Reference Frames for Spacecraft Dynamics and Control

Chris Hall
Aerospace and Ocean Engineering
cdhall@vt.edu
Reference Frames

- A reference frame is a set of three mutually perpendicular (orthogonal) unit vectors.
- Typical notations include
  \( \hat{i}, \hat{j}, \hat{k}, \hat{I}, \hat{J}, \hat{K}, \hat{e}_1, \hat{e}_2, \hat{e}_3, \hat{b}_1, \hat{b}_2, \hat{b}_3 \)
- Typical reference frames of interest for ADCS include
  - ECI (Earth-centered inertial)
  - Perifocal (Earth-centered, orbit-based inertial)
  - ECEF (Earth-centered, Earth-fixed, rotating)
  - Orbital (Earth-centered, orbit-based, rotating)
  - Body (spacecraft-fixed, rotating)
Earth-Centered Inertial (ECI)

- Also called “Celestial Coordinates”
- The **I-axis** is in vernal equinox direction
- The **K-axis** is Earth’s rotation axis, perpendicular to equatorial plane
- The **J-axis** is in the equatorial plane and finishes the “triad” of unit vectors

Towards vernal equinox
Perifocal Frame

- Earth-centered, orbit-based, *inertial*
  
- **The P-axis** is in periapsis direction
  
- **The W-axis** is perpendicular to orbital plane (direction of orbit angular momentum vector, $\mathbf{r} \times \mathbf{v}$)
  
- **The Q-axis** is in the orbital plane and finishes the “triad” of unit vectors
Orbital Frame

- Same as “roll-pitch-yaw” frame
- The $\mathbf{o}_3$ axis is in the nadir direction
- The $\mathbf{o}_2$ axis is in the negative orbit normal direction
- The $\mathbf{o}_1$ axis completes the triad, and is in the velocity vector direction for circular orbits
Body-Fixed Frame

- Typically denoted using “\( \mathbf{b} \)” unit vectors
- The \( \mathbf{b}_3 \) axis is in the nadir direction
- The \( \mathbf{b}_2 \) axis is in the negative orbit normal direction
- The \( \mathbf{b}_1 \) axis completes the triad, and is in the velocity vector direction for circular orbits