

# Design and Development of Wing Structure

Mayuresh Rajesh Pawar, S.G.Thorat

U.G. Student, Department of Mechanical Engineering, MIT ADT University Lonikalbhor, Maharashtra, India

Assistant Professor, Department of Mechanical Engineering, MIT ADT University, Lonikalbhor, Maharashtra, India

**ABSTRACT:** This paper presents the development of a parameterized automated generic model for the structural design of an aircraft wing. Furthermore, in order to perform finite element analysis on the aircraft wing geometry, the process of finite element mesh generation is automated. The generic model that is developed in this regard is able to automate the process of creation and modification of the aircraft wing geometry based on a series of parameters which define the geometrical characteristics of wing panels, wing spars and wing ribs. Two different approaches are used for the creation of the generic model of an aircraft wing which are “Knowledge Pattern” and “Power Copy with Visual Basic Scripting” using the CATIA V5 Software. A performance comparison of the generic wing model based on these two approaches is also performed. In the early stages of the aircraft design process, an estimate of the structural characteristic of the aircraft wing is desirable for which a surface structural analysis (using 2D mesh elements) is more suitable. In this regard, the process of finite element mesh generation for the generic wing model is automated. Furthermore, the finite element mesh is updated based on any changes in geometry and the shape of the wing panels, wing spars or wing ribs, and ensure that all the mesh elements are always properly connected at the nodes. The automated FE mesh generated can be used for performing the structural analysis on an aircraft wing.

## I. INTRODUCTION

Aircraft design is a complex and multi-disciplinary process that involves a large number of disciplines and expertise in aerodynamics, structures, propulsion, flight controls and systems amongst others. During the initial conceptual phase of an aircraft design process, a large number of alternative aircraft configurations are studied and analyzed. Feasibility studies for different concepts and designs are carried out and the goal is to come up with a design concept that is able to best achieve the design objectives. One of the crucial studies in any aircraft design process is the conceptual design study of an aircraft wing. The aircraft wing is one of the most critical components of an aircraft not only from an aerodynamics point of view but also from a structural point of view. The aircraft wing is designed in such a way that it is able to provide the requisite lift while minimizing the drag. Drag is critical from the aerodynamics point of view because it directly affects the performance of the aircraft like fuel efficiency and range. Not only does the wing provide the necessary lift during flight, the aircraft wing is designed structurally to carry the entire weight of the aircraft. Also, in modern commercial aircrafts and fighter airplanes, the aircraft wing has more than one role. It not only carries the fuel required for the flight but is also used to provide storage bays where, the aircraft landing gears can be mounted and stowed during takeoff (which are normally placed inside the wing root of an aircraft). Furthermore, modern commercial airplanes have padded engines which are placed below the wing. This means that the aircraft wing has to be sufficiently strong from the structural perspective to carry the weight of these engines, fuel inside the wing box and internal components. A variety of components are also placed inside the aircraft wing which includes electro-mechanical actuators, fuel lines, and hydraulic, pneumatic and electrical systems amongst others. All of these components are to be compactly placed inside the wing, thus, the aircraft wing has to perform structurally and aerodynamically well to deliver the desired performance. Weight is one of the fundamental critical factors in any aircraft design process and aircraft designers are always on the lookout for ways to minimize the weight of the aircraft. This means that a light weight aircraft should have a light weight wing. A light weight aircraft is thus beneficial for increasing the design performance. In the conceptual phase of an aircraft design process, different design studies are carried out for different components of the aircraft. One of the major portions of these studies is dedicated towards the design of the aircraft wing both from a structural and aerodynamics point of view. However, in this stage High-end CAD software's are not employed as they are thought to be too complex or demanding to be used during this stage. Therefore, the promising design configurations have to be remodelled again later in the detail design process which increases cost and the time to production. It can be very beneficial from a design perspective, if these CAD software's are employed from the start of the aircraft design process. This would enable less remodelling of the design in the detail design process and would also enable increased capability to do modelling and simulation during the conceptual phase. A generic model is thus required in this regard that would speed up the design process of analyzing different aircraft wing configurations. Especially from a structural design perspective. An aircraft designer would thus be able to focus on

different design criteria's and configurations rather than worrying about CAD geometries. The CAD based generic model can eventually also be used for performing aerodynamic and CFD studies on the aircraft wing as well. Furthermore, this model can also help other engineers from other departments like systems and flight controls to check the feasibility of placing internal components at different positions inside the aircraft wing. However, it is required that the CAD model should be sufficiently robust and reliable to be able to cater for different design configurations and geometries. From the structural perspective, aircraft wing should be designed to provide the necessary strength and stiffness at minimum weight. The generic model should enable different structural configurations to be sized so as to provide the required strength and stiffness. In order to do this, the generic model should enable easy to do finite-element analysis of the entire aircraft wing configuration



Figure 1: AIRCRAFT WING SHAPES

## II. MODELLING OF WING

The surface model of the aircraft wing is specifically designed to be used for the finite element analysis of an aircraft wing. The surface model includes only surfaces which represent the wing shape including spars and ribs. The surface model is chosen for the finite element analysis because it is faster to do a finite element analysis on a 2D surface rather than a 3D one. It is also easier to mesh a 2D surface than a 3D one and also it is computationally beneficial. In a conceptual phase, it is also not necessary to carry out a very precise finite element analysis for the aircraft wing. So, a 2D analysis will give sufficient information to be useful in the conceptual phase while saving time and resources compared to a full 3D FE analysis.

## III. AERFOIL SELECTION

### 3.1 AERFOIL GEOMETRY

An airfoil is a surface designed to obtain a desirable reaction from the air through which it moves.

Chord line: Straight line connecting leading edge and trailing edge.

Thickness: Measured perpendicular to chord line as a % of it.

Camber: Curvature of section – perpendicular distance of section mid-points from chord line as a % of it.

### 3.2 ANGLE OF ATTACK

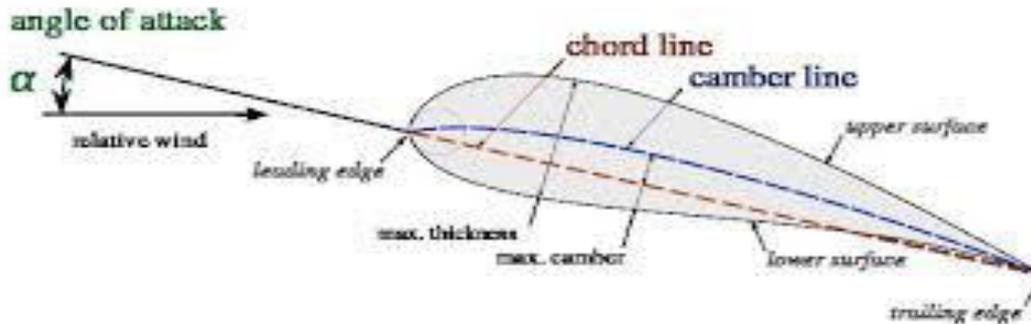


Figure 2: ANGLE OF ATTACK

Angle of attack is the angle between the free stream and the chord line.

Aero foil Selection is based on the factors of Geometry & definitions, design/selection, families/types, design lift coefficient, thickness/chord ratio, lift curve slope, characteristic curves.

The following are airfoil categories:

Early on, airfoil selection was based on trial & error.

- NACA 4 digit was introduced during the 1930's.
- NACA 5-digit is aimed at pushing position of max camber forwards for increased  $C_{lmax}$ .
- NACA 6-digit is designed for lower drag by increasing region of laminar flow.

The modern airfoil is mainly based upon need for improved aerodynamic characteristics at speeds just below speed of sound.

- **NACA 4 Digit:**
  - 1st digit: maximum camber (as % of chord).
  - 2nd digit (x10): location of maximum camber (as % of chord from leading edge (LE)).
  - 3rd & 4th digits: maximum section thickness (as % of chord).
- **NACA 5 Digit:**
  - 1st digit (x0.15): design lift coefficient.
  - 2nd & 3rd digits (x0.5): location of maximum camber (as % of chord from LE).
  - 4th & 5th digits: maximum section thickness (as % of chord).
- **NACA 6 Digit:**
  - 1st digit: identifies series type.
  - 2nd digit (x10): location of minimum pressure (as % of chord from leading edge (LE)).
  - 3rd digit: indicates acceptable range of CL above/below design value for satisfactory low drag performance (as tenths of CL).
  - 4th digit (x0.1): design CL.
  - 5th & 6th digits: maximum section thickness (%c)

It becomes necessary to use high speed airfoils, i.e., the 6x series, which have been designed to suit high subsonic cruise Mach numbers.

IV. WING PARAMETERS

| DESIGN PARAMETERS | VALUES               |
|-------------------|----------------------|
| WING LOADING      | 598Kg/m <sup>2</sup> |
| WING AREA         | 142m <sup>2</sup>    |
| ASPECT RATIO      | 9.45                 |
| WING SPAN         | 36.63 m              |
| TAPER RATIO       | 0.25                 |
| ROOT CHORD        | 6.2 m                |
| TIP CHORD         | 1.55 m               |
| MEAN CHORD        | 4.34 m               |
| DESIGN            | 0.511                |
| SWEEPBACK ANGLE   | 25                   |
| DIHEDRAL ANGLE    | 5                    |

V. OPTIMIZED MODEL RESULTS

Optimization is completed and results are taken 6 iterations to complete the thickness and topology optimization. Topology method using Optistruct is shown in above figure, steps are involved is same like free size optimization. Response is given for volume fraction as 0.3% from the total volume and weight compliance as an objective which will reduce the weight of the component by giving innovative shape to wing. Topology optimization problem setup takes 17 iterations to solve and to give innovative design to develop wing ribs in same shape for production. After getting thickness and topology results redesign of model is designed in CATIA V5R19 software and submitted for production and manufacturing of Wing Rib structure.

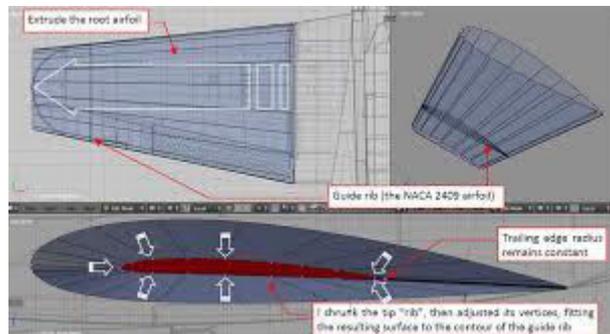


Figure 3. OPTIMIZED MODEL

5.1 STRESS COMPARISON OF TWO MODELS:

| CONTENTS         | BASE MODEL | OPTIMIZED MODEL |
|------------------|------------|-----------------|
| STRESS( MPa)     | 237        | 238             |
| DISPLACEMENT(mm) | 1.98       | 2.21            |
| MASS(kg)         | 28         | 24              |

The above table shows the comparison of stress, displacements and mass of two models, which is below the yield point value of Aluminum 2024-T3 material. Optistruct software was developed to produce an innovative rib design, which resulted in an optimized weight saving over 500kg per aircraft. Wing Rib will sit in aircraft wing structure as shown in below figure

VI. CONCLUSION

The present work illustrates how topology, sizing and shape optimisation tools may be used in the design of aircraft components. The technology has been successfully used in an industrial environment with short industrial time scales

and has on a single application proved to be able to provide efficient stress and stability component designs. Initial studies have shown that care should be taken in the modelling of the load and boundary conditions of the components. For aircraft component design it is also important to be aware of the impact of changing loading situations. The truss type designs obtained using the topology optimization is highly specialized designs optimized for certain loading situations. Load definitions generally change as the design of an aircraft mature, and this could seriously affect the optimality of the structure. It could therefore prove important to carefully select applications for topology optimization and only use the technology on structures with well Defined loading conditions. The variation of pressure is induced in optimized model compared to base model as per the requirement of below yield point stress which is 325 Mpa and as well as the variation of displacement is induced in optimized model compared to base model which is lower than the 3 mm as per the requirement. As per the given requirement the reduction of weight is 16% decreased compared to reference model. Hence the cost analysis also reduces by using the base model and optimized model readings.

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