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Research paper



A Matlab Based Educational Software for the Study on the Effect of Cut-Out in Aircraft Wings

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Abstract

Cut-outs on aircraft wings are unavoidable due to the placement of fuel tanks and retraction of landing gear inside the wing. The stresses acting on an aircraft wing will deviate substantially before and after a cut-out is made and therefore it is crucial to perform stress analysis in an aircraft wing in order to ensure that the wing structure will be able to withstand the applied stress. Stress analysis of such structures is tedious and time consuming due to its statically indeterminate nature. A free stand-alone software based on MATLAB for the computation of stress due to the effect of cut-out in idealized wing torsion box has been developed. The main purpose is to provide the end-user (students or academicians) a useful and user-friendly tool to perform preliminary stress assessment of the effect of cut-out analysis for an idealized wing.

Keywords: *Stress Analysis, Cut-out, Wing, MATLAB, Aircraft Structures*

1. Introduction

The skin of the lower surface of an aircraft wing often requires cut-outs for providing access, inspection of electrical and fuel lines, and also can be used for reducing the structural weight. Cut-outs lead to reduced buckling load capability and stress concentrations. Analysis of such cut outs in aircraft wings is challenging and still an active field of research. Bindu and Ali [1] studied the effect of cutouts on the buckling strength of an aircraft rib using FEA package. Another study by Hamed [2] reported that a circular cut-out made at the bottom of the wing skin would cause a notable decrease in natural frequencies. Narkar [3] carried out a study on the cut-out analysis in wings and showed high stress concentrations in the place of cut-outs. Fuel tanks are usually placed where a cut-out is made and during flight the top surface of the wing experiences compression while the bottom layer experiences tension. As a result, the cut-out made at the bottom skin of an aircraft wing will lead to high levels of stress concentration and are probable locations for fatigue crack initiation, and if initiated, it is necessary to arrest the crack. Thus it can be noted that the analysis of the effect of cutout in aircraft wing is important and it is often carried out by using FEA packages. Students without prior knowledge of FEA may not be able to carry out such analysis, thus a software based on classical methods will help the students learn the effects of cutout effectively.

Moreover, in engineering education computers play a very important role, especially in this era of globalization. It is not only helpful to students but also to lecturers in the teaching and learning process. According to Benjamin S. Bloom [4], there are six levels of knowledge which the student should acquire during the learning process. They are knowledge, comprehension, application, analysis, synthesis, and evaluation. The first three levels can be acquired through the lectures in the classroom, but to acquire the last three higher levels the student has to undergo long assignments or projects. It is not possible for the lecturers and students to carry out long assignments and projects within the limited time provided and this is where educational software play a very important role.

Educational software can be a self-study package which the students can use to solve a wide variety of problems and research. The development of educational software for aircraft or aviation industry is not new. MS Aximer [5] is one of the aerospace software which is designed for both students and professionals. It solves numerical problems which are related to propulsion, aircraft performance, stability and control, aerodynamics, flight vehicle structure, and electric circuits. A computer software for the stress analysis of repaired aircraft structures using the method of composite patch repair has also been developed by George at al [6]. XFOIL [7] is another software which provides an interactive program for the analysis and design of subsonic isolated airfoils. Similarly, Tornado [8], a software based on vortex lattice method for linear aerodynamic wing design was developed using MATLAB is a very useful tool in aeronautical education.

Stress analysis of thin walled sections is the basis of the Aircraft Structure course and an educational software related to thin walled sections has also been developed. One of this software is GT Shear [9] which involves the analysis of shear and bending stress for non-idealized thin walled open sections where the user can free handedly generate any cross section. A MATLAB Graphical User Interface (GUI) based educational software has also been developed Ali and Tazkera [10], for the estimation of loads and corresponding stresses on a wing. It involves the computation of stresses at any point along the span of the wing for a given aircraft. From the literature survey, it was found that no such software available that can perform analysis of the cut-out effect in aircraft wings, which is an essential part of a course on Aircraft structures. Thus in this work, such a software has been developed using MATLAB GUI as it is easy to work with and has supremacy for

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in-built graphic capabilities. For the user, the language underlying for the development of the software is irrelevant and one does not need any previous knowledge about MATLAB and programming skills to navigate through a well-developed GUI [11].

2. Methodology

The effect of cut-out on an idealized wing box for a given external load can be studied by assuming first that there is no cut-out made and the resulting shear flow distribution can be found by the idealized beam theory equations. Then the cut-out can be introduced to see its effect on this shear slow distribution.
The following procedure on the effect of cutout analysis has been adopted from Curtis [12].
As analysis of an idealized wing box even without cutout is statically indeterminate, a cut (not the cut-out) is made at any point in the closed section making the section statically determinate and the unknown shear flow at the cut is known as $q_{so.}$ Next the open section shear flow, q_b, is found by:

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

To find q_{so} we use the moment equilibrium equation,
External moment = Internal moment,

$$S_x \eta_o - S_y \xi_o = \oint q_b p ds + 2Aq_{so} \qquad (2)$$

where S_x, S_y are the shear forces and I_{ij}'s are the moment of inertia of the section and p, η, ξ are the moment arms of the force and q_b about the moment centre. As q_b is known, one can evaluate $q_{s,o}$ from the above equation. Finally the final shear flows on the webs/skin of the box beam are found by,

$$q = q_b + q_{so} \qquad (3)$$

Having found the shear flows for a box section without a cutout, one can introduce a cutout at any bay location which is a substructure removed from the main structure for analysis. The action of the substructure on the main structure is then represented by these surface tractions (q). Then, the presence of the substructure is eliminated by reversing the direction of the surface tractions (q). Thus the stresses which will result throughout the structure can be computed and superimposed point by point into the originally computed stress values. The place where the cut-out has taken place is represented by a state of zero stress since the stresses are cancelled out within and on the boundary of the substructure. The system of internal loads which have been imposed to stimulate the cut-out must be self-equilibrating. At the supports no reaction rises and the stresses that develop throughout the structure in response to the imposed load are such that the resultant force is zero on any cross section. Moreover, the effect of the cut-out made is assumed to be localized. If the length of the cut-out made is *l*, roughly at equal distance of magnitude *l* from each side of the cut-out, the effect of cut-out is said to be negligible. Figure 1(a) indicates a three bay box beam with shear flow q_o applied to a vertical web of the central bay. The central bay is separated from the forward and after bay by the ribs at section B and C. the forward and the after bay's length are just like the length of the center bay which is L. Since there are no external forces applied, the net shear force and twisting moment are zero. The net shear force is absent which means that the shear flows in opposite walls of the rectangular cross section have the same magnitudes, but they are in opposite directions. Figure 1(b) shows the shear flow distributions and directions of the central bay. The adjacent bays shear flows are shown as q_1 and $q_{2.}$

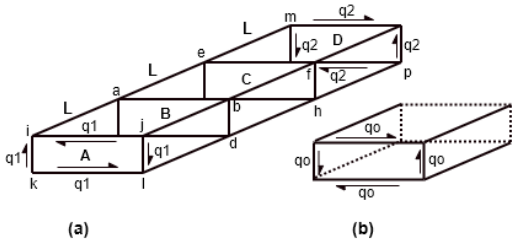

Fig. 1: (a) rectangular box beam with shear flow q_o applied to the vertical panel bdhf of the central bay. (b) Shear flow around a section through the central bay [12].

For obtaining q_1 and q_2 from the given shear flow q_o, any of the four stringers are isolated like a free body and as illustrated in Figure 2(a). We assume that the effect of q_o extends no further than one bay length which is L from the central bay and as a result, the flange loads which act at end of the stringers at points j and n must vanish. The net force which acts on the stringer must be zero so from that it leads to the following equation,

$$-2(q_1 L) + 2(q_o L) - 2(q_2 L) = 0 \qquad (4)$$

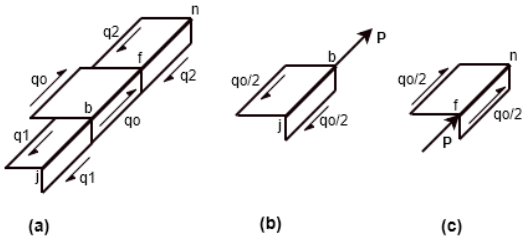

Fig. 2: (a) Free body diagram of a stringer, which the shear flow qo is related to the shear flow in the adjacent bays. (b),(c) Free body diagram of segments of the stringer at the fore bays and the aft bays

From the equation,

$$q_1 + q_2 = q_o \qquad (5)$$

Since by symmetry we know that q_1=q_2,

$$q_1 = q_2 = \frac{q_o}{2} \qquad (6)$$

Finally from Figure 2(b) and Figure 2(c) we find out that,

$$P = 2 \times \left(\frac{q_o}{2} L\right) = q_o L \qquad (7)$$

The force P produced alternates from being tensile and compressive from stringer to stringer around the box. As shown in Figure 3(a), the axial load q_oL is tensile at one end of the stringer segments spanning the central bay and and compressive at the other. A summary of the analysis done upto this point is shown in Figure 3(b).

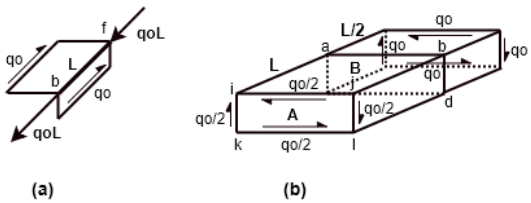

Fig. 3: (a) Free body diagram of a stringer segment spanning the central bay. (b) Free body diagram for one half of the structure, showing the shear flows in central and forward bay.

There is a jump in the shear flows between the ribs which are separating the bays. By considering the equilibirium of a free body diagram as such shown in Figure 4, the shear flow distribution is found.

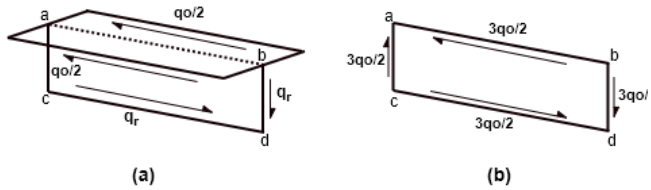

Fig. 4: (a) Free body diagram of a rib at B and a portion of the top panels. (b) The shear flows required for equilibrium of the rib.

3. Results and Discussion

The programming for the analysis of the effect of cut-out in an idealized wing torsion box which has been discussed in the previous section was carried out in MATLAB using the graphical user interface (GUI). The steps which were followed for the development of the software is illustrated in the flow chart in Figure 5. The first window of the software prompts the user to input the boom areas and locations to compute the sectional properties of the cross section. Next the user has to input the lift and drag forces which are acting on the wing torsion box and other necessary parameters. Proceeding further it prompts the user to enter the number of bays and the location of the bay which is to be cut-out. The program developed can do the analysis for any number of bays and any location of bay to be cut-out. Finally, the output stresses are displayed in tabular form. All the inputs and output windows are GUI based, hence it is absolutely user friendly for the students to work with the software. A user manual with solved examples provided with the software makes it further easy for the users to follow. Typical input and output windows are shown in Figure 7.

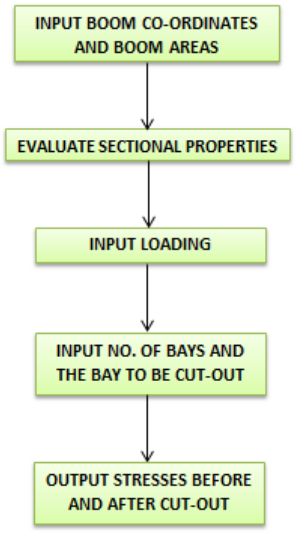

Fig. 5: Flow Chart for the cut-out analysis software.

4. Validation of Results

The individual components of the software are checked to ensure its validity and accuracy of the results obtained by comparing the results obtained from the software with the literature. In this section, the validation of the results obtained was done by using an example from Curtis [12]. In this example we calculate the shear flows in the spar webs and cover skins of the idealized wing box shown in Figure 6 which has a uniformly distributed lift and drag forces of 15lb/in and 3lb/in respectively. The ribs are spaced 20 inches apart and the total length of the wing box is 120 inches. The bottom skin of D-E is removed, which is the fourth bay from the wing tip. It consists of six total number of bays with lift and drag forces acting on it as shown. Tables 1-3 show the comparison of the sectional properties, and the shear flows before and after making a cut-out.

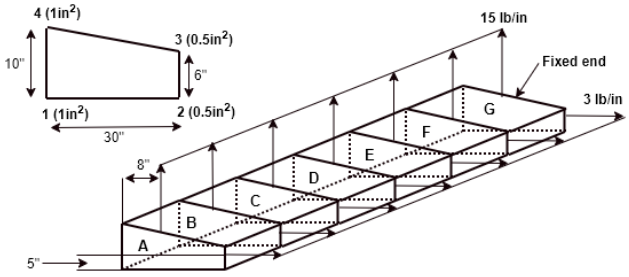

Fig. 6: Cut-out **e**xample problem to be solved with the software

Table 1: Sectional properties comparison

Parameters	Software values	Curtis [12]
$\bar{x}$	10 in	10 in
$\bar{y}$	4.333 in	4.333 in
I_{xx}	61.67 in^4	61.67 in^4
I_{yy}	600 in^4	600 in^4
I_{xy}	- 40in^4	- 40in^4

Table 2: Comparison of results before making a cut-out

Bay	Shear flow	Software values (lb/in)	Curtis [12] (lb/in)
C-D	q_{12}	7.75424	7.75
	q_{23}	24.5763	24.6
	q_{34}	2.75424	2.75
	q_{41}	-59.1525	-59.2
D-E	q_{12}	10.8559	10.8
	q_{23}	34.4068	34.4
	q_{34}	3.85593	3.86
	q_{41}	-82.8136	-82.8
E-F	q_{12}	13.9576	14.0
	q_{23}	44.2373	44.2
	q_{34}	4.95763	4.96
	q_{41}	-106.475	-106

Table 3: Comparison of results after making a cut-out

Bay	Shear flow	Software values (lb/in)	Curtis [12] (lb/in)
C-D	q_{12}	13.1822	13.2
	q_{23}	15.5297	15.5
	q_{34}	8.1822	8.18
	q_{41}	-62.4093	-62.4
D-E	q_{12}	0	0
	q_{23}	52.5	52.5
	q_{34}	-7.00	-7.00
	q_{41}	-76.3	-76.3
E-F	q_{12}	19.3856	19.4
	q_{23}	35.1907	35.2
	q_{34}	10.3856	10.4
	q_{41}	-109.731	-109

Table 2 shows the results for the shear flows on bays C-D, D-E and E-F before the cut-out is made. Table 3 shows the results for the shear flows after a cut-out is made which is the superposition of the shear flows before making a cut-out and the shear flows which arises from the reversed shear flows applied to bay D-E. Moreover, in Table 3 the results are presented only for bays C-D, D-E and E-F since the effect of the cut-out in bay D-E affects only the bay D-E and extends no further than two bays adjacent to bay D-E, which are bays C-D and E-F. The shear flows in the bays A-B, B-C, and F-H are unaltered and thus the shear flows of only the affected bays are shown in the results. The shear flows remain constant throughout each of the bays and there is a jump in shear flows only at the ribs as seen in the results of Tables 2&3. It can be seen that the results from the software and theoretical values match closely with each other.

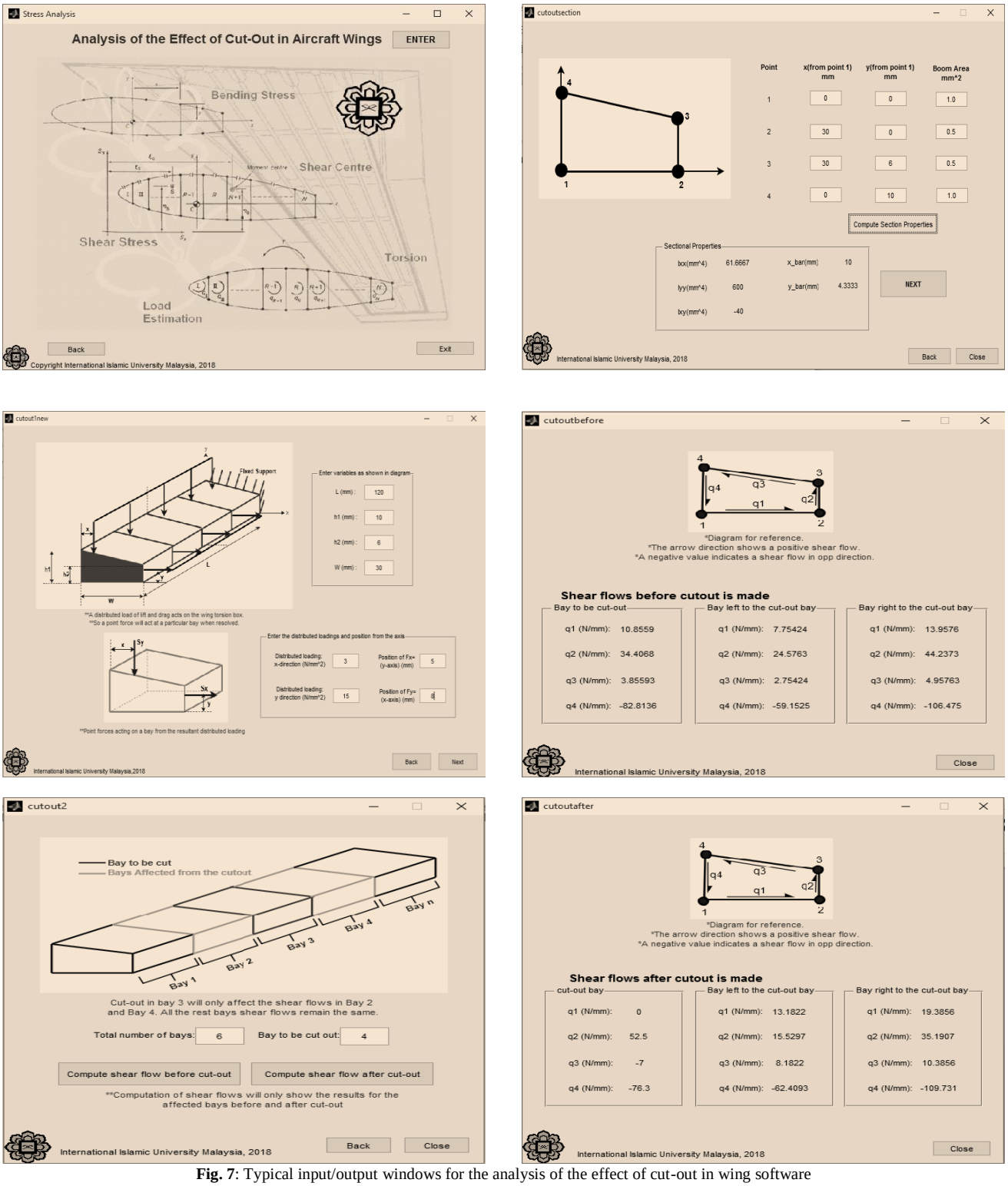

Fig. 7: Typical input/output windows for the analysis of the effect of cut-out in wing software

5. Conclusion

MATLAB GUI based educational software has been developed to study the effect of cut-outs in an idealized aircraft wing torsion box. The software is user-friendly and it can be run by any PC which has a Windows operating system. Validation for every detail of the software has been carried out to ensure that the values obtained match tail to tail with the theoretical values.

The software will be very useful for the students to solve long home assignments easily, where the students will be able to check the accuracy of the results obtained through their manual calculations. Thus, the use of this application will reduce the time needed for validation of results for both students and lecturers. Furthermore, the students can develop their own problems by removing different panels and perform manual calculations and validate their solutions with this software thus gaining more confidence in the topic. The software developed will be a useful tool for effective teaching and learning process of courses on Aircraft Structures.

Acknowledgement

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