The Clean Sky "Smart Fixed Wing Aircraft Integrated Technology Demonstrator": Technology targets and project status

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Keywords: *Large scale flight demonstration, Smart Wing, laminarity, innovative engine concepts, Contra Rotating Open Rotor (CROR)*

Abstract

The "Smart Fixed Wing Aircraft Integrated Technology Demonstrator" (SFWA-ITD) is part of the European Commission funded R&T program "Clean Sky" aiming to demonstrate high potential technology candidates to provide substantial improvements to the ACARE Vision 2020 goals in large scale flight tests. Major targets are to develop an all new low drag "Smart Wing" and to demonstrate the integration of new energy efficient engine concepts, like the Contra Rotating Open Rotor (CROR) to achieve a substantial improvement in fuel burn and noise reduction for large commercial transport aircraft. The paper will present the technical targets, the status and progress in the program.

1 Introduction

Under the obligation of the Amsterdam Treaty, the European Commission is setting out major Frame Programs since 1984 including the important chapter of Research and Technology (R&T). In the field of aeronautics, these R&T frame programs materialized typically through two types of projects, the so called "Specific Targeted Research Project" (STReP), also termed "level 1" project, and the "Integrated Platforms" (IP), also termed "level 2" project. Both are collaborative projects, in which consortia of European industries, Research Establishments and universities define a work plan to transfer promising technologies of common interest, which passed the validation phase in a laboratory environment, into real technical systems for further maturation and proof of concepts. In IP projects, these proof of concept validation studies are typically large scale component tests, in many cases including operational conditions.
STRePs are typically bound to activities on ground and rig tests as well as small component tests in flight with a maximum budget of up to 10M€ and a runtime of three years. Integrated Platforms provide the basis to validate major test components in dedicated flight test campaigns, with a budget of up to above 50M€ and project runtimes of four or five years.
Despite the existence of these major funding opportunities only very few highly promising new technologies in aeronautics did pass the stage of a first proof of concept in STRePs or IPs into a large scale technical application, simply because this step is still too large and associated with high cost and risks, hardly manageable by industry alone.

Accommodated within the 7th European Commission Framework and operationally started in June 2008, the Joint Technology Initiative "JTI" CleanSky" is tailored to push the transit from R&T into industrial application. With a dedicated budget of 1.6B€ and a runtime of 7 years this new "level 3" project has an explicit focus on the greening of the air transport system, with key target to deliver mature green step changing technologies for a future air transport system in large scale demonstrator tests in operational condition.

Being composed out of six individual "Integrated Technology Demonstrators" (ITD), *Clean Sky* shall be the instrument to mature most advanced green breakthrough technologies in the fields of large commercial transport aircraft, regional aircraft, rotorcraft, aircraft engines and aircraft systems as well as special "Ecodesign" principles to consider the economic and ecologic consequences of applying technologies through the complete life cycle. To ensure the readiness for industrial use, the best technology candidates are tested and validated under operational condition, typically at large scale in flight.
A "*Clean Sky* Technology Evaluator" is translating the key intermediate technical results from the ITD´s into quantitative values relevant at aircraft level, fleet level and global level to assess the ecologic and economic benefit in a common complex simulation suite.

2 Key Technology Targets in the Smart Fixed Wing Aircraft – ITD

The Smart Fixed Wing Aircraft – ITD (SFWA-ITD) aims to develop, integrate and demonstrate technologies aiming to greatly improve the environmental friendliness of near future large transport aircraft and business jets and thus to contribute significantly to achieve the ACARE 2020 Vision.
Major specific technology targets in the SFWA-ITD are the development of an all new low drag "smart wing" and the integration of new energy efficient engine concepts, like the Contra Rotating Open Rotor (CROR). In terms of the ACARE goals, SFWA-ITD is aiming to contribute to reduce fuel burn and CO_2 emissions as well as reducing aircraft noise.

The level of CO_2 reduction due to the SFWA-ITD results is set at 10% through the development of an all new low drag "smart wing concept" and the use of passive and active flow and load control concepts at various parts of the wing.
With a consequent application of passive and active flow and loads control technologies in combination with new design and manufacturing methods and new materials, the smart wing shall deliver a 25% percent reduction of wing drag during cruise. In a first major project stage, a large scale natural laminar wing test article will be developed, built and flight tested onboard a modified Airbus A340-300 test aircraft, complemented by a large number of numerical studies and ground based demonstrators.

A second focus is to develop, mature and validate concepts to integrate the most advanced engine concepts into the next generation of large transport and business jet aircraft. These engines, like the Contra Rotating Open Rotor, which could offer more than 20% reduction of fuel burn, require a substantially reworked aircraft configuration to be integrated at aircraft level. In line with these studies, advanced but realistic concepts of noise shielding and a redesign of the rear empennage are part of the SFWA-ITD program.
Under coordination of Airbus and co-coordination of SAAB, the principle program members Dassault, EADS-CASA, SNECMA, Rolls-Royce, Thales, DLR, Dassault, RUAG, Aernnova, Qinetiq, INCAS and "Dutch" cluster of participants are committed upon a flight demonstrator focussed, seven year work plan with a volume of 393M€.
A large number of additional partners will be acquired for dedicated work packages through so called "CleanSky Call for Proposals" during most of the life time of the project.

3 Demonstrator Focused Work Plan

The concept of the "smart" low drag wing and the integration of the CROR power plant have been studied in a substantial number of major research and technology programs since decades. However, the transition into industrial application was never achieved because

- Some required contributing technologies were not available or premature
- Critical technical show stoppers were identified in the R&T projects
- The risk for application without large scale validation and demonstration under

realistic operational condition was unacceptable.
- The programmatic "environment" for an appropriate, huge demonstrator project was not available

The work break down structure of the SFWA-ITD is tailored to overcome these deficits. The setup of the work packages is aligned to develop, integrate, and validate respectively demonstrate the target technologies in flight along passing milestones of increasing Technology Readiness Levels (TRL) similar as defined in [1].

The objective of the SFWA-ITD is explicitly not to start up any new research, but to take the most promising, existing technologies onboard that have been developed in the through previous national or European funded research projects. Major European projects in the area of passive and active laminar wing R&T are, for example, ELFIN I and ELFINII, HYLDA, HYLTEC, ALTTA, and TELFONA e.g. [2-4].

3.1 SFWA Work Package 1 "Technology Development"

SFWA work package 1 contains all key elements of technologies required to develop, design and build an all new smart laminar "low drag" wing, are picked up at typical "laboratory levels" TRL 2 or TRL 3, to be advanced to a TRL 4. This relates to a development at subcomponent or system level with features and performance validated at realistic condition in rig tests. This does not only apply to hardware, but include aerodynamic and structural design and calculation methods or results from previous R&T programs like [5;6], fabrication or repair tools.

The headlines of the WP1 technologies are

- Passive and active technologies for flow control
- Concepts for active and passive load control
- Sensor and actuator network architectures
- Concepts for laminar wing high lift design
- Tools and methods for laminar wing predesign

Note that work package 1 does only contain technologies related to the smart wing. The activities to integrate the innovative power plants consider the availability of all basic technology elements at TRL4 already, which means the related R&T work starts in SFWA work package 2.

3.2 SFWA Work Package 2 "New Configuration"

In this work package the integration of the smart wing, respectively the innovative power plants and pylon takes place as major components, including the preparatory R&T to integrate the major parts into the overall aircraft concept.
For the smart wing a number of dedicated "feature" ground and rig demonstrators are planned to mature and validate the new wing with respect to bird and lightning strike, icing, but also with manufacturing and repair methods of related innovative structures and systems while considering the tough requirements of the wing surface quality.
For the engine integration there will be two path ways to consider the special requirements for business jets respectively large transport aircraft.
In work package 2 all activities related to the integration of laminar wing technologies and integration of innovative power plants including the design of a modified, innovative empennage are addressed, advancing the SFWA technologies from TRL4 to TRL5.

To be able to accommodate further important complementary technologies in addition to the smart wing and innovative engine integration, a work package "Integration of other Components for Green Operation" is added in SFWA WP 2.

The detailed assessment of the value and potentials of the individual SFWA technologies at component and aircraft level are also part of work package 2. This work package is also acting as interface to the CleanSky Technology Evaluator, providing the reference aircrafts, the conceptual aircraft, and the related models for a parametric assessment of the SFWA results.

3.3 SFWA Work Package 3 “Flight Demonstration”

This work package accommodates the flight demonstration activities to validate and demonstrate the SFWA target technologies under real operational condition in an aircraft environment at large or even full size. These demonstrators are providing the key information to advance the SFWA-technologies from TRL5 to TRL6. The flight demonstrators in SFWA are:

1. High Speed Smart Wing Flight Demonstrator
The critical step in the Research and Technology activities towards developing a low drag laminar smart wing is to proof its performance at typical cruise flight condition, at relevant Mach and Reynolds numbers, and representative pressure distribution, in particular at the upper surface of the wing. The demonstration article shall further be representative in geometry and shape, as well as in tolerances and quality with respect to the surfaces. The structure shall feature a typical behaviour under static and dynamic loads in flight. A large size flight demonstration onboard a modified Airbus A340-300 test aircraft is key part of the SFWA-ITD program.

2. Smart Wing Low Speed Flight Demonstrator
When developing an all new low drag “smart wing”, based on the concept to achieve a substantial level of laminarity, the development and integration of an appropriate low speed concept providing appropriate performance and handling qualities for take-off and landing, need to be included from the beginning on. Even though there are a number of “conventional” low speed technologies viable to be combined with the laminar smart wing, there are other, advanced technologies available at TRL3 with the potential to provide additional performance gains to the smart wing. The flight test vehicle shall be selected in summer 2010.

3. Innovative Engine Demonstrator Flying Test Bed (CROR engine - demo FTB)
At the operational launch of CleanSky it was clear that the validation of the CROR engine concept requires a large scale demonstration under operational condition. Coordinated with the engine manufacturers in the CleanSky SAGE-ITD, a coherent development plan was setup, to prepare a full size ground demonstration engine in SAGE and a suitable flight test demonstration in SFWA.

4. Long Term Technology Flight Demonstrator
A key objective of the maturing of the smart wing in the SFWA-ITD is the proof of the viability of the concept and robust performance under real operational condition, providing the benefits predicted in numerical predictions and obtained in earlier laboratory or ground experiments. To validate the long term robustness of specific systems, like sensors, actuators, but also surface coatings and others, a critical, yet large number of testing in operational, i.e. flight condition are required.
In the course of the development and down selection of the best candidate technologies to contribute to the smart wing, dedicated flight test activities will be prepared and conducted. In cases when only very light modifications on the aircraft are necessary, the plan is to involve in service aircraft, if possible in partnership with airlines through call for proposals.

5. Innovative Empenage Demonstrator
The integration of advanced, innovative propulsion concepts to an aircraft requires a number of optimisations and modifications to achieve the best performance of these engines in combination with many other components of the aircraft.
The integration of advanced turbofan or a CROR engine at the rear fuselage requires a major rethinking of the rear fuselage, in particular in view of aerodynamic aspects,

handling quality, but also the handling of static and dynamic loads, issues of noise shielding and certification.
In the early planning phase of SFWA-ITD a dedicated demonstration work package for this objective was anchored in the WBS, *with provision to keep it as g round test*, and to tailor this test in order to give priority to the other SFWA flight demonstrations, in particular the "CROR- engine demo FTB".

4 Preparation and Status of Large Ground and Flight Demonstrators

In the first two years of the lifetime of the SFWA-ITD program, most of the principle definitions of the major flight test demonstrations are made. With the explicit focus of CleanSky to large scale flight demonstrators, the technical planning of the technology development, integration and demonstration is aligned to the preparation, conduct, and exploitation of these demonstration campaigns.
Detailed information about the preparation and status for the three major demonstrator elements will be given in the following paragraph

4.1 "High Speed Demonstrator Passive"

A careful analysis was made to identify the most viable, but also cost and time efficient flight test vehicle to validate the technology of a full size natural laminar smart wing at operational condition, with a special focus on condition in cruise flight.
The main objectives to be met are a fully representative geometry and size, Mach and Reynolds number condition similar to the envisaged flight condition, and a high similarity of the pressure distribution profile at the upper surface of the wing. The structural and manufacturing concept should feature at least a leading edge and upper cover solution close to what is viable for a future production at industrial scales. The critical parameters are linked to the issues of the quality and durability of the upper surface as well as the physical waviness under different load condition, in particular in chord wise direction. The proposed structural concepts have to demonstrate the capacity to accommodate all required systems, for example wing ice protection, lightning strike protection, electrical and fuel systems.
Based on the decision, that a large scale smart wing article rather than a "laminar glove" solution or partial wing segment replacement should be tested, three types of vehicles have been studied with respect to their matching with the requirements. A large "Global Hawk" type UAV, a re-winged Dassault- Dornier Alpha Jet, and the partially re-winged Airbus A340-300 test aircraft. For the UAV solution, the major deficit was the low possible wing loading which led to difficulties to rebuild a pressure profile representative for the target "smart wing". The entire vehicle design had to be essentially modified to be able to provide the required Mach and Reynolds-number. In addition, important arguments against such vehicle was the uncertain situation with respect to availability, as well as a reliable scenario of testing, in particular the large size test area, reliability of the remote control system in combination with heavy test equipment.
Equipped with a dry, relatively low complex wing with a mechanical control system, the Alpha Jet was a good candidate as smart wing flight test vehicle at high speed. The availability was sure as SFWA-ITD member Qinetiq made an explicit offer to use the company owned aircraft in combination with the certification authority for modifications being available at Qinetiq and further project consortium member RUAG. However, a detailed analysis revealed that the design and size of the Alpha Jet was critically below to provide the required combination of Mach number, wing loading and size of the target wing test article. A substantial downscaling of the targeted wing would have been the consequence, leading to unrealistic features of the test article. The fuel capacity of the Alpha Jet standard tank is too small to achieve the flight duration required for reasonable flight tests, and the flight envelope needed to be opened with the re-winged test aircraft in particular at high altitudes. A critical

issue for both flight test vehicle options, the Alpha Jet and the UAV, was that the test article size was at the lower limit, which leads to structural dimensions critical to validate manufacturing methods for future full size smart wings.

Even though being the solution associated with the highest effort and cost, in April 2009 the Airbus A340-300 emerged as only viable choice of the feasibility study.

The principle layout of the flight test demonstration displayed in figure 1 is to replace both sides of the datum Airbus A340-300 wings from the outboard engines on to the wing tips by entirely new smart wing test articles, which gives a smart wing size of approximately 8m span, more than 2m chord at the wing root section with a sweep angle of ~20°. The plan is to keep the system modification in the test article compared to the datum outboard wing as small as possible, maintaining most of the aileron control system, and simply to remove the most outboard slats for the test flights.

The test articles will be mounted to the main aircraft wing via a diffusion zone, which will adapt the different geometries of the two parts of the wing, and an aerodynamic fairing, to disconnect the flow of the midboard from the outboard wing section and provide extra space for potential optical measurement equipment.

Even though a clear advantage of the Airbus A340-300 test aircraft solution is that the applying the smart outboard wing articles will be treated as heavy wing modification rather than an entirely new wing, the preparatory process to receive a "permit to fly" will be extensive and include dedicated simulator and wind tunnel experiments. The next, most important milestone in the preparation to be passed is the preliminary design review scheduled in autumn 2010, in which all principle elements of the aerodynamic concept, system layout and components, as well the structural design and manufacturing concept will be carefully reviewed with respect to their feasibility. To maximize the output of the project, the decision was taken to develop and flight test two parallel structural smart wing concepts at the same time. A segmented metal sheet based layout at the starboard side developed under the lead of Airbus, and a composite based solution with an integral leading edge-upper cover at the portboard side under the lead of SAAB as displayed in figure 2.

It is clear that with the smart wing flight test article it will not be possible to represent all main characteristic features of the envisaged smart wing. That is why in parallel to the preparation of the flight test demonstration articles, a number of dedicated "feature" ground and rig demonstrators will be developed and tested. Key issues to be studied are the robustness against bird and lightning strike, behavior in icing condition and de-icing systems, the integration of a potential Krueger system, the durability of surface coatings, the damage tolerance and damage behavior of the structure, repair concepts and others.

Except the engine manufacturer Rolls-Royce and Snecma, all principle consortium members of CleanSky contribute to the R&T activities of the smart wing in the different stages and work packages of the project. Figure 3 shows the main work shares of the principle contributing SFWA-ITD members to the preparation of the flight test article. A large number of supplemental work packages are subsequently given to additional partners through dedicated so called CleanSky "Call for Proposals".

Owing to complexity, effort and cost associated to the Airbus A340-300 flight test demonstration, the smart wing part of SFWA project is focussing to validate and demonstrate the natural laminar wing concept. The development and testing of an active "hybrid" laminar flow smart wing, which is "stage two" in the SFWA-ITD technology plan, will be pursued at limited level.

In the current SFWA technology roadmap the flight tests are planned to begin in the third quarter of 2014, following up to seven ground-based "feature" demonstrators in the years 2010 to 2013.

4.2 Contra Rotating Open Rotor "Flying Test Bed"

It is evident since more than two decades that the concept of a Contra Rotating Open Rotor engine (CROR) has the potential for a unique reduction of fuel burn providing a high degree of efficiency at cruise speeds close to those typically achieved with conventional turbofan engines.
In particular large demonstrations with the General Electric GE36 unducted fan and the Allison/Pratt & Whitney 578-DX propfan in the mid of the eighties of the last century on a McDonald Douglas MD80 respectively Boeing B727 test aircraft, revealed the technical challenges of the integration of such engines into a large commercial aircraft. The major showstoppers at that time where in particular associated to the excessive internal and external noise and vibration.
In close coordination with engine suppliers Rolls-Royce and Snecma, which are developing a new generation of CROR engines in the frame of the CleanSky SAGE-ITD (Sustainable and Green Engines Integrated Technology Demonstrator), a new approach is made within the SFWA-ITD to integrate these engines into an overall aircraft design. This approach is explicitly including the integration of the engine and engine pylon into a modified fuselage, an entirely new state-of-the–art propeller blade design, concepts of passive and active noise damping and flow control as well as certification issues. Principle objectives are the study of the aerodynamic interaction of engine and pylon with the flow field in the wake of the wing and the aircraft afterbody including in particular the horizontal and vertical tailplane, focus will be on the assessment of noise and vibration at full scale.
Figure 4 shows an Airbus study with including a number of advanced, yet almost invisible, features of a new blade design.
The technology roadmap towards the integration of the CROR engine a short and medium range transport aircraft includes a variety of numerical studies and subscale wind tunnel tests, as well as a test engine demonstration at full scale.
Based on a careful exploitation of different flight test vehicle options, including a modified Fokker 100 respectively an Airbus A320, the choice was made to use the Airbus A340-600 test aircraft. The major reason is that the resulting aircraft "with CROR engine" will still be able to fly with the current Airbus A340-600 test aircraft certification with a "permit to fly". Figure 5 shows the preferred configuration, with the CROR demonstrator engine being attached to the rear port side of the fuselage. To carry the static and dynamic engine loads during the test, a heavy structural modification will be required, as sketched in figure 6.
The next important gate to pass before the detailed design phase for the CROR engine demo-FTB can start is the preliminary design review, which is scheduled early in 2012.The flight with the CROR engine demo FTB is currently planned in summer 2015.

Another SFWA-ITD technology stream is dealing with the potential integration of advanced turbofan engines to Business Jets with different innovative, noise shielding design concepts of the rear fuselage of the aircraft. The prime target with this configuration is to set a new benchmark in the reduction of external aircraft noise.

4.3 Flight Demonstration of Low Speed Smart Wing Technologies

The deployment of the concept of natural laminarity on a smart wing of large transport aircraft or business jets has a number of essential consequences for the overall layout, including the control and high lift devices. The demand of a high quality surface from the leading edge to an extended part of upper cover and the small leading edge radius is leading to a limited number of possible solutions for a high lift concept.
Down selected from number of passive but also active flow control augmented advanced high lift concepts, including the results from relevant ground demonstrations campaigns, e.g. from the FP6 project AVERT (major objective of AVERT is to develop and industrialize novel

active flow control technologies for realistic, wing configuration to significantly reduce airframe drag), the best candidate will be promoted to be matured at large scale in dedicated ground and flight tests. .
The choice for the technology to be tested and the selection of the flight test demonstrator will be made in summer 2010. A this stage, a Dassault Falcon F2000 or F7X business jet or an Airbus A320 are candidate test aircraft vehicles.
The preliminary design review for the modified low speed flight demonstration vehicle is scheduled at the end of March 2011; the flight test is planned in summer 2013.

5 Conclusion and Outlook

The CleanSky SFWA-ITD is a seven year project targeting to develop and mature technologies for an all new low drag smart wing, and the integration of the most advanced engine concepts currently under development at the engine manufacturers. Explicit aim is to reach a high "technology readiness level" through large scale flight demonstrations.
The smart wing concept is based on achieving an extended area of laminar flow in particular on the upper surface of the wing during cruise flight condition. In a major first stage of the project, a natural laminar concept is under development to be flight tested onboard the partially re-winged Airbus A340-300 test aircraft. The detailed design and manufacturing work to prepare the test articles is planned to start in autumn 2010, with a number of supplemental large ground tests, which will be offered to be taken by additional partners through dedicated calls for proposals in the years 2010 to 2013.
Figure 7 shows a sketch of the overall time planning for the three major SFWA-ITD flight demonstration articles.

To prepare the integration of the CROR engine, a major feasibility study is under way in close alignment with related activities at Rolls-Royce and Snecma. Kick-Off of either the preparation of the Airbus A340-600 test aircraft and the production of the full size ground test engines, which will be upgraded to flight test engines in a separate dedicated activity outside of CleanSky, is planned for early 2012.

The author of this document wishes to announce that the research leading to the results as explained in this article has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for the Clean Sky Joint Technology Initiative under grant agreement n° CSJU-GAM-SFWA-2008-001.

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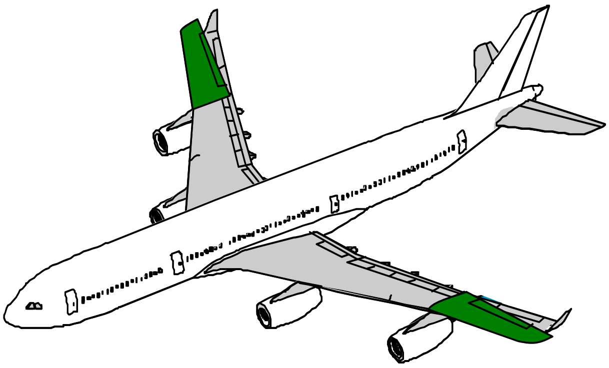

Fig. 1. Sketch of the "High Speed Demonstrator Passive" Airbus A340-300 Test Aircraft with "Smart Wing" Test Articles

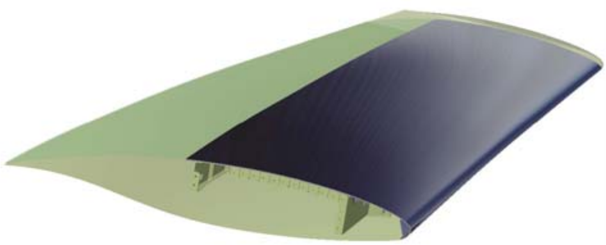

Fig.2. Portboard Smart Wing Demonstrator Article with Integrated Large Upper Panel and Leading Edge (SAAB)

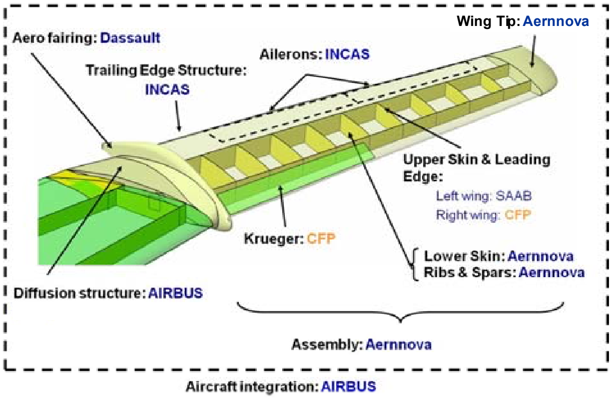

Fig.3. Distribution of Work Shares Between SFWA ITD-Members to Prepare the Smart Wing Flight Test Articles

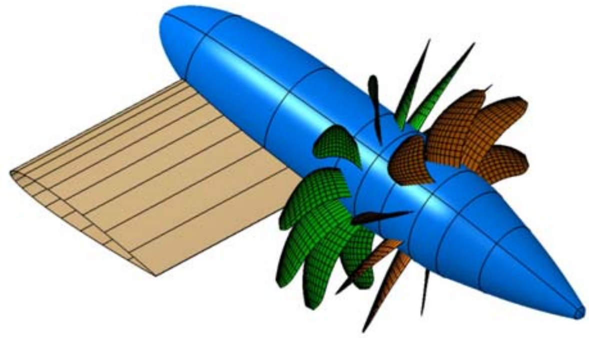

Fig. 4. Airbus Design Study of a CROR-Engine Pusher Concept with Advanced Blade Design

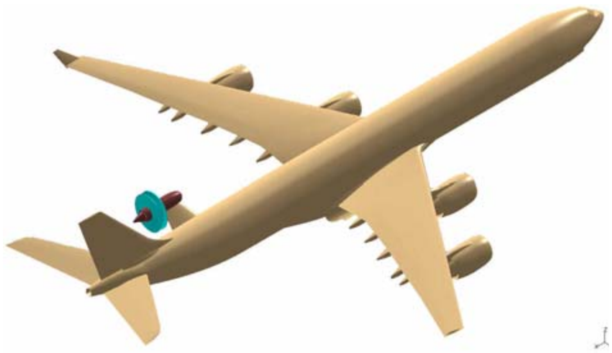

Fig.5. CROR Engine Demonstrator Integrated in the Airbus A340-600 flying test bed.

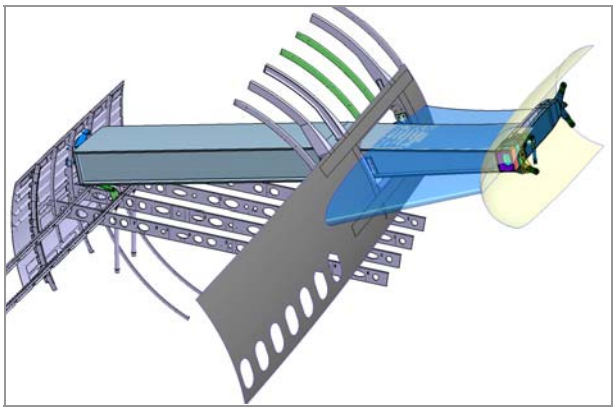

Fig.6. Structural Integration Concept of the CROR Engine Demonstrator to the Fuselage of the Airbus A340-600

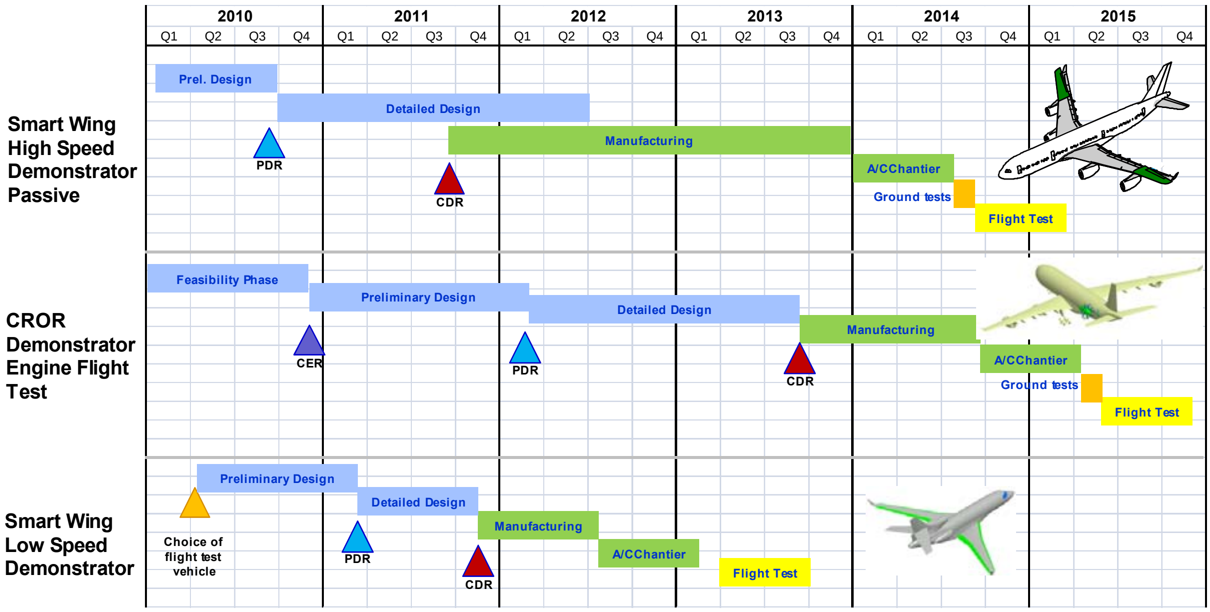

Fig. 7. SFWA-ITD Large Flight Test Demonstrator Schedule (status: June 2010)