THE APPLICATION OF AIRBORNE VIDEO TECHNOLOGIES DURING AIRPLANE AERIAL REFUELING TEST

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Abstract

Video technology has been applied widely in various engineering fields. With the advancement of airplane performance and the development of airplane aerial refueling technique, many new challenges and technological hurdles has occurred, such as determination of refueling system positions, conditions of receiver and tanker airplane, reliability of refueling and so forth. Through using airborne video technology during airplane aerial refueling test, external parameters can be surveyed to provide 3-D hose and drogue position measurements of sufficient accuracy. Some flight research data has been obtained; Preliminary results and important lessons are presented..

1 Introduction

Aerial refueling is one of the most important ways to make airplane fly further distance and loiter long duration. With the advancement of airplane performance and increasing of the demand for airplane aerial refueling, many new challenges and technological hurdles has occurred, such as determination of refueling system positions, conditions of receiver and tanker airplane, reliability of refueling and so forth. Because of utilizing airborne video technology, some external parameters are measured easily.

An obvious benefit of using video system is to insure that pilots in the cockpit can watch the process of aerial refueling in real time and the simplification of post-flight data processing. Depending on the analyzing images of refueling surveyed by two cameras, the space location of hose and drogue system has been computed in time history. As a result, some parameters, like attaching speed, 3D distances, swing amplitude, revolving frequency and so on, are also calculated. Detailed principal of video system work and calculation methods are described simply as follows.

2 The principal of airborne video measure

Three-dimensional coordinates of surveyed target are computed by the principal of space intersection orientation measurement(fig.1). That is to get the moving images of drogue during aerial refueling test through two cameras mounted on test airplane. Then the oriented angles of the measured target point in horizontal projection plane and upright projection plane have been computed utilizing these images. Finally, the space coordinates of target point and some parameters such as swing amplitudes and attaching speed are calculated by value of these angles.

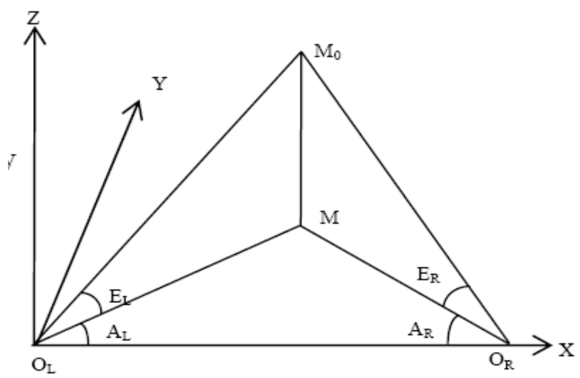

Fig. 1. Sketch of Principal on Space Intersection Orientation Measure

Annotation:

M_0 is the measured target
M is horizontal projection of measured target M_0
O_L and O_R is the location of two cameras respectively
E_L and E_R is the oriented angle of M_0 in horizontal projection plane
A_L and A_R is the oriented angle of M_0 in upright projection plane

3 Test Procedures

3.1 Instrumentation and Test Facilities

The test airplane condition parameters and refueling images are measured by specific transducers as well as photograph devices, these test data and images information are recorded through airborne data acquiring system and airborne video measure system. The speed and altitude transducers in all facilities are used to provide airplane speed and altitude during flight test, two typical cameras are used to provide drogue moving images in course of aerial refueling. Special devices such as data acquiring set, images recorder etc. are utilized to gather test data and images.

Many factors are taken into accounted while the facilities are installed on the test airplane. These factors include location of installation, way of installation, rigidity of joint, environment of operation and so on. So as to ensure test data accuracy and flight test safety.

3.2 Ground calibration of the cameras mounted on airplane

Prior to carry out airplane aerial refueling test, ground calibration for the cameras mounted on the airplane should be done. The purpose of the calibration is to obtain initial physical, mounting geometrical parameters of the cameras by some special instruments and measuring methods. Calibrating content includes measure of inner oriented elements which are location and focus of photo, as well as outer oriented elements which are locations of two cameras and the angles between cameras and photo. When all these data are obtained, oriented parameters are computed by follow expressions:

$$\Delta A=arctg[x/(f\times\cos E_0-z\times\sin E_0)]^2 \qquad (1)$$

$$E=arctg\{[(f\times\sin E_0+z\times\cos E_0)/(f\times\cos E_0-z\times\sin E_0)]\times\cos(\Delta A)\} \qquad (2)$$

$$A=A_0+\Delta A \qquad (3)$$

where

A_0 is initial angle of horizontal orientation for a camera

E_0 is initial angle of upright orientation for a camera

f is the focus of a camera

X and Z are horizontal and upright distance respectively between target point and main point in the image plane

A and E are horizontal and upright orientation angle corrected after missing target

ΔA is correction of horizontal orientation angle

ΔZ is the difference of altitude between two cameras

Utilizing expression from (1) to (3), A_L,E_L,A_R and E_R will be computed.

3.3 Process of The measured data

3.3.1 Calculation of Space Coordinates of Target Point

According to initial parameters mentioned above, the expressions to calculate the three-dimensional coordinates are given as follows:

From first camera:

$$\begin{cases} X_L=B0\times(\sin A_R\times\cos A_L)/\sin(A_R+A_L) \\ Y_L=B0\times(\sin A_R\times\sin A_L)/\sin(A_R+A_L) \\ Z_L=B0\times(\sin A_R\times tgE_L)/\sin(A_R+A_L)+\Delta Z \end{cases} \qquad (4)$$

From second camera:

$$\begin{cases} X_R=B0\times(\cos A_R\times\sin A_L)/\sin(A_R+A_L) \\ Y_R=B0\times(\sin A_R\times\sin A_L)/\sin(A_R+A_L) \\ Z_R=B0\times(\sin A_L\times tgE_R)/\sin(A_R+A_L) \end{cases} \qquad (5)$$

where B0 is the length of baseline between two cameras.

If $|X_L\text{-}X_R|$, $|Y_L\text{-}Y_R|$ and $|Z_L\text{-}Z_R|$ are less than a certain values(allowable error), 3D space coordinates of target(drogue) can be calculated：

$$\begin{cases} X=(X_L+X_R)/2 \\ Y=(Y_L+Y_R)/2 \\ Z=(Z_L+Z_R)/2 \end{cases} \quad (6)$$

3.3.2 Coordinates Rotational Transform

All parameters mentioned above are measured or calculated in photography reference frame. Actually, what we want to research is the relationship between drogue and nozzle, lots of parameters calculated are relative to the nozzle. So, airplane reference frame is appropriate. In order to compare these calculated parameters with those parameters measured in flight and evaluate the precision of the calculated parameters, coordinate rotational transform has been done between photography reference frame and airplane reference frame:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [T] \times \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} \quad (7)$$

where (X,Y,Z) is the coordinates values of the target location in airplane reference frame

(X',Y',Z') is the coordinates values of the target location in photography reference frame

T is transform matrix

3.3.2 Attaching Parameters Calculation

The distance between target point(drogue) and refueling probe is calculated at moment during airplane aerial refueling by:

$$S_i=[(X_i-X_0)^2+(Y_i-Y_0)^2+(Z_i-Z_0)^2]^{1/2} \quad (8)$$

where (X_0,Y_0,Z_0) is the coordinates of refueling probe

(X_i,Y_i,Z_i) is the coordinates of drogue at moment during airplane aerial refueling

i is i^{th} moment

Attaching speed is calculated as follows:

$$V_i= (S_i-S_{i-1}) / \Delta t \quad (9)$$

where Δt is the time difference between two sequential points of the distance(S_i). Revolving frequency of drogue calculation at every moment is as follows:

$$Q = \begin{cases} arctg\left[(P_{y_i}-Q_{y_i})/(P_{x_i}-Q_{x_i})\right]/(2\times pi\times\Delta t) - \\ arctg\left[(P_{y_{i-1}}-Q_{y_{i-1}})/(P_{x_{i-1}}-Q_{x_{i-1}})\right]/(2\times pi\times\Delta t) \end{cases} \quad (10)$$

where $P(x_i,y_i)$ is the pixel ordinates of selected point on the drogue at moment.

$Q(x_i,y_i)$ is the pixel ordinates of selected point on the hose at moment .

4 Example

The time history of several parameters obtained from the process of a certain aerial refueling test is shown in Fig. 2. The positions of drogue (3-D coordinates) compared to the hose are shown in Fig. 2(a) (b) (c) respectively. Fig. 2(d) shows the distance between drogue and hose calculated based on equation (1) to equation (8) at same moment. Fig. 2(e) indicates the change of attaching speed calculated from equation (9) in the same process of aerial refueling test, the green line is calculated attaching speed, the red line is smoothed value of attaching speed.

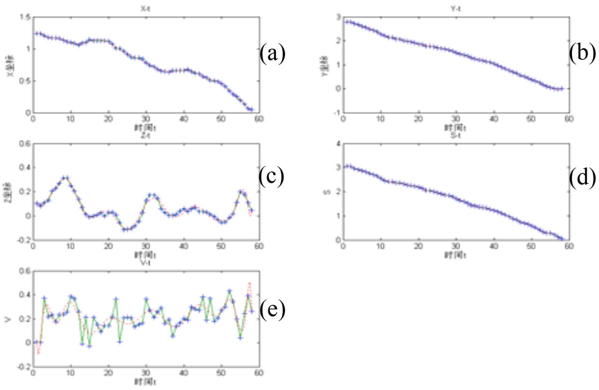

Fig. 2. Parameters time history in a certain airplane aerial refueling test

According to the curve given above, when the distance from drogue to hose is within 0.5 meter and 3 meter, the range of attaching speed is between 0.1 meter per second and 0.6 meter per second. Generally, the attaching speed is 0.4 meter per second approximately, this kind of trend to the attaching speed is similar to the law of flight speed measured simultaneously from the tanker and the receiver.

5 Conclusion

A series of airplane aerial refueling flight test was conducted at different condition. Analysis of these test results reveals that utilizing airborne video technology is very helpful for pilot to control airplane speed during aerial refueling test and increase flight test effectiveness. It is also an useful approach to obtain attaching parameters in flight and ensure flight test safety.

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