806. Research on the performance of buffer for landing gear based on the drop test

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Abstract. Based on the drop test of the articulated main landing gear of Seagull 300 light multifunctional amphibious airplane, a further study has been conducted to establish buffer performance under different air chamber pressures and attitude angles. Through comparative analysis of the test results, the influencing rule of air chamber pressure and attitude angle on the buffer performance parameters (system capacity, vertical load, buffer compression, system efficiency and buffer efficiency) was obtained. The results demonstrate that air chamber pressure has a significant effect on the buffer system efficiency, while the attitude angle influences the system capacity a lot. With air chamber pressure increasing system efficiency decreases first, then gradually increases after reaching its minimum at 2.15 MPa and decreases at last after reaching its maximum at 2.7 MPa. Buffer efficiency decreases first and then increases after reaching its minimum at 2.2 MPa. When the attitude angle is between 3 and 12 degrees, the smaller the attitude angle, the more energy the system absorbs and the better the buffer performance is. The rate of change of performance parameters varies linearly with attitude angle. With the increase of angle, system capacity, maximum vertical load and system efficiency increase, and the change rate of buffer compression decreases correspondingly. The rate of change of system efficiency has the fastest growth.

Keywords: drop test, articulated landing gear, air chamber pressure, attitude angle, buffer performance.

1. Introduction

As an important part of landing gear, the buffer performance affects the structural strength, safe and riding comfort of aircraft [1]. Drop test of landing gear is a kind of dynamic performance test which is conducted in a special device to simulate aircraft landing. It plays an important role in the study of buffer performance. Besides, buffer parameters and attitude angles impact system performance. Therefore, it is important to study buffer performance under different parameters.

The buffer performance has been studied for a long time. Venkatesan intended to optimize the buffer during landing of aircraft in 1977 [2]. Willian and others introduced F-106B airplane active control landing gear drop test performance in 1990 [3]. Gian studied semi-active landing gear performance at different subsidence velocities in 2000 [4]. In China, with the fast development of aviation industry, great importance has been attached to the performance study of absorber system of landing gear in recent years. Aiming at the drop test model, Zhang Zhilin and others studied the absorber performance of landing gear by the way of Runge-Kutta method in 1999 [5]. Shi Haiwen and others studied the spin up and spring back on the drop test bed which impact on the overload [6], and he studied the status of an undercarriage at the touchdown by the way of drop test in 2003 [7]. At the same year, Liu Hui had a research on the effect of semi-active control technology on the absorber performance [8]. Lin Yueguo analyzed and optimized a landing gear based on the drop test in 2007 [9]. In 2008, Gu Hongbin and others summed-up and analyzed the development status of modern landing gear absorber system [10]. In 2010, Liu Min made a detailed analysis on influence of the different layout of engine on landing velocity and attitude [11].

Although the corresponding studies combining drop test have been made, the exact factors which influence the buffer performance have not been analyzed. Buffer parameters have an important impact on performance of landing gear, which could lead to a plane crash.

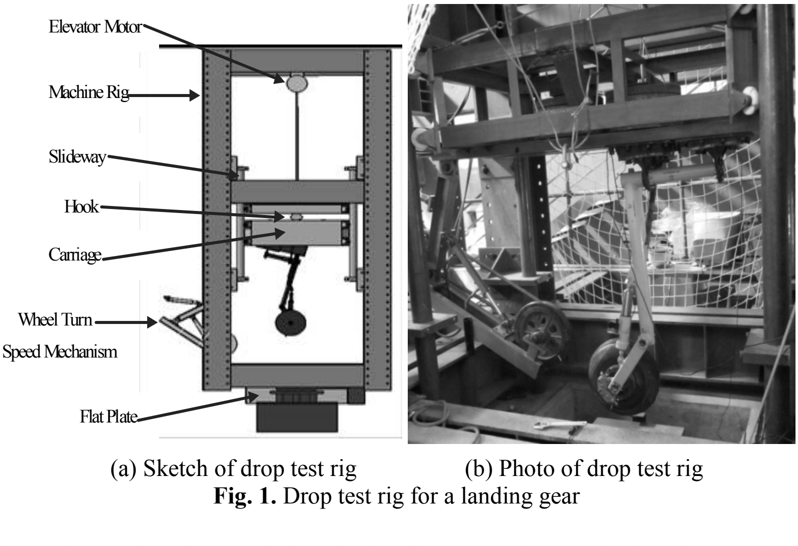
When landing, the different operation of the driver and the environmental factors such as the density of air and the slope of the runway must cause different attitude angles, and make different results of buffer performance. Therefore, it is important to find out the relationship between the performance parameters (system capacity, vertical load, buffer compression, buffer efficiency and system efficiency) and different attitude angle. Zhang Yi analyzed the causes of big attitude angle during the plateau area flight [12].

The article is based on the airworthiness drop test of the Seagull 300 light multifunction amphibious aircraft [13]. Through the adjusting parameters drop test and attitude angle drop test, the variational laws of buffer performance affected by the air chamber pressure and attitude angle have been found to offer the foundation for improving the buffer performance and determining the optimal attitude angle.

2. Drop test

2. 1 Principle of drop test

During the certification process of commercial aircrafts, the drop test is used to assess the energy absorption properties of landing gears. It uses the approach of reducing weight and falling freely from a specified height above the ground. The effective drop weight is simulated by the landing system weight (landing gear, fixture, carriage and additional weight). The attitude angle is simulated by fixture adjustment. The aircraft subsidence speed is simulated by adjusting the system height. The taxiway is simulated by concrete platform, as shown in Fig. 1. Fig. 1(a) presents a simplified scheme of the drop test facility and the landing gear components. Fig. 1(b) shows the layout of the test.



(a) Sketch of drop test rig (b) Photo of drop test rig

Fig. 1. Drop test rig for a landing gear

From Fig. 1 it can be observed that the landing gear is attached to the carriage that runs vertically between two rigs, and is pre-loaded with the equivalent aircraft reduced mass, which represents the portion of the aircraft mass supported by the landing gear in landing impact. The drop system is lifted at a preset height by the pulley institutions and the wheel turn speed mechanism turns the wheel run reversely. If the wheel edge tangent speed reach to the required horizontal speed, and then quickly moves away the mechanism. Soon afterwards take off the hook tied on the drop system and the carriage falls down through the idler pulley roller wheel with the landing gear, hitting the flat plate. The vertical load transducer is installed under the flat plate and the horizontal load transducer is installed on its side.

2. 2 Calculation method of absorber parameters

Due to the articulated main landing gear of the Seagull 300, the absorber axial load F_s is not directly measured. It is calculated indirectly through the measured parameters. According to the drop test data, we obtain the force transmission coefficient curve, as shown in Fig. 2. k_1 shows ratio between the axial force of the absorber and vertical load acting on the axle center, k_2 shows ratio between the axial force of the absorber and the back force which is acting on the axle center. According to the analysis of the landing gear, we get:

$$F_s = k_1 \times P_z + k_2 \times P_x \qquad (1)$$

where P_z is the vertical load acting on the ground, P_x is the horizontal load acting on the ground.

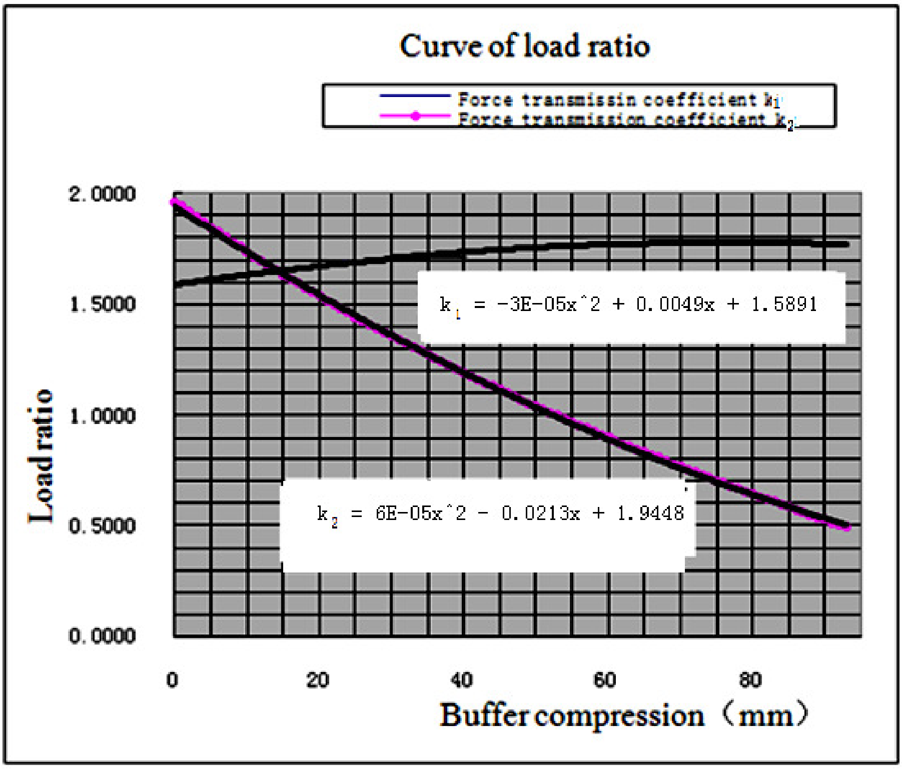


Fig. 2. Force transmission coefficient curves

The conclusion data involves system capacity, system efficiency buffer capacity and buffer efficiency. This data cannot be directly measured and need to be calculated by the test data. The relevant computational formulas are as follows:

System capacity can be shown in Eq. (2):

$$A_c = \int_0^h P_z dh \tag{2}$$

where P_z is the vertical load acted on the ground, h is the center displacement of tire when it touches the ground.

The system efficiency can be shown in Eq. (3):

$$\omega = \frac{A_z}{P_z^{max} h} \tag{3}$$

The buffer capacity can be shown in Eq. (4):

$$A_s = \int_0^{S_c} F_s dS \tag{4}$$

where S is the compression of absorber, S_c is the maximum buffer compression.

The buffer efficiency can be shown in Eq. (5):

$$\omega_S = \frac{A_S}{F_S^{max} S_c} \tag{5}$$

where, F_s^{max} is the maximum axial force of the absorber.

3. Influence of air chamber pressure on buffer performance

The shock absorber of the landing gear is the oleo-pneumatic shock absorber, the air chamber pressure of which has an important effect on the buffer performance. It’s necessary for landing gear to take drop test of adjusting parameters before the official test. The purpose is to make the buffer performance of landing gear achieve optimal state. Therefore, based on the adjusting parameters test, the paper takes further study on the buffer performance under different air chamber pressure accordingly.

The origin air chamber pressure is 1.8 MPa and the absorber system capacity of landing gear is far beyond the designed value before the adjusting parameters test. It is analyzed that the air chamber pressure is not enough, thus, a corresponding scheme is developed to adjust the air chamber pressure. The state properties of the test are listed in Table 1. The adjusting parameters drop test has been conducted under 6 operating conditions (1.8 MPa, 2.0 MPa, 2.2 MPa, 2.4 MPa, 2.6 MPa and 2.8 MPa). Every condition contains six times tests.

Table 1. Drop test properties of landing gear

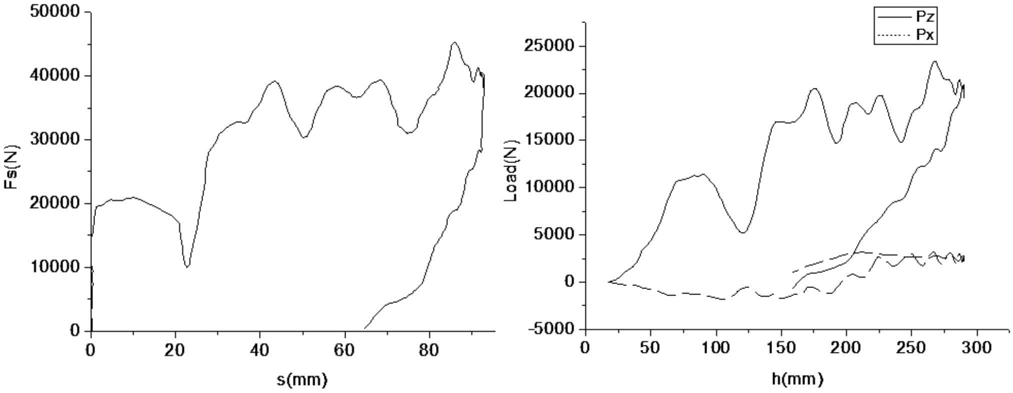
Parameter	Value
Weight of landing gear (kg)	44
Effective weight (kg)	640
Height (m)	0.41
Wheel speed (r/m)	1100
Major-oil-hole diameter (mm)	3.8
One-way oil-hole diameter (mm)	2.0
Oil volume (cm^3)	345
Wheel pressure (MPa)	0.43

The test results are processed, eliminating cases of the maximum and minimum of system capacity. By taking an average of the other four test results, we get the test results data in Table 2. According to Table 2, with the pressure increase, the buffer compression and the system capacity decrease and the maximum vertical load increase within permitted.

Table 2. Result of the adjusting parameters drop test

	Air chamber pressure (MPa)	System capacity (J)	Vertical load (N)	Buffer compression (mm)	System efficiency (%)	Buffer efficiency (%)
Original	1.8	3414	18750	96.3	70.1	77.5
Final	2.0	3385	18992	94.5	60.8	68.1
	2.2	3358	19130	92.2	59.2	66.6
	2.4	3298	19581	91.8	59.4	69.7
	2.6	3254	19885	91	64.1	71.2
	2.8	3205	20030	89.5	65.9	71.0

After the adjusting test, when the pressure in air chamber is 2.8 MPa, the result is the best, as shown in Fig. 3.



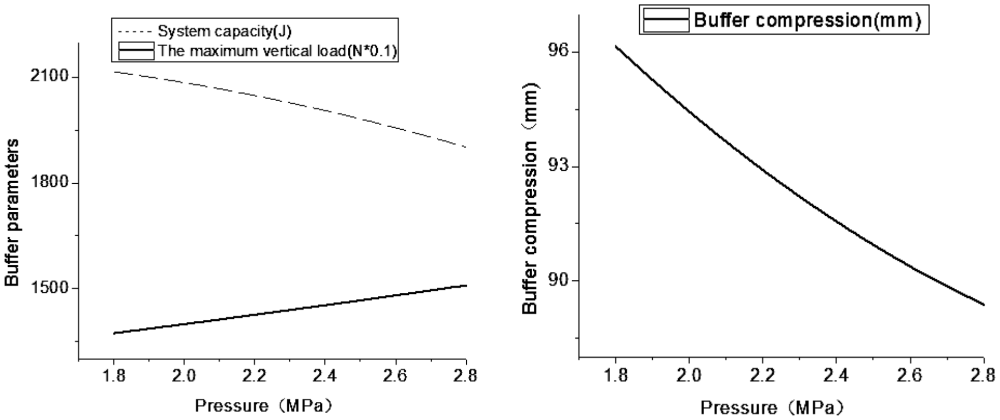
(a) Buffer capacity (b) System capacity

Fig. 3. Air chamber pressure of 2.8 MPa

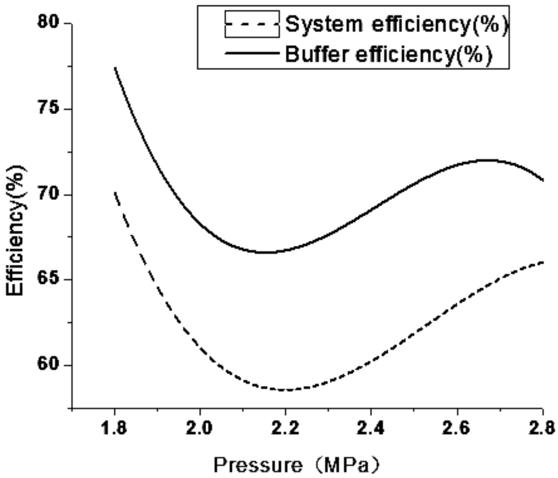
Fig. 4 provides the fitting curve according to the data of Table 2. It indicates that with air chamber pressure increasing, the relationship between the maximum vertical load and the air chamber pressure presents linearity. The system efficiency decreases first, then gradually increases after reaching its minimum at 2.15 MPa and decreases last after reaching its maximum at 2.7 MPa. The buffer efficiency decreases first and then increases after reaching its minimum at 2.2 MPa.

In order to study the influence of air chamber pressure on system capacity, buffer compression, and the rapidity of the effect on buffer performance further, the fitting curves in Fig. 6 are taken differential treatment, and the performance parameter variation rate curves are obtained as shown in Fig. 5, from which we can find that the change speed of system efficiency and buffer efficiency appear first quick back slow trend, while the change speed of maximum vertical load basically is a constant, that is, the maximum vertical load increases linearly. And the change speed of system capacity slows down linearly with a ratio of 150 J/MPa^2, which suggests that the system capacity reduces more slowly with pressure increasing. The buffer compression increases linearly with a ratio of 4 mm/MPa^2. It implies that buffer compression reduces faster and faster with pressure increasing. The change rate of buffer efficiency is consistent with the system efficiency. Their change speed increases first, then decreases, reaching their peaks respectively at 2.5 and 2.3. Figs. 4 and 5 indicate that air chamber pressure has the strongest effect on the efficiency of system and buffer.

Based on the optimal parameters gained by the adjusting parameters test, limited drop test and reserve energy absorption drop test of the main landing gear are accomplished. On the basis of airworthiness certification, different attitude angle drop tests are performed in order to further study the influence of attitude angle on buffer performance.



(a) System capacity and the maximum vertical load of tire (b) Buffer compression



(c) Efficiency of buffer and system

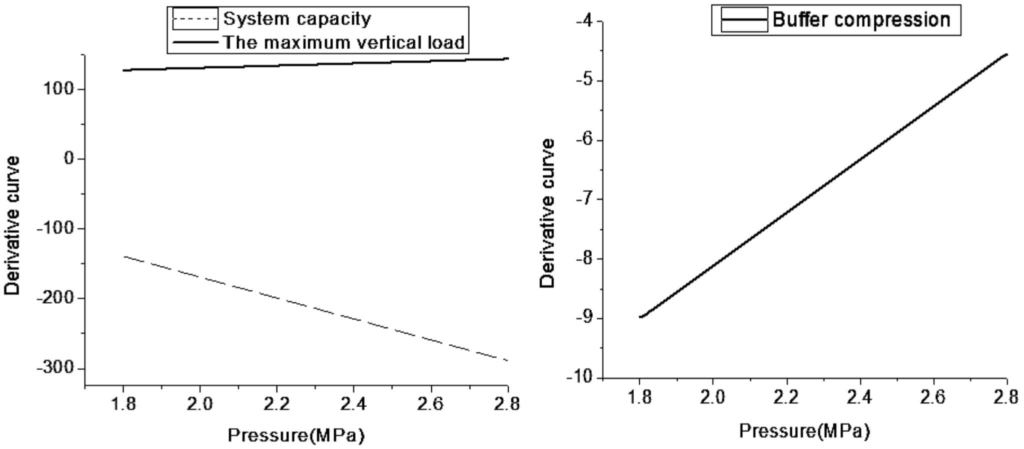
Fig. 4. Absorber performance at different air chamber pressure

4. Influence of different attitude angles on buffer performance

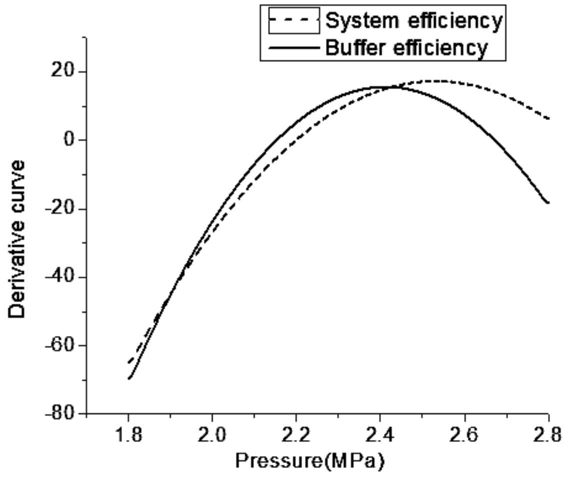
Five working conditions are realized during the test. By adjusting the shim thickness between fixture and carriage, the attitude angle is changed. The angles are 15°, 12°, 9°, 6° and 3° respectively and each of them are tested six times. The condition of the angle 6° is shown in Fig. 6.

Figs. 7 and 8 show one of the six times of 9° and 3° respectively. Compared to Fig. 7, the maximum around in Fig. 8 becomes smoother, which suggests that the landing gear has better buffer performance when the attitude angle is 3 degree.

The test results are processed in the same method as before and are shown in Table 3. It can be observed that with the change of attitude angle from 3 degrees to 12 degrees, the parameters (system capacity, the maximum vertical load, buffer compression and efficiency of buffer and its system) have an increase trend. The result of 15 degree is between 6 degree and 3 degree. The reason is that the landing gear is an articulated structure. One end of the rocker arm connects to the buffer and the other end connects to the wheel. The impact acted on the wheel roll the rocker arm, changing the intersection angle of axis and vertical. When attitude angle is less than initial angle 12.5° of buffer axis and pillar axis, the wheel hit the ground and the angle between the absorber axis and vertical direction will always increase. When attitude angle is more than 12.5°, the wheel will hit the ground and the angle between the buffer axis and vertical direction will decrease first then increase or always decrease. So the result of 15° angle is against the rule of the case from 3° to 12° and the energy absorption is more advantageous than the case of 3° but is poorer than the case of 3° angle.



(a) System capacity and the maximum vertical load of tire (b) Buffer compression

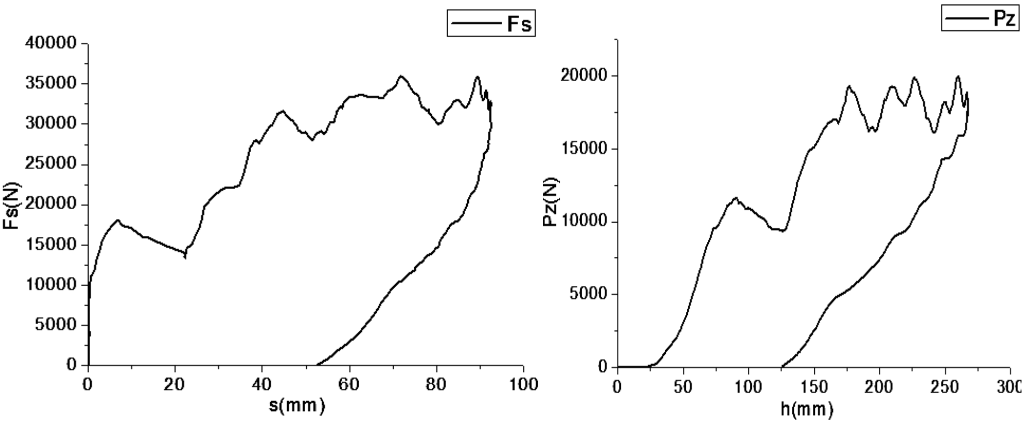


(c) Efficiency of buffer and system

Fig. 5. Change rate of drop test result with different air chamber pressure

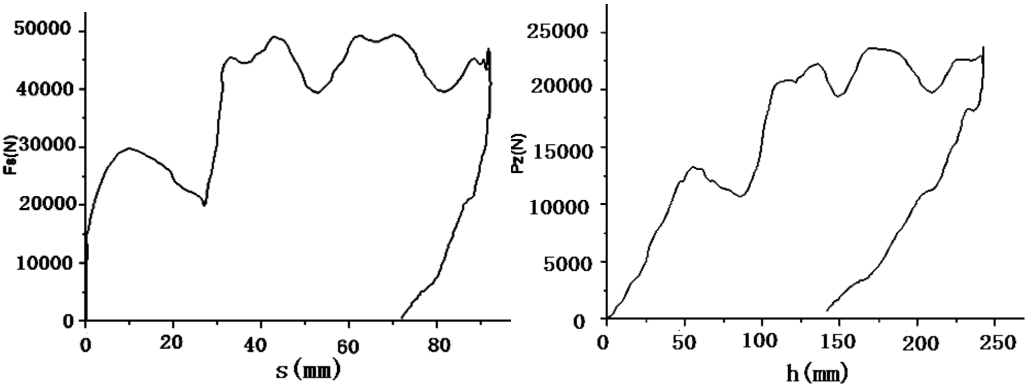
Figure 9 is the fitting curve according the data of Table 3. It shows that the performance parameters decrease with attitude angle increasing from 3° to 12°. System capacity, maximum vertical load of tire and system efficiency have the same change trend. Their variation rates increase gradually with angle increasing. The buffer compression has the opposite change and its variation rate decreases gradually with angle increasing. The buffer efficiency is linear with attitude angle, and the slope is -0.66, that is, the buffer efficiency reduces 0.66 % with the 1° increase.

Fig. 6. The landing gear fixture of the angle 6°



(a) Buffer capacity (b) System capacity

Fig. 7. Capacity graph of 9 degrees limited drop test

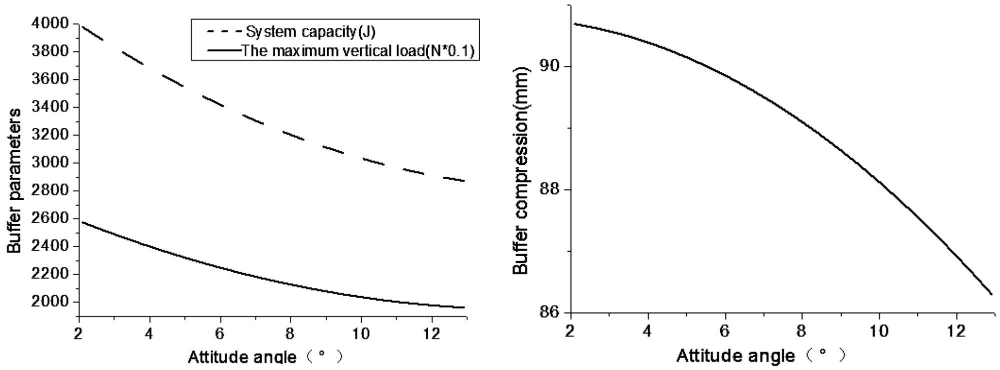


(a) Capacity of absorber (b) System capacity

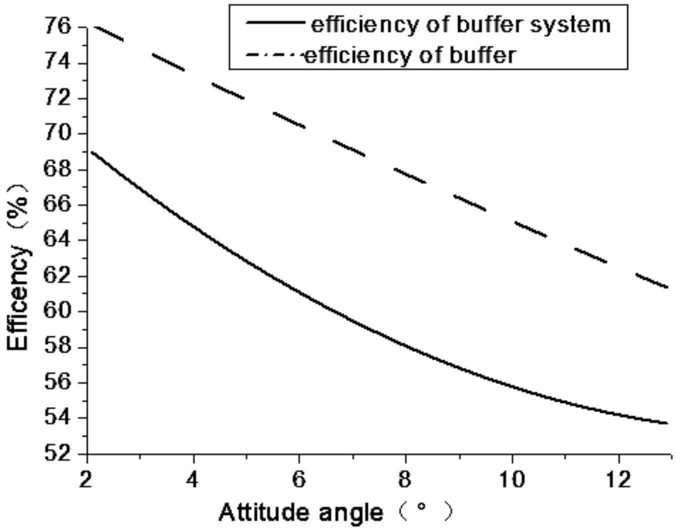
Fig. 8. Capacity graph of 3 degrees limited drop test

Table 3. Result of the different attitude angle drop test

Attitude angle (°)	System capacity (J)	Maximum vertical load (N)	Buffer compression (mm)	System efficiency (%)	Buffer efficiency (%)
15	3581	23150	90.3	62.2	70.5
12	2913	19730	87.0	54	62.4
9	3116	20985	88.4	57.4	66.7
6	3419	22307	90.1	60.5	70.2
3	3835	24960	90.5	67.1	74.9



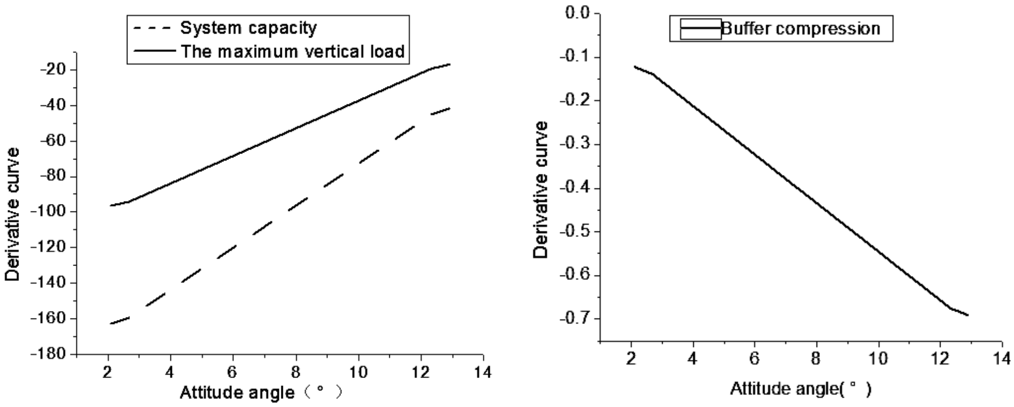
(a) System capacity and the maximum vertical load of tire (b) Buffer compression



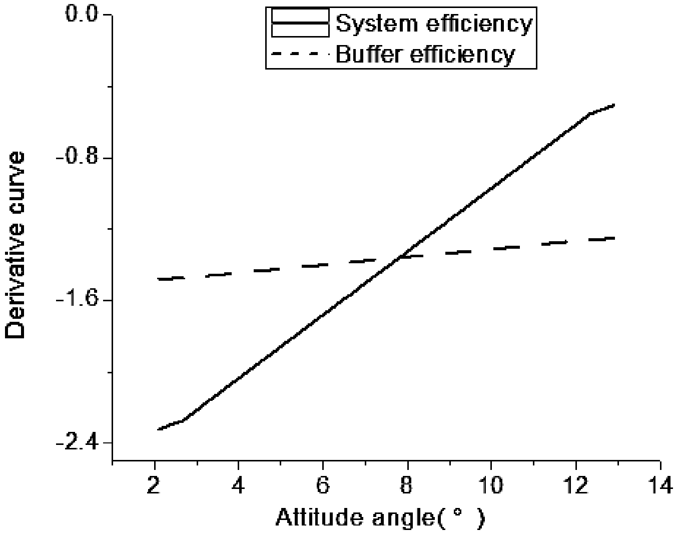
(c) Efficiency of absorber and system

Fig. 9. Drop test result with different attitude angles

In order to further study the change speed of performance parameters with attitude angle, the fitting curves in Fig. 9 are taken differential treatment, and the performance parameter variation rate curves are obtained (Fig. 10). It reveals that the performance parameter rate is linear with attitude angle. The rate of buffer compression decreases with angle increasing. The rate of the rest parameters increases with angle increasing. The rate of system efficiency has the fastest growth.



(a) System capacity and the maximum vertical load of tire (b) Buffer compression



(c) Efficiency of buffer and system

Fig. 10. Rate of drop test result with different attitude angles

5. Conclusion

Based on the landing gear drop test, the effects of air chamber pressure and attitude angle on buffer performance were studied in this paper. The curves of buffer performance followed air chamber pressure and attitude angle are obtained. The following main results are obtained:

1) With air pressure increasing in chamber, the system capacity decreases and its change speed slows down linearly with a ratio of 150 J/MPa^2, and the maximum vertical load increase linearly. With attitude angle increasing, the system capacity and the maximum vertical load decrease and their change speed increase linearly.

2) With air pressure increasing in chamber, the buffer compression decreases and its change speed increases linearly with a ratio of 4 mm/MPa^2, which indicates that the buffer compression reduces faster and faster with pressure increasing. With attitude angle increasing, the buffer compression decreases and its change speed decreases linearly.

3) With air pressure increasing in chamber, system efficiency decreases first, then gradually increases after reaching its minimum at 2.15 MPa and decreases last after reaching its

maximum at 2.7 MPa. Buffer efficiency decreases first and then increases after reaching its minimum at 2.2 MPa. Their change speed increases first, then decreases, reaching their peaks respectively at 2.5 MPa and 2.3 MPa. The air chamber pressure has the strongest effect on the efficiency of system and buffer. With attitude angle increasing, the system efficiency decreases nonlinearly and its change speed increases linearly with a ratio of 0.2, and the buffer efficiency decreases linearly.

4) The pressure increase of air chamber is the main influential factor on the system efficiency and buffer efficiency. Attitude angle mainly influences system capacity.

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References

[1] **Editorial Board of Aircraft Design Manual.** Aircraft Design Manual. 14th Section, Beijing, Journal of Aeronautical Engineering, 2002.

[2] **C. Venkatesan** Optimization of an oleo-pneumatic shock absorber of an aircraft during landing. Journal of Aircraft, Vol. 14, Issue 8, 1977, p. 822-823.

[3] **Willian E. H., John R. M., Robert H. D., Willian A. V.** F-106B airplane active control landing gear drop test performance. NASA Technical Memorandum 102741, 1990, p. 1-12.

[4] **Gian L. G.** Testing of semiactive landing gear control for a general aviation aircraft. Journal of Aircraft, Vol. 37, Issue 4, 2000, p. 606-616.

[5] **Zhang Zhilin, Su Kaixin** Landing impact dynamic analysis of landing gear. Shanghai Journal of Mechanics, Vol. 20, Issue 4, 1999, p. 410-415.

[6] **Shi Haiwen, Zhang Daqian** Influence of imitation condition of spin-up and spring back drag loads on drop test result. Acta Aeronautica et Astronautica Sinica, Vol. 22, Issue 1, 2001, p. 39-41.

[7] **Shi Haiwen, Yang Shuxun** Parameters study at touchdown instant of nose undercarriage of fighter airplane. Acta Aeronautica et Astronautica Sinica, Vol. 24, Issue 6, 2003, p. 517-520.

[8] **Liu Hui** Research on Property and Semi-Active Control of Landing Gear Shock Absorption System. Nanjing: Nanjing University of Aeronautics and Astronautics, 2003.

[9] **Lin Yueguo, Cheng Jialin** Dynamic simulation and optimization analysis for shock absorber for telescopic landing gear. Aircraft Design, Vol. 27, Issue 4, 2007, p. 26-30.

[10] **Gu Hongbin, Liu Hui** Development of research on modern landing gear shock absorber. Aeronautical Science and Technology, 2008, p. 36-41.

[11] **Liu Min, Rong Wei** The analysis for retro-rocket layout effect on return capsule landing attitude. Spacecraft Recovery and Remote Sensing, Vol. 31, Issue 2, 2010, p. 1-9.

[12] **Zhang Yi** Technical analysis of landing of airport 330 at plateau airport. Journal of Chengdu Aeronautic Vocational and Technical College, Vol. 26, Issue 2, 2010, p. 51-52.

[13] **Xue Caijun, Zhang Li** Research on drop test technology for the HO300 aircraft landing gear. Journal of Vibration Engineering, Vol. 24, Issue 3, 2011, p. 299-303.