AER1216 - Fundamentals of UAS Project Demonstration

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Fixed-Wing: *Performance*

Range

1000m level = **2,381.6 km**

2000m level = **2,541.5 km**

Endurance

1000m level = **20.9 hrs**

2000m level = **23.1 hrs**

Fixed-Wing: *Model Dynamics*

$$\begin{pmatrix} \dot{p}_n \\ \dot{p}_e \\ \dot{p}_d \end{pmatrix} = \begin{pmatrix} c_\theta c_\psi & s_\phi s_\theta c_\psi - c_\phi s_\psi & c_\phi s_\theta c_\psi + s_\phi s_\psi \\ c_\theta s_\psi & s_\phi s_\theta s_\psi + c_\phi c_\psi & c_\phi s_\theta s_\psi - s_\phi c_\psi \\ -s_\theta & s_\phi c_\theta & c_\phi c_\theta \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

$$\begin{pmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{pmatrix} = \begin{pmatrix} rv - qw \\ pw - ru \\ qu - pv \end{pmatrix} + \frac{1}{\mathrm{m}} \begin{pmatrix} f_x \\ f_y \\ f_z \end{pmatrix},$$

$$\begin{pmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} 1 & \sin\phi \tan\theta & \cos\phi \tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{pmatrix} \begin{pmatrix} p \\ q \\ r \end{pmatrix}$$

$$\begin{pmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{pmatrix} = \begin{pmatrix} \Gamma_1 pq - \Gamma_2 qr \\ \Gamma_5 pr - \Gamma_6 (p^2 - r^2) \\ \Gamma_7 pq - \Gamma_1 qr \end{pmatrix} + \begin{pmatrix} \Gamma_3 l + \Gamma_4 n \\ \frac{1}{J_y} m \\ \Gamma_4 l + \Gamma_8 n \end{pmatrix}.$$

Fixed-Wing: *Linearization*

$$\begin{bmatrix} \dot{\bar{v}} \\ \dot{\bar{p}} \\ \dot{\bar{r}} \\ \dot{\bar{\phi}} \\ \dot{\bar{\varphi}} \end{bmatrix} = \begin{bmatrix} Yv & Yp & Yr & gcos(\theta^*)cos(\phi*)) & 0 \\ Lv & Lp & Lr & 0 & 0 \\ Nv & Np & Nr & 0 & 0 \\ 0 & 1 & cos(\phi^*)tan(\phi^*) & q^*cos(\phi*)tan(\phi*) - r*sin(\phi^*)r^*tan(\theta^*) & 0 \\ 0 & 0 & cos(\phi^*)sec(\theta^*) & p*cos(\phi^*)sec(\theta^*) - r^*sin(\phi^*)sec(\theta^*) & 0 \end{bmatrix} \begin{bmatrix} \bar{v} \\ \bar{p} \\ \bar{r} \\ \bar{\phi} \\ \bar{\varphi} \end{bmatrix} + \begin{bmatrix} Y_{\delta a} & Y_{\delta r} \\ L_{\delta a} & L_{\delta r} \\ N_{\delta a} & N_{\delta r} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \bar{\delta}_a \\ \bar{\delta}_r \end{bmatrix}$$

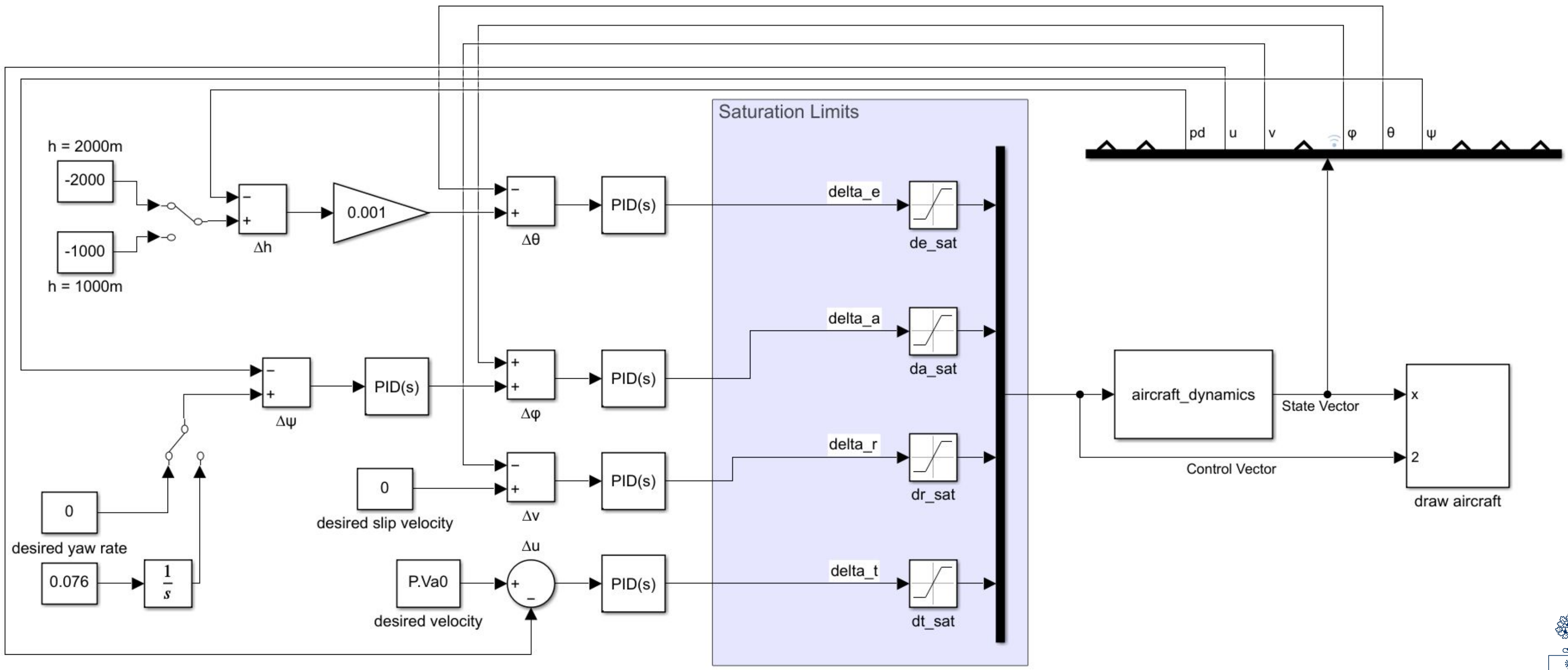
$$\begin{bmatrix} \dot{\bar{u}} \\ \dot{\bar{w}} \\ \dot{\bar{q}} \\ \dot{\bar{\theta}} \\ \dot{\bar{h}} \end{bmatrix} = \begin{bmatrix} Xu & Xw & Xq & -gcos(\theta^*) & 0 \\ Zu & Zw & Zq & -gsin(\theta^*) & 0 \\ Mu & Mw & Mq & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ sin(\theta^*) & -cos(\theta^*) & 0 & u*cos(\phi^*) + w^*sin(\theta^*) & 0 \end{bmatrix} \begin{bmatrix} \bar{u} \\ \bar{w} \\ \bar{q} \\ \bar{\theta} \\ \bar{h} \end{bmatrix} + \begin{bmatrix} X_{\delta e} & X_{\delta t} \\ Z_{\delta e} & 0 \\ M_{\delta e} & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \bar{\delta}_e \\ \bar{\delta}_t \end{bmatrix}$$

Flight dynamics are decoupled into lateral and longitudinal dynamics

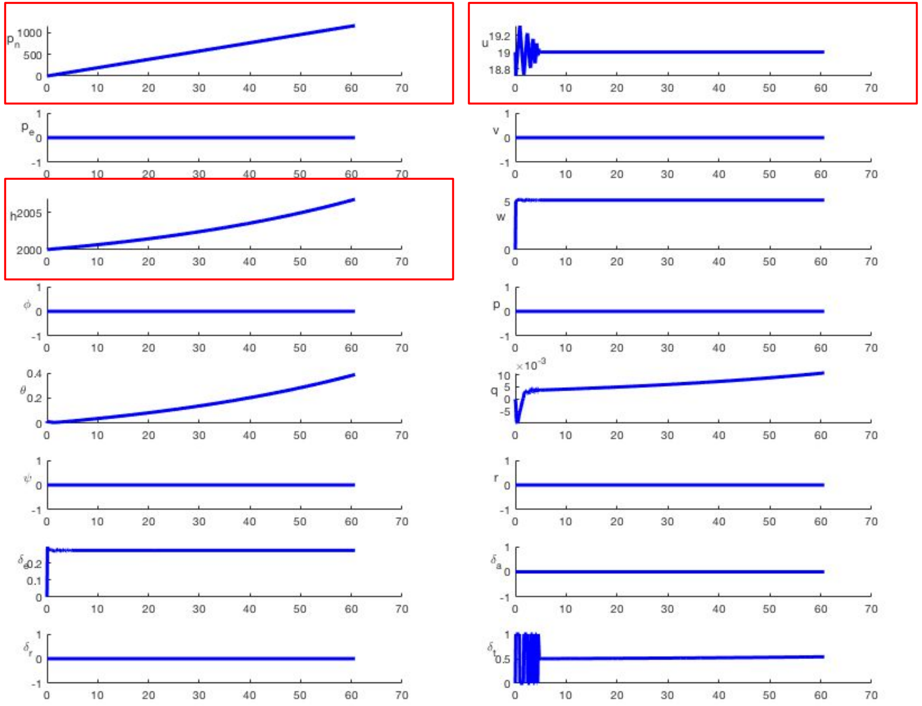
$$\begin{bmatrix} u* \\ v* \\ w* \\ V_a^* \\ p* \\ q* \\ r* \\ \phi* \\ \theta* \\ \varphi* \\ \beta* \\ \alpha* \\ \delta_e^* \\ \delta_a^* \\ \delta_r^* \\ \delta_t^* \end{bmatrix} = \begin{bmatrix} 18.33 \\ 0 \\ 5.01 \\ 19 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.2671 \\ 0 \\ 0 \\ 0.2671 \\ -0.15616 \\ 0 \\ 0 \\ 0.8311 \end{bmatrix}$$

Trim States & Inputs

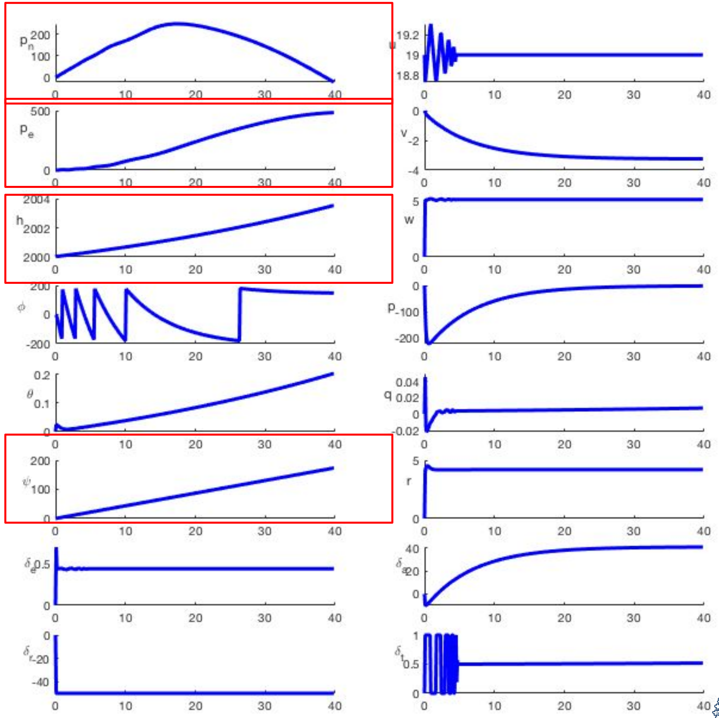
Fixed-Wing: *Controller (Alt. Hold and Coor. Turn)*



Fixed-Wing: *Simulation Results*

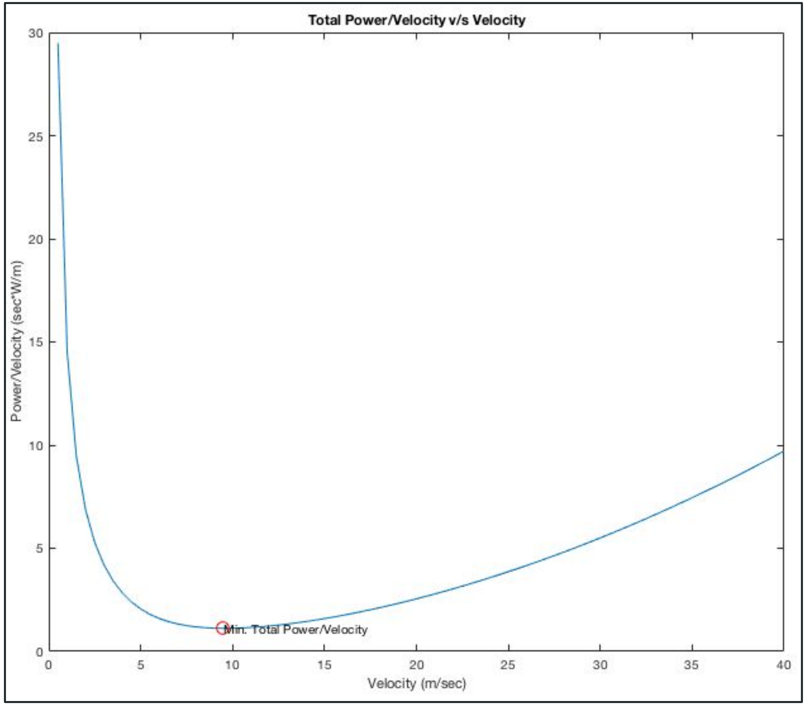


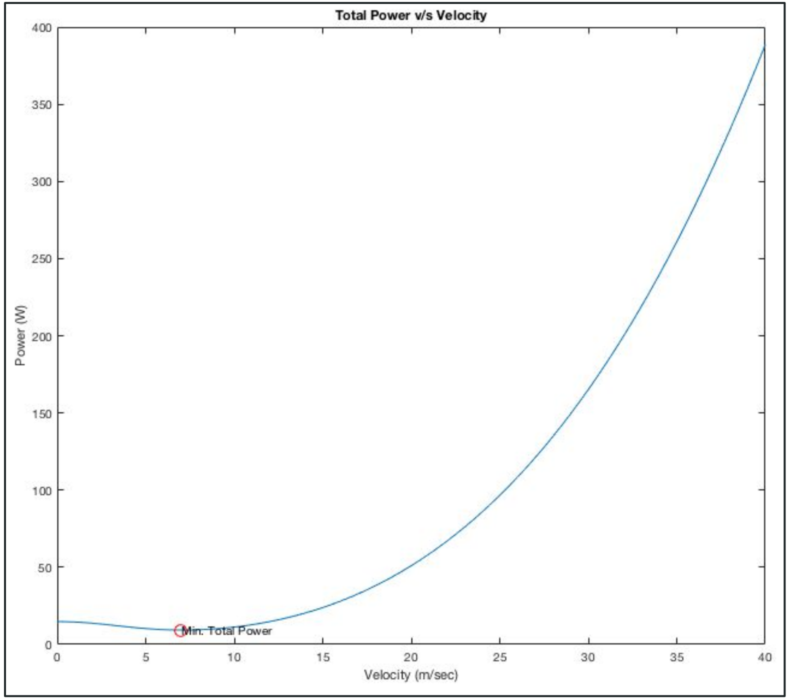
Steady-Level Flight (Altitude and Speed Control)



Level-Coordinated Turn

Multi-Rotor: *Performance*





Max. Range: ~34 km
Flying speed for max. range: 9.5 m/sec

Max. Endurance: ~68 minutes
Flying speed for max. endurance: 7 m/sec

Multi-Rotor: *Model Dynamics*

Earth frame

$$\begin{pmatrix} \dot{p}_n \\ \dot{p}_e \\ \dot{h} \end{pmatrix} = \begin{pmatrix} c\theta c\psi & s\phi s\theta c\psi - c\phi s\psi & c\phi s\theta c\psi + s\phi s\psi \\ c\theta s\psi & s\phi s\theta s\psi + c\phi c\psi & c\phi s\theta s\psi - s\phi c\psi \\ s\theta & -s\phi c\theta & -c\phi c\theta \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

Body frame

$$\begin{pmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{pmatrix} = \begin{pmatrix} rv - qw \\ pw - ru \\ qu - pv \end{pmatrix} + \begin{pmatrix} -g \sin\theta \\ g \cos\theta \sin\phi \\ g \cos\theta \cos\phi \end{pmatrix} + \frac{1}{m} \begin{pmatrix} 0 \\ 0 \\ -F \end{pmatrix},$$

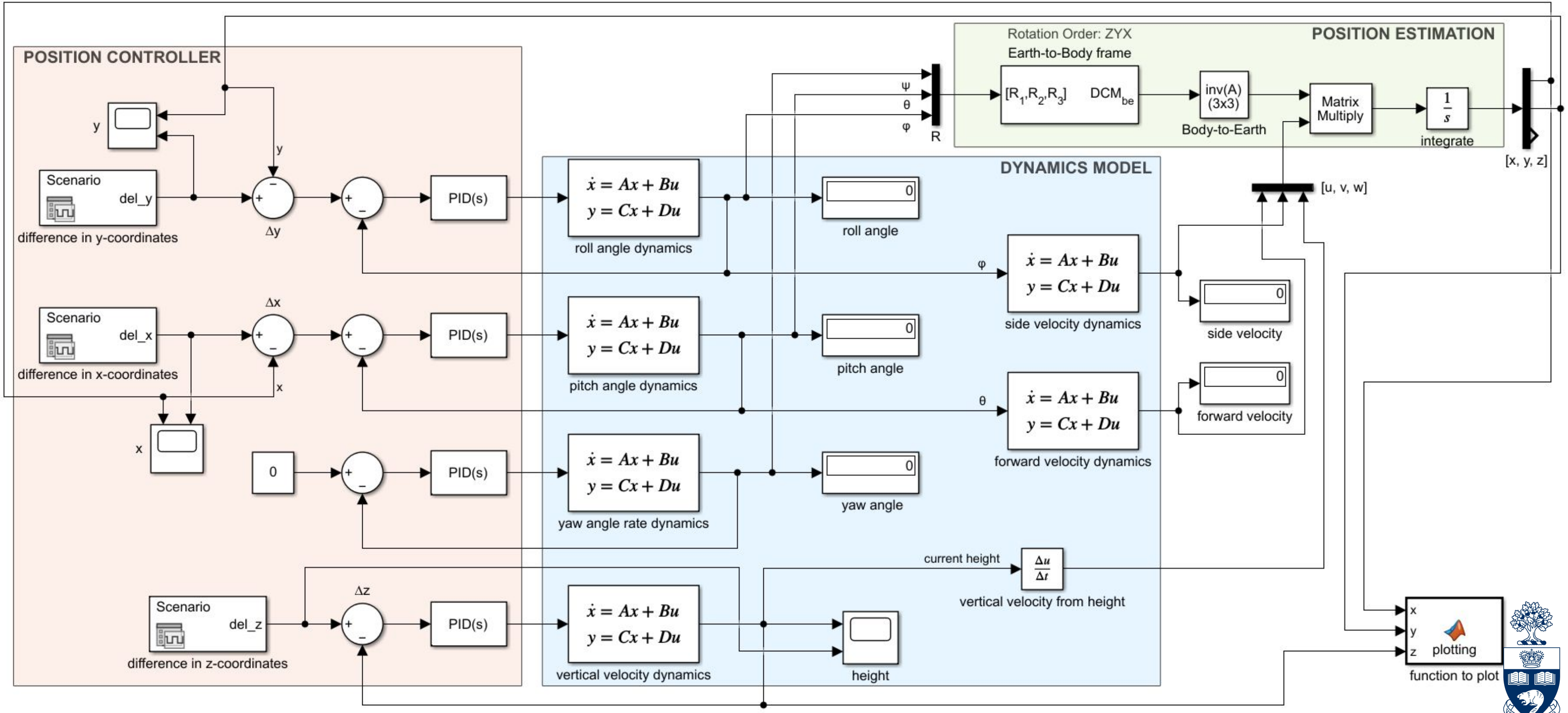
Vehicle frames

$$\begin{pmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} 1 & \sin\phi \tan\theta & \cos\phi \tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{pmatrix} \begin{pmatrix} p \\ q \\ r \end{pmatrix},$$

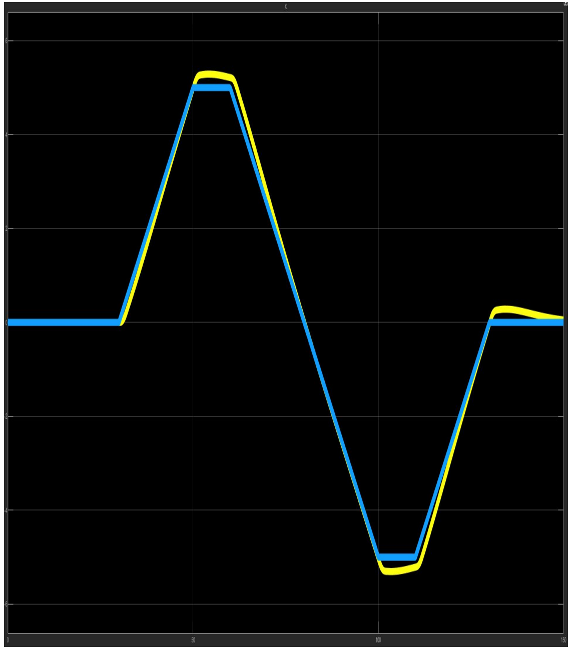
Body frame

$$\begin{pmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{pmatrix} = \begin{pmatrix} \frac{J_y - J_z}{J_x} qr \\ \frac{J_z - J_x}{J_y} pr \\ \frac{J_x - J_y}{J_z} pq \end{pmatrix} + \begin{pmatrix} \frac{1}{J_x} \tau_\phi \\ \frac{1}{J_y} \tau_\theta \\ \frac{1}{J_z} \tau_\psi \end{pmatrix}.$$

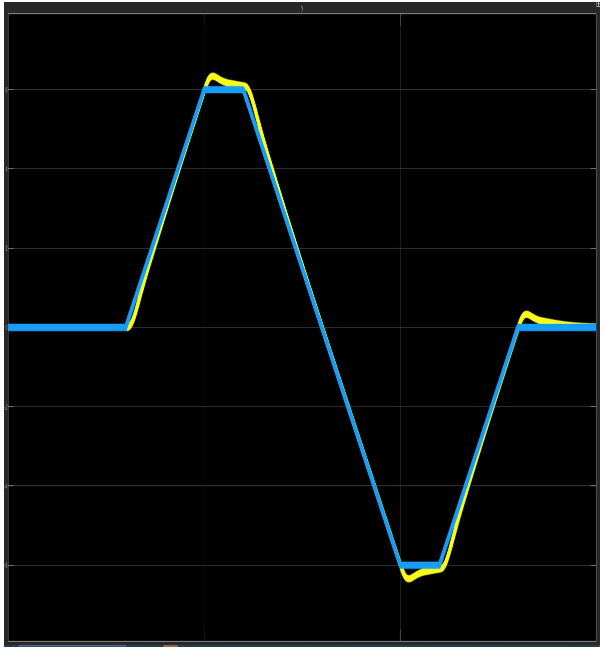
Multi-Rotor: *Controller*



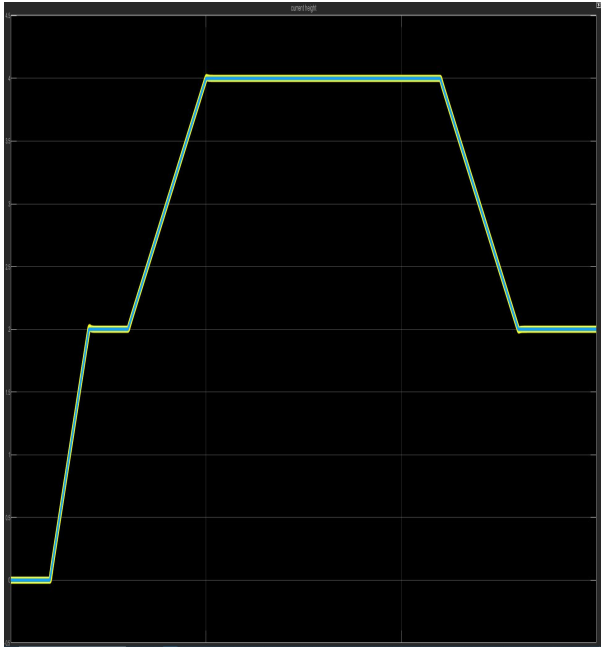
Multi-Rotor: *Simulation Results*



x-coordinate

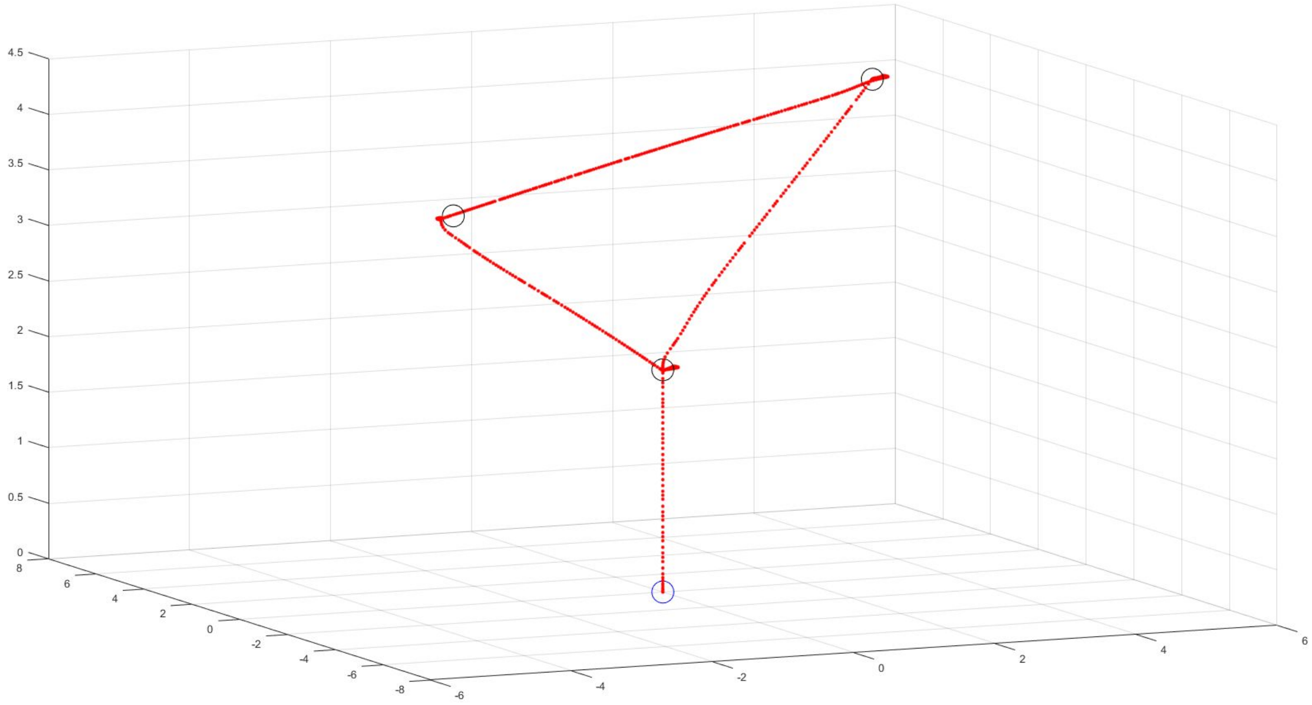


y-coordinate



z-coordinate

Multi-Rotor: *Simulation Results*



Conclusion

- It was observed that linearized system is quite sensitive to trim conditions
- Non-linear dynamics equations are easier to derive and implement; hard to design a controller for the same
- Linear dynamics are mathematically intense to derive; easier to develop a controller and debug during development
- Important to have good visualization tools