

The transition phase of a Gun-Launched Micro Air Vehicle: Nonlinear Modeling and Control

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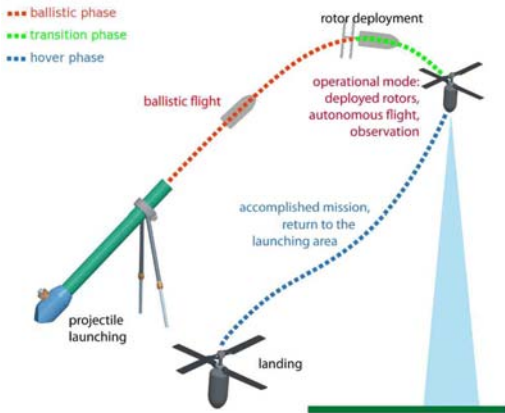
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Outline

- Introduction
- Modeling
- Transition φ problems
- Control
- Simulations
- Experimentation
- Conclusion

GLMAV concept

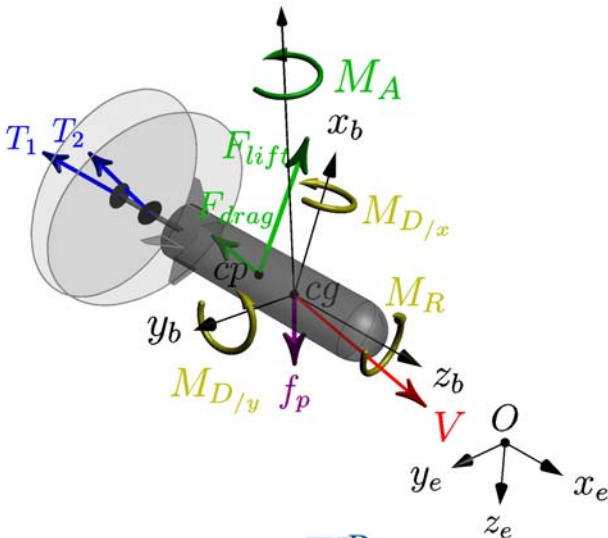
- Joint project between the ISL, the HEUDIASYC, the CRAN and SBG Systems
- Transformation of a projectile into a MAV



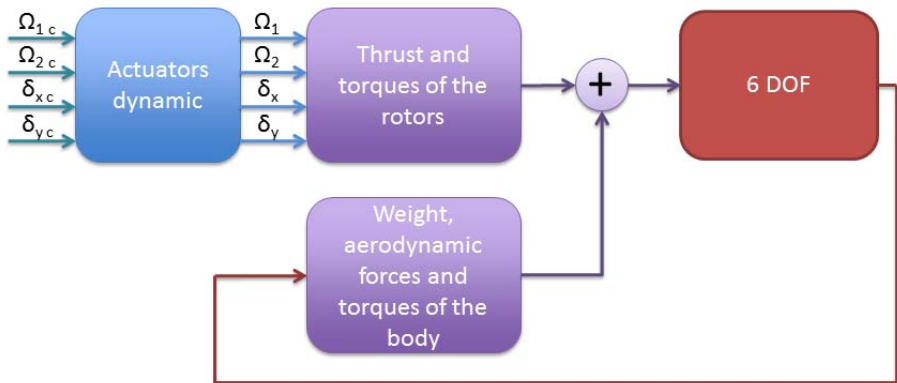
GLMAV vs Conventional MAV

	GLMAV	Fixed-Wing/VTOL aircraft MAV
<i>Target ETA</i>	Very fast	Fast
<i>Energy consumption</i>	No energy used until rotors deployment	Energy used during the whole flight envelope
<i>Hovering control</i>	Swashplate (mechanical complexity)	NA / Control surfaces or tilting-rotor
<i>Crosswind robustness</i>	Low drag	High drag (wings)

Notations



Dynamic model structure



Simulation dynamic model

Translational dynamics

$$m \begin{pmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} - m \begin{pmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \mathbf{T}(\Omega_i, \delta_{c_{x/y}}) + \mathbf{f}_{\text{body}}(\mathbf{V}_{\text{prop}}, \mathbf{V}_{\text{body}}, \mathbf{V}_{\text{wind}}) + \mathbf{f}_p$$

Koehl & al, 2010

Ballistic forces

$$\begin{cases} \mathbf{F}_{\text{drag}} = -qSC_D \frac{\mathbf{V}}{\|\mathbf{V}\|} \\ \mathbf{F}_{\text{lift}} = qSC_L \frac{\mathbf{V}}{\|\mathbf{V}\|} \otimes \left(\frac{\mathbf{z}_b}{\sin\delta} \otimes \frac{\mathbf{V}}{\|\mathbf{V}\|} \right) \end{cases}$$

Simulation dynamic model

Rotational dynamics

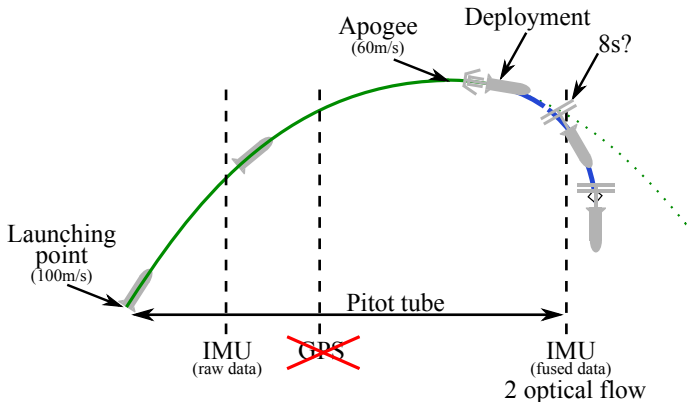
$$\mathbf{I} \begin{pmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{pmatrix} = \begin{pmatrix} L \\ M \\ N \end{pmatrix} - \begin{pmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{pmatrix} \mathbf{I} \begin{pmatrix} p \\ q \\ r \end{pmatrix}$$

$$\begin{cases} L = -d\beta \sin\delta_{c_x} \Omega_2^2 \\ M = d\beta \sin\delta_{c_y} \cos\delta_{c_x} \Omega_2^2 \\ N = \gamma_1 \Omega_1^2 + \gamma_2 \Omega_2^2 \end{cases}$$

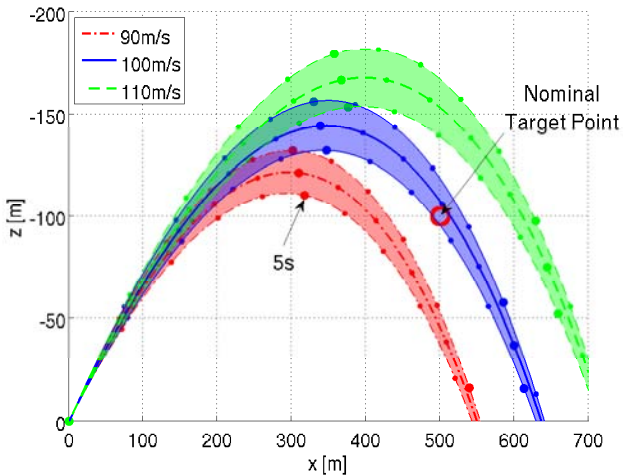
Koehl & al, 2010

$$\text{Ballistic torques} \quad \begin{cases} \mathbf{M}_A = qSDC_M \left(\frac{\mathbf{V}}{\|\mathbf{V}\|} \otimes \frac{\mathbf{z}_b}{\sin\delta} \right) \\ \mathbf{M}_D = -qSDC_H (\mathbf{z}_b \otimes \dot{\mathbf{z}}_b \frac{D}{\|\mathbf{V}\|}) \\ \mathbf{M}_R = -qSDC_I \frac{\omega D}{\|\mathbf{V}\|} \mathbf{z}_b \end{cases}$$

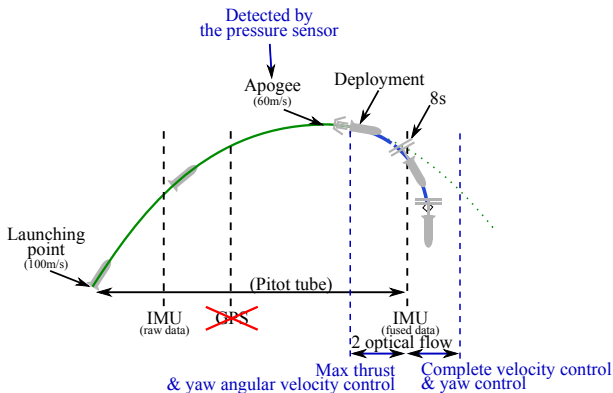
Sensors availability during the ballistic and transition phases



Launching conditions errors



Control strategy during the transition phase



Simplified model for control

MAV has 6DOF

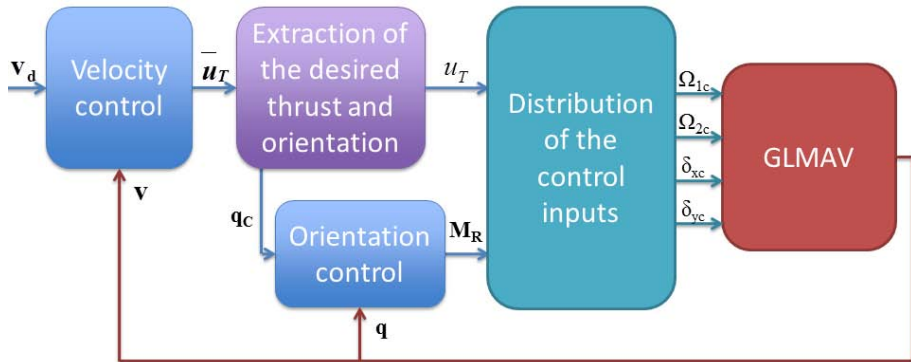
Control inputs :

- thrust: u_T
- rotor torques: \mathbf{M}_R

$$\begin{cases} m\dot{\mathbf{v}} = -m\mathbf{g} + \mathbf{T} \\ \dot{\mathbf{q}} = \mathbf{Q}(\mathbf{q})\omega \\ \mathbf{l}\dot{\omega} = -\omega \otimes (\mathbf{l}\omega) + \mathbf{M}_R \end{cases}$$

$$\begin{aligned} \text{with } \mathbf{T} &= -u_T \mathbf{z}_b = -u_T \mathbf{R}\mathbf{z}_e \\ \text{and } \mathbf{Q}(\mathbf{q}) &= \frac{1}{2} \begin{pmatrix} -\boldsymbol{\epsilon}^T \\ \eta \mathbf{l}_3 + \mathbf{S}_\epsilon \end{pmatrix} \end{aligned}$$

Hierarchical control



Backstepping-based velocity control

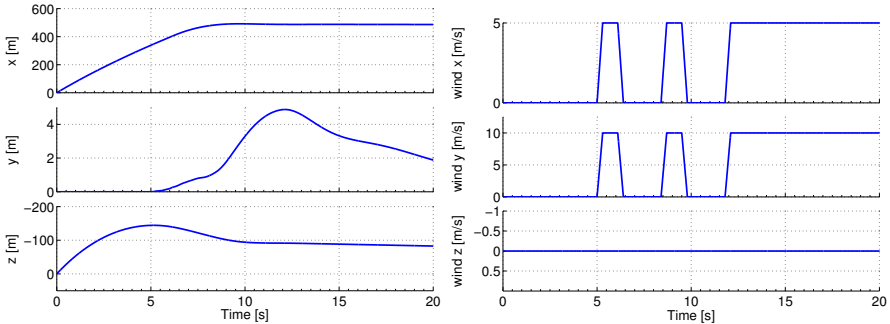
The control laws on the thrust and rotors torques are:

- $u_T = \|\bar{\mathbf{u}}_T\| = \|m(\mathbf{g} - \mathbf{K}_v \delta_v)\|$

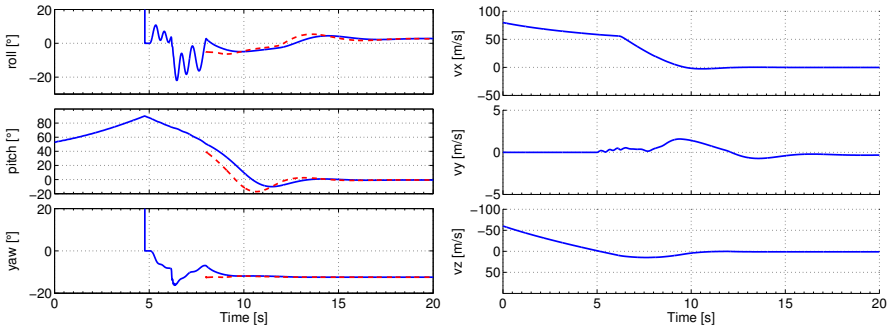
- $\mathbf{M}_R = \mathbf{S}_\omega \omega + \mathbb{1} \left(\mathbf{R}_d^T \left(-\mathbf{K}_\omega \delta_\omega - \frac{1}{2} \tilde{\eta} \tilde{\epsilon} + (\mathbf{K}_q \tilde{\epsilon}^T \tilde{\omega}) \tilde{\epsilon} - (\mathbf{K}_q (\tilde{\eta} (\tilde{\eta} \mathbf{l}_3 + \mathbf{S}_{\tilde{\epsilon}}))) \omega \right) \right)$

Initial conditions:

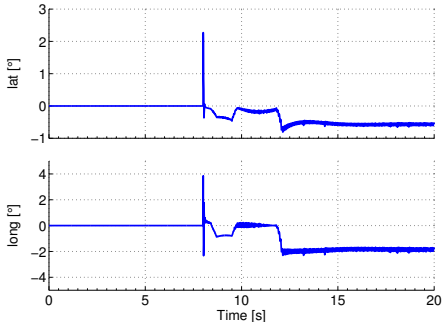
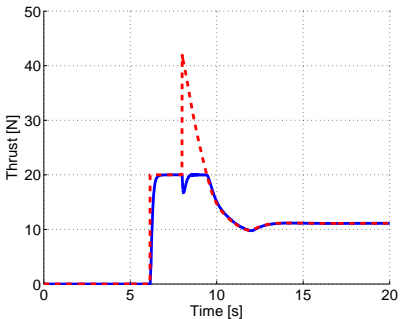
- $Vz^b = 100\text{m/s}$
- $\phi = 90 + 37^\circ$



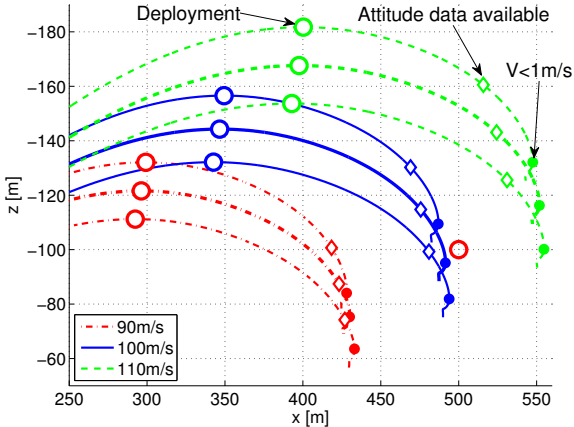
Orientation and velocity



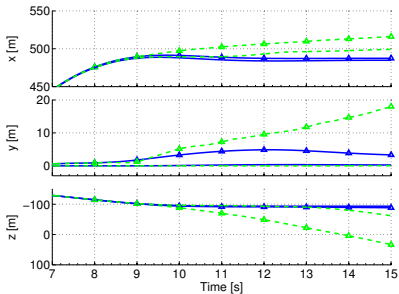
Actuators: thrust and servo-motors



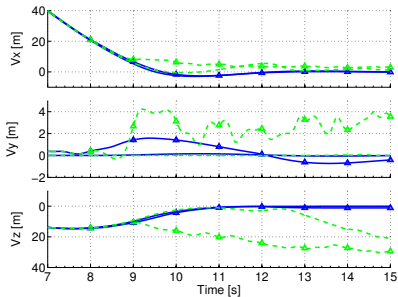
Results with initial conditions errors



Velocity control (blue) / trust control only (green), without and with (triangle markers) wind perturbations

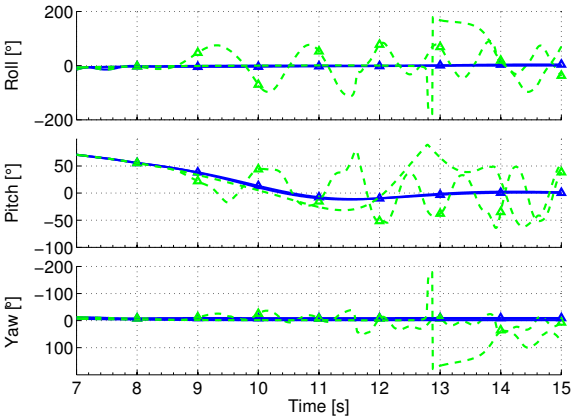


(a) Position



(b) Velocity in inertial frame

Velocity control (blue) / trust control only (green), without and with (triangle markers) wind perturbations

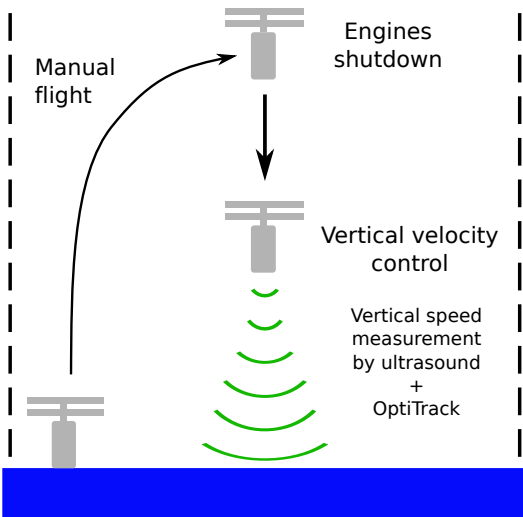


(c) Orientation

Attitude control on the GLMAV-lite

Loading GLMAV.avi

"Deployment" with zero initial velocity



Using a plane to drop the GLMAV

- Less dangerous than using the tube-launch method
- Deployment conditions controlled



Conclusion

- Detailed dynamic model of the GLMAV for the ballistic and transition regimes
- Analyze of the transition phase problems
- Control strategy and non-linear control proposed
- Validation in simulation of the control strategy

Future work

- Implementation of the velocity control phase on the GLMAV-lite prototype

Thanks for your attention.
Any questions ?