SOLAR UAV GUST LOAD AMENDMENT

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Abstract

Loading analysis is the key technology in the process of aircraft design. For UAVs, analysis of the gust load is usually carried out by the Pratty method. But for the solar UAV flight, due to low speed, lightweight, low frequency and large deformation, the validity of Pratty method is worth discussing.

This paper took a certain kind of High Altitude Long Endurance (HALE) UAV as an example, briefly introduced how to calculate the structural payloads of this UAV by means of Pratty method and calculated the structural payloads of the aircraft according to the design standards of UAVs. Besides, through the method of Dynamic analysis of structure in unsteady aerodynamic force, this paper proposed that the problems existing in the calculation process of the UAV's payload can be solved by the aforesaid standards and the error was briefly calculated and assessed.

The analysis result showed that when designing this kind of UAV based on common standards, the actual structural payload was generally overrated. Therefore, the UAV designing standards needs to be rectified based on the structural and aerodynamics characteristics of this kind of UAV.

1 General Introduction

Aircraft structural load calculation is an important part of the design process.Currently, each country aircraft design specifications, regulations are in accordance with the methods and formulas provided in the NACA R1206. Aircraft structural load calculation was largely dependent on the design specification. NACA1206 given a brief gust loads design calculation methods, so that a variety of aircraft structural load calculation becomes very simple and quick.

Since 1915, NASA's first publications have identified a method of gust loads. These years, this approach has been used in aircraft design and verification process, and continuous improvement . These methods are mainly divided into: quasi-steady method, transient and continuous turbulence calculation method. Quasi-steady gust calculation method provides a less accurate, but fast and simple way to calculate[1]. In the mid-1950s, In the mid-1950s, Pratt and Walke revised gusts formula and calculated the gust loads using gust correction factor. Pratt method put out vehicle dynamic response separation from aero-elastic response. He use an flight dynamics equations (EOM) of the stiffness aircraft to determine suffered limit load factor during the gust. The EOM is just a functions of dimensionless time and a dimensionless mass ratio μg. Pratt and Walke [4] assumes a 1-cos gust shape, and solves the dynamics equations to obtain the limit load factor under gust conditions. He used the limit load factor to gain a load reduction coefficient Kg of sharp edge gust[2-3].

$$\mu_g = \frac{2W}{\rho g S \bar{c} C_L^{\alpha}} \quad (1)$$

$$K_g = \frac{0.8\mu_g}{5.3+\mu_g} \quad (2)$$

$$\Delta n_{pratt\_method} = K_g \Delta n_{sharp\_edge} \quad (3)$$

Among them: μg is dimensionless mass, W is the weight of aircraft, L is the lift, ρ is air density, V is the flight speed, S is the reference area of the wing, C_L^{α} is the slope of the curve is the lift, $\bar{c}$ is the average chord length.

Since mid-1950, this approach has become dominant quasi aerodynamics analysis, continues today, as the basic formula of the current domestic and foreign aircraft gust load calculation.

Since the 21st century, when the "Helios", "Pathfinder" as the representative of the high-altitude long-endurance (HALE) unmanned aerial vehicle （UAV） appeared in large numbers, as opposed to other UAVs, this type of aircraft has a low flight speed, low wing loading and large flexible features. For example: a model solar UAV cruising speed is 12m ㎡ s, an order of magnitude less than general aircraft；And so the aircraft wing load is 2.8kg / m2, two orders of magnitude less than general aircraft. It is worth attention that whether the conventional load calculation method is suitable for this kind of aircraft.

2 The influence of low speed on gust load

The calculation of gust load in the Pratt method is based on these assumptions：

1. The gust direction is the vertical direction, and the wind strength along the spanwise direction is consistent.
2. The flying speed of the aircraft is much faster than the gust velocity. The gust velocity and the flying velocity can be synthesized, and the impact of the gust is simply considered as the increase of the wing attack angle.

Under such assumption， it can be considered that the calculation formula of lift of aircraft under gust is as follows:

$$\Delta L = \frac{1}{2}\rho V^2 S C_L^\alpha \Delta\alpha \qquad (4)$$

It is worth noting that this method is based on the assumption that the speed of flight is much faster than the gust velocity. But for the solar UAV, the difference in speed is very small. For this kind of low speed aircraft，if still use the traditional UAV design specification，it can be found that the angle of the formation of the flight velocity and the gust velocity can reach 45 degrees. Of course, the aircraft will be stalled at this moment. Even if under the wind speed the aircraft still maintains normal flight without the occurrence of the stall，the gust load calculation of aircraft will also produce errors. As shown in Figure 1，The reason of this error is that the ratio of gust velocity to flight velocity is large, and the arctan(w/V) can't be replaced by w/V. The speed of flight in gust V_1 can’t be replaced by the speed of flight V and Can’t use the lift verticaling with velocity direction L_1 instead of the lift used to calculate overload factor L.

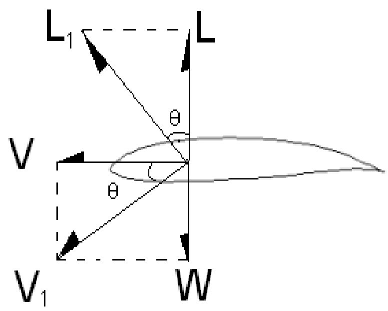

Fig. 1. The load sketch of the wing under the gust

It is for these reasons，The overload coefficient of gust load is overestimated. Taking the gust speed at 5m/s，As shown in Figure 2，the load calculation error of the aircraft at different gust speeds can be obtained.

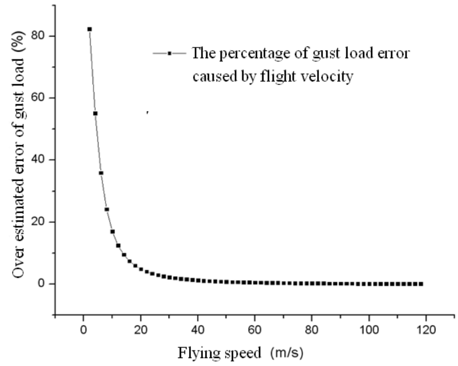

Fig. 2. UAV overload error under gust

In addition, the wind speed doesn't need to be set too high in the calculation of gust load. The design codes require that the aircraft can resist the gust of the 20.1m/s, but under such gust conditions, the aircraft has already stalled. Generally speaking, the HALE UAV only need to resist the gust speed should be half of its highest flight speed， about 7m/s is enough.

3 The influence of low wing load

The low wing load of UAV will also have an effect on the calculation of the the aircraft load. This is because the gust cut coefficient is used in the process of calculating the gust of wind，For the aircraft calculation, the gust cut coefficient is a fitting function which is fitted by the maximum of the overload coefficient by solving the dynamic equation. It can be seen that the gust cut coefficient of the equation has only one variable，which is the dimensionless weight. The accurate calculation method of the gust cut coefficient can be realized by solving the structural dynamic equation of the aircraft, as shown in the following formula[4-5]:

$$\frac{d^2z}{ds^2}+\frac{1}{\mu_g}\int_0^s K_W(s-s')\frac{d^2z}{ds'^2}ds'=\frac{1}{\mu_g}\frac{\bar{c}U_0}{V}\int_0^s K_G(s-s')\frac{d}{ds'}(\frac{U}{U_0})ds'$$

The solution of this equation needs to be realized by Laplace method .Making Laplace changes at both ends of the equation simultaneously, the convolution form equation can be simplified to a linear algebraic equations. The linear equation is simplified and the overload coefficient is calculated by using the inverse Laplasse transform.

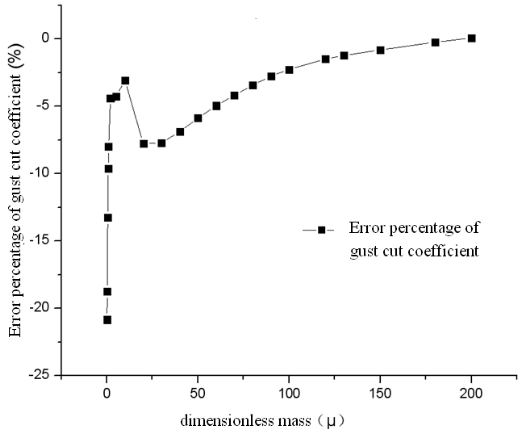

Fig. 3. overload error Due to the low wing loading

And it will be found it through this calculation，that for the general aircraft， for the general aircraft, the gust cut coefficientresults obtained from the equation are very accurate and the error is within 4%，but when the dimensionless mass below 1， the difference of the computation becomes obvious, for a given aircraft as an example, the gust load is overestimated by 15% duing to the low wing load. The calculation error of the overload factor of different load conditions is shown in Figure 3.

4 The influence of large deformation of structure

The elastic structure is relatively complex in load analysis during flight, This requires the coupled calculation of the finite element equation and the flight dynamic equation. In addition, because of the large deformation of the structure, the influence of geometrical nonlinearity is considered in the calculation[6].

The structure model is constructed by nonlinear Euler beam.；the aerodynamic model of the aircraft is based on a simple strip theory， and the flight dynamic equation is constructed by the following equation.

$$m\ddot{x}+c\dot{x}+kx=F \qquad (5)$$

The results show that:

1. For solar powered aircraft, due to the influence of geometrical nonlinearity, the actual wing deformation is smaller than that calculated by the elastic vehicle model, Generally speaking, the calculation method of the elastic plane will overestimate the maximum deformation of the aircraft about 7%.

2. For the solar powered aircraft, generally speaking, with wing stiffness decreases, the corresponding stress will rise accordingly, but the magnitude of this increase is very small, and can be ignored in the process of structural design. When the bending stiffness of EI wing doubled, the stress decreases only around 4‰.

3. The stiffness of the aircraft has little effect on the flight path. Generally speaking, the more flexible the wing is, the greater the motion amplitude of the aircraft is in the wind. But the magnitude of the increase is small, if the stiffness of the wing is reduced to the original half, the motion amplitude of the aircraft is in the wind has only an increase of 3%.

5 The formula for the wind load calculation of HALE UAV

According to the calculation and analysis above, it can be known that the conventional design specification is not suitable for the design of the HALE UAV. This paper will try to propose a new load design formula for the design of solar UAV

According to aircraft design code， aircraft during sea level cruise (flight velocity VC) is required to withstand the gust velocity of 12.25m/s； the extreme wind speed of flight (Vb) is 20.1m/s, and the Maximum gust velocity (flight velocity Vd) that is required to withstand during dive is 7.61m/s. But by the above analysis, the greater the problem encountered in this gust speed is the stall crash. So the first adjustment is about the gust speed，Vb Vc Vd was adjusted to fifty percent maximum speed of flight, forty-five percent of the maximum speed of flight and forty percent of the maximum speed of flight respectively.

Another adjustment is about gust cut coefficient, according to the previous calculation, the formula is adjusted as follows：

$$n = 1 + \frac{\rho S C_L^{\alpha} V \omega}{2G} K_g (-0.4277 k_V^2 - 0.1442 k_V + 1.012) \quad (6)$$

$$K_g = -0.0137 \mu_g^2 + 0.1436 \mu_g - 0.0019 \quad (7)$$

$$\mu_g = \frac{2W}{\rho g S \bar{c} C_L^{\alpha}} \quad (8)$$

Among them：μ_g is dimensionless mass, k_V is named a gust velocity ratio, which is used to indicate the ratio of the wind speed and the flying speed. Through calculation and comparative analysis, the gust load of HALE UAV will be reduced to 40% of the original gust load.

6 Conclusion and Prospect

The wind gust calculation method for UAV design is analyzed in detail in this paper. Research shows that the traditional UAV load design technology is not suitable for new solar UAV. In this paper, the source of each error is analyzed, and the error numerical value is given. It can be seen that the local error of the traditional load analysis method is as high as 40%. Based on this, this paper presents a new gust load calculation method for solar UAV. The validity of the design formula will be verified by the following wind tunnel test and flight test. It is hoped that the results will help the manufacture of solar UAVs.

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