1 Formula reference

1.1 Estimated Augmented States

1. Payload Trim

$$\hat{\mathbf{f}}_d = -\left(m_p g \mathbf{1}_3 + \hat{\mathbf{d}}_\perp\right) \tag{1}$$

2. Total Trim

$$\hat{\mathbf{f}}_t = -m_b g \mathbf{1}_3 + \hat{\mathbf{f}}_d - \hat{\mathbf{d}}_T \tag{2}$$

3. Equilibrium Swing

$$\hat{\mathbf{r}}_d = l \frac{\hat{\mathbf{f}}_{d1:2}}{\left\|\hat{\mathbf{f}}_d\right\|} \tag{3}$$

1.2 Error Quantities

1. Translational Error

$$\mathbf{s}_p = k_p \mathbf{e}_p + \mathbf{e}_v \tag{4}$$

2. Swing Error

$$\hat{\boldsymbol{\mu}} = k_L \left(\mathbf{r} - \hat{\mathbf{r}}_d\right) \tag{5}$$

3. Cross Feeding

$$\hat{\mathtt{R}} = \mathbf{B}\left(\mathbf{v} + \hat{\boldsymbol{\mu}}\right) \tag{6}$$

4. Filtered Cross Feeding (Rates)

$$\hat{\mathtt{F}} = \frac{k_r}{s+\lambda}\hat{\mathtt{R}}(s) \;\mid\; \dot{\hat{\mathtt{F}}} = -\lambda \hat{\mathtt{F}} + k_r \hat{\mathtt{R}} \tag{7}$$

5. Generalized Cross Feeding

$$\hat{\boldsymbol{\zeta}} = k_p \mathbf{e}_p + \hat{\mathtt{F}} - \mathbf{v}_d \;\mid\; \dot{\hat{\boldsymbol{\zeta}}} = k_p \dot{\mathbf{e}}_p - \lambda \hat{\mathtt{F}} + k_r \hat{\mathtt{R}} \tag{8}$$

1.3 Disturbance Estimation Law

1. Disturbance on UAV

$$\hat{\mathbf{d}}_b = \kappa \int_0^t \mathfrak{B}\left(m_b \dot{\mathbf{v}}_b - \mathbf{f}_L - m_b g \mathbf{1}_3 - \hat{\mathbf{d}}_b\right) d\tau \tag{9}$$

2. Disturbance projected to cable perpendicular

$$\hat{\mathbf{d}}_\perp = \boldsymbol{\ell} - \frac{\hat{\mathbf{d}}_b^\top \boldsymbol{\ell}}{l^2}\boldsymbol{\ell} \tag{10}$$

3. Total disturbance

$$\hat{\mathbf{d}}_T = \lambda_T \left(\underbrace{\left(m_p + m_b\right)}_{m_{sys}} \mathbf{v}_p + m_b \mathbf{B}\mathbf{v} - \int_0^t \left(\mathbf{f}_L + \hat{\mathbf{d}}_\perp + \hat{\mathbf{d}}_T + \left(m_p + m_b\right) g \mathbf{1}_3\right) d\tau \right) \tag{11}$$

1.4 Control Law

1. Sync Force

$$\hat{\mathbf{f}}_0 = -m_b \left(\hat{\boldsymbol{\zeta}} + k_L \mathbf{B}\mathbf{v} + \dot{\mathbf{B}}\hat{\boldsymbol{\mu}} \right) \tag{12}$$

2. Swing Compensator

$$\hat{\mathbf{f}}_a = K_0 \left(\mathbf{v}_p + \hat{\boldsymbol{\zeta}} + \underbrace{\mathbf{B}\left(\mathbf{v} + \hat{\boldsymbol{\mu}}\right)}_{\mathtt{R}} \right) \tag{13}$$

3. Translational Compensator

$$\hat{\mathbf{f}}_b = m_p \left(\hat{\boldsymbol{\zeta}} + k_p \mathbf{s}_p \right) \tag{14}$$