OPTOCOM

Grant Agreement number
323384

Project acronym
OPTOCOM

Project Title
Optimal Tooling System Design for Large Composite Parts.

Funding Scheme
JTI-CS-2012-01-GRA-1-049

Date of latest version of Annex I against which the assessment will be made:

2014-01-14

FINAL PUBLISHABLE SUMMARY REPORT

Period covered:

From December 2012 to July 2014

TABLE OF CONTENTS

TABLE OF FIGURES

1 Final Publishable Summary Report

1.1 Executive Summary

This document describes the steps FIDAMC has gone through to fulfil OPTOCOM project in terms of actions that have been taken and its chronology.

OPTOCOM Project, which full title is “Optimal Tooling System Design for Large Composite Parts” is a FP7 project of 12 months (extended to 15 months), which began on December 2012. The project is related to the Call for Papers of Clean Sky: SP1-JTI-CS-2012-01. It is being developed in the frame of the Green Regional Aircraft programme and its activity code is: JTI-CS-2012-1-GRA-01-049.

OPTOCOM consortium is composed of just one partner: FIDAMC, a research institute located in Spain that acts as coordinator.

The general objective of the project is to smartly handle the overall process of the composite integrated parts production reducing costs in two ways. First, by adequately simulating the spring back produced after the curing process and providing solutions in order to reduce the costs of reworking or assembly. Secondly, by simulating the thermal model of the set tooling/composite-part/vacuum bag and auxiliary parts under autoclave conditions to optimize the cure cycle temperatures distribution creating more uniformity in the composite part, lower residual stress, lower energy costs and better environmental friendliness. Given the large number of parts produced and their growth, the importance of the target is large.

1.2 Summary description of project context and objectives

First specific objective of the OPTOCOM project is to carry out all the necessary steps to design and manufacture large tool for a composite complex structural part, typically a single or double curvature fuselage stiffened panel with co-cured or co-bounded stiffeners of about 2x1sqm. The stiffening elements shall be of both “T” type and “Ω” type cross section. Requirements such as high accuracy and rigidity, typical autoclave conditions, CTE matching, durability, minimal weight, provisions for transport, handling and accessories integration for easy demoulding, shall be imposed.

Second, is to develop analytical and FEM models which adequately simulate the distortions and spring back occurring in the curing process. This requires to establish the correct hypothesis and to obtain real material performance behaviour both along the curing process (at different curing states) and when the composite is cured, in order to be introduced into the model.

Third, is to set up FEM simulation models to assess the thermal behaviour and temperature evolution of the set of elements that get in the autoclave in order to optimize the thermal ramps and maps in the composite part in order to obtain quickest possible cycles.

Finally, an analysis of the design and manufacturing tooling costs to assess benefits and procedures is made.

1.3 **Preliminary Works** (July – December 2012)

Preliminary stages were covered with discussions on the documentation needed to opt for the EC grants and compiling technical information about state of the art in composites an aeronautical manufacturing tooling and manufacturing.

Although FIDAMC has worked previously in other European projects, personal involved in this one has not. The person that prepared the offer retired and there was a transition period in order to understand the offer scope and to compile the financial data, grant agreement and legal issues, negotiation report and fulfill the preliminary data on the NEF web facilities.

Several phone and mail conversations with the topic manager concluded with the kickoff of the project in December 2012.

Figure 1: EC Web Facilities Screen Capture

1.4 **Organization of Works and Stages** (December 2012 – March 2014)

To meet the objectives of the project, work has been split up into work packages according the areas described before this greatly reduces the overall project risk. This approach also requires a maturation of the overall objectives which must be tuned to the final purpose: to get optimal tools designs where a minimum post-cure warpage is achieved and minimum cure cycle energy is involved.

Therefore the strategic path to achieve the objective has three stages:

- **First stage**, to establish all aspects for the conceptual design of the tooling to be performed (pre-design of the backing structure, minimum thickness of the Invar plate to be machined to final shape, dimensions of the elongated holes on the invar plate to permit the thermal expansion of the backing structure without interfering the stability of the Invar plate, definition of the pieces between back structure and invar plate reducing the friction produced, etc.). Two different versions of tooling were considered: Invar plate with a steel eggcrate backing structure joined by antifriction plates or invar plate and backing structure joined by tensor bars (adjustable bolts). This was preferred as it allows small adjustment to the surface without re-machining.
- **Second stage**, to develop analytical and FEM models providing or adequately simulating the distortions and spring back occurring in the curing process for what is necessary to establish the correct hypothesis of material performance both along the curing process and when the composite is completely cured. In this phase is critical to get the characteristics and evolution of the viscosity, elastic modulus, tangent modulus, etc, of the resin along the curing process.
- **Third stage**, a FEM simulation will assess the thermal behavior and temperature evolution of the set tooling/composite/vacuum bag to derive data to the structural models of distortion.
- **Fourth stage**, to dump all the innovative experience of the previous steps to design and manufacture a tool capable of meeting the objectives of the proposal.

Division in work packages is closely related to those stages breaking up the project in:

- WP1: Tool Concept Design
- WP2: Springback Simulation
- WP3: Tooling Thermal Behaviour
- WP4: Design, manufacturing and QC of tooling
- WP5: Detailed Cost Analysis
- WP6: Project Management

2 Core of the Report: Objectives, Work Progress and Achievements

Although it was intended to, work packages have been completed not necessarily in the order exposed before.

2.1 Project Objectives

Next paragraphs summarize the objectives related to each of these work packages:

WP1: Tool Concept Design (start-end: M1-M6)

To make an approach of the tooling conceptual design including all accessories and materials required and to establish a pre-dimensioning providing design input to simulation models.

The typical Invar rough plate thickness for this kind of tooling is half inch (12.7 mm) to ensure the capacity or possibility to modify or repair it adding an excessive mass. The approach study shall try to reduce that figure in order to get better thermal behavior and cost.

WP2: Springback Simulation (start-end: M3-M15)

To understand how all aspects of the curing process and the material state change influence the spring back and give solution to improve the fitting of the final shape of the composite component to the theoretical one.

WP3: Tooling Thermal Behaviour (start-end: M5-M11)

To optimize the design of the tool in order to:

- Have a distribution of temperatures as uniform as possible to reduce curing residual stresses.
- To save costs and time by minimizing the tooling mass, reducing autoclave energy requirements, improving the heating rate and shortening the curing cycle.

WP4: Design, manufacturing & QC of Tooling (start-end: M1-M12)

They are to design the overall tooling in accordance with the conceptual design and the conclusions of the springback and thermal models, to manufacture it and to perform the tooling quality control including the measurement of the face profile within the limits to be agreed with the Topic Manager.

WP5: Detailed Cost Analysis (start-end: M14-M15)

The conclusions of all the before work shall be applied to make an assessment of the life cycle cost and time savings to produce optimal toolings. This will include all the steps of the cost and enhance the differences in selecting optimal and non-optimal solutions.

WP6: Project Management (start-end: M1-M15)

The main objective is to set up and provide the project management coordination to ensure that the timing planning, technical objectives, costs and contractual conditions of the project are reached.

2.2 Work Progress and Achievements

WP1: Tool Concept Design (start-end: M1-M6)

In order to start working on the project it was needed to decide the kind of part to be manufacture and design it with a little more detail to be able to start with the pre-design of the tooling and modeling of the FEM archives. The other important part was to define materials that were going to be used.

In Deliverable D1.1 (Ref. 02), state of the art in composite manufacturing tooling was studied, concluding that main tool plate and supporting structure could be analyzed almost independently. A first idea on adaptable mould surface was advanced. Afterwards, this turned to be the one chosen as conveniently separates both parts of the tooling and have some controlled variability for the wanted final part geometry and its final shape was not so dependent on the FEM results of the following studies.

In order to get most of the wanted specifications for the tool (accuracy, rigidity, resistance, matching CTE, durability…) material chosen for its construction was decided to be mostly INVAR 36. For temperatures below 400ºC its CTE is very close to the one of carbon fiber.

With respect to the material to be used for the final part, some of the most commonly used and commercially available were taken into account. After some time trying to obtain all data needed to characterize it, some legal issues related to confidentiality appeared. These caused important delays in subsequent works packages, as that data was needed to model and perform FEM simulations. Finally, deliverable D1.2 (Ref. 03) with material characterization was finished including INVAR 36 as material chosen for the tool and HEXPLY M21/34%/194/T800S-24K from Hexcel for the part to manufacture.

WP2: Springback Simulation (start-end: M3-M15)

At a certain point during the project, because of the problems for characterizing the material and the delays for that part of the project, it was decided to simulate but also physically manufacture several different coupons (small versions of the final part) and compare results in order to adjust them. Some of those coupons intentionally changed one of the plies in its lay-up to obtain a forced deformation.

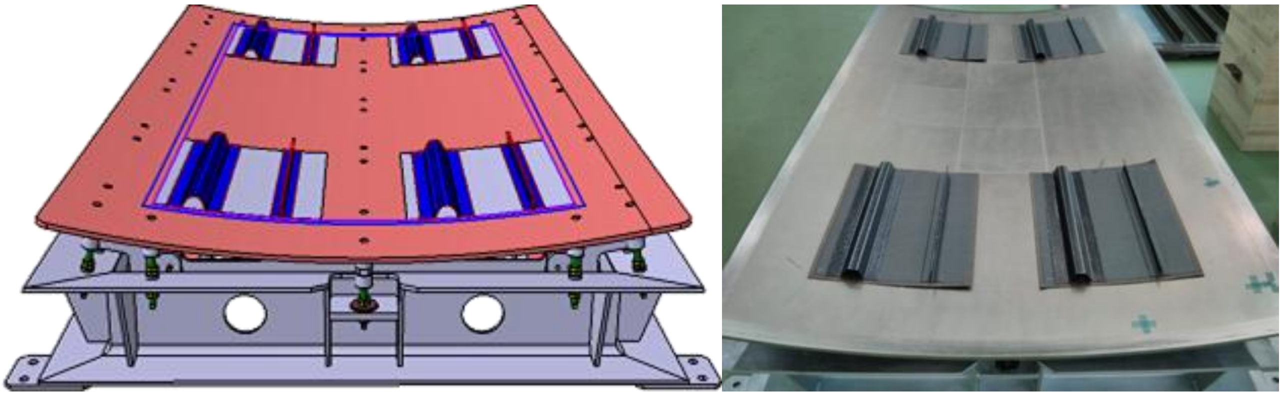

Figure 2: Coupon Manufacturing

This process took much more time than that that was estimated and this was one of the reasons that lead for the decision of design and manufacture an adaptable tooling, as this will bring the benefit of once it is manufactured, a redesign or rework is not needed to adapt it in order to obtain desired final part geometry with some independency of the FEM results.

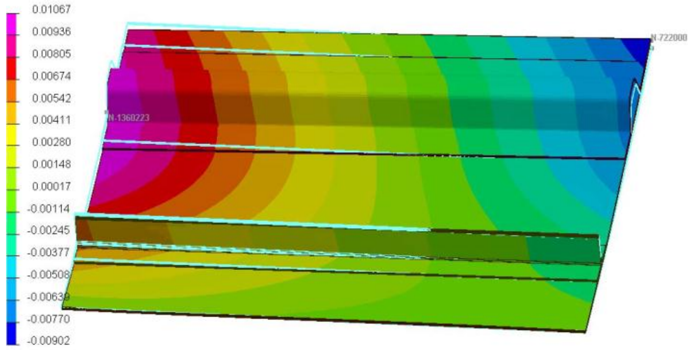

Figure 3: Nonsymmetrical coupon on tooling

Deliverable for this work package, D2.1 (Ref.10) took a long time to be compiled, as FEM simulations did not work properly and did not converge at the beginning. Some data for the material had to be revised (MKamal-Sourour kinetic model, DeBenedetto equation…)

An approach was first performed with smaller coupons that were also manufactured to prove validity of simulations and afterwards with the final part. Some of them designed with differences in skin lay-up. Variables in boundary conditions and homogenizing or not material and meshes were taken into account.

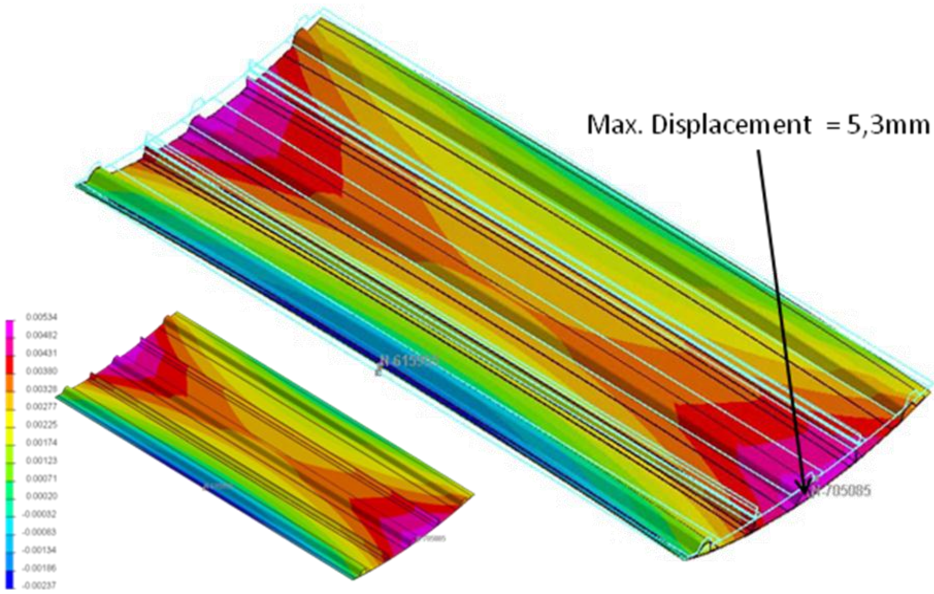

Figure 4: Final part simulated

General conclusion is that that FEM simulations give good qualitative results, but there is an uncertainty factor in quantitative ones. Simulations can predict distortion behaviors, but still need more work and trials to get more accurate values.

WP3: Tooling Thermal Behaviour (start-end: M5-M11)

As a preliminary design of the tool was done, conversations with the FEM team brought some small changes in it, so, final tool was actually manufactured before finishing simulations. The good thing about this was that FEM result could be compared with real ones. FIDAMC included in deliverable D3.1 (Ref. 05) a thermal mapping that was performed with an autoclave cycle.

Two different FEM models were made with 2D and 3D elements resulting with great difference in the number of nodes (calculation times) both obtaining very similar results: during the autoclave cycle there is a very small deformation of the tool (less than a millimeter) and the tool is heated and cooled very uniformly with no significant temperature difference between different points. The thermal mapping confirmed that uniformity.

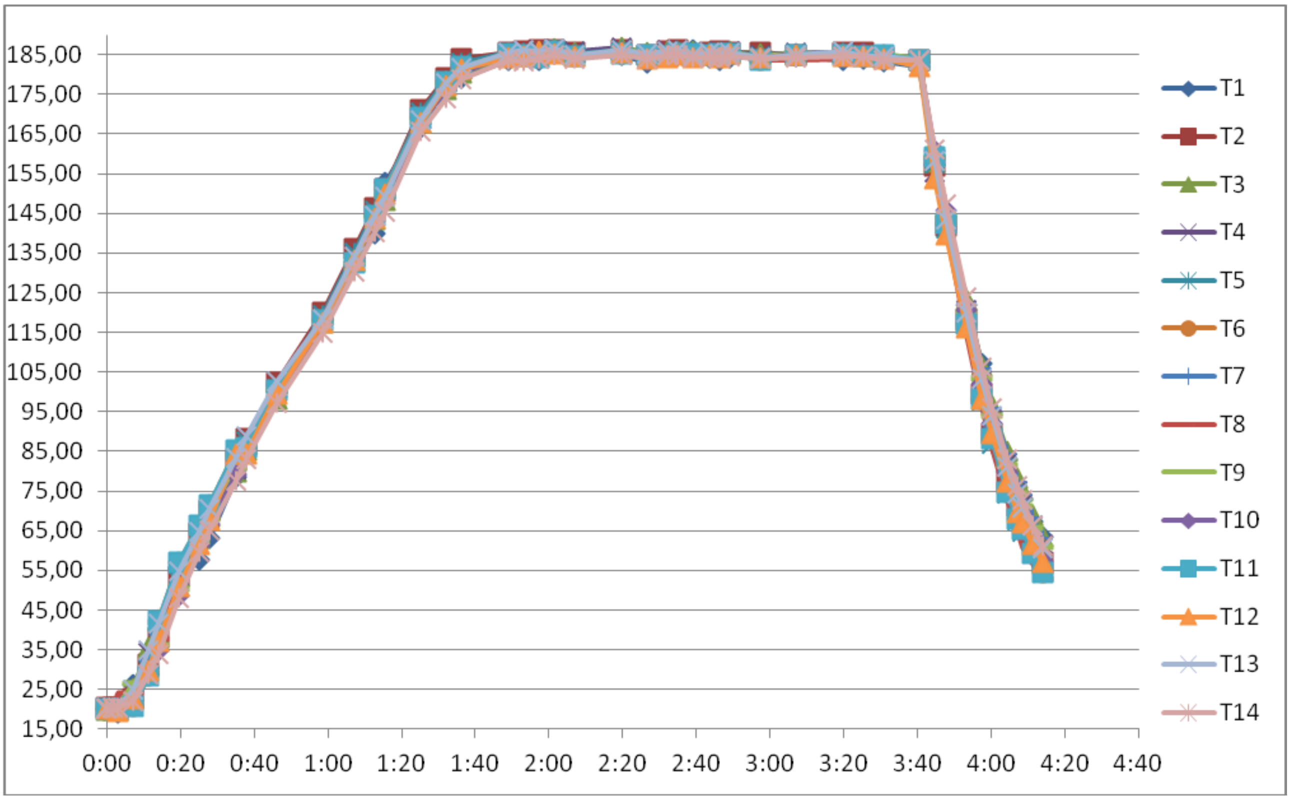

Figure 5: Tool thermal mapping with 14 thermopairs during autoclave cycle

WP4: Design, manufacturing & QC of Tooling (start-end: M1-M12)

As this is considered to be the core for this project, a pre-design of the tooling was done in very early stages, and although several approach were taking into account, due to the problems and delays in WP1, it was soon decided to design and built a tool with a great degree in adaptability in order to have less dependency on the FEM simulations results to modify or having to rework it.

Mostly in Invar 36, OPTOCOM tooling consist on a main mould tool plate is supported by a backing structure by means of tensors that allow certain degree of modification for the surface so that it is possible to obtain slightly different final part geometries with the same tool.

Design was performed entirely over Catia V software. CAD models and drawings was attached to deliverable D4.1 (Ref. 06)

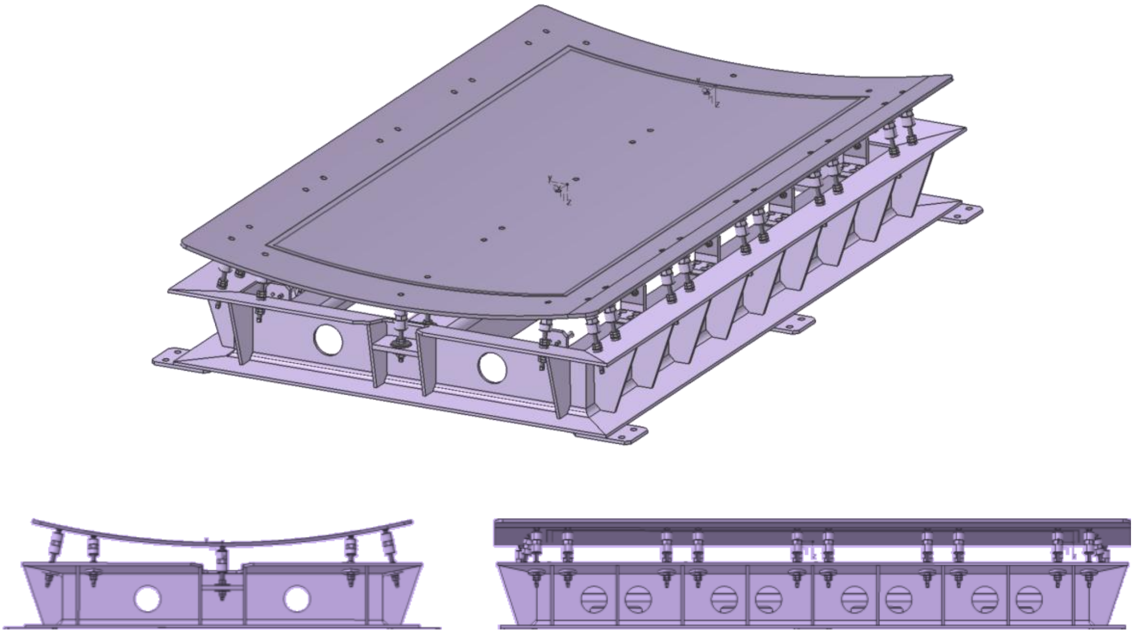

Figure 6: OPTOCOM tooling CAD 3D views

Once design was approved, tool was manufactured. Invar provision takes longer than other materials. Some delays in this work package did not greatly affect the project as the main bottleneck was dealing with material characterization explained in WP1.

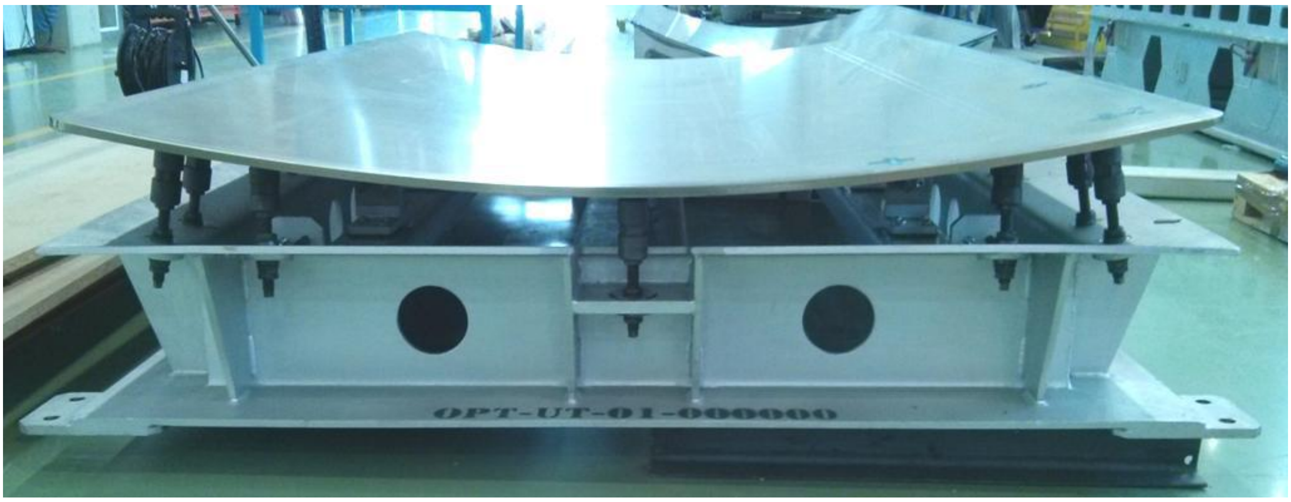

Figure 7: Final OPTOCOM manufactured tooling

In order to help the curing set-up position, backing structure can attach several templates. By manipulating tensors, main plate is driven against those templates to the desired position. Those templates can be easily machined if necessary.

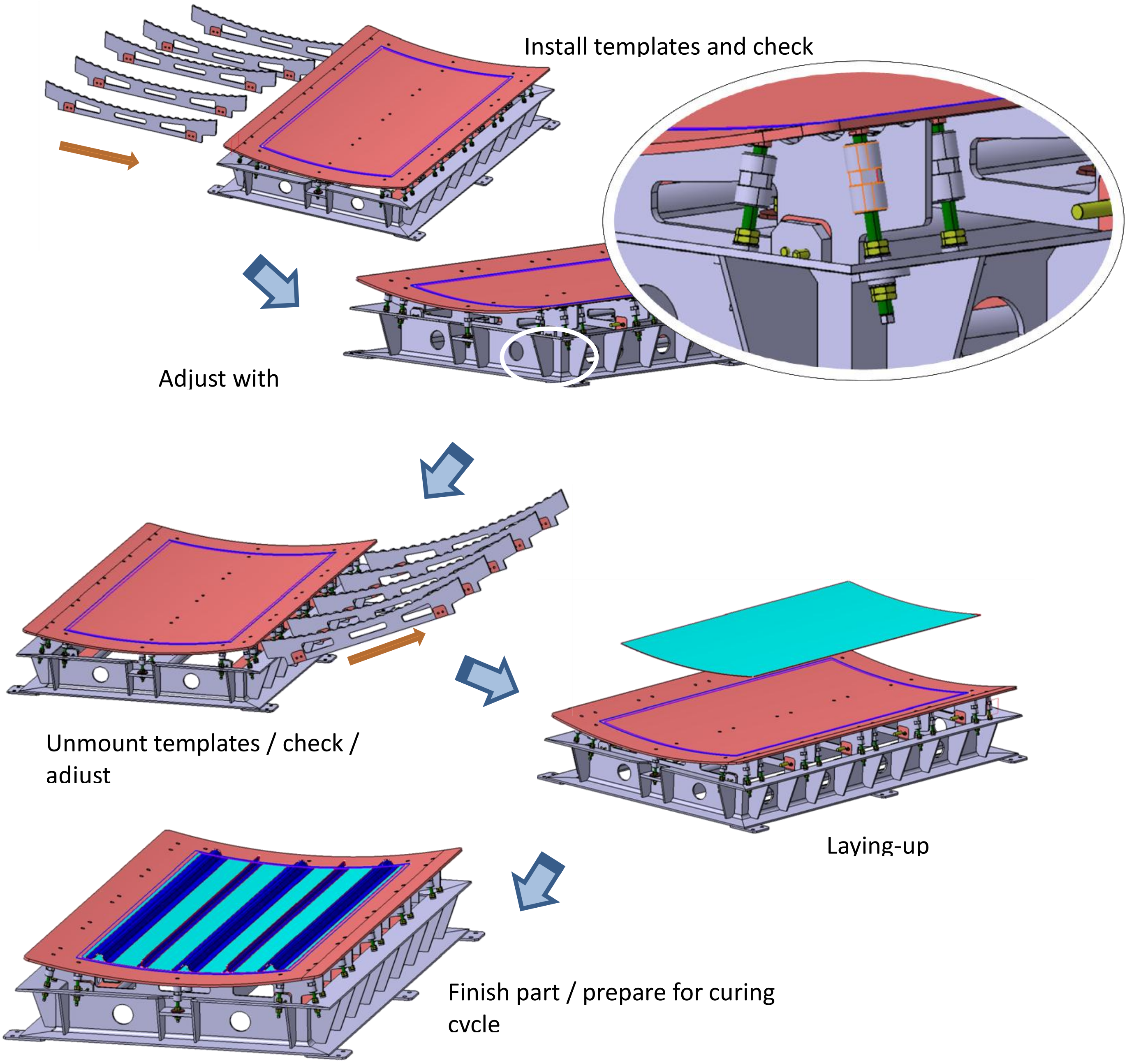

Figure 8: OPTOCOM manufacturing procedure

Only some minor changes were done, mainly holes to facilitate air and temperature flow in the supporting structure. Design, position and number of tensors are some of the points that have to be carefully studied depending on the geometry of the part to manufacture. It greatly depends on surface curvatures, but for aerodynamic surfaces this is usually smooth.

Deliverable D4.2 (Ref. 07) completed previous one by including quality documents and metrology of the manufactured tool.

Last deliverable for this package, (not included in preliminary steps of the project) deals with the manufacturing of a final part with the OPTOCOM tooling. Deliverable D4.3 (Ref. 09) documents that part and the processes taken to get it. This was performed to assure the whole process works properly.

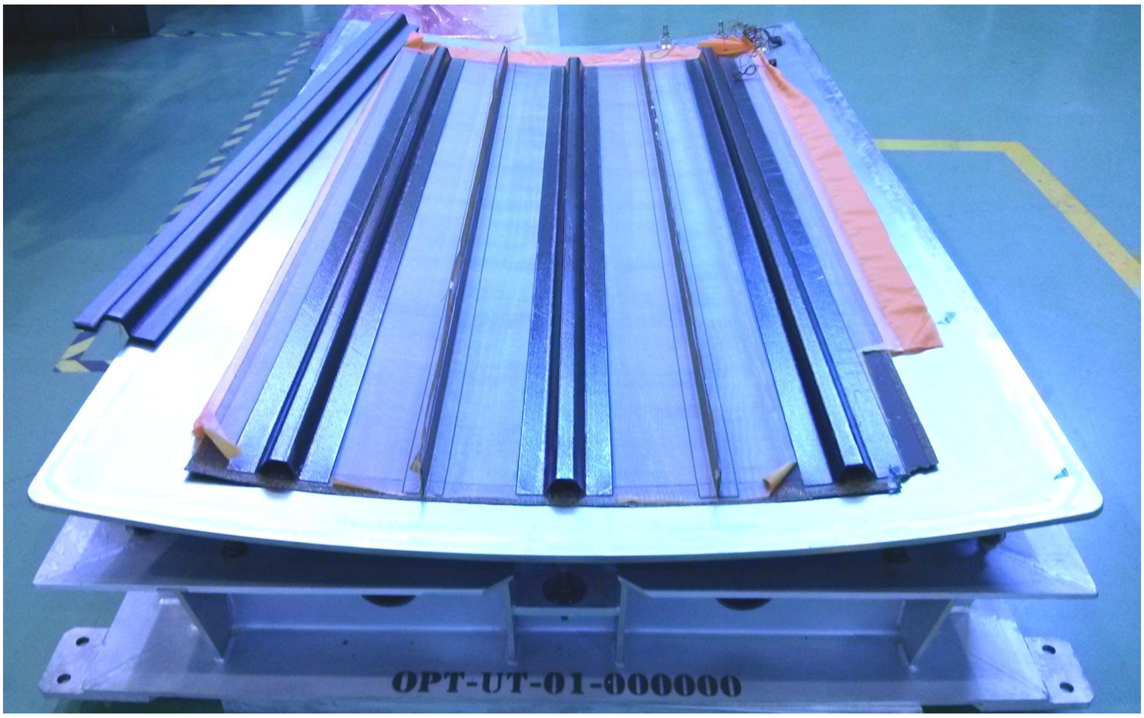

Figure 9: OPTOCOM manufacturing of final part

WP5: Detailed Cost Analysis (start-end: M14-M15)

In deliverable D5.1 (Ref. 10) some of the expected benefits in cost terms were described. Definitive numbers will depend much on the type and rate production desired, but OPTOCOM will bring benefits in all these aspects:

- Saving in autoclave and working hours
- Saving energy consumption
- Saving in CO2 emissions
- Saving in reworking and assembly times

WP6: Project Management (start-end: M1-M15)

Many activities were taken inside this work package including organization, coordination, monitoring progress, financial/administrative issues, communications and managing subcontractors.

In early stages of the project, deliverable D6.1 (Ref. 04) identified some of the risks than the project could find, its probability, impact and contingency plans.

A report of the whole project is described in deliverable D6.2 as well as this final report resume of all the actions taken.

With respect to dissemination of the project: each deliverable has been shared not only with Topic Manager (Mr. Dimitrios Habas from HAI), EC Cleansky Project Officer (Mr. Andrzej Podsadowski) and NEF web facilities, but also with EADS Airbus Innovations division.

OPTOCOM project has also been presented in several visits from people related with composites and aeronautical world at FIDAMC facilities, as the one by Mr. Sébastien Remy (EADS Innovation Works Director) during December 2013.

Also, a description of the work done till that moment was presented in December 2013 during an EADS Innovation Work workshop “Roadmap 120” celebrated in Munich (Germany).

2.3 Relevant Contact Details

Participant and coordinator web page (FIDAMC): www.fidamc.es

Project Manager: Mr. Aquilino García (aquilino.garcia@fidamc.es)

Project Coordinator: Mr. Alberto Mazarro (alberto.mazarro@fidamc.es)

Topic Manager: Mr. Dimitrios Habas (habas.dimitrios@haicorp.com)

EC Cleansky Project Officer: Mr. Andrzej Podsadowski (andrzej.podsadowski@cleansky.eu)

3 References

1. OPTOCOM DoW (part B)
   JTI-CS-2012-1-GRA-01-049-OPTOCOM(3) 14-01-2014
2. Tool Concept Design
   OPTOCOM-TR-01(1) 21-03-2013
3. Test Report
   OPTOCOM-EF-01(3) 17-06-2013
4. Project Risks
   OPTOCOM-TR-02(2) 17-07-2013
5. Tooling Thermal Behaviour
   OPTOCOM-TR-03(1) 10-01-2014
6. Design and Manufacturing Final Tool Structure
   OPTOCOM-TR-04(1) 11-02-2014
7. Quality Control Documents of the Final Manufactured Tool Structure
   OPTOCOM-TR-06(1) 28-02-2014
8. Cost Analysis
   OPTOCOM-TR-08(2) 04-04-2014
9. Quality Control Documents of the Final Manufactured Part
   OPTOCOM-TR-07(2) 07-04-2014
10. Simulation of the Springback of Final Composite Part
    OPTOCOM-TR-05(4) 02-07-2014