Automatic Flight Control

Flight Control of a Fixed-Wing Aircraft

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Flight control of a fixed wing aircraft

- Let us consider the flight control of a fixed wing aircraft.
- The purpose of the controller is to allow the aircraft to flight automatically tracking the set-points in airspeed, altitude and heading.
- This controller is a basic autopilot system.
- The aircraft considered for this control application will be a general model with a simplified propulsion system.

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Fixed wing aircraft model

- The equations of motion for the fixed wing aircraft are

$$\begin{aligned}
\dot{\mathbf{p}}_{\mathbf{e}} =& \mathbf{C}_{\mathbf{b/e}}{}^{T}\mathbf{V}_{\mathbf{b}}, \\
\dot{\mathbf{\Phi}} =& \mathbf{H}\left(\mathbf{\Phi}\right)\mathbf{\Omega}_{\mathbf{b}}, \\
\dot{\mathbf{V}}_{\mathbf{b}} =& \frac{\left(\mathbf{F}_{\mathbf{a,b}}+\mathbf{F}_{\mathbf{t,b}}\right)}{m}+\mathbf{G}_{\mathbf{b}}-\mathbf{\Omega}_{\mathbf{b}}\times\mathbf{V}_{\mathbf{b}}, \\
\dot{\mathbf{\Omega}}_{\mathbf{b}} =& \mathbf{I}_{\mathbf{b}}{}^{-1}\left(\mathbf{M}_{\mathbf{a,b}}+\mathbf{M}_{\mathbf{t,b}}-\mathbf{\Omega}_{\mathbf{b}}\times\mathbf{I}_{\mathbf{b}}\mathbf{\Omega}_{\mathbf{b}}\right).
\end{aligned}$$

Notes

Fixed wing aircraft model

- Where

$$\mathbf{G}_{\mathbf{b}} = \begin{bmatrix} -gs\theta \\ gs\phi c\theta \\ gc\phi c\theta \end{bmatrix},$$

$$\mathbf{F}_{\mathbf{a,b}} = \mathbf{C}_{\mathbf{b/w}}\mathbf{F}_{\mathbf{a,w}} = \mathbf{C}_{\mathbf{b/w}}\begin{bmatrix} -D \\ -C \\ -L \end{bmatrix} = \mathbf{C}_{\mathbf{b/w}}\begin{bmatrix} -\bar{q}SC_{D}, \\ -\bar{q}SC_{C}, \\ -\bar{q}SC_{L}, \end{bmatrix},$$

$$\mathbf{F}_{\mathbf{t,b}} = \begin{bmatrix} F_t \\ 0 \\ 0 \end{bmatrix}.$$

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Fixed wing aircraft model

- And

$$\mathbf{M}_{\mathbf{a,b}} = \begin{bmatrix} l \\ m \\ n \end{bmatrix} = \begin{bmatrix} \bar{q}SbC_{l}, \\ \bar{q}ScC_{m}, \\ \bar{q}SbC_{n}, \end{bmatrix} - \Delta CG_{b}\times\mathbf{F}_{\mathbf{a,b}},$$

$$\mathbf{M}_{\mathbf{t,b}} = -\Delta CG_{b}\times\mathbf{F}_{\mathbf{t,b}}$$

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Fixed wing aircraft model

- The aerodynamic coefficients are modeled by

$$
\begin{aligned}
C_L &= C_{L,0} + C_{L,\alpha}\alpha + C_{L,\delta_f}\delta_f + C_{L,i_h}i_h + C_{L,\delta_e}\delta_e + \frac{c}{2V}\left(C_{L,\dot{\alpha}}\dot{\alpha} + C_{L,q}q\right) + C_{L,M}M, \\
C_D &= C_{D,0} + \frac{(C_L - C_{L,min\,drag})^2}{\pi ARe} + C_{D,M}M, \\
C_C &= C_{C,\beta}\beta + C_{C,\delta_a}\delta_a + C_{C,\delta_r}\delta_r + \frac{b}{2V}\left(C_{C,p}p + C_{C,r}r\right), \\
C_l &= C_{l,\beta}\beta + C_{l,\delta_a}\delta_a + C_{l,\delta_r}\delta_r + \frac{b}{2V}\left(C_{l,p}p + C_{l,r}r\right), \\
C_m &= C_{m,0} + C_{m,\alpha}\alpha + C_{m,\delta_f}\delta_f + C_{m,i_h}i_h + C_{m,\delta_e}\delta_e + \frac{c}{2V}\left(C_{m,\dot{\alpha}}\dot{\alpha} + C_{m,q}q\right) + C_{m,M}M, \\
C_n &= C_{n,\beta}\beta + C_{n,\delta_a}\delta_a + C_{n,\delta_r}\delta_r + \frac{b}{2V}\left(C_{n,p}p + C_{n,r}r\right).
\end{aligned}
$$

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Fixed wing aircraft model

- And the propulsion system is modeled by

$$\mathbf{F_{t,b}} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} F_{t_{max}}\delta_t.$$

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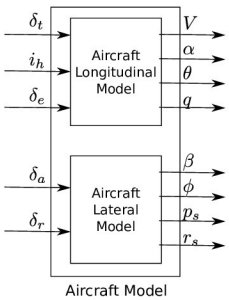
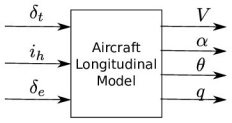
Linearized aircraft model



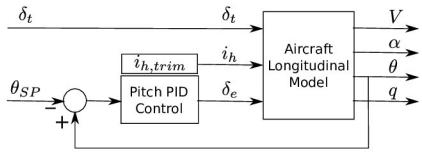
Notes

Linearized aircraft longitudinal model



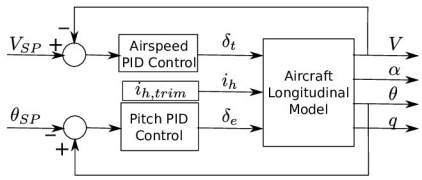
Notes

Pitch control - inner loop (with elevator)



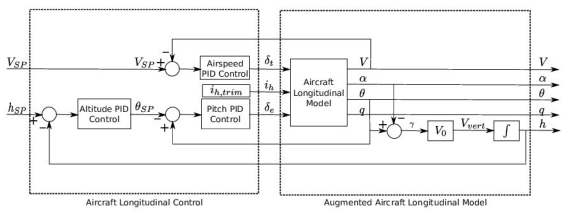
Notes

Airspeed control loop (with elevator)



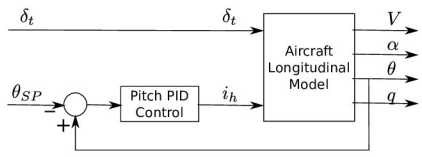
Notes

Altitude control - outer loop (with elevator)



Notes

Pitch control - inner loop (without elevator)



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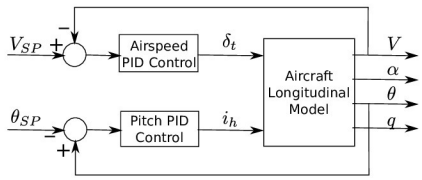
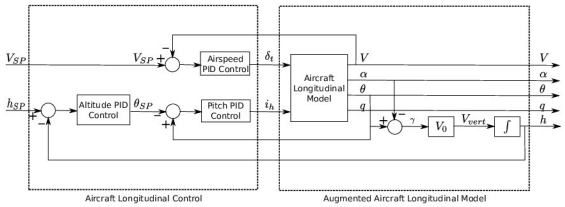
Airspeed control loop (without elevator)



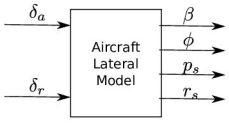
Notes

Altitude control - outer loop (without elevator)



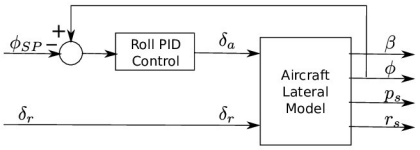
Notes

Linearized aircraft lateral model



Notes

Roll control - inner loop



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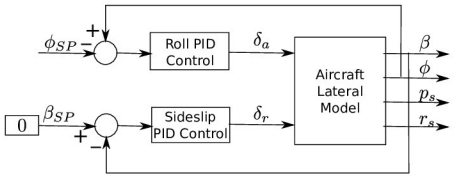
Sideslip control loop



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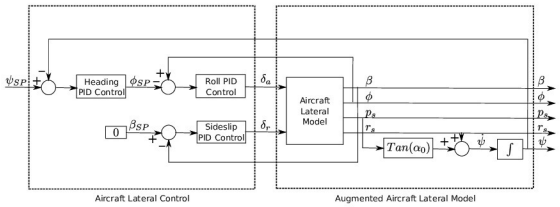
Heading control - outer loop



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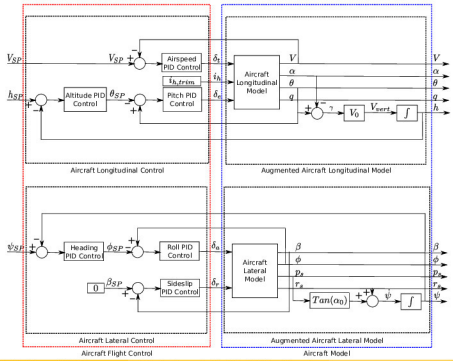
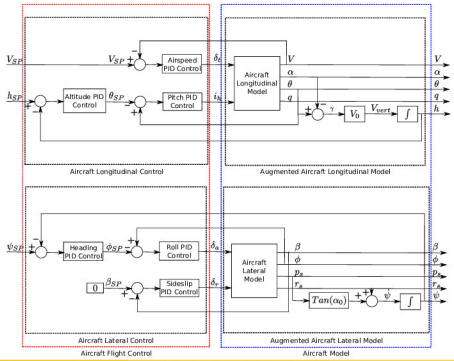
Multiloop control (with elevator)



Notes

Multiloop control (without elevator)



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Design of flight control system

- Design the autopilot control loops in this order
  1. Longitudinal control
     1. Pitch PID.
     2. Airspeed PID.
     3. Altitude PID.
  2. Lateral control
     1. Roll PID.
     2. Sideslip PID.
     3. Heading PID.

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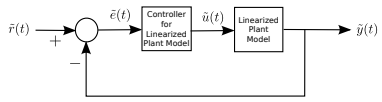
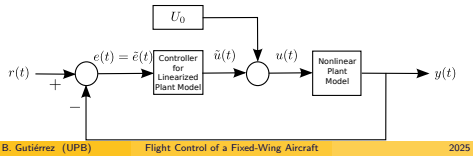
Implementation of linear controllers for nonlinear plants

Design for linearized plant model



Design for linearized plant model implemented with nonlinear plant



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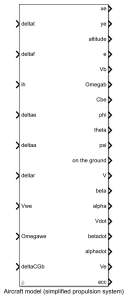
Simulink model for the fixed wing aircraft



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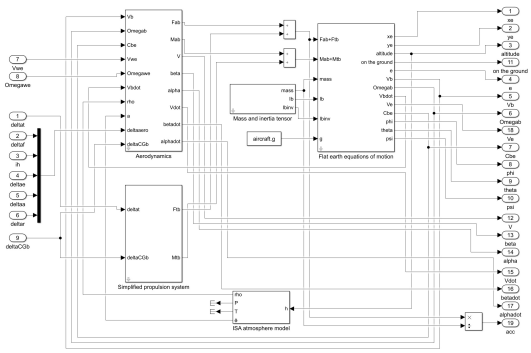
Simulink model for the fixed wing aircraft



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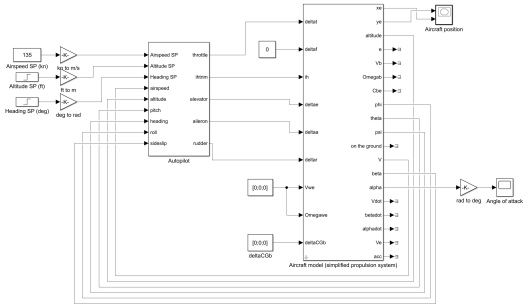
Flight control system



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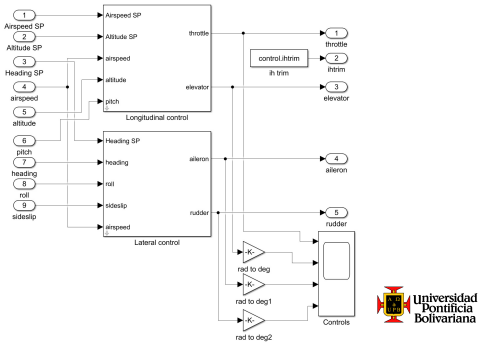
Flight control system



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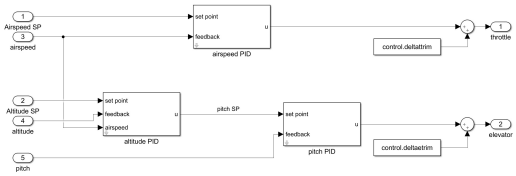
Longitudinal control



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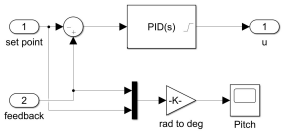
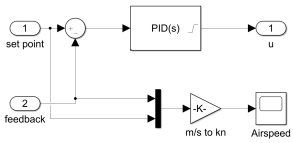
Notes

Inner loop: pitch PID



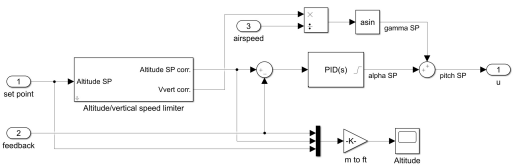
Notes

Airspeed PID



Notes

Outer loop: altitude PID



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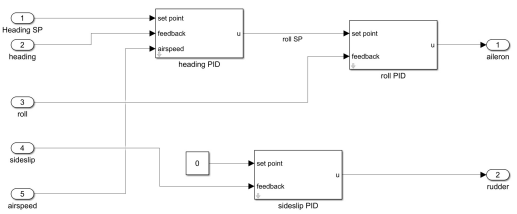
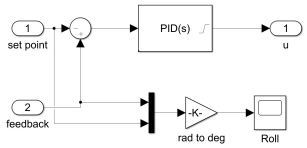
Lateral control



Notes

Inner loop: roll PID



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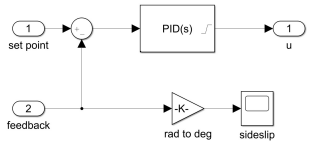
Sideslip PID



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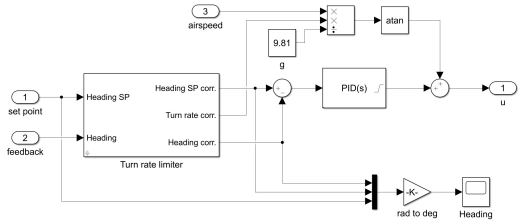
Outer loop: heading PID



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