Optimal Trajectory Exploration: Thrust Vectored Wing

Final Project ECEN 5008

by

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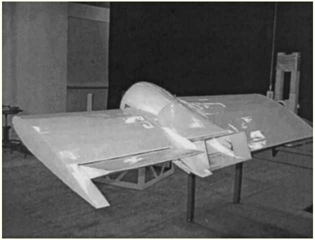
December 10, 2015

Introduction

Topic

- A wing with a magical hand of god thrust on the back
- Examining in two dimensions, x and z, assume no change in y
- Want to fly around a figure eight in these two dimensions
- Also important to be able to transistion between equillibriums

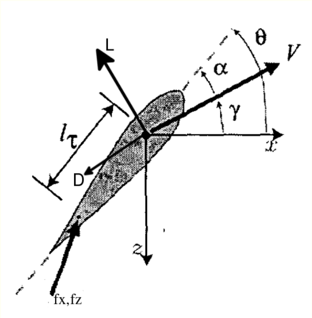


Caltech Ducted Fan

Background

Model

- Angle of attack α, θ is plane angle from x axis
- Thrust vector in x and z applied to a point on towards the back of the plane
- Lift perpendicular to Velocity, Drag parallel to velocity
- Mathematics done in the Velocity frame
- Constants pulled straight from references



Basic model of the Thrust Vectored Wing

Final Dynamics

$$\dot{v} = -\frac{D(v,\alpha)}{m} - g\sin(\theta - \alpha) + \frac{\cos(\alpha)}{m}f_x + \frac{\sin(\alpha)}{m}f_z$$

$$\dot{\alpha} = -\frac{L(v,\alpha)}{mv} + \frac{g}{v}\cos(\theta - \alpha) - \frac{\sin(\alpha)}{mv}f_x + \frac{\cos(\alpha)}{mv}f_z$$

$$\dot{\omega} = \frac{M(v,\alpha)}{J} + \frac{l_\tau}{J}f_z$$

$$\dot{\theta} = \omega$$

$$\dot{x} = v\cos(\gamma) \quad \dot{z} = -v\sin(\gamma)$$

Lift, Drag and Moment

$$L(V,\alpha) = \frac{1}{2}\rho V^2 S C_l(\alpha) \quad D(V,\alpha) = \frac{1}{2}\rho V^2 S C_D(\alpha)$$

$$M(V,\alpha) = \frac{1}{2}\rho V^2 S\bar{c} C_m(\alpha)$$

$$C_l(\alpha) = C_{l_\alpha}\alpha = 3.256\alpha$$

$$C_d(\alpha) = C_{C_{d_0}} + C_{d_\alpha}\alpha^2 = 0.1716 + 2.395\alpha^2$$

$$C_M(\alpha) = C_{M_\alpha}\alpha = -0.0999\alpha$$

$$S = 0.6\text{m}^2, \quad \rho = 1.2\text{kg/m}^3, \quad J = 0.25\text{kg m}^2$$

$$l_\tau = 0.31\text{m}, \quad m = 12\text{kg}, \quad g = 0.6\text{m/s}^2$$

Implementation

Comparison to Sliding Car

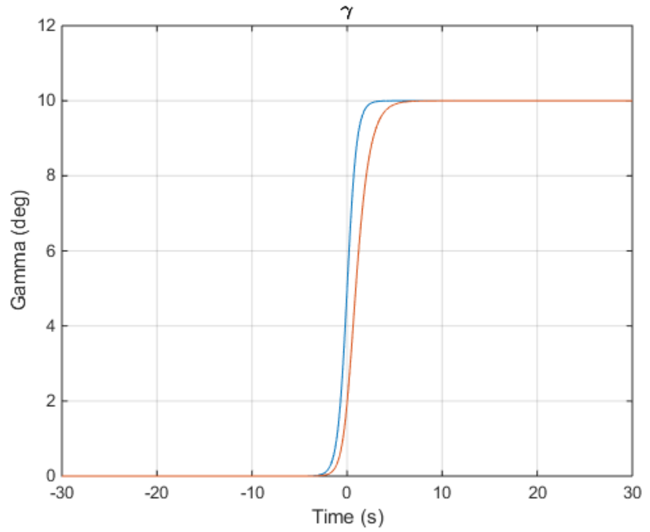
- One extra state compared to the sliding car
- Here the moment is coupled to the thrust and aerodynamic forces
- The θ state exists because of gravity ($g_p = 0.6 m/s^2$)
- Angle of attack is similar to side slip angle

Coding and Derivatives

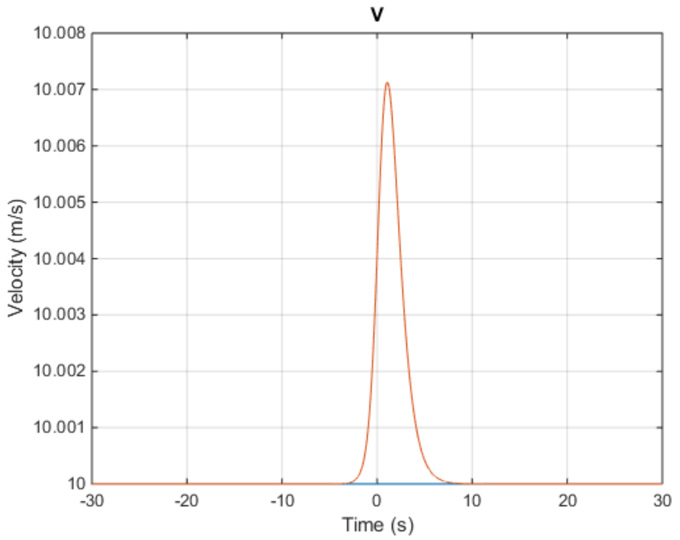
- We already took all the Jacobian and Hessian derivatives
- This is where we saw further effects of coupling with more second order derivatives being non-zero
- For now, we ignore these second order terms
- We trim around a fixed velocity and γ
- We used a partition of unity with the hyberbolic tangent function to transfer from one trim trajectory to another
- To get the flight path we integrated the kinematics of shown above

Results

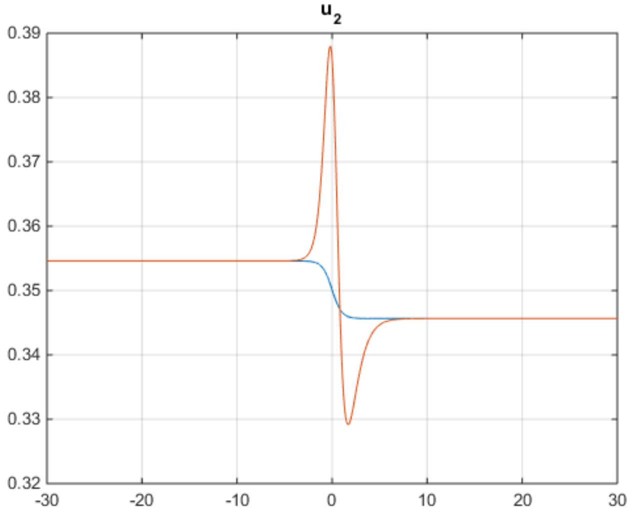
Constant Gain Control



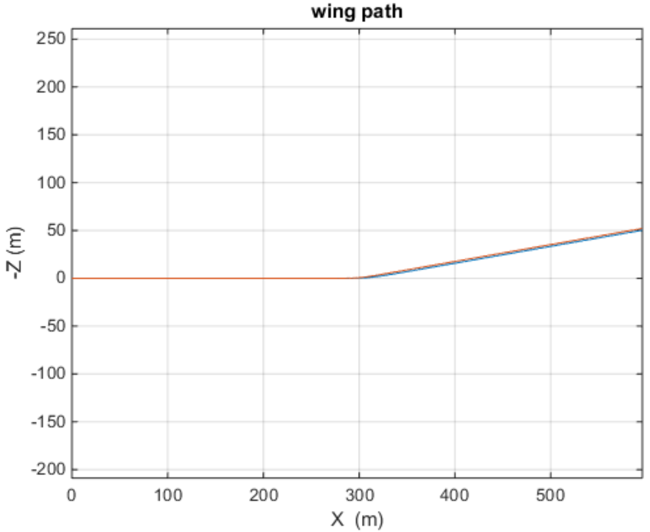
Velocity


V
Velocity (m/s)
10.008
10.007
10.006
10.005
10.004
10.003
10.002
10.001
10
-30
-20
-10
0
10
20
30
Time (s)

u2

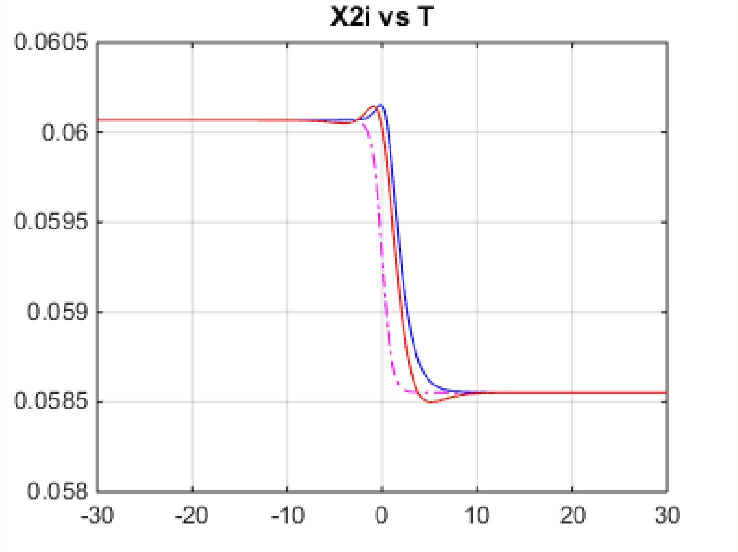


Flight Path

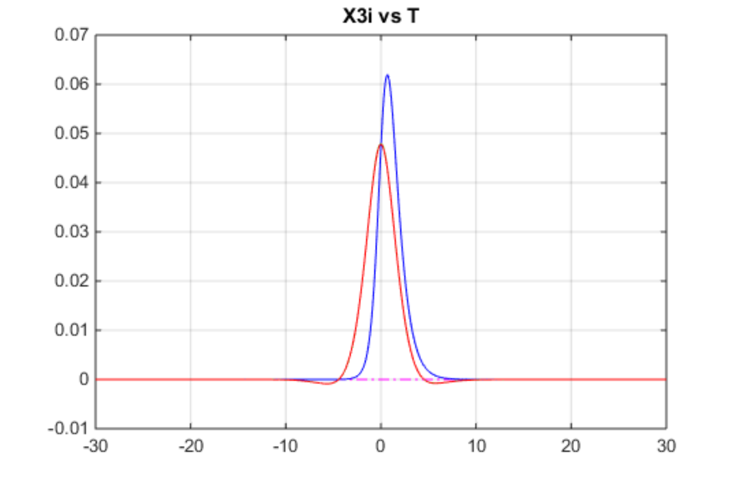


wing path
250
200
150
100
50
0
-50
-100
-150
-200
-Z (m)
0
100
200
300
400
500
X (m)

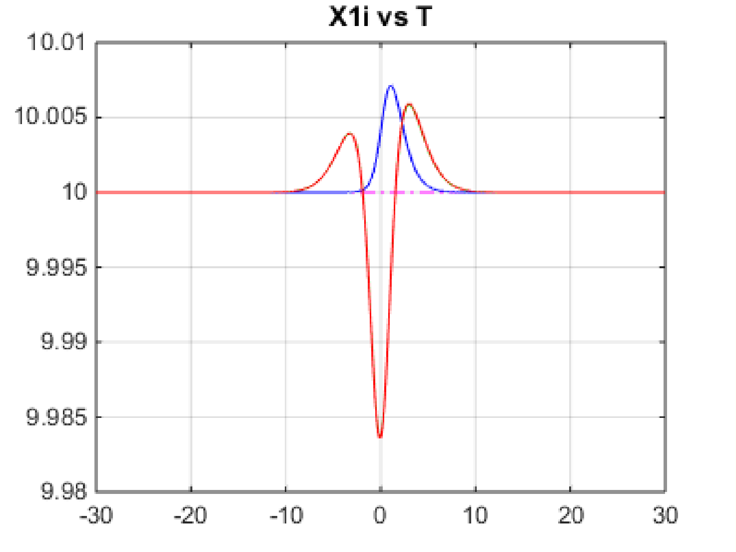
Optimized Time-Varying Control



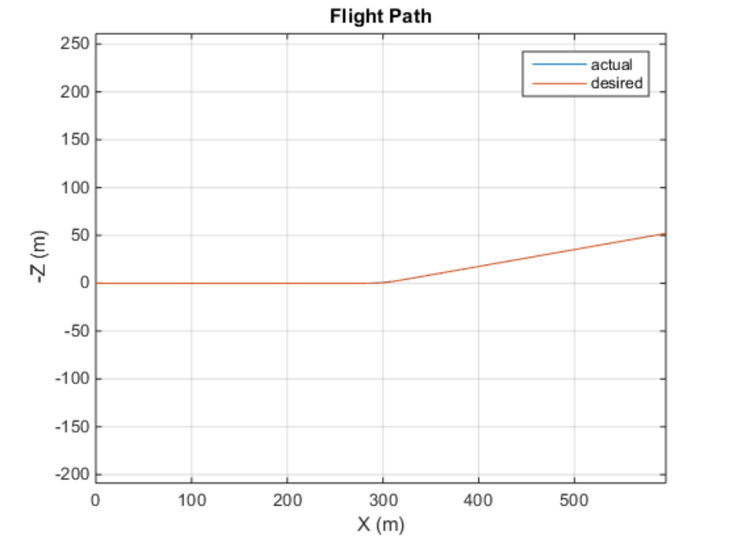
Omega



Velocity

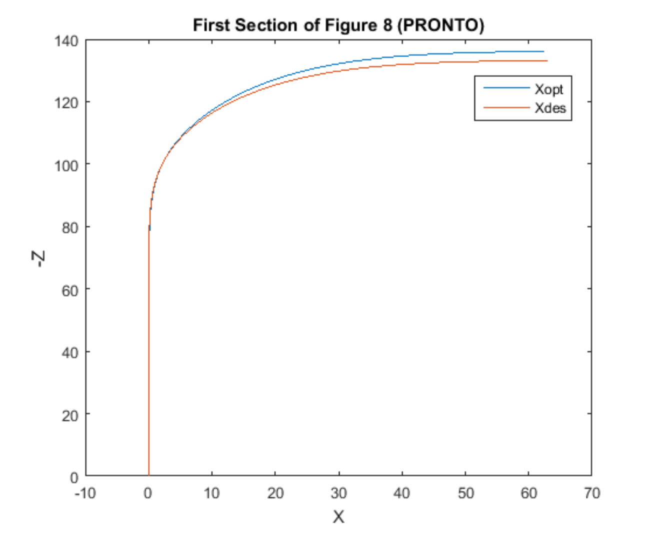


Flight Path

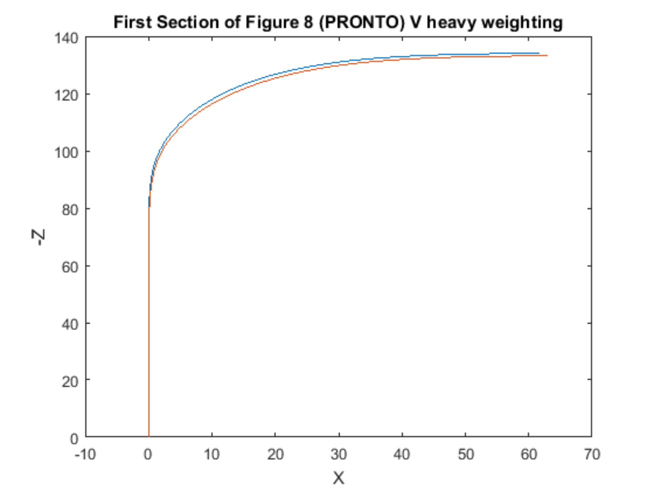


Flight Path
actual
desired
250
200
150
100
50
0
-50
-100
-150
-200
-Z (m)
0
100
200
300
400
500
X (m)

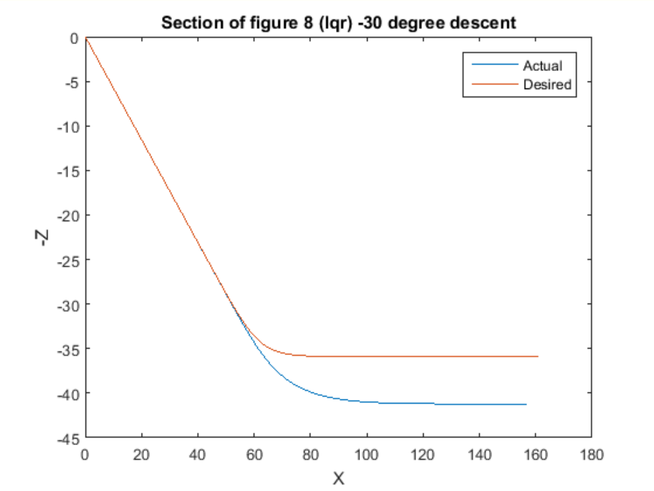
First Part of Figure Eight



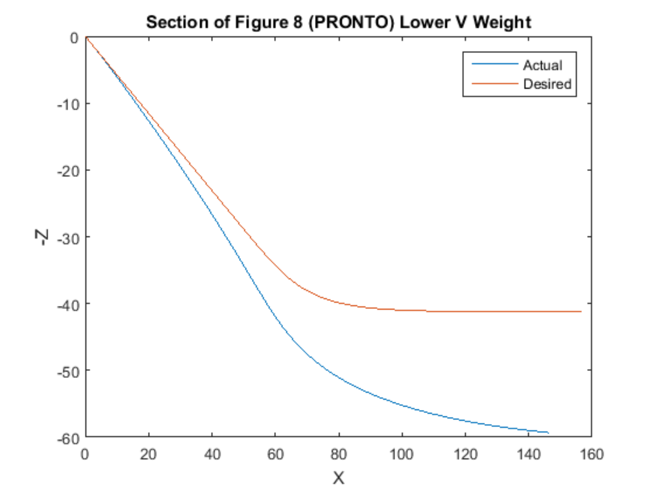
With Weighting



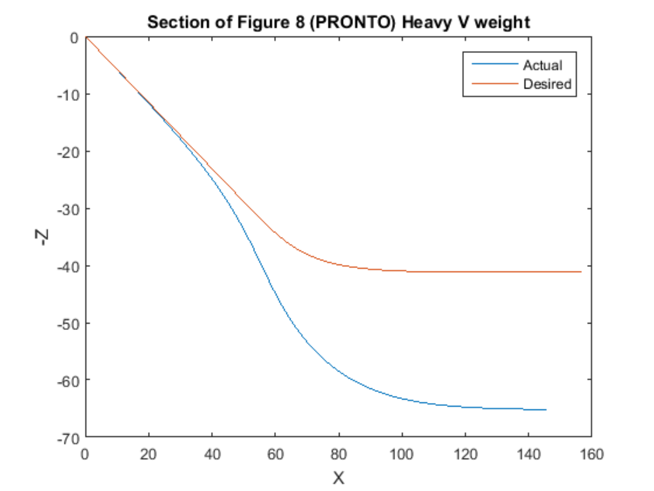
Constant Gain Descent



Low Velocity Figure 8 Section



Optimal Descent Heavy Weight



Conclusion

Concluding Points

- Tracked velocities close to 10 well, but anything over 12 failed to converge
- Descent overshot every time (Thus we crash into the ground)
- Final figure 8 won't be perfect clothoid figure 8
- Certain weights made optimization fail

Further Work

- Cuban Eight Trajectory
- Fix trajectory tracking, especially on the descent
- Include second order terms?
- Make sure optimization gives best results

Questions?

Ben does not approve of this pictures

References I

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