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Research Article

Flap Architecture by Morphing Trailing Edges

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Abstract

This paper proposes flap architecture for a variable camber trailing edge, whose reference geometry is based on a full scale wing for a regional transport aircraft. The compliant rib is based on a truss-like structure where some members are active rods made of Shape Memory Alloy (SMA). These actuators are able to sustain the external loads while allowing controlled shape modification. Elastic elements are incorporated to provide pre-straining for the SMA and therefore allow cyclic actuation. The layout of the structure is obtained from public domain literature, incorporating practical constraints, by focusing on a basic truss-like element and its repetition and position within the overall truss. The aero structural performance is estimated using FE analysis in ANSYS. The SMA behavior is to be modeled using a dedicated routine to evaluate the internal stress. The flap analysis carried out from 2^0 to 24^0 deflections and analyzed for the Stress and strain of each deflection for two types of cross sections of the flap. One is rectangular cross section and another one is circular cross section, also defined best suitable one for trailing edge flap. The design fulfills a number of key requirements: a smooth actuation along the chord; morphed shapes that assure the optimal aerodynamic load distribution for high lift; light weight; low mechanical complexity.

Keywords: *Flap, Morphing, Architecture, Wing, Analysis, Trailing edge.*

1. Introduction

The geometry of a fixed wing is usually the result of a compromise design and its optimal performance occurs only in some flight regimes of a typical mission profile, typically for the cruise condition. The adoption of aerodynamic control surfaces (such as slats, flaps, etc.) allows the expansion of the domain of allowable flight regimes for an aircraft, but at the expense of poor performance or low aerodynamic efficiency. Flexible actuation and sensing materials that can be fully integrated into oddly shaped structural members have numerous applications for use in aerospace systems to provide solutions (Sridhar kota *et al*). Each of these application areas has potential commercial value for providing cost savings, improved performance or improved system reliability. Thus, the idea of adaptive aerodynamic surfaces, that are able to change some features to fit the best optimal shape for a specific regime, promises interesting developments. Following this trend, many investigations have addressed components such as flaps, slats, by pointing out related benefits and drawbacks. More challenging strategies (e.g. variable sweep wings) have been taken into account, remaining, at least for the moment, confined to military applications.

Classical geometry-variation devices, like flaps, exhibit some advantages: they are easy to be integrated within the surrounding structure and do not compromise the wing's structural integrity (Friswell et al 2008). Moreover, they affect a limited zone of the wing; this simplifies the actuation system architecture that can be practically concentrated close to the hinge zone. However, due to their concentrated nature, they produce discontinuities, sharpening of the geometry and worsening the aerodynamic efficiency. Moreover, connecting zones have to support the transmitted loads with inevitable structural weight increase.

To avoid these problems, novel strategies are being considered. The idea of producing smooth variations of the geometry (i.e. Morphing), even in presence of large displacements distributed over a wider portion of the wing (Thill *et al* 2008). The present study follows this trend, investigating the performance and the aerodynamic benefits which can be achieved by comparing a traditional split flap with a smooth, hinge less trailing edge.

A truss structure suitable for the purpose of shape adaptation should enable smooth shape changes, but retain a high degree of stiffness in other deformation components to allow precise operation by a manageable activation system. For this purpose, Variable Geometry Trusses (VGTs) have been largely investigated: a VGT is a truss structural system having a number of length-adjustable actuated members. Although the idea of substituting some of the truss elements with active rods is nothing new, studies have been carried out to date adopting Shape Memory Alloy rods within VGTs, both as structural and

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actuation elements. The introduction of a number of active elements in place of passive truss rods allows the structure to deform and thus increase the elastic energy. Moreover, conventional actuated length-adjustable truss members made of prismatic actuators based on a ball-screw mechanism or those based on hydraulic or pneumatic telescopic cylinders are of relatively high cost and heavy weight: from this viewpoint, the adoption of SMA rods as active members can help to overcome these limitations and allow for aeronautical applications of VGTs.

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2. FEM Procedure Analysis

Based on the aerodynamic procedure and assuming a hinge position at 0.7*c*, the wing airfoil portion between 0.7*c* and 1*c* has been rotated around the hinge point in order to simulate the split-flap down deflection (Fig. 1): assuming all other quantities are constant, the deflection angle δ has been considered in the range 2 - 24 deg to estimate the lift coefficient. In correspondence to a flap rotation δ_i, around the hinge point *A*, the trailing edge moves from the point *P* to the point *P'*. Then, for each hinged flap rotation δ_i, a corresponding morphed flap shape is found for the two cases. In this case, the motion of point *P* to point *P'* is obtained by morphing the flap camber line according to a parabolic arc connecting the point *A* to the point *P'* and tangent in *A* to the unflapped wing airfoil camber-line (Fig. 1).

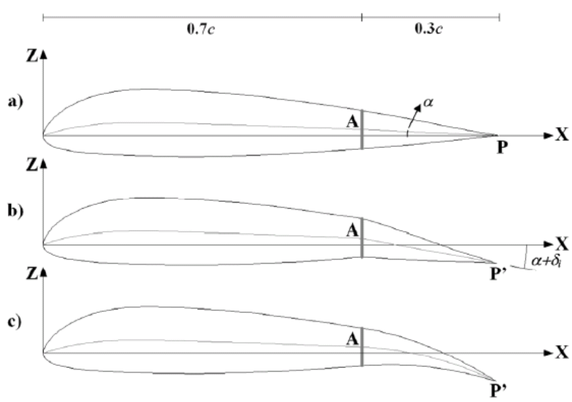

Fig.1 Wing airfoil boundary: a) no flap rotation; b) split flap deflection; c) flap morphing

To predict the performance of the morphed rib, an FE approach using ANSYS, geometry is generated. All of the truss elements, both the passive ones made of aluminum and the active ones made of SMA (Ashish Khandelwal *et al* 2009), are hinged at both ends to create the desired mechanism: due to the expected large displacements and strains within the SMAs, a nonlinear analysis has been performed for circular sections rectangular sections for all materials. At this stage, the focus is the topological optimization of the truss structure: for this reason, the cross section of the aluminum truss elements has been oversized (circular tube with a 10mm diameter and 1mm thickness) to avoid structural instabilities.

The truss structure herein developed is similar to a conventional mechanism, which behaves as a system of rigid bodies (members) interconnected by ideal joints: the study of such a mechanism can be performed using a kinematic approach. The entire truss rods, both passive and active, are supposed to be hinged at both ends (hence no bending actions are allowed).

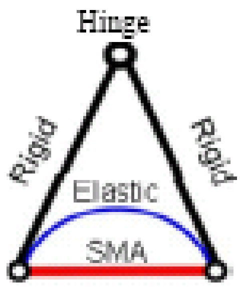

Fig 2. Basic Truss Element Model(Nielsen et al)

The basic truss element taken into consideration is a triangular truss in which one member is realized in active Shape Memory Alloy (Fig. 2); the additional elastic element, required to suitably pre-stress the SMA, will not be considered further here(David Baker et al 2008). A recoverable strain of 3% in length for the SMA elements has been assumed throughout this project, as a compromise between actuation performance and stability with cycles.

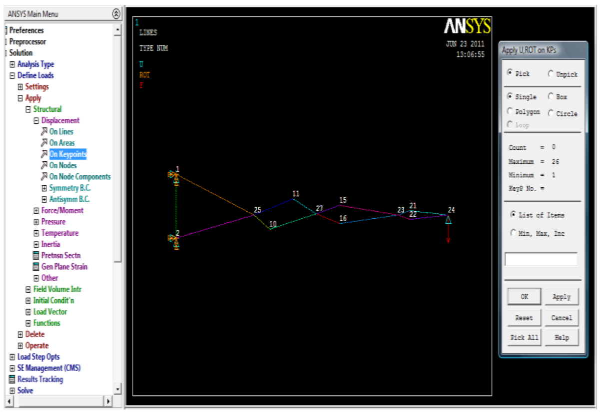

Fig 3. Representation of Boundary conditions and loads of the truss elements.

In ANSYS software by selecting structural analysis from preprocessor will enter into the module. Here key points are created followed by lines in the preferences by modeling option(Marianne Jacobsen1 *et al* 2009). Then for the rectangular and circular cross section of Truss element we choose the Element type as 2D node 188. After giving the Element type the material type defined from the Material properties from material models as structural – linear - elastic - isotropic were selected. The meshing is done by selecting complete truss element. Then on applying the necessary boundary conditions shown in Fig.3 and loads will solve the solution using solver.

3. Results and Discussions

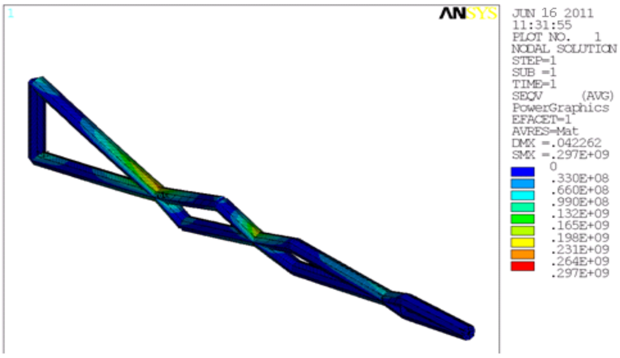

Fig 4. Von mises stress induced in truss elements for cross circular section at 8° deflection

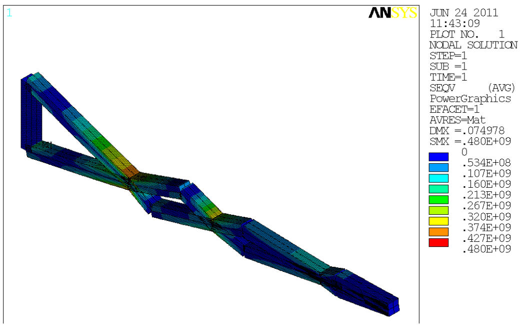

Fig 5. Von mises stress acting in truss elements for rectangular cross section at 14°deflection

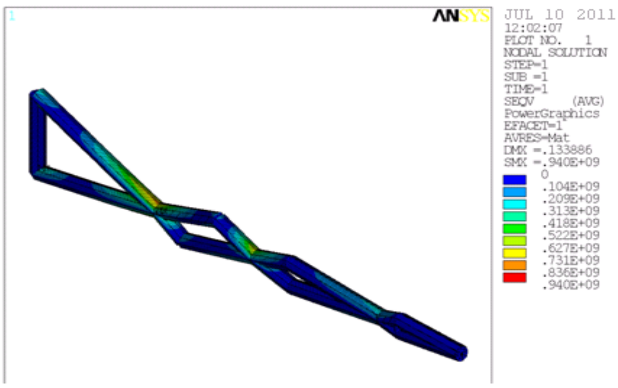

Fig 6. Von mises stress acting in truss elements for circular cross section at 24°deflection

Assuming the left hinge is constrained, the kinematic investigation is carried to improve the geometry variation of this basic triangle, upon SMA activation, by changing the angular aperture of the top vertex and the position of the connection point of the SMA on the rigid rod on the right. The range of top semi-angle is 5 – 8.5 deg, while the SMA connection point can move from 0 to 85% of the right rod length, starting from the bottom; the length of the rigid rods has been assumed equal to one unit.

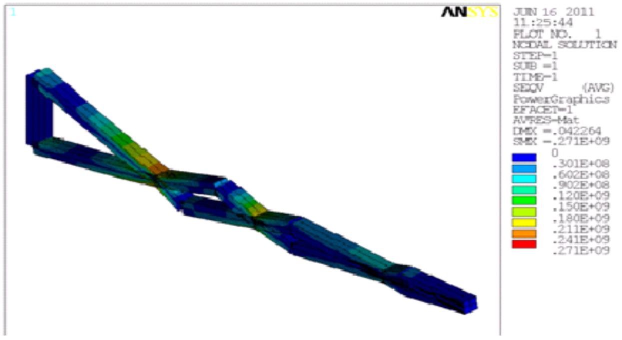

Fig 7. Von mises stress acting in truss elements for rectangular cross section at 8° deflection.

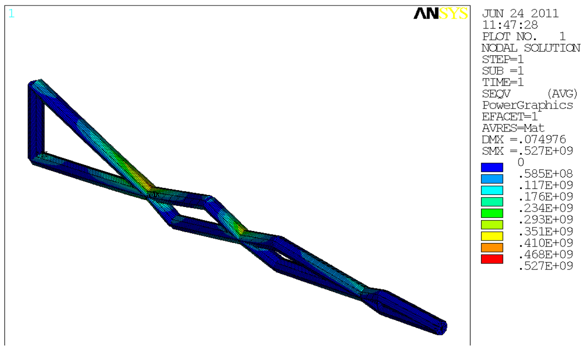

Fig 8. Von mises stress acting in truss elements for circular cross section at 14°deflection.

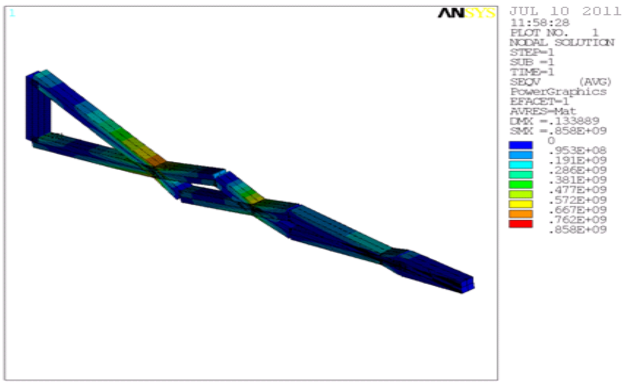

Fig 9. Von mises stress acting in truss elements for rectangular cross section at 24°deflection.

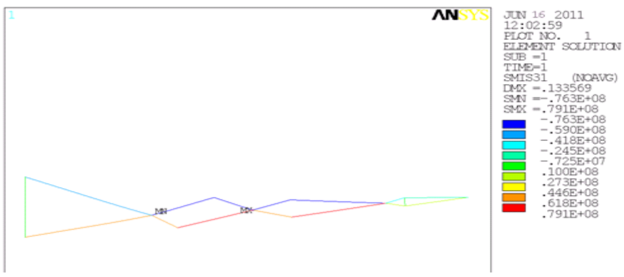

Fig 10. Axial stress induced in truss elements for circular cross section at 8° deflection.

After successful completion of truss element defining and giving the suitable boundary conditions for the different angles the results are being obtained. Then the results are post processed to obtain the shear stress, bending stress and strain displayed in the result view from Fig.4-15. All the results are approximately consistent to the Analytical results (kerr-jia lu *et al 1999*) that we can clearly observe it from the Fig.16-19.

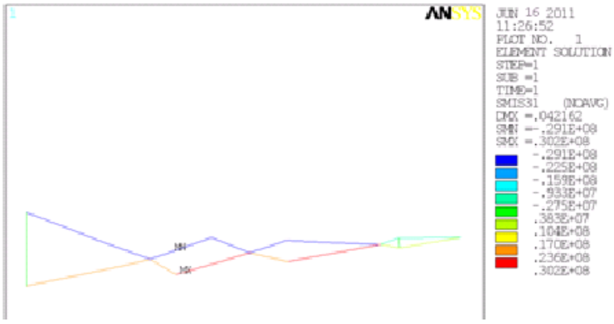

Fig 11. Axial stress acting in truss elements for rectangular cross section at 8^o deflection

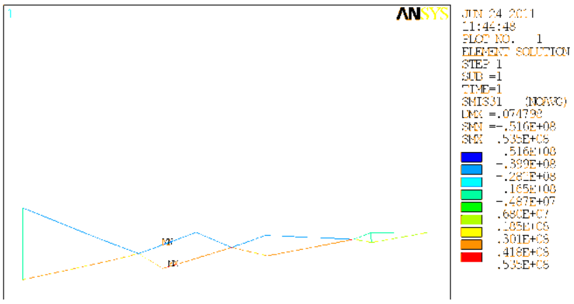

Fig 12. Axial stress acting in truss elements for Rectangular cross section at 14^o deflection

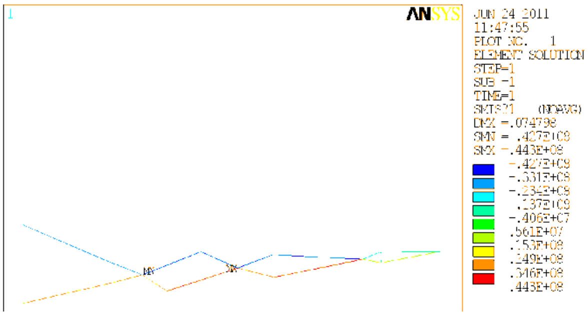

Fig 13. Axial stress acting in truss elements for circular cross section at 14^o deflection

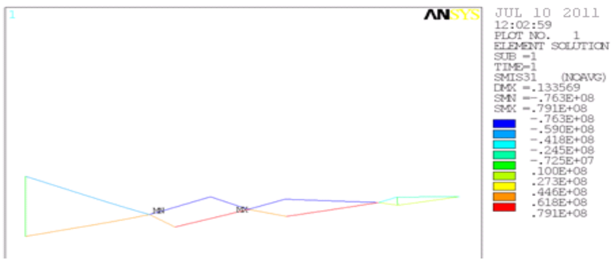

Fig 14. Axial stress acting in truss elements for circular cross section at 24^o deflection.

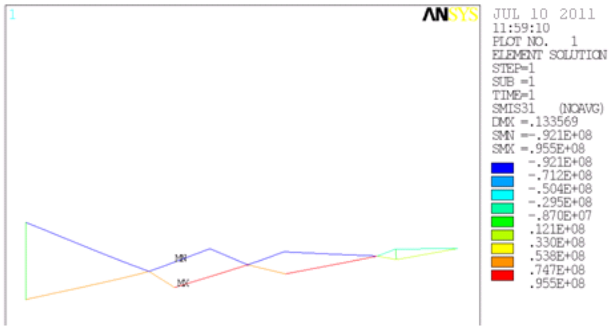

Fig 15. Axial stress acting in truss elements for rectangular cross section at 24^o deflection

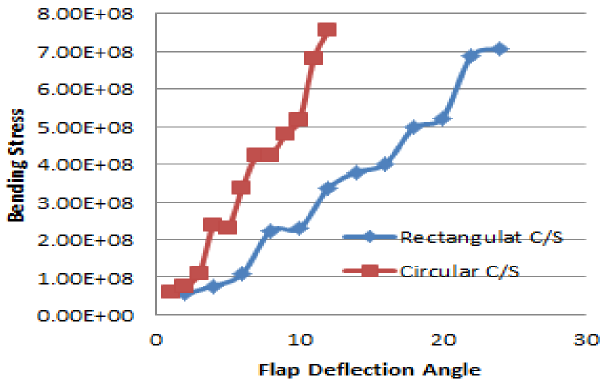

Fig 16. Bending stress calculated for the different degrees of deflection of truss elements

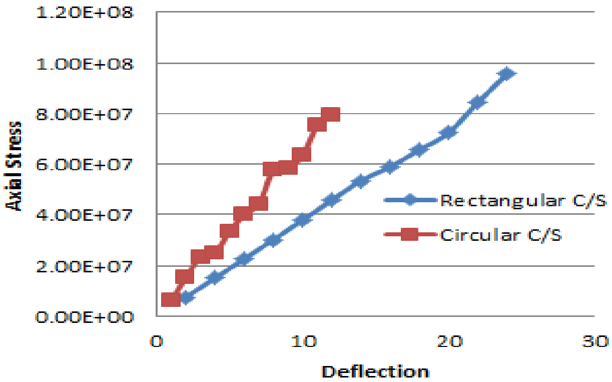

Fig 17. Axial stress for the different degrees of deflection of truss elements

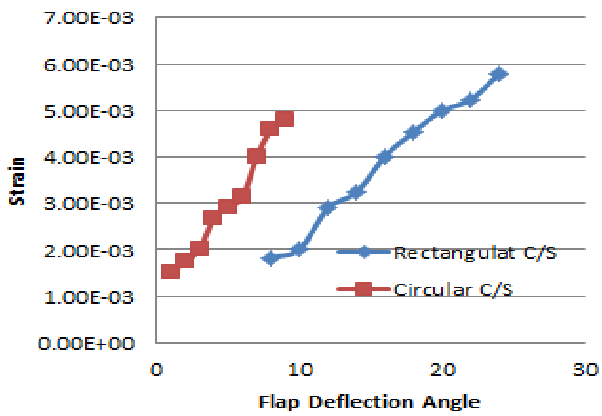

Fig 18. Strain values calculated for the different degrees of deflection of truss elements

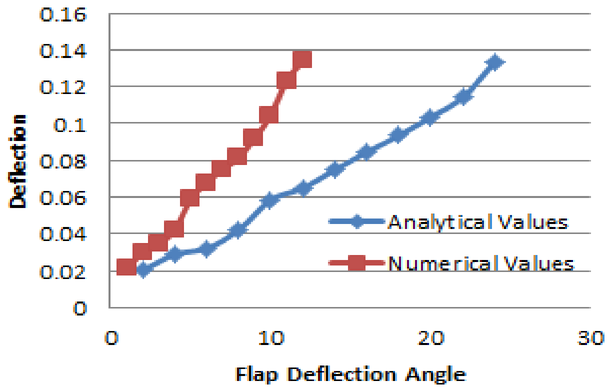

Fig 19. Numerical validation for flap architecture at different deflection angles

Conclusions

1) The layout of the structure is obtained by focusing on a basic truss-like element and its repetition and position within the overall truss.
2) The design features of the architecture have been investigated, for circular and rectangular sections of aluminum materials and it is found that the stresses are varying with the deflection angles in the range of 2-24 degrees
3) As per investigations it has been found that the minimum stress are introduced in the body at an deflection angle of 8 degrees and further when the angle is increased the stress introduced in truss structure has increased drastically.
4) From the observations made it is clear that the Al material is suitable for the deflections less than 8 degrees.
5) From the above statement it is clearly understood that the 8 deg deflection is reasonable for aircraft configuration with Al material as shown in Fig 4,7and 11.
6) Numerical validations of the flap architecture for different angles are validated and it is observed that the error is in the range of 10^{-4} which is under the reasonable.
7) Axial stress are more in rectangular cross section of the truss element than the circular section so the circular section is more reliable for the flap architecture and only reasonable stress are acting in it.
8) The requirements of the further development in the truss elements shape memory alloys (SMA) truss elements are investigated. The structural performance by FE analysis; the SMA mechanical behavior is modeled and the internal stresses are also evaluated.
9) From the results it is clearly understood that the Shape Memory Alloys (SMA) best suitable for morphing of trailing edges in the flap architecture because when compare to aluminum alloy, the SMA Axial stress (see Fig.16 and Fig 17) variation is seen as $1x10^{12}$ N/m^2.
10) The SMA material at 8^0 can be suitably adopted for the flap architecture for the aircraft wing.

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