Optimal Trajectory Generation for Aerial Towed Cable System Using APMonitor

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Outline

- Overview of UAVs
- Overview of Aerial Recovery
  - Basic concept and System dynamics
  - Flight test results
- Motivations of using APMonitor
- Preliminary results in APMonitor
  - Simulation (2D, 1-link cable)
  - OTG (2D, 1-link cable)
  - OTG (3D, 1-link cable)
  - OTG (3D, multi-link cable, no wind)
  - OTG (3D, multi-link cable, constant wind)
- Future work

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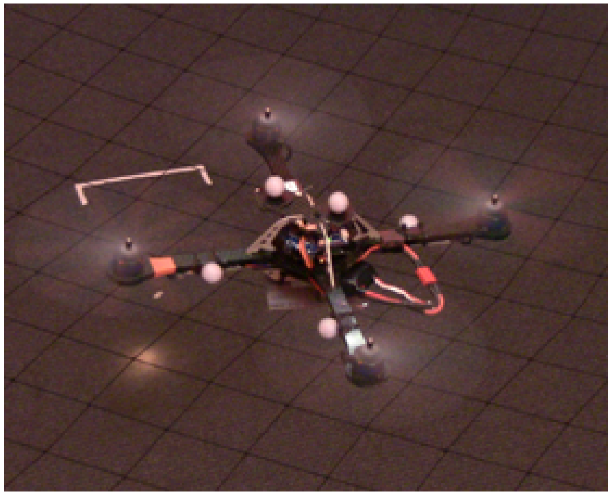
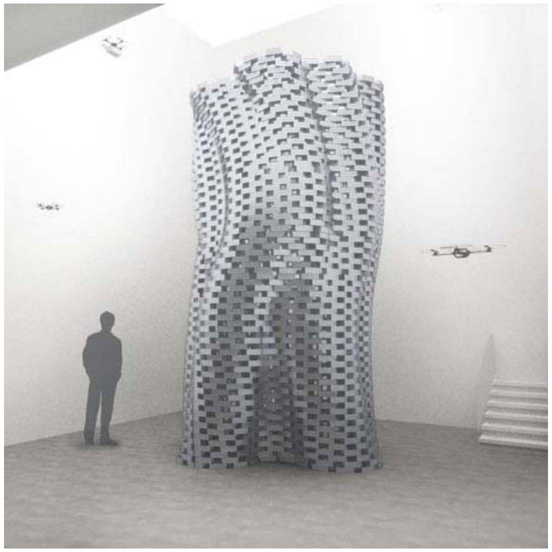
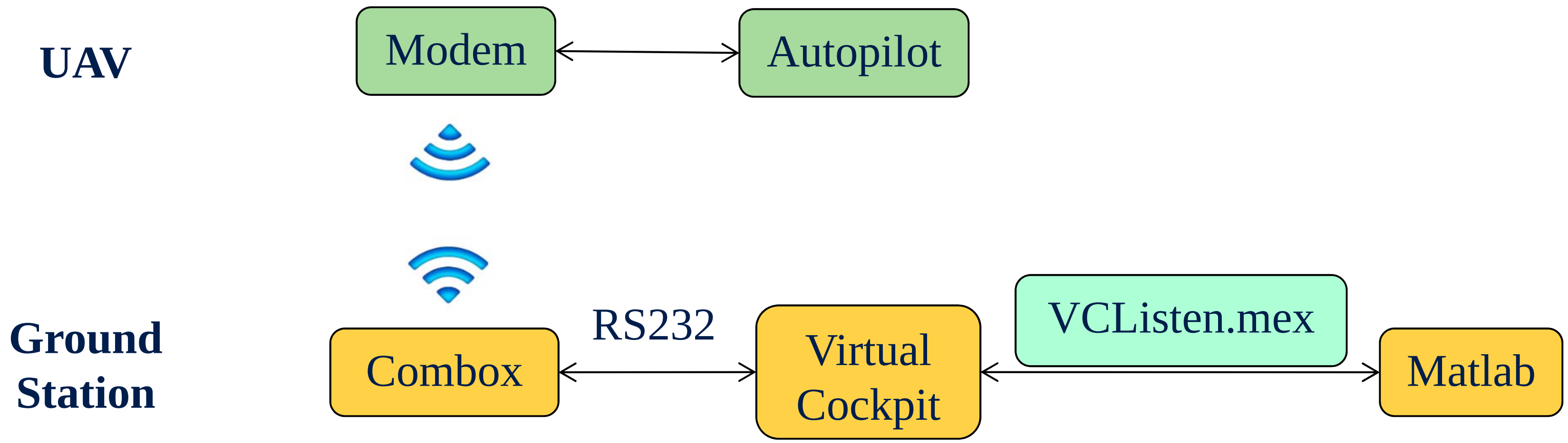
Overview of UAVs





Overview of UAVs

- Communication and Control



Overview of UAVs

- Cool videos!
  - Fixed wing
    http://www.youtube.com/watch?feature=endscreen&v=Xlrqxhz1iGc&NR=1
  - Quadrotor
    - Aggressive Maneuvers
    http://www.youtube.com/watch?v=MvRTALJp8DM
    - Builder
    http://www.youtube.com/watch?v=xvN9Ri1GmuY&feature=player_embedded

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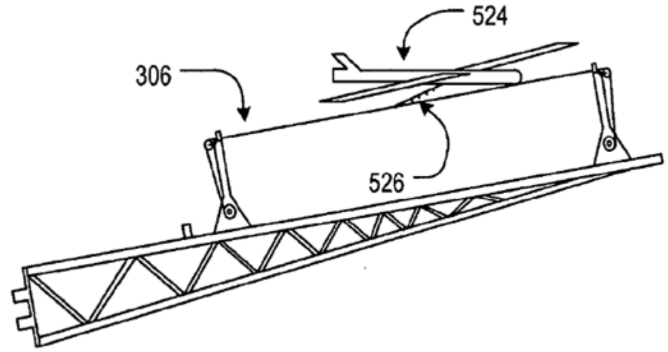
Overview of Aerial Recovery

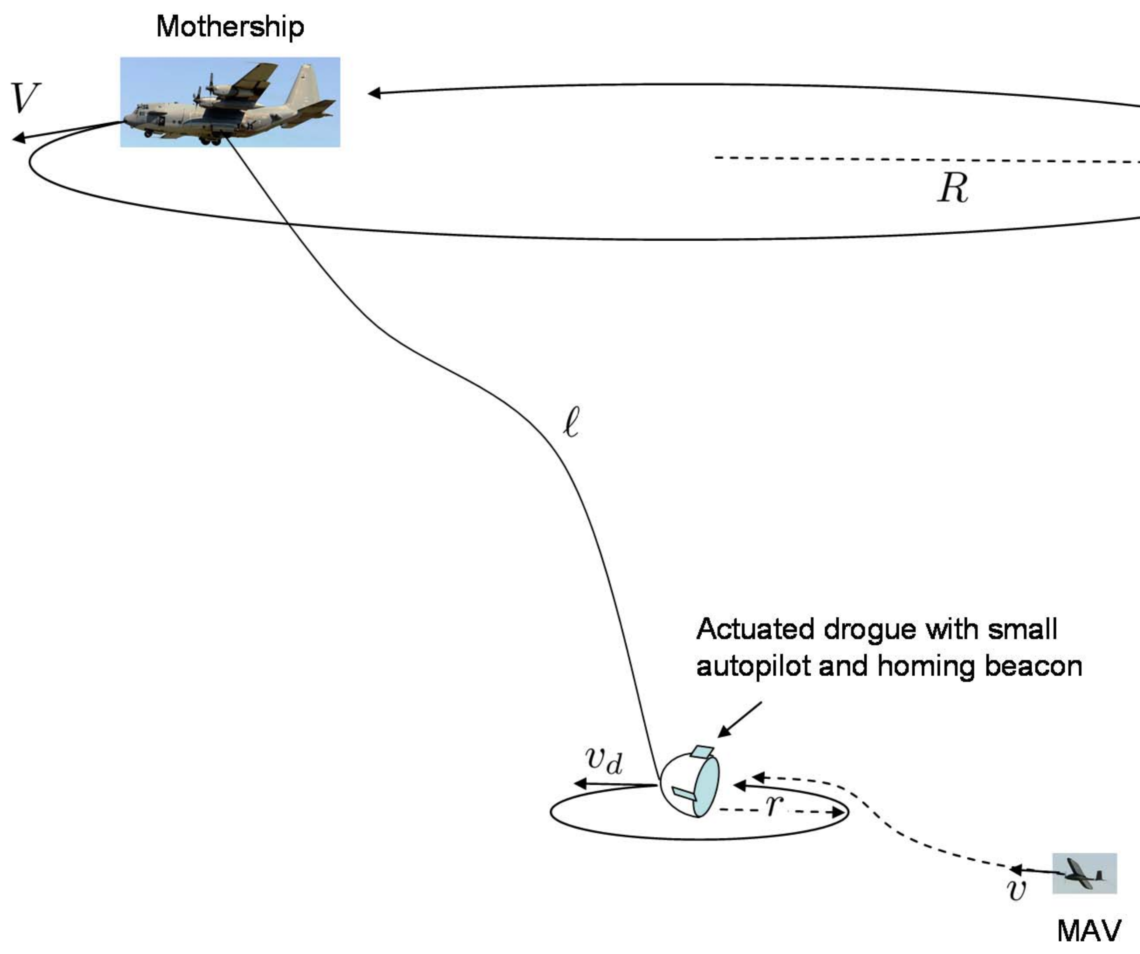
- Question:

  How can we retrieve Micro Air Vehicles (MAVs) in the air after they complete their missions?

Retrieval strategies



Basic concept



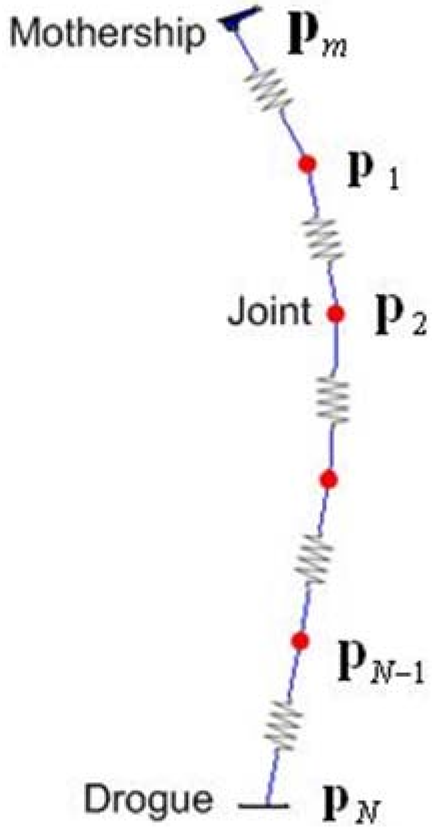
System dynamics

- Cable-drogue dynamics using Newton 2nd law

$$
\begin{aligned}
m_N \ddot{\mathbf{p}}_N &= \mathbf{T}_N + \Omega_N \\
\Omega_N &= \mathbf{G}_N + \mathbf{D}_N + \mathbf{L}_N,
\end{aligned}
$$

$$
\begin{aligned}
m_{j-1} \ddot{\mathbf{p}}_{j-1} &= \mathbf{T}_{j-1} + \Omega_{j-1} - \mathbf{T}_j \\
\Omega_{j-1} &= \mathbf{G}_{j-1} + \mathbf{D}_{j-1} + \mathbf{L}_{j-1} \\
j &= 2, 3, \cdots, N,
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{T}_j &= \frac{EA}{\ell_0} \left(\|\mathbf{p}_{j-1} - \mathbf{p}_j\| - \ell_0 \right) \frac{\mathbf{p}_{j-1} - \mathbf{p}_j}{\|\mathbf{p}_{j-1} - \mathbf{p}_j\|}, \\
j &= 1, 2, \cdots, N,
\end{aligned}
$$



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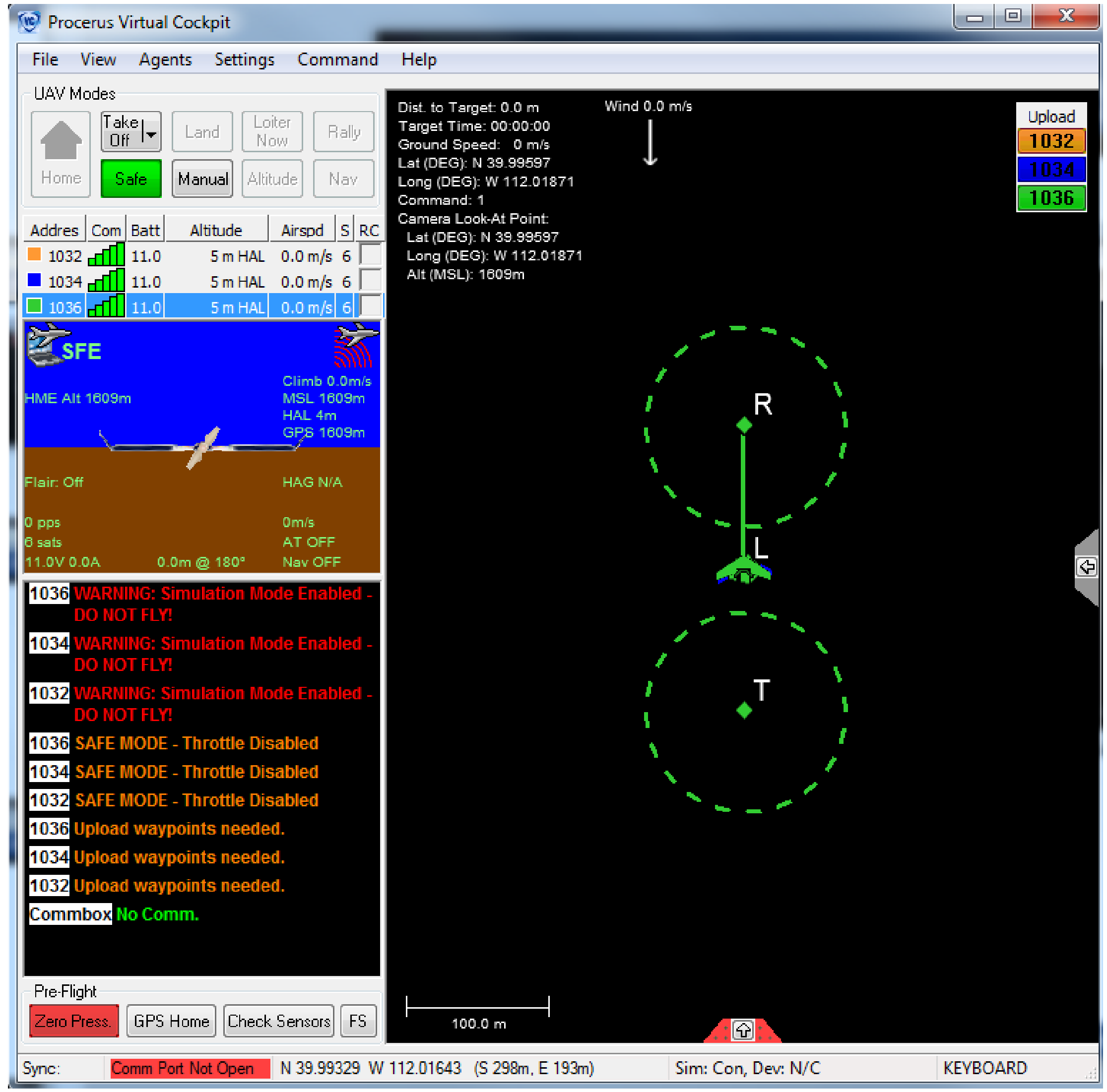
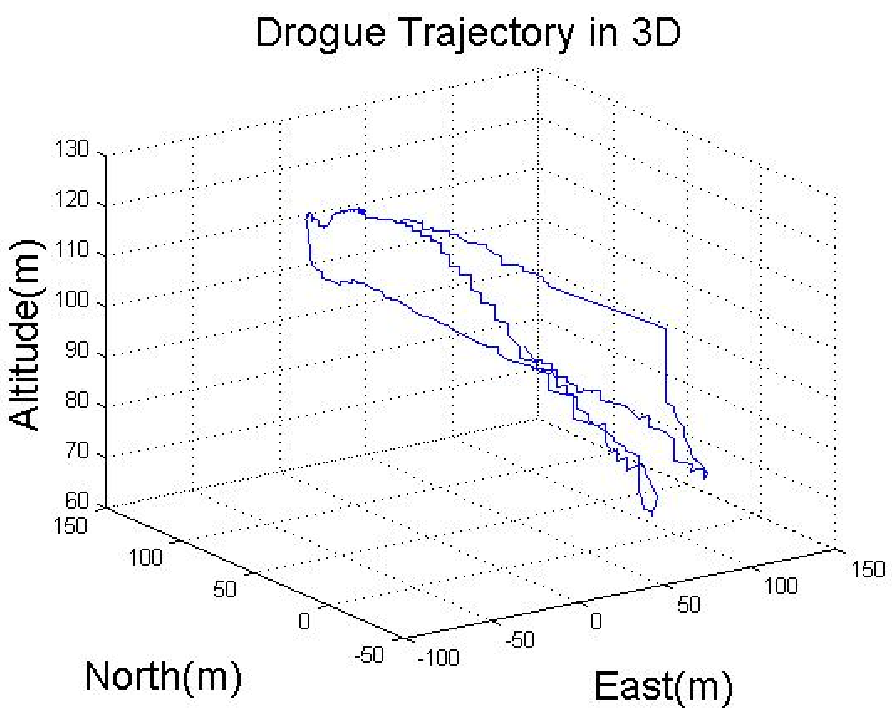
Flight test setup

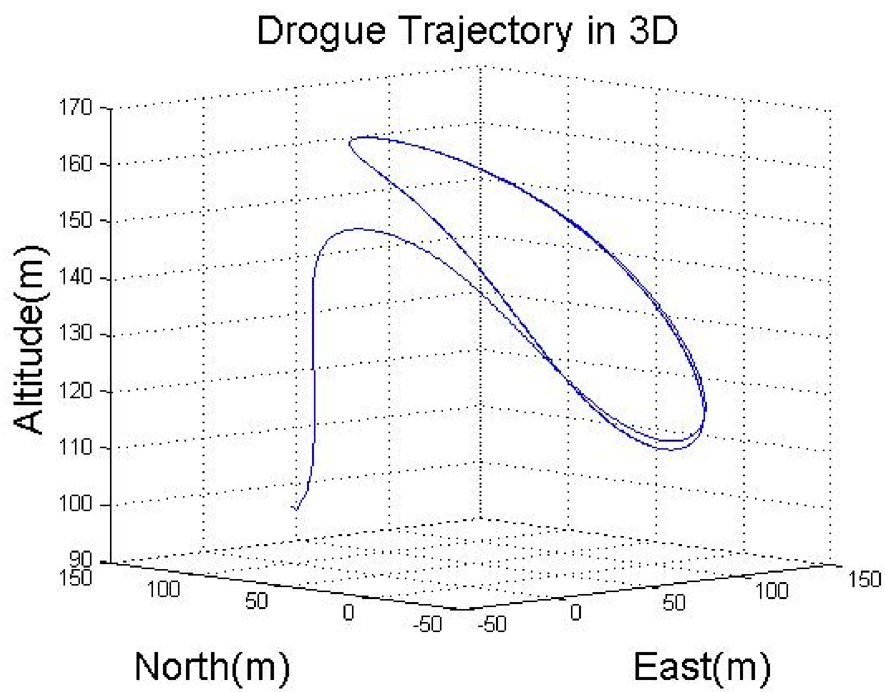


Flight test results

- Drogue orbit with flat mothership orbit in wind

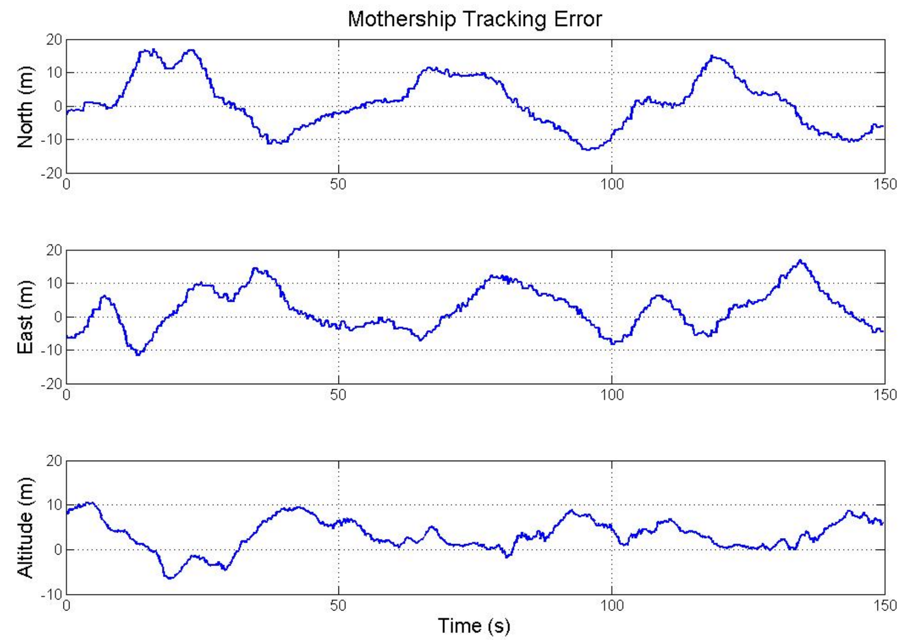


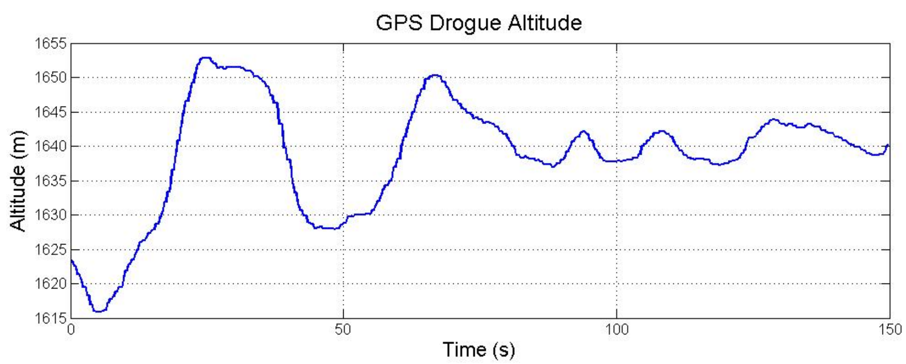
Flight Test

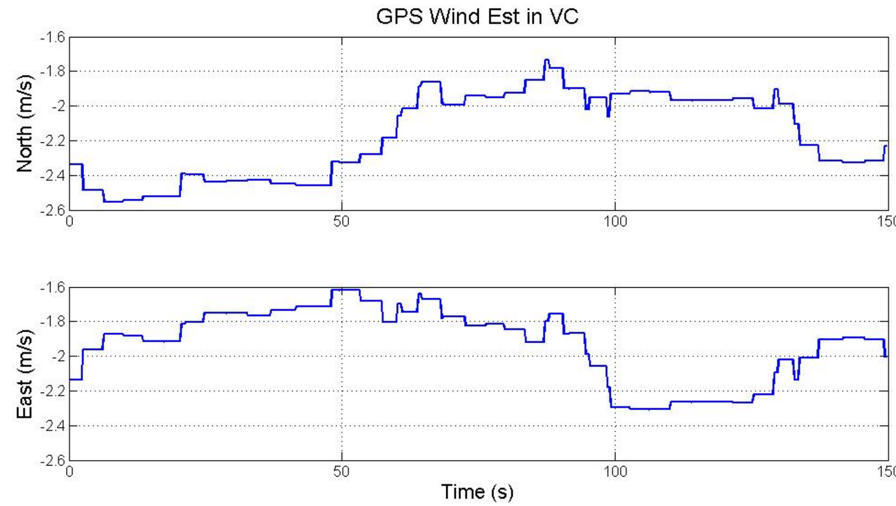


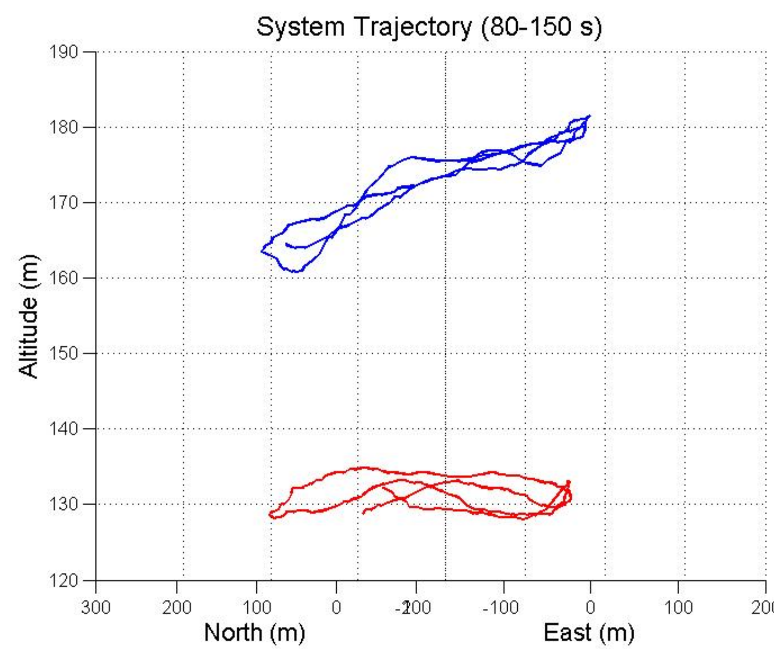
Simulation

Flight test results (cont'd)









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Motivations of using APMonitor

- Replan the desired mothership trajectory each circle using the updated wind estimation
  - Replan every minite
- Constraints: mothership has its operational limits: airspeed, roll angle, pitch angle

$10\ \mathrm{m/s} \leq V_a \leq 20\, m/s \qquad -35 \leq \phi \leq 35^\circ \qquad -15^\circ \leq \gamma_a \leq 35^\circ$

- Large amount of states in dynamic equations
  - 5-link cable = 30 states

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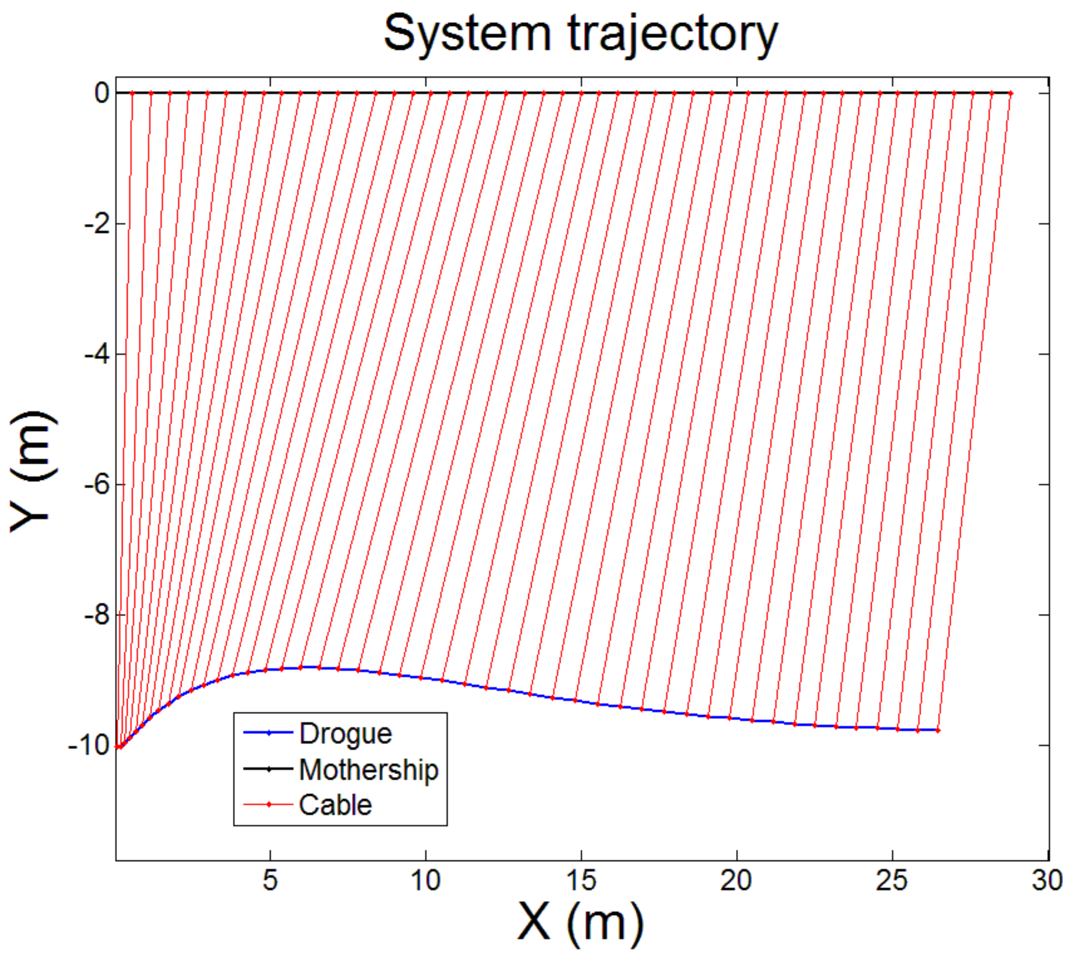
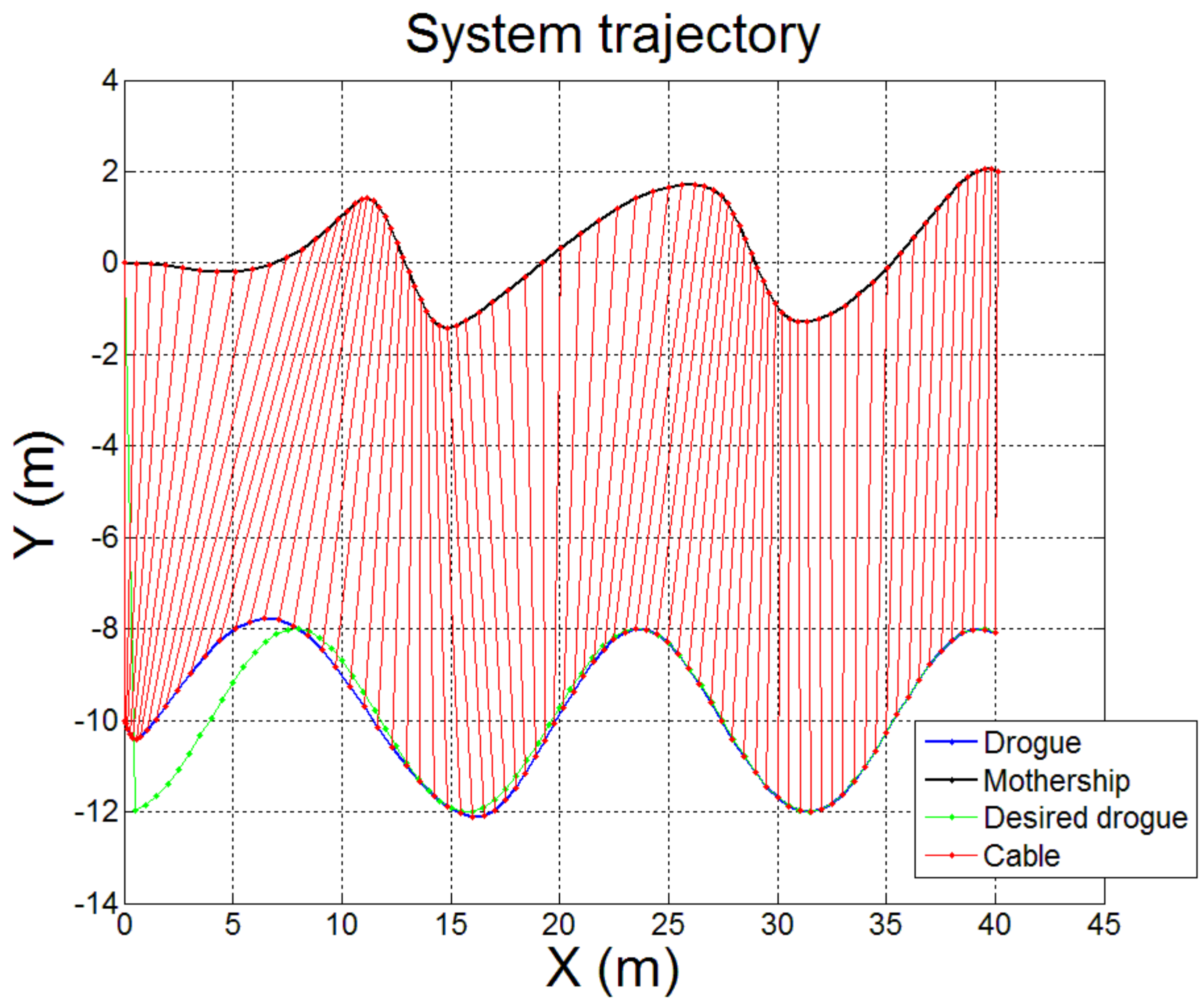
Simulation mode – 2-D 1-link model

- Simulation mode with no constraints
- Solution time: 0.624 sec.



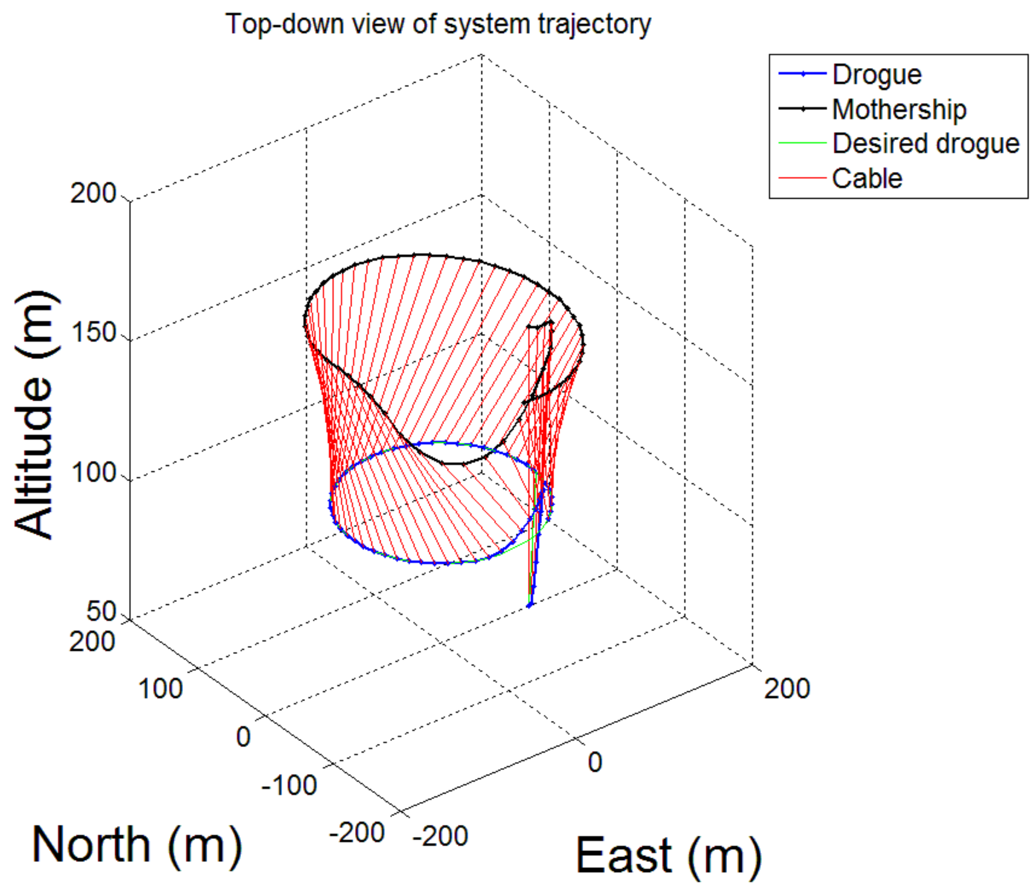
Trajectory Generation (2-D 1-link model)

- “nlc” mode, solver: IPOPT
- CVs:
  - Vm, Tension
- Solution time: 18.17 sec.



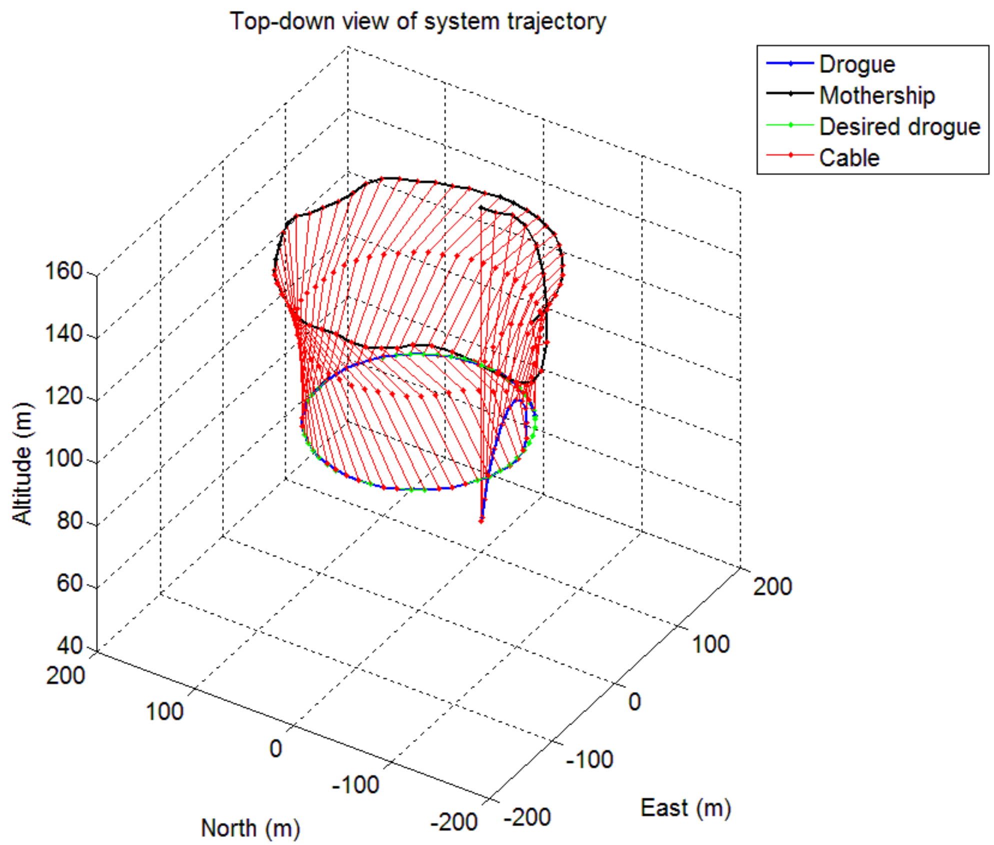
TG (3D, single-link, no wind)

- "nlc" mode, solver: IPOPT
- CVs:
  - Vm, Tension
- Solution time: 14.3328 sec.



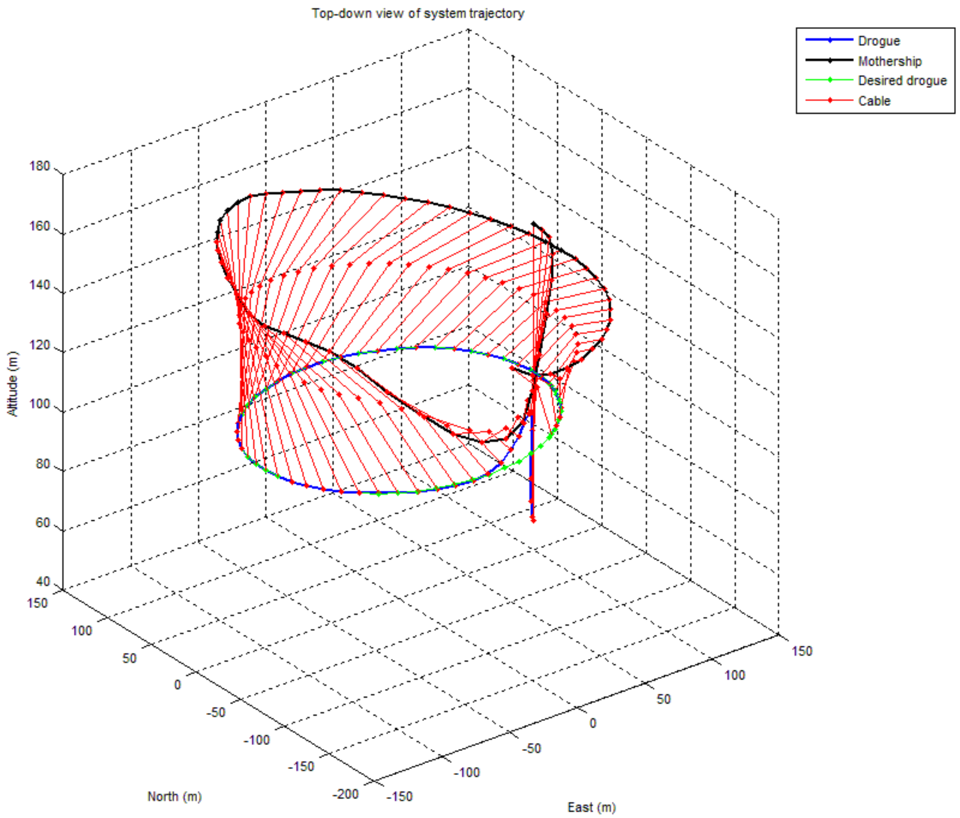
TG (3D, multi-link, no wind)

- “nlc” mode, solver: IPOPT
- CVs:
  - Vm
- Solution time: 141.6326 sec.



TG (3D, multi-link, wind)

- "nlc" mode, solver: IPOPT
- CVs:
  - CVs
- Wind (3,0,0) m/s
- Solution time: 163.6704 sec.



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Future work

- Decrease the solution time
  - different solver
  - different configuration of the problem
- Add more constraints
  - Tension, roll angle, pitch angle, and etc.
- Motion planning of orbit-insertion-removal
  - Fly into an orbit to perform the retrieval and leave out of the orbit
- Orbit regulation problem
  - Find an optimal orbit for the mothership to minimize the drogue altitude deviation

Thank You!

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Questions?