ETH zürich

Safety and reliability of autonomous flying machines Flying Machine Arena

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IDSC

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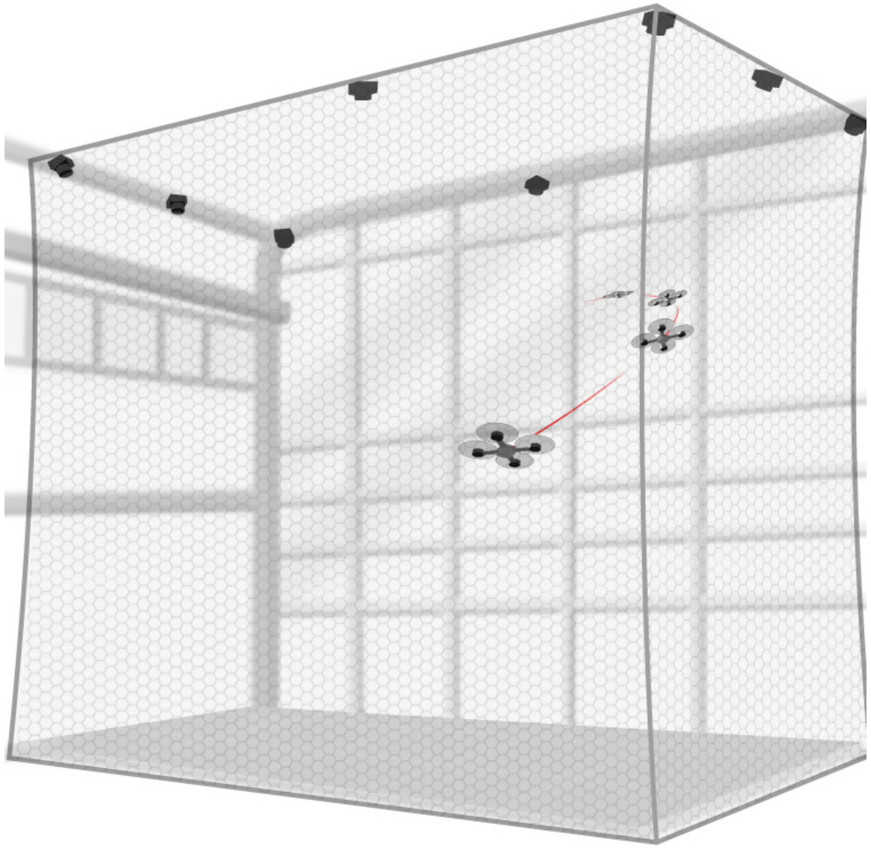
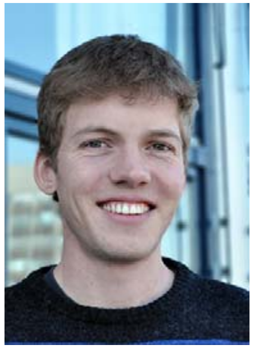
Flying Machine Arena



Federico Augugliaro

Dario Brescianini



Mark Mueller

Robin Ritz

Prof. Raffaello D'Andrea

http://www.idsc.ethz.ch/Research_DAndrea/FMA/participants

Distributed Flight Array

Maximilian Kriegleder

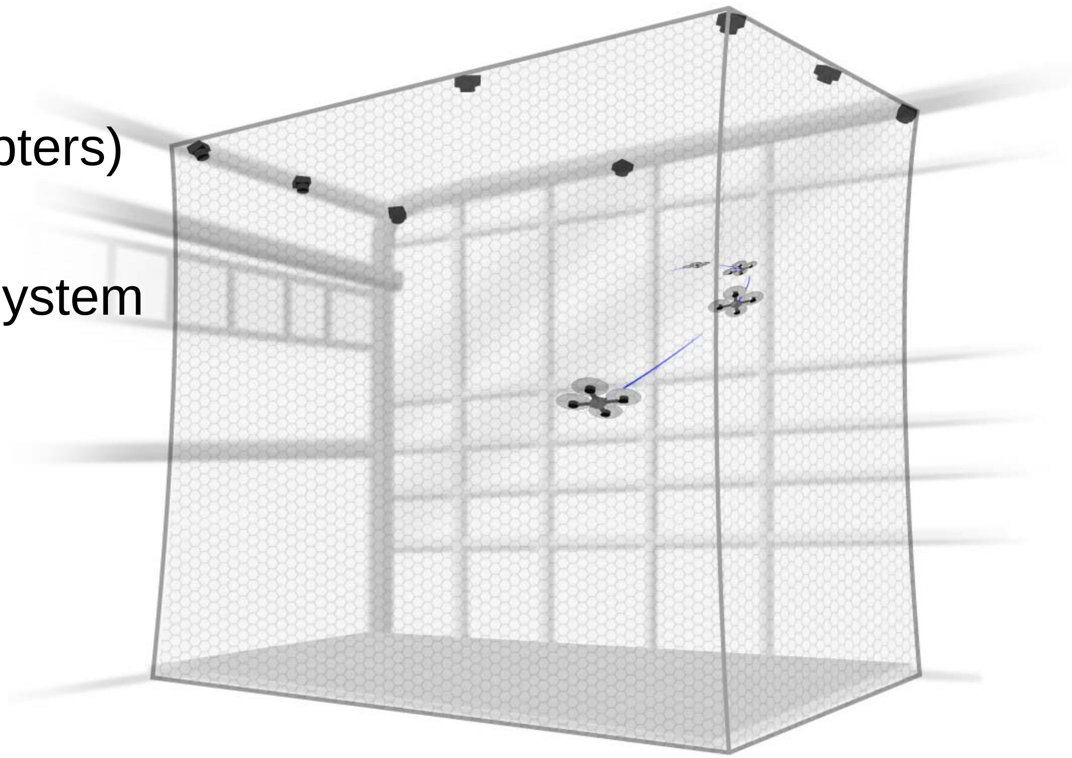
Prof. Raffaello D'Andrea

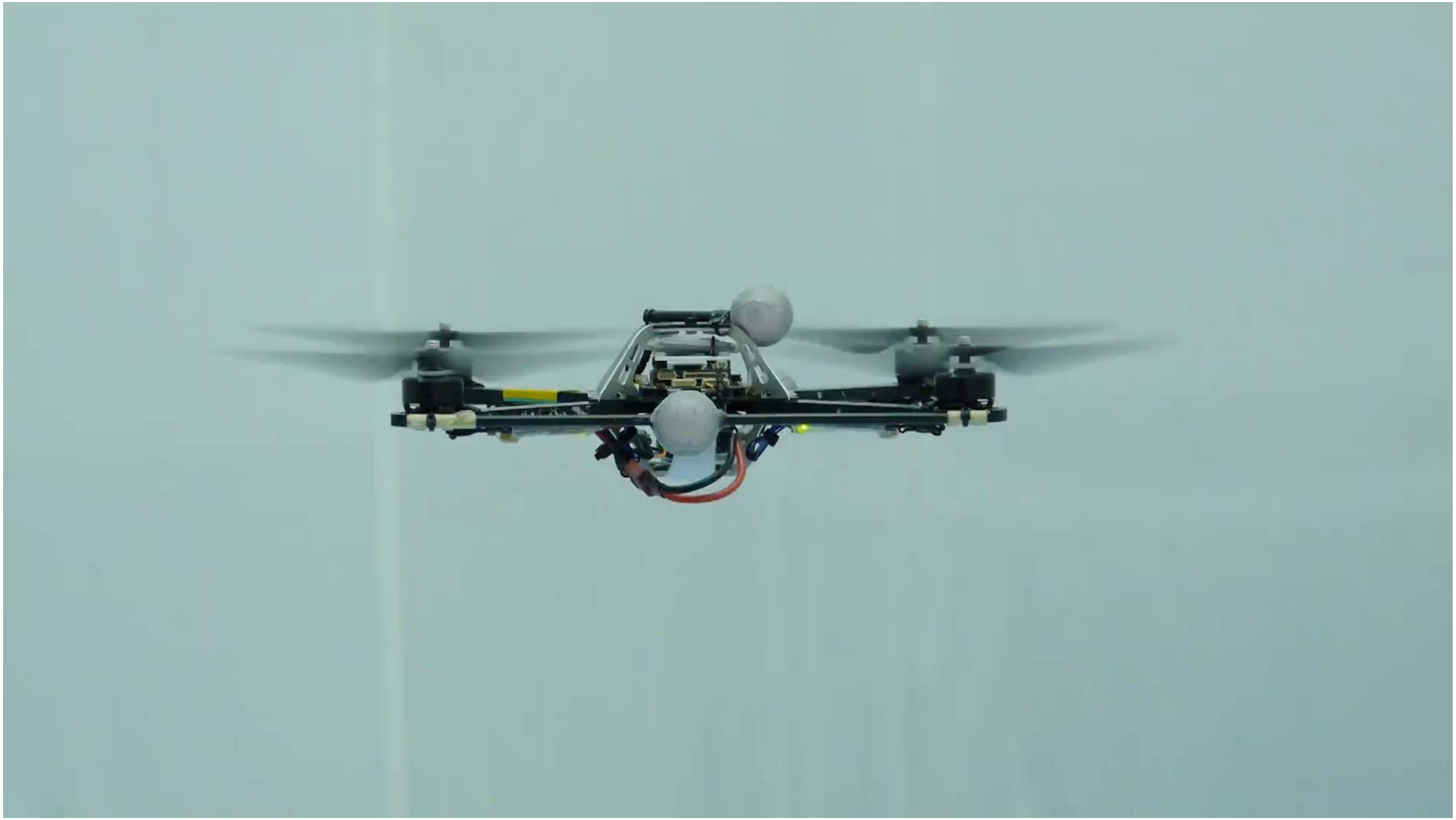
http://www.idsc.ethz.ch/Research_DAndrea/DFA

The Flying Machine Arena

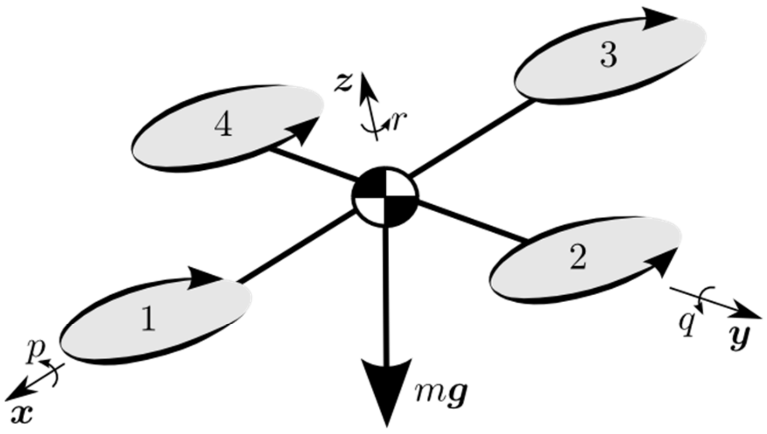
- A 10x10x10m space for autonomous flight

- Main components:
  - Flying vehicles (quadrocopters)
  - Motion capture system
  - Wireless communication system
  - Algorithms



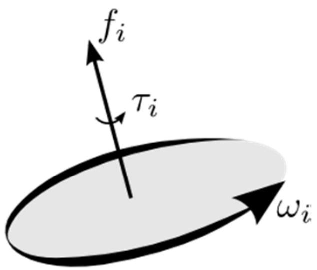


Quadrocopter dynamic model



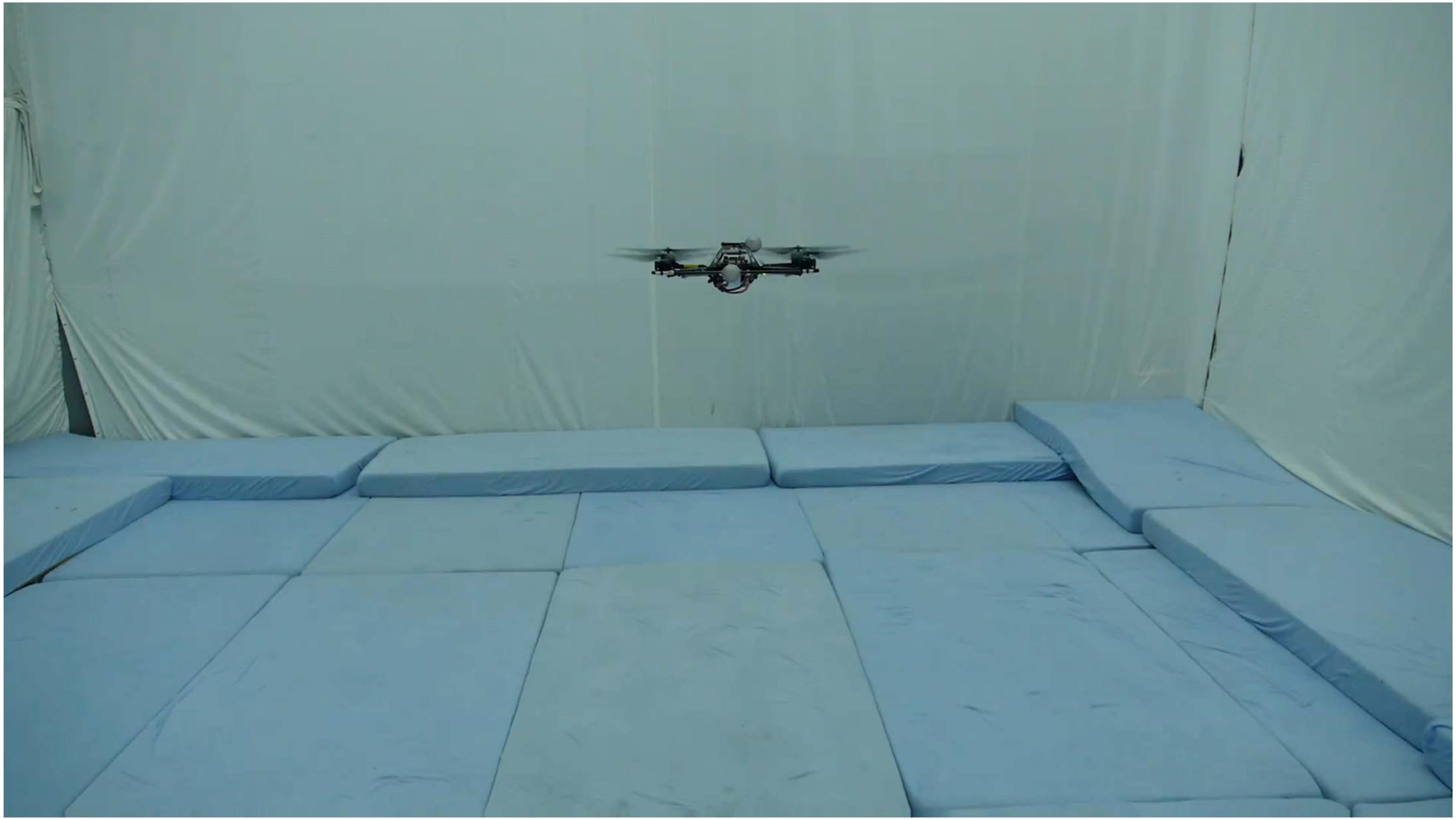
$$\ddot{\boldsymbol{x}} = \frac{1}{m}\mathbf{R}\begin{bmatrix} 0 \\ 0 \\ f_1 + f_2 + f_3 + f_4 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix}$$

$$\dot{\mathbf{R}} = \mathbf{R}\begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix}$$

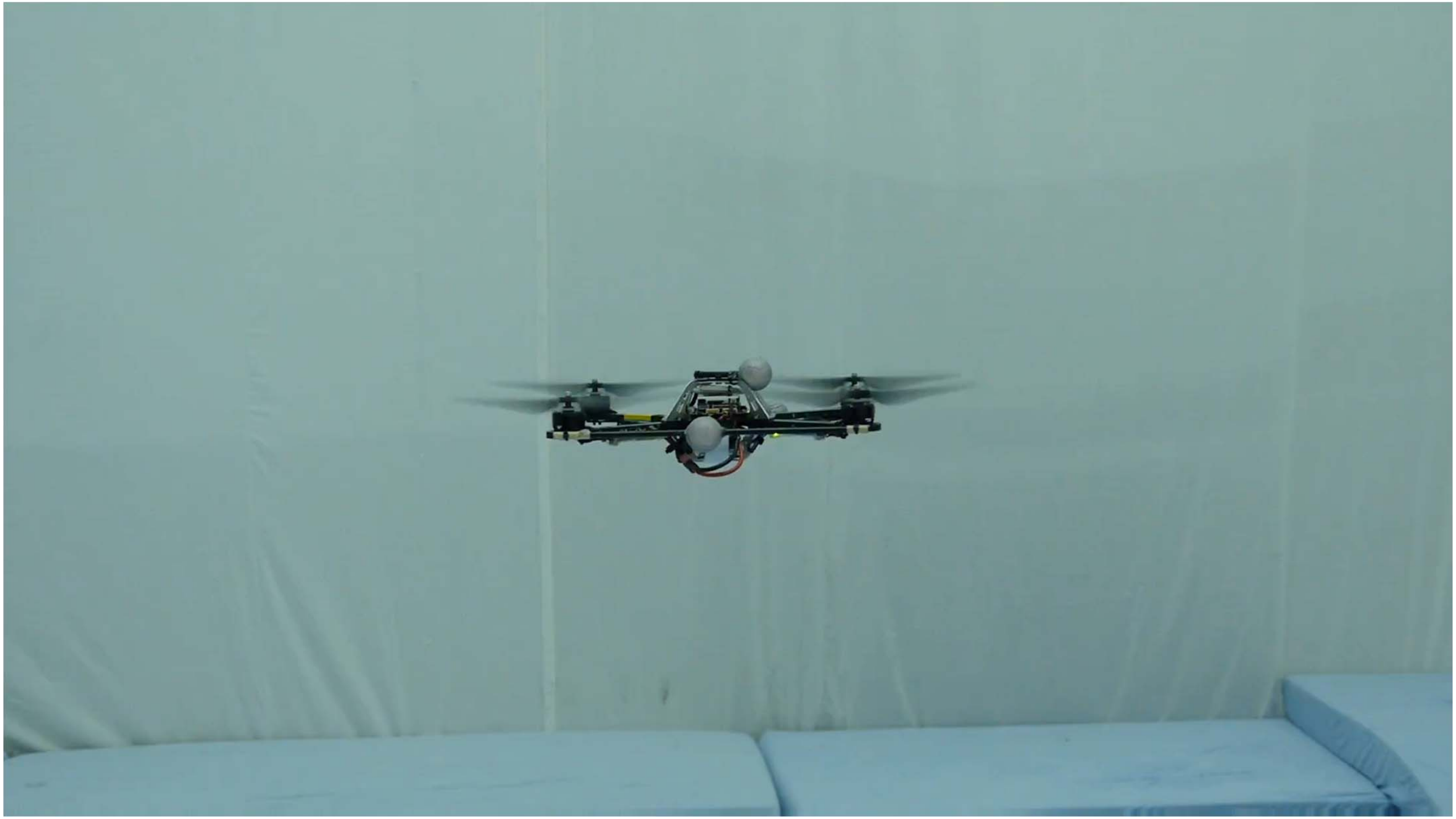


$$\mathbf{I}^B\dot{\boldsymbol{\omega}}^B = -\sum_{i=1}^{4}\mathbf{I}^P\dot{\boldsymbol{\omega}}^{P_i} - \left[\boldsymbol{\omega}^B\times\right]\left(\mathbf{I}^B\boldsymbol{\omega}^B + \sum_{i=1}^{4}\mathbf{I}^P\left(\boldsymbol{\omega}^B + \boldsymbol{\omega}^{P_i}\right)\right) + \boldsymbol{\tau}_{res}$$

Without control

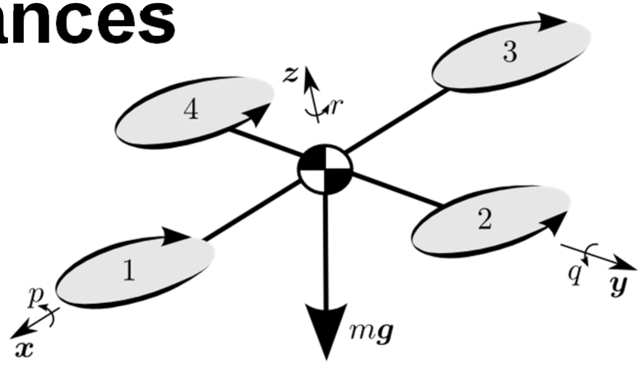


Closed loop



Recovering from large disturbances

Dario Brescianini, Markus Hehn



- Large pitch/roll torques
  - Small yaw torque
- Control attitude through angular velocity
- Prioritize tilt over yaw

$$\ddot{\boldsymbol{x}} = \frac{1}{m}\mathbf{R}\begin{bmatrix} 0 \\ 0 \\ f_1 + f_2 + f_3 + f_4 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix}$$

$$\dot{\mathbf{R}} = \mathbf{R}\begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix}$$

$$\mathbf{I}^B\dot{\boldsymbol{\omega}}^B = -\sum_{i=1}^{4}\mathbf{I}^P\dot{\boldsymbol{\omega}}^{P_i} - \left[\boldsymbol{\omega}^B\times\right]\left(\mathbf{I}^B\boldsymbol{\omega}^B + \sum_{i=1}^{4}\mathbf{I}^P\left(\boldsymbol{\omega}^B + \boldsymbol{\omega}^{P_i}\right)\right) + \boldsymbol{\tau}_{res}$$

Recovering from large disturbances

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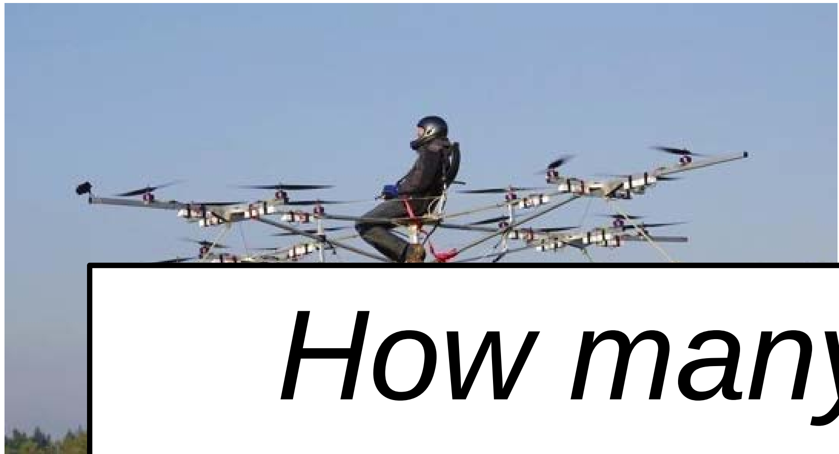
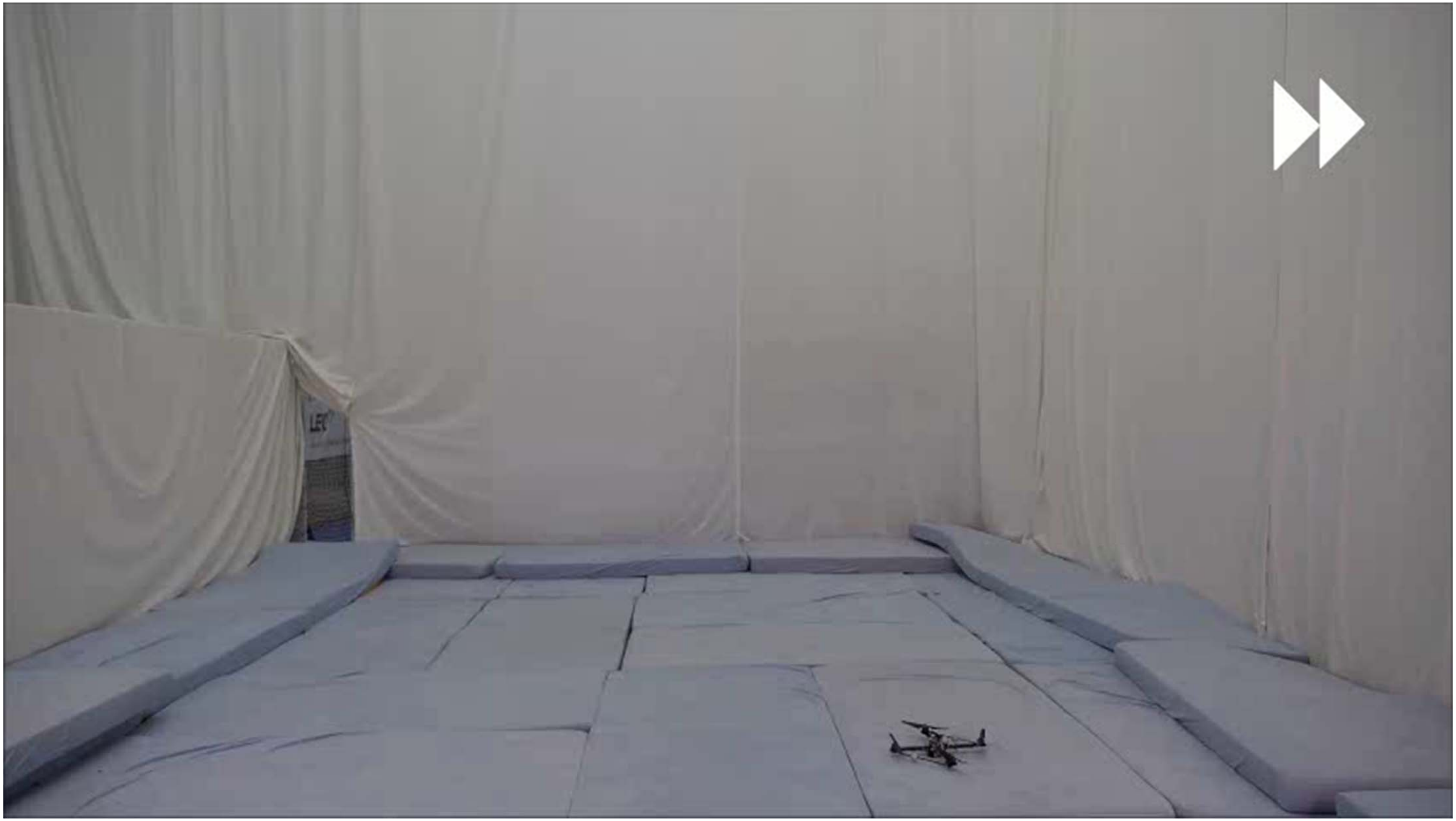
“Typical” multicopters



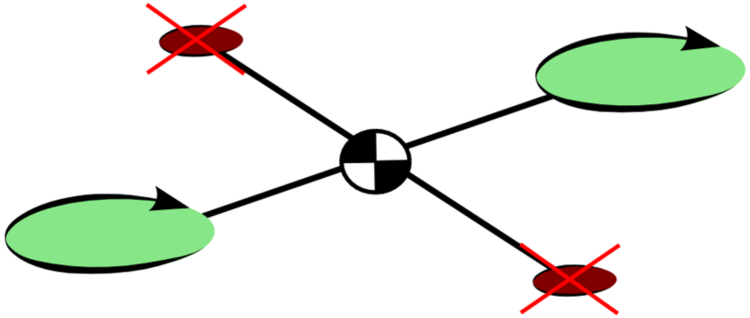
How many propellers do you really need?

E-Volo, Amazon Prime Air
MK Hexa XL, DJI Phantom



System modelling – 2 propellers

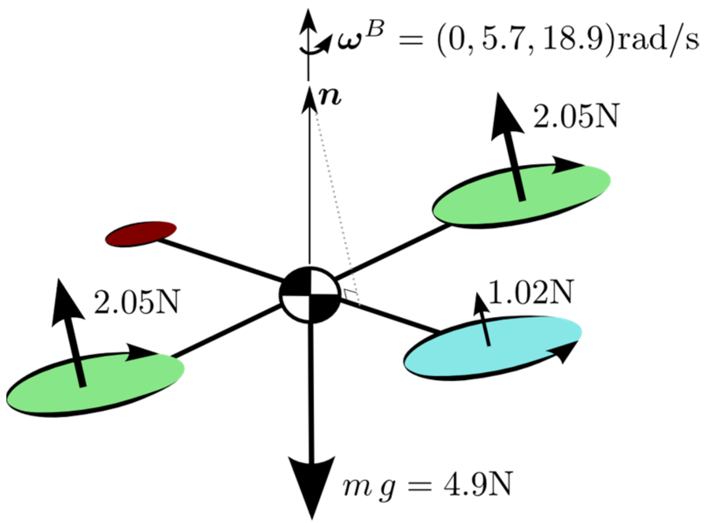
- Can *not* directly affect roll rate



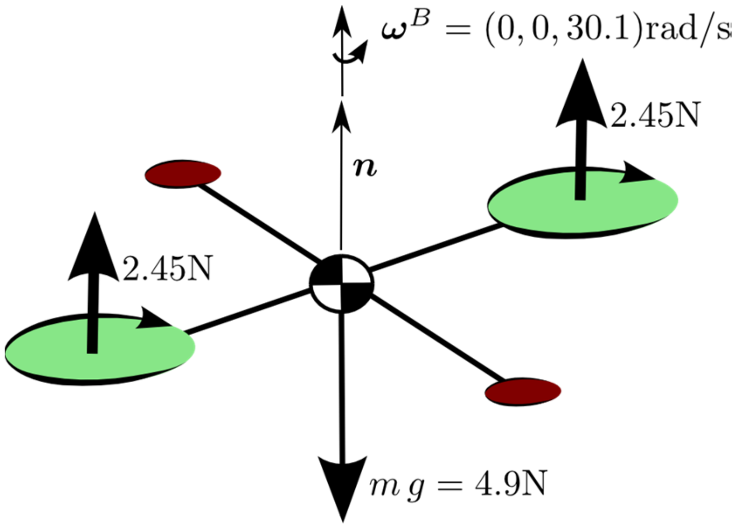
- Have to exploit attitude coupling

$$\boldsymbol{I}^B\dot{\boldsymbol{\omega}}^B + \sum_{i=1}^{4}\boldsymbol{I}^P\dot{\boldsymbol{\omega}}^{P_i} + [\![\boldsymbol{\omega}^B\times]\!]\left(\boldsymbol{I}^B\boldsymbol{\omega}^B + \sum_{i=1}^{4}\boldsymbol{I}^P\left(\boldsymbol{\omega}^B + \boldsymbol{\omega}^{P_i}\right)\right) = \boldsymbol{\tau}_{\text{res}}$$

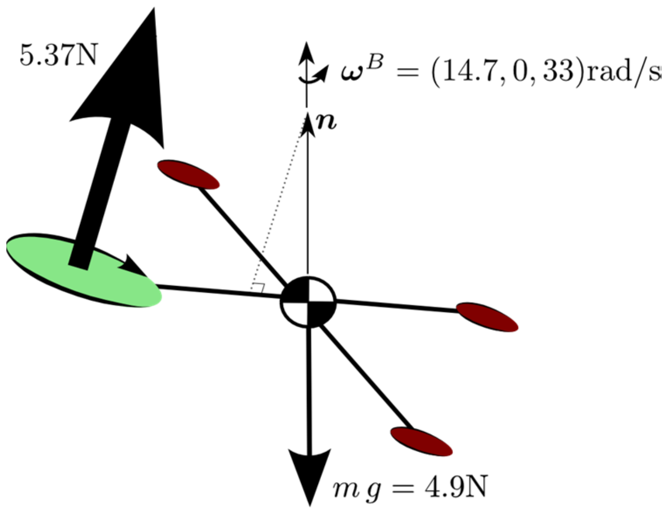
Flying with three propellers

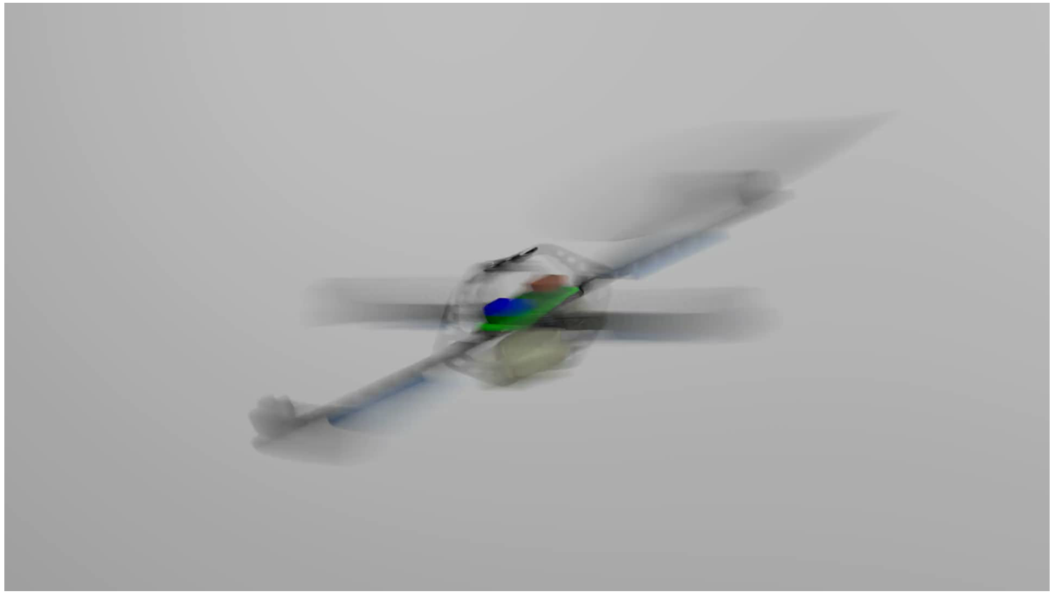


Flying with two propellers



Flying with one propeller





Extension: quadrocopter failsafe

Extension: no motion capture

Demonstrations at lunch