Performance Analysis on Retractable Landing Gear and Design of Ground Test System

Wang Hongxian[1,2], *Nie Hong*[2*]

1. Key Laboratory of Unmanned Aerial Vehicle Technology of Ministry of Industry and Information Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P. R. China

2. State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P. R. China

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Abstract: Landing gears are one of the key components for large or middle unmanned aerial vehicles, and their working performances directly affect flying security and aircraft taking-off and landing performance. Thus, it is meaningful to study the retraction system. Based on CATIA and ADAMS software platforms, a virtual model of landing gear retraction system is built for performance test, and then dynamic simulation is carried out. Afterwards, a test system for landing gear retraction is established, and the test data are compared with the results acquired from dynamics simulation. The main factors which affect the dynamic performance of retractable landing gear are analyzed emphatically. The simulation results show that aerodynamic load has an impact on retraction time, the mass force affects extension process, and the oil hole size of hydraulic actuator has an effect on both retraction time and extension time.

Key words: landing gear; retraction system; dynamic simulation; experiment system

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0 Introduction

Landing gears have been widely deployed for taking-off and landing on large and medium-sized unmanned aerial vehicles (UAVs). In order to reduce the drag in flight, landing gear is usually designed to be retractable. Retraction system has become crucial in modern research because its working performance directly affects safety and mobility of aircraft. Therefore, simulation of landing gear performance and retractable function test on ground are important means to design a certain type of airplane.

Although many domestic and foreign scholars have conducted simulation and ground test to analyze landing gear performance, most current studies do not well combined subsystems. Noel[1] introduced a novel dynamic simulation and optimize the retraction performance by using ADAMS and parameters, which decreased the operation time shorter than that the aircraft manufacturing instructions required. The hydraulic system of test car was analyzed and designed according to the test task by Bao Hongzhi[2-3], which realized the automation based on programm-able logic controller (PLC). Considerable studies on hydraulic system and landing gear test have been performed[4-9], but the influence of various factors on the performance was not analyzed, and the practical verification for hydraulic system is still needed[10-12].

A manned aircraft landing gear is selected as the research object and simulation analysis and experimental verification on the ground are con-

* Corresponding author, E-mail address: hnie@nuaa.edu.cn.

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ducted. The manned aircraft landing gear structure, force mode and hydraulic power sources are much similar with those of UAV landing gear. Thus, it can provide a valuable reference for the preceding study of UAV landing gear.

1 Dynamics Simulation on Landing Gear

1.1 Retractable principle

A simplified landing gear retracting mechanism is shown in Fig. 1[13], where structure 1 is the main strut, structure 2 the outer cylinder actuator strut, structure 3 the cylinder actuator, and structure 4 the up-lock. In retraction process, hydraulic oil enters the actuating cylinder, which pushes bar 3 out from bar 2. When the main strut rotates up to up-lock and locks up, the landing gear retraction is completed. In extension process, the opposite movement process is conducted.

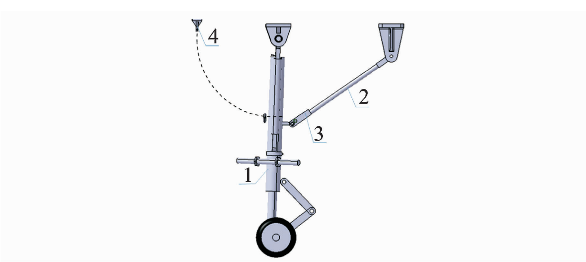

Fig. 1 Virtual assembly model

1.2 Retractable load

On retraction and extension process, the load on retractable mechanism is obtained by equilibrium condition of rotating shaft torque of landing gear from all other loads. These loads include: mass force, aerodynamic drag, inertia force and lock drag, etc.

1.3 Dynamic model of landing gear retraction

A simplified model is built by CATIA, and imported into ADAMS with MSC. SimDesigner. Corresponding constraints are added in landing gear linkage component model, including aerodynamic load, friction, locked drag and inertial force. Then the dynamic model is established. Model parameters are obtained through experiment. The virtual model of landing gear is shown in Fig. 2.

Fig. 2 Virtual prototype model

1.4 Load on dynamic model

Loads, which can strongly influence retractable landing gear are sophisticated and complex. Determining several key large loads for retraction in the process of modeling and simulation is important before focusing on the analysis of the key factors.

Mass properties of parts defined in SimDesigner will be imported into ADAMS along with model. Then, mass force will be automatically generated in software and the action point is located in centroid, which requires no extra setting. Aerodynamic drag is loaded by the ADAMS/Aircraft function. Then, parameters are set on actuating hydraulic cylinder in ADAMS. At last, submit the rest of the parameters are submitted and dynamic simulation of landing gear is completed (Fig. 3).

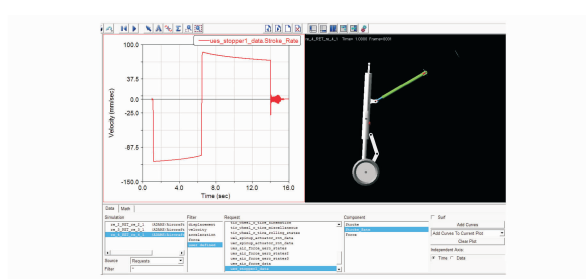

Fig. 3 Dynamics simulation interface

1.5 Influences of key parameters

1.5.1 Influence of aerodynamic drag

In the process of retraction, aerodynamic load exerts a greater impact on the retraction performance, so in ADAMS, specific functions are applied to conduct the simulations.

Directions of aerodynamic load plane are opposite. Aerodynamic load impedes and negatively influence retraction process, while benefiting extension process through positive work. As shown in Fig. 4, aerodynamic load gradually increases with air speed, which may make the wheels more difficult to rise. With further increase of speed, the landing gear may not reach the designated position.

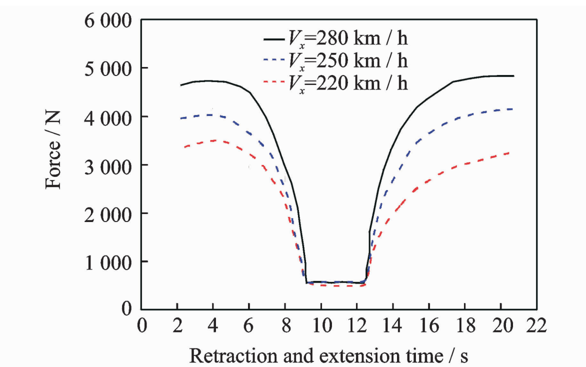

Fig. 4 Aerodynamic load in different speeds

1.5.2 Influence of mass force

The impact of mass force variation is analyzed by changing the value of the gravity acceleration. With the increase of working load, hydraulic actuator load increases, leading the time of retraction process to rise (Fig. 5).

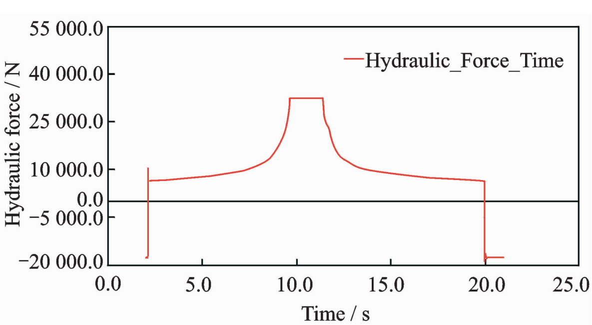

Fig. 5 Actuating cylinder pressure variations with time caused by mass force

1.5.3 Influence of changes of the parameters of actuating cylinder

Load on actuating cylinder with retraction and extension time is given in Fig 6. The effects are quite obvious even there are only small changes in the parameters of the retraction process. In the design of landing gear, selecting the parameters of throttle valve is extremely important. For example, the special size optimization for the throttle valve when they design the landing gear.

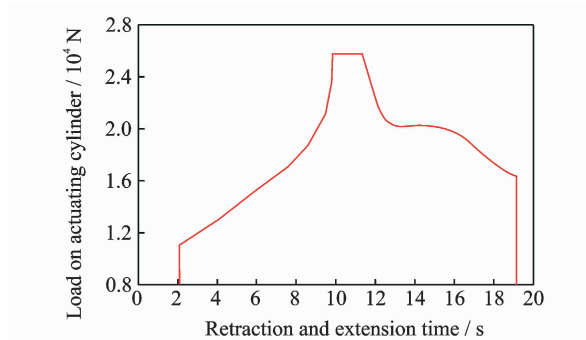

Fig. 6 Actuator load change with time

The parameters of Case 1 and Case 2 (Fig. 7) are respectively shown in Table 1 and Table 2.

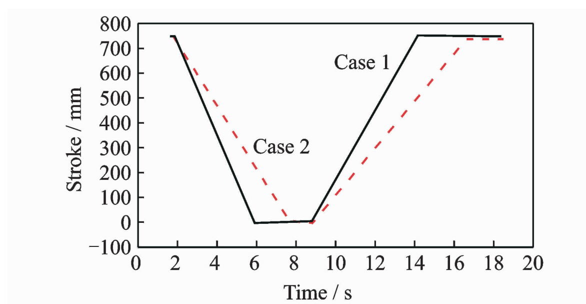

Fig. 7 Actuator stroke changes with time

Table 1 Main parameters in Case 1

Situation	Coefficient in rodless	Coefficient in rod
Retraction motivation	0.1	0.5
Expansion motivation	0.1	0.9

Table 2 Main parameters in Case 2

Situation	Coefficient in rodless	Coefficient in rod
Retraction motivation	0.15	0.5
Expansion motivation	0.15	0.9

In the simulation process of analyzing the influence of hydraulic cylinder parameters, when the initial pressure of the hydraulic cylinder changes respectively, the retraction and extension process will become either too fast or too slow, which indicates that the landing gear system is not working properly. Therefore, when designing parameters, we cannot only rely on the existing mature experience, but also need to adjust the simulation test according to the actual working condition.

2 Design of Retractable Experiment

2.1 Test principles

To meet the technical requirement of test and the performance index, a test system of landing gear retraction is developed, including the test bench, the hydraulic system, the control system and the measurement system.

2.2 Test bench design

As shown in Fig. 8, the test bench is designed according to the requirements of retraction, including the retractable space for landing gear and the magnitude torque. The static strength as well as the stiffness should be checked before test, in order to ensure the accuracy of the test object which usually influenced by the test bench.

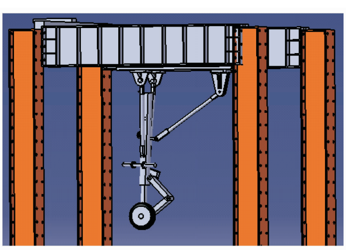

Fig. 8 Test bench

2.3 Hydraulic system design

According to the function and parameters related, a hydraulic system of ground retraction test was designed in Ref. [14]. The original parameters of the hydraulic system and the main technical indexes are shown in Tables 3, 4.

Table 3 Parameters of the hydraulic system

Parameter	Value
System pressure/MPa	31.5
Operation time/s	5—10
Maximum load/N	70 000
Oil tank pressure/MPa	0.15
The maximum flow $Q_{max}/(L \cdot min^{-1})$	40
Actuator stroke L/mm	≥700
Working temperature/(°)	−50—70

Table 4 Main technical indexes

Parameter	Technical indicator
Motor power/kW	22
Hydraulic pump P_{max}/MPa	31.5
The system rated flow $Q/(L \cdot min^{-1})$	40
Valve control voltage/V	DC 24

According to the test parameters and the main technical indicators, the hydraulic test system is selected to provide the power source for the whole landing gear system. Hydraulic principle diagram and test system are shown in Figs. 9, 10.

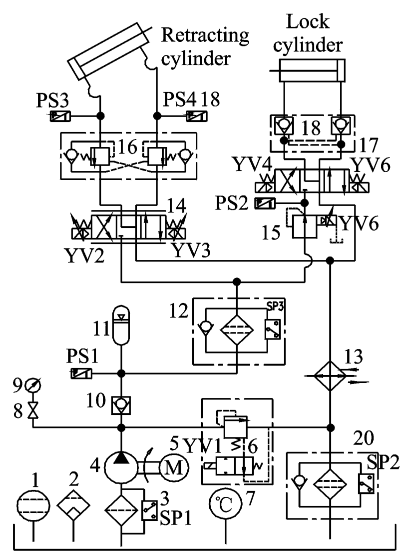

Fig. 9 Hydraulic principle

Fig. 10 Test system

2.4 Loading

During retraction and extension process, loads on landing gear include mass force, aerodynamic drag, inertia force, friction resistance and lock drag, etc.

Aerodynamic load is the only element should be simulated because the landing gear and lock mechanism are all practically applied to actual aircraft. In experiment, it is acquired by simulating the real-time change of aerodynamic load during retraction and extension process[15].

A new method to simulate aerodynamics is put forward. In Fig. 11, T is the force in cube, F the force in landing gear, θ the angle of landing gear extension and retraction, and A the initial point of retraction and termination point of extension. Loads are applied differently for extension and retraction. During the application of aerodynamic load, accuracy of amplitude and direction has been secured.

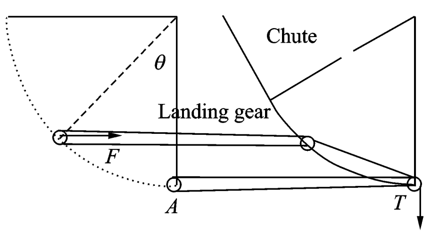

Fig. 11 Aerodynamic loading

2.5 Control system

Control software for experiment has been developed to attain the more complex integration and recycle control for various systems. The control cabinet and the control interface are shown in Fig. 12.

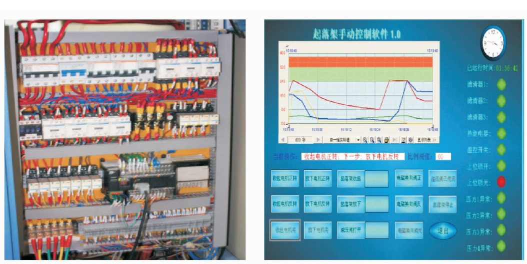

Fig. 12 Control cabinet and control interface

2.6 Measuring system

Strain gauges are pasted on key parts such as actuating cylinder and the upper lock. Displacement sensors have been installed in the strut lug and pressure sensor is applied to measure the tubing pressure of actuating cylinder. The completed test system is capable of measuring key parts, which grants both precision and convenience.

The measurement items in the test include pressure-time curves of rod cavity and rodless cavity, unlocking and locking pressures. Then pressure-time curves of actuating cylinder into and out of the oil cavity can be calculated, and other key parameters can also be calculated further, for example, locked and unlocked pressures of upper lock.

3 Result Comparisons and Analysis on Parameter Influences

3.1 Aerodynamic load outcome

First, the accuracy of the aerodynamic load simulation should be verified because the aerodynamic load is applied by simulation in test. Measured load and theoretical load curves in retraction and extension process in test are shown in Figs. 13, 14.

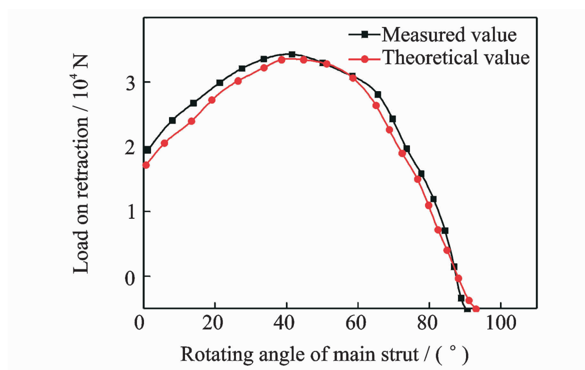

Fig. 13 Results of simulation aerodynamic load in retraction process

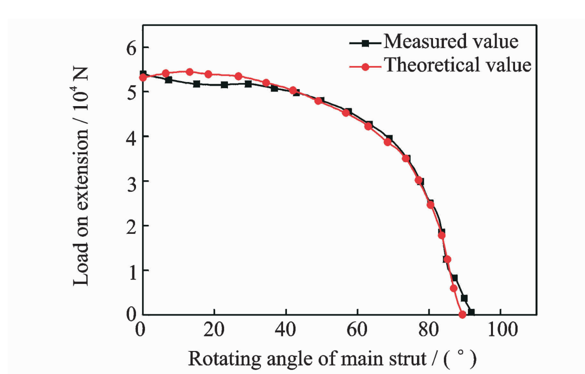

Fig. 14 Simulation results of aerodynamic load in extension process

According to the comparative analysis between simulation and test, the maximal error in loading simulation is less than 5%, while the average error is about 3%. Then, the further analysis of the test result can be carried on.

3.2 Comparison of results

3.2.1 Displacement change of actuator cylinder with time

Simulation data agree well with experimental results, as is shown in Figs. 15, 16. The test result curve is obtained by measuring strain changes during retraction process with the strain displacement sensor, which can convert to the change curve of actuating cylinder with time. In the later stage of retraction process, because the retraction speed of landing gear is too high, the actuating cylinder relief valve starts to work. As a result, there is a certain decline of speed in the later stage of retraction process.

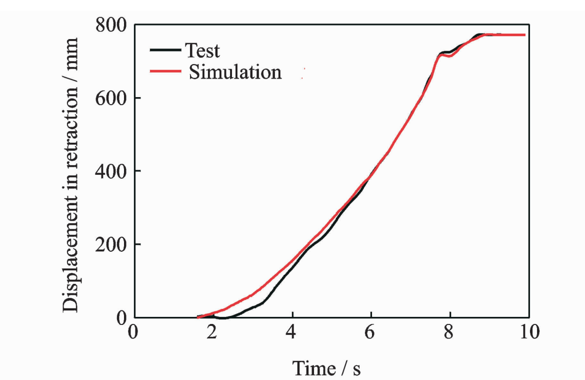

Fig. 15 Displacement change of actuator cylinder with time in retraction process

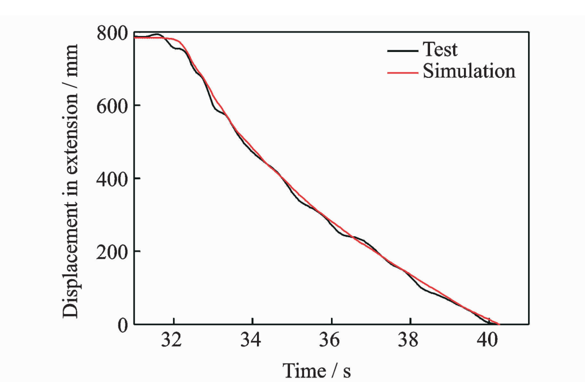

Fig. 16 Displacement change of actuator cylinder with time in extension process

3.2.2 Actuator load analysis

As shown in Figs. 17, 18, pressure changes in two cavities can be measured by pressure sensor in the process of retraction. Then, the curve of pressure changes during the retraction process can be obtained after the acquisition and processing of data.

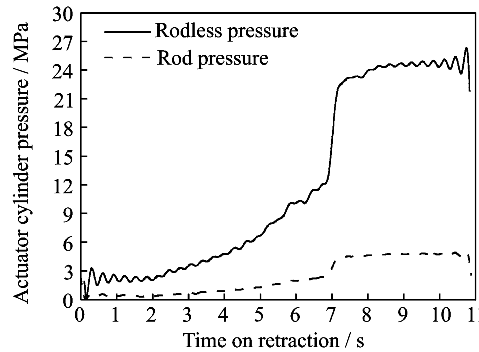

Fig. 17 Pressure changes of actuator cylinder with time during retraction process

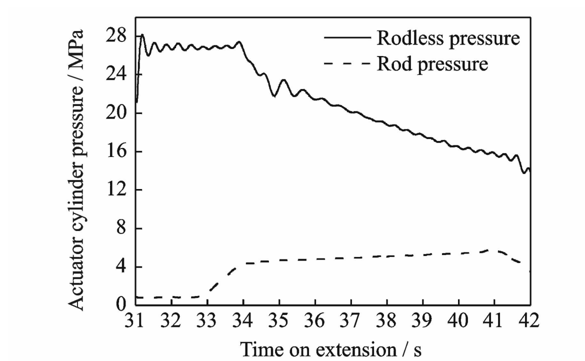

Fig. 18 Pressure changes of actuator cylinder with time during extension process

The actuator load has been achieved through converting pressure curves of two cavities, while simulation results have been acquired by using the dynamic simulation software. The comparison results of them are shown in Figs. 19, 20.

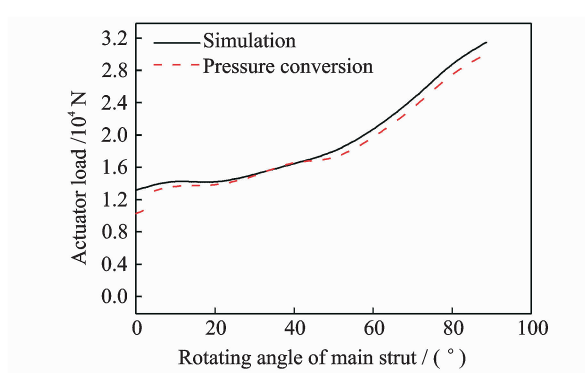

Fig. 19 Load results comparison of actuator cylinder in retraction process

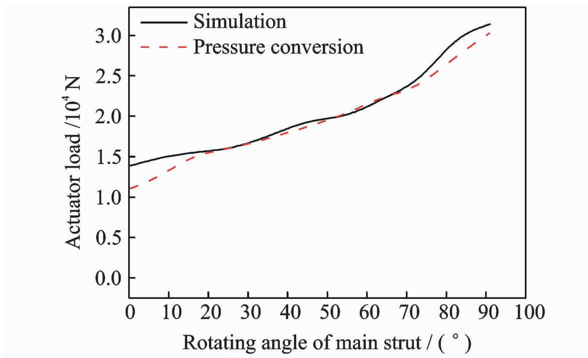

Fig. 20 Load results comparison of actuator cylinder in extension process

The results show that the measured curves and simulation curves are in good agreement, and the average error is less than 3%. Meanwhile, it verifies the feasibility of the testing system, and provides support for the theoretical study and experimental design in the future.

4 Conclusions

The dynamic model of a landing gear retraction system is established and the dynamics simulation is accomplished. Loads in retraction process are analyzed, especially the performance influence of key factors including aerodynamic drag, mass force, and locking drag. Furthermore, a test system for landing gear retraction is developed. Simulation and experimental results are both acquired. Comparision of the two results shows that:

(1) Speed has a great influence on the hydraulic load and retraction time, so speed should be as low as possible in retraction and extension process. Mass force affects operating time by changing the actuating cylinder loading. The main parameters of actuator have a greater impact on certain factors, particularly the retraction time, and may even impede retraction function being completely realized.

(2) The landing gear function of retraction is achieved and the reliability of test system is verified. Simulation results of displacement changes of actuator cylinder with time during retraction and extension processes are in good agreement with those of experimental results. The maximal error in loading simulation is less than 5%. In addition, the actuating cylinder relief valve works, so that there is a certain decline in the later stage of retraction to avoid the speed being too high. Simulation of aerodynamic load on retraction and extension process has a high loading precision. The maximum error is less than 5%.

(3) Test results agree well with the simulation results. And both results are verificationed. It can provide a reference for the simulation and test system design of retractable landing gears on large or middle unmanned aerial vehicles, especially for those with the similar retractable structure.

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Mr. **Wang Hongxian** received B. S. degrees in Nanjing University of Aeronautics and Astronautics in 2010. He majors in retractable landing gear design, CAD / CAE of aircraft structure and system, dynamics of mechanical system, anti-fatigue control technology of mechanical structure.

Prof. **Nie Hong** received Ph. D. degrees in Nanjing University of Aeronautics and Astronautics, respectively, in 1990. He is a "Vision 2010" Postdoctoral Research Fellow in the Microwave Photonics Research Laboratory, University of Ottawa, Ottawa, ON, Canada. From 2010 to present, he has been with the College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics (NUAA), where he is currently a professor and executive director of the Key Laboratory of Radar Imaging and Microwave Photonics (NUAA), Ministry of Education. His research has focused on microwave photonics, which includes Radio over fiber, photonic generation of microwave, mm-wave and THz, photonic processing of microwave signals, photonic microwave measurement and photonic integrated circuits.

(Executive Editor: Zhang Bei)