Study on Dimension of Landing Gear Bogie for Civil Aircraft

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Abstract. In order to study the method on rapid design of bogie dimension for aircraft landing gear, the paper firstly clarifies the dimension definitions of landing gear bogie, then proposes four kinds of constraints which have influence on determination of landing gear bogie dimension: expanded-tire dimension limit, clearance requirement, flotation characteristics requirement and bogie accessories dimension requirement. These four kinds of constraints form an area where can be selected to define the bogie dimension during aircraft initial design phase.

1. Introduction
Aircraft landing gear is one of the most important components as it is used for aircraft takeoff, landing, taxiing, and ground maneuvering. Whether it performs well has direct impact on aircraft operation and safety [1-3]. At the beginning of aircraft development stage, as lack of enough detail inputs, it is a toughly difficulty to configure the landing gear with coordinated layout, high loading capacity, comparable performance and satisfied airport adaptability.

When selecting the right format of landing gear, airport adaptability and safety during takeoff and landing are two most important factors needed to be considered, as large transport aircraft usually has a huge takeoff weight and landing weight. In this case, it is a must to add the number of wheels to decrease the load on each wheel, thus decreasing the average pressure on airport pavement [4]. Presently the wide body aircraft like B787, A350, and A330 adapt four-wheel bogie on each main landing gear, other larger aircraft like B777 adapts six-wheel on each main landing gear.

Selecting a proper bogie dimension is an essential step to landing gear design, which will affect the dimension of landing gear compartment and the adaptability on airport pavement. Presently most researches are concentrated on landing gear arrangement [5], dynamic simulation technology [6-7]. However, specialized research on rapid design of bogie dimension during initial design phase is lacking. To optimize landing gear design and improve the aircraft performance, it is urgent to launch relative research on method to design bogie dimension, from different aspects such as aircraft design requirements, configuration coordination, and airport adaptability.

2. Dimensions definition of landing gear bogie
Four-wheel bogie and six-wheel bogie are the most popular main landing gear patterns for wide body aircraft, relative dimensions are defined as figure 1.

Among them, landing gear bogie dimensions consist of distance between fore and aft tire (R₁), distance between left and right tire (W₁), inner gap between fore and aft tire (C₁), inner gap between left and right tire (C₂), length of bogie (L), and width of bogie (W).
3. Constraints to dimensions of landing gear bogie

During the initial design phase, at least the bellowing four kinds of constraints shall be considered when designing the dimensions of landing gear bogie: expanded-tire dimension limit, clearance requirement, flotation characteristics requirement and bogie accessories dimension requirement.

3.1. Expanded-tire dimension limit

The landing gear will expand during use, in this case called expanded-tire. Considering the dimension of expanded-tire is much necessary to get real clearances between landing gear and its adjacent components, and assure a safe margin. So when conducting clearance checking, the expanded-tire shall be adapted. The dimension of expanded-tire depends on several factors like tire property, high speed centrifugal force, and thermal factor.

Dimensions of tire include tire diameter (D), width of tire cross-section (W), height of tire cross-section (H), as shown in figure 2.

To calculate the dimensions of expanded-tire, expanded factor shall be defined at first step. Expanded factor herein means the ratio of the maximum dimension of expanded-tire and maximum dimension of newly-tire, includes expanded factor for width of cross-section $G_W$, and expanded factor for height of cross-section $G_H$. Both of the two factors can be calculated by following empirical formulas [8].

$$G_H = 1.115 - 0.075A_R$$

$$G_W = 1.04$$

Among them, $A_R$ is the ratio of height and width of tire cross-section. According to the expanded factor, The dimensions of expanded-tire are calculated as follows.

$$W_{\text{expanded-tire}} = G_W \cdot W$$

$$D_{\text{expanded-tire}} = d + 2G_H H$$
3.2. Clearance requirement

Clearance requirement is one of the more fundamental aspects of bogie design. The landing gear shall be accommodated into compartment with very limited space, and keep enough clearance margin with keel beam, bulkhead, and components/equipments inside the compartment.

To determine the clearance, several factors including longitudinal length of the landing gear compartment, width of keel beam, movement track when retracting and extending shall be considered. But during the initial design phase, accurate dimensions of keel beam, landing gear compartment, and components/equipments inside the compartment usually cannot be obtained. However, experiences from similar aircrafts can help to make up an initial value for analysis and calculation.

When designing the landing gear bogie, at least the following four minimum clearances shall be considered: minimum clearance between main landing gear swept envelope and keel beam, minimum clearance between main landing gear swept envelope and fore/aft bulkhead, minimum clearance between main landing gear swept envelope and components/equipments inside the compartment, minimum clearance between retracted position of main landing gear and upper bulkhead / compartment opening.

\[
H_{\text{expanded-tire}} = \left( D_{\text{expanded-tire}} - d \right)/2
\]

Besides, \( d \) represents diameter of rim.

3.3. Flotation characteristics requirement

Flotation characteristic on pavement is critical for aircraft operation, and it is also one of limits for landing gear bogie design [2]. Together with tire pressure, aircraft weight and its distribution between nose and main assemblies, the dimension of landing gear bogie has direct effect on aircraft classification numbers (ACN), which is one of the standard measures of runway requirement [9]. Under a certain aircraft weight and configuration, a larger bogie results in lower ACN, as in this case it means larger area to distribute load on pavement.
For a given aircraft with below characteristics: gross weight is 235 tons, two main landing gears mounted on each side of wing, 99.4% of gross weight on main landing gears, four-wheel bogie and 211 psi pressure in each tire.

According to the upper inputs, the relations between ACN and bogie dimension on both flexible and rigid pavement are shown in figures 4.

Generally, ACN decrease with larger WT and RT. Calculation shows under a given WT, each 10 mm RT increment leads to 0.1-0.2 decrements for ACN on middle strength flexible pavement, and nearly 0.2 decrements for ACN on middle strength rigid pavement.

3.4. Dimensions of bogie accessories requirement

Bogie accessories include brake device, brake control system, antiskid system, actuators, shock absorber and other structural components, as shown in figure 5. Dimensions of bogie accessories and distance between the expanded-tire shall be considered in order to preserve enough installation space, which means both C1 and C2 shall be large enough. However, it is a kind of trade-off study as too large C1 and C2 usually have adverse effect on weight of bogie. During the initial design phase, dimensions of bogie accessories can be referred to similar aircraft.

4. Selected areas for landing gear bogie and design case

Considering all above constraints, the proper bogie dimension is limited within a certain area where surrounded by several constraints, as shown in figure 6. Within these constraints, WT and RT shall be mutually matched and keep enough safety margin to all kinds of constraints.

In the figure, ① and ② represent limits of flotation characteristics, ③ and ④ represent limits of bogie accessories dimension, ⑤ represents considering the limit of expanded-tire, ⑥ and ⑦ represent clearance limits.
A wide body aircraft with 300 seats and 235 tons gross weight is used as a design case. This aircraft has a conventional configuration with following characteristics: four-wheel bogie, tire type used is 1400 mm * 530 mm R23 40PR and tire pressure is 211 psi, length of main landing gear compartment is 3600 mm and width of keel beam is 600 mm, main landing gear bears 99.4% gross weight. Based on the expected operational airports, ACN on middle strength rigid and flexible pavement requires not less than 70. According to the above method indicated in figure 6, bogie dimension of 1580 mm * 1520 mm is picked up for the given aircraft.

Figure 6. Constraint areas to select bogie dimension

It is calculated the corresponding dimension of expanded-tire is 1445 mm * 550 mm, and under the bogie dimension of 1580 mm * 1520 mm, the relative parameters are listed in table 1 and it shows a satisfactory characteristic for the aircraft.

|                          | ACN on middle strength, Flexible | 66 | ACN on middle strength, Rigid | 67 |
|--------------------------|----------------------------------|----|-------------------------------|----|
| Clearance to aft bulkhead| 226 mm                           |    | Clearance to upper bulkhead   | 96 mm |
| Inner gap between fore and aft tires | 41 mm                          |    | Clearance to compartment opening | 96 mm |
| Clearance to fore bulkhead | 229 mm                         |    | Clearance to keel beam        | 62 mm |

5. Conclusions

The paper proposes four kinds of constraints which have influence on design of the landing gear bogie dimension: expanded-tire dimension limit, clearance requirement, flotation characteristics requirement and dimensions of bogie accessories requirement. These four kinds of constraints form an optimize area where can be selected to define the bogie dimension during aircraft initial design phase.

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