



Grant agreement no: 267679

Project acronym: *SMyLE*

Project title: *Shape Memory Alloy Leading Edge*

Instrument: *JTI CLEAN SKY*

Theme: *JTI-CS-2009-2-GRA-02-006*

## **SMyLE Activity Report**

Period covered: from *01 October 2010* to *31 December 2012*

Date of preparation: *26-03-2013*

Start date of project: *01 October 2010*

Duration: *27 Months*

Project coordinator name: *Dr. Theodoros Spathopoulos*

Project coordinator organisation name: *AEROTRON Research*

## TABLE OF CONTENTS

<b>Publishable Executive Summary .....</b>	<b>3</b>
<b>Figure 1: Graphical presentation of the components showing their interdependencies .....</b>	<b>4</b>
<b>Section 1. Project objectives and major achievements.....</b>	<b>7</b>
1.1 General project objectives .....	7
1.2 Project's relation to the state of the art.....	9
1.3 Project objectives, performed work, engaged partners and main achievements .....	10
1.4 Important problems and corrective actions .....	11
<b>Section 2. Workpackage progress of the period.....</b>	<b>12</b>
2.1 WP1 SMyLE architecture and mathematical modeling.....	12
2.1.1 WP overview on objectives, involved partners, planned work and manpower .....	12
2.1.2 Progress towards objectives.....	15
2.1.3 Deviations from the work programme, and corrective actions taken/suggested .....	21
2.1.4 List of deliverables and milestones .....	21
2.2 WP2 SMyLE experiment .....	22
2.2.1 WP overview on objectives, involved partners, planned work and manpower .....	22
2.2.2 Progress towards objectives.....	24
2.2.3 Deviations from the work programme, and corrective actions taken/suggested .....	32
2.2.4 List of deliverables and milestones .....	32
2.3 WP3 SMyLE post-experimental issues and recommendations for future work.....	33
2.3.1 WP overview on objectives, involved partners, planned work and manpower .....	33
2.3.2 Progress towards objectives.....	34
2.3.3 Deviations from the work programme, and corrective actions taken/suggested .....	37
2.2.4 List of deliverables and milestones .....	37
2.4 WP4 Model estimation for measured data interpolation .....	38
2.4.1 WP overview on objectives, involved partners, planned work and manpower .....	38
<b>Section 3. Consortium management.....</b>	<b>41</b>
3.1 Consortium management tasks and their achievements .....	41
3.1.1 WP overview on objectives, involved partners, planned work and manpower .....	41
3.2 Contractors .....	42
<b>Section 4. Other issues .....</b>	<b>43</b>
<b>Annex – Plan for using and disseminating the knowledge.....</b>	<b>44</b>
Part 1. Exploitable Knowledge and its Use.....	44
Part 2. Dissemination of Knowledge .....	46
Part 3. Publishable results .....	47

## **Publishable Executive Summary**

### **Project details**

<b>Project Title:</b>	Shape Memory Alloy Leading Edge - SMyLE	
<b>Project Logo</b>		<b>Coordinator's Details</b>
		Mr. Theodoros Spathopoulos AEROTRON Research E-mail: spaths@hol.gr Phone: +30-210-9826819 Fax: +30-210-9880310

### **Project summary**

SMyLE proposes a technological research program allowing to develop, manufacture and validate actuators by integrating a number of various emerging SMA technologies that result in high performance/ high reliability actuators. The innovative aspects of the proposed technologies are new SMA material concept with high power-to-weight ratio and high performance & reliability optimized for later application into a morphing/adaptive wing. Thanks to these new technologies, the SMyLE actuator system could contribute to lower mass (compared to a conventional mechanical/hydraulic actuator), be fully integrated (at a later stage) into the leading edge of an adaptive wing system.

The purpose of SMyLE is technology based on high performance material and optimized architecture and it is multifold. When applied to the LE of an adaptive wing (at a later stage), the following benefits are strongly evident, i.e.: at first, SMyLE can significantly improve the aerodynamics at the LE vicinity since it offers a greater operational envelope compared to a conventional LE slat device. Secondly, it can serve as deicing protection device, therefore eliminating heavy conventional, as well as electrically demanding, deicing systems. As third, it can be further utilized as a flight control surface replacement, locally improving the aerodynamics in the LE vicinity during flight.

### **Duration**

From 01 October 2010 to 31 December 2012

**Key objectives**

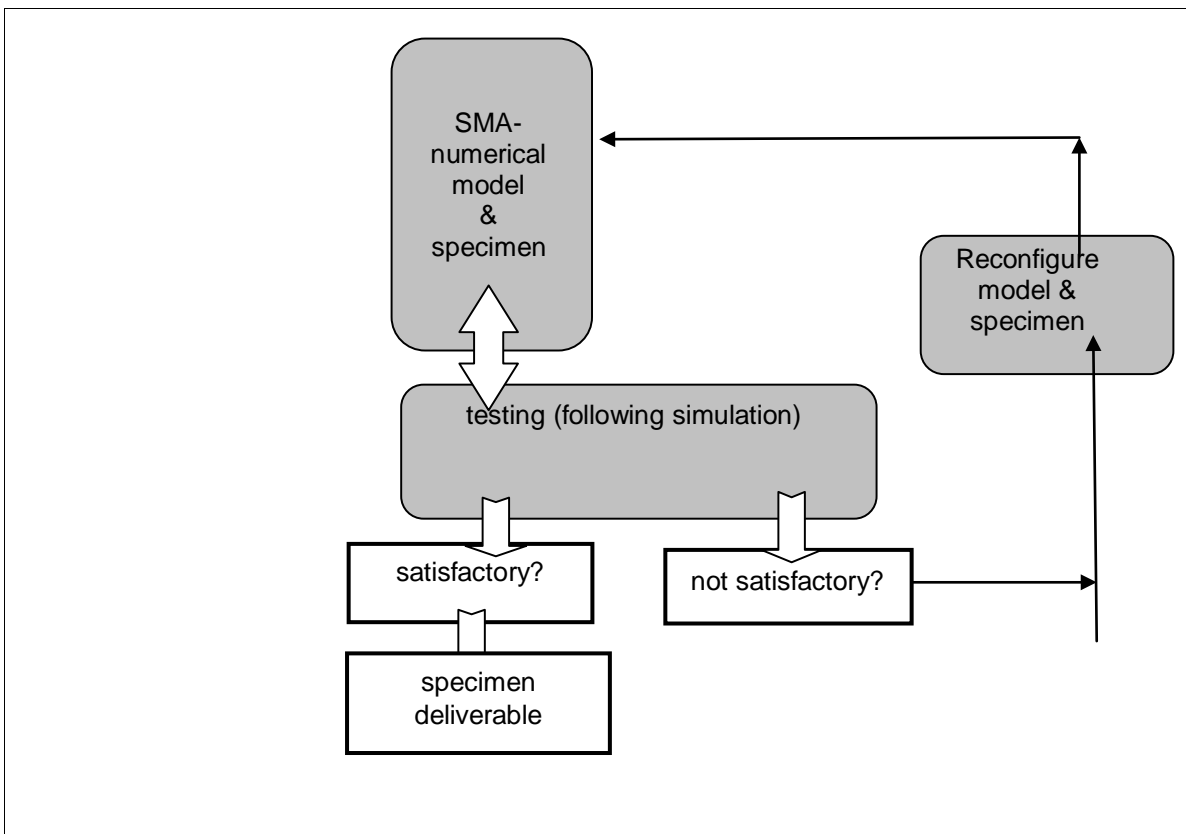
- Literature survey, SMyLE concept perception & architecture, loading conditions, SMA constitutive- and Finite Element (FE) model, surface response prediction, bonding issues
- Determination of experimental conditions, manufacturing of the SMA specimen, mechanical response of the actuator as a function of temperature & load and training
- Examination of specimen operation after testing, identification of aging and/or fatigue mechanisms, redundancy aspects, stability of material response under cyclic actuation at constant & differential stress levels, thermal-cycling experimental work, consideration of fail-safe issues
- Eventual model modification & specimen correction, final delivery of SMyLE specimen, recommendations for future work
- Modeling of mechanical behavior of the SMA actuated structures by appropriate analytical and numerical models

**Consortium**

	Partic. No.	Participant Name	Participant Short Name	Country
CO	1	AEROTRON Research	ARES	EL
CR	1	Integrated Aerospace Sciences Corporation (INASCO)	INASCO	EL

\*CO = Coordinator  
CR = Contractor

**Project Workpackage interdependence**



**Figure 1:** Graphical presentation of the components showing their interdependencies

## **Work performed**

The work has been organized in two reporting periods. The first period P1 from 01/10/12 to 31/07/12 and the second, P2, from 01/08/12 to 31/12/12.

In the first period of the project, the technical work was essentially completed in WP1 and WP2. Work is underway for WP3. Configuration of the SMyLE actuator principles have been proposed and analyzed and the Mechanical-, thermal-, electrical- and hysteresis aspects of the SMyLE actuator investigated. Manufacturing of SMyLE actuated specimen has been done and experimental evaluation has been performed.

In the second period of the project, the technical work was essentially completed in WP2 and WP3. Work was also finalised for WP4. Manufacturing of SMyLE actuated specimen has been done and experimental evaluation has been performed. SMyLE post-experimental issues have been considered and recommendations for future work described. In WP4, a model of simulating (that is obtaining the model output based only input values) the SMA deformation has been developed. The proposed NARX (Nonlinear AutoRegressive with eXogenous excitation) -based approach has been assessed through the application of this methodology to a representative case of a simulated composite beam, equipped with an active SMA layer.

## **Results achieved within the project**

The main output of the reporting period P1 was:

The literature review on SMA based actuators and relevant science and technology  
Choice of constitutive model, assumptions, simplifications and model's requirements, Finite Element (FE) model.  
Determination of experimental procedures for subsequent investigations  
Manufacturing of three different actuator concepts and numerical as well as experimental analysis  
Definition and execution of SMA wire training procedure for mechanical behavior stabilization.

The main output of the reporting period P2 was:

Determination of experimental procedures for subsequent investigations  
Manufacturing of three different actuator concepts and numerical as well as experimental analysis  
Definition and execution of SMA wire training procedure for mechanical behavior stabilization.  
Presentation of a complete methodology for identifying the SMA actuator dynamics based, exclusively, on experimental measurements, without the need of analytic modelling.

## **Final results**

The expected results are a lightweight novel electrically operated Leading Edge actuator with controlled shape configuration. It is expected that a family of actuator solutions can be proposed for different application in an all electric aircraft configuration.

## **Impact**

The use of electrically powered actuators integrating speed and position sensors is expected to enable to save weight, and to increase engine monitoring and diagnostics. Moreover, SMyLE

project will allow to reduce the size of components of generation equipment as well as to achieve significant reduction in maintenance. Another aspect of SMyLE developments is increased reliability because safety has a great impact in aeronautic transports.

## Section 1. Project objectives and major achievements

### 1.1 General project objectives

Field survey and perception of the constituted SMyLE specimen. Numerical modeling of thermomechanical- & electrical aspects with emphasis given on hysteretic effects. Design, manufacturing, and testing of SMA coupons that can be deformed by means of the Shape Memory (SM) phenomenon. Life-cycle assessment, consideration of fail-safe aspects and delivery of at least one successfully operable specimen with predetermined dimensions min (20cm x 100cm x 0.1cm; subject to changes). Recommendations on related future work and derivation of appropriate numerical and /or analytical models of mechanical behavior of the system.

In order to reach those objectives the project has been divided in one management and three technical Work Packages (WP). According to the latest Amendment of the Description of Work (DoW) of 03 October 2012:

Detailed work description

WP no.	Work package title	Type of activity	Lead prtcp nt No	Lead participant short name	Person months		Start month	End month
					ARES	INAS CO		
1	SMyLE architecture and mathematical modeling	RTD	1	ARES	1	0.5	01OCT 2010	31OCT 2010
					4	0.5	01NOV2010	31JAN 2011
2	SMyLE experiment	RTD	2	INASCO	1	5.25	01FEB 2011	30SEP 2012
					1	2.25	01FEB 2012	31OCT 2012
3	SMyLE post-experimental issues and recommendations for future work	RTD	1	ARES	2	1	01SEP 2011	31OCT 2012
					2	0.2	01APR 2012	30NOV 2012
4	Model estimation for measured data interpolation	RTD		ARES	6	0	01JAN 2012	31OCT 2012
		<b>TOTAL</b>			17	9.7		

<b>Del. no.</b>	<b>Deliverable name</b>	<b>WP no.</b>	<b>Nature</b>	<b>Delivery date</b>
1.1	Configuration of the SMyLE actuator (report A)	1	R	31OCT2010
1.2	Modeling of mechanical-, thermal-, electrical- and hysteresis aspects of the SMyLE actuator (report B)	1	R	31JAN2011
2.1	Manufacturing of SMyLE specimen and determination of experimental conditions	2	R	30SEP2012
2.2	SMyLE experiment, aging- & fatigue mechanisms, fail-safe issues (report C)	2	R	31OCT2012
3.1	Improvement of SMyLE specimen (depending on WP2 output)	3	R	31OCT2012
3.2	(following report B and D3.1)-- Modification of SMyLE numerical model (report D)	3	P	30NOV2012

<b>Milestone number</b>	<b>Milestone Name</b>	<b>WP(s) involved</b>	<b>Expected date</b>	<b>Means of verification</b>
1	SMyLE concept architecture	1	31OCT2010	Field survey & innovative thinking
2	Possible identification of new aging- & fatigue mechanisms	2	31OCT2012	Experimental quality validation
3	Eventual modifications of SMyLE constitutive- & FEM model	3	30NOV2012	Field survey, experimental quality validation & innovative thinking

## 1.2 Project's relation to the state of the art

SMyLE proposes a technological research program allowing to develop, manufacture and validate actuators by integrating a number of various emerging SMA technologies that result in **high performance/ high reliability actuators**. The innovative aspects of the proposed technologies are **new SMA material concept with high power-to-weight ratio and high performance & reliability optimized for later application into a morphing/adaptive wing**. Thanks to these new technologies, the SMyLE actuator system could contribute to lower mass (compared to a conventional mechanical/hydraulic actuator), be fully integrated (at a later stage) into the leading edge of an adaptive wing system.

The purpose of SMyLE is technology based on high performance material and optimized architecture and it is multifold. When applied to the LE of an adaptive wing (at a later stage), the following benefits are strongly evident, i.e.: at first, SMyLE can significantly improve the aerodynamics at the LE vicinity since it offers a greater operational envelope compared to a conventional LE slat device. Secondly, it can serve as deicing protection device, therefore eliminating heavy conventional, as well as electrically demanding, deicing systems. As third, it can be further utilized as a flight control surface replacement, locally improving the aerodynamics in the LE vicinity during flight.

### 1.3 Project objectives, performed work, engaged partners and main achievements

The main objectives of the project were:

- Identification of SMyLE specimen candidate architecture.
- Surface properties and the role of surface in fatigue.
- Choice of constitutive model, assumptions, simplifications and model's requirements, Finite Element (FE) model.
- Estimation of SMA material's parameters.
- Loading conditions (**thermo-mechanical & electrical**), hysteresis aspects. Requirements for possible bonding along both sides (i.e. short & long).
- Determination of experimental conditions, i.e. uniform- & nonuniform actuation.
- Manufacturing of *a first sample and testing* under clamped in a stress and/or tension/compression (T/C) scenario.
- Mechanical response of the actuator as a function of temperature & load.
- Training of SMA specimen.
- Examination of *specimen operation after testing*. Identification of aging and/or fatigue mechanisms. Redundancy aspects.
- Stability of material response under cyclic actuation at constant & differential stress levels.
- Thermal-cycling experimental work (i.e. evaluation of temperature effect by completing several actuation cycles at temperatures near the SMA transformation temperature).
- Consideration of fail-safe issues, (e.g. possible recovery action, wire integrity, etc).
- Design of 3 different SMA actuated LE configurations.
- Manufacturing of *number of samples of 3 different configurations and testing* under clamped in a stress and/or tension/compression (T/C) scenario.
- Mechanical response of the actuator as a function of temperature & load.
- Experimental Modeling of SMA Actuators via NARX models.
- Modification of numerical model and structural correction of the SMA specimen in case of unsatisfactory experimental outcome. Final SMA specimen deliverance. Recommendations for future work.

The work performed in the current project period followed consequently the described objectives. In WP1 the work was completed according to the original plan and provided useful inputs to the rest of work packages.

The concept perception involves the development of an SMA functional specimen having in mind the scenario for integrating the output of SMyLE into an adaptive wing's LE (at a later stage). Two different SM actuating principles have been pursued. In the first approach the actuator will be embedded in the coupon in the form of an active layer. This is similar to the composite material layered concept only in this case one or more layers will be capable of inducing predefined and controlled deformation within the structure.

A series of actuating principles have been tested from unidirectional SMA wires at different directions to 2D wire mesh configurations. In the second actuating approach the use of the so called compliant mechanisms will be investigated with the SMA wires as actuating elements. Redundancy and efficiency issues will be taken into account by considering a thread of more than one SMA wires, as actuation element, where applicable. In this way the actuators will be less stressed and a fail-safe approach is promoted.

Choice between micromechanics-based constitutive model (MMCM) and phenomenological constitutive model (PCM) resulted in the adoption of the PCM model for the rest of the project. The parameters of the PCM model have been identified through appropriate experimental procedures.

In WP2 the work has been completed in all tasks. As planned, the most promising concepts have been bench-tested to evaluate characteristics and highlight challenges. Three actuator concepts have been tested in this context: Single SMA wires, embedded SMA wire actuators and a compliant Leading Edge concept. In all concepts, the provided actuation is done by applying current and heating up the SMA to the transformation temperature utilizing a control system based on thermocouples at the actuator. The shape of the specimen has been measured using LVDT measurements at selected areas. These readings could be used as feedback for the control system.

In WP3 assessment of the actuator concepts developed in WP2 has been performed and proposals for potential modifications formulated.

In WP4 SMyLE post-experimental issues and recommendations for future work was performed and the general framework of an estimation method was formulated, based on available information concerning the physics of the system. This is an alternative modeling approach based on the response of the system (parameter estimation). Finally, recommendations for future work in terms of improvements towards application of the investigated technologies on a real a/c LE prototype have been formulated.

#### **1.4 Important problems and corrective actions**

The most significant problems encountered during the reporting period are described below alongside their impact in the planned project execution and the corrective measures taken by the Consortium.

- 1) Due to technical complexity the consortium had to ask for three extension of the time frame of the project.
- 2) With the approval of the project extensions and the progress made by the partners it was possible to achieve most of the project objectives.

## Section 2. Workpackage progress of the period

### 2.1 WP1 SMyLE architecture and mathematical modeling

#### 2.1.1 WP overview on objectives, involved partners, planned work and manpower

<b>Table 4.1 Work package descriptions</b>			
<b>WP1</b>			
<b>Work package number</b>	1	<b>Start date or starting event</b>	Month 1
<b>Work package title</b>	SMyLE architecture and mathematical modeling		
<b>Activity Type</b>	RTD		
<b>Participant number</b>	2		
<b>Participant short name</b>	ARES, INASCO		
<b>Person-months per participant:</b>	5 (ARES) 1 (INASCO)		
<b>WP1 Objectives</b>			
<ol style="list-style-type: none"> <li>1. Identification of SMyLE specimen candidate architecture.</li> <li>2. Surface properties and the role of surface in fatigue.</li> <li>3. Choice of constitutive model, assumptions, simplifications and model's requirements, Finite Element (FE) model.</li> <li>4. Estimation of SMA material's parameters.</li> <li>5. Loading conditions (<b>thermo-mechanical &amp; electrical</b>), hysteresis aspects.</li> <li>6. Requirements for possible bonding along both sides (i.e. short &amp; long).</li> </ol>			
<b>WP1 Description of work</b>			
<b>Task 1.1: Technology Bibliographical detailed survey--SMyLE concept perception and architecture</b>			
<p>Based on the existing technological roadmaps available, an extended research, study and synthesis of existing literature, data, and publications on most recent technologies applicable to SMAs, an innovating material will be developed. This analysis will focus on gathering from literature all relevant key characteristics and performances of SMA materials &amp; related technologies. Within the envelope of the involved manufacturer's capabilities, it is envisaged that two different SM actuating principles will be pursued, i.e. (a) an actuator will be embedded in the coupon in the form of an active layer similar to the composite material layered concept only in this case one or more layers will be capable of inducing predefined and controlled deformation within the structure where a series of actuating principles will be tested from unidirectional SMA wires at different directions to 2D wire mesh configurations, and, (b) the use of the so called compliant mechanisms will be investigated with the SMA wires as actuating elements.</p> <p>Consideration of surface properties (i.e. geometry, roughness, porosity, continuity/waviness; by means of simple transparent analytic methods, e.g. 3rd order polynomial). The distribution of pore-orientation might be reasonably approximated by a random distribution function. The role of surface in fatigue, where the term <i>fatigue</i> should be distinguished between classical, structural (i.e. nucleation and propagation of cracks with subsequent rapture) and functional (i.e. deterioration of SMA's properties like amnesia and loss of reversible strain). A common approach suggests consideration of four (x4) different types of surface morphology, (a) defect free surface after appropriate electro-polishing, (b) surface modification by diffusion processes, (c) surface region modified by deformation processes, (d) coated surface. Particular attention will be paid to the comprehension of the main potential fatigue mechanisms induced under operating conditions, and their influence on SMA material overall reliability.</p>			

**Task 1.2: SMyLE constitutive modeling, loading conditions and surface response prediction.**

Choice between micromechanics-based constitutive model (MMCM) and phenomenological constitutive model (PCM). Assumptions & simplifications (single-crystal SMA, homogenous material, isothermal loading conditions among others). Irrespective of the model's choice under (4), a complete constitutive model that describes the behavior of SMyLE specimen should involve, (a) a thermodynamic potential, i.e. Gibbs- possibly associated with the Helmholtz free energy function (Gibbs is the free energy per unit reference volume whereas Helmholtz is the free energy per unit mass), (b) a nucleation criterion which determines when a phase transition is initiated and how many phase boundaries are nucleated during the phase transition, and (c) a kinetic relation which characterizes the speed at which a phase boundary moves.

Utilizing the laws of thermodynamics in order to obtain constraints on the material response (possibly with refinement on local entropy production rate), the effective stress, martensitic volume fraction, the (martensitic) transformation- & plastic strain, the back- & drag stress, the tangent stiffness tensor & the tangent thermal moduli tensor, hysteresis loops (minor[s] & major) utilizing a suitable model eventually combined with the concept of passivity either [e.g. (inverse) Preisach model, Duhem's differential model, Liu-Huang-Yen model among others).

Consideration of the evolution equations (forward & backward) for the phase transition, secondary effects (e.g. tension/compression asymmetries, elastic properties depending on different phase transformation levels) and 2-way shape memory effects. To account the effects of asymmetric behavior between tension, compression and shear, a set of transformation strain tensors should be introduced in the constitutive model. Accurate constitutive modeling of the stress-strain response requires consideration of the various recoverable inelastic strain mechanisms. Depending on the test temperature, the various deformation mechanisms may occur in conjunction or isolation during various stages of the stress-strain response.

**Alternative approach to constitutive model:**

Appropriately chosen combination of experimentally obtained quantities could yield into a simple analytic model. For example, surface responses of the surface's z-coordinate as a function of stress- & strain quantities at various temperatures & frequencies.

However, this alternative increases the number of experiments (e.g. SMA-specimen examination at a finer temperature range) in an attempt to improve the model's accuracy. Owing to the instantaneous output of the model (e.g. stress vs. strain, surface response at a certain temperature, frequency, load and training), hysteretic effects are already included (through the experimental output) therefore significantly reducing model complexity.

In addition, this approach might require strong numerical treatment of the obtained experimental data until a simple-, low-degree analytic expression can be obtained. For this reason, it is estimated by the applicants that no additional modification to the time table is required concerning this particular task compared to the case that a detailed, constitutive model as initially proposed.

Estimation of SMA material's parameters that, i.e.: (i) are associated with stable transformation cycle, (ii) describe the behaviour of SMA under **cyclic loading**, (iii) govern the SMA behaviour during minor hysteresis loops.

**Loading conditions:**

**(a)—(thermo-mechanical, single cycle):** such as specimen's deformation envelope (following

project input--, the in-plane deformation is restricted not to exceed more than 1cm), short/long side and normal to the surface load limits, passive- & active displacements, thermal equilibriums, isothermal thermomechanical response.

**(b)--(thermo-mechanical with cycling effects):** modification of the employed free-energy function, modeling the effect of tensile/compressive (T/C) cyclic loading on hysteresis loop as reported in the literature + T/C experiments within the frame work of SMyLE. The T/C loading mode reflects in essence a bending case with reference to a LE scenario. Consideration of continuous- & interrupted loading, (post-) thermal buckling & thermally induced flexure aspects.

**(c)-- (electrical):** relative currents & voltages, power consumption.

Criteria for possible bonding along specimen's sides without impeding electric activation.

**Loading conditions (simulating representative environment):**

- SLC--Static Loading Conditions (e.g. tensile loading at wires) for the mechanical characterization of SMA wires tensile loading and derivation of stress-strain curves will be conducted. Further to that relaxation measurements are foreseen where for constant temperature, the wires are subjected to constant deflection and the force is measured as function of time.
- DLC—Dynamic Loading Conditions Dynamic mechanical loading of SMA actuator will be conducted in order to assess their performance in cyclic loading. Tension-tension measurements are foreseen for SMA wires in case there is no actuation and assessment of excreted force in a number of actuation cycles is foreseen.

<b>Deliverables of WP1</b>		
<b>Code number</b>	<b>Date</b>	<b>Description</b>
D1.1	Month 1	Configuration of the SMyLE actuator (report A)
D1.2	Month 4	Mechanical-, thermal-, electrical- and hysteresis aspects of the SMyLE actuator (report B)

**Description of work**

<b>WP no.</b>	<b>Work package title</b>	<b>Type of activity</b>	<b>Lead participant No</b>	<b>Lead participant short name</b>	<b>Person months</b>		<b>Start month</b>	<b>End month</b>
					<b>ARES</b>	<b>INASCO</b>		
<b>1</b>	<b>SMyLE architecture and mathematical modeling</b>	<b>RTD</b>	<b>1</b>	<b>ARES</b>	<b>1</b>	<b>0.5</b>	<b>01OCT 2010</b>	<b>31OCT 2010</b>
					<b>4</b>	<b>0.5</b>	<b>01NOV2 010</b>	<b>31JAN 2011</b>

### 2.1.2 Progress towards objectives

#### SMA science and technology state of the art – (100% completed)

The most updated technological issues of the SMA applications have been highlighted and the current application of the technology presented. The general theory of SMA and their advantages and disadvantages have been discussed (Table 6).

**Table 6: Pros & cons of SMA actuators**

<b>SMAs: (+)</b>	<b>SMAs: (-)</b>
small size	Low energy efficiency
Capability of producing large strains, up to 4% for two-way training and for large actuation forces and up to 10% strain when deformed into a non-linear fashion. Ferromagnetic SMAs have been shown to exhibit strain up to 9.5%.	Relatively large current requirements
Simplicity of actuation system	Might exhibit loss of actuation after repetitive cyclic loading.
low voltage requirements	
silent actuation	
Control is achieved by means of a suitable algorithm	
The pseudo-elastic effect provides two very useful advantages, (a) a non-linearity which allows vibration isolation and large recoverable deformations and, (b) accompanying hysteresis which can dissipate energy therefore reducing vibration-induced loads.	Rapid heat transfer through SMAs might be problematic owing to their high- heat capacity & density. This fact leads to a limited frequency range of system response.
SMAs are capable of actuating in a fully three-dimensional manner, allowing the fabrication of actuation components which extend, bend, twist, or provide a combination of these and other deformations.	

Issues like SMA training, static and fatigue performance has been presented and the thermodynamic behavior has been assessed in terms of constitutive equations. The basic concepts for applicable actuators have been presented and some initial considerations of load capacity have been assessed.

**Table 7: Typical values for load capacity, electrical current and pull force for typical SMA wires<sup>1</sup>**

Diameter Size (mm)	Resistance (ohms/m)	Pull Force* (grams)	Approximate** Current at Room Temperature (mA)	Contraction** Time (seconds)	Off Time 70° C "LT" Wire*** (seconds)	Off Time 90° C "HT" Wire*** (seconds)
0.025	1424.8	8.9	45	1	0.18	0.15
0.038	889.5	20.0	55	1	0.24	0.20
0.050	500.0	35.6	85	1	0.4	0.3
0.076	232.2	80.2	150	1	0.8	0.7
0.102	126.0	142.5	200	1	1.1	0.9
0.127	74.8	222.7	320	1	1.6	1.4
0.152	55.1	320.6	410	1	2.0	1.7
0.203	29.1	570.0	660	1	3.2	2.7

<sup>1</sup> www.dynalloy.com

0.254	18.5	890.6	1050	1	5.4	4.5
0.305	12.2	1282.5	1500	1	8.1	6.8
0.381	8.3	2003.9	2250	1	10.5	8.8
0.508	4.3	3562.6	4000	1	16.8	14.0

\* The pulling force is based on **25,000 psi (172 MPa)**, which for many applications is the maximum safe stress for the wire. However, many applications use higher and lower stress levels. This depends on the specific conditions of a given design.

\*\* The contraction time is directly related to current input. The figures used here are only approximate since room temperatures, air currents and heat sinking of specific devices vary. On small diameter wires ( $\leq 0.006$ " diameter) currents that heat the wire in 1 second can typically be left on without over-heating it.

\*\*\* Approximate cooling time, at room temperature in static air, using a vertical wire. The last 0.5% of deformation is not used in these approximations.

Selection of appropriate SMA model. - Task Completed (100%)

A comprehensive thermo-mechanical model should incorporate the following in order to capture in detail the SMEError! Bookmark not defined.:

- simulation of three-dimensional stress states
- Be able to include rubber-like behavior (superelasticity)
- modeling of hysteresis and subcycles
- computational algorithm to simulate response of complex devices that incorporate SMAs
- minimal experimental testing to obtain characteristic parameters for the computational models and,
- effect of fatigue on mechanical properties.

Constitutive laws can be based on micromechanical models or on phenomenological models. Micromechanical models rely (mainly) on a statistical approach whereas phenomenological models have as foundation experimental considerations. Lagoudas model has been selected and developed within SMyLE framework. Lagoudas model uses Gibbs free energy to define the thermodynamic state of the SMA material. This is a phenomenological model (Macro Model) based on thermodynamics to describe shape memory alloys behavior. This model uses four state variables, temperature, stress, transformation strain  $\epsilon^t$  and martensite volume fraction  $\xi$ . This is one of the most accurate and simultaneously simplest models because it uses only four state variables while is capable to accurately simulate shape memory alloys behavior. The constitutive SMA model has been implemented in ABAQUS commercial FEA code. This is done by using the User material subroutine (UMAT). UMAT is a subroutine provided by ABAQUS in order to define a material's mechanical behavior. References for this subroutine can be found in ABAQUS user manual. An overview of the subroutine presented in the following:

#### Overview

User subroutine **UMAT**:

- can be used to define the mechanical constitutive behavior of a material;
- will be called at all material calculation points of elements for which the material definition includes a user-defined material behavior;
- can be used with any procedure that includes mechanical behavior;
- can use solution-dependent state variables;
- must update the stresses and solution-dependent state variables to their values at the end of the increment for which it is called;
- must provide the material Jacobian matrix,  $\partial \Delta \sigma / \partial \Delta \epsilon$ , for the mechanical constitutive model;
- can be used in conjunction with user subroutine **USDFLD** to redefine any field variables before they are passed in; and
- is described further in "User-defined mechanical material behavior," Section 23.8.1 of the Abaqus Analysis User's Manual.

In this type of analysis is used for ABAQUS standard implicit analysis schemes. In order to proceed to UMAT programming the equations describing the phenomenon are discretized properly in order

to be implemented in UMAT subroutine. The logical diagram of the UMAT subroutine is presented in the following figure.

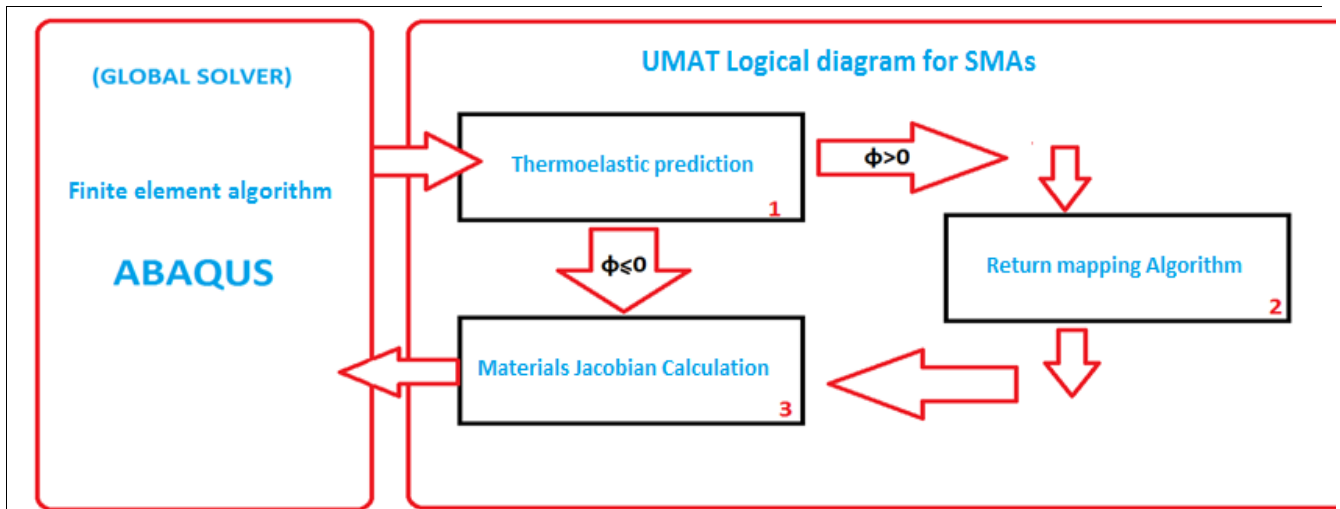


Figure 2: logical diagram of the UMAT subroutine

SMA actuation principles – (100% completed)

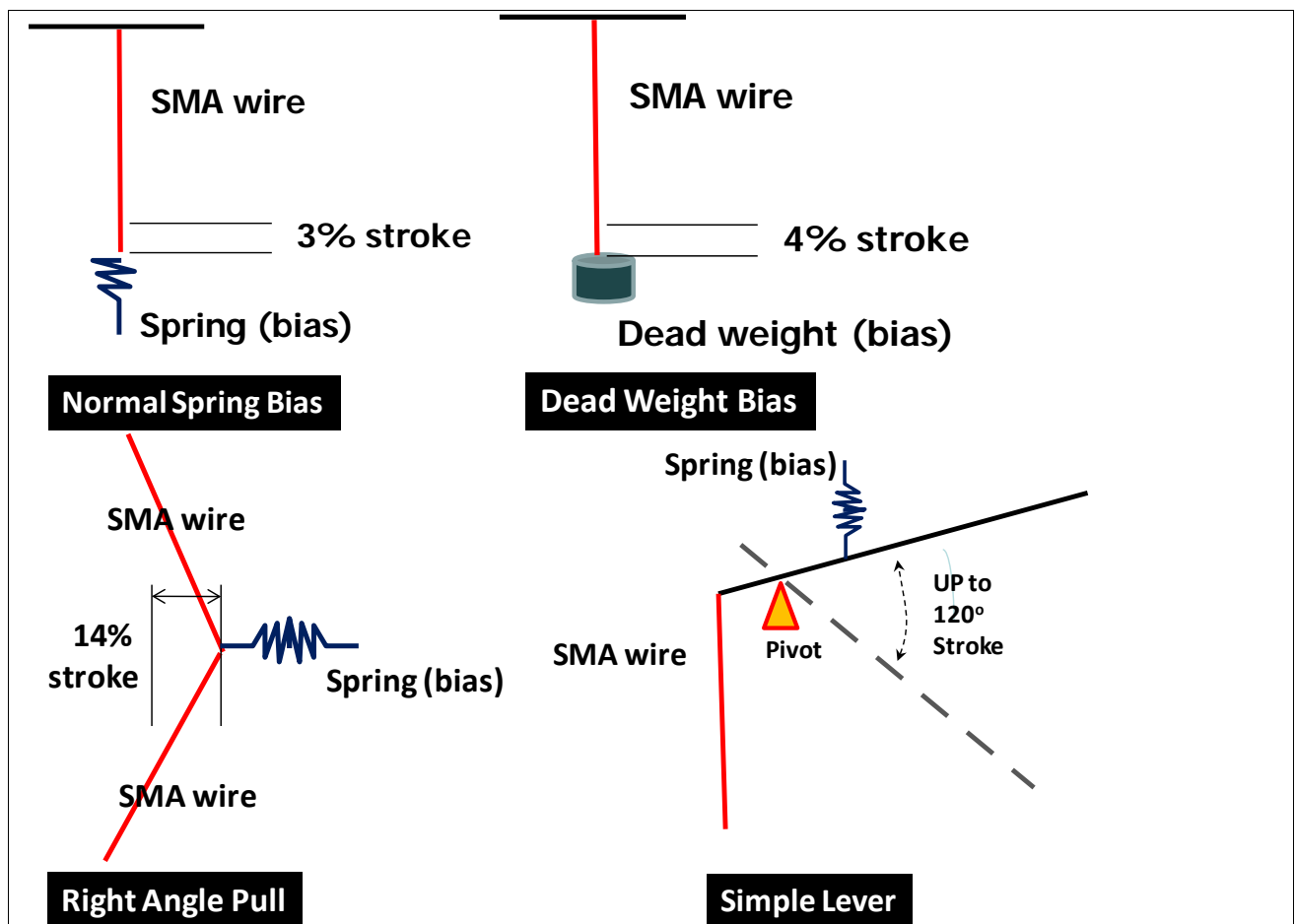
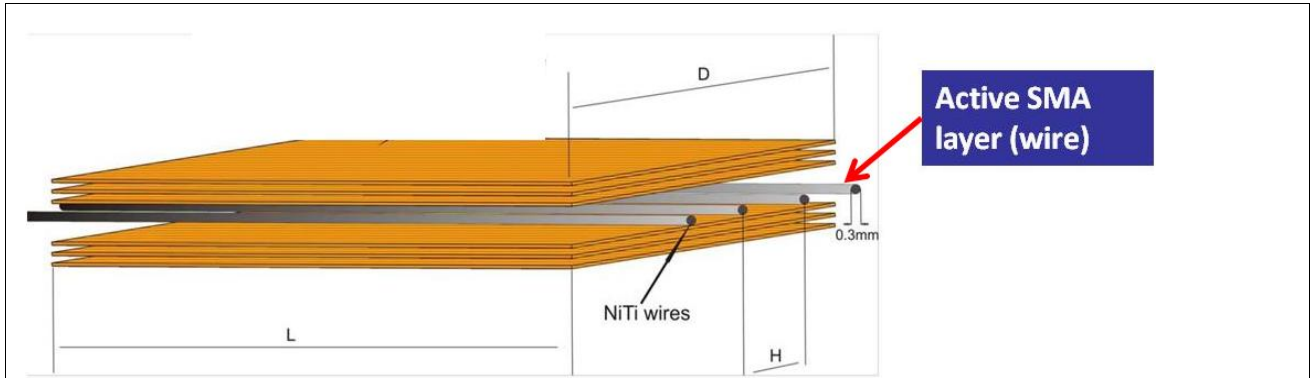


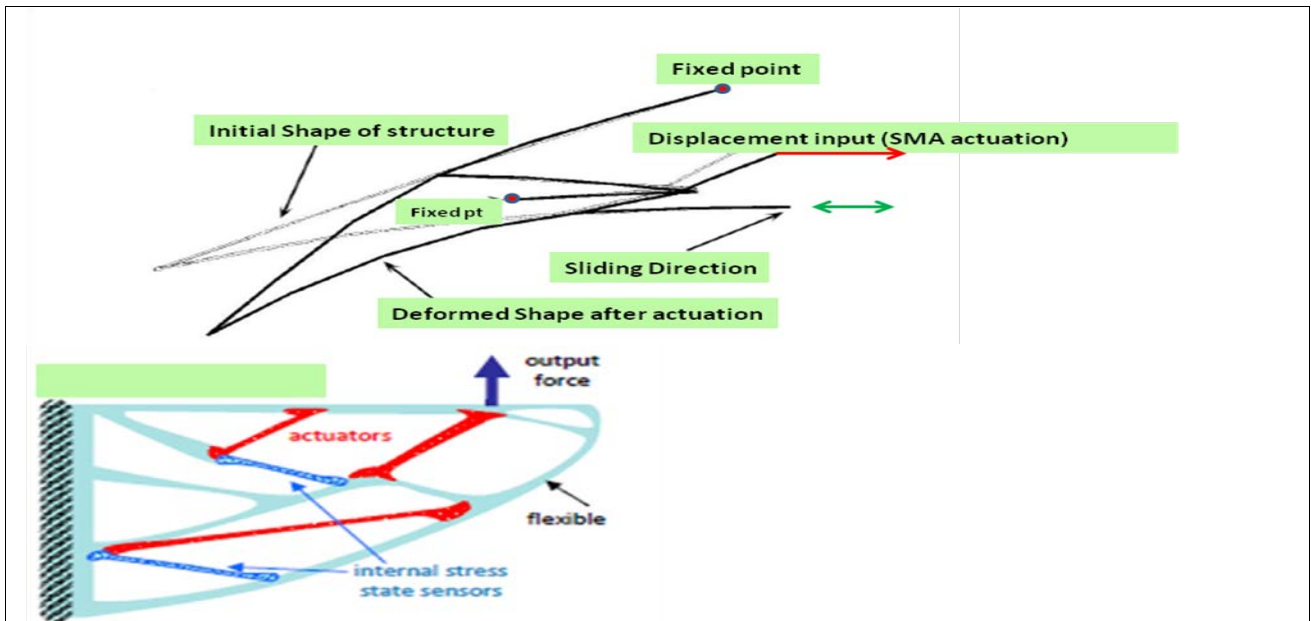
Figure 3: Simple mechanical configurations considered for the loading table

**Table 8:** Load table of SMA wires incorporated in simple mechanisms

	Stroke (Approx.)	0.003'' (0.076mm) wire diameter	0.006'' (0.15mm) wire diameter	0.01'' (0.25mm) wire diameter
Normal Bias Spring	3%	0.18 lb (80 g)	0.73 lb (330 g)	2.05 lb (930 g)
Dead weight Bias	4%	0.18 lb (80 g)	0.73 lb (330 g)	2.05 lb (930 g)
Right Angle Pull	14%	0.04 lb (20 g)	0.18 lb (83 g)	0.51 lb (232 g)
Simple Lever (6:1)	30%	0.024 lb (11 g)	0.1 lb (47 g)	0.29 lb (133 g)



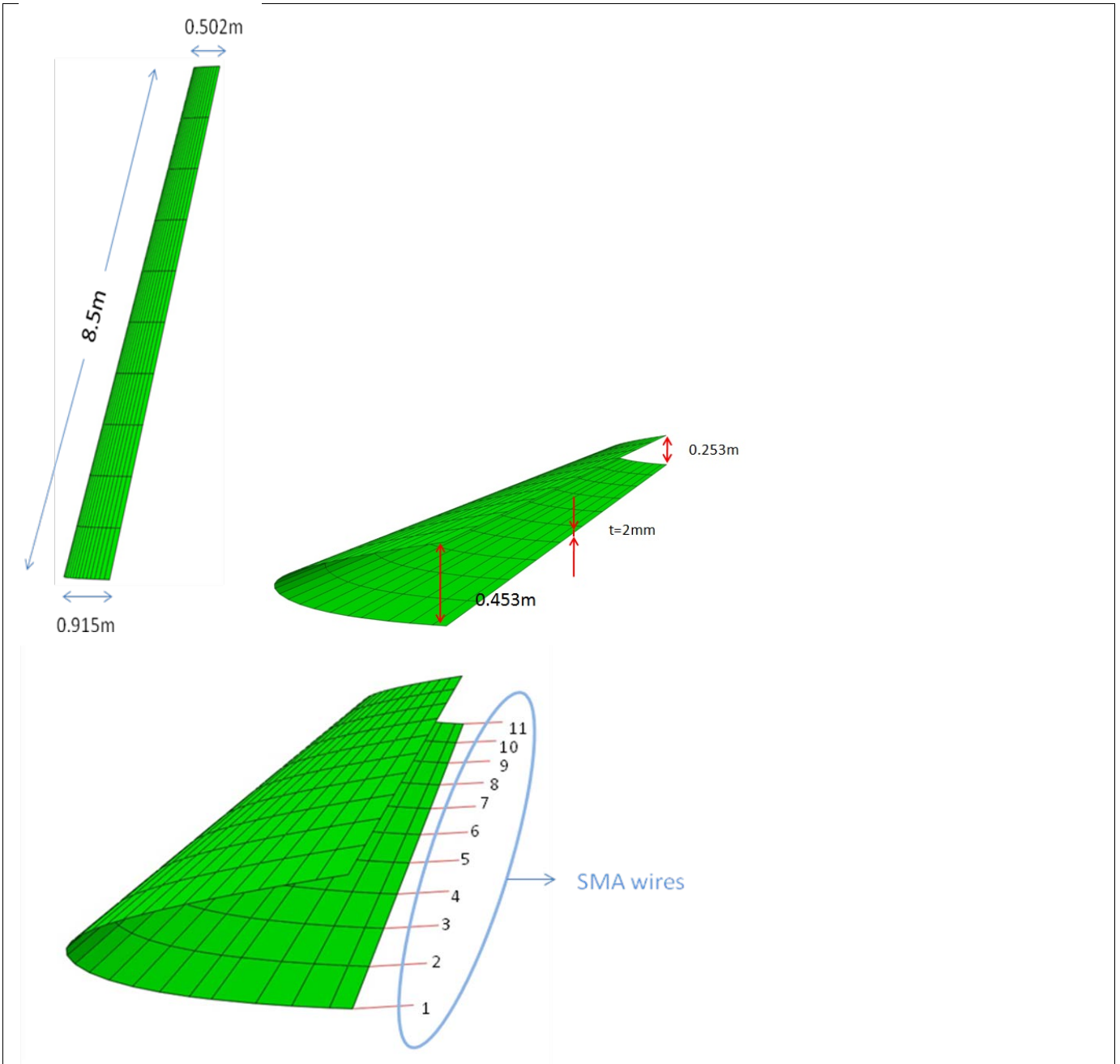
**Figure 4:** One active layer concept



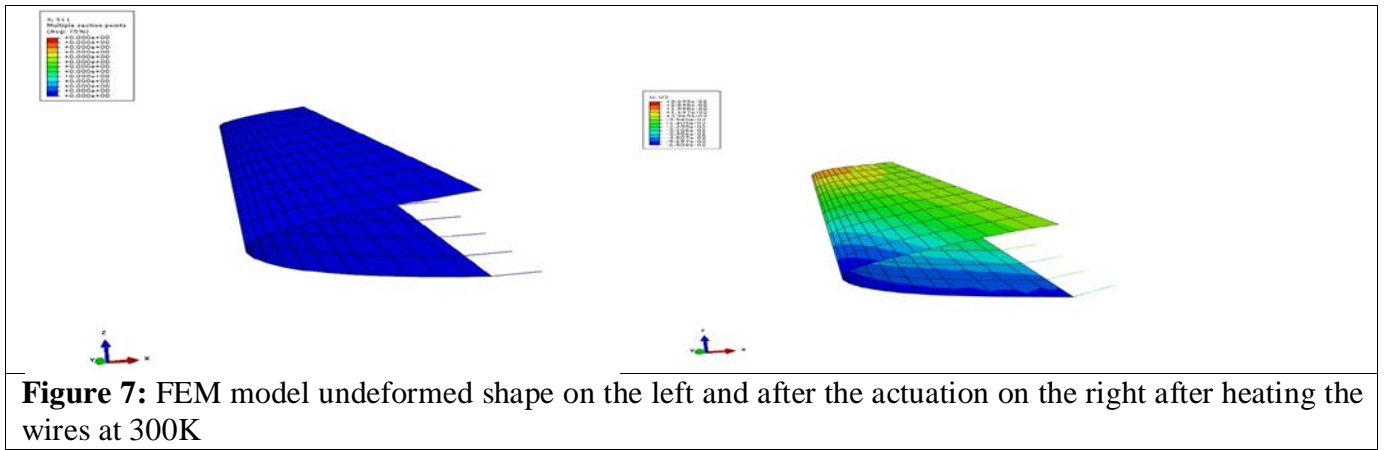
**Figure 5:** Example of a compliant mechanism with compliant members. In the lower sketch a proposal of sensing and actuating elements is outlined

SMA initial LE considerations – (100% completed)

Some initial prediction of a Leading Edge concept has been analyzed:



**Figure 6:** LE FEM model and placement of SMA wires. 11 Shape Memory Alloy wire actuators (D=2mm) of 20cm length attached along the lower edge.



In **Table 9**, FEA results (i.e. strain stress & force) referring to the SMA wires are presented. At the last column is presented the maximum force exerted from the wire to the structure at the end of the heating of the wires.

**Table 9:** Strain stress and force at each of the SMA wires

Wire	$\epsilon_{11}$	$\epsilon_{11}$ (%)	Stress 11(MPa)	Force (N)
1	-0.0403	-4.034	162.50	510.51
2	-0.0466	-4.660	154.52	485.45
3	-0.0540	-5.397	64.31	202.04
4	-0.0546	-5.459	31.77	99.80
5	-0.0550	-5.500	-18.98	-59.63
6	-0.0537	-5.373	77.85	244.56
7	-0.0503	-5.030	149.90	470.92
8	-0.0432	-4.320	158.52	498.01
9	-0.0358	-3.583	168.20	528.42
10	-0.0255	-2.547	181.27	569.48
11	-0.0172	-1.716	191.73	602.34

In **Table 10**, the maximum rotations of the leading edge at eleven different points are presented. Each section corresponds to a SMA wire.

**Table 10:** Rotation of the LE at the sections of SMA attachment

Section	L.E.Rotation (Degrees)
1	-4.137
2	-3.767
3	-3.357
4	-2.903
5	-2.397
6	-1.839
7	-1.239
8	-0.595
9	0.115
10	0.921
11	1.868

### 2.1.3 Deviations from the work programme, and corrective actions taken/suggested

The actual work plan in WP1 is shown at the end of this section. The differences between the original workplan (shown in Section 2.1.1) and the actual one are discussed below. The deviations (on work content, end result, timing and effort level) are explained and the corrective measures that were taken or suggested for the next period are presented.

#### I. WP 1.1 Literature survey, SMyLE concept perception & architecture

Work content, output: The Task is completed (100%). There were deviations with description of work (DoW)

Timing: No deviation with the DoW.

Effort level: No deviation with the DoW.

#### II. WP 1.2 Loading conditions, SMA constitutive- and Finite Element (FE) model, surface response prediction, bonding issues.

Work content, output: No deviation is experienced. The Task is finished (100%).

Timing: No deviation with the DoW.

Effort level: The originally assigned resources are sufficient for the execution of the technical effort. No deviation with the DoW

### 2.1.4 List of deliverables and milestones

**Table 11: Deliverables list for WP1**

Del. no	Deliverable name	WP no.	Date due, month	Actual/Forecast delivery, month	Lead contractor
D1.1	Configuration of the SMyLE actuator (report A)	1.1	31OCT2010	31OCT2010	ARES
D1.2	Modeling of mechanical-, thermal-, electrical- and hysteresis aspects of the SMyLE actuator (report B)	1.2	31JAN2011	31JAN2011	ARES

**Table 12: Milestones list for WP1**

Milestone no.	Milestone name	WP no.	Date due month	Actual/Forecast delivery month	Lead contractor
M1	SMyLE concept architecture	1	31OCT2010	31OCT2010	ARES

**2.2 WP2 SMyLE experiment**

**2.2.1 WP overview on objectives, involved partners, planned work and manpower**

<b>Table 13 WP2</b>			
<b>Work package number</b>	2	<b>Start date or starting event</b>	Month 5
<b>Work package title</b>	SMyLE experiment		
<b>Activity Type</b>	RTD		
<b>Participant number</b>	2		
<b>Participant short name</b>	ARES, INASCO		
<b>Person-months per participant:</b>	2 (ARES) 7.5 (INASCO)		
<b>WP2 Objectives</b>			
<ol style="list-style-type: none"> <li>1. Determination of experimental conditions, i.e. uniform- &amp; non-uniform actuation.</li> <li>2. Manufacturing of a <i>first sample and testing</i> under clamped in a stress and/or tension/compression (T/C) scenario. In accordance with the outcome of the negotiation procedure: (D=100cm, L=20cm. As already mentioned in the relevant negotiation report, the applicant is obliged to notify the topic (or CfP-) manager with immediate effect for any (minor) changes in the L, D specimen dimensions. The manufacturing process will involve commercially available materials. Specific details on the specimen configuration will be decided in conjunction with the prime contractor. As far as the SMA material is concerned Ni-Ti alloys will be the preferred system because of superior performance, stability and availability. Depending on the specific needs commercially available CuAlNi, CuAlBe, and CuZnAl alloys could be adopted as well.</li> <li>3. Mechanical response of the actuator as a function of temperature &amp; load.</li> <li>4. Training of SMA specimen.</li> <li>5. Examination of <i>specimen operation after testing</i>. Identification of aging and/or fatigue mechanisms, having as first boundary hundred (x100) deformation activations. Redundancy aspects.</li> <li>6. Stability of material response under cyclic actuation at constant &amp; differential stress levels.</li> <li>7. Thermal-cycling experimental work (i.e. evaluation of temperature effect by completing several actuation cycles at temperatures near the SMA transformation temperature).</li> <li>8. Consideration of fail-safe issues, (e.g. possible recovery action, wire integrity, etc).</li> </ol>			
<b>WP2 Description of work</b>			
<b>Task 2.1: Experimental conditions, training aspects, and results.</b>			
<p>Manufacturing of SMA actuators in the form of wires and/or thin sheet configuration (max. four concepts). The actuation will take place by means of current application, i.e. heating up the SMA specimen up to the transformation temperature utilizing a control system based on thermocouples at the actuator. Determination of SMA specimen's intermediate transformation temperatures (initially ~65°C; depending on project requirements, SMA with higher transformation temperatures could be utilized reaching ~100°C or above).</p> <p>Surface response measurement as a function of temperature and load. Examination of specimen's behaviour up to failure under static &amp; dynamic conditions for all four concepts in order to select the best candidate.</p> <p>Training of the candidate specimen in one way actuation and return to its original shape by means of the 'spring back' principle (i.e. the developed internal stresses of the deformed structure). The SMA elements will be trained at different positions therefore differential actuation across the length will be possible.</p>			

**Task 2.2: Examination of specimen operation after testing.**

The deformation of the SMA specimen will be measured by means of optical measurements or local strain gauge readings at selected areas. Identification of aging and fatigue mechanisms. Consideration of fail-safe issues (e.g. wire integrity examination).

Reproducibility of the target SMA shapes, aiming to meet the hundred actuation cycles objective. Evaluation of the temperature effect by completing several actuation cycles at temperatures near the SMA transformation temperature. Evaluation of temperature effect by completing several actuation cycles at temperatures near the SMA transformation temperature.

**Measurements:**

- DSC--Dynamic Scanning Calorimetry  
SMA characterization of transition-transformation temperatures and thermal cycling will be carried out. Assessment of thermodynamic characteristics and hysteretic behavior as function of actuating and thermal dynamic loading will be performed.

- Electrical resistance measurement  
The resistance of the SMA actuator will be measured when performing characterization and loading test. The intention will be to use this kind of measurements to the integrity (number of intact actuators) and possibly the state of SMA during activation cycles as the phase change (i.e. martensitic transformation).

**Deliverables of WP2**

<b>Code number</b>	<b>Date</b>	<b>Description</b>
D2.1	Month 24	Manufacturing of SMyLE specimen and determination of experimental conditions
D2.2	Month 25	SMyLE experiment, aging- & fatigue mechanisms, fail-safe issues (report C)

### 2.2.2 Progress towards objectives

Determination of experimental conditions, i.e. uniform- & nonuniform actuation. - Task completed (100%)

The actuation through electrical heating of the SMA wires offers the possibility for uniform as well as non uniform actuation, depending on the transformation ratio between austenite and martensite. The wires will act as load bearing structures and their loading will be done under constant loading (stress) conditions.

Manufacturing of a first sample and testing under clamped in a stress and/or tension/compression (T/C) scenario. - Task completed (100%)

Different actuator concepts have been fabricated and characterized experimentally. 1D wires and 2D embedded configurations have been manufactured.

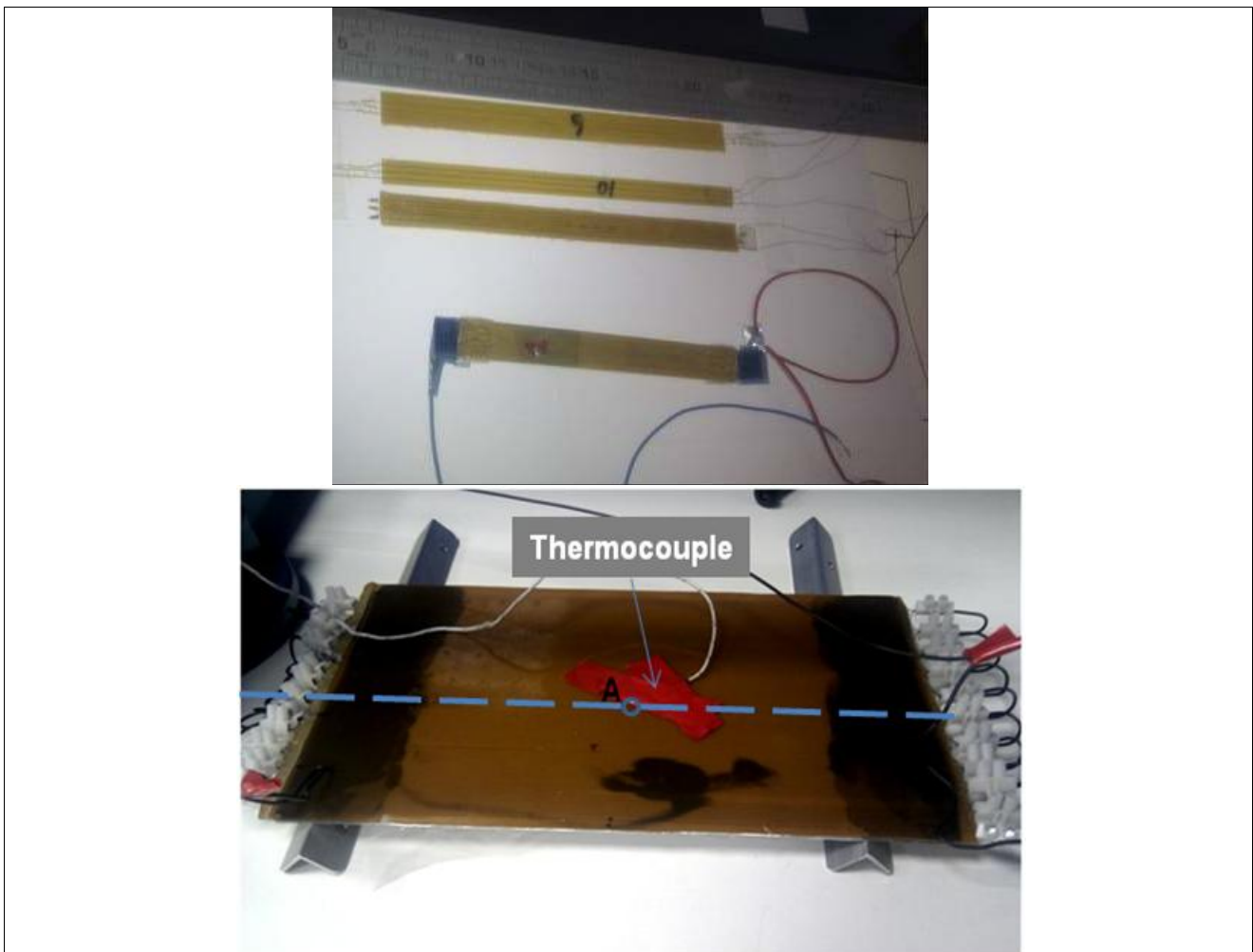


Figure 8: Small coupons with embedded SMA wires. These actuators were used in order to make force measurements and assess the performance of different configurations.

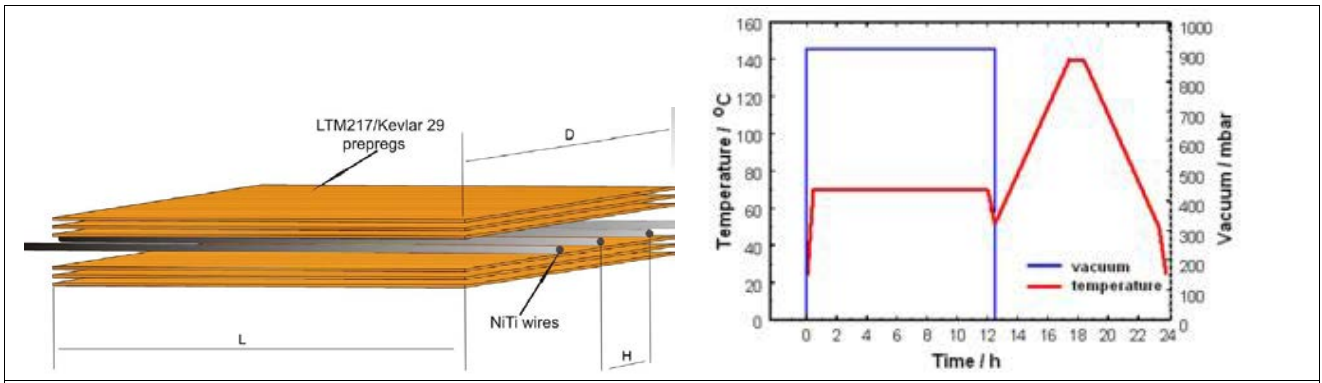


Figure 9: General configuration of specimens featuring SMA wire actuators and the cure cycle followed for their preparation.

Thermal-cycling experimental work (i.e. evaluation of temperature effect by completing several actuation cycles at temperatures near the SMA transformation temperature) - (Task completed (100%))

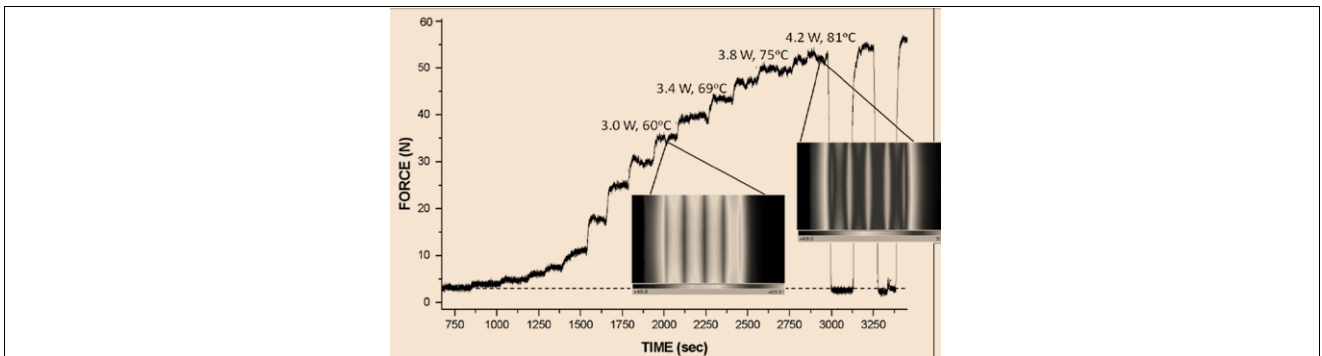


Figure 10: Gradual activation of Type B specimen.

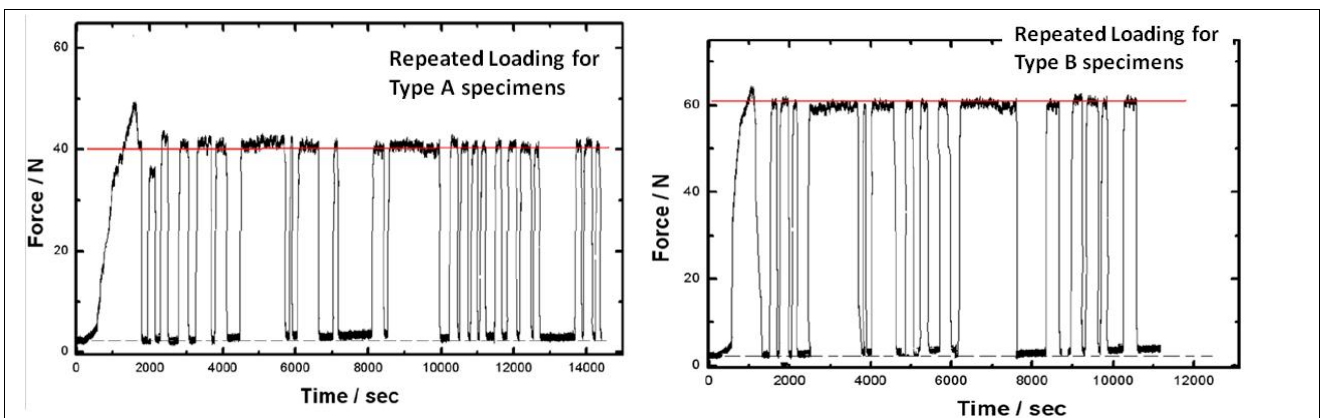
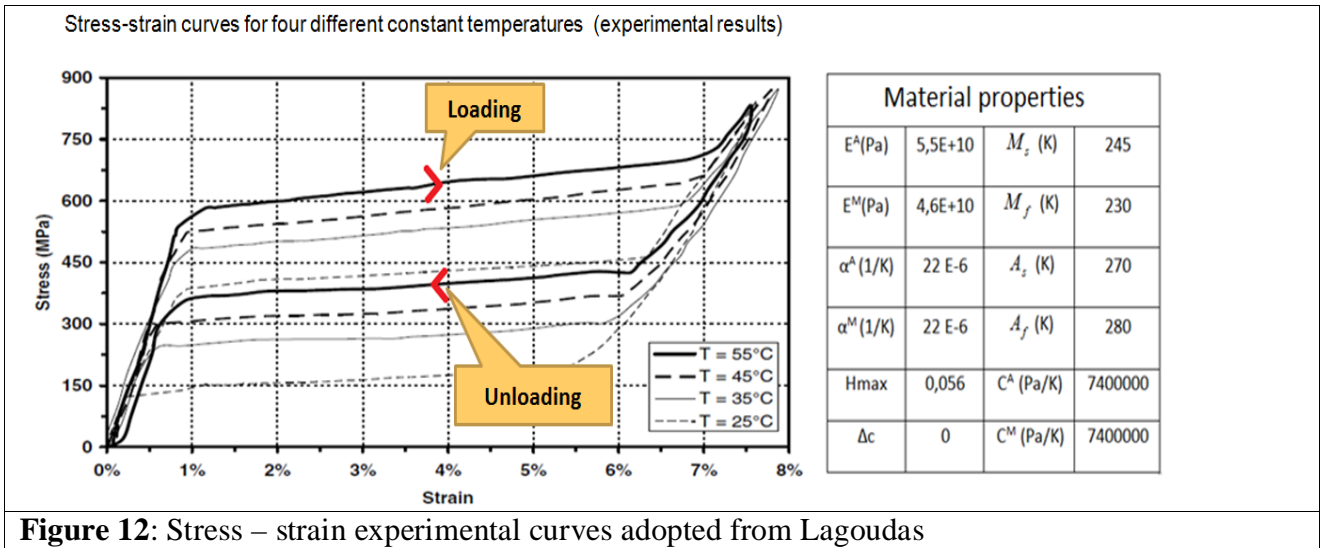


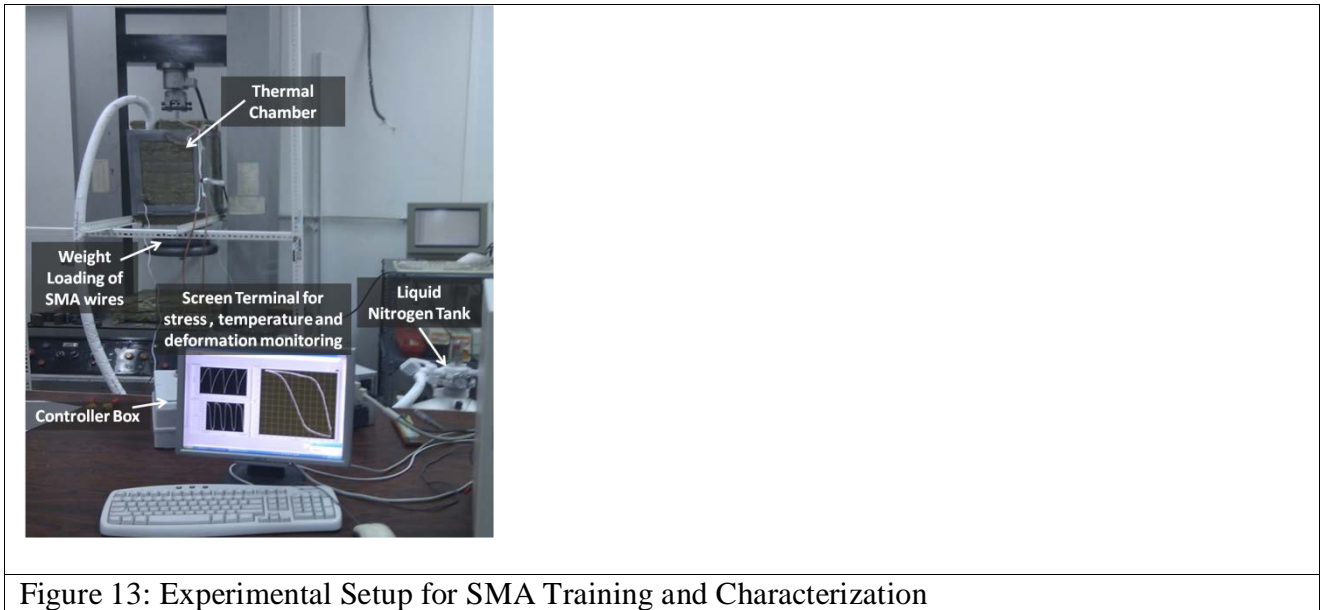
Figure 11: Repeated activation cycles for Type A and Type B specimens.

Mechanical response of the actuator as a function of temperature & load. - Task completed (100%)



Training of SMA specimen. - Task Completed (100%)

A stabilization (training) process of the SMA has been performed in order to obtain the optimum and expected performance of SMAs and ensure the repeatability of the actuator function. The experimental setup for training and temperature characterization of SMA actuators is illustrated in Figure 13.



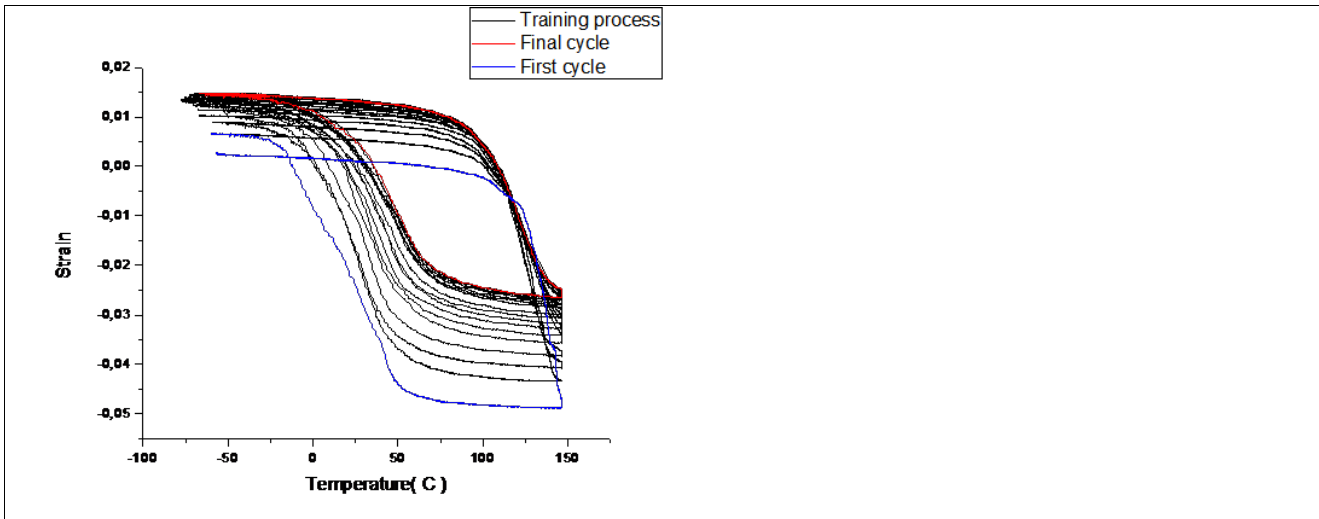


Figure 14: Stabilization (Training) of a SMA wire

Examination of specimen operation after testing. Identification of aging and/or fatigue mechanisms, having as first boundary hundred (x100) deformation activations. Stability of material response under cyclic actuation at constant & differential stress levels. - Tasks completed (100%)

The effects of repeated actuation cycles has been assessed.

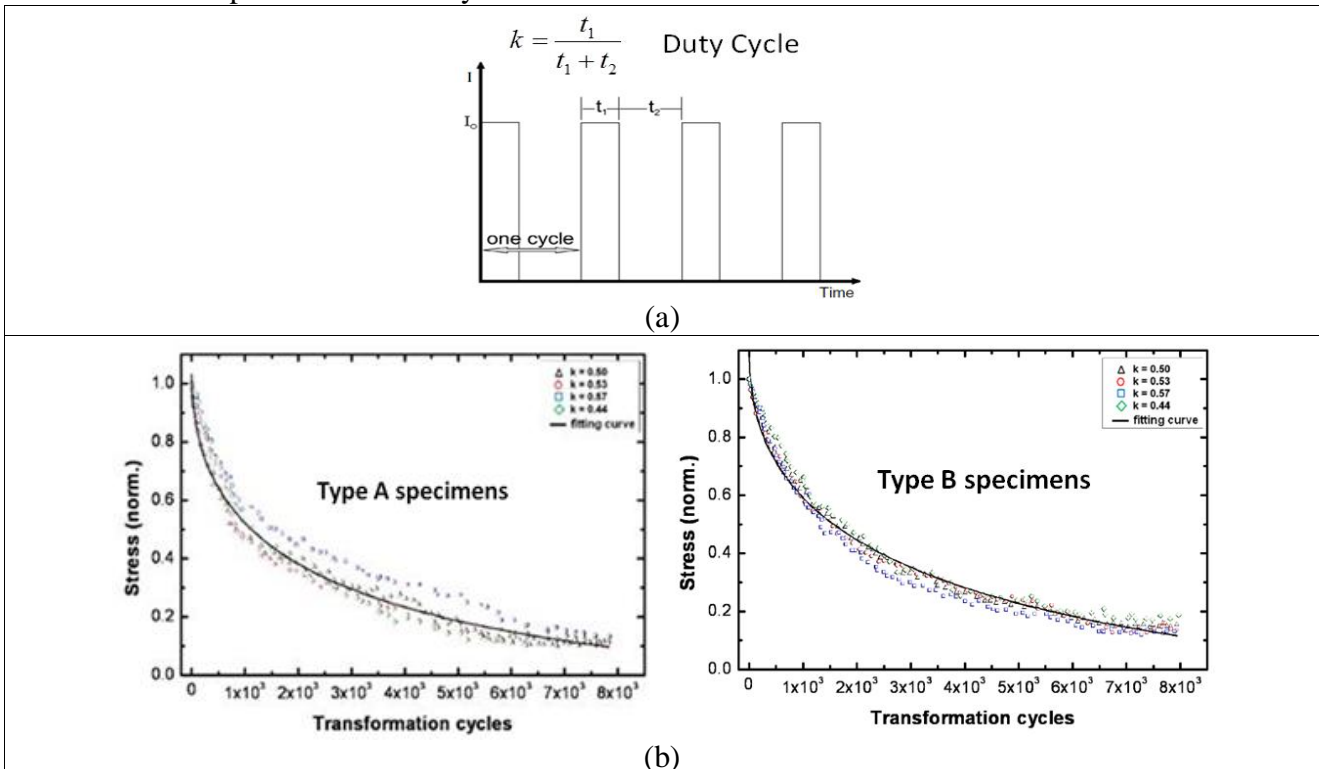


Figure 15: (a) Activation pattern of the SMA actuators and (b) maximum normalized stress as function of the duty cycle.

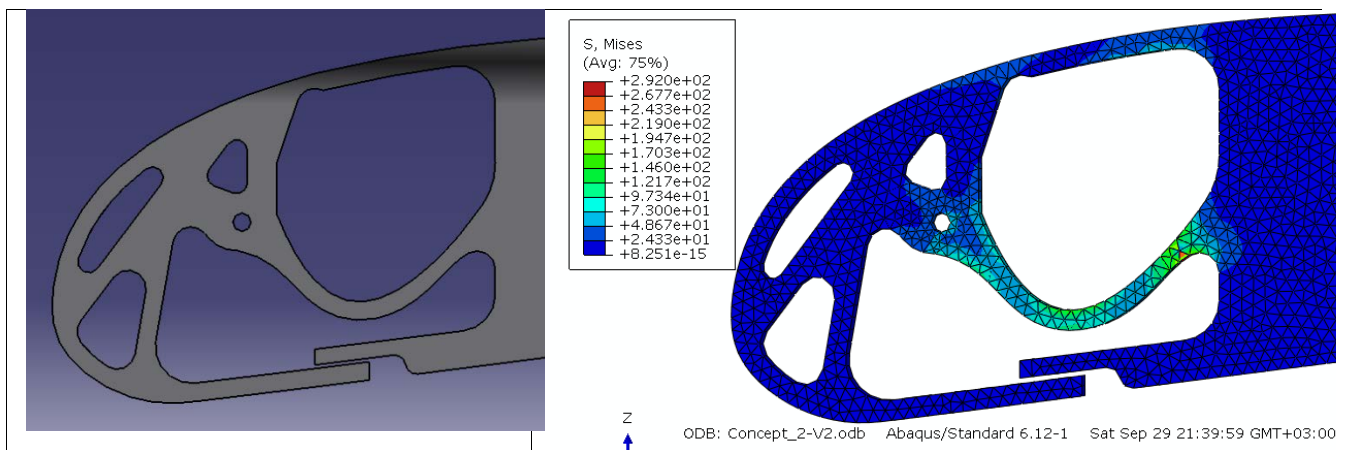
The repeated activation pattern is shown in Figure 15. Here the square wave form of the activation pattern is shown. Time  $t_1$  corresponds to the time for achieving full activation (activation time) and  $t_2$  is the time to return to the unloaded condition (cool down). It was found that the maximum force exerted by the actuator is not dependant on the way of activation but on the number of crystallographic transformations. This is evident from the graphs in Figure 15b.

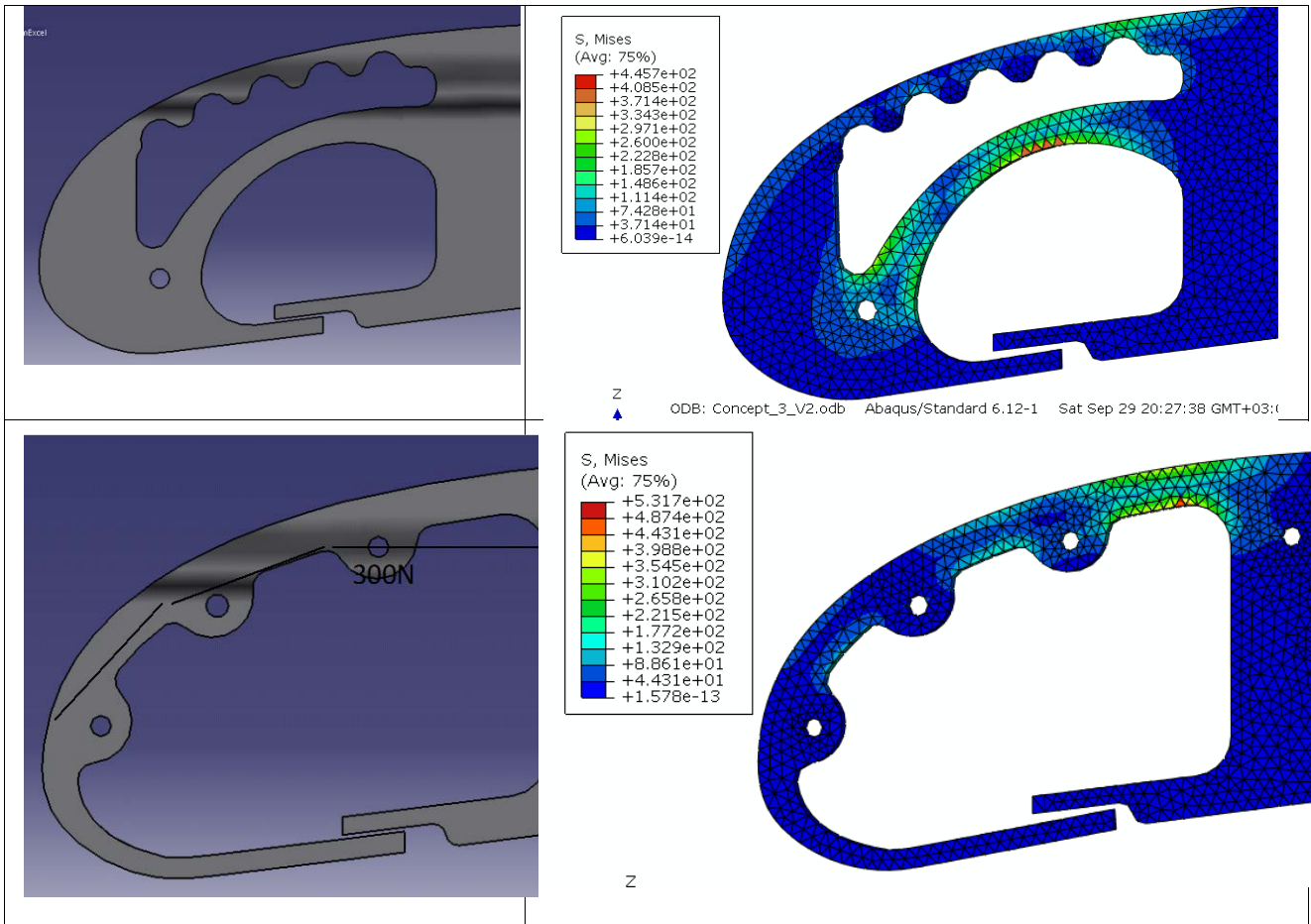
Manufacturing of three different SMA actuated concepts and testing under clamped in a stress and/or tension/compression (T/C) scenario. - Task completed (100%)

Compliant mechanism concepts have been investigated as well. In this case the movement of the structure is not achieved by links and joints but only by the configuration of the geometrical details. In our case various configurations have been studied in terms of achieving the desired final shape and their characteristics are shown in the following

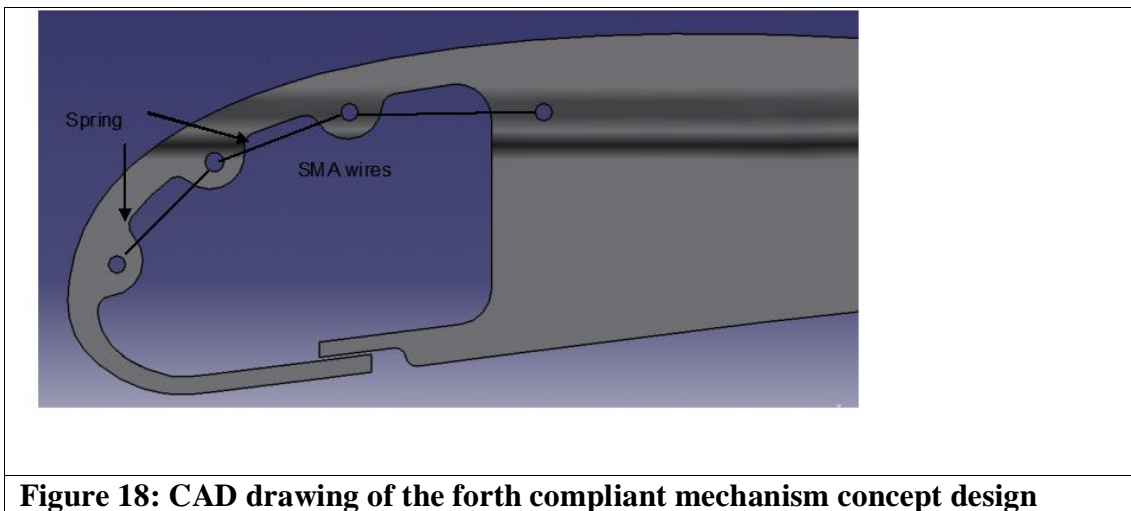


**Figure 16:** Various concepts of compliant leading edge concepts have been manufactured and tested.





**Figure 17:** Various concepts of compliant leading edge concepts have been investigated and their behavior simulated by FEA.



**Figure 18:** CAD drawing of the forth compliant mechanism concept design

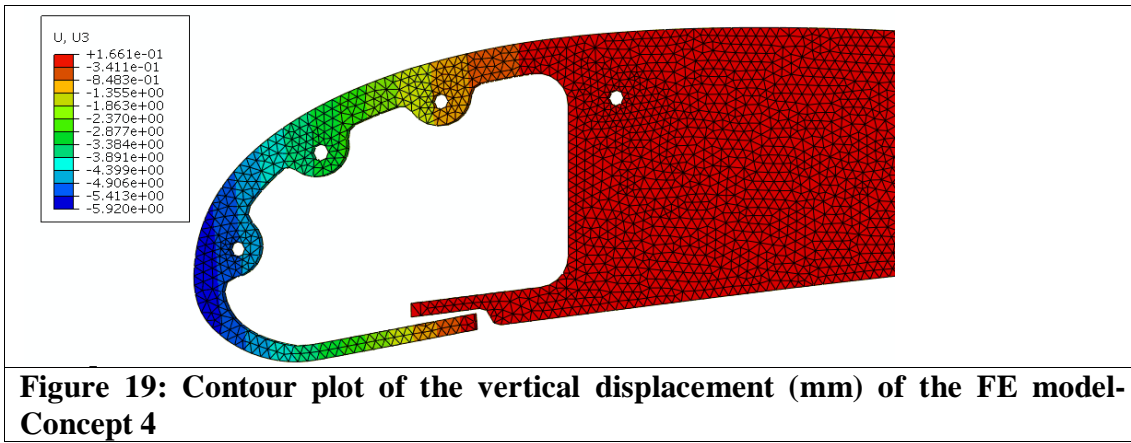


Figure 19: Contour plot of the vertical displacement (mm) of the FE model-Concept 4

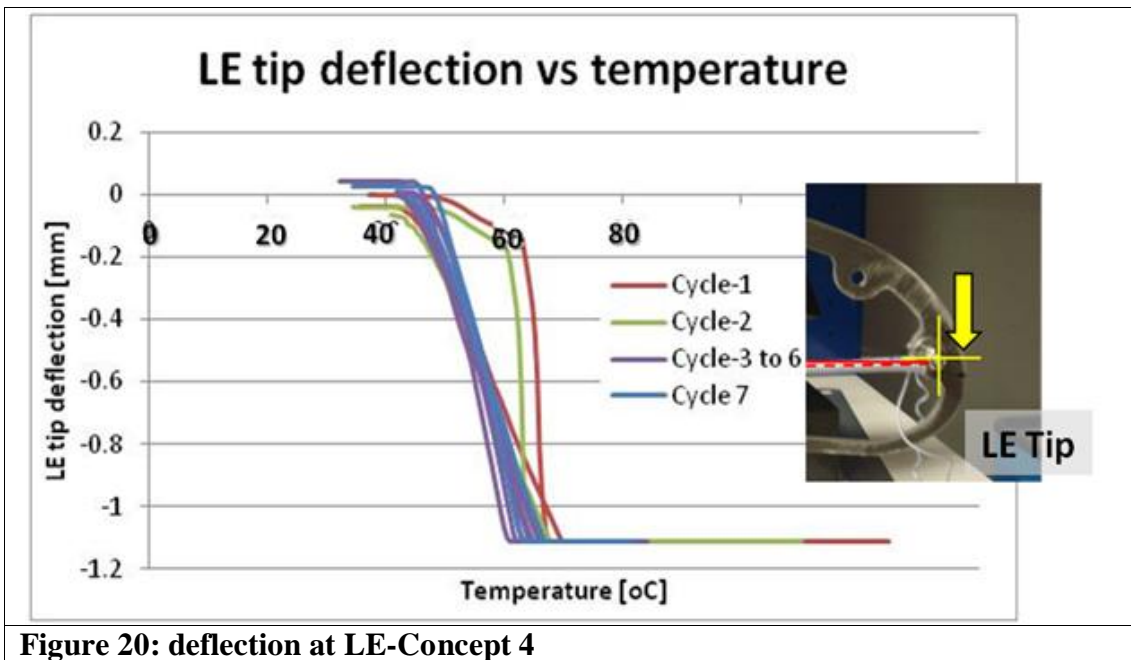
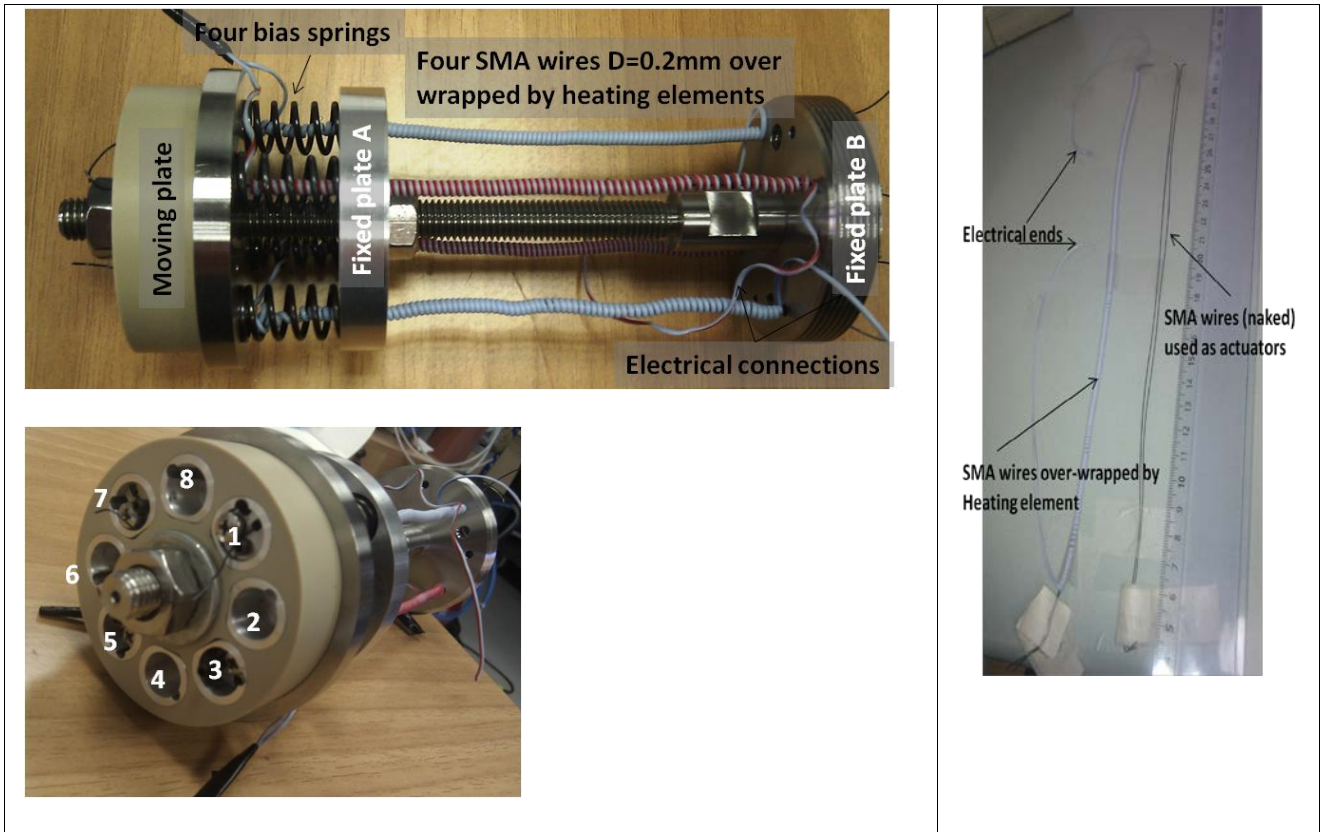
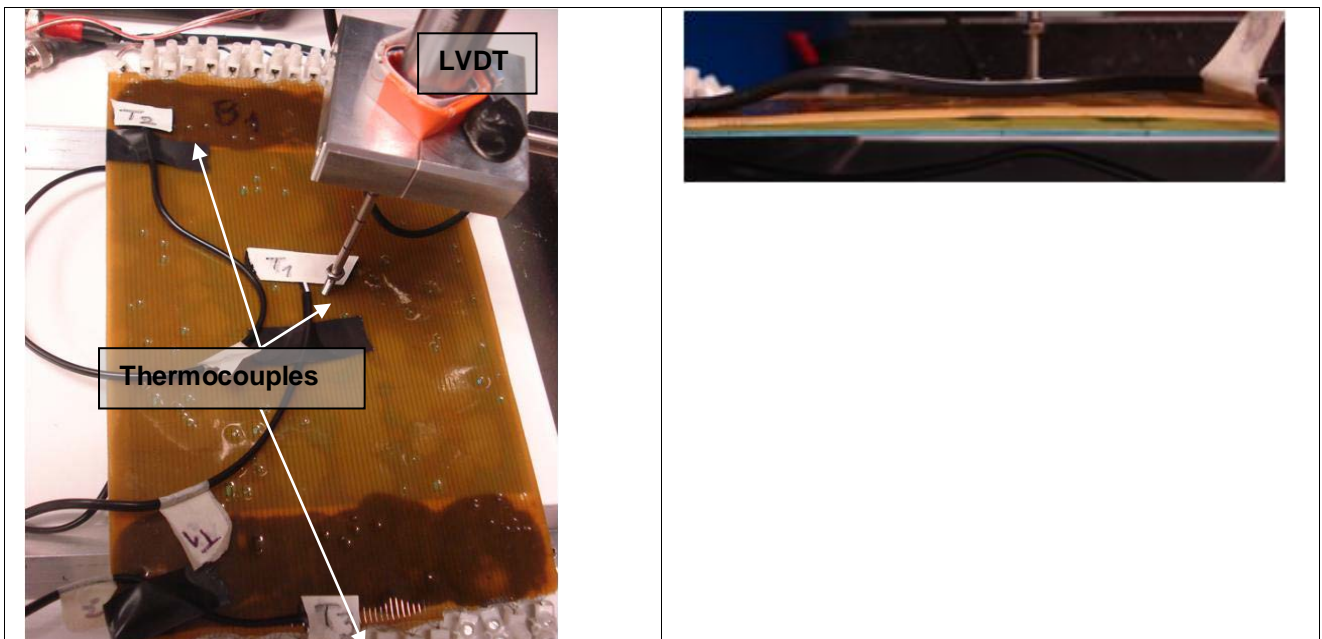


Figure 20: deflection at LE-Concept 4

The linear actuator was manufactured and the construction is shown in the following Figure 8.



**Figure 21:** Linear actuator without cover. In the bottom picture the eight positions of wires is shown. The same number of bias springs can be adopted. On the right the SMA actuator assembly is displayed.



**Figure 22:** Second sample configuration and its deflection of plate in the mid-plane ( $H_B$ )

### 2.2.3 Deviations from the work programme, and corrective actions taken/suggested

The actual work plan in WP2 is shown at the end of this section.

#### I. WP 2.1 Experimental conditions, training aspects, and results

Work content, output: No deviation is experienced. The Task is finished (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The originally assigned resources are sufficient for the execution of the technical effort.

#### II. WP 2.2 Examination of specimen operation after testing

Work content, output: No deviation is experienced. The Task is in progress (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was not adequate for the actual tasks of the WP2.2. This fact will not impact the work content of the tasks and will not affect the overall budget.

### 2.2.4 List of deliverables and milestones

**Table 14: Updated Deliverables list for WP2**

Del. no	Deliverable name	WP no.	Date due, month	Actual/Forecast delivery, month	Lead contractor
D2.1	Manufacturing of SMyLE specimen and determination of experimental conditions	2.1	Oct. 12	Sept. 12	INASCO
D2.2	SMyLE experiment, aging- & fatigue mechanisms, fail-safe issues (report C)	2.2	Nov 12	Oct. 12	INASCO

**Table 15: Updated Milestones list for WP2**

Mile-stone no.	Milestone name	WP no.	Date due month	Actual/Forecast delivery month	Lead contractor
M2	Possible identification of new aging- & fatigue mechanisms	2	Oct 12	Oct. 12	INASCO

**2.3 WP3 SMyLE post-experimental issues and recommendations for future work**

**2.3.1 WP overview on objectives, involved partners, planned work and manpower**

<b>Table 16 WP3</b>			
<b>Work package number</b>	3	<b>Start / End date</b>	M16 / M26
<b>Work package title</b>	SMyLE post-experimental issues and recommendations for future work		
<b>Activity Type</b>	RTD		
<b>Participant number</b>	2		
<b>Participant short name</b>	ARES, INASCO		
<b>Person-months per participant:</b>	4 (ARES) 1.2 (INASCO)		
<b>WP3 Objectives</b>			
<ol style="list-style-type: none"> <li>1. Depending on WP2 outcome -- Modification of constitutive- and finite element model.</li> <li>2. Depending on WP2 outcome -- Modification of SMA specimen.</li> </ol>			
<b>WP3 Description of work</b>			
<b>Task 3.1: Eventual specimen correction</b>			
<ol style="list-style-type: none"> <li>1. Eventual modifications of SMyLE specimen configuration (numerical &amp; structural)</li> <li>2. Final delivery of SMyLE specimen</li> </ol>			
<b>Task 3.2: Recommendations for future work</b>			
<p>It is intended that the following aspects will be briefly included in SMyLE. Owing to the strict timescales involved, reference will be done based purely on bibliographical survey results, i.e.:</p> <ol style="list-style-type: none"> <li>1. Maintenance aspects</li> <li>2. Corrosion- &amp; environmental issues</li> <li>3. Alloying considerations</li> <li>4. Impact loading conditions (low &amp; high speed impact, e.g. aiming to simulate flight through hailstorm)</li> <li>5. Temperature range of safe operation (suggested [-60°C, +50°C]; subject to changes)</li> <li>6. Vibrational- &amp; impact type of loads</li> <li>7. Inclusion of damping &amp; material inhomogeneities into the numerical model</li> <li>8. Interrupted load testing, i.e. partial loading cycles</li> </ol>			
<b>Deliverables of WP3</b>			
<b>Code number</b>	<b>Date</b>	<b>Description</b>	
D3.1	Month 25	Improvement of SMyLE specimen (depending on WP2 output)	
D3.2	Month 26	(following report B and D3.1)-- Modification of SMyLE numerical model and recommendations for future work (report D)	

2.3.2 Progress towards objectives

Modification of constitutive- and finite element model and proposals for future work. - Task completed (100%)

The approximation of the actual behavior of the SMA is very good for the purpose of the project. In the following Figure 16 the comparison of the numerical and experimental results are presented for the case when temperature is constant and above the material is being loaded in tension.

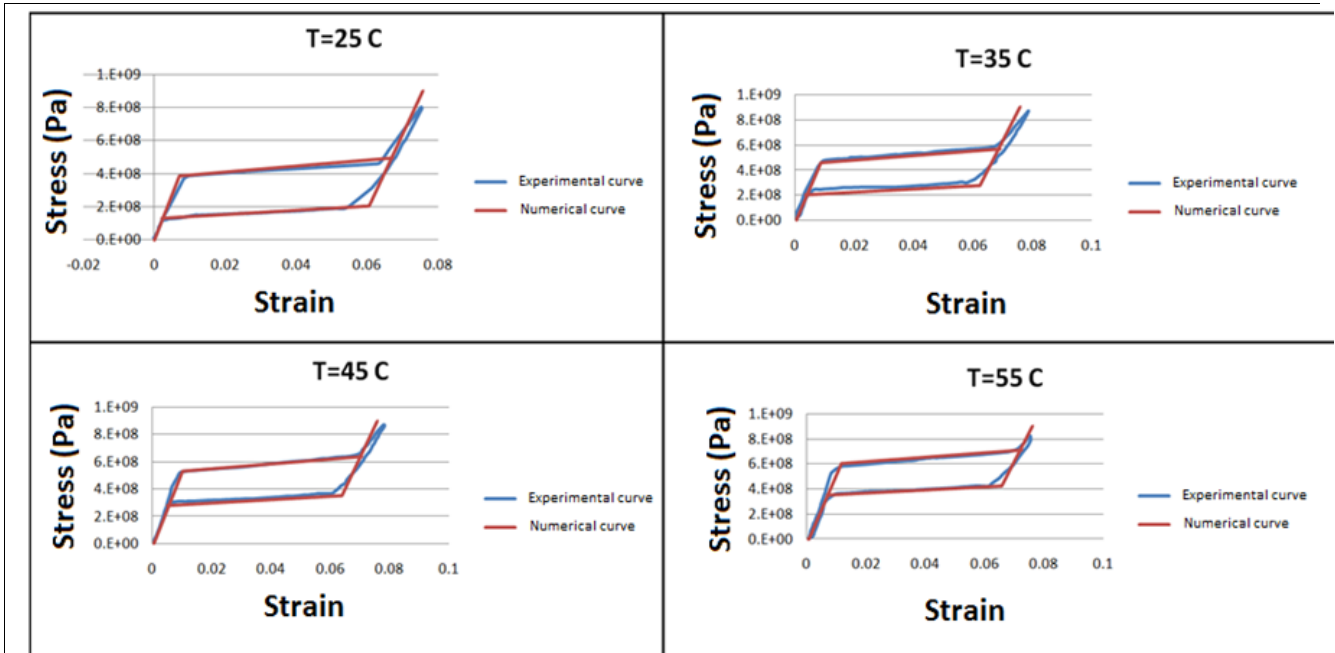


Figure 23: Numerical (red) predictions versus experimental curves (blue)

However if the same numerical model is used under constant stress, when the material, is being cooled until temperature reaches  $T=-300\text{ C}$  and then heated until temperature reaches  $T=900\text{ C}$  (isobaric loading) the fitting is still very good but still leaves space for improvements. In the following figure the comparison of the numerical and experimental results are presented.

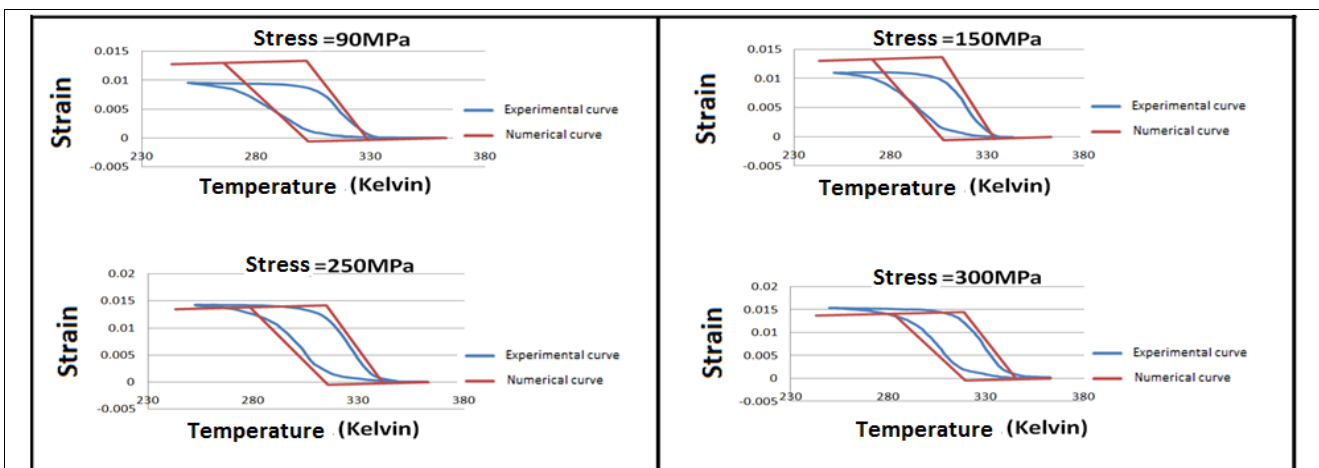


Figure 24: Numerical (red) predictions versus experimental curves (blue)

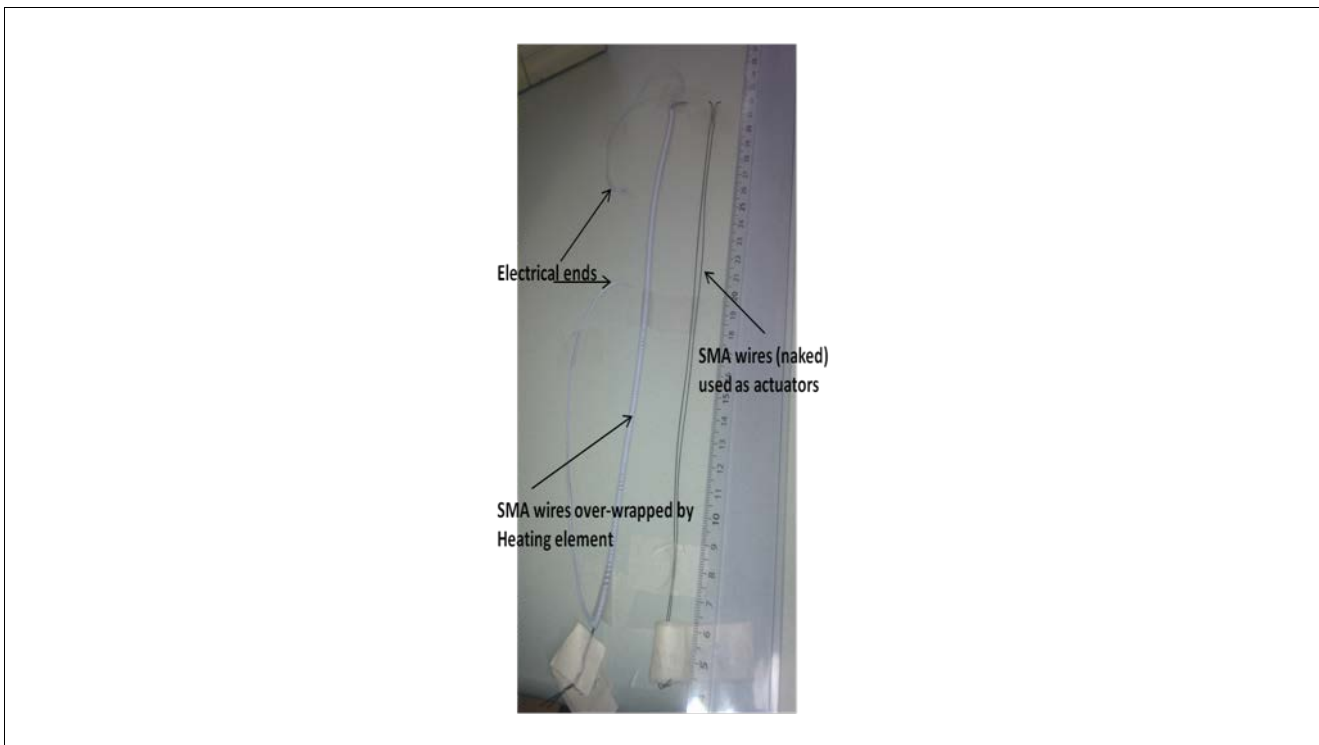
Contrary to the previous case, in this case from the above figure some inaccuracies can be pinpointed.

1. As was expected because of the  $H_{cur}=H_{max}$  assumption the model simulates the strain accurately only when constant high stress values are being applied.
2. Presence of linearity in numerical results, as shown in the figures, where the start, evolution as well as the integration of transformations take place, it comes in contrast to the nonlinear behavior of the experimental results in the some regions. This problem is due to the use of the linear hardening function.

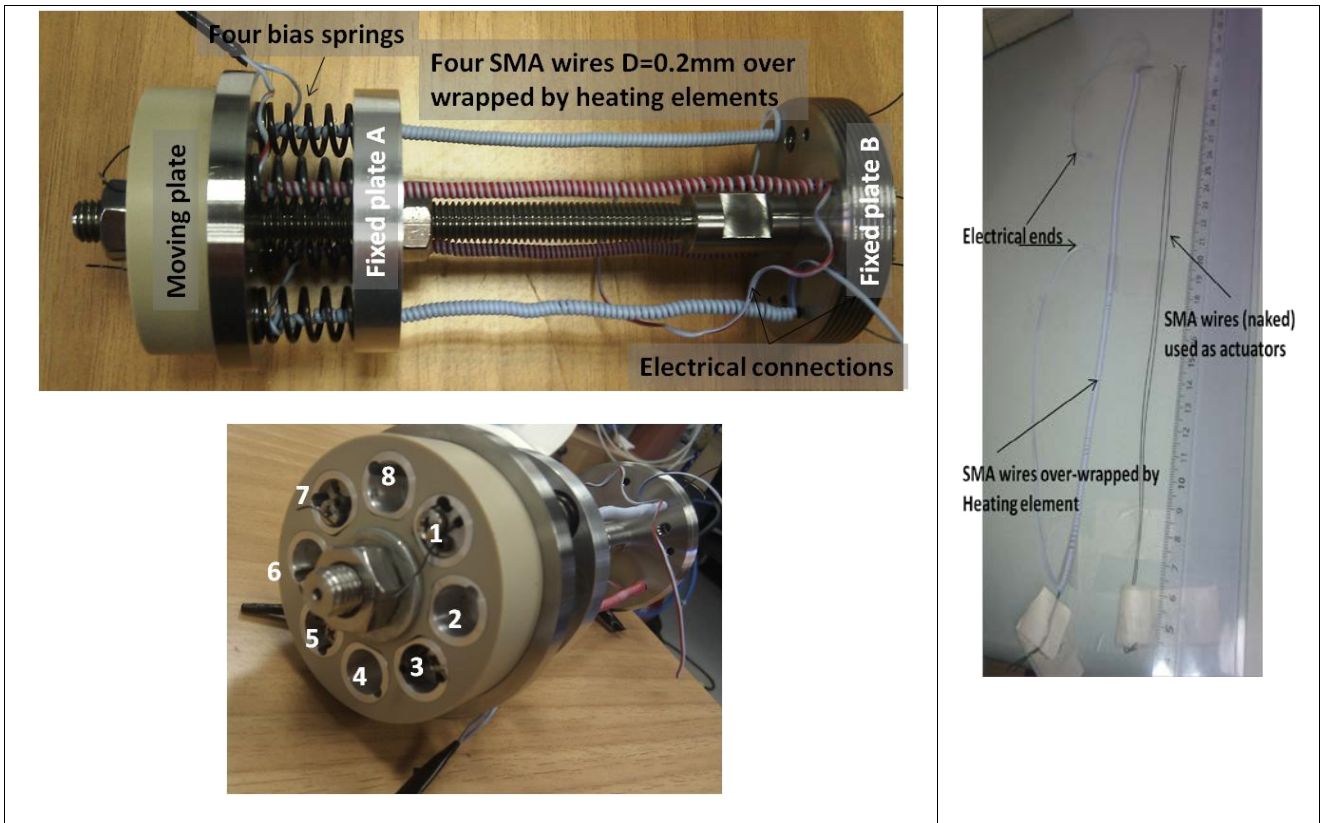
However, the refinement of the models will not be an objective of this project. In conclusion the model of this work produces accurate results in pseudoelastic loading paths and generally in all thermo-mechanical loading paths where austenite transforms directly into detwinned martensite. Also provides very good approximation of transformation limits in all thermo-mechanical loading paths. But as it mentioned in the previous section it has some weaknesses, the  $H_{cur}=h_{max}$  assumption as well as the use of linear hardening function. To this end for future work initially this two problems will be addressed and finally a 3D constitutive model will be imported into ABAQUS in order to simulate and 3d geometries of SMA.

Final delivery of SMyLE specimen. - Task Completed 100%

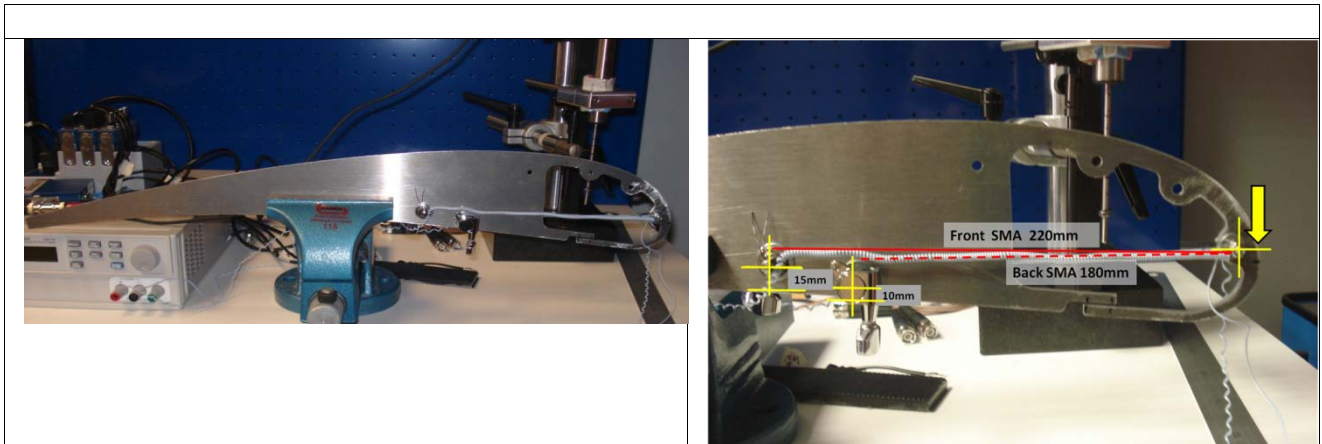
There have been different actuators studied and delivered for the SmyLe project:



**Figure 25::Linear actuator configuration. Two 0.2mm in diameter SMA wires overwrapped by a heating element.**



**Figure 25:** Linear actuator without cover. In the bottom picture the eight positions of wires is shown. The same number of bias springs can be adopted. On the right the SMA actuator assembly is displayed.



**Figure 27:** Compliant LE concept that was evaluated. Deflections were measured from the tip of the airfoil.

### 2.3.3 Deviations from the work programme, and corrective actions taken/suggested

The actual work plan in WP3 is shown at the end of this section

#### I. WP 3.1 Eventual specimen correction

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was not adequate for the actual tasks of the WP3.1. This fact will not impact the work content of the tasks and will not affect the overall budget.

#### II. WP 3.2 Recommendations for future work

Work content, output: No deviation is experienced. The Task is in progress (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was not adequate for the actual tasks of the WP3.2. This fact will not impact the work content of the tasks and will not affect the overall budget.

### 2.2.4 List of deliverables and milestones

**Table 17: Updated Deliverables list for WP3**

Del. no	Deliverable name	WP no.	Date due, month	Actual/Forecast delivery, month	Lead contractor
D3.1	Improvement of SMyLE specimen (depending on WP2 output)	3.1	Oct. 12	Nov. 12	INASCO
D3.2	(following report B and D3.1)-- Modification of SMyLE numerical model and recommendations for future work (report D)	3.2	Nov. 12	Nov. 12	ARES

**Table 18: Updated Milestones list for WP3**

Milestone no.	Milestone name	WP no.	Date due month	Actual/Forecast delivery month	Lead contractor
M3	Eventual modifications of SMyLE constitutive and FEM models	3	Nov. 12	Nov.12	ARES

**2.4 WP4 Model estimation for measured data interpolation**

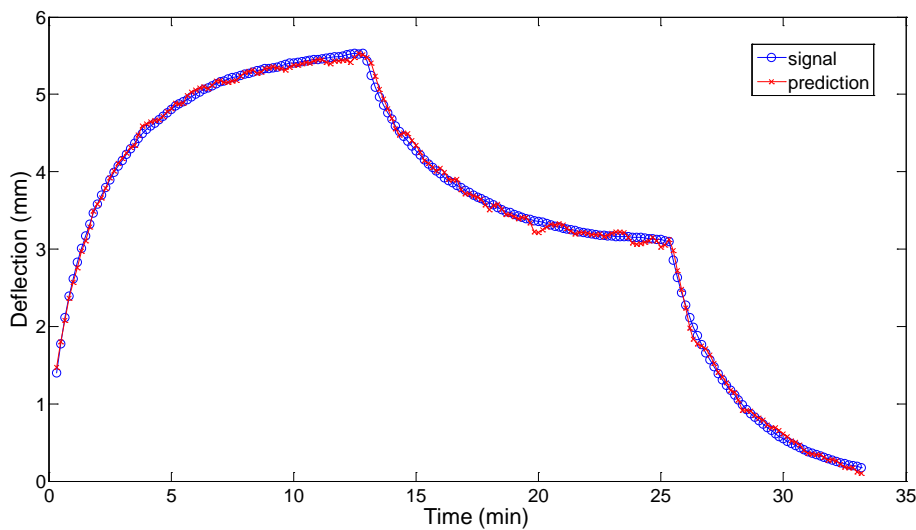
**2.4.1 WP overview on objectives, involved partners, planned work and manpower**

<b>Table 4.4 WP4</b>			
<b>Work package number</b>	4	<b>Start date or starting event</b>	Month 20
<b>Work package title</b>	SMyLE post-experimental issues and recommendations for future work		
<b>Activity Type</b>	RTD		
<b>Participant number</b>	2		
<b>Participant short name</b>	ARES, INASCO		
<b>Person-months per participant:</b>	6 (ARES) 0 (INASCO)		
<b>WP4 Objectives</b>			
To develop a model estimation technique for SMA test data interpolation.			
<b>WP4 Description of work</b>			
<p><b>Task 4.1: General framework</b>                      The general framework of the estimation method will be formulated, based on available information concerning the physics of the system to be identified (estimated). Potential connection with allometric modeling will be explored.                      Inputs: information concerning the physics of the problem. Outputs: General mathematical framework</p> <p><b>Task 4.2: Preliminary results</b>                      Preliminary simulation runs will be performed, in order to have an indication of the system response signal characteristics.                      Inputs: Input signal specification. Outputs: Data files</p> <p><b>Task 4.3: Model estimation method</b>                      The general estimation framework developed in Task 1 will be adapted in order to be able in capturing the general characteristics of the system response signals (preliminary results).                      Inputs: General framework, Preliminary results. Outputs: Specific model estimation mathematical framework</p> <p><b>Task 4.4: Model simulation runs</b>                      The final simulation runs will be performed in order to provide proper data for the final model estimation.                      Inputs: Input signal specification. Outputs: Data files</p> <p><b>Task 4.5: Experimental data</b>                      A series of experiments will be performed in order to provide, real world, experimental data for the validation of the developed estimation method.                      Inputs: Input signal specification. Outputs: Data files</p> <p><b>Task 4.6: Model estimation</b></p>			
<b>Deliverables of WP4</b>			
<b>Code number</b>	<b>Date</b>	<b>Description</b>	
D4.1	Month 24	Delivery of model estimation report	

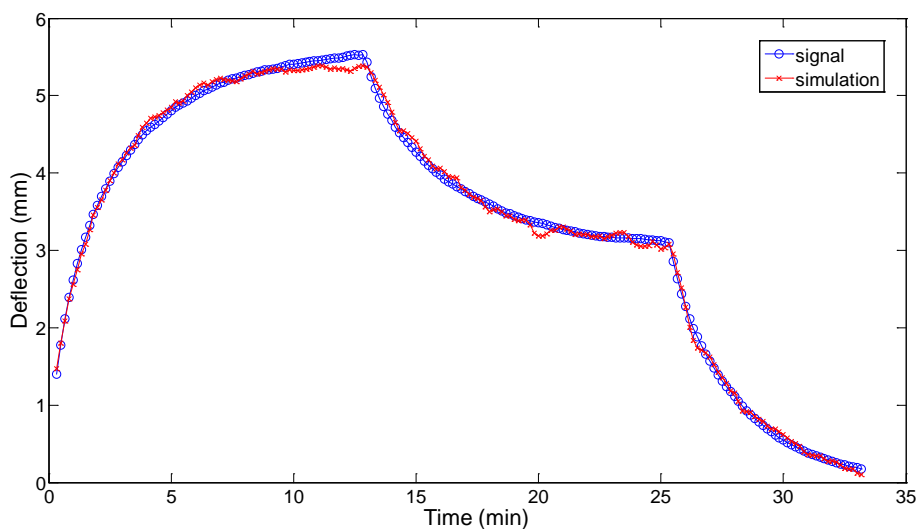
### 2.4.2 Progress towards objectives

#### Develop a model estimation technique for SMA test data interpolation - Task completed (100%)

Aim of this study is to present a complete methodology for identifying the SMA actuator dynamics based, exclusively, on experimental measurements, without the need of analytic modelling. This is presently achieved through the Non linear Auto Regressive with eXogenous excitation (NARX) model class, which is able to capture the dynamical behaviour of a fairly wide range of non linear phenomena. Furthermore, the NARX model class may properly be extended to the Functionally Pooled NARX (FP-NARX) model class in order to capture different and/or varying operating conditions. Furthermore to the NARX model based predictions (and although the whole model estimation procedure is presently clearly focused on the model's predicting ability), the NARX model based simulated response is also presented in **Figure 10**, along with the actual deflection signal. The agreement of the simulated and actual signals, although being (expectantly) slightly inferior to the respective prediction results, is still very good.



**Figure 1: The deflection signal along with the NARX mode-based predicted signal.**



**Figure 2: The deflection signal along with the NARX mode-based simulated signal.**

### 2.4.3 Deviations from the work programme, and corrective actions taken/suggested

The actual work plan in WP3 is shown at the end of this section

#### I. Task 4.1: General framework

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

#### II. Task 4.2: Preliminary results

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

#### III. Task 4.3: Model estimation method

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

#### IV. Task 4.4: Model simulation runs

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

#### V Task 4.5: Experimental data

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

#### VI Task 4.6: Model estimation

Work content, output: No deviation is experienced. The Task is completed (100%).

Timing: The task has been rescheduled according to an overall project extension.

Effort level: The foreseen effort level was adequate for the completion of the actual tasks.

### 2.4.4 List of deliverables and milestones

**Table 17: Updated Deliverables list for WP3**

Del. no	Deliverable name	WP no.	Date due, month	Actual/ Forecast delivery, month	Lead contractor
D4.1	Model estimation report	4.6	Oct. 12	Oct. 12	ARES

### Section 3. Consortium management

#### 3.1 Consortium management tasks and their achievements

##### 3.1.1 WP overview on objectives, involved partners, planned work and manpower

<b>Table 19 WP0</b>			
<b>Work package number</b>	0	<b>Start date or starting event</b>	Month 1
		<b>End date</b>	Month 2
<b>Work package title</b>	SMyLE Management		
<b>Activity Type</b>	Management		
<b>Participant number</b>	1		
<b>Participant short name</b>	ARES		
<b>Person-months per participant:</b>	1		
<b>WP0 Objectives</b>			
1. To coordinate, monitor and report the project progress as well as to review updated exploitation plans			
<b>WP0 Description of work</b>			
<ul style="list-style-type: none"> <li>- Administrative and technical co-ordination of the project.</li> <li>- Circulation of information from the CEC or from partners to the whole consortium.</li> <li>- Organization of progress meetings between partners at 6 monthly intervals</li> <li>- Assessment and review of the progress of the different workpackages and taking action where necessary.</li> <li>- Writing 6 monthly summary progress reports based on input collected from the Workpackage Leaders</li> <li>- Preparation of consolidated periodic activity, management and funding distribution reports</li> <li>- Preparation of consolidated final activity, management and funding distribution reports</li> <li>- Distribution of the annual Project Review reports and further deliverables to the European Commission</li> <li>- Organization of Project Review meetings</li> <li>- Review of updated exploitation plans based on the views, inputs of the partners and especially end users</li> <li>- Resolving any problems occurring between the partners during the project</li> </ul>			
<b>Deliverables of WP0</b>			
<b>Code number</b>	<b>Date</b>	<b>Description</b>	
D0.1	Month 22	SMyLE project final Report	

Table 20: Deliverables list

Del. no	Deliverable name	WP no.	Date due, month	Actual/Forecast delivery, month	Lead contractor
D0.1	Final report (technical progress WP1,2,3), management report, report on funding distribution between contractors, audit certificate	0	July 12	Dec. 12	ARES

Table 21: Milestones list

Milestone no.	Milestone name	WP no.	Date due month	Actual/Forecast delivery month	Lead contractor
M0.1	Kick-off	0	Oct. 10	Dec. 10	ARES
M0.3	Final project review (major milestone)	0	July 12	Dec. 12	ARES

**Main work carried out in the WP:**

- The kick -off meeting has been organised on the 15/12/10 via teleconference
- Three Amendments to the contract were necessary. They were called on the 07 of July 2011, on the 13 September 2012 and on the 3rd of Oct. 2012. The first two ones were called basically to extend the duration of the WP2 and WP3 and the last one to add a new WP, WP4 for allometric modeling of SMA behavior.
- A technical meeting was organised on the 20/01/11 at Patras University in Patras
- A progress meeting with the Topic Manager was organised in Athens on the 19/02/11 in Athens
- A progress meeting with the Topic Manager was organised on the 11/07/2011 at Athens
- Several teleconference meetings were organised for WP1 and WP2.
- A technical meeting was organised on 7/10/2011 at the Topic Manager site in Holzkirchen/Germany

**Main results:**

- Successful kick off teleconference meeting (15/12/2010).
- Three progress meetings for WP1 and WP2 have been organized.
- Definition of a flyer.
- Production of PAR2, PMR2 and Final Report

**Management Issues:**

There are no special issues besides the two amendments done in this period.

**Status versus planning of the reporting period:**

- Project management is well in time with respect to the original planning.

**3.2 Contractors**

The contractors performed at their very best in order to ensure the project's progress up to this point. At all meetings (technical and management), all contractors attended with at least one representative.

## **Section 4. Other issues**

There are no specific requirements set on this project, such as ethical issues. Therefore, there is no input to this section.

## **Annex – Plan for using and disseminating the knowledge**

### **Part 1. Exploitable Knowledge and its Use**

The exploitation of SMyLE aims its application to be integrated on an adaptive wing at a later stage. In addition, it is believed that it can possibly serve as a replacement of other control surfaces, significantly contributing to the aircraft's weight reduction therefore increasing its operational range while reducing the direct operational costs at the same time (e.g. payload increase, maintenance reduction among others). Although not much can be said on the environmental friendliness of shape memory alloys for the time being, the advent & application of SMAs obviously contributes to a greener aircraft.

The main objective of the dissemination plan is to guarantee proper diffusion of knowledge and project results. The dissemination process will be handled so as to spread information among all potentially concerned stakeholders and all levels of policy-makers: such as aeronautics supply industry, safety and certification bodies, standardization bodies, engineering organizations, European and national policy makers, universities, schools and European citizens. The activities that will be used to disseminate SMyLE results are as follows:

- Scientific publications in European Journals
- Presentation in Conferences and Workshops organized on annual basis, such as SPIE Smart Structures/NDE, ASME Conference on Smart Materials, Adaptive Structures & Intelligent Systems, CIMTEC-International Conference on Modern Materials & Technologies, among others.
- Graduate student(s) training involved in the project

The intellectual property monitoring and patent survey is an indispensable prerequisite to ensure that the research and developments are driven properly. It consists in a continuous identification, monitoring and qualification of tangible and intangible results that should be either kept confidential, legally protected, disseminated or transferred to third parties. Dissemination and exploitation of the results will be ensured by the Coordinator in agreement with CfP manager. They will ensure that the issues related to Intellectual Property Rights are properly assessed and managed. The IPR management shall cover milestones and deliverables of the SMyLE project to identify any commercial potential of generated knowledge and information.

At this stage the majority of exploitable knowledge is related to development of methodologies and approaches for numerical modeling of SMA based actuators. Transportation sector is the sector of application for such developments and this includes aircraft design and manufacturing, as well as shipbuilding and automotive industries.

**Overview table**

<b>Exploitable Knowledge</b> (description)	<b>Exploitable product(s) or measure(s)</b>	<b>Sector(s) of application</b>	<b>Timetable for commercial use</b>	<b>Patents or other IPR protection</b>	<b>Owner &amp; Other Partner(s) involved</b>
Modeling of SMA.	Methods	Transport Aircraft ships automotive	Immediate	N/A	INASCO/ARES
Manufacturing of embedded SMA actuators	Methods	Transport Aircraft ships automotive	Immediate	N/A	INASCO
Design rules for SMA based actuated structures	Methods	Transport Aircraft ships automotive	Immediate	N/A	INASCO/ARES
Structure simulation	FEM	Aeronautics	48 months	no	ARES
Model estimation for measured data interpolation	Software code	Transport Aircraft ships automotive	24 months	TBD	ARES

**Key:**

TBD – patent protection to be decided

N/A – protection not applicable

## Part 2. Dissemination of Knowledge

The following Dissemination Table present the dissemination activities performed during Period 1 and Period 2 of the project and those planned to be performed within the project duration. The Dissemination Table is updated with the partners' activities and plans at each Consortium meeting.

### Overview table

Planned/ actual dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible / involved
Nov. 12	Flyer	General	International	300	ARES/INASCO
June 13	Presentation in a conference, published paper (6th ECCOMAS Conference on Smart Structures and Materials, SMART2013, Politecnico di Torino, 24-26 June 2013)	Scientific	International	300	ARES/INASCO

### **Part 3. Publishable results**

Project's publishable results may be found in the conference paper, AIRFOIL'S LEADING EDGE MORPHING BASED ON SMA ELEMENTS by D. Karagiannis, D. Stamatelos and Th. Spathopoulos, 6th ECCOMAS Conference on Smart Structures and Materials, SMART2013, Politecnico di Torino, 24-26 June 2013