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Design and Analysis of Universal Multifunctional Leaf Spring Main Landing Gear for Light Aircraft

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***Abstract*—**A universal multi-function leaf spring main landing gear was designed for light aircraft. The main landing gear combined with the leaf spring, skidding, and wheels enables it to have a good takeoff and landing performance on various grounds such as the hard, snow, grass and sand grounds. Firstly, the characteristics of different landing sites were studied in this paper in order to analyze the load of the main landing gear on different types of grounds. Based on this analysis, the structural design optimization along with the strength and stiffness characteristics of the main landing gear has been done, which enables it to have good takeoff and landing performance on different types of grounds given the relevant regulations and standards. Additionally, the impact of the skidding on the aircraft during the flight was also taken into consideration. Finally, a universal multi-function leaf spring type of the main landing gear suitable for light aircraft has been developed.

***Keywords*—**Landing gear, multi-function, leaf spring, skidding.

I. Introduction

At present, wheel landing gear and ski landing gear have been broadly used in light aircraft. The wheel landing gear is usually applied to the hard grounds, while the ski landing gear is mainly used to the soft ground. However, such single form of landing gear has limitations. Only if the landing space is specific for the landing gear, the aircraft could safely take off or land. Given the present cases, the landing gear of DHC-6 is the most practical. However, a series of drive and control devices greatly increased the weight of the landing gear. So, a fixed wheel–skid landing gear is used in this design. There has not been a complete case on the fixed wheel-skid landing gear yet. Only a brief description was presented in the reference [1]. In order to enable the aircraft to adapt to different landing spaces, including the hard, snow, grass and sand grounds, the following design is discussed.

II. The Takeoff and Landing Grounds

A. Parameters of Grounds

Before the specific design, different types of landing space should be analyzed. Among the grounds, the hard grounds are similar to the normal airport. So, the situation on the soft such as snow and grass is the focus of this section.

In terms of the interaction between sand and snow fields and skids, from a micro perspective, both sand and snow are subject to elastic and plastic deformation [2], and in the current engineering research, the following simplified Bekker Model [3] is usually adopted to describe the relationship between the intensity of pressure and subsidence:

$$p = Kz^n \tag{1}$$

where p denotes the average normal pressure that a skid applies to the ground, K denotes sand deformation modulus; z denotes skid subsidence depth, n denotes sand deformation index, and both K and n can be obtained from experiments.

In order to ensure the use of the landing gear in sand and snow fields, the ground pressure 24.14 kPa of the skid in the snowfield is selected as the design value [1] in this paper, and when it is used for a sandy terrain, smaller subsidence can be obtained. At the same time, as the landing gear has the highest potential utilization rate in desert areas, with the group surface sample of Taklimakan Desert as the benchmark, the value of K is 1945 kN/m^{n+2}, and the value of n is 0.972.

Based on the pressure mentioned above and the design load, the skid plane size can be calculated with the pressure formula, and then the skid subsidence under the design load can be calculated by (1). According to the subsidence and skid rigidity requirements, the skid thickness can be obtained.

B. Load Analysis

With the light sports aircraft with the maximum takeoff weight of about 600 kg as the main research object in the design, coupled with the hard landing theory, the load value for check is determined. Currently, the vertical acceleration limit of an airliner ranges from 1.8 to 2.2 g. Apart from the landing gear, the design weight is about 582 kg. After conservative rounding of the load applied to the main landing gear, 18000 N is taken as a verification value.

In terms of force characteristics, wheel landing gear and skid landing gear are compared. The comparison result shows that the force on the two kinds of landing gear is the same. While on soft grounds, only the initial loaded form has gone through changes, with the concentrated load initially applied to the wheel changed to being borne by the concentrated load on the wheel and the uniformly distributed load on the skid. The load finally transmitted to the leaf spring and the fuselage shows no essential differences from that involved in hard grounds.

III. Design Scheme

A. Overall Scheme

A front three-point layout is adopted for the landing gear, and wheel-skid integration design is adopted to allow the free

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distribution of the applied load between the skid and the wheel during aircraft takeoff and landing on the grounds with different hardness. At the same time, the leaf spring design of the main landing gear contributes to a simple structure, increased system reliability, sufficient structural strength and stiffness and lighter structural weight. The whole process of the design mainly refers to CCAR-23-R3 [4] and CCAR-25-R4 [5].

B. The Design of Leaf Spring

1) Leaf Spring and Connectors

The leaf spring is both a structural member and a cushioning part. The landing gear is connected with the lug reserved in the lower part of the fuselage frame via two articulation pieces and transmits load. A limit pin is added to the leaf spring to restrict the transverse degree of freedom of the whole leaf spring. In order to enable the leaf spring to better exert its buffering ability, the two articulation points should be as close to the center as possible. Besides, the leaf spring should be parallel to the ground as far as possible, which means the part perpendicular to the main load should be as long as possible to make the most part of the leaf spring involved in the deformation buffer process. In addition, in order to avoid the stress concentration caused by the inconsistent deformation between the lead spring made of composite material and the aluminum alloy articulation pieces, rubber sheet is filled between the surfaces of the two kinds of materials and rigidly fixed to the articulation piece. It is worth noting that, due to different tension-compression strength of the leaf spring material, a trapezoidal cross-section is used in the design instead of a rectangular cross-section, thereby optimizing the normal stress distribution within the cross section. Weight reducing treatment is also conducted in the connector design.

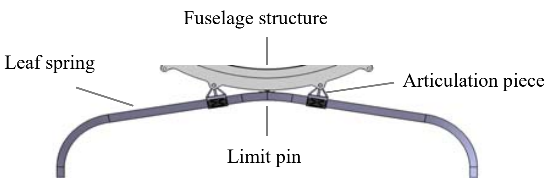

Fig. 1 Leaf spring scheme adopted in the design

Based on the design above, a three-dimensional model is simplified, and ABAQUS is used to conduct finite element analysis of the simplified model. The calculation shows that all components meet the strength requirements and that the strength of the top and bottom surface of the leaf spring is close to the respective allowable values. The deformation (as shown in Fig. 2) of the leaf spring matches the experimental result involved in existing research [6].

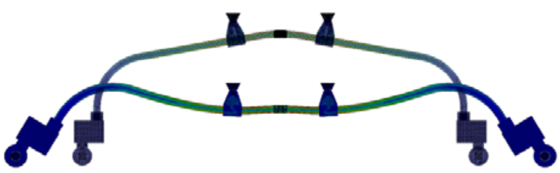

Fig. 2 Deformation of the leaf spring before and after loading

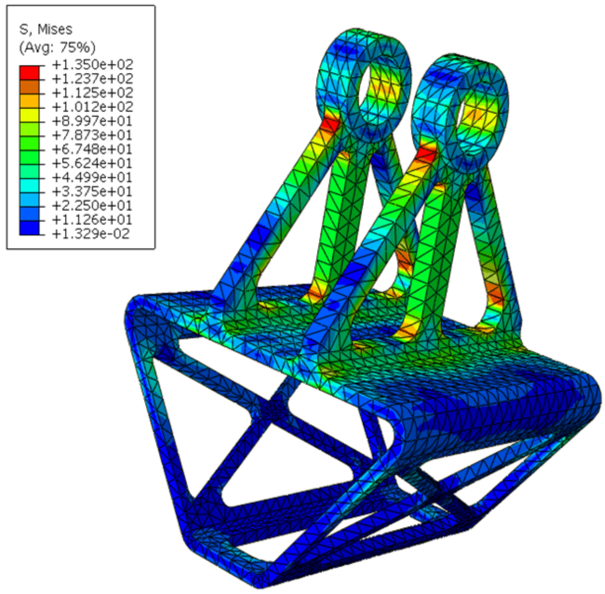

Fig. 3 Stress distribution of articulation piece

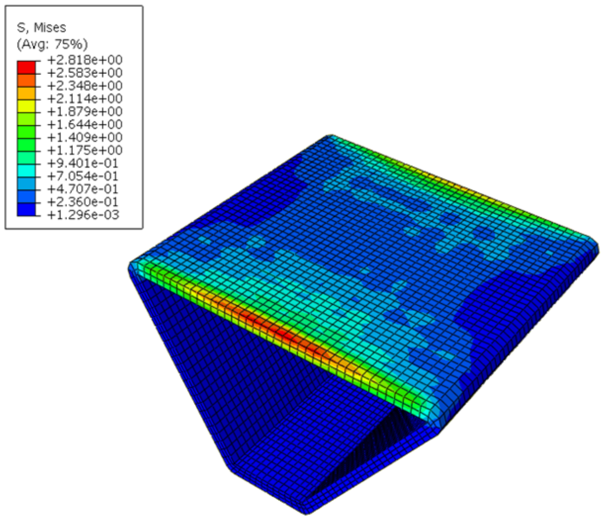

Fig. 4 Stress distribution of rubber gasket

C. Wheel-Skid Combination

1) Design Method

It has been stated in the overall scheme that the design is based on a wheel-skid combination, with both the wheels and the skid connected to the wheel axle, all of them being able to rotate around the wheel shaft, the wheel bottom going through the skid and extending a certain length, as shown in Fig. 5. During plane takeoff run and landing run on any field, the ground load can realize automatic distribution between the wheel and the skid based on the actual ground hardness.

Based on calculation, the total area of the skid of the main landing gear is 1.34 m^2. An approximately rectangular planar shape is usually adopted for skids. With comprehensive consideration given to various factors, a length-width ratio of 3 is taken in the design. In the length direction, the wheel is in the middle of the skid; in the width direction, considering about the 20° deflection of the wheel part along the longitudinal axis caused by the leaf spring deformation under the ultimate load, the width of the part of the skid located inside the wheel is set to be 250 mm to avoid the collision between the inner edge of the skid and the ground in case of leaf spring deformation.

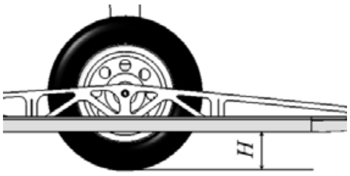

Fig. 5 Height of the skid in relation to the wheel

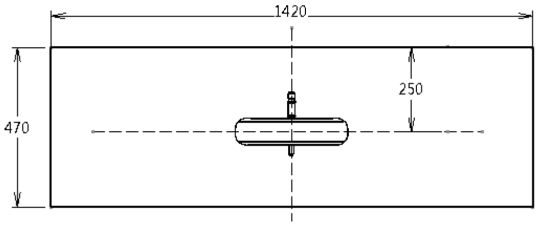

Fig. 6 Plane layout of the skid

The final skid design is as shown in Fig. 7, with the front end of the skid to be upturned by 15°, the sharp corners of the original rectangle eliminated to enable it cross over obstacles of certain height [1]. Two longitudinal and three horizontal rib plates are installed on the skid to ensure its rigidity and strength. The overall average thickness of the skid is about 60 mm, and the height of the forefront is 80 mm.

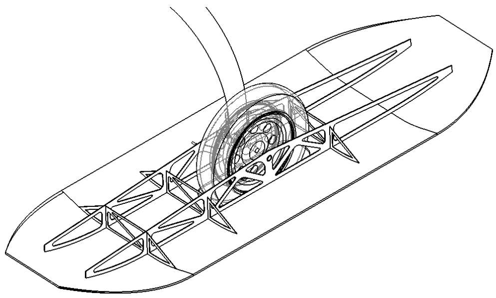

Fig. 7 Skid design diagram

2) Connection Method

In order to ensure that the skid can restore its neutral position rapidly when the plane lands, a restoration shock absorber is added between the wheel and the skid assembly and placed inside the wheel-skid assembly. The leaf spring, the wheels, and the restoration connecting rod are rigidly fixed via a key structure; the skid is articulated with the leaf spring pillar at the wheel. The two ends of the shock absorber are articulated with the skid and the restoration connecting rod respectively. The working principle is as shown in Fig. 8. The connecting method of the leaf spring, the skid, and the wheel is as shown in Fig. 9.

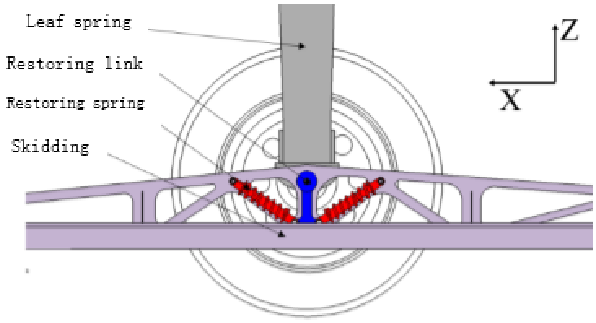

Fig. 8 Schematic diagram of the return spring

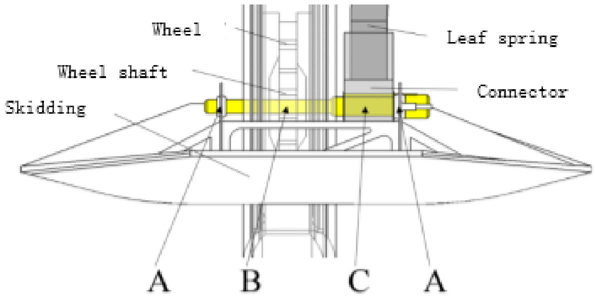

Fig. 9 Connection of the leaf spring, the wheel and the skid

The design features easy installation to enable users to rapidly realize the switchover between the wheel-skid assembly and other available landing gear assemblies.

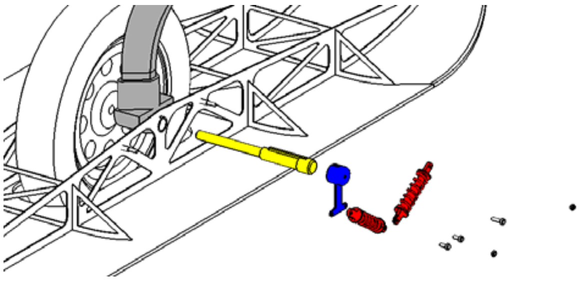

Fig. 10 The assembly of the wheel and the skid

Based on the design above, finite element analysis of key structures, including the wheel axle, the bracket and the skid, is conducted, of which the wheel axle is made of steel, and the bracket and the skid are made of aluminum alloy. In terms of load, the load distribution involved in three kinds of landing conditions is attempted. The calculation shows that all components can meet the strength requirements.

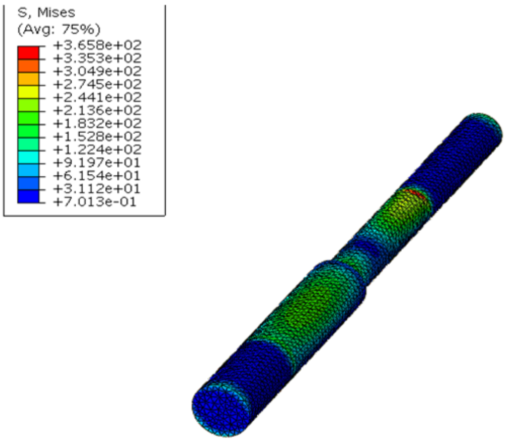

Fig. 11 Stress distribution of the wheel axle

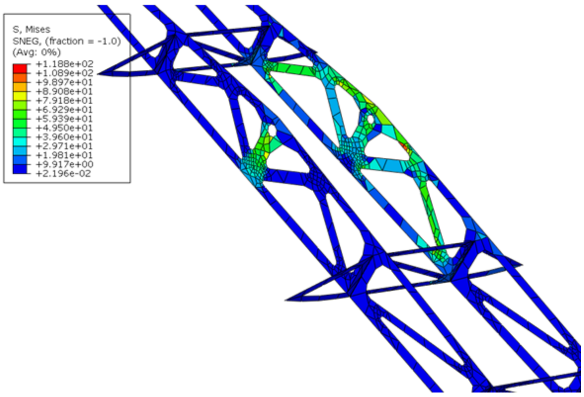

Fig. 12 Stress distribution of the skid bracket

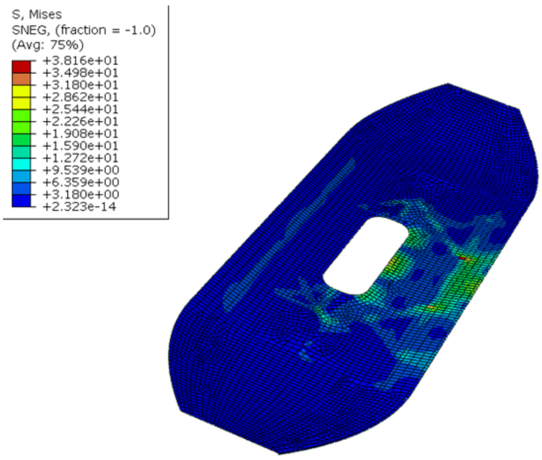

Fig. 13 Stress Distribution of the Skid

3) The Swing of the Skid

As the relative position of the skid and the wheel is not fixedly connected, and in the flying process of aircraft, the skid can swing due to the unsteadiness of the airflow, and such swing may increase flight resistance and affect the airplane flow field, causing certain hidden danger. Based on MATLAB simulation calculation, due to the small swing of the skid in the air, the role of the damper is ignored temporarily in the estimation process. The TD series spring-type shock absorbers manufactured by a certain company are selected for the spring, with the elastic coefficient being 46 N/mm. It is obtained that, in response to 1° deflection of the skid, the shock absorbing spring can reduce a torque of 30.5 N·m, i.e. 1° deflection generated in the case of 21.48 N torque difference between both ends. The wind resistance acting on the skid can be obtained through simple estimation:

$$F = \frac{1}{2} C_d \cdot A \cdot \sin\alpha \cdot \rho \cdot v_r^2 \tag{2}$$

It is obtained based on the calculation under the cruising conditions that the wind resistance acting on one skid is about 39.54 N. It can be seen through calculation that the resistance uniformly acting on the skid can cause the skid to produce swing of not more than 1° under the suppression of the shock absorber, and the effect of such swing is negligible.

D. Summary of the Main Landing Gear Design

The final main landing gear design is as shown in Fig. 14.

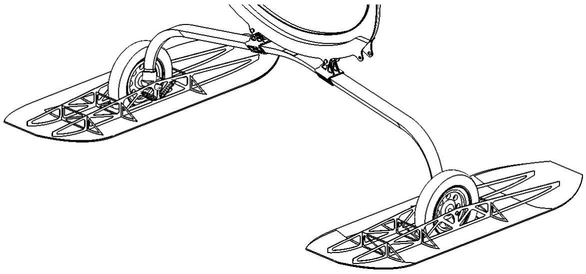

Fig. 14 Main landing gear

IV. Conclusion

In the design process, quantitative verification and optimization work of leaf spring, a key bearing structure, and its connecting mechanism is conducted, with the final design result achieving the desired goal in terms of strength, stiffness and weight. The design and analysis of the wheel-skid assembly is dominated qualitatively and supplemented quantitatively according to the functional requirements. The calculation and analysis of key skid size parameters are conducted. In addition, analysis of the mechanism for the interaction between the skid and the ground is conducted, with the relevant calculation method given. However, the selection of some parameters and the analysis of the load on the landing gear under more working conditions remain to be further studied.

The design has the following advantages: no lifting mechanism, hydraulic system or control system, reducing system weight and improving stability; direct connection between the skid and the wheel axle, no middle lifting mechanism, contributing to more direct and stable load transmission; higher system applicability, suitable for takeoff and landing fields with any hardness, automatic distribution of ground load between the wheel and the skid; on the soft runway, the wheel with part sinking into the ground can provide certain braking force to compensate for the disadvantage of the skid being unable to brake itself; the wheel with part sinking into the ground can provide yawing moment by differential braking to compensate for the disadvantage of the skid being unable to swerve; a leaf spring with a trapezoidal section is designed, contributing to the good buffer and energy absorption effects of the landing gear, greatly reducing the weight of the structure.

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