Design of Aerodynamic of an Airplane Wings

Prasad Satish Divekar[1], Dr.Thippeswamy Ekbote[2]

[1]Student, [2]Associate Professor and PG Co-Ordinator
Mechanical Engineering Department,
B.I.E.T College, Davangere-577004 Karnataka, INDIA.

Abstract: **The design and development of morphing (shape shifting) aircraft wings—an innovative technology that has the potential to increase the aerodynamic efficiency and reduce noise signatures of aircrafts—was carried out. This research was focused on reducing lift-induced drag at the flaps of the aero foil and to improve the design to achieve the optimum aerodynamic efficiency. The design of an aircraft is a prolonged process that consists mainly of three design phases which are: the conceptual design, the preliminary design, and the detailed design. The phase of conceptual design, which is the umbrella of the present research, deals mainly with developing a layout of the aircraft's external geometry, major systems and components; and determining the gross weight and the performance characteristics that the airplane must have in order to achieve its design goals. The main objective of the present paper is to introduce an environment for a real time simulation of the aircraft motion based on the specifications of the flight mission profile; performance parameters, the geometry and the weight of the airplane to verify the adherence of the conceptual design geometric product to the initial design requirements. In addition, the structural capability of the selected wing and sub components to withstand the generated aerodynamic loads.**

***Keywords*: AirPlane Wings.**

1. Introduction

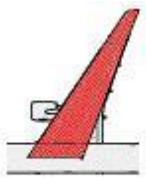
This aircraft design has essentially evolved to a payload compartment with wings and a tail, in the form of a conventional design. The reason for this design is twofold: Ease of construction and a result of analyzing the scoring function of the course. Since we decided to carry tennis balls for our payload, it is vital that our design of the payload compartment while being large enough to house the balls, also exhibited minimum aerodynamic features required to complete a fast lap of the course, while being light. The aircraft industries are constantly looking for newer and more innovative ways to increase aerodynamic efficiency to reduce fuel consumption. In recent years, this has become more challenging as conventional aircraft configurations have been pushed to the very limit of aerodynamic efficiency. This implies that non-conventional technology and design needs to be developed to have a substantial effect of increasing aerodynamic efficiency.

In recent years ―morphing‖ has received great interest. Morphing implies the change of shape of aircraft structures tailored to optimize aircraft performance. This is because conventional aircraft design is a compromise to meet various flight conditions—for example a design to optimize take-off is not necessarily compatible with the optimal design for cruise mission. The definition of wing morphing is the continuous smooth and flexible change of the wing shape in order to maximize aerodynamic efficiency. A comprehensive review on morphing technologies was conducted by Rodriguez. Two morphing aircraft structure concepts were developed through DARPA funding. The first concept was developed by Lockheed Martin in which the structure has the ability to reduce the wing area while transitioning from loiter to high speed Mach number and the second concept—the NextGen MFX-1 aircraft—is based on flexible skin, which provides the capability for the wings to change shapes tailored to the specific mission profile.

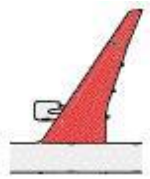
This paper explores the design and development of a new type of wing technology called shape shifting or morphing aircraft wings. Morphing aircraft wings are based on the dynamics of a bird wing, fundamentally ensuring that flow remains smooth and disruption is minimized. This is accomplished by eliminating the surface dislocations between the wing and the flaps, reducing and delaying the formation of vortices caused by lift-induced drag. These benefits will further increase aircraft performance by reducing take-off distances, landing distances, increasing climb rates, increasing stability and reducing the overall noise generated by the airframe. In addition, the increase in lift can also lead to a reduction in wing size, which implies a reduction in overall weight and a further reduction in fuel consumption.

2. Wing Areas

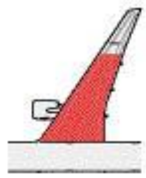
The definition of wing area is not obvious and different companies define the areas differently. Here, we always take the reference wing area to be that of the trapezoidal portion of the wing projected into the centerline. The leading and trailing edge chord extensions are not included in this definition and for some airplanes, such as Boeing's Blended Wing Body, the difference can be almost a factor of two between the "real" wing area and the "trap area". Some companies use reference wing areas that include portions of the chord extensions, and in some studies, even tail area is included as part of the reference area. For simplicity, we use the trapezoidal area in this text.



Reference Wing



Area Exposed Wing Area



Area Affected by Flaps

In addition to the reference area, we use the exposed planform area depicted above in the calculation of skin friction drag and the wetted area which is a bit more than twice the exposed planform area.

3. Wing Design Parameters

However, as the span is increased, the wing structural weight also increases and at some point the weight increase offsets the induced drag savings. This point is rarely reached, though, for several reasons.

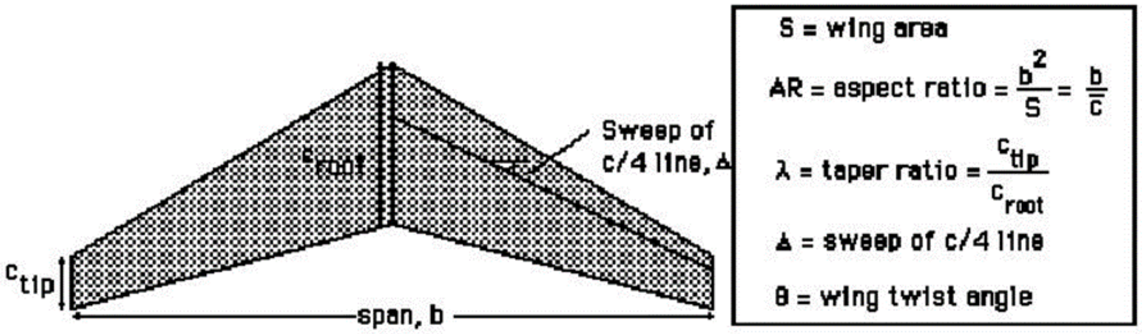


Figure 1: Design Parameters of Air Plane Wing

- The optimum is quite flat and one must stretch the span a great deal to reach the actual optimum.
- Concerns about wing bending as it affects stability and flutter mount as span is increased.
- The cost of the wing itself increases as the structural weight increases. This must be included so that we do not spend 10% more on the wing in order to save .001% in fuel consumption.
- The volume of the wing in which fuel can be stored is reduced.
- It is more difficult to locate the main landing gear at the root of the wing.
- The Reynolds number of wing sections is reduced, increasing parasite drag and reducing maximum lift capability.

Area

The wing area, like the span, is chosen based on a wide variety of considerations including:

a. Cruise drag
b. Stalling speed / field length requirements
c. Wing structural weight
d. Fuel volume

These considerations often lead to a wing with the smallest area allowed by the constraints. But this is not always true; sometimes the wing area must be increased to obtain a reasonable CL at the selected cruise conditions. Selecting cruise conditions is also an integral part of the wing design process. It should not be dictated a priori because the wing design parameters will be strongly affected by the selection, and an appropriate selection cannot be made without knowing some of these parameters. But the wing designer does not have complete freedom to choose these, either. Cruise altitude affects the fuselage structural design and the engine performance as well as the aircraft aerodynamics. The best CL for the wing is not the best for the aircraft as a whole. An example of this is seen by considering a fixed CL, fixed Mach design. If we fly higher, the wing area must be increased by the wing drag is nearly constant. The fuselage drag decreases, though; so we can minimize drag by flying very high with very large wings. This is not feasible because of considerations such as engine performance.

Sweep

Wing sweep is chosen almost exclusively for its desirable effect on transonic wave drag. (Sometimes for other reasons such as a c.g. problem or to move winglets back for greater directional stability.)

a. It permits higher cruise Mach number, or greater thickness or C_L at a given Mach number without drag divergence.

b. It increases the additional loading at the tip and causes spanwise boundary layer flow, exacerbating the problem of tip stall and either reducing C_{Lmax} or increasing the required taper ratio for good stall.
c. It increases the structural weight - both because of the increased tip loading, and because of the increased structural span.

d. It stabilizes the wing aeroelastically but is destabilizing to the airplane.
e. Too much sweep makes it difficult to accommodate the main gear in the wing.

iii. Thickness

The distribution of thickness from wing root to tip is selected as follows:

a. We would like to make the t/c as large as possible to reduce wing weight (thereby permitting larger span, for example).

b. Greater t/c tends to increase C_{Lmax} up to a point, depending on the high lift system, but gains above about

12% are small if they're at all.
c. Greater t/c increases fuel volume and wing stiffness.

d. Increasing t/c increases drag slightly by increasing the velocities and the adversity of the pressure gradients.
e. The main trouble with thick airfoils at high speeds is the transonic drag rise which limits the speed and C_L at which the airplane may fly efficiently.

iv. Taper

The wing taper ratio (or in general, the planform shape) is determined from the following considerations:

a. The planform shape should not give rise to an additional lift distribution that is so far from elliptical that the required twist for low cruise drag results in large off-design penalties.
b. The chord distribution should be such that with the cruise lift distribution, the distribution of lift coefficient is compatible with the section performance. Avoid high C_l's which may lead to buffet or drag rise or separation.
c. The chord distribution should produce an additional load distribution which is compatible with the high lift system and desired stalling characteristics.
d. Lower taper ratios lead to lower wing weight.
e. Lower taper ratios result in increased fuel volume.
f. The tip chord should not be too small as Reynolds number effects cause reduced C_l capability.
g. Larger root chords more easily accommodate landing gear.

Here, again, a diverse set of considerations are important. The major design goal is to keep the taper ratio as small as possible (to keep the wing weight down) without excessive Cl variation or unacceptable stalling characteristics. Since the lift distribution is nearly elliptical, the chord distribution should be nearly elliptical for uniform Cl's. Reduced lift or t/c outboard would permit lower taper ratios.

v. Twist

The wing twist distribution is perhaps the least controversial design parameter to be selected. The twist must be chosen so that the cruise drag is not excessive. Extra washout helps the stalling characteristics and improves the induced drag at higher CL's for wings with additional load distributions too highly weighted at the tips. Twist also changes the structural weight by modifying the moment distribution over the wing. Twist on swept-back wings also produces a positive pitching moment which has a small effect on trimmed drag. The selection of wing twist is therefore accomplished by examining the trades between cruise drag, drag in second segment climb, and the wing structural weight. The selected washout is then just a bit higher to improve stall.

4. Wind Tunnel Testing

Wind tunnel testing was carried out on two of the three models, the conventional NACA 009 wing and the optimized morphing wing. All wings have the same span and chord as well as the same flap dimensions: Wing Span—0.3 m, Aerofoil Chord—0.15 m, Flap Span—0.172 m, Flap Chord—0.055 m, Flap Angle—25_ (remains the same throughout testing), Wing rotated at a point of 26.7% of chord (thickest point along the chord) to accommodate the fixture bar. This was also applied to CFD simulation. AF100 low speed open loop wind tunnel equipped with 3 components balance connected to a separate display unit to measure the forces acting on the model was utilized. The wind tunnel test section dimensions, Length = 0.6 m, Width = 0.3 m and Height = 0.3 m.

Aerofoil NACA 009 was selected primarily to reduce profile drag as much as possible, as this study is concentrating on vortices being generated by the deployment of flaps. There were also costing and simulation issues to consider, being self-funded cost had to be kept down for 3D printing models. It was noted that cambered aerofoils required a higher cell count, which limited mesh refinement. The models were 3D printed using the University printing facility rapid prototyping machine and then sanded down to remove the rough surface created during the 3D printing process. Once the model is finished, a 12 mm steel bar is installed at the aerodynamic centre, 40 mm from the leading edge.

Figure 2: (**a**) The finished 3D printed conventional wing aerofoil model; (**b**) The finished 3D printed optimized morphing aerofoil mode

Each model was installed in the wind tunnel test section and tested at 0, 5, 10, 15 and 20 degrees angle of attack with a wind speed of 25 m/s. The data was collected at set intervals every 0.5 s for 20 s at all degrees of angles of attack, this provides a large amount of data which can then be analyzed to ensure accurate results. Lift and drag data was then used to derive coefficient of lift and drag. The difference in coefficient of lift between the optimized morphing wing and the conventional wing. The optimized morphing wing has an increase in coefficient of lift by 14.8%, 8.4%, 4% and 2.6% at 0, 5, 10 and 15 degrees angle of attack respectively.

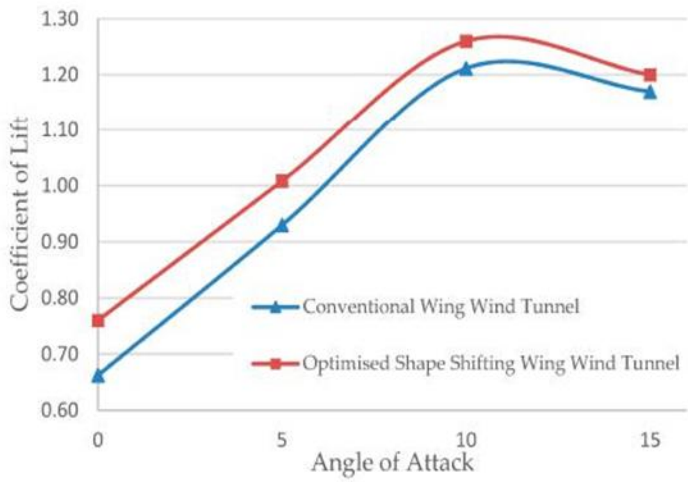


Figure 3:The coefficient of lift on the conventional wing and optimized morphing wing as angle of attack increases.

5. Wind Tunnel Result Discussion

Wind tunnel tests showed that both the initial morphing wing and the optimized wing have significant improvements over conventional wing. Although further improvement from the initial morphing wing is minor and would cause an increase in overall cost and complexity for the design. The wind tunnel data confirmed that the morphing wing design has the potential to increase the lift generated, by up to 14.8% at 0 degrees angle of attack.

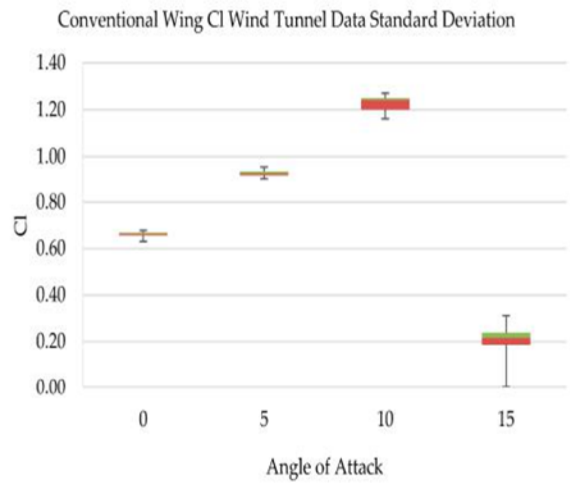


Figure 4: Conventional wing lift coefficient wind tunnel data standard deviation.

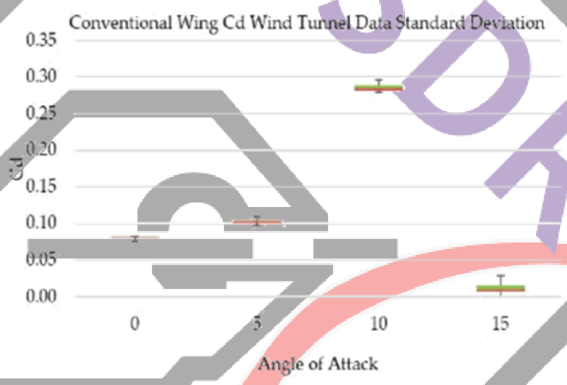


Figure 5: Conventional wing drag coefficient wind tunnel data standard deviation.

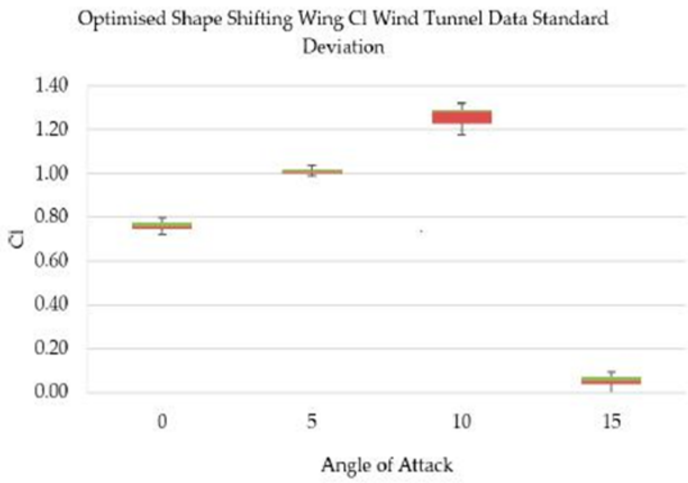


Figure 6: Optimized wing lift coefficient wind tunnel data standard deviation

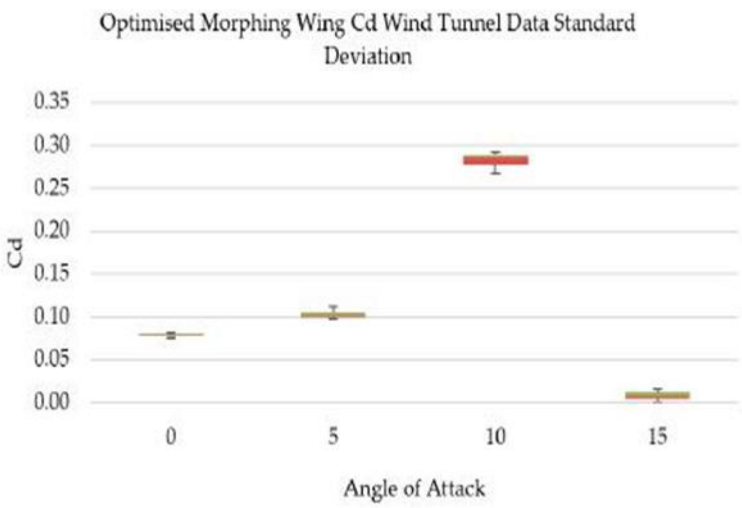


Figure 7. Optimized wing drag coefficient wind tunnel data standard deviation.

6. Conclusions

The main objective of this paper was to design and develop a morphing wing technology based on implementation of transition regions between the wing and the flap, which was simpler than the current sophisticated technology, ideally reducing the timescale for operational use. To achieve this, wing models were created and tested through CFD simulation to determine the aerodynamic performance of the wing. Also wind tunnel tests were carried out to measure lift and drag coefficients and to determine noise level reduction compared to conventional wing.

References

[1] C. Nae, V.M. Pricop, Report on base model definition full a/c AC-1 and AC-2, CESAR Deliverable Report No.D1.1.1-1, 2006.

[2] W. Stalewski, Parametric Modelling of Aerodynamic Objects - The Key to Successful Design and Optimisation, Proceedings of The International Conference of the European Aerospace Societies Congress, 24-28 October 2011, Venice, Italy.

[3] J. Rokicki, W. Stalewski, J. Żółtak, Multidisciplinary Optimisation Of Forward- Swept Wing, in Evolutionary Methods for Design, Optimization and Control, T. Burczynski and J. Périaux [eds.], c CIMNE, Barcelona, Spain, 2009.

[4] W. Stalewski, J. Żółtak, Multi-objective and Multidisciplinary Optimization of Wing for Small Aircraft, Proceedings of The International Conference of the European Aerospace Societies Congress, 24–28 October 2011, Venice, Italy.

[5] S. Wakayama, I. Kroo, Subsonic wing planform design using multidisciplinary optimi- sation, Journal of Aircraft, 32, No 4, 1995.

[6] S. Obayashi, S. Jeong, K. Chiba, H. Morino, Multi-objective design exploration and its application to regional-jet wing design, Transaction of Japan Society Aero. Space Scientist, 50, No. 167, 1–8, 2007

[7] A. Oyama, Multidisciplinary optimization of transonic wing design based on evolutionary algorithms coupled with CFD solver, Proceedings of ECCOMAS 2000, Barcelona, September 2000.