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Dynamic Analysis of Skid Landing Gear of UAV Under Ground Contact Condition BASED on Finite Element Method

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Abstract. In this paper, 3D modeling software is used to conduct structural modeling of skid landing gear of parachute landing recovery UAV, and then LS/DYNA analysis module of ANSYS software is used to conduct dynamic simulation analysis of the landing gear, which is used to simulate the structural working condition of the landing gear when the UAV lands at different attitudes and speeds and impacts the soil and concrete ground. Based on the changes of the momentum, deformation and stress of the landing gear during the simulation period, it is necessary to ground the UAV with a steady attitude Angle on the soil soft landing surface. At the same time, through the analysis of the maximum equivalent stress and safety factor of the landing gear structure at the moment of impact, the connection of the landing gear components is most vulnerable to impact damage, and it is necessary to strengthen the structure and carry out margin control on the structure, which provides theoretical guidance for the structural improvement of UAV recovery device in the future.

Keywords. Skid landing gear, finite element analysis, dynamic simulation analysis, ANSYS

1. Foreword

1.1. Research Background

Finite element analysis is to use mathematical approximation method to simulate real physical system. Using simple yet interacting elements (i.e. units), a real system with an infinite number of unknowns can be approximated with a finite number of unknowns. In China, Dai Bei verified the feasibility of applying composite materials to skid landing gear of a UAV through statics analysis [1]. Ping Jin used ADAMS/Aircraft software to establish a strut landing gear model, and carried out simulation and analysis of its landing dynamic performance. The results were in good agreement with the test results, which proved the reliability of simulation analysis of landing gear by using software [2]. Abroad, Cheng-Ho Tho, Chad E. parks and others analyzed the landing performance of helicopter skis with rectangular section [3]. Black, R.J. studied tire dynamics in detail and discussed its influence on dynamic performance of aircraft landing gear [4-9]. Previous researches mainly focused on the static structure

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of landing gear, landing simulation of wheeled landing gear and material optimization of composite landing gear, but less on the landing condition of skid landing gear of fixed-wing UAVs.

1.2. Study Purpose and Significance

The purpose of this paper is to establish the finite element model of the skid landing gear of parachute landing recovery UAV, conduct dynamic simulation of its landing process, explore the energy absorption of the landing gear in different ground landing processes and possible structural failure points, and provide a basis for the structural improvement and strengthening of the skid landing gear of UAV in the future and the overall aircraft landing control design.

2. Establishment of Skid Landing Gear Model

Skid landing gear is a key component used in UAV parachute landing recovery and crash landing, and its performance is directly related to the flight landing safety of UAV. Skid landing gear is mainly composed of three parts: main landing gear, diagonal brace and cushion strut.

The skid landing gear structure of UAV is an assembly, so each part of the UAV is modeled separately and then assembled. In the module of CATIA parts design, the first sketch is drawn, and then the solid model is generated by rib command, boss command and hole command, and the smooth surface and thread are generated by the creation surface construction at each connection, and the chamfering is generated at the sharp edge. Finally, the material selection of the structure is carried out.

The skidding landing gear model for finite element analysis should be simplified, and the chamfering, fillet and connection thread which do not affect the overall analysis should be ignored. The finite element analysis model is shown in the figure 1 below:

Figure 1. Simplified model of landing gear.

3. Dynamic Simulation Analysis Based on Finite Element Method

3.1. Pre-processing of Dynamic Simulation Analysis

The preprocessing of finite element analysis generally includes the selection of analysis type, material loading, mesh division, constraint load and contact definition. This paper mainly analyzes the instantaneous condition of skid landing gear touching the ground, so LS/DYNA analysis module is used for analysis.

3.1.1. Material Definition

In this paper, the skid landing gear is made of structural steel. In order to compare the forces between the landing gear impacting soil material and the rigid material, the soil contact surface material is defined as "soil" and the rigid contact surface material is defined as "concrete".

Cam-Clay constitutive model:

The Cam-Clay model was proposed by Roscoe and his colleagues in Cambridge University in 1963 on the basis of relevant flow rules and energy conservation equation, and the work-hardening law was applied to the Cam-Clay model to elaborate the plastic deformation characteristics of soil, which constituted the first relatively complete plastic constitutive model of soil. The model can reflect the elastic-plastic deformation of soil, especially considering the plastic volume deformation of soil. However, due to the limitation of traditional plastic theory, the model does not fully consider shear deformation.

In the Cam-Clay model, the normal compression line of soil can be expressed as:

$$e = e_0 - \lambda \ln p \tag{1}$$

Where e is the pore ratio; e_0 is the initial porosity ratio; λ is the slope of the compression line; p is the average principal stress.

By differentiating equation (1), we can obtain:

$$de = -\frac{\lambda}{p} dp \tag{2}$$

It can be seen from equation (2) that when the average principal stress p increases, the stiffness of the soil gradually increases and the bulk strain gradually decreases, which reflects the compressive and rigid characteristics of the soil. In order to describe the dilatancy of soil, the following dilatancy equation is adopted in the Cam-Clay model:

$$\frac{d\varepsilon_v^p}{d\varepsilon_d^p} = \frac{M^2 p^2 - q^2}{2pq} \tag{3}$$

Where M is the stress ratio in critical state. q is generalized shear stress; $d\varepsilon_v^p$ and $d\varepsilon_d^p$ are plastic volume strain increment and plastic shear strain increment, respectively. Equation (3) reflects the relationship between plastic strain increment ratio and stress level. When the critical state is reached, the stress ratio is the critical state stress ratio:

$$q = Mp \tag{4}$$

According to equations (1), (3) and (4), and by using the associated flow rule, the yield surface and plastic potential surface equations of the Cam-Clay model can be obtained:

$$f = g = \frac{\lambda - \kappa}{1+e_0}\ln\frac{p}{p_0} + \frac{\lambda - \kappa}{1+e_0}\ln(1+\frac{q^2}{M^2 p^2}) - \varepsilon_v^p = 0 \quad (5)$$

Where κ is the slope of the isotropic rebound line of normal consolidated soil; ε_v^p is the plastic volume strain.

As the Cam-Clay model is an elastic-plastic model established in the $p-q$ coordinate system, the yield curve on the π-plane is Mises circle, so it can not describe the three-dimensional characteristics of soil reasonably. And it takes plastic volume strain as the hardening parameter, so it can not reflect the positive dilatancy and softening characteristics of soil.

Some soil parameters are set in the following table 1:

Table 1. Partial parameters of soil materials.

Elastic modulus of soil	75MPa	Plastic slope parameter	0.014
Poisson's ratio	0.25	The slope of the critical state line	1.24
Shear modulus	30MPa	Initial yield surface size	0.24132MPa
initial void ratio	0.3	Minimum yield surface size	0.00241MPa
Soil density	1580kg / m3	Soil bearing stress	0.03MPa

3.1.2. Grid Division

In order to prevent the element distortion in a certain layer caused by the huge stress and strain in some areas of the model during the simulation solution process, the solution cannot be carried out or the solution results are incorrect, so the automatic mesh redivision and the size adjustment of geometry elements must be carried out during the pre-processing of finite element analysis.

In this analysis, the Automatic method was used to quickly generate tetrahedral mesh. For the sled landing gear, geometric element size was adjusted. The element size was set to 1mm, the feature clearing size was kept at the default value of 0.5mm, and the element size growth rate was 1.5. As the ground is not a key component in this analysis, its larger unit size will not affect the final result of the analysis. The unit size of the ground geometry is adjusted to 5mm, the default value of 0.81612mm with clear features is maintained, and the unit size growth rate is 1.5.

3.2. Setting of Initial Conditions and Simulation Analysis

For impact simulation of UAV skid landing gear, it is necessary to consider the boundary definition of impact ground. Define the impacted ground as immovable fixed support, and define the surface four sides of the impacted ground as fixed support when the impacted ground is defined as flexible body.

Since the impact of the landing carriage is completed in a very short time and simplifies the analysis environment, the friction between the two at the collision moment is negligible.

The initial velocity of the anti-skid landing gear is set in the form of velocity component in the global coordinate system: X component = 0mm/s; Y-component = 2260mm/s; Z component = -5000mm/s; Standard acceleration of gravity =-9806.6mm/s^2; The parts are converted to have a deflection Angle of 5° along the Y-axis and a deflection Angle of -5° along the X-axis at the moment of touching the ground. The distance between the landing gear and the ground is 10mm. Since the body structure of UAV is relatively complex and mass loading is an indispensable part of this analysis, the UAV weight is added to the landing gear in the form of distributed mass load in this paper.

In ANSYS-LS/DYNA module, in order to achieve accuracy of analysis, reduce analysis redundancy, prevent energy spillover, improve analysis accuracy and speed up analysis according to computer performance, some Settings need to be improved before the formal simulation analysis operation. Two sets of calculation time are set for the convenience of subsequent working condition analysis. The first set is 5s for the working condition analysis of the whole touchdown process, and the second set is 0.1s for the first touchdown rebound condition and landing gear strength analysis. The time step safety factor is set to 0.9, the maximum number of cycles is set to 10000000, and the binary file size scale factor is 70.

3.3. Failure Criteria

3.3.1. Maximum Equivalent Stress Failure Theory (Von Mises-Hencky Failure Criterion)

This theory, also known as the shear energy theory or the maximum deformation theory, is mainly used to evaluate the strength of ductile metal materials. According to this theory, if the equivalent stress in a structure is equal to or exceeds a specific stress limit, it may cause structural failure:

$$\sigma_e \geq S_{\mathrm{limit}}$$

Express the theory as a design objective:

$$\frac{\sigma_e}{S_{\mathrm{limit}}} < 1$$

Safety factor:

$$F_s = \frac{S_{\mathrm{limit}}}{\sigma_e}$$

3.3.2. Maximum Shear Stress Failure Theory

The theory states that a particular combination of principal stresses leads to failure limits if the maximum shear stress is equal to or exceeds a particular shear stress:

$$\tau_{\max} \geq fS_{\text{limit}}$$

The ultimate strength is usually the yield strength of the material. That is, the shear strength of a material is usually defined as the yield or ultimate strength of f times ($f<1$). In strict application of the theory, $f=0.5$:

$$M_s = F_s - 1$$

Safety factor:

$$F_s = \frac{fS_{\text{limit}}}{\tau_{\max}}$$

If the safety factor is greater than 1, it is in a relatively stable state. If the safety factor is equal to 1, it indicates that the material is in a critical state of failure. If the factor is less than 1, the measured unit is in a failure state at this moment, and the failure state may be transmitted to the whole structure.

3.4. Post-processing and Comprehensive Analysis

In order to visually see the landing gear in the whole impact process. We post-processed the calculation results to obtain visual animation and fitting charts. The solution terms such as equivalent stress, kinetic energy, momentum, stress ratio and safety factor were added to the solver to obtain the landing gear landing conditions under different conditions.

The figure shows the dynamic simulation analysis results of the whole process of landing gear landing and touching the ground:

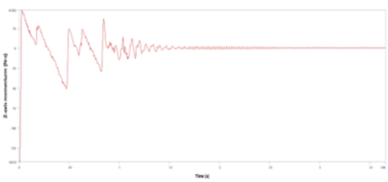

Figure 2. Momentum-time plot in the Z direction.

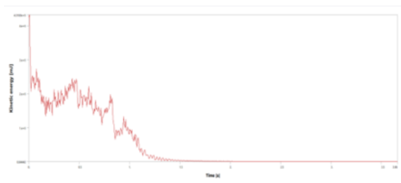

Figure 3. Energy-time diagram.

As can be seen from momentum-time diagram and energy-time diagram in the Z-axis direction of figures 2 and 3, the landing gear touchdown process is a process of periodic change in time. In the whole touchdown process, the landing gear has the largest momentum attenuation and energy attenuation in the first touchdown rebound, and then the attenuation value of each rebound will decrease and finally stop after several touchdown rebound processes.

Considering that the energy absorption and part of the energy of the landing gear buffer pillar may be absorbed by the ground, in order to obtain a more accurate landing condition to study the structural safety performance of the landing gear, we carried out a more detailed simulation analysis of the landing gear's first landing rebound process.

The figure shows the working conditions of 100kg UAV landing on the ground within 0.1s of the rigid concrete ground and the soil ground respectively.

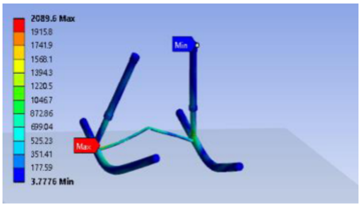

Figure 4. Maximum equivalent stress (concrete).

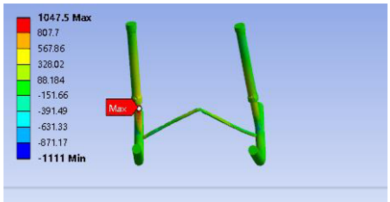

Figure 5. Z-axis normal stress (concrete).

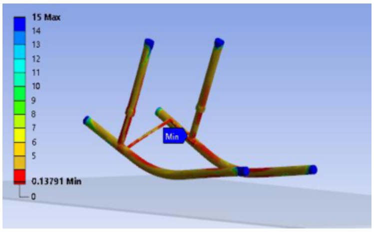

Figure 6. Minimum element of safety factor (Concrete).

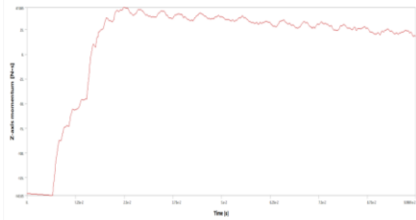

Figure 7. Momentum-time variation (Concrete).

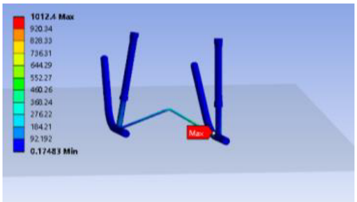

Figure 8. Maximum equivalent stress (soil).

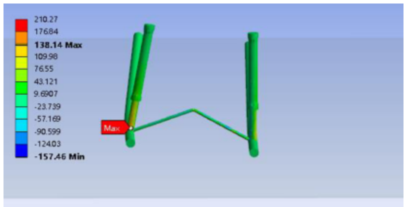

Figure 9. Z-axis normal stress (soil).

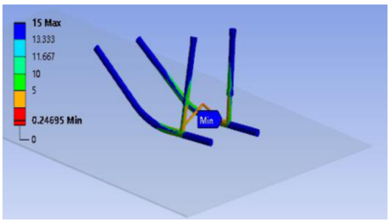

Figure 10. Minimum element of safety factor (soil).

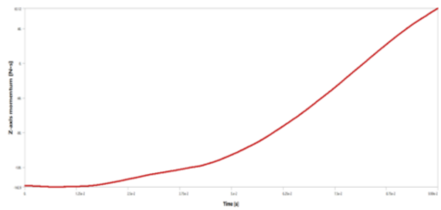

Figure 11. Momentum-time variation (soil).

Table 2. Values of characteristic units at the moment of first touchdown.

Surface material	Maximum equivalent stress	Maximum normal stress in z-axis direction	Von Mises-Hencky minimum safety factor	Minimum safety factor of critical shear stress
Concrete	2089.6Mpa	1047.5Mpa	0.13791	0.12549
Soil	1012.4Mpa	210.27Mpa	0.24695	0.22652

According to the dynamic simulation, no matter the landing gear hits the rigid concrete ground or the soil ground, the maximum stress element appears at the connection between the main skid and the inclined strut at the moment of each touching the ground (As shown in figure 4 and figure 8), and the safety factor of a few elements is less than 1 (As shown in table 2). In addition, during the analysis period, the maximum normal stress element of the buffer strut has the maximum periodic deformation and the maximum Z-axis direction. Therefore, we can analyze this condition:

1. For the skid landing gear of UAV, the safety coefficient of some characteristic units is less than 1 at the moment of impact on the ground (As shown in figure 6 and figure 10). According to the failure criterion, the connection between the main body of skid and the inclined strut is the most vulnerable to structural failure and plastic damage, which has an impact on the landing safety of UAV. Therefore, it is necessary to strengthen the structure of the joint and the margin treatment to improve the overall structural strength; The safety factor of landing gear on soil is greater than that on concrete, so it is safer for UAV to land on soil plastic ground.

2. It can be seen from the analysis of the momentum chart of the landing gear that the maximum periodic deformation of the cushion pillar also occurs in the whole process of touching the ground. The momentum change rate of the concrete ground when it first touches the ground is much greater than that when it impacts the soil(As shown in figure 7 and figure 11), and the larger normal stress value in the z-axis direction is distributed along the cushion pillar(As shown in figure 5 and figure 9). The results show that the cushion strut plays a major role in energy absorption during landing gear landing, and the soil ground also participates in some energy absorption, while the concrete ground hardly participates in energy absorption.

4. Summary

Through the dynamic simulation of the skid landing gear of UAV touching the ground, the following conclusions can be drawn:

1. When the UAV is recovering from parachute descent, due to the influence of wind direction and other meteorological conditions, the whole body will have lateral speed and vertical downward speed when it touches the ground. In the process from the moment of touching the ground to the first rebound, the connection between the main body of the landing gear and the inclined strut has the maximum stress-strain, and the connection between the main body of the landing gear and the buffer also has a large stress-strain. The failure of some units indicates that these two joints are the most prone to fracture, which has a huge impact on the landing safety of UAVs. Therefore, structural strengthening treatment should be carried out on these two joints and component activity margin should be increased.

2. When the UAV lands on the ground of different materials, the soil plastic impact ground can absorb more energy than the concrete rigid ground. Therefore, when the UAV flies in the field, it should land on the suitable plastic ground to minimize the damage caused by the ground impact overload on the body and airborne equipment.

References

[1] Dai B. Modification design of a UAV landing gear.Nanjing University of Aeronautics and Astronautics.2016.

[2] Jin P, Nie H. Dynamic simulation analysis model and parameter optimization design of landing gear.Journal of Nanjing University of Aeronautics and Astronautics. 2003;35(5):498-502.

[3] Tho CH, Sparks CE, Sareen AK. Efficient helicopter skid landing gear dynamic drop simulation using LS/DYNA. Journal of the American Helicopter Society. 2004; 49(4):483-492.

[4] Black RJ. Application of tire dynamics to aircraft landing gear design analysis. NASA Conference Publication. 1983; pp. 71-93.

[5] Liu WB. Static analysis and structure optimization of UAV landing gear based on finite element method. 2014

[6] Jiang NC, Liu GF, Dai Y, Wang KX, Zhang ZQ, Wang HM, Zhang CL. Research on dynamic design method of skid landing gear based on ANSYS. Modern Machinery. 2008; (1).

[7] Yun QW, Han L, Zhang Y, Ye X. Simulation analysis of soil crash of helicopter skid landing gear. 2014.

[8] Zhang Y. Design and energy absorption characteristics analysis of composite skid landing gear. 2017.

[9] Yang LD, Zhang XX. Improvement of cam-clay model based on generalized plastic mechanics. 2005