Fixed-wing UAV with transitioning flight capabilities: Model-Based or Model-Free Control approach? A preliminary study.

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Outline

What is a hybrid UAV ?

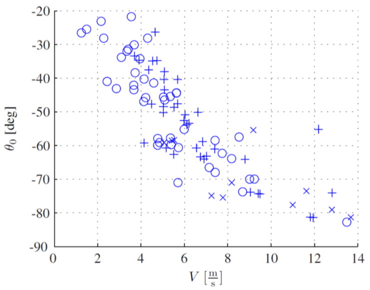
MAVion

Dark-Knight

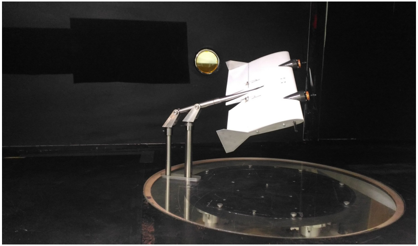
Wingtra

Cyclone

Problematic



- Identification
- Modeling
- Wind-tunnel campaigns
- Costly and time consuming
- Attitude control
- Position control
- Navigation



Objective

- Control the entire flight envelope
- Great disturbance rejection
- Uncertain parameters
- Adaptable to different hybrid UAVs

State of the art

Proportional Integral Derivative (PID)

[...] Although simple to tune without the knowledge of the model, PID controllers are limited in terms of disturbance rejection [...]

Linear Quadratic Regulator (LQR)

An accurate model of the system is required.

Incremental Nonlinear Dynamic Invertion (INDI)

INDI uses teste flight data to tune the control coefficients. *Of course, to do this, the MAV needs to be flying with predefined control parameters.*

Model-Free Control

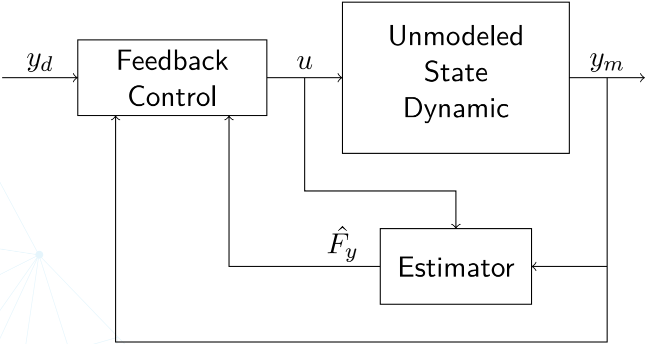


FIGURE – Overall Model-Free Control schema.

Model-Free Control

MFC principles

$$y_m^v = F + \alpha u \tag{1}$$

$$s^2 Y_m(s) - s y_m(0) - \dot{y}_m(0) = \frac{F}{s} + \alpha U(s) \tag{2}$$

$$2Y_m(s) + 4s\frac{dY_m(s)}{ds} + s^2\frac{d^2Y_m(s)}{ds^2} = \frac{2F}{s^3} + \alpha\frac{d^2U(s)}{ds^2} \tag{3}$$

$$\frac{2Y_m(s)}{s^3} + \frac{4}{s^2}\frac{dY_m(s)}{ds} + \frac{1}{s}\frac{d^2Y_m(s)}{ds^2} = \frac{2F}{s^6} + \frac{\alpha}{s^3}\frac{d^2U(s)}{ds^2} \tag{4}$$

Model-Free Control

Estimator

$$\hat{F} = \frac{5!}{2T^5} \int_{t-T}^{t} [(T-\sigma)^2 - 4\sigma(T-\sigma) + \sigma^2] y_m(\sigma) d\sigma - [\frac{\alpha}{2}\sigma^2 (T-\sigma)^2] u(\sigma) d\sigma \tag{5}$$

Control-loop

$$u = -\frac{\hat{F}}{\alpha} + \frac{y_d^{(v)} + \mathcal{K}(\xi)}{\alpha} \tag{6}$$

Model-Free Control

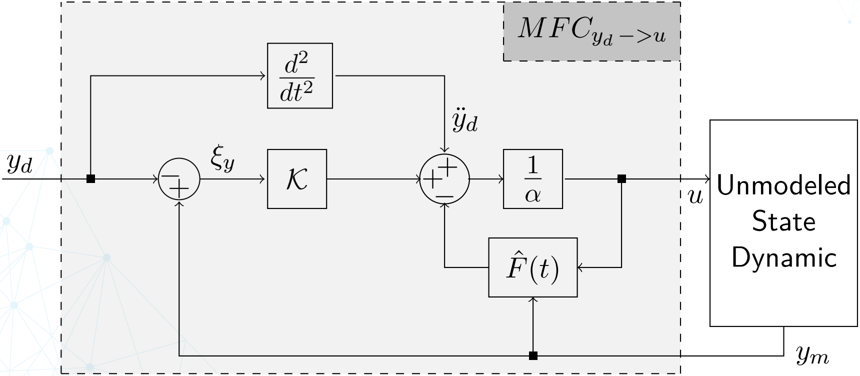


FIGURE – Detailed Model-Free Control schema for a second-order system.

Control architecture

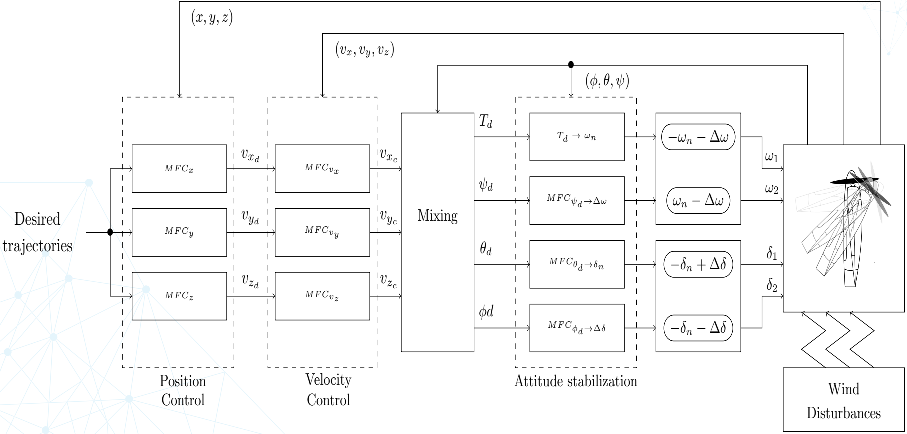


FIGURE – MFC architecture for Hybrid UAVs.

Hover-forward flight

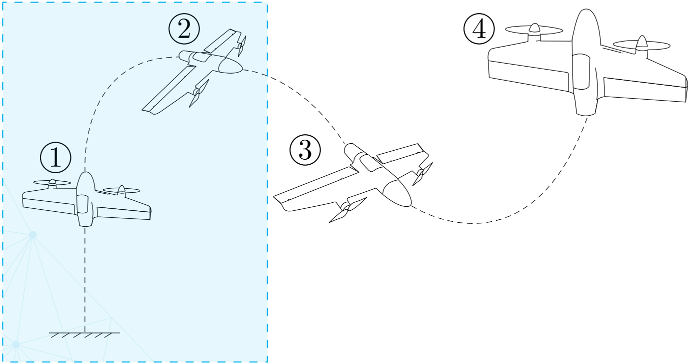
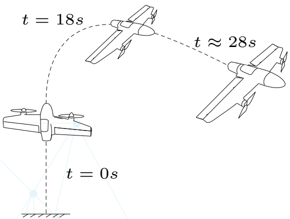
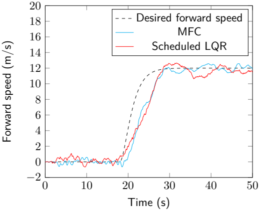
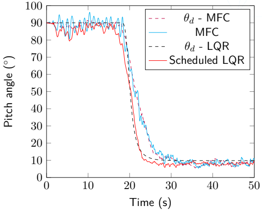


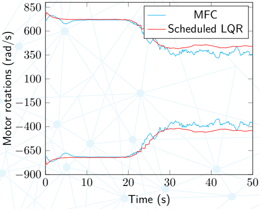
FIGURE – Typical flight modes of Hybrid UAVs : 1-Take-Off ; 2-Transition ; 3-Forward ; 4-Hover.

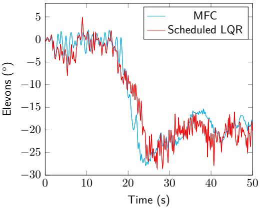
Hover-forward flight (LQR vs MFC)

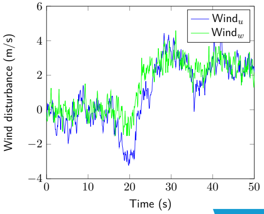












Hover-forward flight (LQR vs MFC)

TABLE – LQR vs MFC : RMSE - Hovering flight

y	Scheduled LQR	MFC	SI Units
Pitch angle (With wind)	4.8131	3.2893	[°]
Forward speed (With wind)	0.3170	0.2293	[m/s]

TABLE – LQR vs MFC : RMSE - Entire flight envelope

y	Scheduled LQR	MFC	SI Units
Pitch angle (No wind)	3.0646	1.5131	[°]
Forward speed (No wind)	0.8699	1.4613	[m/s]
Pitch angle (With wind)	4.5357	2.7858	[°]
Forward speed (With wind)	1.8349	1.4700	[m/s]

Forward flight

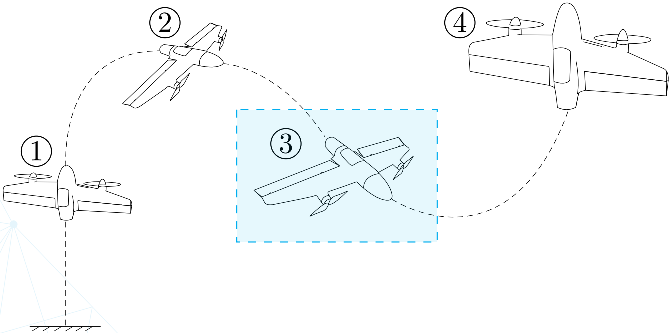
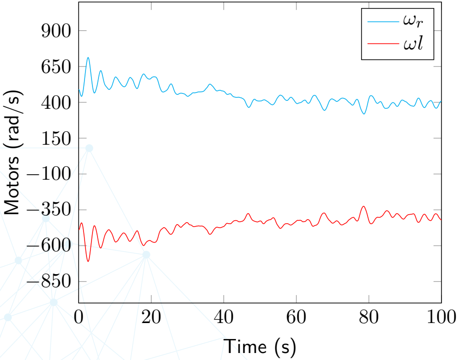


FIGURE – Typical flight modes of Hybrid UAVs : 1-Take-Off ; 2-Transition ; 3-Forward ; 4-Hover.

Forward flight

Forward flight - actuators



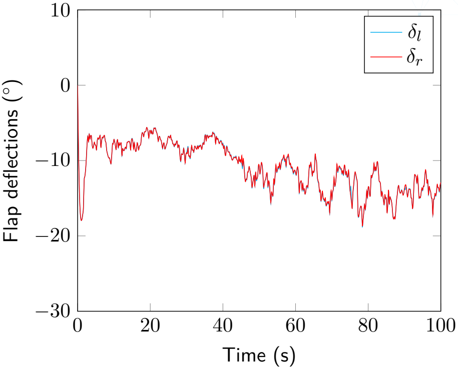


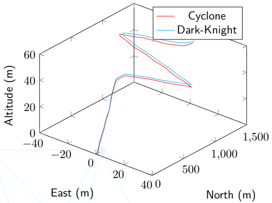
FIGURE – Propeller speeds ($\omega_l < 0$ and $\omega_r > 0$) due to counter-rotation sense and the elevon deflections (δ_l and δ_r), convention negative for pitch-up.

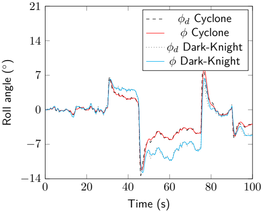
Uncertain parameter analysis

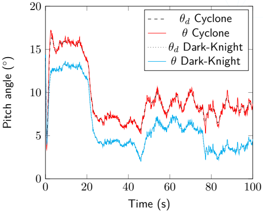
TABLE – Fixed-Wing specifications

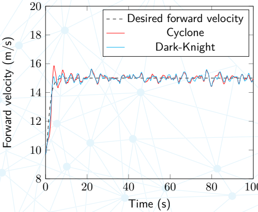
Parameters	Cyclone	Dark-Knight	SI Units	Δ %
Mass	0.852	0.586	[Kg]	45.39
I_{xx}	0.0036	0.0072	[Kg m^2]	52.3
I_{yy}	0.0036	0.0072	[Kg m^2]	52.47
I_{zz}	0.0036	0.0072	[Kg m^2]	51.2
Propeller radius	0.2032	0.1524	[m]	33.33
Mean Chord	0.17	0.175	[m]	2.94
Wingspan	0.88	1	[m]	13.64
Wing area	0.1496	0.175	[m^2]	16.98

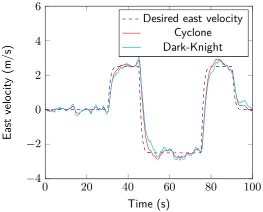
Uncertain Parameter Analysis

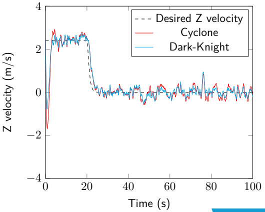




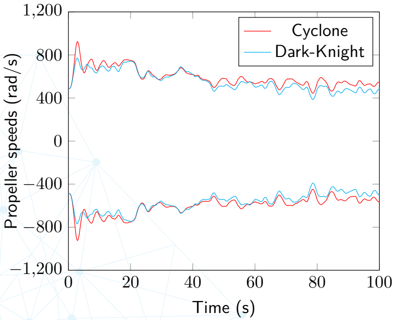


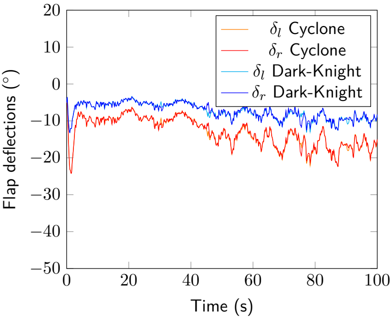






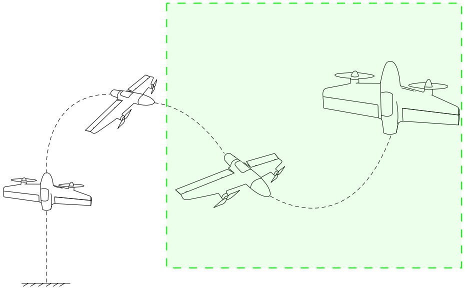
Uncertain Parameter Analysis - Actuators





Perspectives

- Forward-hover transition
- Stability analysis
- Position control
- Navigation
- Real flights



Acknowledgments

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Conclusion

Thanks for your attention !