Discrete Sliding Mode control of small UAS in tight formation flight under information constraints

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Outline

$\Rightarrow$ Why tight formation flight with small UAS?

$\Rightarrow$ Problem Statement

$\Rightarrow$ Predictive Discrete Sliding Mode Guidance laws

$\Rightarrow$ Overview & where to go from here

Small UAS

=

Inexpensive

Easy to operate

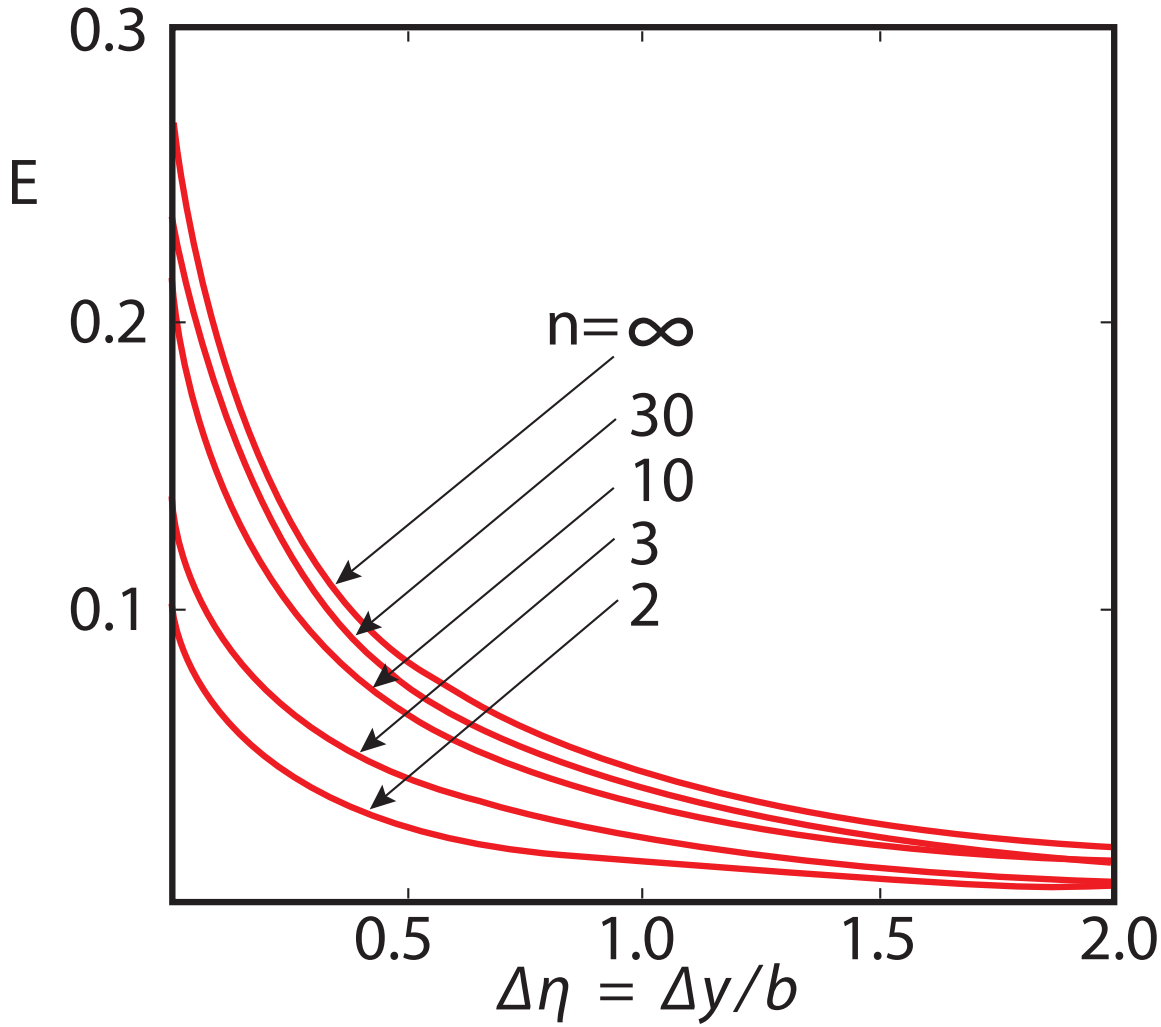
Small UAS

=

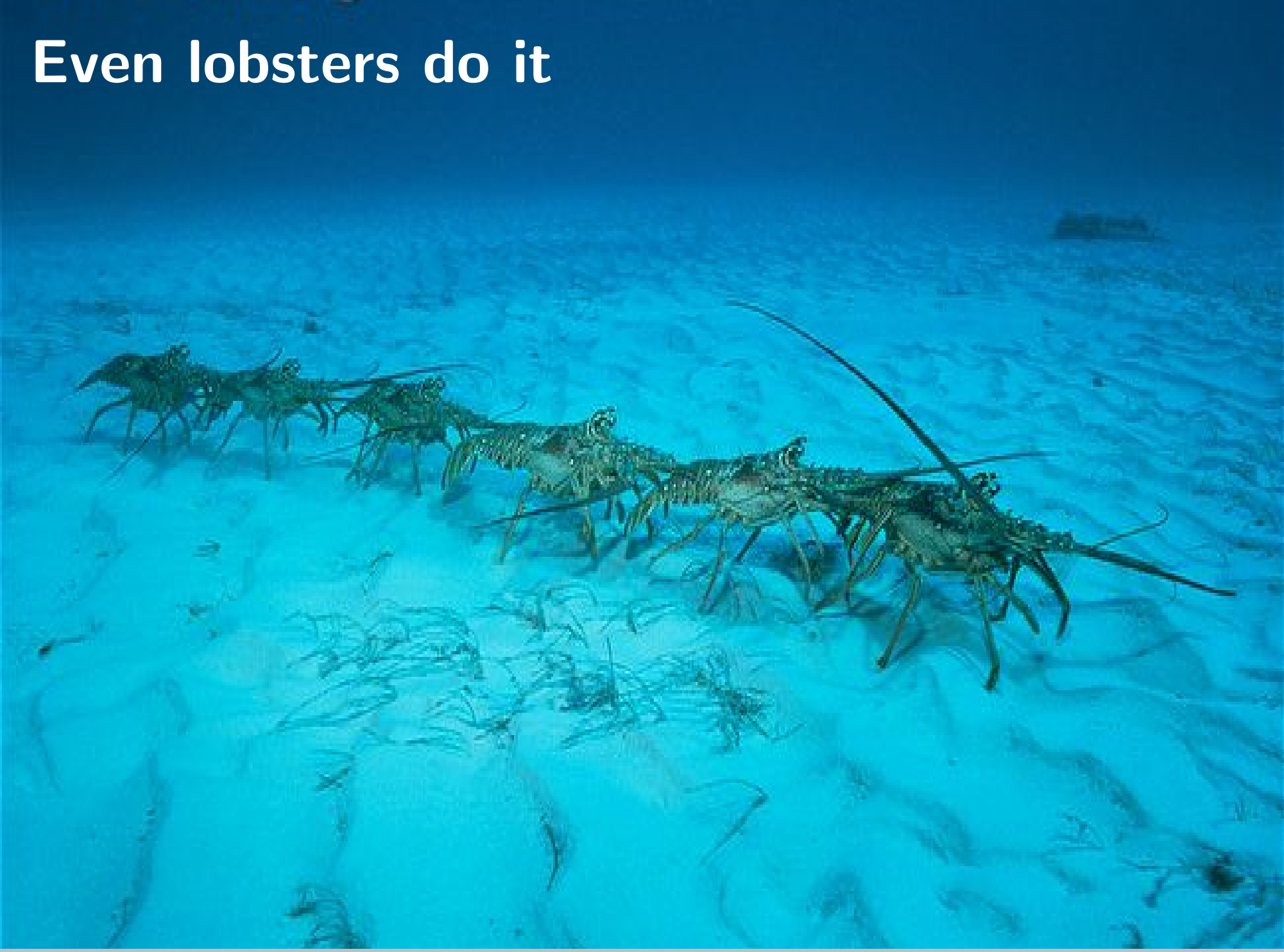
Small payload

Small endurance

Tight, large formations enhance range[1]

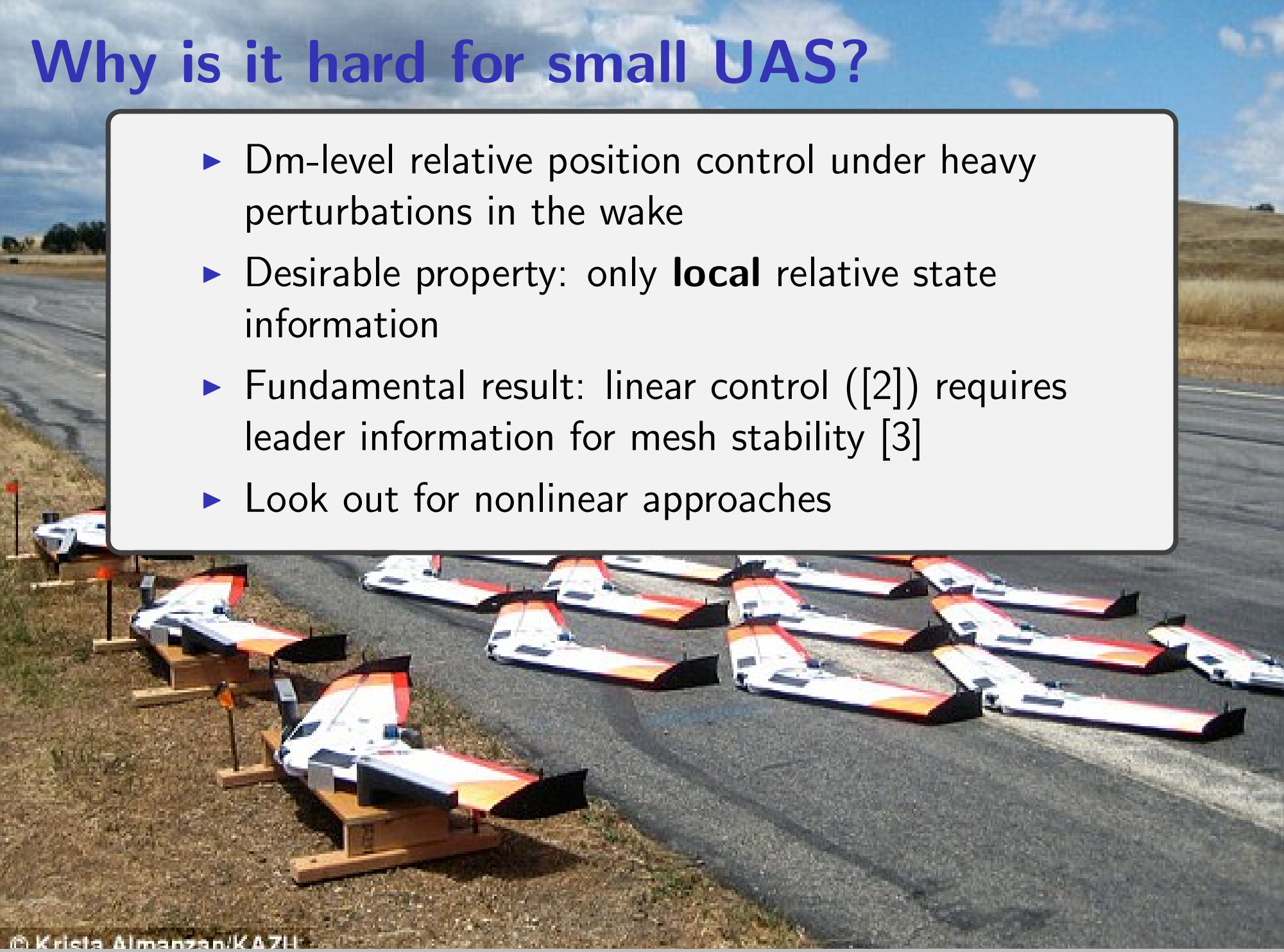


Even lobsters do it

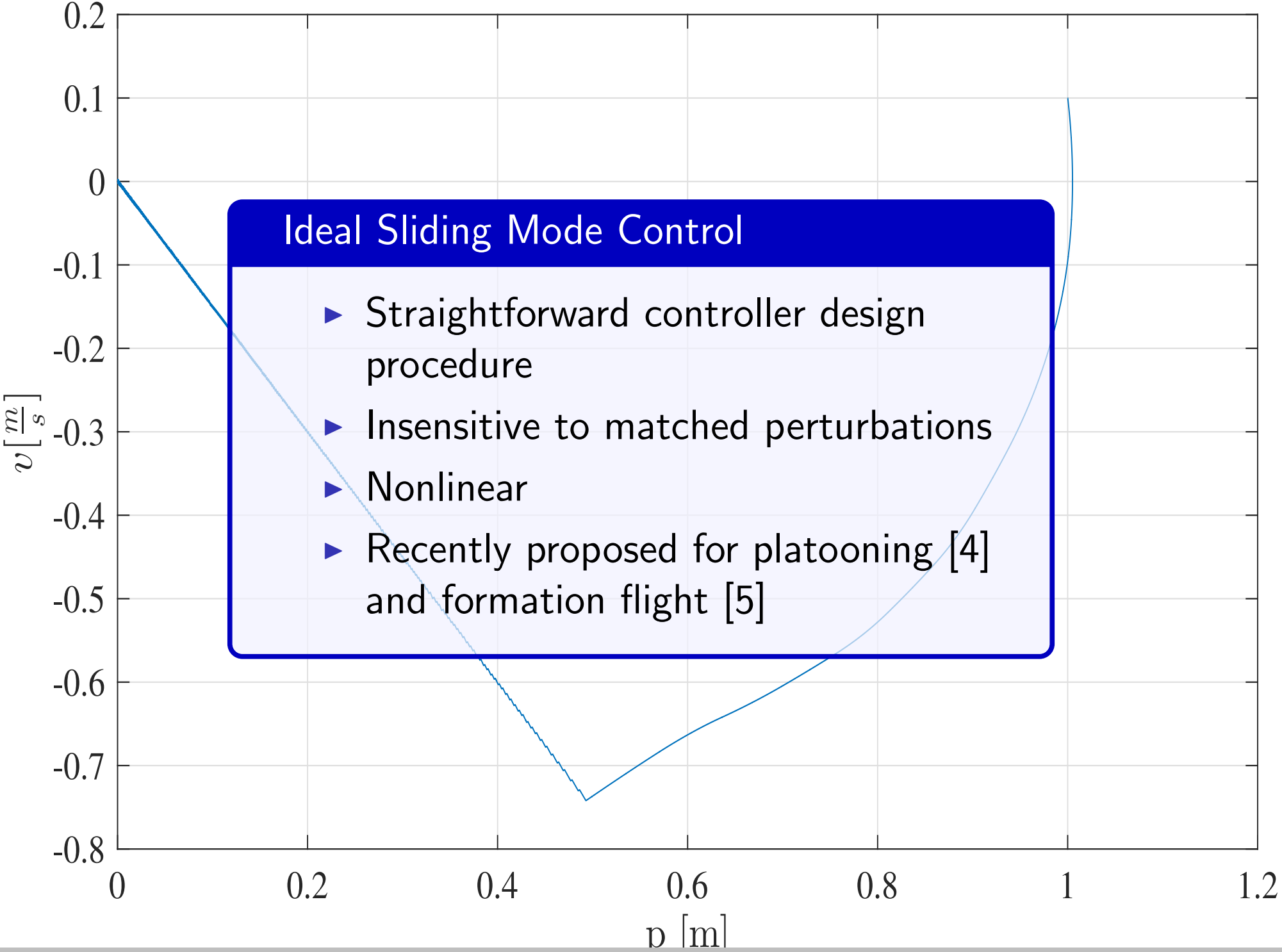


Why is it hard for small UAS?

- Dm-level relative position control under heavy perturbations in the wake
- Desirable property: only **local** relative state information
- Fundamental result: linear control ([2]) requires leader information for mesh stability [3]
- Look out for nonlinear approaches

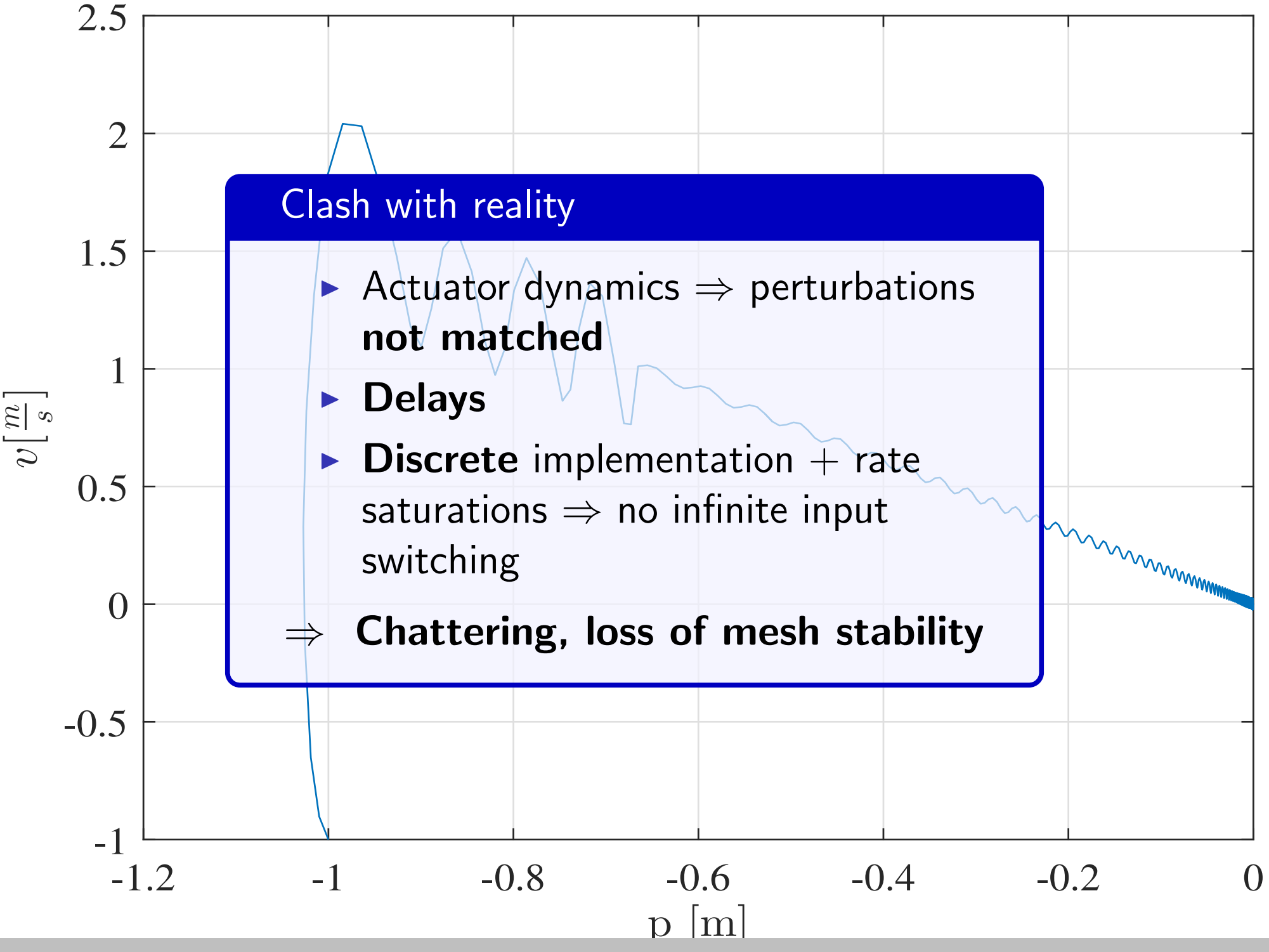


One candidate:
Sliding Mode Control:
performance & mesh stability



Ideal Sliding Mode Control

- Straightforward controller design procedure
- Insensitive to matched perturbations
- Nonlinear
- Recently proposed for platooning [4] and formation flight [5]



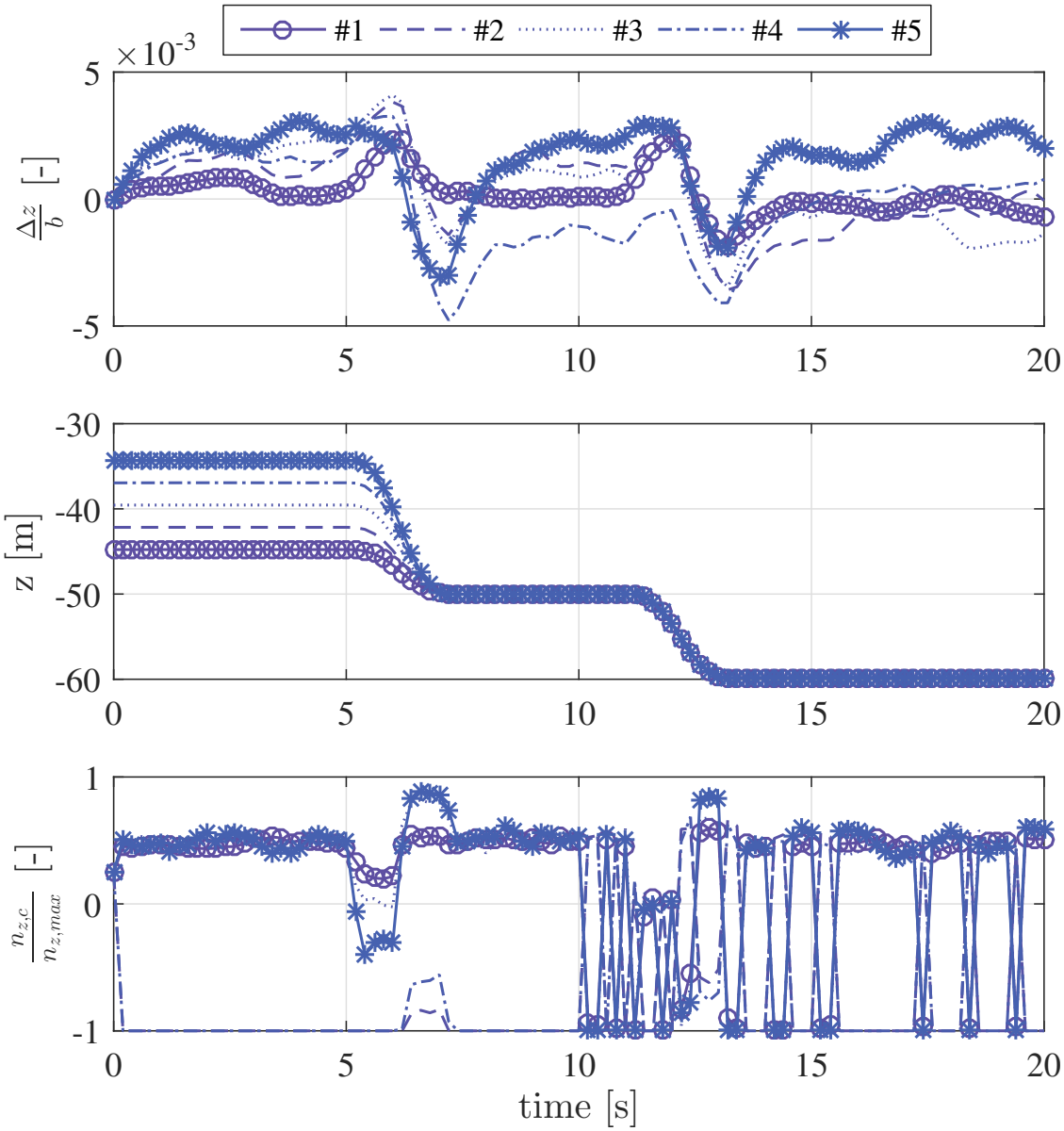
Clash with reality

- Actuator dynamics $\Rightarrow$ perturbations **not matched**
- **Delays**
- **Discrete** implementation + rate saturations $\Rightarrow$ no infinite input switching

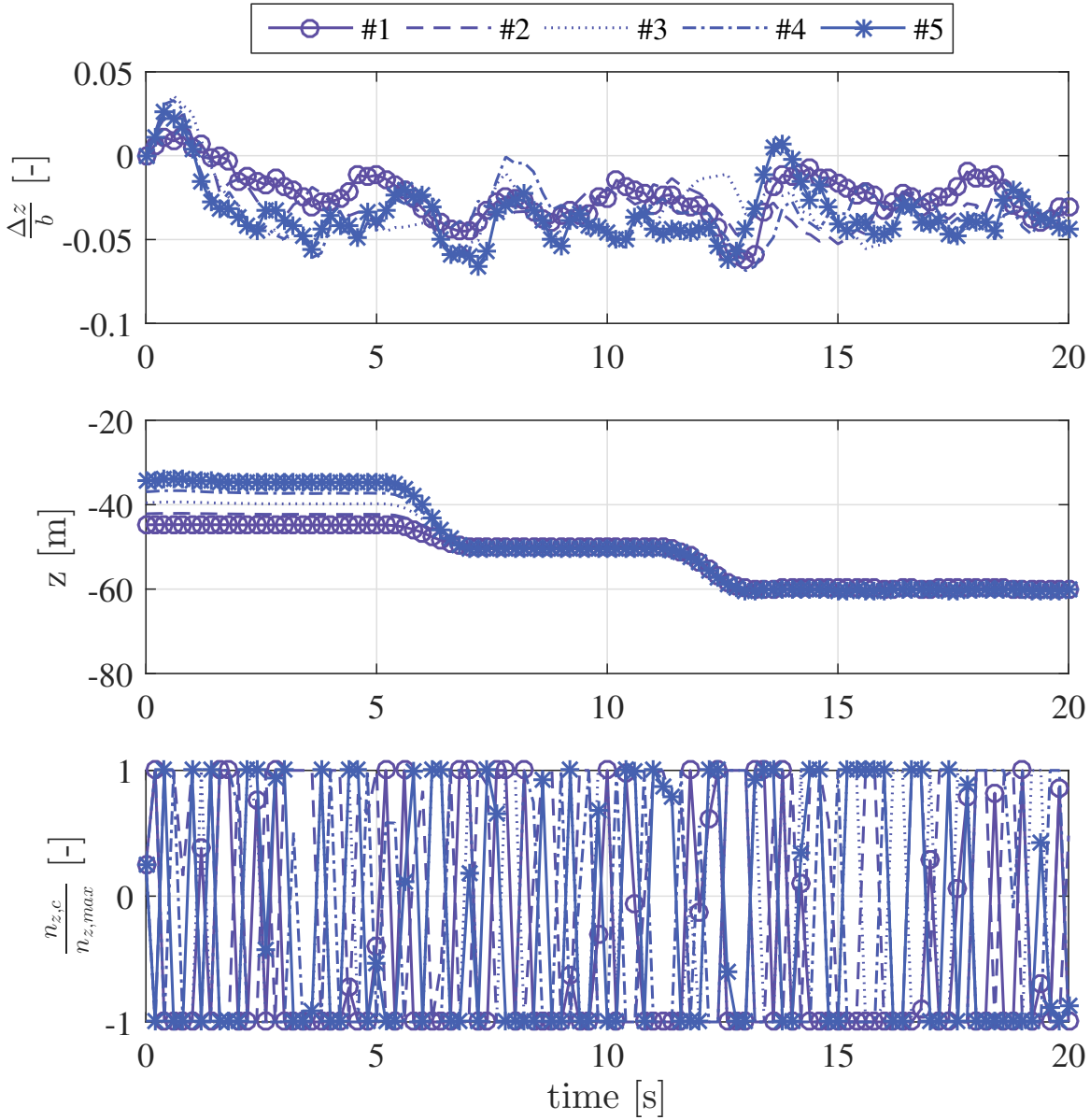
$\Rightarrow$ **Chattering, loss of mesh stability**

Continuous Time Sliding Mode Control applied to the UAS guidance loop: Longitudinal maneuver

Longitudinal: TSCSMC [5] at 1000Hz



Longitudinal: TSCSMC at 100Hz



Predictive Discrete Sliding Mode Control

PDSMC

- Extends recent approach [6]
- Design directly in discrete time
- Preserve spirit of Sliding Mode Control: stay in boundary layer of sliding surface
- Minimizes boundary layer without tuning

Predictive Discrete Sliding Mode Control

What it looks like

$$\sigma(k) = \mathbf{G} \begin{pmatrix} \Delta\mathbf{p}(k) \\ \Delta\mathbf{v}(k) \end{pmatrix}$$

$$\sigma(k+1) = \sigma(k) + T(\mathbf{\Phi}'_k(k) + \mathbf{\Phi}'_u(k) + \mathbf{u}(k))$$

$$\underset{\mathbf{u}(k)}{\text{minimize}} \qquad |\sigma(k+1)|$$

Predictive Discrete Sliding Mode Control

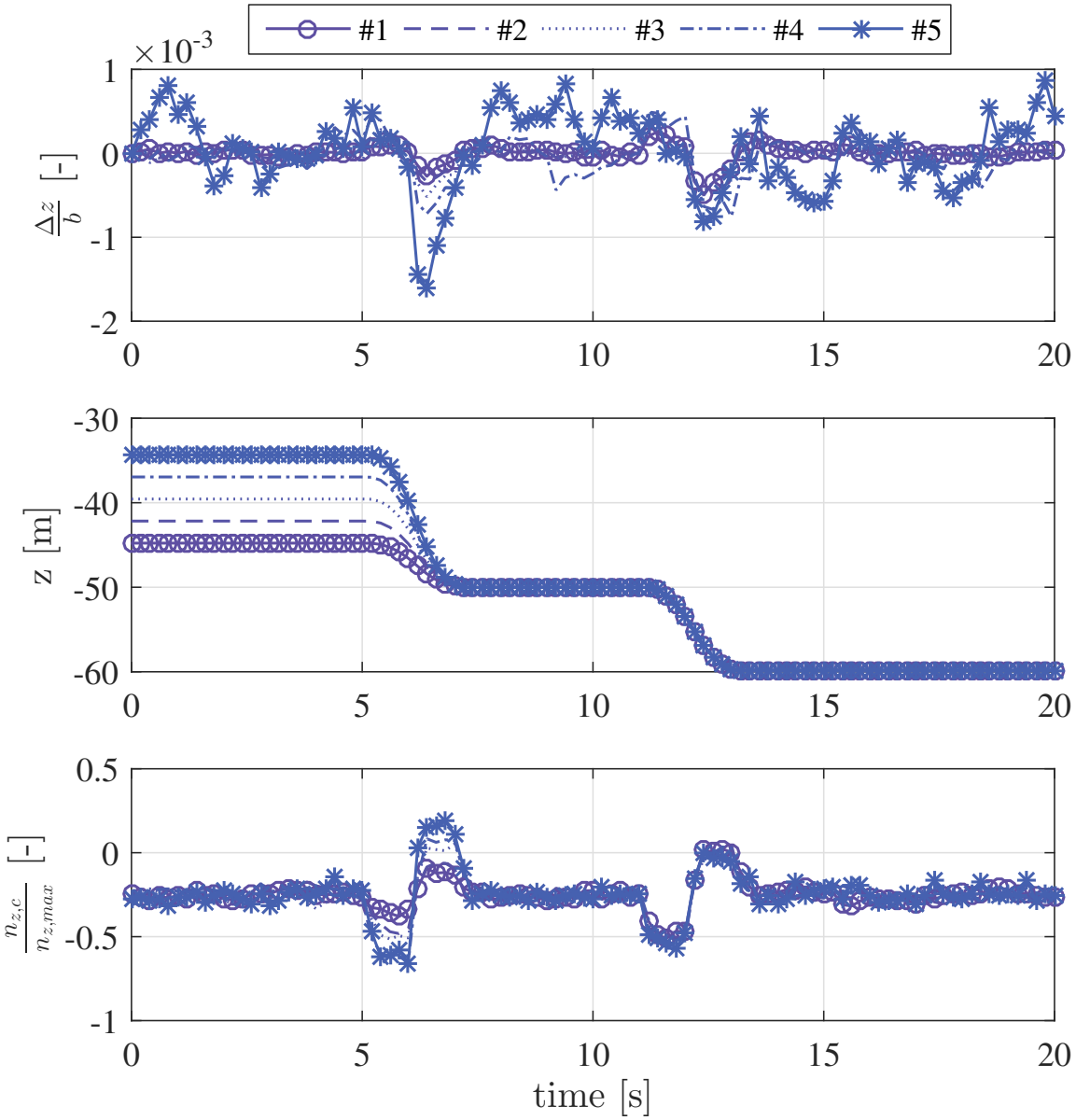
Adding hard magnitude and rate constraints

$$\begin{aligned} \underset{\mathbf{u}(k)}{\text{minimize}} \quad & |\sigma(k+1)| \\ \text{subject to} \quad & \mathbf{U}_{min}(k) \leq \mathbf{u}(k) \leq \mathbf{U}_{max}(k) \end{aligned}$$

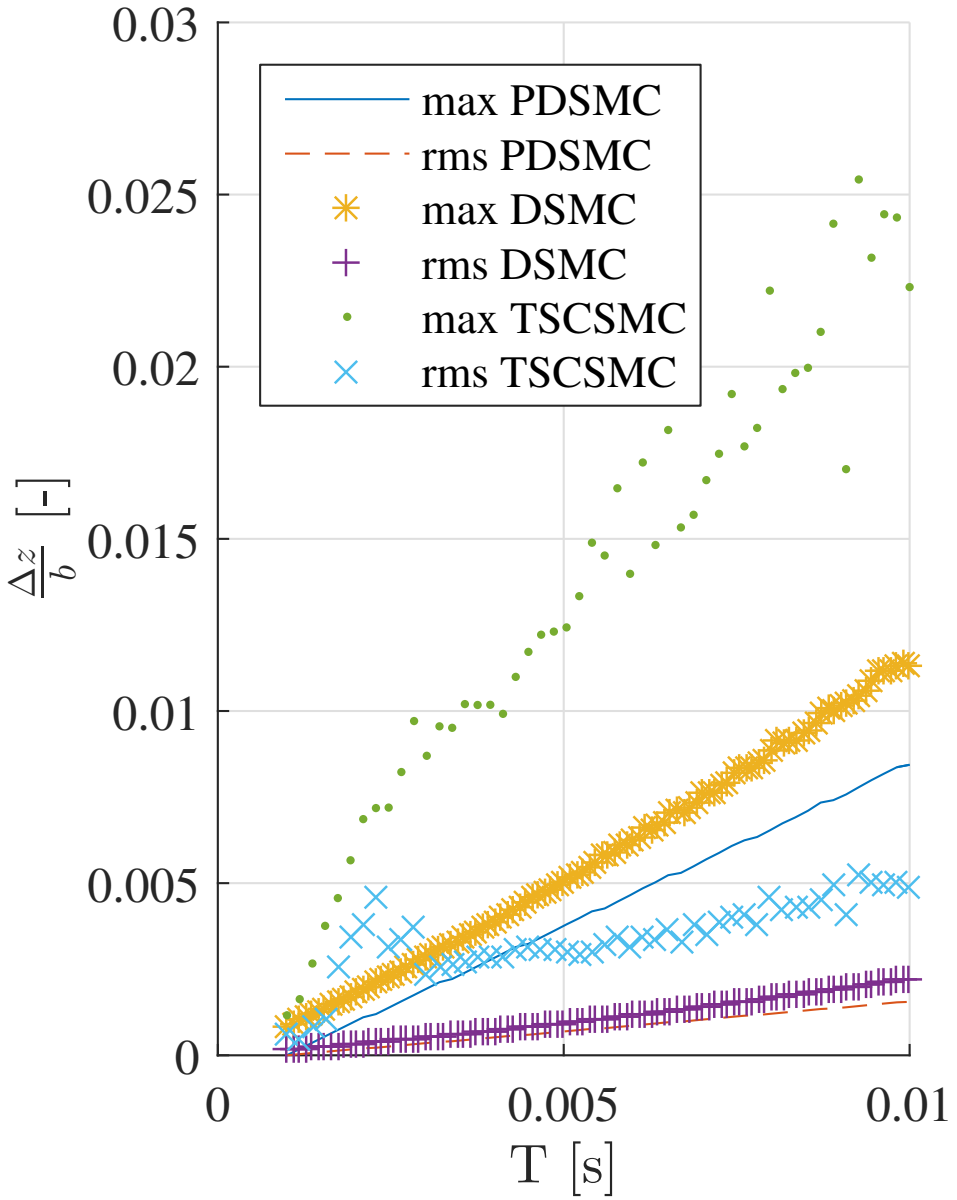
$$|\mathbf{u}(k) - \mathbf{u}(k-1)| \leq \boldsymbol{\Delta}\mathbf{U}$$

$$\begin{aligned} \mathbf{U}_{max}(k) &= sat(\mathbf{u}(k-1) + \boldsymbol{\Delta}\mathbf{U}, -\mathbf{U}, \mathbf{U}) \\ \mathbf{U}_{min}(k) &= sat(\mathbf{u}(k-1) - \boldsymbol{\Delta}\mathbf{U}, -\mathbf{U}, \mathbf{U}) \end{aligned}$$

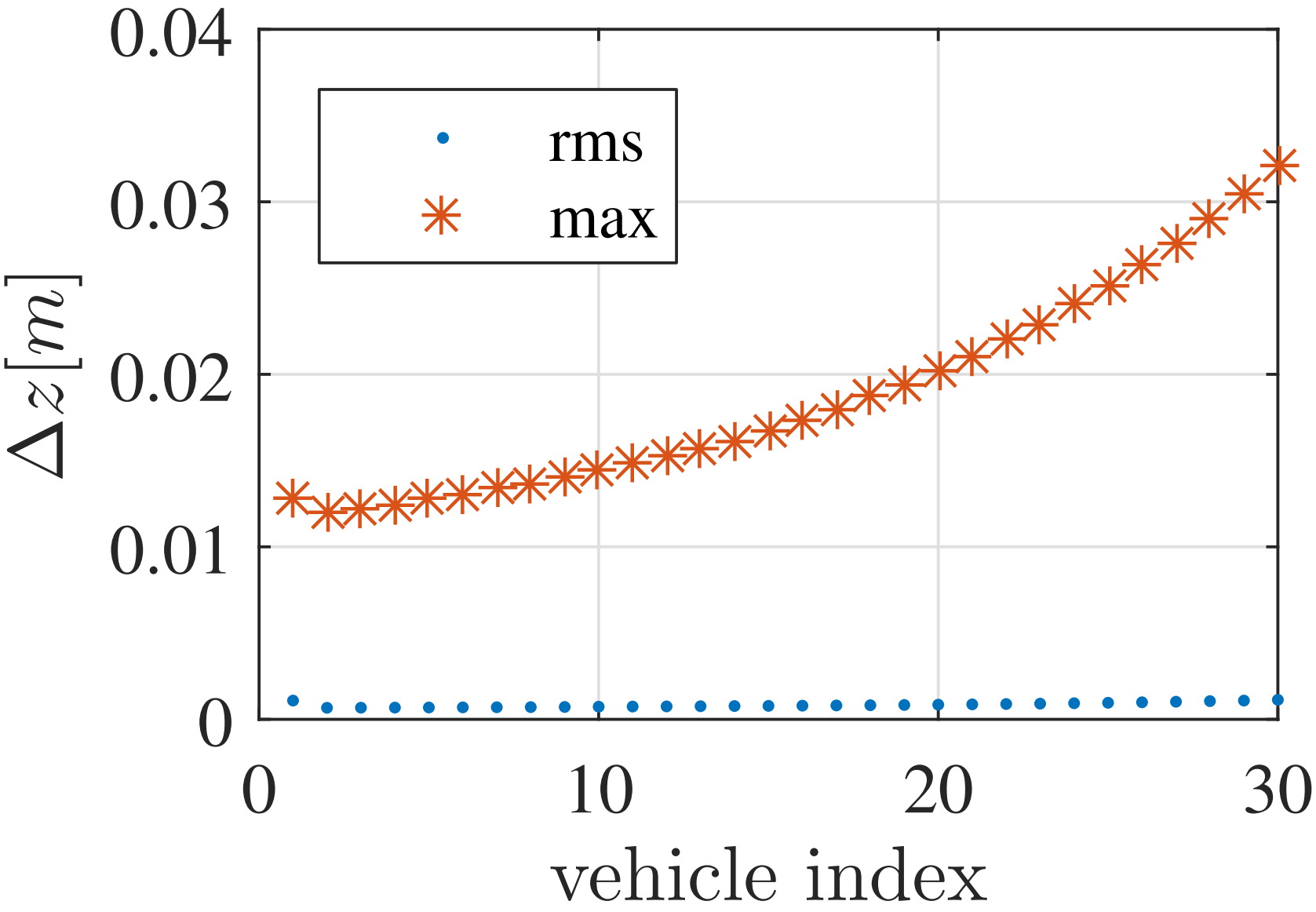
Simulation: PDSMC at 100Hz



Figures of Merit vs. sampling time



What about scalability?



Conclusion & Outlook

- PDSMC alleviates discretization issue of TSCSMC controller for TFF
- Extends existing PDSMC approaches to respect inner loop constraints

- Extend PDSMC further: inner loop dynamics, lower sampling rates, observation noise
- Better understand and quantify mesh instability


D. Hummel, "Aerodynamic aspects of formation flight in birds," *Journal of theoretical Biology*, 1982.


E. Shaw and J. K. Hedrick, "Controller design for string stable heterogeneous vehicle strings," in *Decision and Control, 2007 46th IEEE Conference on*, pp. 2868–2875, IEEE, 2007.


P. Seiler, A. Pant, and K. Hedrick, "Disturbance propagation in vehicle strings," *Automatic Control, IEEE Transactions on*, vol. 49, no. 10, pp. 1835–1842, 2004.


F. Fahimi, "Sliding-mode formation control for underactuated surface vessels," *Robotics, IEEE Transactions on*, vol. 23, no. 3, pp. 617–622, 2007.


D. Galzi and Y. Shtessel, "UAV formations control using high order sliding modes," in *American Control Conference, 2006*, pp. 6–pp, IEEE, 2006.

B. M. Houda, D. Khadija, and N. A. Said, "New discrete predictive sliding mode control for non minimum phase systems," *International Journal of Computer Applications*, vol. 70, no. 11, 2013.