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Impact Loading Analysis of Light Sport Aircraft Landing Gear

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Abstract. This paper examined the critical loading condition of a light sport aircraft's main landing gear during the impact loading condition. The new category airplane was established by the FAA in 2004. The light sport aircraft has great market demand for personnel entertainment purpose and regional transportation. The main object of this research was to establish a static and dynamic loading simulation model for the aluminum alloy landing gear of a light sport aircraft. This work also examined the critical loading parameters of the main landing gear, including the maximum take-off weight and maximum stall speed. The analysis was performed using ANSYS and LS-DYNA to establish the finite element model after simplifying the geometric characteristics and verifying the results by energy conservation, hourglass energy, and sliding energy. The study tested aluminum plates with a thickness from 15~25 mm. The results showed all the samples could sustain the required loading condition, except for the thickness of 15mm that failed under impact loading. The simulation model provides a cost-saving process compared to a real crashworthiness drop test to test the main landing gear's compliance with regulations.

Introduction

In recent years, owing to light sport aircrafts being one of the rapid growth areas in the general aviation industry, civil aviation authorities have taken steps to amend and make new regulations for users and manufacturers. The light sport aircraft (LSA) final rule launched by the FAA became effective on September 2004 [1].The rule created an entirely new category of aircraft and accepted consensus standards developed by ASTM.

The FAA defines a light sport aircraft as an airplane with a maximum takeoff weight of 1,320 lbs (600 kg) for aircrafts not intended for operation on water [2]. Its maximum airspeed in level flight with maximum continuous power (V_H) cannot be more than 120 knots (222 km/h), and its maximum stall speed (V_{S1}) is 45 knots (83 km/h). It can't have more than two seats (including the pilot). The plane must have fixed landing gear, a single reciprocating engine, and a fixed or ground-adjustable propeller. In LSA regulation, the FAA mainly issued two kinds of certificates: (1) S-LSA, a Special Light-Sport Aircraft is a factory-built and sold ready-to-fly aircraft designed and constructed in accordance with the ASTM consensus standards. Aircrafts under this certification may be used for sport and recreation, flight training, and aircraft rentals. (2) E-LSA, the Experimental Light-Sport Aircraft, means the aircraft is made from a kit or a plan, or if the aircraft has previous been operated as an ultralight vehicle under FAR Part 103. Aircrafts under this certification may be used for sport, recreation, and flight instruction for the owner of the aircraft.

Since the FAA created the new rule, 50 models of ready-to-fly LSA have become available for purchase and more than 3,000 light-sport aircraft have been certified in a 4 year period [3]. The NCAM (National Consortium for Aviation Mobility) anticipates the light-sport industry to grow to $2.5 billion over the next ten years in the U.S. [4]. Along with the substantial progress, two major manufacturers-Cessna Aircraft and Cirrus Design will put their new LSA on the market, which will significantly affect the LSA industry.

Landing Gear Design and Related Requirements

The landing gear is one of the most safety-critical systems on the aircraft. The main function of landing gear should be to sustain the weight of the aircraft and absorb the impact energy of landing, as well as to protect the passengers from possible injury. This paper examines the critical loading condition of a light-sport aircraft's main landing gear during the impact loading condition. This study utilized the finite element method to analyze the landing gear in the static and dynamic loading conditions, in which the main variables are maximum take-off weight and possible impact speed.

The transportation category and general aviation aircraft have more mature development for landing gear design requirements, such as FAR Part 23.477, Part 23.479~23.486, Part 25.473, and MIL-A-8862. The landing gear design is well documented in several articles, such as Stowell [5] and Roskam [6]. Although the landing gear system design has fully developed, it is mostly applicable to large aircraft and is rely on empirical wok as the basis for analysis. NASA began the AGATE project in 1994, mainly for aircraft crashworthiness research, that is, in the event of an accident the overall structural design of aircraft should maximize the survival rate of passengers [7]. NASA implemented the drop test to compare the simulation results. NASA also supported many organizations engaged in related research, such as Chai and Mason [8], to incorporate multidisciplinary design optimization (MDO) methods in the conceptual design phase. However, most published literatures on landing gear design still focused on large-scale air transport.

In the light aircraft design specifications, Canada LAMAC adopted "Light Plane Airworthiness Standards (LPAS)" in 1988 to establish "Design Standards for Advanced Ultra-Light Aeroplanes" [9]. The standard applicable to the maximum takeoff weight of 350 kg (single seat) and 560 kg (two-seat), and the maximum stall speed should be less than 72km/hr. The design criteria for landing gear in LAMAC specification is in the Chapter C-Structure section 38~45 and Appendix B-Basic Landing Condition. However, it mostly contains empirical formulas and assumes the airplane has spring shocks or hydraulic shock absorbers. The European CS-VLA (Very Light Aeroplanes) has landing gear sections listed in the CS-VLA 479~483 and CS-VLA 723~733, although there is more details on VLA static and dynamic requirements, but the specification still assumes the use of shock absorbers. FAA issued the AC 90-89A "Amateur-Built Aircraft and Ultralight Flight Testing Handbook" as the guidelines for LSA verification, but it did not include design information. FAA incorporated ASTM to build the consensus standards in 2002. However, ASTM F2245-07 "Standard Specification for Design and Performance of a Light Sport Airplane" in §5.8 Ground Load Conditions bearing on the strength of the landing gear also assumed the use of a shock absorber. However, due to cost considerations, most LSA manufacturers seldom use shock absorbers in the landing gear.

Simulations and Results

This work used the Zenith STOL CH 701 [10] aircraft as the simulation object. The gross weight of the CH 701 is 500kg. Figure 1 shows the specifications of the CH 701. The main function of landing gear is to absorb and dissipate impact energy during landing to avoid damage to the vehicle structure, while the rate of descent is the main cause of the vertical loading factor. According to Roskam [6], a probability of less than 1/100 of landing sink speed for piston engine aircraft is around 3.3 fps (1.0 m/s). This work used that vertical drop speed as dynamic modeling basis. This study only considered a two point level landing, in which the main landing gear sustained most of the energy.

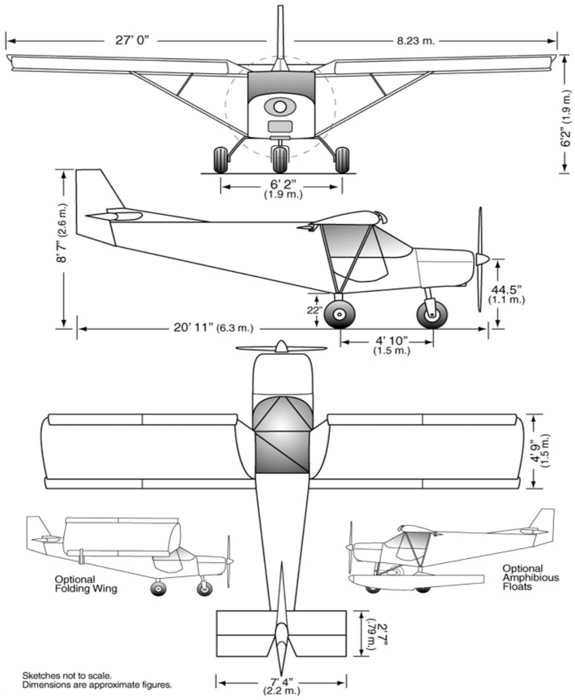

Fig. 1 The specification of Zenith STOL CH 701 [10]

This research used Pro-E to build a 3-D model of the landing gear (figure 2) and removed the tires and unnecessary engineering characteristics to simplify the calculation processes (figure 3). HyperMesh is used for meshing processes. This article used ANSYS and LS-DYNA to perform the static and dynamic loading simulation. Those results were verified by the following requirements: (1) total energy (both dynamic and potential energy) should be conservative; (2) hourglass energy should be no more than 5% of internal energy; (3) sliding energy has to be positive when the landing gear impacts the solid plate.

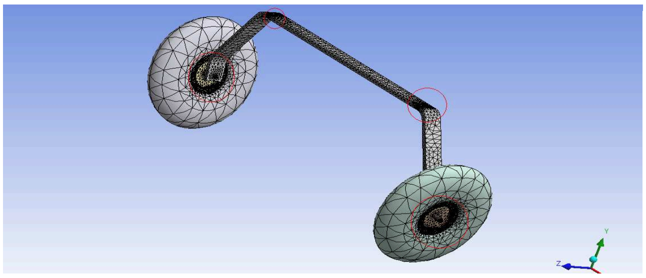

Fig.2 Three dimensional model of the landing gear.

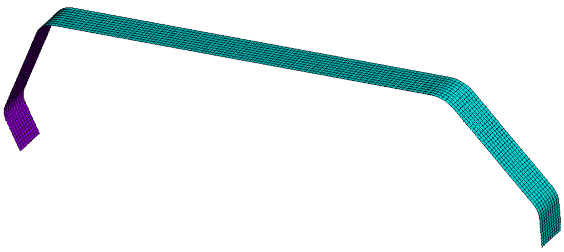

Fig. 3 Simplified three dimensional model of the landing gear.

For comparing the energy consistency between adjacent elements, this work meshed the structure both in hexahedral mode and shell mode. The hexahedral model had 3,924 elements and 6,570 nodes. The results using the shell mode were 1,944 elements and 2,170 nodes. Figure 4 shows both models had a maximum equivalent stress at point A and B. The difference in the maximum stress for those two meshing methods was 9.26%. However, comparing the energy difference between adjacent nodes of these two modes, the average variations for hexahedral elements and shell elements were 5.40% and 3.29%, respectively. The shell mode meshing method not only had less calculation time and but also more energy consistency. Therefore, we use the shell element for the dynamic simulation modeling.

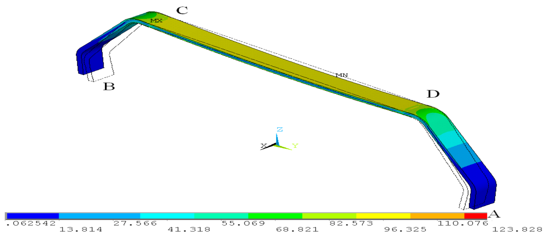

Fig. 4 The stress distribution of landing gear during static loading.

As well as the original design thickness 20mm of 6061-T6 aluminum alloy used in the landing gear this work also analyzed the thickness 15 mm and 25 mm for comparison purposes. Figures 5 and 6 show the relationship between stress, strain and weight, respectively. The three thicknesses of landing gear could all sustain the take-off weight without exceed the yielding stress of 6061-T6 alloy (276 MPa). Compared to the original design t=20mm, when t=15mm, the weight reduced by 25%, the maximum load capacity reduced by 57.3%, and the maximum strain increased 79%; when t=25mm, the weight increased by 25%, the maximum load capacity increased by 55.7%, and the maximum strain decreased by 64.2%.

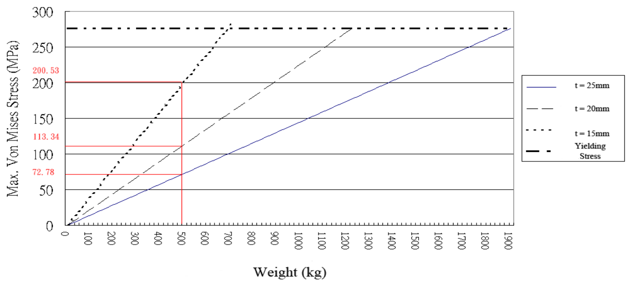

Fig. 5 The stress vs. weight for various thickness of landing gear.

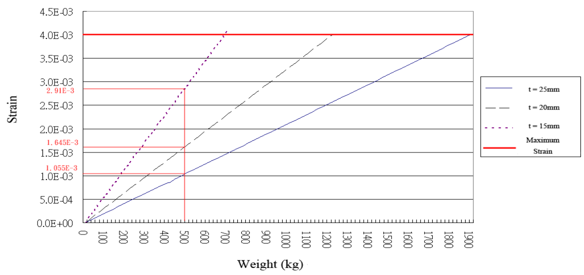

Fig. 6 The strain vs. weight for various thickness of landing gear.

The maximum take-off weight of 500kg used in dynamic loading simulation, at a two-point level landing condition and landing speed was 1.0m/s (3.3fps) in the z-direction impacted on a rigid plate. The dynamic simulation used LS-DYNA as the post-processor. These results were verified by energy conservation, hourglass energy and sliding energy, and are shown in figures 7 and 8, respectively. Figure 7 shows the kinetic energy reached a minimum of T=0.02 sec. when the landing gear impacted the rigid plate and rebounded at T=0.04 sec. As shown in figure 8 Line A, the hourglass energy has no or negligible change with time. Figure 8 also showed the variation in sliding energy (Line B) was within the range of 5% internal energy. Both the hourglass energy and sliding energy satisfied the above-mentioned requirements.

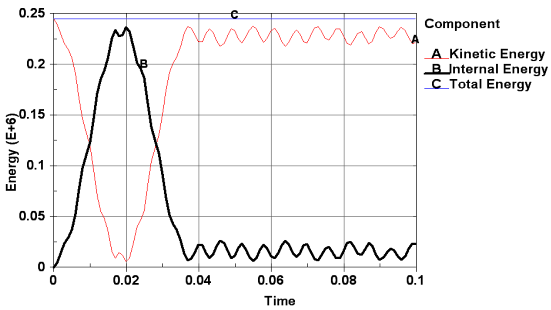

Fig. 7 The change of total energy (kinetic and strain energy) with time during dynamic loading.

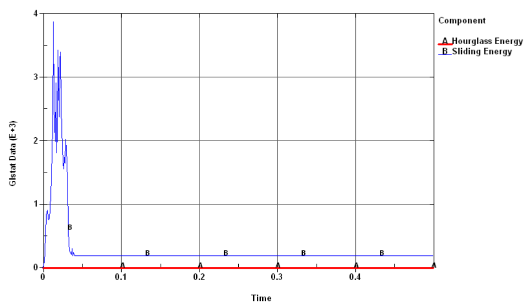

Fig. 8 The change of hourglass energy and sliding energy with time during dynamic loading.

Figure 9 shows the stress distribution diagram of t=20mm landing gear during impact. The maximum stress of t=20mm was 276 MPa on point A and B at T=0.02 sec. The maximum stress of t=15mm and t=25mm was 282 MPa and 275 MPa, respectively. As shown in the results, t=15mm already exceeded the yielding stress of 6061-T6 Al alloy and the maximum stress of t=20mm and t=25mm during impact loading was almost the same.

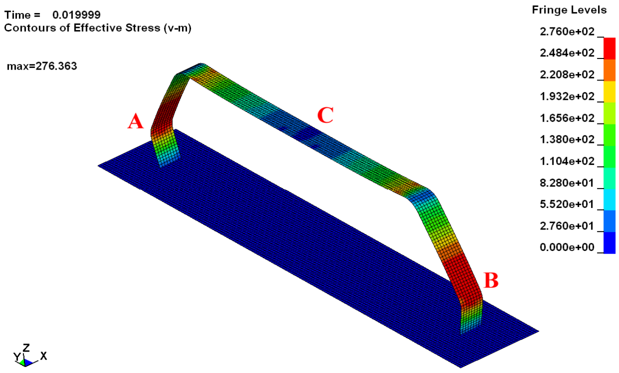

Fig. 9 The stress distribution of t=20 mm landing gear under impact loading.

Conclusion

This research analyzed a landing gear's static and dynamic loading simulation of a light sport aircraft. This work compared two different meshing modes. The shell elements method had more energy consistency between adjacent nodes.

In static analysis, the boundary condition restricts the node displacement between the junction of the main landing gear and the fuselage structure. The two end points of the landing gear sustained the weight of vehicle. The results showed all three thicknesses of landing gear could sustain the gross weight of the aircraft without exceeding the yield stress and strain.

The dynamic analysis approach increases the mass element between the junction of the main landing gear and fuselage structure as the boundary condition. The dynamic stimulation model used the 1.0 m/s as the drop speed and the weight of aircraft 500 kg for analysis. The results were verified by energy conservation, hourglass energy and sliding energy. The thickness t=15 failed under impact loading. There was a negligible effect when the landing gear thickness changed from 20 mm to 25 mm.

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