DEVELOPMENT OF AUTO-GENERATING AERODYNAMIC LOADS FOR WING-BOX FINITE ELEMENT MODEL BASED ON SCHRENK METHOD

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Ringkasan. Pada makalah ini dijelaskan proses pengembangan aplikasi program komputer untuk menghitung distribusi gaya angkat sayap dan proses otomasi untuk meletakkan gaya dari tiap jarak-rib ke nodal-nodal tetangga dari model elemen hingga. Pada lingkungan Catia V5, Visual Basic .Net dipakai secara intensif untuk mengakses beberapa *Component Object Models* (COMs) yang dimiliki Catia dengan membuat beberapa *user interfaces* untuk kondisi terbang dan menghubungkannya ke model elemen hingga yang sudah dibuat pada penelitian sebelumnya. Metoda Schrenk dipakai untuk menghitung distribusi gaya angkat pada sayap, dimana gaya tersebut dikalikan dengan faktor limit load dan faktor keselamatan untuk memenuhi persyaratan dari kelaikan udara. Gaya angkat dihitung pada tiap jarak-rib yang terletak pada satu titik di seperempat panjang garis chord yang disebut *Handler*. Hal serupa, tiap permukaan atas sayap dari jarak-rib yang disebut *Agent* bertindak sebagai media untuk mentransformasikan gaya dari handler ke nodal-nodal tetangga di tiap jarak-rib. Model yang mirip dengan struktur sayap pesawat N250 dipakai sebagai studi kasus untuk menunjukkan perilaku program komputer ini. Hasil ini berguna sebagai suatu alat bantu dalam perancangan struktur sayap rigid yang melibatkan analisa aerodinamika dan analisa kekuatan struktur.

Abstract. This paper describes the development of computer application for computing the wing lift distribution and auto-locating each sectional lift force to the appropriate nodes of wing-box finite element model (FEM). In Catia-V5 environment, Visual Basic .Net is intensively utilized to access several Catia’s Component Object Models (COMs) by implementing several user interfaces for collecting flight data from user and for linking to the wing-box finite element model that already created in the previous work. The distribution of lift force is governed by Schrenk method, where the distribution is multiplied by limit load factor and safety factors in order to conform to the airworthiness requirement. The lift force is computed for each rib-space area and located on a point of quarter chord called a Handler. Correspondingly each upper wing surface of rib-space called Agent conducts as media to transform each lift force from a handler into their associated nodes of FEM. To demonstrate this work, a hypothetical N250 wing box structures is utilized for a case study. The result of this work is very useful to be utilized for wing design involving aerodynamic and structure analysis.

Keywords*: FEM, Programming Catia V5, Schrenk method, Visual Basic .Net*

1 Introduction

To locate automatically some distributed loads into the appropriate nodes of finite element model is highly demanded for the purpose structural design by using finite element analysis. Some benefits of automation are not only makes the design process become faster but also prevent inconsistency caused by unintentional human errors.

Naturally aerodynamic loads act on the surface of vehicle are in the form of pressure distribution, for example aerodynamic of wing surfaces. This paper presents some approach for calculating lift aerodynamic loads based on Schrenk method and for implementing a transformation technique from local lift force to the nodes of wing-box in finite element model (FEM).

In order to enrich the capability of aerodynamic load computation, at Faculty of Mechanical and Aerospace Engineering (FMAE), several methods have been developed for the purpose of wing structural analysis using finite element model. Three different methods of aerodynamic load computation have been developed namely Schrenk method, Transonic Small Disturbance method (TSD), and Finite volume method. The computation using TSD method had been developed successfully in 2009, and the utilization of finite volume method will be carried out in 2012.

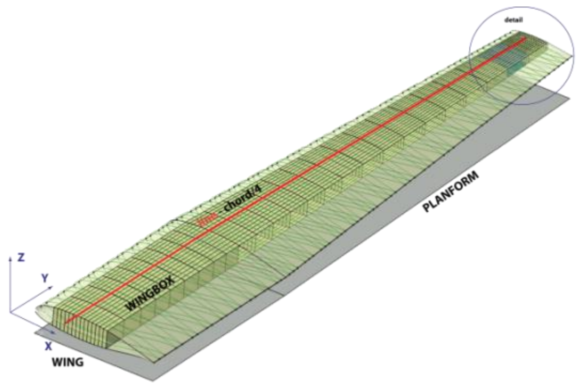

Figure 1 Wing Surfaces and Wing-box Structural Layout and planform

Compare to the two methods, the implementation of Schrenk method is relatively simple and take only a short time for calculating lift distribution. This solution is suitable to be applied in the early structural analysis which some level of accuracy is relaxed.

For low subsonic speed, lifting line theory is widely used for predicting wing lift distribution, which is for practical use this computational approach was introduced by Schrenk [1,2]. Schrenk method requires only some parameters of wing planform. So in this work it is crated automatically the projection of wing surfaces into xy-plane as shown in Figure 1. Most of wing-box FEM is in three dimension model which is not in the planform, so this difference may become one problem that has to be solved in the load transformation.

Some dependencies of aerodynamic load computation to wing surface and wing box structural model are shown in Figure 2. In the previous work [3], it was completed a computer code for generating parameterized wing surfaces in Catia environment. In addition the computer application is able to access airfoil database created in Excel file for interactive airfoil selection. So the wing surfaces conduct as parent for the next object creation in conjunction with Catia and other computation.

Subsequently the computer codes for generating parameterized wing structural layout and finite element model of wing box structures was carried out in previous work [3]. Consequently the implementation of Schrenk method in Catia environment will certainly depend on the result of two previous works.

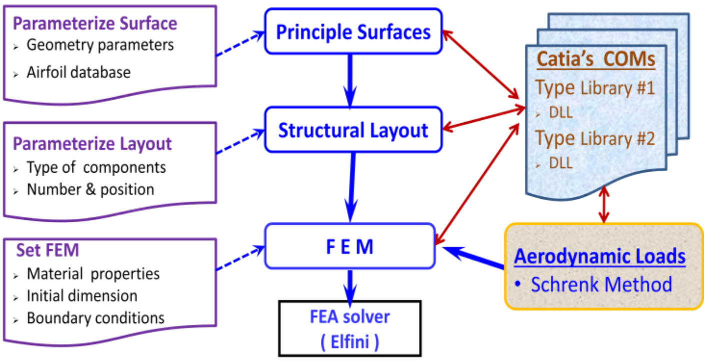

Figure 2 Diagram of aerodynamic load generation for wing-box model

Using Visual studio .Net, several component object model (COM's) of Catia are employed to generate automatically wireframe and surface of wing, including utilization of airfoil database system [7,8]. By establishing link to the wing surfaces, a layout of wing-box structure can be created using particular user interface such as for determining the number and location of layout structures. As the wing surface becomes parent for a structural layout, so any changes in the wing surfaces can be propagated to wing layout automatically. In Figure 2 it is displayed the hierarchy of generated wing surfaces and structural layout.

In conjunction with locating local lift force, it is required to define the role of handler and agent. A point in quarter chord line in planform plane conducting a location of local lift force is defined as a handler. In vector form, the distance between a handler to the surrounding nodes can be computed. In similar notion, an agent is defined as the upper wing surface between two ribs. In this paper we propose to employ agent to be the media of load transformation. Besides that each piece of upper wing surface also conducts as a parent for some nodes of structural layout and FEM as illustrated in Figure 2. Therefore the upper wing surface is able to link information to its children, such as the coordinates of nodes, to a selected handler. Consequently, the transformation from local lift force to the nodes of finite element model can be carried out by using the rule of one-to-many-point transformation [4,8].

In the very early step to grab the idea of auto-locating loads, there were several prior works carried out in partially manual-automation in an attempt to find out some features of general algorithms during and after the implementation. By implementing some simplifications, Ruliana [5] employing Visual Basic for Application (VBA) for computing wing lift distribution using Shrenk's method. Meanwhile, Susanto [6] developed partial automation to generate the finite element model of wing-box structure. Then, an object oriented approach was implemented to achieve the state of fully automation and some improvements of algorithms as published in [4].

2 The Applicable Methods

2.1 The Approach Of Loads Transformation

In general, Schrenk method divides the spanwise lift coefficient distribution into two type distributions namely basic and additional lift coefficient distributions [1,2]. To implement the distribution along spanwise, it is created several sections from root to wing tip by applying a particular section arrangement, so the number of sections in each ribspace can be set by user. Figure 3 illustrates that each ribspace contains three Schrenk wing sections.

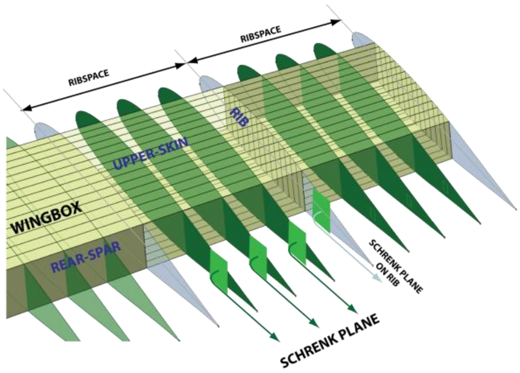

Figure 3 Location of Schrenk wing sections in conjuction with rib-space

As mentioned that Schrenk method works with the projection of each ribspace to the planform of xy-plane. As each section represents a specific panel area, it can be employed as a reference for computing lift coefficients. Figure 4 shows the projection of wing section to the xy plane, where the definition of panel area is around each chord line.

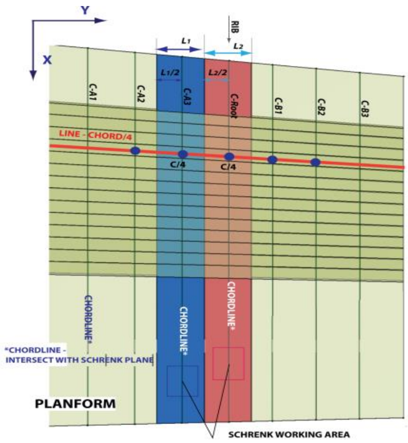

Figure 4 Panel are of Schrenk wing sections on wing planform

Considering that each panel area around wing section, $\Delta S_{(y)}$, is defined on xy-plane, consequently, each lift force of section, $\Delta L_{(y)}$ has direction to positive z-axis. In Schrenk method, it is assumed that each point of quarter chord line (called a Handler) will be the origin of distributed local lift forces [1,2]. In general statement, the location of each lift force is independent to the location of nodes. Figure 5 illustrates the local lift force pass through the structural layout of wing box.

For the purpose of wing structure certification, it is compulsory to multiply each local lift force calculated by Schrenk method by applying a correction of limit load and safety factor. Perry [1] describes that the ultimate local force is combination of those factors as expressed in a mathematical model as follows,

$$\Delta L_{(y)} = 1.5\, n_{\lim}\ 0.5\,\rho V^2\, c_{l(y)}\ \Delta S_{(y)} \tag{1}$$

where,

$\Delta L_{(y)}$: Ultimate lift force in z-direction,

$c_{l(y)}$: local lift force coefficient on particular flight condition

$n_{\lim}$: limit load factor of flight condition

$\Delta S_{(y)}$: local panel area on each wing section

ρ : density of air on fight condition

V : free stream on fight condition

In this case study [4] the value of limit load factor is about 2.9 and the value of safety factor is 1.5 that both of them are considered to be input for calculation. While, $c_{l(y)}$ is local lift coefficient along wing span which its distribution is modeled according to Schrenk method and will be described in Section 2.3.

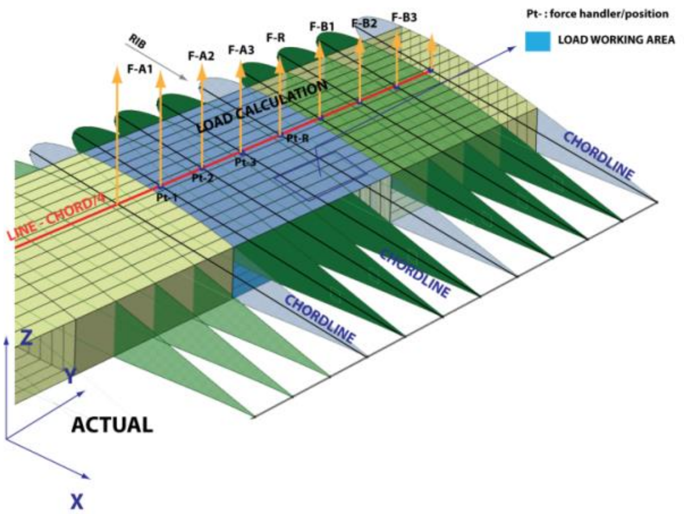

Figure 5 Location of local lift force in quater chord line and the nodes of wing-box layout

2.2 Linear Interpolation

As the spanwise direction corresponds to y-axis, so several parameter of wing are indicated by variable of (y). So in the following formulation all variable is denoted by variable (y).

In application of Schrenk method there are several parameter of equation has to be interpolate due to the data of wing parameters are usually provided only in the end sections of wing planform, for instance in the root, kink and tip section. As illustration, some wing parameters are chord length at a distance of (y), lift coefficient slope at distance of (y), which they are described in the Section 2.3.

The formula for linear interpolating is taken from common straight line mathematical model. It is supposed that a point coordinate denoted by *(par,y)*, then the model of straingt line passing through point-1 and point-2, where point 1 can be root or kink, while point2 can be kink or tip. So between the two points, the model of interpolation is described as follows:

$$par = \left(\frac{par_2 - par_1}{y_2 - y_1} \right) (y - y_1) + par_1 \qquad (2)$$

whre,

(par_1, y_1) is the parameters at point-1

(par_2, y_2) is the parameters at point-2

2.3 Mathematical Model of Schrenk Method

In Schrenk method, the value of additional lift coefficient distribution is evaluated at c_{la1} =1. To predicted other lift distribution for example at cruise condition, it is necessary to know the value of lift coefficient at cruise flight condition, $C_{Ldesign}$. So the spanwise lift coefficient distribution can be expressed as follows [1],

$$c_{l(y)} = (c_{lb} + C_{Ldesign}\, c_{la1})_{(y)} \qquad (3)$$

where,

c_{lb} : basic lift distribution

c_{la1} : additional lift distribution at c_{la} =1

2.3.1 Basic Lift Distribution

As mentionws that total basic lift coefficient disribution is zero along the wing span. Schrenk method provides the mathematical models that the variation of basic angle of attack and lift coefficient slope are dominat variables. So , the model is expressed in equation (4a) and (4b) as follows [1];

$$c_{(y)}\, c_{lb} = 0.5\, c_{(y)}\, a_{(y)}\, \alpha_{b(y)} \tag{4a}$$

$$\alpha_{b(y)} = (\alpha_{(y)} + \alpha_{o\,\mathrm{Re}f}) \tag{4b}$$

where,

c_{lb} : basic lift coefficient distribution

$c_{(y)}$: chord length at distance of (y)

$a_{(y)}$: lift coefficient slope at (y)

$\alpha_{b(y)}$: distribution of basic angle of attack

$\alpha_{(y)}$: angle of attack at distance of (y)

$\alpha_{o\,\mathrm{Re}f}$: angle of attack of wing reference

A distribution of basic angle attack is depended on the location of wing zero angle of attack, $\alpha_{o\,\mathrm{Re}f}$, and variation local angle of attack with respect to the reference as shown in equation (4b). Then the variation of local angle is depended on parameters such as wing setting, geometrical twist and location of reference as expressed by the following formula [1],

$$\alpha_{(y)} = \alpha_{setting} + (\theta_{twist(y)} - \alpha_{0\,\mathrm{Re}f}) \tag{5}$$

Where,

$\alpha_{setting}$: wing setting with respect to x-axis

$\alpha_{(y)}$: local angle of attack

$\theta_{twist(y)}$: local twist angle at (y) distance

$\alpha_{0\,ref}$: reference of angle of attack

Finally the reference of angle of attack is expressed by equation (6) ,

$$\alpha_{o\,ref} = \frac{\int_0^{b/2} a_{(y)}\, \alpha_{(y)}\, c_{(y)}\, dy}{\int_0^{b/2} a_{(y)}\, c_{(y)}\, dy} \tag{6}$$

2.3.2 Additional Lift Coefficient

The mathematical model for additional lift coeffient distirbution is formulated dominantly by the wing planform and the local slope distribution as expessed in the following equation [1],

$$c_{(y)}\, c_{la1} = 0.5 \left\{ \frac{a_{(y)}}{\bar{a}} c_{(y)} + \frac{4S}{\pi b} \sqrt{1-\eta^2} \right\} \tag{7}$$

where,

S : wing area
b : wingspan
η : the ratio of local distance to the half wing span
A : aspect ratio

This distribution is resemble to an elliptic distribution, where at root chord the value of additional coefficient is depend on the ratio of local slope over the average slope of lift coeficient. The avarage lift slope is formulated by the following model [1],

$$\bar{a} = \frac{\int_0^{b/2} a_{(y)}\, c_{(y)}\, dy}{(S/2)} \tag{8}$$

3 Development of Application

This section describes what and how the application was developed to be a software application that can be utilized by engineer in order to assist an analysis of wing design.

Catia V5 R19 allows any user to access its functions by using particular language of development such Visual Basic and Visual C++ .net. There are provided already several type-libraries packed in the component object models (COMs) [8]. In this work, several type-libraries have been employed for accessing wireframe and surfaces, and for performing mathematical calculation.

Visual Basic has been selected due to its simplicity to access COMs and creating graphical user interface. As object oriented approach is applied to solve the whole problem, the implementation is realized by the number of classes and object interactions.

In implementation, it is needed to create a class for performing the basic lift coefficient calculation and another class to represent additional lift coefficient computation. Meanwhile linear interpolation is utilized to compute many local parameter of wing such as angle of attack and lift coefficient slopes.

To link the user to a Catia-file containing several parameters of wing structural layout and wing finite element model, it is create a user interface as shown in Figure 6. In the window dialog, on document type icon, when user press the icon then the application will search the object name of Catia file for establishing link to the value of CatPart, for example this GUI shows the object names called N250RZ [4,9,10].

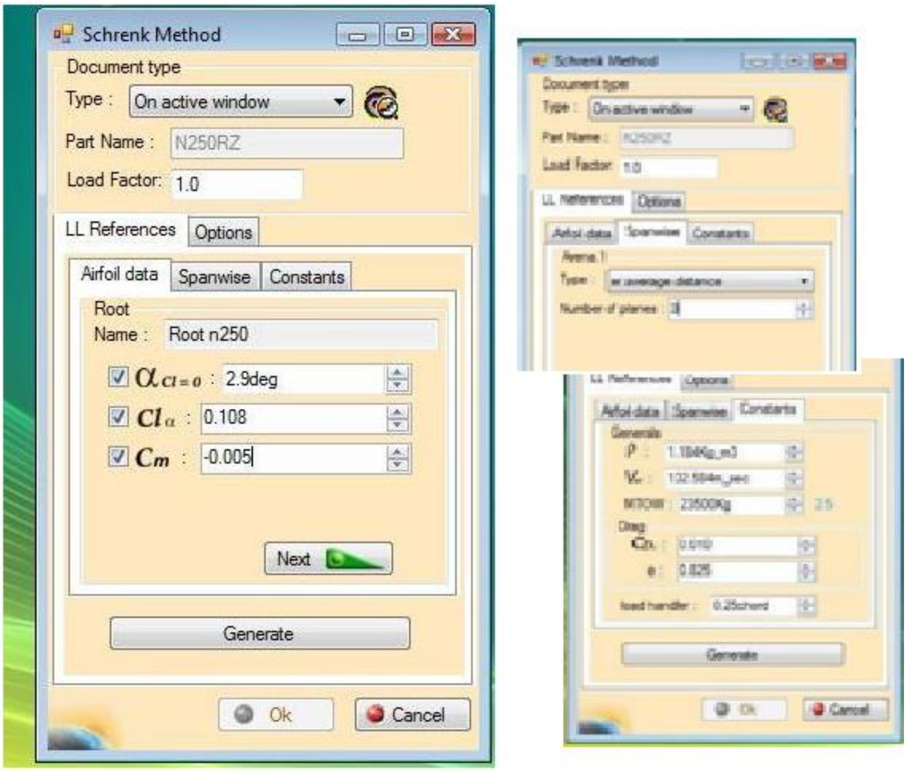

Figure 6 User interface for the input data of Schrenk method

The tab called Airfoil Data is given for linking to the existing data of airfoil performance at root, kink and tip of wing. Another tab called Spanwise provides a user to enter the number of wing sections in each ribspace for Schrenk method. While the last tab called Constant become input for flight condition. On right side of Figure 6 it shown the pop up window dialog when a user press these tabs.

Yet in the left side of Figure 6, limit load factor can be supplied to GUI, which is by value of 1.0 for cruising condition. This load factor becomes an input to compute equation (1). When all necessary data have been entered by user, then the lift forces can be calculated by pressing a button called Generate. When there is no error occurs, then all the result of computation is presented in a file of notepad.

4 The Results of Load Transformation

It is verified the result of application to data presented in Chapter 9 of [1] as presented in Figure 7. In this figure, the three markers indicate lift coefficients for basic, additional and total taken from [1]. While the three lines visualize the result of computation for basic, additional and total lift coefficients. From Figure 7, it can be concluded that the results of computation give good agreement with data presented [1].

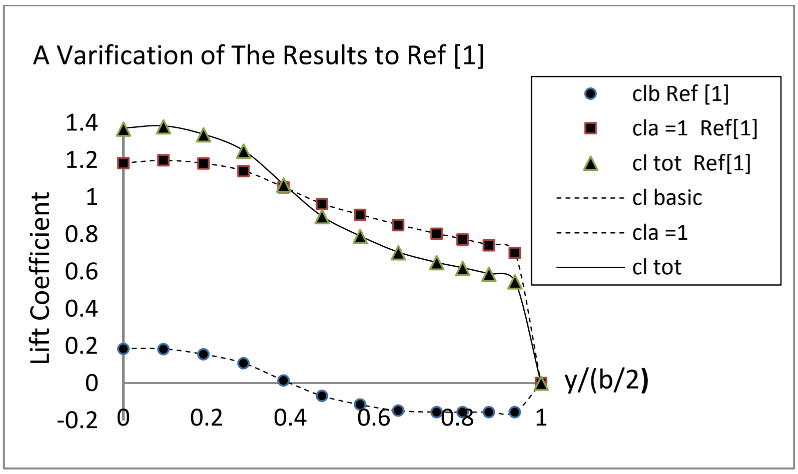

Figure 7 A verification the result of program to basic and additional lift coefficient available in [1].

Figure 8 presents the result of conversion from notepad file into excel file in order to visualize the basic, additional and total lift coefficient curves. Yet in the

Figure 8, horizontal axis is η as defined in equation (7) and vertical axis is lift coefficient.

In Figure 8, it is shown that the basic distribution relatively constant from root to kink due to the rectangular planform and the same airfoil for inner wing. While for outer wing, the distribution varies slightly linear and reach negative values due to tip wing twist and the change of airfoil type from kink to tip. For additional lift distribution, at the calculated lift coefficient $c_{L\ design}$= 0.45, the curve tend to flat in inner wing and decrease toward the tip direction. The total lift coefficient, given by equation (3), is sum up from the two curves. Consequently, the curve of total lift coefficient is higher at root section and then reduce steadily from kink toward wing tip that those curves compare to the curve of additional lift coefficient.

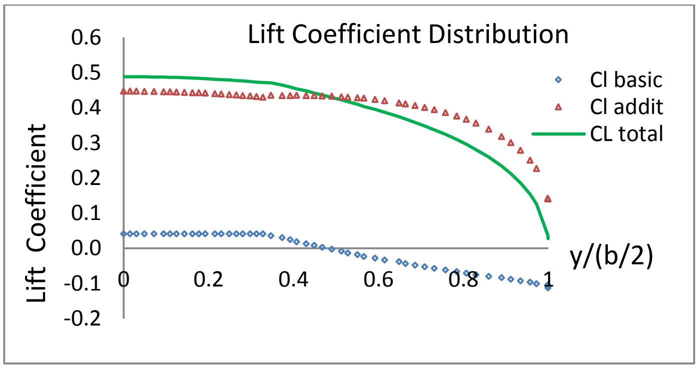

Figure 8 The distribution of lift coefficient for the wing of N250RZ

The wing-box structure has a symmetrical plane, so the finite element model is only represented by half wing model. To finalize the model, it is required to define some boundary condition to the model. In this model the nodes on the plane of symmetry is restrained in both direction namely x and y directions. Other boundary conditions are applied to nodes representing wing–body join. The restraint in x and z direction are applied for the one node o front spar and the one node of rear spar on wing–body join. The material and geometrical properties for the wing structure have been done in the previous work [4].

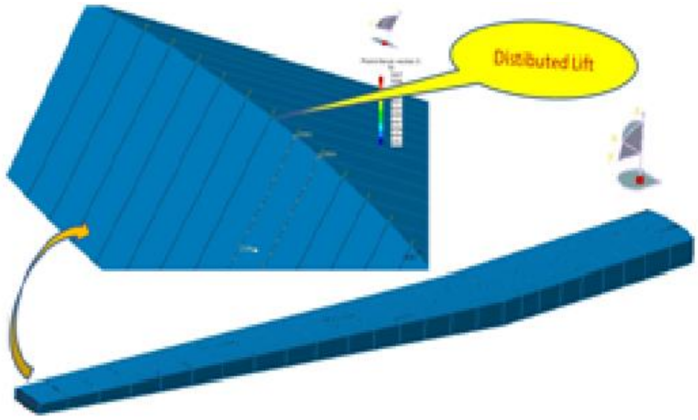

Figure 9 Visulization of loads on the nodes of FEM around wing tip

When the local load transformation is executed by clicking the button of OK on Figure 6, the nodes of FEM associate with its rib-space collect the magnitude load in z-direction. The process is carried out one by one until all local lift forces are transformed. Figure 9 shows the result of transformation, where the upper nodes around wing tip are filled by appropriate force. In this case study, the total time for completing the transformation of haft wing is about 170 minutes. In addition there are 24 sections for half wing model, so for upper wing is about (24 x 30) nodes conduct as final target of transformation.

The assessment on the validation of transformation had been carried out in the previous work [4] and it shown the same result compared to the result did manually. As the procedure of transformation for this work is carried out in the same technique, so in deductive way it can be accepted that the result of this transformation has performed in accepted result.

After all boundary condition is set to FEM, the wing-box model is now ready for execution. Catia V5 provides finite element solver called Elfini, so it is utilized to solve the model. Figure 10 shows the response of finite element analysis in a type of displacement and stress of elements.

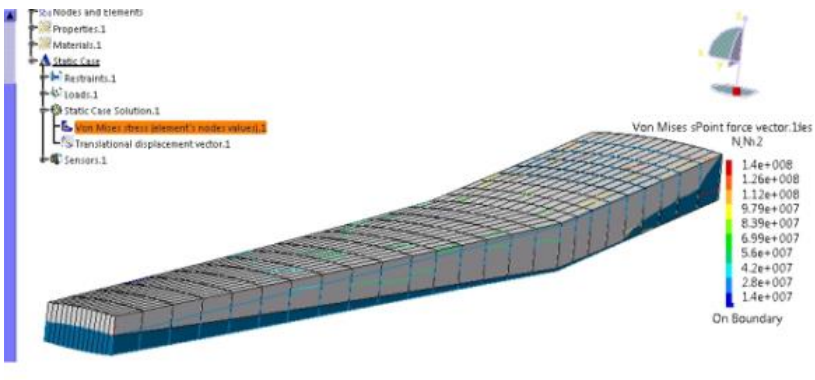

Figure 10 The response of wing-box finite element analysis of N 250RZ

In a complex structure such as this wing-box model, the response of finite element analysis can be utilized as the first check whether the transformation of loads results in correct loads transformation. In near future work, by using this wing-box model will be carried out an implementation for structural optimization. Later on some benefits of the development load generation can be shown when the process of optimization performed. In order to achieve a relatively global optimum a type of stochastic algorithm such as simulated annealing will be considered.

Although this research is focused for calculating aerodynamic load and their transformation, this concept can be implemented as well for non aeronautic fields such as automotive design and ship design.

5 Conclusion and Recommendation

5.1 Conclusion

a) In general, the use of visual basic .Net is suitable for dealing with Catia's component objects models (COMs) and effective to access the airfoil database created in Excel file.

b) The result of computation namely basic and additional lift coefficients give good agreement with data presented in [1].

c) The use each upper wing surface between ribspace is appropriate to conduct as an agent for transforming every local load to the associative nodes of finite element model. Therefore, the implementation auto-locating automation could prevent human error during data entry.

5.2 Recommendation

a) It is suggested to apply other aerodynamic loads such as drag force and pitching moment distribution in order to simulate all forces of wings.

b) As the test was carried out for wing with single kink, it is required to develop further the computer program and perform various testing, so the application could be utilized for wings with multiple kinks.

c) As the result of finite element analysis can be carried out successfully, further development such as an implement of structural optimization is strongly recommended. Hopefully, in the future this computer program can be utilized as a comprehensive tool for wing design.

6 Acknowlwdgment

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