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APRICOS

Advanced Primary Composites Structures

Synthesis Report

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Aerospatiale -- British Aerospace -- Alenia -- Dassault -- Saab -- CASA -- Eurocopter Deutschland -- S.A.B.C.A. -- NLR - INTA -- University of Calabria

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1. Summary

Key words : Aeronautics - Fuselage Structure - Carbon Fiber Reinforced Plastics - Resin Tranfer Molding - Generic panel

Abstract :

The APRICOS programme has focused on the technologies necessary for the development of composite fuselage structures with the aim to demonstrate a 30% life cycle cost saving over conventional metal aircraft. This target saving contained elements of initial purchase cost, mass saving (which might be translated into terms of range, payload and fuel costs) maintenance and operational costs. Different materials and process technologies were compared for the various component parts within a generic demonstrator panel. The results have permitted the identification of predesign and processing technologies for advanced, affordable, composite fuselages. In parallel to technology development, key technical areas linked to the introduction of composite structures for fuselage applications have been clearly identified.

Based on specification developed in a previous BE programme, a certification approach has been proposed and design requirements identified.

Stress methods for post buckling analysis and design criteria for skin stiffener failure were developed and validated against test results. Furthermore, impact behaviour of structures were extensively investigated and models successfully developed.

Material specification for fuselage structures has been agreed and 10 materials evaluated. A philosophy of ranking was developed and materials compared using spidergraphics.

Design concepts were presented for different applications and suitable technologies for the different elements have been identified. Innovative composite technologies were developed for the different elements : Liquid Resin Infusion and Resin Film Infusion for self stiffened skins and Resin Transfer Molding for frames and doors.

Using these technologies developed at subcomponent level, scale up has been demonstrated for the generic panel manufacturing. Assembly of such a structure was achieved under industrial conditions. Technology readiness has been gained during this project.

From the cost analysis performed all along the project, it was concluded that a composite fuselage can be feasible. The very ambitious goal of a 30 % lower LCC than today’s metallic fuselage structures has not been achieved in the completed analysis work, but the target cost has been approached. In some partner studies, the estimated LCC reduction has been in the 15% range, which is very encouraging indeed.

The APRICOS project was the first step along the R & D path required to achieve product's in service. By providing initial confidence for the cost issue and technological feasibility of a large composite fuselage it contributed significantly to the longer term industrial targets set for the aeronautics technologies. It permitted to have a common understanding and an harmonized approach of the technical solutions for a composite fuselage. This has resulted in the development of common knowledge, for material and processes tested and a common certification philosophy.

The large amount of benefits that came from this programme justified a follow up of the research to reach the next steps of the building block approach in terms of concept validation through a full scale barrel test and in terms of technology development trough more integrated full scale structures, in order to achieve the goal of a composite fuselage in service.

2. The Consortium

Consortium Description

Eleven partners composed the Consortium.
Eight of them were industrial companies. They were a large representation of European aeronautical industries while the programme dealt with the specificities of different types of aircraft ranging from business jets to wide bodies and including commuter and supersonic aircrafts. This wide participation of aircraft manufacturers was linked to the nature of the work developed in APRICOS, which was mainly of industrial responsability : certification procedures, design concepts and manufacturing processes development.
Two of them were research centers and their contrinution has been mainly linked to experimental testing .
The unique university contributed to fundamental modelling aspects.

Aircraft manufacturers

- Aerospatiale Matra Airbus Project leader
- British Aerospace Systems
- Alenia
- Dassault Aviation
- Saab
- CASA
- Eurocopter Deutschland
- S.A.B.C.A.

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3. Technical achievements

The main objective with APRICOS was a significant life cycle cost over conventional metallic aircraft. The method to carry out this is through reduce initial purchase cost of elements, mass saving, maintenance and operational cost.
In parallel, different techniques were used to show the technological feasibility of a generic fuselage panel. The approach to the problem is through the building block approach developed in the aeronautical field. Studies started with evaluation of material using coupons continuing with the validation of concepts with sub components and end by demonstration. The work is structured in to work packages and broken down to work items. The results are presented for each individual work package.

Work package 1, Technical specification: Requirements and analysis

The work done in the frame of WP1 has dealt with the potential technical problems linked to the introduction of composite structures for fuselage applications.

- A certification plan for a composite pressurised fuselage has been proposed, identifying all areas where the particularities of composites should induce new certification routes. All the certification requirements mentioned in JAR/FAR 25 (and particularly those of ACJ 25.603) have been systematically analysed, and an acceptable mean of compliance has been proposed. Although a lot of technical progress remain necessary before considering introducing a composite fuselage on a commercial aircraft, it is believed that there are no critical issues linked to the certification procedure. A more "critical" issue (although not critical as far as safety is concerned) is certainly the introduction of durability criteria for the design of composite fuselages. It appears that this kind of criteria could be the critical one for the weight efficiency of the fuselage (since it determines the thickness of the skin), and so further work remain necessary to determine relevant durability criteria.

- Impact damage behaviour and post-impact strength prediction has been another major point. The impact threat has been identified, thanks to statistical analysis of the recorded impacts on civil aircraft metallic fuselages. Significant improvements have also been reached concerning the understanding of damage mechanisms as well as post-impact strength prediction, for which the applicability of simple analytical tools or more complex explicit Finite Element analyses has been demonstrated. One of the next logical step of these studies will be to translate the identified threat into a design criteria regarding impact resistance to be taken into account for the sizing of composite fuselage panels. This involves deriving from the available data an impact condition (energy, diameter, etc.) to which the structure should resist without any repair needed, and using then the impact damage behaviour models to size the structure against this impact.

- Buckling analysis and the assessment of post-buckling behaviour and strength was the other identified major field. Finite element tools allowing an efficient assessment of the post buckling behaviour have been developed and validated. A methodology for assessing post-buckling strength has been proposed, based on a skin/stiffener disbonding criterion established thanks to elementary test results. This methodology has also been validated thanks to experimental results on test panels. The proposed approach being acceptable for real structures justification in terms of Finite Element cost, this preliminary result is very important to propose fuselage panels without mechanical fasteners assembly. The next step will be to validate this approach for various geometries and technologies on curved stiffened panels.

To conclude with, it is believed that the key technical areas linked to the introduction of composite structures for fuselage applications have been clearly identified, and that the technical improvements achieved have settled the basis for future works necessary to achieve the goal of a composite fuselage.

Work Package 2, Materials and Processes

Since the use of new composite materials and processes offers considerable benefit potential to the APRICOS programme, the selection of new promising material combinations is one of the key points for the development of life cycle cost saving composite fuselage structures which was the main target of the APRICOS programme.
Thus the objective of WP 2 was to obtain a selection of commercially available material/process combinations for use in components related to fuselage structures.
Thermoset prepregs and preforms in combination with RTM and RFI were the selected technologies. A selection of specific materials for these technologies was made on the basis of general concept definitions (WP 3) and structural requirements (WP 1).
A prescreening evaluation was carried out on 10 materials in order to select the best candidates for the applications to subcomponents (WP 4). See table below :

Code:	**Material:**
	Laying:
A	977-2 / HTA
B	5250-4 / HTA (Prepreg)
C	XE 12 / HTA
	RTM/LRI:
D	5250-4 / HTA G 986 (RTM)
E	PR 520 / HTA G 986
F	RTM 6 / HTA, G 808
G	RTM 6 / HTA, 2.5 D fabric
H	Cycom X 823 / HTA G 986
	RFI:
I	3501 / HTA G 947
K	8552 / HTA G 986

Materials selected for pre screening evaluation.

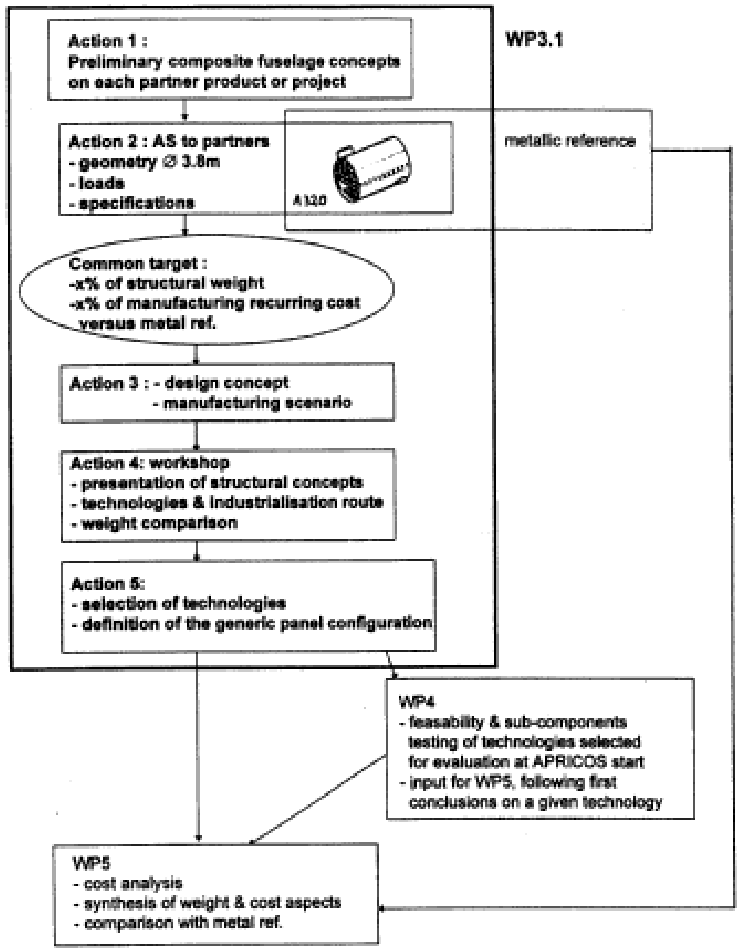
Based on these results, 6 candidates were selected for material characterization. Tests were performed with samples to establish predesign values.

The first output of WP2 was to issue the specification of materials with the definition of criteria the materials have to fulfill with respect to the future applications and requirements.
A philosophy of material ranking has been developed taking into acount the performance and the manufacturability of the materials.
Two graphs (Spidergraphs) were issued per material to have an overview of the performance of the material. One for the mechanical and physico chemical properties, one for the manufacturing properties.
All three prepreg materials have relatively well balanced properties without significant weak points Among the RTM materials there are 4 candidates which show a significant lower level of ILSS values against prepregs and RFI materials with the exception of the BMI candidate.
In general the good mechanical/physical properties have to be exchanged with the lowest level of manufacturing properties.

As a main conclusion there was no material found to have properties not fullfilling the fuselage requirements. A database with material properties has been established.

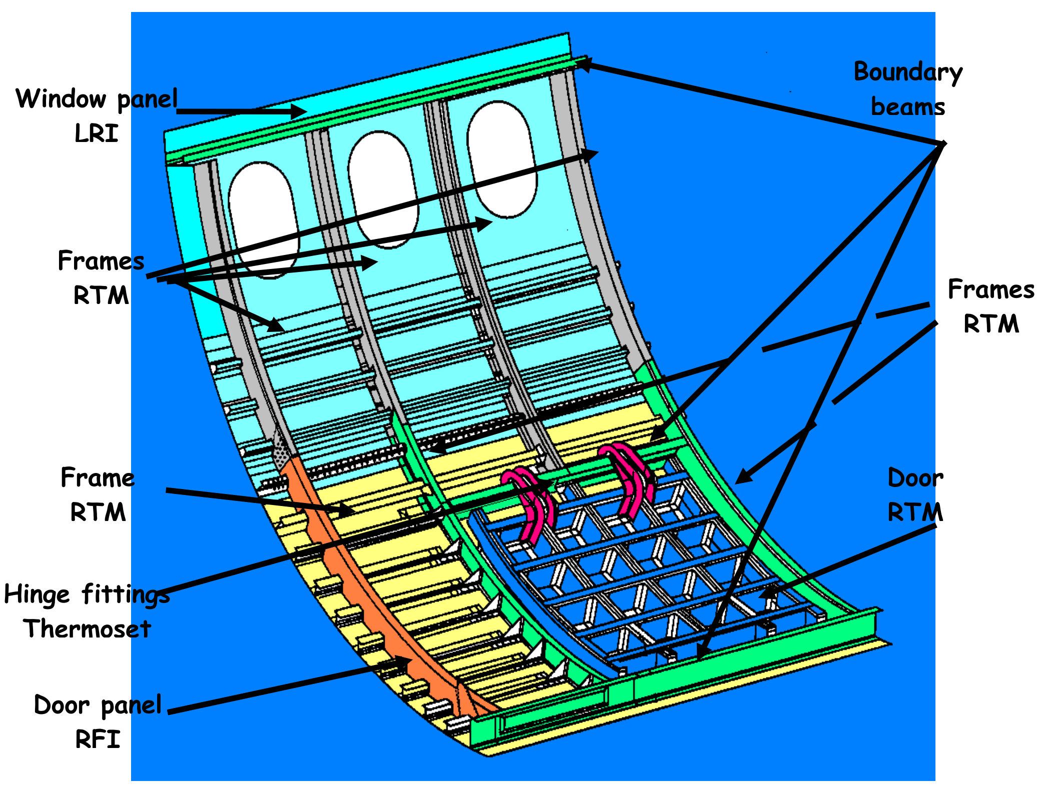
Work Package 3, Design and manufacture concepts

In the framework of APRICOS, the WP 3 objective was to discuss preliminary design and manufacturing concepts for a composite fuselage application.
Firstly, each aircraft manufacturer performed design concept studies on their own product. Secondly, a common exercise on a Airbus A320 fuselage section led to a selection of technologies and concepts, which have oriented the generic panel configuration for feasability purpose and cost element feedback
The output of the WP consisted in the detailed configuration of the generic panel to be manufactured in WP4, which has permitted the first feasabilities of the selected innovative technologies in order to get cost elements input for Work Package 5.
The figure on the following page summarizes the activities that have been performed in WP3.
From the wide variety of possible composite manufacturing scenarios, all the partners converged mainly on a monolithic concept using classic High Strength carbon fibre. One minisandwich variation was proposed to decrease the number of stringers by a factor of 2.
One key leading idea was to minimize assembly cost by pushing integration to compensate the composite material cost handicap. The associated manufacturing routes involve either Resin Transfer Molding and derivatives for co-cured hat stringers + skin and bolted frames, or Automated Tow Placement for the skin on precured stringers + riveted RTM frames.
As the last workshop led to a high community of point of views, the technologies to be investigated were limited to RTM and derivatives, and the configuration of generic panel defined. See picture next page.



Logic of design work in WP3

Generic panel configuration



Work Package 4, Sub-components testing and demonstrator

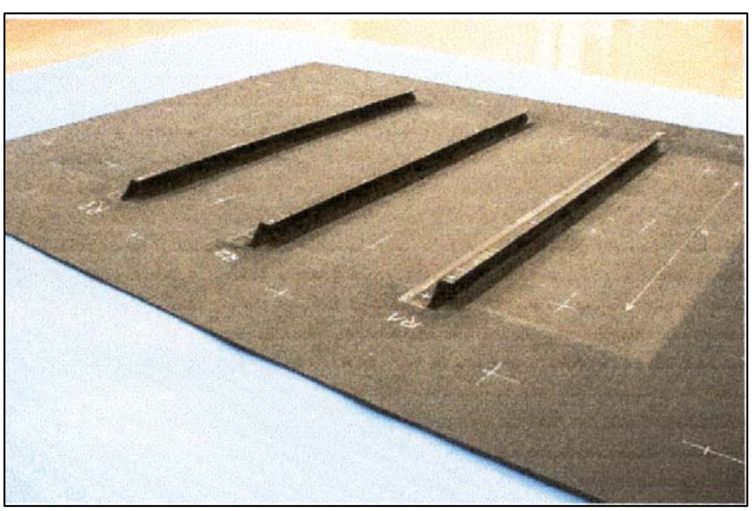
The objectives of the work package are, to validate the most innovative concepts defined in WP 3 by testing of sub components. It is also to demonstrate the feasibility of a fuselage panel in the selected technologies. The selected technologies should be cost effective for a fuselage structure.The work package is divided into design of sub-components, manufacturing, testing and finally design and manufacturing of the generic panel.

<u>Subcomponent activities</u>

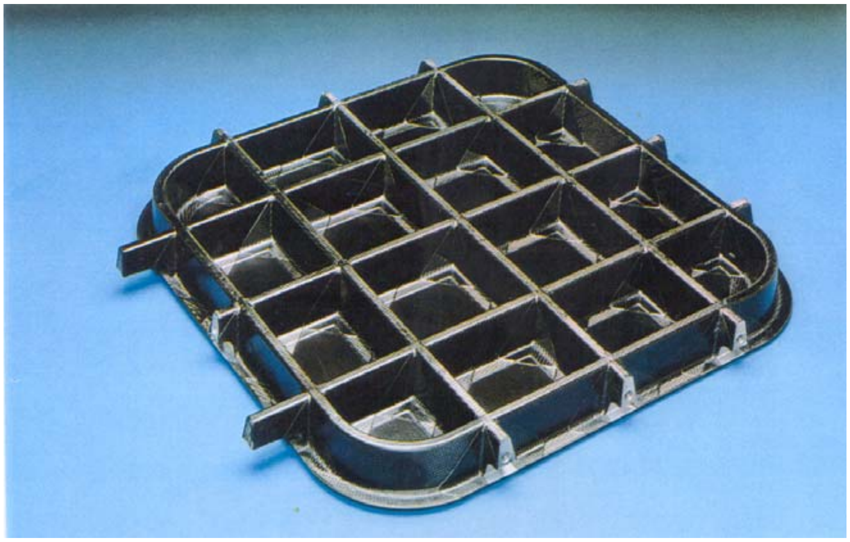
Examples of the sub-components that are design and manufactured are as follows.

Integrally stiffened panels representative of a fuselage skin, which are processed by the RFI process in one shot and tested in compression and shear.

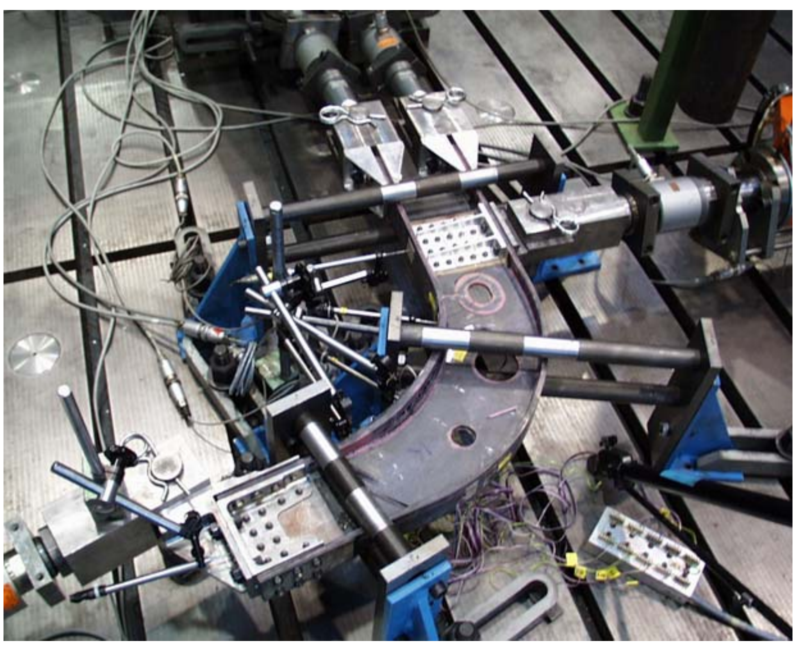
Panels are processed with co-bonding assembly route with pre-cured stringers and tested in shear.



A door with integral hinges is produced using RTM technique and tested under pressure.



A curved RTM U channel frame is manufactured and tested.



The results coming from the subcomponent activities allowed assessing the emerging technology RTM and its derivatives (LRI, RFI) for the manufacturing of elements that compose a fuselage structure (skin, stringer, frame, door). These technologies constitute a promising way for the future.

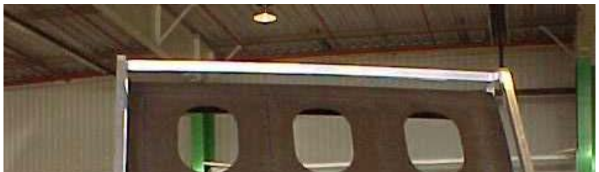
With the mechanical tests performed in this task, it's now possible to have an idea of the behaviour of different concepts, which could be applied, on an aircraft fuselage structure. Design criteria developed within WP1 were validated trough mechanical tests performed on WP4.

<u>Generic panel</u>

The generic panel was mainly a demonstrator of technological feasibility representative of a fuselage structure. Technologies and concepts were chosen in WP3 thanks to preliminary studies. The loads for sizing and the geometry are coming from the Airbus A320 fuselage. The objectives were :

- to assess and develop new technologies such as RTM, LRI and RFI for fuselage parts
- to identify the problems which could appear during the manufacturing of aircraft detail parts for fuselage
- to verify that concepts selected within WP3 are suitable for assembly, in an industrial environment.

Detail parts have been successfully manufactured using the selected technologies without major problems thanks to subcomponents activities.
The assembly operation was performed without any problem. The geometry and tolerances on composite detail parts was enough tight to make the assembly easy. No liquid or solid shimming was used.
The skin surface finish obtained with the two technologies considered in this task were acceptable, but it should be better for the inner surface of the RFI panel. In order to improve the surface finish on the RFI panel, feasibility tests have been successfully performed after the delivery of the panel for the generic panel
Two concepts for the frame to stringer intersections were considered. The first one- frame attached to the skin using clips- used on the door panel was satisfactory regarding the assembly. The second solution-frame with mousholes attached directly to the skin – used on the window panel) was more risky because of the concept with the joggles on the frames. In a first approach, it seems that thanks to the accuracy of the parts manufactured by RTM, it's not necessary to shim the different elements.
The door integration on the generic panel, shown that the good geometry of both panel and door led to a very slight mismatch.
The build sequence used for the demonstrator is not fully representative of a real fuselage section, but some of the problems that could occur during the assembly of this kind of structure, were highlighted.



Generic panel

As a conclusion, the work done on the generic panel is an intermediate step between feasibility tests and the manufacturing of a full-scale fuselage. It was a way to develop tooling concepts and manufacturing sequences. Manufacturing processes associated with selected concepts have been demonstrated from a technological point of view and could be proposed for a full scale demonstration at fuselage section level.

Work Package 5, Cost Analysis

APRICOS WP5 work has consisted of the following main activities and has generated the listed main results:

- The generation and definition of **costing ground rules** in order to objectively compare cost reduction progress between the partners and to be able to share cost data while protecting company confidential information. Also, a **methodology for joint cost estimation** of future application of conceptual technologies has been introduced and used by the partners, including assessment of uncertainties.

- Selection and evaluation of **partner-specific fuselage reference structures** in order to identify cost drivers in metal designs and to measure the cost-efficiency of APRICOS composite technologies in different applications against the current metallic baseline

The main cost drivers in today's metallic designs have been typically identified as:

- part count (high number of separately handled piece-parts)
- high number of joints and fasteners, extensive manual or automated assembly
- long lead times
- weight
- corrosion and other damage requiring maintenance

- **Selection and joint evaluation of four potential composite technologies** applied to a conceptual redesign of a 6 m long typical section of a **standard body Airbus fuselage**.

A first iteration assessment of the recurring production cost (using definitions valid only in this case) of four composite fuselage concepts; RFI 4 panels, AFP 4 panels, LRI 4 panels and AFP full barrel, compared to an assumed baseline metallic fuselage has been performed and resulted in the following conclusion : the recurring production cost (manufacturing and materials) is reasonably within range with the current production cost for metallic aircraft structures and that is has a real potential for further improvements.

The non-recurring production costs have been assessed as being higher for a composite fuselage than for a conventional metal solution, a fact which can be attributed to the differences in technology maturity. The partner reported non-recurring cost disadvantage for composite fuselages is still reasonable, especially when considering the expected delivery rates available for amortisation.

The very ambitious goal of a 30 % lower LCC than today's metallic fuselage structures has not been achieved in the completed analysis work, but the target cost has been approached. In some partner studies, the estimated LCC reduction has been in the 15 % range, which is very encouraging indeed.

4. Exploitation plans and follow-up actions

Follow up actions

APRICOS has been an encouraging first step along the R&D path required to achieve composite fuselage in service and the partners wishes to continue the research on composite fuselage and will request support from the EC for new projects.

Two such RTD projects, which cover the next steps of the building block approach in terms of concept validation through a full scale barrel test and in terms of technology development trough more integrated full scale structures will be proposed :

- The European FP5 project TANGO, studying application of composite **fuselage panel technologies** to standard and large body aircraft

- The proposed European FP5 project FUBACOMP, studying **full barrel integration** of composite technologies to small diameter aircraft fuselages

Objectives of each partner for exploitation

Each partner within the consortium has different use of the results from APRICOS.

Aerospatiale will use their results for the forthcoming future large aircraft programme. New technologies developed will be introduced on self stiffened monolithic thin structures.
The LRI technology will also be proposed as a candidate for a panel on the Composite barrel test of TANGO.

BAE SYSTEMS Airbus
Background understanding and analytical methods obtained from the Apricos programme contributed to the design effort for the Airbus A340-600 thermoplastic ‘D’ nose project.

Compression after impact strength is the primary indication for damage tolerance for composite structures. The process of assessing vulnerability to impact damage and resulting residual strength has been implemented on ICAD. This will make a positive contribution to work on current projects such as A400M and TANGO.

Results from impact and damage tolerance programme have been disseminated within BAE SYSTEMS Airbus and contributed to general awareness of impact and damage tolerance issues concerning composite structures.

Development of an interaction failure criterion for ply drops and application of this methodology into ‘Mathcad’ for in-house detail stress analysis.

Alenia is intended to use the APRICOS results in terms of experience gained in RFI process for the forthcoming TANGO programme.
The experience gained by Alenia from the A.PRI.CO.S Programme will be exploited on:
Activities foreseen for new Research Programmes like:

- T.A.N.G.O, where Alenia is involved for the Lateral Wing Box and Fuselage Work Packages;
- FUBACOMP;
- COMPLETE;
- DATAC.

The good results obtained from preliminary cost analysis too, lead R.F.I. process to be a valid alternative
to pre-preg configurations, for future applications and not for fuselage structure only.

Dassault Aviation exploitation :

For cost effective businessjet fuselage application, the two following points are pushing Dassault Aviation to increase and accelerate his effort on composite fuselage development :

- APRICOS conclusions are very encourageous for businessjet. Due to the small diameter, very high integrated concept have been identified, such as a full barrel approach, which drastically reduces the assembly cost. Then, manufacturing and mechanical sub-components validations led to identify and select promising technology routes.
- The USA competitor "Raytheon" is lauching on production two businessjets utilising a composite fuselage made out 2 or 3 fully integrated sections. He is claiming mass saving, more cabin volume and manufacturing cost reduction.

Therefore, as the technologies application and design concepts are very linked to the size of the pressurized cabin, Dassault Aviation is willing to join a proposal called FUBACOMP (to be submitted in PCRD-5 2nd call). The objective is to go to a fully unitised section validation, which could cover "small diameter" applications such as tilt rotor, businessjet or commuters…

CASA is committed to take advantage of the results of APRICOS

- Understanding of the strengths/weakness of this application
- Evaluation of new materials
- Evaluation of new cost effective manufacturing processes

Improved analysis capability of composites
in the forthcoming projects: A3XX rear fuselage section and New Engine Cowlings
CASA will be working on further programmes and additional developments in order to fully demonstrate the economical and technical viability of the composite fuselages
(TANGO programme)

Eurocopter Deutschland will as a result of new experience gained from work with the APRICOS project change their process technology for frames from pre-preg technology to RTM fibre placement.

Saab will use all results to some extent. The results are useful for the continued work in follow-on FP5 projects, for ongoing and planned subcontract work for AIRBUS partners and for general improvements in different areas of composites technology. Improved cost efficiency and ability to better select between alternative composite technologies, designs and manufacturing routes is the major exploitable knowledge gained from participation in APRICOS

S.A.B.C.A. intends to propose and to use the results obtained in this programme for participation in new aeronautical projects (composite fuselage panels integration and manufacturing, door manufacturing,...).

INTA intends to use the test rig development in APRICOS for future tests and to use their gained experience in future R&D projects related with composites (EDAVCOS, TANGO,…)

Unical
With the APRICOS project Unical had the opportunity to validate, inside an industrial environment, the reliability of the numerical strategies we conceived for the analysis of thin-walled structures. Moreover we extended our approach in order to properly model composite structures.
The developed code is either an efficient computational tool or a valid framework which will be used in our future researchs:

- refinement of the mixed formulation;
- development of a shell element to model generic shaped panels

Results have been published in [5], [6] and [7].

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