A TECHNIQUE OF LANDING GEAR LOADS CALIBRATION WITH STRAIN GAGES

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Abstract

This paper presents a technique of landing gear calibration for ground loads using strain gage. The emphasis is placed on the six-component loading platform, the calibration process, and the method to get loads equation based on influence-coefficient. Some flight data are also provided.

1 Introduction

Landing gear is one of the most important airplane components to be used for aircraft takeoff, landing, taxiing, parking and steering on ground. In order to verify the structural design loads and the structural strength, it is necessary to measure landing gear loads in flight test. Generally ground loads calibration test is to remove the landing gear from the test aircraft, then fix them in specially designed test rig and apply loads to the landing gear. In this way, the connection stiffness between landing gear and rig can not fully be simulated as the real connection stiffness with the aircraft. This will affect the accuracy of the result of loads measurement.

To deal with this issue, landing gear loading calibration platform with which can simulate the real load condition of the landing gear in use was developed. It has been proved that the loading platform can meet the landing gear calibration requirement. This paper introduces the calibration test with the load platform and gives a landing gear load measurement of a certain type of airplane as an example.

2 strain gauges installation

The strain gauge bridge positions for the main landing gear are shown in Figure 1, which respectively in the shock strut, axle, torque link and drag brace. Two measuring sections are selected on the strut, and on each section install some strain gauges which are sensitive to longitudinal loads and lateral loads, and some strain gauges sensitive to torque. On the axle some strain gages sensitive to vertical bending and shear, are mainly used to measure the vertical load; the strain gauges on the torquelink are most sensitive to the torque during turning. The drag brace mainly bear loads along itself, and select two positions to measure tension and compression strain on it.

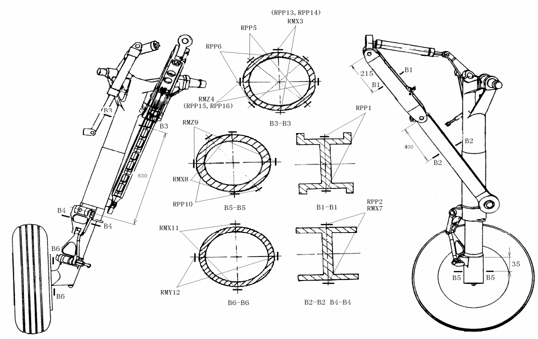

Figure 1 Strain gauges installation schematic of an aircraft main landing gear

3 Loading platform

The Loading platform is developed for the landing gear load calibration test (figure 2). The platform consists of three parts. The upper part is a six-component force balance, which can measure three directions loads and three directions moments acted on the surface of the platform. The lower part is the fixed and support structure. The middle parts are the bearings of high glazed structure which permit the upper part and the lower part make a relative displacement during the process of loading, and reduce the friction between the upper part and the lower part of the platform. So that the load acted on the upper platform can be mostly transmitted to the wheel of the landing gear.

Fig 2 Schematic diagram of the loading platform

The functions of the platform are as follow:
i) Support aircraft: in the process of test, landing gears of the test aircraft are put on three loading platforms and the aircraft is supported by the platforms.
ii) Applying loads: there are four joints in the platform; loads can be applied from these joints.
iii) Transmit loads: loads acted on the platform can be transmitting to the landing gear wheel through the surface of the platform.
iv) Measuring loads: the six-component balance inside the platform can measure loads acted on the wheel.

4 Load calibration test

4.1 Definition of loads

According to the mechanical characteristics of landing gear, the three mutually perpendicular components of ground-to-wheel load which act on the landing gear are illustrated in Fig. 3 and are defined as follow:

Py: Vertical load applied at wheel axle mid point, acting normal to the axle; positive upwards.

Px: longitudinal load applied at wheel axle mid point, acting normal to the axle and to Py; positive forward. Mainly simulate land and taxiing condition.

Fx: Drag load applied at tire ground contact point, acting parallel to Px; mainly simulate brake condition.

Fz: lateral load applied at tire ground contact point, acting normal to Py and Fx; positive inboard.

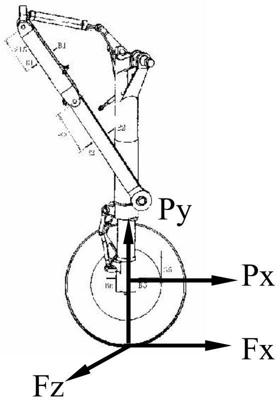

Fig 3 Calibration load point and direction diagram

4.2 Test condition

In order to simulate the actual loads mode of landing gear in land and ground operation, loads cases applied on landing gear include single load and combination loads under different shock strut stroke. And combination loads include two-direction and three-direction loads. All the load cases are showed in table 1.

4.3 Loading and aircraft constraint

In the process of ground loads calibration, the landing gears of the test aircraft will be put on three loading platforms respectively, and the aircraft keep level attitude. The aircraft weight can be used first to apply vertical loads to the landing gear. In order to increase the calibration load, some special parts such as aircraft store point can be used to apply downward loads. The brake load can be applied at the platform directly, and the acted load can be transmitted to the tire through the surface of the platform which has a high friction coefficient with the tire. The wheel center longitudinal loads can be applied with soft belt which is wrapped around the wheel. Lateral load can be applied directly in the loading platform.

Table 1 Load cases of calibration test

Load condition	Serial number	Load direction	Load acting point
single loading	1	Py	Wheel center
	2	Px	Wheel center
	3	Fx	Tire contact point
	4	Fz	Tire contact point
Two- directions combination loading	5	Py+Px	Wheel center
	6	Py+Fx	Tire contact point
	7	Py+Fz	Tire contact point
Three- directions combination loading	8	Py+Px+Fz	Wheel center and Tire contact point
	9	Py+Fx+Fz	Tire contact point

To implement landing gear loading test directly in aircraft, the balance and restraint of aircraft is a major issue related to test safety in loading process. Generally, application of load in calibration test is to build a self-equilibrium force system to keep the aircraft balance. For example, to apply lateral loads to left main landing gear and right main landing gear simultaneously can be easily implemented. More complex condition is to apply combination loads to three landing gears. For example, to balance the lateral loads acted on nose landing gear, an opposite side loads is applied to one of the main landing gear, and the resulting torque's balance is to apply reverse longitudinal loads to the two main landing gear so make a reverse torque. The equilibrium diagram is shown in Figure 4. Balanced load can be calculated according to their acting point, center gravity of the aircraft and the load equilibrium relationship of the landing gear.

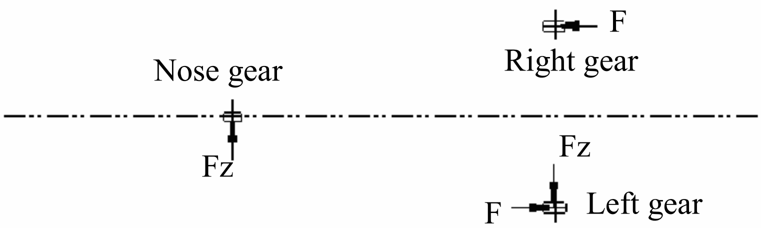

Fig 4. Schematic of Lateral load balance of nose landing gear

4.4 Data reduction

The output of the gauges on a leg can be related to the applied loads on it. In normal usage loads, the relationship is of linear relation; written out by the matrix as,

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_i \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & a_{i3} & a_{i4} \end{bmatrix} \begin{Bmatrix} Px \\ Py \\ Fz \\ My \end{Bmatrix} \qquad 1)$$

Where [aij] in the Formula is called influence coefficient matrix. Through influence coefficient analysis can determine the sensitivity of the bridges. Generally, an ideal bridge's influence coefficient to longitudinal load or to lateral load has linear relationship with the stroke, and vertical load influence coefficient has nothing to do with stroke. But actually it almost hasn't such a bridge. Fig 5 show the four influence curves of a bridge on the main landing gear which is sensitive to side load. Form the curves can be seen, the value of side load influence coefficient is most, and the relationship with the stroke showed a roughly linear relationship. The other three load influence coefficients approximately have nothing to do with the stroke. But their responses are correspondingly obvious too. This indicates mixed response characteristics of the bridge.

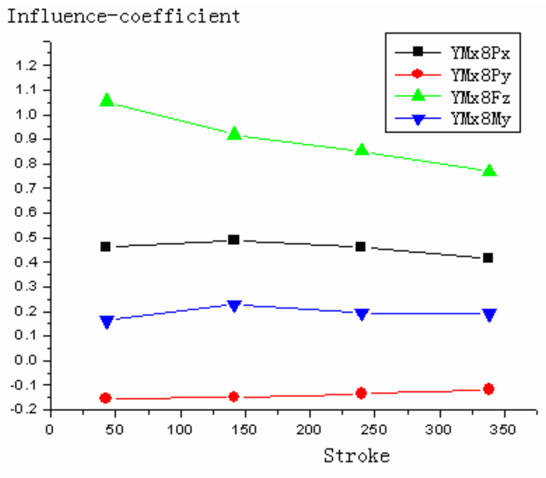

Fig 5 The Influence-coefficient curves of a strain gage bridge on main landing gear

According to the influence-coefficient analysis, better bridges can be selected to establish load equation with method of iterative regress. The general form of load equations can be expressed as matrix,

$$\begin{Bmatrix} Px \\ Py \\ Fz \\ My \end{Bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & \cdots & b_{1i} \\ b_{21} & b_{22} & b_{23} & \cdots & b_{2i} \\ b_{31} & b_{32} & b_{33} & \cdots & b_{3i} \\ b_{41} & b_{42} & b_{43} & \cdots & b_{4i} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_i \end{Bmatrix} \qquad 2)$$

5 Flight test

Typical landing gear load measuring flight test subjects include takeoff, landing, braking, turning, gliding and so on. This paper doesn't describe the flight situation in detail, but in order to explain the accuracy of the measured data, one take-off and landing flight test results are given, and a brief analysis, too.

Figure 6 shows the loads history curves of the main landing gear during take-off. In the process of take-off roll, longitudinal and lateral loads are small, vertical load increases in first, then oscillation decrease. This is due to roll speed increases, front wheel off the ground and other effects. And the change process of shock strut stroke can also be seen from the chart. Point A in the curve is that the landing gear entirely off ground in which three –direction loads all reduced to minimum.

Figure 7 shows the loads and shock absorber travel time history during aircraft landing. From the figure can be seen vertical load increases to maximum with the compression of shock stroke travel, then decreases due to the plane bounced. However, the change of the SAT is not as the same time as the change of the loads, but slightly lagging behind the load, which is consistent with actual results. The value of the vertical loads has relationship with sink speed, landing weight and attitude and so on. During landing, the wheels start turning from still, and finally achieve the same roll speed with the aircraft. In this process wheel load experienced a change of spin-up, spring-back and Oscillation. The maximum spin-up load is the lowest point in Px curve, and the maximum spring-back load is the highest point in Px curve. The spin-up and spring back load is about 0.3 ~ 0.8 times of vertical load by statistical analysis, and generally appears in the vicinity of the maximum vertical load. This is not completely consistent with strength specification requirement. In symmetrical landing process, lateral load is small. When landing with a large crosswind or asymmetric landing conditions, side loads would greatly increase.

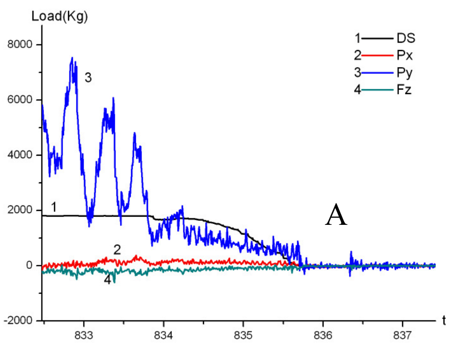

Fig 6 Take off Load-time histories of Main Landing Gear of one aircraft in one flight

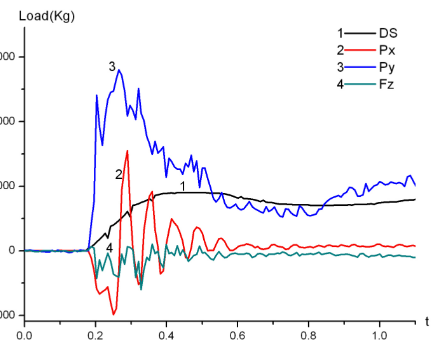

Fig 7 Landing Load-time histories of Main Landing Gear of one aircraft in one flight

6 conclusions

This paper describes in detail the process of landing gear loads calibration test using loading platform. The loading platform has been successfully used in several types of aircraft landing gear loads survey. It has be demonstrated that the test platform can simulate the actual load condition of landing gear during landing, braking, turning, and taxiing, and is an ideal calibration equipment for landing gear.

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