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Simulation Analysis on the Problem of Opening Main Parachute Used in UAV Recovery System

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Abstract. The paper introduces simulation model of a certain kind UAV's recovery procedure by using Matlab/Simulink software. The problem of time point to open main parachute (t_m) in this UAV Recovery System is analyzed by simulation results of this model, and a series of meaningful conclusion is drawn. When recovery system works while UAV is flying steadily, t_m becomes earlier as velocity increases, and later as pitch angle increases. t_m is earliest when relieve drag parachute reefing at the time when control subsystem stops working. Larger the drag characteristics of the fully opened drag parachute is, earlier t_m is, and larger the drag characteristics of the reefing opened drag parachute is, later t_m is. These results are benefit for UAV recovery system design of this kind.

Introduction

The deployment and inflation of a parachute recovery system are extremely complex aerodynamics phenomena. In order to understand these phenomena, flight tests are often required. Satisfied results can be obtained from this kind of tests. However, there are some limitations such as no enough test data due to measuring methods and more costly as demands placed on parachute recovery system increasing. Therefore, simulation methods are becoming more and more widely used in this field.

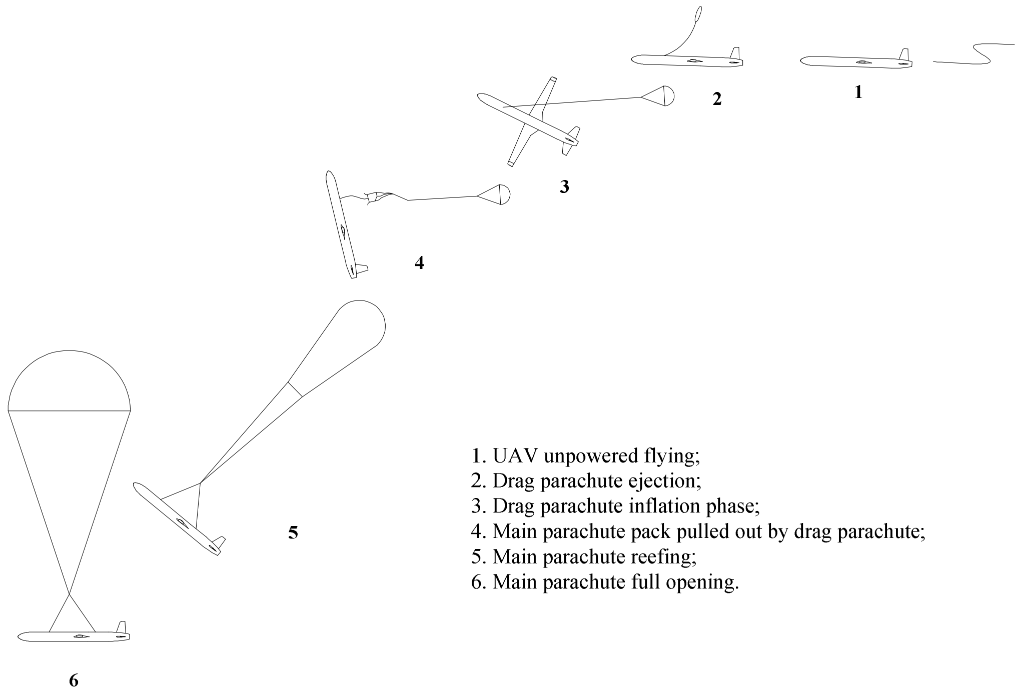

Fig. 1 Recovery Procedure

In recent years, using Computational Fluid Dynamics (CFD) methods to solve problems such as Fluid-Structure Interaction (FSI) is often discussed in many articles[1,2,3,4]. LS-DYNA is proved to be the most suitable software to simulate parachute deployment and inflation problems, but tremendous computational recourses are required, which sometimes means impossible to get calculation solution[5,6,7]. Dynamic simulation software such as Matlab is also widely used to solve these kinds of problems, and satisfied results can be easily obtained[8,9,10,11,12].

In this article, Matlab/Simulink software is used to simulate parachute deployment and inflation problems. A certain kind of UAV's parachute recovery system consists of drag parachute and main parachute. Its recovery procedure is shown in Fig. 1. This procedure is the final step in UAV's fight, whose reliability has close relation with UAV's safe landing. As a result of arrangement need, recovery system is installed in the forepart of the UAV, which is uncommon and harmful to UAV's landing safety. Therefore, proper parachute opening procedure becomes key factor to landing success. This kind of problem is merely discussed. Based on this problem, this paper makes simulation model by using Matlab/Simulink software to analyze problem of time point to open main parachute.

Problem Analysis

When main parachute begins to work (pulled from parachute cabin), the path main parachute will be pulled out allows no barrier. This factor demands a certain angle σ, which is an angle between parachute ax (along parachute connecting belt and its extension line) and UAV ordinate ax. Based on UAV's geometry shape, shown by Fig. 2, the minimum σ is given by:

$$\sigma_{\min} = \max(\sigma_1, \sigma_2) = \max(11.56°, 8.15°) = 11.56° \quad (1)$$

In fully deployed working procedure of drag parachute, as long as this angle is larger than 11.56 ° , it is safe to pull out main parachute. What σ_1 and σ_2 mean are shown in Fig. 2.

Define t_m as time point to open main parachute after parachute recovery system begins to work. We can get t_m by determining when $\sigma_{\min}$ appears using simulation calculation.

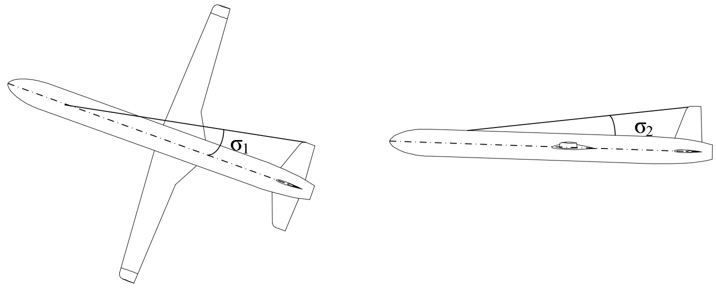

Fig. 2 σ_1 and σ_2

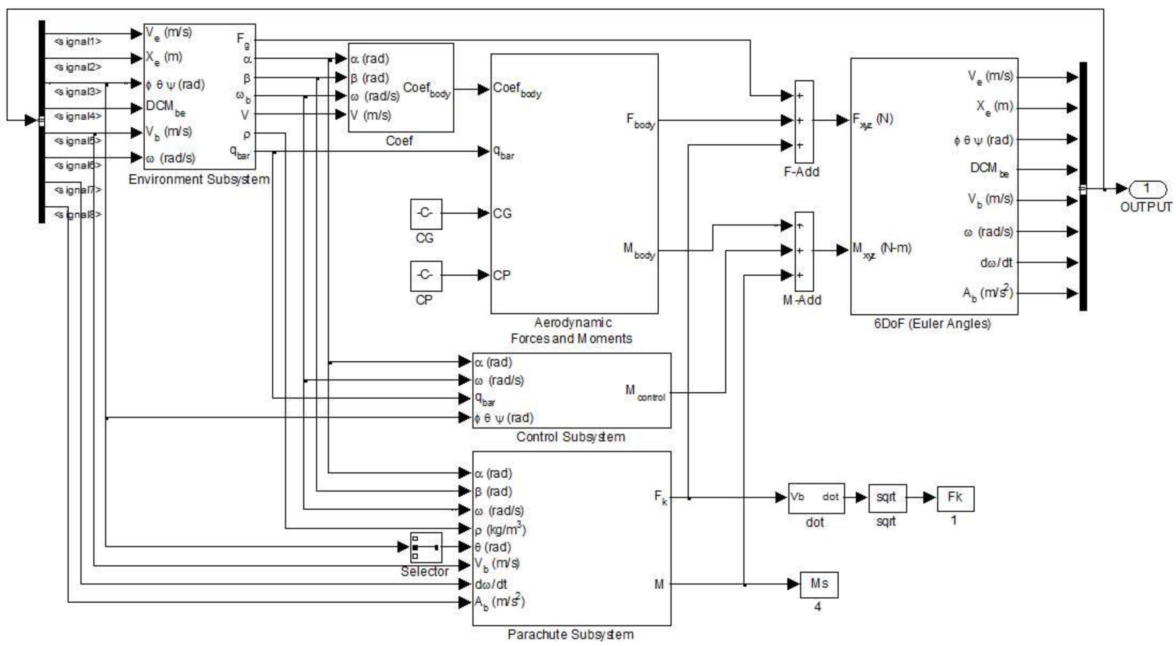

Fig. 3 Matlab/Simulink Simulation model

Simulation Model

Simulation model of UAV recovery procedure made by Matlab/Simulink software is shown in Fig.3, including several blocks such as environment parameter calculate subsystem, 6-DOF (Euler Angles) subsystem, parachute subsystem, control subsystem and aerodynamic forces and moments subsystem. More information about this model can be found in reference [13]. As described in reference [13], calculate results from this model closely agree with drop test results.

Simulation Result

Many factors affect t_m. In this section, we select the UAV initial motion parameters (including velocity, pitch angle at the time recovery system begins to work) and the drag parachute parameters (including drag parachute reefing relieved time t_{dpr}, drag parachute reefing opened characteristics CA_{reef}, drag parachute fully opened characteristics CA) to analyze their influences on t_m.

Influence by UAV Initial Movement Parameters. Simulation calculation is made for a series of Mach numbers selected from 0.2 to 0.6. Result in Fig. 4. shows that when velocity is about 95m/s(Mach number 0.28), t_m is the latest, or 7.4s. When velocity is smaller than 95m/s, t_m is later while velocity increases. But meanwhile, UAV fight attitude is not steady when velocity is smaller than 95m/s. When velocity is above 95m/s, t_m is earlier while velocity increases. In general, Fig.4 shows that higher velocity means early t_m when UAV is flying steadily.

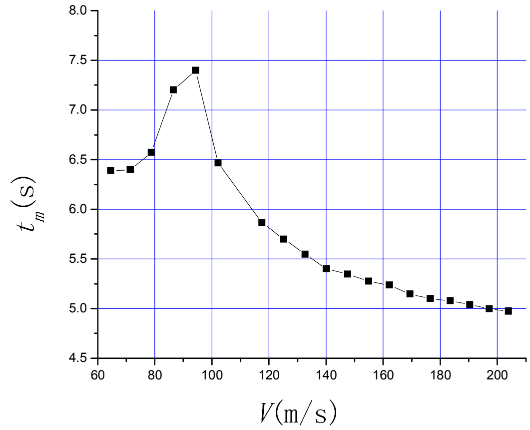

Fig. 4 Velocity Influence

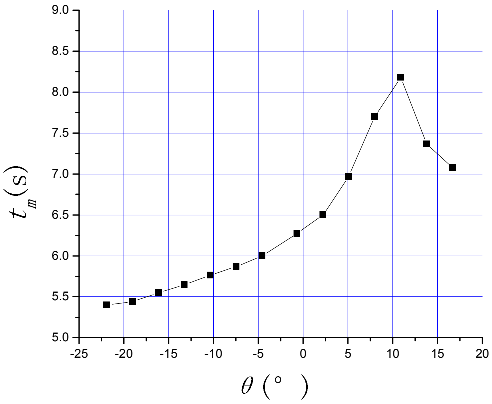

Fig. 5 Pitch Angle Influence

Simulation calculation is made for a series of pitch angles selected from -20° to 20°. Result in Fig. 5 shows that in the range of -22°~11°, t_m is later while pitch angle increases. When pitch angle is larger than 11°, t_m is earlier while pitch angle increases. According to drop tests and simulation results, UAV fight attitude is not steady when pitch angle is too large. In general, Fig.4 shows that higher velocity means early t_m when UAV is flying steadily before recovery system starts to work.

Influences by UAV Drag Parachute Parameters. Simulation calculation is made for a series of drag parachute reefing relieved time t_{dpr} selected from 0.5s to 6.5s. Result in Fig. 6 shows that, t_m=5.549s is earliest while v is 3.5s, which agrees with control stop working time $t_{control}$. By simulation calculation of different $t_{control}$ (2s, 3.5s and 4s), we have the earliest t_m if we relieve drag parachute reef when control system stops working, as shown in Fig. 7.

Simulation calculation is made for a series of drag parachute fully opened characteristics CA selected from 1.0 m^2 to 7.0 m^2. Result in Fig. 8 shows that, t_m is earlier while CA increases. Fig.8 shows that larger CA means early t_m.

Simulation calculation is made for a series of drag parachute reef opened characteristics selected from 0.1 m^2 to 1.6 m^2. Result in Fig. 9 shows that, t_m is later while CA_{reef} increases. Fig.9 shows that larger CA_{reef} means late t_m.

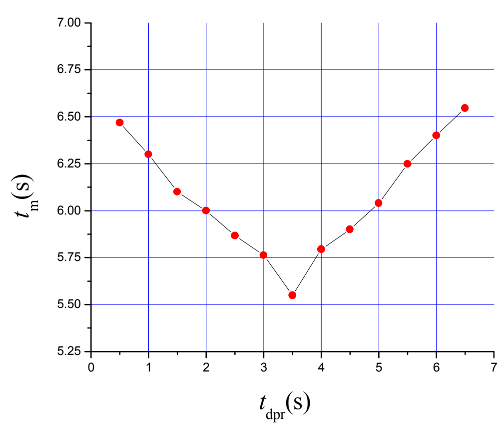

Fig. 6 Drag chute reefing relieved time influence

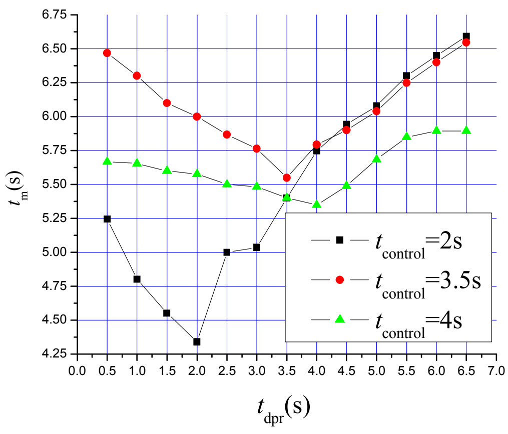

Fig. 7 Control time influence

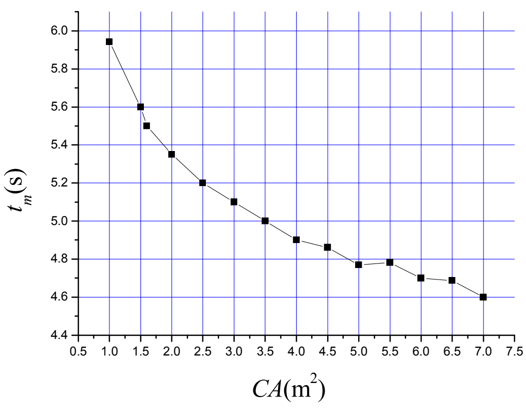

Fig.8 *CA* influences

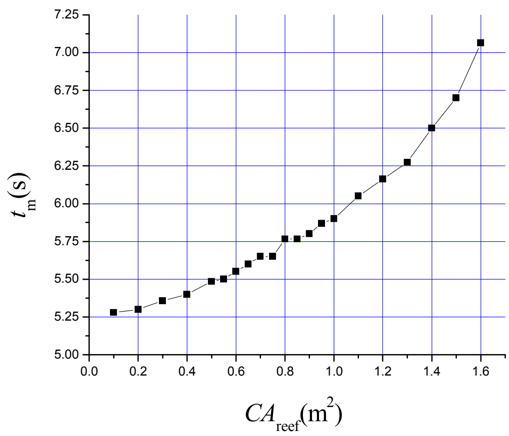

Fig.9 CA_{reef} influences

Summary

Based on simulation calculation, conclusions are drawn as follows.

When recovery system works while UAV is flying steadily, t_m becomes earlier as velocity increases, and later as pitch angle increases. t_m is earliest when relieve drag parachute reefing at the time control stop working. The larger the drag characteristics of the fully opened drag parachute is, t_m is earlier, and the larger the drag characteristics of the reefing opened drag parachute is, t_m is later. These results are benefit for UAV recovery system design.

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