Wing Design for Subsonic Aircraft

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***Abstract*: Major structural part of an aircraft is the wing which is used to produce the lift during flying conditions. Wing is inclined at certain angle of attack with stall regions. When the flow passes over an airfoil due to the pressure difference at top and bottom surface of the wing the lift force is generated. The aim of the present study is to design the rectangular wing of subsonic aircraft using 3D EXPERIENCE &analysis through SIMULIA with Al alloy to find von-mises stress which is developed in the wing design.The wing is designed in solid modelling software using 3D EXPERIENCE and analysis is done using finite element method by using SIMULIA. Static structural analysis of the wing is done to find deformation, stress, and strain induced in the wing structure wing. Production of the lift to drag ratio for the tailless aircraft is high. The stability of an aircraft is considered for the flying wing is dependent on the design and configuration of the wing construction for production of lift in major conditions of flight. With the known values of von mises stress and displacements and strainsthe region of slip where the failure may occur and zones of failures are introduced before braking through rectanngular wing structural analysis.**

***Keywords:* Aircraft wing Design, Structural Analysis, Finite element analysis, material selection.**

I. INTRODUCTION

A wing is a surface used to produce an aerodynamic force normal to the direction of motion by travelling in air or another gaseous medium, facilitating flight. For a wing to produce "lift", it must be oriented at a suitable angle of attack relative to the flow of air past the wing. When this occurs, the wing deflects the airflow downwards, "turning" the air as it passes the wing. Since the wing exerts a force on the air to change its direction, the air must exert a force on the wing, equal in size but opposite in direction. This force manifests itself as differing air pressures at different points on the surface of the wing.A region of lower-than-normal air pressure is generated over the top surface of the wing, with a higher pressure existing on the bottom of the wing. These air pressure differences can be either measured directly using instrumentation or they can be calculated from the airspeed distribution using basic physical principles, including Bernoulli’s Principle which relates changes in air speed to changes in air pressure.

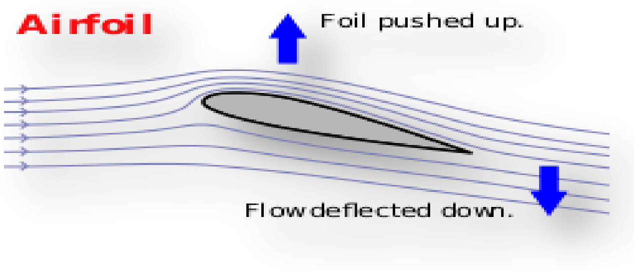


Fig 1: Flowover an Aerofoil

The lower air pressure on the top of the wing generates a smaller downward force on the top of the wing than the upward force generated by the higher air pressure on the bottom of the wing. Hence, a net upward force acts on the wing. This force is called the "lift" generated by the wing.

Fig 2: Aircraft configuration with wings

II. DESIGN AND CONSTRUCTION

This section deals with some of the considerations involved in wing design, including the selection of basic sizing parameters and more detailed design. Wing is the most important aspect of aircraft design, which decides how well the airplane will fly. Wing design or shape depends upon the mission requirements: type of aircraft, performance, speed, operating altitudes, gross weight, and space requirements for engine and fuel tanks. Depending upon mission requirements, wing configuration can be selected as rectangular wing. Wing construction is basically the same in all types of aircraft. Most modern aircraft have all metal wings, but many older aircraft had wood and fabric wings. To maintain its all-important aerodynamic shape, a wing must be designed and built to hold its shape even under extreme stress. Basically, the wing is a framework composed chiefly of spars, ribs, and (possibly) stringers

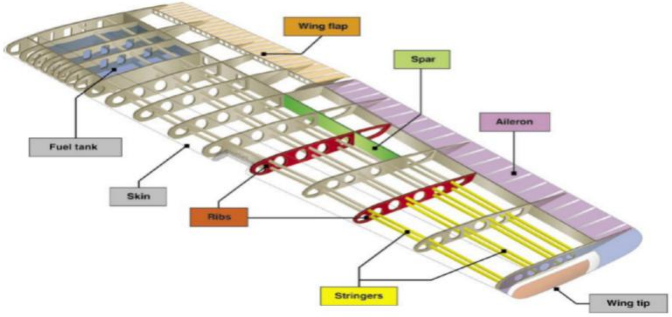


Fig.3: Basic Design of a Tapered Wing

The design methodology follows an engineering design process starting by setting the target mission specifications of the design. Then, a statistical analysis of other flying wings data of similar mission specifications is performed. After that, a preliminary design is performed by studying the variation of the geometrical parameters and their effects over the design requirements: lift, drag and moment, to conclude with a near optimum preliminary design. This preliminary design undergoes aerodynamic analyses by different programs and methods. Composite structures, contact stress, thermal problems, Method of interpolation is solved by FEM.

2.1 Control surfaces

Control surfaces Control surfaces of tailless aircraft are interesting part of design due to the absence of conventional tail. Tailless aircraft meanswith or without vertical tail and purely without horizontal tail. The control surfaces for pitch and yaw control for these aircraft are totally different from conventional aircraft. The absence of tail rudder could be substituted by other control surfaces such as split drag flaps, inboard and outboard ailerons, winglets rudders and Thrust Vectoring. The problem of absence of the elevator can solved by substituting it with elevons. The elevons are aircraft control surfaces that serve the functions of both the elevators and the ailerons. They are installed on each side of the aircraft at the trailing edge of the wing.

2.2 high lift devices

Those which alters the geometry of an airfoil

- Trailing edge flaps
- plain flap
- split flap
- slotted flap
- fowler flap
- zap flap
- Leading edge slots
- Leading edge flaps

Those which controls the behaviour of boundary layer

- Boundary layer suction
- Boundary layer blowing

Ex: Jet flap

There are few devices which operates on both the principles

Ex: slotted flap , fowler flap

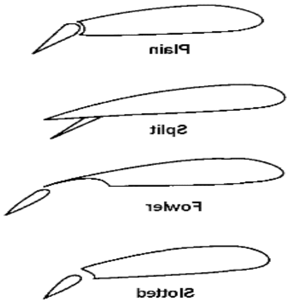


Fig: types of flaps

2.3. Skin

- Resists the applied torsion and shear forces by Transmitting aerodynamic forces to the longitudinal and transverse supporting members.
- Supports the longitudinal members in resisting the applied bending and axial loads.
- Supports transverse members in resisting the hoopor circumferential stresses when the structure is under pressure loads.

Fig: aircraft wing with skin

III. STRUCTURE

For different aircrafts the approach of the structural design is different in concept of design and frame body analysis in. Some paragliders, comprise only flexible materials that act in tension and rely on aerodynamic pressure to hold their shape. A balloon similarly relies on internal gas pressure but may have a rigid basket to carry its payload. Early aircraft, including airships, often Employed flexible doped aircraft fabric covering to give a reasonably smooth aero shell stretched over a rigid frame. Later aircraft employed semi-monocoque techniques, where the skin of the aircraft is stiff enough to share much of the flight loads. In a true monocoque design there is no internal structure left. The key structural parts of an aircraft depend on what type it is.

The principal structural parts

a. *spars*
b. *ribs*
c. *Stringers.*

- *The spar* is often the main structural member of the wing, running spanwise at right angles to the fuselage. The spar carries flight loads and the weight of the wings while on the ground.
- *Ribs* determine the shape and thickness of the wing (airfoil).
- *Stringer* (aircraft), a strip of wood or metal to which the skin of an aircraft is fastened.

3.1. Aspect ratio

To investigate aspect ratio in detail were the Wright Brothers, using a wind tunnel they constructed. They found that a long, skinny wing (high aspect ratio) has less drag for a given lift than a short, fat wing (low aspect ratio). This is due to the 3-D effects.

As most early wings were rectangular in shape, the aspect ratio was initially defined as simply the span divided by the chord. For a tapered wing, the aspect ratio is defined as the span squared divided by the area (which defaults to the earlier definition for a wing with no taper).

When a wing is generating lift, it has a reduced pressure on the upper surface and an increased pressure on the lower surface. The air would like to "escape" from the bottom of the wing, moving to the top. This is not possible in 2-D flow unless the aerofoil is leaky.

Operational Empty Weight (OEW) – Weight of structure, power plant, furnishings, and systems, plus standard and operational items (personnel, equipment, and supplies necessary to operate the aircraft).

Payload – Weight of passengers, cargo, bags, weapons, or special equipment (determined by Zero Fuel Weight minus OEW).

Maximum Zero Fuel Weight (MZFW) – Maximum weight allowed before usable fuel must be loaded in defined sections of the aircraft as limited by strength and airworthiness requirements.

3.2. Properties of sections

$$X_c = \frac{\Sigma x_i \, dA_i}{A}$$

$$Y_c = \frac{\Sigma y_i \, dA_i}{A}$$

A "centroidal axis" is any axis that passes through the centroid. An axis of symmetry is always a centroidal axis The moment of inertia I is a difficult-to-define parameter that appears in bending and buckling equations. Moment of inertia can be viewed as the cross-section’s resistance to rotation about some axis, assuming that the cross-sectional shape has unit mass. Moment of inertia is the sum of the elemental areas times the square of the distance to the selected axis.

$$I_x = \Sigma y_i^2 \, dA_i$$

$$I_y = \Sigma x_i^2 \, dA_i$$

$$I_p = J = \Sigma r_i^2 \, dA_i = I_x + I_y$$

When a plane rolls, the lift produced by the wings is no longer acting straight upwards, but is now acting upwards and towards the lower of the two wings. Because of this, the plane will now turn towards the low wing. Because of this, ailerons can be used to steer planes left or right.

3.3. Load Calculations

Table 1: properties of the calculations

Aircraft type	Subsonic Aircraft
Fuel Storing	Wing & Fuselage
Engine Thrust	500N
Range	5000m
Service ceiling	3000m
Endurance	45 min
Maximum Dive Speed	80 km/h
Maximum Load Factor	+7.0/-2.5g
Wing Loading	200kg/m^2
Take-off Weight	1600kg
Taper Ratio(λ)	**1** (Rectangular Wing)
Density of Air	0.736kg/m^3 (At 5000m Altitude)
Aspect ratio	4
Stall Speed (V_{Stall})	31.1m/s

Assume the steady state and level flight condition of the aircraft for designing the wing.

IV. SOLID MODELLING OF NACA 2415 AIRFOIL

An airfoil generates lift by changing the velocity of the air passing over and under itself. The airfoil angle of attack and/or camber causes the air over the top of the wing to travel faster than the air beneath the wing. Bernoulli's equation shows that higher velocities produce lower pressures, so the upper surface of the airfoil tends to be pull upward by lower-than-ambient pressures while the lower surface of the airfoil tends to be pushed upward by higher-than-ambient pressures. the Integrated differences in pressure between the top and bottom of the airfoil generate the net lifting force.

4.1Airfoil Selection Criteria

Selecting an airfoil is a part of the overall wing design. Selection of an airfoil for a wing begins with the clear statement of the flight requirements. For instance, a subsonic flight design requirement is very much different from a supersonic flight design objective. On the other hand, flight in the transonic region requires a special airfoil that meets Mach divergence requirements. The designer must also consider other requirements such as airworthiness, structural, manufacturability, and cost requirements.

4.2. Thickness Calculation

As guidance, the typical values for the airfoil maximum thickness-to-chord ratio of majority of aircraft are about 6% to 18%.

i. For a low-speed aircraft with a high lift requirement (such as cargo aircraft), the typical wing (t/c) max is about 15% - 18%.
ii. For a high-speed aircraft with a low lift requirement (such as high subsonic passenger aircraft), the typical wing (t/c) max is about 9% - 12%.
iii. For the supersonic aircraft, the typical wing (t/c) max is about 6% - 9%.

The solid modelling of the airfoil was made with the help of 3D EXPERIENCE as shown in Figure. The chord of the airfoil was selected as 800mm and extruded to a wing span of 1000mm. wing is drafted by importing coordinates of NACA2415coordinates. Fig shows the CATIA 3D model of aircraft wing with NACA 2415 profile.

Table 2: NACA 2415 coordinates

Name	NACA 2415
Chord(mm)	800
Radius(mm)	0
Thickness(%)	100
Origin (%)	0
Pitch(deg)	0
Airfoil surface	
X(mm)	Y(mm)
800	1.256
797.92	1.784
791.44	3.352
780.72	5.912
765.864	9.376
747.016	13.64
724.384	18.584
698.2	24.048
668.728	29.904
636.288	35.984
601.232	42.136
563.92	48.2
524.76	54.024
484.192	59.448
442.648	64.32
400.592	68.496
358.488	71.824
316.776	74.176
275.584	75.272
235.752	74.928
197.776	73.12
162.088	69.888
129.136	65.304
99.288	59.504
72.896	52.64
50.256	44.92
31.616	36.528
17.16	27.68
7.024	18.552
1.288	9.288
0	0
3.096	-8.848
10.464	-16.824
22	-23.88
37.552	-29.984
56.92	-35.096
79.888	-39.192
106.2	-42.256
135.56	-44.312

167.68	-45.408
202.224	-45.624
238.856	-45.064
277.208	-43.864
316.896	-42.176
357.896	-40.024
399.408	-37.384
440.976	-34.384
482.136	-31.144
522.448	-27.776
561.472	-24.384
598.768	-21.024
633.936	-17.776
666.576	-14.688
696.32	-11.816
722.832	-9.208
745.8	-6.896
764.976	-4.928
780.128	-3.352
791.08	-2.2
797.696	-1.496
800	-1.256

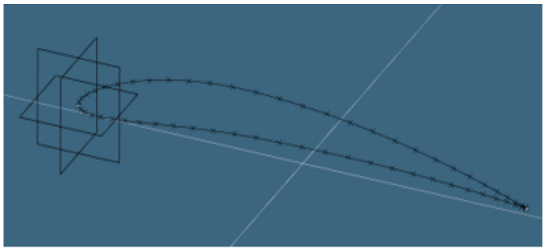


Fig 4: importation of coordinates of wing

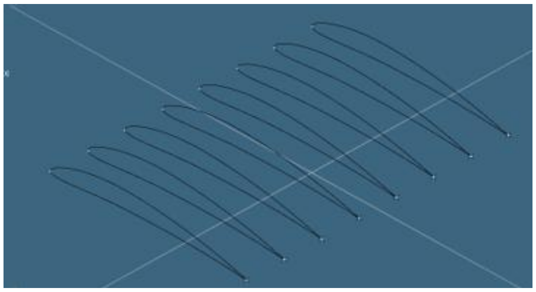


Fig 5: airfoil sections of aircraft wing

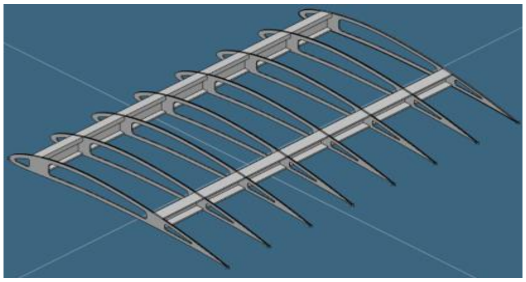


Fig 6:3D model of aircraft wing with I &C Sections

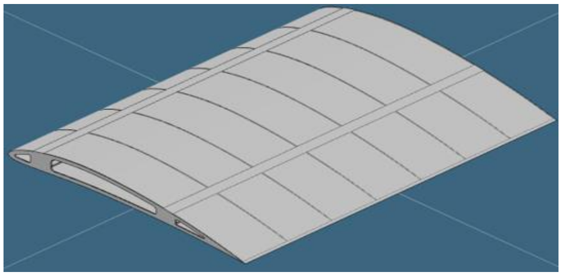


Fig 7:3D model of aircraft wing

4.3. Introduction to FEA

The finite element method (FEM) is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method approximates the unknown function over the domain. To solve the problem, it subdivides a large system into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function.

Steps in FEA

In FEA or any type of analysis of engineering simulation there are few basic steps to be followed

1. Preprocessing
2. Solver
3. Post-processing

4. Validation by Analytical or Experimental method.

4.3.1.pre-processing

Dividing our domain into finite number of parts for imposing Mathematical equations on it called as Discretization In industry it also called as a Meshing.

4.3.2. Solver

Solver is like a black box of commercial software. It involves applying boundary conditions and initial value generation in it. Numbers of codes are prepared to solve this mathematical equation by software company directly.

4.3.3. Post processing

All solved problems are in numeric format. For visualization purpose it is mandatory to represent these results in Graphics. Stress contour, Pressure contour, Strain contour are plotted.

4.3.4. Validation

It is very important step in engineering analysis point of view. Result obtains by FEA or any other method should be validated by any one of analytical or experimental method.

V. STRUCTURAL ANALYSIS IN SIMULIA

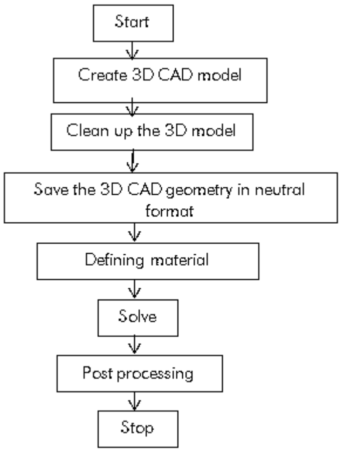


Fig8: SIMULIA step by step process

- Prepared Assembly in 3D EXPERIENCE for wing and Save as this part and Exporting into SIMULIA.
- Apply Material for aircraft wing.

5.1. Material Details:

The Material for the complete wing to be considered is Aluminium Alloy 2024-T3 with the properties mentioned in the table below.

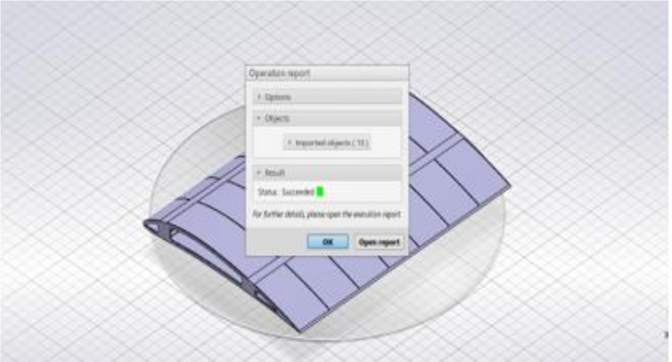
Table 3: material details of AL alloy

Density (ρ)	2770 kg/m^3
Modulus of Elasticity (E)	7.1E10 Pa
Poisson's Ratio (υ)	0.33
Tensile Yield Strength	280 MPa
Shear Yield Stress (K)	201.5 N/mm^2
Maximum Allowable Stress	300 mm^2

1. Mesh the aircraftwing
2. Define boundary condition for Analysis Boundary conditions play an important role in finite element calculation here, one end isfixed.
3. Define type of Analysis &Apply the pressure on aircraftwing
4. Run theAnalysis Get the Results.

5.2. Structural analysis of Aircraft wing:

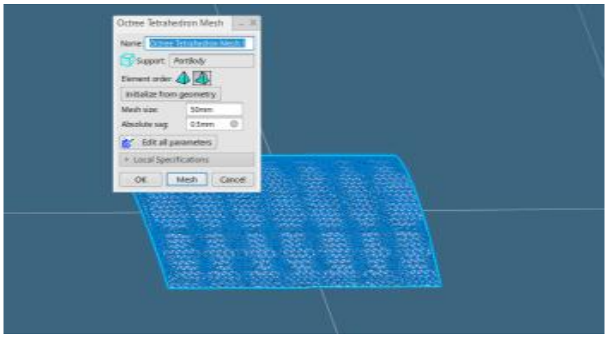
Static analysis determines the displacements, stresses, strains and forces in structures and components caused by loads that do not induce significant inertia and damping effect. Steady loading and response conditions are assumed; that is, the loads and structures response are assumed to vary slowly with respect to time



Status : Succeeded

For further details, please open the execution report

Fig 9:3 D model of aircraft wing with skin



Name: Octree Tetrahedron Mesh

Support: PartBody

Mesh size: 50mm

Fig 10:3D model of aircraft wing with mesh

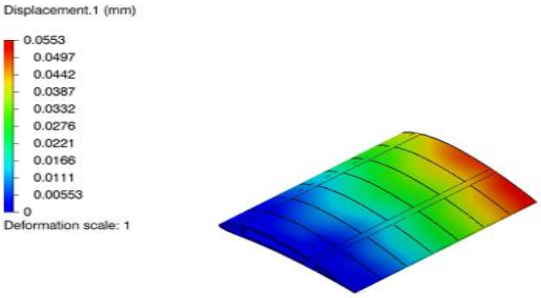


Fig 11: analysis of 3D model of aircraft wing

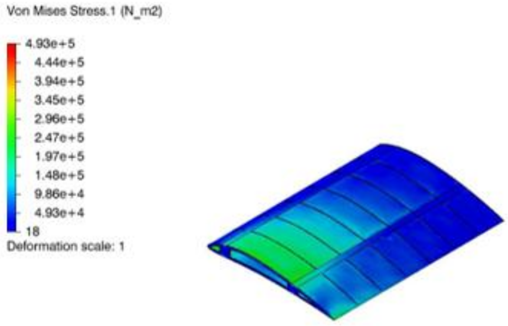


Fig 12: stress distributions of aircraft wing

VI. RESULTS

Sl. No.	Output Parameters/ Wing Type	Rectangular Wing
1	Applied Load	60N
2	Displacement	42.6mm
3	Von-mises Stress	3.07e+08N/m2
4	Strain	0.0173
5	F.O.S.	2
6	Logarithmic strain	0.00381
7	Yielding	1

Table 4: Analysis outputs

VII. CONCLUSIONS

1. Stress analysis of rectangular wing is carried out and the displacement for the applied load and von-mises stress developed on rectangular has been determined.
2. The stress developed is carried out to find the region of slip and the zone of entering of failure in the
3. Construction of the rectangular wing which occurs due to the load applied on the wing.
4. From the results the slip region which is useful to find where fretting damage and fatigue life of the wing design occurs.

FUTURE WORKS

1. The Components and the skin of the air wing can be constructed using composite materials in order to achieve the lower size to weight ratio, it can be economical and highly efficient.
2. Design of Fuselage can be done leading to the construction of a complete aircraft as a long-term project.
3. With Various types of wing constructions leads to the performance of the future work of stresses to find more regions of failures.

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