

Optimal Trajectory Generation for Aerial Towed Cable System Using APMonitor

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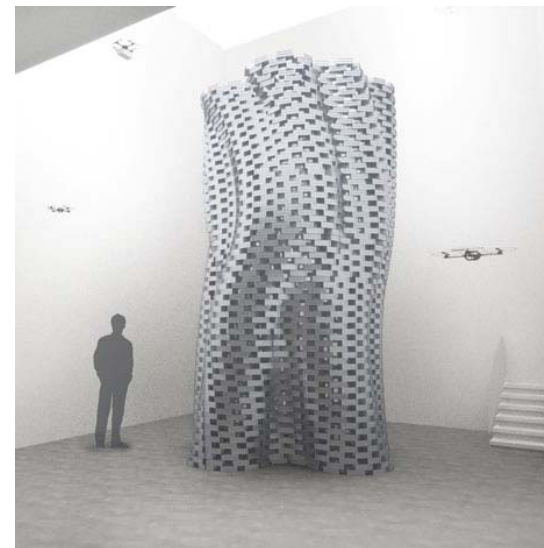
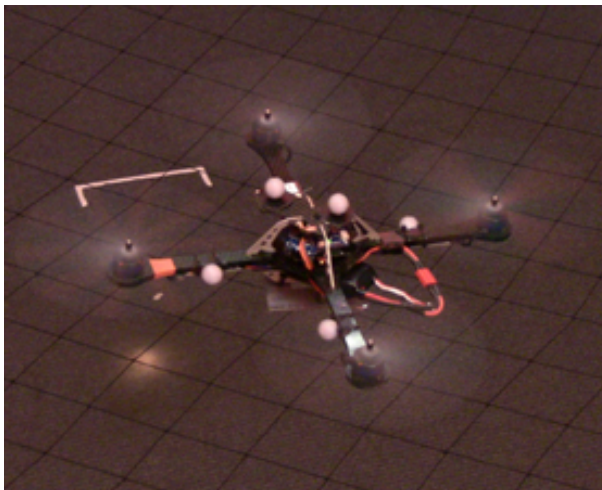
Outline

- 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

Outline

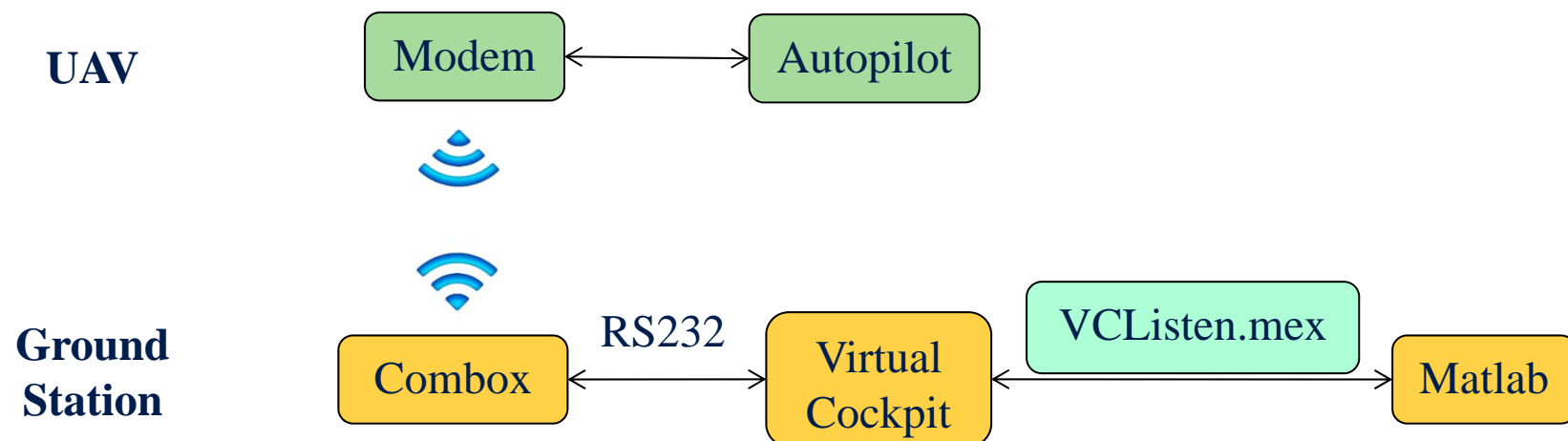
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Overview of UAVs



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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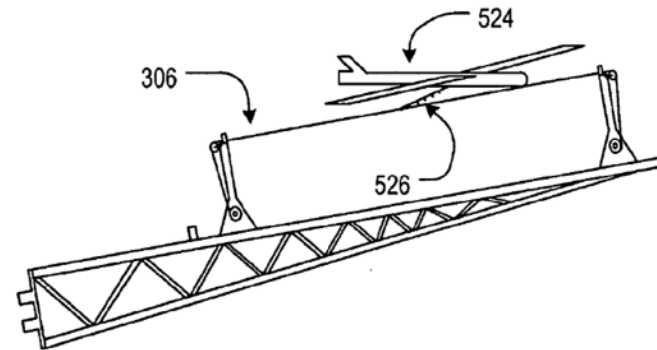
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Overview of Aerial Recovery

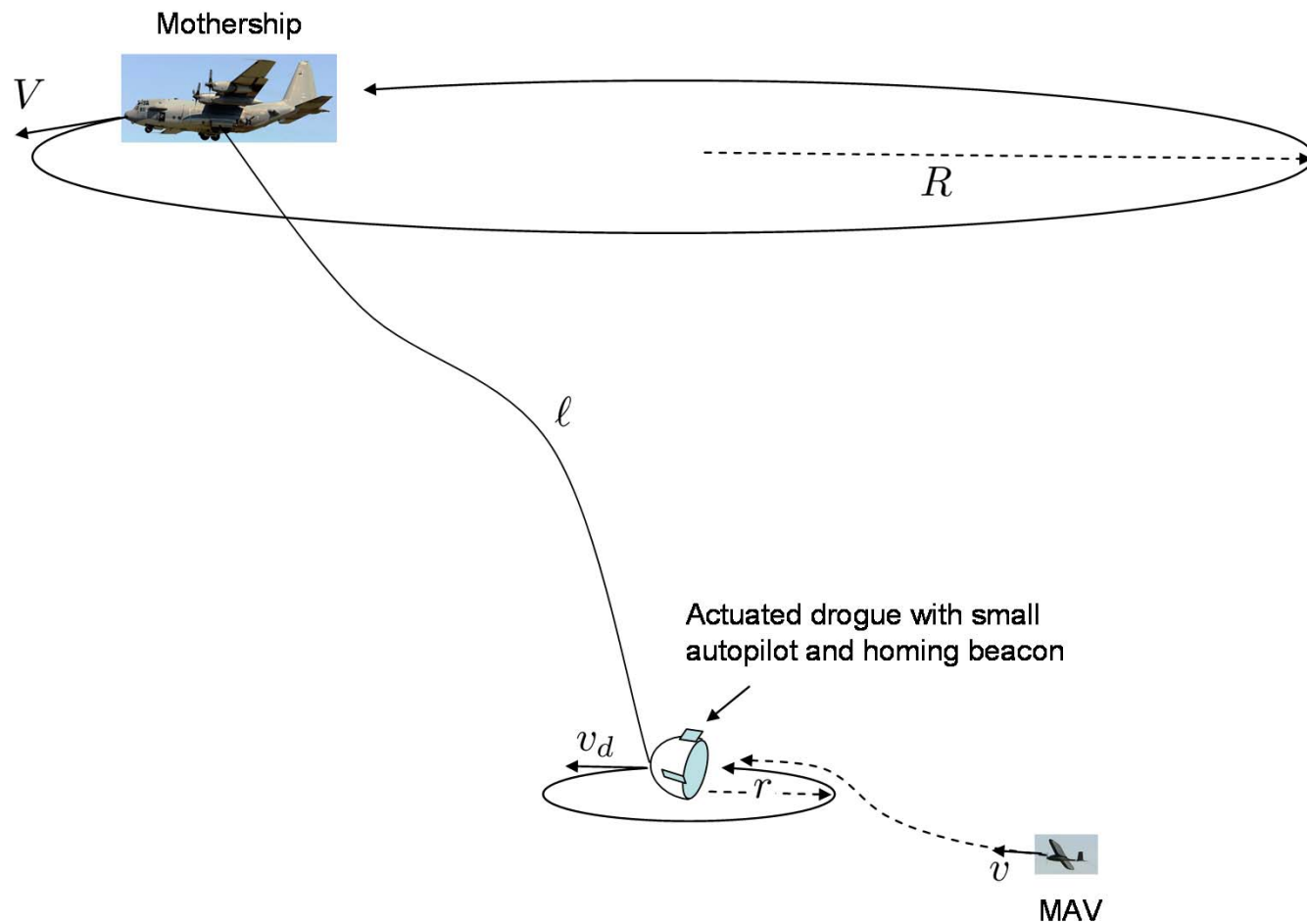
➤ Question:

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

$$m_N \ddot{\mathbf{p}}_N = \mathbf{T}_N + \Omega_N$$

$$\Omega_N = \mathbf{G}_N + \mathbf{D}_N + \mathbf{L}_N,$$

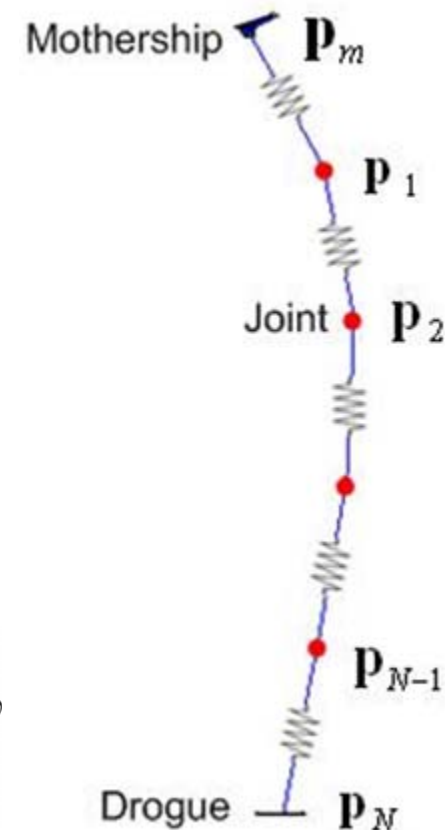
$$m_{j-1} \ddot{\mathbf{p}}_{j-1} = \mathbf{T}_{j-1} + \Omega_{j-1} - \mathbf{T}_j$$

$$\Omega_{j-1} = \mathbf{G}_{j-1} + \mathbf{D}_{j-1} + \mathbf{L}_{j-1}$$

$$j = 2, 3, \dots, N,$$

$$\mathbf{T}_j = \frac{EA}{\ell_0} (\|\mathbf{p}_{j-1} - \mathbf{p}_j\| - \ell_0) \frac{\mathbf{p}_{j-1} - \mathbf{p}_j}{\|\mathbf{p}_{j-1} - \mathbf{p}_j\|},$$

$$j = 1, 2, \dots, N,$$



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Flight test setup



Procerus Virtual Cockpit

File View Agents Settings Command Help

UAV Modes

Home Take Off Land Loiter Now Rally

Safe Manual Altitude Nav

| Address | Com | Batt | Altitude | Airspd | S | RC |
|---------|----------|------|----------|---------|---|----|
| 1032 | [Signal] | 11.0 | 5 m HAL | 0.0 m/s | 6 | |
| 1034 | [Signal] | 11.0 | 5 m HAL | 0.0 m/s | 6 | |
| 1036 | [Signal] | 11.0 | 5 m HAL | 0.0 m/s | 6 | |

SFE

HME Alt 1809m

Climb 0.0m/s
MSL 1809m
HAL 4m
GPS 1809m

Flair: Off HAG N/A

0 pps 0m/s
8 sats AT OFF
11.0V 0.0A 0.0m @ 180° Nav OFF

1036 WARNING: Simulation Mode Enabled - DO NOT FLY!
1034 WARNING: Simulation Mode Enabled - DO NOT FLY!
1032 WARNING: Simulation Mode Enabled - DO NOT FLY!
1036 SAFE MODE - Throttle Disabled
1034 SAFE MODE - Throttle Disabled
1032 SAFE MODE - Throttle Disabled
1036 Upload waypoints needed.
1034 Upload waypoints needed.
1032 Upload waypoints needed.
Commbx No Comm.

Pre-Flight
Zero Press GPS Home Check Sensors FS

Dist. to Target: 0.0 m
Target Time: 00:00:00
Ground Speed: 0 m/s
Lat (DEG): N 39.99597
Long (DEG): W 112.01871
Command: 1
Camera Look-At Point:
Lat (DEG): N 39.99597
Long (DEG): W 112.01871
Alt (MSL): 1809m

Wind 0.0 m/s

Upload
1032
1034
1036

R
L
T

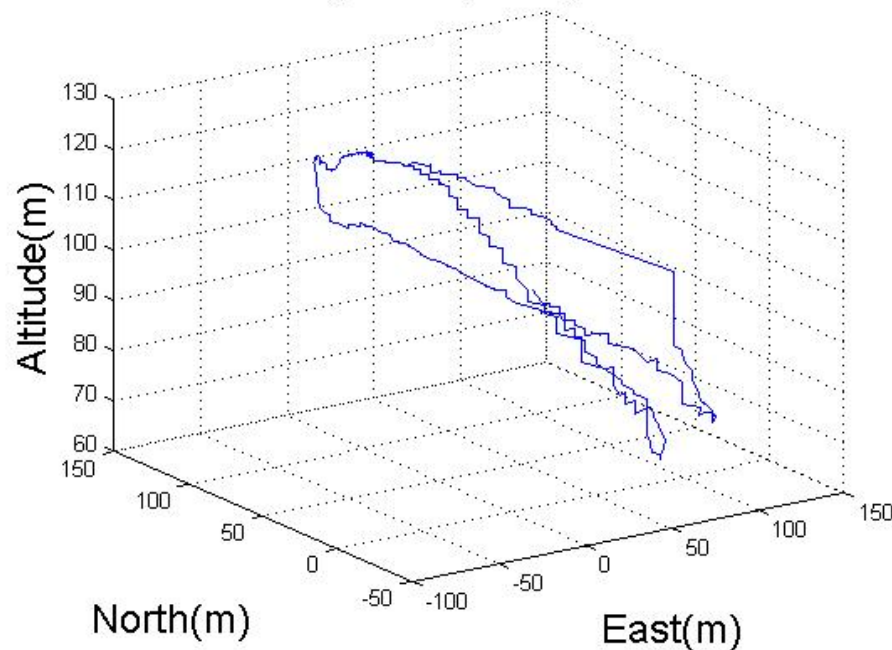
100.0 m

Sync: Comm Port Not Open N 39.99329 W 112.01643 (S 298m, E 193m) Sim: Con, Dev: N/C KEYBOARD

Flight test results

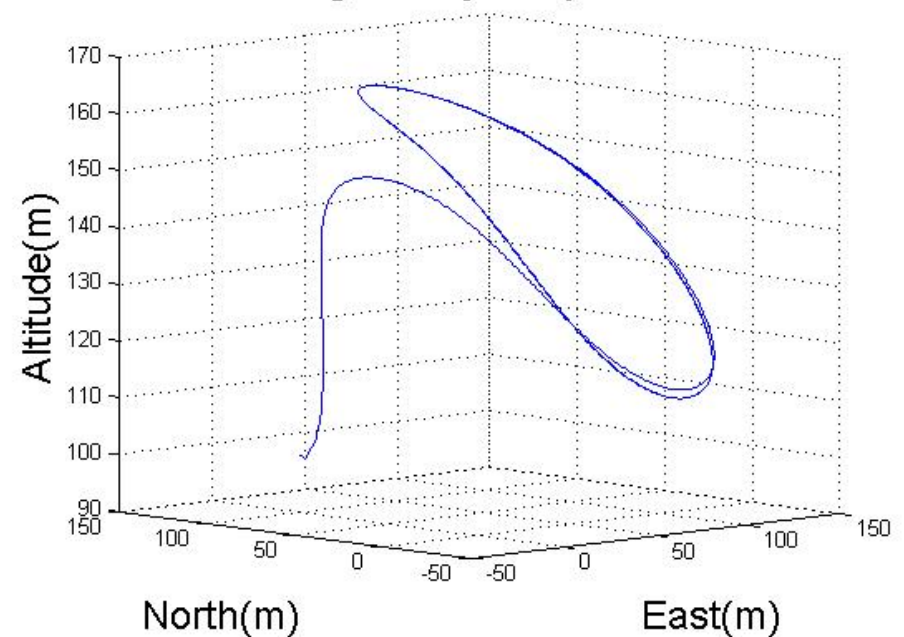
- Drogue orbit with flat mothership orbit in wind

Drogue Trajectory in 3D



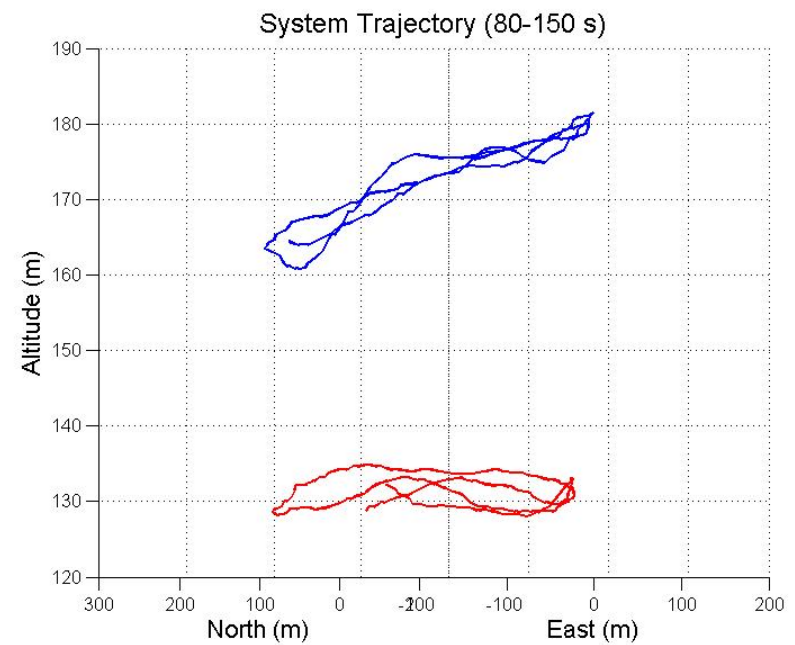
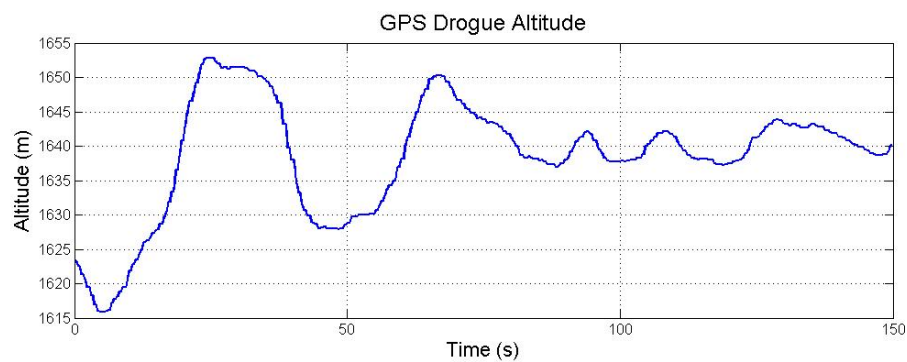
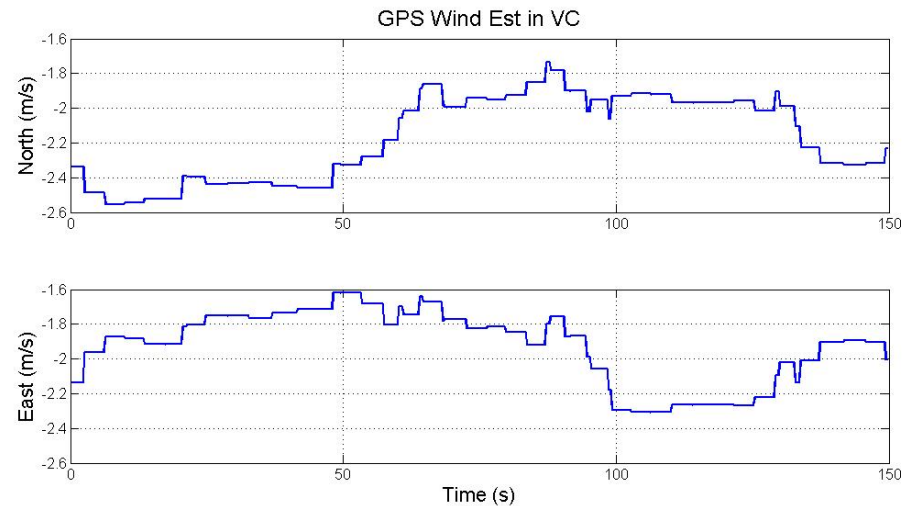
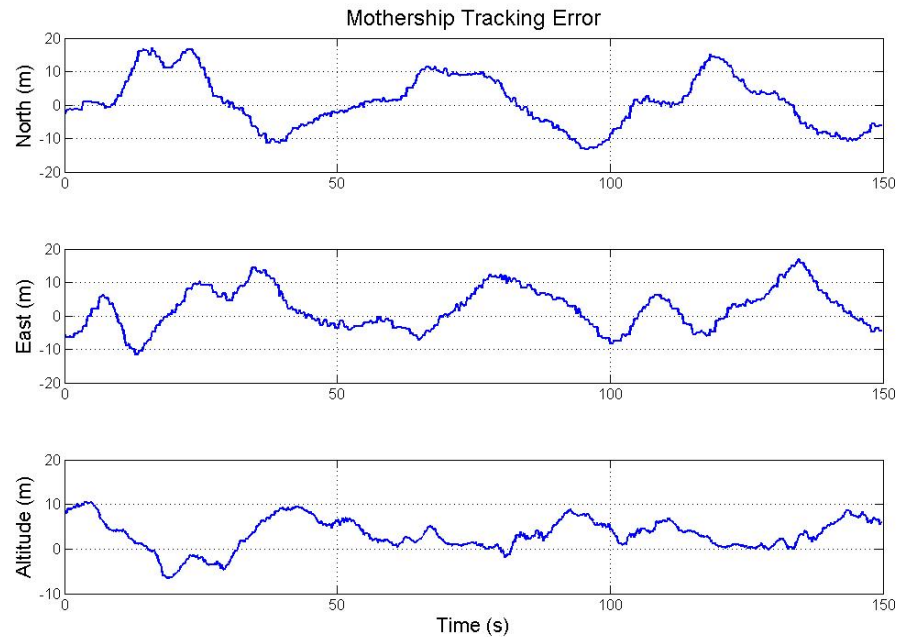
Flight Test

Drogue Trajectory in 3D



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 minute

- Constraints: mothership has its operational limits: airspeed, roll angle, pitch angle

$$10 \text{ m/s} \leq V_a \leq 20 \text{ m/s} \quad -35 \leq \phi \leq 35^\circ \quad -15^\circ \leq \gamma_a \leq 35^\circ$$

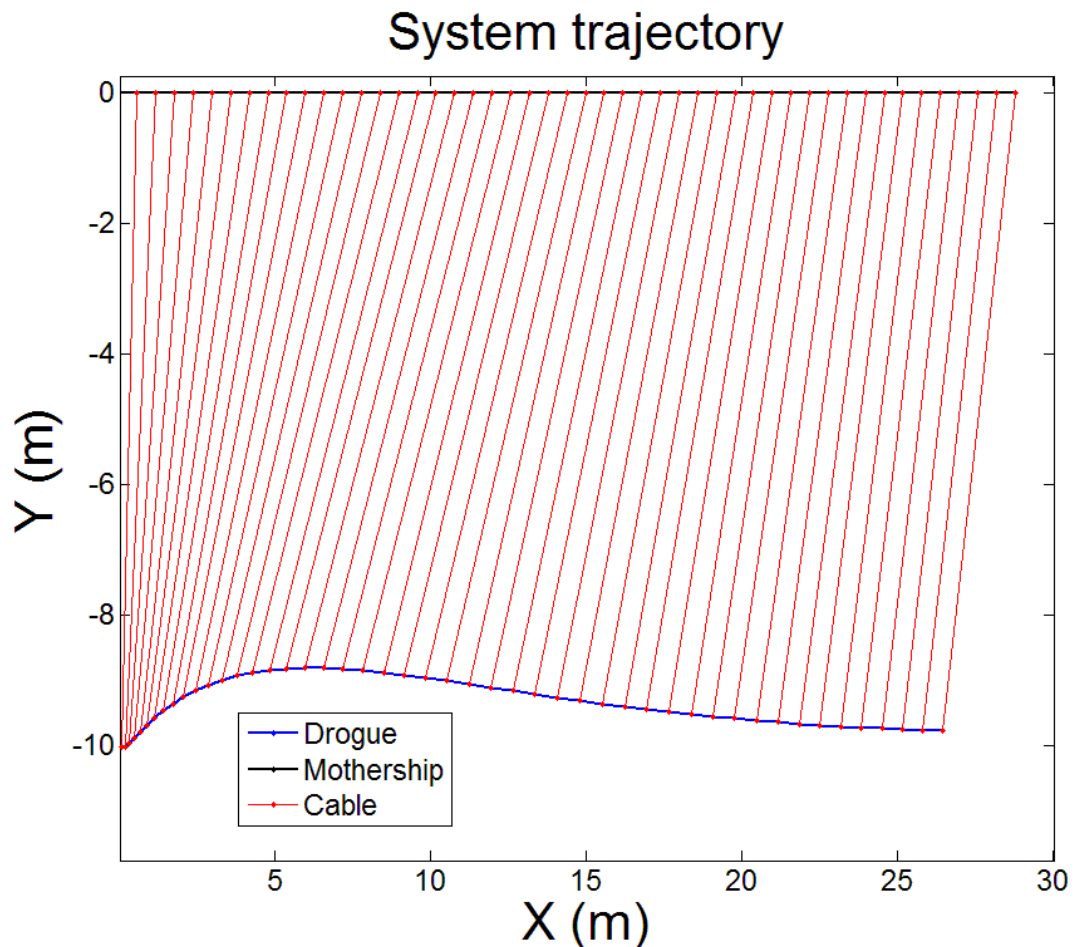
- Large amount of states in dynamic equations
 - 5-link cable = 30 states

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Simulation mode – 2-D 1-link model

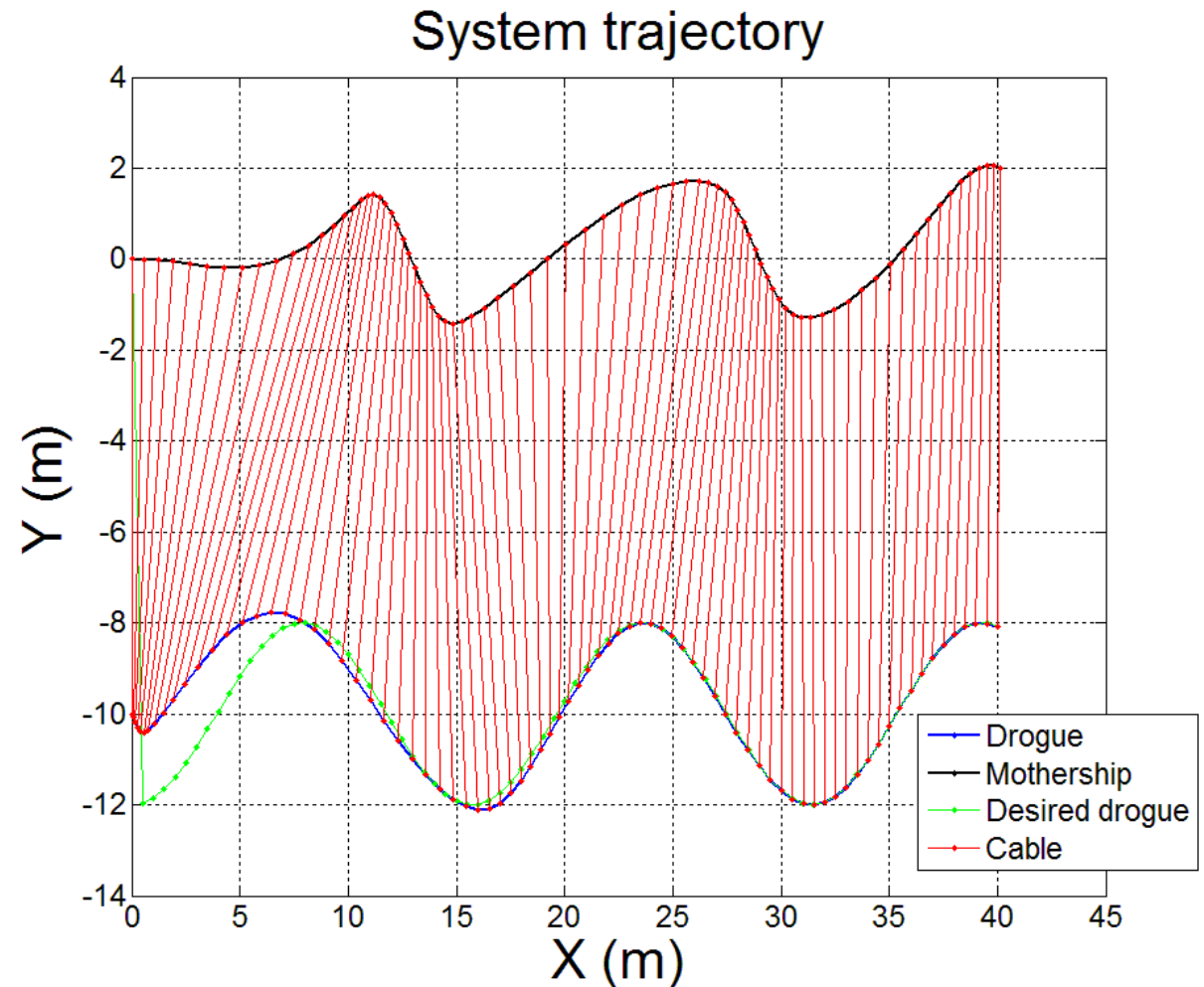
- Simulation mode with no constraints
- Solution time:
0.624 sec.



Trajectory Generation (2-D 1-link model)

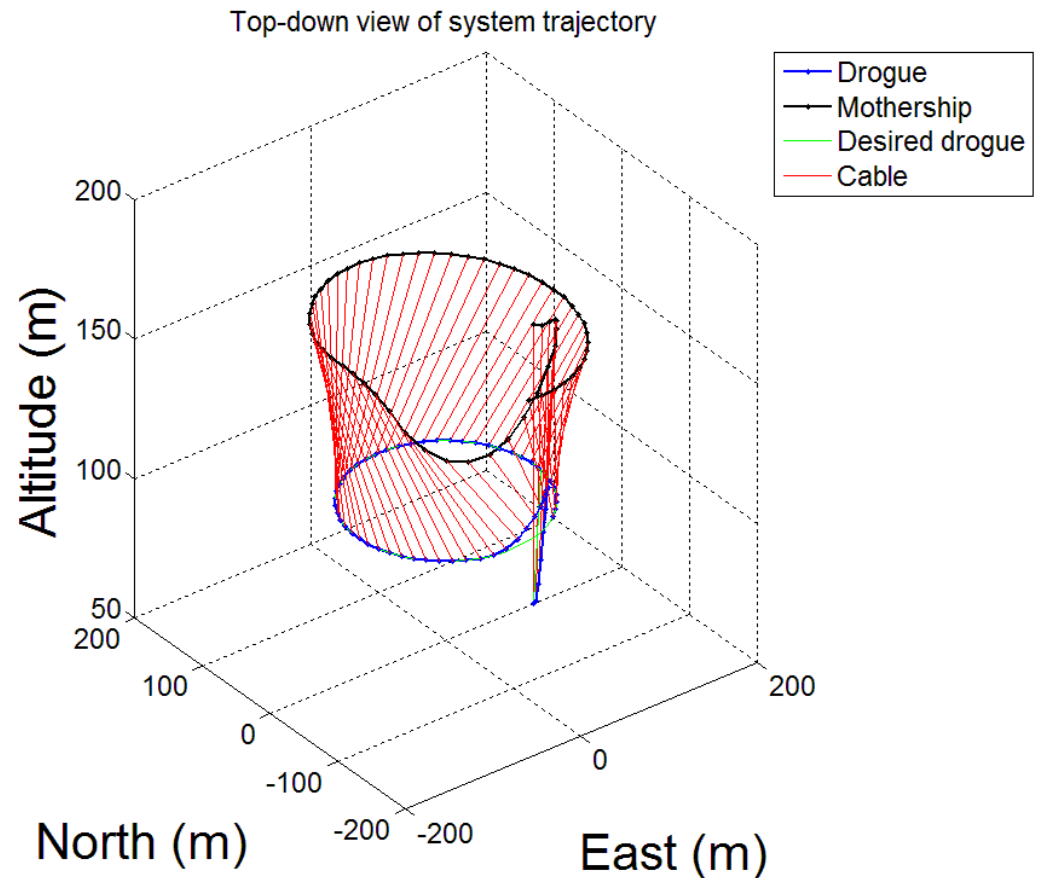


- “nlp” mode, solver: IPOPT
- CVs:
 - V_m , Tension
- Solution time:
18.17 sec.



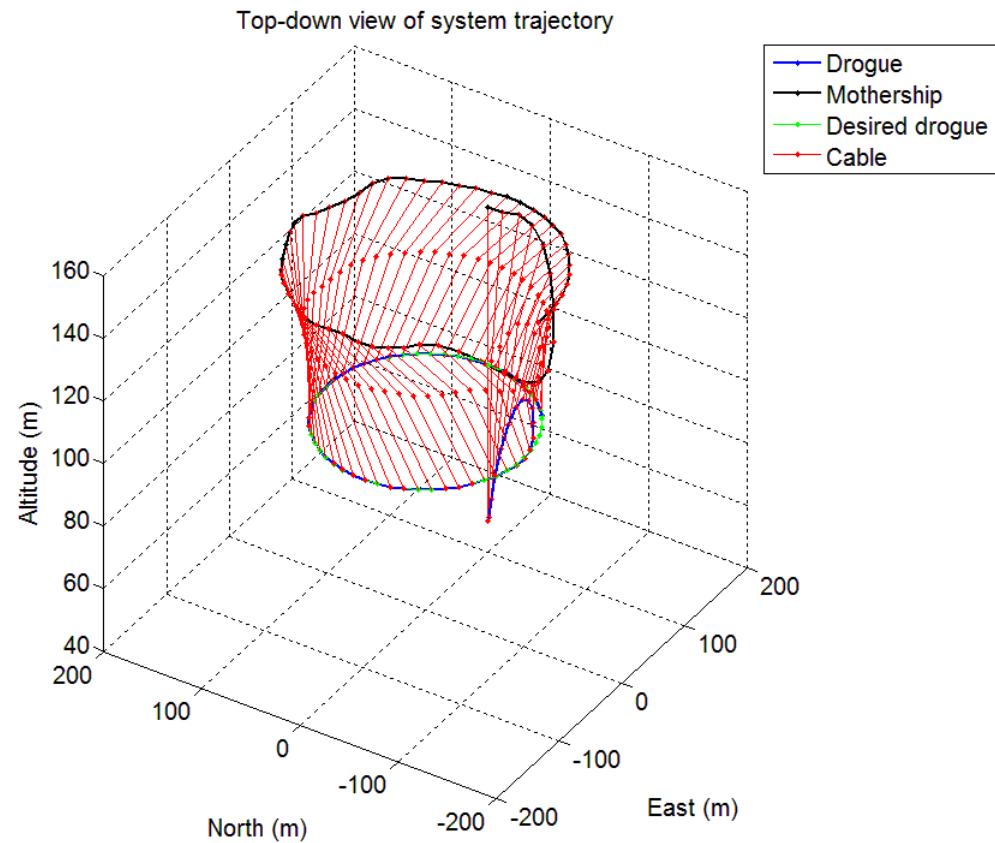
TG (3D, single-link, no wind)

- “nlp” mode, solver: IPOPT
- CVs:
 - V_m , Tension
- Solution time:
14.3328 sec.



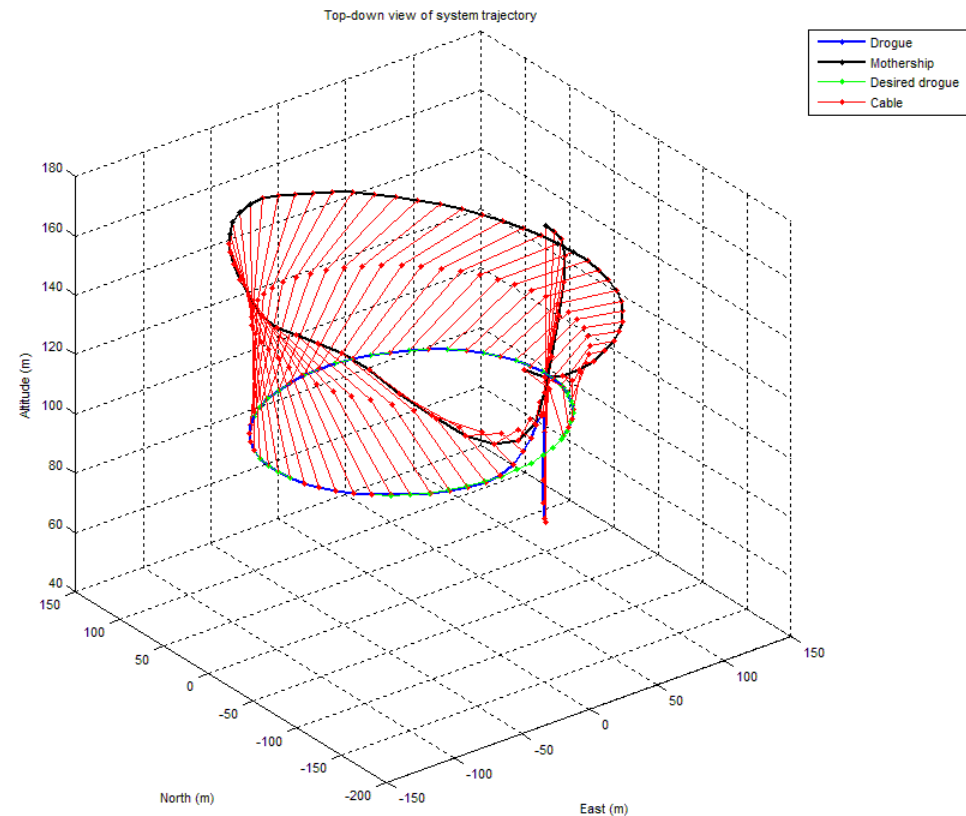
TG (3D, multi-link, no wind)

- “nlc” mode, solver: IPOPT
- CVs:
 - V_m
- 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**

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?