Comparing Optimization and Estimation Techniques for Low-Thrust Spacecraft Rendezvous

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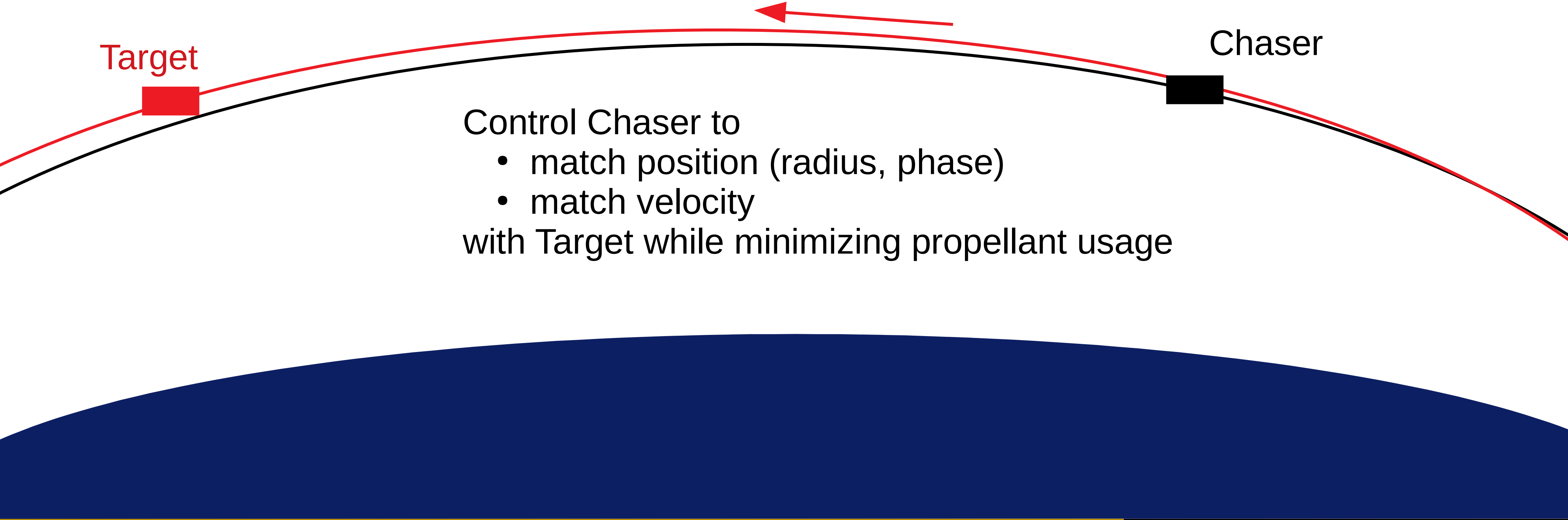
AAE 568 Course Project, Purdue University

Problem Motivation

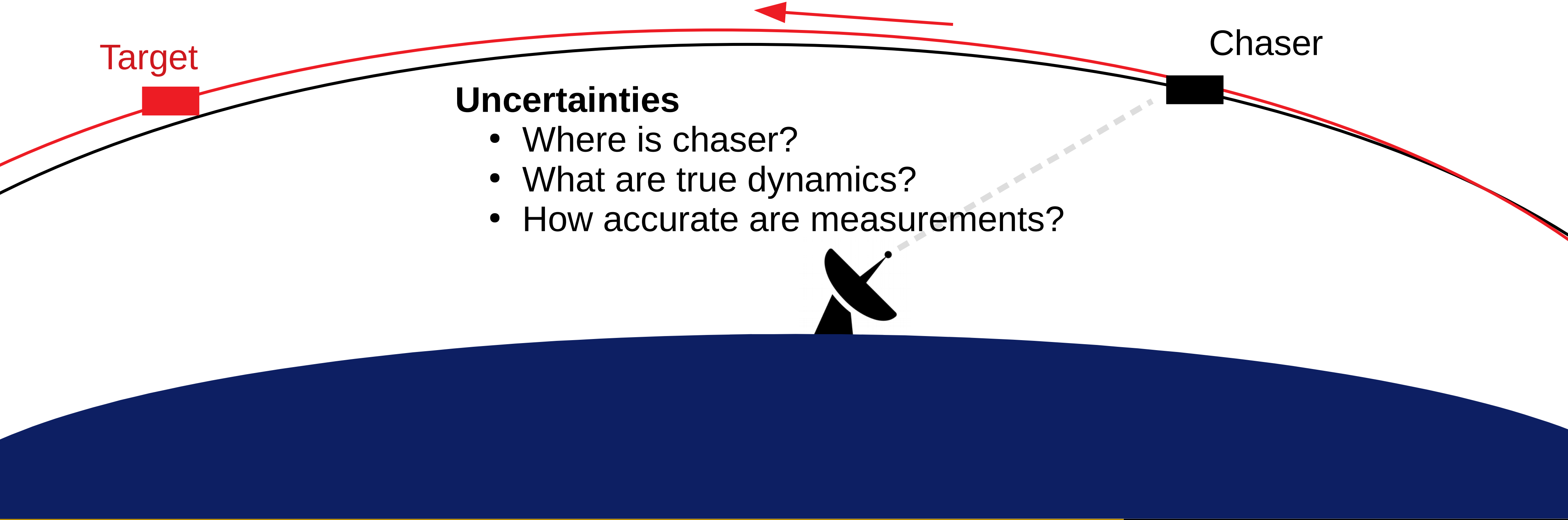


Control Chaser to

- match position (radius, phase)
- match velocity

with Target while minimizing propellant usage

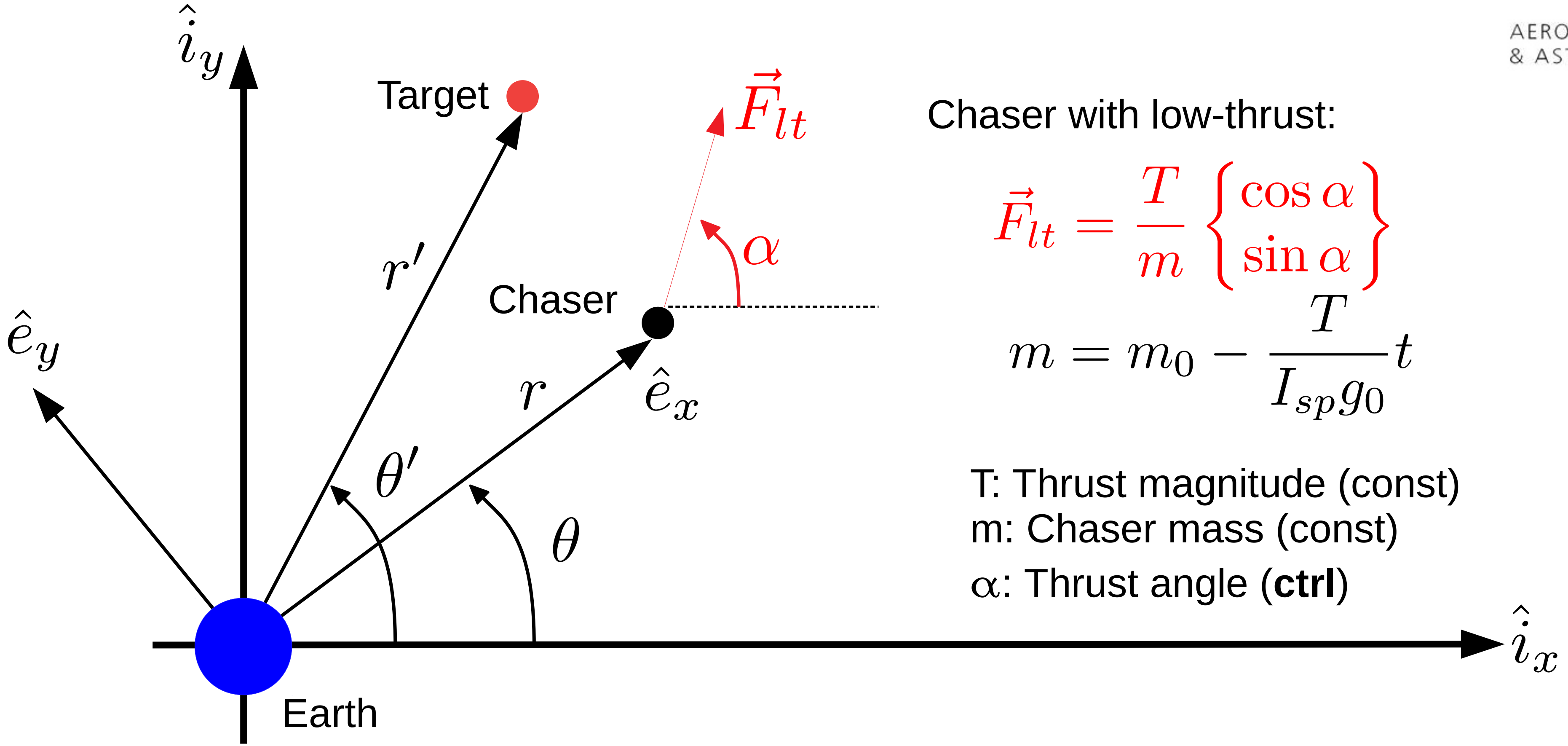
Problem Motivation, Cont'd



Uncertainties

- Where is chaser?
- What are true dynamics?
- How accurate are measurements?

Low-Thrust Control



Chaser with low-thrust:

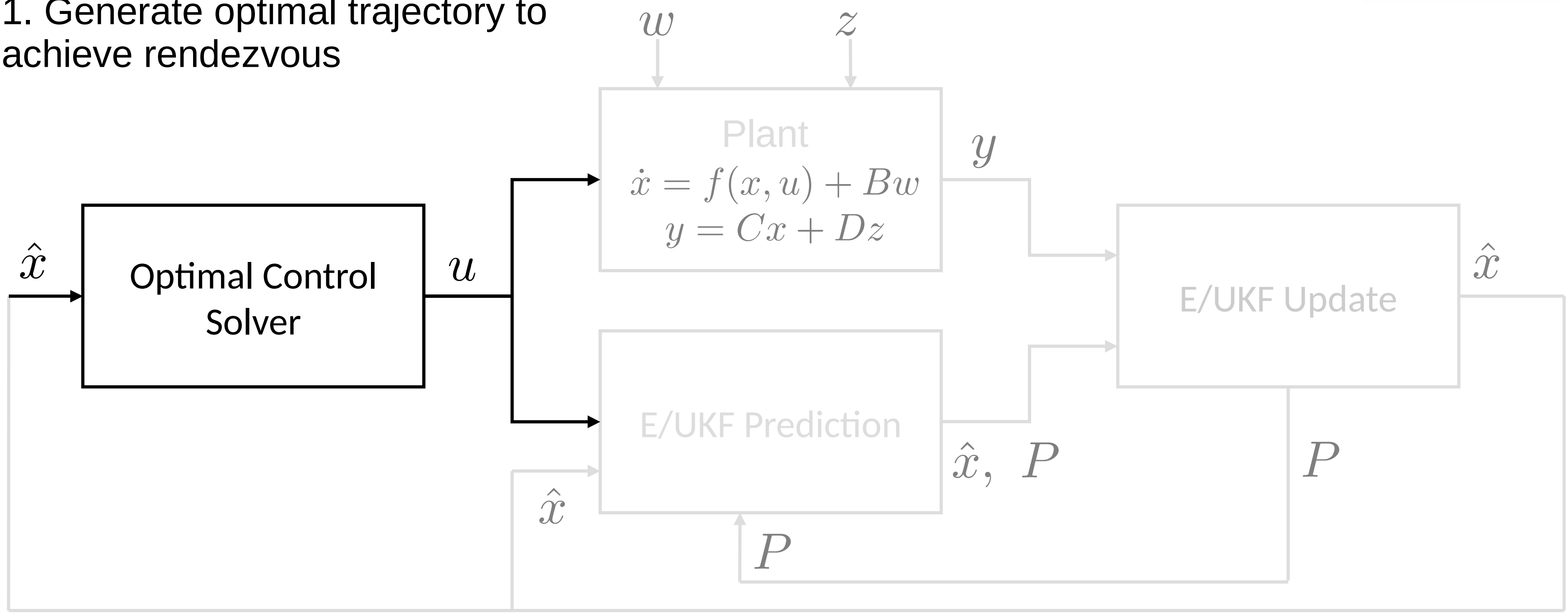
$$\vec{F}_{lt} = \frac{T}{m} \begin{Bmatrix} \cos\alpha \\ \sin\alpha \end{Bmatrix}$$

$$m = m_0 - \frac{T}{I_{sp} g_0} t$$

T: Thrust magnitude (const)
m: Chaser mass (const)
α: Thrust angle (**ctrl**)

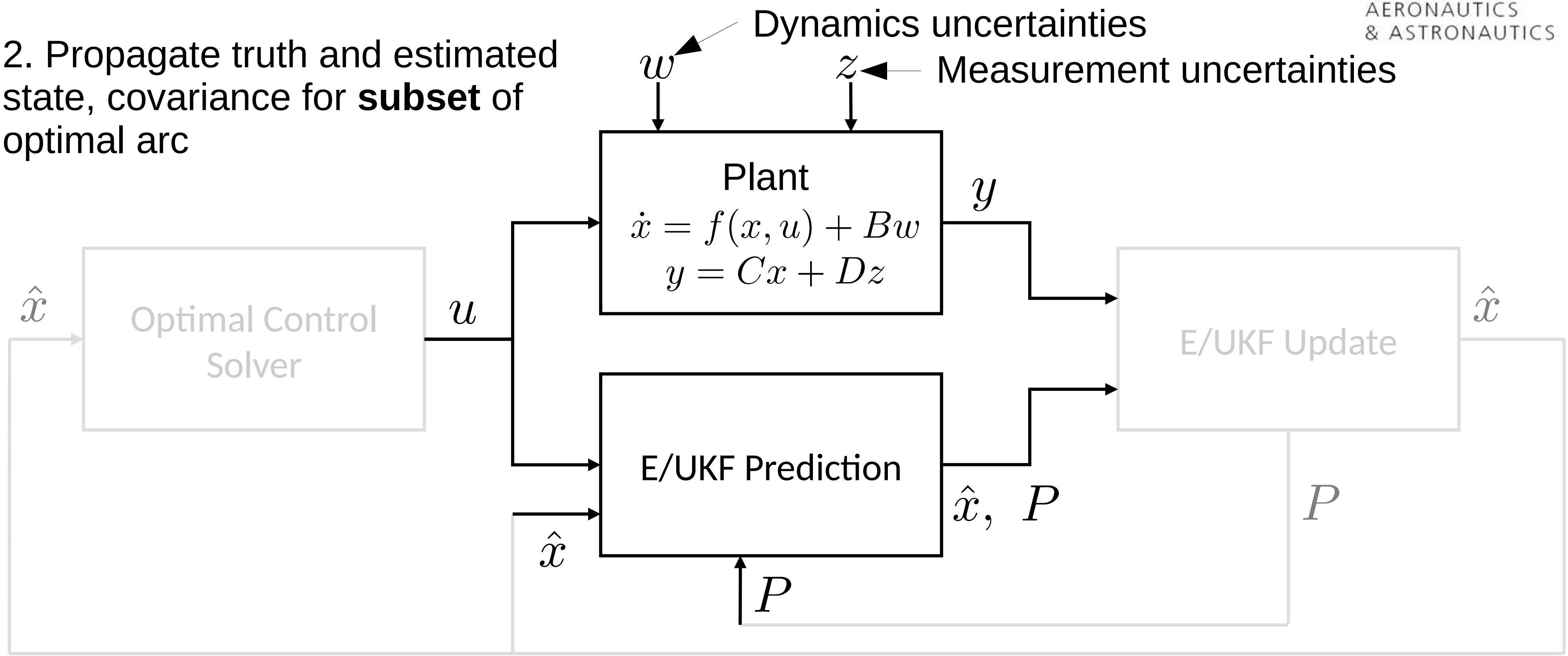
Problem Overview

1. Generate optimal trajectory to achieve rendezvous



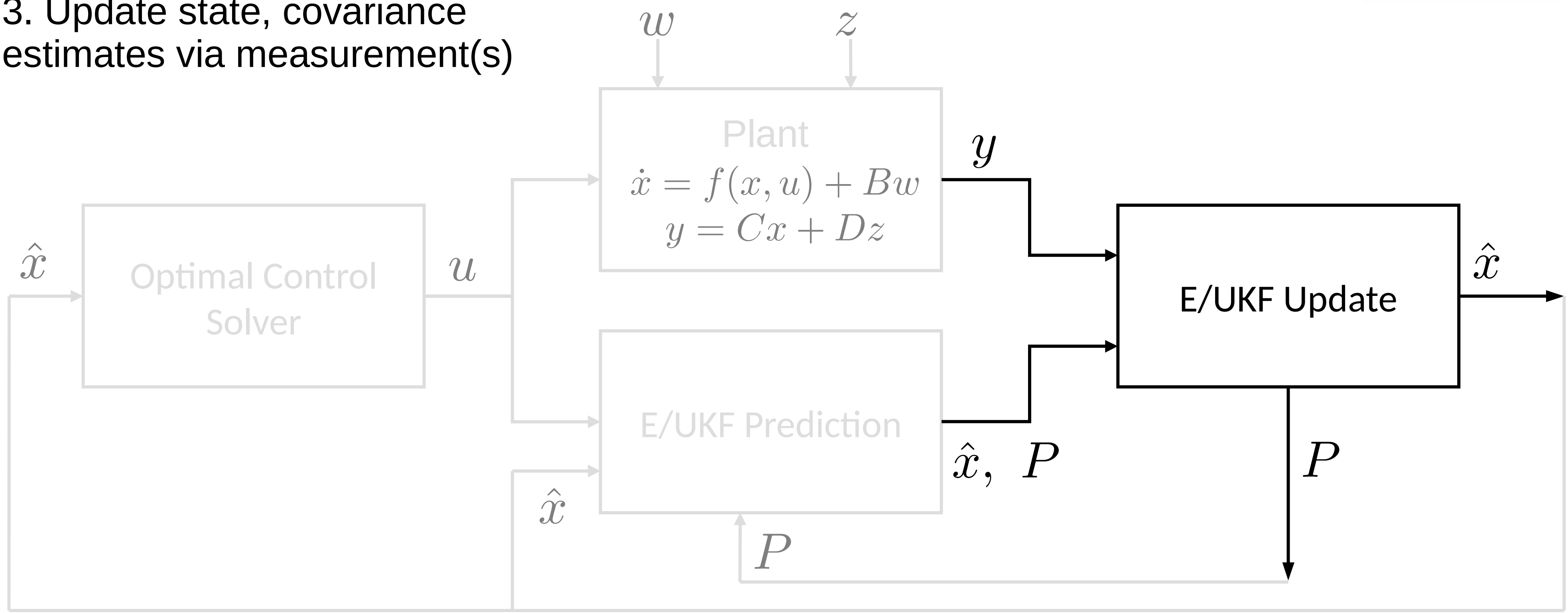
Problem Overview

2. Propagate truth and estimated state, covariance for **subset** of optimal arc



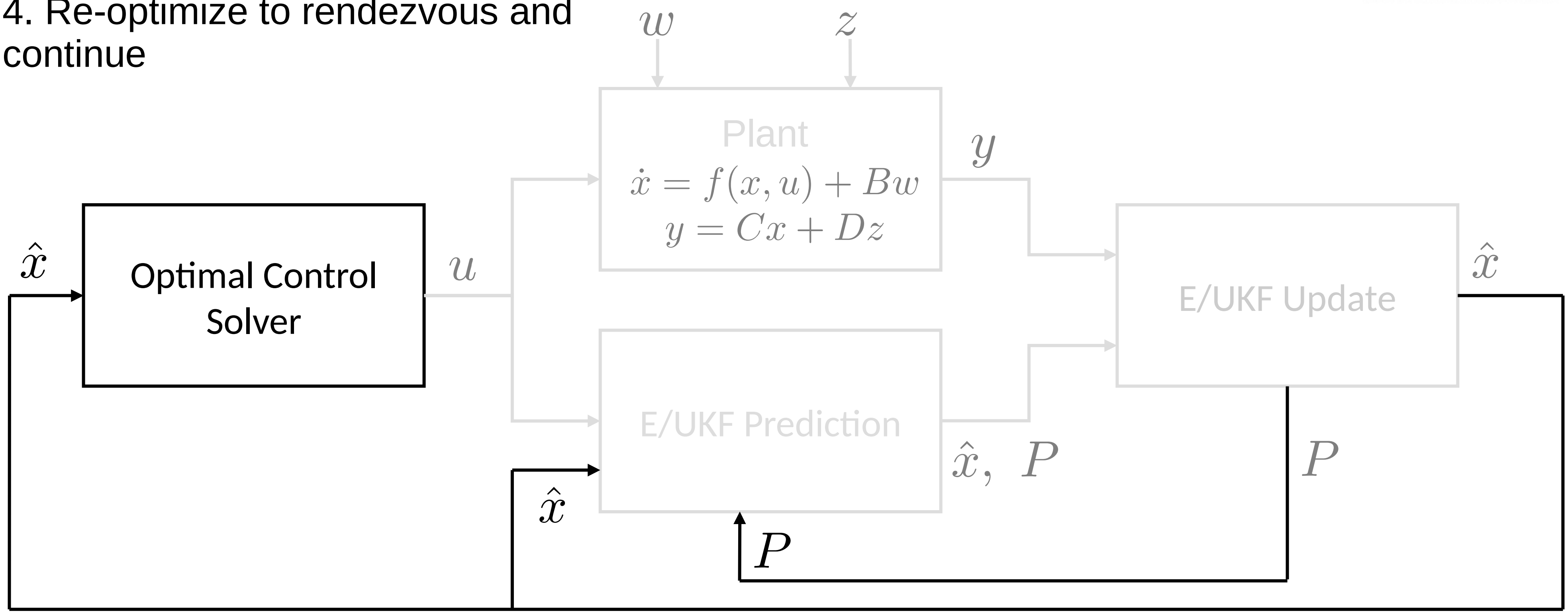
Problem Overview

3. Update state, covariance estimates via measurement(s)



Problem Overview

4. Re-optimize to rendezvous and continue



Optimization Problem Definition

Goal: minimize propellant usage = maximize m_f = minimize t_f

$$\min_{\alpha} \; J = t_f$$

Subject to:

$$\dot{\vec{x}} = \begin{Bmatrix} \dot{r} \\ \dot{\theta} \\ r\dot{\theta}^2 - \frac{\mu}{r^2} + \frac{T}{m}\left(C_\alpha C_\theta + S_\alpha S_\theta\right) \\ -2\frac{\dot{r}\dot{\theta}}{r} + \frac{T}{mr}\left(S_\alpha C_\theta - C_\alpha S_\theta\right) \end{Bmatrix} \qquad \vec{x}(t_f) = \begin{Bmatrix} r' \\ \theta'_0 + \dot{\theta}' t \\ \dot{r}'_0 \\ \dot{\theta}'_0 \end{Bmatrix}$$

$$\vec{x}(t_0) = \begin{Bmatrix} r_0 & \theta_0 & \dot{r}_0 & \dot{\theta}_0 \end{Bmatrix}^T, \qquad t_0 = 0 \qquad\qquad t_f = \text{free}$$

Indirect Optimization

Direct Optimization

Compare Optimization Methods

Estimation Problem Definition

PURDUE™
AERONAUTICS
& ASTRONAUTICS

Extended Kalman Filter

Unscented Kalman Filter

Estimation Method Comparison

Example: Indirect + EKF Results