drag, hence an almost unchanged SFC;

A trade-off between various costs allowed optimising the actuator configuration. A Finite Element Model validation of a 3-actuator configuration was performed. The acquisition cost of a blocker door-less T/R was finally established and compared with that of a conventional T/R.

Door-type T/R

Another option was investigated by Aircelle for the T/R concept: a door-type T/R with only two small doors. The objective of this simplified door construction was to achieve a lower cost of door assembly and a better structure integration of the door design.

The reverse performance was validated by means of CFD analysis, providing a reverse efficiency of 18% to 20% compared with 30% to 35% for current door-type T/R. The efficiency can be trimmed to the objective of 22% by increasing the door size without jeopardizing the concept advantages.

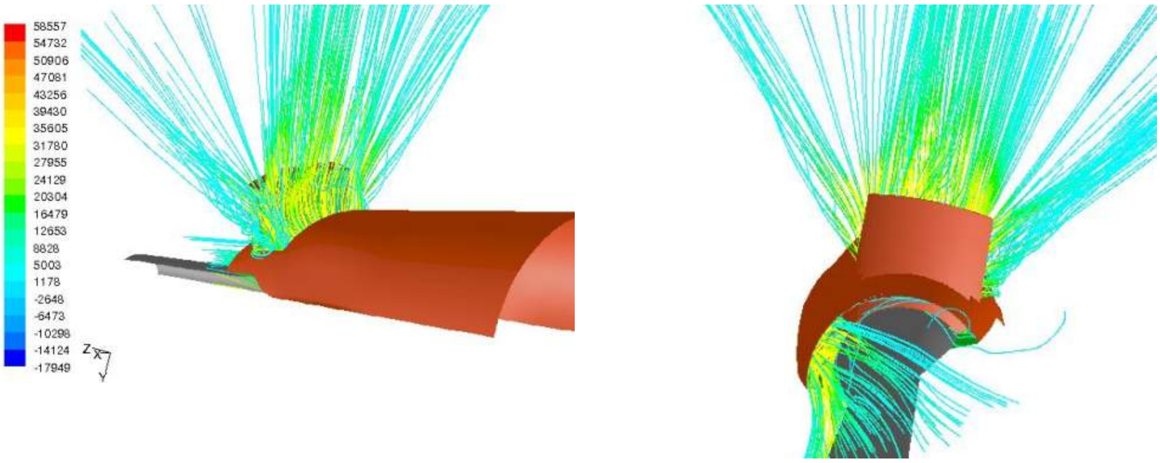


Figure 101: CFD analysis of Aircelle door-type T/R

Various design options for the door construction were analysed and compared. The baseline design was full composite material. Advanced composites such as thermoplastics and Resin Transfer Moulding (RTM) were also investigated and found promising. A metallic design (“automotive-like”) was considered as well but the low manufacturing rates would not justify the investment. Cost estimations were provided and compared with that of a conventional cascade reverser.

In addition, nacelle maintenance cost contributors were identified and the impact of the different concepts was assessed, e. g.: gains in Direct Maintenance Cost were mostly due to the simple actuation system proposed.

A summary of the whole T/R study conducted by Aircelle is proposed in the table below.

The Task 3.3 recommendation to Task 1.3 was to select the blocker door-less concept with an Inconel exhaust for the SFB aircraft, which provides almost the best NPV result with relatively low risk to achieve the target. Further gains with higher-risk solutions are possible, yet additional integration activities would be required beyond the framework of NACRE.

	Blocker door-less	Simplifed two-door	O-duct	3 vs 4 actuators
Weight (% of T/R)	-7%	-15%	-5%	-1.5%
RC (% of T/R)	-10%	-9%	-2.5%	-2%
Maintenance cost (% of T/R maintenance cost)	~ 1%	~ -2 to -5%	Same	~ -2 to -4%
Pressure loss / drag	Same	+0.3%	-0.1%	N/A
Reliability / Reparability	Better / Same	Better / Better	Unknown / Better	Better / N/A
Risk / Readiness	Low risk – TRL5	Medium risk – TRL4	High risk – TRL2-3. Probably too risky for a low-cost design	High risk – TRL2. Needs O-duct config

Systems study

For systems, several solutions were identified in order to reduce costs or improve other parameters:

- Reduction of engine electric power requirement trade-offs;
- Full electric engine:
  - Current systems (hydraulic, mechanic) have reached an asymptote;
  - Gains in maintenance;
  - Gains in terms of reconfiguration and detection of errors;
  - Gains on SFC;
  - Synergy of PPS electric commands (nacelle+engine).
- Use of new oils that can sustain higher temperatures;
- Smart actuators.

Based on a qualitative assessment, because of too big uncertainty at this low maturity level, the most interesting solutions were selected for final integration in ST1.3.3 [D3.3-3]:

- Reduction of engine electric power requirement;
- More electric engine;
- Electric commands synergies at powerplant system level, if possible.

Engine trade-off study

Further to the definition of the reference engine, the objective of reducing Engine Maintenance Cost was pursued by optimising the engine and the aircraft for a given mission. This activity led to the definition of a new engine specification, targeting:

- Better SFC;
- Neutral weight;
- Neutral acoustics;
- Better DMC.

Fan diameter and engine architecture trade-off studies were conducted in order to identify the optimum architecture with this new specification. Hence, the “SFB optimised engine” featured a 66-inch diameter fan with an “F-4-7-0-1-4” architecture. The following balanced results were achieved:

- Slightly better SFC;
- Better weight;
- Worse acoustics;
- Better DMC.

The recommendation to Task 1.3 was that the final SFB engine and A/C design should integrate reduced thrust and power requirements and the same architecture philosophy as above for the SFB optimized engine.

Powerplant system positioning

The aim was to optimise the PPS positioning for minimum Block Fuel (BF), taking into account the impact of engine position on structure and aerodynamics. For each engine position, the relation between manufacturing tolerances (i.e. manufacturing bumps) and aero penalties had to be established. The calculation of optimum positioning variables for negative values of BF was performed by taking into account two different uncertainty levels of random parameters. A trade-off study for the Criteria bounds was also performed. Several case studies were performed using INASCO's JPDM tool and respective results were analysed.

These results evidenced that increasing the manufacturing tolerance leads to an exponential deterioration of the Block Fuel. Positioning the engine far enough away from the wing in the longitudinal direction:

- could prevent wing contamination leading to a potentially more robust design;
- could enable positioning the engine higher vertically thus increasing even more the benefit.

A wide pylon was found to be beneficial.

Finally the following recommendations were made to Task 1.3:

- To position the engine quite away from the wing in the X-direction;
- To position the engine in a high position in the Z-direction.

Low cost pylon concepts

The general purpose for the low cost pylon concepts was to reduce manufacturing costs, mostly by simplifying the manufacturing process.

Two innovative pylon concepts (the “H-pylon” and the “rounded pylon”) were defined by Airbus. A reference pylon was also defined and designed. The corresponding evaluation of the impact at aircraft level was performed for all pylons, in terms of aerodynamics, weight and costs.

Reference Pylon

The reference pylon embedded state-of-the-art A320 pylon design adapted to the SFB requirements and assumptions. Material and cycles trades allowed concluding that:

- Titanium was better that steel;
- A 20,000-cycle inspection interval gives a better result than a 5,000-cycle interval.

RC have been optimised for the last 20 years, hence the comparison with the other concepts may be unfair.

H pylon concept

A reduction of the pylon manufacturing cost was targeted with the H pylon, by reducing the number of parts and by fairing the lateral panels, which are then not manufactured and rolled. Furthermore the manufacturing process was simplified. However the all benefits of this concept are outweighed by the weight increase, with a negligible impact on RC.

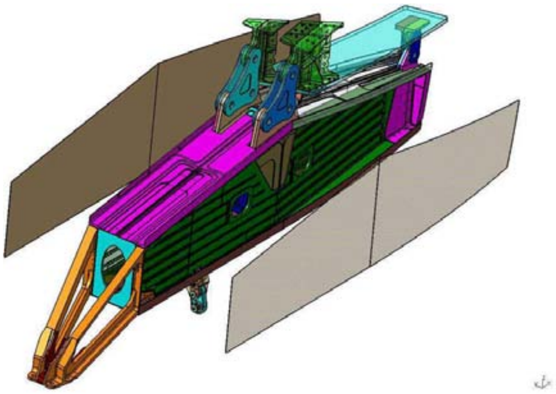


Figure 102: H-pylon concept

Rounded pylon concept

The rounded pylon concept also aimed at reducing the pylon manufacturing cost, this time by using simpler mounts as well a simpler manufacturing process. Thanks to a different engine positioning (ΔZ~160 mm) there appears to be an important aerodynamic benefit. The RC benefit is large but so is the uncertainty as well.

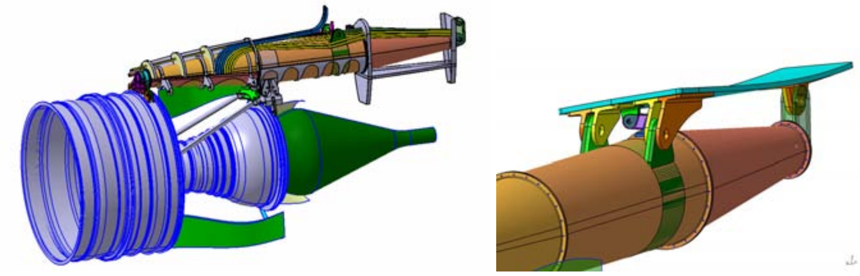


Figure 103: Rounded pylon concept

The main conclusions from the low-cost pylon study:

- a robust reference pylon concept was defined for long inspection intervals;
- Titanium was favoured for the primary structure;
- The rounded pylon could be a good option, provided the remaining uncertainties are addressed.

The final recommendation for Task 1.3 was to integrate a rounded titanium pylon with a 20,000-cycle inspection interval.

Final Conclusion

Several technologies have been evaluated and some have been shortlisted for the NACRE SFB aircraft. Some other need further studies to reduce risk and could have their place in future collaborative projects.

This Task finished in Year 3 of the project and the following recommendations were delivered to Task 1.3:

- Nacelle: select a blocker door-less T/R associated with an Inconel exhaust.
- Engine systems: reduce engine electric power requirement, still with a more electric engine and synergies on electric commands at PPS level.
- Engine: utilise the same engine cycle and architecture design philosophy as the optimised engine defined in Task 3.3.
- Powerplant system positioning: position the engine quite away from the wing in the X-direction / in a high position in the Z-direction
- Pylon: rounded pylon made out of titanium and designed for an inspection interval of 20,000 cycles.

WP 4 – Novel Fuselage

Task 4.1 – Powered Tails

Task objectives at beginning of the project

Task 4.1 aimed at exploring the integration of engines over the rear fuselage for maximum shielding of engine noise sources and best achievable fuel burn, initiated in the FP5 ROSAS project. This is an innovative rear integrated fuselage design including the empennage, together with the presence of large nacelles in this area: all components are close together and highly interact with each other. This new concept also requires structural architecture and integration studies, mainly driven by engine burst risk mitigation work undertaken in Subtask 3.2.3.

Two different Powered Tail concepts were to be defined and optimised aerodynamically through an integrated approach in order to master interactions between aircraft components and obtain best possible performance. Detailed aerodynamic investigation and noise characterization would be addressed in Task 3.1. Specific structural issues induced by this unconventional configuration, such as engine attachments or nacelle integration would also be tackled.

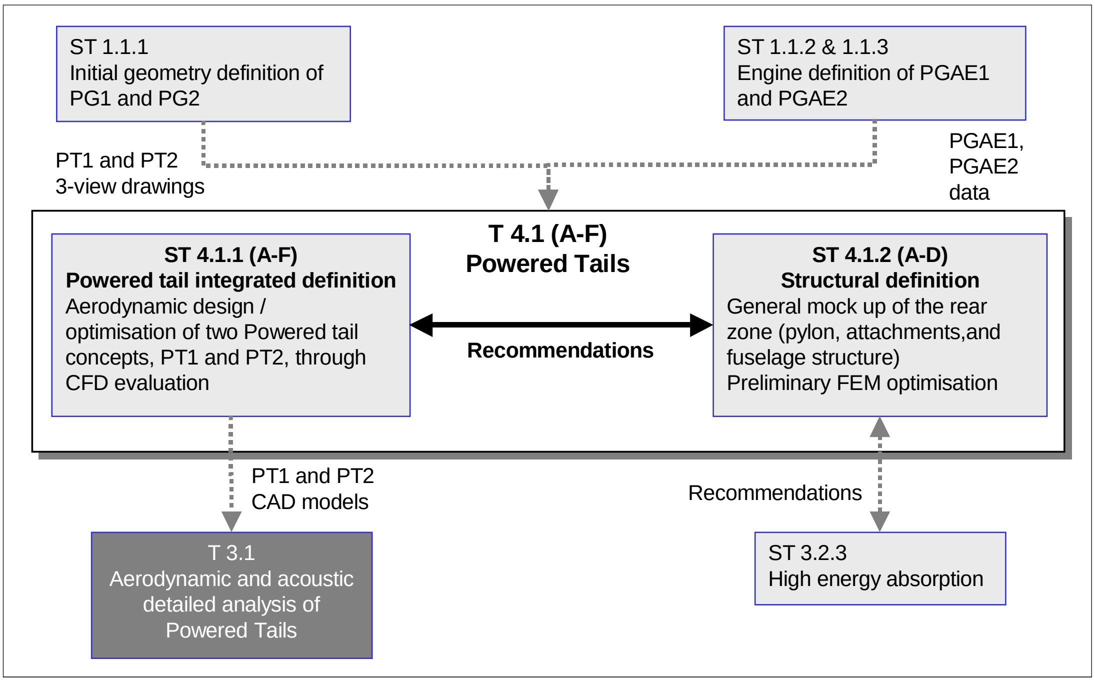


Figure 104: Task 4.1 Flowchart

Subtask 4.1.1 Powered Tail integrated definition

This Task was devoted to the integrated rear fuselage/powerplant/tails shape definition of two Powered Tail concepts, PT1 and PT2, to obtain best achievable performance at cruise conditions. They represent the rear fuselage parts of PG1 and PG2 aircraft concepts issued from Task 1.1. PT1 would be derived from the ROSAS “Rear Fuselage Nacelle” (RFN) configuration (nacelle/pylon configuration), and PT2 would address a similar installation approach, but for an open rotor engine. They would be both associated to a same datum wing and forward fuselage.

For both concepts, aerodynamic shape design and refinement would be performed. FP5 ROSAS project showed that an integrated design is necessary because the proximity of all powered tail elements induces high interactions leading to shocks and flow separations, and therefore generates drag penalty and tail disturbance. Hence, rear fuselage, tails and powerplant would be jointly considered through an iterative process including high speed Computational Fluid Dynamics (CFD) evaluation, in order to improve flow field in this area, to identify possible critical issues and to investigate potential solutions.

An intermediate PT1 and PT2 shape status would be delivered to ST3.1.1 to begin detailed aerodynamic investigations so that specific issues related to this unconventional configuration, such as low speed tails efficiency or engine air supply are taken into account. Refined CFD-ready CAD models of the two concepts would be delivered to Subtasks 3.1.1 and 3.1.2 for final assessment, as well as aerolines, with surface quality in line with aerodynamic wind tunnel model requirements, for model manufacture of PT1.

Initial engine manufacturer recommendations for nacelle equipment allocation space or structural recommendations for component sizing, addressed in ST4.1.2 would be considered.

Subtask 4.1.2 Structural definition

The objectives of Subtask 4.1.2 were to perform structural concept studies on this unconventional configuration. The new powerplant location would impact the rear fuselage structure and required a specific investigation to get some innovative solutions in terms of structural sizing, structural concepts and design principles. Investigations would be conducted on engine attachment, pylon concepts, pylon to fuselage attachment nacelle concepts, system routes, for example. Some new approach on complex structural nods would be suggested.

On PT1 concept, a complete structure mock-up was planned to be developed. It would include the main components definition (preliminary drawing) including rear fuselage section. The CAD model (CATIA V5) would be delivered to other domains. A FEM of the zone (simplified) would be developed to optimise the structure (stress, thickness...). From this study, weight estimations would be given. Appropriate concepts arrangement would be launched through feasibility studies.

FP5 ROSAS preliminary studies on nacelle concepts would be carried on and would comply with multidisciplinary constraints. Different nacelle concepts would be proposed and reviewed under JAR requirements, airline expectations and some industrial aspects. In particular, certification aspects for powerplant installation would be addressed in cooperation with structure specialists; feasibility, shape, space allocation and systems, weight, choice of material, maintainability and operability would also be investigated with respect to the particularity of this powerplant installed high above the ground and therefore with limited and/or difficult access. Engine manufacturer requirements on novel mounting arrangements as well as aerodynamic recommendations on engine equipment location and size would also be taken into account. These studies would be supported by a simplified Finite Element Method of nacelle components and would result in a preliminary structural design of a nacelle for PT1 concept and some recommendations for preferred design options. The PT2 concept study would focus on the load path from engine mounts, through pylon structure, into the fuselage - taking into account the nacelle for potential load sharing function.

Technical Achievements

Subtask 4.1.1 Powered Tail integrated definition

First, a datum forward part (fuselage + wing), common to the two powered tail concepts, has been defined. Two Powered-Tail concepts, PT1 with turbofan engines, and PT2 with CROR, were designed.

The PT1 design process required 3 design loops in order to optimise the rear end. These designs were evaluated at cruise conditions, target Mach number of 0.77, but the aircraft behaviour was also checked at Mach 0.80. Since PT1 shapes were going to be tested in a wind tunnel, computations were performed at the corresponding Reynolds number, in addition to flight Reynolds number. All results are detailed in [D4.1-8]. Specific aerolines for model manufacture were derived from the final shapes [D4.1-7].

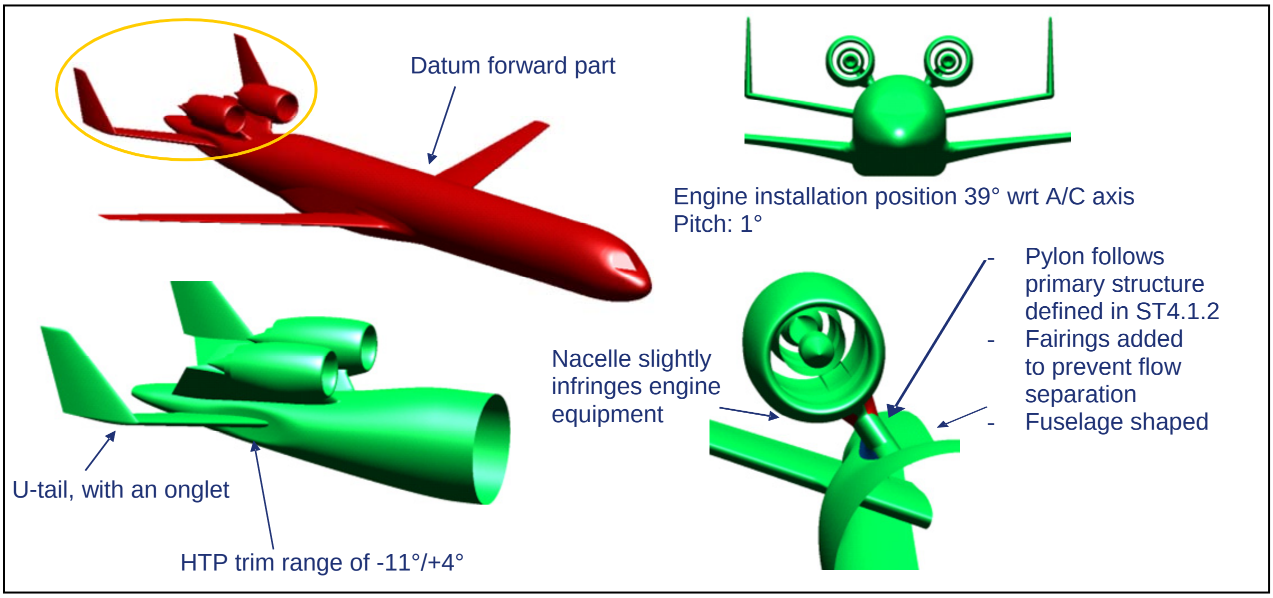


Figure 105: Design performed in Task 4.1 – PT1 Configuration

Computations on the final design showed that:

- PT1 final shape is safe at Mach 0.77, Cl 0.5, wind tunnel and flight Reynolds number: there is no longer any flow separation on the rear part;
- At Mach 0.8, a small risk of flow separation remains on the outer side of the pylon and nacelle intersection (note: the wing has already diverged).

This final design was delivered to Subtask 3.1.1.

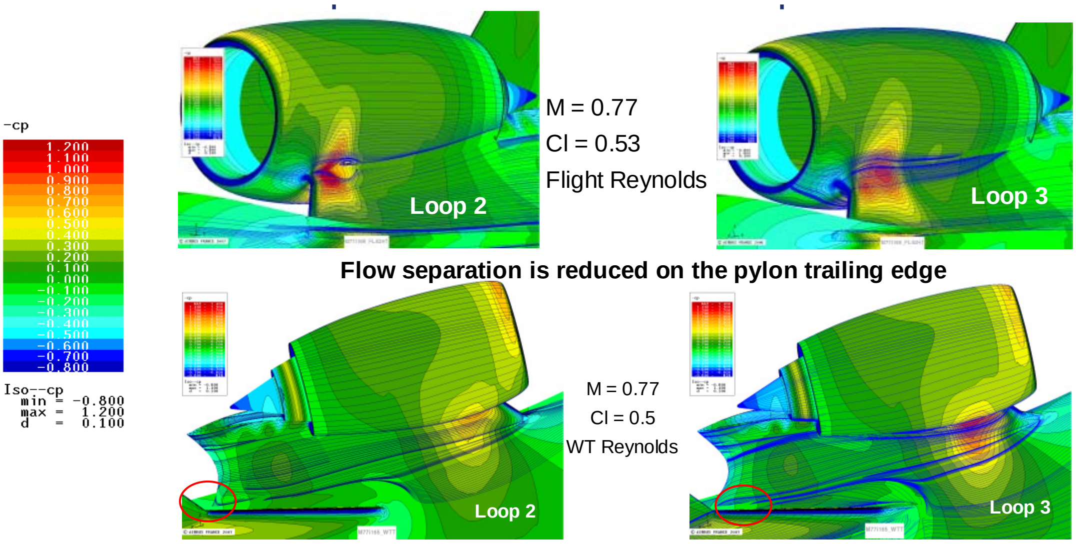


Figure 106: PT1 aerodynamic assessment, M=0.77, Cl =0.53

Three design loops were also performed for the PT2 configuration. It especially features a forward swept HTP, which was selected versus a backward swept HTP because of an improved situation with respect to UERF whereas no adverse behaviour was highlighted in the aerodynamic and structural analysis.

The CFD investigation showed reasonable results [D4.1-9] and the geometry was delivered to Subtask 3.1.1. As discussed also in Subtask 3.1.1, further work on the PT2 configuration design would be required, in particular once a refined HQ assessment is done on the impact of the open rotors. Also the impact of channel flow should be further reduced. Additional analysis of the design can be found under Subtask 3.1.1 section.

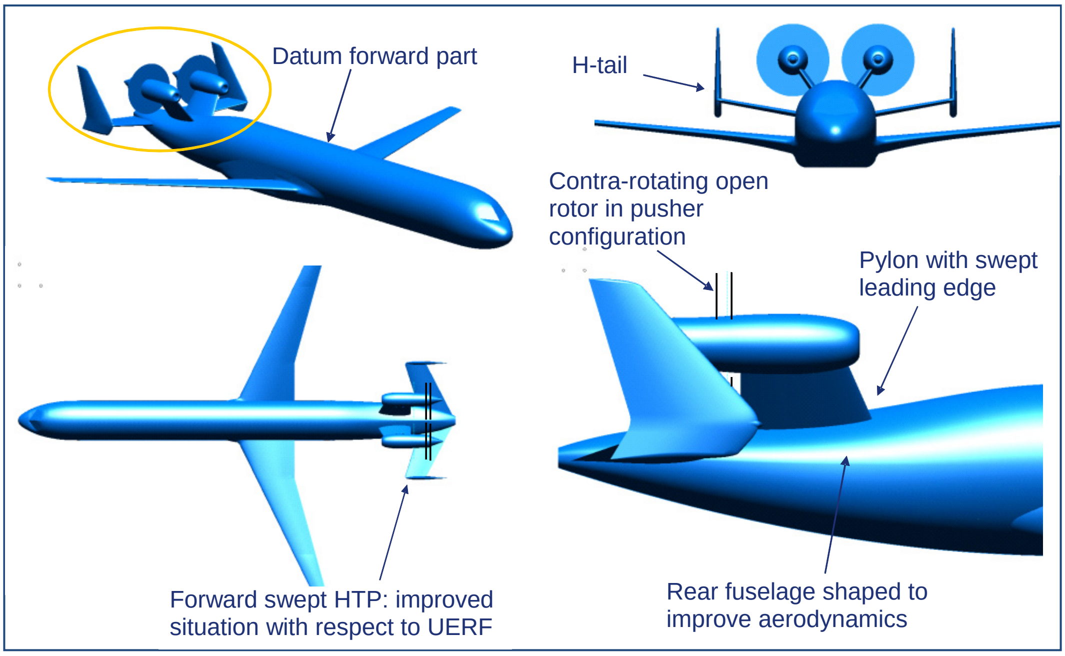


Figure 107: Design performed in Task 4.1 – PT2 Configuration

Subtask 4.1.2 Powered Tail Structural definition

For the PT1 rear end the structural definition was performed, implementing an innovative engine mounting solution. Rear fuselage structural optimisation was done according to the following constraints:

- Statically determined pylon attachments;
- Pylon removal capability;
- Engine Burst criteria: no engine detachment due to Disc Burst impact through waiting fail-safe mounts;
- Load balance optimisation between pylon and fuselage;
- Trimmable HTP load introduction into fuselage optimisation.

The of the HTP interface with the fuselage for the PT1 configuration features a trimmable HTP hinged in two points on the HTP Rear Spar. The rotation is driven by the screw jack, located at the aircraft centre line, in the HTP Front Spar. To introduce unsymmetrical HTP Loads (Fuselage torsion), a closed box is defined above the HTP box and in the upper part of the fuselage. The box is linked to the fuselage section by two 'V' struts.

The FEM structural analysis of the PT1 rear end showed that the rear end structural concept can sustain all the load cases and that fuselage structure damaged by engine disc burst can sustain 0.7 limit loads. It also provided a weight estimate of PT1 rear end, which was delivered to Task1.1.

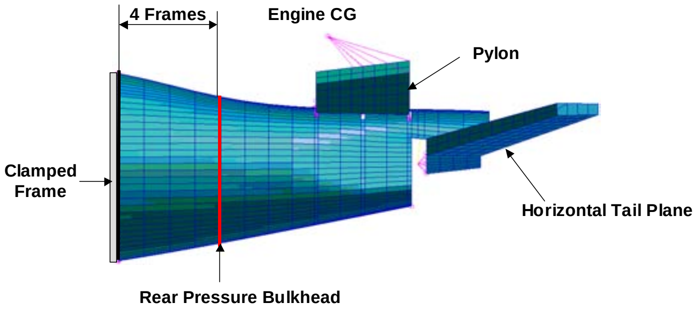


Figure 108: PT1 rear end FEM structure

The relocation of PT1 engine systems was studied because the initial layout brought some strong constraints on nacelle aerolines, with an impact on aerodynamic performance. Several solutions were assessed and the solution with Accessory Gear Box (AGB) in the pylon fairing was favoured due to lower risk.

Several nacelle opening concepts were identified in order to ensure engine system accessibility for this unusual powerplant location:

- Fan cowls installation with spine on fan case;
- Fan duct installation: translating external fan duct:
    - Outer Duct slides on a track supported by the pylon track;
    - Track extended further aft (maintenance position) on Aft Pylon Fairing (APF);
    - IFS and bifurcation are hinged to turbine case at the rear, fan case strut on the front.

For PT2 Configuration, Rolls-Royce worked on whole engine FE modelling and analysis. The beam on the rear engine mount required some feedback on the pylon concept and concerning the distance between pylon trailing edge and propeller was expected from aerodynamics and acoustics (see Task 3.1).

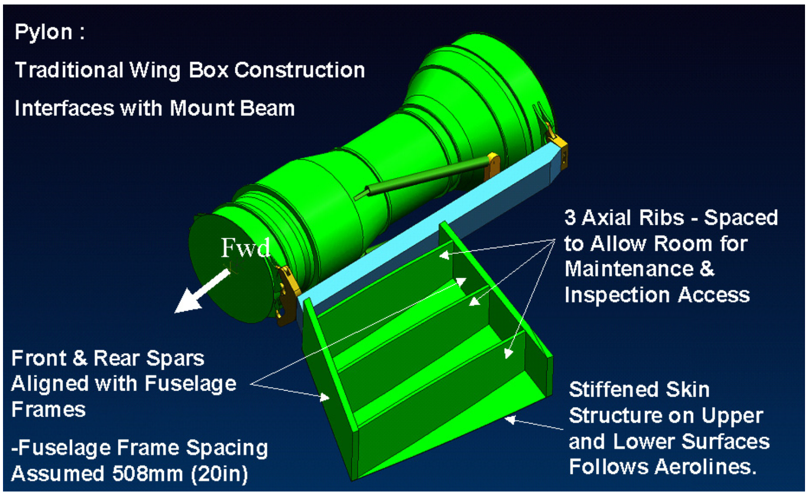


Figure 109: Pylon mounting concept

DLR investigated their pylon concept under different normal and failure loads. A finite element model was created and used to investigate engine performance via asymmetric tip clearance predictions under maximum thrust, gravity and lift-off loading critical cases, providing results that are comparable to existing engine data. Optimisation was achieved using large scale FEM to find the structure topology for the initial concept. The FEM analysis allowed for local sizing.

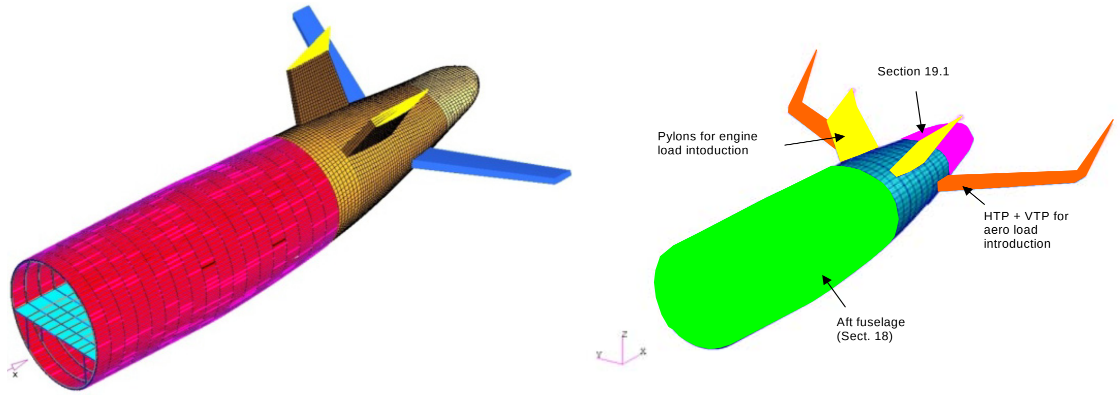


Figure 110: FEM models for topography study and sizing

In conclusion, a complete concept cycle was undertaken using a topology optimisation and FEM sizing process. The general feasibility of topology optimisation on large structures was shown.

Topology optimisation is powerful but requires skilled caution. The weight derivation results showed that the PT1 estimated higher weights compared to PT2 but the comparability of these results needs to be verified. Finally, the robustness of the solution also needs to be proven with regards to relevance of selected sizing load cases and assumptions for loads introduction.

Final Conclusion

Within Task 4.1 the development of powered tails concepts in terms of structural design, aerolines, nacelle concepts, pylon mounting and engine system relocation was performed. In particular, two different Powered Tail concepts, PT1 and PT2, have been designed, taking into account structural constraints. An aerodynamic optimisation was undertaken before delivery of shapes to Task 3.1 for detailed analysis. The structural definition of both Powered Tails has been performed, delivering innovative engine mounting solutions, along with rear-end weight estimates (delivered to WP1). Finally a study on the specificity of nacelle design with respect to its unusual location on the A/C was conducted, providing the weight impact of several promising solutions envisaged for PT1 engine systems relocation and enabling the identification of nacelle opening system concepts.

All results were delivered to Task 3.1 for detailed CFD and acoustic assessments and to Task 1.1 for overall aircraft integration of the rear end.

Task 4.2 – Advanced Cabin

Task objectives at beginning of the project

The objective of Task 4.2 was to initiate preliminary technical studies of Wide-Fuselage Payload Driven Aircraft concepts. This would enable the NACRE team to understand the fundamental advantages and challenges relating to aircraft designed around the requirements of the payload (passenger or freight). This approach to design can be referred to as “inside out” i.e. wrapping the structural and performance aspects around the needs and desires of passengers. This approach to design could result in fuselage designs that are non-circular. Furthermore concepts would be established that increase cabin flexibility with regard to improved economics and increased functionality.

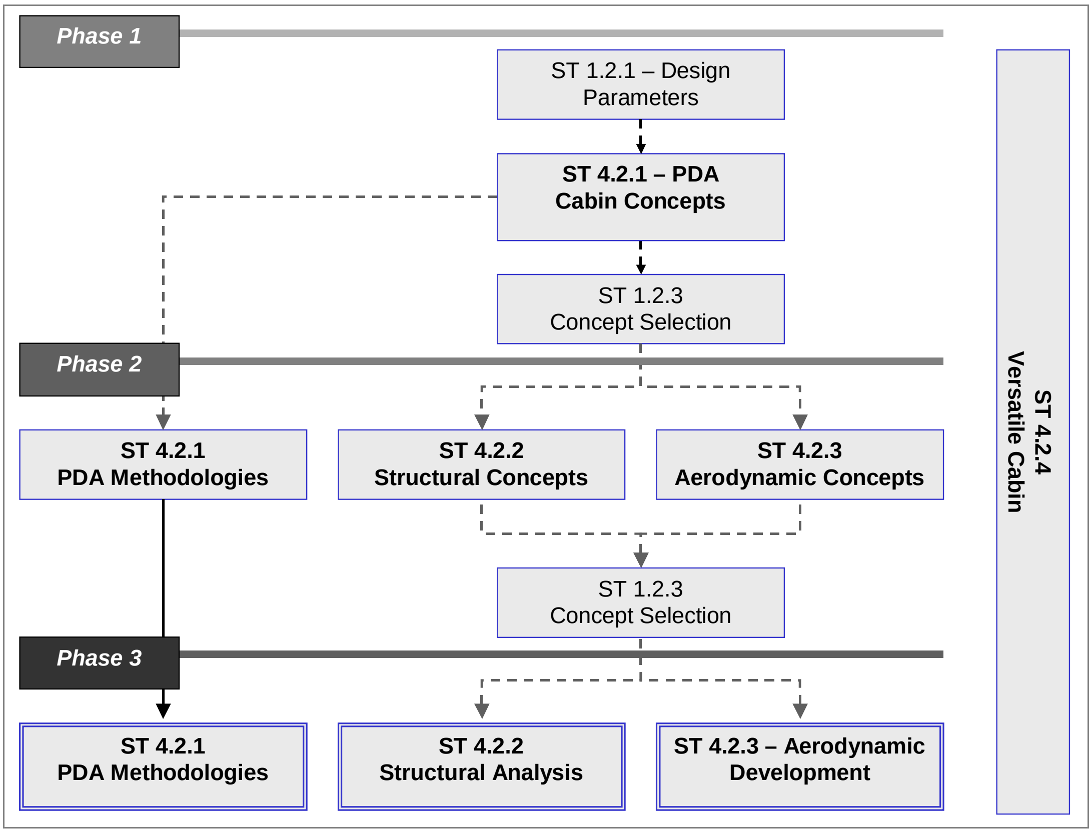


Figure 111: Task 4.2 Flowchart

Subtask 4.2.1 PDA Cabin Concepts

This Subtask aimed at developing Payload Driven cabin concepts that focused on the unconstrained requirements of the passenger (i.e. the payload). Generic cabin shapes would be studied to understand if non-circular fuselage concepts are advantageous for a passenger. Methodologies to model the needs of passengers would also be developed to enhance future Payload Driven Aircraft concepts. Top-level study guidelines (e.g. number of passengers) would be provided by Task 1.2.

Any promising non-conventional concepts were studied in Subtasks 4.2.2 (structures) and 4.2.3 (aerodynamics) to understand the performance affects/opportunities of the proposed cabins. If the promising cabin concepts were similar to conventional cabin designs then Subtasks 4.2.2 and 4.2.3 would be stopped and the effort re-allocated. This would be decided at the end of phase 1.

Subtask 4.2.2 PDA Structural Concepts

The objective of this Task was to propose “skins and skeletons” for the promising cabin concepts developed in Subtask 4.2.1 (PDA Cabin Concepts). The skin and skeleton concepts are described as:

- Skin – is the external shape that is needed to protect the cabin arrangements proposed from the forces and environment of flight.
- Skeleton – is the structural arrangement needed to achieve the skin profile without seriously impacting the cabin arrangement.

i.e. the inside (cabin) would define the outside geometry.

This can be illustrated as in Figure 112 below.

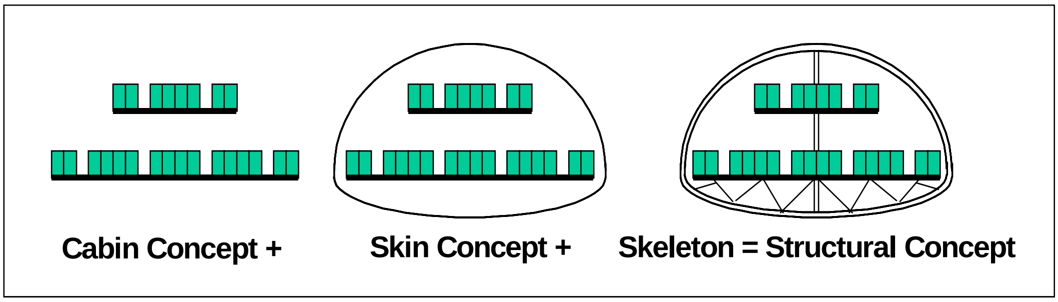


Figure 112: PDA structural concept definition strategy

The first phase of this Subtask (second phase in overall Task) would concentrate on developing concepts for an efficient structural skin and skeleton for the cabin. A decision gate at the end of this concept phase would choose which concepts should be developed in further detail during the final phase of the Subtask.

Subtask 4.2.3 PDA Aerodynamic Concepts

This Task aimed at proposing appropriate aerodynamic “skins” for the promising cabin concepts developed in Subtask 4.2.1 (PDA cabin). The purpose of this skinning was to exploit any aerodynamic advantage the promising shapes may offer or to understand the aerodynamic limitation of these cabin concepts. These aerodynamic skins would be developed in isolation to those being developed in Subtask 4.2.2 (Structural concepts) to understand the respective drivers on geometry.

As well as defining appropriate aerodynamic skins for the cabin global aerodynamic concepts would be proposed for lift and control surfaces as illustrated in Figure 113 below.

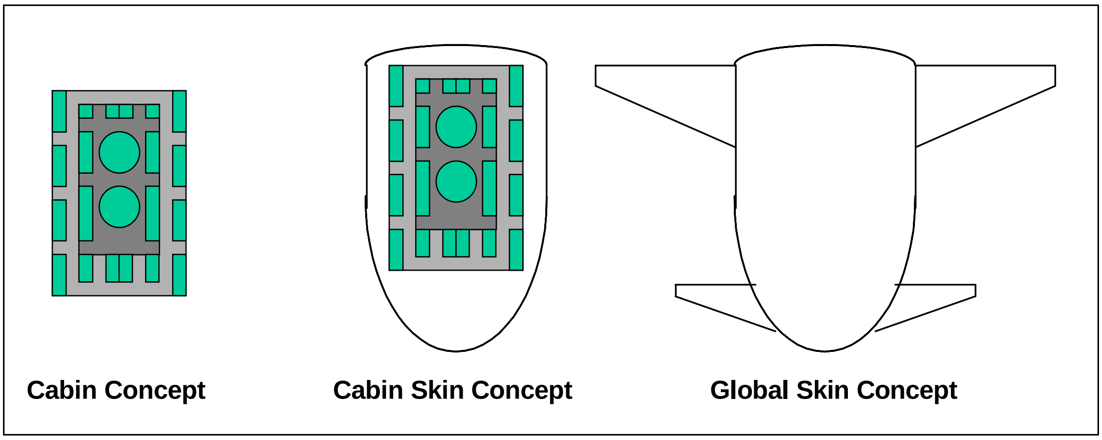


Figure 113: PDA aerodynamic concept definition strategy

Subtask 4.2.4 Versatile Cabin

This Task aimed at developing and evaluating concepts that could enhance the operation of an aircraft cabin in terms of improved economics or increased functionality. Concepts would be developed to increase the functionality and versatility of a cabin for integration of cabin components. Generic concepts would be evaluated in the first phase of this Task. Any promising concepts would be evaluated during the following phase.

An additional activity was planned to study the handling and installation of sound insulating wall panels. The panels used would have the potential benefit of reducing noise in the cabin compared with traditional materials and designs. However, the cost and weight of these panels is currently higher than conventional panels. Therefore cost effect and lighter installation concepts are needed to improve the viability of the concept.

Furthermore, there would be a feasibility study concerning the potential of active structural acoustic control (ASAC) concepts for the employment in aircraft cabins and fuselages. ASAC concepts are a novel and active approach to reduce the sound radiation of a vibrating structure by controlling the structural vibration itself. It was already shown that such systems are most effective in the low frequency range and, thus, can complement typical passive noise reduction applications to further enhance the airplane cabin comfort. Since examples for the implementation of ASAC into large-scale structures are still very scarce, their potential for the use in airplane fuselages needed to be assessed.

Technical Achievements

Subtask 4.2.1: PDA Cabin Concepts

Overall integration

A CAD fuselage model was developed including sleeper compartments and detailed social area for visualisation [D4.2-5].

With input from Subtask 1.2.1, first a set of Overall Design Guidelines was defined. These guidelines provided information on: mission, flight duration and capacity for the PDA family of concepts. Hence, the future PDA cabin and aircraft concepts started to be developed for long range flights up to 16 hours for 250 to 450 pax.

A second set of guidelines (Top-Level Cabin Design Guidelines) from Subtask 1.2.1 describes the target groups of the future passengers and main expected cabin functions. The target groups for a PDA were identified as being single traveller, group traveller and passengers with reduced mobility. According to the purpose of their travel, these three target groups can be subdivided into two different traveller groups, further called private/leisure traveller and business traveller.

According to the different expected activities onboard of a PDA, the main activities are sitting, sleeping, eating and drinking, working, sanitary facilities and different ways of entertainment. According to medical support for elderly people, the possibilities of medical issues inside the PDA were investigated. The same refers to crew rest compartment for a PDA because of the need to recover from the long-range flights.

The third set of guidelines (Functional Cabin Design Guidelines) applies to the cabin components and cabin operations like boarding and deplaning, hand luggage handling, emergency evacuation and cabin service.

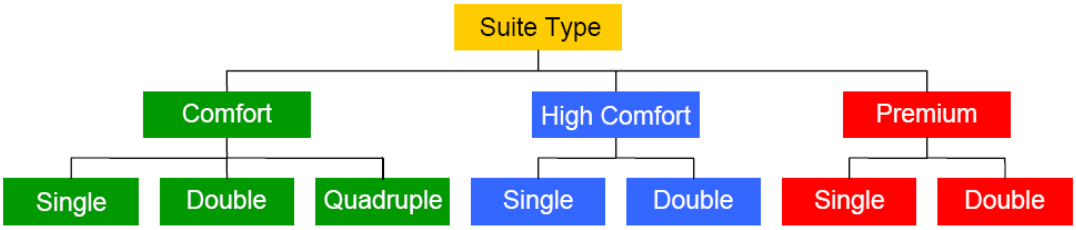
With a view to develop at least three different cabin concepts at the end of phase 1, Subtask 4.2.1 was divided into four different work packages. The first work package dealt with the investigation of today's and future passenger statistics. Out of these statistics, the second work package investigated the possible future passenger's needs for a PDA by the TUM. In the third and fourth work packages under leadership of Airbus, the different PDA modules were developed around passengers' needs and expected activities. With the result of the latter work packages, three different cabin concepts were developed close to the end of phase 1 in Month 14 (May 2006). After the development, INASCO assisted Airbus with their decision-making tool for the concept selection in Task 1.2.

The results of the first work package provide an addendum to the top-level cabin design guidelines, with a short report on future passengers' statistics provided by TUM. Within this short report four major traveller groups were investigated and quantified. Furthermore, the typical size of the traveller groups and the number of flights undertaken by them were investigated. Furthermore, anthropometric studies were undertaken as an input for future ergonomic and safety developments of the PDA. In the second work package, led by TUM, the possible future passenger needs were investigated. The needs were derived from the main activities expected as defined in the top-level design guidelines.

The third work package on the development of module properties, led by Airbus and EADS, dealt with answering the following five questions in order to develop the modules for PDA regarding the passenger-orientated cabin development:

- What will passengers do on long-haul flights (expected activities)?
- How will passengers do these activities?
- When will passengers do these activities?
- With whom will passengers do these activities?
- And where will passengers do these activities?

The answers to these questions enabled to develop modular cabin/sleeper compartments plus a social area where food and beverages are provided. Regarding the cabin compartments are defined for three comfort levels. All compartments are furnished with seat, bed, closet, IFE, table, mini bar and wash basin. In addition the second comfort level compartment comprises a lavatory, the third an additional shower. All compartments are available as single or double compartment; the basic version is also available as quadruple compartment. With the statistics of future passengers provided by TUM, 92 compartments were defined for 200 passengers as shown in Figure 114 below.



Furnishing Type	Comfort	High Comfort	Premium
Bed with integrated seat	X	X	X
Foldable table	X	X	X
Closet	X	X	X
Washbasin	X	X	X
Lavatory		X	X
Shower			X

Compartment Type	Percentage of Compartment Type	Compartment Size	No. of compartments	No. Passengers	Percentage overall	Percentage in Compartment type
Comfort	78	Quadruple	30	120	60	77%
		Double	6	12	6	7%
		Single	24	24	12	16%
High-Comfort	18	Single	16	16	8	55%
		Double	10	20	10	45%
Premium	4	Single	4	4	2	50%
		Double	2	4	2	50%
Total	100	-	92	200	100	-

Figure 114: Definition of comfort level and number of cabin/sleeper compartments for the PDA

The next step was to establish a packaging concept for the compartments on condition that each compartment has an outside window, and for the public areas, e.g. entrance area, restaurant, bar/café.

With different packing concepts and internal assessment, three cabin arrangement concepts were developed: Two cylindrically-arranged cabins (“V-Cylinder” – wide cabin and “H-Cylinder” – more conventional) and one lens-shaped cabin (“V-Lens” – wide cabin without constant section). For all concepts the compartments were arranged on two floors on both sides of the cabin, having outside windows each, comprising space in the cabin centre for a public area for restaurant, bistro, amusement arcade and shops. The upper deck floor leaves out the cabin centre to obtain a high ceiling for the public area. Upper-deck compartments can be reached by a gallery, offering a view down to the public area. The required space for the restaurant and bistro area for the basic H-Cylinder concept for 200 passengers was conducted by EADS. Figure 115 below presents the three different cabin concepts coming out of phase 1 in ST4.2.2.

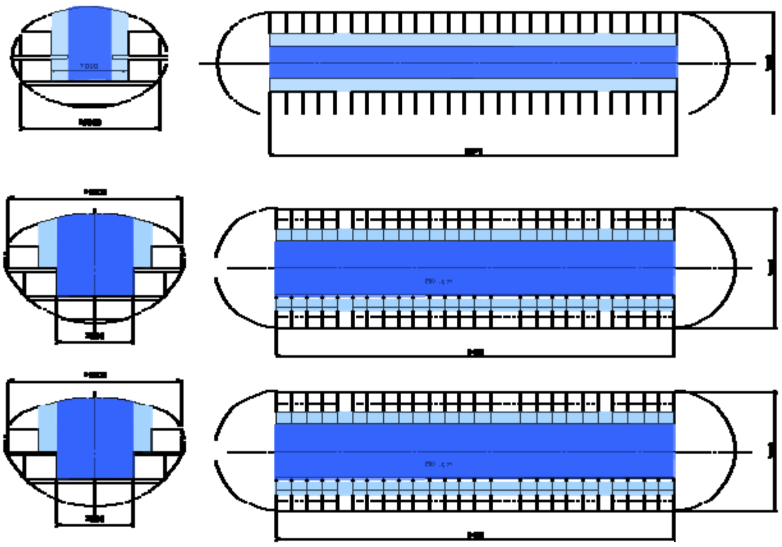


Figure 115: First packing concepts for PDA cabin coming out of phase 1

The next step – in phase 2 – was a more detailed description of the entrance area and staircases as well as iterative cabin adaptations according to requirements from ST4.2.2 and ST4.2.3 (aerodynamics and structure). First of all, the two principles of social area arrangement – “Privacy and Floating” – were developed by EADS.

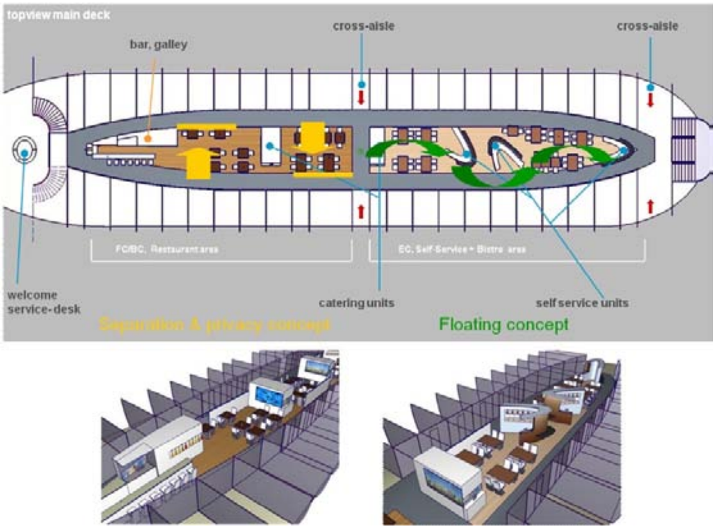


Figure 116: H-Cylinder Social Area design principles – “Privacy and Floating”

In phase 3, TUM conducted a second survey at the Munich airport to investigate the passengers' acceptability of the sleeper compartments developed. An assessment of preferences for different equipment features and their benefit for increased willingness-to-pay by different passenger types was done. Recommendations for further refinement of sleeper compartments to increase passenger's comfort can be found in [D4.2-5].

For the social area, the integration of social area into three different structural concepts (0-strut, 1-strut, 2-struts) and cabin concepts (H-Cylinder, V-Cylinder and V-Lens) was conducted and assessed. Figure 117 below shows the integration of the different structural concepts into the H-Cylinder cabin concept.

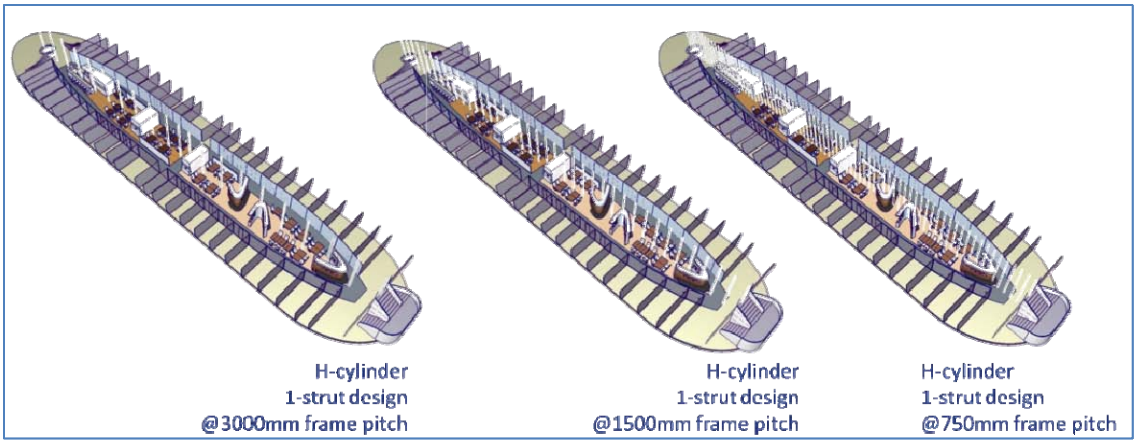


Figure 117: Integration of structural concepts into H-Cylinder cabin concept

Subtask 4.2.2: PDA Structural Concepts

The large fuselage concepts were investigated and structural concepts were developed for the "H-Cylinder", "V-Cylinder" and "V-Lens" cabin designs [D4.2-8].

For the different cabin concepts three different structural concepts were developed respectively by Onera, DLR and TsAGI. FE models of these concepts are shown in Figure 118 below.

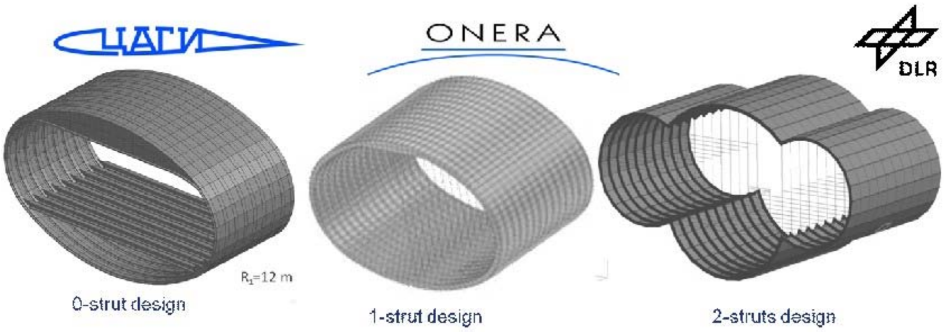


Figure 118: FE models of parametric barrels with 0-strut, 1-strut and 2-struts

To be able to assess the different structural concepts applied on the developed cabin concepts, different boundary conditions were defined:

- Predefined load cases (internal pressure, bending and torsion);
- Predefined parameter variations (Experimental plan /DoE);
- Predefined structure modelling (e.g. FEM, barrel length).

With these boundary conditions, all three partners developed FE models and determined the preliminary weight per unit length, based on inside pressure driven skin dimensions and statistical weight estimation of frames, stringers, panels, etc.

The most significant weight results are the minimum weights per unit length for the primary structure:

Weight per unit length (kg/m)	**0-strut**	**1-strut**	**2-struts**
H-Cylinder	537	478	363
V-Cylinder	838	505	393

Subtask 4.2.3: PDA Aerodynamic Concepts

The activities were completed with the development and the final assessment of the aerodynamic concepts for the three cabin and fuselage concepts: H-Cylinder, V-Cylinder and V-Lens) [D4.2-7].

With the definition of the initial three different cabin concepts in ST4.2.1, DLR investigated the V-Cylinder; VZLU was responsible for the H-Cylinder and IBK for the V-Lens. All partners conducted parametric aerodynamic investigations. A comparison of possible aerodynamic fuselage shapes to host the PDA cabin concepts in given in Figure 119 below.

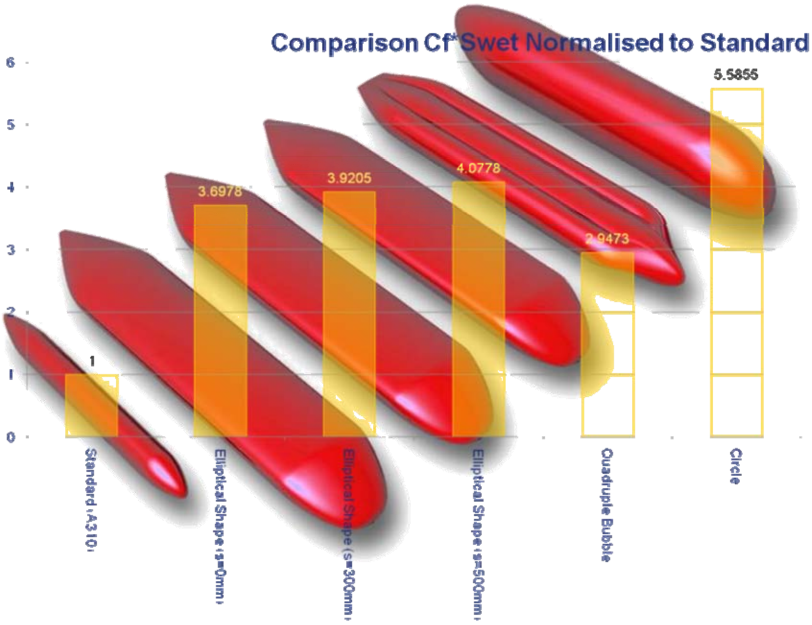


Figure 119: Comparison of friction drag for PDA concepts vs. A310-like conventional A/C provided by DLR

All designs showed low values of wave drag with a careful design of nose and tail sections. **The aircraft level performance was not evaluated. However it is obvious that such concepts are far from being comparable with conventional aircraft with similar mission and payload but not the same comfort.**

Instead, no matter what the mission and payload, and even the overall aircraft integration aspects, the purpose of Task 4.2 was to trigger innovation at component level, and more particularly for cabin design, by thinking out of the conventional box. Modules and compartments as investigated in NACRE in Task 4.2 could well be developed into future airframes, with other integration constraints, especially for very long range aircraft.

Subtask 4.2.4: Versatile Cabin

Develop concepts for increased cabin versatility

Most airlines offer premium class passengers seats, which can be converted into full flat beds. So far, economy class seats cannot be converted into beds without a significant impact on the seat capacity. The idea is to offer economy class passengers flat beds in the crown area, above the overhead stowage bins and ceiling panels.

First investigations showed that the best way to accommodate beds in the crown area is transversally aligned, at both sides of a centre aisle. For a bed width of 750mm two beds can be accommodated above each seat row. Height above the beds is just sufficient, only standing height in the centre aisle is not too good.

Standing height in the centre aisle can be increased, if the lower part of the aisle protrudes into the space between both centre stowage bins, above the supply channel, forcing the bins slightly apart. This also leads to a slight reduction of stowage volume. Several parameter variations (cabin height, cargo hold height) lead to increased sleeping comfort as well as walking comfort in the aisle.

Finally the cross section has been modified in a way, that the upper part is not longer circular, but consists of several circular arcs with different radii, in order to offer space where needed, but without significant increase of cross section perimeter. All variations have been evaluated and a most promising solution has been identified.

Active structural acoustic control

Literature study regarding vibroacoustics of aircraft fuselages and ASAC for such structures were conducted and based on the results Finite-Element model of stiffened cylinder including structurally implemented actuators and enclosed fluid was setup. With a numerical tool to compute the modal coupling of structural and fluid modes for enclosed sound fields (basis to analyze the vibroacoustic coupling), the investigation of active noise control was finalised.

Definition of tests in acoustics and stress of honeycomb plates with modified cores

Acoustic tests of slotted, unslotted and crushed honeycomb plates were performed. The results provide indication that good noise insulation potential can be achieved with some of the innovative panel concepts with improvements compared with classical panels. Additional tests will be required to further check concept feasibility and for the purpose of optimising the honeycomb structures.

Final Conclusion

Task 4.2 developed Payload -Driven cabin concepts that focus on the unconstrained requirements of the passenger (i.e. the payload).These requirements were mainly privacy, sleeping quality and provision of a social area.

Figure 120: Visualisation of H-cylinder cabin concept integrated into the H-Cylinder 2-strut structural concept

The second passenger survey showed that the sleeper compartments developed were highly preferred by today's passengers and feedback was very positive. In total three different generic cabin shapes were studied to understand if non-circular fuselage concepts are advantageous not only for passengers but also in terms of weight and aerodynamic drag.

All developed aerodynamic shapes showed a potential of low wave drag during cruise with a careful design of nose and tail section. Therefore, additional drag is mainly generated by higher friction drag due to higher wetted area.

Furthermore, it could be shown that not all structural designs can be realised without any impingement of PDA concepts. These drawbacks are mainly for the 1-strut design and for the 2-strut V-cylinder cabin concept.

The final conclusions of favourable combinations of cabin, structural and aerodynamic shapes for a PDA can be summarised as follows:

	0-strut	**1-strut**	**2-struts**
H-Cylinder	**OK**	only with frame pitch > 1500mm	**OK**
V-Cylinder	OK	only with frame pitch > 1500mm	appearance like H-Cylinder

Finally, it must be understood that performing additional overall aircraft design work based on these concepts does not make sense at this stage. **It is obvious that such concepts are far from being comparable, in terms of weight, drag or fuel burn, with conventional aircraft with similar mission and payload but not the same comfort.**

Instead, no matter what the mission and payload, and even the overall aircraft integration aspects, the purpose of Task 4.2 was to trigger innovation at component level, and more particularly for cabin design, by thinking out of the conventional cylindrical fuselage. Modules and compartments as investigated in Task 4.2 could well be developed into future airframes, with other integration constraints, especially for very long range aircraft.

Task 4.3 – Cost-efficient Fuselage

Task objectives at beginning of the project

The primary objective of Task 4.3 was to investigate innovative low cost designs of simple fuselage for advanced aircraft concepts in CFRP (Carbon Fibre Reinforced Plastic). Definition of concepts and multidisciplinary fuselage design would be driven by the requirements, manufacturing and maintenance costs, developed in Task 1.3, especially in terms of manufacturing and maintenance costs. Links with Subtask 2.1.3 would be established to integrate all aspects of the new SFB wing constraints onto the fuselage.

Taking into account the whole fuselage (from the nose to the rear), the cost efficient fuselage Task would explore fuselage architectures and system installations, based on two families of concepts, through global design and sizing approaches. For one family of concepts, this Task would use TANGO results and ALCAS improvements of sizing for specific areas and non-linear behaviour, when available.

The Cost-efficient Fuselage Task would address the major aspects of fuselage design, such as quick and easy system installation, innovative manufacturing technologies, advanced structure design, weight assessment for advanced materials, development and manufacturing schemes, and on operation and maintenance cost.

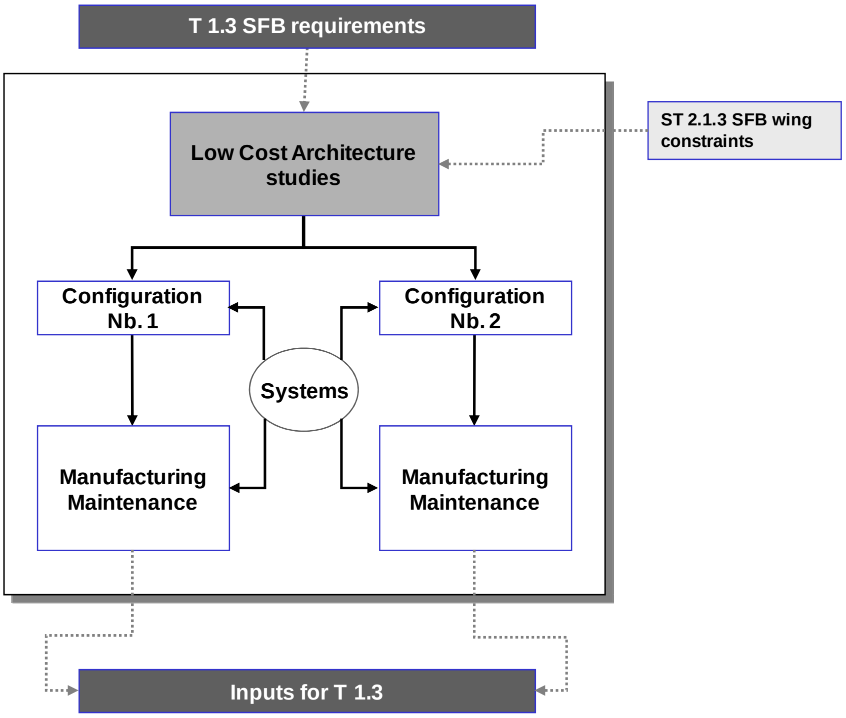


Figure 121: Task 4.3 Flowchart

Subtask 4.3.1 – Fuselage and system concepts

The first step of this Subtask would consist in the analysis of the technical requirements and economics criteria coming from Task 1.3 in order to define the hypothesis for developing the low-cost fuselage concepts and system installations.

Then a benchmarking of advanced fuselage concepts would be performed by Airbus, addressing the pros and cons concerning architecture, manufacturing, assembly and maintenance considerations. Two best concepts would be developed into details by Airbus. The definition of those two advanced fuselage concepts would address the following issues:

- Analysis of global architecture versus:
    - System space allocation and integration
    - Low-cost improvement for manufacturing and assembly
    - Concepts (monolithic, double-shell, large/long panels, …)
    - Cabin installation
- Identification of the different concepts, technologies, materials and manufacturing options linked to the different areas of the fuselage.

Different system installation concepts, which would allow performing system installation in parallel to the structure assembly, would be proposed and compared. Those system installation concepts had to be compliant with both architecture configurations.

Once the global architecture was defined, specific areas such as window sections (VZLU) and floor and cargo compartments (DLR) needed to be detailed as major impacts on cost efficiency were expected.
Finally for each concept, a weight assessment would be derived as an input back to Task 1.3.

Subtask 4.3.2 Manufacturing and Maintenance Studies

For each fuselage concept, the manufacturing and the consequence of the in-service life would be analysed. DLR would analyse one concept and Alenia the other one with the support of Airbus. For each configuration this would lead to the development of the whole manufacturing scheme including:

- Manufacturing of elementary parts linked to advanced technologies;
- Assembly of the main sub-elements;
- Final assembly of the fuselage.

For both configurations Airbus would study the maintenance and in-service life. DLR would evaluate the potential of health monitoring for those two concepts in terms of the consequences on weight and maintenance.

Airbus would develop and detail the selected system installation solution. The manufacturing of such a fuselage and the consequences of the in-service life would be analysed in this Subtask. For each architecture solution, this should lead to:

- Development of the whole manufacturing and assembly scheme;
- Operation and maintenance studies;
- Potential of health monitoring concepts for composite components.

Technical Achievements

Most of the ST4.3.1 at the beginning of 2007 activity was focused on structural details such as window belt, pax floor or cargo compartment. Five cabin window shapes have been created by DLR and have been sent to VZLU for stress analysis. In parallel to this, DLR developed different window belt, pax floor and cargo compartment structure concepts based on SFB requirements.

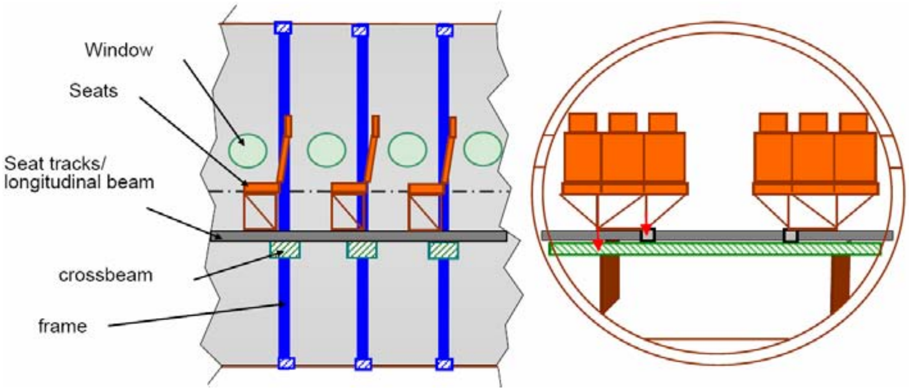


Figure 122: New Fixed Frame Pitch Floor Concept

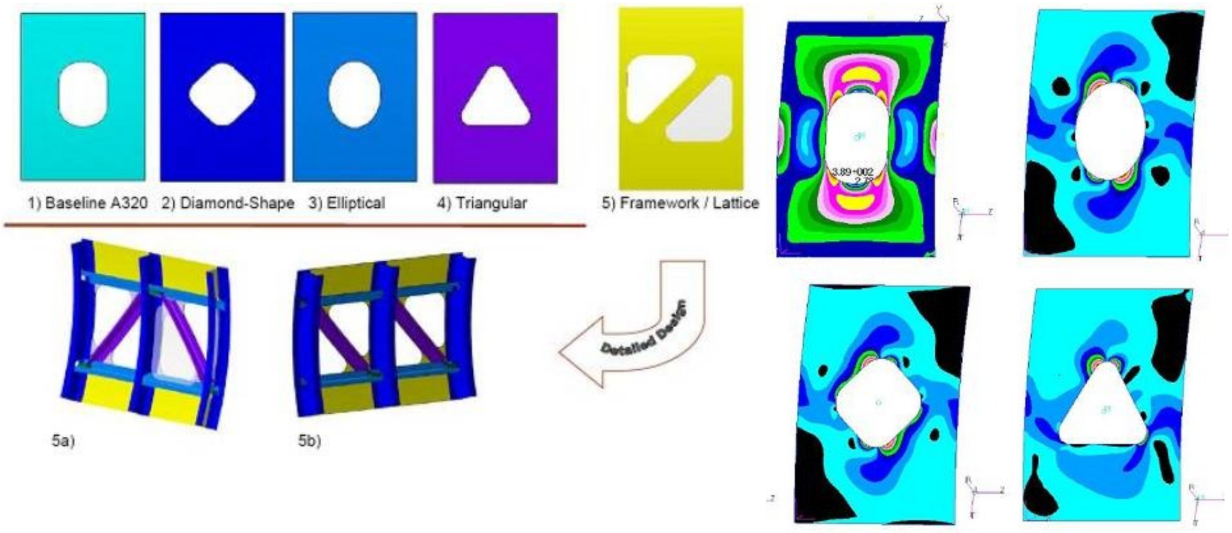


Figure 123: First window concepts proposed for the SFB

Then, the overall fuselage architecture study started looking at the centre section which is one of the most complex areas of the fuselage and potentially one of the most costly areas within the Task 4.3 perimeter.

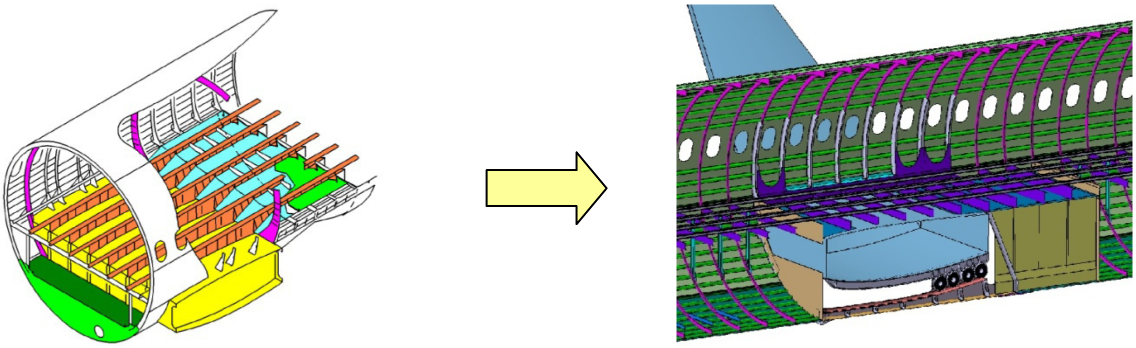
The location and the type of interface between the wing and the fuselage were agreed, allowing the fuselage Task to work deeper on the centre section structure. Subtask 4.3.1 SFB fuselage activity was divided into 2 parts:

- Overall centre section investigation: wing position, fuselage orbital joints (Airbus)
- Part manufacturing cost evaluation tool (DLR)

The very first design proposal for the wing attachment needed to change the wing relative position in the fuselage to fit the parts located at the interface. That is why an overall aircraft assessment was launched in relation with Task 1.3.

As the wing position has a direct impact on the wing to fuselage junction and on the fuselage centre section, the fuselage structure design activity was frozen until the results of the trade-off studies of the wing position in the fuselage (vertical position) were available from the SFB empennage Task (ST2.3.2). As a consequence of this study, the wing position was confirmed at its initial location due to the penalty at aircraft level and the design activity of the centre section started again with the new constraint.

In order to produce enough structure details for the weight assessment but also for the cost assessment, a lot of work was done on the CAD model and drawings dedicated to the fuselage Keel Beam (to clarify the keel beam interfaces with the fuselage), the bushing fittings (rear and front), the Fixed Centre Box, the horizontal pressure bulkhead and the fuselage side boxes.



Baseline

Proposal

Figure 124: Simplified centre fuselage structure

A dedicated trade off, performed within the Sub-subtask 4.3.1.2 showed that such a wing-to-fuselage junction concept could lead to a huge lead time reduction at Final Assembly Line level (approx 70% reduction), also entailing interesting cost reduction at the same level.

The detailed design of the pax floor and some fuselage typical areas (frames and stringers) was provided to VZLU in order to check some part thicknesses versus some specific loading cases and to perform some quick trade off studies concerning new proposals such as the increased frame pitch (directly linked to the fixed seat pitch concept) to compare the different proposals to the baseline [D4.3-1].

The sandwich studies for the fuselage structures are also summarized in [D4.3-1]. For the mixed fuselage configuration, including monolithic and sandwich architecture areas, special emphasis was given for the interfaces between these two architectures. These investigations resulted in interface design solutions that combine monolithic and sandwich structures in a cost-effective and light-weight manner.

The ramp design studies around the cut-outs of pax and cargo doors were focused on weight reduction and on the simplification of the assembly for the door surrounding structures.

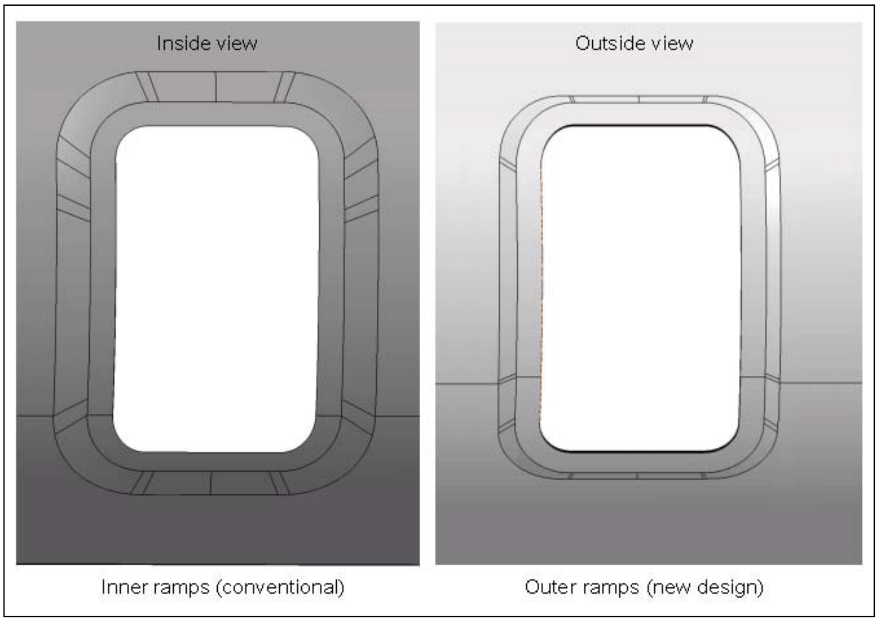


Figure 125: Design study of improved cut out reinforcements

The difference to the classical design principle of ramps is the fact that the ramps are not only built on the inner side of the skin panels but to have ramps on both sides of the panel.

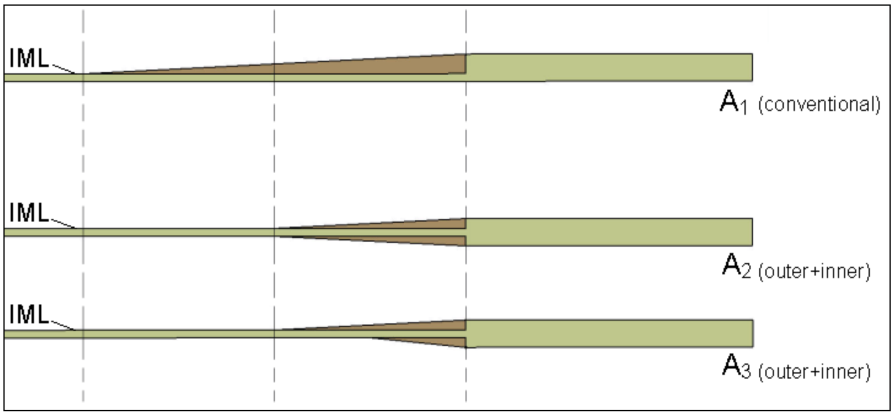


Figure 126: Ramp size comparison between conventional and new designs

The benefits of this design principle for the improved ramps are a reduced weight and an easier assembly due to less tolerance issues for the surrounding structure. Another benefit is the increased robustness of the panel in case of impacts from outside around the cut-outs due to the protrusion of the reinforcement. As a drawback of this design principle a slight increase of drag was assessed that can be minimized by the chosen slope in the DOF.

Beside the structure activity, several meetings linked to Subtask 4.3.1 and the system installation activity were held to review the compliance of the system installation principles and the structure concepts. The system installation proposal used the global configurations of the SFB pressurized fuselage documented in [D4.3-1] and [D4.3-2] in order to implement their proposals in the SFB fuselage structure.

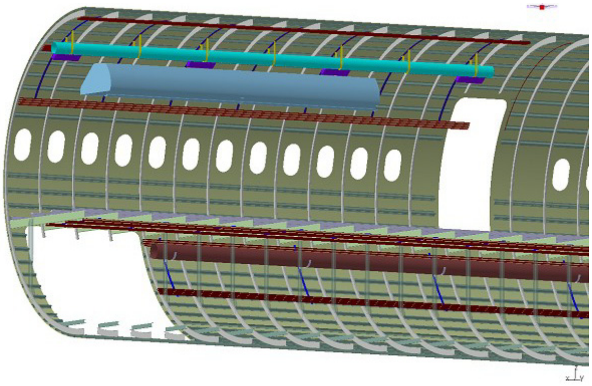


Figure 127: SFB structure with generic systems and cabin items

This activity addressed pure system topics such as Electrical Structure Network (ESN) to solve CFRP structure issues or system and cabin furnishing brackets to ease and reduce assembly effort [D4.3-6].

Finally, Subtask 4.3.1 ended on the weight assessment of the SFB fuselage. The weight assessment covered the concepts developed in the Sub-subtask 4.3.1.2 as the changes applied to the centre section were the major contributors to the SFB fuselage weight.

Moreover, due to the centre section design changes and a question raised during the NACRE Annual Review meeting in Warsaw (April 2008), it was decided to slightly change the topic of [D4.3-5] from overall maintenance studies for the SFB composite fuselage to specific maintenance study of the elastic bushings used for the wing to fuselage joint. This deliverable closed the activity performed in the frame of Subtask 4.3.1. Indeed, the cost assessment part of the study was agreed to be performed in the frame of Task 1.3 using inputs from Task 4.3 such as design details and weight.

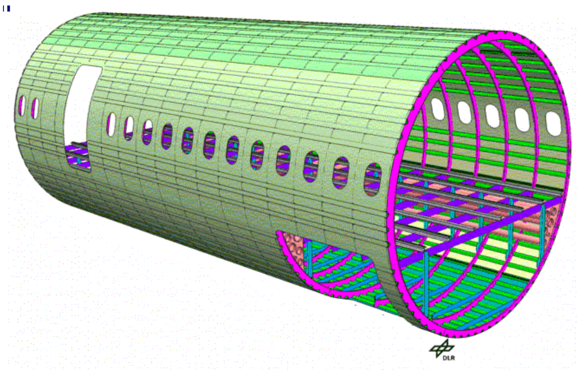
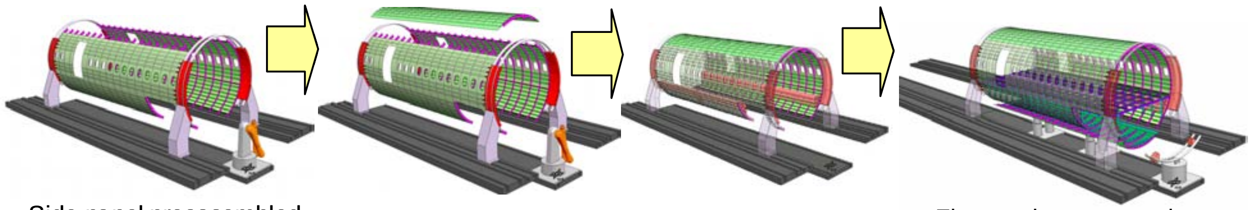


Figure 128: SFB typical section for the first manufacturing and assembly exercise

On the second Subtask 4.3.2, DLR and Alenia worked on a first proposal for the panel splitting of the SFB fuselage. This first proposal consisted in a typical fuselage section with all the cut-outs included (cargo and pax doors and cabin windows). After the delivery of this first assembly exercise CAD model to the partners [D4.3-2], they started working on two main topics:

- assembly schemes of the section
- specific part manufacturing (stringers, skin and frames)

The assembly process can nearly fully be automated while changing the order of assembly: 1st pre-assembly of panels with stringers and frame segments, then positioning in jig - on rails; 2nd crown panel integrated; 3rd systems and floor integrated; 4th closing the barrel by lower panel. No negative influences on overall aircraft efficiency were raised.



Side panel preassembled with stringers and frame segments on rail system

Pre-assembled crown-panel (integrated by robot)

System installation in modules

Floor and crown panel robot integration

Figure 129: First Exercise Assembly Process

Following this first study, new objectives were defined and a second assembly exercise was launched. This new exercise focused on the assembly of a second barrel, located in a double curvature area of the SFB fuselage (rear part). Moreover, the manufacturing aspect was also investigated through the skin and stringer manufacturing (selection of the material and associated processes).

This second study has shown that this double curvature area (more complex than the previous one) could entail higher manufacturing cost depending on the way the local changing of section was considered. At the same time, new proposals have been presented by the DLR and Alenia to reduce the manufacturing cost as much as possible such as by modifying the shape of the fuselage or the skin stiffening elements (e.g. use of sandwich structure).

Both proposals offered great cost reduction even if they entailed some issues at fuselage and aircraft level (structure repairs issues or slight drag penalty). Nevertheless, those studies and results, which are described in [D4.3-3] and [D4.3-4], present good opportunities for future research. Figure 130 below presents the status of Subtask 4.3.2 at the end of the second exercise.

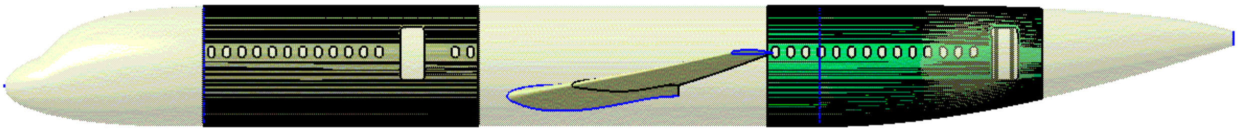


Figure 130: Fuselage areas that were under study during the first and second exercises

Finally a last exercise was performed concerning the centre fuselage section, in order to complete the fuselage manufacturing and assembly study.

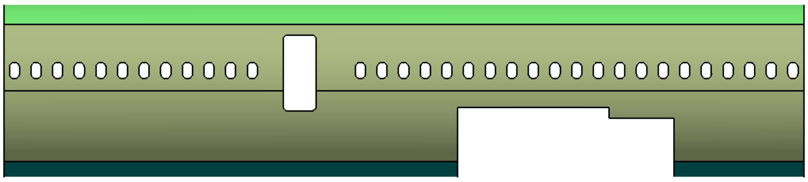


Figure 131: SFB fuselage wide centre section

Using the latest design data coming from Subtask 4.3.1, this exercise allowed mainly performing a trade between the two final challengers for the manufacturing technologies that are the so-called Pre-preg versus the Liquid Composite Moulding. The results showed that the LCM technology offered great cost reduction improvements compared to Pre-preg (approx. 30% based on DLR study).

However, the maturity of such a technology is low compared with Pre-preg, which explains why an industrial choice today would tend to select Pre-preg as the final manufacturing process, whereas in the future the LCM technology will probably become a more interesting option.

Final Conclusion

Composite fuselage structure

Potential cost-saving improvements have been identified thanks to new design proposals. The best way to get the full benefit of composite material was found to remove junctions as much as possible. Additionally, a fixed seat-pitch concept could reduce costs by enabling a higher frame pitch and by reducing the parts count reduction, but also reduces cabin versatility.

The simplified fuselage shape is a key enabler for the manufacturing processes of cost-efficient parts.

Systems and system installation

The benefit of CFRP structures are hindered by electrical integration issues. By proposing and achieving the integration of functions, the new proposals investigated here showed that the cost and weight penalties can be challenged.

Manufacturing and assembly

Material cost still has a huge impact on component cost. Interesting proposals were identified, such as Liquid Composite Moulding vs. Pre-preg process, or simplified stiffening elements, in order to reduce the cost of elementary parts.

Limitations

- Local studies were limited to basic load cases;
- The validity of material trade-off studies are limited, since material technologies evolve rapidly;
- The “levers” for Structure and Systems are difficult to identify;
- The assessment of the overall aircraft manufacturer cost is still a very difficult task.

Final weight results

Based on the detailed design performed in Task 4.3, the SFB final fuselage weight was evaluated and found to be 14.5% lower than the reference (Standard EIS ~1990 reference fuselage weight).

However it was slightly higher than the target weight of the SFB fuselage baseline provided initially by Task 1.3 [D1.3-1] [D1.3-2]. This difference is mainly due to the wing to fuselage junction which is approximately 200 kg heavier than the reference joint and slightly linked to different weight calculation methods. The weight benefit coming from the new design proposal did not fully overcome the weight penalty coming from other design-to-cost improvements.

Final cost considerations

Whereas some great cost savings have been identified at manufacturing and assembly level thanks to new manufacturing processes and new design proposals, the final cost results at aircraft level, summarized in the deliverable [D1.3-4], present a cost increase compared to the Task 1.3 baseline aircraft. This cost increase is mainly resulting from the airline operation cost increase. It must be highlighted here as well that the baseline aircraft differs from the reference aircraft, since its purpose was firstly to offer a target, and if possible a challenging one. The fact that the final weight result from Task 4.3 shows a shortfall compared with this target given by Task 1.3 simply means that the target served its purpose to pull innovation.

Finally, the design studies performed in the scope of Task 4.3 for the pressurized fuselage and especially the wing to fuselage joint, the long panel proposal and the double curvature studies offer excellent subject matters for future research. However, this study also proved that an overall fuselage cost reduction (for both manufacturer and airline) can only be achieved if the aircraft manufacturing cost reduction does not increase the weight of the fuselage. As soon as the weight increases, the operator cost increase fully covers the manufacturer cost benefits. Weight and cost are the two main criteria that must always be combined and never decoupled.

Part 3.

CONCLUSION ON MAIN TECHNICAL ACHIEVEMENTS

WP 1 – Novel Aircraft Concepts

Over the full duration of NACRE, WP1 was the starting point and the end point of all activities. Although not all the results were meant to be ultimately integrated into the novel concepts from WP1, the Integration Tasks had to provide their feedback and assessment to the Component Tasks, in order to down-select the component concepts through trade studies or just to provide the evaluation at aircraft level.

In Task 1.1 (Pro-Green A/C), most results from Task 4.1 and Task 3.1 were integrated into PG1 and PG2 tails concepts (installation drag target, weight, acoustics):
For the PT1 a Contra-rotating turbofan (CRTF) with a low-diameter fan enables a compact nacelle, thus easing the installation and integration on top of fuselage, has a low fan noise, is light-weight, but it has a slightly higher specific fuel consumption, and its balance between the noise sources may not be optimum for RFN installation. For the Turbofan noise shielding configuration (‘RFN’ installation of a TF), the noise reduction potential is proven, for a reduced aerodynamic and weight penalty, with mature methods validated on tests.

For the PT2, Rolls-Royce presented the revised engine definition (PGAE2) in July 2008. The Contra-rotating Open Rotor (CROR) provides a good solution for fuel burn reduction. The geared architecture seems to be the most efficient; however the noise characteristics could not be defined to a high level of accuracy. The effect of a noise-shielding configuration on the Open Rotor seems to be promising, however the methods are not mature yet a need to be validated with tests. Furthermore some noise sources were not modelled. This installation seems challenging (pylon design), but the behaviour of the engine once installed is satisfactory.

For PG1, the baseline FS wing was updated with the main results from Task 2.1 (laminar wing, with droop nose devices); the trajectories for noise assessment were produced and the aircraft noise assessment was performed. The final result is an interesting block fuel reduction potential, but loss of laminarity would lead to a large penalty. The wing weight penalizes short missions. The landing gear position and arrangement would require a deeper investigation.

For PG2, the baseline HARLS wing was updated for PG2 with the main results from Task 2.1 (wing C selected). Several combinations of high lift systems were investigated for best balance between noise and block fuel. Trajectories for noise assessment were produced for two of the HLD. The HARLS wing offers an interesting block fuel reduction potential but with an increased weight that penalizes larger wing areas and fuel-volume limited aircraft. Challenging landing gear arrangements were investigated: A mono centre landing gear + outriggers could be the best solution. The airframe noise reduction potential was identified, using of a low-noise gear, a low-noise high lift system, the aircraft noise can benefit from this airframe noise reduction all the more as the engine noise is efficiently reduced with a noise-shielding empennage.

Task 1.2 (Payload Driven Aircraft) was mostly devoted to the Flying Wing configuration work and family concepts analyses, providing also tight monitoring to Task 2.2 Flying Wing for the detailed design aspects, which were uncorrelated from configuration evolutions, and to Task 4.2 Advanced Cabin, which led to the Flying Cruiseliner concept.

On the Flying Wing part, the intermediate configuration FW1bis integrated a 32” wider cabin than FW1, although planform and all related references remained unchanged. The transition area slightly increased in thickness. The aerodynamic database delivered by Task 2.2 was fully used for the Handling Quality study, which allowed adjusting the position of the main landing gear.

The FW2 configuration work was where most of the effort to collect component information was devoted. Task 3.2 provided the most significant new configuration feature with the engines positioned above the main body. The initial planform proposal was driven by aerodynamic performance, HQ and engine integration space requirements. Cabin and cargo bay shape and landing gear layout principle were taken from FW-1bis. FW-1bis fins were reduced in size by 25%, to account for the lower lever-arm of “outer” engine. The structure layout for engine integration was adapted from [D3.2-6] to curve trailing edge in

FW2-planform instead of the straight one in FW-1. However, the structure design of the interface between centre-body and “outer-wing” was completely new.

Despite being the least obvious in terms of benefit from integration, Task 1.3 (Simple Flying Bus A/C – SFB) achieved numerous successes. First of all, the requirements for the SFB reference aircraft were developed [D1.3-1] along with an SFB Baseline aircraft configuration for use as a starting point for SFB component studies (M1.3-1, [D1.3-2]).

The development in ST1.3.2 of an SFB Baseline engine matched to the thrust requirements of the SFB Baseline aircraft (M1.3-2, [D1.3-3]).

Communication was facilitated between the SFB Component Tasks during the project to that ensure final component concepts are compatible. In addition, beyond general advice regarding aircraft costs and prioritisation of effort to reduce costs, the technical support to the SFB component tasks took various forms:

- Subtask 2.1.3: Attendance at ST2.1.3 progress meetings. Development of various “sized” wing planforms in support of ST2.1.3 activities
- Task 2.3: Involvement in an advisory role in the selection of an appropriate reference configuration for Task 2.3 activities
- Task 3.3: Dialogue to ensure the engine meets the aircraft’s thrust requirements
- Task 4.3: Drag assessments at overall aircraft level of different aft fuselage shapes and external door stiffener profiles.

The Task leader ensured the continued development of the SFB “Design Space” document to record the support provided by Task 1.3 to the NACRE SFB tasks. In this frame, final SFB component data (geometry, weights, drag, materials, etc.) were collated in preparation for final evaluation:

- Subtask 2.1.3: Unkinked wing design with simplified flap system
- Task 2.3: Double-hinged elevators resulting in 9% tailplane area reduction. Double-hinged rudder resulting in 15.3% fin area reduction.
- Task 3.3: Low DMC engine, Simplified pylon design; Simplified nacelle design
- Task 4.3: Large panel composite fuselage; Novel wing-fuselage join-up; Simplified conical tailcone geometry

Finally the preparation of capability for the final evaluation task saw the development of SFB economic evaluation methods and model. Technical and economic re-evaluation of each final SFB component was performed at aircraft level (M1.3-3). Each SFB final component was evaluated separately by incorporation onto the SFB Baseline aircraft, which was then resized as necessary to meet the performance requirements. The resulting aircraft were analysed to calculate recurring costs and operator’s and manufacturer’s internal rate of return. An additional “complete configuration” incorporated all final SFB components together, with similar analysis.

- The increased wing area of the unkinked wing resulted in increased drag and a performance penalty that outweighs any cost reductions due to the simplified design.
- Fort the empennage, a performance benefit from reduced empennage areas was assessed, but it had a marginal effect on cost (due to relatively small components), which may even be outweighed by increased system complexity of double-hinged flight controls.
- Better fuel burn than Baseline engine results in better performance for the SFB optimised engine. Cost reductions from low-DMC engine and simplified structure and systems are beneficial at overall aircraft level.
- A novel wing-fuselage join-up displays a small cost improvement (FAL is only a small cost overall), but penalty of heavier fuselage results in worse performance and fuel burn penalty.

The final comprehensive deliverable [D1.3-4] summarises the final SFB components, the technical and economic re-evaluation process and results, conclusions for each SFB component, overall lessons learnt and potential future follow-up work.

In Task 1.4 (Innovative Evaluation Platform) the assessment of the interest of a flying scale aircraft model (IEP) as an innovative alternative to existing experimental tools towards the efficient development of unconventional aircraft concepts was finalized. The Critical Project Review (M1.4-1) was held on schedule (October 2006) at INTA's drone test range close to Seville (CEDEA). However, the specification phase was longer than anticipated and early design choices had to be performed. In order to avoid huge delays, manufacturing (moulds, structure and electronics) had to be run to some extent in parallel to the actual design. The IEP specification and design document [D1.4-3] was finally issued in March 2008. During 2008, the design and manufacturing of the various parts were completed, and a number of "acceptance" tests were conducted to mitigate technical risk before actual flight: static structure loading tests, low-speed aerodynamic and handling wind tunnel tests, landing gear systems tests. Other tests were performed to achieve the required confidence on elements such as powerplant piloting and performance, engine noise radiation in static conditions. Finally, the systems integration started first in Warsaw with the landing gear, then from May 2009 at Stuttgart for all remaining systems. This phase proved also much longer than planned, lasting until early 2010. So-called hardware-in-the-loop tests, or "iron-bird", were conducted to simulate the systems control and in-flight behaviour. Numerous additional validation tests were conducted for all integrated systems, including landing gear retraction tests in October 2009, fuel system in November 2009, a flight test of the Flight Management and Control System and the Autopilot on 25th November 2009. On the 20th January 2010, the IEP was rolled out at Hahnweide airport near Stuttgart. It was shipped to Warsaw on 11th February 2010 for the flight test campaign. As the preparation work for the flight tests progressed, formal First Flight Preparation meetings were held both at Stuttgart (01-02 February 2010), to validate the systems and integration, and at Warsaw (22-23 February 2010), to validate the flight test management and procedure, including all aspects of safety and responsibility. The first ground runs were tried on 25th February 2010 at Modlin airport near Warsaw. Unfortunately the testing conditions were not adequate and the test campaign could not be completed in the frame of the project. Some of the features of the IEP are unique for this type of "light" UAV (<150kg): autopilot, retractable landing gear, altitude laser sensor. They were designed to enable the model to serve as a testing platform in particular for noise measurements, but also for flight dynamics and even recovery from hazardous conditions. These capabilities must be exploited in a follow-up project in order to better understand the potential of the modular IEP testing platform concept.

WP 2 – Novel Lifting Surfaces

WP2 has seen significant technical progress and successes during the 5 years of the NACRE project. As a general summary, these successes include:

- Agreement of common assumptions for transition prediction for FSW;
- Cabin evacuation trials were executed successfully;
- First study of flying wing ditching behaviour completed;
- Wind tunnel tests of flying wing controls performed;
- Many multi-disciplinary theoretical studies completed;
- Novel component design improved;
- Data generated for calibration of concept level tools;
- Knowledge passed to WP1 for integration at overall aircraft design level;
- 32 deliverables completed;
- 12 presentations made to external conferences, mainly on Advanced Wing;
- 2 Patents (1 pending) on Innovative Empennage.

The HARLS wing and Forward Swept Wing subtasks of Task 2.1 completed a total of 4 joint deliverables, although the last two were each split into the separate reports for each wing design. The deliverables generally showed the progress during the project covering baseline assessments, phase 1, phase 2 and then final integrated wing solutions.

For the HARLS wing a new design space around AR~14 was investigated, leading to a new wing that had a 2.6% block fuel improvement compared to the baseline. A high-lift device trade study was performed to improve noise and highlight the potential noise/block fuel trade. This study showed a drooped nose device plus double slotted flaps could improve approach noise by 1.8EPNLdB but coupled with a 1% fuel burn penalty. A range of low noise landing gear concepts were also studied showing the advantages and disadvantages. Partners set up a process to analyze landing gear noise and showed that noise optimised designs could give significant noise reduction of up to 5.9dBA. It is believed that further work is required on the practicalities of a thin wing design.

The FSW studies led to partner agreement on N factor calibration and improved the NLF extent and wing shape optimisation capability. The work recommended a lower sweep wing and improved the overall wing design. The studies highlighted the issues around separation at the wing-fuselage junction at low speed and the likely requirements for roughness, steps and gaps. Wing weight and divergence were shown to be less of a problem. More work is required on this concept in terms of the ability to manufacture the required surface tolerances, the kinematics and design of the novel high-lift devices and position of the landing gear relative to the centre wing box.

The manufacture driven wing studies of Task 2.1 produced 4 deliverables, again each related to the different phases of work. This Subtask investigated a wide range of concepts to try and reduce cost, although many were shelved. Landing gear design showed a 19% LG cost improvement combined with a significant weight advantage. Metallic wing studies showed a 10% wing box cost saving through integrated stringers and straight spars. Low cost studies on CFRP wings were kept at concept level. A centre-line joint combined with a discrete fuselage interface was shown to give a 10% wing cost improvement with minimal weight penalty. The un-kinked planform with a single triple supported flap concept was less successful for the specific WP1 case but was shown to be potentially beneficial for a large wing with body mounted landing gear. The work has shown that low cost component concepts are available but have to be assessed on a case by case basis. Move detailed work is now needed to prove the feasibility and the cost advantage of the centre-line joint with discrete fuselage interfaces.

The Flying Wing Studies of Task 2.2 produced 16 deliverables, with 6 from the Cabin Subtask, 3 related to Control and 6 related to Structure. The other deliverable was an overall Flying Wing Summary but this also included many of the final control study results not reported elsewhere.

The Flying Wing Cabin Subtask was highly successful in demonstrating that the NACRE FW configuration has the potential of satisfying safety criteria and is arguably capable of providing an equivalent or better level of safety to today's conventional aircraft. Simulations showed that evacuation is possible in less than

90 seconds and cabin trials confirmed evacuation simulation is realistic. In addition, fire simulation showed that flashover occurs 25% later than on a conventional aircraft.

The Flying Wing Structures Subtask refined the weight prediction and enabled more reliable weight prediction, although these still need to be consolidated further at OAD level. Concepts were developed for the attachment of outboard wings and still enable accessibility in the cabin with minimum weight impact. Here an advantage was seen for the truss concepts. Finally ditching behaviour analysis was extended to non-linear simulation including suction forces. This showed that forces are higher for such a flat bottom structure and gave recommendations to improve the structural safety on ditching. More work is still clearly needed in consolidating the Flying Wing structural design and understanding the overall weight.

The Flying Wing Control Subtask completed wind tunnel tests on double split ailerons (crocodile flaps) and on large winglets with split flaps. These rigid control devices were assessed along with new aeroelastic control devices. An aerodynamic database was produced for the baseline Flying Wing configuration and refined during the project. This was used to produce an aircraft model integrated into a simulator environment which showed that the Flying Wing can be controlled in normal flight conditions. However, take-off with one engine inoperative needs careful design and whilst the situation can be improved by having the engines mounted closer to the centre-line, the split ailerons proved to be essential for the baseline configuration.

The Innovative Empennage studies of Task 2.3 produced 8 deliverables in total, although 4 were split into A and B sections representing double-hinged rudder (DHR) and double-hinged elevator (DHE) detailed studies respectively. The other 4 deliverables covered the down selection of concepts, the handling qualities trades and then a summary of the double-hinged concepts and morphing technology.

The double-hinged concepts achieved notable empennage size reductions whilst still meeting handling quality requirements. A DHR reduced the VTP size by 15% with a possible weight saving and the DHE reduced the HTP size by 9%, although here the weight is expected to remain neutral. It should be noted that these are specific cases and the size reduction strongly depends on the sizing manoeuvre.

The morphing studies were separated into a variable surface HTP and morphing LE investigations. The former could allow reducing the HTP surface but would carry a significant weight penalty due to the additional kinematics and actuation. More work is required in understanding the value of the morphing empennage technology, and the SADE project should address some of the key challenges.

The Work Package Leader has made an assessment of the approximate Technology Readiness Levels (TRL) for each Subtask group of technologies/concepts. This should be considered as representative because it is not always appropriate to assess TRL at a group level. However, the assessment is as follows:

TRL1	Morphing Empennage
TRL2	Forward Swept Wing
TRL2	Manufacture Driven Wing
TRL2	Flying Wing structures
TRL2/3	HARLS wing and general ProGreen wing studies
TRL3	Flying Wing control
TRL4	Flying Wing cabin
TRL4	Double-Hinged Concepts

In conclusion, there have been significant technical successes and the TRL of novel lifting surfaces have clearly been further advanced.

The key areas where more detailed work is required on novel concepts are as follows:

- The practicalities of thin HARLS wing design;
- The ability to design and manufacture laminar surfaces and suitable high-lift devices;
- Prove feasibility and value of centre-line joint with discrete fuselage interfaces;
- The structure and overall weight estimation of a Flying Wing;
- Understand the value of morphing structures.

WP 3 – Novel Powerplant Installation

Within WP3, a number of technologies were matured over the complete NACRE project duration as well, amongst which several successes must be highlighted and praised:

- High-speed wind tunnel tests of PT1 configuration efficiently performed;
- Acoustic wind-tunnel test database for jet and fan noise successfully collected;
- Noise shielding prediction methodologies developed further and validated;
- CROR activities largely progressed understanding of noise source characteristics;
- Semi-buried inlet flow behaviour improved with boundary layer control and impact on engine efficiency better understood;
- Successful development and implementation of extraordinary high-energy absorption testing techniques, with four series of most impressive tests;
- Innovative thrust reversers show attractive features;
- Novel pylon concepts were developed for reduced cost;
- 30 deliverables completed;
- 1 patent on a Noise Shielding architecture concept;
- 4 patents on Innovative Cost-efficient Thrust Reversers and Pylon concepts.

For the rear-engine aerodynamic integration activity, numerical and high speed experimental aerodynamic assessment of PT1 configuration with contra-rotating turbofan engines has been achieved. It showed very good correlation between CFD and test results, and highlighted no showstopper from a design point of view. Numerical aerodynamic assessment of PT2 configuration with contra-rotating open rotors, in spite of difficulties with respect to propeller aerodynamic simulation, demonstrated no showstopper either. However, both propulsion system configurations (turbofan & Open Rotor) reduce tail control surface efficiency; these effects need to be accounted in a/c conceptual design. Performance results of both powered tails have been delivered to WP1 for overall PG aircraft assessment.

Further WTT's will be required to validate PT1 analysis at low speed and to validate PT2 analyses, with powered open rotors. Further development of CFD & design methodologies, using more complex tools, will be needed in order to to provide more accurate assessment of aircraft performance and enable proper comparison with a conventional configuration.

On the aeroacoustic side, numerical activities on PT1 have been performed, such as coupling between Onera and Airbus tools to predict installation effects. Numerical activities on TPS source modelling and installation effects have been performed. Numerical results were compared to experimental measurements. Significant shielding of jet and turbomachinery noise sources has been demonstrated through analytical prediction and experimental validation. A detailed experimental database for the effects of tail acoustic shielding has been generated. Acoustic shielding prediction methodologies have been generated and validated against the experimental database, showing encouraging agreement.

An acoustic WTT will be required for PT2 configuration. Further development of the noise prediction methodology will be required to better match test data.

In Task 3.2, the preliminary investigations on the advantages and drawbacks of different radical engine installations for the PDA configuration has been done, taking into account all aspects and constraints, and led to the selection of a generic architecture. Then, different engine installations have been defined, taking into account the aerodynamic aspects. Two reference shapes, corresponding to burying the engines by 8% and 15% of the fan diameter, have been assessed for different aerodynamic conditions. The main objective was to try to improve the engine intake performance of the previously defined engine installations. Some modifications of the inlet shape have been done but led to a limited improvement of intake performance. The possible improvements of performance with flow control techniques (suction, boundary layer trap, vortex generators) were assessed in cruise conditions: these techniques could generate significant improvements on performance.

The main conclusions were that no showstopper was identified for a semi-buried engine installation. The most critical aerodynamic conditions are the cruise ones compared to the low speed ones, and the increase of the burying level leads, as expected, to a decrease of the engine intake performance due to the ingestion by the intake of the aircraft fuselage boundary layer.

These results require however experimental validation. A detailed evaluation of the effects of boundary layer ingestion on engine performance and airframe drag is required to accurately assess overall aircraft performance.

In aeroacoustics, the propagation of the engine fan noise in the intake and in a limited region outside were calculated with advanced methods to analyse the phenomena and to assess the effect of burying the engine. In addition, the influence of acoustic liners installed inside the inlet was evaluated. The acoustic evaluation of semi-buried installations indicates the potential for significant reduction in external noise, improving with increased burying. Nevertheless, more detailed analysis is required to determine optimum inlet profile & liner configuration and to assess precise levels of noise reduction.

The analysis of mount concepts for a semi-buried over-wing engine installation shows potential for significant weight reduction.

For the analysis of high-energy absorption by a structure part in the event of an engine disc failure, a testing programme was established, based on pre-test simulations. Overall, four series of high-energy impact testing campaign have been successively performed from 2006 to 2010, leading to a total of nine launches. Several threat parameters were investigated such as mass, energy of the fragment, but also its orientation and the inclination of trajectory. Post-test activities were performed for correlation of N.L.F.E.M. models up to 150kJ for the metallic aluminium target.

For the experimental assessment of the effect of rotation motion, specific bench device has been designed and manufactured by GkNIPAS laboratory that generates rotation motion of the projectile close to the fragment ideal kinetics. The development and validation of rotation device has been performed by GkNIPAS through testing with the support of TsAGI, Airbus, Rolls-Royce, and Snecma. The final launch was performed on 18 March 2010, just days before the NACRE final meeting.

On a separate framework, a study on the energy absorption features of the nacelle structures with regards to small fragments threat was undertaken. Impact tests on laminate and sandwich structures were performed and were also used for N.L.F.E.M. models validation purpose.

On the specific field of energy absorption at engine case level, an estimation of the energy absorbed for the third disc fragment was performed using N.L.F.E.M. prediction tools.

As a conclusion, results of FE analysis, engine debris release assessment, and small fragment and disc impact testing will be used to create a methodology for the design of absorption/deflection shields to facilitate optimum propulsion system positioning for PDA, PG (& other) aircraft configurations. Analysis shows the importance of modelling release of all 3 1/3rd disc fragments. Rotation of the disc fragment also has an important effect and requires further analytical and experimental investigation.

In Task 3.3, two innovative pylon concepts (H pylon and rounded pylon) have been defined along with a reference pylon and the corresponding evaluation of the impact at aircraft level has been performed. The H-pylon offered only limited or no advantage whereas the rounded pylon, more interesting for the purpose of reducing cost, was recommended to be integrated in the SFB A/C configuration. A computation matrix of structure and aerodynamic results has been defined and the corresponding computations have been performed through the JPDM tool to identify the optimum. The results have been checked and interpreted. Furthermore, amongst other concepts a low-cost, low-weight, low-maintenance blocker door-less cascade thrust reverser has been defined, evaluated and proposed for integration in the final SFB aircraft concept. Several trends associated with different engine maintenance cost drivers have been identified and delivered. Several engine architectures also been defined and assessed at both engine and aircraft level.

The assessment of approximate TRL for each Subtask group of technologies/concepts as made by the Work Package Leader is as follows:

TRL2	Three-actuator blocker door-less thrust reverser
TRL2/3	O-duct for simplified door thrust reverser
TRL3	Powered Tail 2 aerodynamics
TRL3	Acoustic shielding prediction methodologies
TRL3	Semi-buried inlet aerodynamics with boundary layer control
TRL3	Semi-buried inlet noise reduction
TRL3	Semi-buried inlet engine mounts for weight reduction
TRL3	Blocker door-less thrust reverser associated with Inco625 exhaust
TRL3	Cost-optimised engine design philosophy
TRL3	Rounded titanium pylon
TRL4	Powered Tail 1 aerodynamics
TRL4	Powered Tail 1 noise shielding
TRL4	Shield design methodology for high-energy disc burst
TRL4	Simplified two-door thrust reverser

As a conclusion, NACRE has provided a good example of utilising capability across Europe to tackle a wide range of challenging problems, delivering innovative solutions and valuable results. From the list above it is notable that significant technical successes have been achieved for novel powerplant system installations and that the maturity of the investigated concepts has been progressed. Collaborations provide cost-efficient research, with valuable funding gearing for industrial partners from EC contributions.

WP 4 – Novel Fuselage

WP4 has been a frame for very different approaches to innovation in NACRE, ranging from the “blue-sky” inside-out cabin designs based on fundamental passenger needs, to more basic technologies, yet with high yield for future aircraft such as cost-efficient structure concepts and sub-components for the fuselage. Still all the activities within this Work Package have delivered substantial progress in know-how and technical improvement in their areas:

- Integrated aerodynamic design of powered tails successfully completed;
- Improved understanding of feasibility of CROR integration at the rear end;
- Smart design philosophy for innovative structures, in particular usage of topology optimisation;
- Very innovative architecture and structure concepts for challenging pylon designs;
- Unconstrained approach to cabin design;
- Overall fuselage cost-saving simplification proposed;
- Simplified central fuselage structure with CWB removal addressed;
- Solutions for composite fuselage systems installation successfully laid out;
- Weight and Cost identified as two inseparable design levers;
- 31 deliverables completed;
- 12 patents, mostly related to the Cost-efficient Fuselage Structure concepts

Within Task 4.1 the development of powered tails concepts in terms of structural design, aerolines, nacelle concepts, pylon mounting and engine system relocation was performed. In particular, two different Powered Tail concepts, PT1 and PT2, have been designed, taking into account structural constraints. An aerodynamic optimisation was undertaken before delivery of shapes to Task 3.1 for detailed analysis. The structural definition of both Powered Tails has been performed, delivering innovative engine mounting solutions, along with rear-end weight estimates (delivered to WP1). Finally a study on the specificity of nacelle design with respect to its unusual location on the A/C was conducted, providing the weight impact of several promising solutions envisaged for PT1 engine systems relocation and enabling the identification of nacelle opening system concepts.

In Task 4.2 the payload-driven aircraft PDA was investigated in terms of cabin, structures and aerodynamics for three concepts of packing the individual cabin modules: H-Cylinder, V-Cylinder and V-Lens. Aerodynamic and structural fuselage concepts were modelled and investigations of sleeper compartments and social areas were performed. Based on the results of these investigations, structural and aerodynamic PDA cabin concepts were developed.

On the cabin side, one of the main results are the inadequacy of parts of the concepts versus the CS 25 regulations that led to minor change in the concepts or suggestions to the CS 25 regulations. For the Structures, FEM calculations of the structural concepts and weight assessments for performance comparison were performed. Finally the drag assessment of H-cylinder, V-cylinder and V-lens shapes was achieved, including a comparison of the aerodynamic results.

The concepts developed here are far from being comparable at aircraft level with conventional aircraft with similar mission and payload, although not for same comfort. Instead, no matter what the mission and payload, and even the overall aircraft integration aspects, the purpose of Task 4.2 was to trigger innovation at component level, and more particularly for cabin design, by thinking out of the conventional box. Modules and compartments as investigated in NACRE in Task 4.2 could well be partially developed into future airframes, with other integration constraints, especially for very long range aircraft.

Concepts were developed for increased cabin versatility, with the definition of reference for usage of crown area for the versatile cabin. The feasibility of fitting overhead beds in the crown area was investigated by varying the cabin parameters such as main deck ceiling height, cargo hold height, in order to improve usable space, including the adaptation of the fuselage cross-section in order to offer space where needed.

Within Task 4.3 the cost-efficiency philosophy for the design of a SFB fuselage was developed further. The activities for manufacturing and assembly for cost-efficient parts and components for the SFB fuselage were performed for monolithic and sandwich structures. A weight assessment was delivered to Task 1.3.

The cost-efficient fuselage design studies included the development of a tool to evaluate parts manufacturing costs, the investigation of system installation principles, an overall centre section investigation for wing position and fuselage orbital joints, the development of a cost-efficient wing-to-fuselage junction principle, the assessment of the SFB fuselage weight. A complete fuselage structure was produced for further studies within the assembly exercise. A study on floor concepts was conducted for different frame pitches and the fixed seat pitch concept. Finally, the rear section shape was simplified in order to reduce manufacturing costs.

For the manufacturing and assembly studies, proposals were made for the panel splitting of the SFB fuselage concerning the cut-out requirements. Manufacturing of Skin and Stringers was analysed in order to allow selecting both material and process. Manufacturing schemes of the stiffened skin were developed and the consequences on the cost were assessed. The specific cost drivers for the double-curvature area were identified. Assembly schemes were defined for the cylindrical and the double-curvature fuselage sections. Finally, manufacturing schemes were defined for the double-curvature area of monolithic and sandwich structures.

LIST OF ACRONYMS AND ABBREVIATIONS

A/C	Aircraft
ACARE	Advisory Council for Aeronautical Research in Europe
ACFA 2020	Active Control for Flexible 2020 Aircraft (FP7 1st Call Level 1 project)
AGB	Accessory Gear Box
ALCAS	Advanced Low Cost Aircraft Structure (FP6 2nd Call integrated project)
AoA	Angle of Attack
APF	Aft Pylon Fairing
ARTE21	Aeronautic Research and Technology for Europe in the 21st Century
ASAC	Active Structural Acoustic Control
ASD	AeroSpace and Defence Industries Association of Europe
AST	Advanced Subsonic Transport
AWIATOR	Aircraft Wing with Advanced Technology Operation (FP5 project)
BCM	Back-up Control Module
BEM	Boundary Element Method
BF	Block Fuel
BPF	Blade Passing Frequency
BPR	By-Pass Ratio
CAA	Computational Aero-Acoustics
CAD	Computer-Aided Design
CDR	Critical Design Review
CEV	Centre d’Essais en Vol (French Flight Test Centre)
CPR	Critical Project Review
CFD	Computational Fluid Dynamics
CFRP	Carbon Fibre Reinforced Plastic
CG	Centre of Gravity
CO2	Carbon Dioxide
COC	Cash Operating Cost
COTS	Commercial-Off-The-Shelf
Cp	Pressure coefficient
CROR	Contra-Rotating Open Rotor
CRTF	Contra-Rotating Turbofan or “Contrafan”
CSM	Control System Module
DBD	Data Basis for Design
DHE	Double-Hinged Elevator
DHR	Double-Hinged Rudder
DMC	Direct Maintenance Cost
DND	Droop-Nose Device
DOC	Direct Operating Cost
DREAM	valiDation of Radical Engine Architecture systems (FP7 1st Call Level 2 project)
DSF	Double-Slotted Flap

EASN	European Aeronautics Science Network
EBU	Engine Built Unit
EC	European Commission
EDR	Electronic Data Repository
EEFAE	Efficient Environmental Friendly Aero Engine (FP5 project)
EIS	Entry Into Service
EPNL	Effective Perceived Noise Level
ERA	European Research Area
EREA	European Research Establishments Association
ESN	Electrical Structure Network
EU	European Union
EUROLIFT	European high lift (FP5 project)
EUROPIV 1 & 2	European Cooperation on Particle Image Velocimetry (resp. FP4 & FP5 projects)
FAL	Final Assembly Line
FAR	(US) Federal Airworthiness Requirements
FB	Fuel Burn
FCS	Flight Control System
FEM	Finite Element Method
FFR	First Flight Review
FHA	Functional Hazard Assessment
FND	Fixed Nose Droop
FP	Framework Programme
FS	Forward Swept
FSM	Flying scale model
FSW	Forward-Swept Wing
FTR	Flight Test Range
FW	Flying Wing
GA	General Arrangement
HARLS	High Aspect Ratio Low Sweep
HELIX	Innovative Aerodynamic High Lift Concepts (FP5 project)
HIL	Hardware-In-the-Loop
HLD	High-Lift Device
HQ	Handling Qualities
HS	High Speed
HTP	Horizontal Tail-Plane
ICA	Initial Cruise Altitude
IEP	Innovative Evaluation Platform (see FSM)
IFE	In-Flight Entertainment
IFS	Inner Fixed Structure
IMG4	Industrial Management Group for Aircraft, Aero Engines, Equipment and ATC
IPR	Intellectual Property Right
IRR	Internal Rate of Return
JAR	(European) Joint Airworthiness Requirements
JDPM	Joint Probabilistic Decision Making
L/D	Lift to Drag ratio (=aerodynamic efficiency)
LCM	Liquid Composite Moulding
LE	Leading Edge
LEE	Linearized Euler Equations
LPT	Low-Pressure Turbine
LS	Low Speed
M	Mach number
MAC	Mean Aerodynamic Chord
MCLG	Mono Centre Landing Gear
MDO	Multidisciplinary Optimisation
MLG	Main Landing Gear
MMD	Manufacturing, Maintenance and Disposal
MOB	Multidisciplinary Design and Optimisation for Blended Wing Body Configuration (FP4 project)
MTOW	Maximum Take-Off Weight
MWE	Manufacturer's Empty Weight
NAG	NACRE scientific Advisory Group
NASA	(US) National Aeronautics and Space Administration
NEXUS	Unconventional Aerodynamics (UK national funded project)
NLF	Natural Laminar Flow
NLG	Nose Landing Gear
NEFA	New Empennage For Aircraft (FP5 project)
NLFEM	Non Linear Finite Element Model

NOx	Nitrogen x-Oxides
NRC	Non-Recurring Cost
OAD	Overall Aircraft Design
PAX	number of Passengers
PDA	Payload Driven Aircraft
PDR	Preliminary Design Review
PG1	Pro-green aircraft concept Nb. 1
PG2	Pro-green aircraft concept Nb. 2
PGAE1	Pro-green advanced engine Nb. 1
PGAE2	Pro-green advanced engine Nb. 2
PPR	Preliminary Project Review
PPS	Powerplant System
PSSA	Preliminary System Safety Assessment
PT1	Powered Tail Nb. 1
PT2	Powered Tail Nb. 2
R&D	Research and Development
R&T	Research and Technology
RAIN	Reduction Airframe and Installation Noise (FP4 project)
RANS	Reynolds-Averaged Navier Stokes
RBF	Radial Basis Function
RC	Recurring Cost
RFN	Rear Fuselage Nacelle
ROSAS	Research On Silent Aircraft conceptS (FP5 project)
RPG	Reference Pro Green aircraft configuration
RPM	Revolutions Per Minute
RPM	Random Particle-Mesh
RSFB	Reference SFB aircraft configuration
RTM	Resin Transfer Moulding
S&C	Stability and Control
SACSO	Suspension Active pour essais en soufflerie
SADE	Smart High Lift Devices for Next Generation Wings (FP7 1st Call Level 1 project)
SILENCE®	Significantly Lower Community exposure to aircraft noise (FP5 project)
SFB	Simple Flying Bus
SFC	Specific Fuel Consumption
SHE	Single-Hinged Elevator
SHR	Single-Hinged Rudder
SME	Small and Medium Enterprise
SPL	Sound Pressure Level
SRA	Strategic Research Agenda
Sref	Reference area
SSF	Single-Slotted Flap
TANGO	Technology Application to the Near-term business Goals and Objective of the aerospace industry (FP5 project)
TBC	To Be Confirmed
TBD	To Be Defined
TE	Trailing Edge
TELFONA	Testing for Laminar Flow on New Aircraft (FP6 2nd Call project)
TFN	Through-Flow Nacelle
THS	Trimmable Horizontal Stabiliser
THSA	Trimmable Horizontal Stabiliser Actuator
TLAR	Top Level Aircraft Requirements
TOGA	Take-Off and Go Around
TPS	Turbine-Powered Simulator
T/R	Thrust Reverser
TRL	Technology Readiness Levels
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
USA	United States of America
VELA	Very Efficient and Large Aircraft (FP5 project)
VITAL	enVIronmenTALy Friendly Aero Engine (FP6 2nd Call integrated project)
VIVACE	Value Improvement through a Virtual Aeronautical Collaborative Enterprise
VTP	Vertical Tail-Plane
W2AR	Reduced mass flow
WP	Work Package
WTT	Wind Tunnel Test

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NACRE CONSORTIUM

AI	Airbus SAS
A-D	Airbus Operations GmbH
A-E	Airbus Operations SL
A-F	Airbus Operations SAS
A-UK	Airbus Operations Ltd
Alenia	Alenia Aeronautica SpA
ARA	Aircraft Research Association Ltd
CIRA	Centro Italiano Ricerche Aerospaziali ScpA
DA	Dassault Aviation
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
EADS	EADS Deutschland GmbH (Innovation Works)
FOI	Swedish Defence Research Agency
ACL	Aircelle S.A.
IBK	Ingenieurbüro Dr. Kretzschmar
INASCO	Integrated Aerospace Sciences Corporation
INTA	Instituto Nacional de Técnica Aeroespacial
M-D	Messier-Dowty Ltd
MTU	MTU Aero Engines GmbH
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory)
Onera	Office National d'Etudes et de Recherches Aérospatiales
PEDECE	Projecto, Empreendimentos, Desenvolvimento e Equipamentos Científicos e de Engenharia
Piaggio	Piaggio Aero Industries SpA
RR-D	Rolls-Royce Deutschland Ltd & Co. KG
RR-UK	Rolls-Royce plc
SN	Snecma S.A.
TsAGI	Federal State Unitary Enterprise Aerohydrodynamic Institute
VZLU	Vyzkumny a zkusebni letecky ustav, a.s.
TCD	Trinity College Dublin
UOG	University of Greenwich
TUM	Technische Universitaet Muenchen
KTH	Kungliga Tekniska Högskolan
UST	Universität Stuttgart
PW	Politechnika Warszawska (Warsaw University of Technology)
ARTTIC	ARTTIC
ISVR	University of Southampton
DP	Dowty Propellers (GE Aviation Systems Ltd)

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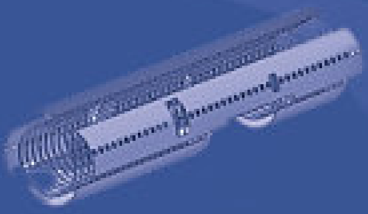

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