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Structural Radar Research of Airbus Defense and Space as Clean Sky Partnership

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Abstract

Airbus Defense and Space (former EADSCASA) is participating as formal Spanish company into European Frame Programs within different platforms and Integrated Technology Demonstrators (ITD). Starting as ITD co-leader in Clean Sky 1 within Green Regional Aircraft (GRA) covering a wide range of research streams and now in Clean Sky 2, where its involvement has been enlarged to AIRFRAME ITD co-leadership and as responsible of the Flight Test Bed 2 (FTB#2) in REGIONAL Integrated Aircraft Demonstrator Platform (IADP). Paper provides and overview of those research streams that have been matured to be implemented onto ground of flight demonstrators.

1. Introduction

Any future a/c design will require more eco-efficiency into the whole life cycle. Reading from Clean Sky principles and translating them as requirements into the a/c design and manufacturing, it should mean;

- Less CO2 in the entire aircraft life cycle
- Less noise ground footprint
- Less energy into the component production
- Less scrap primary material
- Less consumption of manufacturing liquids & ancillary
- More recyclability

In Clean Sky **Airbus Defense & Space** structures team has focused its attention in an overall airframe weight reduction target of 10%, maintaining or improving, as far as possible, aircraft functionalities using as reference experience extracted from C295. It therefore will mean improving manufacturing eco-efficiency looking for cost reduction and cadency improvement.

In Clean Sky1(CS1) a wide spread of new technologies were evaluated with the main purpose to enable some eco-efficiency during the whole operational life of the aircraft observing a chance to improve manufacturing processes to save cost. To obtain the maximum benefit of the overall research being planned, C295 cockpit was selected as reference component on which innovative design & manufacturing techniques would be assessed. Although well-known structure, the full set of variables involving the design requirements of this component, including constraints for cockpit systems integration, mean a significant challenge to meet proposed targets.

The structural research (material multi-functionality, design architecture, manufacturing, assembly, repairs and testing) has been developed onto ground demonstrators. Overall learning and usefulness can be extended into many other primary and secondary aero structures and space platforms. Several types of demonstrators are involved, since MT1 or MT2 cockpits [1] [2] or leading edges with special features (i.e morphing) until full external wing (winglet and morphing flap included) to be tested on ground prior being mounted on FTB#2 (Flight Test Bed 2) - update of C295 P1airframe platform- for flight test survey.

Research topics of significant importance started in CS1, some of them continued in CS2 to help meeting overall program goals are:

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- "One shot " multifunctional co-cured stiffened double curved stiffened skin based on thermoset material
- High structural integration combined with Out of Autoclave (OoA) processes with different types of materials and manufacturing technologies:
  - Flat and curved stiffened skin made in thermoplastic ISC (In Situ consolidation)
    - External Wing Upper Cover [4]
      - ✓ Continuous forming stiffener
    - Thermoplastic highly curved (i.e leading edge) or double curved stiffened skins suitable for secondary structures usage (i.e cowling)
  - Different configurations of primary structural elements (stiffened sandwich and laminates) made in Liquid Resin Infusion (LRI) using different type of materials (fabric and tape)
  - Outer wing lower skin-spars-stringers one shot "Liquid Resin Infused" (LRI) part with automatic dry fiber placement lamination [3]
  - Metallic structural elements manufactured using new set of high performance alloys

Other structural topics being searched deal with testing technologies as NDT, virtual testing or interferometry and different structural operational enhancements within the field of acoustic, dynamic impact or structural health monitoring (SHM)

Suitability of all the researched technologies has required the issue and development of different types of Call for Proposal (CfP) and collaboration of multiple types of european partners, since private companies till research centers and universities, some of them integrated in special consortiums called Core Partners during Clean Sky 2 (CS2)

2. Structural Technology Radar onto Clean Sky Demonstrators

Airbus Defence and Space has split the structural field in different sectors within a topic substrate to cluster somehow related research. Figure 1 illustrates one example of radar sectoring and Figures 2 and 3 the major demonstrators of CS1 & CS2 where the overall clustering research has been applied.

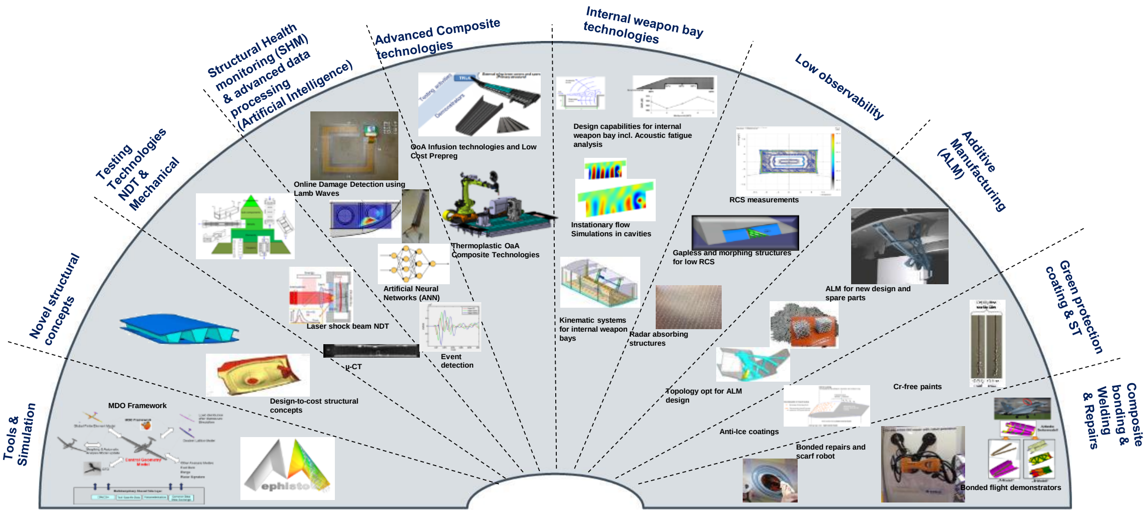

Figure 1: Structural Technology Radar Illustration

Table 1 keeps track of those technology "sectored" streams being developed and implemented onto correspondent flight or ground demonstrators of CS1 & CS2. Some of them were a result of internal research initiative without external involvement and later, further developments proposed to be continued as partnership into specific collaboration projects. ICARO, TARGET, DESAFÍO, APOLO, DAICA, LAEMA, NAMPRA or PRELEMA become some of those projects within Spanish National finance umbrella, beside other European initiatives within a wider frame of H2020 as SMAES, FORTAPE or specific Call for Proposal being lunched in the overall frame of different ITD: GRA-LW (Compass, Hybria, Crashing or Puma among others…), Eco-Design (Isinther) in CS1. Also within AIRFRAME and REGIONAL in CS2, as Core Partner collaboration (OUTCOME, PASSARO, EWIRA) and correspondent CfP (Inescape, Iiams, Rib-Am, Rib-On, Elcocos, Formit, Aimen among others). A great effort through research proposals has been pushed forward and intensively supported by Airbus Defence and Space.

DOI: 10.13009/EUCASS2019-652

Table 1: Structural Radar with Technology Linkage

<table>
<tr><th>Structural & Material Radar Sector</th><th colspan="2">Technology</th><th colspan="2">Tasks Indications</th></tr>
<tr><td>Green Protection Coating</td><td colspan="2">Nanomaterials</td><td colspan="2">Nanoparticles to dope coating substrate</td></tr>
<tr><td rowspan="2">Materials survey</td><td colspan="2">Alloys & Process</td><td colspan="2">New light alloys for sheets forming applications</td></tr>
<tr><td colspan="2">Composite Tangling</td><td colspan="2">Multifunctional concepts and application in design of structural elements</td></tr>
<tr><td rowspan="8">Advanced Composite and Integration</td><td rowspan="2">Green Manufact. (OoA)</td><td>RTM-LRI</td><td>New resins, process characterization (i.e permeability & variability), simulation.</td><td rowspan="2">Panels manufacturing, coupons extraction & testing
Assessment of design details tolerances
Inspection techniques
Test elements manufacturing</td></tr>
<tr><td>TP-ISC</td><td>Out of Autoclave stiffener manufacturing feasibility
High curvature stiffened elements manufacturing feasibility (i.e L.E)</td></tr>
<tr><td colspan="2" rowspan="3">Dynamic Characterization</td><td colspan="2">Compilation of data base for different material /process applied onto solid laminate structure type (dynamic impacts)</td></tr>
<tr><td colspan="2">Stiffened sandwich configuration with different skins-core joint (dynamic impacts)</td></tr>
<tr><td colspan="2">Materials and structural concepts suitable for acoustic improved functionality</td></tr>
<tr><td colspan="2">Design on Full 3D</td><td colspan="2">Adaptation to Design CATIA rules of new multifunctional material lay-up´s and other detail manufacturing aspects for highly integrated elements and multiple manufacturing techniques</td></tr>
<tr><td rowspan="2">Repairs</td><td>LRI</td><td colspan="2" rowspan="2">Structural Repairs in High integrated Structures</td></tr>
<tr><td>TP-ISC</td></tr>
<tr><td rowspan="2">Novel Structural Concepts</td><td colspan="2">High Integration</td><td rowspan="2">Design & Manufacturing feasibility surveys on demonstrators</td><td>Lift Surface Box, Fuselage & Fairings</td></tr>
<tr><td colspan="2">Morphing Devices</td><td>Winglet, Flap, Leading Edge and Movable Fairings</td></tr>
<tr><td>SHMS</td><td colspan="2">Elastic waves</td><td colspan="2">Multi-sensors net development for event-damage detection on CFRP highly integrated structural elements</td></tr>
<tr><td rowspan="7">Tools & Simulation</td><td colspan="2">Structural field</td><td colspan="2">Development of software and adaptation / integration of commercial tools complementing, enhancing or revising existing ones. Dynamic Impacts, Vibro-acoustic, Non-Linear strength and High temperature structural behaviour</td></tr>
<tr><td colspan="2">Elastic waves</td><td colspan="2">Development of structural models and sensors for elastic waves evolution in presence of multi-impact and thermal fields</td></tr>
<tr><td colspan="2" rowspan="3">Manufacturing Process</td><td colspan="2">Liquid Resin Infusion for Composite Fibre Clusters Tapes & Fabrics</td></tr>
<tr><td colspan="2">Thermoplastics ISC (Different Materials)</td></tr>
<tr><td colspan="2">Hot Stamping on metallic alloys for highly integrated Fuselage Frames & Wing Ribs</td></tr>
<tr><td colspan="2">EMC</td><td colspan="2">Software Tool validation on hybrid full cockpit with equipments</td></tr>
<tr><td colspan="2">Testing</td><td colspan="2">Virtual Testing</td></tr>
<tr><td rowspan="4">Testing Technology</td><td colspan="2">Interferometry</td><td colspan="2">Application of Interferometry to mechanical for detailed displacements field measurements</td></tr>
<tr><td colspan="2">Thermography</td><td colspan="2">Development of techniques for NDT complementary inspection.</td></tr>
<tr><td colspan="2">SHMS application</td><td colspan="2">Wide spread usage of SHM sensors and techniques</td></tr>
<tr><td colspan="2">p-U acoustic</td><td colspan="2">pressure-velocity based in situ absorption measurement</td></tr>
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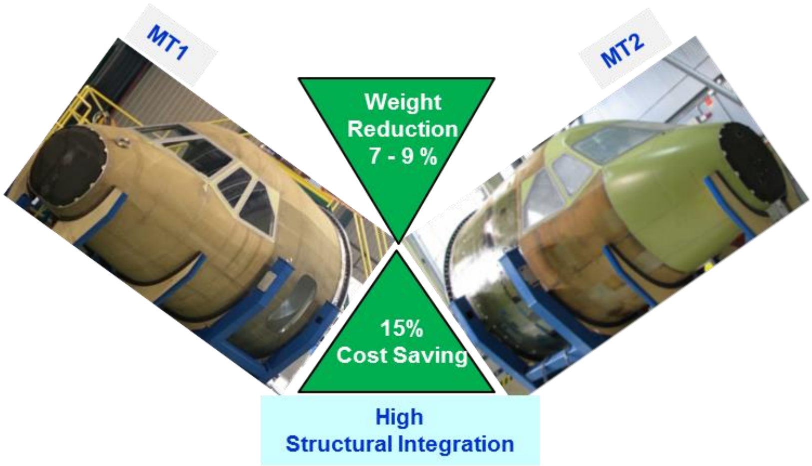


Figure 2: CS1 GRA-LW Demonstrators to be exploited in CS2

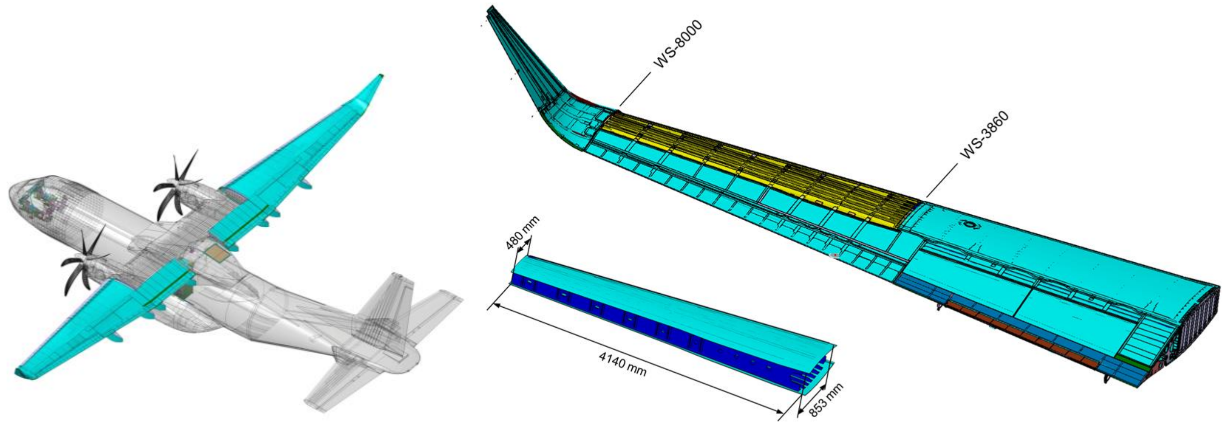


Figure 3: CS2 FTB#2 External Wing Box Flight Demonstrator

3. Materials and Applications

Different types of surveys have been carried on materials suitable of being used together with appropriate processing onto different structural elements to be conditioned by specific design requirements and in service scenarios.
In some cases, enhanced metallic alloys suitable of being used under eco-effective manufacturing process have been directly investigated. Also manufacturing compatibility of collaborative material characteristics as results of tangling combination have been covered through multipurpose (multifunctional) laminates (surface protection included) research, whose conceptual design substantiation has been proved through a wide set of verification and qualification testing – Mechanical, Vibro-acoustic, Dynamic characterization, EMC and Erosion – to evaluate their performance from coupon until components level.

From all surveys, four have become the most interesting to continue increasing Technical Readiness Level (TRL)

- Metallic alloys suitable of keeping treatment performance after hot stamping
- Acoustic layer inserted in CFRP thermoset with EMC protection mesh
- Dry fabric and tape material laid up automatically followed by liquid resin infusion (LRI)
- Carbon fibre (CF)/ Glass fibre (GF) / copper mesh (when become applicable), embedded in thermoplastic PEEK resin for
    - "In Situ Consolidation" (ISC) manufacturing and welding to
        - Press formed or ALM substructure (stringers or ribs) made in compatible material

A complementary research is foreseen to take place on materials / configuration for:

DOI: 10.13009/EUCASS2019-652

- Better acoustic isolation with improved dynamic impact characteristics for internal fuselage furniture applications
- Improved dynamic impact resistance for specific protective applications (i.e bird strike, ice and hail)
- Low cost thermoplastic usage applicable to secondary structural items

During CS1 some of the previous topics have reached TRL>3, therefore further developments, especially when there were still way for benefit in terms of cost and weight saving, has been continued during CS2. Larger manufacturing process maturity, better design "allowables" and functional performances, have been explored to accomplish foreseen goals previously identified [3] [4].

4. Structural Design

Once the material candidates and practical tangling has been identified, aspects dealing with useful design must be highlighted to create structural configuration able of being manufactured. Some of them are consolidated at coupons level but others need larger scale elements to be considered. The topics being investigated within this paragraph deal with

- Multifunctional laminates consolidation for practical usage
  - "Allowables" determination and failure modes identification
  - Acoustic and dynamic impact behaviour
  - Electromagnetic Compatibility (EMC) and Lightning strike performance
- Vibro-acoustic simulation
  - FEM-FEM simulation and correlation with ground demonstrators
  - Enhancements identification (window frame)
- Composite Dynamic Characterization
  - Settlement of impact behaviour and data base
  - Dynamic impact simulation techniques (Bird Strike, Crash & Hard Landing)
    - Behavioural tuning with test results on different type of structures
- Electromagnetic Compatibility (EMC) Simulation
  - Software development
    - Structural material/configuration
    - Systems integration into airframe component
  - Tuning with test results
- Elastic waves and other techniques (travelling waves)
  - Multi-type Sensor Net Development (MSN)-SHMS
  - Sensors/Equipment usage survey
- Structural prototyping on new manufacturing techniques
  - Additive Layer Manufacturing on
    - Aluminium
    - Thermoplastic
  - Thermoplastics consolidation
    - In situ consolidation (ISC)
    - Co-consolidation and welding
    - Continuous forming (rolforming)
- Application of Full 3D using CATIA
  - Digital Mock-up exploitation
  - Multifunctional layers integration (patterns definition)
- Strength prediction and failure modes simulation through FEM
  - Test results validation

DOI: 10.13009/EUCASS2019-652

Figure 4: Illustration of procedure to enable different types of material performance into component design

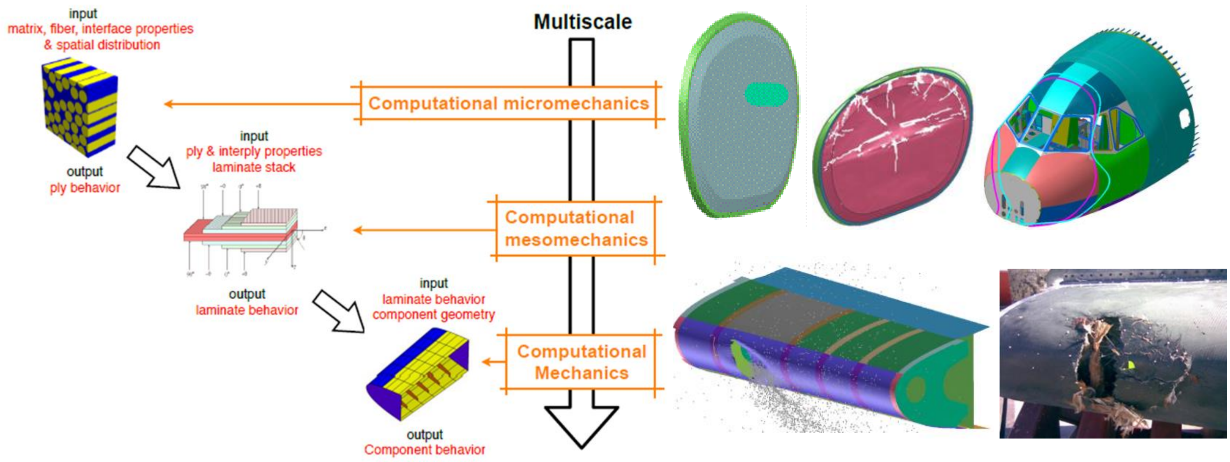


Figure 5: Illustration of procedure to enable material dynamic impact performance into component design

5. Manufacturing Techniques

Medio ambiental contraints require exploration of new production alternatives more ecoefficient jointly to innovative enhancements in current processes of design and manufacturing more integrated structures to save weight reducing costs. Although effort has been made on composite materials, also mettalic alloys under sheet configuration have been searched.

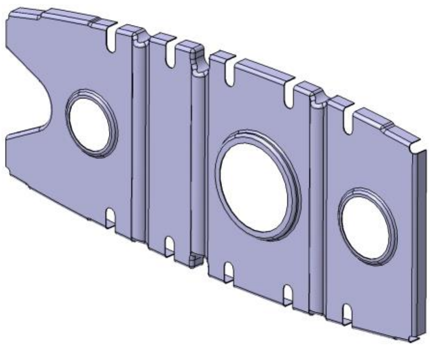
Hot stamping for large substructure metallic elements as fuselage frames and wing ribs and infused liquid resin (LRI) or in-situ consolidated thermoplastic resin (TP-ISC) manufacturing techniques are promising in terms of overcoming the aforementioned drawbacks to achieve desired objectives.

Investigation on new materials, treatments and characteristics influencing mechanical properties have been handled simultaneosly from design and manufacturing perspective to set the bet way to get complex elements, highly integrated, consolidated or cured out of autoclave with optimal manufacturing cost.

Those manufacturing thechniques being searched, together with their foreseen aplication are:

DOI: 10.13009/EUCASS2019-652

- Highly integrated primary structure
    - "One shot" co-cured stiffened multifunctional "double curved" solid laminate
    - High Integration of bulk frames infusion LRI (plus process simulation)
        - Solid Laminate (Lower Former FR-9)
        - Stiffened Sandwich (Forward Pressure Bulkhead FR-1)
        - Lower skin & Spars of FTB#2 Wing Box
    - High Integration thermoplastic ISC
        - Small curvature (FR-4 of MT1/MT2; Upper skin of FTB#2 external wing box)
            - ✓ Thermoplastic continuous forming (Stringers-Formit)
        - High / Double curvature (leading edge & cowling)
    - Fuselage frame / Wing Rib made in hot stamping light alloy sheet technique
- Secondary structure
    - Thermoplastic Low Cost (window frame)
    - ALM prototyping (window frame)
- Tooling technologies
    - Composite Low Cost (material & manufacturing)
    - Low Cost based on ALM
- Repairs and Maintenance
    - Standard repair on highly integrated curved stiffened skin (pre-preg)
    - Thermoplastic ISC co-consolidation & welding
    - RTM-LRI structural items
        - Prepreg patch application
        - Dry material patches plus resin injection
    - Resin injection to fix external multifunctional layers



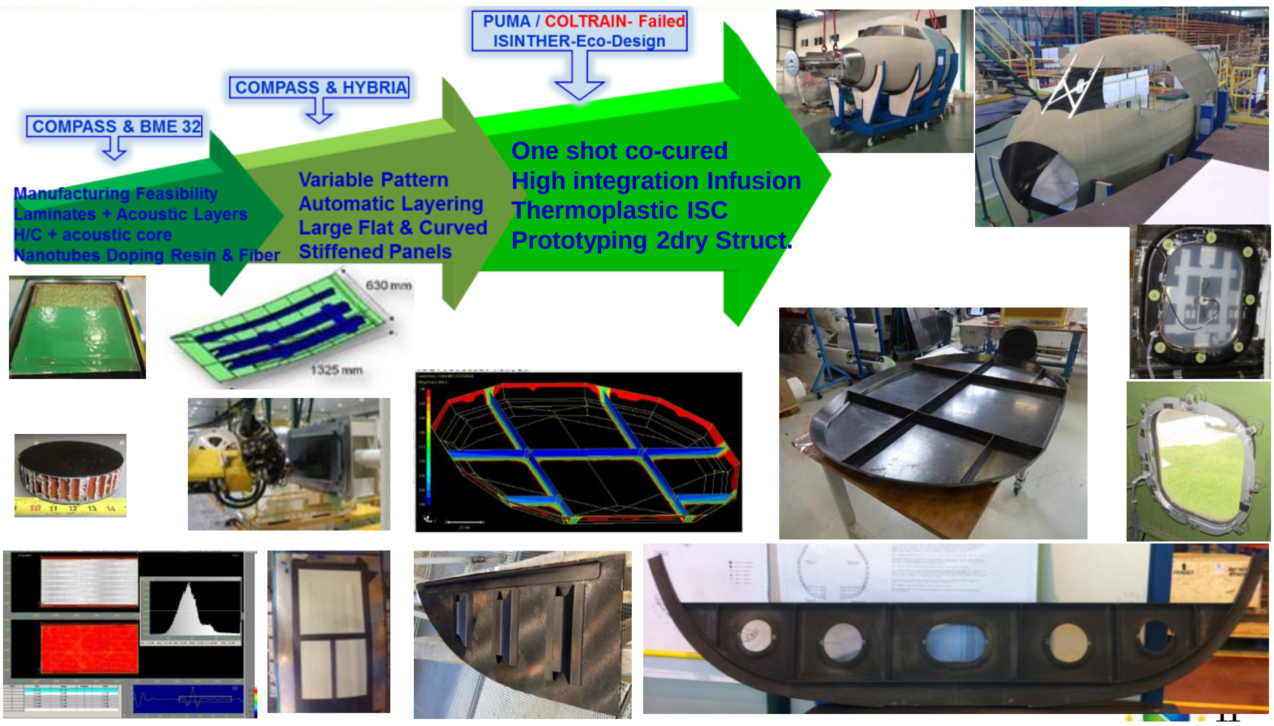


Figure 6: Illustration of manufacturing techniques that have been surveyed

Up on the base of first trials with infusion within GRA-LW of CS1, additional R&T activities have been conducted in other projects to improve, mature and enlarge the applicability of the Liquid Resin Infusion techniques into more complex structures combined with automation manufacturing [3]. Technologies capabilities and manufacturability

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aspects as suitable gaps, thickness variability, defectology and overall tolerances issues have been explored since details up to wing box portions and representative stiffened panels ready for qualification testing, previous to final component design and production to be ready for major test qualification. Figure 8 [3] illustrates foreseen road map.

Figure 8: Illustration of LRI Manufacturing Road Map

Figure 9 [4] illustrates foreseen road map for thermoplastic ISC research. Manufacturing of small an highly shaped elements are investigated in parallel by using different head machine prototypes adaptable to a continuous manufacturing process development. Inherent difficulties make for less curvature items be ahead in TRL than those much more highly shaped.

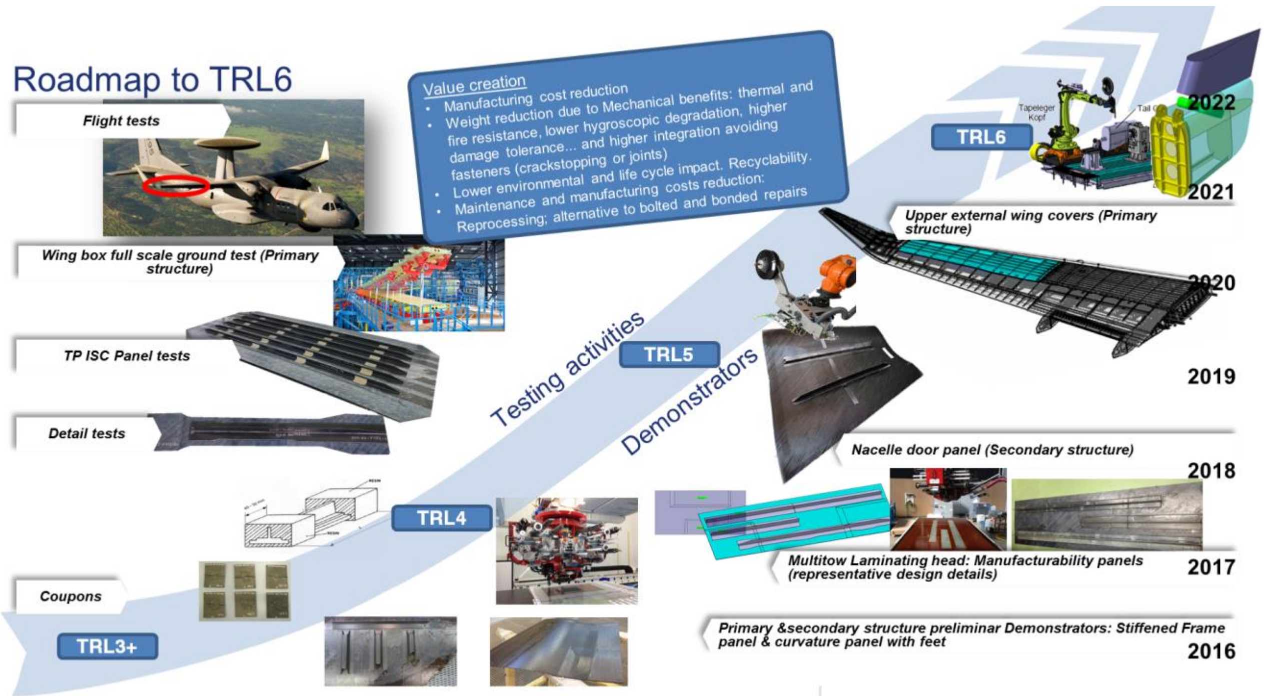


Figure 9: Illustration of TP-ISC Manufacturing Road Map

DOI: 10.13009/EUCASS2019-652

Although repairs involvement has not been appropriately highlighted in any of previous road map illustrations, to avoid misunderstanding, it becomes inherent to the actual development and is being jointly developed in each case. Also high curvature elements with complex shape for secondary structure as leading edges or cowling and other type of primary structure as emergency or ventral doors even enhanced pressure bulked components made in sandwich will be explored into CS2 to consolidate benchmarking material / process usage. See Figure 10

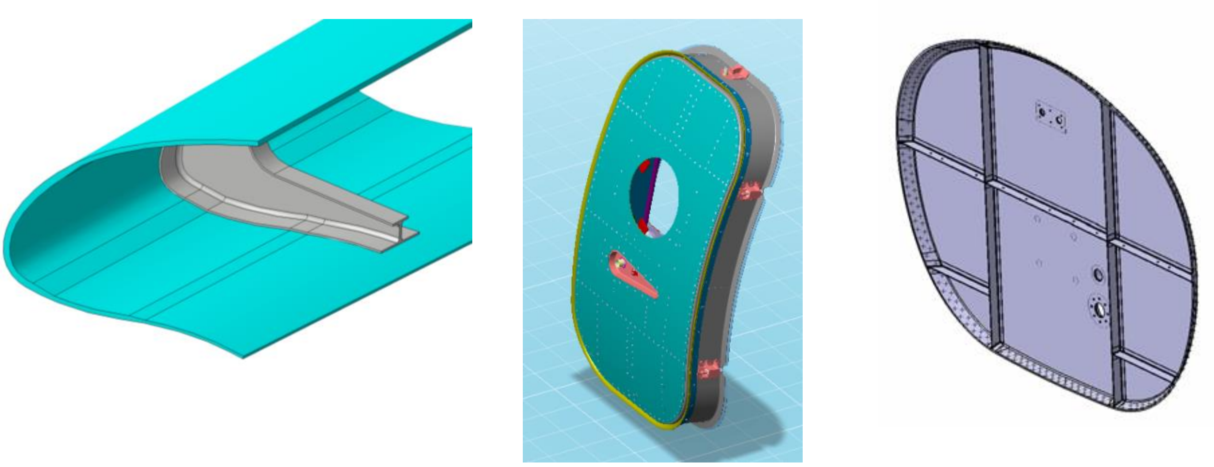
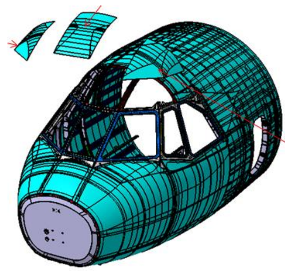


Figure 10: Illustration of complex shape elements proposals

6. Assembly Techniques

In a further step new assembly strategies have been studied to introduce same cocepts of ecoefficiency and cost saving into this sceneario. Research has been done to be directly aplicable to the different demostrators being produced. Some techniques have been explored on MT1 & MT2 cockpit demostrators meanwhie other have teken place during external wing assembly in CS2



- Assembly processes based on external skin datum
  - Cockpit Demos
    - MT1
    - MT2
  - External Wing of FTB#2

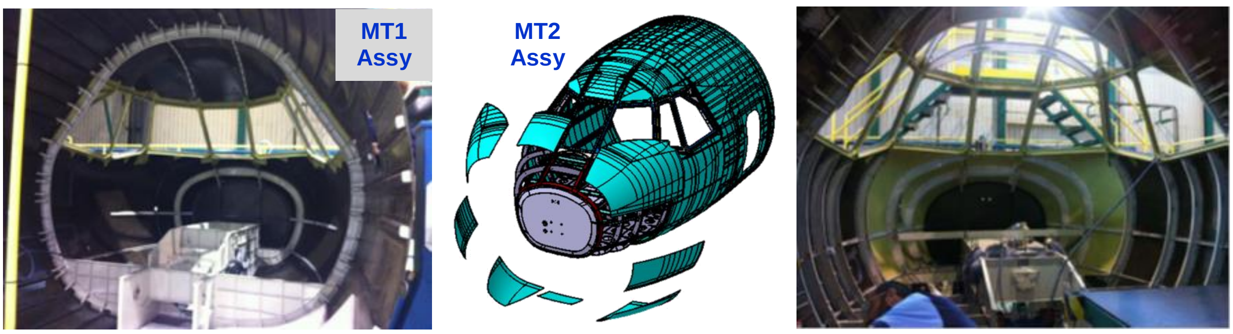


Figure 10: Illustration of MT1 & MT2 Assembly

- Assembly of the structures and Cost-effective processes through the development of Jig less methodology by minimizing the use of ancillary / auxiliary industrial means

  Two different streams have been declared, tested and concluded:

  - **Jig less** methodology based on **reverse engineering**
  - **Jig less** methodology based on **co-ordinated and semi-coordinated holes**

DOI: 10.13009/EUCASS2019-652

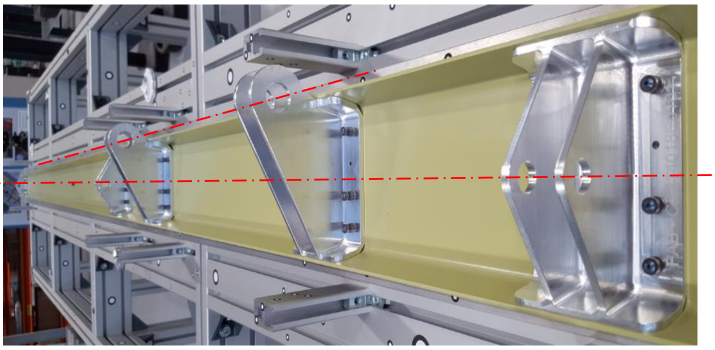


Figure 11: Illustration of **Jig less** methodology based on **reverse engineering**

7. Testing Technologies

Many technologies useful for testing measurement are being investigated to get enough maturity and reliability for practical use into the analysis:

- Interferometry (DIC)
  - Multi-impact mid energy testing
  - Vibrational testing
- Thermography
  - NDT application
  - Structural behaviour in hot environment
- SHM sensors and measurement techniques
  - Fiber optics FBG (Fiber Bragg Grating)
  - OBR (Optical Becjscatter Refectometry)
  - MEM´s
- p-U acoustic (pressure-velocity based in situ absorption measurement method)

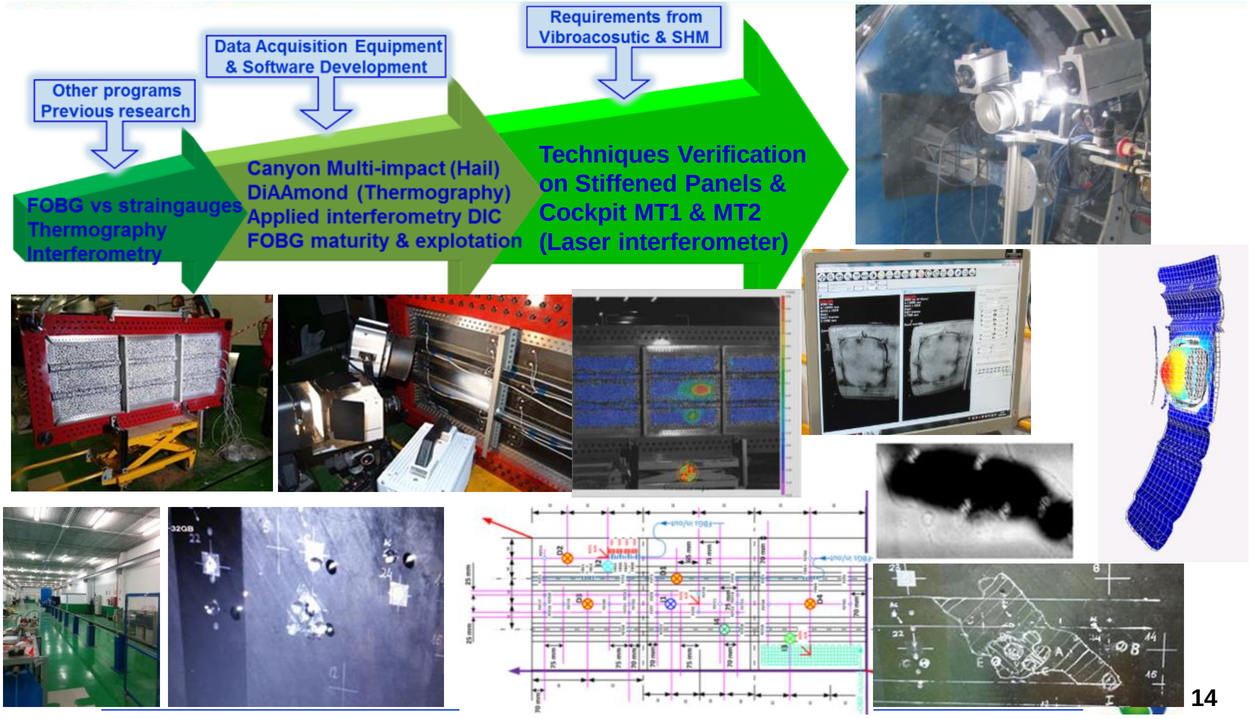


Figure 12: Illustration of manufacturing techniques that have been surveyed

DOI: 10.13009/EUCASS2019-652

8. Verification and Qualification Tests

- Mechanical (Strength /Fatigue/Damage Tolerance/Residual Strength)
- Vibroacoustic
- SHM Event/Damage Detection
- EMC

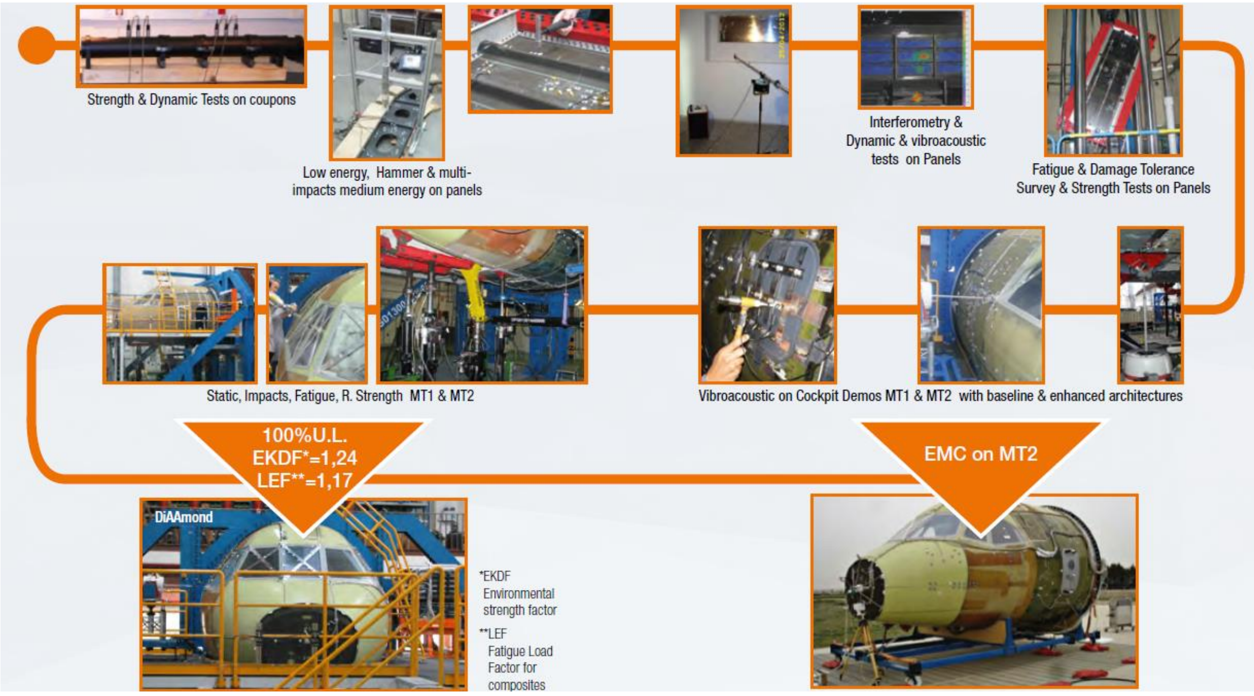


Figure 13: Illustration of testing activity carried on Clean Sky1

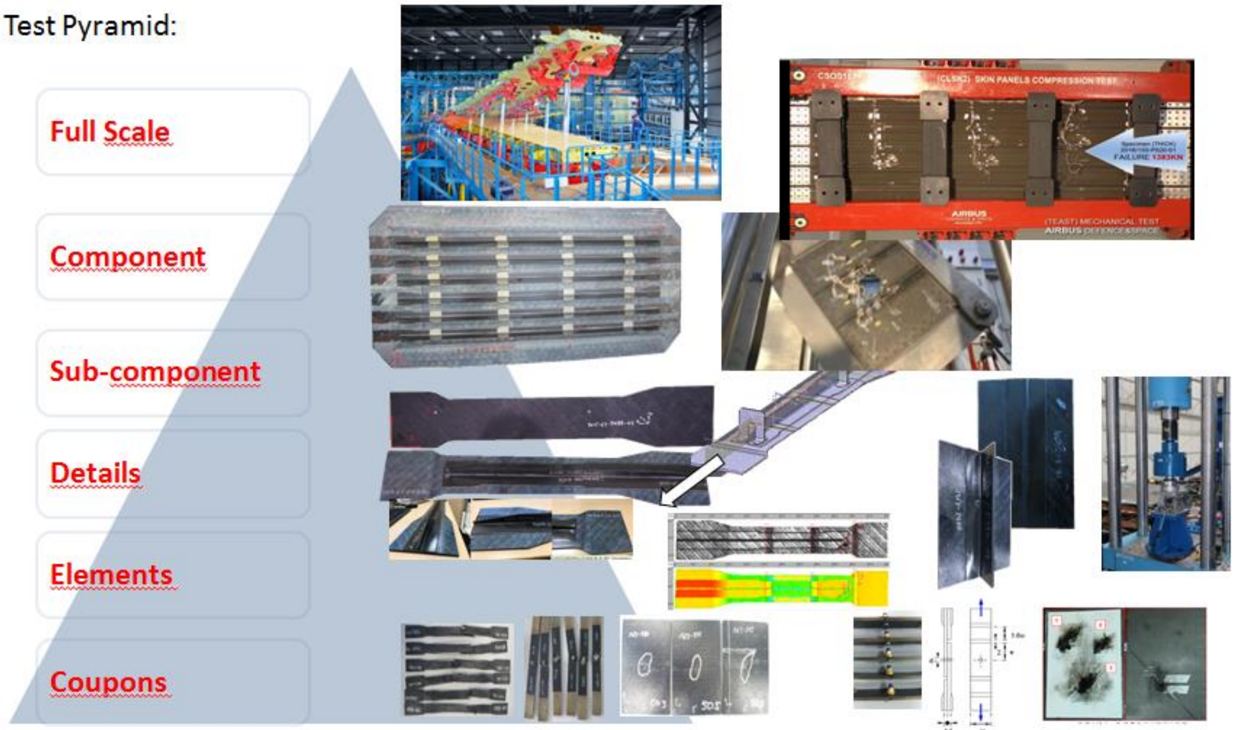


Figure 14: Illustration of “External Wing FTB#2” Test Plan

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9. Acknowledgments

All of what has been previously described has been achieved due to the commitment and professionalisms of the Airbus Defense and Space (ADS) Design, Stress, Manufacturing and Structural Test Engineering teams working in the project conceiving, designing, sizing and testing the demonstrators and the components described in this article. Also becomes result of a close collaboration with a great set of partners and outsources, some of them coming through CfP both in CS1 and CS2 as NLR/Airborne, APPLUS or MTORRES, others as CORE Partners consortiums in CS2; OUTCOME, PASSARO, EWIRA.
Special mention has to be raised to FIDAMC, close to ADS and significantly involved in all the technologies being developed in regard with composite material and their manufacturing processes.

10. References

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