Aerodynamic optimisation of a morphing leading edge airfoil

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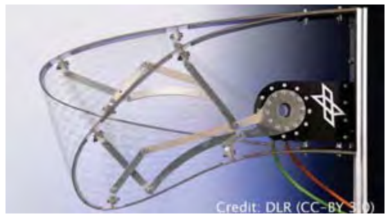
COMETES

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

UNIVERSITÀ DEGLI STUDI DI PADOVA

1. What is morphing?

- Morphing indicates the ability of manipulating certain characteristics of a vehicle to better match the vehicle's state to the environment and increase its performance
- Aircraft are usually designed for optimal performance at a fixed operating point, that can represent only a small portion of the flight envelope, penalizing the overall efficiency
- A morphing leading edge is a compliant structure deformed by an internal actuator device, without gaps in the surface responsible for drag and noise generation

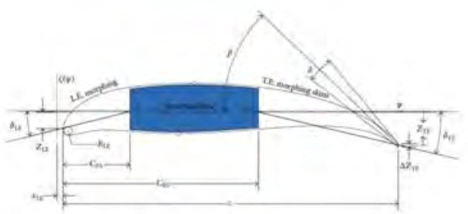


2. Aim of the study

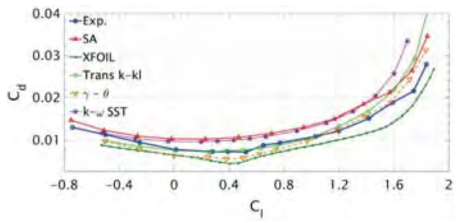
- Identify an optimization strategy for morphing leading edge airfoil in terms of:
  - Shape parameterization
  - Constraints on deformability
  - Optimization algorithm
  - Aerodynamic model
- Provide an estimate of possible improvements of aerodynamic performance using a morphing leading edge

3. Shape parameterization

- A dedicated procedure for Constant Arc Length (CAL) parameterization applied to CST technique is developed
- Each profile is morphed by keeping the same arc length $L_m = L_0$
- Constraint on length variation limits axial strain and enhance actual feasibility
- Morphing involves only 25% of chord



4. Aerodynamic model validation



- Steady RANS CFD solver (Ansys Fluent) for aerodynamic performance calculation
- Grid sensitivity and turbulence model influence widely analysed
- Two RANS models selected for optimisation (Spallart-Allmaras and $\gamma - Re_\theta$) + a potential flow solver (XFOIL)

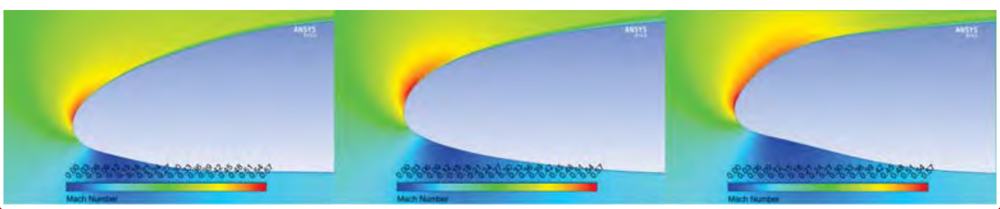
5. 2D Optimization for drag minimisation

$$
\begin{aligned}
\text{minimize} \quad & C_d(\mathbf{x}), \mathbf{x} \in \Omega \\
\text{such that:} \quad & |L_m - L_0|/L_0 \leq 1e-6 \\
& |A_m - A_0|/A_0 \leq 0.05 \\
& C_{l,b} - C_l \leq 0 \\
& (C_{m,b} - C_m)/C_{m,b} \leq 0.1 \\
& \Omega = \mathbf{x} \in \mathbb{R}^5 | \mathbf{Lb} \leq \mathbf{x} \leq \mathbf{Ub}
\end{aligned}
$$

with boundary conditions:

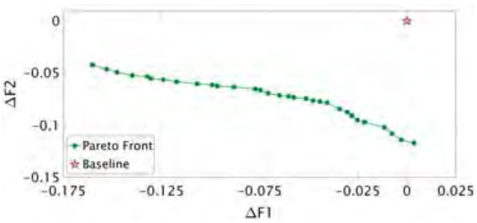
$$Re = 6E06, M = 0.20, \alpha = 15°$$

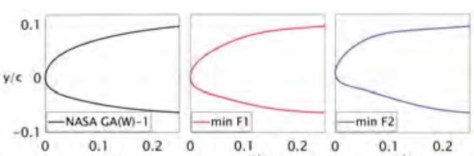
Index		B/L	Opt.	Rel.Var [%]
Cd	XF	0.0312	0.0253	-23.4
	SA	0.0400	0.0364	-8.98
	$\gamma - \theta$	0.0342	0.0281	-17.93
Cl	XF	1.942	2.058	6.00
	SA	1.889	1.895	0.51
	$\gamma - \theta$	1.890	2.023	7.35
L/D	XF	62.19	81.34	30.7
	SA	47.11	52.03	10.43
	$\gamma - \theta$	55.28	71.09	30.85



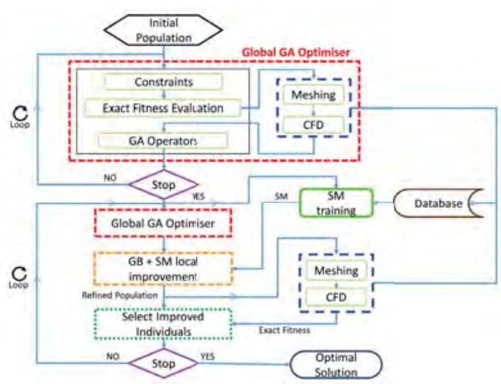
6. Multi-point optimisation

$$\text{minimize:} \begin{cases} C_d(\mathbf{x}) \,@\, \alpha = 4°, \mathbf{x} \in \Omega \\ C_d(\mathbf{x}) \,@\, \alpha = 15°, \mathbf{x} \in \Omega \end{cases}$$



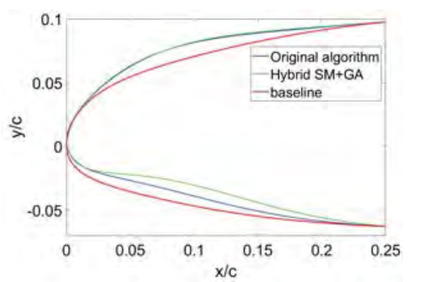


7. Metamodel-assisted hybrid optimization loop



Index	Original	Hybrid	Rel. var. [%]
C_d	0.0281	0.0283	0.71
C_l	2.023	2.037	0.69
L/D	71.09	72.00	1.28

- Hybrid algorithm: genetic alorithm (GA) for global search, gradient-based (GB) for local refinement around each individual using surrogate model (SM)
- Artificial neural network (ANN) for fitness estimation, trained on data from previous generations
- 2D optimisation repeated with hybrid model achieving a solution close to the original one
- Computational time reduced by 12%, number of CFD calls reduced by 19%



8. References

[1] Andrea Magrini and Ernesto Benini. Aerodynamic optimization of a morphing leading edge airfoil with a constant arc length parameterization. *Journal of Aerospace Engineering*, 31(2):04017093, 2018.