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Simulative technology for auxiliary fuel tank separation in a wind tunnel

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Abstract In this paper, we propose a simulative experimental system in wind tunnel conditions for the separation of auxiliary fuel tanks from an aircraft. The experimental system consists of a simulative release mechanism, a scaled model and a pose measuring system. A new release mechanism was designed to ensure stability of the separation. Scaled models of the auxiliary fuel tank were designed and their moment of inertia was adjusted by installing counterweights inside the model. Pose parameters of the scaled model were measured and calculated by a binocular vision system. Additionally, in order to achieve high brightness and high signal-to-noise ratio of the images in the dark enclosed wind tunnel, a new high-speed image acquisition method based on miniature self-emitting units was presented. Accuracy of the pose measurement system and repeatability of the separation mechanism were verified in the laboratory. Results show that the position precision of the pose measurement system can reach 0.1 mm, the precision of the pitch and yaw angles is less than 0.1° and that of the roll angle can be up to 0.3°. Besides, repeatability errors of models' velocity and angular velocity controlled by the release mechanism remain small, satisfying the measurement requirements. Finally, experiments for the separation of auxiliary fuel tanks were conducted in the laboratory.

1. Introduction

It is an important capability for military aircraft in flight to release external stores such as weapons and auxiliary fuel tanks when necessary. However, due to the interaction between the aerodynamic environment and dynamical characteristics of the external stores, the released store may collide into the aircraft, threatening the regular performance of the aircraft and the safety of the pilot. Therefore, it is of great significance to conduct safety research for the separation of external stores during the design and service process of the aircraft. The commonly-used captive trajectory simulation (CTS) system is used to simulate the trajectory of external stores (such as missiles bombs and auxiliary fuel tanks) after they are separated from an aircraft, which helps to guide the proper arrangement of stores on the plane, as well as the control of stores' release

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parameters.[1] Among many research methods, the free drop method is one of the most typical experimental methods for store separation simulations in wind tunnels. The free drop method, with which the external store is ejected from the aircraft, falls down freely, and the trajectory of the external store is captured by high-speed cameras, has been widely used in simulative experiments for flight testing.

Traditionally, the free drop experiment system for store separation in wind tunnel mainly includes a separation system and a high-speed measuring system. Currently, the simulative separation system mainly consists of a suspending mechanism and an ejection mechanism. In 2008, Johnson proposed a separation system for external stores using an explosive bolt to ensure suspension and a double-spring loading device to provide the load.[2] When the ejection signal came, the explosive bolt ruptures by being energized. Meanwhile, the store was ejected by the ejection load provided by the springs. With this strategy, the initial kinematic parameters of the store could be adjusted by changing the preload of the springs, thus pose characteristics of the store were under control. However, since the ejection load came from springs, constraints would occur because the characteristics of the springs such as the elastic coefficient were limited to a small range.

In 2009, Murray et al. in the University of Mississippi presented an ejection system based on double-cylinder loading and ball brake suspending.[3] The store model was firstly retained on the pylon by the ball brake, then it would be ejected by the double-cylinder loading device triggered by the releasing signal. The system provided adjustable release force as well as velocity with intense adjustment, and was highly repeatable. However, it was difficult to control the two cylinders simultaneously and the system maintenance would be a tough job with its complex configuration. The EDO Corporation developed a vertical ejection device with a multi-linkage mechanism and a cylinder as the power producer.[4] Making the best of the precisely calculated and optimized linkages, the system was capable of controlling parameters such as the initial systemic velocity, acceleration, angle and angular velocity of the store at a given air pressure and flow. Unfortunately, the system was mainly designed for the ejection of buried stores instead of external stores, because the pylon under the wing was too small to contain a multi-linkage mechanism during the separation experiment in the wind tunnel. Additionally, some of the linkages were likely to extend outside the plane, affecting the air flow field of the test section, which might cause errors in the result. Guan and Cai indicated that spoilers are capable of controlling the flow pattern inside the plane cabin, which helps to guide the control of yaw angles of buried stores.[5] However, the study does not cover all the release characteristics (both the position and attitude) of the store, which is difficult to meet the measurement requirements discussed in this paper.

When it comes to pose measurement of aircraft stores, high-speed cameras are usually applied to capturing the 2D images of the target and pose parameters can be obtained by analyzing those images. In the early 1960 s, the dynamic similitude method was firstly utilized to study the separation characteristics of stores. It mainly adopted a multiple-exposure method to record the pose and trajectory of the target in the same film and subsequent analysis was based on that film. The scheme is widely used owing to its simplicity and less refits to the original wind tunnel facilities. The method presents a simple method for qualitative observations and store separation studies. But large errors may occur when it comes to quantitative analysis due to the insufficient information in one single image. A video model deformation (VMD) method has been developed and applied by NASA on the basis of model deformation measurement.[6–9] VMD was based upon digital photogrammetry using recorded and processed digitized video images from a CCD camera. A single-camera, single-view photogrammetry was applied to determining object plane coordinates and angles corresponding to retro-reflective markers placed at known locations.[10] Though the method helps to achieve a non-contact, flexible and real-time measurement of the model, wind tunnels with small space are not able to conduct the experiment since a high-power light source is required for the retro-reflective markers. The commercially available Optotrak™ system measuring the aeroelastic deformation and the angle of attack of planes was produced by Northern Digital Incorporated (NDI) of Ontario, Canada.[11] Small infrared emitting diodes (IREDs), instead of reflective markers, are employed as markers which are mounted rigidly in or on the object to be measured. Then high-speed cameras are employed to capture the images of the target. Using the Optotrak™ system, wind tunnels with low brightness are also capable of conducting the measurement and a light source was no longer required. Disadvantages lie in the inability to measure the over-all parameters except for aeroelastic deformation and angle of attack. Other methods employ cooperating markers attached to the model surface to serve as feature points, such as the single camera method proposed by Martinez et al.[12] and the pose measurement for high-speed rolling targets proposed by Jia et al.[13] Retro-reflective targets and a high-power light source were used in their experiment. Both of the above methods have achieved efficient pose measurement of the targets. However, the quality and signal to noise ratio (SNR) of the images were decreased due to the strong light reflection from the observation window.

Here, we design a simulative separation and measurement system for the free drop experiment of external stores in a transonic wind tunnel. This paper is organized as follows: Section 2 introduces the simulated release mechanism of an auxiliary fuel tank and the scaled model according to the geometric and dynamic characteristics of an actual auxiliary fuel tank whose type is highly classified. The dynamic characteristics of the auxiliary fuel tank are then measured and adjusted utilizing a binocular-vision system. Section 3 outlines the acquisition method of high-speed image sequence in dark wind tunnels based upon miniature self-emitting units. In Section 4, we detail the measuring process for the pose parameters of the released model using the binocular vision system developed in this paper. Moreover, experiments are conducted to verify the precision of the measuring system as well as the stability of the simulative separation mechanism. Finally, the conclusion is given in Section 5.

2. Design of release mechanism and scaled model

Since both the simulative release mechanism and scaled model determine the reliability of the experimental results, we mainly introduce the design of those two elements in this section.