1 General Introduction
The ESA Future Launchers Preparatory Programme (FLPP) is the basis for new paradigms, investigating the key elements, logic and roadmaps to prepare the development of the European Next Generation Launch Vehicle (NGL). The NGL has to be flexible enough to cope with new missions - in addition to conventional GTO or SSO - as well as with the evolving payloads market. This achievement is broached studying three main areas relevant to ELVs: system concepts, propulsion and technology, containing structures development.

The wide range of advanced ELV concepts and their corresponding vehicle architectures introduces a number of ‘top-down’, systems perspective design requirements which correspond to a variety of structural concepts and relevant technologies. Technology ‘bottom-up’ approach is also addressed. The composite structure developments presented here are performed within the ESA FLPP and GSTP programmes.

In parallel with the hardware development, supporting processes are also developed, such as NDI. For this, a specific paper is presented separately at ICCM19; “DETECTION OF DEFECTS IN COMPOSITE STRUCTURES WITH 3D LASER VIBROMETER”, P. Pérès, D. Barnoncel, W. Staszewski

In this paper, we will present innovative research on composite material structures and show an extended application range for composite materials and novel design concepts for launcher applications. This includes both unpressurized structures as well as pressurized cryogenic propellant tanks.

2 Pressurized CFRP Cryogenic Tanks
The cryogenic propellant environment increases the complexity for the development of composite material structures. Topics like material compatibility with oxygen and hydrogen, permeability, and internal thermal stresses requires additional effort in development and verification. NDI methods have to be developed and verified to more stringent requirements.

Micro-cracking of composite materials has to be managed to guarantee compliance with leakage requirements.

ESA performs development activities for both thermoset resin composites as well as thermoplastic resin composites for cryogenic propellant tank applications. Complementary studies on liner technologies are also performed.
2.1 Cryogenic Thermoset Propellant Tank

Subscale demonstrator representative of the LH2 compartment of the propellant tank is established for technology and manufacturing demonstration.

Technological challenges:
- Cryogenic propellant compatibility of thermoset resin systems: Materials screening and characterization including permeability tests.
- CFRP main joints including open holes, Y-interface, etc.
- Non-metallic liners based on tailored thermoset resin and high aspect ratio nanoparticles for improved leakage barrier properties.

For this activity a material screening of 8552/IM7 vs M21E/IMA has taken place. Following material development tests have been performed:
- LOX Compatibility tests
- Permeability tests (R.T. & LN2)
- Cryogenic mechanical characterization tests (4K).

First test articles have been identified, manufactured and tested in order to have a first set of material properties for the structure and material configuration chosen.

<table>
<thead>
<tr>
<th>Test Articles</th>
<th>Load</th>
<th>Number of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edgenise compression test</td>
<td>Compression</td>
<td>10</td>
</tr>
<tr>
<td>Standard panel</td>
<td>Core Edgenise cross sectional</td>
<td>10</td>
</tr>
<tr>
<td>Standard panel with monolithic end</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Test articles representative of the lower interface</td>
<td>Tensile</td>
<td>2</td>
</tr>
<tr>
<td>Test articles representative of the Y joint</td>
<td>Compress</td>
<td>2</td>
</tr>
<tr>
<td>Test articles representative of the cover locking inserts</td>
<td>Pull</td>
<td>5</td>
</tr>
<tr>
<td>Test articles representative of the X joint</td>
<td>Shear</td>
<td>6</td>
</tr>
</tbody>
</table>

Then breadboards have been identified, built and tested in order to obtain the MoS to be used in the analysis predictions in the final tank demonstrator FEM.
- Flat panel representative of the lower I/F
  This is an angular Breadboard manufactured by hot forming.
- Flat panel representative of the lower skirt
  This is a standard sandwich panel (with an aluminium core) with a monolithic end.
The thickness increases from the center to the contour. This increment has been realised with non-continuous layers. The cover has been manually layer with laser light guidance to place each CFRP stripe.

- Flat panel representative of the union of the cover with the skin
- Flat panel representative of Xring
- Flat panel representative of the liner

Permeability tests have been done on the base CFRP material (in the chosen lay-up) and on the configuration material+liner. The results of those have identified that the base material has a low permeability to liquid Helium, therefore the demonstrator will be without a liner.

Currently successful manufacturing of a first tank has been performed at EADS CASA ESPACIO via hand lay-up on a male detachable tooling.

After curing and tooling extraction, the tank has been submitted to an ultrasonic inspection and to a dimensional inspection and finally machined to its final shape and dimensions.
The process for produce the subscale tank will be Fiber Placement. It seems the most appropriate process, since it can be laminate the cylindrical part and the domes in one shot.

The laminate-curing tool is collapsible and can be dismantle in small pieces through the axes. This characteristic makes possible laminate with the cylinder and the domes in one single part.

The proposed tests to be performed on the tank are:

- Pressure loads
- Static mechanical loads
- Static mechanical loads + Pressure loads
- Thermal tests

The primary loads are introduced in the tank by the interfaces. Some different load cases will be applied in order to check different environmental conditions.

The main objective of these tests is to check the technologies implemented on the produced scaled demonstrators.

Achievements:

- Material characterization in cryo environment
- Design and analytical verification of full scale cryo-tank and demonstrator tank.
- Successful demonstration of one shot manufacturing of tank demonstrator with integrated interfaces.

Target TRL 3-4 at the completion of the activity, 2013.
2.2 Cryogenic Thermoplastic Propellant Tank

Thermoplastic Composites provides a big performance potential in cryogenic applications due to the superior toughness compared to thermoset resin composites.

Technological challenges:
- Material characterization incl. cryogenic environment and permeability
- Development of Induction Welding and Amorphous Interlayer Bonding.
- Process development and characterization by sample tests and breadboards
- Sub Scale demonstrator tank, verified in test environment with pressure and external loads

Achievements:
- Material characterization in cryo environment
- Permeability characterization of material and joints in room temperature and LN2 temperature.
- Design and analytical verification of cryotank and demonstrator tank.
- Breadboard test programme with analytical model correlation
- Tank cylinder manufacturing by automated fiber placement with in-situ consolidation.
- Permeability test campaign on demonstrator subcomponents as well as assembled tank.

3 Unpressurized CFRP Structures

Development of unpressurized CFRP structures are focuses of mass optimization, cost reduction as well as AIT simplification by a higher level of integration. Several activities are running focusing on technology maturation for new materials, processes an design concepts.
3.1 Thermoset Interstage Structures

A new design concept has been realized by novel manufacturing methods. A subscale demonstrator structure will be subjected to qualification-like verification campaign.

Technological challenges:
- Implementation of new materials to assure low cost and to guarantee the supply in the long term.
- Co-curing of the “Omega” stringers and the skin in only one shot
- I/F rings obtained by integrating RTM pieces in a cylindrical shell, co-bonding with the entire structure in shell curing process

The material used is M21E/IMA except for the circumferential stringers, which are in fabric 8552. Following breadboards have been produced:
- Flat panel with 3 omega stringers
- Lower integrated ring with 90 degrees fibers
- Lower integrated ring with RTM wedge
- Lower integrated ring with 2 omega stringers

Integrated CFRP Interface in interstage structure

A demonstrator of 1.2m height and 2m diameter is under manufacturing at the moment.
Tool for the lay-up and curing of the full barrel has been finalized.

A first caul plate has been laminated and cured.

After demonstrator manufacturing and assembly, a stiffness test and a strength test will be finally performed.

Achievements:
- Successful manufacturing demonstration of a novel manufacturing method with co-curing of omega stringers and integrated bolt interface.
- Demonstration of very high load carrying capability for integrated bolt interface in CFRP.

Target TRL 5 at the completion of the activity, end 2013.
3.2 Thermoplastic Interstage Structure

Subscale demonstrator subjected to qualification-like verification campaign.

Full scale design

Technological challenges:
- Automated fiber placement, AFP, with in-situ consolidation, on integrally heated tool.
- Assembly of stringers by Induction Welding or Amorphous Interlayer Bonding, AIB.
- Development of new tooling concept for integrally heated layup tool for AFP
- Breadboard test campaign for development and specific features such as access hole, equipment attachment point
- Secondary bonding of thermoplastic laminates using tailored epoxy chemistry and surface pretreatments.

Omega stiffener in CFRP/PEEK

Automated Fibre Placement with in-situ consolidation

Induction welding test sample

Target TRL 5 at the completion of the activity, 2015
3.3 CFRP Engine Thrust Frame

For optimization of Upper Stage structure mass, a development of CFRP Thrust Frame. New manufacturing methods for stringer stiffened skins is being developed as well as a CFRP End Cap manufactured by RTM. Subscale demonstrator on Breadboard level for different panel concepts as well as End Cap.

Technological challenges:
- Large temperature gradients and severe environments on the cryogenic upper stage.
- Automated fibre placement for stringer stiffened cone structure with one shot manufacturing.
- RTM Manufacturing of end cap

A panel development programme for both thermoset and thermoplastic resin systems has been performed both for manufacturing process developments and optimization, as well as a characterization with mechanical breadboard testing for the different concepts.

Achievements
- Full scale design and analytical verification of CFRP Thrust Frame
- Manufacturing demonstration of one shot manufacturing method for stringer stiffened panel.
- Subscale verification tests on panels and end cap.
- Mathematical model correlation for subscale test campaign

Target TRL 3-4 at the completion of the activity, 2013. A follow on activity with full scale tests to TRL 6 is under initiation.
3.4 Out-of-Autoclave Processing of large Thermoplastic Structures.

This activity is dedicated to development, manufacturing and testing of an upper stage tank/payload cone/equipment bay interface Y-ring, using 3D CFRP preforms together with RTM technology.

Technological challenges:
- Design and manufacturing of 3D advanced preform(s)
- Compilation of engineering data from testing samples
- Detailed design of the Y-ring after selection of a suitable preform concept in a trade-off
- Manufacturing and testing (under flight loads) of a sub-scale 360 degree demonstrator

Achievements:

After characterization and manufacturing trials on Breadboard level, a full scale demonstrator will be built and tested.
The target TRL of this activity is 5, in 2014.
3.5 Out-of-Autoclave Processing of large Thermoplastic Structures.

Manufacturing out-of-autoclave and out-of-over reduces investment cost and is the results from the studies show that material properties can reach promising levels. This activity was based on large panel manufacturing demonstration with performance verification on smaller Breadboard hardware.

Technological challenges:
- Processing out of autoclave/oven
- Integrally heated tooling
- Vacuum bag only, no external pressure
- High laminate quality and strength
- 2 m² manufacturing demonstration, curved stringer stiffened panel.

4 Future activities

Development of unpressurized CFRP structures are focuses of mass optimization, cost reduction and AIT simplification. Several activities are to be initiated focusing on technology maturation for new materials, processes and design concepts to pave the way for Ariane 6 and future European Launch Vehicles.