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Flexible Wing of HALE UAV using Two-way Fluid Structure Interaction Method

B. Junaidin[1], M. A. Moelyadi[2], Muljowidodo[3],
[1,2] Faculty of Mechanical and Aerospace Engineering, Institute of Technology Bandung, Indonesia.
[3]Center for Unmanned System Studies, Institute of Technology Bandung, Indonesia.

Abstract— Simulation of High Altitude Long Endurance (HALE) UAV wing using two-way fluid structure interaction (FSI) method is presented. To achieve its mission, the HALE wing was designed to have high aspect ratio. With longer wing span, the HALE UAV may produce less induced drag and lift-loss which caused by the decrease in wingtip vortex strength. However, the wing structure with longer span becomes more elastic that may yield large deformation when aerodynamic loads applied. This deformation influences flow characteristics at the surrounding of the wing causing the change of aerodynamic loads distribution on the wing. Subsequently, this new load provides a new deformation to the wing structure and vice versa. This interaction in a couple process called as fluid structure interaction (FSI). This method for the HALE wing simulation is provided in ANSYS 15.0 software. The unsteadiness and viscous flows at low speed are evaluated using the solution of time-dependent Reynolds Averaged Navier-Stokes (RANS) with SST k-ω turbulent model. In addition, multi-block structured grids are generated to provide more accurate viscous result and to anticipate negative volume of the mesh which may occur due to the wing deformation during simulation. Five different simulations with variation of material characteristics including Young's modulus and Poisson's ratio are carried out. The results include global aerodynamic characteristics at various material characteristics.

***Keywords*—HALE wing aerodynamic performance, wing material characteristics, fluid structure interaction method**

I. Introduction

RECENT research trends show high interest on the development of High Altitude Long Endurance (HALE) Unmanned Aerial Vehicle (UAV) [1,2,3]. Some examples such as Helios NASA, Global observer, Solitair and Centurion NASA are shown in Figure 1 that have been developed for both operational and technology demonstration.

Patrolling The play role of HALE UAV in space is to provide low cost alternative for space mission including scientific data collection, telecommunication relay, environmental sensing, surveillance and military reconnaissance. For accomplishing these mission, the UAV must be capable of operating at extremely high altitudes to obtain maximum coverage and extended mission duration. For the long-endurance requirement, the UAV should be designed to have high aerodynamic efficiency and light weight structure by applying high-aspect ratio wing.

Figure 1 High altitudes and long endurance UAVs examples

Application of high-aspect ratio wing provides less induced drag, but its wing structure becomes more elastic. The elastic wing may result large deformation structure when aerodynamic loads applied. Actually, the structure deformation will affect aerodynamic load distribution on the wing that continuously creates further deformation to the wing structure. So that, for the elastic wing there is a couple between aerodynamic load and structure deformation.

Researches on aerodynamic-structure coupling called as fluid structure interaction (FSI) have been done by several researchers. In aerospace application, Garelli et al. [7] used FSI method for a rocket engine nozzle. The same method has been used by by Ramji [8] for an airfoil. Furthermore, a loosely coupled FSI scheme was used by Dang et al. [9] for an aeroelastic wing problem for high aspect ratio using constant volume tetrahedron interfacing technique for coupling computational fluid dynamics (CFD) and computational structural dynamics (CSD). Moreover, Chen et al. [10] used fully coupled FSI scheme for 3D wing flutter analysis. They showed the importance of reliable and efficient flutter analysis for airplane wings and aircraft-engine turbo-machinery blades.

The objective of this research is to study coupling between aerodynamic load and structure deformation of flexible HALE wing using FSI numerical method. In this method, the coupling of two different numerical programs, namely computational fluid dynamics (CFD) and computational structural dynamics

(CSD) is carried out. The CSD code obtains aerodynamic loads through fluid solid interface at the wing surfaces from the CFD code. The deformed shape from the CSD code is further coupled with the CFD, from which new loads are determined. This iterative process is continued until a suitable level of convergence is achieved. In this study, five different simulations are conducted with variation in material characteristics including Young's modulus and Poisson's ratio.

II. Fluid Structure Interaction

The iterative FSI method solves each field separately and solution variables are passed iteratively from field to field until convergence is achieved. In this study, two-way strongly coupled method is used because large deformation of the structure cannot be neglected. The diagram of the two-way strongly coupled method is shown in Figure 2.

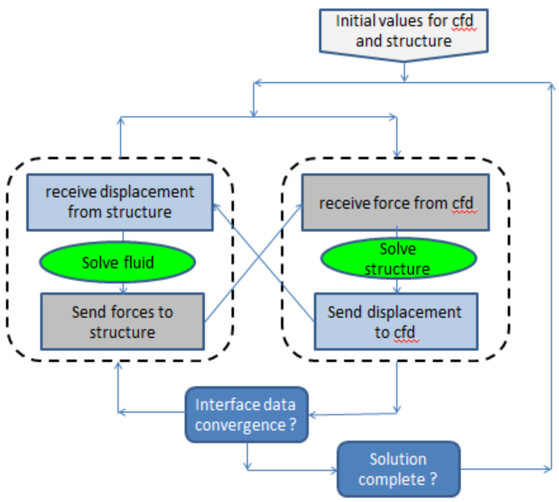

Figure 2 Two-way Coupling interaction between structure and fluid

In the method the calculation result of fluid from the CFD is used as input structure calculations, then the result of structure calculations from the CSD is used as input of the fluid calculation. The coupling process occurs continuously until the simulation boundary conditions are met. In this study, the results of the structure calculation are displacement and velocity, while aerodynamic forces and moment subjected on the structure are the output of the fluid calculation.

III. Simulation Modeling

Simulation was performed using both transient computational structural dynamics code and computational fluid dynamics code; where aerodynamic and structural models were constructed independently. Each model requires independent mesh, boundary conditions, analysis parameters, and output definition.

A. *Modelling and Transient Structural Physics*

The definition Three-dimensional modeling of the HALE wing is carried using CATIA V5 software with the parameter specifications as shown in Table 1.

No	Parameter	Design Model
1	C (m)	0.4 at root and tip of inner wing 0.4 at root and 0.25 at tip of outer wing
2	y (m)	4.2 for inner wing 1.5 for outer wing
3	Wing aerofoil	EMX-07
4	Λ (deg)	0 at inner wing and 4.2 at 0.25C outer wing
5	Γ (deg)	0 at inner wing and 9.8 at LE outer wing

Table 1 Wing model specification.

In The geometry of the HALE wing is imported into the transient computational structural dynamic code. The initial analysis is performed using steel with the following properties: density, ρ=7850 kg/m3, Young's modulus, E=2.0×1011 N/m2, and Poisson's ratio ν=0.3. In the mechanical application, the solid body namely the HALE wing is meshed with various grid density.

B. *Fluid Flow Modelling*

The fluid flow around the flexible HALE wing is low speed that can be modelled as unsteady, incompressible, and viscous flow. Turbulence model uses shear stress transport (SST) model.

To obtain the numerical solution, boundary conditions inlet, outlet, wall, and far field are defined as shown in Figure 3. The wall boundary is defined as 'no-slip wall' which normal and tangential velocity is equal to zero. In addition, the outlet and far field boundary conditions are defined with relative pressure and opening pressure respectively equal to zero. The physical parameters at the inlet boundary is determined from free stream condition based on HALE UAV operation altitudes at 20000 feet [6] as given in Table 2.

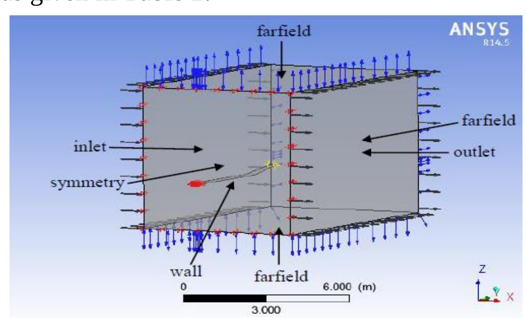

Figure 3 Boundary conditions used in simulation

Physical Parameters	Values
Static Temperature	248.5 K
Static Pressure	46562 N/m^2
Density	0.653 kg/m^3
Velocity	17.88 m/s

Table 2 Physical Parameters of Simulation

Corresponding author:
M. A. Moelyadi (email: moelyadi@ae.itb.ac.id, moelyadi.mochammad@gmail.com)

IV. Results and Discussion

A. *Lift Coefficient of HALE wing*

The Figure 4 shows unsteady and quasi-steady lift coefficients of the HALE wing at various displacement. The upper line of unsteady lift coefficient of the wing is resulted from its downward motion and the lower one from its upward motion. Compared to the quasi-steady result, the unsteady result gives additional lift coefficient during the downward motion. This is due to upward induced velocity during the downward motion. The maximum additional lift coefficient is yielded when the wing at the middle position. While, the decrement of lift coefficient is yielded during the upward motion and the minimum lift decrement occurs when the wing at the middle position. The difference of lift coefficients between unsteady simulation and steady simulation at the peak and lowest positions have less values because there are no induced velocity occurred. After several cycles (time), the lift coefficient of the HALE wing goes to equilibrium values.

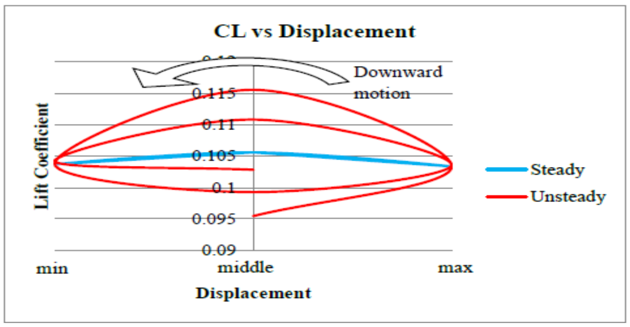

Figure 4 Four- Unsteady and quasi-steady Lift coefficient of HALE wing.

Figure 5 shows effects of elastic material properties including Young's modulus and Poisson ratio on lift coefficient of the wing at various displacements of the wing. Increasing Young's modulus gives the decreased lift coefficient of the wing in the downward motion. While, the lift coefficient increases in the upward motion. Furthermore, increasing Poisson ratio provides higher lift coefficient during the downward motion and lower lift coefficient during the upward motion. The effect of variation of Poisson's ratio to lift coefficient is not as much as Young's modulus effect as shown in Fig. 5.

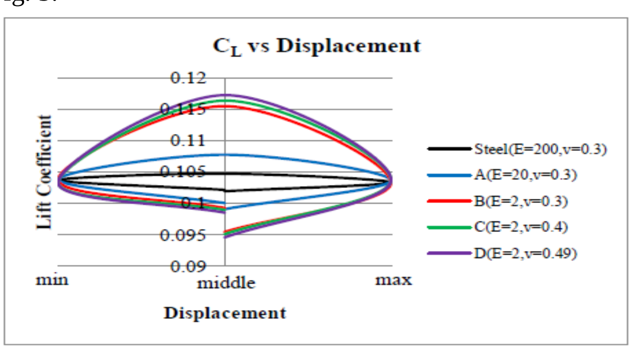

Figure 5 Effect of Young's Modulus and Poisson's ratio on Lift coefficients of HALE.

B. *Drag coefficient of HALE wing*

Our Figure 6 shows drag coefficients in unsteady and quasi-steady conditions at various displacements of the wing. For unsteady condition, higher drag coefficient of the wing is yielded during the upward motion and the lower drag coefficient of the wing is resulted during the the downward motion. Compared to the quasi-steady result, unsteady result gives higher the decrement of drag coefficient during the downward motion.

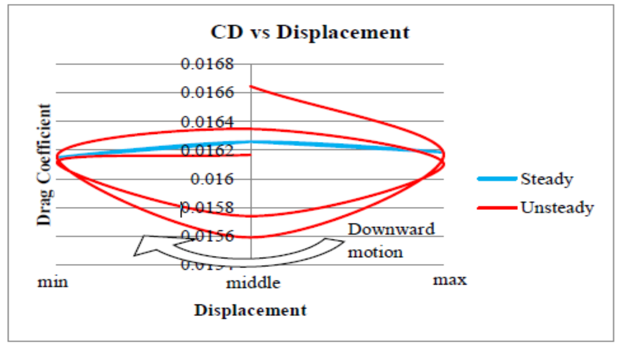

Figure 6 Unsteady and quasi-steady drag coefficients of HALE wing.

Figure 7 shows effect of elastic material properties including Young's modulus and Poisson ratio on drag coefficient of the wing. During downward motion higher Young's modulus gives the lower drag coefficient of the wing during the downward motion. While, the drag coefficient increases for higher Young's Modulus during upward motion.

Consider to the effect of Poisson's ratio, during downward motion the wing drag coefficient increases at higher Poisson's ratio. Moreover, the higher Poisson's ratio of the wing material causes the decrement in lift coefficient during the upward motion. The additional lift coefficient occurs at the middle position when the maximum local velocity is produced. Poisson's ratio gives less influence in drag coefficient compared to Young's modulus.

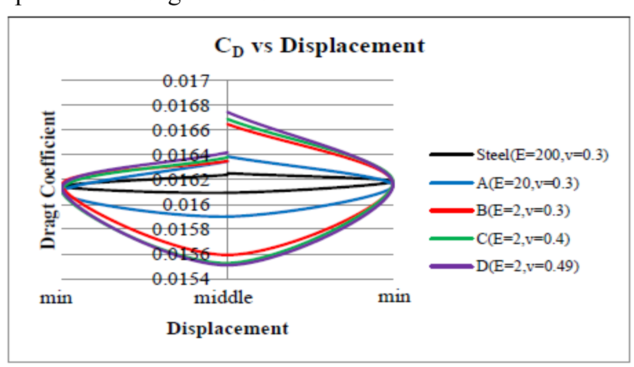

Figure 7 Effect of Young's Modulus and Poisson's ratio on drag coefficient of HALE wing.

C. *Flow characteristics*

Figure 8 shows instantaneous velocity contours around the leading edge for downward and upward motions. The stagnation point indicated by a minimum velocity moves slightly downward during the downward motion. Upward local flow velocity during the downward motion gives higher local angle of attack so that the minimum velocity point occurs at the lower position around the leading edge of the wing. This causes increased lift coefficient during upward motion, lift force decreases.

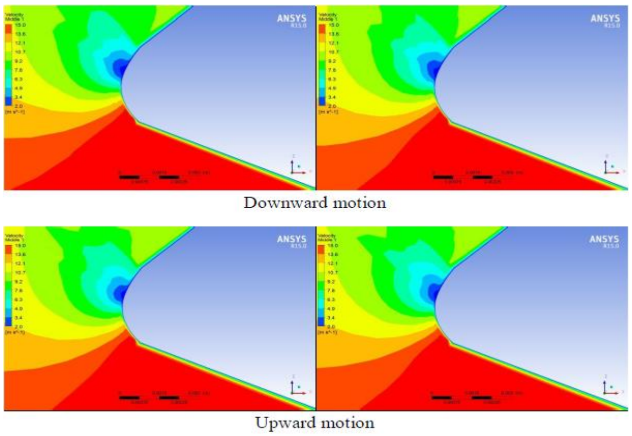

Figure 8 Velocity contour around leading edge at position 0.7 of half span during downward and upward motions.

V. Conclusion

Simulations of the flexible HALE wing have been done using two-way FSI method for simpler geometry of the HALE wing. The downward motion gives higher lift coefficient and lower drag. Low to moderate of the wing Young modulus material is more suitable for generating higher lift coefficient with lower drag coefficient of the wing. Poisson’s ratio gives less significant influence in aerodynamic characteristics of the wing compared to Young’s modulus.

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