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The Effects of Force on the Structure Deformation of Wing for Flapping-wing

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Abstract: This paper investigated the effects of aerodynamic force and inertial force on the structure deformation of wing. The aerodynamic force was tested from the wind tunnel experiment. The study indicated the quantity of aerodynamic force and inertial force is equal. The maximum deformation was produced by aerodynamic force or resultant force when wing is located on horizontal situation. The study of wing structure deformation provide guide for design and optimization of wing for flapping-wing.
Keywords: Flapping-wing; aerodynamic force; inertial force; structure deformation

1. INTRODUCTION

It's earnestly long to design an aircraft like birds or insects which can flight slowly and short takeoff and landing and implement high-difficulty maneuvers action such as swerve quickly and backward flight for designer of aircraft. Above excellences of birds or insects greatly depend on structure deformation and flapping ruler of wing. Bird changes flight pose and aerodynamic force through adjusting bend and torsion deformation of wing. Flapping-wing is a new-concept aircraft which mimics the flight of bird or insect. The flapping wing generates lift and thrust without excessive size or weight. Hence the flapping wing is an efficient/useful option in designing Micro Air Vehicles.

The change of wing structure deformation not only influences aerodynamic force but also changes flight pose for flapping wing. A lot of research organization attempt to improve aerodynamic efficiency of wing and control ability through various methods. It is lack of mature aerodynamic mechanism to guide the design of flapping wing. Therefore the report of wing design is about that the study singly of wing structure or aerodynamic mechanism. For example, S.A.Combes of Washington investigates flexural stiffness influences on insect wings scaling and wing venation. Zeng rui uses the unsteady vortex lattice method to

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calculate the unsteady aerodynamic of flapping-wing in Nanjing university of aeronautics and astronautics. Naval postgraduate school of California university investigates the thrust characteristic through a series of wind experiment. However, there still remain some key challenges that need to be overcome before a flapping-wing can be realized. The relative contributions of inertial and aerodynamic forces on the wing deformations are unclear from flapping-wing studies. This paper investigates structure deformation of wing take into account material property of wing through modeling finite element modeling to simulate aerodynamic force and inertial force. The aerodynamic force was tested through the wind experiment. The inertial force was obtained through practical wing. It establishes groundwork to study the relationship between aerodynamic force and structure deformation during the whole flapping cycle.

2. EXPERIMENTS SETUP

2.1 Wing model

The wings of flapping-wing are lightweight, flexible structures. The wing planform tested was shown in fig.1 with aspect ration of 4 and total wing area of 400 cm2. This wing is used through all of these tests to avoid the influence of wing geometrical parameters. The wing is constructed by Mylar sheet as a skin and kryptol as a spar. The weight of wing is 4 gramme. The centroid of wing is located on 100 millimeters from wing root to wing tip.

2.2 Wind tunnel

The experiments were carried out in special micro air vehicle wind tunnel of NPU(Northwestern Polytechnical University).It is a low speed open jet tunnel which has a test cross section 50x50 cm2. The experimental setup is shown in fig.2. The experimental Reynolds numbers were performed at 1.02×10^4 <Re< 6.9×10^4 . The average turbulence level was 0.22%. The precision of experiment is 0.47%.

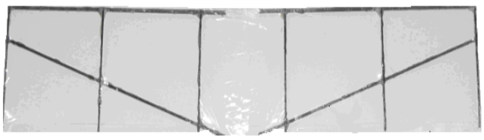

Fig. 1: Wing model

Fig. 2: The MAV Wind tunnel of NPU

2.3 The flapping mechanism

The wing was derived by the flapping mechanism shown in fig. 3. This mechanism is named as crank link mechanism. It comprises the connecting rod and gear. All the connecting rods are made of aluminium-alloy, which have high specific strength .The gears are made of plastic, which have not only high stiffness but also very light. The overall mass of the flapping mechanism is 15g. The maximum angle of flap is 77.21 degree. The theory figure of flapping mechanism was shown in fig4. In the fig 4, l_1 =5.2mm, l_2 =23.2mm, l_4 =8.4mm, l_6 =24.86mm, $\theta=15.15^\circ$, l_1 is the radius of crank and l_2 is the length of connecting rod and l_4 is the length of the other connecting rod and l_6 is the distance between wing joint and the center of crank running and θ is initial installed angle.

The flapping angle is measured by the use of a sliped rheostat, and all signals are acquired by the use of DSP board. The sliped rheostat was fixed on left rocker of flapping mechanism. The voltage produces change when wing lies on different flapping phase. The change of flapping angle was expressed through the chang of rheostat voltage. The controlling parameters of experiments are the free stream velocity (U) and the flapping frequency (f), the free stream velocity in the test section had been controlled by adjusting the speed of the blower fan. The flapping frequency was controlled by adjusting the input voltage of D.C motor.

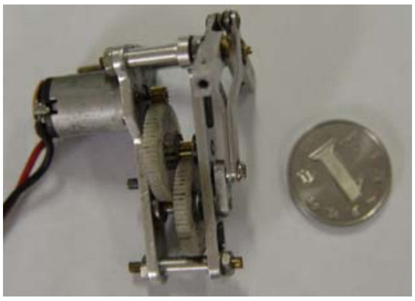

Fig. 3: The flapping mechanism

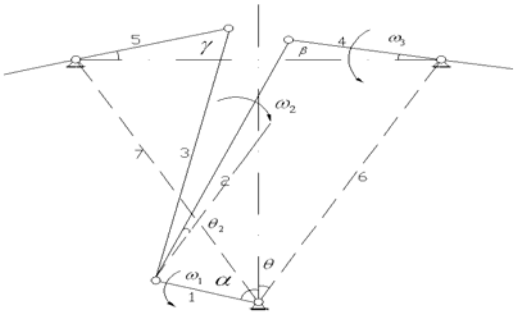

Fig. 4: Theory figure of flapping mechanism

2.4 The aerodynamic force

The wind tunnel test was performed when velocity is 10m/s and flapping frequency is 7.81 Hz and the attack angle is 0°. The relationship between aerodynamic force and instantaneous flapping angle was shown fig5. The instantaneous lift of wing was shown table1 when wing is located on different instantaneous flapping phase. In table1, a flapping cycle was divided equally into eight proportions.T/8 expresses that wing is beginning to down stroke from the maximum flapping amplitude.

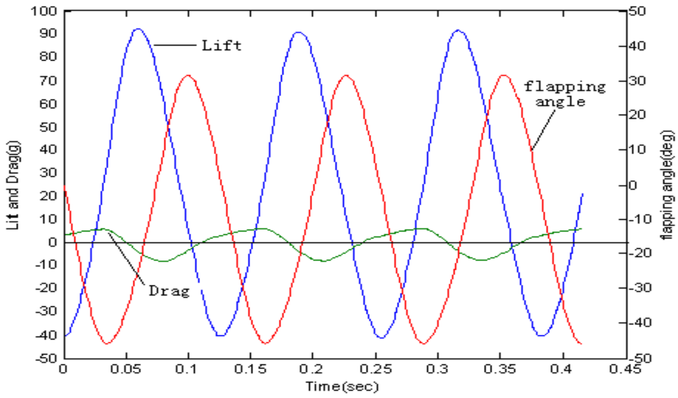

Fig. 5: Lift and Drag with instantaneous flapping phase

Table 1: Lift with different instantaneous flapping phase

Flapping phase	T/8	2T/8	3T/8	4T/8	5T/8	6T/8	7T/8	8T/8
lift(gram)	23	90	78	59	10	-32	-40	-28

2.5 Inertial force of wing

The wing generated inertial force periodically. The direction of inertial force is reverse with the flapping orientation of wing. The formula is:

$$F_{inertial} = -\sum_{i=1}^{n} m_i a_i \qquad (1)$$

Where m_i is the mass of wing element and a_i is linear acceleration of wing element, n is the number of wing element. The variety of inertial force at different instantaneous flapping phase was shown in table2.

Table 2: Variety of Inertial force at different instantaneous flapping phase

phase		T/8	2T/8	3T/8	4T/8	5T/8	6T/8	7T/8	8T/8
Angular acceleration (deg/s^2)		113736	53261.76	0	-45060.3	-85228.2	-43796.8	0	66709.48
Inertial force (gram)	25%	4.179435	2.147675	0	-1.85695	-3.12072	-1.76715	0	2.690543
	50%	12.53831	6.443025	0	-5.57086	-9.36215	-5.30143	0	8.071629
	75%	20.89717	10.73837	0	-9.28477	-15.6036	-8.83571	0	13.45271
	100%	29.25605	15.03373	0	-12.9987	-21.845	-12.37	0	18.8338
	resultant force (gram)	66.87096	34.3628	0	-29.7112	-49.9314	-28.2742	0	43.04869

3. STRUCTURE DEFORMATION OF WING

3.1 The finite element model

We used Patran to create a simplified finite element model to investigate the structure deformation of wing. Our goal was not to reproduce the behavior of a real wing but rather to create a general model of a wing to explore how aerodynamic force and inertial force affects on deformation .In this paper, Beam element is adopted for spar boom, bar element is adopted for rib of wing, shell element is adopted for the membrane. The FEM grid was shown Fig6. The kryptol is made of T300. The performance of material was shown table3. E_{1t} is axial tensile elastic modulus. E_{1c} is longitudinal compressive elastic modulus. E_{2t} is horizontal tensile elastic modulus. E_{2c} is horizontal compressive elastic modulus. G_{12} is shear modulus. ν_{12} is Poisson's ratio. The elastic modulus is 1.4Gpa and Poisson's ratio is 0.4 and density is 1.2gcm-3 for wing membrane.

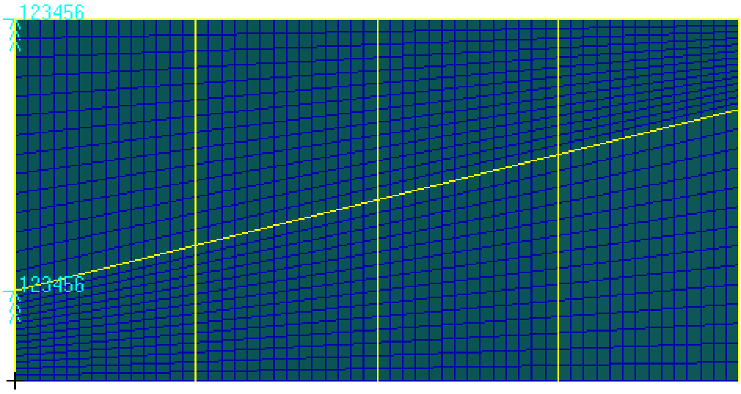

Figure 6: Wing simulated model

Table 3: Material performance of T300

E_{1t}/GPa	E_{1c}/GPa	E_{2t}/GPa	E_{2c}/GPa
136	111	9	9.5
G_{12}/GPa	ν_{12}	density $(g\square cm^{-3})$	
4.9	0.316	1.5	

3.2 Boundary condition

The wing didn't move right-and-left along horizontal orientation when the flapping-wing flight. The wing did the same movement when fuselage ups and downs movement. Therefore the root of forward spar and diagonal spar were clamped.

3.3 Load

The aerodynamic force and inertial force of wing was put on rib of wing according to actual distribution.

3.4 Results and discussion

The variety of structure deformation of wing with force of wing is shown in table 4.The structure deformation of wing was shown Fig 7 when the aerodynamic force is 88.7g. The structure deformation of wing was shown Fig 8 when the aerodynamic force is -71g.The structure deformation of wing was shown Fig 9 when inertial force is 66.9g.The structure deformation of wing was shown Fig10 when inertial force is -49.9g.The maximum deformation of wing occurs the horizontal station by aerodynamic force or resultant force . In this state, projective area of wing is maximum, the aerodynamic force is maximum, and the inertial force is minimum. The maximum inertial force and the minimum inertial force occurs vertex and nadir of the maximum flapping range.

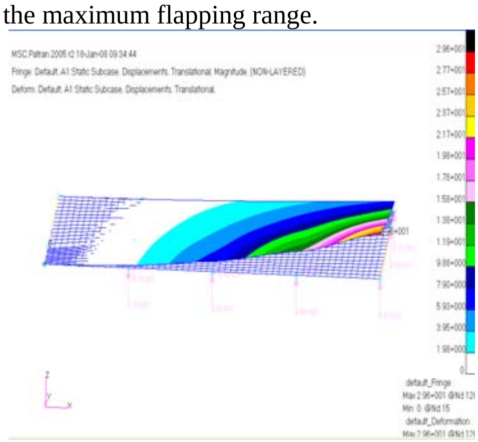

Figure 7: deformation of wing (Lift=88.7g)

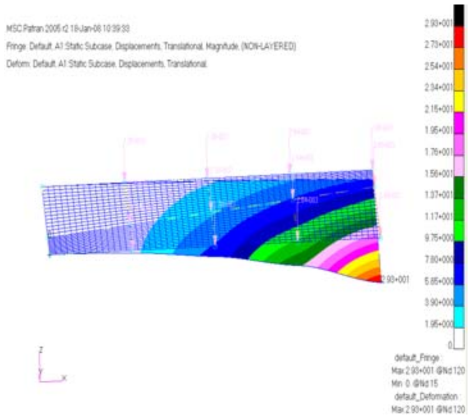

Figure 8: deformation of wing (Lift=-71g)

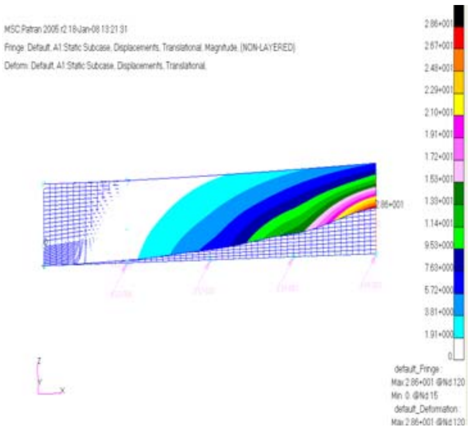

Figure 9: deformation of wing (Inertial force=66.9g)

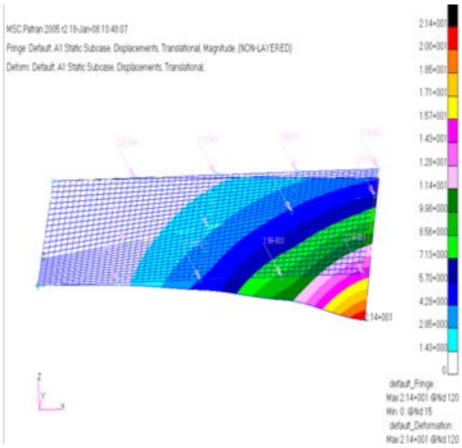

Figure10: deformation of wing (Inertial force= -49.9g)

Table 4: Structure deformation of wing

Flapping phase	Aerodynamic force (gram)	Inertial force (gram)	resultant force (gram)	Maximal deformation by aerodynamic force (gram)	Maximal deformation by Inertial force (gram)	Maximal deformation by resultant force (gram)
T/8	-43.871	66.87096	23	-11.8	28.6	16.8
2T/8	55.6372	34.3628	90	7.61	14.7	22.31
3T/8	78	0	78	29.6	0	29.6
4T/8	88.7112	-29.7112	59	19	-12.7	6.3
5T/8	59.9314	-49.9314	10	10.8	-21.4	-10.6
6T/8	-3.7258	-28.2742	-32	-7.63	-12.1	-19.73
7T/8	-40	0	-40	-29.3	0	-29.3
8T/8	-71.0487	43.04869	-28	-19.2	18.4	-0.8

4. CONCLUSION

This paper indicates aerodynamic force and inertial force have great influence on structure deformation of wing. The aerodynamic force is primary. The mainly reason is the affects of inertial force on structure deformation of wing is reduced because flapping frequency is low and elastic model is single compare with insect.

Inertial force was changed, and aerodynamic force and flight pose were changed follow. The inertial force is the greater, input power is the greater. The energy is consumed. We not only take into account the role of aerodynamic force but also decrease inertial force influence in structure deformation.

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