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Lift Load Determination on Wing Structure of Transport Category Aircraft

Sumanth V Madhav[1] & Vinod B[2]
[1] *Mtech Student, Department of Mechanical Engineering,*
Vidyavardhaka College of engineering, Mysuru.
[2]*Asst Prof, Department of Mechanical Engineering,*
Vidyavardhaka College of Engineering, Mysuru.

Abstract: Aircraft wing is a type of fin with a surface area which produces aerodynamic force for flight or propulsion through a fluid medium. Wings have an airfoil shape which is a streamlined cross-sectional shape producing lift. In an airframe, wing structure carry majority of lift load which tend to bends it upwards during flight. In this work a methodology is defined to determine lift load on an aircraft wing using commercially available CAD modelling software by referring wing dimensions of an existing transport category aircraft. Lift load on wing surface is determined using CFD software customized to design airfoils, wings and planes which operate at low Reynolds number. Finally, minimum angle of attack required to lift the aircraft which has to be greater than or equal to weight of the airplane load is determined.
Keywords: Lift load, Aircraft awing, Aero-foil shape, Angle of attack

1. Introduction

Aircraft wing produces aerodynamic force for flight or propulsion through a fluid medium. Wing is a framework in its simplest form made up of spars and ribs and covered with outer skin. Wings have an airfoil shape which is a streamlined cross-sectional shape producing lift. In an airframe, wing structure carry majority of lift load during flight. Basic principle behind wing design is based on Bernoulli's Principle when applied to a wing shows that air travelling over the top surface of the airfoil gains dynamic pressure and due to loss of static pressure a pressure difference is created between upper and lower wing surface which generates lift which opposes weight of airplane. Lift can be increased with change in angle of attack and critical angle of attack is an important parameter in wing design. Generally, around 14 degrees is the maximum critical angle beyond which airfoil will stall.

2. Wing Design

Modern aircrafts have a metallic or composite wing unlike older aircrafts with wood or fabric. In order to maintain its aerodynamic shape, a wing must be designed to withstand its shape under extreme stress. In general, designing a new wing is fairly a complex process which depends on many factors such as safety protocols, physical and economic constraints, manufacturer demand, end customer, environmental factors and many more. Considering complexities involved, wing of an existing transport category aircraft which is designed to fulfill all regulations and norms has been identified and for the purpose of study wing is re-designed with minor changes in terms of overall dimension.

3. Methodology to Determine Lift Load

3.1. Wing Identification

Wing of Transport Aircraft identified for this project is "BN2B-26 Islander" a twin-engine ten-seat light utility aircraft and commuter airliner produced by the British manufacturer Britten-Norman as shown in figure below. It is a rugged and durable aircraft that has good field performance, low operating costs and easy maintenance. One unusual feature is that there is no center aisle between seats in the main cabin instead there are three doors along each side of the fuselage for passenger boarding. Wing specification of existing and modified wing design is as shown in table 1 below.

Figure 1: BN2B-26 Islander Aircraft

Table 1: BN2B-26 Islander Wing specification

Wing Specification	Existing Wing	Modified Wing
Wing Span	14.940 m	*12.274 m
Fuselage Width	1.210 m	*1.210 m
Chord Length At Root	0.2030 m	*1.437 m
Chord Length At Tip	0.2030 m	*0.761 m
Max Speed Of The Aircraft	77.77 m/s	77.80 m/s
Wing Area	30.20 m^2	*13.43 m^2
Dihedral & Sweep Back Angle	NO	NO
Aero foil At The Root	NACA 23012	NACA 23012
Aero foil At The Tip	NACA 23012	NACA 23012
Length Of Each Wing	6.865 m	*6.137 m
Mach Number	0.229	0.229
Density of Air	1.225 kg/m^3	1.225 kg/m^3
Reynolds Number	150000	150000
Maximum Wing Loading	99.2 kg/m^2	99.2 kg/m^2
Maximum Take-off Weight	2993 kg	2993 kg
Load Carried By Two Wings	2544 kg	2588 kg
Load Carried By Each Wing	1272 kg	*1294 kg

* indicates specifications changed in modified wing

3.2. Wing Modeling

Wing structure is modeled using CATIA V5R21 Computer Aided Design software. Aero foil shape is NACA 23012 type, airfoil coordinates at wing tip and root are extrapolated to determine wing span. Aero-foil drawings are created at wing root & tip for surface grid another sketch is created using a guide curve. The guide curve is required in creation of wing, it links the trailing edge of root and tip. Volume is created from previous drawings and outer surface wing shell is created. Finally, components of wing are assembled together using rivets.

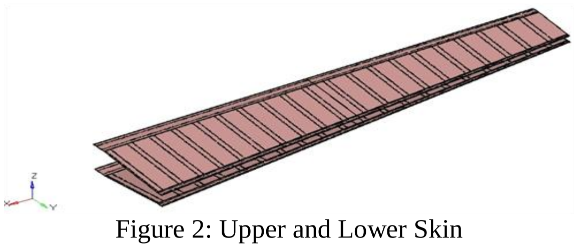

Figure 2: Upper and Lower Skin

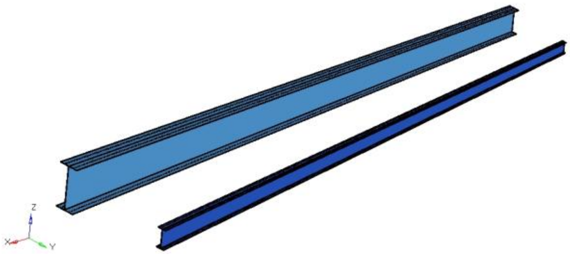

Figure 3: Front and Rear Spar

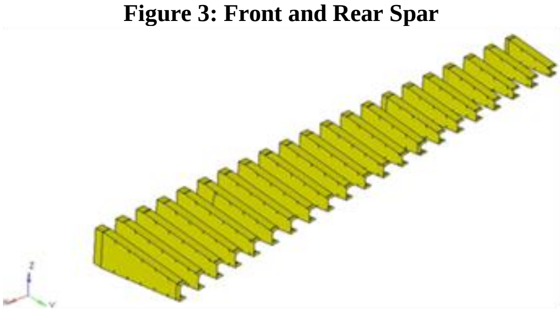

Figure 4: Ribs

Figure 5: Stingers

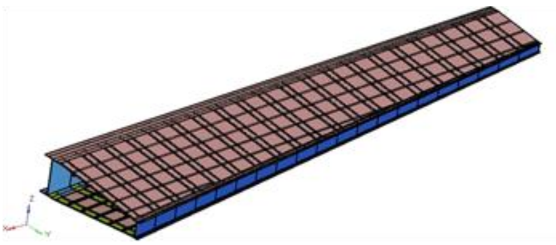

Figure 6: Wing assembly

Table 2: Thickness details of wing components

Sl. No	Wing components	Count	Thickness
1	Skin Panel	2	2.0 mm
2	Spar	2	5.0 mm
3	Rib	21	2.5 mm
4	Stringer	8	2.5 mm
5	Rivets (diameter)	6241	2.5mm

3.3. Lift Load Determination

Lift load distribution on wing surface is determined using XFLR5 which is a computational fluid dynamics software customized for wing performance calculation and is available as open source. A grid is created on wing surface using option 3D Panels option which in turn permits application of lift load on each grid cell. Without redoing all the aerodynamic lift load calculations, final wing dimensions are adjusted for dimensionless coefficients. With aerodynamic study, modification of wing chord and its span is important and structural model parameterization allows these changes without modification. Steps involved in designing and analyzing a wing in XFLR5 software is shown below.

3.3.1. Direct Foil Design

In direct foil design aero-foil shape can be modeled by creating grids or standard foil files can be selected stored in runtime database. Grid refinement increases probability to obtain approximate results. However, complications are involved during computation and refinement in grid is attributed to degree of precision expected in end result. Modifications of camber, thickness, max camber positions and max thickness allow change in foil shape. Aerofoil shape NACA23012 is adopted in BN2B-26 Islander and hence the same is used from standard aerofoil library as shown in figure below.

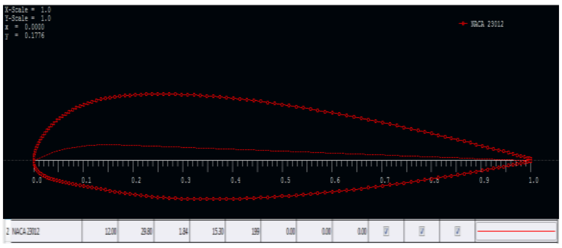

Figure 7: NACA23012 Aerofoil Shape

3.3.2. Wing and Plane Design

In XFLR5 each panel is defined by its length, tip chords and root, leading edge offset at tip chords and root, dihedral angle and mesh. For analysis wing is defined as a set of panels. In VLM elements span-wise length of a panel should be at least to minimum length of VLM elements on other panels. Division by zero could result from panels with insufficient length. The wing is shown on a horizontal planform for ease of interpretation. Both in wing design dialog box and 2D view.

Realistic representation of geometry can be seen only in 3D view. The reference area for all wing and plane aerodynamic coefficients is the main wing's area. Flap are not included in wing design as buckling occurs more near the wing root. A plane consists in a main wing, and optionally of a secondary wing, an elevator, one or two fins, and a body. Objective of this thesis is to check buckling in wing, other entities are not considered for analysis.

Steps involved in wing design using XFLR5 software is as follows,

1. Open a new wing design window
2. Define data for wing such as span length (Y-axis), chord length (X-axis), offset, dihedral, twist angle, foil type, distance & panels along X & Y direction.
3. Providing above data will give overall wing dimension along with aero-foil shape at each rib.
4. In polars update required data such as polar name, free stream speed, polar type, aerodynamic data and wing analysis method.
5. Wing is symmetric about X-axis and lift load is found for full wing. But buckling analysis is performed only for half wing.
6. Minimum lift load required for BN2B-26 Islander wing is 2544 kg.
7. By changing angle of attack from -2.0° to 5.7° lift load required for each wing is calculated until a minimum value of 1272 kg is achieved. Lift load calculation for 5.77° angle of attack is shown below.

3.3.3. Wing area & chord length

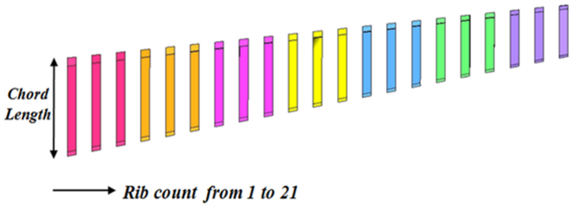

Figure 8: Rib count from root to tip

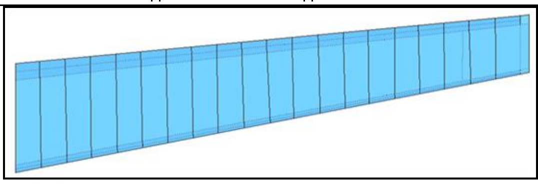

Figure 9: Skin panel area between ribs

Table 3: Wing and rib data

Rib	Rib Location in mm	Chord Length in mm	Area in m^2
1	0	1437	0.423
2	300	1400	0.422
3	600	1367	0.397
4	900	1334	0.407
5	1200	1301	0.382
6	1500	1267	0.378
7	1800	1234	0.368
8	2100	1201	0.353
9	2400	1168	0.349
10	2700	1135	0.34
11	3000	1101	0.318
12	3300	1068	0.329
13	3600	1035	0.304
14	3900	1002	0.286
15	4200	968	0.297
16	4500	935	0.268
17	4800	902	0.264
18	5100	869	0.261
19	5400	834	0.251
20	5700	800	0.233
21	6143	761	0.081

Wing design specifications in XFLR5 for modified BN2B-26 Islander wing:
Total area of each wing = 6.712 m^2
Y distance in mm= 0 to 6000 mm
Chord in mm= 2030 mm
Offset distance= 0 mm
Twist & Dihedral angle = 0^0 deg
Aerofoil type = NACA 23012 from root to tip
X & Y direction panel count = 1 panel
X & Y direction distance type = uniform

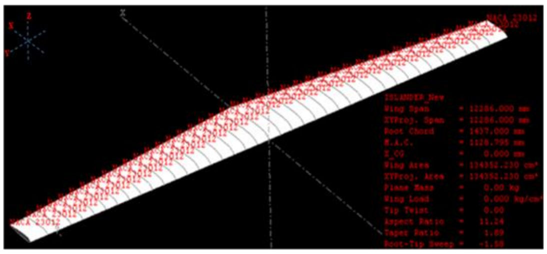

Figure 10: Aero-foil shape at root and wing tip

3.3.4. Lift load calculation

An aircraft's lift capabilities can be measured from the following formula:

$L = (1/2)\ d \times v^2 \times s \times CL$

L = Lift load in kg

d = density of air 1.225 kg/m^3

v = velocity of an aircraft 77.80 m/s

s = wing area of aircraft in m^2

CL = co-efficient of lift is determined for NACA 23012 type airfoil & 5.77° angle of attack. Results are tabulated as shown in table below.

Sample calculation:

To determine lift load for y-span=0.15m

L= 0.5×1.225×77.80×77.80×0.4227×0.50105= 80.04 kg

Table 4: Lift load calculation for 5.77° angle of attack

y-span in m	Chord in m	CL in kg. m/s2	width in m	Area in m2	Lift load in kg
0.15	1.419	0.50105	0.3	0.4227	80.04
0.45	1.384	0.50993	0.3	0.4223	81.39
0.75	1.351	0.51649	0.3	0.3975	77.59
1.05	1.318	0.52189	0.3	0.4073	80.33
1.35	1.284	0.52654	0.3	0.3824	76.09
1.65	1.251	0.53039	0.3	0.378	75.77
1.95	1.218	0.53333	0.3	0.3684	74.26
2.25	1.185	0.53555	0.3	0.3531	71.47
2.55	1.152	0.53702	0.3	0.3493	70.88
2.85	1.118	0.53790	0.3	0.3398	69.07
3.15	1.085	0.53787	0.3	0.3179	64.61
3.45	1.052	0.53656	0.3	0.3289	66.68
3.75	1.019	0.53387	0.3	0.3041	61.36
4.05	0.985	0.52960	0.3	0.2856	57.16
4.35	0.952	0.52285	0.3	0.2967	58.62
4.65	0.919	0.51229	0.3	0.2675	51.8
4.95	0.886	0.49619	0.3	0.2645	49.6
5.25	0.852	0.47145	0.3	0.2609	46.49
5.55	0.817	0.43006	0.3	0.2514	40.86
5.92	0.781	0.34408	0.3	0.314	40.83

Lift load required for each wing = 1294 kg

4. Results

Table 5: Load comparison table

Load details	Existing Wing	Modified Wing
Lift load on each wing	1272 kg	1294 kg

From the above table it can be concluded that lift load on modified wing is greater than existing wing and hence under ideal conditions modified wing can withstand lift load.

5. Conclusion

Objective of this work is to define a methodology to determine lift load for airplanes using commercially available CAD and CFD software's. Wing design by large is a complex process and hence to simplify for the purpose this study an existing aircraft wing is re-designed. Lift load distribution on wing surface is calculated using XFLR5 which is customized CFD software to determine wing performance. From this study several conclusions were drawn,

1. This method is suitable only for aircrafts operating at low Reynolds number.
2. XFRL5 is freely available as open source software which is customized for wing performance calculation. However other CFD packages such as ANSYS – Fluent, COSMOL multiphysics, Open FOAM can be used for more precise results.
3. Change in value for angle of attack can significantly improve lift load value. But designer should ensure that it does not exceed 14 degrees since it is the maximum critical angle beyond which airfoil will stall.
4. Lift load is calculated for standard values of air density and velocity of aircraft.
5. With the complexity of wing structure and pay load on airplane, wing design approach may differ. The above approach remains similar for most of aircrafts.

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