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

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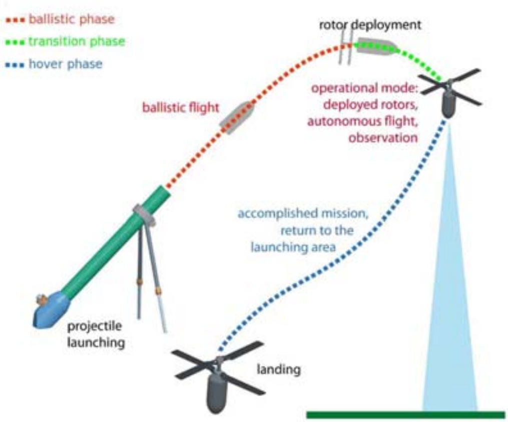
Outline

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

GLMAV concept

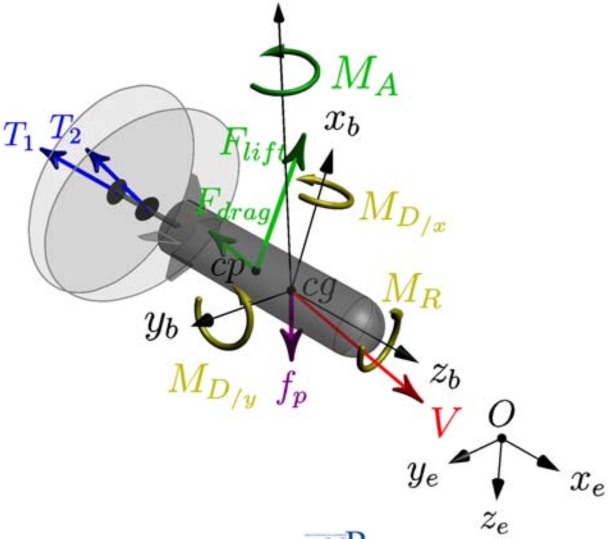
- Joint project between the ISL, the HEUDIASYC, the CRAN and SBG Systems
- Transformation of a projectile into a MAV



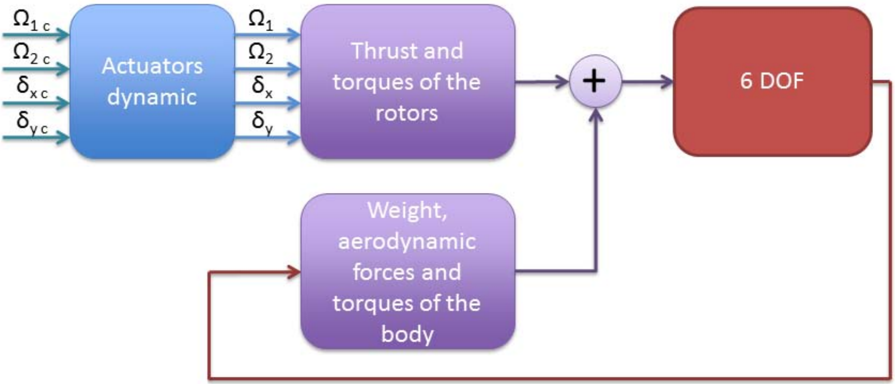
GLMAV vs Conventional MAV

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

Notations



Dynamic model structure



Simulation dynamic model
Translational dynamics

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

$$\begin{pmatrix}X\\ Y\\ Z\end{pmatrix}=\mathbf{T}(\Omega_i,\delta_{c_{x/y}})+\mathbf{f_{body}}(\mathbf{V_{prop}},\mathbf{V_{body}},\mathbf{V_{wind}})+\mathbf{f_p}$$

Koehl & al, 2010

Ballistic forces
$$\begin{cases}\mathbf{F_{drag}}=-qSC_D\dfrac{\mathbf{V}}{\|\mathbf{V}\|}\\ \mathbf{F_{lift}}=qSC_L\dfrac{\mathbf{V}}{\|\mathbf{V}\|}\otimes\left(\dfrac{\mathbf{z_b}}{sin\delta}\otimes\dfrac{\mathbf{V}}{\|\mathbf{V}\|}\right)\end{cases}$$

Simulation dynamic model
Rotational dynamics

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

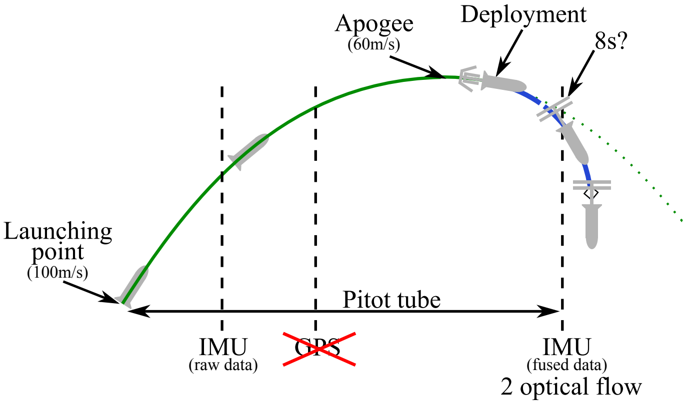
$$\begin{cases} L = -d\beta sin\delta_{cx}\Omega_2^2 \\ M = d\beta sin\delta_{cy} cos\delta_{cx}\Omega_2^2 \\ N = \gamma_1\Omega_1^2 + \gamma_2\Omega_2^2 \end{cases}$$

Koehl & al, 2010

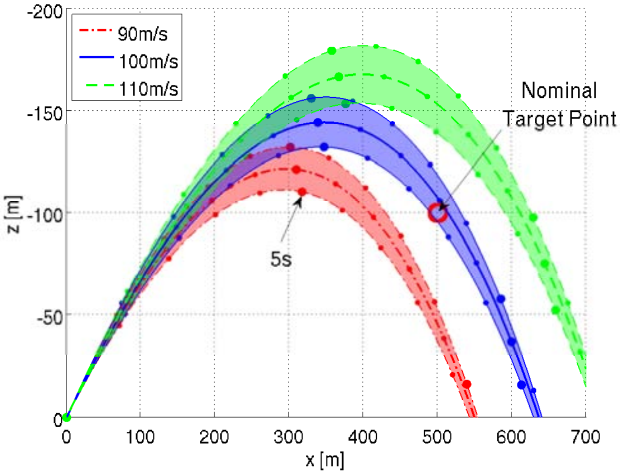
Ballistic torques

$$\begin{cases} \mathbf{M_A} = qSDC_M(\frac{\mathbf{V}}{\|\mathbf{V}\|} \otimes \frac{\mathbf{z_b}}{sin\delta}) \\ \mathbf{M_D} = -qSDC_H(\mathbf{z_b} \otimes \dot{\mathbf{z}}_\mathbf{b}\frac{D}{\|\mathbf{V}\|}) \\ \mathbf{M_R} = -qSDC_l\frac{\omega D}{\|\mathbf{V}\|}\mathbf{z_b} \end{cases}$$

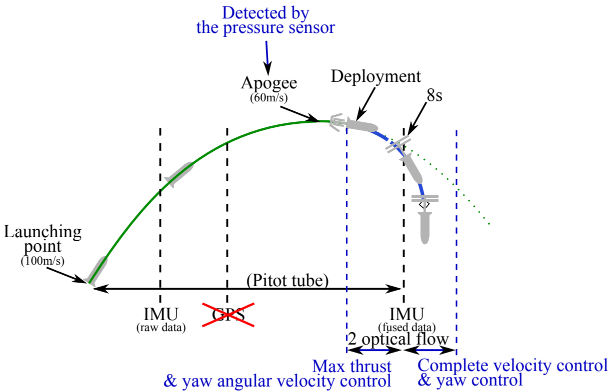
Sensors availability during the ballistic and transition phases



Launching conditions errors



Control strategy during the transition phase



Simplified model for control

MAV has 6DOF

Control inputs :

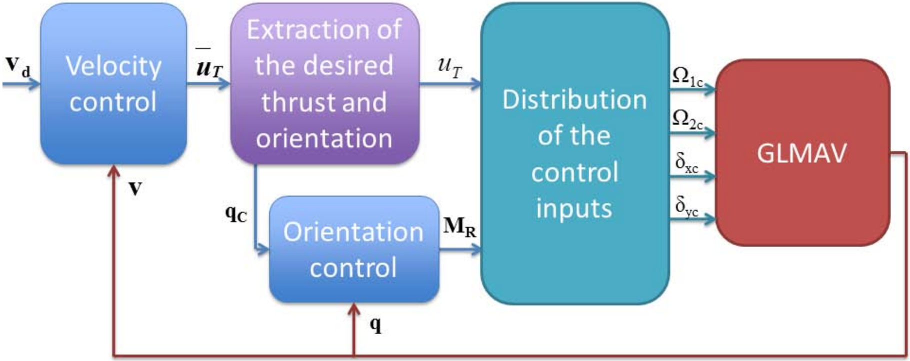
- thrust: u_T
- rotor torques: $\mathbf{M}_R$

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

with $\mathbf{T} = -u_T\,\mathbf{z_b} = -u_T\mathbf{R}\mathbf{z_e}$

and $\mathbf{Q}(\mathbf{q}) = \frac{1}{2}\begin{pmatrix} -\epsilon^T \\ \eta\mathbf{I_3} + \mathbf{S}_\epsilon \end{pmatrix}$

Hierarchical control



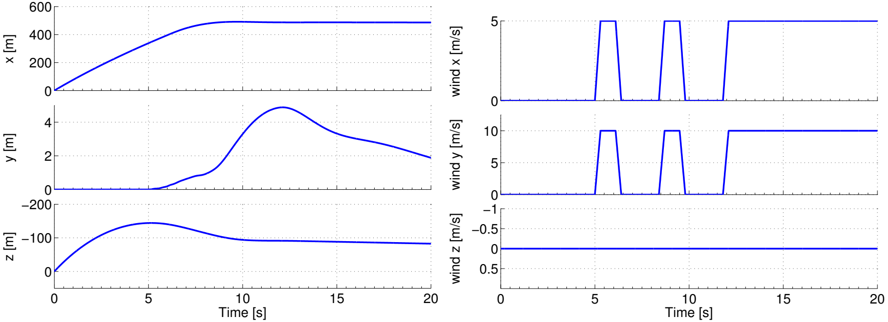
Backstepping-based velocity control

The control laws on the thrust and rotors torques are:

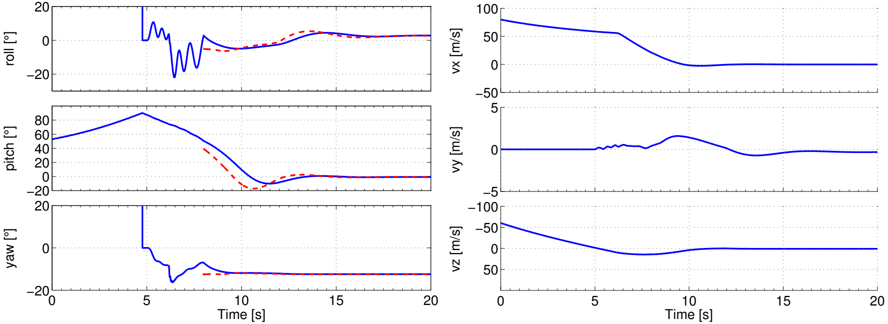
- $u_T = \left\| \overline{\mathbf{u}}_\mathbf{T} \right\| = \left\| m \left(\mathbf{g} - \mathbf{K_v} \delta_\mathbf{v} \right) \right\|$
- $\mathbf{M_R} = \mathbf{S}_\omega \mathbb{J} \omega + \mathbb{J} \left(\mathbf{R_d^T} \left(-\mathbf{K}_\omega \delta_\omega - \frac{1}{2} \widetilde{\eta} \widetilde{\epsilon} + \left(\mathbf{K_q} \widetilde{\epsilon}^\mathbf{T} \widetilde{\omega} \right) \widetilde{\epsilon} - \left(\mathbf{K_q} \left(\widetilde{\eta} \left(\widetilde{\eta} \mathbf{I_3} + \mathbf{S}_{\widetilde{\epsilon}} \right) \right) \right) \omega \right) \right)$

Initial conditions:

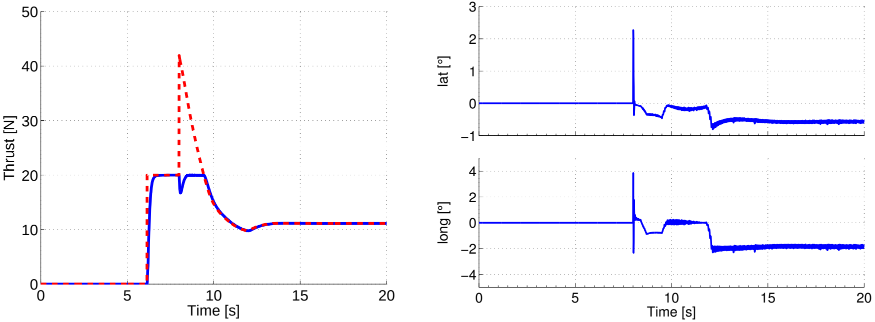
- $Vz^b = 100m/s$
- $\phi = 90 + 37°$



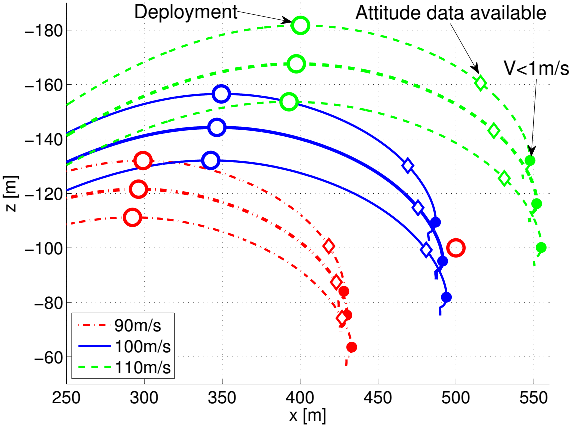
Orientation and velocity



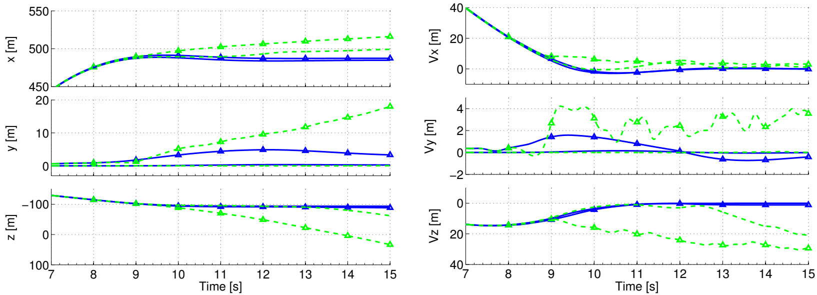
Actuators: thrust and servo-motors



Results with initial conditions errors

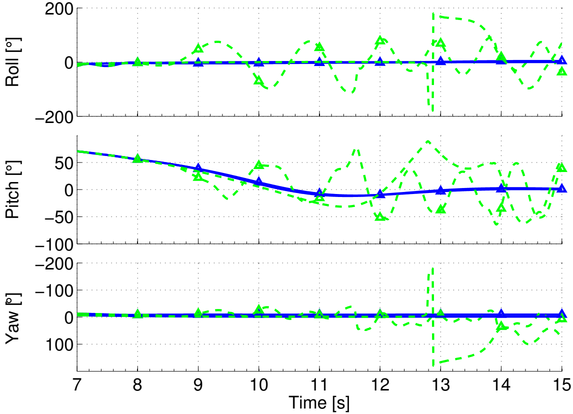


Velocity control (blue) / trust control only (green), without and with (triangle markers) wind perturbations



(a) Position (b) Velocity in inertial frame

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

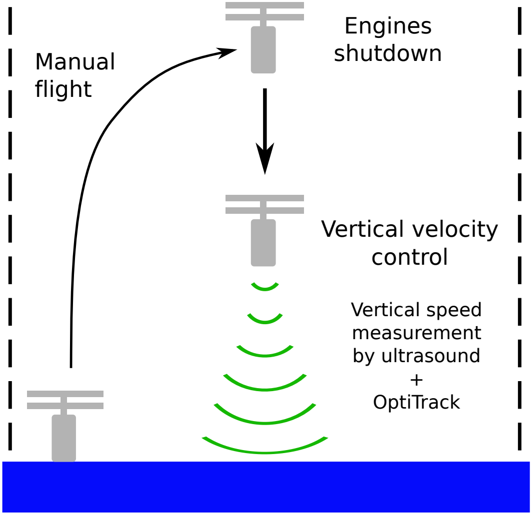


(c) Orientation

Attitude control on the GLMAV-lite

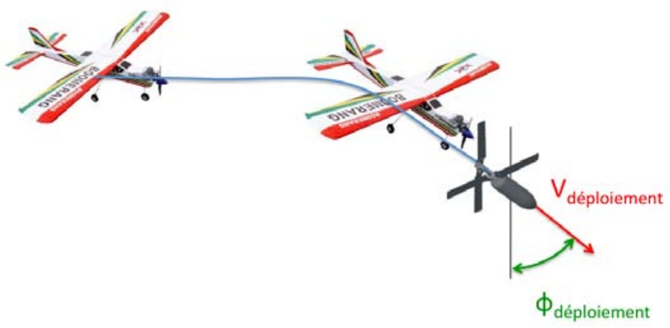
Loading GLMAV.avi

"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 ?