International Journal of General Engineering and Technology (IJGET)
ISSN(P): 2278-9928; ISSN(E): 2278-9936
Vol. 3, Issue 5, Sep 2014, 23-32

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

COMPUTATIONAL STUDIES ON AILERON MORPHING IN UAV (COMPUTATIONAL STUDIES ON VARIABLE TRAILING EDGE IN UAV)

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ABSTRACT

Research on aircraft morphing has exploded in recent years. Morphing aircraft have the ability to actively adapt and change their shape to achieve different missions efficiently. Materials advancements have helped to increase possibilities with respect to actuation and, hence, a diversity of concepts and unimagined capabilities. In general, a conventional aileron on an UAV wing can reduce the aerodynamic efficiency due to geometric discontinuity. On the other hand, the aerodynamic performance can be improved by using a shape-morphing aileron wing instead of a separated aileron. Two dimensional computational studies were carried out for various angles of attack with different aileron deflection angles at constant Mach number 0.1 for both morphed wing and un-morphed wing and got 1.49 as maximum average increment in C_l/C_d using morphed aileron wing. Increment in C_l/C_d results increase in range of UAV flight and reduction in fuel consumption. And also discussed a few aspects related to the physical aileron morphing mechanism.

KEYWORDS: Aileron Morphing, Aileron Morphing Mechanism, Aerodynamic Characteristics

INTRODUCTION

Morphing Mechanism

Morph can be defined as “to cause something to change its outward appearance”. Each aircraft today has a wing that matches the purpose for its use. The inspiration for the concept of morphing wings comes from birds. As contradictory as it may seem, nature is much more far ahead in the effectiveness of flight that any other man made aircraft found today. Birds are able to adapt their wings to the conditions that need to be met at the time. Many of the research in the aircraft industry are looking for the development of an aircraft wing that is able to mimic this kind of ability.

An airplane with this kind of technology would be able to perform different roles that may seem paradoxical at first. A commercial plane with this technology could be able to adapt its wings for high lift during takeoff, extend them fully for optimum cruising, fold them lightly for efficient descent and change them back to high lift for landing. The advantages for this kind of technology are quite impressive and would allow aircraft to get the most efficiency during flight as well as its adaptability to harsh environments.

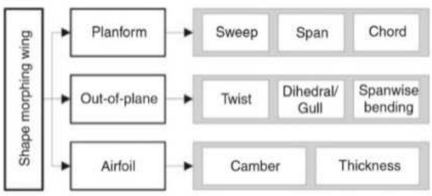


Figure 1: Shape Morphing Wing

OBJECTIVES

The main objectives of this paper were as follows:

- To maintain a high L/D during cruise, implementing Aileron morphing
- To reduce fuel consumption, implementing sweep mechanism
- To carryout computational studies on Aileron morphing and variable sweep morphing.
- To determine whether the implementation of the morphing wing system is economically feasible.

MODEL SELECTION

Aircraft Determination

Once the baseline aircraft requirements and category is chosen, hobby websites are searched for aircraft that would meet the project requirements. The list is then narrowed down to Calmato-40 Nitro Airplane.

Selected Model Specification

The specifications of selected model as follows:

- **Body:** Balsa wood
- **Wingspan:** 61 in / 1550mm
- **Wing Area:** 42.3 square dm
- **Length:** 55.1 in / 1400mm
- **Weight:** 2440-2660gm
- **Engine:** 2 cycle 40-55 size

The selected model includes landing gear, fuel tank, and ratio control.

AILERON MORPHING

Introduction

The maximum achievable lift-to-drag ratio (L/D) in cruise flight is a very important performance parameter. It can be defined as

$$\mathbf{L/D = C_L/C_D} \tag{1}$$

The lift-to-drag ratio also has a significant effect on a UAV flight range as given in the **Breguet** equation for constant velocity and lift coefficient

$$Range = \frac{V}{c}\frac{C_L}{C_D}\ln\frac{W_{TO}}{W_{LAND}} \tag{2}$$

Where, V is the velocity, c is a constant, W_{TO} is the take-off weight and W_{LAND} is the landing weight. Since C_L/C_D is directionally proportional to the range, an increase in the C_L/C_D will cause the range of the UAV to also increase. It has been acknowledged that morphing wing technology has the potential of increasing the aerodynamic efficiency

(L/D ratio).

Aileron Morphing

Varying the camber trailing edge in a wing can have beneficial properties for the control of an aircraft such as during take-off and landing when the lift distribution along a wing is required to dramatically change. Ailerons provide roll control for conventional aircraft. Ailerons must be appropriately sized and located to ensure su□cient roll control.

If we use conventional aileron, there will be a geometrical discontinuity. Due to this geometrical discontinuity which causes profile drag. If it is avoided, we can get better performance characteristics. This is achieved by applying aileron morphing.

Working

The prototype is shown in Figure where the SMA springs are fixed at one end to the wing box towards the leading edge of the aerofoil while the other end is attached tangentially to a rotating cylinder fixed to the aileron. In order to produce rotation of the aileron in both the upward and downward directions, the springs are arranged in an upper and a lower layer. An applied current is used to produce heat which controlled the spring actuators. The electrical power is controlled by a three-way switch which is used to control the electrical power that provided three possible settings: current delivery through the upper layer of springs (aileron deflection up), current delivery through the lower layer of springs (aileron deflection down), or no current supplied (power-off/standby). The two critical design considerations that are used to evaluate the feasibility of the smart actuation system are SMA material response time to heating and maximum force on the aileron during a simulated flight.

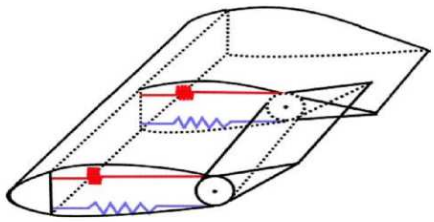


Figure 2: Working Mechanism

Analysis

Conventional and morphed NACA 0012 aileron airfoil is meshed using GAMBIT and then solved using FLUENT at various angle of attack for different flight condition. This analysis has done for both conventional aileron wing and Morphed aileron wing for comparison of results.

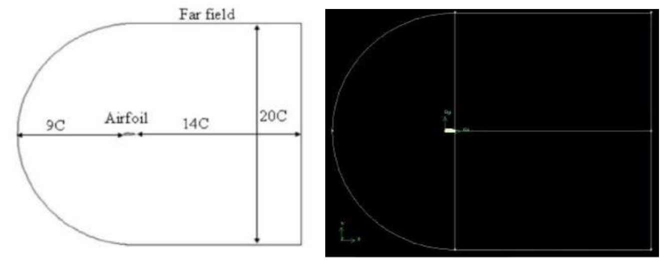


Figure 3: Mesh Creation in GAMBIT

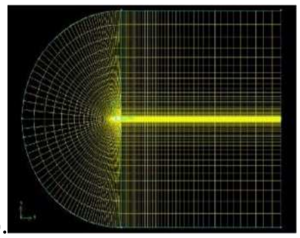
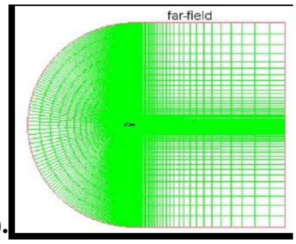
(a).  (b). 

Figure 4: Meshed Airfoil Window in GAMBIT (a) and Fluent (b)

Mach number = 0.1, Gauge Pressure = 101325 Pascal, ɣ = 1.4, Viscosity = $1.789*10^{-5}$ kg/m/s, Temperature = 300 K, Enthalpy = 2464.245 J/kg, Density = 1.176674 kg/m^3, Aileron clearance: 0.02C. Typical Un-morphed, morphed aerofoil and C_L, C_D calculations are shown in figure 5 and 6.

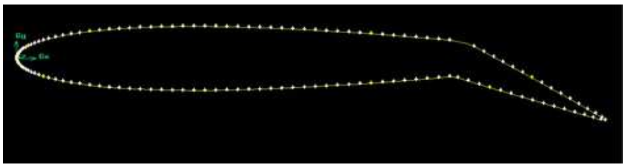


Figure 5: Morphed Aileron Deflected 25 Degree Down

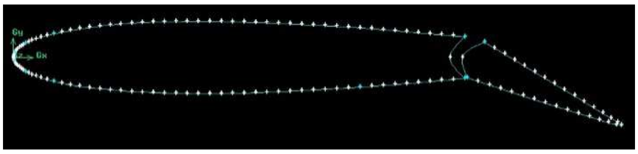


Figure 6: Un-morphed Aileron Deflected 25 Degree Down

C_L and C_D are calculated for different aileron deflection at different angle of attack of wing for both conventional and morphing wing. The values of C_L and C_D for various α (in degree) are tabulated below.

Table 1: Conventional Wing with Aileron Deflection of Zero Degree

α	C_L	C_D	C_L/C_D
0	-0.00213	0.02544	-0.08397
3	0.30183	0.03216	9.38417
6	0.56244	0.05374	10.46542
9	0.74328	0.08848	8.39985
12	0.87596	0.14004	6.25500
15	0.96523	0.20141	4.79229

Table 2: Morphed Wing with Aileron Deflection of Zero Degree

α	C_L	C_D	C_L/C_D
0	-0.00221	0.02482	-0.08903
3	0.31611	0.03098	10.20089
6	0.58373	0.05326	10.95813
9	0.76070	0.08732	8.71102
12	0.88728	0.13562	6.54197
15	0.97837	0.19862	4.92575

Table 3: Conventional Wing with Aileron Deflection of 5 Degree Up

α	C_L	C_D	C_L/C_D
0	-0.26239	0.03137	-8.36355
3	-0.00165	0.03520	-0.04710

6	0.24112	0.04040	5.96801
9	0.43320	0.07167	6.04371
12	0.58163	0.11658	4.98881
15	0.66510	0.16003	4.13049

Table 4: Morphed Wing with Aileron Deflection of 5 Degree Up

α	C_L	C_D	C_L/C_D
0	--0.21927	0.02816	-7.78490
3	0.01737	0.03310	0.52486
6	0.26396	0.03943	6.69365
9	0.44909	0.06462	6.94880
12	0.59513	0.10532	5.65035
15	0.67463	0.15830	4.26168

Table 5: Conventional Wing with Aileron Deflection of 5 Degree Down

α	C_L	C_D	C_L/C_D
0	0.34235	0.03214	10.64963
3	0.63863	0.04630	13.79270
6	0.84998	0.07469	11.37940
9	0.97201	0.09386	10.35563
12	0.98022	0.18865	5.19591
15	0.96112	0.24016	4.00196

Table 6: Morphed Wing with Aileron Deflection of 5 Degree Down

α	C_L	C_D	C_L/C_D
0	0.35094	0.02864	12.24940
3	0.65176	0.04242	15.36224
6	0.86423	0.07135	12.11156
9	0.99893	0.09105	10.97055
12	1.00221	0.16892	5.93300
15	0.98716	0.22217	4.44328

Table 7: Conventional Wing with Aileron Deflection of 10 Degree Up

α	C_L	C_D	C_L/C_D
0	-0.58242	0.01699	-34.27290
3	-0.27169	0.03299	-8.23496
6	0.00453	0.03537	0.12829
9	0.19574	0.05020	3.89860
12	0.42974	0.07868	5.46166
15	0.59016	0.12340	4.78218

Table 8: Morphed Wing with Aileron Deflection of 10 Degree Up

α	C_L	C_D	C_L/C_D
0	-0.45106	0.01469	-30.70560
3	-0.22409	0.03051	-7.34490
6	-0.08684	0.03299	0.63187
9	0.02084	0.04759	4.29370
12	0.48646	0.07807	6.23080
15	0.62145	0.12091	5.13969

Table 9: Conventional Wing with Aileron Deflection of 10 Degree Down

α	C_L	C_D	C_L/C_D
0	0.63986	0.04032	15.86606
3	0.91224	0.05762	15.83095
6	0.98962	0.09103	10.87036
9	1.158659	0.15069	7.68878
12	1.149762	0.20068	5.72918
15	1.05289	0.27823	3.783857

Table 10: Morphed Wing with Aileron Deflection of 10 Degree Down

α	C_L	C_D	C_L/C_D
0	0.65218	0.03815	17.09498
3	0.92038	0.05677	16.21023
6	1.08558	0.08959	12.11719
9	1.17401	0.13546	8.66657
12	1.16616	0.19060	6.11811
15	1.10709	0.25140	4.40371

Table 11: Conventional Wing with Aileron Deflection of 15 Degree Up

α	C_L	C_D	C_L/C_D
0	-0.92059	0.05001	-18.40457
3	-0.62358	0.03589	-17.37246
6	-0.27861	0.03326	-8.37535
9	0.04463	0.04702	0.94919
12	0.22596	0.07235	3.12321
15	0.38962	0.12310	3.16493

Table 12: Morphed Wing with Aileron Deflection of 15 Degree Up

α	C_L	C_D	C_L/C_D
0	-0.82610	0.04832	-17.09365
3	-0.56013	0.03379	-16.57567
6	-0.25074	0.03248	-7.71783
9	0.04681	0.04396	1.06481
12	0.24309	0.06909	3.51851
15	0.39613	0.11013	3.59692

Table 13: Conventional Wing with Aileron Deflection of 15 Degree Down

α	C_L	C_D	C_L/C_D
0	0.92934	0.05698	16.30898
3	1.14896	0.07853	14.63034
6	1.22683	0.14238	8.61603
9	1.197888	0.20436	5.86141
12	1.13852	0.25385	4.484867
15	1.11865	0.32986	3.39124

Table 14: Morphed Wing with Aileron Deflection of 15 Degree Down

α	C_L	C_D	C_L/C_D
0	0.94769	0.05401	17.54424
3	1.16266	0.07634	15.22940
6	1.24042	0.12147	10.21103
9	1.23191	0.18629	6.61259

12	1.14402	0.24439	4.68107
15	1.12997	0.31656	3.56954

Table 15: Conventional Wing with Aileron Deflection of 20 Degree Up

α	C_L	C_D	C_L/C_D
0	-1.23685	0.08108	-15.25312
3	-1.04301	0.05301	-19.67356
6	-0.71285	0.04186	-17.02704
9	-0.362865	0.04356	-8.32981
12	-0.03588	0.06021	-0.59594
15	0.22302	0.08830	2.52553

Table 16: Morphed Wing with Aileron Deflection of 20 Degree Up

α	C_L	C_D	C_L/C_D
0	-1.19685	0.07990	-14.9792
3	-0.99834	0.05109	-19.53926
6	-0.68706	0.04050	-16.96107
9	-0.33449	0.04155	-8.04851
12	-0.03366	0.05668	-0.59390
15	0.23558	0.08615	2.73426

Table 17: Conventional Wing with Aileron Deflection of 20 Degree Down

α	C_L	C_D	C_L/C_D
0	1.16559	0.07641	15.25421
3	1.34103	0.11381	11.78210
6	1.41965	0.15280	9.2906
9	1.41865	0.22598	6.27759
12	1.31658	0.27732	4.74732
15	1.26583	0.35296	3.58632

Table 18: Morphed Wing with Aileron Deflection of 20 Degree Down

α	C_L	C_D	C_L/C_D
0	1.17375	0.07473	15.70582
3	1.35246	0.10234	13.21526
6	1.43002	0.14633	9.77253
9	1.42339	0.20106	7.07937
12	1.32574	0.25755	5.14750
15	1.27002	0.33129	3.83348

Table 19: Conventional Wing with Aileron Deflection of 25 Degree Up

α	C_L	C_D	C_L/C_D
0	-1.38552	0.09863	-14.04755
3	-1.16597	0.06820	-17.09405
6	-0.80673	0.05567	-14.48944
9	-0.46363	0.05207	-8.90266
12	-0.13968	0.06098	-2.29053
15	0.14783	0.08703	1.69844

Table 20: Morphed Wing with Aileron Deflection of 25 Degree Up

α	C_L	C_D	C_L/C_D
0	-1.24659	0.09419	-13.23443
3	-1.04962	0.06650	-15.78301
6	-0.76286	0.05353	-14.25062
9	-0.44455	0.05044	-8.8134
12	-0.12341	0.05969	-2.06723
15	0.15621	0.08623	1.81145

Table 21: Conventional Wing with Aileron Deflection of 25 Degree Down

α	C_L	C_D	C_L/C_D
0	1.33700	0.10058	13.29272
3	1.48659	0.12820	11.59525
6	1.48930	0.17277	8.62009
9	1.33019	0.21925	6.06678
12	1.26126	0.30080	4.19301
15	1.25942	0.37255	3.38053

Table 22: Morphed Wing with Aileron Deflection of 25 Degree Down

α	C_L	C_D	C_L/C_D
0	1.39219	0.09465	14.70766
3	1.51101	0.12124	12.46208
6	1.48397	0.17020	8.71853
9	1.36959	0.15524	8.82207
12	1.29829	0.28647	4.53189
15	1.28008	0.36008	3.55500

RESULTS AND DISCUSSIONS

The aerodynamic coefficients analysis are carried out by fixing the aileron deflection as a constant for different wing angles of attack at constant Mach number=0.1. From the C_L and C_D values of different conditions,

C_L/C_D values are calculated. The observation of maximum increment in C_L/C_D using morphed aileron wing from plots and corresponding wing angle of attack are shown in table 23.

Table 23: Observation of Maximum Increased C_L/C_D from Plots

	Angle of Attack at Which Maximum C_L/C_D Difference Obtained (α in Degrees)	Maximum Increment in C_L/C_D Using Morphed Aileron Wing
From figure 9	3	0.81672
From figure 10	9	0.90509
From figure 12	0	1.59977
From figure 13	0	3.56730
From figure 14	0	1.22893
From figure 15	0	1.31092
From figure 16	6	1.59500
From figure 17	9	1.28130
From figure 18	3	1.43316
From figure 19	3	1.31104
From figure 20	0	1.41494

Maximum Average Increment in C_L/C_D Using Morphed Aileron Wing=1.49674

The lift-to-drag ratio has a significant effect on a UAV flight range (Range=f $\{C_L/C_D\}$). From the plots and table, observed that the morphed aileron wing gives increased C_L/C_D ratio than the un-morphed aileron wing. Due to increase in C_L/C_D ratio, the range of morphed aileron wing UAV flight also increases. So, there will be reduction of fuel consumption in the morphed aileron wing UAV compared with the un-morphed aileron wing UAV.

CONCLUSIONS

The aerodynamic coefficients of morphed aileron wing and un-morphed aileron wing are investigated by using standard software packages GAMBIT and FLUENT. Obtained C_L/C_D values for Un-morphed aileron wing and Morphed aileron wing are plotted with respect to α. When comparing the C_L/C_D value, got 1.49674 as maximum average increment in C_L/C_D using morphed aileron wing. Thus the morphed aileron wing gives better aerodynamic coefficients than the un-morphed aileron wing. Increment in C_L/C_D will result increase in range of UAV flight and reduction in fuel consumption. If the wing shape changes more smoothly then, the flow separation will be suppressed and the aerodynamic characteristics will be improved. MATLAB simulation and a prototype morphed aileron wing are planned to fabricate to demonstrate the aileron morphing and variable sweeping. This will be investigated in our future study.

ACKNOWLEDGEMENTS

The authors acknowledge Dr. S .Raja, senior principal scientist, STTD from the “National Aerospace Laboratories” in Bangalore for entitled ‘Computational Studies on Aileron Morphing in UAV’.

Nomenclature

C_L = Co-efficient of lift

C_D = Co-efficient of drag

α = Angle of attack

UAV = Unmanned Aerial Vehicle

SMA = Shape Memory Alloy

C_L/C_D or L/D = Lift to drag ratio

S = Wing platform

M = Mach number

Re = Reynolds number

q = Dynamic Pressure

V = Velocity

δ =Aileron deflection angle

ɣ = Specific heat ratio

W_{TO} = Take-off weight

W_{LAND} = Landing Weight

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