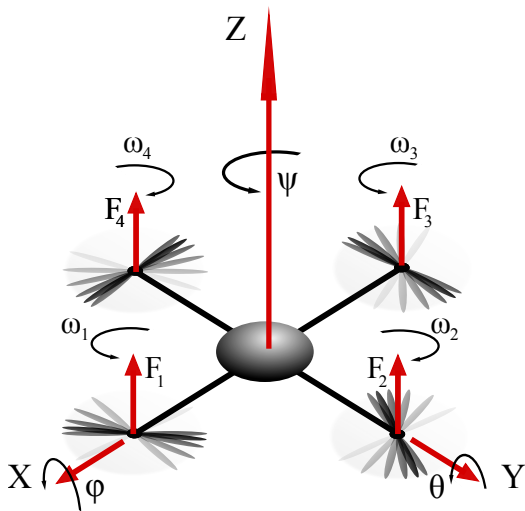


# Forces and Torques



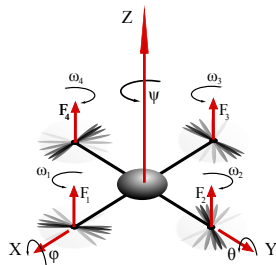
# Newton-Euler Equations

Forces

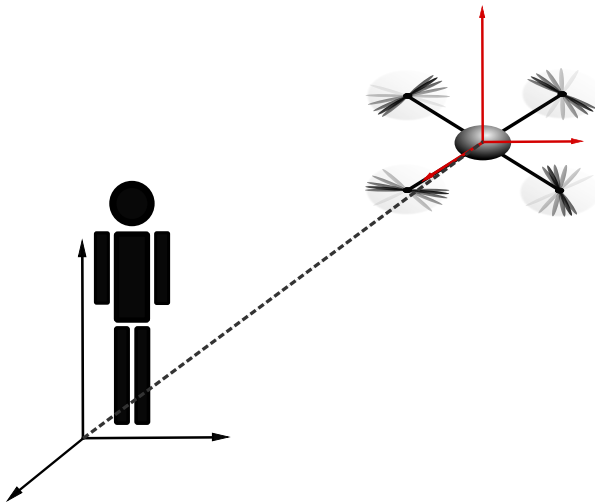
$$F_{\text{ext}} = F_g + \sum_{i=1}^4 F_i$$

Torques

$$\tau_{\text{ext}} = \sum_{i=1}^4 \tau_i + (\tau_\varphi + \tau_\theta)$$



# Coordinate systems



# Quaternions

$$q = a + ib + jc + kd \quad a, b, c, d \in \mathbb{R}$$

representing rotation  $\Leftrightarrow \|q\| = 1$

Advantage  $\rightarrow$  no singularities

Problem  $\rightarrow \|q\| = 1$  additional constraint

# Dynamics

Equations representing dynamics...

$$T(x, u) = M \cdot \begin{pmatrix} \dot{x}_8 \\ \vdots \\ \dot{x}_{13} \end{pmatrix} + \Theta(x)$$

...expressed as system of differential equations

$$\frac{d}{dt} \begin{pmatrix} x_1 \\ \vdots \\ x_7 \\ x_8 \\ \vdots \\ x_{13} \end{pmatrix} = \begin{pmatrix} \dot{x}_1 \\ \vdots \\ \dot{x}_7 \\ M^{-1}(T(x, u) - \Theta(x)) \end{pmatrix}$$

Refinement of the model

→ wind

→ aerodynamical forces