

航天飞行动力学

第三次作业 —— 飞行方案设计

一、题目

1. 导弹参数：

- * 导弹质量 $m_0 = 320kg$
- * 发动机推力 $P = 2000N$
- * 初始速度 $V_0 = 250m/s$
- * 初始位置 $x_0 = 0m$
- * 初始高度 $H_0 = 7000m$
- * 初始弹道倾角 $\theta = 0^\circ$
- * 初始俯仰角 $\varphi_0 = 0^\circ$
- * 初始攻角 $\alpha_0 = 0^\circ$
- * 初始俯仰角速度 $\dot{\varphi}_0 = 0rad/s$
- * 初始速度 $V_0 = 250m/s$
- * 参考长度 $S_{ref} = 0.45m^2$
- * 参考面积 $L_{ref} = 2.5m$
- * 升力系数 $C_y = 0.25\alpha + 0.05\delta_z$
- * 阻力系数 $C_x = 0.2 + 0.005\alpha^2$
- * 俯仰力矩系数 $m_z = -0.1\alpha + 0.024\delta_z$

2. 大气密度计算公式：

$$\begin{cases} \rho_0 = 1.2495 \text{ kg/m}^3 \\ T_0 = 288.15K \\ T = T_0 - 0.0065H \\ \rho = \rho_0 \left(\frac{T}{T_0} \right)^{4.25588} \end{cases} \quad (1)$$

3. 飞行方案：

(1) 当 $x < 9100m$ 时，采用瞬时平衡假设

$$\begin{cases} H^* = 2000 \times \cos(0.000314 \times 1.1 \times x) + 5000 \\ \delta_z = k_\varphi \times (H - H^*) + \dot{k}_\varphi \times (H - H^*) \\ \delta_z = k_\varphi(H - H^*) + \dot{k}_\varphi H \\ m_s = 0.0kg/s \end{cases} \quad (2)$$

(2) 当 $24000m > x > 9100m$ 时, 等高飞行方案, 采用瞬时平衡假设。

$$\begin{cases} H^* = 3050m \\ \delta_z = k_\varphi(H - H^*) + \dot{k}_\varphi H \\ \delta_z = k_\varphi(H - H^*) + \dot{k}_\varphi H \\ m_s = 0.46kg/s \end{cases} \quad (3)$$

(3) 当 $x > 24000m$ 且 $y > 0$, 目标位置为 $x_m = 30000m$, 采用比例导引法和瞬时平衡假设

$$\begin{cases} x_m = 30000m \\ m_z^\alpha \alpha + m_z^{\delta_z} \delta_z = 0 \\ m_s = 0.0kg/s \end{cases} \quad (4)$$

注: 舵偏角约束 $|\delta_z| \leq 30^\circ$

二、公式推导

1. $x < 24000m$ 的飞行方案:

基于“瞬时平衡”假设, 将包含 20 个方程的导弹运动方程组简化为铅垂平面内的质心运动方程组。

$$\begin{cases} m \frac{dV}{dt} = P \cos \alpha - X - mg \sin \theta \\ mV \frac{d\theta}{dt} = P \sin \alpha + Y - mg \cos \theta \\ \frac{dx}{dt} = V \cos \theta \\ \frac{dy}{dt} = V \sin \theta \\ \frac{dm}{dt} = -m_s \\ \alpha_b = -\frac{m_z^{\delta_z}}{m_z^\alpha} \delta_{zb} \\ \delta_z = k_\varphi(H - H^*) + \dot{k}_\varphi (\dot{H} - \dot{H}^*) \\ H^* = 2000 \times \cos(0.000314 \times 1.1 \times x) + 5000 \end{cases} \quad (5)$$

代入各物理量定义式：

$$\left\{ \begin{array}{l} \frac{dV}{dt} = \frac{P \cos \alpha - X}{m} - g \sin \theta \\ \frac{d\theta}{dt} = \frac{P \sin \alpha + Y}{m} - \frac{g \cos \theta}{V} \\ \frac{dx}{dt} = V \cos \theta \\ \frac{dy}{dt} = V \sin \theta \\ \frac{dm}{dt} = -m_s \\ \alpha_b = -\frac{m_z^{\delta_z}}{m_z^\alpha} \delta_{zb} \\ \delta_z = k_\varphi (H - H^*) + \dot{k}_\varphi (\dot{H} - \dot{H}^*) \\ H^* = 2000 \times \cos(0.000314 \times 1.1 \times x) + 5000 \\ Y = (0.25\alpha + 0.05\delta_z) \times \frac{1}{2}\rho V^2 \times S_{ref} \\ X = (0.2 + 0.005\alpha^2) \times \frac{1}{2}\rho V^2 \times S_{ref} \end{array} \right. \quad (6)$$

2. $x > 24000m$ 的飞行方案：

(1) 末段第一种计算方法：

$$\left\{ \begin{array}{l} r \frac{dq}{dt} = V_m \times \sin \eta - V_T \sin \eta_T \\ \tan q = \frac{y_T - y_m}{x_T - x_m} \\ \frac{d\theta^*}{dt} = k \frac{dq}{dt} \\ \theta^* - \theta_0 = k(q - q_0) \\ \theta_0, q_0? \\ \delta_z = k_\theta(\theta - \theta^*) + k_{\dot{\theta}}(\dot{\theta} - \dot{\theta}^*) \end{array} \right. \quad (7)$$

(2) 末段第二种计算方法：

只需要给出比例导引系数根据运动学方程

$$\left\{ \begin{array}{l} r \frac{dq}{dt} = V_m \times \sin \eta - V_T \sin \eta_T \\ \tan q = \frac{y_T - y_m}{x_T - x_m} \\ \frac{dq}{dt} = \frac{-V_m \sin(\theta - q)}{r} \end{array} \right. \quad (8)$$

由比例导引法 $\dot{\theta}^* = k\dot{q}$, 可得动力学方程第二式

$$mV_m \dot{\theta}^* = P \sin \alpha + Y - mg \cos \theta \Rightarrow mV_m k \dot{q} = P \sin \alpha + Y - mg \cos \theta \quad (9)$$

由于攻角较小, 进行线性化可得

$$mV_m k \dot{q} = P\alpha + Y^\alpha \alpha + Y^{\delta_z} \delta_z - mg \cos \theta \quad (10)$$

由于瞬时平衡 $m_z = 0$, 可得

$$-0.1\alpha + 0.024\delta_z = 0 \Rightarrow \delta_z = 0.1\alpha/0.024 \quad (11)$$

代入，可得

$$\alpha = \frac{mV_mk\dot{q} + mg \cos \theta}{P + Y\alpha + Y^{\delta_z}(0.1/0.024)} \Rightarrow \frac{mV_mk\dot{q} + mg \cos \theta}{P + C_y^\alpha q S_{ref} + C_y^{\delta_z} q S_{ref}(0.1/0.024)} \quad (12)$$

最后得到弹道方程为

$$\left\{ \begin{array}{l} \frac{dV}{dt} = \frac{P \cos \alpha - X}{m} - g \sin \theta \\ \alpha = \frac{mV_k\dot{q} + mg \cos \theta}{P + C_y^\alpha q S_{ref} + C_y^{\delta_z} q S_{ref}(0.1/0.024)} \\ \frac{dx}{dt} = V \cos \theta \\ \frac{dy}{dt} = V \sin \theta \\ \dot{\theta}^* = k\dot{q} \\ \dot{\theta}^* = \dot{\theta} \\ \tan q = \frac{y_T - y_m}{x_T - x_m} \\ \frac{dq}{dt} = \frac{-V \sin(\theta - q)}{r} \\ \delta_z = 0.1\alpha/0.024 \end{array} \right. \quad (13)$$

源代码 1: main.py

```
1  """
2  弹道计算程序
3  """
4
5  import numpy as np
6  from matplotlib import pyplot as plt
7
8  # 展示高清图
9  from matplotlib_inline import backend_inline
10 backend_inline.set_matplotlib_formats('svg')
11
12 plt.rcParams['font.sans-serif'] = ['SimHei']
13 plt.rcParams['axes.unicode_minus'] = False
14
15 # 导弹参数
16 S_ref = 0.45
17 L_ref = 2.5
18
19 # 放大系数
20 K_phi = -0.6
21 K_phi_dot = 0.5 * K_phi
22 K_q = 3
23
24
25 # 仿真时间步
26 timestep = 0.001
27
28 # 导弹状态定义
29 class statu():
30     __slot__ = ['Time', 'X', 'H', 'V', 'theta', 'mass', 'alpha', 'deltaz']
31
32     # 位置
33     # 速度
34     # 欧拉角
35     # 角加速度
36     # 舵偏角
37
38     # 初始化
39     def __init__(self, Time, X=0, H=0, V=0, theta=0, mass=0):
40         self.Time = Time
41         self.X = X
```

```
42     self.H = H
43     self.V = V
44     self.theta = theta
45     self.mass = mass
46     self.alpha = 0
47     self.deltaz = 0
48     self.q = 0
49
50     # 显式Euler法, 给定飞行高度
51     def Euler(self, before, dmass):
52         self.Time = before.Time + timestep
53
54         self.X = before.X + before.V * np.cos(before.theta) * timestep
55         self.H = before.H + before.V * np.sin(before.theta) * timestep
56
57         self.deltaz = K_phi * (self.H - High_goal(self.X)) + K_phi_dot * (before.V * np
58             .sin(before.theta) - High_goal_dot(self.X))
59
60         if self.deltaz > 30:
61             self.deltaz = 30
62         elif self.deltaz < -30:
63             self.deltaz = -30
64
65         self.alpha = 0.24 * self.deltaz
66
67         Y = (0.25 * self.alpha + 0.05 * self.deltaz) * 0.5 * air(self.H) * before.V *
68             before.V * S_ref
69
70         X = (0.005 * self.alpha * self.alpha + 0.2) * 0.5 * air(self.H) * before.V *
71             before.V * S_ref
72
73         self.mass = before.mass - dmass * timestep
74         if dmass == 0:
75             P = 0
76         else:
77             P = 2000
78
79         self.V = before.V + (P * np.cos(self.alpha * 3.14159625 / 180) - X - self.mass * 9.8 *
80             np.sin(before.theta)) / self.mass * timestep
81         self.theta = before.theta + (P * np.sin(self.alpha * 3.14159625 / 180) + Y - self.
82             mass * 9.8 * np.cos(before.theta)) / self.mass / self.V * timestep
83
84     # 比例导引法, 给定目标位置
```

```
80     def Euler2(self, before, Xm, Ym):
81         self.Time = before.Time + timestep
82
83         self.X = before.X + before.V * np.cos(before.theta) * timestep
84         self.H = before.H + before.V * np.sin(before.theta) * timestep
85         self.mass = before.mass
86         self.r = np.sqrt((self.X - Xm)*(self.X - Xm) + (self.H - Ym)*(self.H - Ym))
87         self.q = np.arctan((self.H - Ym)/(self.X - Xm)) / 3.14159*180
88         self.dq = - before.V * np.sin(before.theta - self.q*3.14159/180)/ self.r *
            timestep / 3.14159*180
89
90         self.theta = before.theta + K_q * self.dq * timestep
91
92         P = 0
93
94         self.alpha = (self.mass* before.V * K_q * self.dq*3.14159/180 + self.mass *
            9.8 *np.cos(self.theta))/(P + (0.25 + 0.05 / 0.24) * 0.5 * air(self.H) *
            before.V * before.V * S_ref ) / 3.14159*180
95
96
97         self.deltaz = self.alpha / 0.24
98
99         if self.deltaz > 30:
100             self.deltaz = 30
101         if self.deltaz < -30:
102             self.deltaz = -30
103
104         X = (0.005 * self.alpha * self.alpha + 0.2) * 0.5 * air(self.H) * before.V *
            before.V * S_ref
105
106         self.V = before.V + ( (P*np.cos(self.alpha*3.14159/180) - X)/self.mass - 9.8*np
            .sin(self.theta) ) * timestep
107
108 # 大气参数
109 def air (High):
110     rho0 =1.2495
111     T0 = 288.15
112     Temp = T0 - 0.0065*High
113     rho = rho0 * np.exp(4.25588*np.log(Temp / T0))
114     return rho
115
116 # 飞行方案
117 def High_goal(X):
```

```
118     if X <= 9100:
119         return 2000 * np.cos(0.000314 * 1.1 * X) + 5000
120     elif X <= 24000:
121         return 3050
122     else:
123         return 0
124
125 def High_goal_dot(X):
126     if X <= 9100:
127         return -2000 * 0.000314 * np.sin(0.000314 * 1.1 * X)
128     elif X <= 24000:
129         return 0
130     else:
131         return 0
132
133
134 # 飞行初始状态
135 statu_n = [statu(0, 0, 7000, 250, 0, 320)]
136 statu_n[0].alpha = 0
137 statu_n[0].deltaz = 0
138
139 Time_goal = np.arange(0,200,timestep)
140 X_goal = np.arange(0,24000,10)
141 H_goal = [High_goal(i) for i in X_goal]
142 plt.plot(X_goal,H_goal, 'b--', alpha=0.5, linewidth=1, label='飞行方案高度')
143
144 while statu_n[-1].X < 9100:
145     statu_n.append(statu(statu_n[-1].Time + timestep))
146     statu_n[-1].Euler(statu_n[-2],0)
147     #print(statu_n[-1].alpha)
148
149 while statu_n[-1].X <= 24000:
150     statu_n.append(statu(statu_n[-1].Time + timestep))
151     statu_n[-1].Euler(statu_n[-2],0.46)
152     #print(statu_n[-1].alpha)
153
154 # statu_n[-1].Euler2(statu_n[-2],30000,-30000)
155
156 while statu_n[-1].X <= 30000 and statu_n[-1].H > 0:
157     statu_n.append(statu(statu_n[-1].Time + timestep))
158     statu_n[-1].Euler2(statu_n[-2],30000,0)
159     print(statu_n[-1].q)
160
```



```
161
162 X_data = [n.X for n in statu_n]
163 H_data = [n.H for n in statu_n]
164 plt.plot(X_data,H_data, 'r-.', alpha=0.5, linewidth=1, label='实际飞行高度')
165
166 # 飞行高度绘图
167 plt.legend() #显示上面的label
168 plt.xlabel('X') #x_label
169 plt.ylabel('H')#y_label
170 plt.ylim(0,8000)
171 plt.xlim(0,30000) #仅设置y轴坐标范围
172
173
174 plt.figure(2)
175 T_data = [n.Time for n in statu_n]
176 deltaz_data = [n.q for n in statu_n]
177 plt.plot(T_data,deltaz_data, 'r-.', alpha=0.5, linewidth=1, label='舵偏角$\delta z$')
178 plt.legend() #显示上面的label
179 plt.xlabel('Time(s)') #x_label
180 plt.ylabel('$\delta z$')#y_label
181 plt.ylim(-50,50)
182 plt.xlim(0,200)
183 """
184 plt.figure(3)
185 M_data = [n.mass for n in statu_n]
186 plt.plot(T_data,M_data, 'r-.', alpha=0.5, linewidth=1, label='实际飞行速度V')
187 plt.legend() #显示上面的label
188 plt.xlabel('Time(s)') #x_label
189 plt.ylabel('速度V')#y_label
190 plt.ylim(250,350)
191 plt.xlim(0,200)
192 """
193 plt.figure(4)
194 V_data = [n.V for n in statu_n]
195 plt.plot(T_data,V_data, 'r-.', alpha=0.5, linewidth=1, label='实际飞行速度V')
196 plt.legend() #显示上面的label
197 plt.xlabel('Time(s)') #x_label
198 plt.ylabel('速度V')#y_label
199 plt.ylim(100,250)
200 plt.xlim(0,200)
201
202 plt.show()
```

源代码 2: work.tex

```
1 \documentclass[UTF8]{ctexart}
2 \newcommand{\mycmdB}[1]{\heiti #1}
3 \renewcommand{\normalsize}{\fontsize{12}{12}\fangsong}
4 \usepackage{listings}
5 \usepackage{xcolor}
6 \usepackage{amsmath}
7 \usepackage{graphicx}
8 \usepackage{float}
9 \usepackage{indentfirst}
10 \usepackage{longtable}
11 \usepackage{fancyhdr}
12 \usepackage[a4paper, left=2.5cm, right=2.5cm, top=3cm, bottom=2
    cm]{geometry}
13 \usepackage{matlab-prettifier}
14 \usepackage{latexcolors}
15
16 \setlength{\parindent}{2em} %2em代表首行缩进2个字符
17
18 % 页眉页脚设置
19 \pagestyle{fancy}
20 \fancyhf{}
21 \lhead{2021300045}
22 \chead{李宗霖}
23 \rhead{第\thepage 页}
24
25 % 去除图注冒号
26 \usepackage{caption}
27 \captionsetup[table]{labelsep=space} % 表
28 \captionsetup[figure]{labelsep=space} % 图
29
30 \CTEXsetup[format={\Large\bfseries}]{section}
31
32 % 源代码引用
33 \renewcommand{\lstlistingname}{源代码}
34 \lstset{
35     basicstyle          = \zihao{5} \ttfamily,           % 基
        本代码风格
36     keywordstyle        = \bfseries,                      % 关键字风格
37     commentstyle        = \ttfamily\itshape,              % 注释的风格,
        斜体
38     stringstyle         = \ttfamily,                      % 字符串风格
39     flexiblecolumns,    % 别问为什么, 加上这个
40     numbers             = left,                            % 行号的位置在左边
41     showspaces          = false,                          % 是否显示空格, 显示了有点
```

```

    乱，所以不现实了
42     numberstyle      =    \zihao{5}\ttfamily,      % 行号的样
        式，小五号，tt等宽字体
43     showstringspaces  =    false,
44     captionpos        =    t,      % 这段代码的名字所呈现的位
        置，t指的是top上面，b指下面
45     frame             =    lrtb %lrtb,      % 显示边框
46 }
47 \lstset{
48     language          =    matlab,
49     basicstyle         =    \zihao{5}\ttfamily,      % 基本代
        码风格
50     rulesepcolor      =    \color{gray}, % 代码块边框颜色
51     breaklines        =    true, % 代码过长则换行
52     numbers           =    left, % 行号在左侧显示
53     numberstyle       =    \zihao{5}\ttfamily, % 行号字体
54     showspace        =    false, % 不显示空格
55     columns           =    fixed, % 字间距固定
56     %morekeywords     =    {as}, % 自加新的关键字(必须前后
        都是空格)
57     %deletendkeywords =    {compile} % 删除内定关键字；删除
        错误标记的关键字用deletekeywords删！
58 }
59
60 \lstdefinestyle{Python}{
61     language          =    Python, % 语言选Python
62     basicstyle        =    \zihao{5}\ttfamily,
63     numberstyle       =    \zihao{5}\ttfamily,
64     keywordstyle      =    \color{blue},
65     keywordstyle      =    [2] \color{teal},
66     stringstyle       =    \color{magenta},
67     commentstyle      =    \color{red}\ttfamily,
68     breaklines        =    true, % 自动换行，建议不要写太长的行
69     columns           =    fixed, % 如果不加这一句，字间距就不固
        定，很丑，必须加
70     basewidth         =    0.5em,
71 }
72
73 \begin{document}
74
75 \begin{center}
76     {\zihao{-2} \bf 航天飞行动力学}\\
77     {\zihao{3} 第三次作业\ ——\ 飞行方案设计}
78
79 \end{center}

```

```

80 |
81 | \section*{\zihao{-4} 一、题目}
82 | \noindent {\heiti 1.导弹参数: }
83 |
84 | \begin{itemize}
85 |     \item[*] 导弹质量 $m_0=320\text{kg}$ 
86 |     \item[*] 发动机推力 $P=2000\text{N}$ 
87 |     \item[*] 初始速度 $V_0=250\text{m/s}$ 
88 |     \item[*] 初始位置 $x_0=0\text{m}$ 
89 |     \item[*] 初始高度 $H_0=7000\text{m}$ 
90 |     \item[*] 初始弹道倾角 $\theta=0^\circ$ 
91 |     \item[*] 初始俯仰角  $\varphi_0=0^\circ$ 
92 |     \item[*] 初始攻角  $\alpha_0=0^\circ$ 
93 |     \item[*] 初始俯仰角速度 $\dot{\varphi}_0=0\text{rad/s}$ 
94 |     \item[*] 初始速度 $V_0=250\text{m/s}$ 
95 |     \item[*] 参考长度 $S_{\text{ref}}=0.45\text{ m}^2$ 
96 |     \item[*] 参考面积 $L_{\text{ref}}=2.5\text{m}$ 
97 |     \item[*] 升力系数 $C_y=0.25\alpha+0.05\delta_z$ 
98 |     \item[*] 阻力系数 $C_x=0.2+0.005\alpha^2$ 
99 |     \item[*] 俯仰力矩系数 $m_z=-0.1\alpha+0.024\delta_z$ 
100 | \end{itemize}
101 |
102 | \noindent {\heiti 2.大气密度计算公式:}
103 | \begin{align}
104 |     \begin{cases}
105 |         \rho_0=1.2495\text{ kg/m}^3 \\
106 |         T_0=288.15\text{ K} \\
107 |         T=T_0-0.0065H \\
108 |         \rho=\rho_0\left(\frac{T}{T_0}\right)^{4.25588}
109 |     \end{cases}
110 | \end{align}
111 |
112 | \noindent {\heiti 3.飞行方案: }
113 |
114 | \begin{itemize}
115 |     \item[(1)] 当 $x<9100\text{m}$ 时, 采用瞬时平衡假设
116 |         \begin{align}
117 |             \begin{cases}
118 |                 H^*=2000\times\cos(0.000314\times1.1\times x) \\
119 |                 \quad +5000 \\
120 |                 \delta_z=k_\varphi\times(H-\text{H}^*)+k_\varphi \\
121 |                 \quad \varphi\times(H-\text{H}^*) \\
122 |                 \delta_z=k_\varphi(H-H^*)+\dot{k}_\varphi\varphi \\
123 |                 \quad H

```

```

122         \end{cases}
123     \end{align}
124     \item[(2)] 当 $24000\text{m} < x < 9100\text{m}$ 时，等高飞行方案，采用瞬时平衡
        假设。
125         \begin{align}
126             \begin{cases}
127                 H^*=3050\text{m} & \\\
128                 \delta_z=k_\varphi(H-H^*)+\dot{k}_\varphi H & \\\
129                 \delta_z=k_\varphi(H-H^*)+\dot{k}_\varphi H & \\\
130                 m_s=0.46\text{kg/s} & 
131             \end{cases}
132         \end{align}
133     \item[(3)] 当 $x > 24000\text{m}$ 且 $y > 0$ ，目标位置为 $x_m=30000\text{m}$ ，采用
        比例导引法和瞬时平衡假设
134         \begin{align}
135             \begin{cases}
136                 x_m=30000\text{ m} & \\\
137                 m_z^{\alpha}\alpha+m_z^{\delta_z}\delta_z=0 & \\\
138                 m_s=0.0\text{kg/s} & 
139             \end{cases}
140         \end{align}
141 \end{itemize}
142
143 注：舵偏角约束 $|\delta_z| \leq 30^\circ$ 
144
145
146
147
148 \section*{\zihao{-4} 二、公式推导}
149
150
151 \noindent {\heiti 1.  $x < 24000\text{m}$ 的飞行方案：}
152
153 基于“瞬时平衡”假设，将包含20个方程的导弹运动方程组简化为铅垂
    平面内的质心运动方程组。
154 \begin{align}
155     \begin{cases}
156         m\frac{\mathrm{d}V}{\mathrm{d}t}=P\cos\alpha-X-mg\sin\theta & \\\
157         mV\frac{\mathrm{d}\theta}{\mathrm{d}t}=P\sin\alpha+Y-mg\cos\theta & \\\
158         \frac{\mathrm{d}x}{\mathrm{d}t}=V\cos\theta & \\\
159         \frac{\mathrm{d}y}{\mathrm{d}t}=V\sin\theta & 
    \end{cases}

```

```

160      \\\
      \frac{dm}{dt}=-m_{\text{s}} \ \hfill

161      \\\
      \alpha_b=-\frac{m_z^{\delta_z}}{m_z^{\alpha}}\delta_{zb} \ \hfill
      \\\
162      \delta_z = k_{\text{varphi}} \left(H-H^*\right) +\dot{k}_{\text{varphi}} \left(\dot{H} -\dot{H}^*\right) \ \hfill \\\
163      H^*=2000\times \cos\left(0.000314\times 1.1\times x\right)+5000\hfill
164  \end{cases}
165 \end{align}
166
167 代入各物理量定义式：
168 \begin{align}
169   \begin{cases}
170     \frac{dV}{dt}=\frac{P\cos\alpha-X}{m}
      -g\sin\theta\hfill \\\
171     \frac{d\theta}{dt}=\frac{P\sin\alpha+Y}{m}-\frac{g\cos\theta}{V}\hfill \\\
172     \frac{dx}{dt}=V\cos\theta \ \hfill

      \\\
173     \frac{dy}{dt}=V\sin\theta \ \hfill

      \\\
174     \frac{dm}{dt}=-m_{\text{s}} \ \hfill

      \\\
175     \alpha_b=-\frac{m_z^{\delta_z}}{m_z^{\alpha}}\delta_{zb} \ \hfill
      \\\
176     \delta_z = k_{\text{varphi}} \left(H-H^*\right) +\dot{k}_{\text{varphi}} \left(\dot{H} -\dot{H}^*\right) \ \hfill \\\
177     H^*=2000\times \cos\left(0.000314\times 1.1\times x\right)+5000\hfill \\\
178     Y=\left(0.25\alpha+0.05\delta_z\right)\times \frac{1}{2}\rho V^2 \times S_{\text{ref}}\hfill \\\
179     X=\left(0.2+0.005\alpha^2\right)\times \frac{1}{2}\rho V^2 \times S_{\text{ref}}
180   \end{cases}
181 \end{align}

```

```

182
183
184
185 \noindent {\heiti 2.$x>24000m$的飞行方案：}
186
187 \noindent {(1) 末段第一种计算方法：}
188
189
190 \begin{align}
191     \begin{cases}
192         r\frac{dq}{dt}=V_{\{m\}}\times\sin\eta-V_{\{T\}}\sin\eta_{\{T\}} \quad \backslash\backslash
193         \tan q=\frac{y_{\{T\}}-y_{\{m\}}}{x_{\{T\}}-x_{\{m\}}} \quad \backslash\backslash
194         \frac{d\theta^*}{dt}=k\frac{dq}{dt} \quad \backslash\backslash
195         \theta^*-\theta_{\{0\}}=k(q-q_{\{0\}}) \quad \backslash\backslash
196         \theta_{\{0\}},q_{\{0\}}? \quad \backslash\backslash
197         \Delta z=k_{\{\theta\}}(\theta-\theta^*)+k_{\{\dot{\theta}\}}(\dot{\theta}-\dot{\theta}^*)
198     \end{cases}
199 \end{align}
200
201 \noindent {(2) 末段第二种计算方法：}
202
203 只需要给出比例导引系数
204 根据运动学方程
205
206 \begin{align}
207     \begin{cases}
208         r\frac{dq}{dt}=V_{\{m\}}\times\sin\eta:-V_{\{T\}}\sin\eta_{\{T\}} \quad \backslash\backslash
209         \tan q=\frac{y_T-y_m}{x_T-x_m} \quad \backslash\backslash
210         \frac{dq}{dt} =\frac{-V_m\sin(\theta-q)}{r}
211     \end{cases}
212 \end{align}
213
214 由比例导引法 $\dot{\theta}^*=k\dot{q}$ ，可得动力学方程第二式
215 \begin{align}
216     mV_m\dot{\theta}^*=P\sin\alpha+Y-mg\cos\theta\rightarrow
217     mV_mk\dot{q}=P\sin\alpha+Y-mg\cos\theta
218 \end{align}
219 由于攻角较小，进行线性化可得
220 \begin{align}
221     mV_{\{m\}}k\dot{q}=P\alpha+Y^{\{\alpha\}}\alpha+Y^{\{\Delta z\}}\Delta z-mg\cos\theta
222 \end{align}

```

```

223
224 由于瞬时平衡 $m_z=0$ ，可得
225 \begin{align}
226     -0.1\alpha+0.024\delta_{\{\tilde{z}\}}=0\Rightarrow\delta_{\{\tilde{z}\}}=0.1\alpha/0.024
227 \end{align}
228
229 代入，可得
230 \begin{align}
231     \alpha=\frac{mV_{\{m\}}k\dot{q}+mg\cos\theta}{P+Y^{\{\alpha\}}+Y^{\{\delta_{\{z\}}\}}(0.1/0.024)}\Rightarrow\frac{mV_{\{m\}}k\dot{q}+mg\cos\theta}{P+C_{\{y\}}^{\{\alpha\}}qS_{\{ref\}}+C_{\{y\}}^{\{\delta_{\{z\}}\}}qS_{\{ref\}}(0.1/0.024)}
232 \end{align}
233
234
235 最后得到弹道方程为
236
237 \begin{align}
238     \begin{cases}
239         \frac{dV}{dt}=\frac{P\cos\alpha-X_{\{m\}}-g\sin\theta}{\\
240         \alpha=\frac{mV_{\{m\}}k\dot{q}+mg\cos\theta}{P+C_{\{y\}}^{\{\alpha\}}qS_{\{ref\}}+C_{\{y\}}^{\{\delta_{\{z\}}\}}qS_{\{ref\}}(0.1/0.024)}\\
241         \frac{dx}{dt}=V\cos\theta\\
242         \frac{dy}{dt}=V\sin\theta\\
243         \dot{\theta}^{\{*\}}=k\dot{q}\\
244         \dot{\theta}^{\{*\}}=\dot{\theta}\\
245         \tan q=\frac{y_{\{T\}}-y_{\{m\}}}{x_{\{T\}}-x_{\{m\}}}\\
246         \frac{dq}{dt}=\frac{-V\sin(\theta-q)}{r}\\
247         \delta_{\{z\}}=0.1\alpha/0.024
248     \end{cases}
\end{align}

```



```
249 \end{align}
250
251
252
253
254 \clearpage
255 \lstinputlisting[
256     style      =   Python,
257     caption    =   {\bf main.py},
258     label      =   {main.py}
259 ]{./code/main.py}
260
261 \clearpage
262
263 \lstinputlisting[
264     style      =   Matlab-editor,
265     caption    =   {\bf work.tex},
266     label      =   {work.tex}
267 ]{work.tex}
268
269 \end{document}
```