Grant agreement no: 296617

Project acronym: *SMyTE*

Project title: *Advanced concepts for trailing edge morphing wings - Design and manufacturing of test rig and test samples - Test execution*

Instrument: *JTI CLEAN SKY*

Theme: *JTI-CS-2011-1-GRA-02-015*

Publishable Summary

Date of preparation: *15-10-2013*

Start date of project: *01 February 2012* Duration: 12 *Months*

Project coordinator name: Mr. *Dimitri Karagiannis*
Project coordinator organisation name: *INASCO*

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Executive Summary

Project details

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Project Logo		Coordinator's Details
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Project summary

SMyTE 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 SMyTE actuator system could contribute to lower mass (compared to a conventional mechanical/hydraulic actuator), be fully integrated (at a later stage) within a regional aircraft.
The purpose of SMyTE is technology based on high performance material and optimized architecture and it is multifold. When applied to perform camber variations of a movable flap, it increases airfoil performance with respect to specific requirements which will lead to following benefits i.e.: at first, SMyTE can significantly improve TE aerodynamics offering a greater operational envelope compared to a conventional TE flap device. Secondly, by eliminating conventional flap actuation mechanisms it can provide weight benefits and thus reduction of fuel consumption. As third, being utilized as a flight control surface replacement, it locally improves the aerodynamics in the TE vicinity during flight further adding to drag and fuel reduction.

Duration
From 01 February 2012 to 31 January 2013

Key objectives

- Design and mechanical analysis of the so called Deeply Embedded Shape Memory Actuator (DESA) architecture mechanism. Based on the inputs from T1.1 and the data for the SMA actuators provided by the Topic Manager the DESA architecture will be designed and analysed by in-house developed FEA modules that allow for accurate simulation of the shape memory effects. The output of this task will be 3D CAD models and design drawings that will be used for DESA manufacturing.
- Design analysis and manufacturing if the test rig and the interface for DESA and Smart Actuated Compliant Mechanism (SACM) architectures. The design of the test rig will be supported by FEA analysis in order to assure that proper safety margins for static and dynamic loading exist and that the dynamic characteristics of the test rig will not influence the dynamic response of the trailing edge concepts that will be eventually

assessed. The outcome of this task will be 3D CAD models and manufacturing drawings of the test rig.

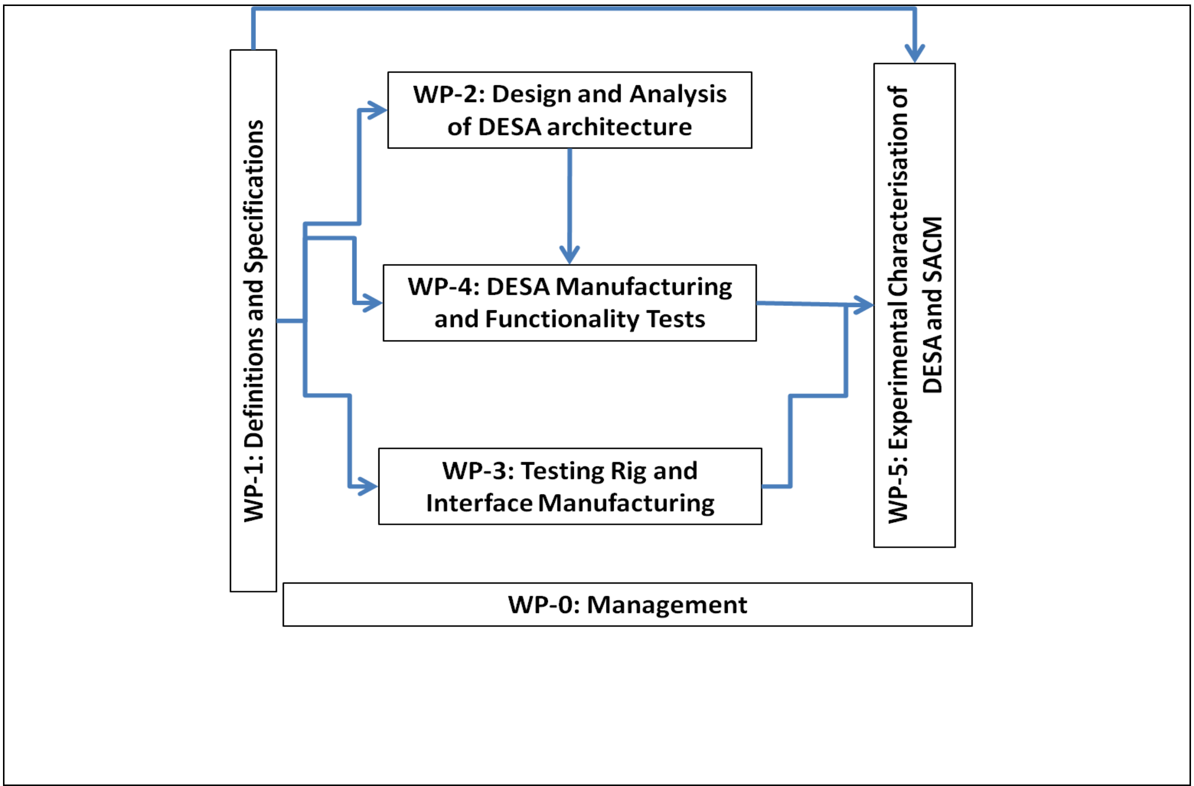
- Manufacturing of the DESA prototype. Functionality tests will be carried out in order to fine tune the different components (SMA actuators and bias elements-springs) and proof the concept.
- Experimental characterisation of DESA and SACM architectures

Consortium

	Partic. No.	Participant Name	Participant Short Name	Country
CO	1	Integrated Aerospace Sciences Corporation (INASCO)	INASCO	EL
CR	2	AEROTRON Research	ARES	EL
CR	3	University of Patras	UoP	EL

*CO = Coordinator
CR = Contractor

Project Workpackage interdependence



Results achieved

The main output of the project were:

- DESA Specifications, SACM Specifications, Test rig specifications and Test Plan Specifications according to the requirements set
- 3D CAD model of DESA architecture, FEA analysis and manufacturing drawings.
- Design, FEA analysis and manufacturing drawings for the fabrication of appropriate test rigs and interface for the testing of DESA and SACM prototypes
- Manufacturing of DESA prototype and functionality tests. Training of SMA actuators.
- Perform Mechanical Characterization tests on SACM and DESA prototypes
- Improvements on actuation cycle shortening of the SMA wire actuators

Achieved end results

The achieved end results are a lightweight novel electrically operated Trailing 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, SMyTE project will allow to reduce the size of components of generation equipment as well as to achieve significant reduction in maintenance. Another aspect of SMyTE developments is increased reliability safety having great importance in aeronautic transport.

1. Project objectives and major achievements

1.1 General project objectives

The SMyTE project aims to develop state-of-the-art SMA actuator specimen(s), undergoing controlled deformation and to perform tests on a suitably designed and assembled test rig with its related interface components to assure the characterisation of SACM and DESA demonstrators and the validation of numerical schemes used during design phase. At a later stage, it is further aimed to be applied on the trailing edge of an adaptive/morphing wing. For this reason several aspects such as fail-safe, test execution under different type of static and dynamic loads are considered reflecting in fact the future applicability of the current project. The project is divided in five Tasks that will lead to the achievement of the SMyTE objectives.

In order to achieve these objectives the project has been organized into one management and five technical work packages (WP). Due to the requirements of the proposed activities all technical tasks are further broken down into tasks. This has fostered better monitoring of the activities and tractable achievements.

1.2 Project's relation to the state of the art

SMyTE 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 SMyTE actuator system could contribute to lower mass (compared to a conventional mechanical/hydraulic actuator), be fully integrated (at a later stage) within a regional aircraft.
The purpose of SMyTE is technology based on high performance material and optimized architecture and it is multifold. When applied to perform camber variations of a movable flap, it increases airfoil performance with respect to specific requirements which will lead to following benefits i.e.: at first, SMyTE can significantly improve TE aerodynamics offering a greater operational envelope compared to a conventional TE flap device. Secondly, by eliminating conventional flap actuation mechanisms it can provide weight benefits and thus reduction of fuel consumption. As third, being utilized as a flight control surface replacement, it locally improves the aerodynamics in the TE vicinity during flight further adding to drag and fuel reduction.

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

The main objectives of project pursued in its two reporting periods were:

- DESA Specifications, SACM Specifications, Test rig specifications and Test Plan Specifications according to the requirements set
- 3D CAD model of DESA architecture, FEA analysis and manufacturing drawings.
- Design, FEA analysis and manufacturing drawings for the fabrication of appropriate test rigs and interface for the testing of DESA and SACM prototypes
- Manufacturing of DESA prototype and functionality tests. Training of SMA actuators.
- To improve SMA wire actuator actuation cycle.

The work performed in the current project followed consequently the described objectives.

WP1: Definition and Specifications

In WP1**,** the work was completed according to the original plan and provided useful inputs to the rest of work packages. More specifically the various project requirements are covered within the following tasks:

- T1.1 DESA Specifications
- T1.2 SACM Specifications
- T1.3 Test rig specifications
- T1.4 Test Plan Specifications

WP-2: Design and Analysis of DESA architecture

In WP2 the work has been completed in all tasks.WP 2 concerns the design and mechanical analysis of the DESA architecture mechanism. Based on the inputs from T1.1 and the data for the SMA actuators provided by the Topic Manager the DESA architecture was designed and analysed by in-house developed FEA modules that allow for accurate simulation of the shape memory effects. With the aid of these modules the static and dynamic behaviour of the DESA architecture will be modelled and critical design parameters will be evaluated. The output of this task was the 3D CAD models and design drawings that will be used for DESA manufacturing.

WP-3: Testing Rig and Interface Manufacturing

The third work package deals with design analysis and manufacturing if the test rig and the interface for DESA and SACM architectures. The design of the test rig was supported by FEA analysis in order to assure that proper safety margins for static and dynamic loading exist and that the dynamic characteristics of the test rig will not influence the dynamic response of the trailing edge concepts that will be eventually assessed. The outcome of task T3.1 was the 3D CAD models of the test rig and manufacturing drawings of the test rig. With the manufacturing drawings from T3.1 a metallic frame-like construction has been manufactured that is able to host DESA and SACM architectures. This will allow the testing under several operative, defined in the test plan. Works in WP3 have been completed.

WP-4: DESA Manufacturing and Functionality Tests

WP 4 deals with the manufacturing of the DESA prototype. Based on the manufacturing drawings of WP-2 the prototype has been manufactured. Functionality tests were carried out in order to fine tune the different components (SMA actuators and bias elements-springs) and proof the concept. Within WP4 and more specifically in T4.1 mechanical characterisation of the SMA actuators (in the form of SMA wires) has been performed as well as proper thermo-mechanical “training”. Both these activities have been proven necessary because the material data from SMA manufacturers tend to be unreliable with considerable batch to batch variations. Works in WP4 have been completed.

WP-5: Experimental Characterisation of DESA and SACM

WP 5 deals with the experimental characterisation of DESA and SACM architectures. This will be done with the aid of the test rig that is manufactured in WP-4. The response of the two architectures under investigation will be assessed under static loads and dynamic excitation. At the end of P1 characterisation tests have been finished. Works will be ongoing for the improvement of DESA actuators.

Commercially available SMA has been used and an initial basic characterization phase was completed. The mechanical response of the actuator has been measured as function of temperature and load application. The aim is to have the material behavior under static and dynamic conditions up to failure. The SMA wires have been trained in one way actuation and will contract upon current application. The required force to bring the specimen back to initial position is provided by the internal stresses of the deformed structure that will “spring back” to its original shape after current is stopped. For the initial trials and to proof the concept, an intermediate transformation temperature SMA has been used (~65ºC).

Special care is given in the work performed in the framework of WP5.2, which was focused on improving the SMA actuation cycle. For this purpose the SMA wire actuators were tested on a special experimental set up that allows different cooling rates of the wires. The result was 50% shorter actuation cycles.

2. Work Performed

2.1 WP1 Definition and Specifications

All project definitions were made in this Work Package (WP). In the following figure the morphed and unmorphed airfoil geometries are shown.

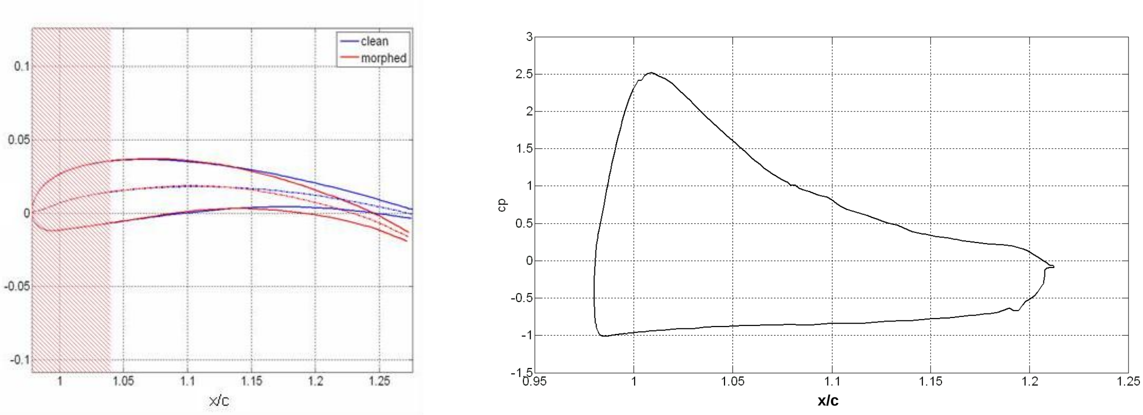


Figure 1: Flap clean and morphed shapes (left) and Flap pressure coefficient vs. normalised chord (right)

2.2 WP2 Design and Analysis of DESA architecture

WP 2 deals with the design and mechanical analysis of the DESA architecture mechanism. Based on the inputs from WP1 and the data for the SMA actuators provided by the Topic Manager the DESA architecture has been designed and analysed by in-house developed FEA modules that allow for accurate simulation of the shape memory effects.

For the purpose of this work package a phenomenological macro model for the SMA actuators have been selected. The macro model is adopted due to its simplicity, reasonable accuracy when treating phase transformation, ability for implementation in three dimensional problems and ability for integration in commercially available structural analysis tools (Finite Element Analysis (FEA)). In the current analysis ABAQUS FEA package UMAT utility has been used to model the thermomechanical response of the SMA material. 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 5.**

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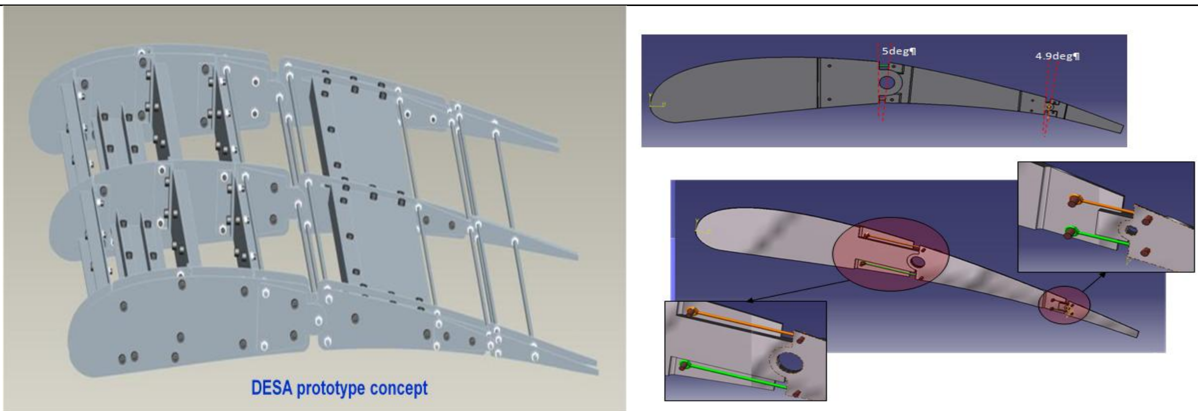


Figure 2: Final design of DESA concept. Two hinge design ensures proper morphing shape. Green SMA wires when activated (internal) cause the wing to morph. Activation of the orange wire returns the wing to its original un-morphed shape.

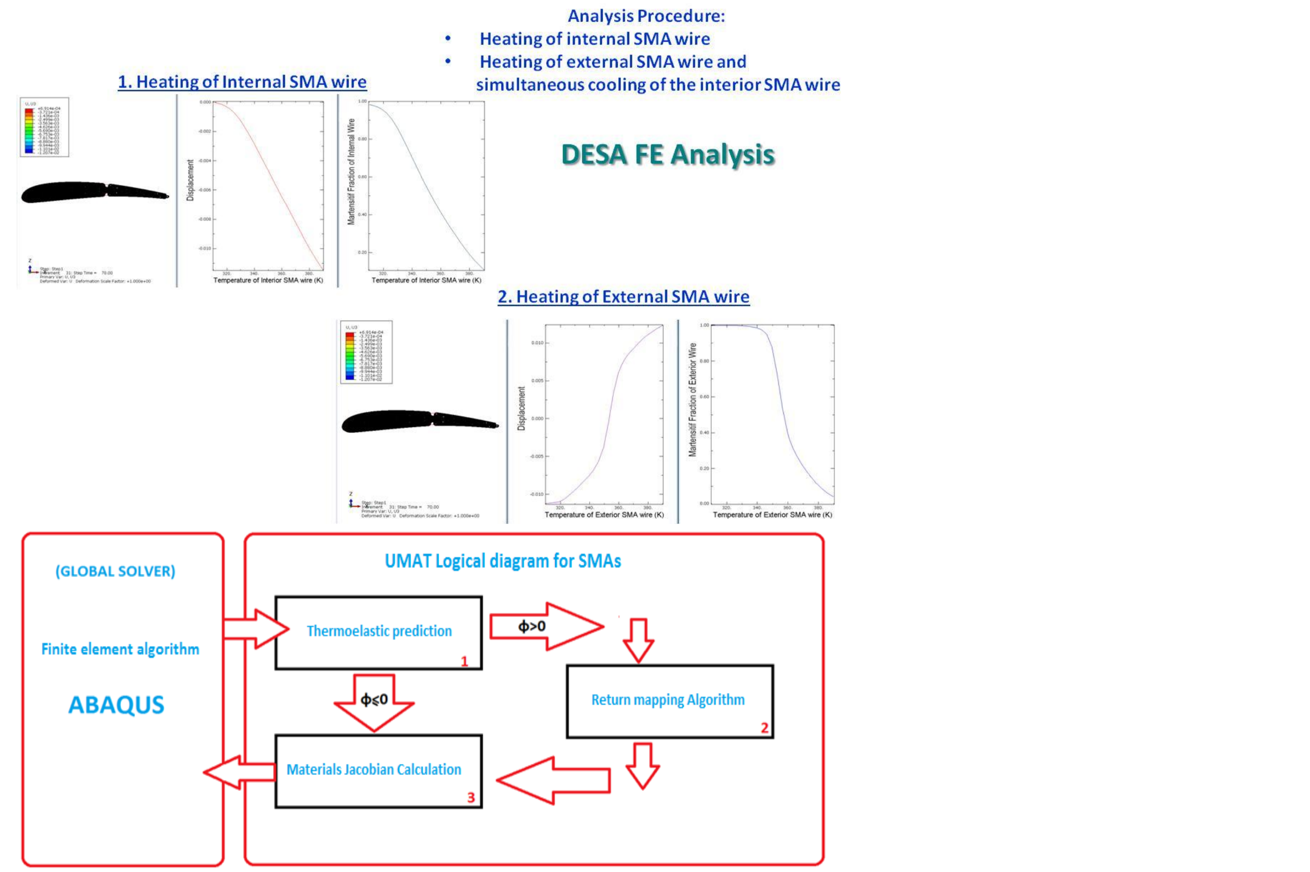


Figure 3: Study of morphing and un morphing sequence of the DESA active section by specially developed FEM in ABAQUS.

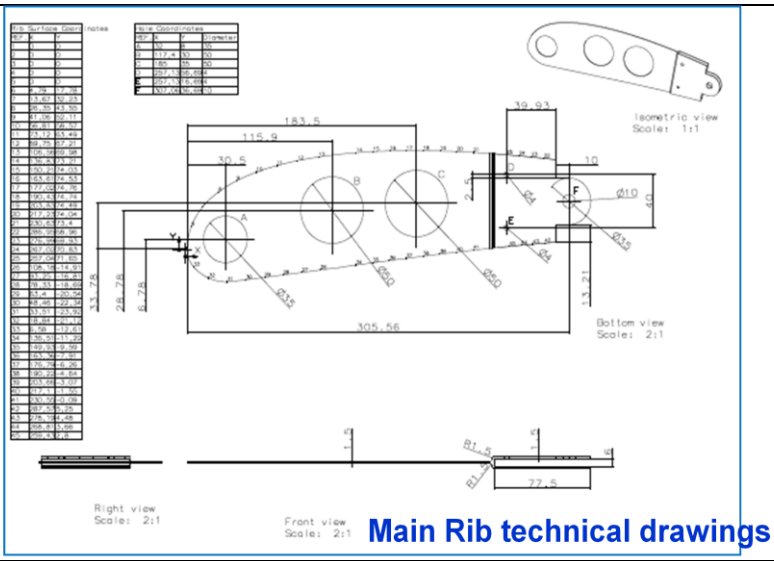


Figure 4: Example of engineering drawings of the first section of the DESA prototype .

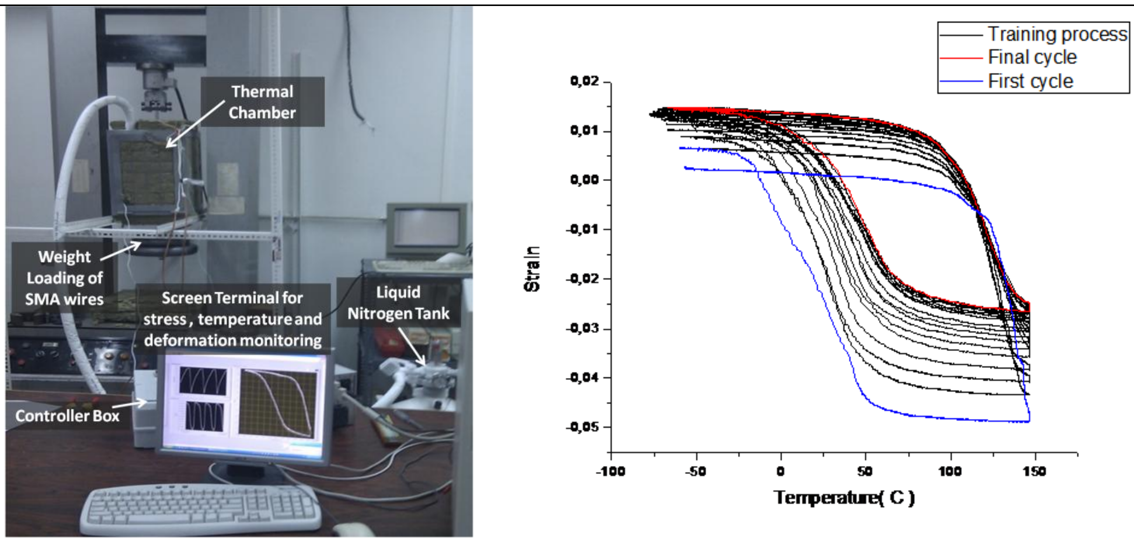
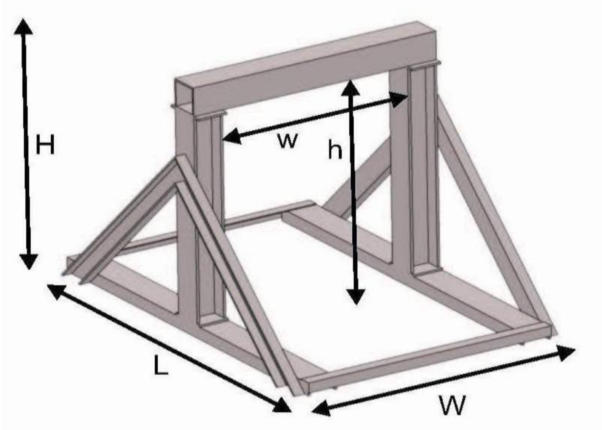


Figure 5: Experimental Setup for SMA Training and Characterization

2.3 WP3 Testing Rig and Interface Manufacturing

In WP-3 a dedicated test rig and related interface component has beendesigned analysed and assembled. This test rig, allows the testing under several operative conditions (loads for several mission phases like take-off / landing, cruise), defined in the test plan.



Length	L=2m
Width	W=1.3m
Height	H=1.2m
Internal clearance width	w=0.9m
Internal clearance height	h=1.1m
Mass	280kg
Color: off-white	7035

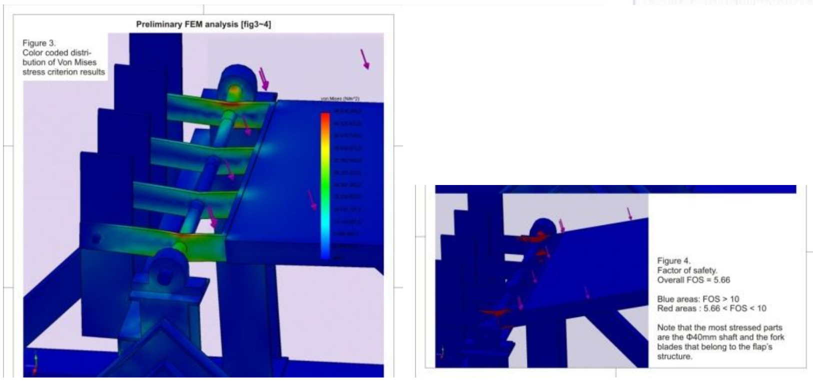


Figure 6: Test rig general dimensions and details. At the bottom FEA of different load cases.

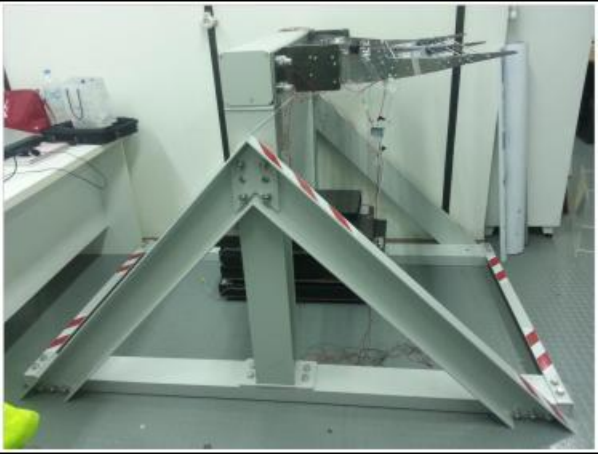


Figure 7: Manufactured test rig with DESA attached on it.

2.4 WP4 DESA Manufacturing and Functionality Tests

In WP 4 the DESA prototype has been manufactured based on the manufacturing drawings of T2.3. An important element for efficient utilisation of SMA actuators is the proper "training". Training is done via a series of isobaric and isothermal tests and is essential for repeatable and dependable actuation cycles. Finally, functionality tests have proofed the concept and prepared the DESA prototype for subsequent testing.

Figure 8: DESA prototype manufactured and tested on the test rig..

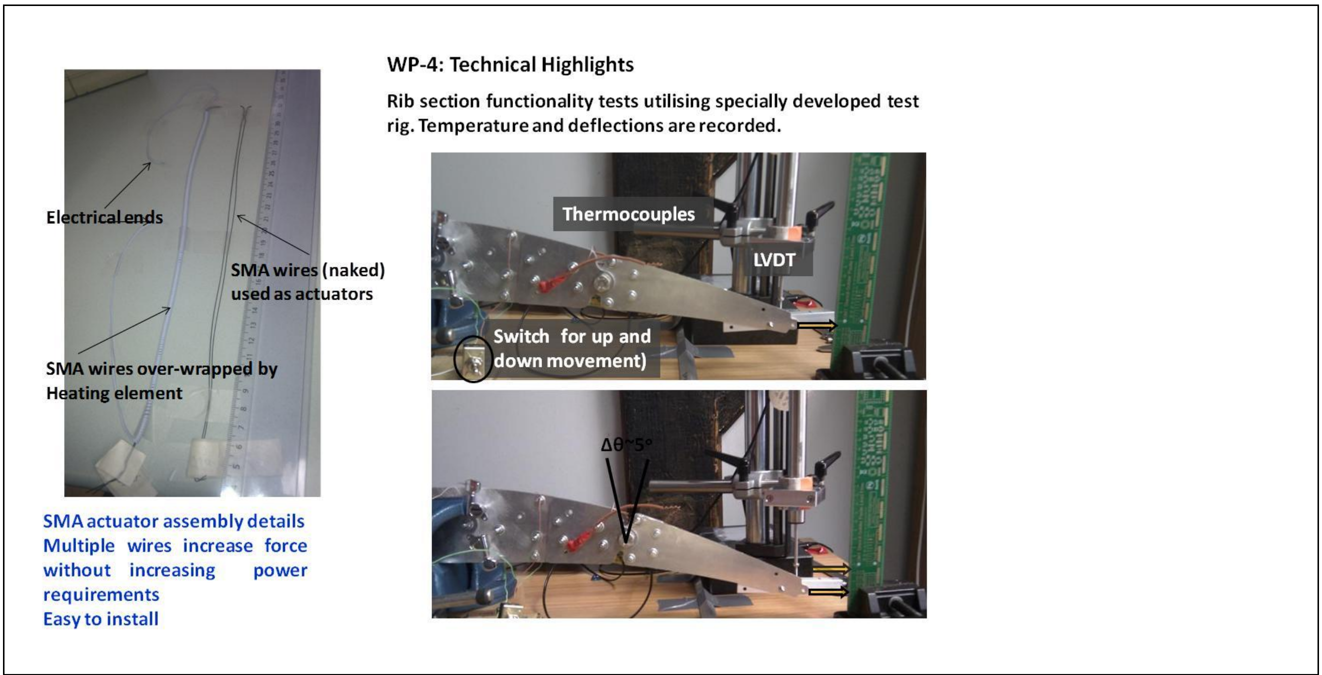


Figure 9: Elements of DESA prototype undergoing feasibility testing.

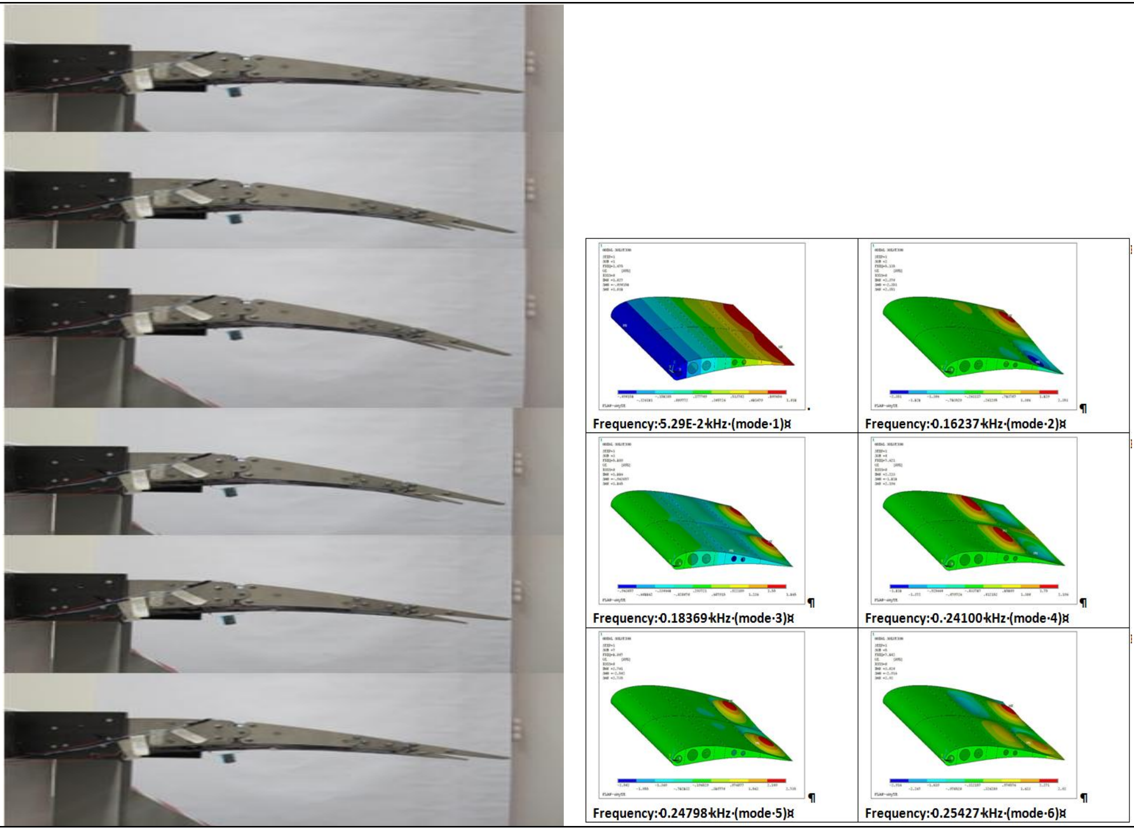


Figure 10: Functionality tests on the DESA prototype (left) and results of modal analysis.

2.5 WP5 Experimental Characterisation of DESA and SACM

In WP-5 DESA and SACM architectures were experimentally characterised under static loads and dynamic excitation. The work entails the following activities which are valid for both prototypes:

- Full characterization of the active static response of active flaps and thermomechanical state of actuators under the specified static loads

- obtain modal characteristics of active flaps under specified actuator states and static flap loads

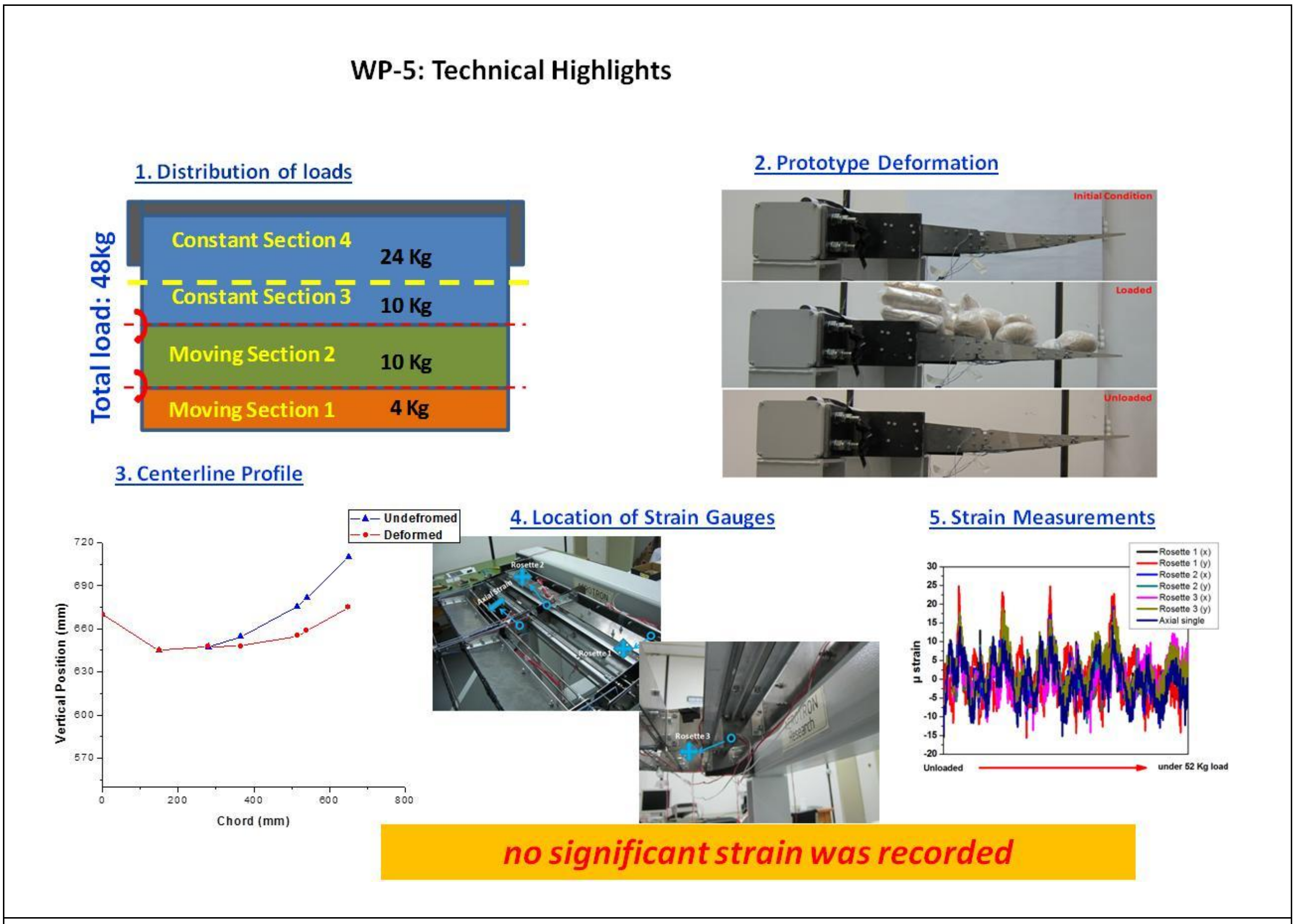


Figure 11: Static testing of DESA prototype.

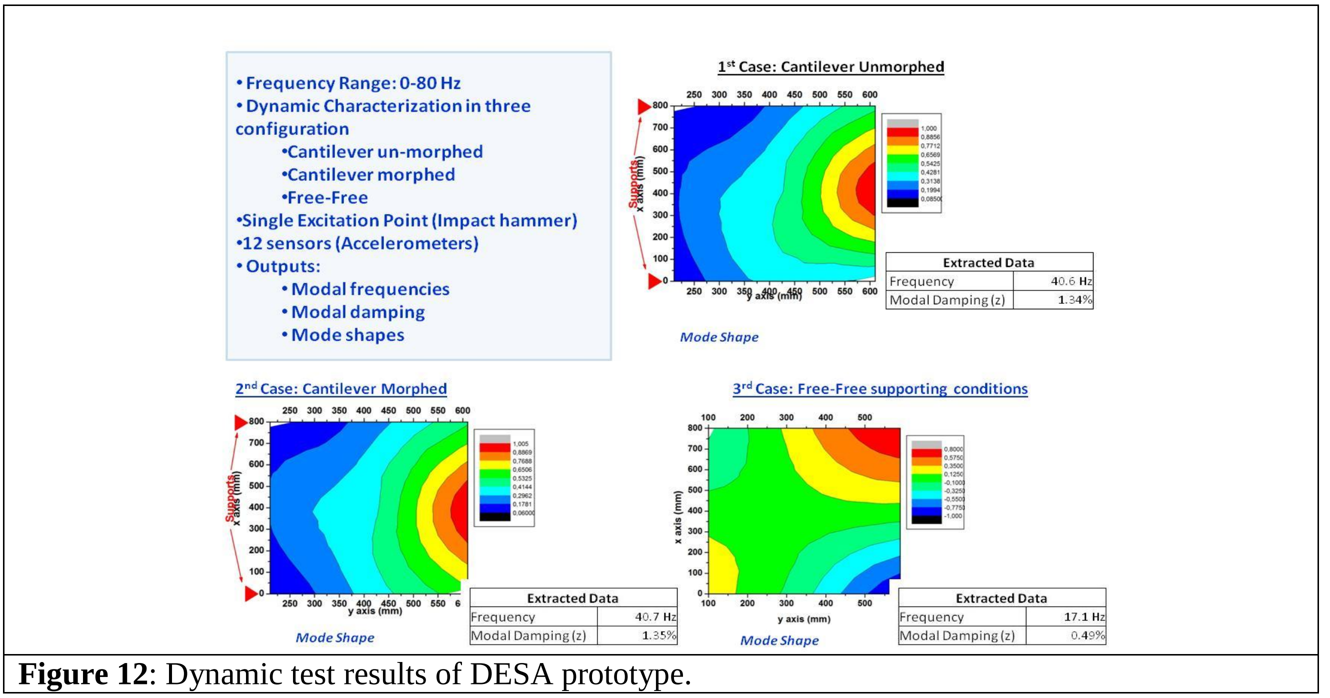


Figure 12: Dynamic test results of DESA prototype.

Plan for exploitation of project results

At this stage the majority of exploitable knowledge is related to development of methodologies and approaches for numerical modelling 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.

<u>Overview table</u>

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	**Timetable** for commercial use	**Patents** or other IPR protection	**Owner** & Other Partner(s) involved
Modeling of SMA.	Methods	Transport Aircraft ships automotive	Immediate	N/A	INASCO
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
Structure simulation	FEM	Aeronautics	48 months	no	ARES

<u>Key:</u>
TBD – patent protection to be decided
N/A – protection not applicable

Dissemination of Knowledge

The following Dissemination Table present the dissemination activities performed during Periods 1 and 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.

<u>Overview table</u>

Planned/ actual dates	**Type**	**Type of audience**	**Countries addressed**	**Size of audience**	**Partner responsible / involved**
6/11/2012	Presentation of project at the AIRTEC conference in Frankfurt/Germany	IInternational	20	30	ARES
15/01/2013	Presentation of project in University of Patras Mechanical Engineering Dept.	National	1	30	INASCO