Topic:

Aerodynamic Shape Optimization For Morphing Wing Technology using DAFoam

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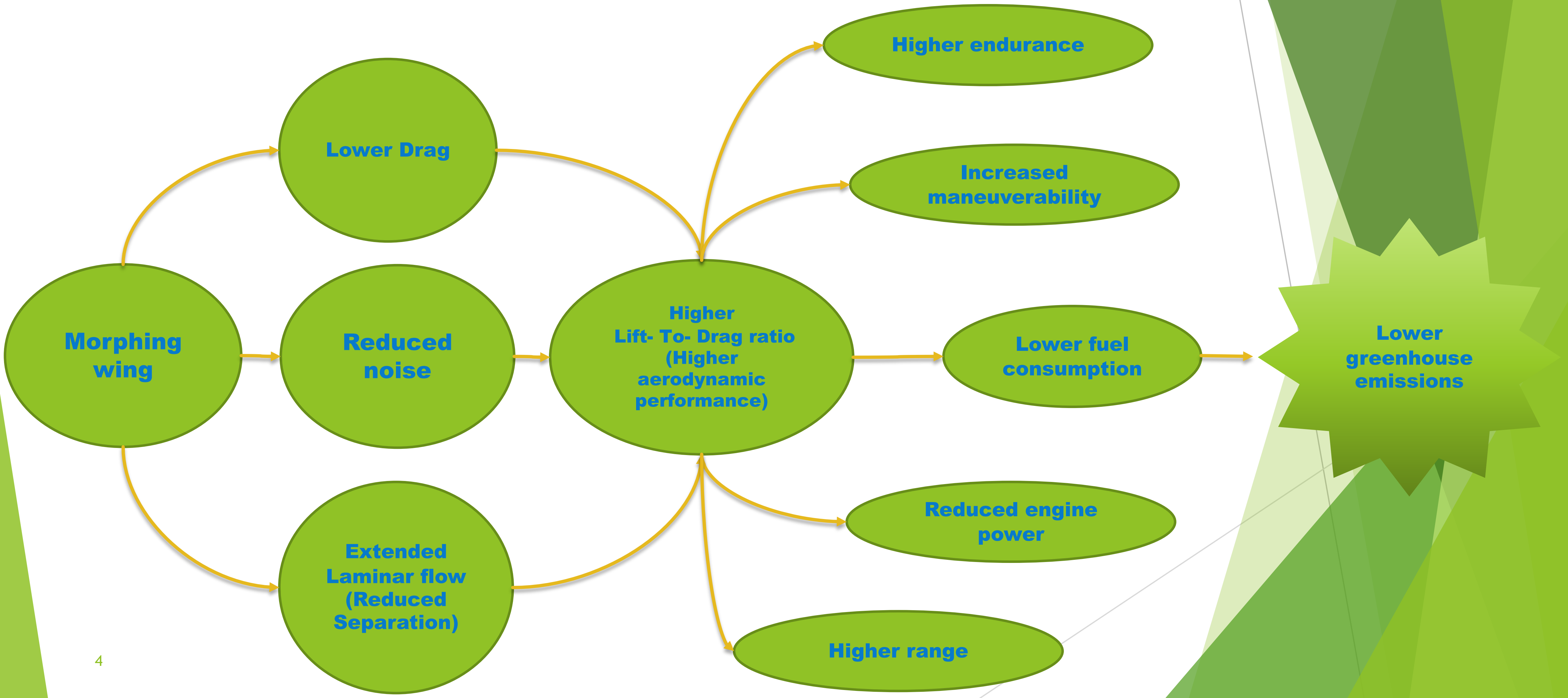
Morphing Wing

- Morphing wing is a highly-advantageous adaptive wing technology for next-generation aircraft which targets wings shape deformation in a way to adapt the wing for the specified flight condition , having the best aerodynamic performance.
- This concept is mimicked from nature by the inspiration from bird's flight.

Why using morphing Wing?

- Morphing wings have unquestionable advantages that makes them potential candidate to be used in next generation aircraft.



Introduction to LARCASE and UAS-S45

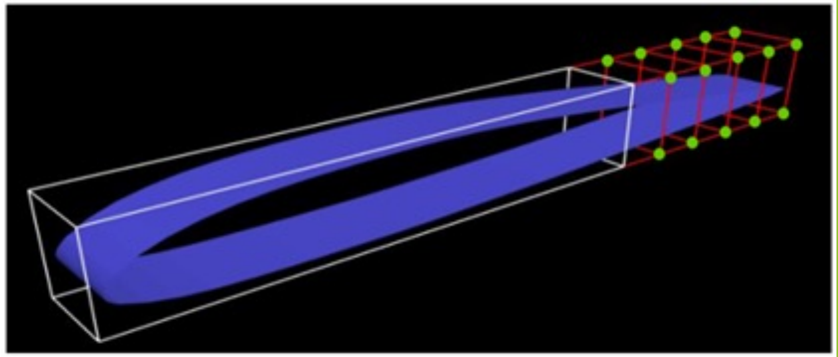
Toward greener and more intelligent aviation

The Research Laboratory in Active Controls, Avionics and Aeroservoelasticity (LARCASE) is a multidisciplinary research group that focuses on the fields of aeroservoelasticity (aerodynamics, computational fluid dynamics, aeroelasticity and aircraft controls) and the modeling and simulation of airplanes and helicopters. LARCASE is directed by Prof. Ruxandra Mihaela Botez since 2003.

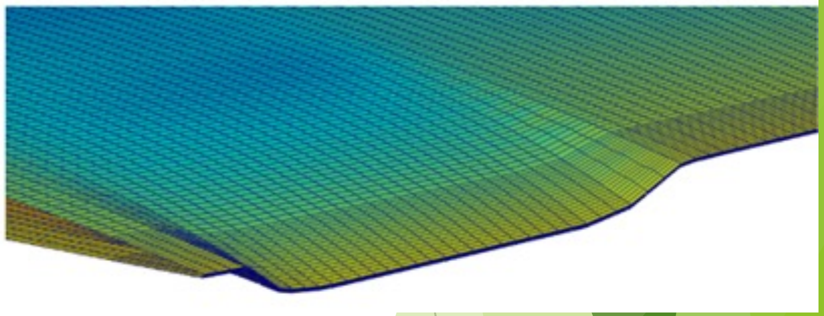
UAS-S45 is a surveillance and reconnaissance unmanned aerial system, designed and manufactured in Mexico.

Aerodynamic Optimization of Morphing Wing with DAFoam

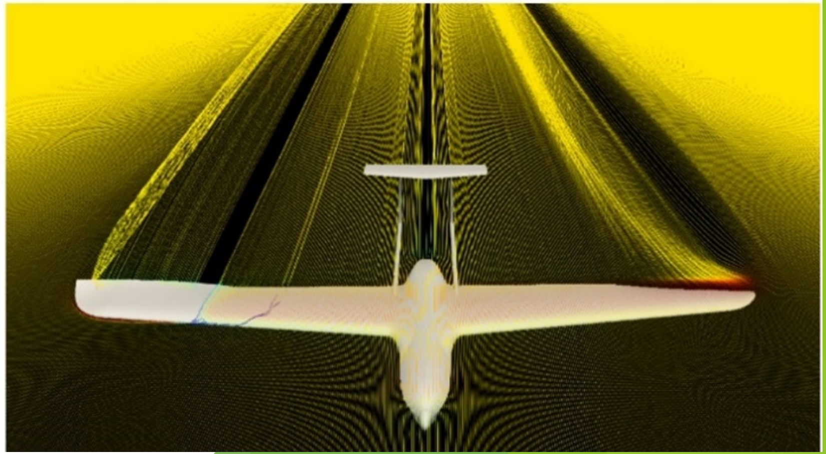
- Free-Form Deformation Parameterization on the Aerodynamic Optimization of Morphing Trailing Edge



- Study of Seamless Morphing Trailing Edge Flaps for the UAS-S45 using High-Fidelity Aerodynamic Optimization



- Novel Twist Morphing Aileron and Winglet Design for UAV Control and Performance



Free-Form Deformation Parameterization on the Aerodynamic Optimization of Morphing Trailing Edge

applied mechanics

MDPI

Article

Free-Form Deformation Parameterization on the Aerodynamic Optimization of Morphing Trailing Edge

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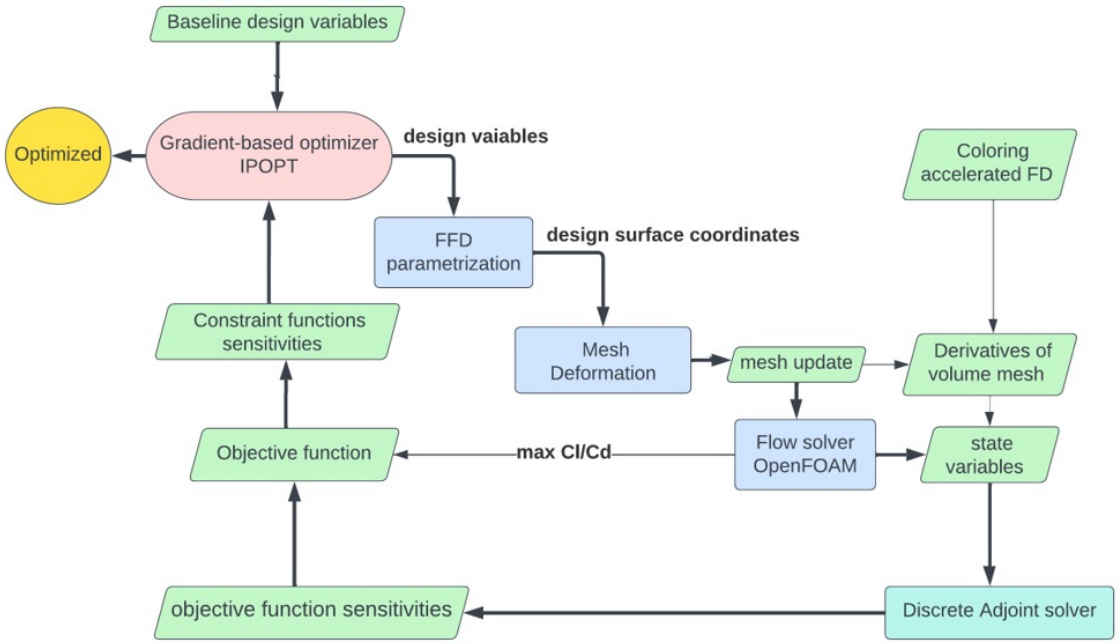
Abstract: Every aerodynamic optimization is proceeded by a parameterization of the studied aerial object, and due to its influence on the final optimization process, careful attention should be made in choosing the appropriate parameterization method. An aerodynamic optimization of a morphing trailing edge is performed using a free-form deformation parameterization technique with the purpose of examining the influence of the initial conditions of the parameterization on the optimization results, namely on the number of control points. High-fidelity gradient-based optimization using the discrete adjoint method is established by the coupling of OpenFOAM and Python within the DAFoam optimization framework. The results indicate that the number of control points has a considerable effect on the optimization process, in particular on the convergence, objective function value, and on the deformation feasibility.

Keywords: deformative parametrization; gradient-based optimization; UAS-S45; morphing flap; FFD control points; DAFoam optimization framework; OpenFOAM

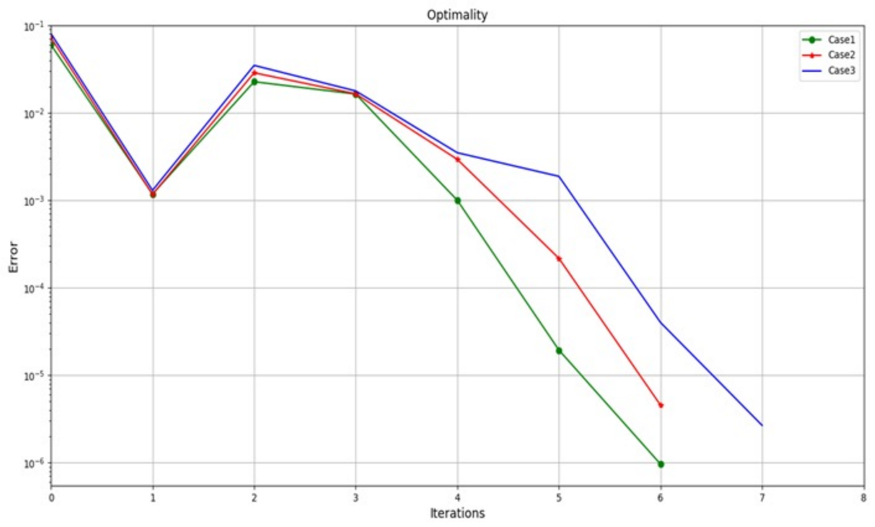
Optimization with DAFoam

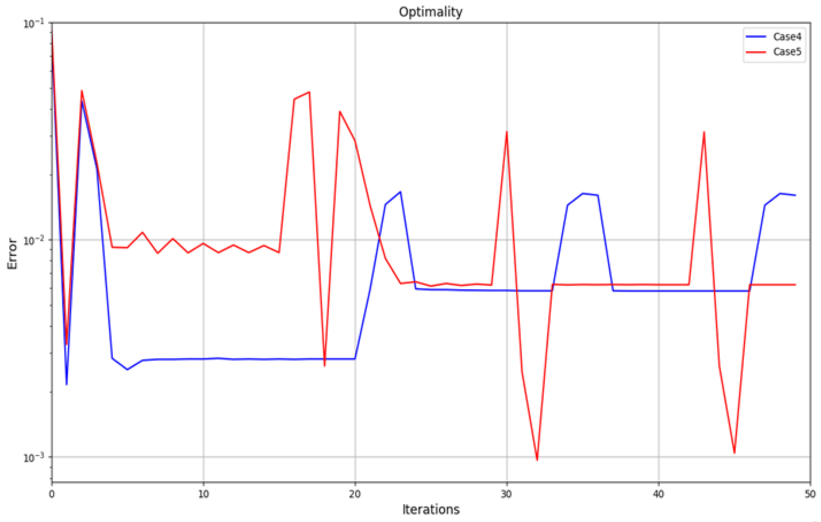
Function/variable	Description	Case				
Objective function		**1**	**2**	**3**	**4**	**5**
$max.\quad C_l/C_d$	Lift-to-drag ratio					
With respect to:						
y	TE FFD control points	8	12	16	20	24
α	Angle of attack	1	1	1	1	1
	Total design variables	9	13	17	21	25
Subject to:						
$C_l = 0.38514$	Constraint function					
$0 \leq \Delta y \leq 15\, mm$	Design variable bounds					
$\Delta y_{z=0}^{upper} = \Delta y_{z=1}^{upper}$	Linear constraint					



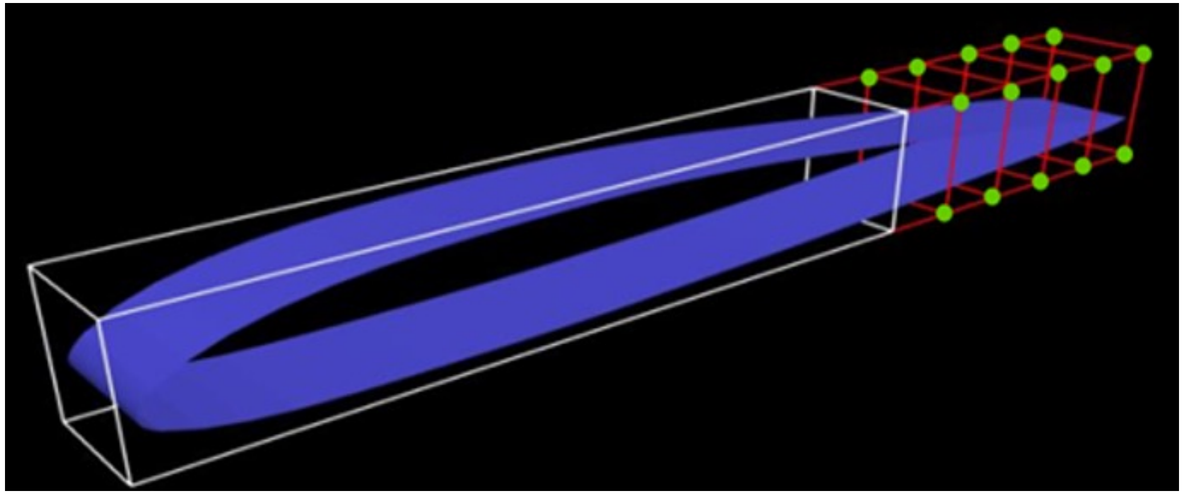
Results

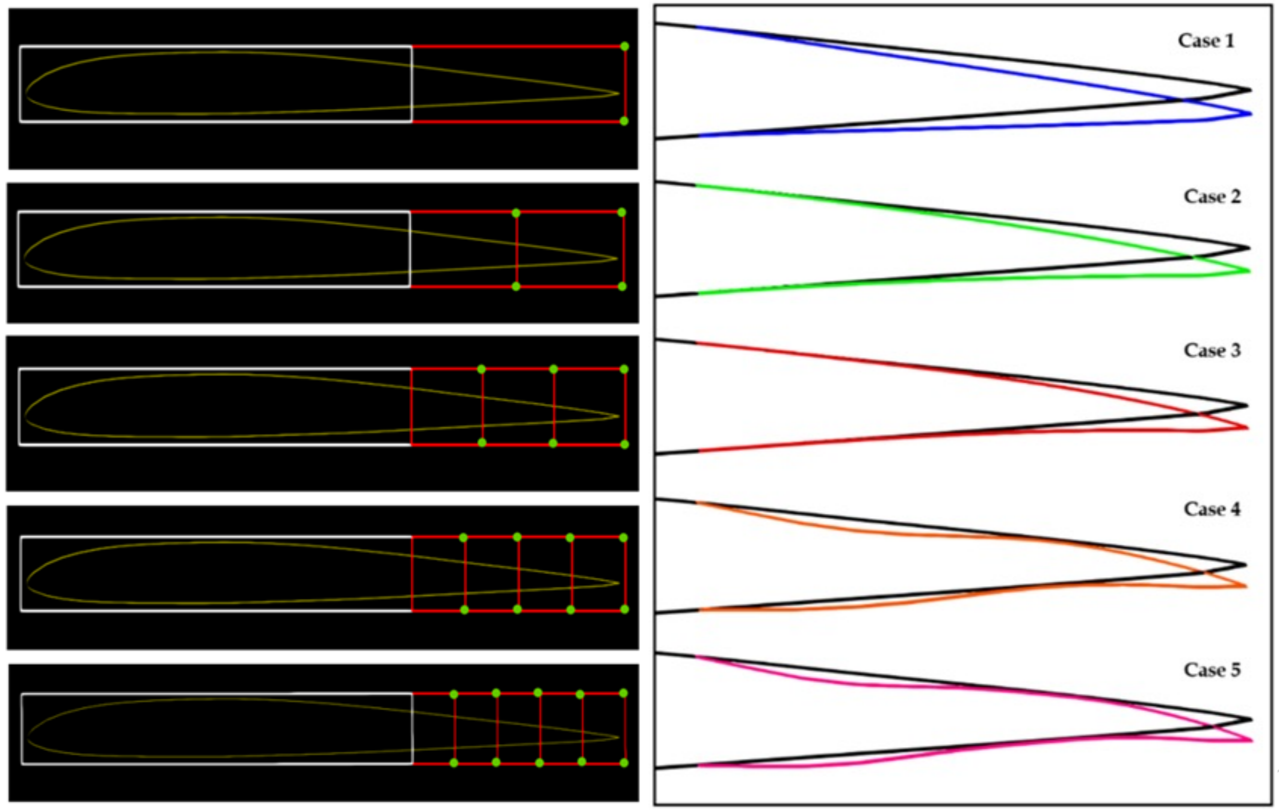
Case nr.	Control points	Run time (sec.)	Itr. nr.	Optimality error	Initial Cl/Cd	Opt. Cl/Cd	Gain %
1	8	218.732	6	9.63e-07	34.548	38.522	10.3
2	12	258.512	6	4.55e-06	34.532	39.547	12.7
3	16	504.096	7	2.67e-06	34.524	40.058	13.8
4	20	10925.43	50	1.60e-02	34.523	39.002	11.5
5	24	12203.12	50	6.20e-03	34.521	38.663	10.7





Results





Seamless Morphing Trailing Edge Flaps for the UAS-S45 using High-Fidelity Aerodynamic Optimization

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FULL LENGTH ARTICLE

Seamless morphing trailing edge flaps for UAS-S45 using high-fidelity aerodynamic optimization

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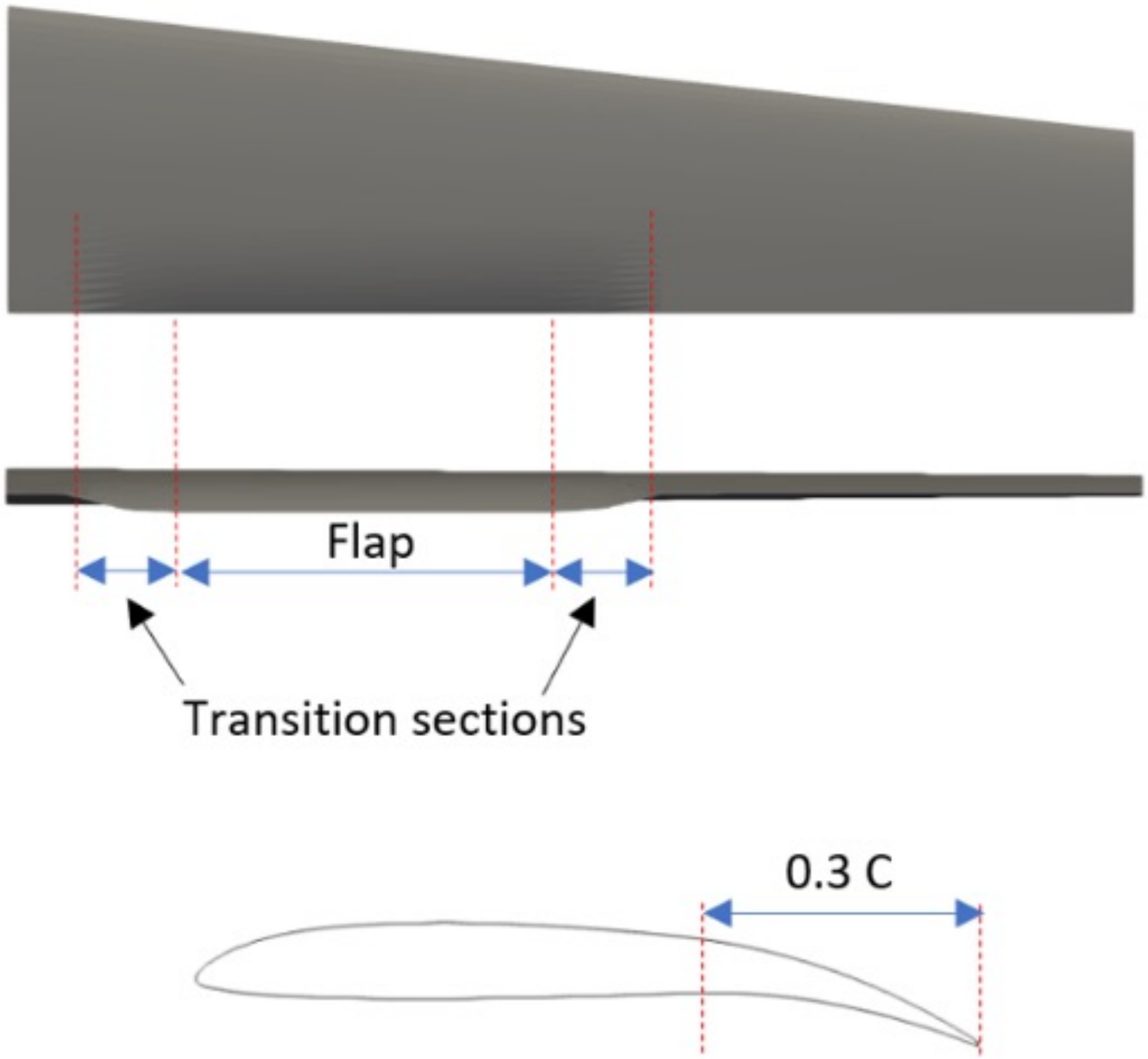
KEYWORDS

Seamless morphing trailing edge flap;
Aerodynamic optimization;
Gradient-based optimization;
Climb flight condition;
Gliding descent;
Flight range;
Endurance

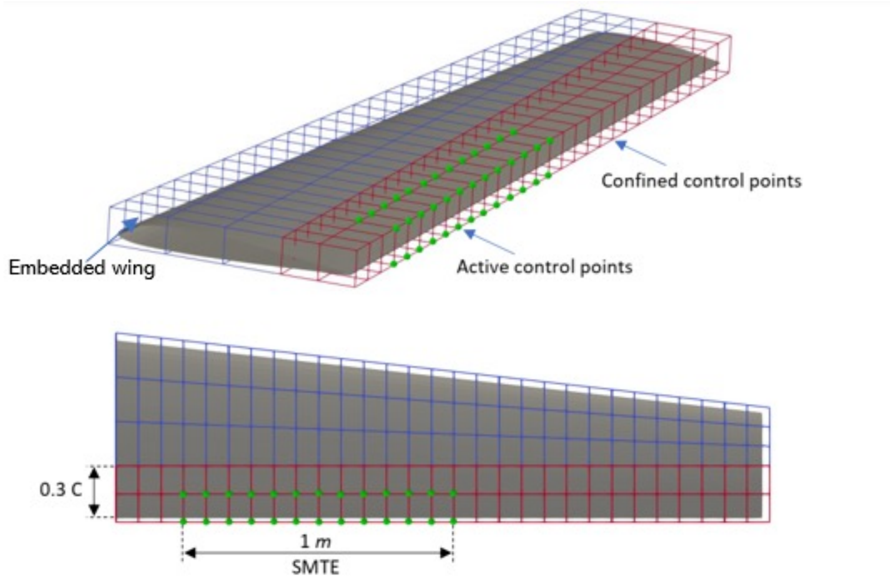
Abstract The seamless trailing edge morphing flap is investigated using a high-fidelity steady-state aerodynamic shape optimization to determine its optimum configuration for different flight conditions, including climb, cruise, and gliding descent. A comparative study is also conducted between a wing equipped with morphing flap and a wing with conventional hinged flap. The optimization is performed by specifying a certain objective function and the flight performance goal for each flight condition. Increasing the climb rate, extending the flight range and endurance in cruise, and decreasing the descend rate, are the flight performance goals covered in this study. Various optimum configurations were found for the morphing wing by determining the optimum morphing flap deflection for each flight condition, based on its objective function, each of which performed better than that of the baseline wing. It was shown that by using optimum configuration for the morphing wing in climb condition, the required power could be reduced by up to 3.8% and climb rate increases by 6.13%. The comparative study also revealed that the morphing wing enhances aerodynamic efficiency by up to 17.8% and extends the laminar flow. Finally, the optimum configuration for the gliding descent brought about a 43% reduction in the descent rate.

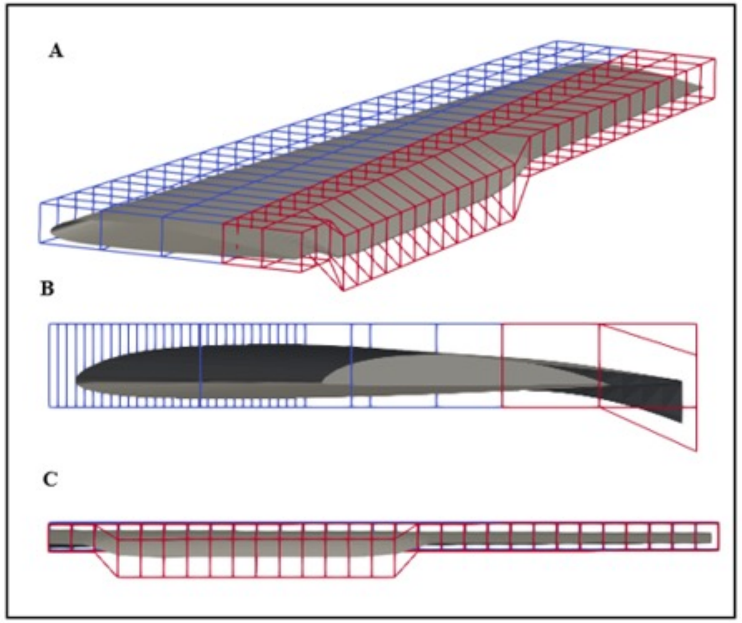
Seamless Morphing Trailing Edge (SMTE) Flap



FFD

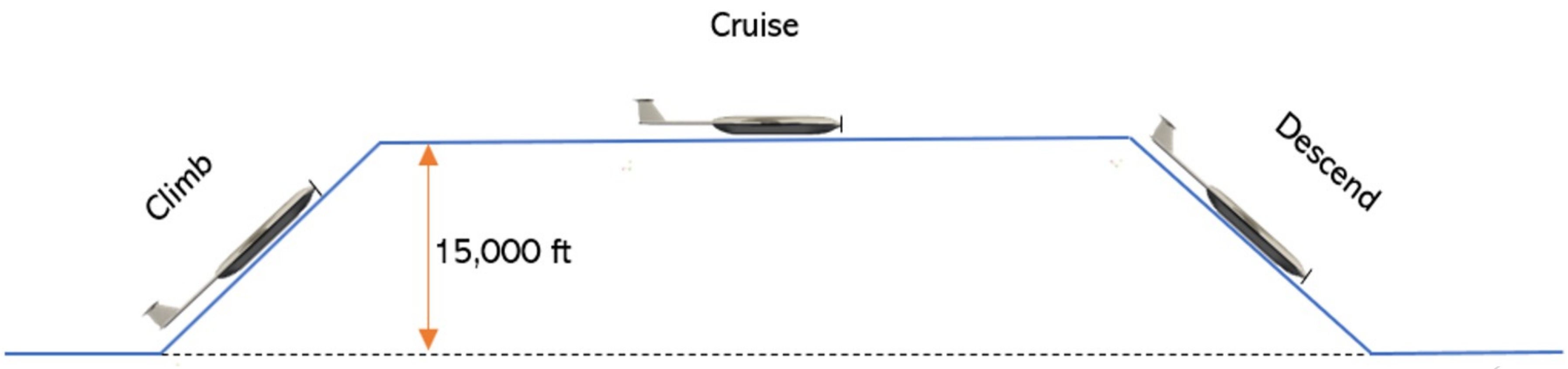
- For a wing with SMTE flap, the control points on the flap section are free to move in the upwards and downwards directions, the rest of control points are confined to zero deflection, and thus only 52 out of the 360 control points are active





Flight Conditions and Objectives

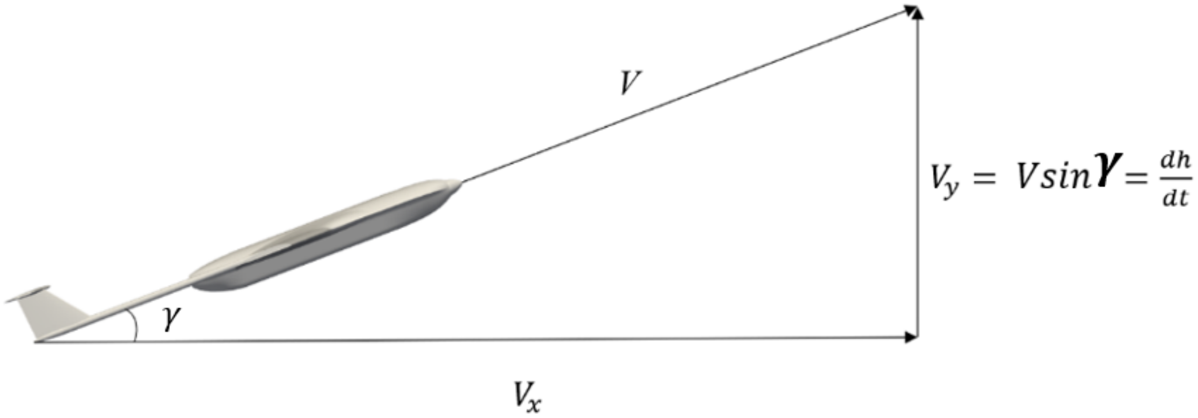
Flight condition	Goal	Objective function
Climb	Increasing climb rate	$min \quad {C_D}/{C_L^{3/2}}$
Cruise	Increasing range (flight distance)	$max \quad {C_L}/{C_D}$
	Increasing endurance (flight time)	$max \quad {C_L^{3/2}}/{C_D}$
Gliding Descent	Reducing descent rate	$min \quad {C_D}/{C_L^{3/2}}$



Climb

$$P_{req} = \left(\frac{2W^3}{\rho S}\right)^{1/2} \frac{C_D}{C_L^{3/2}}$$

$$\frac{P_{av} - P_{req}}{W} = V\sin\gamma$$

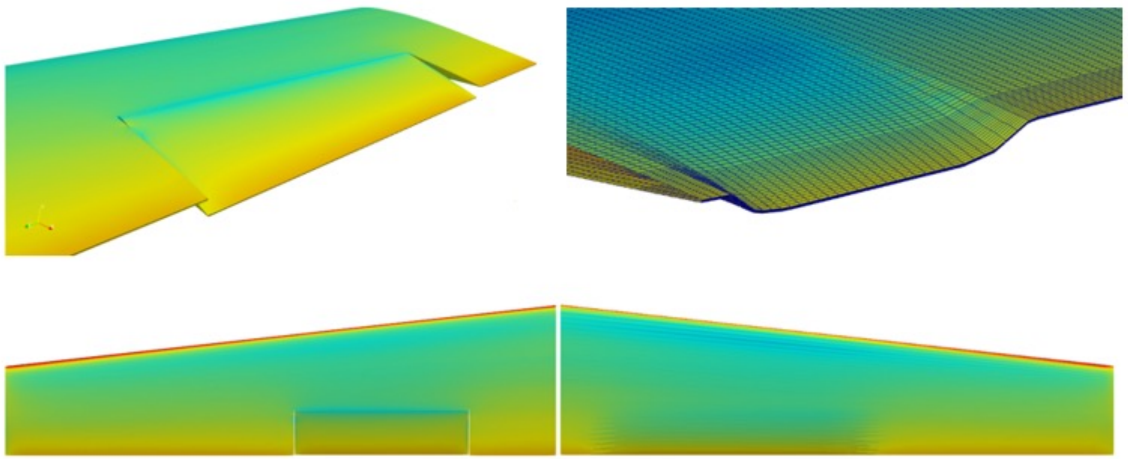


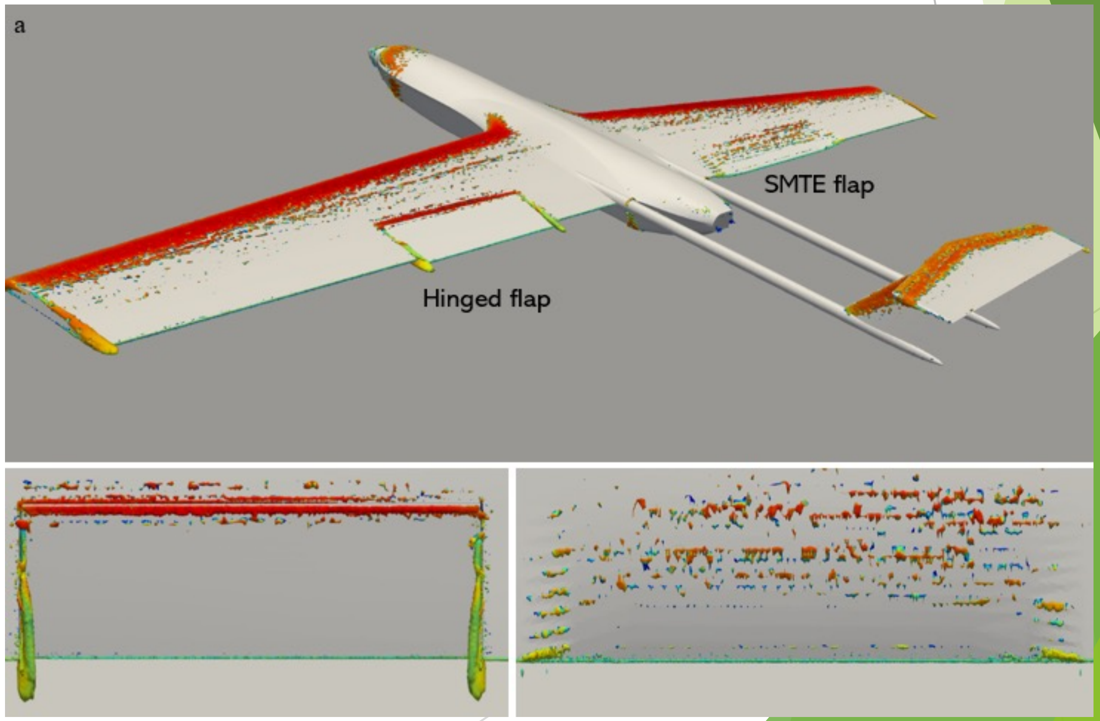
Configuration	γ (°)	Flap deflection (mm)	C_L	C_D	$\frac{C_D}{C_L^{3/2}}$	Required power (%)	Climb rate (%)
S45+SMTE Flap	5	18.4	0.75342	0.03493	0.05341	-3.8	+ 6.13
Clean Wing	5	0	0.61797	0.02697	0.05552	-	

Cruise- Comparison of hinged flap versus SMTE flap

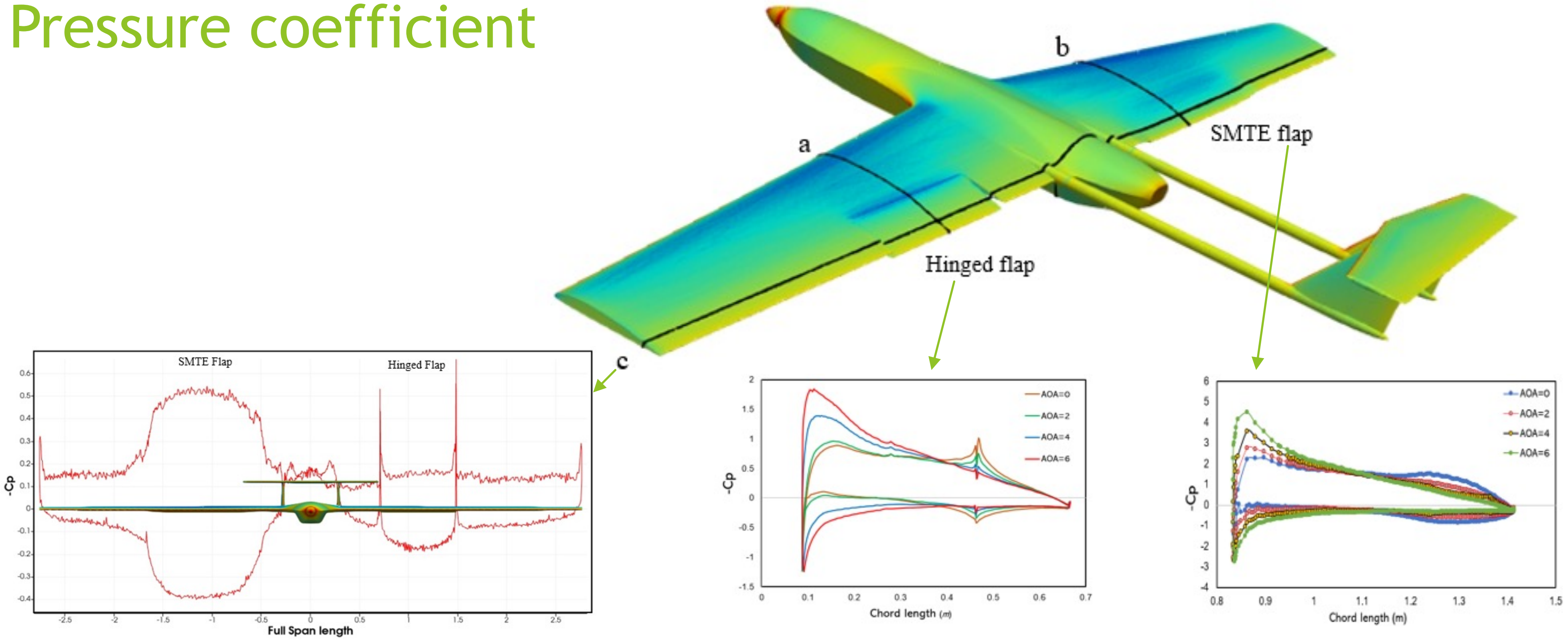
SMTE flap out-performed the hinged flap in the following aspects:

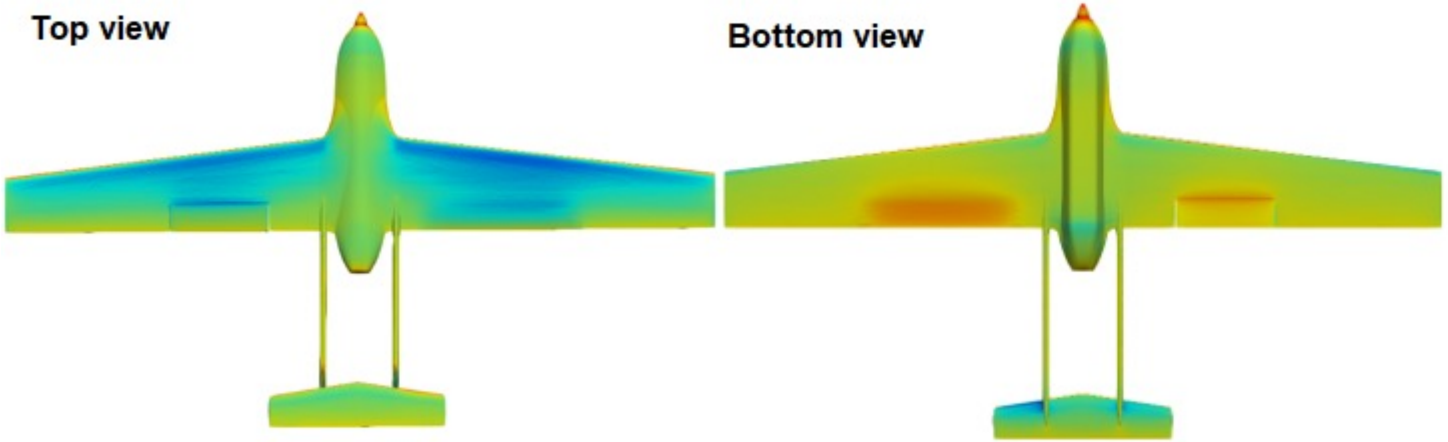
- Extending laminar flow on wing upper surface,
- Improving the flow stability by restricting its turbulence behavior,
- Improving aerodynamic efficiency and range by up to 17.8% compared to the hinged flap, and by up to 33% compared to the clean wing configuration.



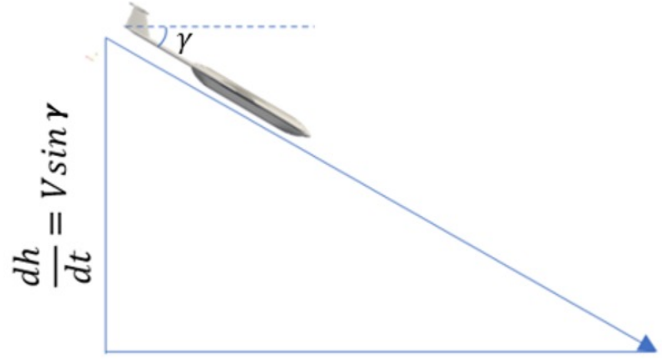


Pressure coefficient

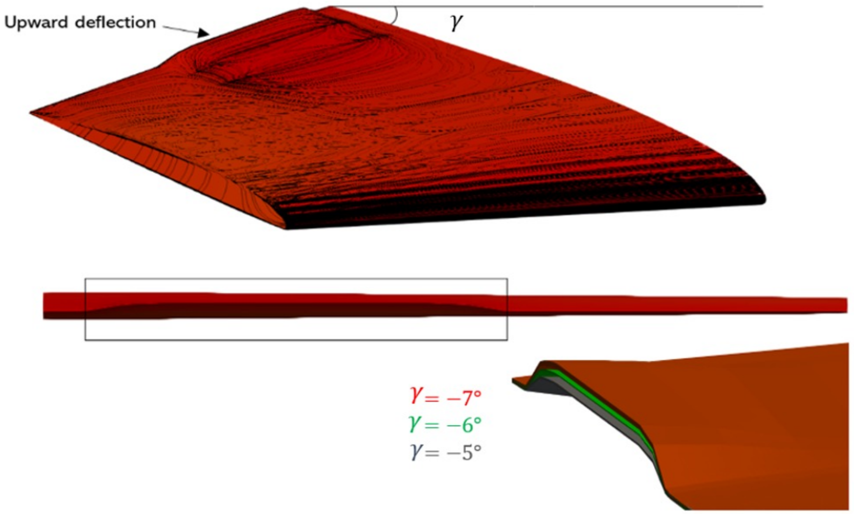


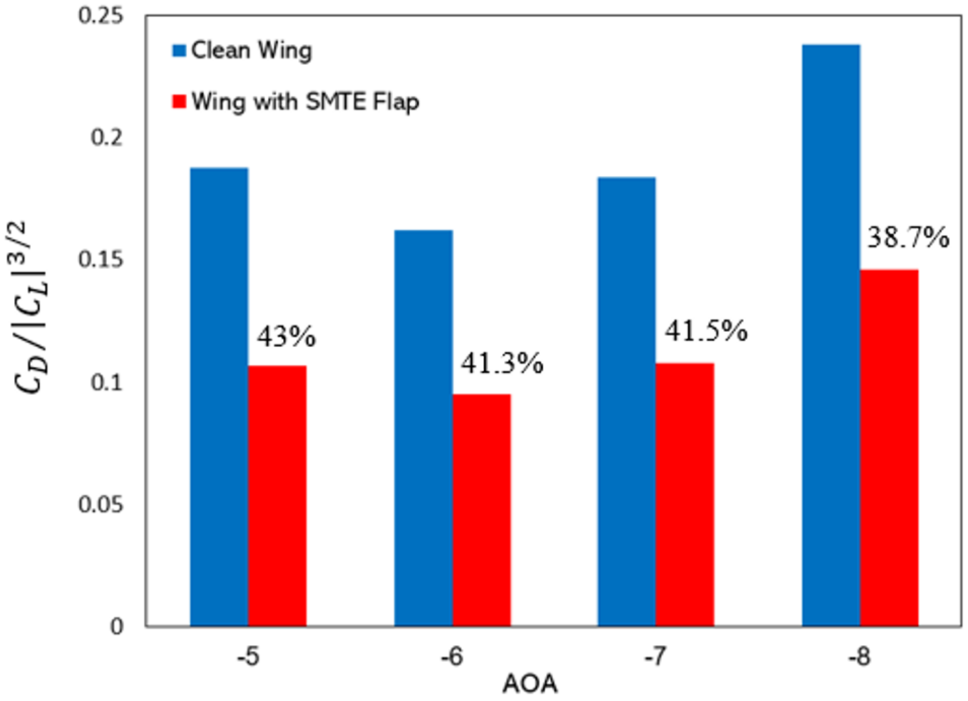


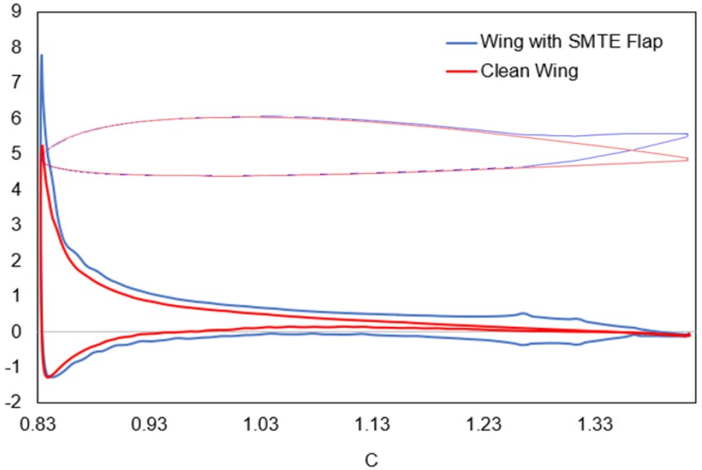
Descend



$$\frac{dh}{dt} = \sqrt{\frac{2W}{\rho S}}\,\frac{C_D}{C_L^{3/2}}$$







drones

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Article

Novel Twist Morphing Aileron and Winglet Design for UAS Control and Performance

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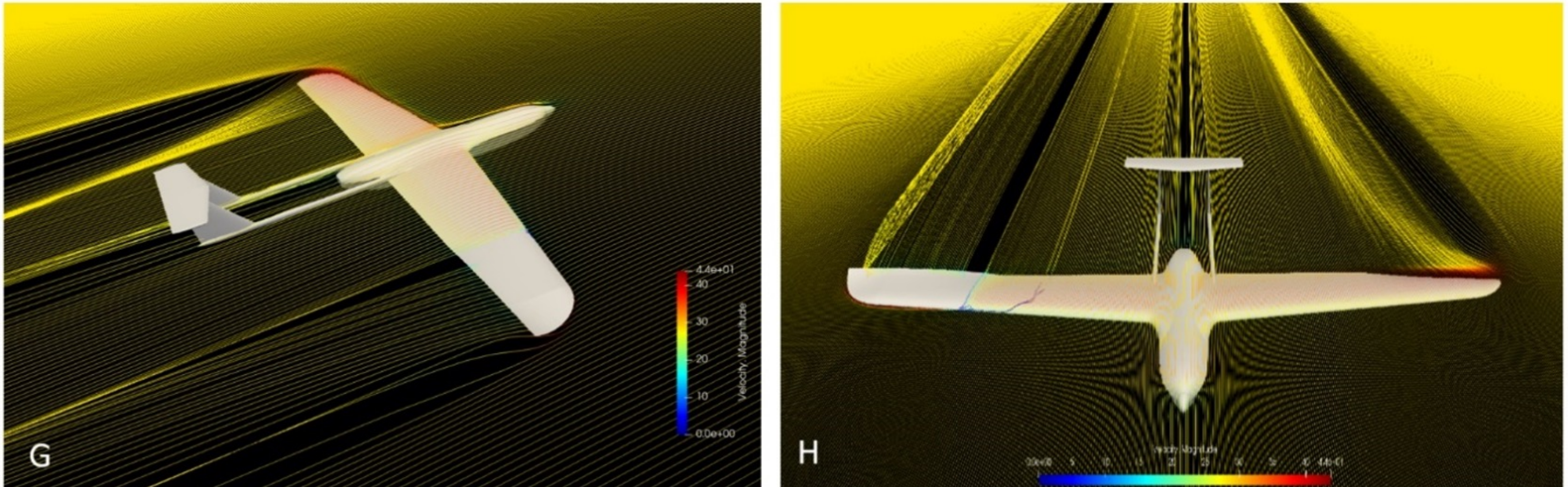
Abstract: This study introduces a novel "twist morphing aileron and winglet" design for the Unmanned Aircraft System UAS-S45. Improving rolling efficiency through twist-morphing ailerons and reducing induced drag through twist-morphing winglets are the two main objectives of this study. A novel wing design is introduced, and a high-fidelity gradient-based aerodynamic shape optimization is performed for twist morphing ailerons and twist morphing winglets, separately, with specified objective functions. The twist morphing aileron is then compared to the conventional hinged aileron configuration in terms of rolling efficiency and other aerodynamic properties, in particular aircraft maneuverability. The results for twist morphing ailerons show that the novel morphing design increases the aileron efficiency by 34% compared to the conventional design and reduces induced drag by 61%. Next, twist-morphing winglets are studied regarding the induced drag in cruise and climb flight conditions. The results for twist morphing winglets indicate that the novel design reduces induced drag by 25.7% in cruise flight and up to 16.51% in climb; it also decreases the total drag by up to 7.5% and increases aerodynamic efficiency by up to 9%.

Keywords: Rolling efficiency; aileron performance; downwash; induced drag; twist morphing aileron; twist morphing winglet

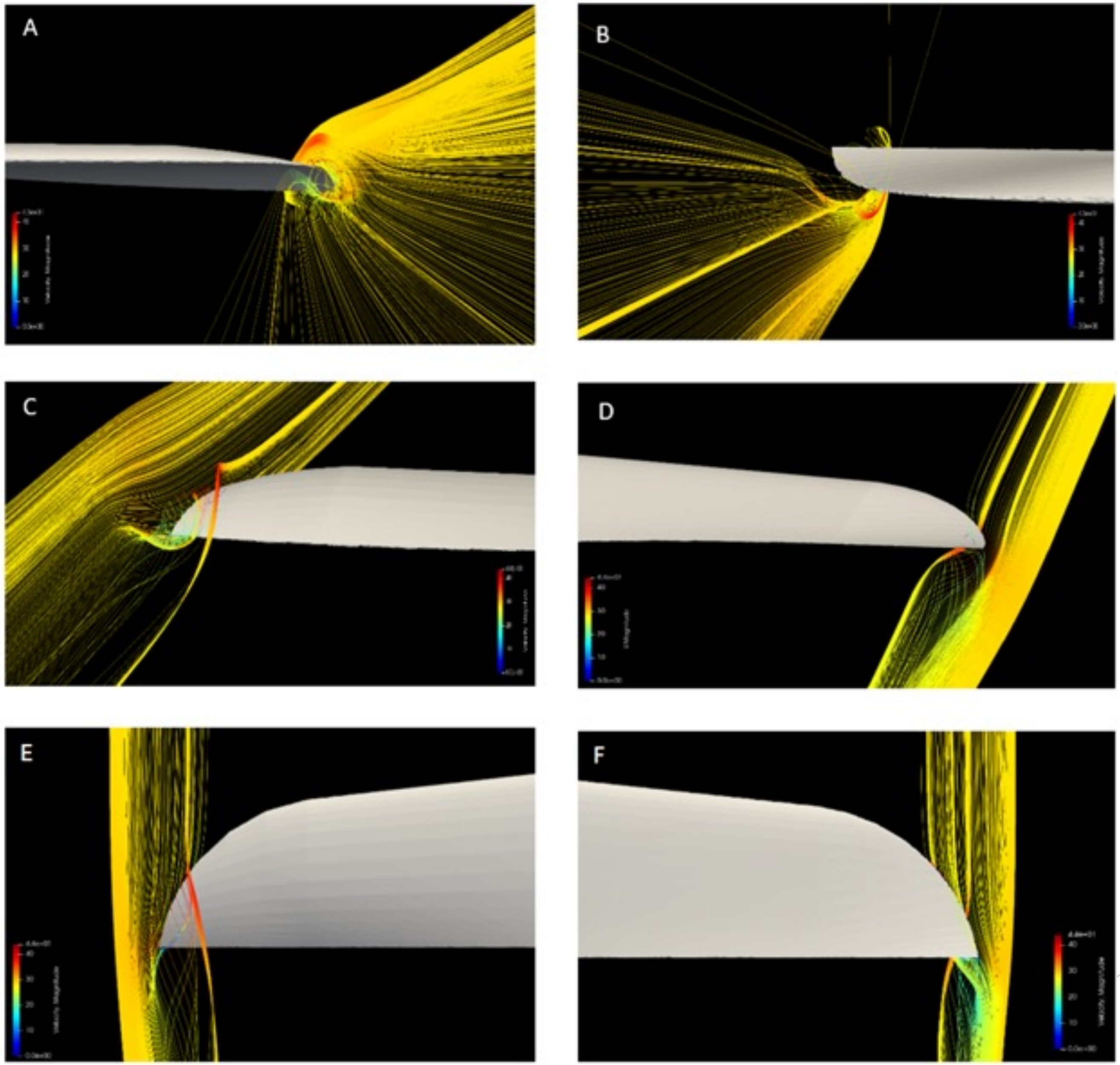
Objectives of the Study

- Improving aileron efficiency by introducing novel twist morphing aileron
- Reducing induced drag at wingtip by introducing twist morphing winglet



Flow visualization around twist morphing ailerons

Left wing
Downward twist



Right wing
Upward Twist

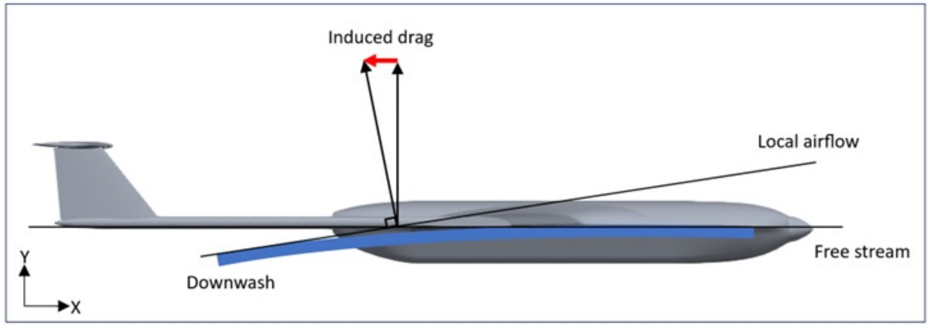
Results

Ailerons	AOA (°)	C_L	C_D	Roll Moment Coefficient (C_r)	Induced Drag (C_{Di})	(C_r) variations (%)
Hinged ailerons	0	0.289	0.0427	0.463	0.00296	-
Twist Morphing ailerons	0	0.188	0.0395	0.701	0.00115	+34

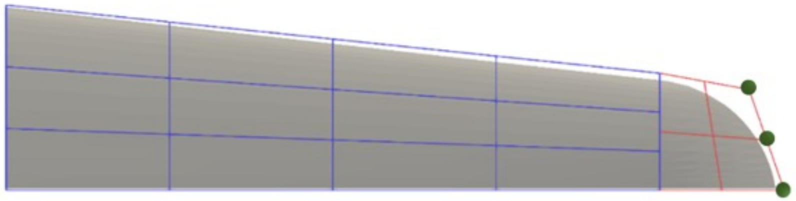
An increase in roll moment is directly interpreted as an increase in the ailerons' control power as well as in their roll rate, translating into higher aileron efficiency and rapid roll maneuver, respectively

Twist morphing winglet

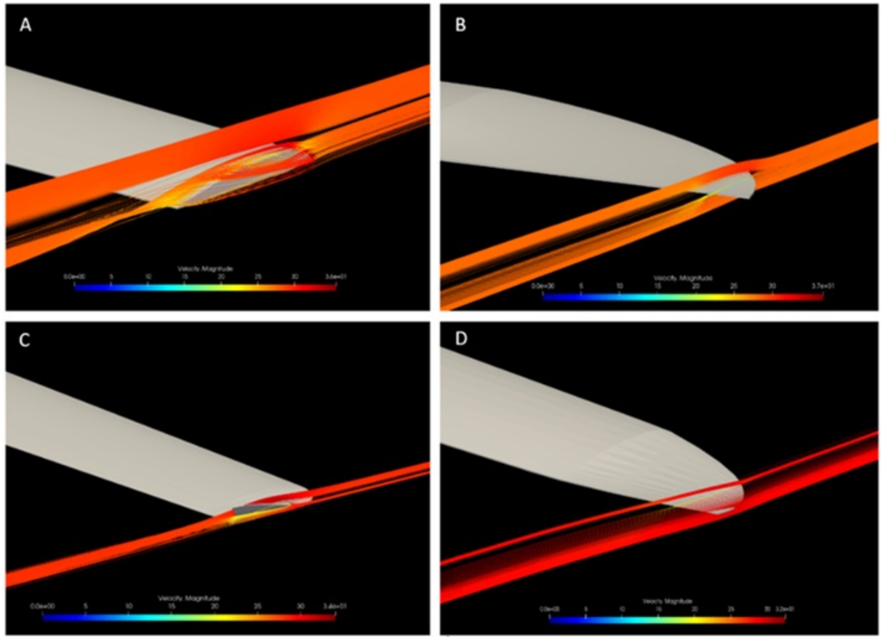
Function/variable		Description	Total number
Objective function			
min	C_L^2	*objective function*	1
w.r.t:			
	Y	*FFD control points*	52
	T	*Twist*	1
Subject to:			
$C_D \leq C_{D\ nominal}$		Constant drag	
$AOA_{initial} = AOA_{final}$		*Constant Angle of attack*	1
$V \geq V_{initial}$		*Volume constraint*	52
$-300\ mm \leq \Delta y \leq 300\ mm$		*Design variable bounds*	2
$-500mm < T \leq 500\ mm$		*Twist deformation bounds*	12



$$C_{Di} = \frac{C_L^2}{e \times \pi \times AR}$$



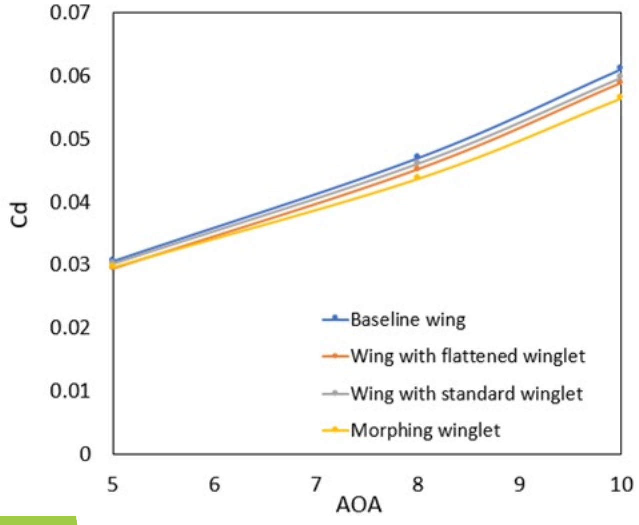
Twist morphing winglet

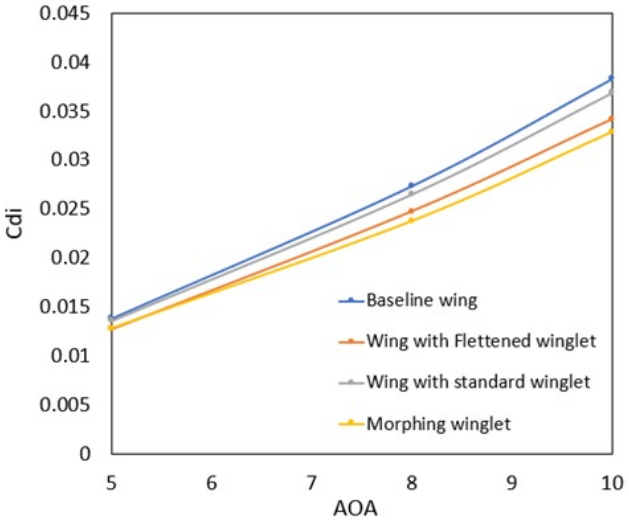


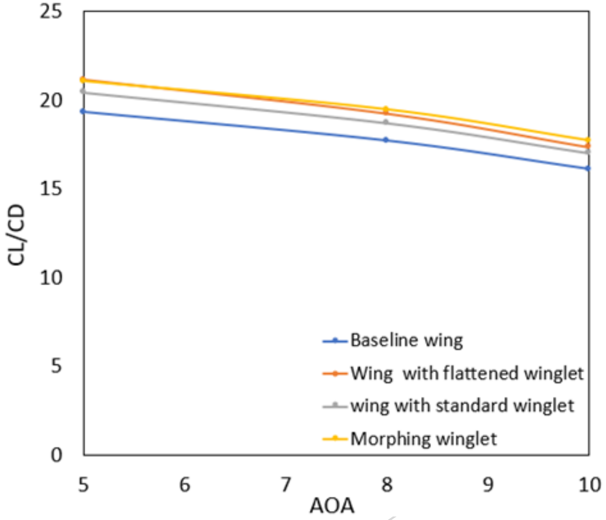
Wingtip	*AR*	C_L	C_D	C_{Di}	C_{Di} Variation %
A	11.55	0.1788	0.0170	0.0012591	0.0
B	13.9	0.1894	0.0167	0.0011736	-7.28
C	12.83	0.1937	0.0169	0.0013303	+5.35
D	13.9	0.1749	0.0170	0.0010016	-25.70

Twist morphing winglet at Climb

Wingtip	γ (°)	C_{Di} Reduction (%)
B	5	-8.66
	8	-10.44
	10	-12.04
C	5	-1.99
	8	-3.28
	10	-3.92
D	5	-7.90
	8	-15.10
	10	-16.51







3D prototype of the SMTE flap

Conclusion

Aerodynamic optimization of morphing wing in these studies showed that DAFoam is an efficient optimization framework for the for all types of aerodynamic optimization problems, in particular 3D optimizations with hundreds of design variables.

Thanks for your attention