# MORPHING WINGS IN AIRCRAFTS

ME252| DESIGN OF MACHINE COMPONENTS | May - June 2020

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA, SURATHKAL

DEPARTMENT OF MECHANICAL ENGINEERING

# DECLARATION

We, hereby declare that this mini-project work entitled "**MORPHING WINGS IN AIRCRAFTS**" submitted to the Mechanical Department, NITK, is a record of the work done by this team under the guidance of **Dr. Sharanappa Joladarashi** and **Dr. Subhash Chandra Kattimani**. We have taken care in all respects to honor the intellectual property right and have acknowledged the contribution of others for using them in academic purpose and further declare that in case of any violation of intellectual property right or copyright we will be fully responsible for the same.

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# ACKNOWLEDGEMENTS

First and foremost, given the wrath of the pandemic, we are grateful to the almighty and the society for giving us the opportunity for compiling this project report.

Then we take this opportunity to express our sincere and deep sense of gratitude to The Mechanical Department of NITK, for giving us an opportunity to work on this mini-project.  Although we were unable to work on a prototype, it has been a good learning experience for us.

Our humble and heartfelt acknowledgements to our esteemed Professors Dr Sharanappa Joladarashi and Dr Subhash Chandra Kattimani for their vision in this course

We also thank our friends, who have helped us during this study. In addition, we thank one and all who have been instrumental in helping us complete this mini-project.

# CONTENTS

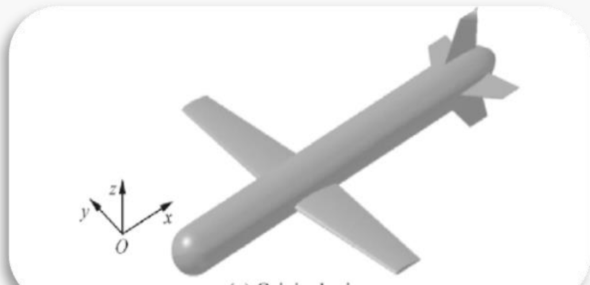
# EXECUTIVE SUMMARY

Morphing wing aircraft have attracted great interests in the past few decades because of their capability in changing wing shape according to different flight conditions for obtaining an optimum performance both aerodynamically and structurally.

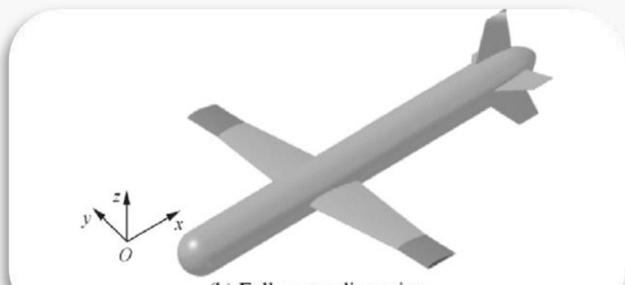
Morphing wing aircraft, compared to conventional rigid wing aircraft, are more capable in achieving optimum performance under different flight conditions. In recent times span changing aircraft have attracted great interests due to the advantage in obtaining the desirable lift-to-drag ratio and specific fuel consumption, especially for configurations whose wing is the predominant structure and these span changing aircraft span changing aircrafts mostly are based on multi-degree-of freedom (MDOF) mechanisms, such as the telescopic wing concept and the scissor mechanism configuration.

Although MDOF mechanisms are capable in performing complicated tasks, the large number of actuators required makes the structure difficult to fabricate, heavy and hard to control. The mechanical strength of smart materials limits their applications to small aircraft

In our model, a method using a single degree-of-freedom (SDOF) mechanism which is developed based on the concept of Sarrus linkage is used Computational Fluid Dynamics (CFD) analysis on the aerodynamic performance of a morphing wing aircraft using this mechanism is conducted. Maximum stress within the mechanism structure is also found using Finite Element Method (FEM).




(a) Original wing




(b) Fully extending wing

# NOMENCLATURE

$M$ = mechanism mobility

$N$ = number of links (including the fixed link)

$j$ = number of joints

$f$ = degree-of-freedom of the joints

$l$ = length of links

$D$ = distance between the two-parallel links

$\alpha$ = angle between the driving link and the fixed link

$v$ = velocity of the link

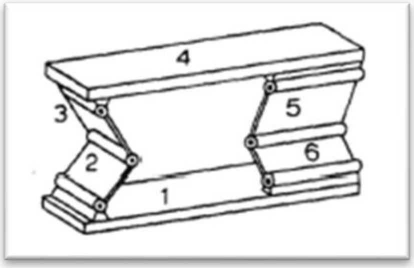
$L$, $D$ = lift/drag force

$C_L$, $C_D$ = lift/drag coefficient

# MODEL DEVELOPMENT

1. <u>A LOOK INTO THE MECHANISM</u>

We present the linkage whose design is based on Sarrus linkage, an SDOF (single degree-of-freedom) mechanism, for span-changing wings. Sarrus linkage is a member of the over-constrained linkage family.

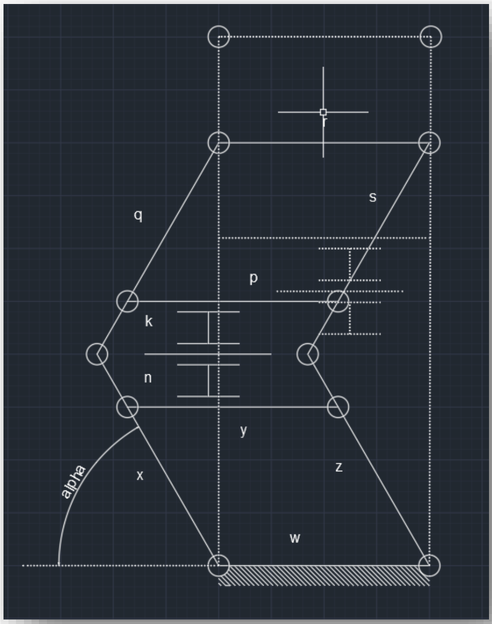



Demonstration of a conventional Sarrus Linkage

- As shown in figure it is constructed by jointing two members with a fixed relative screw axis by eliminating the prismatic joins of two screw slider cranks.
- The two sets of three parallel hinges are usually oriented perpendicular to each other.
- Since link 1 and 4 are always parallel to each other, the relative motion between these two links is desirable for the wing span morphing application.

Compared to the MDOF mechanism, the structure of this mechanism is simpler, and therefore its actuation is much easier. This potentially ensures the reliability of this mechanism when applied on large-scale aircraft.

## 2. SYNTHESIS OF THE LINKAGE




The schematic of the morphing wing mechanism is shown in Figure. The basic structure of this mechanism is developed from a Sarrus linkage which is the middle portion. The mobility or DOF of the mechanism can be calculated from the Kutzbach-Gruebler's equation:

$$\boxed{M = 6.\ (N\text{-}1\text{-}J) + \sum_{i=1}^{j} f_i}$$

Where

**M** - is the mobility of the mechanism,
**N** - is the number of links (including the fixed link),
**F** - is the degree-of-freedom of the joint,
**j** - is the number of joints.

In this design,
N=10 (including the fixed link) and j=13.
All the joints presented are revolute joints, hence $f_i$=1 for 1≤ i ≤j. Therefore

$$M = 6.\ (N\text{-}1\text{-}J) + \sum_{i=1}^{j} f_i \quad = 6.\ (10\text{-}1\text{-}13) + 13 = -\ 11$$

which indicates that it is a highly constrained mechanism

In this mechanism, links x, z, q, s have the same length, i.e.

$$\boxed{l_x = l_z = l_q = l_s = l}$$

Also, links w, y, p, r are the same in length, i.e.

$$\boxed{l_w = l_y = l_p = l_r = \delta}$$

Therefore, the closed chains formed by w, x, y, z and p, q, r, s are two identical parallelograms. These two parallelograms are connected by linking q, x and s, z respectively with two revolute joints. The middle sessions of p and y are connected by a linkage formed by two identical links k and n, which makes links p and y become mirror image with respect to each other.

3. CALCULATIONS

Consequently, the mechanism becomes symmetrical about the middle line that connects the q-x joint and the s-z joint. Since the mechanism is SDOF, the rotational motion of link x (or s, q, z, n, k) would result in the linear motion of link r, and the direction of this linear motion is always perpendicular to the link w, which is fixed on the main body of the wing.

For the ease of actuation, the mechanism is driven by link *x*. Defining *α* as the acute angle between x and w, t as the thickness of the link and D as the instantaneous displacement of r from w, due to the symmetry of the mechanism about the middle line, it can be found that

$$\boxed{D = 2l \sin(\alpha) + 2t \ (0 \leq \alpha \leq 90^0)}$$

The velocity of the link can be found out by differentiating it, hence the velocity of link r is

$$\boxed{V = D' = 2l\, \alpha' \cos \alpha \ (0 \leq \alpha \leq 90^0)}$$

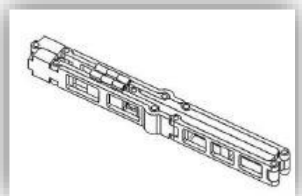
above equations indicates that the relationship between the displacement D and angler α is nonlinear.

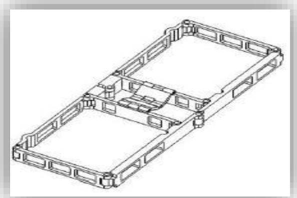
The mechanism is modelled for the performance analyses of the morphing wing mechanism. In this model,

- ✓ **l equals to 8.9 cm**
- ✓ **δ equals to 6.0 cm.**
- ✓ **The thickness t of each link is 0.25 cm.**

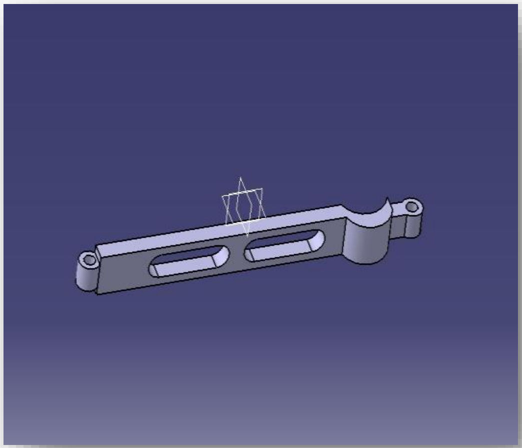
In the structure, all the links are chased to reduce the weight of the mechanism. However, to ensure adequate strength of the mechanism, necessary structural supports are remained for each link instead of hollowing the whole structure.

Besides, 2.5 mm fillets are added to each sharp corner of the link so as to prevent possible stress concentrations.

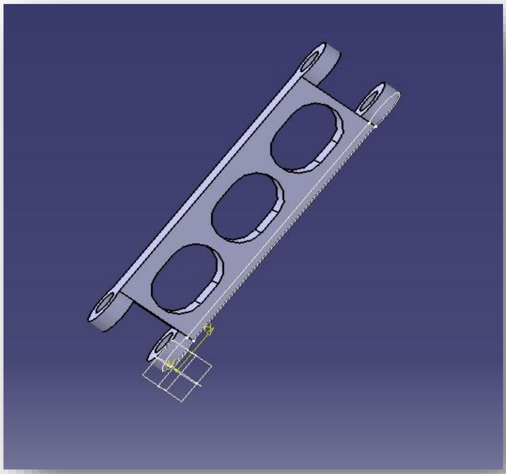




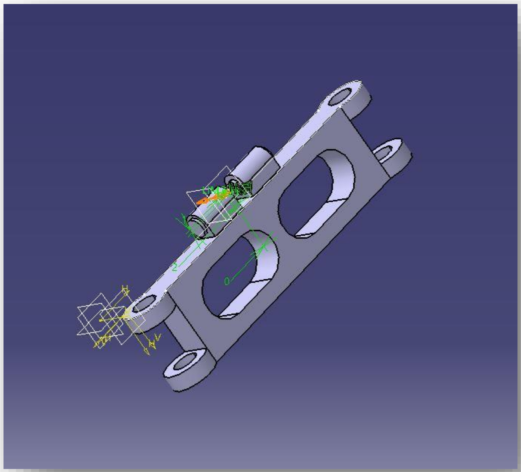
The individual links used in the Sarrus linkage were modelled in CatiaV5 the snapshots are depicted below:



While designing the links we have considered the stress concentration regions



The Holes are made in order to decrease the weight of the links. Also, they are the stress-free regions. So, it is safe to scrap that material out



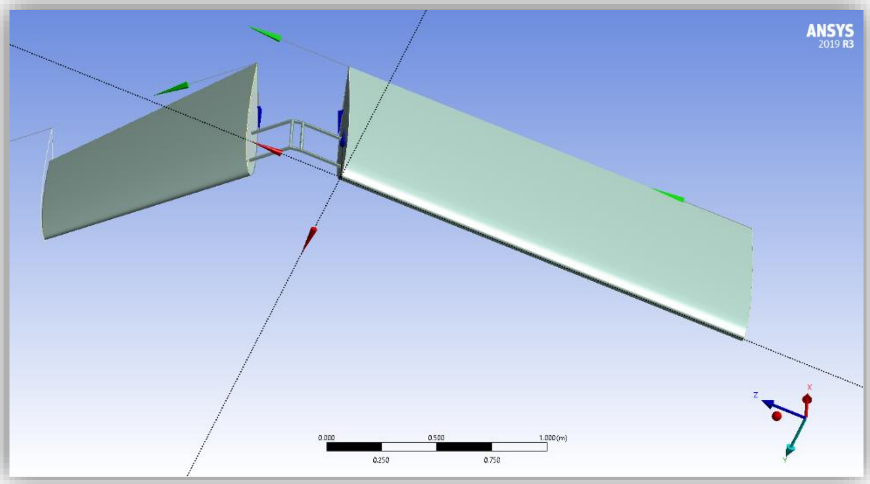
When the mechanism is fully extended, the maximum displacement **$D_{max}$ is 18.3 cm**. When it is fully contracted, the displacement of the mechanism is merely the total thickness of the links placed along the wing span. Since there would be 6 layers of the link), the mechanism has its minimum displacement **$D_{min}$ equals to 1.5 cm**.

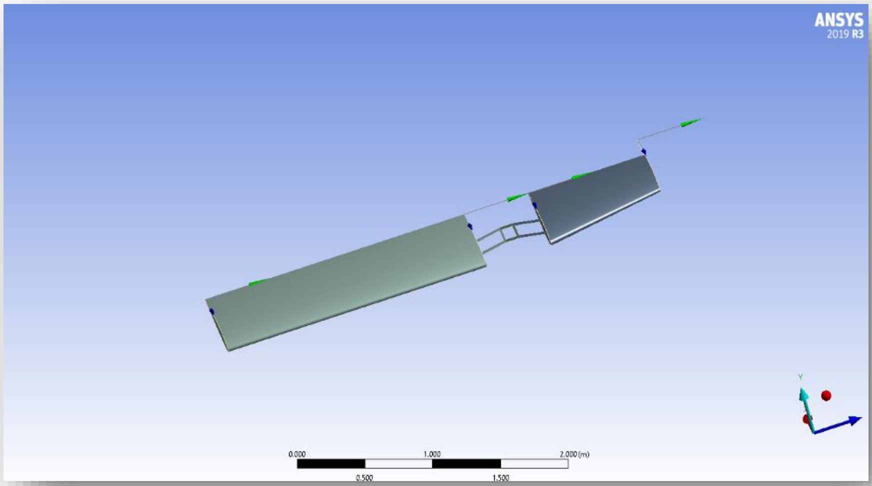
We define the **extension ratio (Ψ)** as:

$$\boxed{\Psi = \frac{Dmax - Dmin}{b + Dmin}}$$

The extension ratio that this mechanism helped us achieved is 23.5 % which led to some interesting results.

The orientation of the mechanism



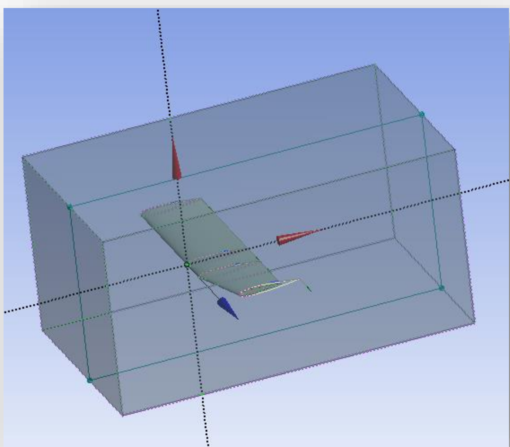




Full-Extended Mode

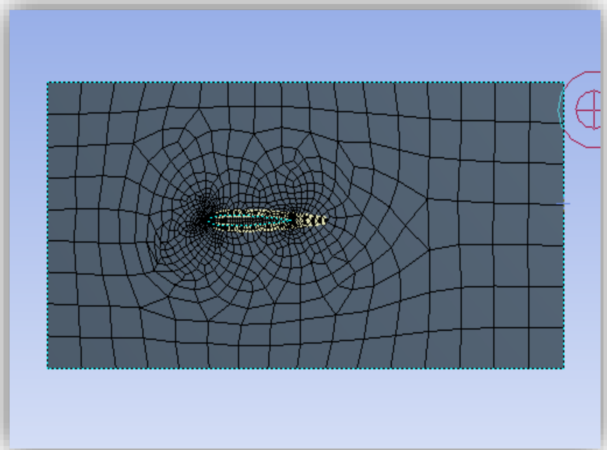
## 4. PERFORMANCE ANALYSIS

To evaluate the aerodynamic advantage, it brings and the structural integrity, the designed morphing mechanism is deployed on a model airplane wing, the air flow around the wing is simulated using CFD, and the stress within the mechanism is analysed using FEM simulations.

The model airplane wing used in this study is shown below. The mechanism is intentionally is covered with a thin skin for easy meshing purposes but the span of the wing is kept same to show the orientation of the mechanism. Even in the actual flights, the exposed portion of the wing will be covered by a membrane using stiff material hence to complete the aerodynamic surface required to generate lift.



Enclosure of the aerofoil in a wind tunnel



Meshed wind tunnel

Wind Tunnel testing of the aerofoil.

**CFD SIMULATION:**

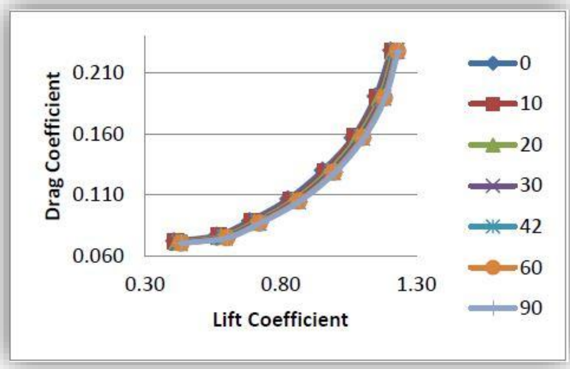
The Computational Fluid Analysis was carried out using FLUENT in ANSYS R19.3. For this model aircraft wing, the designed air speed U is about 5m/s to 10m/s. Assuming that the flight is at sea level, the air density ρ and viscosity μ is 1.225 kg/m3 and $1.78 \times 10^{5}$ kg/m-s, respectively. The Reynolds number for the aircraft flying at its design point is therefore

$$\boxed{Re = \frac{\rho u c}{\mu} \sim 1.8 \times 10^{5}}$$

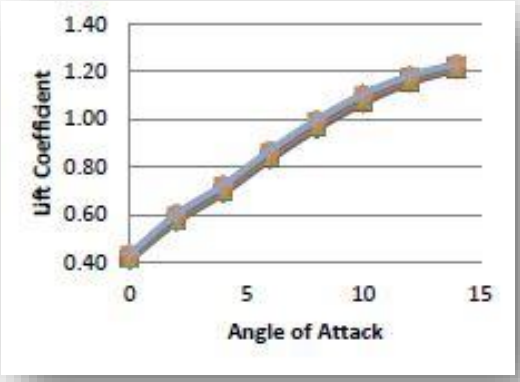
Since the Reynolds number for the normal flight condition seems below the transition Reynolds number i.e., $5 \times 10^5$, the flow is laminar for smooth wing surfaces. However, given the fact that the wing surfaces are actually very rough, it would be more appropriate to assume the flow to be turbulent.

The Morphing wing model is simulated at seven different driving angle $\alpha = 10^{0,}\ 20^0, 30^0, 60^0, 90^0$. The number of nodes for the flow field meshes ranges from 60000 to 70000

<u>RESULTS:</u>



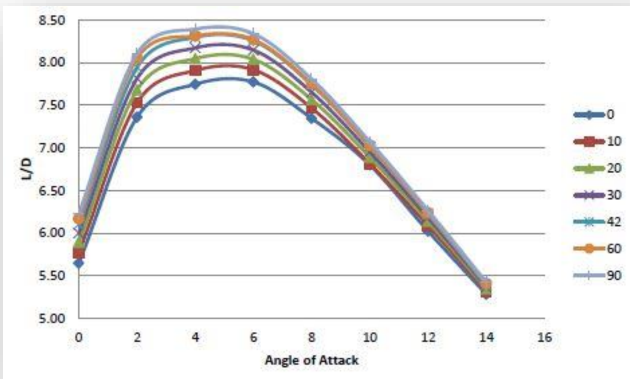

Drag vs Lift Coefficient for the morphing wing




Lift Curves

Percentage changes in lift coefficients for the morphing wing model under different configurations

| PERCENTAGE CHANGES IN LIFT COEFFICIENTS FOR THE WING | | | | | |
|---|---|---|---|---|---|
| Angle of Attack | 10 | 20 | 30 | 60 | 90 |
| **2** | 1.30% | 2.70% | 3.90% | 6.50% | 7.40% |
| **4** | 1.20% | 2.30% | 3.60% | 5.10% | 6.90% |
| **6** | 1.10% | 2.30% | 3.40% | 4.70% | 5.80% |
| **8** | 1.00% | 2.00% | 3.00% | 4.30% | 5.40% |
| **10** | 0.40% | 0.90% | 1.90% | 2.80% | 4.60% |




L/D ratio versus angle of attack for different model configurations.

Therefore, the deployment of the morphing mechanism enhances the aerodynamic performance of the airplane model by increasing its L/D at low angles of attack, which is useful to increase the maximum range or endurance of an aircraft in cruise.

**STRESS ANALYSIS:**

The CFD simulations provide the force distribution information over the entire wing surface, with which stresses within the morphing mechanism can be analysed. In the current study, we are interested in finding the maximum stresses and locating them.

So, when the aircraft is in the air, the lift forces, drag components, lead to a pressure distribution over the surface of the wing which can be obtained by using the lifting line theory (parabolic uniform pressure distribution) formulated by Prandtl which is based on the horse shoe vortices.

This pressure may intern lead to some stresses in the linkage, the analysis of which is carried out in ANSYS R19.3 Static Structural module.

It can be seen that a local peak of the maximum stress appears when the driving link angle is around 30◦, i.e. when the mechanism extends to half of its full extension range. And the maximum stress goes up again starting from about 45◦ extension until it reaches the global maximum value at 90◦ extension.

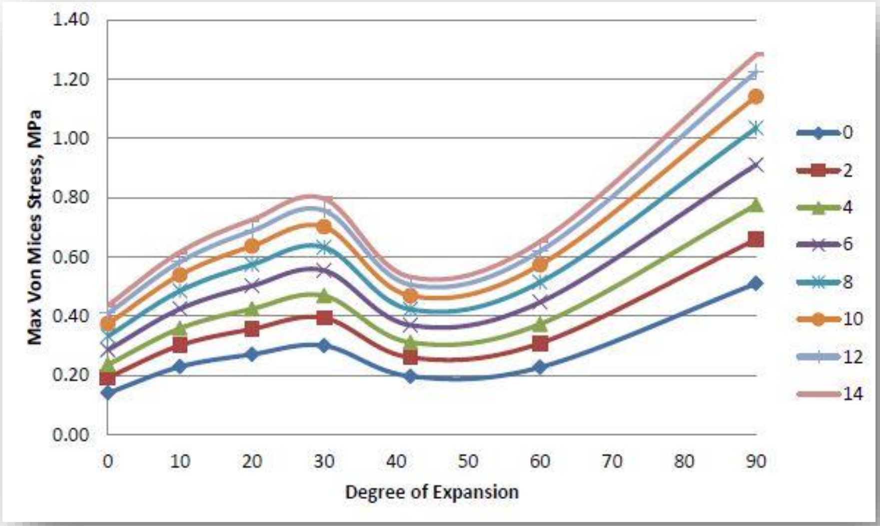
It is also found that the local peak values are about twice, and the values at 90◦ extension are about three times the maximum stress values at 0◦ extension. The largest value among all maximum stresses is 1.3 MPa when the wing model has extension at angle of attack.

There may be a mechanical disadvantage at the hinge in the middle portion of the mechanism, which makes the hinge more sensitive to the external aerodynamic loads than any other places in the structure.

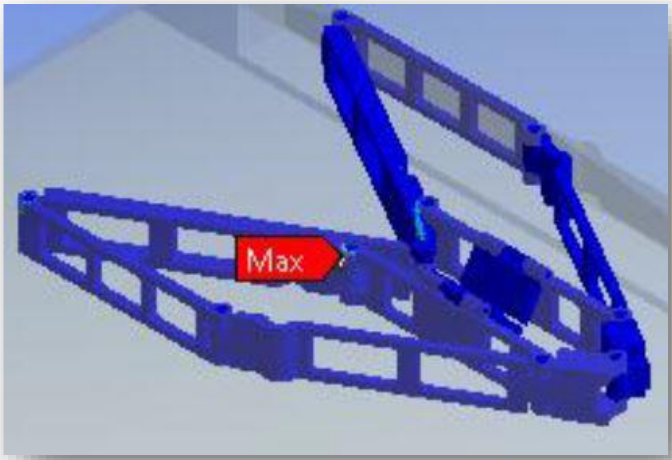
It is expected that the maximum stress locates at the root of the mechanism.

***Based on the knowledge acquired from this course one can safely conclude that, Aluminium T6061 with a yielding stress 275 MPa is very safe to be used for the current airplane model.***

So, the Graphical Result is:

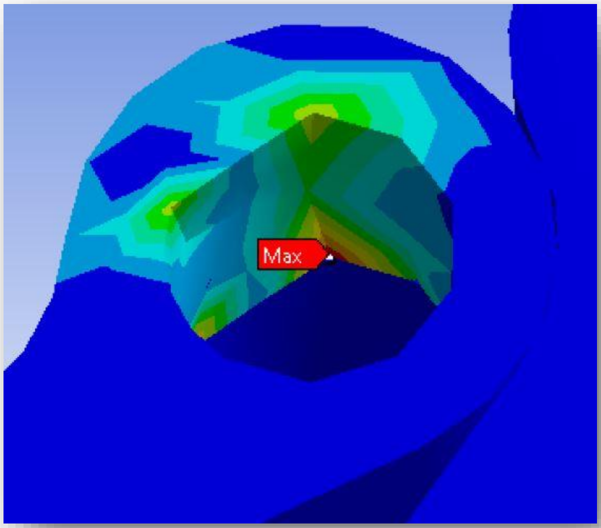


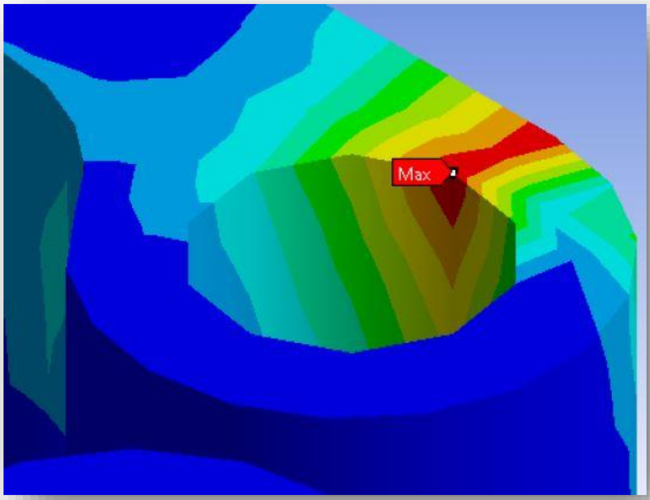

Variation of the Von Mises Stress with the Degree of Expansion




The Pictures depicts the stress distribution, due to the pressure created as a result of lift.

The Stresses that are developed at hinges at different angles of expansion.



# CONCLUSIONS

This study presented a novel conceptual design of an SDOF mechanism. Brief kinematics analysis was given. CFD and FEM simulations were conducted to study the aerodynamic performance of a morphing wing model and find the maximum stress within the mechanism. Some conclusions can be drawn here

- ✓ The deployment of the mechanism has slight influence on the lift or drag coefficient while having a relatively strong influence on the lift to drag ratio L/D.
- ✓ A local peak of the maximum stress appears when the mechanism extension is around 30◦, i.e. when the mechanism extends to half of its full extension range. And the maximum stress goes up again starting from about 45◦ extension until it reaches the global maximum value at 90◦ extension.
- ✓ During the extension of the mechanism, the maximum stress appears at two different locations. The reason may stem from two factors: one is the mechanical disadvantage of the mechanism and the other is the increase of the bending moment with the mechanism extension.

  As a newly developed control means for aircraft, the morphing wing mechanism needs to be analysed as an integrated component in an aircraft system by considering aerodynamics, structural dynamics, and flight mechanics. In the future, its influence on the longitudinal, lateral and directional behaviour of the aircraft is immense and it has ability to bring a huge difference in the aero industry.

# RECOMMENDATIONS

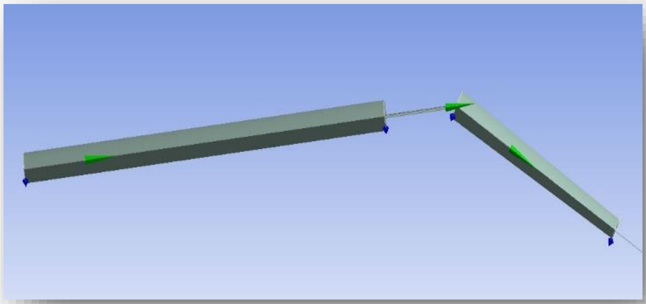
After a fruitful analysis, it is clear and safe to say that span-morph wings are very helpful in manipulating the lift coefficient and L/D ratio as per our requirement by adding a mechanism of the above sort.

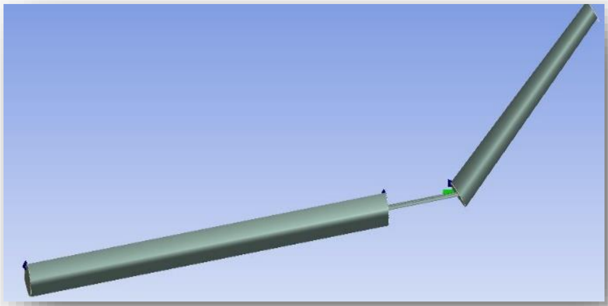
This mechanism can be automated using IoT and can adjust by its own given the flight conditions which the pilot wants to achieve.

So, given the improvement of the lift, inspired from the flapping of the bird wings, **we intend to add an upward and downward motion to the extended part of the wing.**

This also helps in increasing the lift considerably but the structural strength and ease of actuation is a question. Theoretically it seems feasible because when the wings move and up down this leads to tweaking of the flow pattern of the air over the airfoil. This leads to the decrease of the drag as result of change of pressure difference.

This idea may seem like below:





The Morphing wing concept is an active interest of research which started as a span Morph research, it has evolved into a bio wing represent an actual replica of a bird wing. NASA has been a pioneer in this technology over the past decades.

# FUTURE SCOPE

The Future Scope of Morphing wings is directed towards “Bio-inspired wings”. Apart from the aerodynamic concept of morphing wing it has also combined with material science making way for the researchers and the engineers to create new sort of materials which are flexible and strong enough to morph the shape of the wings which are known as “Dynamic Wings”.

## References:


- ✓ “Fundamentals of Aerodynamics” by John Anderson
- ✓ "Morphing aircraft concepts, classifications, and challenges” A.K. Jha


### Software Environments used

- ✓ CATIA V5
- ✓ ANSYS R19.3
- ✓ AUTOCAD 2020

THE END

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