AUTOMATION DESIGN AND ANALYSIS OF THE WING BASED ON AERODYNAMIC AND STRUCTURE ASPECT RESPECTIVELY

I G.N. SUDIRA*, BAMBANG K. HADI, M. AGOES MOELYADI, DJAROT WIDAGDO
Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology (ITB)
Jl. Ganesha 10 Bandung 40132 Jawa Barat – Indonesia
**Email: sudiraign@yahoo.com*

Abstract

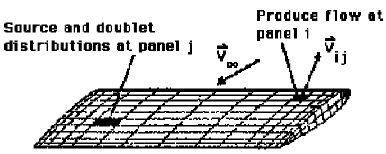
Configuration/Geometry definition, grid generation/mashing, and modeling in wing design and analysis process usually spend much time to support calculation by computer program. Much effort has been performed by engineering group to simplify design process and also for accelerating execution time. This paper describe a method to design and analysis aerodynamic and structure of the wing by automatic technique in geometry preparation. For aerodynamic aspect, wing geometry for a certain configuration is created automatically using computer program for replacement of manual method. NWDU is the software for creating an input of “panel method base code” in the form of panel system that consist of basic input, grid point (wing coordinate) and wake point. Some aerodynamic characteristics are demonstrated in corelation with a certain wing configuration. For structural aspect, automatic technique was applied on structure modeling, including structural layout as the input of FEM analysis. Geodesic structure of wing box component was choosen as test case of the method application. Grid Generation (GG) software was developed to generate structure modeling automatically as an input of Finite Element Method (FEM).

Key Word: Automation, Geodesic, NWDU, VSAERO, GG, FEM

Introduction

Aerodynamic Aspect

Wing are highly complex and also main component of the aircraft due to its function of lifting surface, as depicted on Fig 1.1. Wing configuration and surface grid / mashing are usually generated manually using comercial drawing software. Manual process in generating wing geometry as the input of CFD program usually spend much time and open time it does not comfortable for CFD user especially for high iteration of geometry changes. Much effort has been performed by engineering group to simplify design process and also for accelerating execution time. This paper describe a method to design and aerodynamic analysis of the wing by automatic technique in geometry preparation. Wing geometry for a certain configuration is created automatically using computer program for replacement of manual method. NWDU is the software for creating an input of “panel method base code” in the form of panel system that consist of basic input, grid point (wing coordinate) and wake point. Some aerodynamic characteristics are demonstrated in corelation with a certain wing configuration.

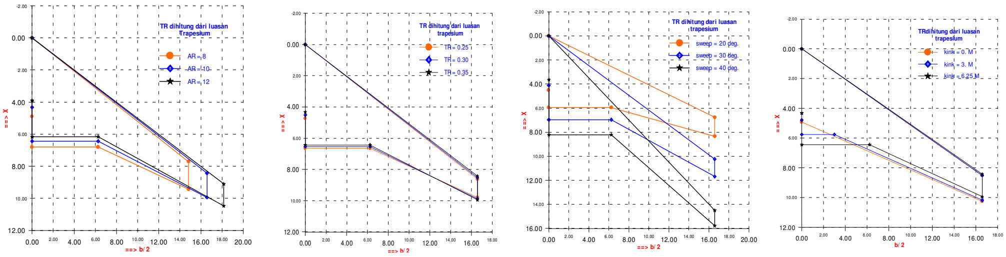


(a) Surface Grid on Wing

(b) Flow Simulation using VSAERO

Figure 1.1. Grid system on wing surface and flow simulation using VSAERO code, [Kroo Ilan]

Many wing parameters and also design variable can be evaluated independently by isolated manner of each parameter or design variable. For example, planform parameters namely aspect ratio, taper ratio, sweep angle, kink location, and area can be isolated in generating wing configuration, [see Fig.1.2]. Using selected airfoil, wing configuration can be generated automatically by NWDU and also connected with CFD code (VSAERO) to calculate aerodynamic characteristic simultaneously. Using this method, iteration process of wing design can be accelerated and also contribution of man power in geometry preparation can be minimized.



(a) **(b)** **(c)** **(d)**

Figure 1.2. Change of planform shape due to parameter design variation; (a) aspect ratio, (b) taper ratio, (c) sweep angle, and (d) king location [Sudira, 2014]

Structural Aspect

For structural aspect, automatic technique was applied on structure modeling for preparation of the input of FEM analysis. Grid Generation (GG) software was developed to generate structure modeling automatically as the input of FEM analysis. Fast execution time of FEM was also created for preparation of optimization process. Geodesic structure of wing box component was selected for test case of this method.

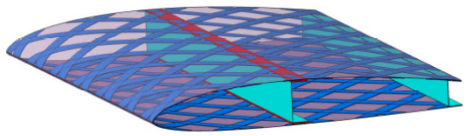


Figure 1.3 Geodesic Wing Box Model [Urík, 2008]

Beams with web arangement as the component of untapered wing box was generated by GG program for preparation of FEM input. The example of geodesic structure can be seen on Fig. 1.3.

Objective and Benefit

The intention of this report is introducing simultaneous method of wing design and analysis by automation process of wing geometry preparation before calculated by CFD program for aerodynamic aspect and FEM for structural one. This method can minimize man power contribution, simplify design process, and acceleration of design process.

Automation Methods

Aerodynamic Aspect

For aerodynamic design aspect, a certain configuration identified by surface grid was created automatically using computer program. NWDU is the software for creating an input of "panel method base code" in the form of panel system that consist of basic input, grid point (wing coordinate) and wake point. The main performance of NWDU is creating wing configuration that was started from planform definition, and furthermore airfoil installation, automatic mashing (panelling), until input preparation for CFD code. Manual preparation of wing geometry using drawing software can be replaced by NWDU for supporting CFD code in calculating aerodynamic characteristic. Planform parameters namely aspect ratio (AR), taper ratio (TR), sweep angle, kink location, and area can be isolated in generating wing configuration, [see Fig.1.2].

Formula for creating planform shape/coordinates as depicted on Fig 2.1 are,

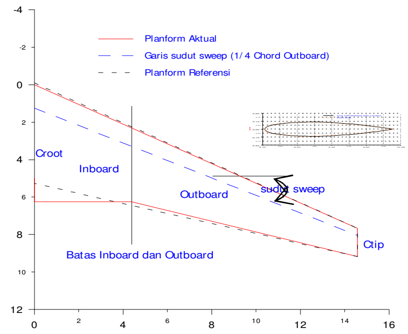


Figure 2.1 Planform shape and Airfoil [Sudira, 2014]

$$\mathrm{AR} = \frac{b^2}{S} \tag{2.1}$$

$$\mathrm{TR} = \frac{Ct}{Cr} \tag{2.2}$$

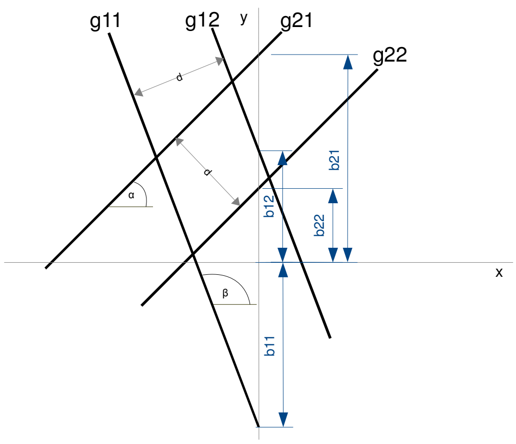
where Ct and Cr are tip and root chord respectively, meanwhile b and S are length of wing span and wing area respectively.

Change of span wise design variabel such as wing profile, local angle of attack, and thickness distribution can be conducted by NWDU as well according to requirement of design process. NWDU output can be used for VSAERO input and VSAERO output is formated for FEM input. Using this method, design and analysis of the wing can be performed simultaneously from aerodynamic field to structural one.

Structural Aspect

For structural aspect, automation process was applied on geodesic structure of wing box component. Computer program for automatic grid generation of geodesic structure was created to prepare FEM input. Geodesic structure can be generated using straight line equation below, with angle and distance among line are determined as design variable.

$g11 : y = a_1 x + b_{11}$
$g12 : y = a_1 x + b_{12}$
$g21 : y = a_2 x + b_{21}$
$g22 : y = a_2 x + b_{22}$



Node or grid point of geodesic structure can be generated by matrix operation as follow;

$$\begin{pmatrix} x_i \\ y_i \end{pmatrix} = \begin{bmatrix} -a_1 & 1 \\ -a_2 & 1 \end{bmatrix}^{-1} \begin{pmatrix} b_{1i} \\ b_{j1} \end{pmatrix}$$

Next step of design and analysis of geodesic structure is strength calculation using FEM. To anticipate of optimization process on geodesic structure design, fast FEM program was created. In this case, FEM was created on three dimensional beam element as depicted on Fig.2.2.

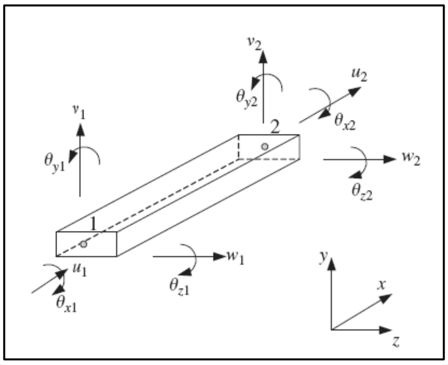


Figure 2.2 Frame elemet in space with twelve DOFs, [Liu G.R., 2003].

Element displacements vector,

$$\mathbf{d}_e = \begin{Bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \\ d_7 \\ d_8 \\ d_9 \\ d_{10} \\ d_{11} \\ d_{12} \end{Bmatrix} = \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \theta_{x1} \\ \theta_{y1} \\ \theta_{z1} \\ u_2 \\ v_2 \\ w_2 \\ \theta_{x2} \\ \theta_{y2} \\ \theta_{z2} \end{Bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \\ \\ \\ \end{matrix}\right\} \text{displacement components at node 1} \\ \left.\begin{matrix} \\ \\ \\ \\ \\ \\ \end{matrix}\right\} \text{displacement components at node 2} \end{matrix}$$

Stiffness matrix

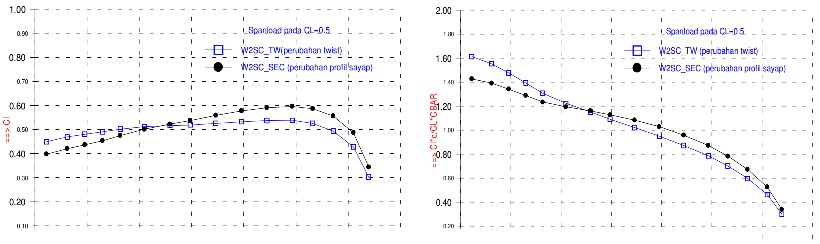
$$\begin{array}{cc} & \begin{matrix} u_1 & v_1 & w_1 & \theta_{x1} & \theta_{y1} & \theta_{z1} & u_2 & v_2 & w_2 & \theta_{x2} & \theta_{y2} & \theta_{z2} \\ \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow \end{matrix} \\ \mathbf{k}_e = & \begin{bmatrix} \frac{AE}{2a} & 0 & 0 & 0 & 0 & 0 & \frac{-AE}{2a} & 0 & 0 & 0 & 0 & 0 \\ & \frac{3EI_z}{2a^3} & 0 & 0 & 0 & \frac{3EI_z}{2a^2} & 0 & \frac{-3EI_z}{2a^3} & 0 & 0 & 0 & \frac{3EI_z}{2a^2} \\ & & \frac{3EI_y}{2a^3} & 0 & \frac{-3EI_y}{2a^2} & 0 & 0 & 0 & \frac{-3EI_y}{2a^3} & 0 & \frac{-3EI_y}{2a^2} & 0 \\ & & & \frac{GJ}{2a} & 0 & 0 & 0 & 0 & 0 & \frac{-GJ}{2a} & 0 & 0 \\ & & & & \frac{2EI_y}{a} & 0 & 0 & 0 & \frac{3EI_y}{2a^2} & 0 & \frac{EI_y}{a} & 0 \\ & & & & & \frac{2EI_z}{a} & 0 & \frac{-3EI_z}{2a^2} & 0 & 0 & 0 & \frac{EI_z}{a} \\ & & & & & & \frac{AE}{2a} & 0 & 0 & 0 & 0 & 0 \\ & & & & & & & \frac{3EI_z}{2a^3} & 0 & 0 & 0 & \frac{-3EI_z}{2a^2} \\ & & & & \textit{symmetry} & & & & \frac{3EI_y}{2a^3} & 0 & \frac{3EI_y}{2a^2} & 0 \\ & & & & & & & & & \frac{GJ}{2a} & 0 & 0 \\ & & & & & & & & & & \frac{2EI_y}{a} & 0 \\ & & & & & & & & & & & \frac{2EI_z}{a} \end{bmatrix} \end{array}$$

E : elastic modulus
G : shear modulus
J : polar moment of inertia
u , v , w : *displacement* in x, y, z direction

Results and Discussion

Aerodynamic aspect

Typical wing load for twisted and untwisted wing resulted by VSAERO can be seen on Fig 3.1. Wing profile resulted by NWDU to support VSAERO on preparation geometry input can be seen on Fig.3.2. In this case, complex wing configuration was demonstrated to proof that simplication of design process in aerodynamic group can be conducted using automation method. Complex configuration and simple one can be executed without significant diferent time to provide geometry and aerodynamic characteristic. Isobar line as shown on Fig. 3.3 is usually used to control spanwise stall fenomena during aerodynamic analysis. Based on this short discussion, it can be described that dificulty in geometry preparation during iteration process of aerodynamic wing design can be overcome by automation method.



(a) CL (b) $Cl*c/CL*C_{avg}$

Figure 3.1. Typical wing load for twisted and un-twisted case

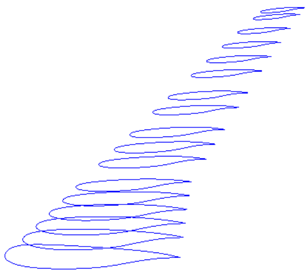


Figure 3.2. Typical wing profile

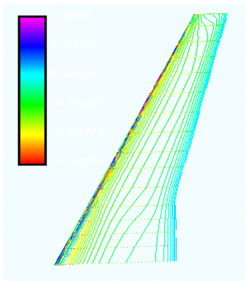
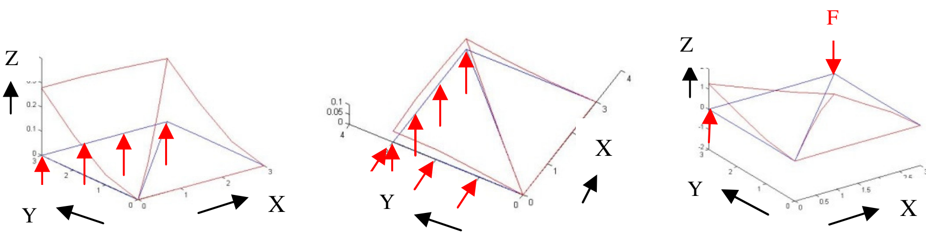


Figure 3.3. Typical isobar line

Structural aspect

Two main point as the results of structural aspect are structural modeling using automatic grid generation for geodesic structure and element movement due to typical load using FEM program.

For simple and limited number of element as ilustrated on Fig. 3.4 experiences element movement due to forces, F, in x and z direction. For simple element shape [Fig.3.4], will not provide dificulty in generating structure model. But generally, geodesic structure is formed by web beam with its angle and distance among them. For this case, it is needed to generated geodesic structure automatically as depicted on Fig. 3.5.



(a) (b) (c)

Figure 3.4 Ilustration of simple element displacement due to forces, F, for (a) in z direction; (b) in x and z direction and (c) in z direction

Fig. 3.5 shows beam element movement due to force, F, for typical geodesic structure that was generated automatically by computer program to support FEM calculation.
By using automatic process to generate geodesic structure, then aplication of genetic algorithm to supoort structure design optimization is opened to be done.

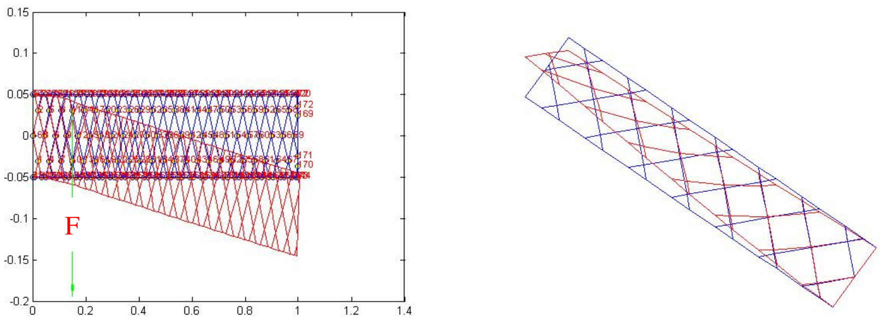


Figure 3.5 Beam element movement due to force, F, for typical geodesic structure that was generated automatically by computer program to support FEM calculation.

Automatic process in geometry preparation for geodesic structure is similar with what has been done in aerodynamic aspect especially for surface grid generation as the input of CFD code.

Conclusion

Automatic process for geometry preparation to support calculation using CFD code for aerodynamic aspect and FEM for structural aspect can simplify and accelerate wing design process.

References

Kroo Ilan, Applied Aerodynamics, A Digital Textbook, Stanford University, info@desktopaero.com, P.O. Box 20384, Stanford, CA 94309, (650) 424-8588 (Phone);

Liu G.R. and Quek S. S., 2003, *The Finite Element Method - A Practical Course*, National University of Singapore, ISBN 0 7506 5866 5.

Sudira IG.N., 2014, Otomatisasi Proses Desain Dan Analisis Aerodinamika Sayap Pesawat Terbang Dengan Perangkat Lunak Nwdu-Vsaero

Urík T., Mališ M., (2008), Innovative Composite Structures For Small Aircraft, Brno University of Technology, Institute of Aerospace Engineering, Technická 2896/2, Brno, 616 69, Czech Republic, ICAS 2008