Impact of Turbulence on Unmanned Aerial Vehicles

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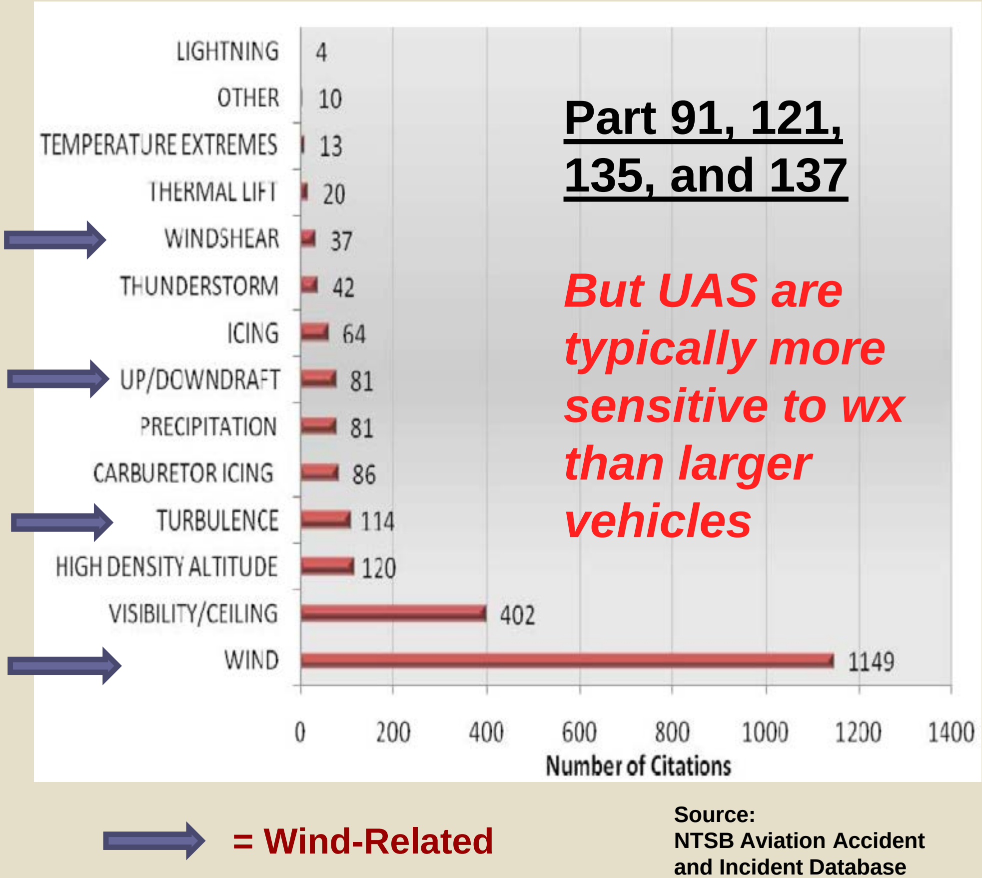
Weather impacts on UAS operations

- **Key Wx factors**:
  - Steady wind: headwind, tailwind, crosswind
  - Wind shear
  - Turbulence and discrete gusts
  - C&V
  - Heavy precip.
  - Icing
  - Air density
  - Temperature

FAA Weather Related Aviation Accident Study 2003-2007



Source:
NTSB Aviation Accident and Incident Database

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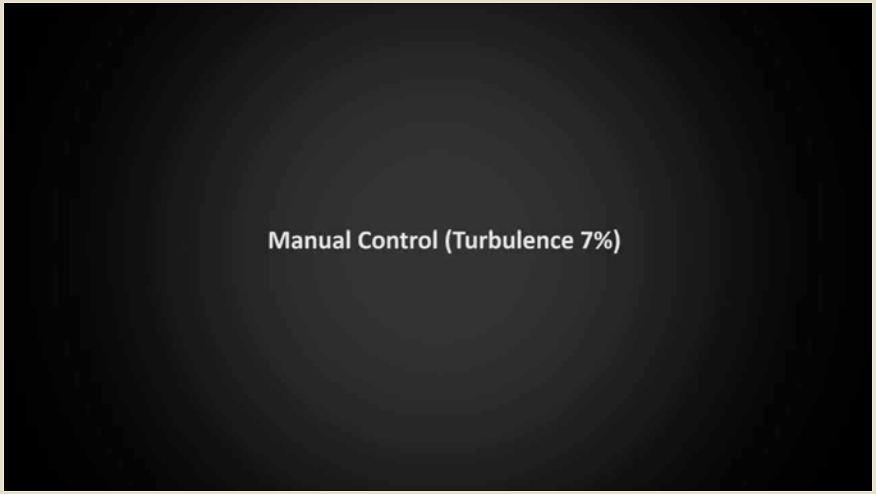
Most UAS are small, rigid, light, and slow moving => high sensitivity to wind gusts

- Quadcopter in gusty conditions
  source: https://youtu.be/h-s9RbKNUyE

- Fixed wing UAS: w/ and w/o autopilot courtesy, RMIT UAS Research Team (RUASRT), RMIT©



Fixed-wing vs. multirotor UAS

- Many fixed-wing UASs can be considered as "scaled-down" conventional aircraft.
- Most multirotor UAS are very different from conventional helicopters.

There is a large established literature regarding the effect of winds/turbulence on fixed-wing aircraft and conventional helicopters – but very little relative to multirotors & unconventional fixed-wing UAS.

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Wind and turbulence impacts on airborne vehicles

- Three classes of forces:
  - Aerodynamic
  - Propulsive
  - Gravitational

The effect of wind and turbulence are mainly manifest through aerodynamic forces

- *We consider control forces (e.g., elevator, ailerons, rudder) as aerodynamic in nature.*
- *Propulsive forces due to propellers (thrust) can also be considered aerodynamic.*

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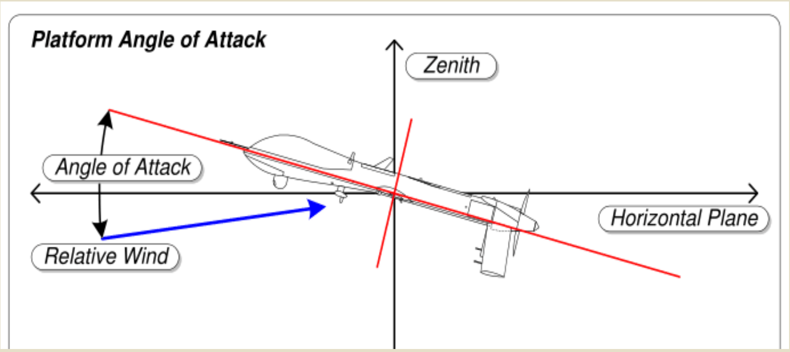
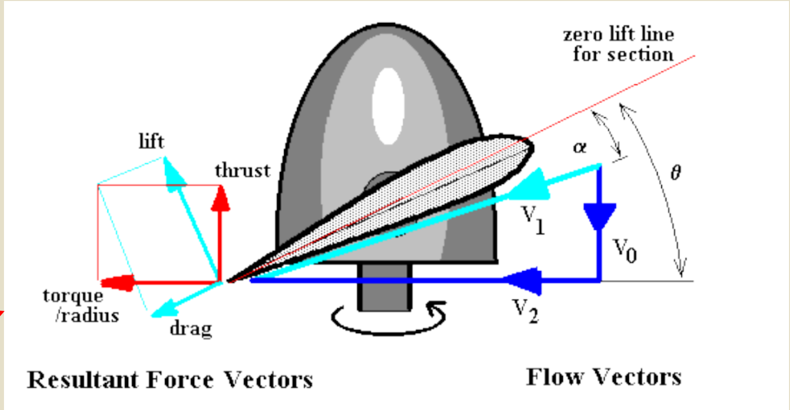
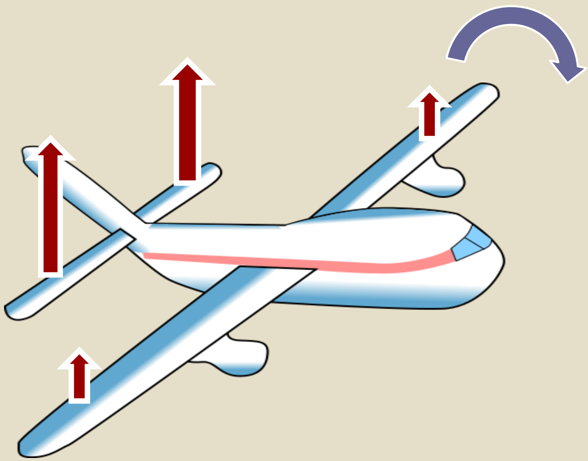
Aerodynamic forces: Lift

- Since an airborne vehicle must counteract gravity to stay aloft, it is the vertical component of the lift force that is key.
- *The relative motion of the lifting surface through the air produces the lift*
  - For *fixed-wing* vehicles, it's the forward motion of the wing and tail.
  - For *multirotors* it's the rotary motion of the propeller.

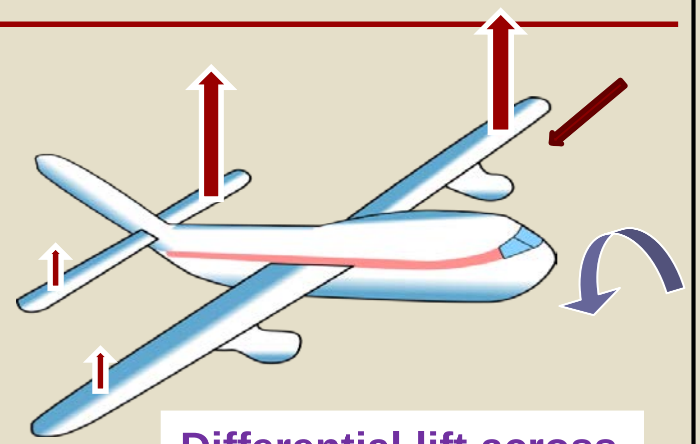




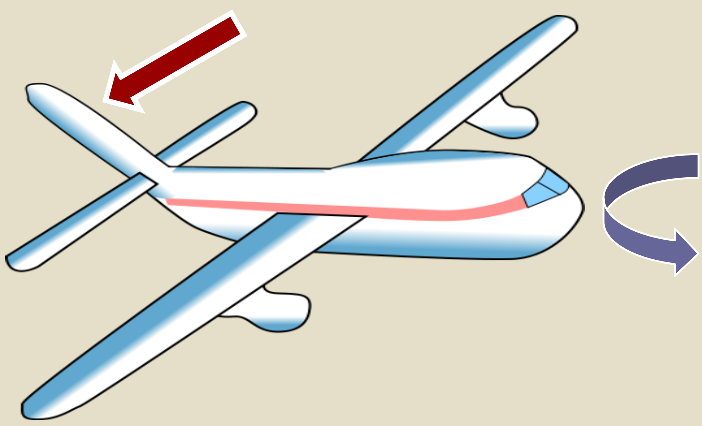
Fixed-wing vehicle: Lift forces produce translational (mainly vertical) and rotational motions



Differential lift on wing and tail produces pitching moment



Differential lift across wing (or tail)
or side wind (dihedral effect) produces rolling moment



Side wind on vertical tail surface produces yawing moment

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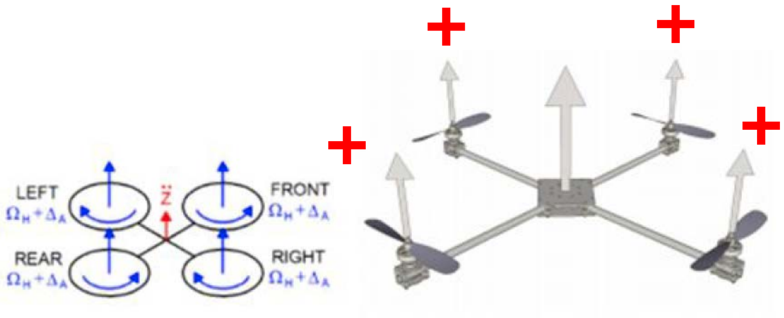
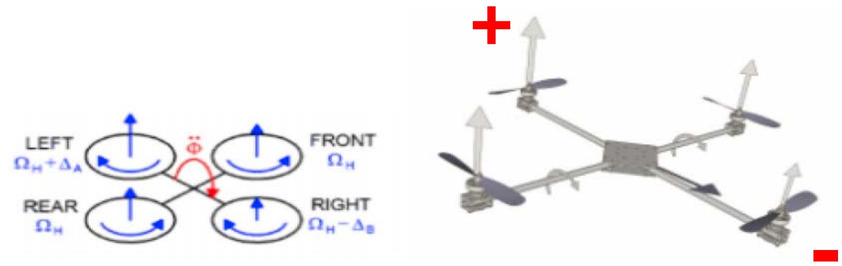
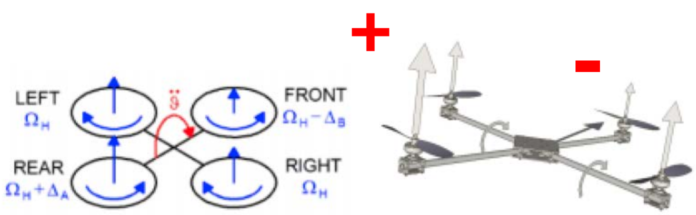
Quadrotor motion and orientation changes via differential thrust and torque



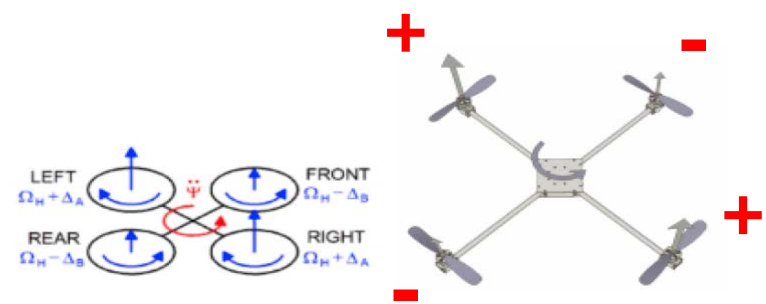
Vertical motion via uniform thrust



Rolling motion and translation via differential "left-right" thrust



Pitching motion and translation via differential "front-rear" thrust



Yawing motion via adjacent-paired differential reactive torque

Modeling impact on UAS due to winds & turbulence

- Clearly, loss of lift resulting in large vehicle translations (e.g., hitting the ground) is important.
- For manned vehicles, another important metric is large vertical accelerations (e.g., impact on occupants, stress on vehicle).
- Not yet clear what other metrics might be relevant to UAS (e.g., large attitude changes that result in stability & control problems).

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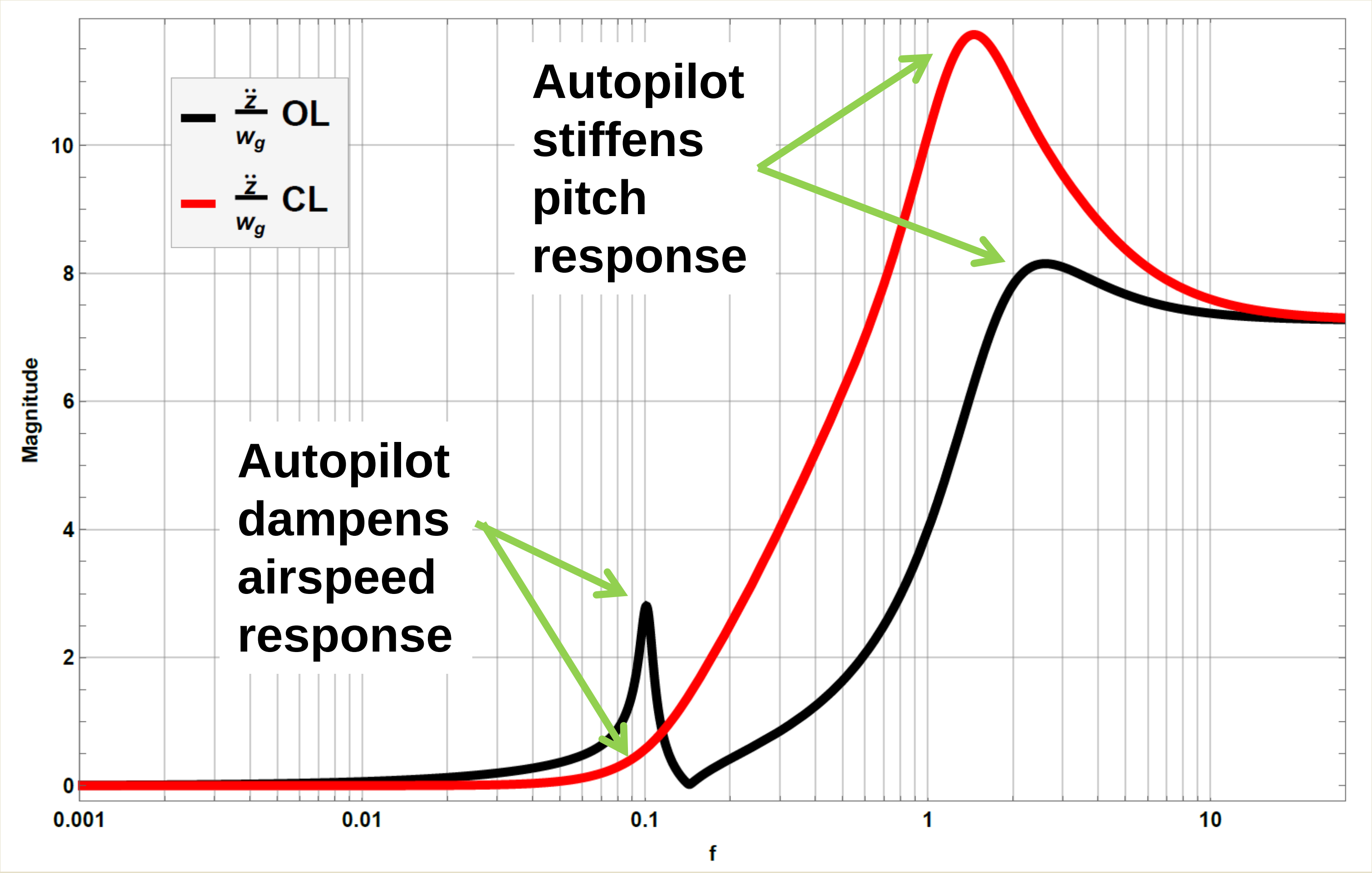
Autopilot has a significant effect on vertical acceleration response to vertical gust



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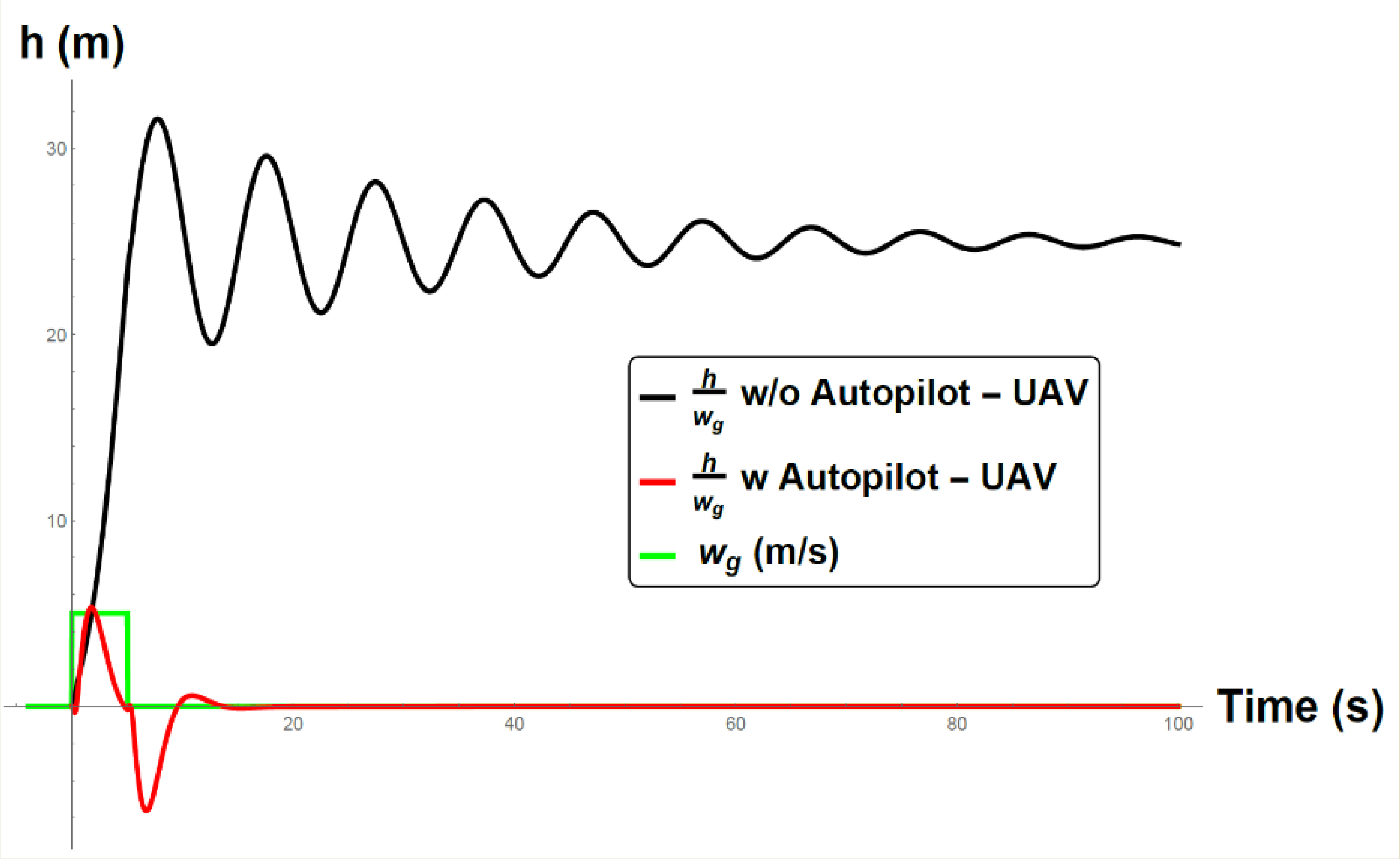
Autopilot has a dramatic effect on UAS height response to vertical gust



Vertical Displacement Response to Updraft

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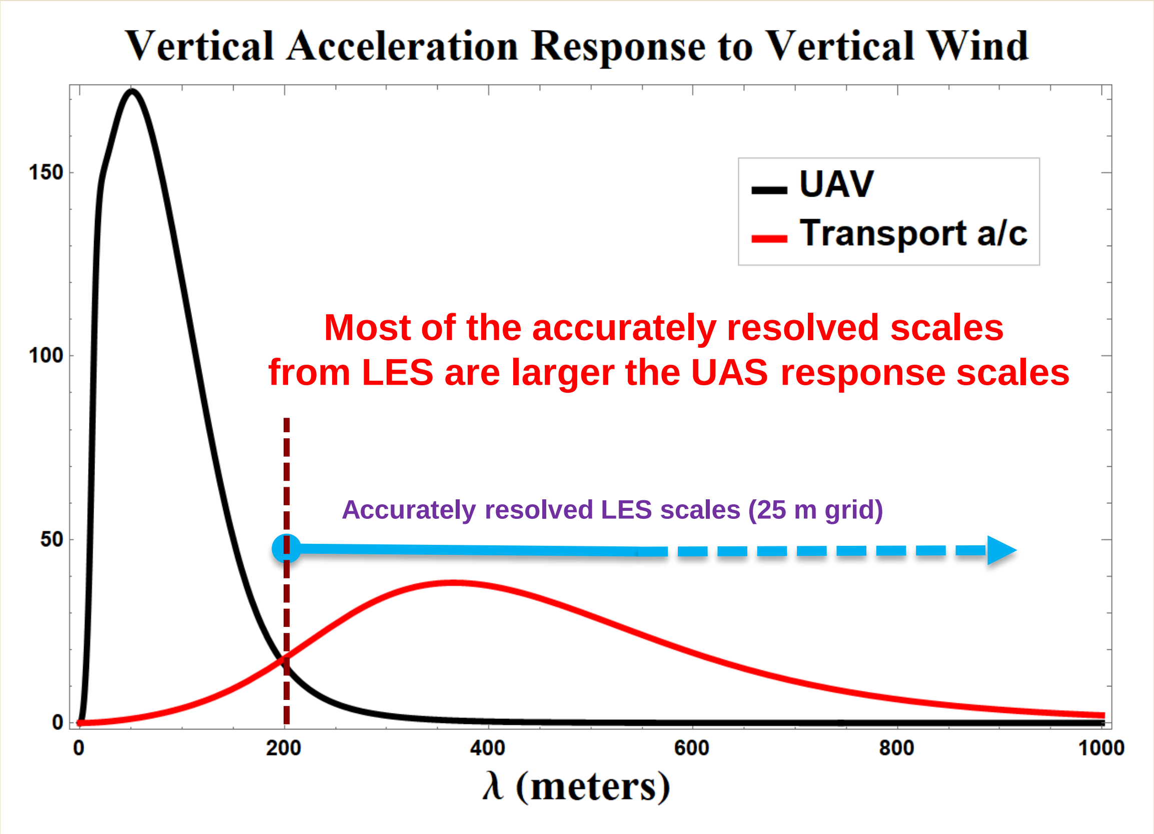
The importance of including realistic winds in UAS flight modeling and simulation

- Accurate UAS flight simulation requires accurate winds at UAS scales (m-10’s m).
- LES model output is inherently filtered; e.g., 25 m spatial resolution results in accurate winds at ~200 m.



Solution: merge LES wind with subgrid turbulence

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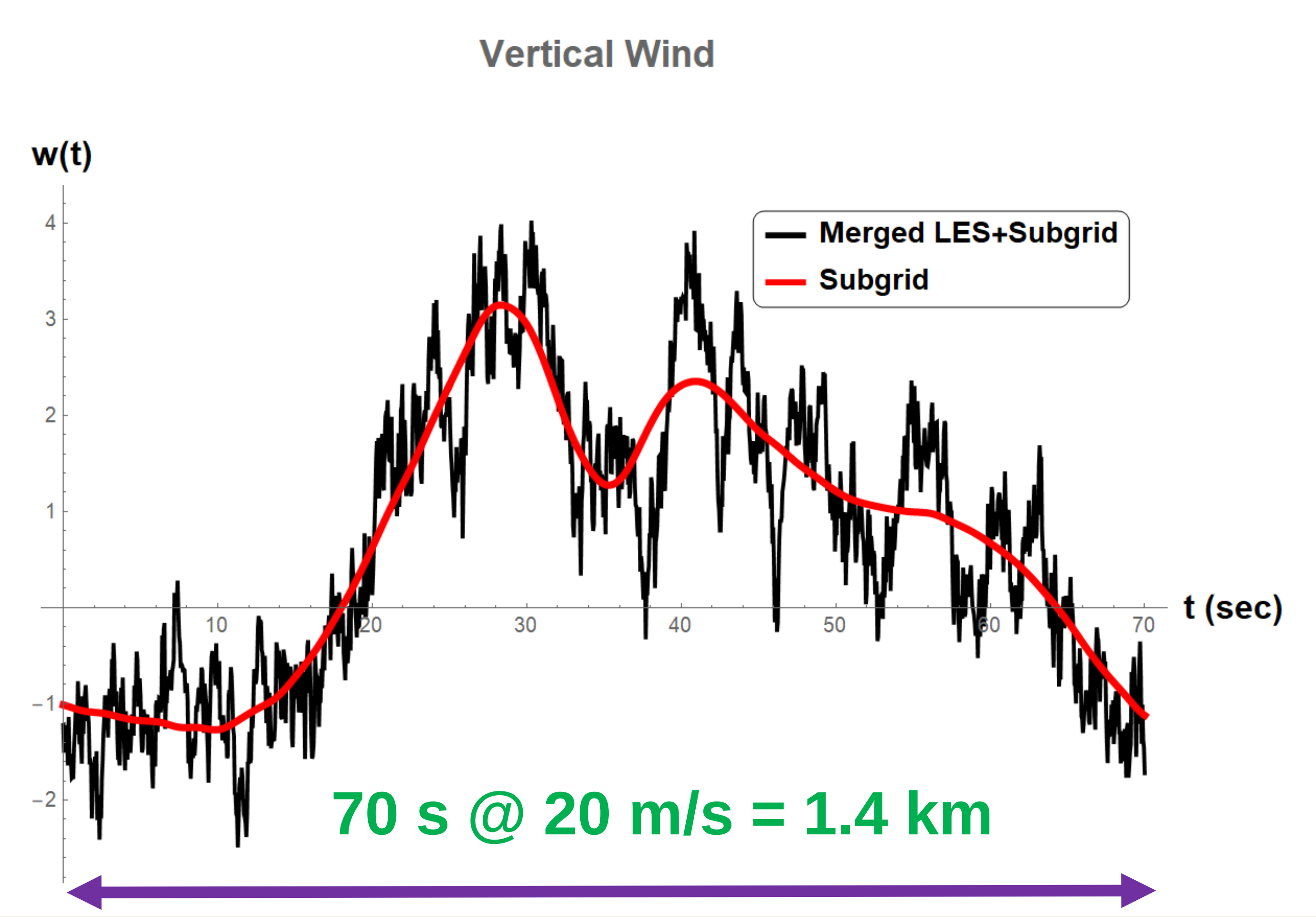
LES + subgrid merging example



Result: realistic large and small scale wind

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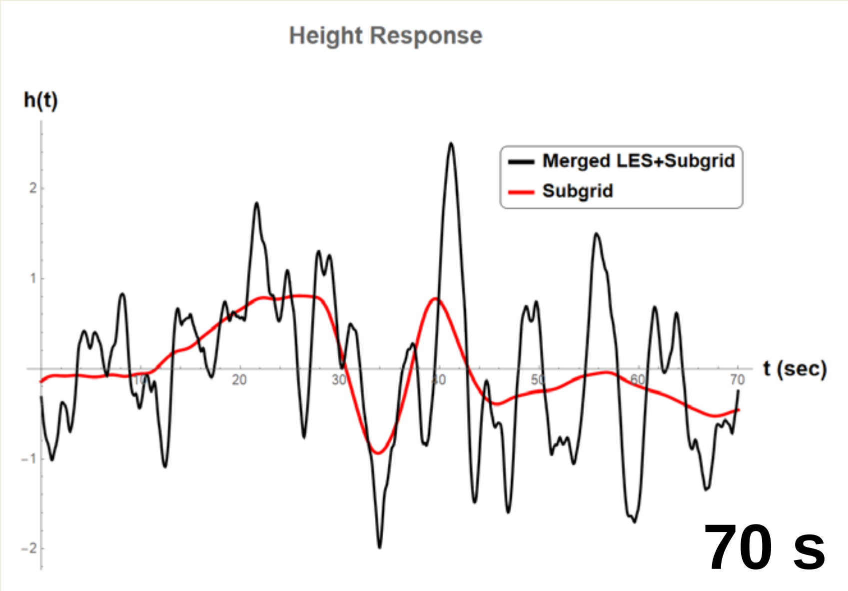
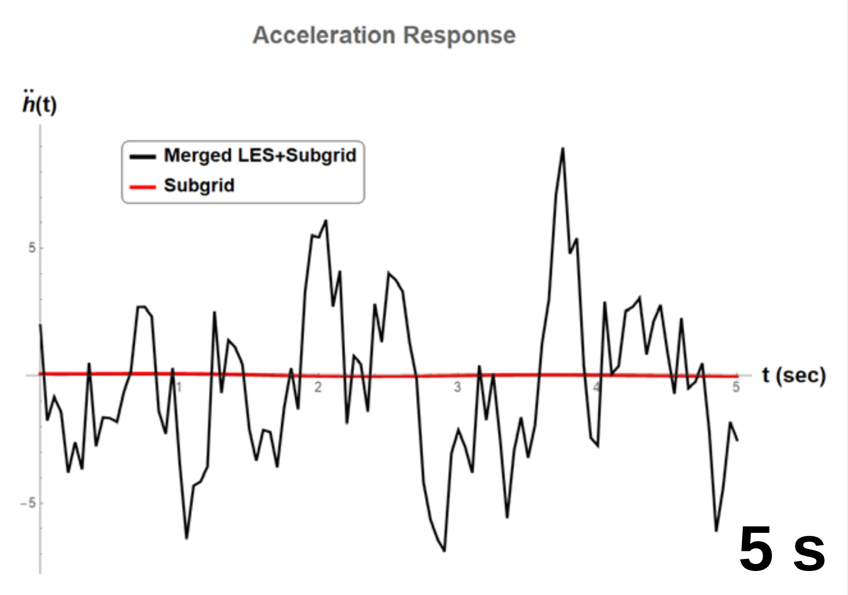
UAS simulation through LES and LES+subgrid wind fields

Height Response



Acceleration Response



Using LES-only gives ballpark results for height, but is inadequate for acceleration simulation

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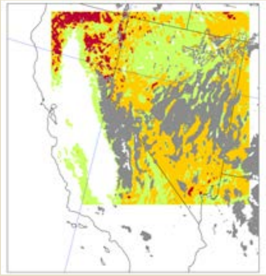
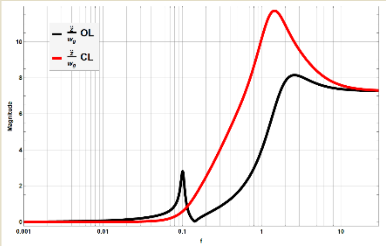
Application of research to operations

HRRR 3km data cutout

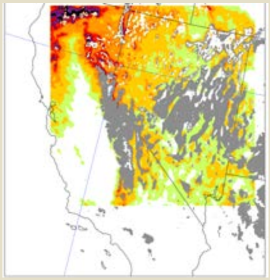
GTG Turbulence Product



UAS turbulence response



UAS impact values



Goal: End-to-End Turbulence Forecasting/Nowcasting System for UAS Operations

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Where do we go from here?

- **User needs assessment:**
  - What are the wind/turbulence impact variables of importance (performance and/or stability & control metrics)?
  - What are the required temporal/spatial scales?
  - What are the accuracy requirements?
  - How is the information provided to users (decision support systems)?
- **Research activities:**
  - Vehicle modeling/simulation (fixed-wing and multirotor).
  - Translation algorithms (model output -> vehicle impact).
  - Flight test/demos.

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