

# The Plane's Diving Maneuvering Characteristics Simulation in Vertical Surface

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**Abstract:** The characteristics of flight dynamics in each diving section are analyzed, and then the dynamic models are built. After simulating the plane's diving maneuvering flight, the parameters changing curves with and without external stores are plotted. And the results could provide theoretical basis to improve the plane's maneuvering performance.

**Keywords:** vertical surface; diving; flight simulation; maneuvering characteristics; maneuvering performance

## I. INTRODUCTION

Diving is the common motion of tactical flight[1][2], and can speed up the plane in a very short time. The flight path can be divided into three parts: curved section of entering diving, straight section of diving and the curved section of exiting diving. Since the altitude would lose rapidly when diving, in most cases the time of diving won't last long. During this time, entering and exiting diving are a large portion. Thus, the performances calculating make a big difference.

## II. CENTRIPETAL FORCE DURING DIVING

The direction of centripetal force when entering diving is straight down the tangent line of flight path, while exiting diving the direction is straight up. The centripetal force when entering diving is:

$$F_x = G \cos \theta - Y \quad (1)$$

The centripetal force when exiting diving is:

$$F_x = Y - G \cos \theta \quad (2)$$

## III. CALCULATING MODEL OF ENTERING DIVING

The plane's altitude decreases with the velocity increasing rapidly when entering diving. When exiting diving the plane's velocity increases less. Obviously, the bigger the centripetal force is the smaller the radius of flight path is.

From Eq.(1)

$$F_x = \frac{mV^2}{r} = G \cos \theta - Y \quad (3)$$

So

$$r = \frac{mV^2}{G \cos \theta - Y} = \frac{V^2}{g(\cos \theta - n_y)} \quad (4)$$

Rewrite the acceleration, where  $dL$  stands for the unit length,

$$\frac{dV}{dt} = \frac{dV^2}{2dL} = \frac{dV^2}{2rd\theta} \quad (5)$$

When entering diving, the plane's movement equations are[3]

$$\begin{cases} m \frac{dV}{dt} = P \cos(\alpha + \varphi_p) - Q - G \sin \theta \\ -mV \frac{d\theta}{dt} = -P \sin(\alpha + \varphi_p) - Y + G \cos \theta \end{cases} \quad (6)$$

The first formula in Eq.(6) is simplified into

$$m \frac{dV}{dt} = P + G \sin \theta - Q \quad (7)$$

Combing Eq.(5) and Eq.(7):

$$m \frac{dV^2}{2rd\theta} = P + G \sin \theta - Q \quad (8)$$

Then

$$\Delta V^2 = \frac{2rg}{G} (P + G \sin \theta - Q) \Delta \theta \quad (9)$$

From Eq.(9), a  $\Delta V_1^2$  can be got. When certify  $\Delta V$ ,

$Q = C_x S \frac{\rho V_1^2}{2}$ , where  $V_1$  is the initial velocity when entering diving. If the plane levels off before diving, the projective shadow of gravity at the tangent line of flight path is equal to  $G \sin \frac{\Delta \theta}{2}$ .

After calculating  $\Delta V_1^2$ , supposing the square of velocity is  $\Delta V_1^2 + V_1^2$ ,  $r_2$  can be got from the formula below[4]

$$r_2 = \frac{V_1^2 + \Delta V_1^2}{g(\cos \theta - n_y)} \quad (10)$$

Then  $\Delta V_2^2$  can be got from Eq.(9). Obviously, after the flight path deflects  $2\Delta \theta$ , the square of velocity is  $\Delta V_2^2 + \Delta V_1^2 + V_1^2$ . Then find  $r_3$  and  $\Delta V_3^2$ . Repetitive computation until  $\sum \Delta \theta$  is equal to slant angle of flight path. The changing of velocity when entering diving can be got from the increment of velocity  $\Delta V_2^2 + \Delta V_1^2 + V_1^2 + \dots$ .

The time of entering diving is

$$\sum \Delta t = \frac{r_1 \Delta \theta}{V_1} + \frac{r_2 \Delta \theta}{\sqrt{V^2 + \Delta V_1^2}} + \frac{r_3 \Delta \theta}{\sqrt{V^2 + \Delta V_1^2 + \Delta V_2^2}} + \dots \quad (11)$$

#### IV. CALCULATING MODEL OF STRAIGHT SECTION OF DIVING

When during the straight section of diving,  $\frac{d\theta}{dt} = 0$ , combine Eq.(6), the simplified equations are[4]

$$\begin{cases} \frac{dV}{dt} = \frac{g}{G} (P - Q - G \sin \theta) \\ Y = G \cos \theta \end{cases} \quad (12)$$

The limit velocity of diving is

$$V_d = \sqrt{\frac{2(P - G \sin \theta)}{C_x \rho S}} \quad (13)$$

Often, the diving velocity is close to the limit velocity of diving, and the resistance increases rapidly. At the moment, the acceleration of diving decreases and the accelerated performance of diving become worse.

The diving velocity vs. flight altitude is[4]

$$\frac{dV}{dt} = \frac{dV}{dH} \frac{dH}{dt} = V \sin \theta \frac{dV}{dH}$$

And

$$\frac{dV}{dH} = -\frac{g}{V} \frac{P - C_x \frac{1}{2} \rho V^2 S}{G \sin \theta} \quad (13)$$

#### V. CALCULATING MODEL OF EXITING DIVING

The loss of altitude is a important target of diving performances. When exiting diving, the pilot would pull rod to increase attack angle and let the plane's flight path curve up. When the path is close to horizontal, the pilot pushes rod to decrease attack angle. The movement equations are[4]

$$\begin{cases} \frac{dV}{dt} = -g \sin \theta \\ \frac{d\theta}{dt} = \frac{g}{V} (n_y - \cos \theta) \end{cases} \quad (14)$$

From Eq.(14)

$$\frac{dV}{d\theta} = -\frac{V \sin \theta}{n_y - \cos \theta} \quad (15)$$

the velocity and the slant angle of flight path are  $V_1$  and  $\theta_1$  when exiting diving, while they are  $V$  and  $\theta$  when finishing diving. Where,  $\theta = 0$ ,  $n_y$  is constant [4]

$$V = \frac{n_y - \cos \theta_1}{n_y - 1} V_1 \quad (16)$$

And

$$\Delta H = \frac{1}{2g} (V^2 - V_1^2) \quad (17)$$

The loss of altitude is

$$\Delta H = \frac{V_1^2}{2g} \left[ \left( \frac{n_y - \cos \theta_1}{n_y - 1} \right)^2 - 1 \right] \quad (18)$$

#### 5. SIMULATION

The state of engine keeps unchangeable in each flight section in simulation. The initial conditions are: the diving angle  $\theta = -30^\circ$ , the initial diving altitude 7000m, the initial diving velocity  $V_0=300\text{m/s}$ . And the simulated curves are shown in Fig.1~4.

It is shown that the bigger the plane's velocity is, the more the loss of altitude is. When the plane takes mounts, the resistance coefficient increases, the loss of plane's energy grows bigger. So the capability of acceleration gets worse, and the changing process of altitude becomes slower.

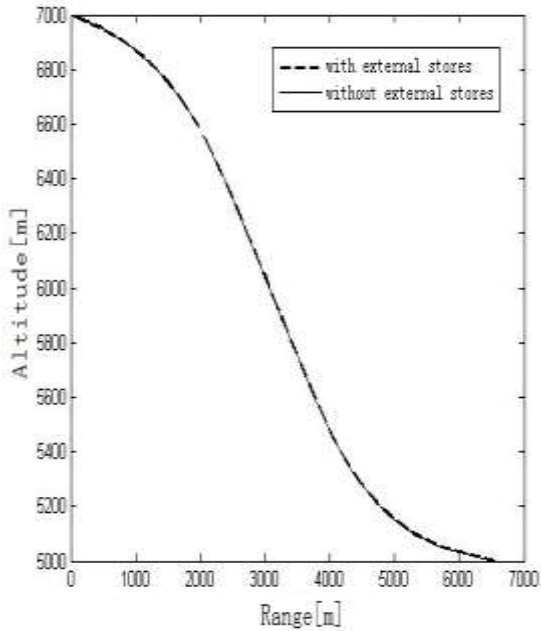


Figure 1. Diving curves

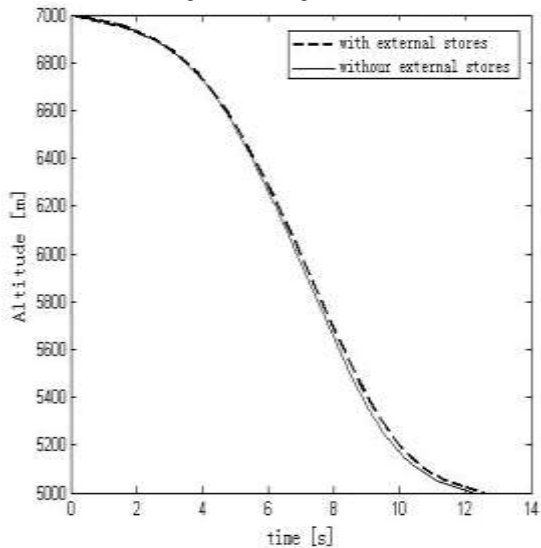


Figure 2. Altitude vs. time

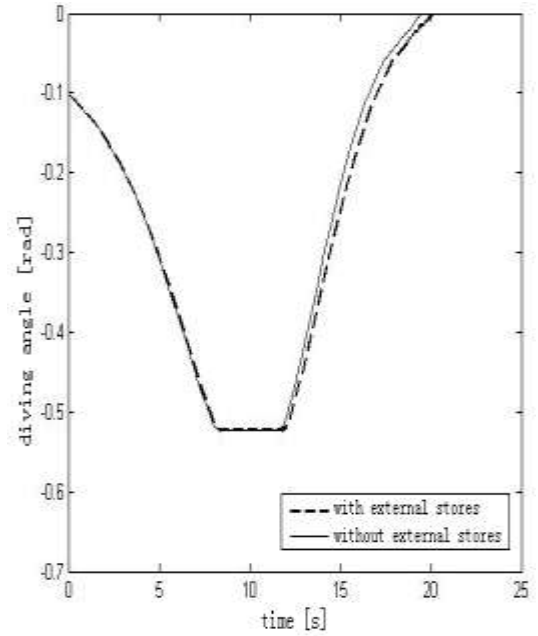


Figure 3. Diving angle vs. time

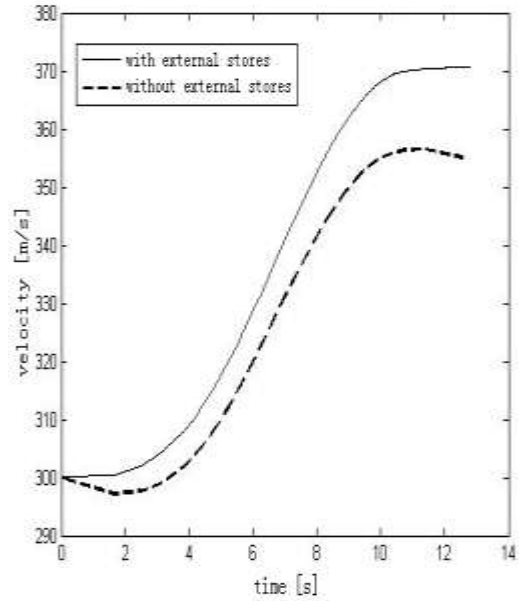


Figure 4. Velocity vs. time

## VI. CONCLUSION

The diving maneuvering flight in vertical surface is discussed, the flight dynamics models of each diving section are built. Compared the different conditions between with and without external stores, the changes of diving performance are reflected. The results could provide theoretical basis to improve the plane's maneuvering performance.

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