

DEVELOPMENT OF EDUCATIONAL SOFTWARE FOR STRESS ANALYSIS OF AN AIRCRAFT WING

J. S. MOHAMED ALI*, TAZKERA SADEQ

Department of Mechanical Engineering, Kulliyah of Engineering, International Islamic
University Malaysia (IIUM), P.O. Box No. 10, 50728, Kuala Lumpur, Malaysia

*Corresponding Author: jaffar@iium.edu.my

Abstract

A stress analysis software based on MATLAB, Graphic user interface (GUI) has been developed. The developed software can be used to estimate load on a wing and to compute the stresses at any point along the span of the wing of a given aircraft. The generalized formulation allows performing stress analysis even for a multispar (multicell) wing. The software is expected to be a useful tool for effective teaching learning process of courses on aircraft structures and aircraft structural design.

Keywords: Education, Software, Stress analysis, Aircraft wings, MATLAB.

1. Introduction

It's a well known fact that computers have brought in a great revolution in the field of engineering education with the basic power point presentations in the class room lectures to the advanced educational softwares. Educational softwares and educational games have contributed to a great level in the teaching learning process; the otherwise difficult concepts for students to understand were made easy by these tools.

The importance and role of educational software in engineering education is well brought out by Timothy [1] in his work on MDSolids: an educational software for Mechanics of Materials. He pointed out that, out of six levels of the Blooms taxonomy given by Benjamin S. Bloom [2] namely: knowledge, comprehension, application, analysis, synthesis and evaluation; the students learn the first three levels from the classroom lectures, but to acquire the other three higher levels, students need to either carryout a project or long assignments. As both the lecturers and students don't find time for these projects/long assignments

Nomenclatures

A_R	Area of the R^{th} cell, m^2
B	Boom area, m^2
b	Wing span, m
c	Wing chord, m
f	Safety factor
G	Modulus of rigidity, N/m^2
GUI	Graphical User Interface
I_{ij}	Moment of inertia along i, j axes, m^4
MS	Margin of safety
M_x, M_y	Bending moments along x and y axes respectively, Nm
N	Number of cells
n^{op}	Operational load factor
P	Concentrated load, N
p_{exc}	Distributed excessive load, N/m
q	Shear flow, N/m
S	Wing Area, m^2
S_x, S_y	Shear forces along x and y axes respectively, N
t	Thickness of the web/skin, m
T	Torque, Nm
W	Aircraft weight, N
W_w	Wing structural weight, N
<i>Greek Symbols</i>	
δ_{ij}	Length of the web ij divided by its thickness
θ	Twist of cell, rad
σ	Bending stresses, N/m^2
τ	Shear stresses, N/m^2

for each course, the students are not able to gain the expected outcomes of the course. It is here that educational software comes for help, which is a self study package, with students learning on their own without taking away the time of lecturer. The students can repeat and research with variety of problems in a short time and gain confidence in the subject thus achieving the outcomes of the course, further, the lecturers can use this software for framing short term projects.

Apart from the MDSolids [1]: an educational software for mechanics of materials, numerous other educational softwares useful for engineering students have been reported in the literature such as Rodriguez, et al. [3] and Zigic and Lemckert [4] for to teach telecommunication engineering and water quality modeling respectively. Software similar to MDSolids, is present for lower level subjects such as mechanics of materials [5, 6], statics and dynamics, where as for advanced level subjects such as machine design, aircraft structures, etc. where really one needs a software, it is just left with home assignments. Moreover the students of advanced courses such as aircraft structures finds it very difficult to understand the concept of advanced mechanics of materials topics such as unsymmetric bending, shear centre and shear of open and closed unsymmetrical section. Hence an educational software associated with such advanced courses

will be very useful to the students and it will act as a complementary tool to traditional teaching and learning methods.

Moreover students solving problems on independent chapters of bending, shear and torsion could not visualize and relate its application on the analysis and design of aircraft structures. A comprehensive short term project based on a available software given to the students starting from the load estimation until the final estimation of stresses on an aircraft wing will make them crystal clear about the application of these advanced topics in analysis and design of aircraft structures.

To bring in all the important concepts taught in the aircraft structures course namely: unsymmetric bending, shear centre and shear of open and closed unsymmetrical section; a multi spar wing has been chosen for analysis so that one can analyse multicell problems which is considered to be the most difficult problems among students. These multispar wings will produce chordwise multi-cell airfoil sections and as the number of cells increases, it becomes more and more difficult to conduct stress analysis manually. Therefore, this work aims to develop a software that can conveniently compute stresses at any section along the span of a multi-spar wing. The program will be made general so that it may be applied to various types of aircraft with a variable combination of number of spars, material of wing, wing dimensions as well as locations of concentrated structural loadings. The software also incorporates options to compute bending, shear and torsional stresses individually if the internal load values are known before. The graphical user interface development environment (GUIDE) along with application programming in MATLAB version 7 has been used to develop the software.

2. Methodology

A multispar design of a fighter wing with its corresponding airfoil section (cross section of wing) represented as a multicell box as shown in Fig. 1 has been considered for stress analysis. Although the skin of the nose of the airfoil section carries some shear load, it is small in comparison to the shear load carried by the webs and therefore, it is often neglected, moreover the trailing edge of the airfoil section is usually occupied by flaps/aileron and thus it can be neglected from the multicell box beam. Thus multicell airfoil section in Fig. 1 with leading and trailing edge skins removed (shown as dotted line in Fig. 1) can be idealized to get a basic idealized multicell box beam as given in Fig. 2 which is made of shear only resisting thin skins/webs and with booms (concentrated areas) resisting the entire bending load. Thus in this analysis the skin/web is considered to be ineffective in bending.

Having chosen the multispar wing, the next step is to evaluate the loads and the resulting stresses as illustrated in the flow chart in Fig. 3. Initially the load estimation is carried out, and then these load distributions will be used to evaluate the bending moment and shear force on any spanwise section of the wing. Subsequently, the resulting direct stresses, shear stresses and shear centre of a multi-spar wing will be determined.

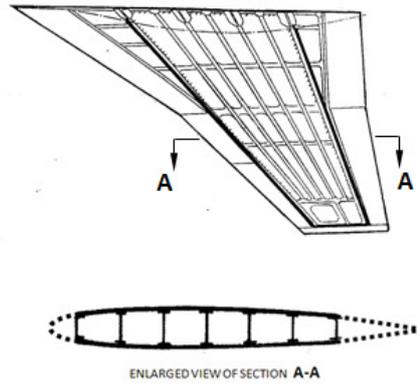


Fig. 1. Typical Multispar Wing with its Sectional View [9].

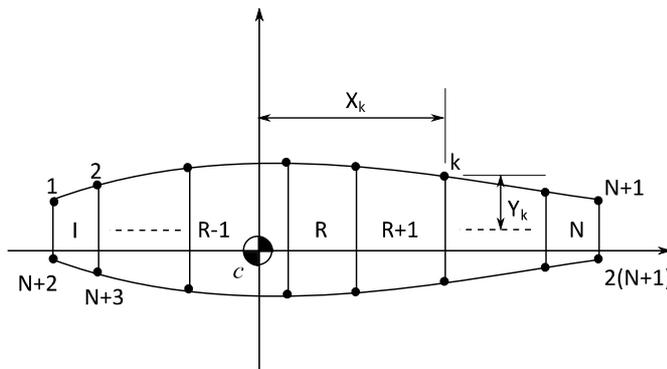


Fig. 2. Idealized Section of a Multicell Wing.

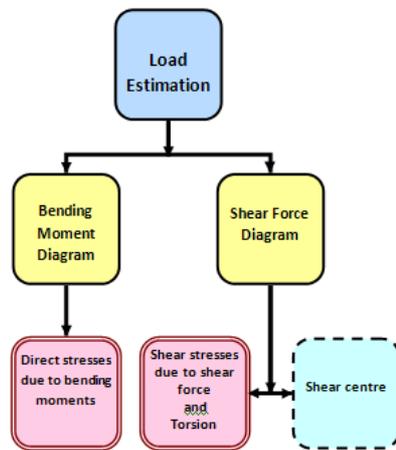


Fig. 3. Flowchart for Stress Analysis.

2.1. Load estimation

Wing Load Distribution

Under various flight conditions, the aircraft will experience bending, shear and torsional loading. The wing is exposed to various types of loadings such as aerodynamic lift and drag forces, concentrated loads due to engines, missiles or undercarriage and wing structure distributed mass loads. As the drag loads are very minimal compared to lift forces, its effect has been neglected in further calculations.

The aerodynamic and mass loads of the wing are distributed along the wing in proportion to the chord distribution along the span of the wing. As the distributed aerodynamic load (p_a) and the distributed structural weight of the wing (p_{wing}) are directed in opposite directions, the excessive distributed load (p_{exc}) is determined as

$$p_{exc} = p_a - p_{wing}$$

$$p_{exc} = \frac{(W - W_w)fn^{op}}{S}c \quad (1)$$

where c is the spanwise chord distribution, W and W_w are the weight of the aircraft and wing respectively, f is factor of safety, n^{op} is the limit load factor and S being the wing area.

The concentrated load from the units located on the wing are determined from

$$P_{unit} = P_{unit}fn^{op} \quad (2)$$

These forces are applied through the centre of gravity of the units and are considered to be directed perpendicularly to the plane of the chords acting downwards.

The half span of a wing may be approximated to a cantilever beam loaded with distributed excessive load p_{exc} and concentrated forces for the units located on the wing as shown in Fig. 4. The shear force and bending moment diagrams are obtained from the wing load distribution as a first step of stress analysis process. The developed software generate the load distribution, shear force and bending moment distribution along the span of the wing once the input to calculate p_{exc} is given.

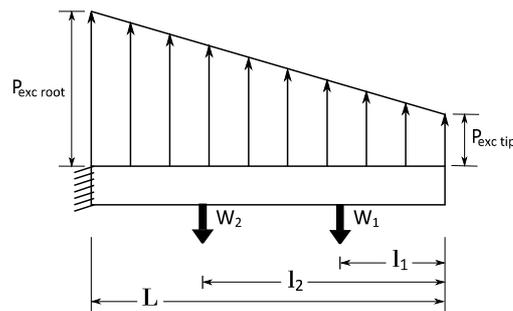


Fig. 4. Resultant Load on the Wing.

2.2. Bending stresses

The procedure to evaluate the bending stresses and the shear stresses given below are based on Megson [7]. The bending moment at any chordwise section along the span of the wing can be determined from its bending moment diagram. In an idealized multispar wing the bending moments are resisted by spar booms (spar flanges) only, which produces direct bending stresses in the booms. The direct stress system for such a wing section with general load is given by:

$$\sigma_z = \frac{M_y I_{xx} - M_x I_{xy}}{I_{xx} I_{yy} - I_{xy}^2} x + \frac{M_x I_{yy} - M_y I_{xy}}{I_{xx} I_{yy} - I_{xy}^2} y \tag{3}$$

As shown in Fig. 2, the coordinates (x,y) in Eq. (3) represents the location of any boom area on the cross-section and the sectional properties are referred to the axes Cxy in which the origin coincides with the centroid of the cross section area. The second moments of area are given as

$$\left. \begin{aligned} I_{xx} &= \int y^2 dA = \sum Ay^2 \\ I_{yy} &= \int x^2 dA = \sum Ax^2 \\ I_{xy} &= \int xy dA = \sum Axy \end{aligned} \right\} \tag{4}$$

2.3. Shear stresses

Unlike bending moments, the shear force at any chordwise section along the span produces shear stresses that are resisted by the skin and the webs of the spar. The shear force at any section can be obtained from the shear force diagram evaluated from the load estimation part. In order to evaluate shear stresses, a general N-cell section as shown in Fig. 5 is used to develop the equations required for shear. The cell comprises of booms and skin panels and the wing section is subjected to shear loading S_x and S_y , whose line of action do not necessarily pass through the shear centre S . Therefore, the resulting shear flow distribution is due to the combined effects of shear and torsion.

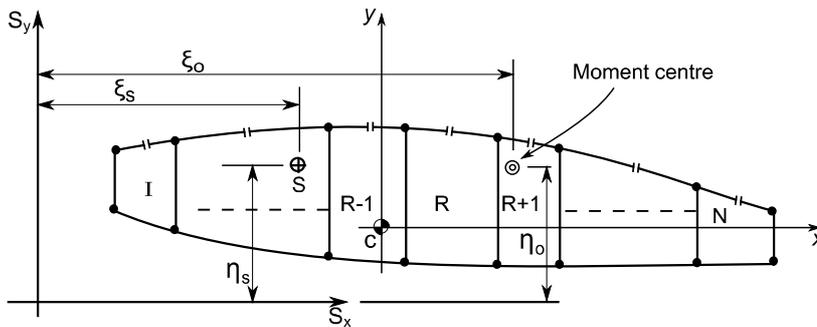


Fig. 5. Multi-cell Wing Section Subjected to Shear Loads.

The procedure followed in this work to evaluate the shear stress for a multicell problem is as following:

Step 1: Statically indeterminate multicell beam made up of N cells as shown in Fig. 5 can be made statically determinate by ‘cutting’ a skin panel in each cell, thus there are N unknowns which are the values of closed section shear flow at the cuts of each cell, i.e $q_{s01}, q_{s02} \dots q_{s0N}$.

Step 2: Find the open section shear flow q_b given by

$$q_b = - \left(\frac{S_x I_{xx} - S_y I_{xy}}{I_{xx} I_{yy} - I_{xy}^2} \right) \left(\sum_{r=1}^n B_r x_r \right) - \left(\frac{S_y I_{yy} - S_x I_{xy}}{I_{xx} I_{yy} - I_{xy}^2} \right) \left(\sum_{r=1}^n B_r y_r \right) \quad (5)$$

Step 3: Use compatibility condition $\theta_1 = \theta_2 = \theta_3, \dots, \dots, \dots = \theta_{(N-1)} = \theta_N$ that provides $(N-1)$ equations

where θ_R is the twist per unit length of a R th cell which can be given as

$$\theta_R = \frac{1}{2A_R G_R} \oint q \frac{ds}{t} \quad (6)$$

As for a closed section $q = q_b + q_{s0}$, then θ_R becomes

$$\theta_R = \frac{1}{2A_R G_R} \left[-q_{s,o,R-1} \delta_{R-1,R} + q_{s,o,R} \delta_R - q_{s,o,R+1} \delta_{R+1,R} + \oint_R q_b \frac{ds}{t} \right] \quad (7)$$

where

- $\delta_{R-1,R}$ - $\int ds/t$ for the wall common to the R th and $(R-1)$ th cells,
- δ_R - $\int ds/t$ for all the walls enclosing the R th cell and
- $\delta_{R+1,R}$ - $\int ds/t$ for the wall common to the R th and $(R+1)$ th cells.

Step 4 : Use Moment Equilibrium equation

External Moment = Internal Moment

$$S_x \eta_0 - S_y \xi_0 = \sum_{R=1}^N \oint_R q_b p ds + \sum_{R=1}^N 2A_R q_{s,o,R} \quad (8)$$

where p is the moment arm of the force due to q_b about the moment centre.

Equations obtained from step 3 and step 4 can be written in a matrix form as:

$$[A_{ij}]_{NXN} \{q_{s,o,i}\}_{NX1} = \{B_{ij}\}_{NX1} \quad (9)$$

where N is the number of cells.

From Eqs. (5)-(8), one can see that elements of matrix A_{ij} is a made up of δ_{ij} and elements of B_{ij} is made up of q_b and δ_{ij} . By solving the system of linear simultaneous algebraic Eqs. (9) with the known values of q_b (from Eq. (5)), the unknown shear flows $q_{s,o,i}$ where $i = 1, 2, \dots, N$ can be found. Once $q_{s,o}$ is obtained for all the cells, the final shear flows for each cell can be obtained from the

relation: $q_i = q_{bi} + q_{so,i}$. Finally, the shear stresses on any web or skin can be obtained by dividing the shear flow by the respective thickness of the web or skin.

2.4. Shear centre

The shear centre is a point in the cross section through which shear loads produce no twisting effects. To locate the shear centre of a N cell section, an arbitrary shear load is applied at the shear centre and the resulting shear flow is evaluated. The procedure is as follows

Step 1: Similar to the shear stress analysis, firstly introducing cuts to make the structure statically determinate results in N unknowns which are the values of closed section shear flow of each cell $q_{so1}, q_{soII} \dots q_{soN}$.

Step 2: Find the open section shear flow q_b as given by Eq. (5).

Step 3: Use the condition that shear loads acting through the shear centre of a section produces zero twist, $\theta = 0$, i.e. $\theta_1 = \theta_2 = \theta_3 \dots \theta_N = 0$, which results in N equations that can be written as

$$[K_{ij}]_{NXN} \{q_{soi}\}_{NX1} = \{M_{ij}\}_{NX1} \tag{10}$$

where K_{ij} is a made up of δ_{ij} and M_{ij} is made up of q_b and δ_{ij} . By solving the system of simultaneous equations (10), the unknown shear flows (q_{soi} where $i=1, 2 \dots N$) can be determined. Once $q_{s,o}$ is obtained for all the cells, the final shear flows for each cell can be obtained from the relation: $q_i = q_{bi} + q_{so,i}$.

Step 4: Use moment equilibrium equation to determine the position of the shear centre.

2.5. Shear stresses due to torsion

The multicell wing section illustrated in Fig. 6 comprises N cells and carries a torque T which generates individual but unknown torques in each cell. Therefore, a constant shear flow $q_I, q_{II}, \dots q_N$ is generated in each cell which are the unknowns to be determined. The procedure to determine these unknowns are as follows

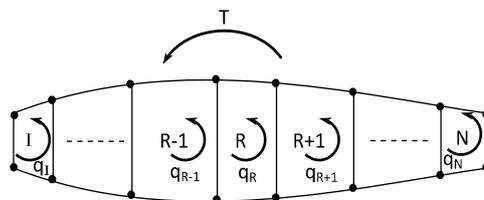


Fig. 6. Multicell Wing Section Subjected to Torsion.

Step 1: Use the condition that the total torque is

$$T = \sum_{R=1}^N 2A_R q_R \tag{11}$$

where A_R is area of each cell.

Step 2: Use compatibility condition $\theta_1 = \theta_2 = \theta_3 \dots \dots \dots = \theta_{(N-1)} = \theta_N$ that provides $(N-1)$ equations.

Therefore, Step 1 and Step 2 will give N number of equations for N unknowns which can be arranged in a matrix form, as:

$$[D_{ij}]_{NXN} \{q_{soi}\}_{NX1} = \{E_{ij}\}_{NX1} \quad (12)$$

where N is the number of cells, D_{ij} is made up of δ_{ij} and E_{ij} is made up of T . By solving the system of simultaneous equations in Eq. (12), the unknown shear flows can be obtained in each cell. Finally the shear stresses on any web or skin due to torsion can be found by dividing the shear flow by the respective thickness of the web or skin.

3. Results and Discussion

From the foregoing discussion one can understand the difficulty in solving multicell problems manually in the classroom lectures. From equations (9),(10) and (12) it can be realized that to analyze any multicell beam made of N cells under shear or torsion, as well as for to find the shear centre location one has to solve N simultaneous algebraic equations. In this work, MATLAB built-in solver was used to solve these equations. The programming for the stress analysis components discussed in the previous sections was carried out in MATLAB version 7 using the graphical user interface development environment (GUIDE). Even though the formulation presented is for general unsymmetric multicell box beam, the programming has been done only for symmetric multicell sections since most of the high speed aircraft wings are symmetric. The software is user friendly and no prior knowledge of MATLAB is required to utilize it. The programming is made based on generalized formulation in order to apply it to various aircraft wing configurations with different combinations of wing material, number of spars, dimensions of the wing section as well as locations of structural concentrated loadings. The software can also be used to analyze a single cell as a special case.

The first pop up window of the program gives the user the option to carryout either load estimation and to find values of shear force and bending moment at any section on the wing or if these values are already known, the user may directly find the bending stresses, shear stresses due to shear, shear stresses due to torsion or the shear centre independently without going through the load estimation.

The inputs for stress analysis are generally the number of spars, loads, boom areas with its location and the web length with thickness. These inputs are prompted from a window with an input title as shown in Fig. 7, so it is absolutely easy to work with. If one needs to start from the basic load calculation then additional inputs such as the spanwise chord distribution $c(y)$, the weight of the aircraft W and wing W_w respectively, the factor of safety f , the limit load factor n^{op} and the wing area S are needed. The output will be the load distribution, shear force and bending moment diagrams which are given graphically, then it can be followed by stress analysis where the output will be stresses listed along with

their reference boom area or webs. Typical input and output GUI windows are shown in Figs. 7 and 8 respectively.

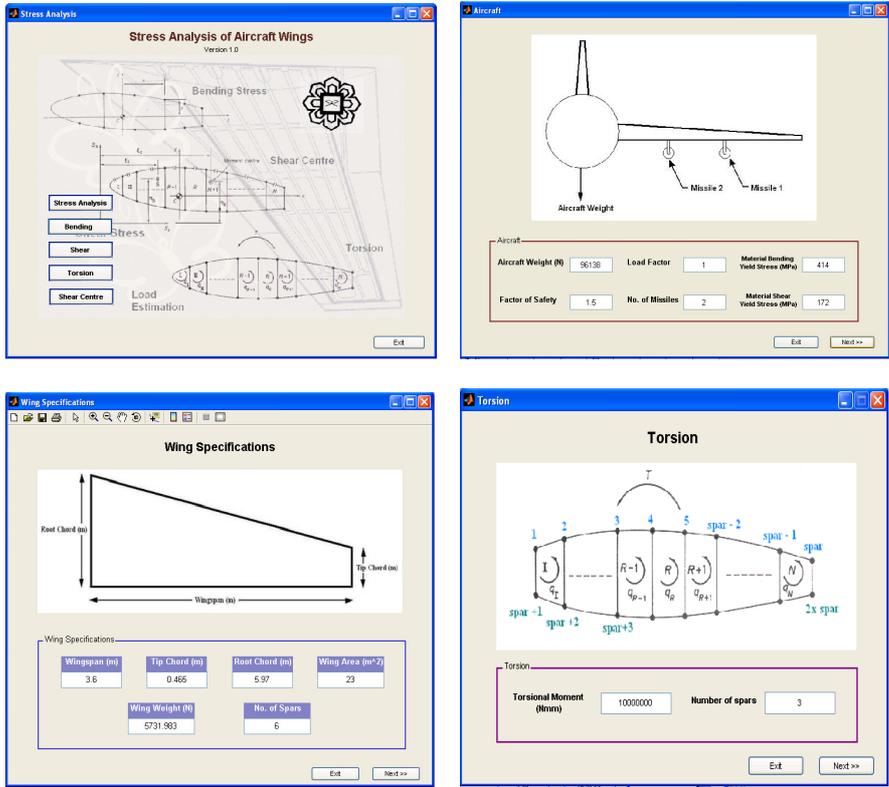


Fig. 7. Typical MATLAB GUIDE Input Windows.

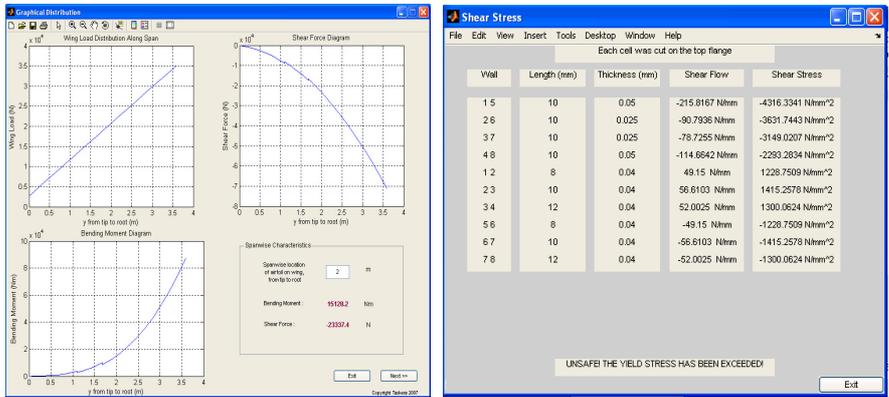


Fig. 8. Typical MATLAB GUIDE Output Windows.

3.1. Validation

3.1.1. Validation for bending stress

Figure 9 shows a two-cell section for which bending stress analysis has been conducted with an external bending moment of 100 kNm applied on the vertical plane. The final results obtained from the program are compared with the results from Megson [7] for two typical booms as in Table 1.

Table 1. Validation for Bending Stress.

Boom	Direct Stresses	Megson [7] (10 ³) N/mm ²	Software (10 ³) N/mm ²	Error%
1	σ_1	59.0	59.2535	0.42%
6	σ_6	-47.0	-47.1229	0.26%

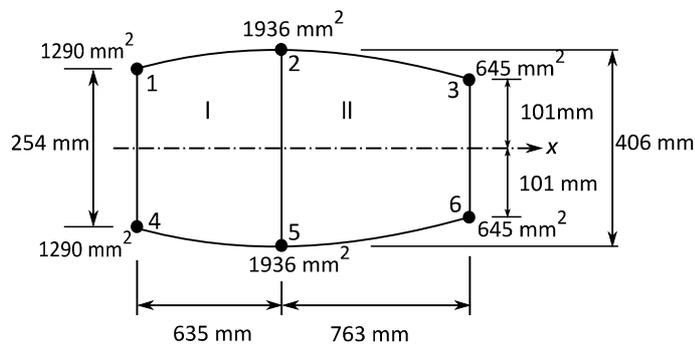


Fig. 9. Two Cell Section under Bending.

3.1.2. Validation for shear stresses due to shear load

Curtis [8] provided a solution for shear stresses due to shear load for the three-cell problem shown in Fig. 10. The results from the literature are compared with computed results as shown in Table 2.

Table 2. Typical Shear Stress Results for a Three Cell Section.

Wall	Curtis [8] Shear Stress N/mm ²	Software Shear Stress N/mm ²	Error%
1 5	-4316.0	-4316.3341	0.01%
2 6	-3631.6	-3631.7443	0.01%
3 7	-3149.2	-3149.0207	0.01%

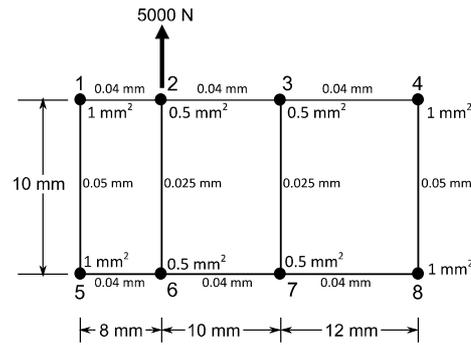


Fig. 10. Three Cell Section under Shear.

3.1.3. Validation for shear stresses due to torsion

Niu [9] has given the solution of a two-cell problem under pure torsion. The section is shown in Fig. 11. The results from the program are compared with [9] in Table 3.

Table 3. Validation for Shear Stresses due to Torsion.

Wall	Niu [9] Shear Stress N/mm ²	Software Shear Stress N/mm ²	Error %
1 4	22420	22421.5247	0.01%
2 5	560	560.5381	0.10%

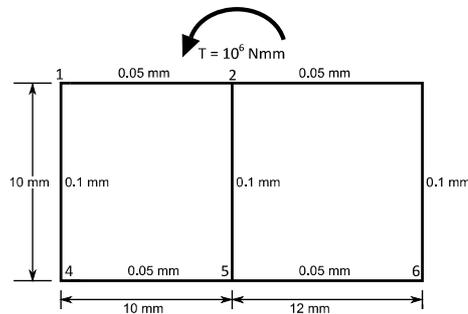


Fig. 11. Two Cell Section under Torsion.

3.1.4. Validation for shear centre

The shear centre of the five-cell problem in Fig. 12 has been evaluated by Bruhn [10] and the present software is validated for shear centre against this results. The shear centre is taken to be a distance, *x*, from the web of the first spar as shown in Fig. 12. The results are compared in Table 4.

Table 4. Validation for Shear Centre.

Bruhn [10]	Software	Error [%]
19.47 mm	19.3603 mm	0.56%

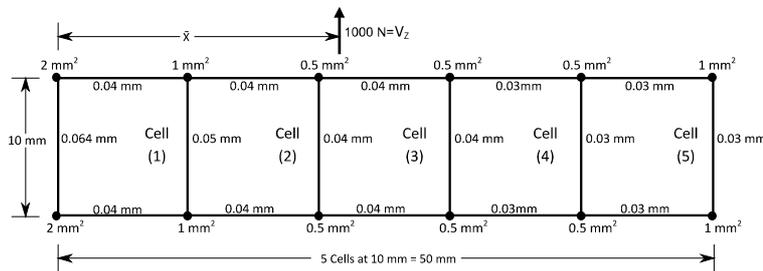


Fig. 12. Five Cell Section.

From Tables 1-4, it can be seen that the results for all the four cases are in good agreement with the literature values. Therefore, the program has been validated for all the stresses and shear centre computations. As the program has been validated, various case studies may be conducted to determine the capability of the program.

3.2. Case studies

3.2.1. Case I: Loads and stresses on an aircraft wing

To demonstrate the capability of the software, a typical fighter aircraft with delta wing configuration shown in Fig. 13 is chosen for analysis. There are two concentrated mass loadings on each half span wing. The wing is assumed to be made of a multispar which can be represented as a multicell box beam. The specifications of the aircraft wing are as listed in Table 5.

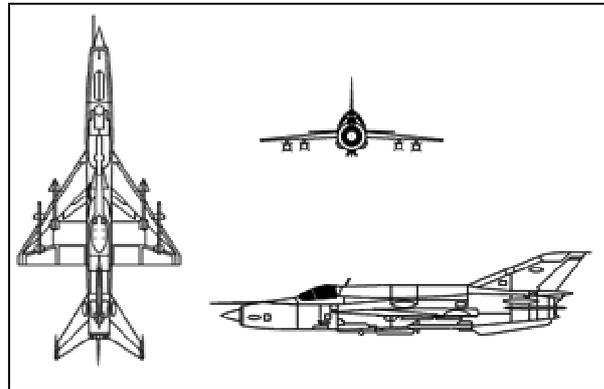


Fig. 13. The Three Views of the Typical Fighter Aircraft [11].

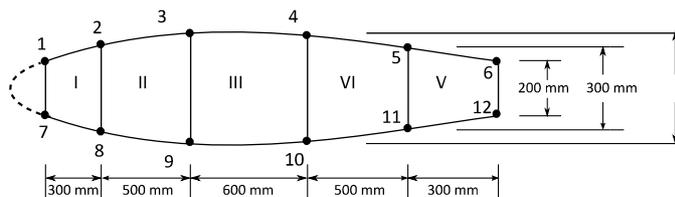
Table 5. Aircraft Specifications.

Item	Notation	Value	
Half-wing Span	b	3.6	m
Wing Area	S	23	m ²
Root Chord	c_r	5.97	m
Tip Chord	c_t	0.465	m
Missile weight (each)	w_i	870.6	N
Maximum Take-off weight	W	96800	N
Wing Structural Weight	W_w	5730	N

The aircraft is considered to be in steady level flight with an operational load factor of 1 and a factor of safety of 1.5 is assumed. The load estimation part of the program will compute the distributions of wing load, bending moment and shear force. The results are displayed on a graphical user interface. The user may key in the location of the desired section on the wing and the value of shear force and bending moment at that section will be interpolated from the graph and displayed to the user. The resulting graphical user interface is shown in Fig. 8.

The results show that the bending moment and shear force is highest at the root and lowest near the tip, as expected. Therefore, the values of bending moment and shear force at any point along the span of the wing may be determined and consequently used to find the bending and shear stresses for any section across the span of the wing.

Following the load estimation process, the stresses are evaluated at different locations along the span of the wing. The multispar wing is assumed to be made of five-cell wing section as shown in Fig. 14, which represents a typical airfoil section used for high-speed aircraft. The details of a typical wing section are assumed as in Table 6. It should be noted that the taper effect of the wing has been included only in the load estimation process but the shear stresses and bending stresses are evaluated neglecting the taper effect.

**Fig. 14. A Typical Five-cell Section.**

The values from Table 6 are given as the input through GUI windows including the input for span, will get the output as required stresses listed at that

span. Thus using this software the bending stress at any boom area on any section along the span of the wing can be determined (Typical results for 2 booms are in Table 7). Similarly, the shear stresses at any spar web and skin panel at any section along the span of the wing may be determined (Typical results for 2 walls are in Table 8 and the typical GUI output is in Fig. 8).

Table 6. Typical Wing Section Specifications at the Root of the Wing.

Boom No	Boom Area (mm ²)	Wall	Thickness (mm)	Cell Area (mm ²)
1, 7	1290	Spar Webs	3	
2, 8	1936	1 2, 7 8	3	
3, 9	645	2 3, 8 9	3	Cell 1: 215000 Cell 2: 250000 Cell 3: 255000
4, 10	1290	3 4, 9 10	3	Cell 4: 155000 Cell 5: 115000
5, 11	1936	4 5, 10 11	2.5	
6, 12	645	5 6, 11 12	2.5	

Table 7. Variation of Bending Stresses along the Span of the Wing for Five Cell Section.

Direct Stresses	$x = \frac{1}{4} L$ N/mm ²	$x = \frac{1}{2} L$ N/mm ²	$x = \frac{3}{4} L$ N/mm ²
σ_1	0.37241	1.7578	6.0458
σ_2	0.55862	2.6367	9.0687

Table 8. Variation of Shear Stresses due to Shear along the Span of the Wing for Five Cell Section.

Wall	$x = \frac{1}{4} L$ N/mm ²	$x = \frac{1}{2} L$ N/mm ²	$x = \frac{3}{4} L$ N/mm ²
1 7	1.303	3.8617	8.3688
3 9	1.3675	4.053	8.7833

3.2.2. Case II: Preliminary design

The stress analysis software developed can be used as a preliminary design tool. The final stress values obtained can be weighed against the direct and shear yield stresses of the wing structural material by defining margin of safety (*MS*) as

$$MS = \frac{\sigma_{yield}}{\sigma_{applied}} - 1 \geq 0 \quad \text{for direct stress}$$

$$MS = \frac{\tau_{yield}}{\tau_{applied}} - 1 \geq 0 \quad \text{for shear stress} \quad (13)$$

This measure aids in failure prediction as well as a means to determine appropriate dimensions of wing structural components.

Table 9. Bending Stresses with Margin of Safety.

Boom	Bending Stress N/mm²	Margin of Safety (MS)
1	59.2535	5.99
2	94.7123	3.37
3	47.1229	7.79

Using this package a preliminary design can be made by carrying out parametric analysis by choosing the boom areas, web length/thickness or material properties as a parameter. In each case, the software lists down the stresses with the display whether the design is safe or not. Table 9 shows the typical results of bending stresses for 2 cell section (Fig. 9) under a bending moment of 100 kNm with the material yield stress of 414 MPa. The values of the Margin of Safety can be used by designers to check if the boom area chosen produce direct stresses within the allowable stress limits or not. Thus the designer can continue to vary the boom areas until an optimum design is obtained. Similarly other parametric study can be carried out to arrive at a preliminary structural design which will be very useful for a course on conceptual aircraft design and airframe structural design.

4. Conclusions

MATLAB GUIDE based stress analysis package have been developed. The software is user friendly and no prior knowledge of MATLAB is required to work with it. The program has been developed to handle aircraft wings with multispar configurations under different loading conditions. The software can generate the load distribution based on the inputs and plots the shear force and bending moment diagram and evaluates the stresses along the span of the wing on demand.

Parametric analysis for different materials of wing, boom areas, web thickness and different loadings on the wings can be carried out using this package. Thus the package can be used for preliminary design and sizing of an aircraft wing. The present software is expected to be a useful tool to enhance the teaching learning process of courses on aircraft structures and aircraft structural design. Work is in progress to develop similar software for an aircraft fuselage and to couple it with this existing software to come out with complete aircraft structural design software useful for the students.

Acknowledgement

The authors would like to acknowledge the Research Management Centre, International Islamic University Malaysia for support of this work.

References

1. Philpot, Timothy A. (2000). MDSolids: Software to bridge the gap between lectures and homework in mechanics of materials. *International Journal of Engineering Education*, 16(5), 401-407.
2. Bloom B.S. (1956), *Taxonomy of educational objectives, Handbook 1: The Cognitive domain*. David McKay, New York, NY.
3. Rodriguez, J.M.; Gonzalez, V.; Gonzalez, J.E.; Rueda C.; De Haro, L.; and Martin-Pascual, C. (2001). Development of educational software for the teaching of telecommunication engineering by using MATLAB. *European Journal of Engineering Education*, 26(4), 361-374.
4. Zigic, Sasha; and Lemckert, Charles J. (2007). Development of an interactive computer-based learning strategy to assist in teaching water quality modeling. *Computers & Education*, 49(4), 1246-1257.
5. Turcotte, L.H.; and Wilson, H.B. (1998), *Computer applications in mechanics of materials using MATLAB*. Prentice-Hall, Upper Saddle river, NJ.
6. Lardner T.J.; and Archer, R.R. (1994) *MECHMAT in Mechanics of Solids: An Introduction*. McGrawHill, New York, NY.
7. Megson, T.H.G. (1999). *Aircraft structures for engineering students*. New York: John Wiley & Sons Inc.
8. Curtis, H.D. (2000). *Fundamentals of aircraft structural analysis*. International Ed. New York, U.S.A: McGraw Hill.
9. Niu, M. (1999). *Airframe stress analysis and sizing*. (2nd Ed.) Hong Kong Conmilit Press Limited.
10. Bruhn, E.F. (1973). *Analysis and design of flight vehicle structures*. Indiana, U.S.A: Jacobs Publishing, Inc.
11. Gary's combat aircraft reference guide (2003). Retrieved September 18th, 2006.<http://www.inetres.com/gp/military/ar/fb/Mig-21.html>.