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

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**FAA Weather Related Aviation Accident Study 2003-2007**

- **Part 91, 121, 135, and 137**
  - But UAS are typically more sensitive to wx than larger vehicles

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Source: NTSB Aviation Accident and Incident Database
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®

Manual Control (Turbulence 7%)
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.
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.
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
Quadrotor motion and orientation changes via differential thrust and torque

Vertical motion via uniform thrust

Pitching motion and translation via differential “front-rear” thrust

Rolling motion and translation via differential “left-right” 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).
Autopilot has a significant effect on vertical acceleration response to vertical gust.

Autopilot stiffens pitch response.

Autopilot dampens airspeed response.

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

Vertical Displacement Response to Updraft
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
LES + subgrid merging example

Result: realistic large and small scale wind

70 s @ 20 m/s = 1.4 km
UAS simulation through LES and LES+subgrid wind fields

Using LES-only gives ballpark results for height, but is inadequate for acceleration simulation
Application of research to operations

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

- HRRR 3km data cutout
- GTG Turbulence Product
- UAS turbulence response
- UAS impact values
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.