Simulation Analysis of Aircraft Taxiing Dynamic Load on Random Road Roughness

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Abstract

For the high complexity of airport runway dynamic load field test, the paper did simulation analysis by means of ADAMS/Aircraft software, used the standard model of the prototype aircraft, and generated different levels of pavement with the white noise linear filtering method, to study the dynamic load laws of nose wheel and main wheels under different pavement. Simulation results show that: the poorer the runway pavement, the greater peak of aircraft dynamic load coefficient of pavement will be. Compared with the measured data, it indicating that the roughness is the main factor of aircraft dynamic load peak.

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Key words: Aircraft taxiing; Road roughness; Dynamic load; ADAMS/Aircraft; Simulation

1. Introduction

Road roughness is one of the most important indicators of pavement performance, influencing safety of taxiing and driving comfort, determining the dynamic load force of the plane. When the aircraft is taxiing on uneven road surfaces, the wheels generate additional dynamic load on the pavement. It directly impact on the development of plastic deformation of the points, so that the accumulation of plastic deformation on different points differ, which accelerates the pavement roughness.

We often simplify the pavement design with static load multiplied by the dynamic load coefficient in the past. With the development of aviation technology, the weight of transport airplane both military and civilian increases, and landing gear is even more complex, load characteristics of existing aircraft during takeoff and landing have changed as well. The previous dynamic load factor can not describe the response...
from the wheels to the pavement accurately any more. Making an on-the-spot dynamic load test \cite{2} for various types of aircraft is certainly a mammoth job, which would take a lot of manpower and resources. Therefore, in this paper we described road roughness with power spectral density, and built model plane with simulation software ADAMS, then we did simulated roll on different levels of road surface to get a random dynamic loads of the airplane.

2. Random road roughness incentive model

Road roughness means the road surface deviations from the base plane. The actual road surface roughness is based on the spatial frequency power spectrum density. GB7031-86 expresses the power spectral density of the ground roughness as a power function from, proposing the power spectral density equation (1) as a fitting expression:

\[ G_d(n) = G_d(n_0) \left( \frac{n}{n_0} \right)^{-\omega} \]

Where \( n \) means spatial frequency, \( m^{-1} \); \( n_0 \) means the reference spatial frequency, \( n_0=0.1m^{-1} \); \( G_d(n_0) \) means the power spectrum density of road under the reference spatial frequency, known as the road roughness coefficient, \( m^3 \); \( \omega \) is the frequency index, slope of dual-logarithm coordinate, determining the frequency structure of road frequency spectral density, \( \omega=2 \).

GB divide road roughness into A~H-level, as shown in Table 1.

Table 1. Pavement Classification Standard

| Pavement level | A  | B  | C  | D  | E  | F  | G  | H  |
|----------------|----|----|----|----|----|----|----|----|
| \( G_d(n_0) \) Geometric mean | 16 | 64 | 256 | 1024 | 4096 | 16384 | 65536 | 262144 |

Road files simulated by ADAMS were based on linear filtering of white noise, which generated right and left rut vertical sections of the main landing gear from A~H , 8 files altogether. The correlation coefficient of two ruts \( R_l \) was taken as 0.8 (\( R_l=0 \) means not relevant, \( R_l=1 \) means related).

3. Results and Analysis

For the simulation of aircraft roll, we need to establish the whole assembly model, which include body subsystem, nose gear subsystem, main gear subsystem, nose gear wheel system, main gear wheel system, and brake subsystem (optional). As Aircraft module provides a large number of typical aircraft templates, users could call the necessary subsystem directly to achieve the establishment, and modify parameters as their wishes. If the template doesn’t meet the requirements of the users, they can create new templates, set the specific parameters of the subsystem. Finally, the assembly command will assemble the subsystems into an airplane model. Aircraft design and analysis are not our focal points. However we focus on studying the situation of airport pavement under load by means of the virtual prototype model. So we chose the standard module of ADAMS to build a standard prototype model which has been validated, shown in Fig. 1.
Then define the parameters of the aircraft structure, as shown in Table 2.

Table 2. Aircraft configuration parameter

| Parameter                                                                 | Value                  |
|---------------------------------------------------------------------------|------------------------|
| The overall quality of the aircraft                                       | 23432.6 kg             |
| X coordinate of the aircraft gravity center                               | 11.43 m                |
| Z coordinate of the aircraft gravity center                               | 2.54 m                 |
| X-axis moment of inertia at aircraft gravity center                       | 58527.9 kg·m²          |
| Y-axis moment of inertia at aircraft gravity center                       | 87791.9 kg·m²          |
| Z-axis moment of inertia at aircraft gravity center                       | 58527.9 kg·m²          |

Simulated in taxiing platform, taken 40km/h as representative rate to indicate aircraft roll speed. Simulated equilibrium time as 2s, 200 steps. Obtained the simulation results, mainly analyzed the pavement vertical load response to different levels of road roughness and speed.

4. Results and Analysis

4.1. Influence from pavement level on main wheel dynamic load

In order to study the main landing gear single wheel (one of the main wheels) dynamic load under different road roughness levels, the paper simulated and got the dynamic loading process, and see Fig. 2 and Table 2.
Fig. 2. Changes of main wheel longitudinal load along the track under different levels of pavement

Table 3. Main wheel dynamic load

| Pavement level | A       | B       | C       | D       | E       | F       | G       | H       |
|----------------|---------|---------|---------|---------|---------|---------|---------|---------|
| Load average (N) | 94682.9 | 94684.4 | 94688.3 | 94696.3 | 94707.8 | 94736.8 | 94789.8 | 94851.8 |
| Maximum load (N) | 94881.2 | 95315.8 | 95702.1 | 96679.7 | 98015.1 | 100365  | 104233  | 114710  |
| Minimum load (N) | 94435.5 | 94126   | 93602.3 | 92828.8 | 91748.5 | 89395.1 | 84785.8 | 78820.1 |
| Standard deviation | 70.1    | 206.1   | 407.3   | 693.9   | 1133.3  | 1875.9  | 3229.2  | 5881.4  |
| Dynamic load coefficient | 0.997   | 0.994~  | 0.989~  | 0.980~  | 0.969~  | 0.944~  | 0.895~  | 0.832~  |
| ~1.002 | 1.007   | 1.011   | 1.021   | 1.035   | 1.060   | 1.101   | 1.212   |

In this roll simulation, the speed of the plane was lower, so the paper ignoring the impact of the lift. Fig. 2 and Table 3 shows with the lower level of pavement, road roughness increased, the main wheel dynamic load peaks increased, data dispersion increased, along with the dynamic load factor range increased.

Measured results [2] was in A-level road surface, the main wheel dynamic load ranged up to 1±0.75, while the simulation made smaller changes in the scope 0.997~1.002. This mainly because the airplane dynamic load change is tripartite: (1) vibrations caused by various factors aircraft itself, including the engine's eccentric rotation, periodic vibration caused by tire tread and pilot operation does not stable; (2) cause of road roughness; (3) cause of aircraft-road surface interaction coupling. And the most significant
influence on dynamic load is from pavement roughness, the other two influence little but may have a greater dynamic load factor. Our simulation did not consider the impact from (1) and (2), so it appeared a large probability of 83.7% for dynamic load factor at 1 ± 0.05 in measured results. However, due to accidental factor, dynamic load coefficient has a large range of change, but the probability of its occurrence is very small. Comparing measured results, we can see that simulation can reflect the dynamic load conditions impacted by road roughness.

4.2. Influence on nose wheel from road roughness

In order to study the nose wheel dynamic load under different road roughness levels, the paper simulated and got the dynamic loading process, and see Fig. 3 and Table 4.

Fig. 3. Changes of nose wheel longitudinal load along the track under different levels of pavement
Table 4. Nose wheel dynamic load

| Pavement level | A     | B     | C     | D     | E     | F     | G     | H     |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Load average (N) | 20138.4 | 20140.8 | 20144.1 | 20148.5 | 20160.2 | 20194.9 | 20256.1 | 20350.6 |
| Maximum load (N) | 20303 | 20670 | 20739.1 | 21225.8 | 21937.7 | 23385.9 | 26199.2 | 32522.6 |
| Minimum load (N) | 19796.3 | 19603.9 | 19388.1 | 18771.3 | 17931 | 16593.2 | 13976.9 | 8821.79 |
| Standard deviation | 26.5 | 92.8 | 183.0 | 361.0 | 653.5 | 1149.6 | 1982.2 | 3604.9 |
| Dynamic load coefficient | 0.983~ | 0.973~ | 0.963~ | 0.932~ | 0.890~ | 0.824~ | 0.694~ | 0.438~ |

Fig. 3 and Table 3 shows nose wheel dynamic load changes on different level of pavement. With lower level of pavement, road surface roughness increased, aircraft’s front wheel dynamic load on pavement increased, dynamic load factor increased, and dynamic load factor range increased. Contrast dynamic load coefficient peaks of front and rear wheels, Fig. 4, we can see that nose wheel dynamic load coefficient is always bigger then that of main wheels.

5. Conclusion

(1) Simulated aircraft taxiing on different levels of pavement by means of ADAMS/Aircraft, studied influence from road roughness levels on airplane dynamic load characteristics of front and main wheels.

(2) The lower level pavement, the greater dynamic load peak between aircraft and pavement, and the greater range as well.

(3) Actual dynamic load range is larger than simulating result, because road roughness is the major factor in aircraft dynamic load. Other incidental factors may cause larger dynamic load, but its probability is small. Therefore, simulation could provide aircraft dynamic load result influenced by single factor of road roughness.

(4) Sliding at different levels of pavement, the front wheel dynamic load factor is always bigger then that of the main wheels.

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