Static and random vibration analysis of an air freight package

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Abstract. Due to the significant speed advantage, air freight has become the preferred long-distance transportation method for precision electronic instruments and other high-value products. In order to avoid the impact of air load conditions on the safety of cargo and aircraft, it is necessary to calculate and check the carrying capacity of cargo package. In this paper, finite element analysis has been applied on design of an air freight package. Firstly, make force analyze, and use the maximum force for static analysis to solve stress distribution. Then, make modal analysis and random vibration analysis to obtain the 3σ stress and deformation. According to static analysis, the maximum equivalent stress of the package under emergency conditions is less than σb. According to dynamic analysis, the probability that the maximum stress of the package is greater than 56.69 Mpa does not exceed 0.3%.

1. Introduction
Air freight is the most rapid transport manner, compared with land or sea transport, air freight can deliver cargos to destination in shortest time, which is suitable for long distance transport of high value and low weight cargos, such as electronic instrument. [1-7].

During the take-off, manoeuvring flight and landing of the aircraft, due to the influence of various factors such as engine noise, air turbulence, landing shock, etc., complex operating conditions with acceleration shock and random vibration excitation are formed in the cabin. [8-9]

In order to ensure that the cargo can be safely transported to the destination, the air freight cargo package must have sufficient strength and fatigue resistance, otherwise structural fracture or fatigue failure will occur, which will affect the safety of the cargo and the aircraft. [10] Therefore, it is necessary to check the capacity and reliability of the package.

In this paper, static and dynamic finite element analysis has been applied on design of air freight cargo package. Firstly, introduce the structural characteristics and load conditions of a certain type of the air freight cargo package. Secondly, using static structural tool for static analysis, set mass point, loads, acceleration and supports, solve the stress distribution of the package under various working conditions. Thirdly, using modal and random vibration tools for modal analysis and random vibration analysis, solve the 3σ stress and deformation distribution of the package under actual working conditions. At last, the stiffness and strength performance of the package are verified.
2. About the air freight package

2.1. Structure

Structure of the air freight package is shown in Fig.1. The air freight package consist of two parts, upper package and lower package, the upper package is made up of composite materials, the lower package is made up of composite materials and metal materials. The density of composite materials are relatively low, and made less contribute to strengthen the entire structure, which will not be described in detail in this article.

![Figure 1. Structure of the airborne package.](image)

2.2. Material

Material properties of the steel frame are shown in table 1.

| Material                  | Q235A   |
|---------------------------|---------|
| Elastic Modulus(E)        | 206Gpa  |
| Possion's ratio(γ)        | 0.3     |
| Yield strength(δ_s)       | 235Mpa  |
| Breaking strength(δ_b)    | 370Mpa  |

2.3. Connections

2.3.1. Connection between the package and the cargo. The cargo and the package are connected by six bolts, bolt’s mounted position is shown Fig.2.

The maximum weight of the cargo doesn't exceed 80kg, the net weight of the package is 100kg, mass centers and other necessary data are shown in Fig.2
2.3.2. Connection between the package and the freight plane. The package is fixed on the freight plane by iron chains. There are four pull loops on the package used for connecting, one end of the chains connect the pull loops, and the other end of the chains connect the tightening points of the freight plane. Connection method and necessary data are shown in Fig.3.

3. Air freight conditions

3.1. Accelerate load condition
The cargo loading in the cabin will be suffered acceleration loads during transportation. Acceleration loads is an overload factor, its application process is slow and keep stable for a long time so that there is enough time to disperse the internal load, and without dynamic response, we can analyze it by static analysis method.

During flight, the acceleration load inside the cabin is shown in Tab.2.
| Direction | Load   |
|-----------|--------|
| +X        | Forward| 3g    |
| -X        | Backward| 1.5g  |
| Y         | Sideward| 1.5g  |
| -Z        | Downward| 4.5g  |
| +Z        | Upperward| 2g    |

The force on the pull loops of the package depends on the external load. Under emergency working condition, stress in the package is biggest. According to the principle of torque balance, generate the static equation.

\[ F \cdot \sin \alpha \cdot X_1 + F \cdot \cos \alpha \cdot Z_2 = M_c \cdot a \cdot (Z_c + Z_1) + M_p \cdot a \cdot (Z_p + Z_1) - (M_c + M_p) \cdot g \cdot X_2 \]  \hspace{1cm} (1)

\[ F = \frac{M_c \cdot a \cdot (Z_c + Z_1) + M_p \cdot a \cdot (Z_p + Z_1) - (M_c + M_p) \cdot g \cdot X_2}{\sin \alpha \cdot X_1 + \cos \alpha \cdot Z_2} \]  \hspace{1cm} (2)

\[ a_{\text{max}} = 9g \]  \hspace{1cm} (3)

The maximum force on the pull loop is

\[ F_{\text{max}} = 14372.99N \]  \hspace{1cm} (4)

**3.2. Random vibration condition**

During transportation, the package is subjected to broadband random vibration excitation, the vibration excitation range is 15~2000Hz. The random vibration power spectral density is shown in Fig.4.

![Random vibration power spectral density](image.png)

**Figure 4.** Random vibration power spectral density.
4. Static analysis

4.1. Mesh the finite element
In order to reduce the calculation scale, the structure of the metal scheme is simplified, geometric features such as chamfers and fillets in the model are deleted. The final meshed finite element model is shown in Fig.5. There are 76972 elements and 189674 nodes.

![Figure 5. Finite element model.](image)

4.2. Set loads and constrains
Simplify the cargo as an point mass, set loads and constraints as Fig.3 shown.

![Figure 6. Load and constraint settings.](image)

4.3. Solve
Equivalent stress nephogram of the steel frame is shown in Fig.7, maximum stress $\sigma_{\text{max}}=325.85\text{Mpa}$.

$$\sigma_s=235\text{Mpa} < \sigma_{\text{max}}=325.85\text{Mpa} < \sigma_b=370\text{Mpa}$$

(5)
The structure has yield deformation, but has not enter the break zone. It can ensure that under an emergency condition, the structure will not be broken and damaged, and the strength meets the requirement.

![Equivalent(von-Mises) stress nephogram of the steel frame.](image)

**Figure 7.** Equivalent(von-Mises) stress nephogram of the steel frame.

5. Dynamic analysis

During flight, broadband random vibration excitation will be generated. Once the vibration frequency is the same as the natural frequency of the cargo, resonance will occur, which will lead to structural fatigue damage, so it need to do random vibration analysis.

5.1. Modal analysis

Perform modal analysis, the first 6 modes natural frequencies of the solved structure are shown in Tab.3.

| Modal | Frequency |
|-------|-----------|
| 1     | 60.07     |
| 2     | 74.07     |
| 3     | 88.68     |
| 4     | 444.55    |
| 5     | 585.77    |
| 6     | 589.48    |

*Table 3. The first 6 modes natural frequency of the structure.*

The first 6 vibration modes nephogram of the steel frame is shown in Fig.8.
5.2. Random vibration analysis

According to the environmental conditions of the cabin, apply random vibration excitation spectrum to the structure to solve the equivalent stress and deformation distribution of the structure. In the random normal distribution, $\sigma$ represents the standard deviation, and the corresponding probability of 99.73% is $3\sigma$. The $3\sigma$ stress cloud diagram and deformation nephogram of the steel frame under random vibration excitation are shown in Fig.9.

**Figure 8.** Equivalent(von-Mises) stress nephogram of the steel frame.
Figure 9. The equivalent (von-Mises) stress and deformation nephogram of the steel frame.

Under the situation of random vibration, the displacement of the steel frame is relatively small, and the probability that the maximum stress is greater than 56.69 Mpa does not exceed 0.3%.

Yield limit of steel frame material, safety factor \( f = 1.5 \), from the theory of shape change specific energy.

\[
\sigma < \left[ \frac{\sigma_s}{f} \right]
\]

(6)

Therefore, the freight package structure meets the stiffness and strength requirements under the airborne vibration environment.

6. Conclusions

This article study the statics and dynamics finite element calculation methods of an air freight package, calculates the response characteristics of an certain type of the steel frame structure, which under acceleration loads and random vibration loads, and analyzes the maximum equivalent stress and deformation, achieved an ideal design goal.

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