DEMMOW – detailed model of a morphing wing: development of separate components models

M. Bruyneel, A. Mawet
GDTech, Belgium

E. Marinone, G. Carossa
Leonardo Company Aircraft Division, Italy

Abstract

High-lift devices like slats and flaps have been used for a long time to improve the performance of the aircraft depending on the flight conditions. Wingtip and winglet have become popular solutions to decrease the drag coming from wing tips vortices and to increase the fuel efficiency. These components are assembled on the wing box structure to form the full wing. Classical high-lift devices are expensive, complex and heavy. They are therefore not acceptable solutions for the current trends on efficient and green aircrafts. Recent developments based on adaptive/morphing structures may overcome the limitations of classical high-lift devices, and so provide better solutions while reaching the objectives in terms of efficiency and environmental impact. Furthermore, control laws of wingtip and winglet surfaces may be defined in order to obtain a wing loading control and alleviation system (LC&A technologies). The idea is to adapt the shape of the wing to the flight condition by using morphing techniques. The compliant and/or kinematic mechanisms as well as the actuation system are now inserted in the wing and used to change its shape. Using morphing concepts allows shape change without generation of discontinuities in the flow (no aerodynamic gap). This paper presents the activities undertaken in the DEMMOW project (CleanSky 2, n°755621) by Leonardo Company Aircraft Division and GDTech. The goal of the project was to develop a high fidelity integrated non-linear MBS-FEM model of a morphing wing, including several structural components (composite box, morphing winglet, droop nose and adaptive trailing edge), with kinematic joints and actuators. Multi-body dynamics modelling of the mechanical system is addressed by the finite element method extended to multi-body systems including flexibility and non-linearities related to large displacements and rotations, and to morphing parts that can include compliant structures and non-linear materials, leading to a flexible wing concept.

1. Context and goal of the DEMMOW project (Cleansky 2)

Figure 1 illustrates a typical wing architecture including high-lift devices like slats and flaps classically used to improve the performance of the aircraft depending on the flight conditions, as well as wingtip and winglet that are used to decrease the drag coming from wing tips vortices and to increase the fuel efficiency. These components are assembled on the wing box structure to form the full wing.

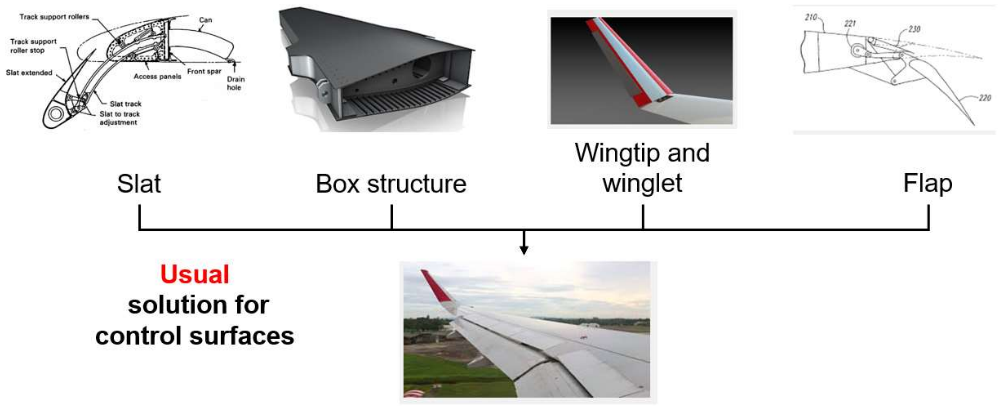

Figure 1: Illustration of a wing with clasical high-lift devices, winglet and wingtip

In Figure 2, some conventional concepts for leading and trailing edges are described [1,2]. They are based on “moving solid elements”, and rely on mechanical actuation and classical kinematic joints like hinges and sliders.

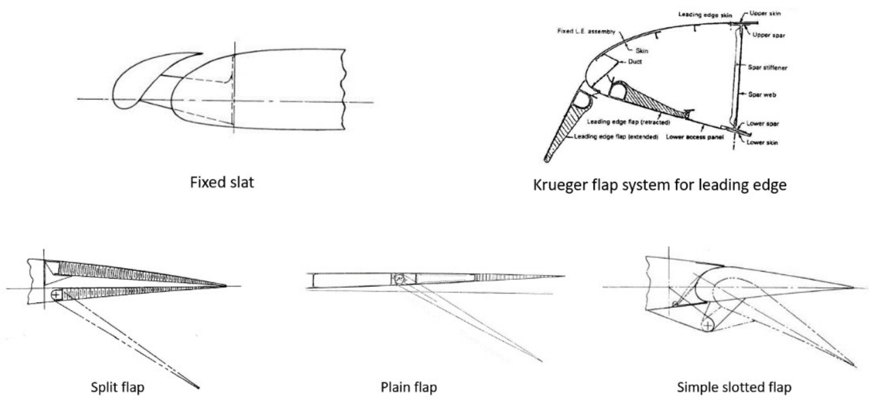

Figure 2: Conventional high lift devices for leading and trailing edges

Classical high-lift devices of Figure 2 are expensive, complex and heavy. They are therefore not acceptable solutions for the current trends on efficient and green aircrafts. As explained in [9], recent developments based on adaptive/morphing structures may overcome the limitations of classical high-lift devices, and so provide better solutions while reaching the objectives in terms of efficiency and environmental impact. The idea is to adapt the shape of the wing to the flight condition, by using morphing techniques. The compliant and/or kinematic mechanisms as well as the actuation system are now inserted in the wing and used to change its shape. Using morphing concepts allows shape change without the generation of discontinuities in the flow (no aerodynamic gap). Some concepts for a morphing leading edge (droop nose) are presented [2]. The realization of the Dornier concept in [3] is very interesting, as it includes the finite element analysis, the manufacturing and the testing of the droop nose system. It is seen that a mechanism based on kinematic joints (hinges) is used to adapt the shape of the morphing part. The skin is made of GFRP composite material of variable thickness, what can provide the necessary flexibility to reach the desired deformed shape. In [4] it is explained how topology optimization can be used to determine the design of a compliant mechanism used for a morphing leading edge. In [2], lots of references are provided for morphing trailing edges. In [5], one idea is to create an articulated chain by connecting blocks (that may be considered as rigid in a first approximation) with hinges in order to enable a modification of the airfol camber line. A multi-material skin made of elastomers and aluminium is used to allow deformations while carrying aerodynamic loads. In [6], a concept for a morphing wingtip is proposed, with a flexible corrugated skin made of composite material. Finite element analyses are used to validate the design approach. A mechanical demonstrator is developed.

As a first conclusion, morphing devices are based on an adaptation of classical high-lift designs. Kinematic joints and/or compliant structures are used as internal mechanisms to induce the deformation of the part. A key point is the design of the skins, which must have the necessary flexibility to reach the desired deformed shapes and the sufficient rigidity and strength to sustain the aerodynamic loading. Composite and non-linear materials like elastomers can be used. Science popularisation papers with general information are given in [7] and [8]. Additional information can be found in the very detailed review of [9].

The goal of the DEMMOW project is to develop a high fidelity integrated non-linear MBS-FEM model of a morphing wing (and of its components), as illustrated in Figure 3.

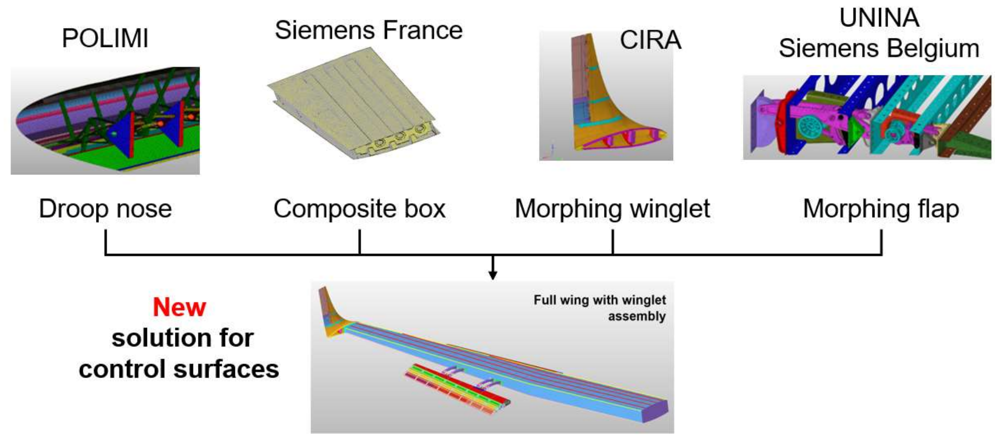

Figure 3: Goal of DEMMOW project

This research activity is done in the frame of Cleansky 2, with Leonardo Company Aircraft Division as Topic Manager. Specifications, design and/or finite element models of the components in different format (Abaqus, NASTRAN, SAMCEF) are developed by Leonardo partners in the context of Airgreen 2 program (POLIMI, CIRA, UNINA, Siemens, see Figure 3). These models are not suited for a MBS-FEM unified model of the full wing. Indeed, they are built with linear finite element libraries, therefore not based on large displacements and rotations formalisms, and they don't include specific modelling of kinematic joints. They are therefore converted to SAMCEF format, including mechanical, kinematic and control elements, and so creating a full virtual prototype. The virtual prototype must be reliable and represent reality. It will then become the companion of the physical prototype. The principle is illustrated in Figure 4, in the frame of the pyramid of tests.

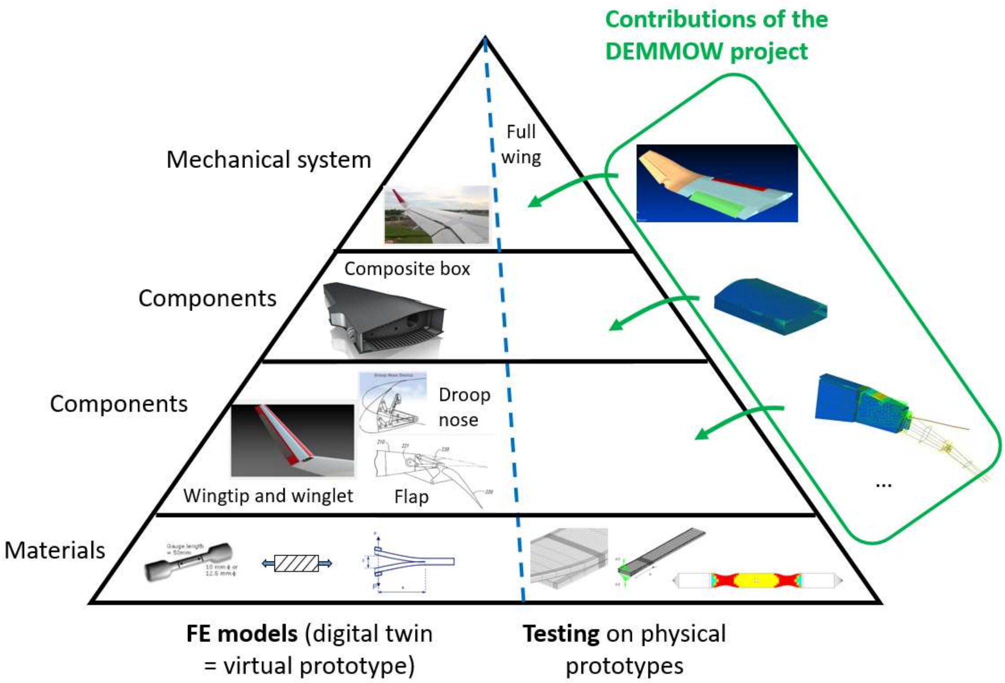

Figure 4: Pyramid approach to develop the model of the full morphing wing

2. Modelling approach

The modelling approach relies on a general purpose implicit finite element software, which includes a structural finite element library and a kinematic joints library (see Figure 5). Non linearities take the form of large displacements and rotations, contact and material non-linearities. All the~~se~~ non-linearities can be naturally included in a MBS-FEM model as explained in [10], where the formulation and solution of the FEM problem are described: the system of equations to be solved is given in (1), where **M** is the mass matrix, $\ddot{\mathbf{q}}$, $\dot{\mathbf{q}}$ and $\mathbf{q}$ are the accelerations, the velocities and the displacements, respectively, while $\mathbf{g}$ are the forces.

$$\mathbf{M}\ddot{\mathbf{q}} = \mathbf{g}(\dot{\mathbf{q}}, \mathbf{q}, t) = \mathbf{g}^{external} - \mathbf{g}^{internal} \tag{1}$$

When constraints $\mathbf{\Phi}$ are considered in the problem (e.g. relations between degrees of freedom to make a motion useful to a desired purpose, i.e. kinematic constraints), the problem to be solved is based on the stationarity of an augmented Lagrangian defined by the kinetic and potential energies and two additional terms related to the constraints including a penalty and the Lagrangian multipliers. It turns that the system of nonlinear equations to be solved is given in (2), with $\mathbf{B}$ the gradient of the constraints, p the penalty factor and k a scaling factor. As far as time integration is concerned, the Newmark or the HHT schemes are used. The nonlinear system is solved by the Newton-Raphson method.

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{B}^T (k\boldsymbol{\lambda} + p\mathbf{\Phi}) = \mathbf{g}(\dot{\mathbf{q}}, \mathbf{q}, t) \\ k\mathbf{\Phi}(\mathbf{q}, t) = 0 \end{cases} \tag{2}$$

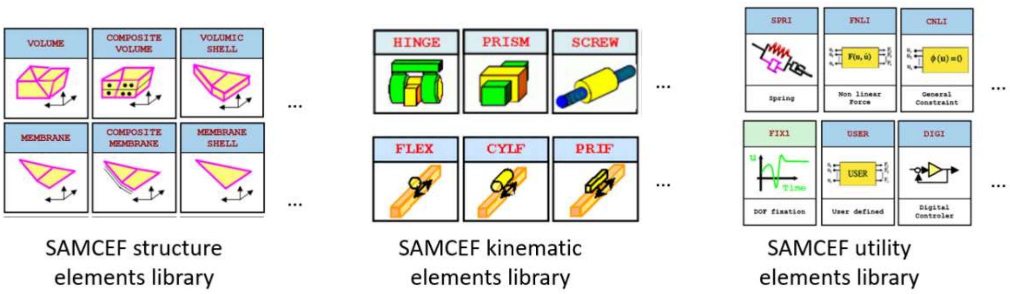

Figure 5: SAMCEF elements library for developing non-linear MBS-FEM models

This principle is illustrated in Figures 6 and 7, on simplified designs of a trailing edge and of a drop nose. Additional illustrations can be found in [11, 12] for the development of a MBS-FEM model of a robot with controllers.

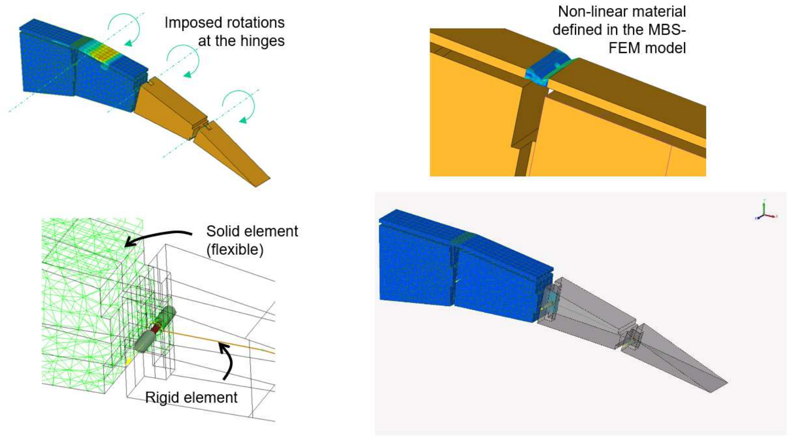

Figure 6. Using SAMCEF to develop a first (simple) model of an adaptive trailing edge component: definition of the hinges between the blocks

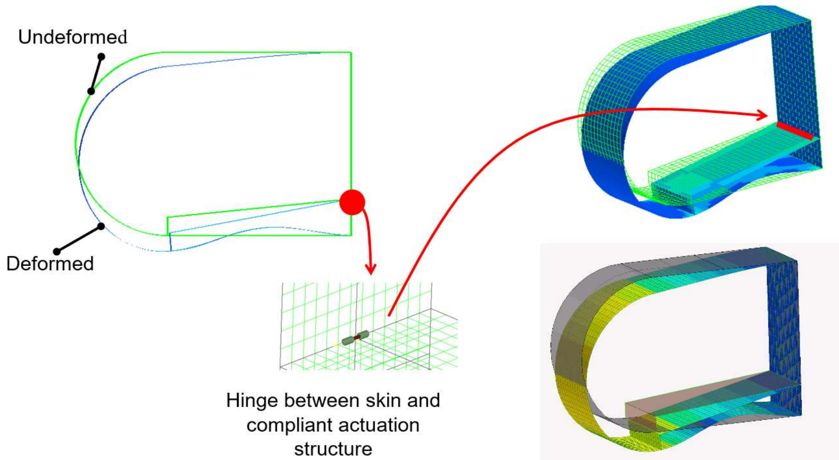

Figure 7: Using SAMCEF to develop a first (simple) model of a droop nose

3. Model of the wing components

The modelling principle described in the previous section is now applied on the components of the morphing wing.

In Figure 8, the model of the droop nose is developed, and a comparison is done regarding the way the elements of the internal actuation mechanism are modelled, either with solid or shell finite elements. Comparison between these two modelling approaches reveals that results are very similar. The droop nose model is then adapted in order to be mounted on the wing box, as illustrated in Figure 9.

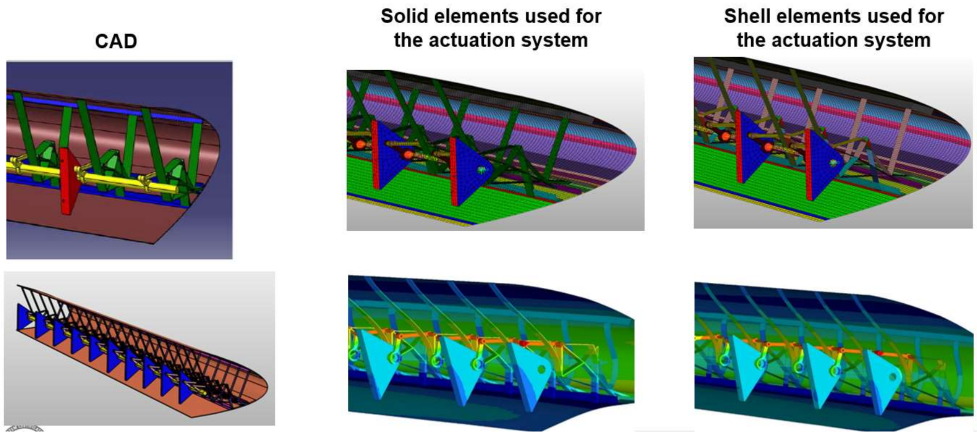

Figure 8: Model of the droop nose – comparison solid-shell

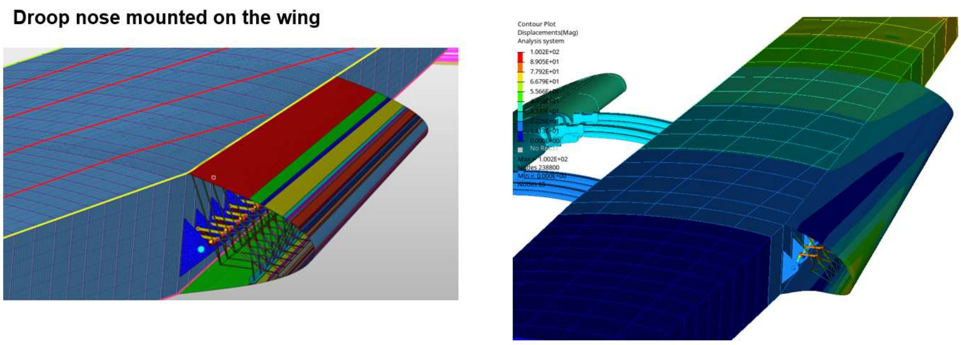

Figure 9: Droop nose mounted on the wing box

Figures 9 and 10 show details of the models developed for the winglet and for the morphing flap.

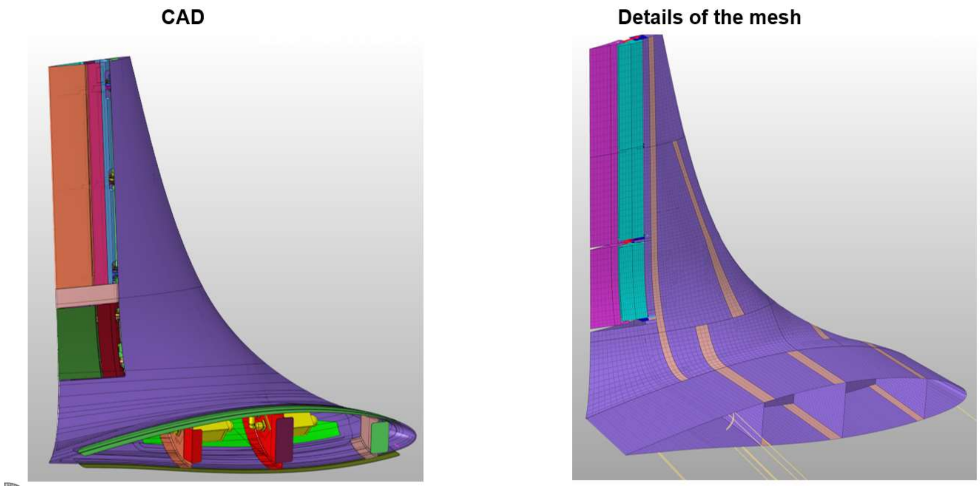

Figure 10: Model of the adaptive winglet

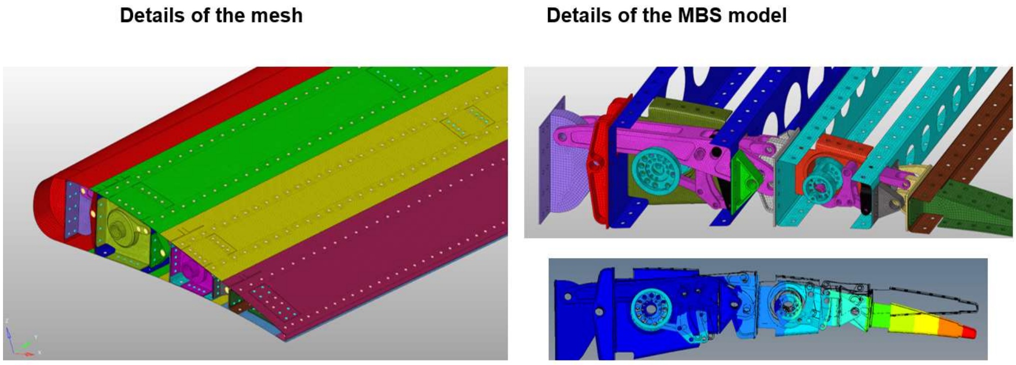

Figure 11: Model of the morphing flap

Finally, Figure 12 illustrates the morphing devices (droop nose, morphing flap and adaptive winglet) mounted on the composite wing box, to form the full morphing wing.

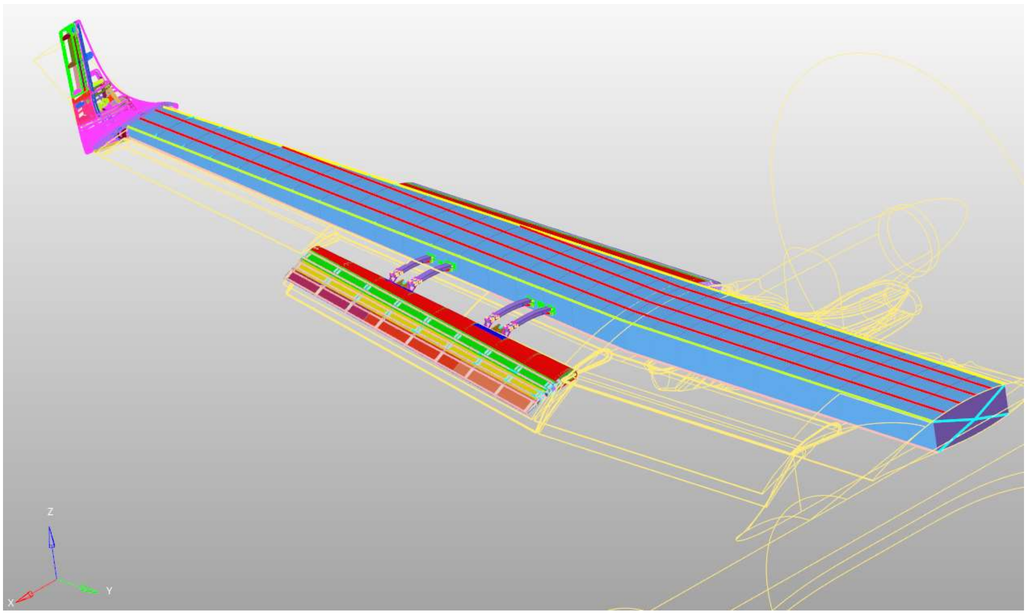

Figure 12: Morphing devices mounted on the wing box

4. Conclusions

This paper presented the first results of the DEMMOW project (CleanSky 2, n°755621). The goal of the project was to develop a high fidelity integrated non-linear MBS-FEM model of a morphing wing, including several structural components (composite box, morphing winglet, droop nose and adaptive trailing edge), with kinematic joints and actuators. Here, separate components of the morphing wing were modelled. Multi-body dynamics modelling of the mechanical system was addressed with the SAMCEF software. The finite element method extended to multi-body systems including flexibility and non-linearities related to large displacements and rotations, and to morphing parts that can include compliant structures and non-linear materials, leading to a flexible wing concept, was used. Next steps of the project will be to model the full wing and to compare simulation and physical test results.

5. Acknowledgements

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6. References

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