

CONVENTIONAL AIRCRAFTWING PRELIMINARY DESIGN

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Abstract – The plain Wing Box of a two setter conventional aircraft is modelled with the help of Catia. This is exported to other software/tools. in order to be subjected to analysis of its torsional strength. stress/bending moment distribution shear. etc... on the component parts of the wing box. The type of wing selected with its component parts are described in details in regards to its individual contribution and necessity to the overall wing box structural strength and manufacturability. For the case of simplified study. the first wing has been chosen to have a circulation cross section for the stringers (skin stiffeners). two trans-versing spar (span wise) and several axially (with reference to the fuselage axis) placed webbed rib between the spars.

Also describing the basic structure of a wing and the components used in it. The function of stringers and spars. the longitudinal stiffeners in the wing. The designing of spars in a wing is also shown with the help of screenshots in CATIA V5 software. Load representative of an aircraft will be considered in this study. The wing-box model is further analyzed with Ansys software for structural optimization (i.e. Mass. Stress, twist etc.). through the consideration of different parameters.

1. INTRODUCTION

The three most important. structured components of an aircraft. namely the wings. fuselage and empennage. are considered from the point of view of stressing as beams or cantilevers with variable loading along their lengths. Aircraft wing consists of basic components like stringers running along the wing spar ribs positioned at different stations along span wise direction. front and rear spars; upper and lower skins as shown in fig. 1. Each of these components act like a beam and torsion member as a whole. The wing-box is built in the assembly jigs where all the ribs and spars are loaded in a specific sequence.

This is given in five stages:

- 1) Complete structure assembly. i.e. ribs. front spar. rear spar.
- 2) Slaved and drilling of top skin panel.
- 3) Slaved and drilling of bottom skin panel.
- 4) Installation of bottom skin panel.

- 5) Installation of top skin panel.

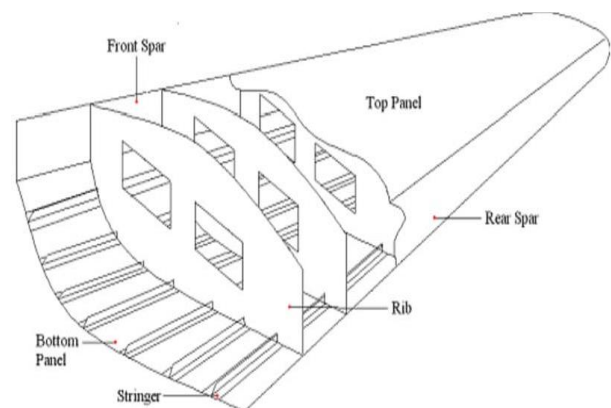


Figure 1.1 Wing box components

Assembly of the wing box is a very time consuming and labor-intensive process using manual drilling and fastening methods with dedicated jigs and fixtures. Preferably. much of this process should be carried out automatically. Removal of the misalignments occurring during part-to-part assembly is however a necessary pre-automation challenge. Recent studies conducted in Airbus UK highlights dimensional problems within aircraft structure during the assembly process. It has been observed that a completed wing that has come out of the assembly jig was twisted due to change in the structural shape during assembly. This could be attributed to the rib profile that may have changed during installation of the panels. This emphasizes a serious difference between the expected profile and the profile obtained during and after the assembly process.

1.1 PURPOSE

The wing box structure will be designed and analyzed for a two setter conventional aircraft.

1.2 REQUIREMENTS FOR ITS GIVEN MISSION PROFILE

Range : 926km = 3040000ft Vcruise : 66.88m/s = 219.44ft/s hcruise : 2440m = 8000ft Wcrew : 100kg = 220.26lb Wpayload : 100kg = 220.26lb

Obtained results from the aircraft design project:

The takeoff mass (W0). empty mass (We) and fuel mass (Wf) of the designed aircraft are estimated from the calculations as follows:

$$W0 = 2041.88lb = 926.18119 \text{ kg } We = 1222.19lb$$

$$Wf = 216.988lb = 98.5kg$$

Thrust to mass ratio and wing loading

Wing loading can also be calculated as the ratio of maximum takeoff mass to wing wetted area.

$$Swet(wing) = 19.82m^2$$

Wing loading (Wtakeoff/Swet(wing)) = 2041.88/19.82 = 103.02 lb/ft^2 Hence we can say that a safety factor of about 1.776 was consider to take the wing loading as 17 lb/ft^2

1.3 WING GEOMETRY SIZING

The actual wing area can be calculated simply as the take-off mass divided by the takeoff wing loading. But this wing area is the reference area of the theoretical. trapezoidal wing and includes the area extending into the aircraft centerline. Both values are found above and in previous study. Therefore;

$$Swing = W0/(W/S)0 = 1764.805/17 = 103.806ft^2 = 9.644m^2$$

The aspect ratio has been chosen as 7 before. The span of the wing can be found now:

$$b_{wing} = \sqrt{AR \times S_{wing}} = 26.96 \text{ ft} = 8.217m$$

We can find the root and tip chords by using the geometric equations below: Taper

Croot = 2S / b(1+λ) = 5.5ft= 1.677m ratio (λ) has been chosen as 0.4 before;

$$Ctip = λ Croot = 0.6708m$$

| Geometry | b (m) | Croot (m) | Ctip (m) | Ĉ (m) | Ŷ (m) |
|----------|-------|-----------|----------|--------|-------|
| Wing | 8.217 | 1.677 | 0.6708 | 1.246 | 1.761 |

| | |
|---|-----------------------|
| Horsepower To Mass Ratio (hp/W)takeoff | 0.085 |
| Wing Loading (W/S)takeoff | 17 lb/ft ² |
| Clmax (Plain Flaps) | 1.8 |
| Vstall (sea level. standard day. landing conf.) | 52.77 knots |
| Vstall (sea level. standard day. takeoff conf.) | 59 knots |
| Vstall (sea level. standard day. cruise) | 55.95 knots |
| Vstall (5000ft. hot day. landing conf.) | 59.22 knots |
| Take off Ground Roll (sea level. standardday) | 1000ft(304.8) |
| Take off field length (seal level. standardday) | 1300ft(396.24m) |
| Landing Ground Roll (seal level .standardday) | 755.56ft(230.3m) |
| Landing Field Length (seal level .standardday) | 1355.56ft(413.18m) |
| Altitude (for best range) | 24447.43ft(7451.6m) |
| Mbest range (sea level) | 0.214 |
| (L/D)max | 13.52 |
| hpcruise/hptakeoff | 0.415 |
| Vbest endurance (loiter) (sea level) | 61.5 knots |
| Instantaneous Turn Rate (cruising altitude) | 34.658 deg/s |
| Climb Gradient (G) (Beginning of Climb) | 0.2332 |
| Rate of climb (Vy) (Beginning of Climb) | 27.87 ft/s |
| Climb Gradient (G) (End of Climb) | 0.0835 |

Table 10.1. Characteristics of wing

| | |
|------------------------|-----------|
| Characteristics | WING |
| Airfoil | NACA 4415 |
| Aspect Ratio | 7 |
| Wing Sweep(l.e.) | 8.6° |
| Wing Sweep(c/4) | 4° |
| Taper ratio (λ) | 0.4 |
| Twist | untwist |
| Dihedral | 0° |
| Incidence | 2° |
| Wing Tip | Sharp |
| Wing Vertical Location | Mid |

| | | | | |
|-------------|-------|-------------------------|-----------------------------------|-----------------------------------|
| | | <i>Clean at M = 0.2</i> | <i>Takeoff Flapped at M = 0.2</i> | <i>Landing Flapped at M = 0.2</i> |
| $C_L - C_D$ | C_D | $0.038+0.054$ $2C_L$ | $0.0656+0.05$ $42C_L$ | $0.0932+0.0542$ C_L |

Table 10.3. Drag calculations

| | | <i>Clean at M = 0.2</i> | <i>Takeoff Flapped at M = 0.2</i> | <i>Landing Flapped at M = 0.2</i> |
|---------------|---------------------------------|-------------------------|-----------------------------------|-----------------------------------|
| CL - α | $C_{l\alpha}$ (1/deg) | 0.0929 | 0 1 1 | 0.11 |
| | C_{Lmax} | 1.526 | 0 1 1 | 1.862 |
| | $\alpha_{L=0}$ (deg) | -1.2 | - 5 3 5 | -7.42 |
| | α_{Clmax} (deg) | 14.67 | 1 2 6 6 | 11.51 |
| | $\Delta\alpha_{Clmax}$ (deg) | 2 | 2 | 2 |

Table 10.2. Lift calculations

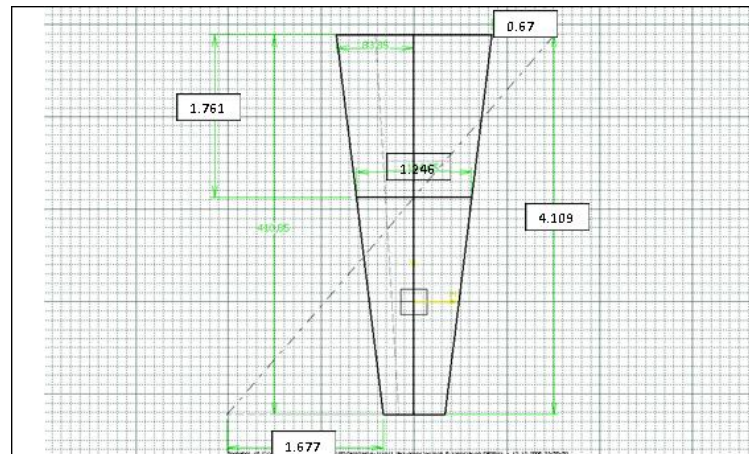


Figure 1.2 Top view of the wing

When the wing is designed, it is considered that the length of the entering part to fuselage as nearly 0.30m. This part exists at the location of the maximum fuselage diameter. However, the aileron and flap lengths sums are approximately 3.4m. After flap there is 0.42m to the fuselage. In order to not close the flap to fuselage it is selected the distance between the flap and fuselage on wing is 0.30m. Flaps, ailerons, elevator and rudder dimensions are determined in previous study "Initial Sizing".

Flaps: Flaps are placed on the wing which is 40% of the span and 24% of the chord. $cf / cw = 0.24$; $bf / bw = 0.40$

$$cw = 1.246m \text{ and } cf = 0.24 \times 1.246 = 0.299m$$

$$bw = 8.217m \text{ and } bf = 0.40 \times 8.217 = 3.2868m \text{ (For each wing = 1.6434m)}$$

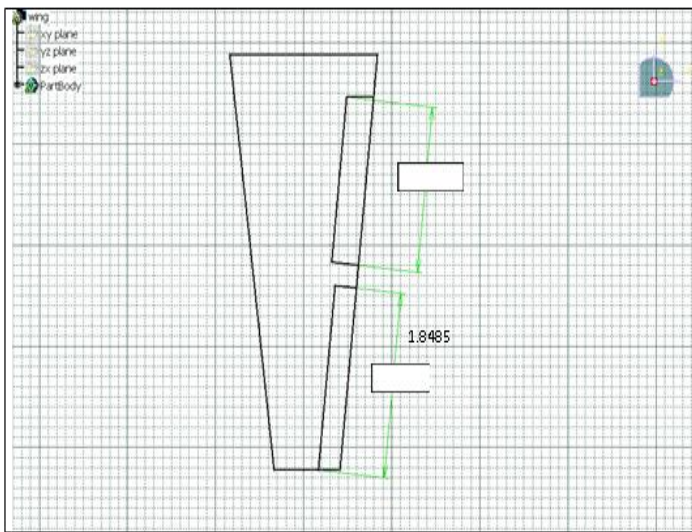


Figure 1.3 The sketch of the wing with flap and aileron

1.4 LOCATION OF CENTRE OF GRAVITY POINT

For a stable aircraft, the wing should be initially located such that the aircraft center of gravity is at about 30% of the mean aerodynamic chord. When the effects of the fuselage and tail are considered, the center of gravity would be about 25% of the total subsonic aerodynamic center of the aircraft [1].

The mean aerodynamic chord of wing is 1.246m. According to above information, the location cg point is 0.3115m. The desired location of the cg point is shown in Figure

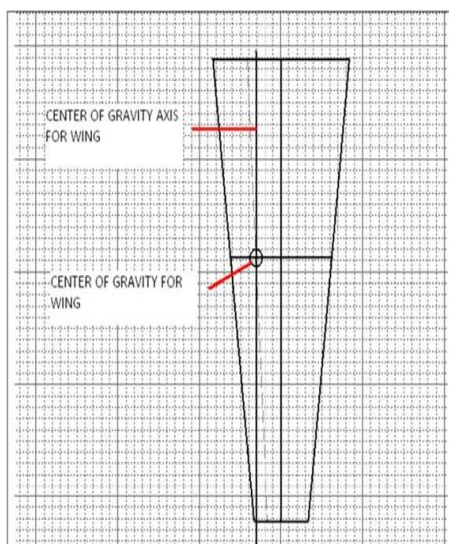


Figure 1.4 Location of C.G on the wing

1.5 FUEL SYSTEM

$$V_{total} = 2V_{wing} = 0.155156m^3$$

$$M_{Total} = (0.85) (785) (0.156) = 104.1kg$$

This obtained value is really good value for this design. The required mission fuel mass is 98.5kg. However, for integral tanks there is foam in the wing to prevent fire and leak. This foam covers 2.5% of the volume Also 2.5% of the fuel is absorbed by the foam. When these losses are considered, remaining fuel is nearly the same the mission fuel.

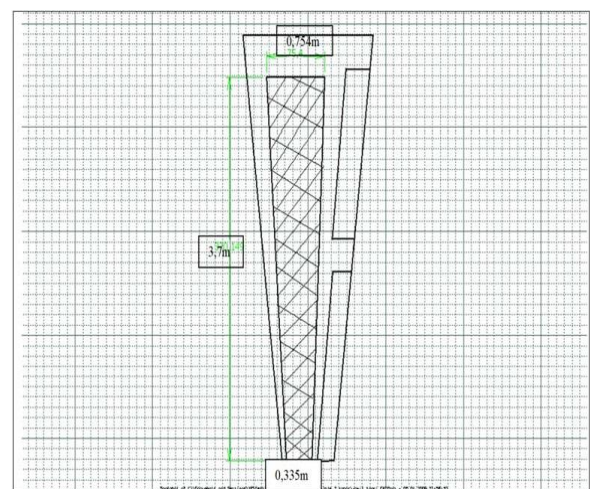


Figure 1.5 Fuel tank in the wing

2. WING BOX CAD MODELLING

2.1. Introduction

The model of the conventional wing box for half span the full wing, is done using the Catia software. Its dimension was obtained from the previous aircraft design project on two-seater conventional aircraft which is also in the references list. A circular cross section was considered/modelled first for its stringers. So that in subsequent analysis, a different cross section can be considered and compared with the circular one for better structural strength.

2.2. Parameters

$$\text{Wing Sweep (L.E.)} = 8.6^\circ$$

$$\text{Half Span, } b_{wing}/2 = 8.217/2 = 4.1085m$$

$$\text{Root Chord, } C_{root} = 1.677m$$

$$\text{Tip Chord, } C_{tip} = 0.6708m$$

Front Spar is located 15% of chord length from L.E. Rear Spar is located 70% of chord length from L.E. 9 webbed rib with 410.67m spacing between each.

Circular stringers with 0.03m diameter. Stringers and its location on the cover surface at root chord (same ratio for the tip chord) are:

8 stringers on the bottom cover (between the two spars) with spacing of 0.10121m from the front spar.

8 stringers on the top cover (between the two spars) with spacing of 0.10145m from the front spar.

4 stringers on the L.E. cover with spacing of 0.10145m from the front spar Airfoil NACA 4415

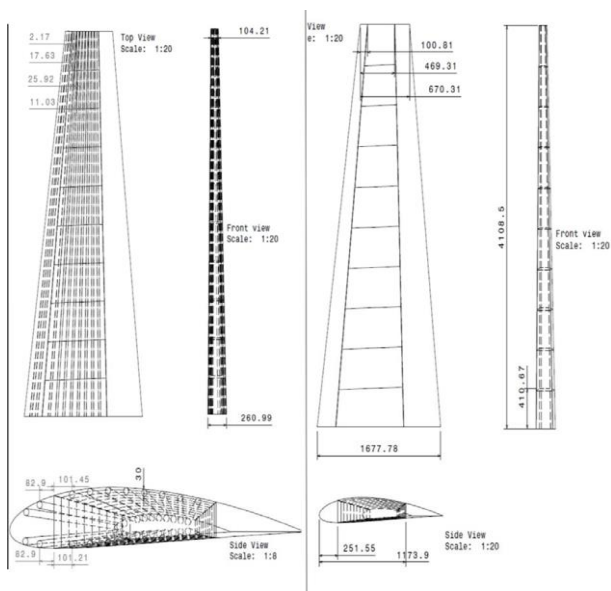


Figure 2.1 Model Dimensions

3. PROCEDURE

- Open Catia V5
- Go to airfoil tool website. search and plot NACA 4415 for chord length of 1. 677m and 0.6708m. Save both as .csv file.
- Open the first (root airfoil coordinate) .csv file in excel. Copy the x. y. z coordinate to 'GSD_PointSplineLoftFromExcel.xls' and run the micro to plot the airfoil spline and curve in Catia automatically.
- Repeat the above step for the second (tip airfoil coordinate) .csv file. but first edit it by adding 4.1085m to its z-coordinate and 0.1512m to its x-coordinate (obtained by $4.1085 \cdot \tan(8.6^\circ)$)
- After the curves have been plotted I Catia. Using wireframe and surface design. extrude the root airfoil to the tip one

(since it is a simple wing geometry with no kink. guide lines are neglected).

- Make two points for both root and tip chord line at 15% and 70% chord length.
- Extrude these lines to form the front and rear spar. up-to the cover surface.
- Draw 9 lines normal (perpendicular) to the rear spar up-to the front spar with equal spacing of 0.41067m
- Extrude these lines up-to the cover surface to form the webbed ribs.
- Sketch circles (18 circles) of 0.030m diameter both at the root and tip airfoil and make the constrained tangentially to airfoils. And make guide lines to join the circles span wise sequentially at the tangential point.
- Use sweep feature to generate the tube-like stringer on the cover surface.
- Make and draft of the wing box with and without stringers. rendered iso view and other wireframe view with appropriate dimensions for top. front and side views.
- Save work and create a new part work
- The new part project is created by copy the old one. This is modified to produce a partially webbed rib. using the fill feature to an external (rib edges) and internal (Circular sections as shown below) boundary. This circles are tangential to an offset of 30mm from the rib edge. The spacing between the are set using dependency formula as relation. This formula is dependent on the rib size:

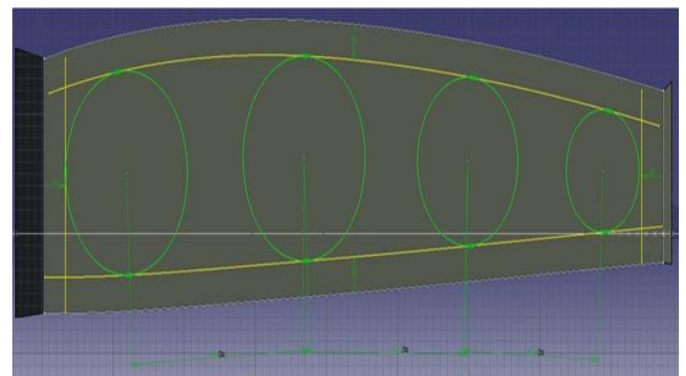


Figure 3.1 geometry for internal circular boundary of the rib

- Another partially webbed rib of circumscribed quadrilateral internal boundary is modelled. with the following geometry shown below. The quadrilaterals are tangential to the inertial circular boundary to make the comparative study between them. a relative value. But this is still constrained by the offset of the top and bottom edge of the rib. A corner of 10° arch is used to sharp the quadrilateral. Each constrain is created with a formula to help its replicability on all ribs.

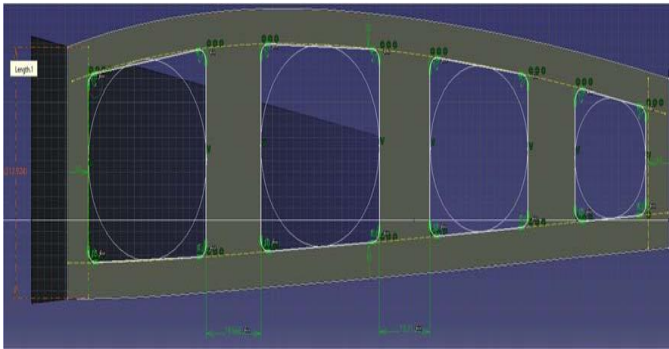


Figure 3.2 Geometry for internal circumscribed quadrilateral boundary of the rib

•Save work and exit

4. MODELLED RESULT (RENDERED VIEW):

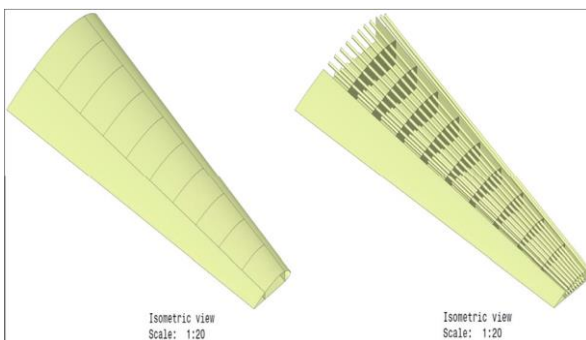


Figure 4.1 Wing-box model (rendered view)

5. CONCLUSION

The preliminary CAD design is done with the help of Catia V5 software. This modelled is initially done to analyze the importance of stringers. In subsequent modelling the fuel tank will also be included with some adjustment to the wing box geometry.

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8. BIOGRAPHIES

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