

# Etriolla – Publishable Summary

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## **Summary description of the project context and main objectives**

The project tackles the CfP JTI-CS-2012-1-GRA-02-019. Within the project a Wind-Tunnel-Model was designed, built and tested that is capable of being tested with two main purposes:

- Assess the extent of laminarity on the wing
- Evaluate the performance of LC&A system in the trailing edge of the wing

The geometry of the full-size laminar flow wing geometry, the scaled wind tunnel model wing was optimised to delay the onset of Laminar - Turbulent transition for a range of angles of attack, including the effects of aeroelastic deformations. CFD computations were undertaken using Euler, full Navier-Stokes and stability analysis. Further work then considered the optimisation of trailing-edge ailerons positioned along the entire semi-span of the wing to reduce the drag at off-design conditions.

A statically aeroelastic scaled structural model had to be designed in order to ensure that the deflections (twist, bending) were representative in the wind tunnel tests. This objective proved to be challenging as the stiffness of the scaled wing was difficult to achieve, particularly as it is impossible to simply shrink all of the dimensions; in particular the skin thicknesses are constrained by what is possible to manufacture. There were also considerable challenges provided by the requirements to move the control surfaces and also to enable all of the required testing instrumentation. A further constraint was the surface roughness.

Validation of the structural modelling was provided by a series of static and dynamic tests applied to the wing in a vertical configuration. Static loads were applied via a specially designed collar at the top of the model and the deflections measured at 15 positions. From these tests it was possible to determine the bending and torsional stiffness and to update the Finite Element model. Following to these tests a vibration test was performed to measure the natural frequencies, damping ratios and mode shapes of the wing.

Finally, a wind tunnel test campaign was performed in the S1 ONERA tunnel at Modane. The test was used to demonstrate the laminarity extent for different cruise and off-design conditions, to assess the performance of the trailing edge loads alleviation devices, and to evaluate the effectiveness of the modelling. Global force and moments, Infra-Red, model deformation and accelerometer measurements were made.

## **Description of the work performed since the beginning of the project and the main results achieved so far**

### **WP 2 Optimisation/ Development of Load-Control and Alleviation Concepts**

A study of wing laminar-turbulence transition was made by FOI for the full aircraft design with wing, tails and fuselage in flight condition ( $M=0.74$ ,  $CL=0.54$ , 33,000 ft altitude –  $Re=22\text{mil}$ ) in order to have an independent calculation of the wing performance. The FOI results have a good accordance with (previous) Alenia calculations. It could be shown, that the wing performance ( $L/D$ ) is significant higher with laminar flow.

Additional a laminar-turbulent transition study was made for the WT-model in flight conditions ( $M=0.74$ ,  $Re=15 \times 10^6$ ) by modelling the WT walls, too. It could be shown that also the WT model has enough area with laminar flow.

Last the existing LC&A device settings have been optimized w.r.t  $L/D$  for cruise and off-design conditions in an optimization loop. This leads to a performance increase of 1% in cruise condition. Alternative configurations of LC&A devices (division into smaller pieces that allow finer setting) did not lead to a performance increase. So the original configuration was used for the WT model.

### **WP 3 WT Model Mechanical Design & Manufacturing**

#### **Elastic model**

During the first two reporting periods an elastic model of the wing at a scale of 1:3.05 was designed and partially manufactured. It was a very complex model consisting of hundred of parts including five trailing edge devices (three miniflaps and two ailerons) which could be actuated during the test in the wind tunnel by remote control. This model was designed to have a similar static elastic behaviour as the real wing and was provided with three rows of pressure taps, force and position sensors for the movables and two accelerometers.

The next (sub) sections describe the 1<sup>st</sup> model design and according manufacturing activities.

#### **Requirements elastic model**

Derived from the job description (elastic and laminar WT model; LC&A optimisation) and further boundary conditions (WT testing conditions; available machines and resources, ...) a lot of requirements had to be collocated, described and considered for design. Requirements come from following fields:

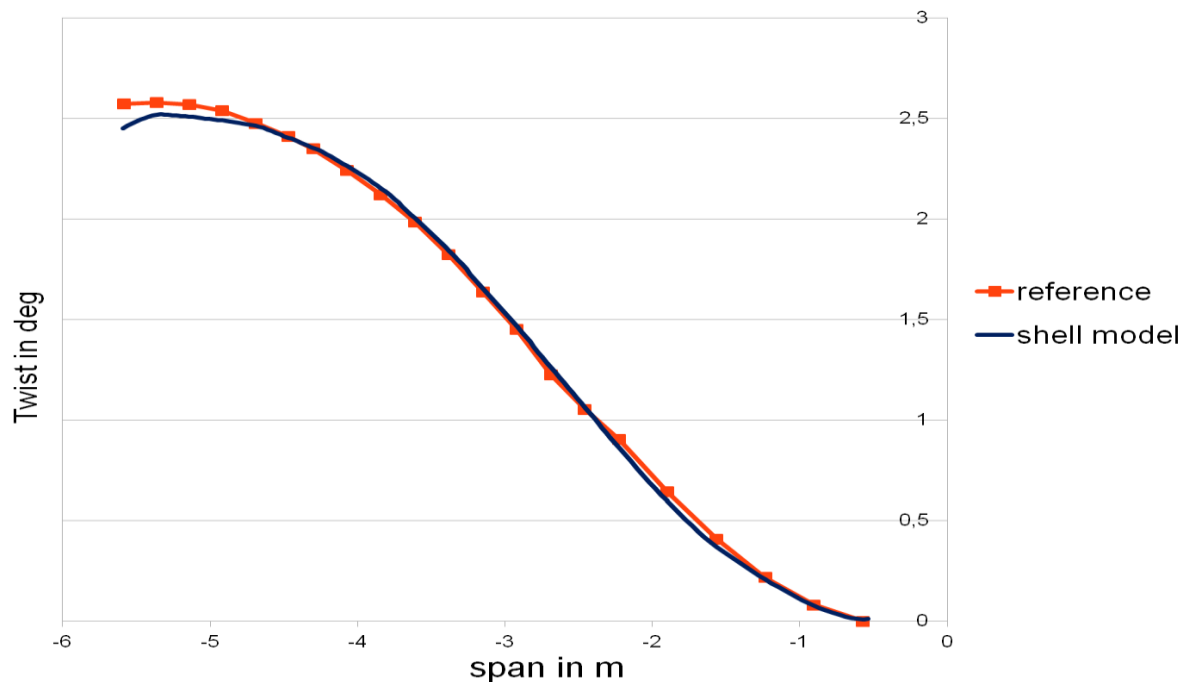
- aerodynamic
- structure
- handling and transportation
- WT design and safety requirements
- WT testing conditions
- Measurement requirements

- Manufacturer constraints

Some of the requirements lead to a conflict of goals and had to be balanced by design. Requirement trade off was performed together with the TM. The most important design boundary conditions are given in the next sections.

- In order to have a high Re-number the model must be as big as possible. So the scaling factor for WT model geometry was set to 3.05.
- Target curves
  - The AC twist curve in cruise condition must be similar to the WT-model twist curve in cruise condition.
  - The AC bending curve in cruise condition should be similar to the WT-model bending curve in cruise condition divided by scaling factor 3.05.

comparison twist curves - reference versus shell model

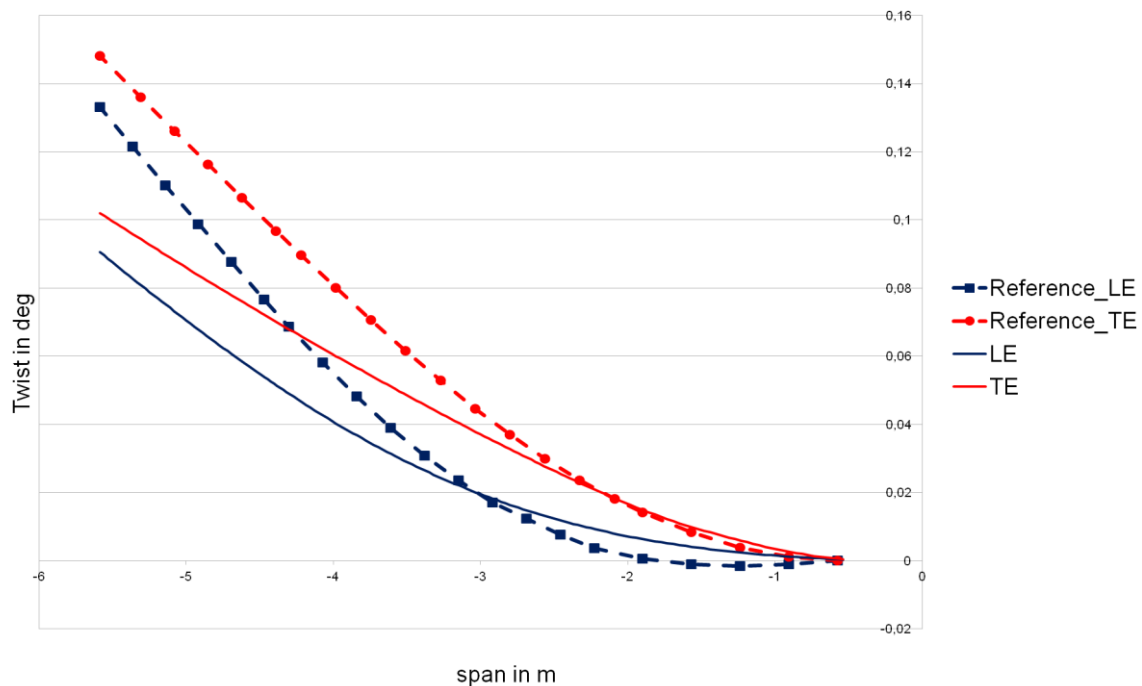


Picture 1 comparison twist curve model - reference (=target curve) versus shell model

Reaching the bending curve is of less importance compared to reaching the target twist curve since torsion has a strong impact on local AoA and therefore on local lift/drag ratio. Reducing bending is mainly important for structural reasons in order to cope with high stresses.

Picture 1 and Picture 2 show the behaviour of the design curves and their comparison with the reference curves resulting from scaling the input-wing box. It can be seen that for twist the overall correlation is very good, while for bending some deviations can be accepted.

Displacement comparison target curves versus shell model



Picture 2 comparison bending curve WT candidate - target curves

### Configuration study elastic model

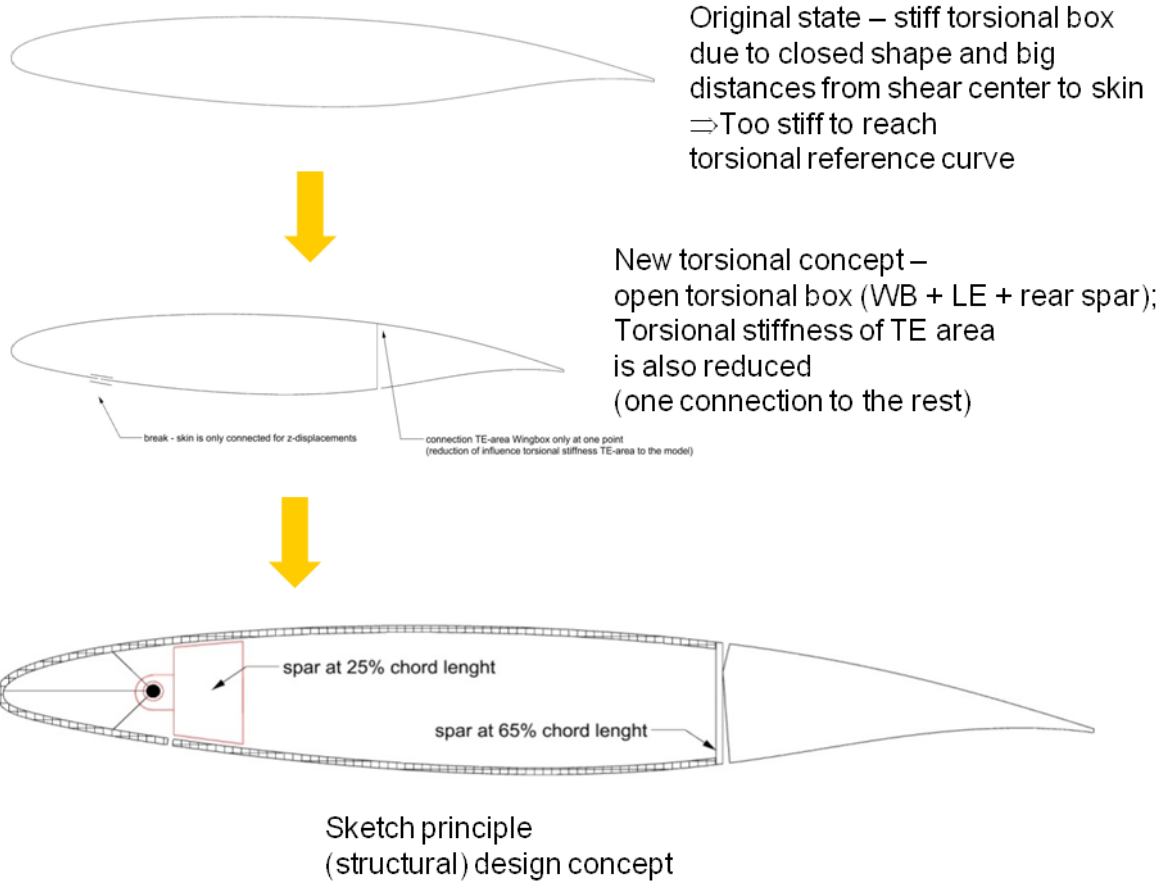
In order to find a feasible solution for the WT-design different configuration studies with more than 40 structural models were performed and assessed by IBK. To accelerate the process parametric and modular models have been developed to be able to study the influence of single solutions to the global behaviour.

Parallel an optimization tool was engineered and fine tuned by the IBK team. With that tool IBK was able to check if promising configurations are able to meet the requirements by varying the selected parameters. This led to final the configuration – called “WT-candidate” which is able to meet the requirements. For the WT-candidate different global and partial structural models were developed and refined during design process.

### Elastic Wing design

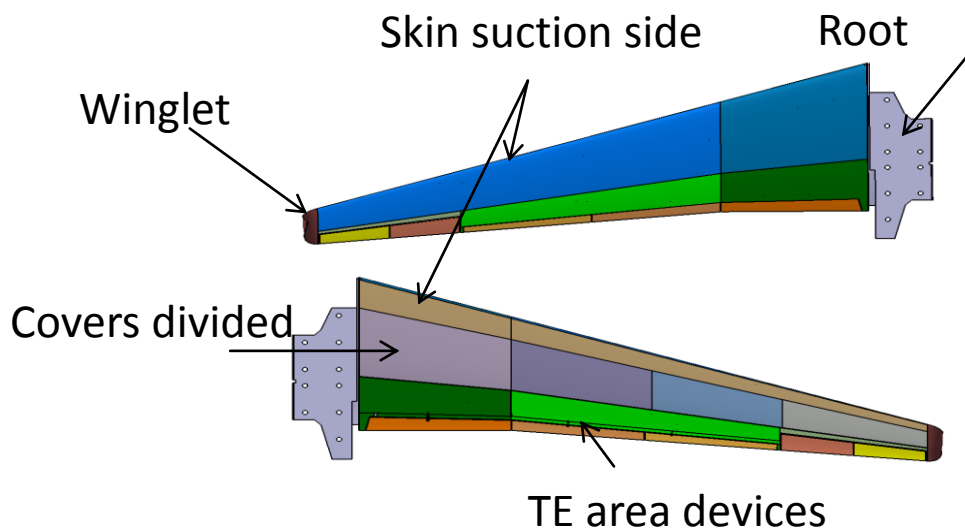
Configuration studies showed that a “usual” WT model (soft shell; stiff core) design is not possible within the given conditions. The outer shell had to be made with a minimum thickness due to laminarity and manufacturing reasons. Reaching the target twist curve was not possible without exceeding the stress limits given by the WT design rules. The extreme case “model only with outer shell and minimum thickness” was too stiff for twist and too soft for bending. To reach the given requirements it was necessary to decouple twist and bending and to increase bending stiffness by a parallel softening of the torsional stiffness.

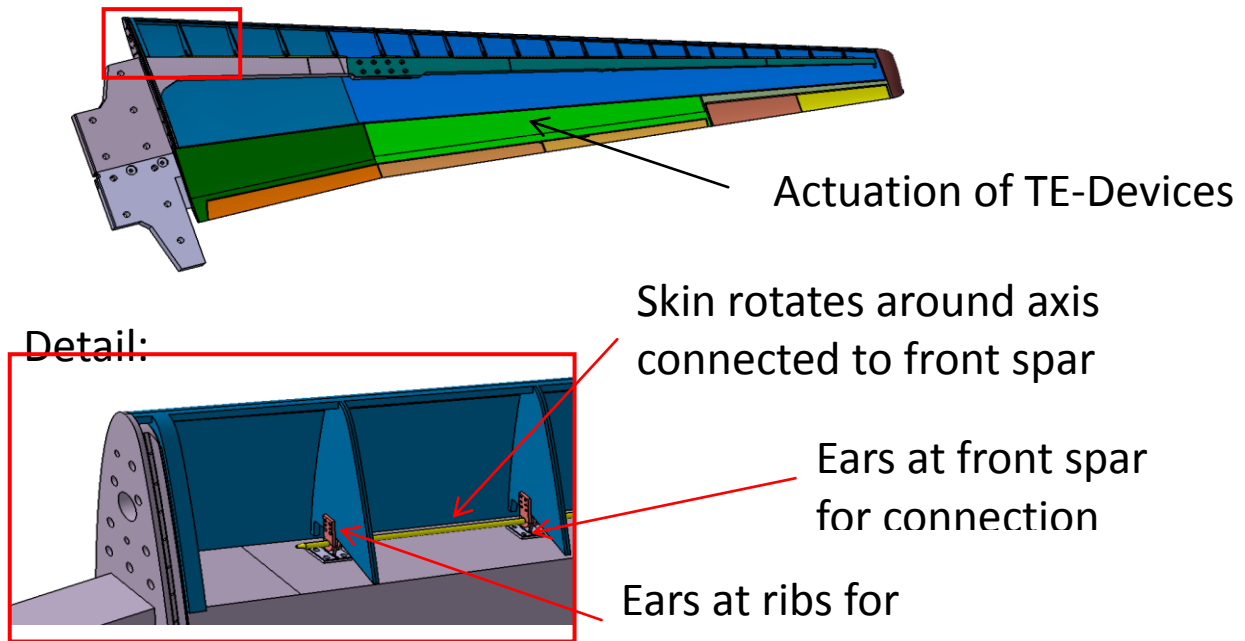
This targets were reached by introducing a stiffer front spar which is connected via a hinge line to the shell (decoupling twist and bending), and an open wing box cross section to reduce torsional stiffness. All in all this mix of means resulted in a model design fulfilling the twist-requirements.



Picture 3 sketch development of structural concept

The WT model has a length of ca. 5,7m. Used Materials are steel and Aluminium (see Picture 3). The Model is fully remote actuated (in order to save expensive WT time), and has a modular structure with aluminium skin and a steel front spar and root. The shrouds can be dismantled from the rest of the model to allow separate testing and calibration of model instrumentation.





### ***Manufacturing***

During manufacturing occurred a machine failure on the most important machine which was needed to manufacture most parts. All attempts to repair the machine failed. To minimize the impact of the machine failure on the project, different approaches were investigated - for example to manufacture parts on other machines. (which needed some redesign) At the end it was not possible to overcome the situation and the manufacturer REVOIND left the consortium.

### ***Final model***

After the retirement of REVOIND alternative new solutions were considered.

Due to the large number of parts and the unknown status and quality of REVOIND work it was decided to make a reset (to be independent from REVOIND work) and start a new design with relaxed constraints in order to make it possible to save the project within the limits of remaining time and budget.

### ***Requirements final model***

In agreement with the Topic Manager the following boundary conditions acted as guide rails for the new requirements:

- 1) The new model should be as innovative as possible (laminar, L/D optimisation with LC&A devices)
- 2) The reasons for the complicated original approach should be eliminated to save time and money and to avoid further complications:
  - a) The requirement to design an elastic model led to a very complex design process for the 1st model – so the requirement of elastic model with similarity regarding twist and bending was dropped.
  - b) The limits of milling machines smaller than the model led to a high number of connections inside the WT model and made design, analysis, manufacturing and assembling process unnecessary complicated. With the selection of a

new manufacturer these limits can/ could be overcome, because a requirement for manufacturer selection is machinery that can deal easily with the model size and the amount of work to do.

Summarizing following constraints and requirements had to be fulfilled:

- Time and budget
  - Time for design and manufacturing ~ 3month; incl. delivery time for material
  - Budget – new model design and manufacturing within the remaining budget
- Keep innovative character
  - Laminar surface for measurement of laminar extend
  - LC&A test campaign required => movable flaps
  - Possible later upgrade of model (instrumentation)
- Technical
  - Manufacturing and assembly process as simple as possible
  - Optimized configuration setting time for the LC&A campaign
  - Satisfy WT requirements (Onera design rules)
  - Roughness (laminar surface) up to 60% chord on upper side and 20% chord on lower side  $Ra=0,25$ ; remaining aerodynamic surfaces  $Ra=0,8$
  - Shape deviation tolerance 0,1mm
- Transport and logistic
  - Simple transportation procedure that covers limitations/ conditions of all affected parties (REF, UOB, ONERA)

A comparison of the properties of the old and the new model is provided below:

Original ETRIOLLA model	ETRIOLLA2 model (RP3 period)
<i>Elastic</i> behaviour comparable to the full-scale wing	Almost <i>stiff</i> model in deformed shape
“hollow model”	“full” model
Scale 1:3.05 (highest possible Re)	Scale 1:3.05 is the same
LC&A devices ( <i>automatic</i> setting)	LC&A devices ( <i>manual</i> setting)
Steps / gaps / contaminants	Steps/ contaminants, no gaps
cp-distribution by pressure tap	No pressure taps, but root prepared for

measurement and PSP-paint	later tests with pressure taps (wire channel); global force measurement at the balance
Undeformed (=cold) shape of model	Deformed (=hot) shape of model
Model deformation measurement	Model deformation measurement
Accelerometers	Accelerometers

Table 1 comparison properties old and new model

### Design final model

The new model consists of

- One Winglet
- Two Ailerons
- Three LC&A devices
- Main Wing
- Root with clamping

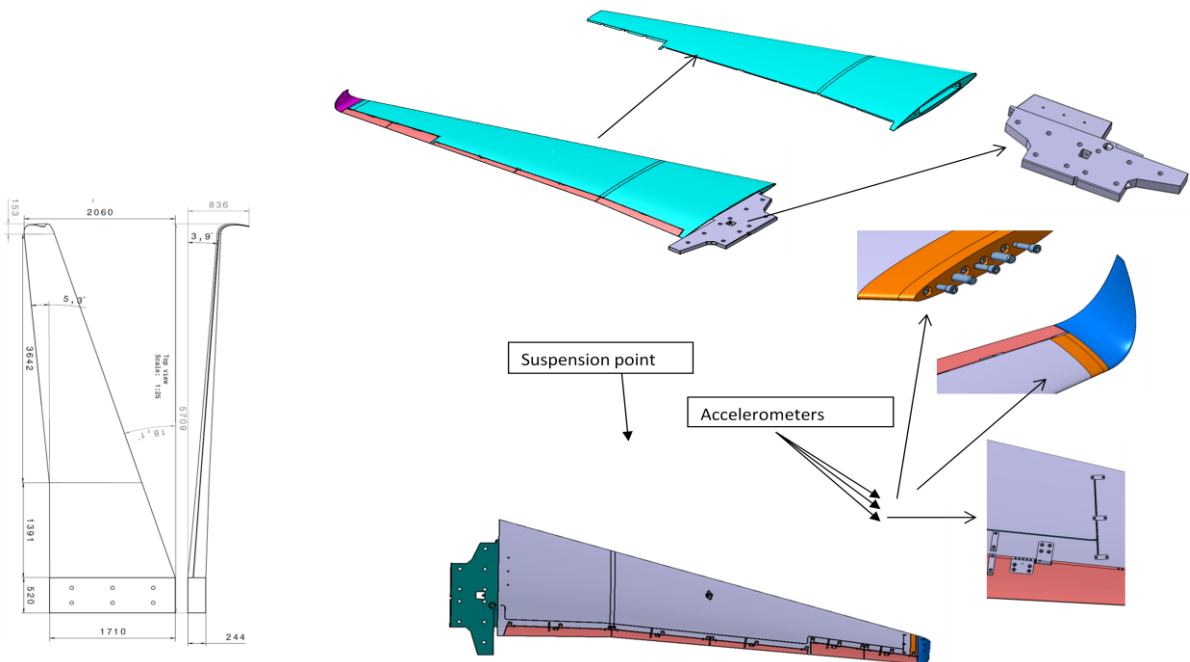


Figure 1 Quick overview new model design

The Ailerons and flaps are movable and can be fixed in certain positions; the positions have been determined according to test matrix.

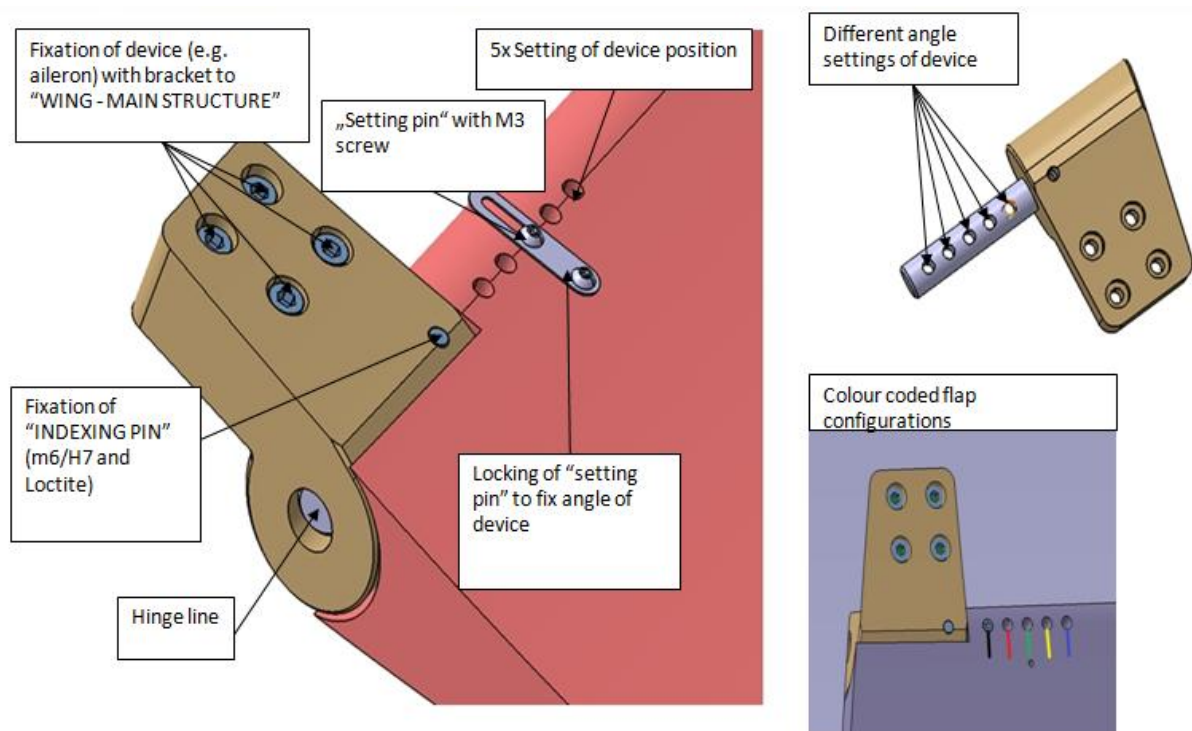


Figure 2 Details movable flap design

### *Manufacturing final model*

With the wing totally assembled, the finishing was done in one shot, on a big CNC machine. It took the whole month of august, and a great cure and attention was dedicated to control the different temperatures between the night and the daily hours. Ailerons were set up at zero angle, and the surfaces machined as a prosecution of the wing surface, without any interruption. That produced such an accurate milling to have a final CMM control within a few cents.

When the whole surface was totally milled, the next point was to drill the holes in the hinges to set the different angle of the ailerons.

The design of the trolley was done by the end of July, and so, on side of the final milling of the wing, Steel trolley was produced and painted in the same august months.

Particular care was dedicated to move the wing from the CNC machine to the trolley, and then rotate upside down the wing, pivoting in the root. It has to be done outside the facility, because the level of the roof was lower than the necessary room for the pivoting. A proper crane was luckily found on time.

Polishing was a totally handmade job. Sand paper with different granularity, 4 persons for almost one week

CMM control was done by a laser tracer system by Leika. Setting angles of the ailerons controlled by the flat bridges fixed at any ailerons. The results of quality check were satisfying.



Figure 3 Finished model in trolley

#### **WP 4 Static and Dynamic ground vibration tests**

For the WP 4 (Static and dynamic ground vibration test) test preparation work and static and dynamic Test have been successful performed. The tests showed a good repeatability, and no danger of flutter or other unwanted effects. FE predictions and test results are consistent. A big influence of the overall results was found for the clamping properties – they are different in the test lab and WT.

#### **WP 5 Wind tunnel tests**

WT test have been successfully performed in 11/2016. Due to the limited budget and to the fact that TE devices were not motorized, the entire test matrix was not performed, but ONERA realised the maximum program achievable in the 17 occupancy hours allowed for the test. The quality of the model surface was very good, very few turbulent wedges were observed.

Especially the laminar extent on the wing was beyond expectations (up to 70%).

#### **WP 6 Assessment of project results**

The assessment of project results has been performed. Following conclusions can be made:

- The WTT-laminarity extent is beyond prediction. The wing laminarity development is well proven.
- The LCA-devices can be used to improve aerodynamic efficiency by combined or individual device deflection
- Areas that could be further investigated are:
  - Full turbulent data
  - Sectional pressure distributions (full turbulent vs. transition)
  - Further LCA device investigations
  - Step-gap, Insect contamination etc.

## Expected impacts

The expected general impact will be:

- Regarding JTI-CleanSky this project will help in solving important questions about natural laminar flow and its applications on GRA-wings as well as the performance of LC&A systems. On an international level this increases Europe's competitiveness in natural laminar flow applications as well as LC&A systems on regional aircrafts. Both technologies (NLF and LC&A design) lead to reduced fuel burn by
  - Reducing drag (NLF)
  - Reducing weight (LC&A)and the impacts are therefore in line with the ACARE-goals

Apart from a national level each partner that contributes to the project has several advantages:

Insight into high fidelity test results for an advanced technology aircraft wing

- A reference project that shows competence on an international level as well as successfully working together as a multi-disciplinary team
- All partners in the consortium have the opportunity to further increase their know-how. In case of the SMEs this can be further exploited by transferring IP generated in this project into industrial applications. The research facilities strengthen their competence in their field of work.
- One university is present in the consortium; members of FOI and IBK are giving lectures at universities, too. This allows transferring knowledge achieved in this project to future engineering generations.