# Research on Strategies and Systems for Morphing Aircraft

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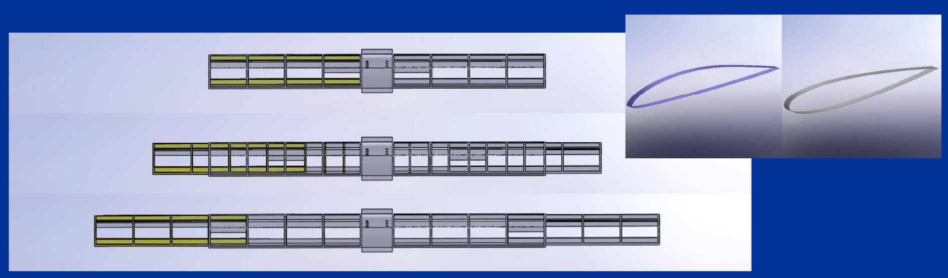
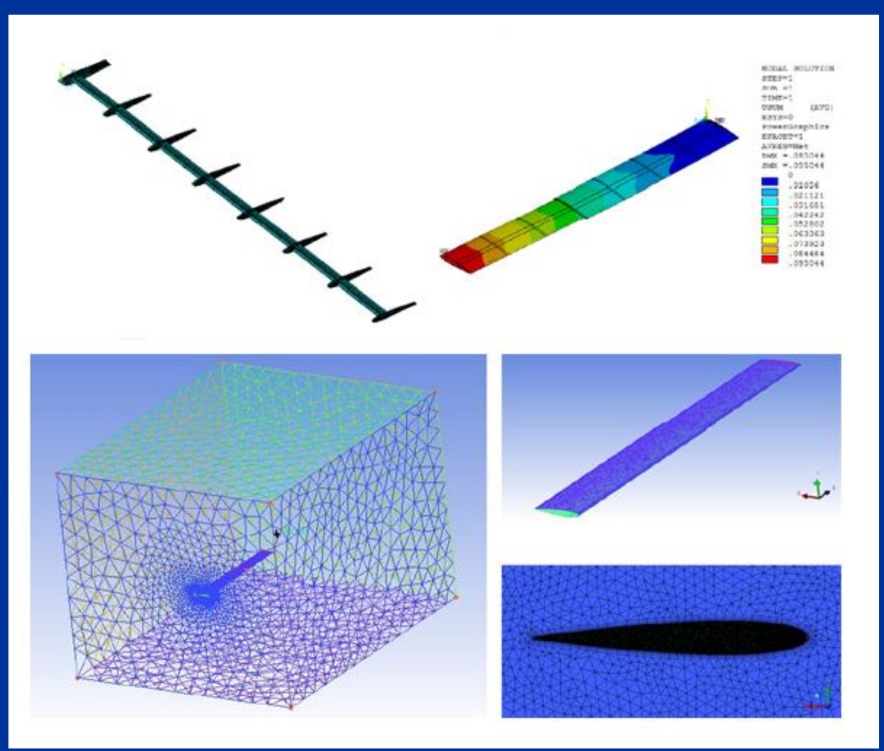
## Concept: A telescopic wing with airfoil shape change capability

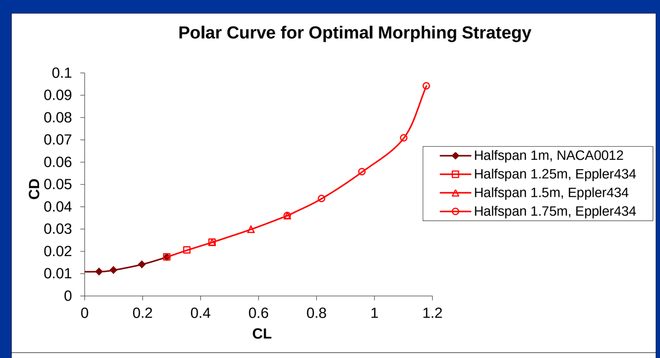


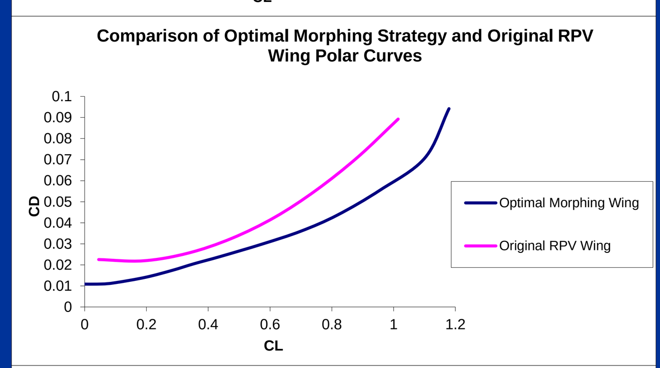
- Two 1m half span wings are fitted one inside the other.
- The inner wing slides out up to 0.75m from the outer wing at both wing sides.
- Wing airfoils change between NACA0012 and Eppler434 (highs peed-low speed)

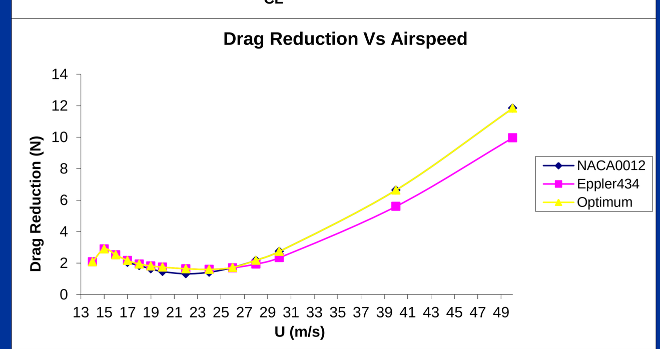
### Coupled fluid-structure (CFD-FEM) analysis was made for different wing configurations in order to:

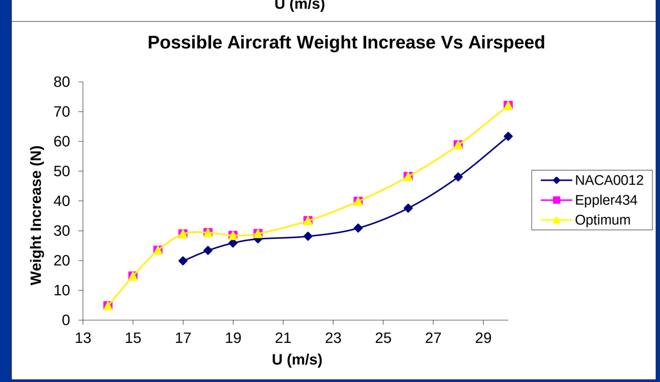
- Obtain polar curves (Drag vs. Lift) for the different wing configurations varying both span and airfoil.
- Select the best configurations in each CL segment.
- Obtain the polar curve for optimal morphing strategy .
- Compare the optimal strategy performance with a fixed wing in use.
- Calculate the possible benefits from the morphing capability and strategy in aircraft weight increase and/or drag reduction.






### Experimental Telescopic Wing was built to:

- Learn composite materials construction techniques.
- Study actuation systems.
- Assess wing weight
- Gain insight on real structural deformation.
- Assess actuation force and energy requirements and speed.

**Experimental Wing Geometry**

| Dimension (half wing) | Quantity |
|---|---|
| Inner wing chord | 0.210 m |
| Inner wing span | 0.950 m |
| Outer wing chord | 0.280 m |
| Outer wing span | 1.000 m |
| Central section span | 0.144 |
| Span variation | 2.144 - 3.644 m |
| Span increase | Up to 70.0% |
| Area Variation | 0.600 – 0.915 $m^2$ |
| Area increase | Up to 52.5% |
| Aspect ratio variation | 7.66 – 14.51 |
| Aspect ratio increase | Up to 89.4% |

**Measured morphing time and energy requirements for different experimental morphing wing loading conditions**

| Loading | Outer wing tip load (N) | Inner wing tip load (N) | Total deployment time (s) | Total retraction time (s) | Total deployment energy (J) | Total retraction energy (J) | Max current intensity (A) |
|---|---|---|---|---|---|---|---|
| 0g | 0.0 | 0.0 | 17.0 | 17.5 | 58.14 | 59.85 | 0.57 |
| 1g | 16.0 | 9.0 | 18.0 | 18.5 | 71.28 | 73.26 | 0.66 |
| 1.5g | 24.0 | 13.5 | 19.5 | 20.0 | 84.83 | 87.00 | 0.88 |
| 2g | 32.0 | 18.0 | 21.5 | 22.5 | 110.30 | 115.43 | 1.14 |

### CONCLUSIONS:

•Strategies for drag reduction with morphing estimate extra loading at take off speed of 15m/s to be 15N in a 100N weight aircraft and drag reductions from 1.7 to 12N, depending on aircraft speed.

•An experimental morphing telescopic wing based on the described concept was built and tested on ground to assess construction feasibility and pitfalls, possible improvements in actuation mechanisms and actuation energy.

•The experimental morphing wing weight exceeded the extra loading at take off speed in 9N. It is expected that different construction techniques can reduce wing weight below the threshold of 30N, when morphing at low speed flight becomes beneficial.

•Actuation speed and energy consumption are suitable for quasi static morphing in level flight. A 2200mAh capacity battery could maintain continuous actuation for 1.7 hours under a 2g loading.

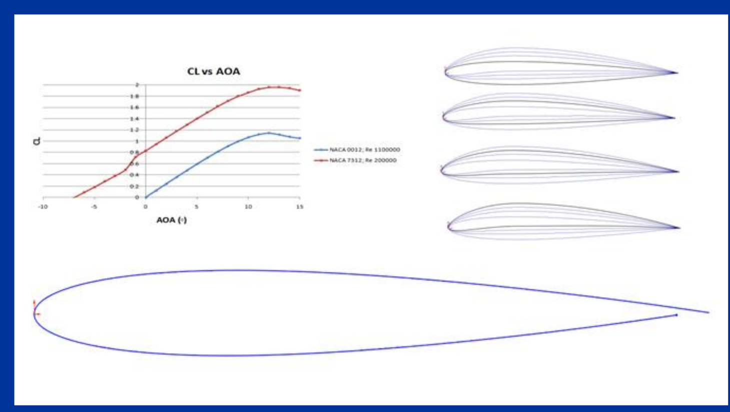
•Wing deformation under 2g loading does not compromise structural integrity but may affect aerodynamics due to the hollow outer wing sections deformation.

•The leading edge opening of the inner wing is still a functional problem to be solved before flight tests.

**Reference:**

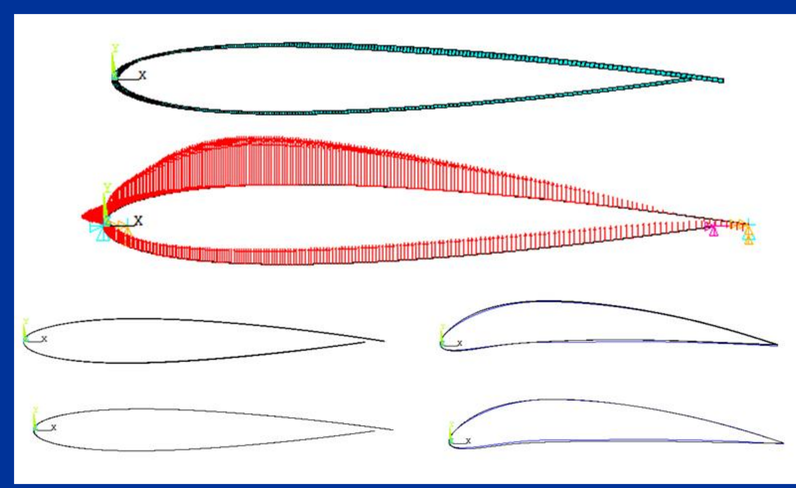
J. Vale, A. Leite, F. Lau and A. Suleman, Design and Development of Strategies and Structures for Wing Morphing, The Applied Vehicle Technology Panel Symposium (OTAN-AVT-168) , Évora, 2009.

## Concept: Camber morphing based on non-uniform shell thickness distribution



- The goal of the concept: add a moderate camber morphing capability, without adding extra complexity to the telescopic wing.
- The solution: approximate the airfoils shapes between NACA0012 and NACA 7312, varying the airfoil camber from 0% to 7%.
- Morphing is obtained by joining the upper and lower airfoils' trailing edges, with a proper thickness distribution along the airfoil, sacrificing airfoil symmetry.

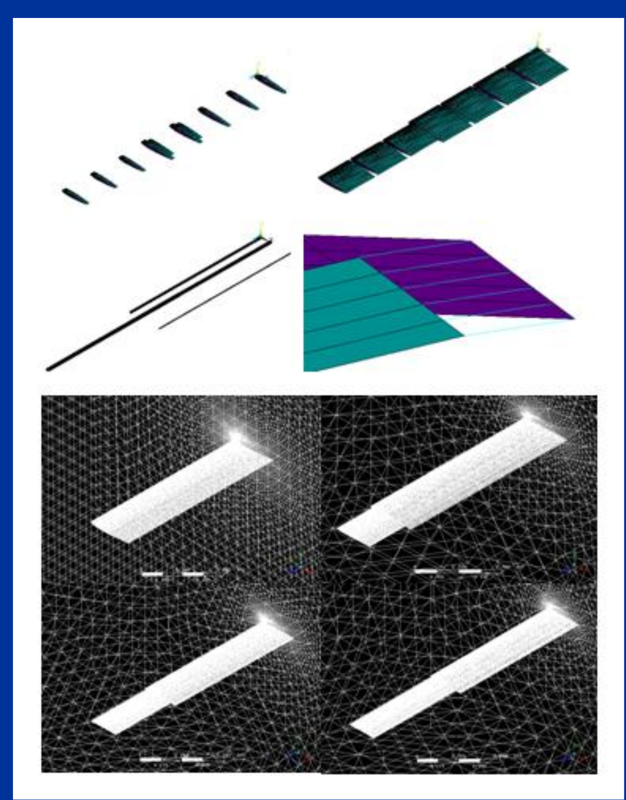
### Thickness distribution optimization based on FEM analysis made to:



•Minimize weight.
•Obtain the desired airfoil shape with small error when actuated both in unloaded and loaded state.
•Maintain the unactuated shape both in unloaded and loaded state.
•Withstand resulting stresses from aerodynamic loading both in actuated and unactuated state.
•Assess actuation force.

### Unidirectional Structural-Fluid (FEM-CFD) analysis made to:

- Obtain aerodynamic forces and moments variations with span and camber change, as well as speed and angle of attack (AOA).
- Interpolate and obtain analytical functions of the aerodynamic coefficients (CL and CD), suitable for fast usage of optimization algorithms.
- Optimize the morphing wing configuration for best performance in a number of aerodynamic performance parameters when mounted on an aircraft with predetermined characteristics (power, drag, weight, etc.)
- Compare the performance parameters with those obtained when a fixed wing optimized for cruise speed at 30m/s is mounted on the same aircraft.



**Performance parameters results and comparison between morphing and optimized fixed wing**

| Wing | Morphing | Optimum | Relative Difference |
|---|---|---|---|
| Span (m) | 1 - 1.7 | 1 | 0% - 70% |
| Camber | 0 - 7% | 5.3%@root -0%@tip | |
| Area ($m^2$) | 0.52 - 0.81 | 0.42 | 23.81% - 92.86% |
| Max Speed (m/s) | 56.87 | 56.48 | 0.68% |
| Stall Speed (m/s) | 12.23 | 19.79 | -38.23% |
| Drag @ 20 m/s (N) | 9.08 | 11.58 | -21.54% |
| Drag @ 30 m/s (N) | 15.32 | 15.23 | 0.60% |
| Drag @ 56 m/s (N) | 46.67 | 47.52 | -1.78% |
| Max Climb Angle (◦) | 22.64 | 21.71 | 4.32% |
| Max ROC (@ 41m/s) (m/s) | 9.69 | 10.70 | -9.49% |
| Max Range (Km) | 284.70 @ 19m/s | 265.88 @ 27m/s | 7.08% |
| Max Range (@ 27m/s) | 267.40 | 265.88 | 0.57% |
| Min Glide Angle (◦) | 3.55 | 6.59 | -46.16% |
| Max Endurance (min) | 251.07 | 143.60 | 74.84% |

### CONCLUSIONS:

•According to the optimization results, the concept is feasible both in terms of geometric changes and actuation requirements.

•The procedure used in the morphing wing analysis allowed the analytical description of the aerodynamic behaviour of the morphing wing, suitable for fast optimization of the wing configuration for the best values of different performance parameters.

•A performance comparison was made between the morphing wing and a fixed wing optimized for cruise at 30m/s, accounting for weight penalties on the morphing wing structure and actuation system relative to the fixed wing weight.

•For reasonable (although arbitrary) weight estimates, results show that the most significant penalty is in maximum ROC (9.49% reduction).

•The greatest benefits are in stall speed, endurance and glide angle (38.23% decrease, 46.16% decrease and 74.84% increase respectively). Moderate benefits are in range and climb angle (7.08% and 4.32% increase respectively).

•Comparing the morphing wing to the limit case of a weightless optimum fixed wing it can be verified that performance is degraded due to weight penalty, although major benefits remain significant.

•Further studies are needed to establish criteria to asses the morphing benefits in a heuristic point of view.

**Reference:**

J. Vale, F. Lau and A. Suleman, Development of an Adaptive Camber Capability for a Telescopic Morphing Wing, Symposium on Smart Structures and Systems Technologies (S(3)T[2010]) , Porto, 2010.

**ACKNOWLEDGEMENTS**

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