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Research on 3D Wing Bending Deformation when Changing Aerodynamic Parameters

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***Abstract*—*When the aircraft is operating, aerodynamic forces will act on the wings and make them tend to become bending deformation or both bending and twisted deformation. This paper presents the results of researching the behavior of bending deformation of wings (excluding the case of twisted wing) when changing the aerodynamic parameters of wings (incidence angle, velocity). This research is programmed and calculated in a closed program: The calculations for the number of aerodynamic load distribution on wings will be transferred directly to the program of calculating the wing deformation to minimize the calculation error of of input parameter. The program of calculating aerodynamic forces uses the method of calculating the number of combined doublet and source singularity, the program of calculating the wing elastic deformation uses the method of calculating the number of degenerate 3D elements.*

***Keywords*—** *Aerodynamic - elastic 3D interaction, 3D wing bending, calculating the number of aerodynamic forces.*

I. Introduction

The aerodynamic and wing elastic problems are two completely different ones but they always exist on aircraft wings when it flies. The aerodynamic problem is solved from the wing surface spreading to the surroundings, whereas the elastic problem is solved by behaviors from the inside of wings. These two problems belong to two different fields of mechanics: fluid mechanics and solid mechanics. Therefore, other authors who solve the aerodynamic problem usually calculate, simulate or determined experimentally and will consider the wings to be absolutely hard. The authors who solve the elastic problem often use aerodynamic forces as point forces (not using force distribution).

Kollias et al. [1] studied the calculation of lift coefficient and drag coefficient for Naca 64A010 wing for a model aircraft, the incidence angle was studied from 0 to 9 degrees, Low Reynolds number in the range of 100,000, velocity 1.82 m/s. The calculation program used is a numerical calculation simulation program (wings are considered to be absolutely hard).

Xiao Yu Wang [2] et al. studied simulation by Fluent software in combination with experiments (wings are absolutely hard) to calculate the lift and drag coefficients of Naca 0018 wing with incidence angle up to 30 degrees, flow rate 20 m/s, Reynolds number is 320,000.

Asif Shahriar Nafi et al. [3] studied the calculation for diagonal wings of an aircraft at negative transient velocity or more with Mach numbers from 1.2 to 1.4. The wing used is "Biconvex Airfoil" with a span of 1.5 m, chamfer angle of 2.7 degrees. Aerodynamic forces were calculated by numerical simulations and wings were considered to be absolutely hard.

Nguyen Hong Son et al. [4] calculated the aerodynamic forces of Naca 0012 wing for the negative transient current. Of which the aerodynamic force was calculated numerically showing the result that it was the distribution force and the test verified that the wing was considered to be absolutely hard.

Liu Youhua [5] studied the calculation of elastic deformation for scaled wings (profil Naca 0015 - 0006, 4 ribs) by finite element method according to degenerate 3D models. Of which the input parameter of aerodynamic forces is the point force.

La Hai Dung [6] built a numerical model for flutter wing problems of the flight instrument, of which aerodynamic forces were calculated numerically by a discrete vortex model that resulted in the aerodynamic force in the form of distribution, but the elastic experimental model uses the point force as acting one.

In this work, the author presents a part of research on calculating the aerodynamic force and elastic deformation both by 3D numerical calculation. Of which the aerodynamic force is the input of the elastic deformation problem which is the distribution force. The wing after being impacted by aerodynamic forces will be greatly deformed, which means that the stress in the structure will be high value. Limits for the elastic deformation of wings are evaluaed by checking the stress distribution and comparing the maximum stress of the wing with the allowable stress of the material in order to make judgments about the relationship between aerodynamics and structures.

II. Numerical Calculation Program

Aerodynamic force calculation: The aerodynamic force is calculated numerically in 3D by the combined doublet and source singularity method [9], [10]. The result of calculation program is a 3D pressure distribution force field on the upper side and lower side of wings as shown by the 3D pressure coefficient distribution graph. The program has been evaluated and verified with experiments and other published works [4], [7], [8].

Calculation for elastic deformation of wings: Wings are numercially calculated in 3D for elastic deformation with input parameters which are aerodynamic forces calculated in the above program. The program of calculating the wing elastic deformation is programmed by finite element method. Because the wing element is thin, the element of wings is constructed as a degenerate 3D element [5], [7], [11], [12]. The result of the numerical calculation program is the stress field and 3D deformation on the upper, lower side of wings.

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III. SURVEYING THE BENDING STATE OF WINGS WITH THE CHANGE OF INCIDENCE ANGLE AND VELOCITY

A. Wing bending with the change of aerodynamic forces when changing the incidence angle

Considering the rectangular wing with profil Naca 2412, span b/c = 4, free flow velocity $M_\infty = 0.4$ with 3 cases of incidence angle $\alpha = 0^o$, $\alpha = 2^o$, $\alpha = 4^o$. From these parameters, the 3D aerodynamic calculation program shows the result of distribution of pressure coefficient as shown in Figure 1. Aerodynamic pressure acting on the wing with the incidence angle $\alpha = 4^o$ is greater than the case of incidence angle $\alpha = 2^o$, and much greater than the case of incidence angle $\alpha = 0^o$

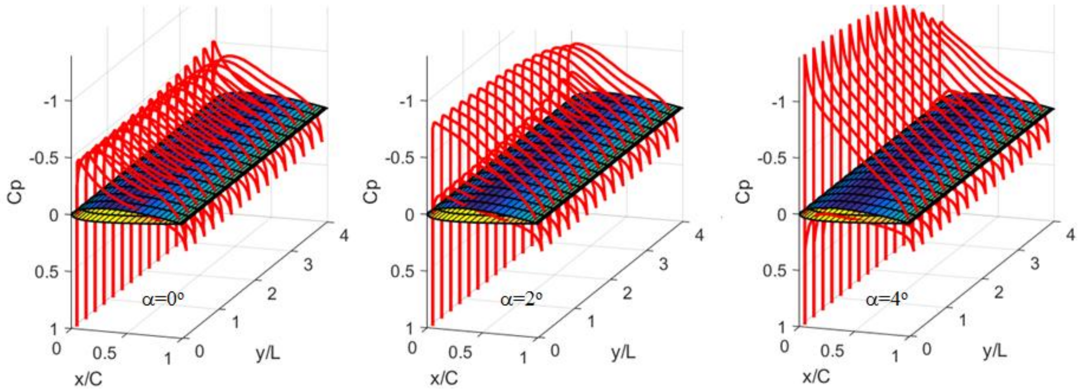

Figure 1. Pressure distribution with three incidence angles $\alpha=0^o$, $\alpha=2^o$, $\alpha=4^o$

The structural parameters of wings are considered to be unchanged: empty wings, no ribs with skin thickness t = 0.004 m, the material of wing skin is dura (2024-T3) with elastic module $E = 7.31 \times 10^{10}$ N/m and allowable tensile stress $[\sigma] = 11 \times 10^7$ N/m Poisson's coefficient $\upsilon = 0.33$. With the cases of aerodynamic force-bearing wings as in Figure 1, solving the elastic deformation problem of wings and the result of Von-Mises stress at the cross section of root wing is shown in Figure 2. According to the movement direction, the stress position with the highest value is on the half of profil from the edge and there is a difference between the upper side ad lower side of wing. Comparing the three graphs at different incidence angles shows that the maximum stress with the case that aerodynamic forces are created by the incidence angle = 0 degrees is much smaller than the allowable stress. In the case of an incidence angle $\alpha = 4^o$, the maximum stresses at the upper side and lower side of wing exceed the limit of allowable stress.

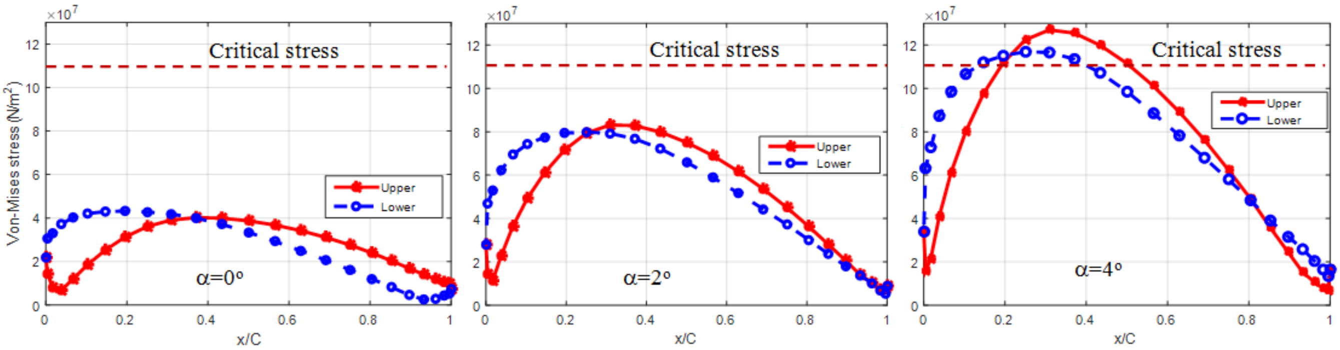

Figure 2. Stress at the root wing- comparing 3 cases of incidence angle $\alpha=0^o$, $\alpha=2^o$, $\alpha=4^o$

These calculations show that the incidence angle (the incidence direction of velocity) has a great influence on aerodynamic forces and thereby strongly affect the deformation and stress in wings. In case the incidence angle is small ($\alpha = 0^o$), the wing is ensured to be durable with a high safety factor. But when increasing the incidence angle ($\alpha = 4^o$), the maximum stress in wings has exceeded the elastic limit with a fairly large value at the root wing.

B. Wing bending with the change of aerodynamic forces when changing the velocity

The changes of free flow velocity will change the aerodynamic force, thereby affecting the deformation of wings. Considering the cases where the velocity changes with $M_\infty = 0.3$; $M_\infty = 0.4$; $M_\infty = 0.5$ on the shape of unchanged wing aerodynamic, unchanged incidence angle and unchanged internal structure pf wings. Wings which are considered are rectangular ones, profil Naca 2412, b/c = 4, incidence angle $\alpha = 3^o$, flight height h= 3000 m. Aerodynamic forces expressed in the form of distribution of lift coefficient on the wingspan in the three cases that free-flow Mach numbers vary are shown in Figure 3. The internal structure of wings is a hollow wing with two ribs, with parameters: the skin thickness t = 0.003 m, the material of skin is dura ($E = 7.31\times 10^{10}$ N/m^2, Poisson's coefficient $\upsilon = 0.33$), two ribs are located at 0.25 m and 0.75

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m from the leading edge compared to the chord direction, the first rib has parameters: t_1 = 0.01 m, t_2 = 0.01 m, t_3 = 0.015 m, the second rib has the thickness of rib foot and the width of rib wall equal to 80% of the first rib (Figure 3). The wing has 16 spars with a thickness of 0.008 m. The material of ribs is alloy steel ($E = 20\times10^{10}$ N/m^2, Poisson's coefficient $\upsilon = 0.3$).

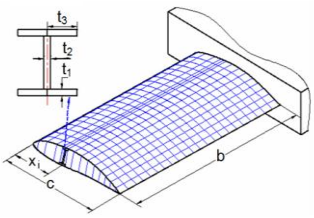

Figure 3. Structure of the wing with ribs and rib spars

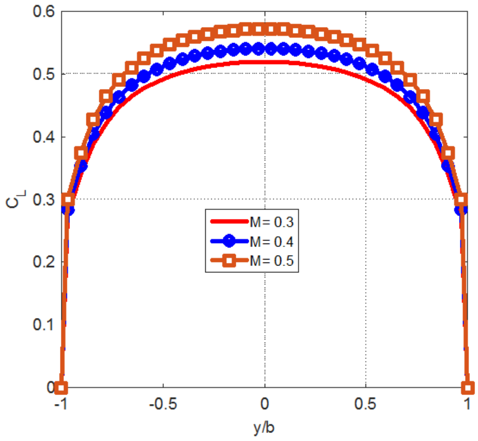

Figure 4. Lift coefficient on wingspan M_∞ = 0.3; 0.4; 0.5.

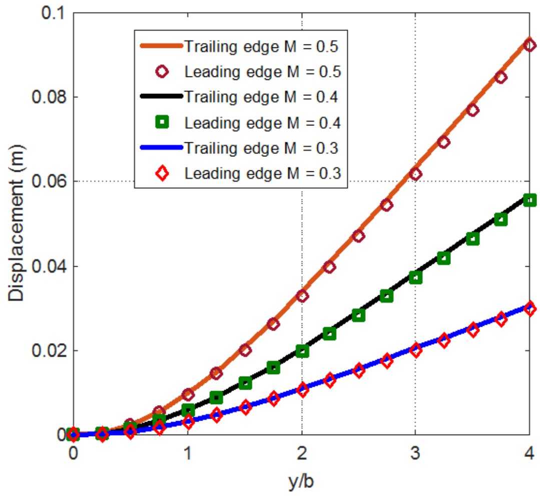

Figure 5. Displacement at the leading and trailing edge M_∞ = 0.3; 0.4; 0.5.

Under the influence of external aerodynamic forces (Figure 4), the wings are deformed with displacement of the leading edge and trailing edge shown in Figure 5. The resulting graphs of displacement also show a clear effect of the free flow velocity value on the deformation of wings. With M_∞ = 0.3, displacement at the wing end is 0.026 m, this value increases to 0.058 m when M_∞ = 0.4 and 0.095 m when M_∞ = 0.5.

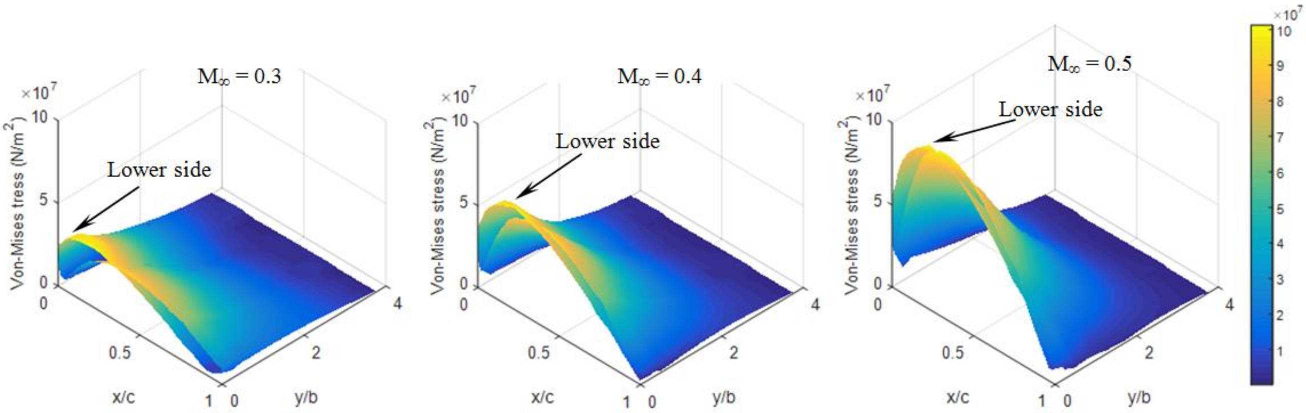

Figure 6. Stresses at the upper side and lower side of wings when M_∞ = 0.3; 0.4; 0.5.

The 3D distribution to Von-Mises stress on the upper side and lower side of wings with three cases that free-flow Mach numbers vary is shown in Figure 6. In such three cases, the stresses reach maximum value at the crosssection of root wings. The highest stress value equals 10.2×10^7 N/m^2 in the case of M_∞ = 0.5, much greater than the maximum stress value of 6.3×10^7 N/m^2 in the case of M_∞ = 0.4 and the lowest maximum stress in the case of M_∞ = 0.3 with a value of 3.6×10^7 N/m^2. In all three cases above, the maximum stresses are within the elastic limit.

IV. Conclusions

The aerodynamic and elasticity problems always exist at the same time when the aircraft is operating, in fact the aerodynamic force is the 3D distribution force, therefore the wing elasticity problem is calculated with the input parameter as the aerodynamic load distribution which is also calculated numerically to be required for ensuring more reliable results.

Because the wing has a structure with only one head binding to the body, when the aircraft operates under the effect of very large aerodynamic forces, the wings always tend to become elastic deformation. This deformation is very large and the stress at the root wings will be the greatest.

When increasing the incidence angle and the free flow velocity, the aerodynamic force will increase sharply, this increased value depends on the form of wing profil. Therefore, for each wing structure, its strength must be tested according to the incidence angle and velocity.

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