Wind Tunnel Testing Verification Method for Flight Test Pilots Emergency Departure from Commercial Aircraft

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Abstract. According to airworthiness regulations, the first or previous several commercial aircraft for flight test must be installed with an air emergency departure system to ensure that the members of the pilots safely escape from the aircraft in the event of an irretrievable flight emergency. Large-scale commercial aircraft mostly adopt the lower-single-wing and wing-hanging-engine configuration. Emergency departure channel is generally designed on the side or bottom of the front fuselage, when pilots had to leave the aircraft, who may hit the aircraft components, such as landing gear, engines and wings. Therefore, it must be verified whether the test pilot can safely leave the aircraft from the emergency exit during the aircraft design process. This paper introduces the method about how to verify the safety of test pilots though wind tunnel testing. The key of method is to measure the trajectory of pilot in wind tunnel by simulating conditions of flight and pilot emergency departure. The method illustrated can be used for design and verification of emergency departure system.

1. Introduction
The emergency departure system is an indispensable system for the first or previous several commercial aircraft used for flight test according to airworthiness regulations [1]. Medium and long range commercial aircrafts, including Bombardier’s C Series, Airbus A350 and A380, are equipped with such system. Normally the structure, avionics and other related systems will be modified to meet the airworthiness requirements for aerial emergency departure based on the prototype [2].

The key to verify the safety of the air emergency departure is to obtain the trajectory of the test pilot from emergency departure exit. Generally, numerical calculation, wind tunnel testing and flight test could be used to verify safety of flight test pilots emergency departure. Although the numerical calculation has the advantages of short cycle and low cost, it is difficult to meet the requirements of the accuracy of dynamic flow field simulation under complex flight conditions[3], especially in the stall state. Wind tunnel testing can not only simulate complex flow fields, but also has high accuracy to simulate the test pilot leaving the aircraft. The flight test is used through projecting the dummy pilot model from the exit to judge the safety of the trajectory, and this method is relatively risky, which cost a lot and lags behind design and development. In summary, the wind tunnel test is the most suitable and reliable verification method.

2. Testing Principles
In order to ensure the trajectory of the center of gravity of the model and the attitude of turning around the center of gravity is similar to the real object, the following principles should be met which are that the model's geometric shape should be similar to the real object, the air speed for wind tunnel testing and real flight are equal and dynamical similarity between the model and the real object. In other
words, not only the aerodynamic force acting on the model, but also the effect of the model's gravity [4] must be considered.
The wind tunnel testing should follow dynamical similarity. The testing speed is generally low, therefore the effect of Mach number is not considered and the effect of Reynolds number is negligible. Froude number should be Equal, that is:

\[
\frac{V^2_m}{l_m g_m} = \frac{V^2_f}{l_f g_f}
\]  

(1)
The subscript \(m\) in formula (1) represents state of the scaled model, and \(f\) represents state of the full-scale model. \(V\) represents speed, \(l\) represents characteristic length, \(g\) represents gravitational acceleration and \(m\) represents mass.

According to the dynamic similarity rule of formula (1), the following similarity conditions can be obtained:

a) Speed similarity criterion:

\[ u_m = \frac{u_f}{\sqrt{K}} \]  

(2)

In formula (2), \(u\) represents speed, and \(K\) represents the inverse of the model scale ratio, \(K = \frac{l_f}{l_m}\).

b) Quality similarity criteria:

\[ m_m = \frac{m_f}{K^2 \Delta} \]  

(3)

\(\Delta\) represents the relative density of air, \(\Delta = \frac{\rho_f}{\rho_m}\).

c) Similarity criterion of moment of inertia around the center of mass:

\[ I_m = \frac{I_f}{K^2 \Delta} \]  

(4)

In the formula (4), \(I\) represents the moment of inertia around the center of mass.

3. Testing Equipment and Model

3.1. Wind tunnel and measuring equipment

As to the wind tunnel selection, the bigger the size of wind tunnel section is, the better the similarity is. Normally it is better to choose the wind tunnel with a section larger than 3m×3m, which will make the pilot easy to keep similarity. Generally, low-speed force&moment measuring wind tunnels larger than order of 3 meters’ section can meet the requirements of tests, such as DNW LLF in the Netherlands, CARDC FL-12 \ FL-13 and AVIC FL-9/FL-10 in China, etc. The emergency departure test is different from force&pressure test, and delivery of test is trajectory data of the pilot model. Because emergency departure is an instantaneous dynamic process, and the duration usually lasts about 0.2s\(-0.3s\), high-speed (HD) camera should be equipped to capture the trajectory. HD cameras need to be installed in three positions at least, which are better to be located at the entrance of the test section, the side of the test section and the bottom of the test section.

3.2. Aircraft model

The full model of aircraft could fulfill the requirements of different positions of emergency exit, and the components, such as fuselage, wings, engines, tails, landing gears, should be included. In addition, the model could realize deflection of slat &flap and retraction of landing gear to simulate various flight conditions of the aircraft. The model scale is determined according to the requirements of the wind tunnel blockage. The requirements of model design and manufacture are consistent with the requirements of the conventional wind tunnel model.

3.3. Model support system
The emergency departure exit of commercial passenger aircraft is generally located at the side or bottom of the front fuselage, and the trajectory of the pilot is below the fuselage and wings. Therefore the model should be supported with rear sting or back sting to reduce the affluence of support sting.

3.4. Pilot model
The pilot model includes human body model and parachute carried. The similarity of the pilot model with pilot should be considered, including external dimensions, weight, posture, and moment of inertia around the center of gravity should be. The overall dimensions and weight of pilot and parachute can be formulated according to standard. The posture of the human body is calculated based on the statistics of the pilot’s parachuting posture. The general posture is mostly the two-handed knee-guard posture. The pilot model could be designed in CATIA, and the moment of inertia of the model around the center of gravity can also be calculated from the CATIA. The size, weight, center of gravity, and moment of inertia of the model will have a significant influence on the test results, therefore, the model should be fabricated strictly in accordance with the 3D geometry of the model and debugged according to the requirements of mass and moment of inertia. The detection review should be performed to ensure the model can reflect the true situation of pilot. The pilot model may be damaged in the wind tunnel, so a certain number of backup models need to be prepared.

3.5. The departure device
The departure device is used to ensure that the test pilot model could leave the aircraft smoothly from the departure channel during the wind tunnel testing, which should be designed according to the location of the exit and the way of departure. Two types of devices could be used, which are free departure devices and pressured departure devices. The free departure device could ensure the model departure by cutting off the connection between the pilot model and the aircraft model. Normally the pilot model could be connected to the aircraft model by fusible constantan wire or magnetic connection. Preassured departure devices realizes the departure of the pilot model by acting pressure on pilot model, and the pressure is provided with high pressure gas source from 1 to 15Mpa.

4. Testing Conditions and Arrangements

4.1. Testing conditions.
Emergency departure of pilots will take place with irreparable situation during the flight test. Irreparable flight test conditions, such as stall, will be critically simulated in wind tunnel. Theses typical test conditions include terminal conditions of altitude, stall speed, aircraft attitude, angle of attack at stall and the takeoff and landing configuration. Stalling is used as a typical example to illustrate selection of the dangerous working conditions.

4.1.1. Altitude. Air density vary slightly in low altitude from 200m to 1000m, when stalling occurs, it is very difficult to recover in the case of high descent rate, so the critical altitude allowing the parachute open is about 200m. Because there are more than one pilot during the test flight, 700m is selected as the test altitude for low altitude in order to ensure that the test pilots has time to jump off the aircraft. 3000m and 5000m are as middle altitude.

4.1.2. Speed. Stall speed and the maximum skydiving speed are considered as limited speed. Maximum skydiving speed is determined according to the type of door at the exit of the aircraft [5], and the stall speed of takeoff, cruise, and landing are selected at the maximum weight.

4.1.3. Attitude angle. Flight attitude is also an important condition that affects the trajectory, so the angle of attack at stall and a relatively large side slip angle (± 10°) are selected for wind tunnel testing. In addition, the initial departure speed of the pilot model and the anti-air blow device are also important conditions that affect the trajectory of the aircraft.

4.2. Testing content
Wind tunnel testing could be carried out by method of controlling variable, and the variables include conditions of altitude, speed and attitude angle for each model configuration. Each run of test monotonously changes one variable A and keeps the other variables constant. Then, monotonically change another variable B and keep the other variables constant. Due to the large number of variables, the runs of test will be huge if the test is performed exactly as described above. In order to improve this situation, the terminal envelope method can be used to simplify test runs, that is, to perform tests under various terminal test conditions to obtain the test results in extreme cases, and then derive other conditions according to the law.

5. Testing Procedure and Results Analysis

5.1. Testing steps
The testing procedure is different from the conventional force&pressure test, which mainly includes the following steps.

a) Mount aircraft model in the wind tunnel test section with back support or rear support, and install the HD cameras. Run the test at the given speed and model attitude, and start the departure device to make the pilot model separate from the aircraft model under the given initial speed, the pilot model will keep rolling down with the action of gravity and aerodynamics.

b) Capture the motion trajectory and attitude of the pilot model and check whether the pilot model is leaving from exit with expected initial speed and attitude, then record the data if the conditions are ensured.

C) Inspect whether the pilot model is damaged after the each run, including inspection of the moment of inertia. If model is damaged, it should be repaired as much as possible. If the model cannot be repaired, replace the model with backup.

d) Each run should be interpreted and analysed, and then the test parameters are adjusted according to actual needs.

5.2. Results analysis
According to HD video, the motion trajectory of the pilot model at the boundary conditions could be drawn, and dangerous boundary could be recognized according to the distance between the pilot model and the aircraft component. Meanwhile impacts of the altitude, flight speed, angle of attack, side slip angle, and different configuration could be given. The results could be divided into three levels, which are safety, danger and collision. The safety means that motion trajectory of the pilot model is far away from the aircraft model. Danger means that motion trajectory of the pilot is close to components (such as the engine, wings, landing gear, etc.) without colliding with the aircraft model. Collision means that the pilot model collided with the aircraft model.

6. Conclusions
Wind tunnel testing verification method for emergency departure of pilots from commercial aircraft is demonstrated in this paper, including the selection of wind tunnels and equipment, pilot model design, test conditions setting, test steps, and results analysis. The method could be used to provide technical basis and reference for airworthiness verification of commercial aircraft emergency departure.

References
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