

Aerodynamics Optimization of Propeller-Small Control Surface of HALE UAV using Genetic Algorithm

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Abstract— Currently, High Altitude Long Endurance (HALE) unmanned aerial vehicle has been attracting much attention to researchers. HALE-ITB vehicle have been developed for multiyear program with the purposes of surveillance and communication operating at target altitudes of 60000 feet with endurance more than 12 hours. For starting the program, an initial configuration of the HALE vehicle has been design for a flight at altitude of 20000 feet and 2 hours flight endurance. In order to achieve this mission, the vehicle is designed to have higher aspect ratio of the wing, with lower weight. The determination of location of propellers and small controls on segmented wings become a critical issue due to aerodynamic load and thrust as well as stability of the HALE UAV. The optimum location of the propeller and control position is optimized using Simple Genetic Algorithm. The flow solution around the HALE vehicle is obtained by solving Reynolds Averaged Navier-Stokes equations. As a results, the optimum location of propeller combined with the control surface is obtained when the location is a further forward and lower position and increasing the control surface size. This yields higher aerodynamic characteristics and give better longitudinal stability.

Keywords— HALE UAV, aerodynamic characteristics, propeller and small control surface position, Genetic algorithm

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NOMENCLATURE

AoA	angle of attack
c	chord length
C_D	coefficient of drag
C_L	coefficient of lift
C_M	coefficient of pitching moment
D	drag
L	lift
M	pitching moment
ρ	density
S	wing area
V	velocity

I. INTRODUCTION

CURRENTLY, there have been developed many HALE UAV's using wing tails for aircraft stability reason such as Qinetiq Zephyr [1], X-HALE, SoLong and Sunrise. However, some have being developed without tail. For the UAV without

tail (tailless) configuration, a small control surface become one alternative for stability device for the HALE UAV driven by propeller positioned on each segmented wings. The control surface may be positioned in front of the wing and behind the propeller to produce stability effects. Optimizing the position of the propeller-canard is a crucial issue in designing the UAV with tailless configuration.

Snorri Gudmundsson in the book “General Aviation Aircraft Design: Applied Methods and Procedures” explained that control surface (canard) can be used in exchange of horizontal tail for maintaining the longitudinal stability of the aircraft [1]. Zurriati Mohd Alli, Wahyu Kuntjoro and Wirahman Wisnoe wrote in the journal with title “The Effect of Canard Configurations to the Aerodynamics of Blended wing Body”, that canard have effect the lift coefficient, increasing drag and improve the stability of the aircraft [2].

This paper focuses on the optimization of the placement of propeller-canard on segmented wings of HALE UAV using computational fluid dynamics approach. In addition, the canard parameters includes span size with constant aspect ratio and relative position to centroid of propeller. The optimum position is decided by comparing the aerodynamic stability characteristic of HALE UAV.

II. HALE UAV MODEL

A. HALE UAV model

The HALE UAV is designed using a straight wing with a tailless configuration. This is carried out for substituting the previous design with horizontal tail-plane. This UAV will be powered by nine motor with position evenly divided along the wing. The HALE UAV model is shown on Figure 1. The EMX 07 airfoil used for the wing and NACA 0012 used for canard are shown in Figure 2 and Figure 3, respectively.

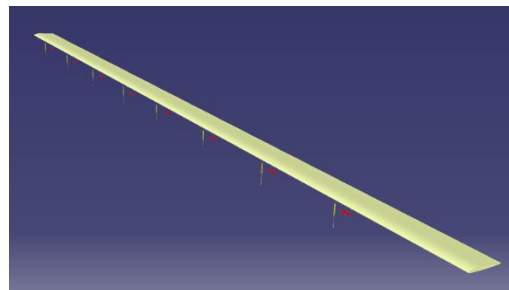


Figure 1 Configuration Model of HALE UAV

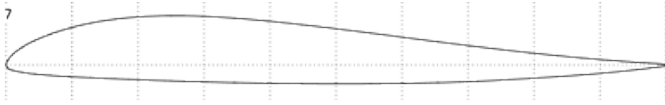


Figure 2 Wing Airfoil (EMX 07) [4]



Figure 3 Canard Airfoil (NACA 0012) [3]

Table 1 HALE UAV dimension

Wing	
Airfoil type	EMX-07
Chord length	0.6 m
Span length	18 m
Propeller	
Diameter	0.4 m
RPM	3000
Position	0.4 m in front of wing
Canard	
Airfoil	NACA 0012
AR	3
Span	0.2 m
Position	0.2 m in front of wing

The dimension of the HALE UAV is acquired from the Design, Requirements and Objectives.

B. Aerodynamics performance

The aerodynamic performance of HALE UAV can be evaluated by computing forces (lift and drag) and moments and its aerodynamic characteristics. The aerodynamic characteristics was obtained by simulating the designed HALE UAV using ANSYS ICEM CFD software. The equation for Lift (L), Drag (D), and pitching moment (M), are given as follows:

$$L = \frac{1}{2} \rho \cdot V^2 \cdot S \cdot C_L \quad (1)$$

$$D = \frac{1}{2} \rho \cdot V^2 \cdot S \cdot C_D \quad (2)$$

$$M = \frac{1}{2} \rho \cdot V^2 \cdot S \cdot C_M \cdot c \quad (3)$$

To identify the longitudinal stability of an aircraft, it can be indicated by the value of pitching moment coefficient with respect to the change of angle of attack (C_{M_α}). The value of the C_{M_α} should be in negative value in order to achieve the stability condition, namely $C_{M_\alpha} < 0$.

III. SIMULATION METHOD

A. Governing equation

Governing equation used in ANSYS ICEM CFX is Reynolds Averaged Navier-stokes including continuity, momentum and total energy equations as follows:

- The Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \quad (4)$$

- The Momentum equation

$$\frac{\partial(\rho \mathbf{U})}{\partial t} + \nabla \cdot (\rho \mathbf{U} \times \mathbf{U}) = -\nabla p + \nabla \cdot \boldsymbol{\tau} + S_M \quad (5)$$

where the stress tensor, $\boldsymbol{\tau}$, is related to the strain rate by

$$\boldsymbol{\tau} = \mu \left(\nabla \cdot \mathbf{U} + (\nabla \cdot \mathbf{U})^T - \frac{2}{3} \delta \nabla \cdot \mathbf{U} \right) \quad (6)$$

For evaluation viscous effect, shear stress transport (SST) turbulent model is used

- The Total Energy Equation

$$\begin{aligned} \frac{\partial(\rho h_{\text{tot}})}{\partial t} - \frac{\partial p}{\partial t} + \nabla \cdot (\rho \mathbf{U} h_{\text{tot}}) \\ = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (\mathbf{U} \cdot \boldsymbol{\tau}) + \mathbf{U} \cdot S_M \\ + S_E \end{aligned} \quad (7)$$

where h_{tot} is the total enthalpy, related to the static enthalpy $h_{(\tau,p)}$ by:

$$h_{\text{tot}} = h + \frac{1}{2} U^2 \quad (8)$$

B. Simplified HALE UAV model

In order to reduce computation time and used memory in the simulation, we simplify the model with one segment with the span of 2 meter together with the propeller and canard that positioned in front of and parallel to the wing as shown in Figure 4. This simplification is carried by applying symmetry boundaries at both ends of the wing.

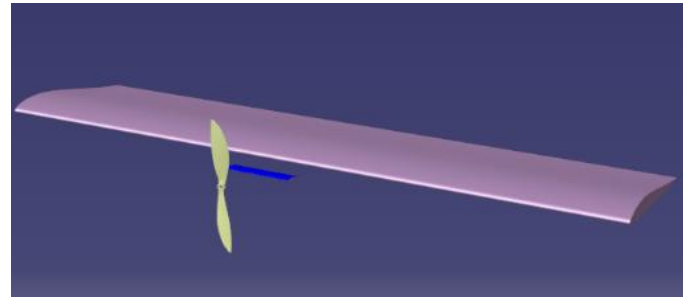


Figure 4 Simplification model of HALE UAV

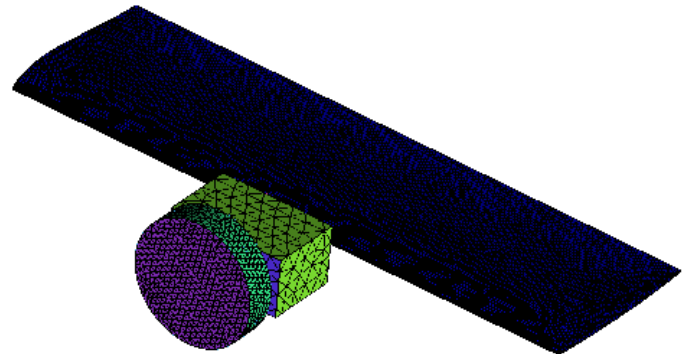


Figure 5 Simplification model mesh generation

C. Domain computation and mesh generation

The simulation uses three blocks of domain computation namely propeller domain, canard domain and the remaining domain (Figure 5). The connection between domains uses interfaces. In order to consider the effect of propeller rotation, the frozen model is used namely the flow is rotated and the propeller is in rest. Having the computation domain, unstructured meshes on boundary surfaces and inside the computational domains are generated using Delaunay triangulation. Prism meshes closed to the surfaces are generated in order to capture the viscous effect near object surface.

After the mesh generated, the boundary condition that lies in the object before is defined and then continuing with running the simulation. In this case, there are five type of boundaries including are Inlet, Outlet, Symmetry, Far-field and Interface are determined. In several boundary condition, values of physical parameters is taken from air property data in flight condition. The boundary condition can be seen in Figure 6.

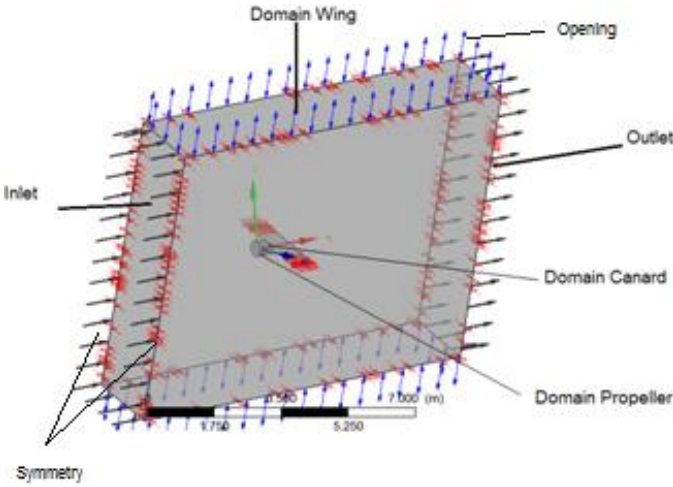


Figure 6 Boundary condition

Table 2 Air property data

Height	20000	ft
	6096	m
Density	0.667	kg/m ³
Total Pressure	46650	Pa
Total Temperature	248.4	K
Gravity	9.788	m/s ²
Viscosity	1.595×10 ⁻⁵	kg/m·s
Speed of Sound	316.43	m/s

IV. OPTIMIZATION PROCESS

The optimization using genetic algorithm starts with choosing random individual inside the limitation of the design. Moreover, in order to get new generation from individuals, crossover process are carried out for different type of design. In addition, mutation can be happen to replace individual that have low performance. In this simulation we decide the performance using this fitness function J :

$$J = \frac{C_{M\alpha}}{C_{M\alpha} - 0.1} \cdot 100 \quad (9)$$

A. Parents generation

On the parents generation, three random individual are chosen from the limitation of the propeller-canard position on Z-coordinate, namely from -50 mm to +50 mm, and on X-coordinate is in the range of 200 mm to 300 mm front leading edge and the canard span is in the range of 20 cm to 40 cm. The chosen individual can be seen in Table 3.

Table 3 Parents generation

No	Prop-Canard X-Pos.(mm)	Prop-Canard Z-Pos.(mm)	Canard Span Size(cm)
1	200	-50	20
2	250	0	30
3	300	+50	40

B. First generation

We crossed over the parents generation and we get six new individual, the first crossover is crossing the X-position of propeller-canard. The result of first generation can be seen in Table 4.

Table 4 First generation

No	Prop-Canard X-Pos.(mm)	Prop-Canard Z-Pos.(mm)	Canard Span Size(cm)
1	250	-50	20
2	200	50	30
3	300	-50	20
4	200	50	40
5	300	0	30
6	250	50	40

C. Second generation

We crossed over the first and we get six new individual, the first crossover is crossing the Z-position of propeller-canard. The result of first generation can be seen in Table 5.

Table 5 Second generation

No	Prop-Canard X-Pos.(mm)	Prop-Canard Z-Pos.(mm)	Canard Span Size(cm)
1	250	0	20
2	200	-50	30
3	300	50	20
4	200	-50	40
5	300	50	30
6	250	0	40

The fitness value of each generation can be seen in the Figure 7 and this value will be the factor to determine individual for next generation which the better individual will be selected.

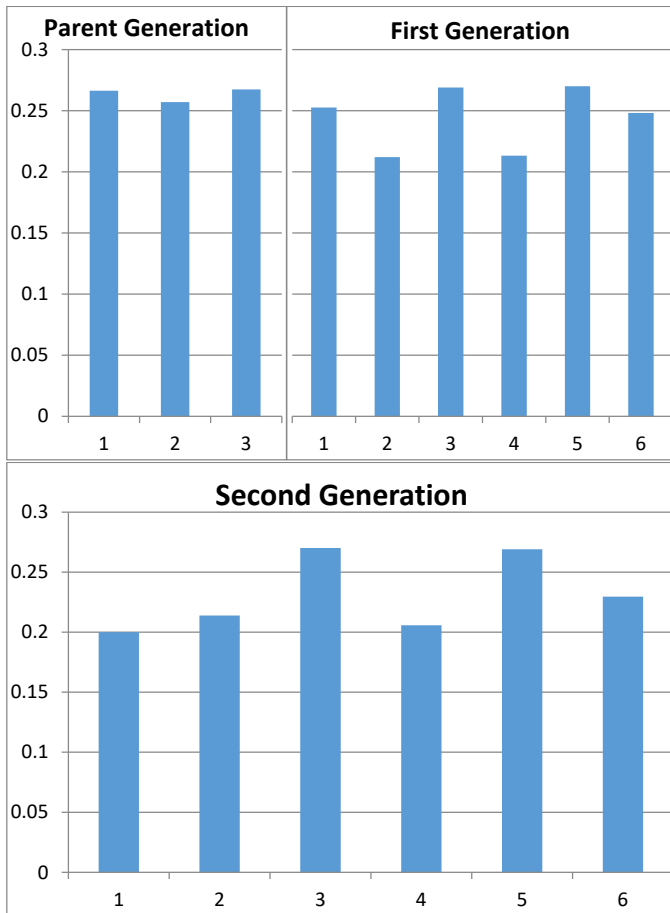


Figure 7 Fitness value of parent, first and second generation

From the result above, we can see the individual that have better fitness value, from the first generation we take number 1, 3, 5, and 6 while from second generation we take number 3 and 5.

D. Third generation

From the chosen individual before, we crossed it over again and this time we cross the canard span size and we get new individual again. The result after crossover is shown in Table 6.

Table 6 Third generation

No	Prop-Canard X-Pos.(mm)	Prop-Canard Z-Pos.(mm)	Canard Span Size(cm)
1	300	-50	30
2	300	0	20
3	250	50	20
4	300	50	40
5	300	-50	40 (mutation)
6	250	-50	30

The fitness value from the third generation is shown in Figure 8.

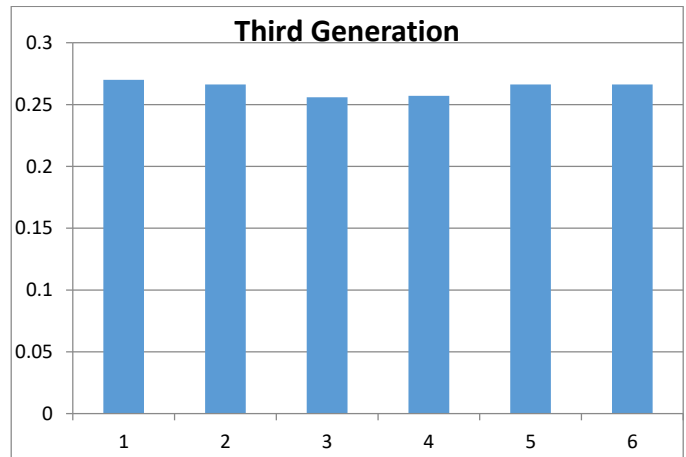


Figure 8 Fitness value of third generation

V. RESULT AND ANALYSIS

A. Configuration analysis

From the optimization process, we get the design that have the best fitness value. The configuration that we choose is:

Table 7 Chosen configuration

No	Prop-Canard X-Pos.(mm)	Prop-Canard Z-Pos.(mm)	Canard Span Size(cm)
1	300	-50	30

We take a look at the aerodynamics performance as given in Figure 9.

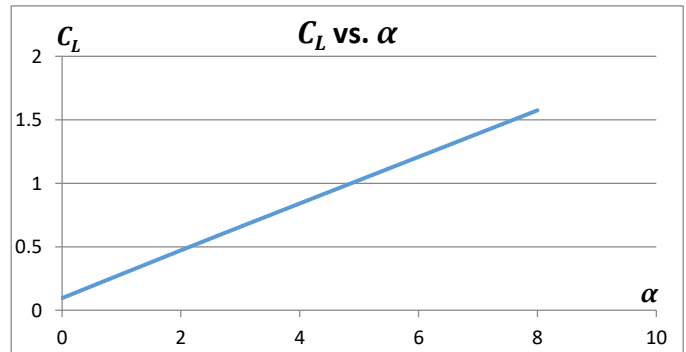


Figure 9 CL vs. alpha curve

The coefficient of lift to angle of attack of the aircraft has a positive slope which means every time the angle of attack increasing, the lift coefficient is gradually increase. This condition has met one of the requirement to have a longitudinal stability.

From the result above, it given the information about the C_{M_α} value of the aircraft. The value of the C_{M_α} is -0.037 which achieve the requirement of the aircraft longitudinal stability as it is explained before. This means the aircraft configuration is stable in longitudinal condition.

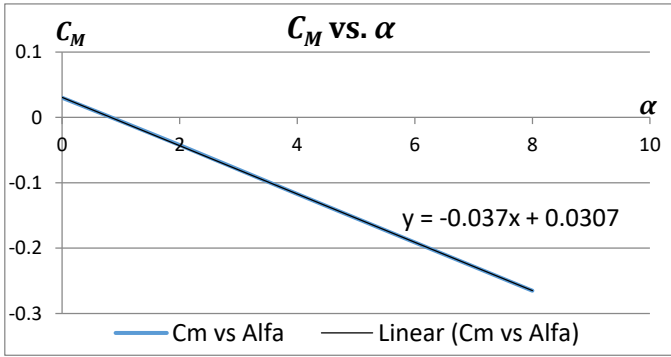


Figure 10 C_M vs. α curve

The other configuration aerodynamics characteristics is shown in the figure below.

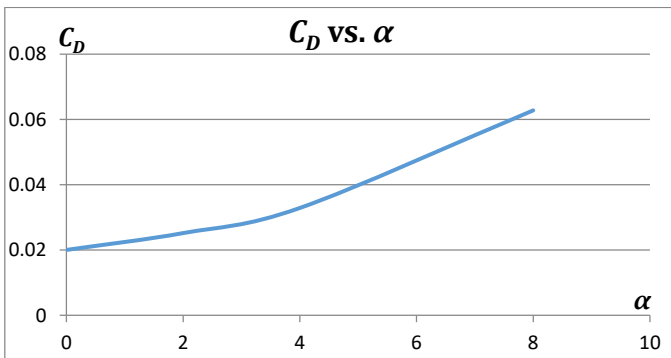


Figure 11 C_D vs. α curve

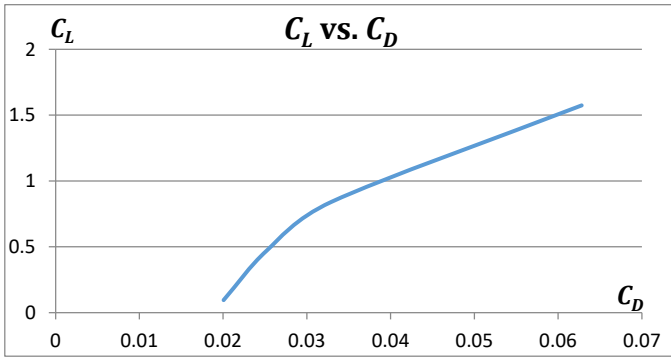


Figure 12 C_L vs. C_D curve

B. HALE UAV analysis

From the optimized design that we get, we used the configuration into HALE UAV to identify the aerodynamics characteristic of the UAV. In this case, we simulate the half span on the UAV and we give symmetry boundary condition on the root position so that we can decrease simulation time while it is still represent the UAV. The simulation condition can be seen in [Figure 13](#).

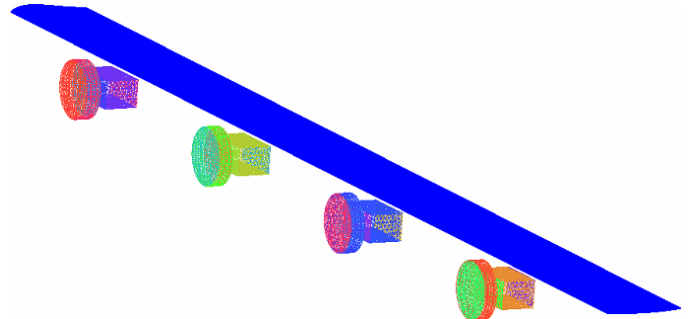


Figure 13 Half-span HALE UAV simulation

From the simulation, we get the aerodynamics characteristics and we compare it with clean wing condition and the segment wing of HALE UAV.

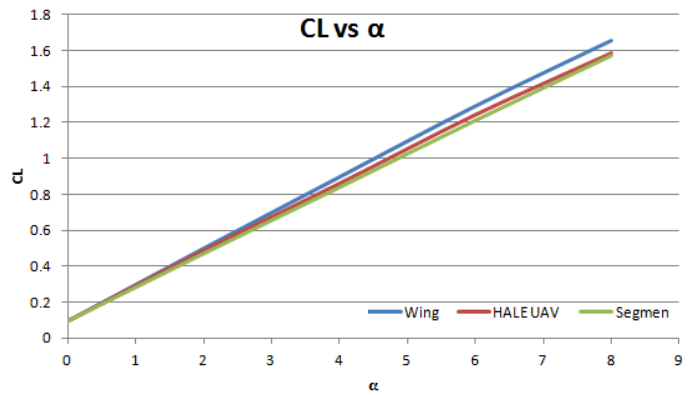


Figure 14 C_L vs. α comparison

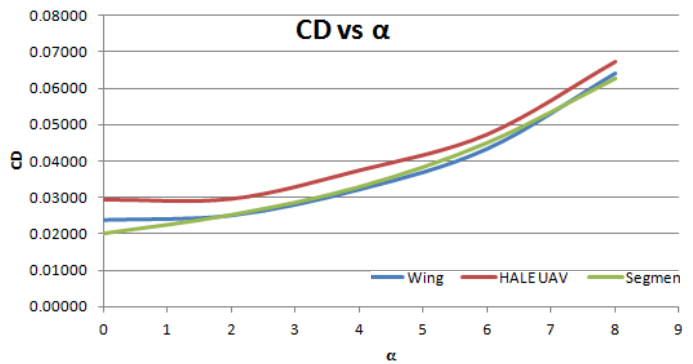


Figure 15 C_D vs. α comparison

We can get information from the C_L vs. α comparison that there are no too much different on the slope of aircraft C_L is between the wing clean and segment. This mean the lift value from each variant is similar.

For the C_D value, we can see that the HALE UAV has the biggest C_D rather than clean wing and segment. This is give proof that by adding component in the UAV makes the drag value increase.

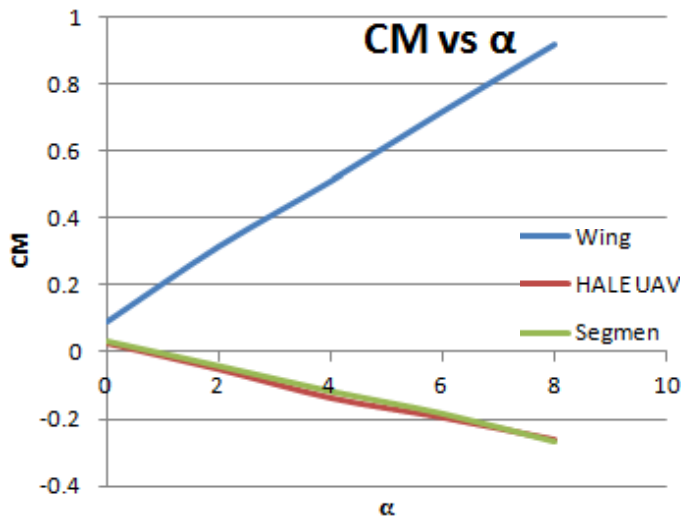


Figure 16 C_M vs. α comparison

And for the $C_{M\alpha}$, the figure shown that wing only could not achieve the longitudinal stability of the aircraft while the HALE UAV and its segment have a similar value which means the segment can represent the HALE UAV in longitudinal stability.

VI. CONCLUSIONS

The using of Genetic Algorithm can yield better performance. The optimization time may influence by the position of propeller-canard and the size of canard. The using of segment concept can simplify the simulation and the result does not have too much different.

The use of canard can give better longitudinal static stability of the HALE UAV. Increasing the canard size yields higher lift and increase longitudinal stability but increasing drag.

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