ETH zürich

Unified Path Following Guidance for Hybrid VTOLs

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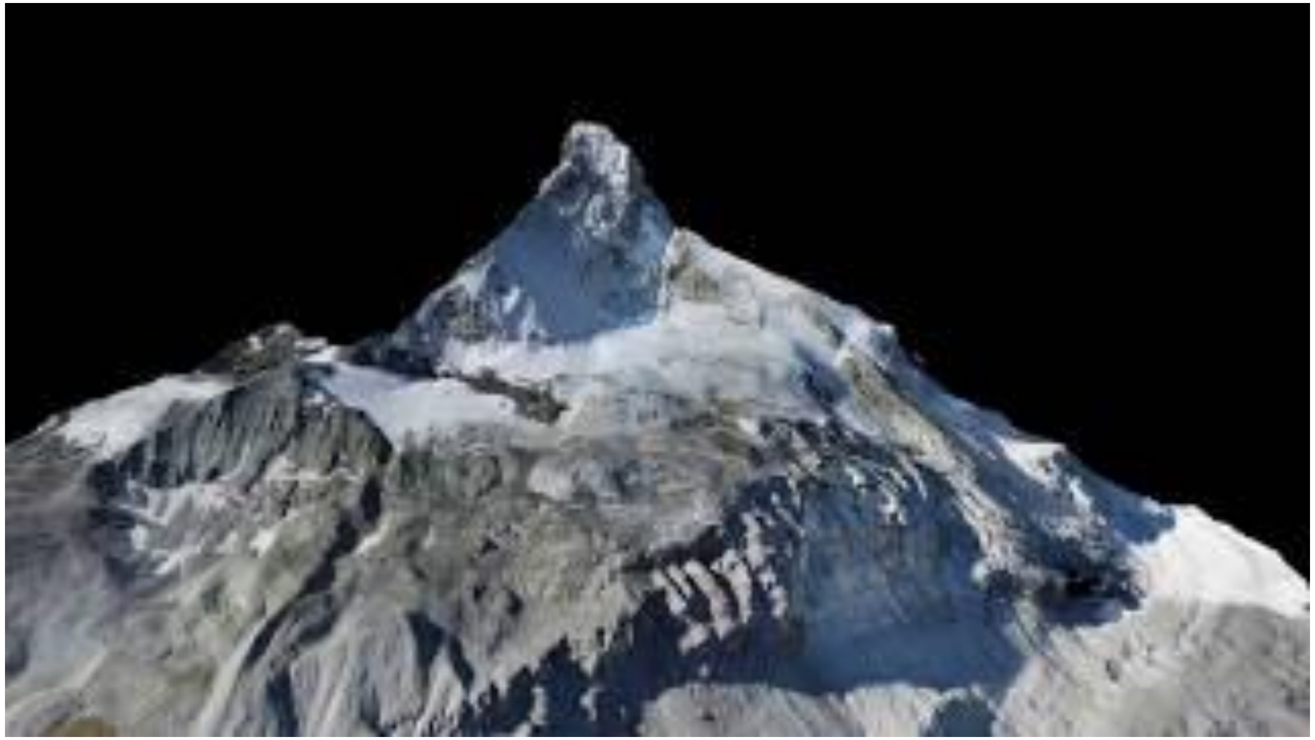
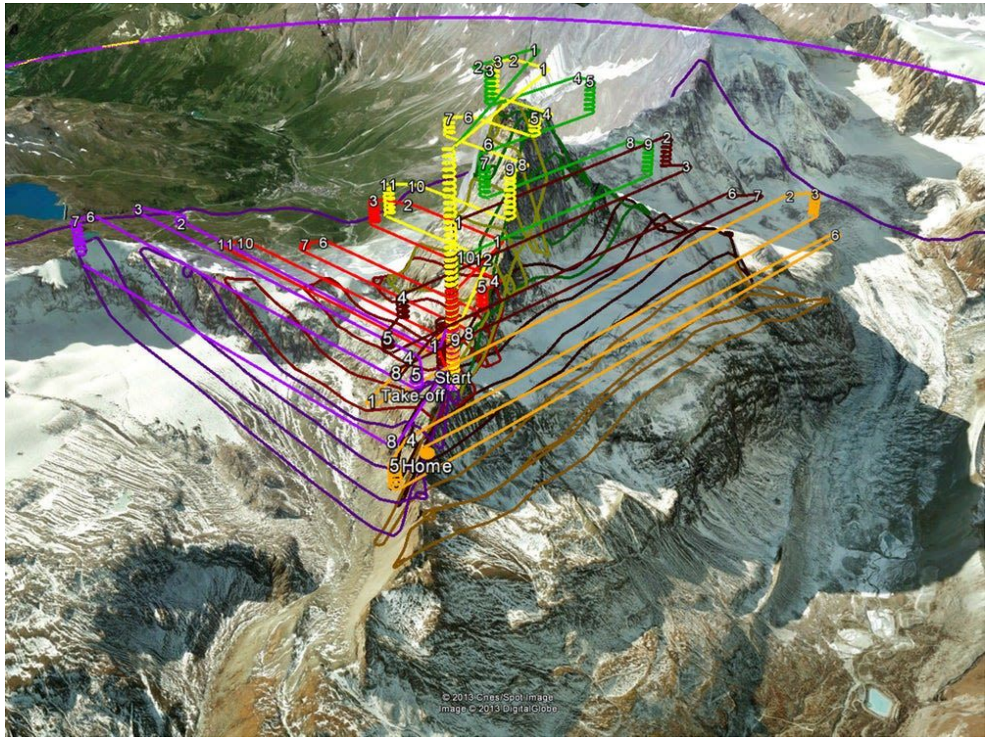
Bachelor Thesis
Autonomous Systems Lab, ETH Zurich

Motivation

Motivation




Start
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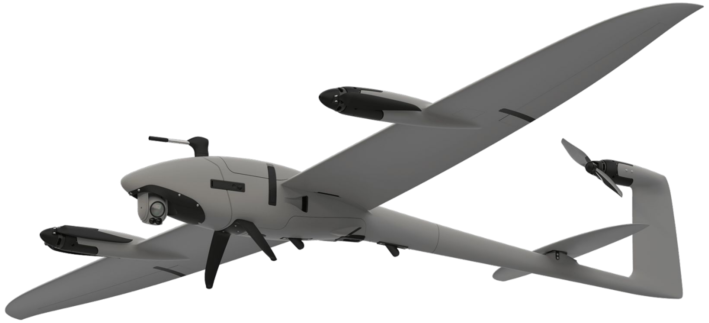
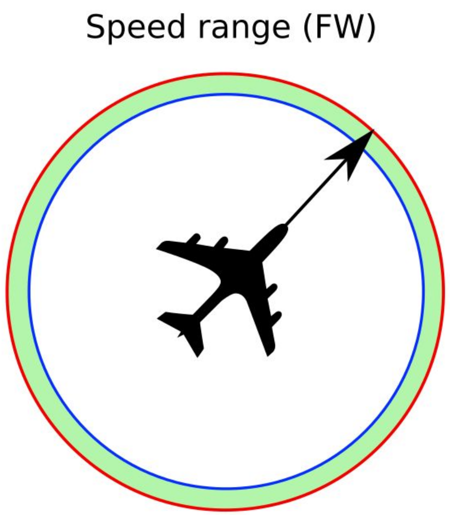
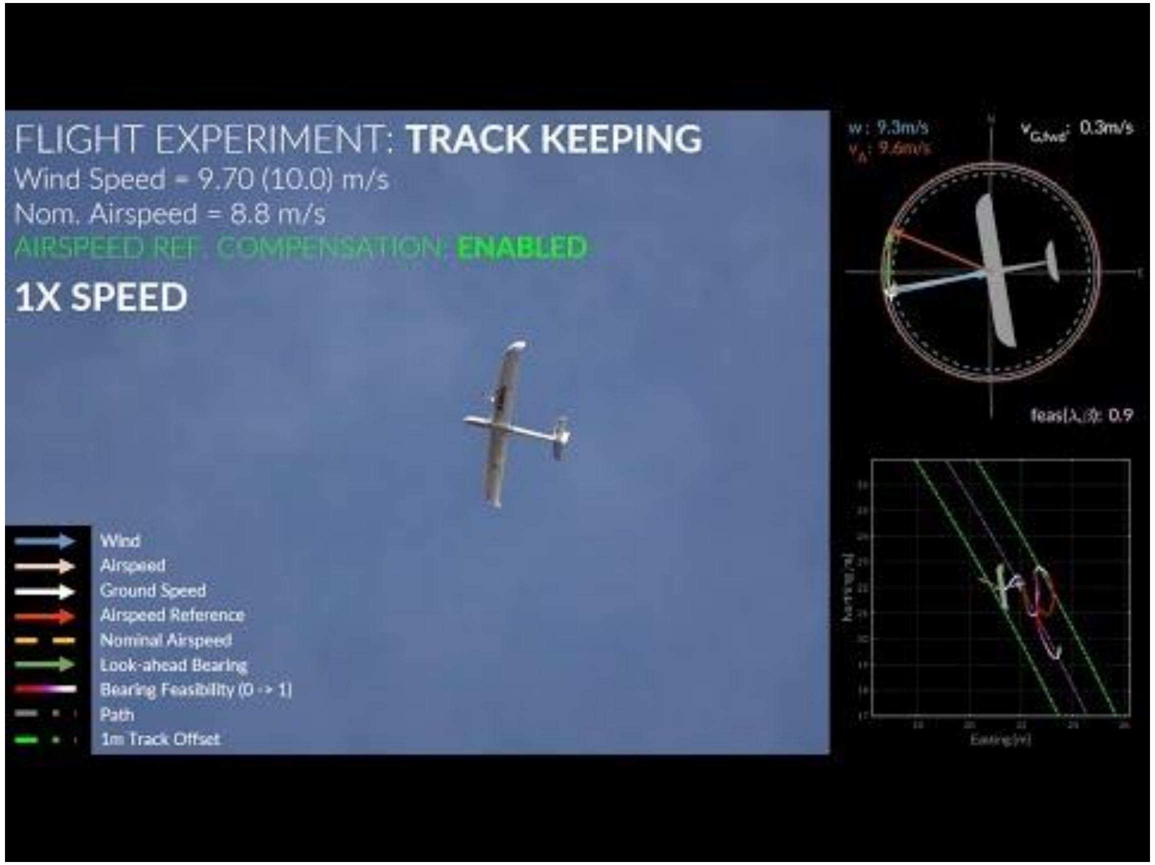


Related Work

Related Work: Path Following on Fixed Wing

- **Nonlinear Control** [Stastny, IROS, 2019]

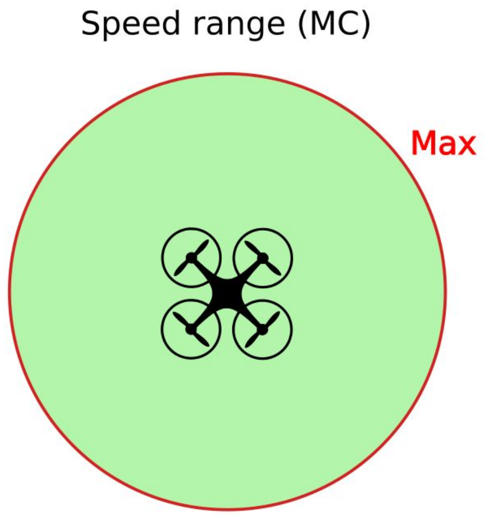


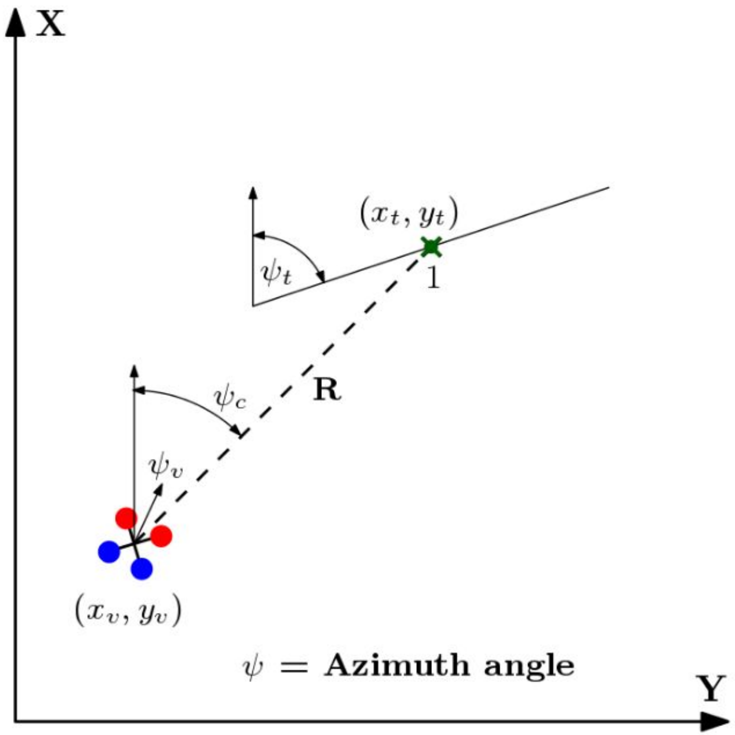


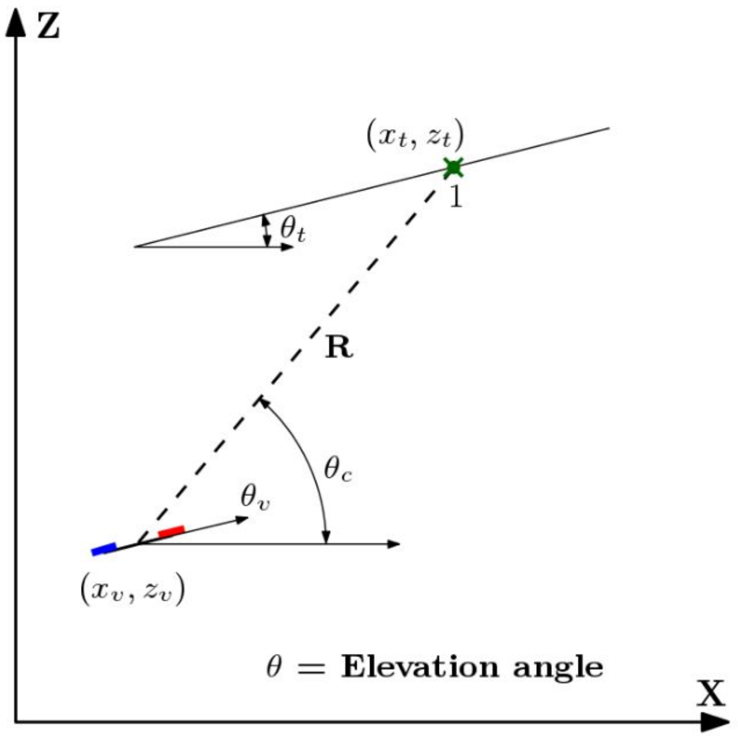
T. Stastny. “On Flying Backwards: Preventing Runaway of Small, Low-speed, Fixed-wing UAVs in Strong Winds”. IROS, 2019

Related Work: Path Following on Multirotor

- **Virtual Target Pursuit** [Manjunath, 2016]



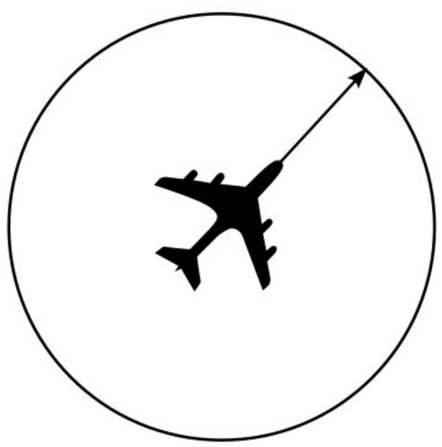




Manjunath, A. R.. “Path following by a quadrotor using virtual target pursuit guidance.” (2016).

Problem Definition

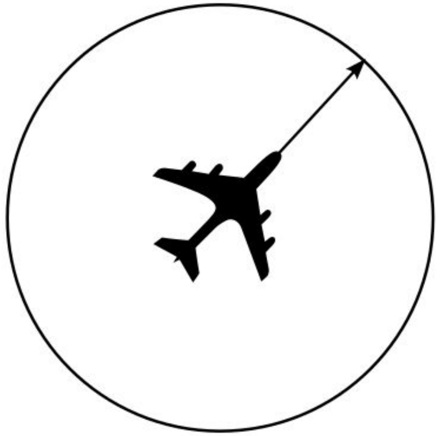
Limitation of conventional Fixed Wing Path Following



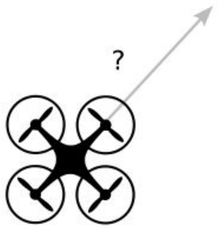
- Fixed Wing flies at a constant '**Nominal speed**'

Limitation of conventional Fixed Wing Path Following

Nominal Speed (FW)



Nominal Speed = 0 (MC)

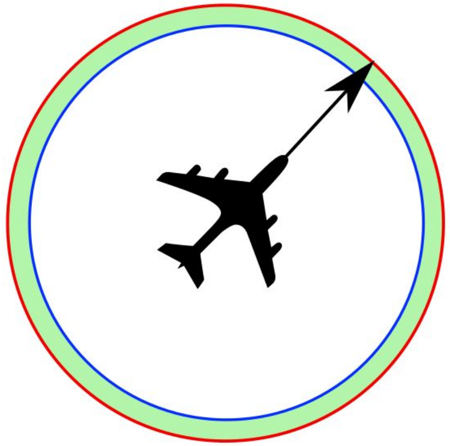


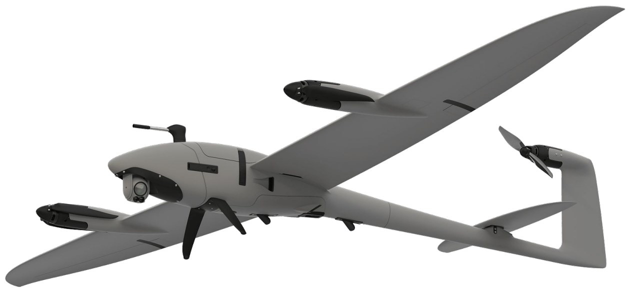
- Fixed Wing flies at a constant '**Nominal speed**'
- Multirotors can have a huge speed range, including **'stopping'**.
  - Using FW guidance on MC results in unintended approach path that isn't meant for the ground velocity profile

Goal

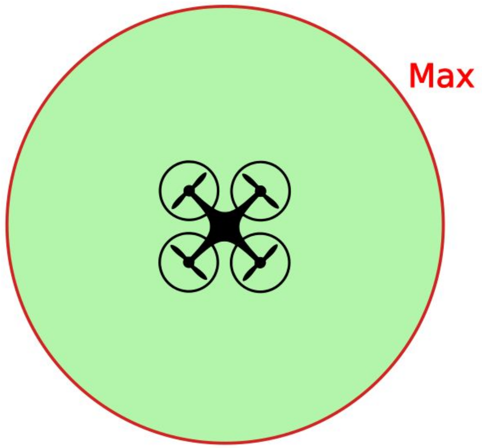
“**Unified Path Following Guidance** that can be used by **Fixed Wing, Multirotor, and Hybrid VTOL** utilizing their **full maneuverability envelope**”

Speed range (FW)





Speed range (MC)

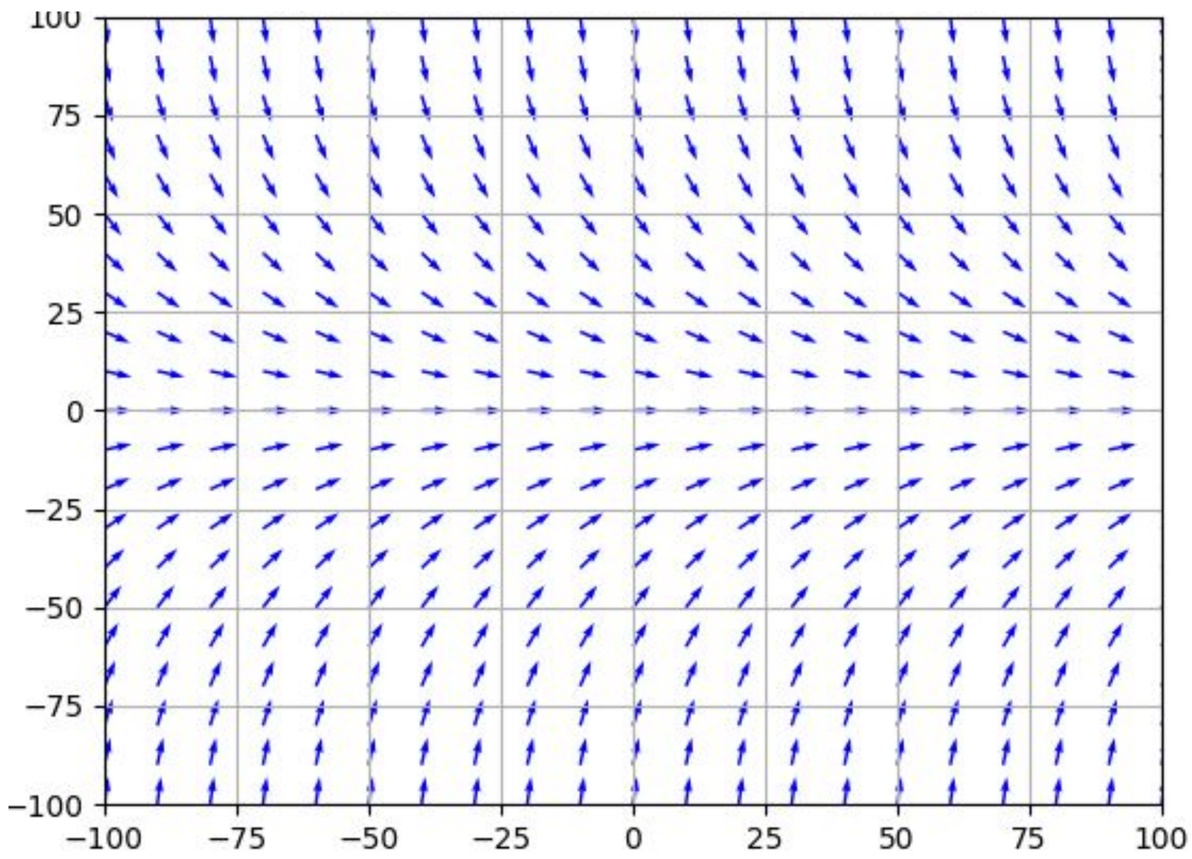


Approach

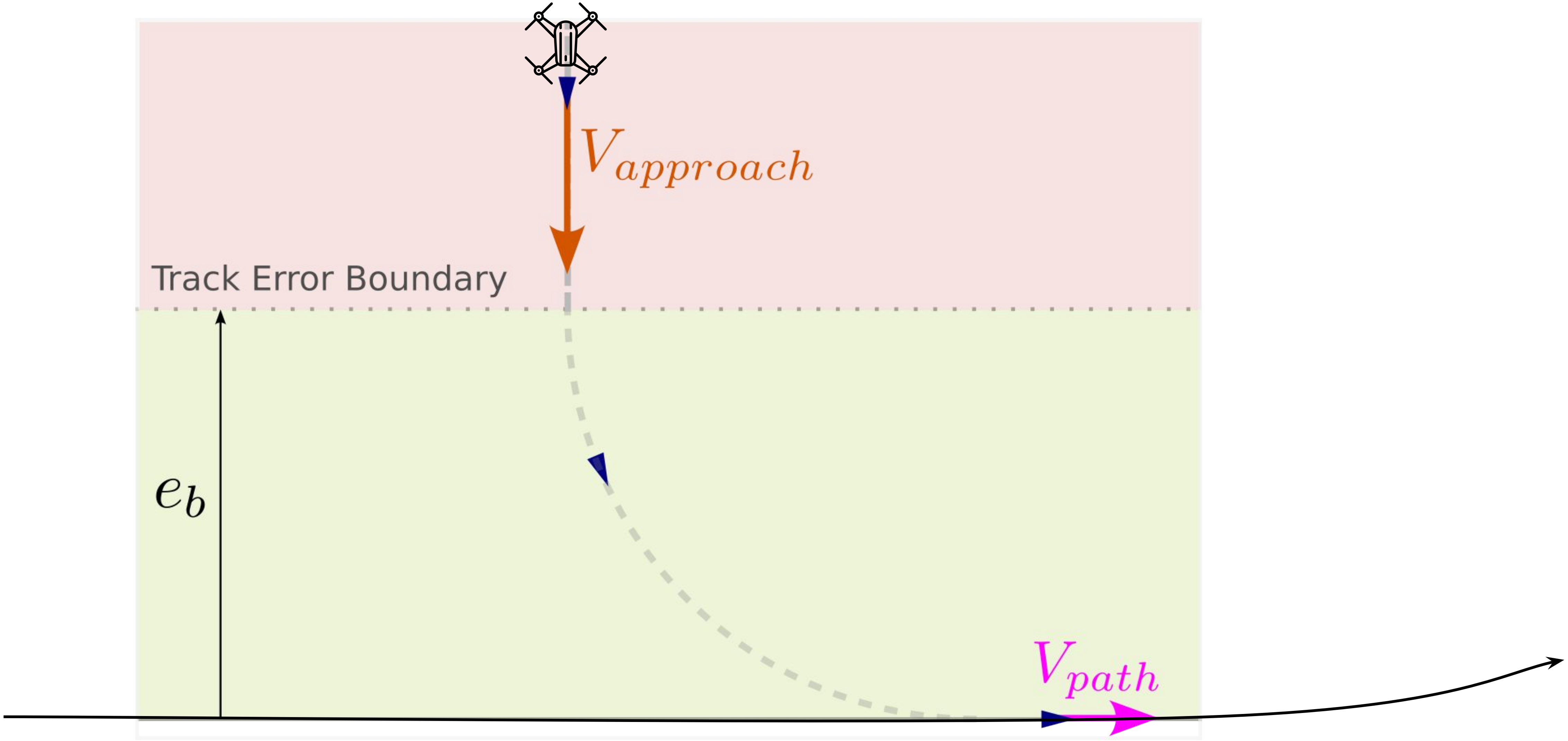
- **Vector Field** Method
  - If vector is followed, converges to path
  - Desired course setpoint is generated

1. Geometric: more **generic**
2. Can be followed by **any** vehicle type!

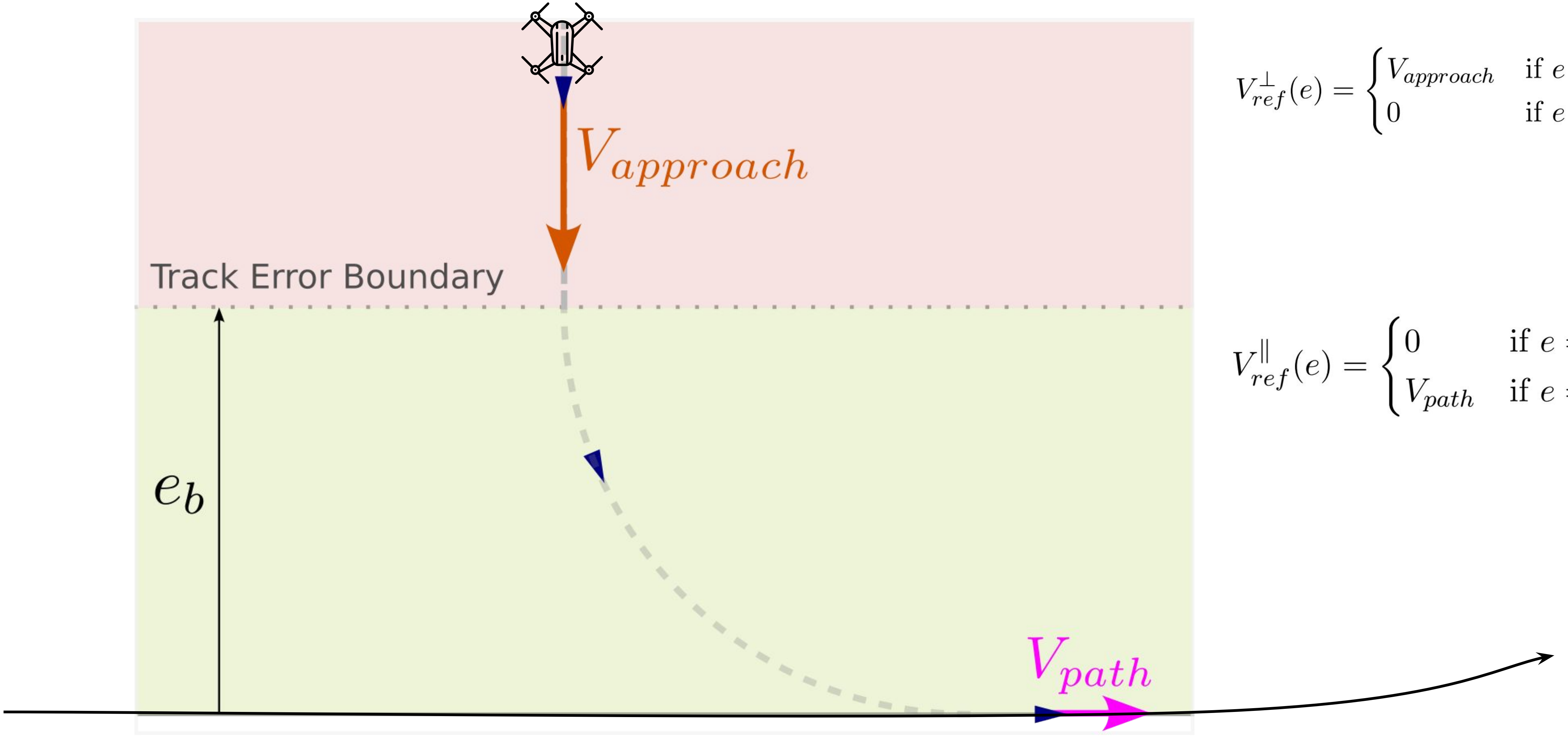
Other methods: Optimal control, etc.



Approach: Overview



Approach: Problem Definition



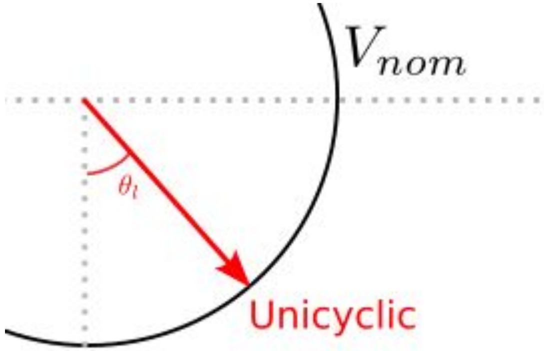
$$V_{ref}^{\perp}(e) = \begin{cases} V_{approach} & \text{if } e = e_b \\ 0 & \text{if } e = 0 \end{cases}$$

$$V_{ref}^{\parallel}(e) = \begin{cases} 0 & \text{if } e = e_b \\ V_{path} & \text{if } e = 0 \end{cases}$$

Methods

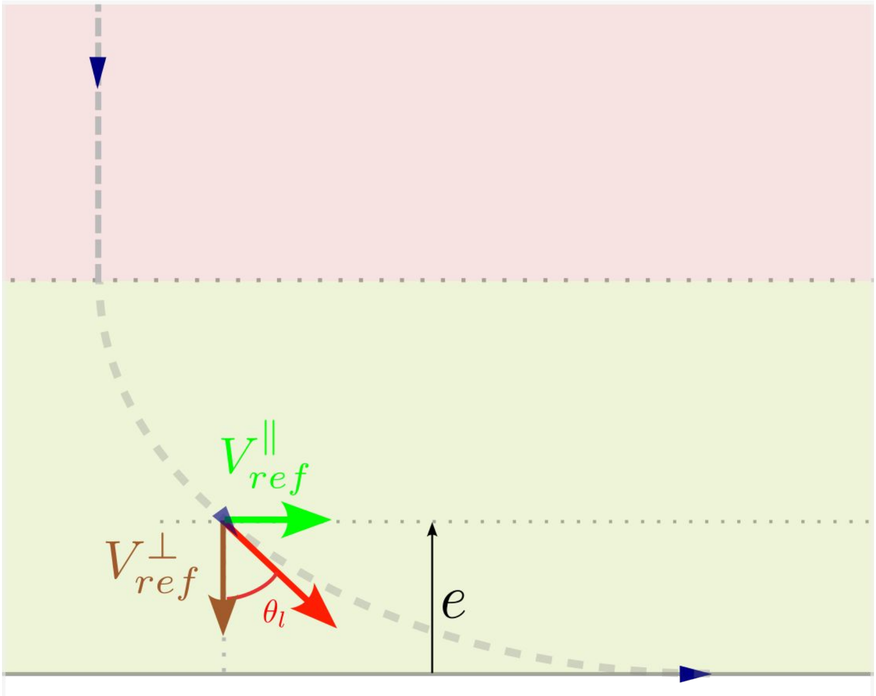
Methods

Unicyclic (Original)



$$V_g^{||} = V_{nom} * sin(\theta_l)$$

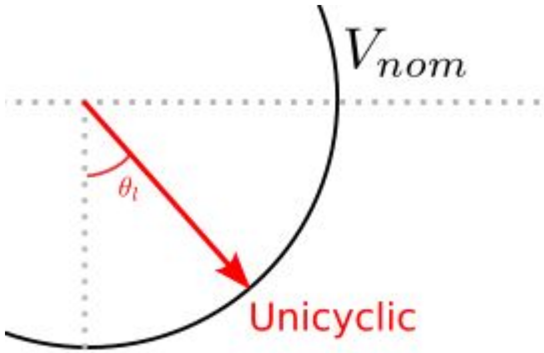
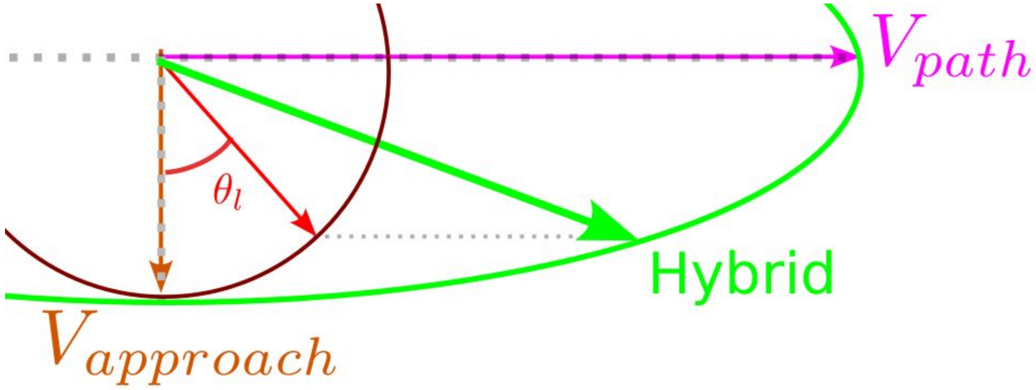
$$V_g^{\perp} = V_{nom} * cos(\theta_l)$$



$$\bar{e} = \frac{e}{e_b}$$

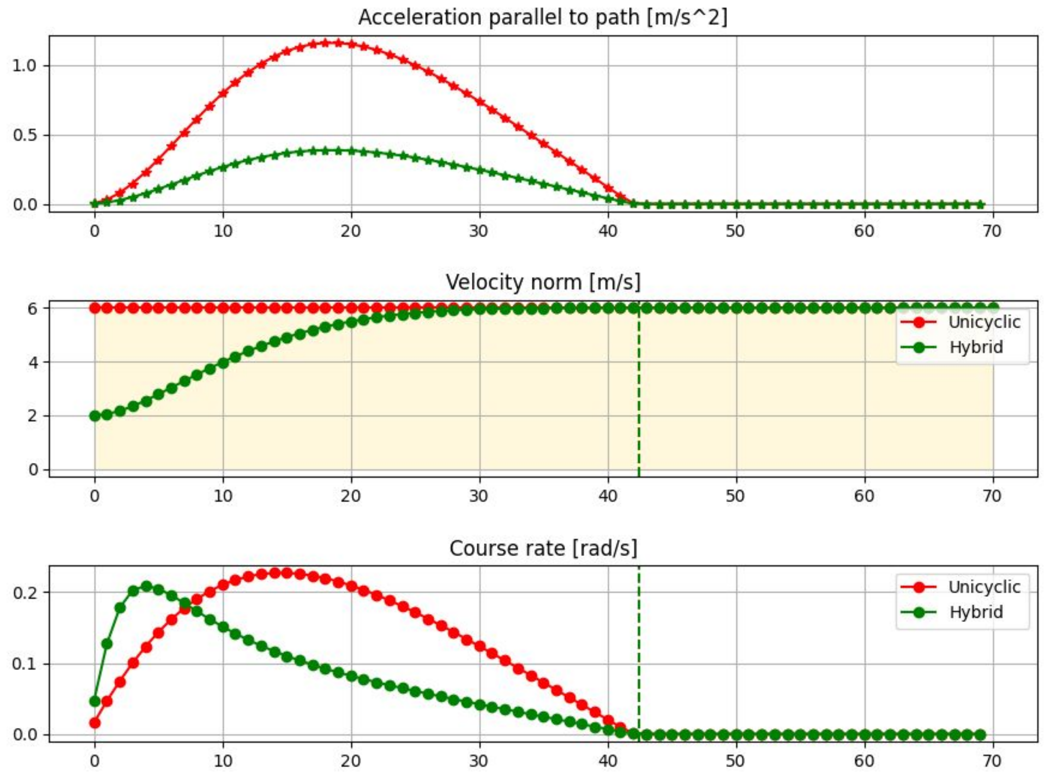
$$\theta_l = constrain(\frac{\pi}{2}(1 - \bar{e})^2,\ 0,\ \frac{\pi}{2})$$

Methods

Unicyclic (Original)	Hybrid (Proposed)
	
$V_g^{\parallel} = \boxed{V_{nom}} * sin(\theta_l)$ $V_g^{\perp} = \boxed{V_{nom}} * cos(\theta_l)$	$V_g^{\parallel} = \boxed{V_{path}} * sin(\theta_l)$ $V_g^{\perp} = \boxed{V_{approach}} * cos(\theta_l)$

Evaluation

Evaluation Criteria

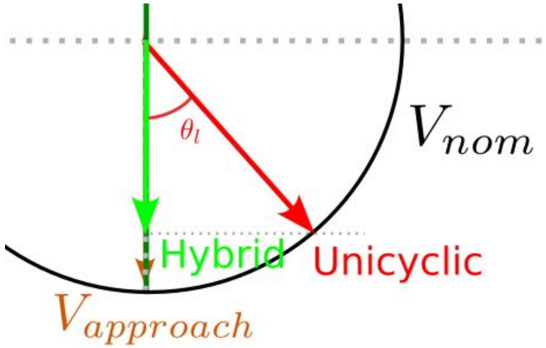


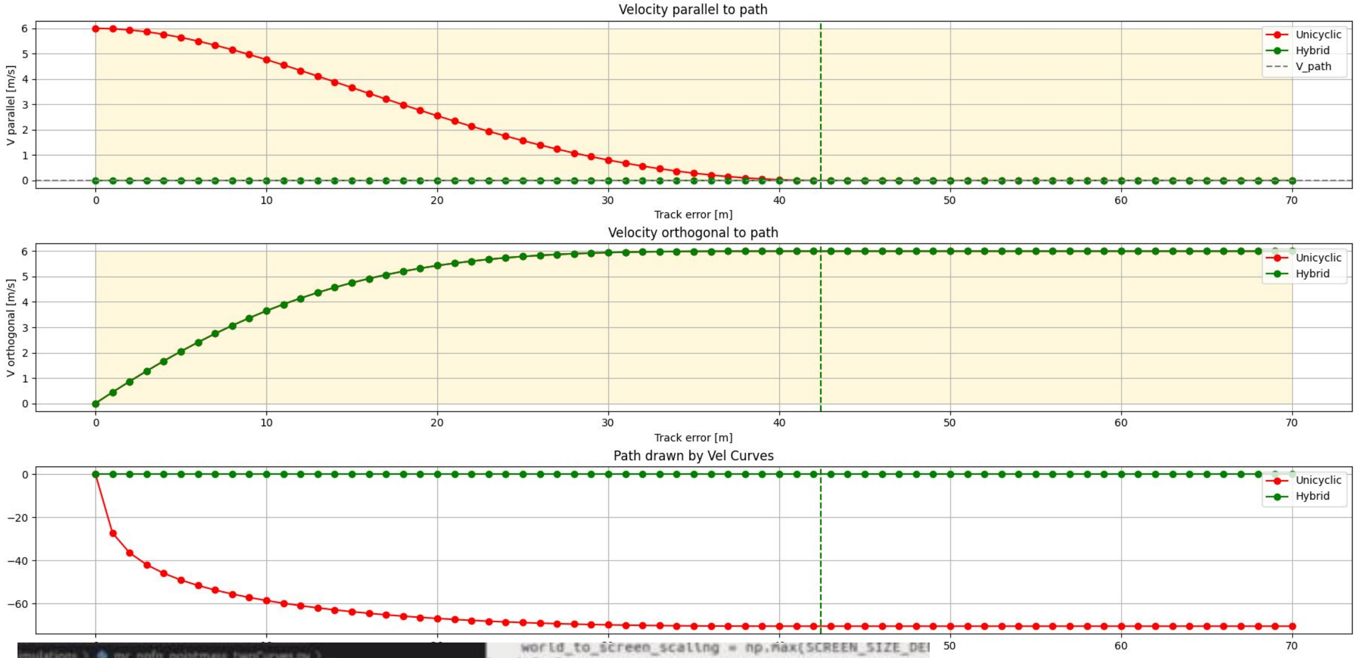
- **<u>Approach speed</u>:** Does it approach at required speed?
- **<u>Path speed</u>:** Does it reach the speed on path?

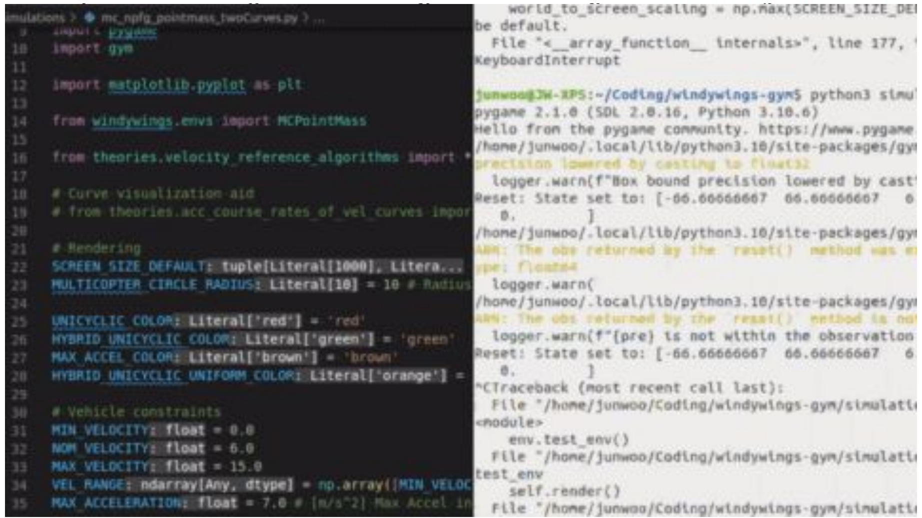
- **Monotonicity**: Monotonic ground speed profile
- **Acceleration**: Doesn’t exceed vehicle’s limit
- **Course rate**: Doesn’t exceed vehicle’s yaw rate limit (FW)

Evaluation: Zero speed on path

Parameter	Value
V_{nom}	6
$V_{approach}$	6
V_{path}	**0**

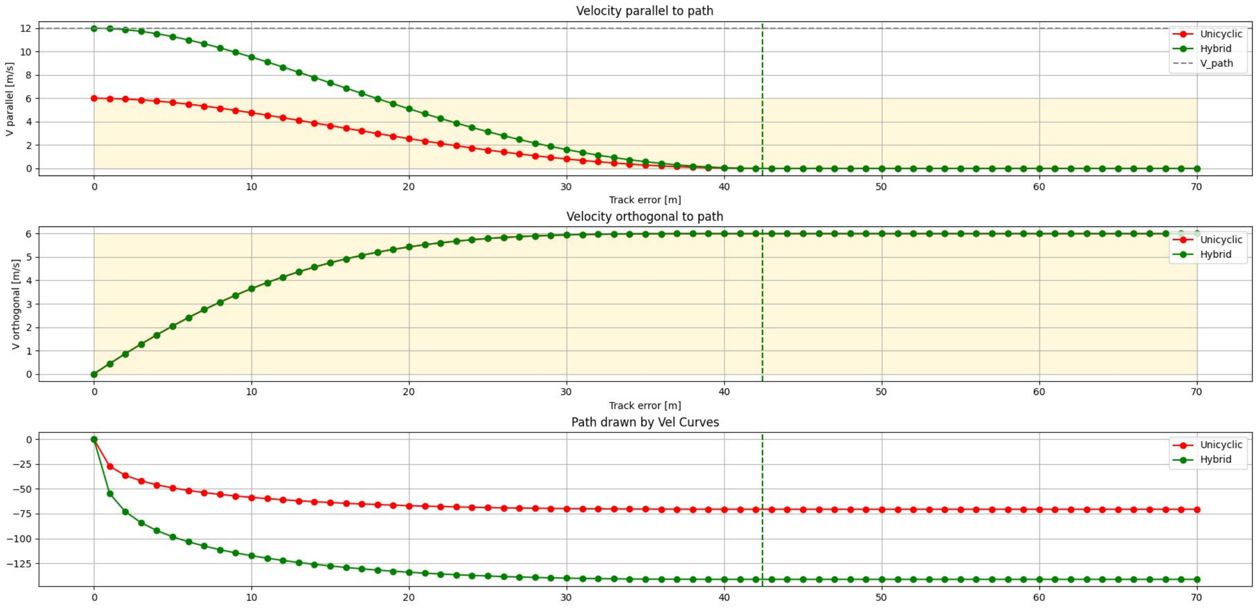


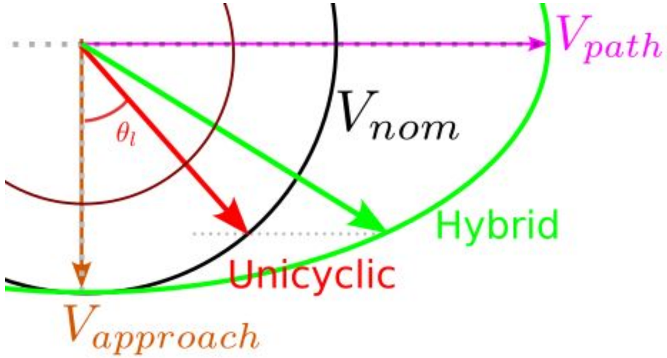




Evaluation: High speed on path

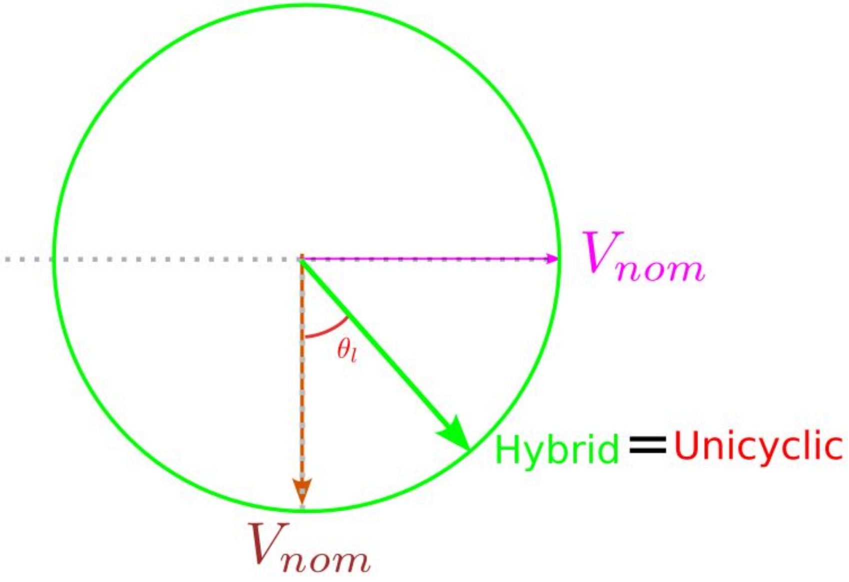
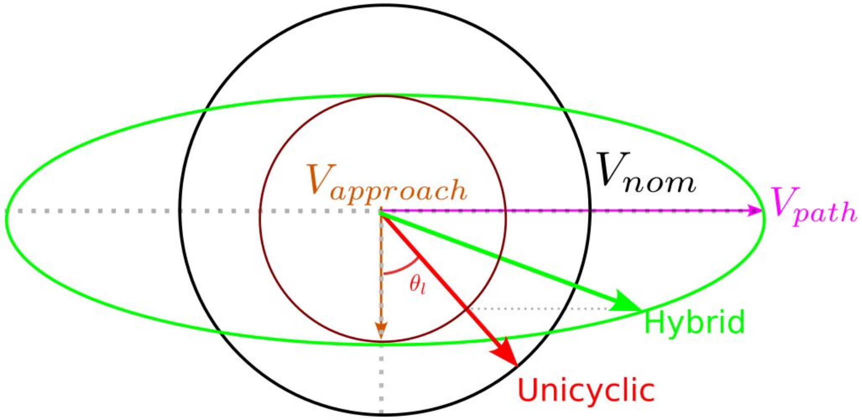
Parameter	Value
V_{nom}	6
$V_{approach}$	6
V_{path}	**12**





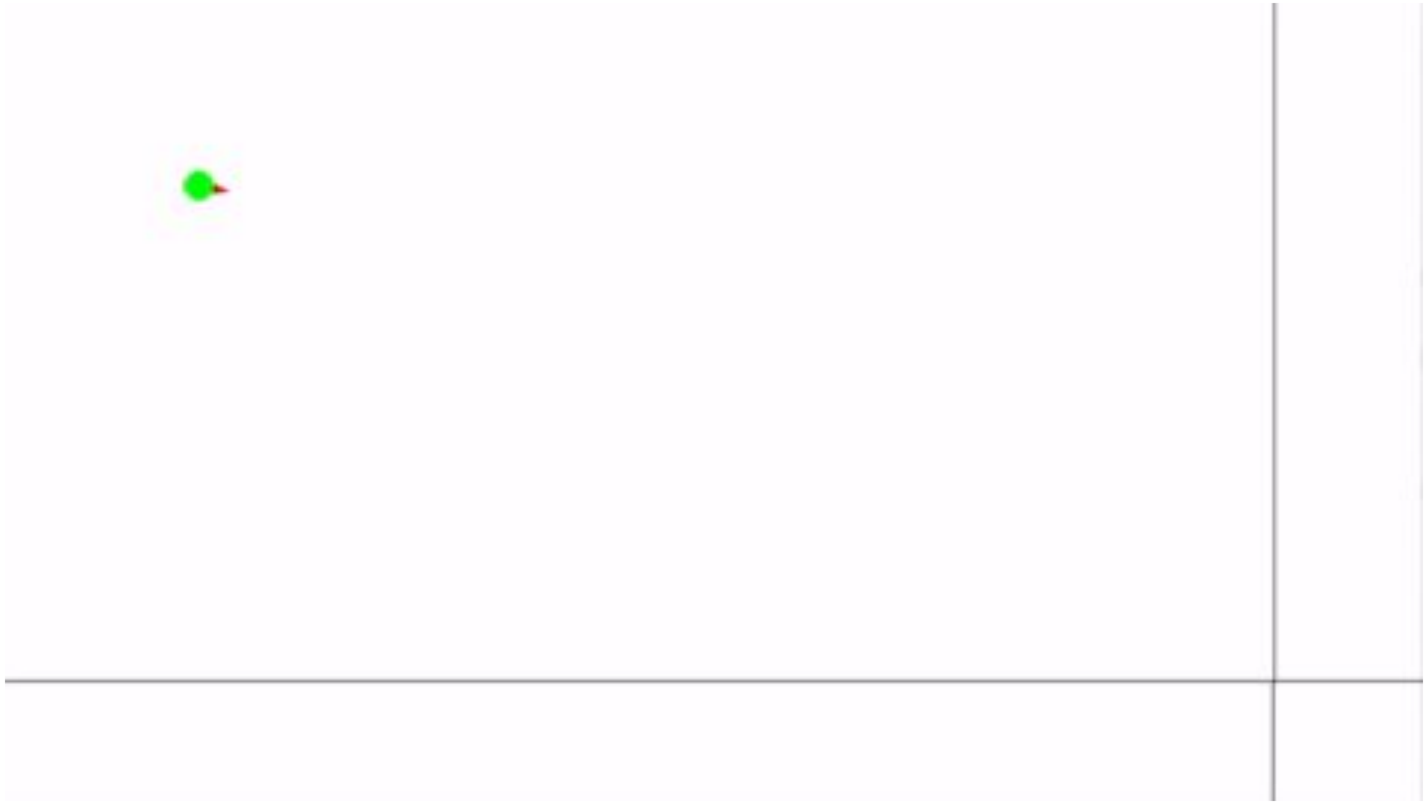
Evaluation: Is the FW case still supported?

- Fixed Wing (Unicyclic) is just a **special case** where: $V_{approach} = V_{path} = V_{nom}$

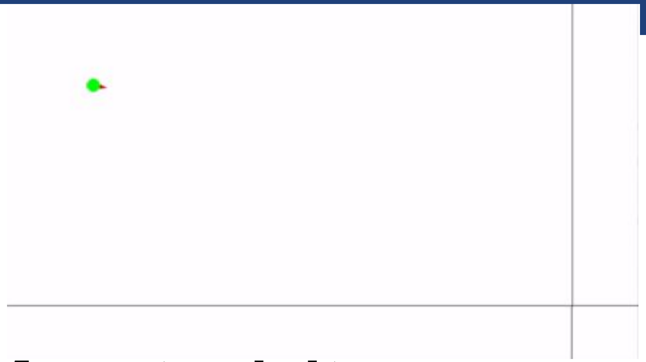
$V_{approach} = V_{path} = V_{nom}$	**Hybrid**
	

Result: Simulation

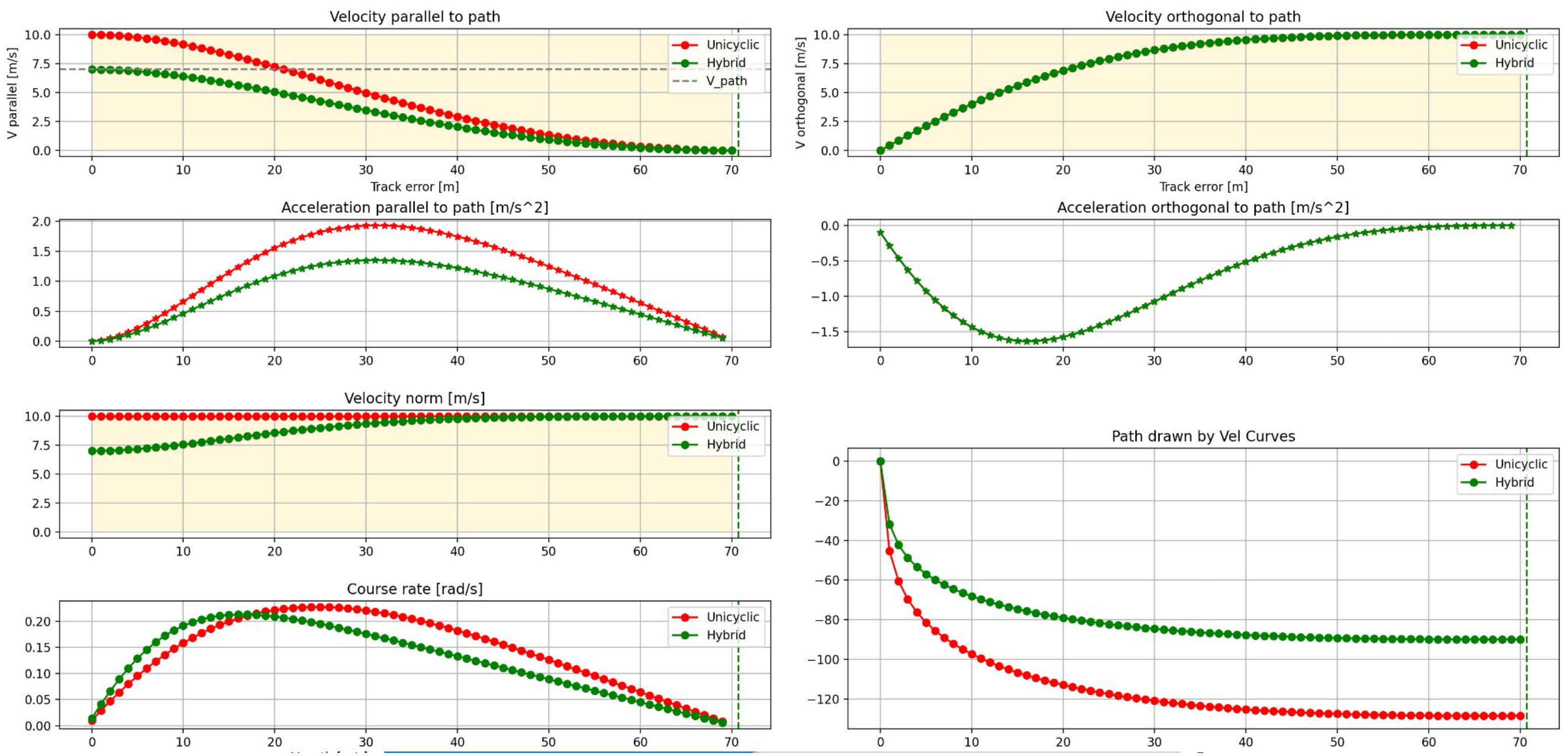
Unicyclic: 10 m/s nominal speed
Hybrid: 10 m/s approach & 7 m/s path speed



Result: Simulation



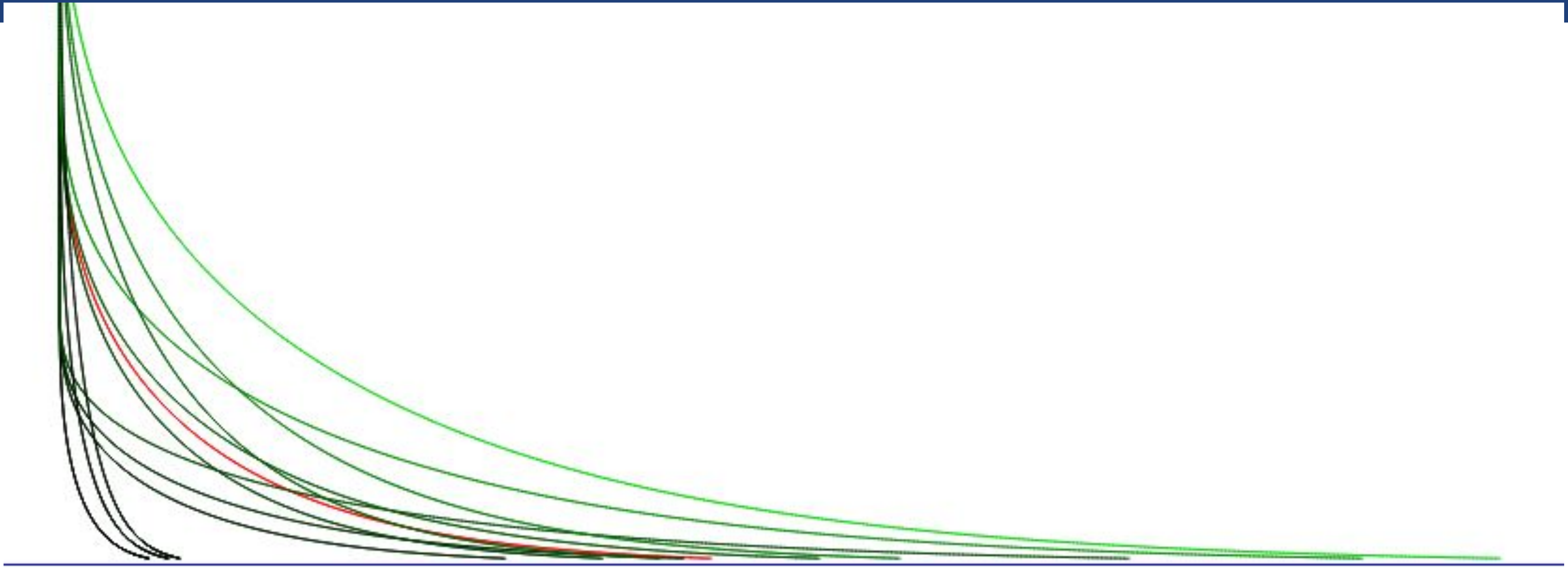
Fixed Wing: 10 m/s nominal speed
Multirotor: 10 m/s approach & 7 m/s path speed



- **Monotonicity:** Guaranteed (Ellipsoidal velocity)
- **Acceleration** limit is within Fixed wing's limit (feasible for MC)

Discussion and Outlook

- Achievements 🎉
  - **Unified Path Following** formulation applicable to both multirotor and fixed wing
- Limitations 🙈
  - **Dynamic constraints** hasn’t been considered (Acceleration / Jerk)
- Future Work 💪
  - Implementation & Testing on a **real** Hybrid VTOL
  - Incorporating **wind** into guidance (air velocity profile)



Thank you 🙌

Special thanks to: Jay, Florian, David, and Thomas

QnA Backup slides

Path Following Evaluation Criteria

Criteria	Description	Evaluation
Time to convergence on a path [s]	Time required by the vehicle to converge to the path when following the ground velocity vector field with no error $t_{conv} = -\int_{e_b}^{0} \frac{1}{V_g^{\perp}} de = e_b \cdot \int_{0}^{1} \frac{1}{V_g^{\perp}} d\hat{e}\ (when\ e_b\ is\ constant)$	Smaller the better
Track error boundary length [m]	e_b	Smaller the better
Converging path parallel distance [m]	Path-parallel distance travelled to converge to path when following ground velocity vector field with no error $d_{conv} = -\int_{e_b}^{0} V_g^{\parallel} \cdot \frac{e}{V_g^{\perp}} de = e_b \cdot \int_{0}^{1} V_g^{\parallel} \cdot \frac{\hat{e}}{V_g^{\perp}} d\hat{e}\ (when\ e_b\ is\ constant)$	Smaller the better
Velocity on Path fulfilled [bool]	$V_g^{\parallel} = V_{path}\ when\ \hat{e} = 0$	Needs to be True
Speed **monotonicity** [bool]	Whether the magnitude of velocity grows or decreases consistently throughout track error boundary $Monotonicity = \{\frac{d}{de}\lVert V_g(e)\rVert \geq 0 \mid for\ all\ e \in [0, e_b]\}$ Or $\{\frac{d}{de}\lVert V_g(e)\rVert \leq 0 \mid for\ all\ e \in [0, e_b]\}$ This can be compared via: $V_g^{\perp}(\frac{d}{d\hat{e}}V_g^{\perp}) + V_g^{\parallel}(\frac{d}{d\hat{e}}V_g^{\parallel})$	Needs to be True
Total **acceleration RMS** [m/s^2]	Root-Mean-Square value of acceleration $acc_{rms} = \frac{1}{e_b} * \sqrt{-\int_{e_b}^{0} (\lVert\frac{d}{dt}V_g(e)\rVert^2)\, de} = \sqrt{\int_{0}^{1} (\lVert\frac{d}{dt}V_g(\hat{e})\rVert^2)\, d\hat{e}}\ (when\ e_b\ is\ constant)$ $= \frac{1}{e_b}\sqrt{\int_{0}^{1} (\lVert V_g^{\perp} \cdot \frac{d}{d\hat{e}}V_g(\hat{e})\rVert^2)\, d\hat{e}} = \frac{1}{e_b}\sqrt{\int_{0}^{1} ([(V_g^{\perp}]^2 \cdot [(\frac{d}{d\hat{e}}V_g^{\perp})^2 + (\frac{d}{d\hat{e}}V_g^{\parallel})^2\ ])\, d\hat{e}}$	Smaller the better
Maximum acceleration total [m/s^2]	Maximum total acceleration $acc_{max} = max\{\frac{d}{dt}V_g(e) \mid for\ e \in [0, e_b]\} = \frac{1}{e_b} \cdot max\{V_g^{\perp} \cdot \sqrt{(\frac{d}{d\hat{e}}V_g^{\perp})^2 + (\frac{d}{d\hat{e}}V_g^{\parallel})^2}\ for\ \hat{e} \in [0, 1]\}\ (when\ e_b\ is\ constant)$	Smaller the better

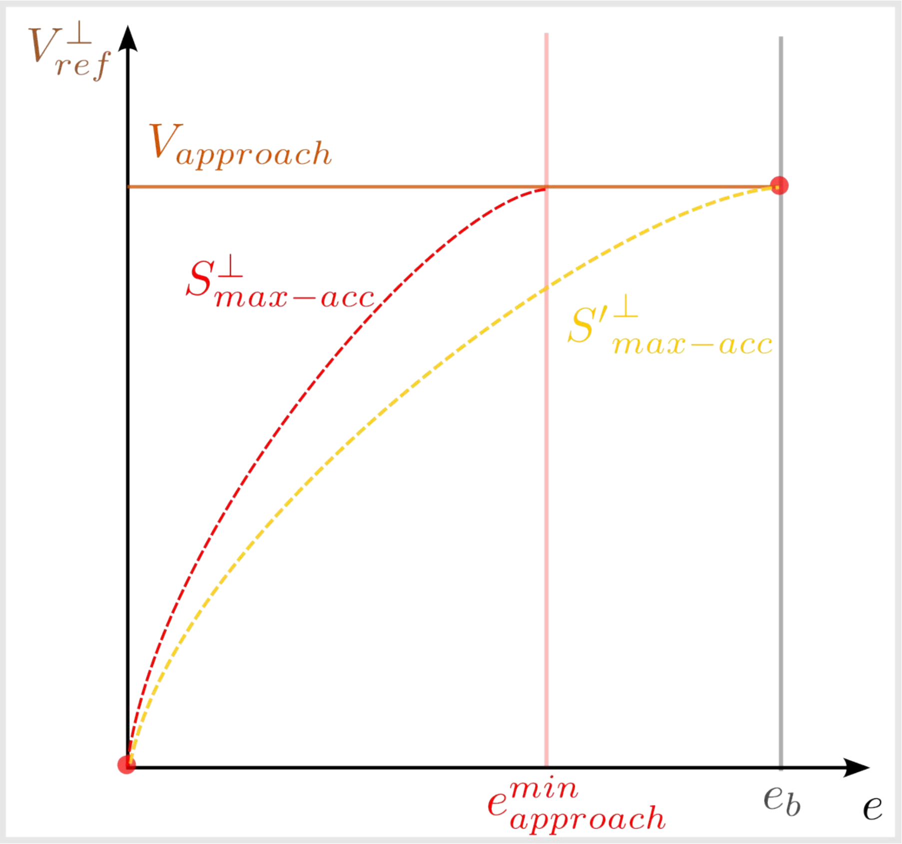
Maximum Acceleration Method: Orthogonal Velocity

$$e_{approach}^{min} = \frac{V_{approach}^2}{2a_{max}^{\perp}}$$

$$\text{With } e_b = \frac{V_{approach}^2}{2a_{max}^{\perp}}$$

$$S_{max-acc}^{\perp}(e) = \begin{cases} \sqrt{2a_{max}^{\perp}} * \sqrt{e} & \text{if } e < e_b \\ V_{approach} & \text{if } e \geq e_b \end{cases}$$

$$\begin{aligned} S'^{\perp}_{max-acc}(e) &= S^{\perp}_{max-acc}\left(\frac{e_{approach}^{min}}{e_b} * e\right) \\ &= \begin{cases} \sqrt{\frac{2a_{max}^{\perp} e_{approach}^{min}}{e_b}} * \sqrt{e} & \text{if } e < e_b \\ V_{approach} & \text{if } e \geq e_b \end{cases} \\ &= \begin{cases} V_{approach} * \sqrt{\frac{e}{e_b}} & \text{if } e < e_b \\ V_{approach} & \text{if } e \geq e_b \end{cases} \end{aligned}$$



$$V_{ref}^{\perp}(e) = \begin{cases} V_{approach} & \text{if } e = e_b \\ 0 & \text{if } e = 0 \end{cases}$$

Maximum Acceleration Method: Parallel Velocity

$$\frac{d}{de}V^{\|}_{ref}(e) \geq -\frac{a^{\|}_{max}}{S'^{\perp}_{max-acc}(e)}$$

$$= \begin{cases} -\frac{a^{\|}_{max}}{V_{approach}} * \sqrt{\frac{e_b}{e}} & \text{if } e < e_b \\ -\frac{a^{\|}_{max}}{V_{approach}} & \text{if } e \geq e_b \end{cases}$$

$$\text{Since } V_{path} = \int_{e^{min}_{path}}^{0} -\frac{a^{\|}_{max}}{V_{approach}}\sqrt{\frac{e_b}{e}}de,$$

$$= -\frac{a^{\|}_{max}\sqrt{e_b}}{V_{approach}} * [2\sqrt{e}]^{0}_{e^{min}_{path}},$$

$$\text{Therefore, } e^{min}_{path}|_{S'^{\perp}_{max-acc}} = [\frac{V_{path}V_{approach}}{2a^{\|}_{max}}]^2 * \frac{1}{e_b}$$

$$V^{max}_{path}|_{S'^{\perp}_{max-acc}} = S^{\|}_{max-acc}(e=0)$$

$$= \int_{e_b}^{0} -\frac{a^{\|}_{max}}{V_{approach}}\sqrt{\frac{e_b}{e}}de$$

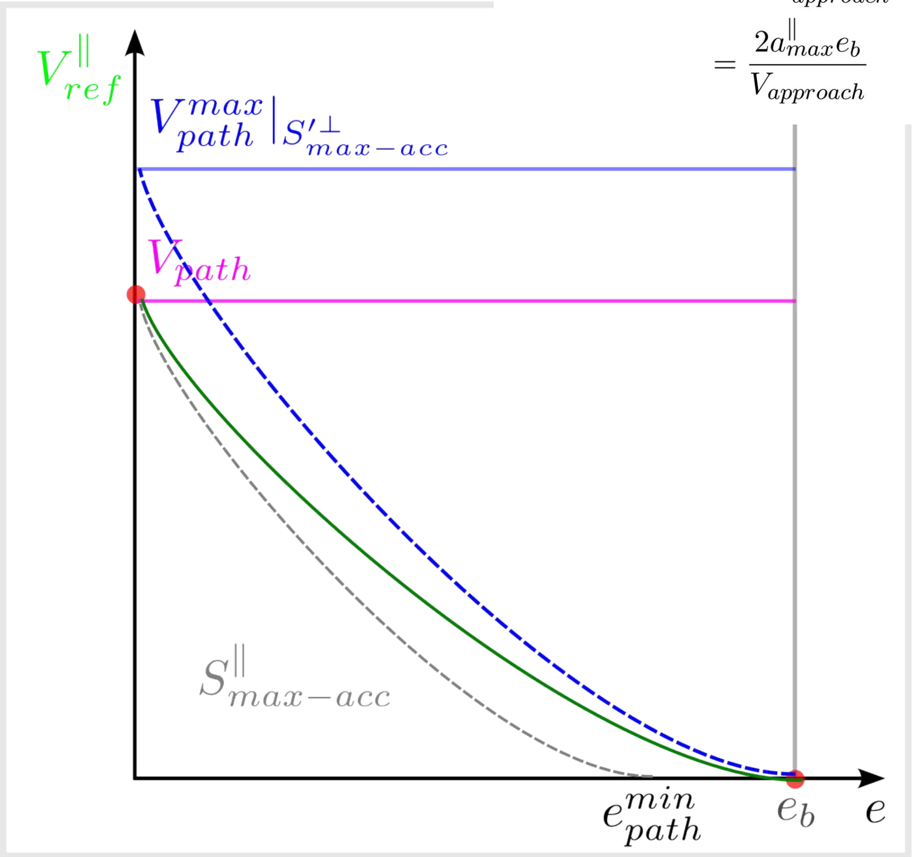
$$= -\frac{a^{\|}_{max}\sqrt{e_b}}{V_{approach}} * [2\sqrt{e}]^{0}_{e_b}$$

$$= \frac{2a^{\|}_{max}e_b}{V_{approach}}$$

$$S'^{\|}_{max-acc}(e) = S^{\|}_{max-acc}(\frac{e^{min}_{path}|_{S'^{\perp}_{max-acc}}}{e_b} * e)$$

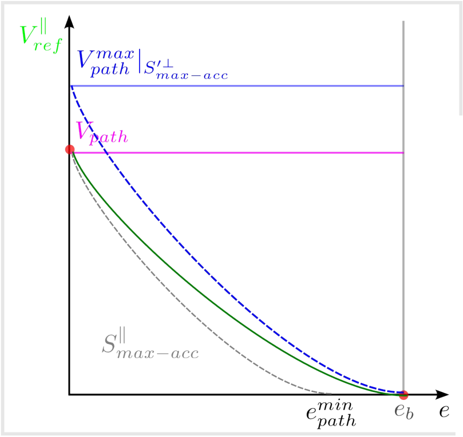
$$= \begin{cases} V_{path} - \frac{2a^{\|}_{max}\sqrt{e_b}}{V_{approach}} * \sqrt{\frac{e^{min}_{path}|_{S'^{\perp}_{max-acc}}}{e_b} * e} & \text{if } e < e_b \\ 0 & \text{if } e \geq e_b \end{cases}$$

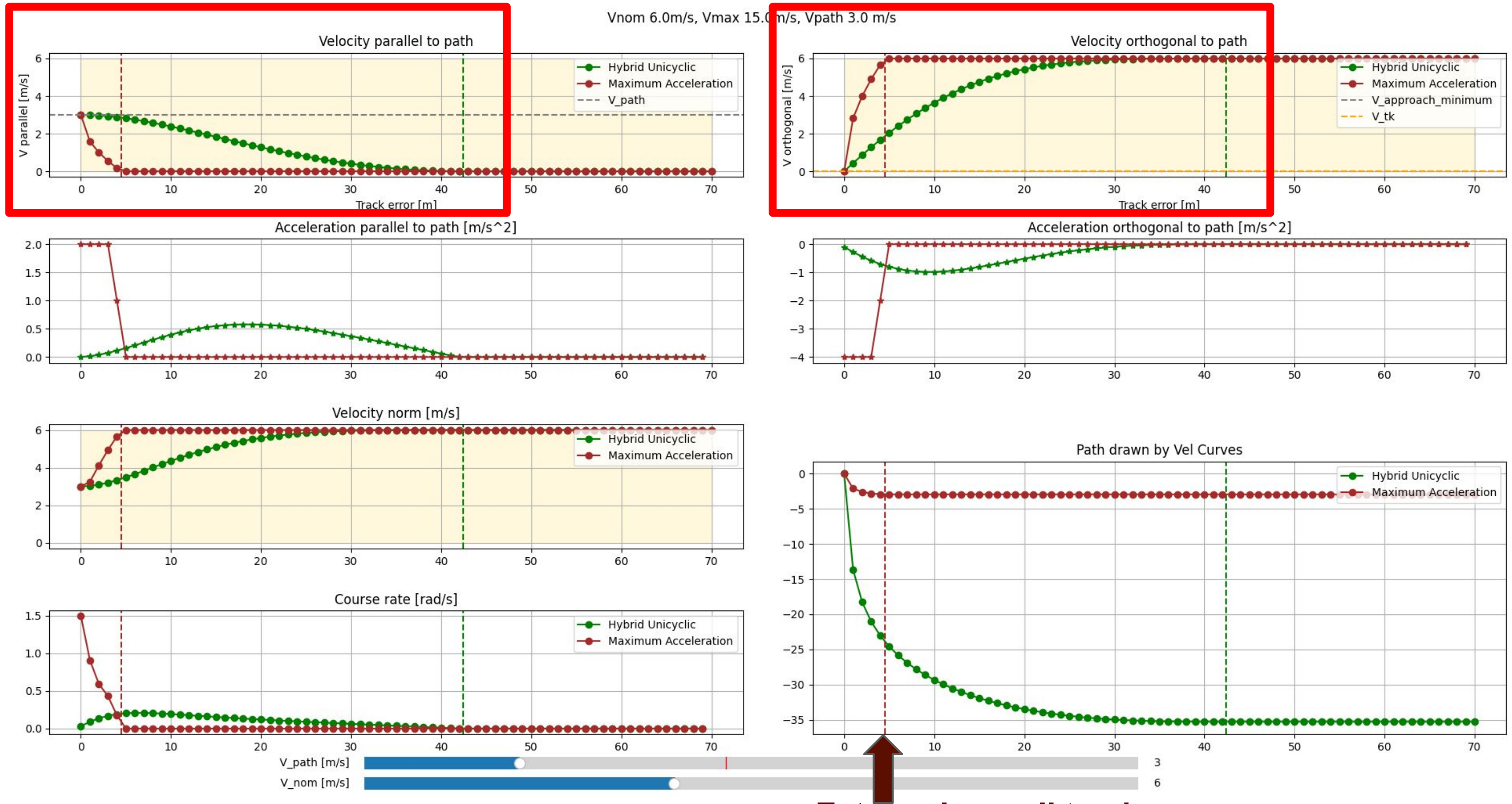
$$= \begin{cases} V_{path} * (1 - \sqrt{\frac{e}{e_b}}) & \text{if } e < e_b \\ 0 & \text{if } e \geq e_b \end{cases}$$



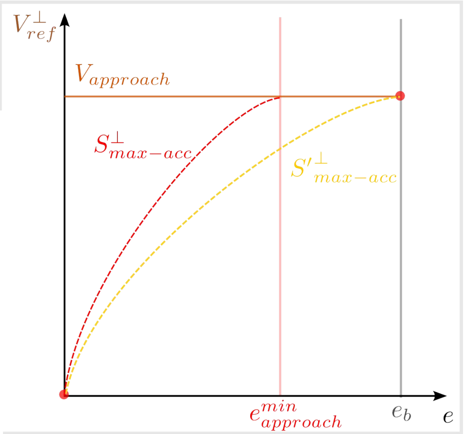
$$V^{\|}_{ref}(e) = \begin{cases} 0 & \text{if } e = e_b \\ V_{path} & \text{if } e = 0 \end{cases}$$

Maximum Acceleration method

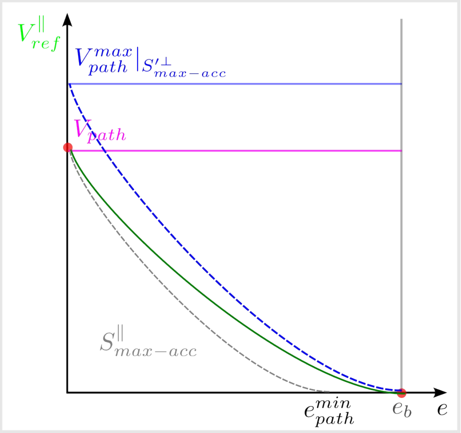


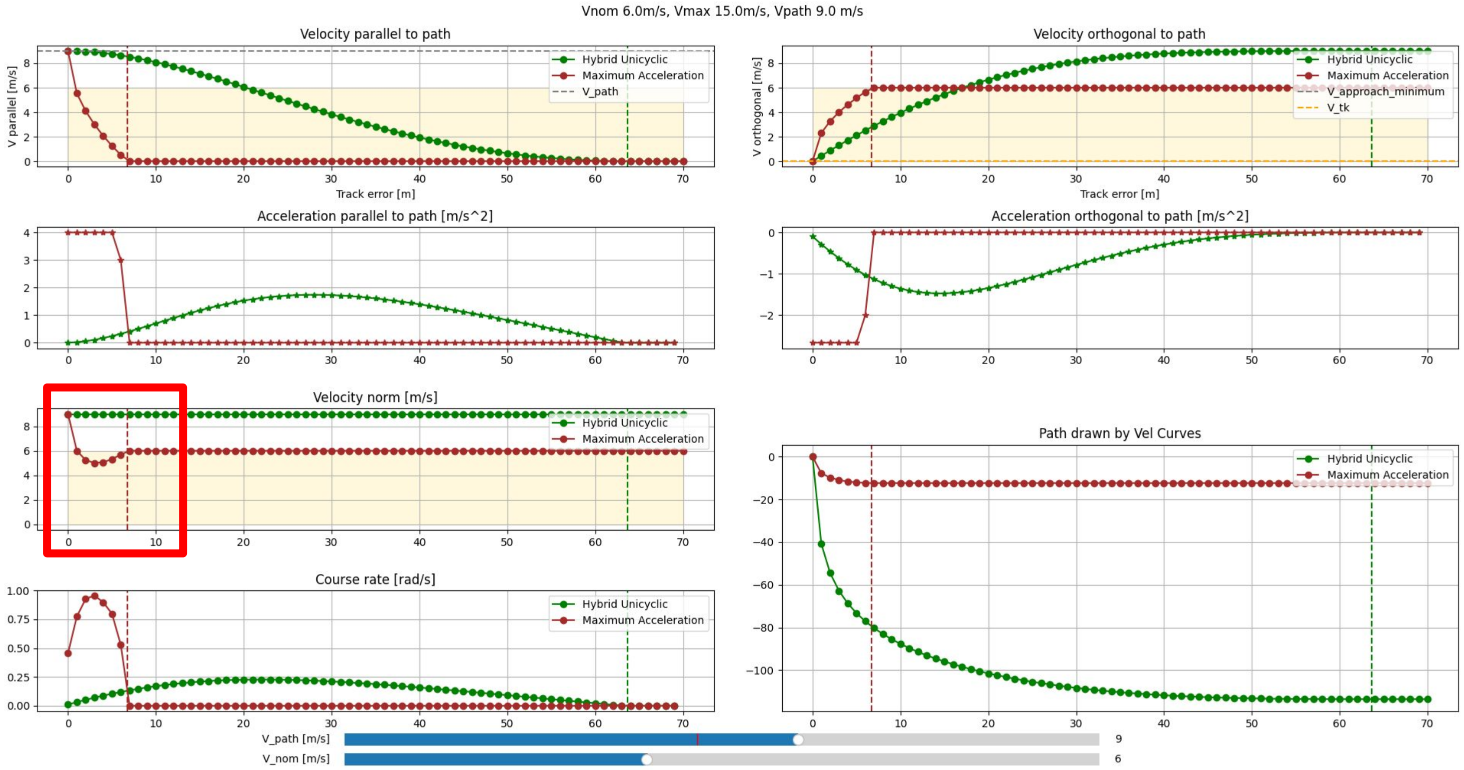


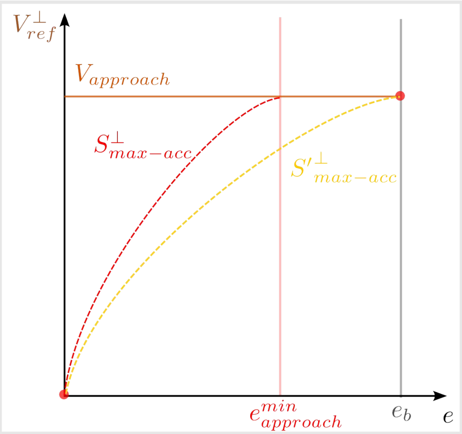
Extremely small track error boundary



Maximum Acceleration method







Monotonicity not satisfied

Maximum Acceleration Formulation

e = Current cross track error to path

t_{const} = Track error boundary calculation time constant

e_b = Track error boundary

$\hat{e}$ = Normalized track error boundary $(= \frac{e}{e_b})$

V_{nom} = Nominal speed of the vehicle (cruise)

Θ_{la} = Look ahead angle (away from orthogonal component to the path)

$V_g^{\perp}$ = Orthogonal ground reference velocity (towards the path)

$V_g^{||}$ = Parallel ground reference velocity (along the path)

$e_{approach}^{min}$ = Minimum track error boundary to satisfy approaching velocity constraint

e_{path}^{min} = Minimum track error boundary to satisfy on path velocity constraint

$a_{max}^{\perp}$ = Maximum orthogonal (to path) acceleration limit

$a_{max}^{||}$ = Maximum parallel (to path) acceleration limit

j_{max} = Maximum jerk limit

$$V_{approach} = max(V_{nom}, V_{path})$$

$$e_{approach}^{min} = \frac{[V_{approach}]^2}{2a_{max}^{\perp}}$$

$$e_{path}^{min} = [\frac{V_{path}V_{approach}}{2a_{max}^{||}}]^2 * \frac{1}{e_{approach}^{min}} = [\frac{V_{path}}{a_{max}^{||}}]^2 * \frac{a_{max}^{\perp}}{2}$$

$$if(e_{approach}^{min} < e_{path}^{min})$$

$$e_{approach}^{min} = e_{path}^{min} = [\frac{V_{path}V_{approach}}{2a_{max}^{||}}]$$

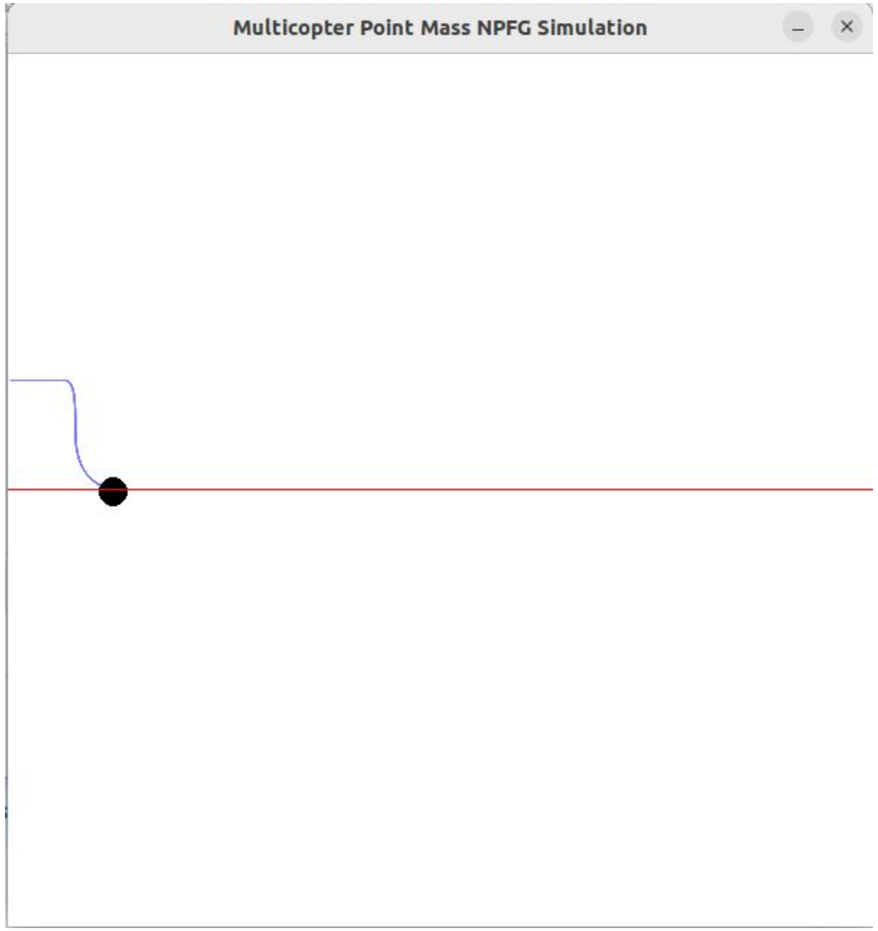
$$e_b = max(e_{approach}^{min}, e_{path}^{min})$$

$$V_g^{||} = V_{path} * (1 - \sqrt{\hat{e}})$$

$$V_g^{\perp} = V_{approach} * \sqrt{\hat{e}}$$

$$return\ [V_g^{||}, V_g^{\perp}]$$

Limitation of the unicyclic path following algorithm



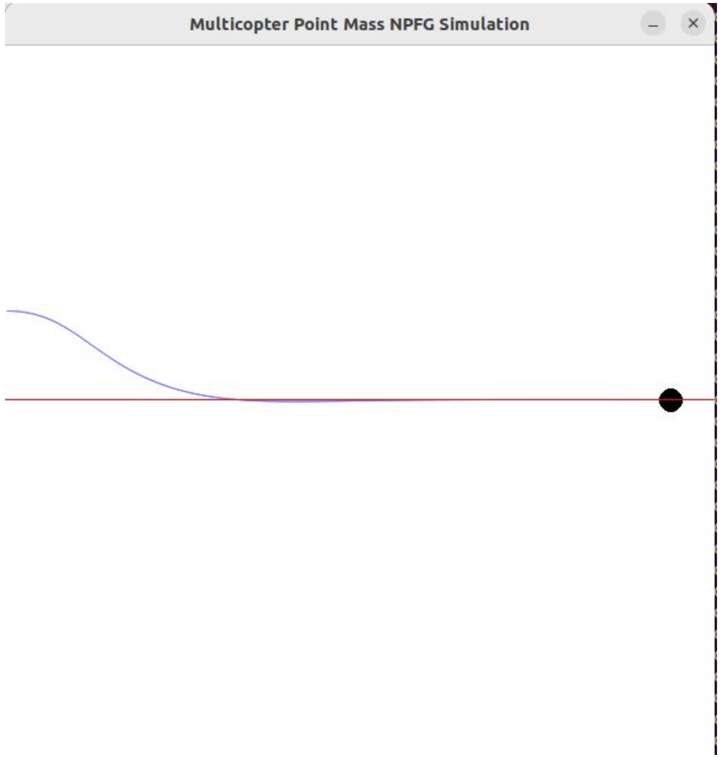
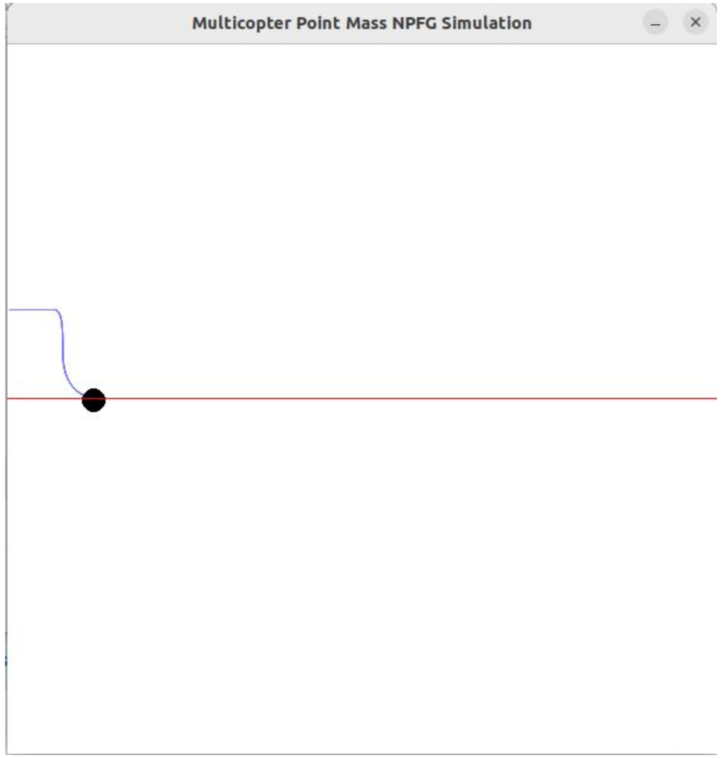
What do we do when we want to go **slower** on the path?

- Unicyclic Path Following assumes that vehicle maintains the 'nominal airspeed', so **it can never stop.**
- Reducing nominal airspeed produces **weird artifacts**

What about going **faster**?

- We can set nominal airspeed to a higher value, but it **alters the definition of 'cruise speed'** (energy optimal speed)

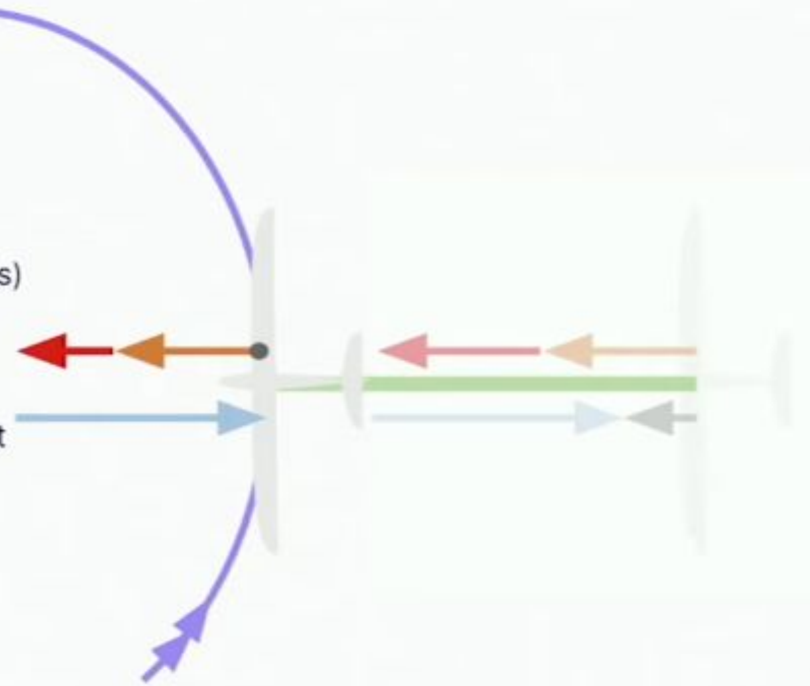
Track-keeping

User-set minimum ground speed = 5.0 m/s	User-set minimum ground speed = 0.0 m/s
	

Limitations of NPFG Track-keeping feature

Track keeping

- Enable: `NPFG_TRACK_KEEP=1`
- Set `FW_GND_SPD_MIN=0`
- Far away from the track, `NPFG_GSP_MAX_TK` (m/s) is is the maximum **forward** ground speed NPFG will command in its effort to return to the path
- The commanded ground speed aid is **zeroed** out once safely on the path



Limitations of NPFG Track-keeping feature

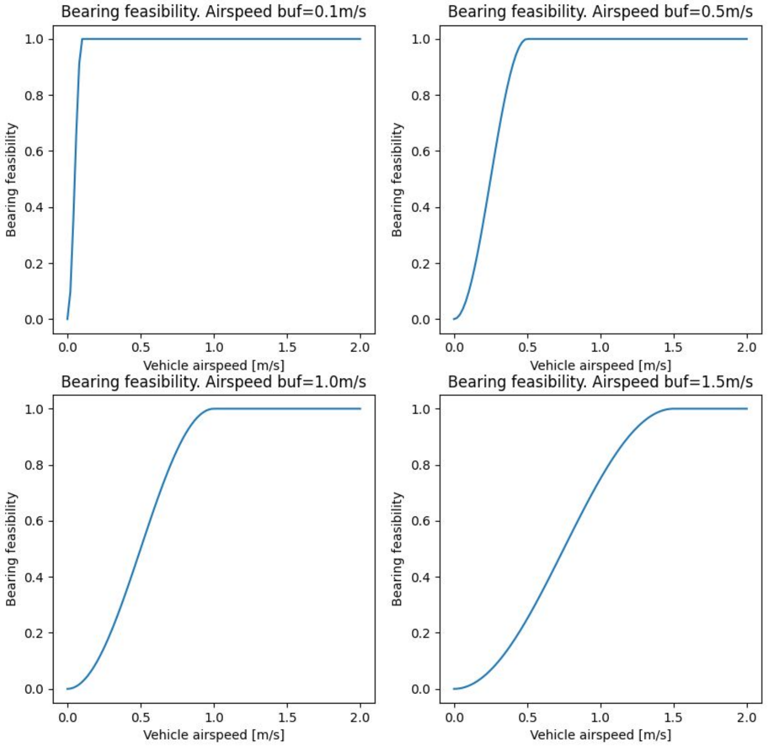
```cpp
float NPFG::minGroundSpeed(const float normalized_track_error, const float feas)
{
	// minimum ground speed demand from track keeping logic
	min_gsp_track_keeping_ = 0.0f;

	if (en_track_keeping_ && en_wind_excess_regulation_) {
		// zero out track keeping speed increment when bearing is feasible
		// maximum track keeping speed increment is applied until we are within
		// a user defined fraction of the normalized track error
		min_gsp_track_keeping_ = (1.0f - feas) * min_gsp_track_keeping_max_ * math::constrain(
						 normalized_track_error / NTE_FRACTION, 0.0f,
						 1.0f);
	}

	// minimum ground speed demand from minimum forward ground speed user setting
	float min_gsp_desired = 0.0f;

	if (en_min_ground_speed_ && en_wind_excess_regulation_) {
		min_gsp_desired = min_gsp_desired_;
	}

	return math::max(min_gsp_track_keeping_, min_gsp_desired);
} // minGroundSpeed
```

Bearing Feasibility

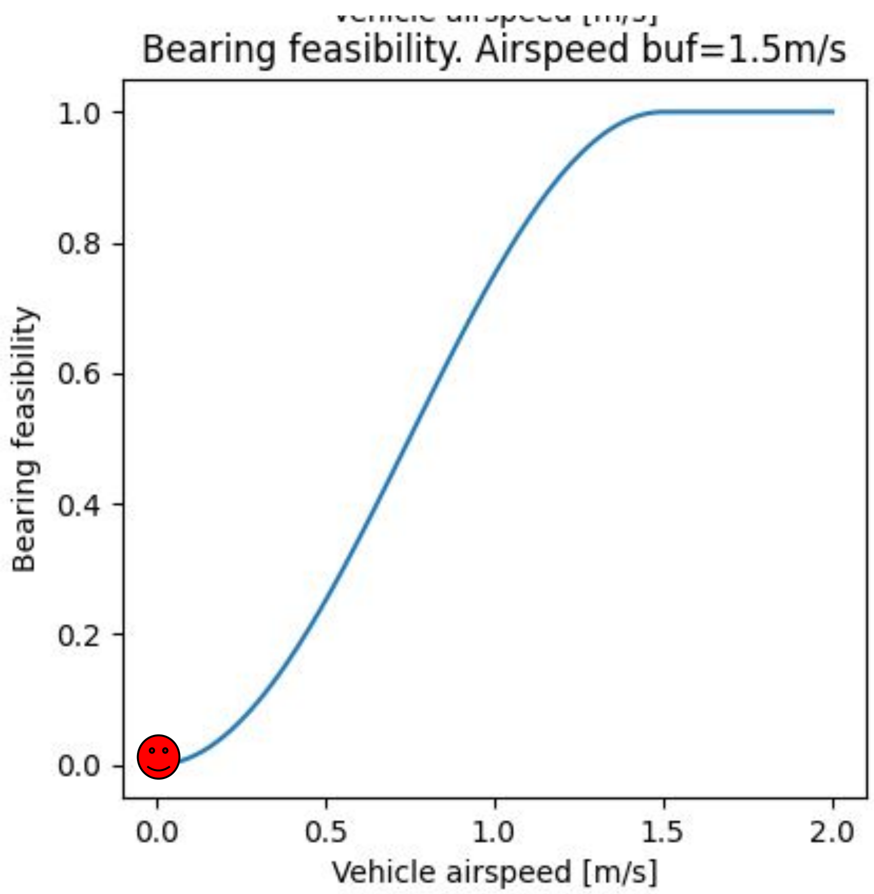
Minimum Ground Speed = 1 - feasibility X Minimum Ground Speed Track-Keeping

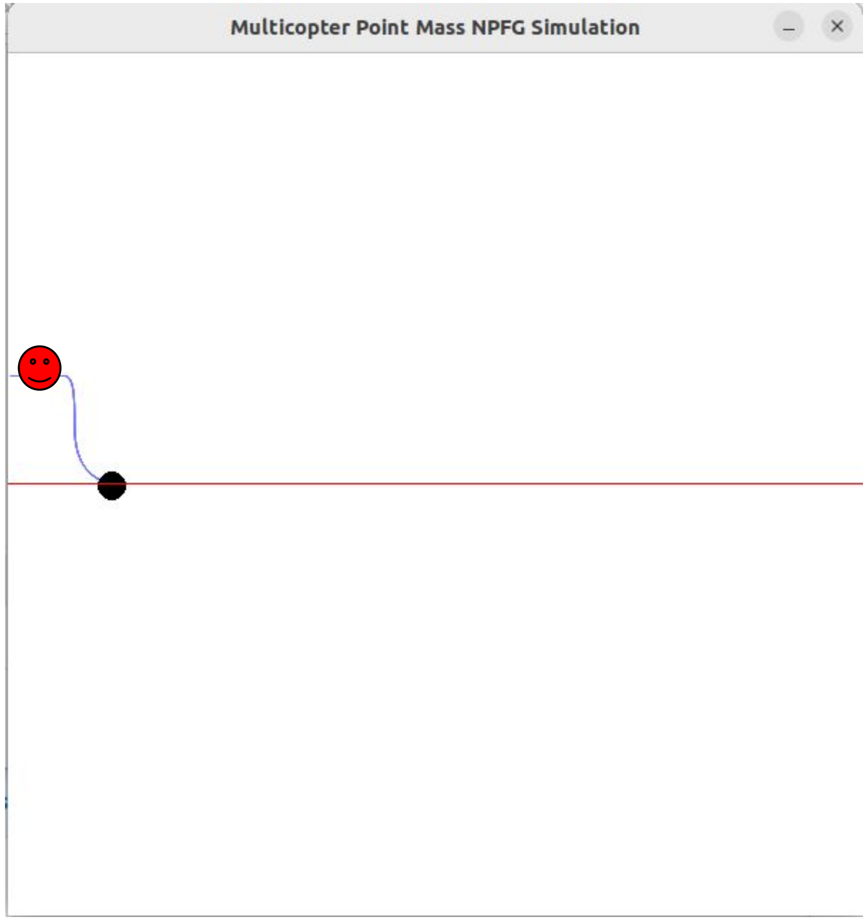
Bearing Feasibility

Minimum Ground Speed = 1 - feasibility X Minimum Ground Speed Track-Keeping

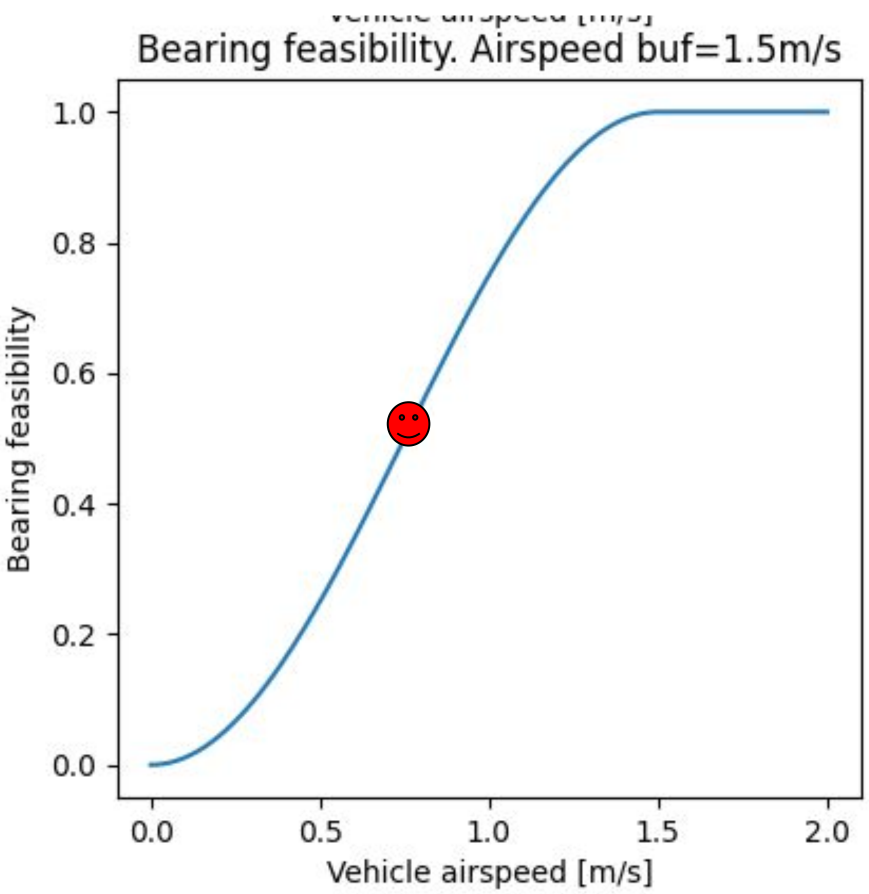


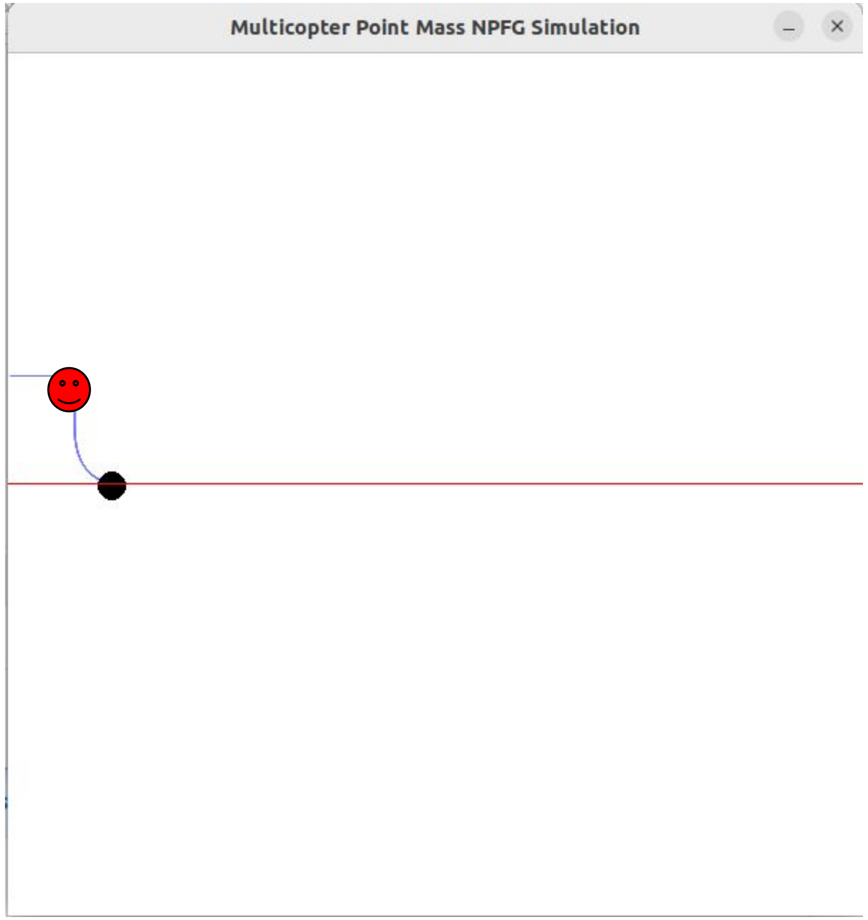
Bearing Feasibility



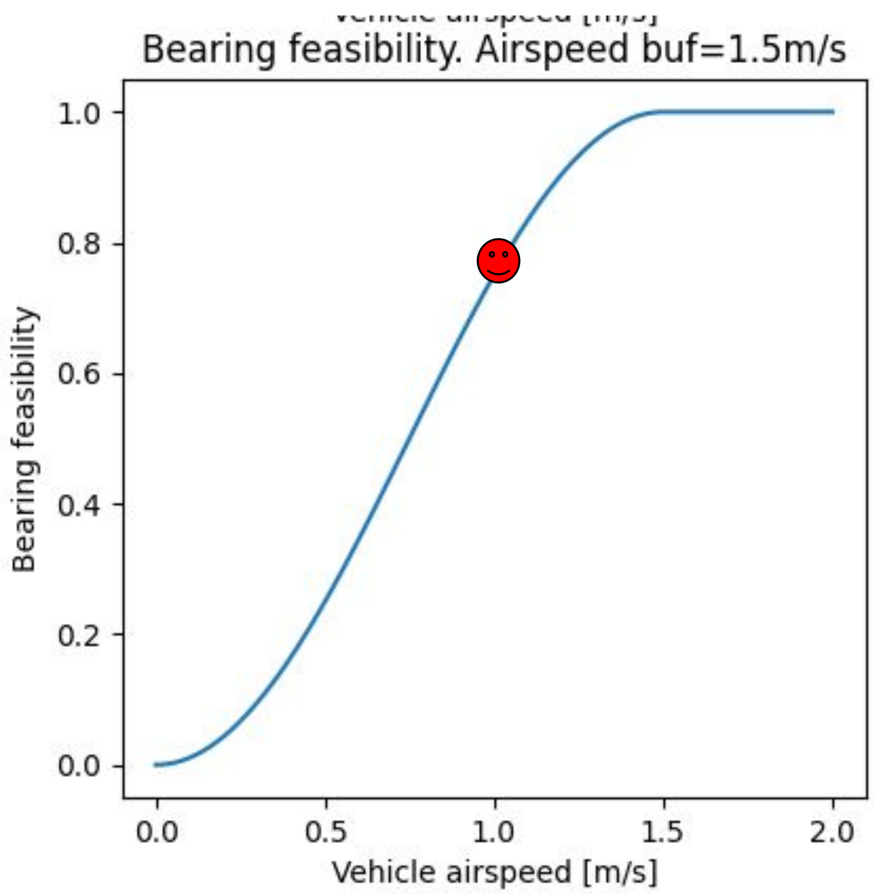


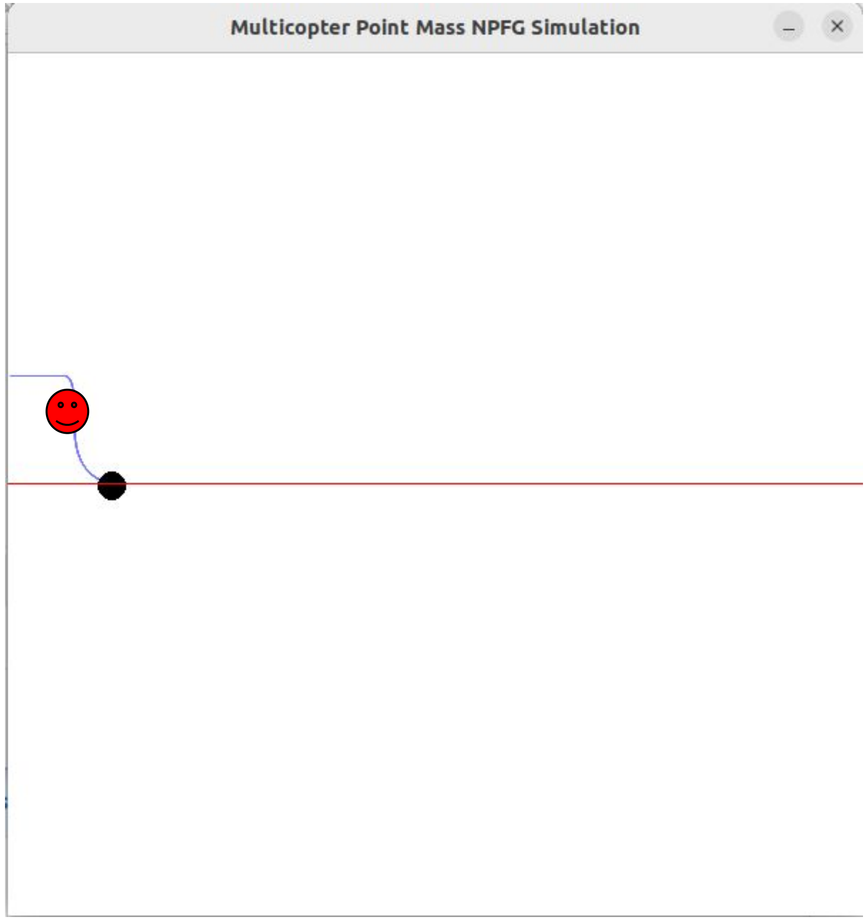
Bearing Feasibility



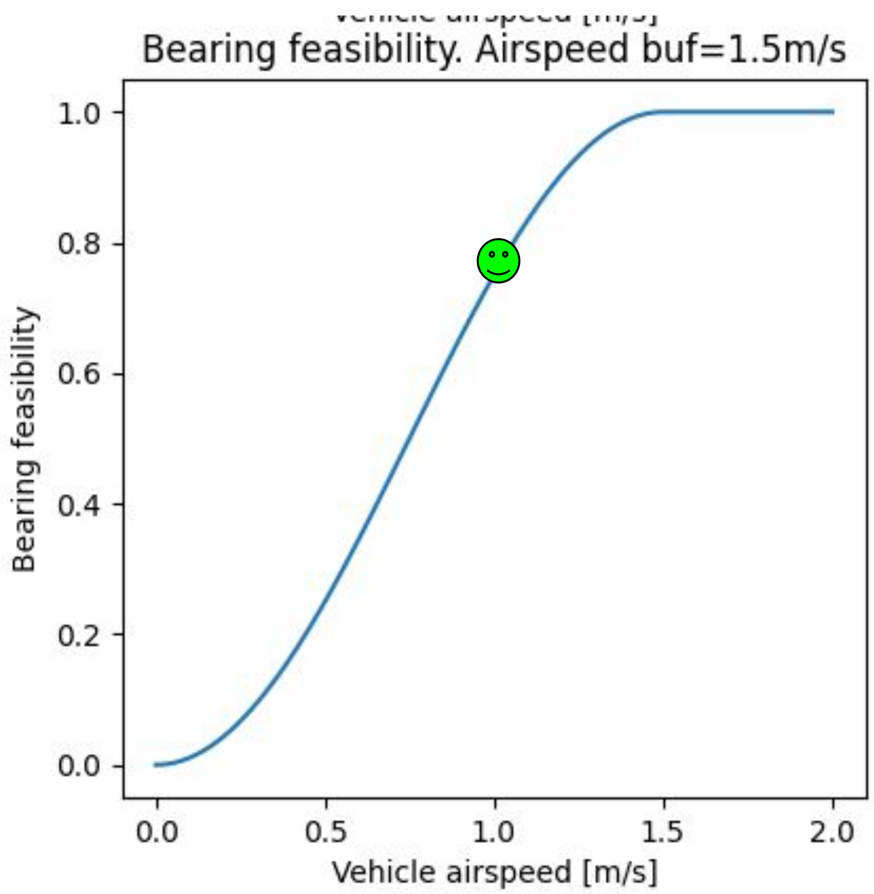


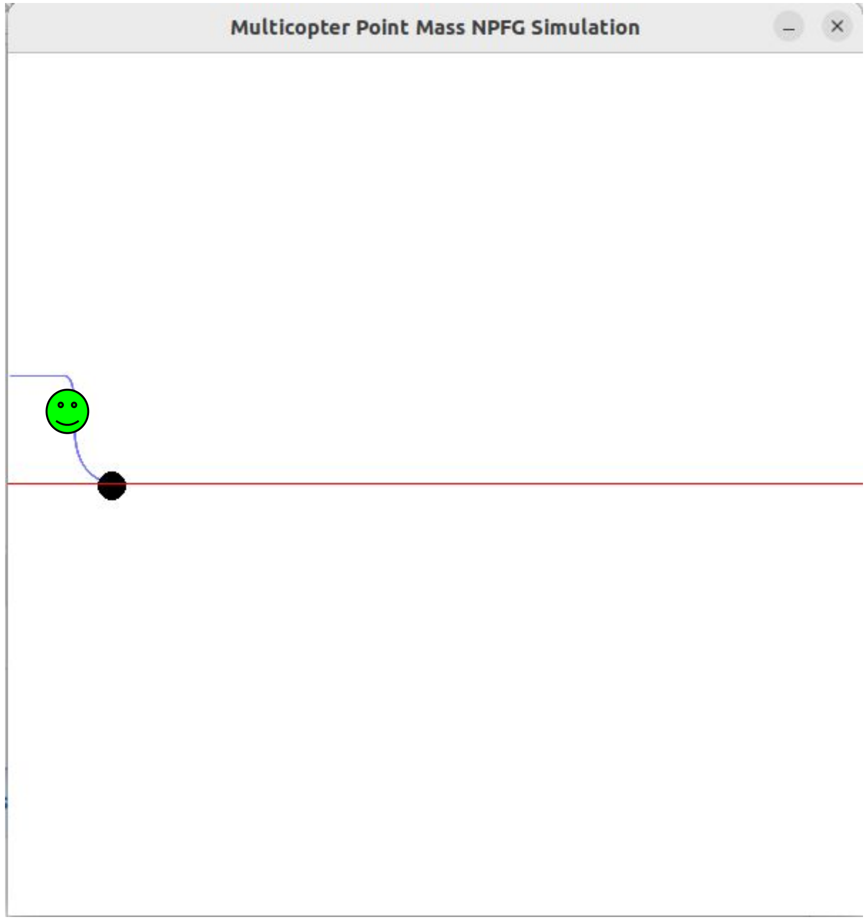
Bearing Feasibility



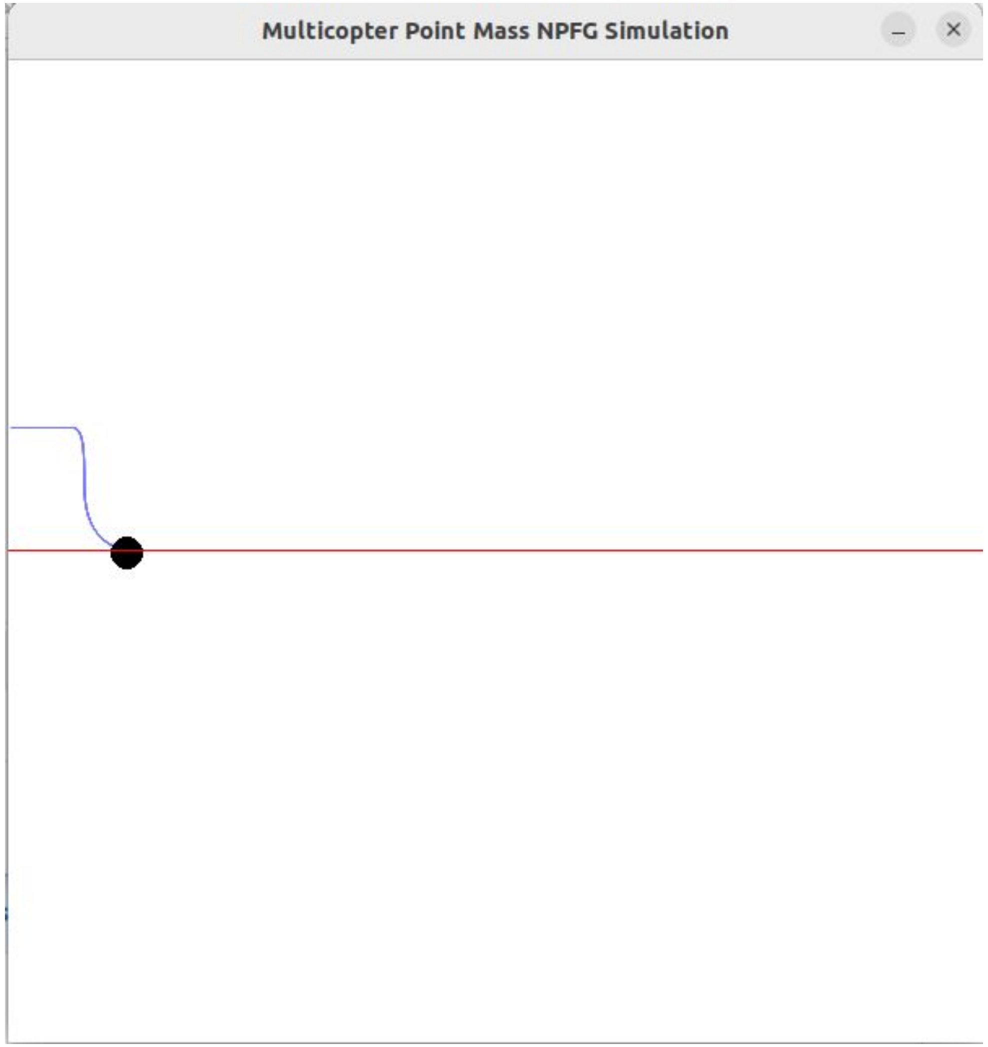


Bearing Feasibility





Multicopter vs Fixed-wing dynamics

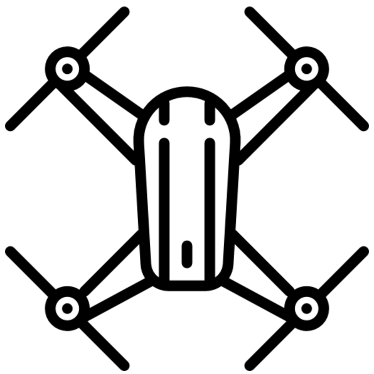


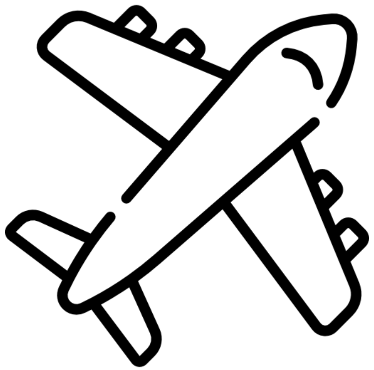
Appendix

Slides that I won't be using

ETH zürich

Constraints of Multirotor and Fixed Wing System





Acceleration (Body Frame)
- Lateral
- Longitudinal

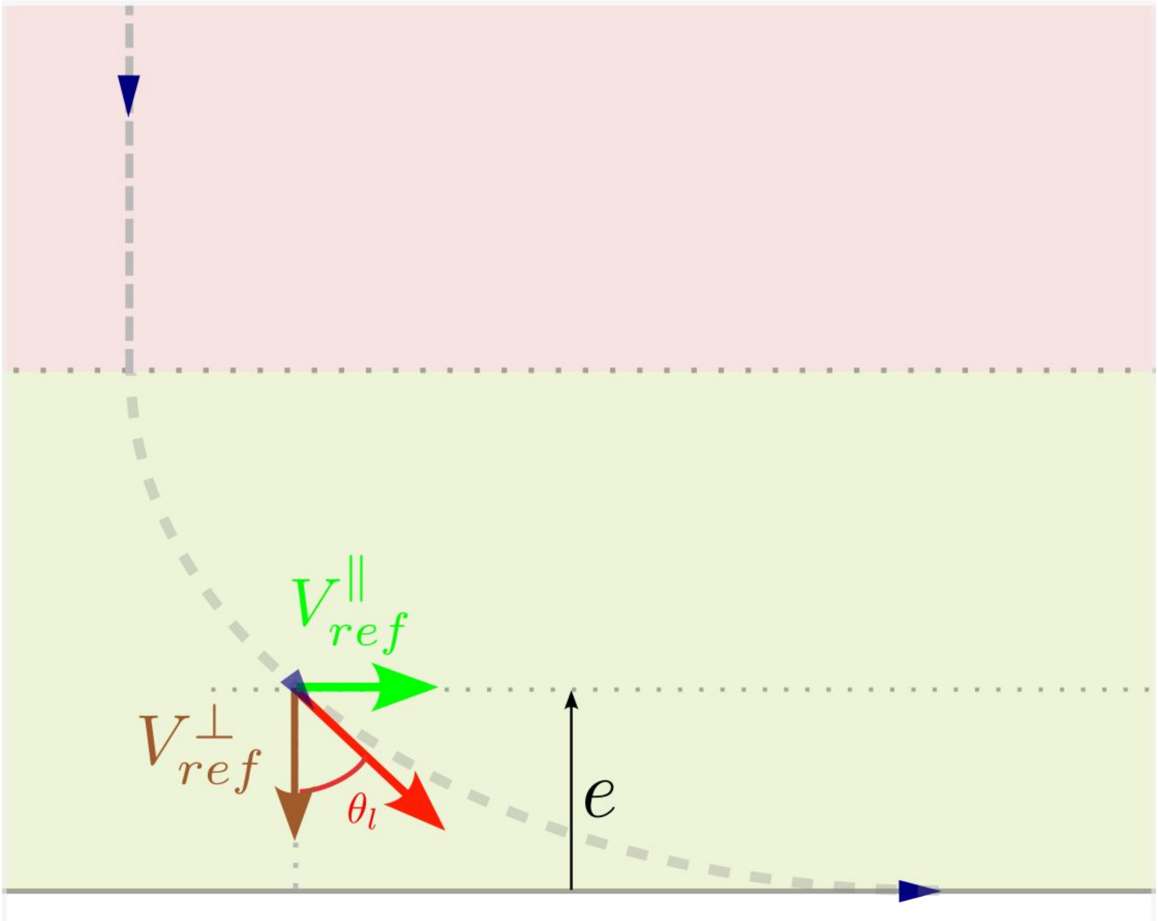
Velocity
- Variable

Acceleration
- Lateral (Yaw coupled)
- Longitudinal

Velocity
- Constant

Methods

Look ahead angle



Unicyclic

$$V^{||}_{g} = V_{nom} * sin(\theta_l)$$

$$V^{\perp}_{g} = V_{nom} * cos(\theta_l)$$

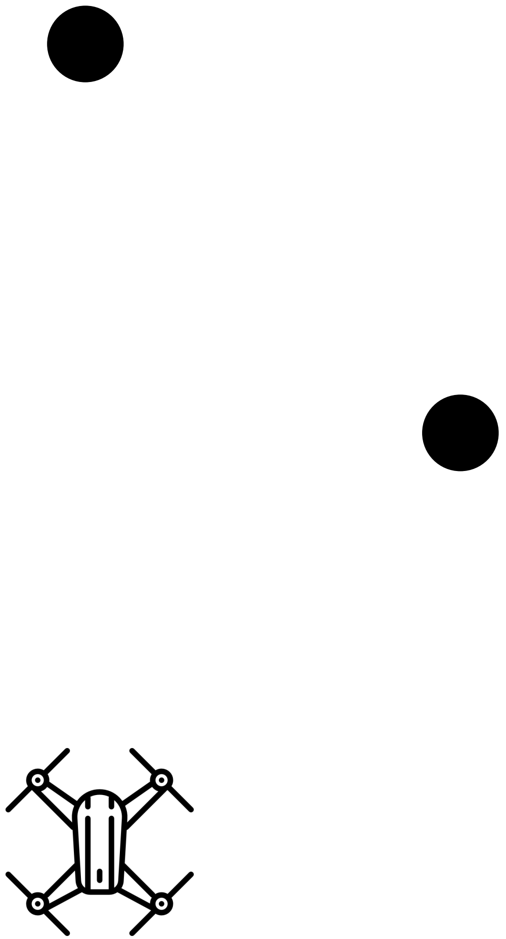
Hybrid Unicyclic

$$V^{||}_{g} = V_{path} * sin(\theta_l)$$

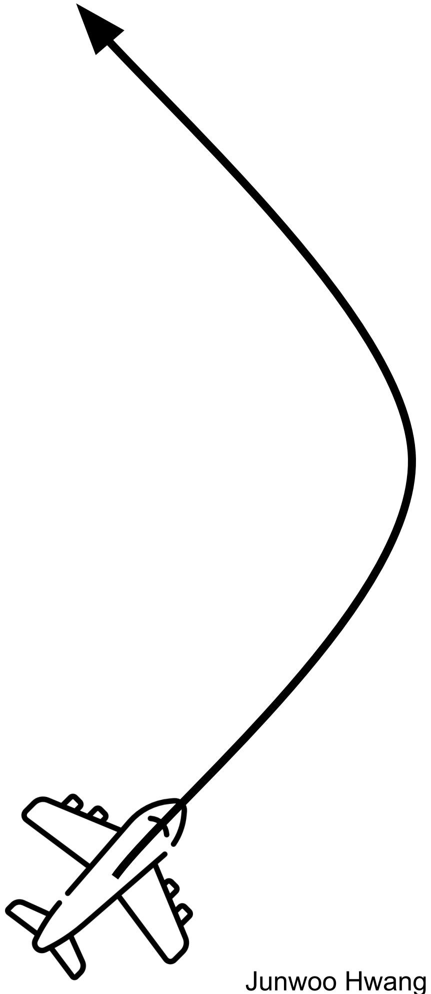
$$V^{\perp}_{g} = V_{approach} * cos(\theta_l)$$

Path Following for Multirotor / Fixed Wing

Holonomic

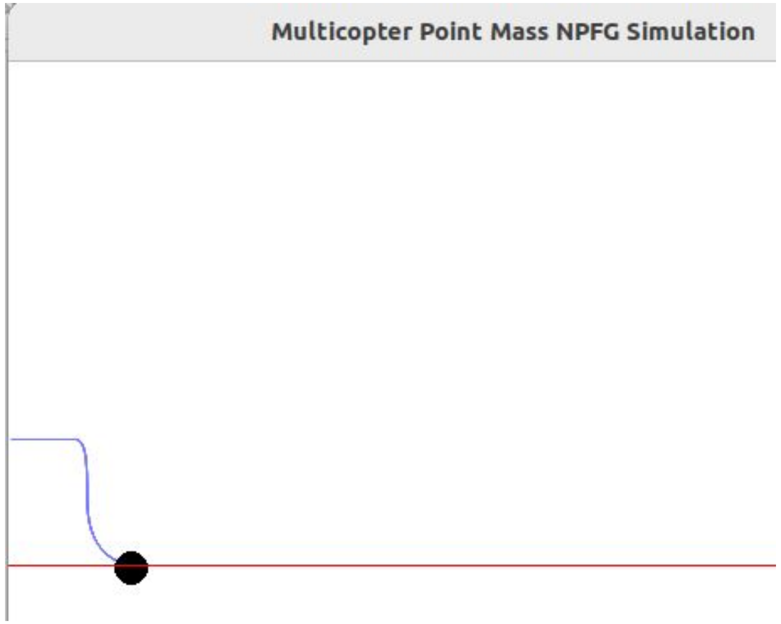


Non Holonomic



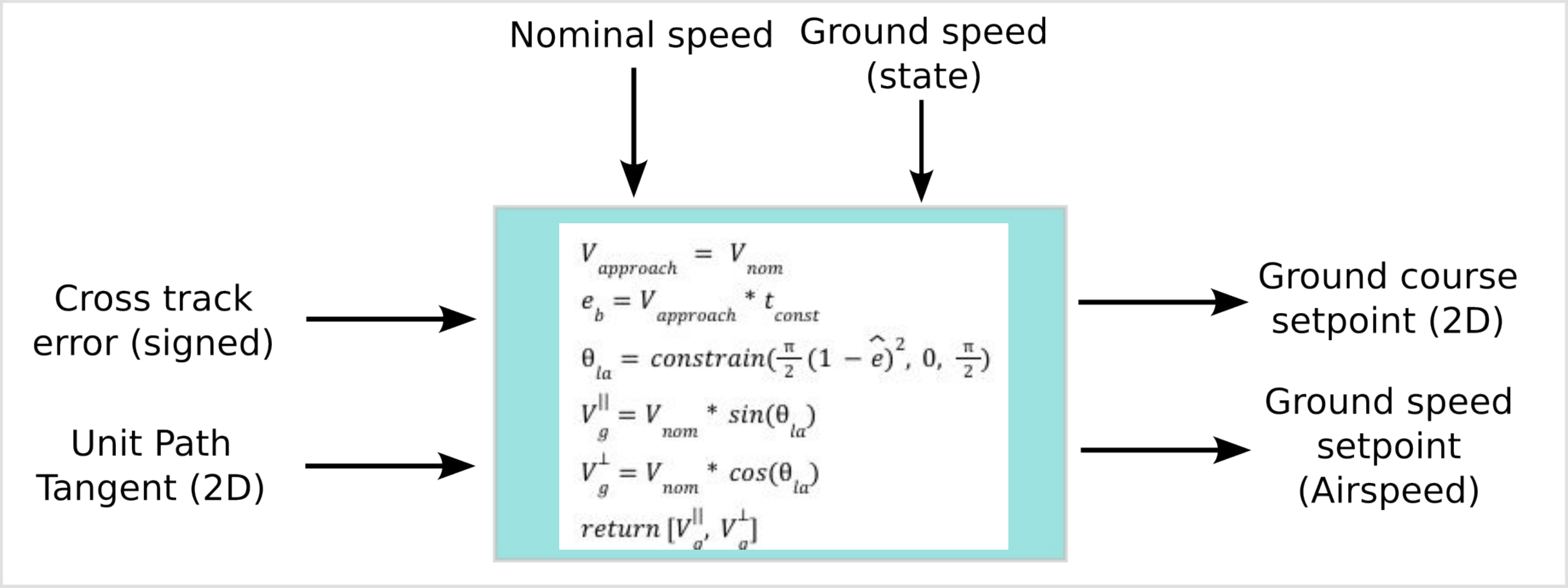
Why do we need Unified Path Following?

- **Fixed Wing Path Following doesn't work on Multirotor!**



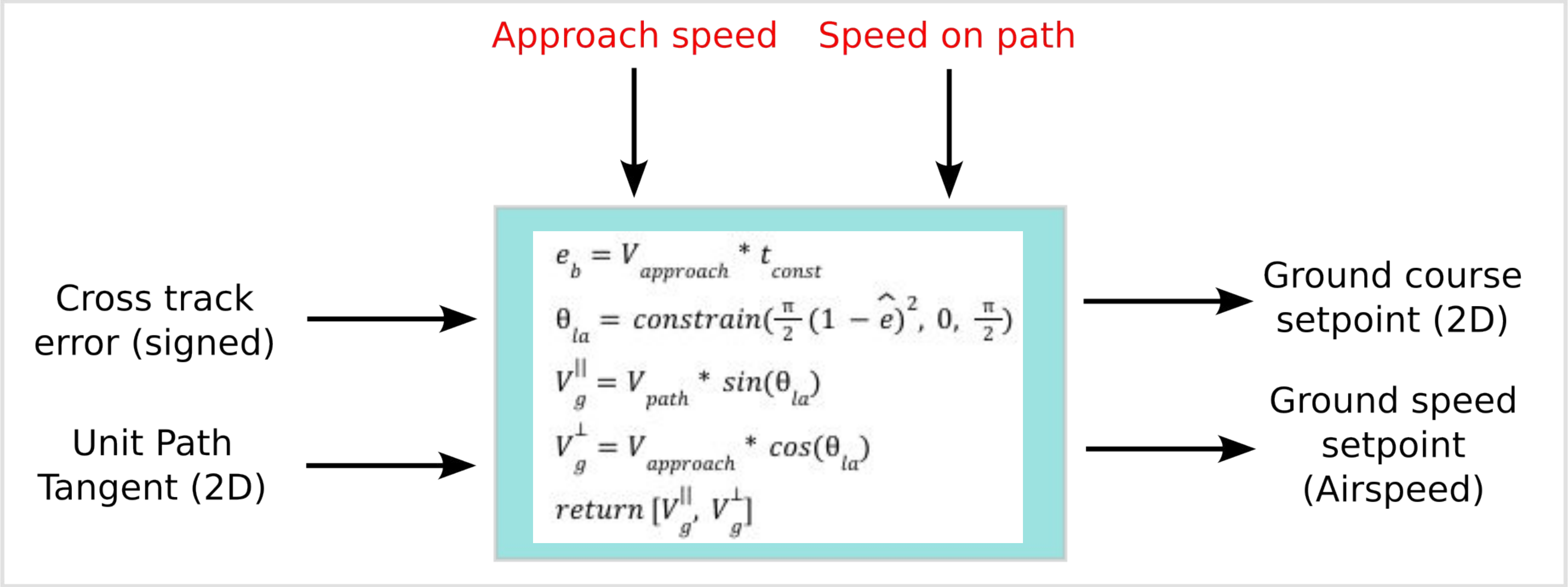
Base Method

Unicyclic Method [Stastny, IROS, 2019]



Proposed Method

Hybrid Unicyclic Method



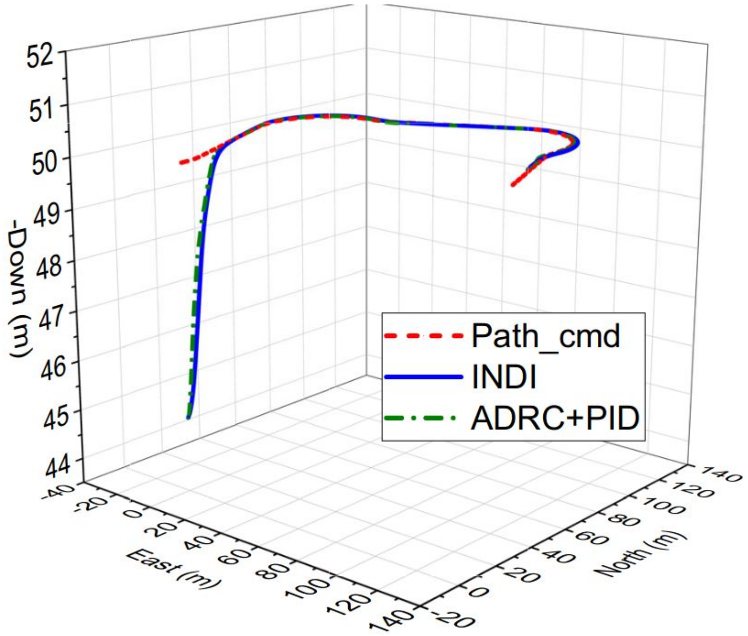
Test Conditions

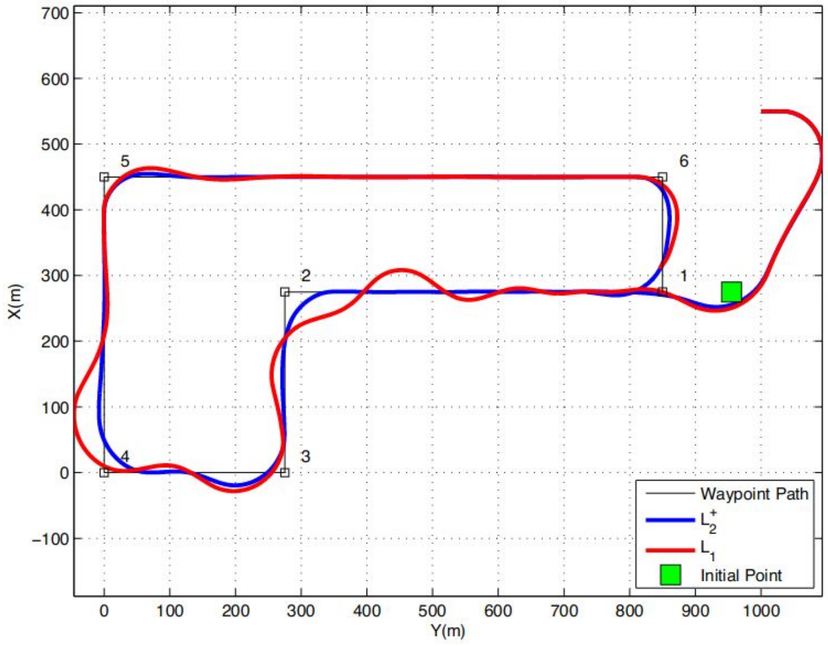
For evaluating the Ground Velocity curve:

- **No wind**
- **Track error boundary is fixed** (Only look-ahead angle & speed is varied)
- **Approach speed is fixed** (To allow consistent entry for comparison)
- Vehicle tracks ground velocity perfectly (first order system)

Limitations

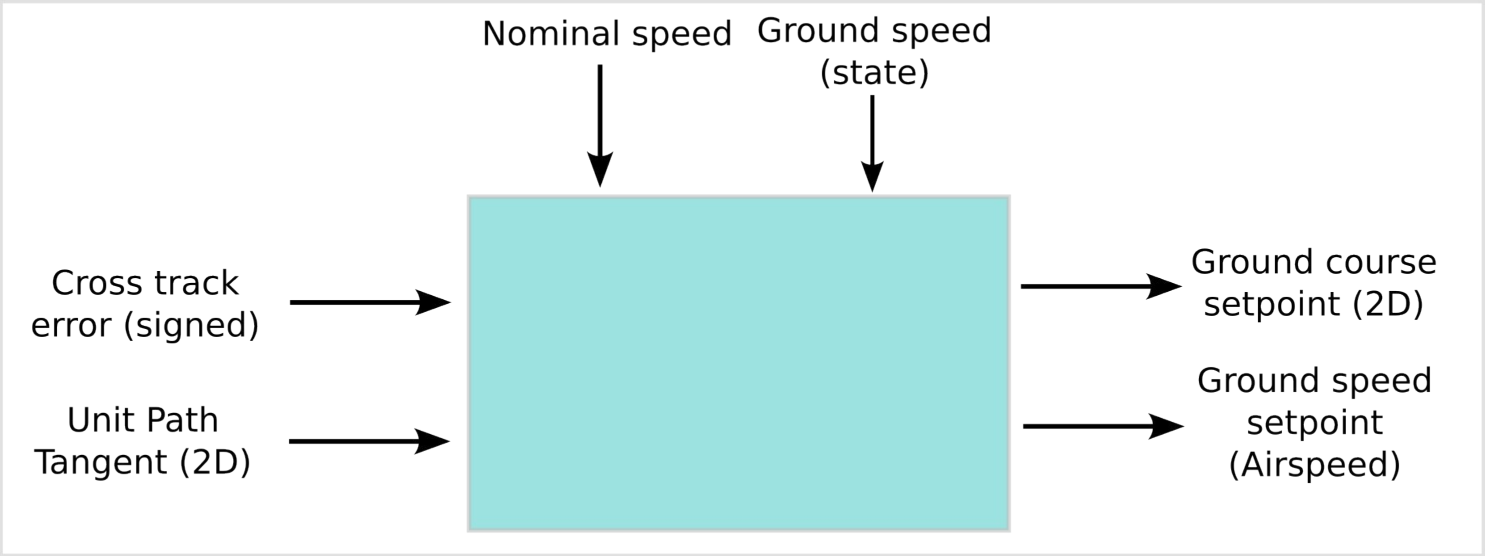
- **Constant speed assumption** for Multirotor (Limited maneuverability)
- **No generic Path Following Guidance** that suits both modes of operation



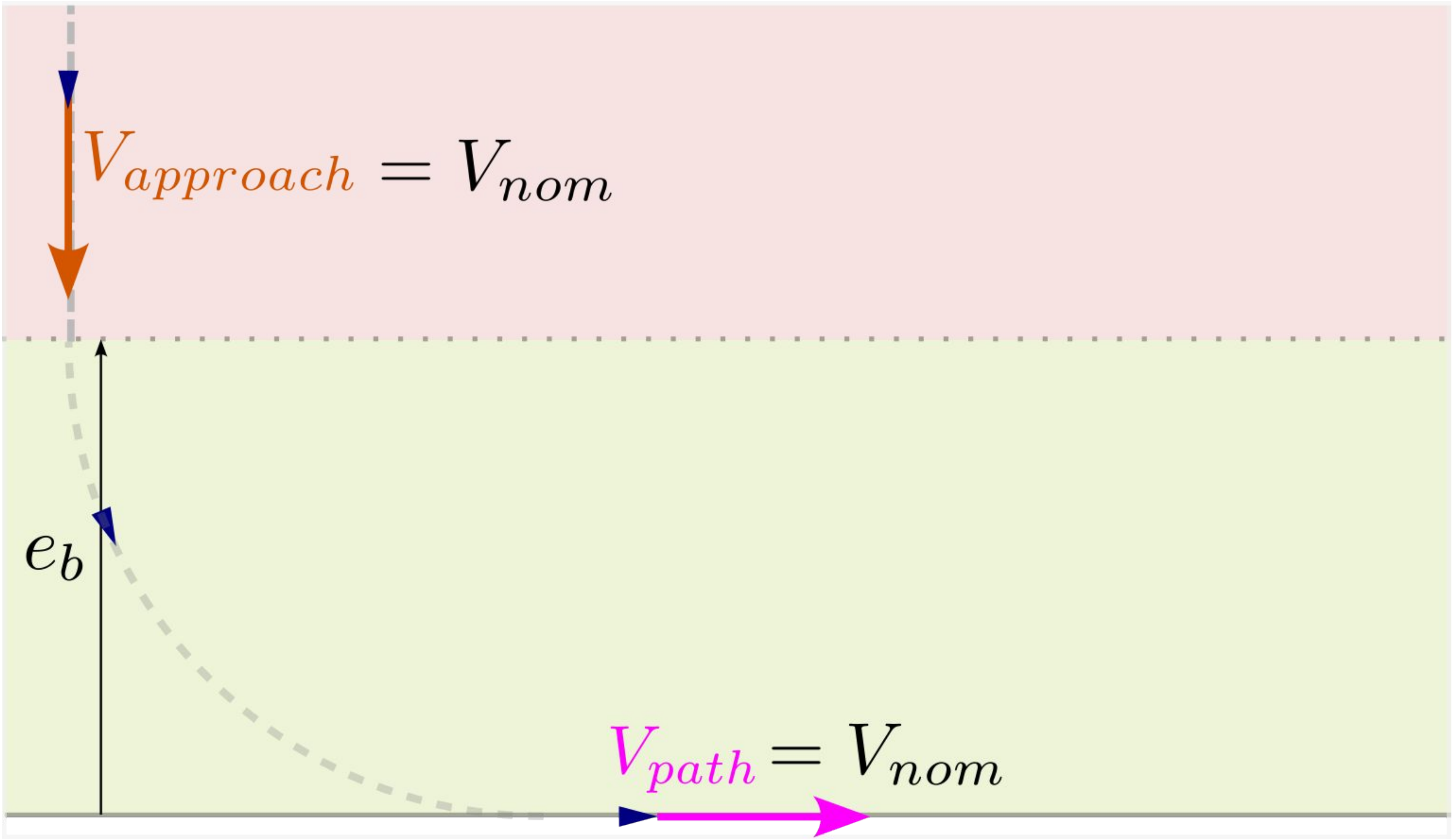


Base Method

Unicyclic Method [Stastny, IROS, 2019]

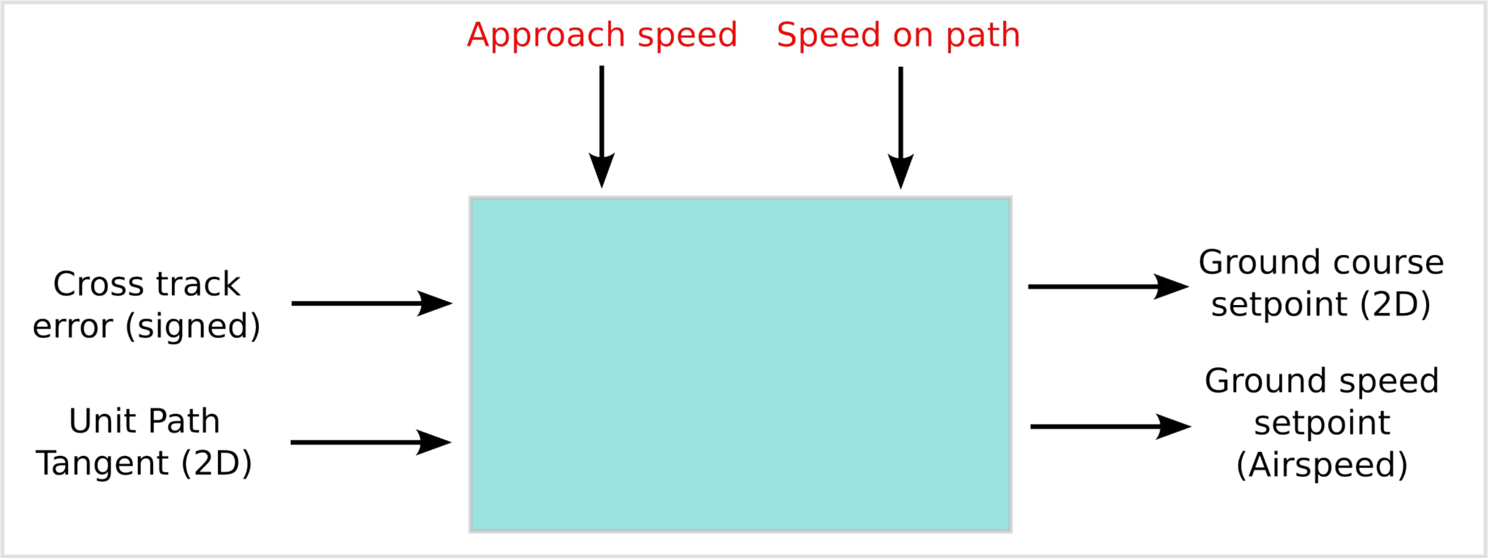


Base Method

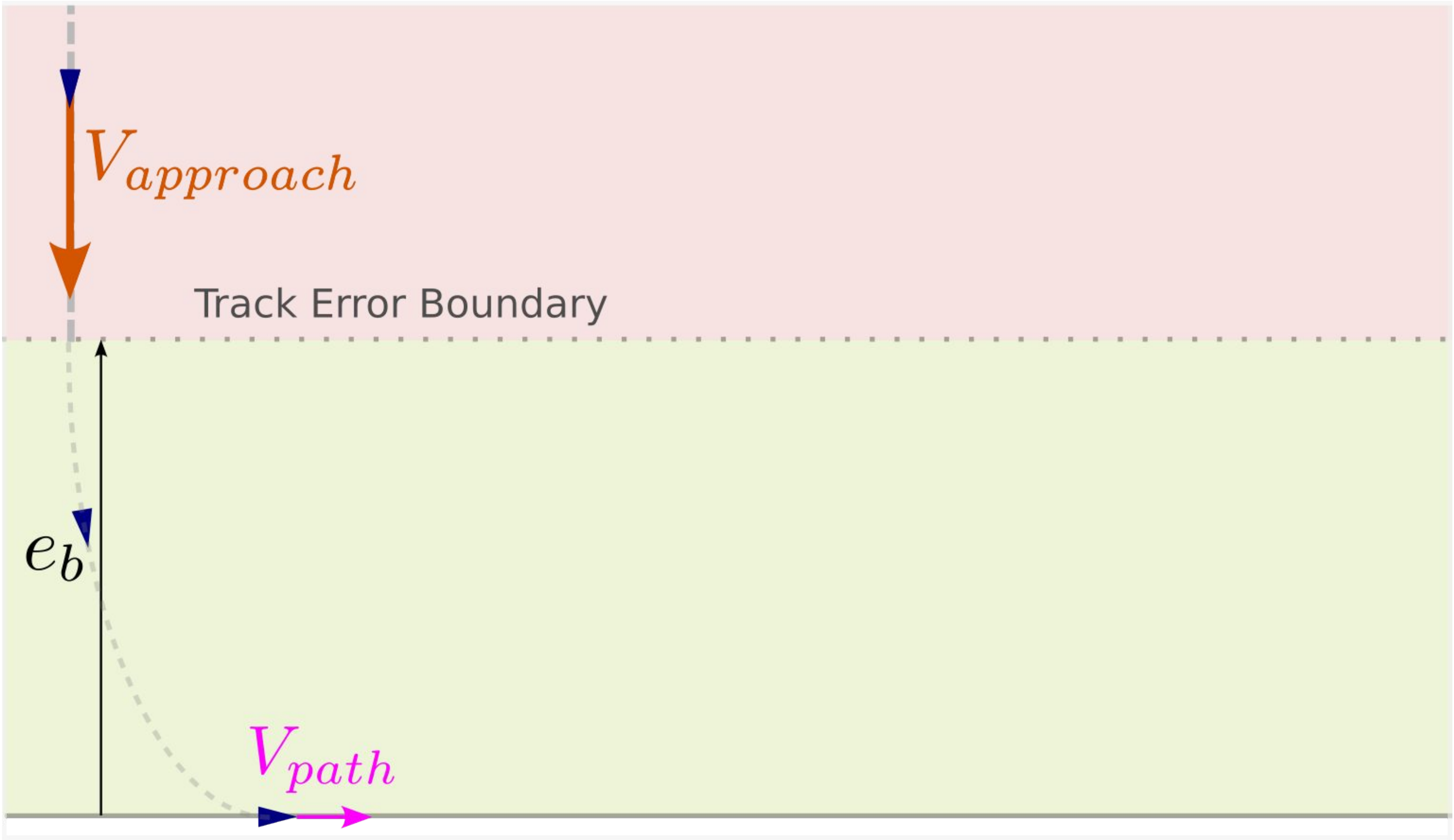


Proposed Method

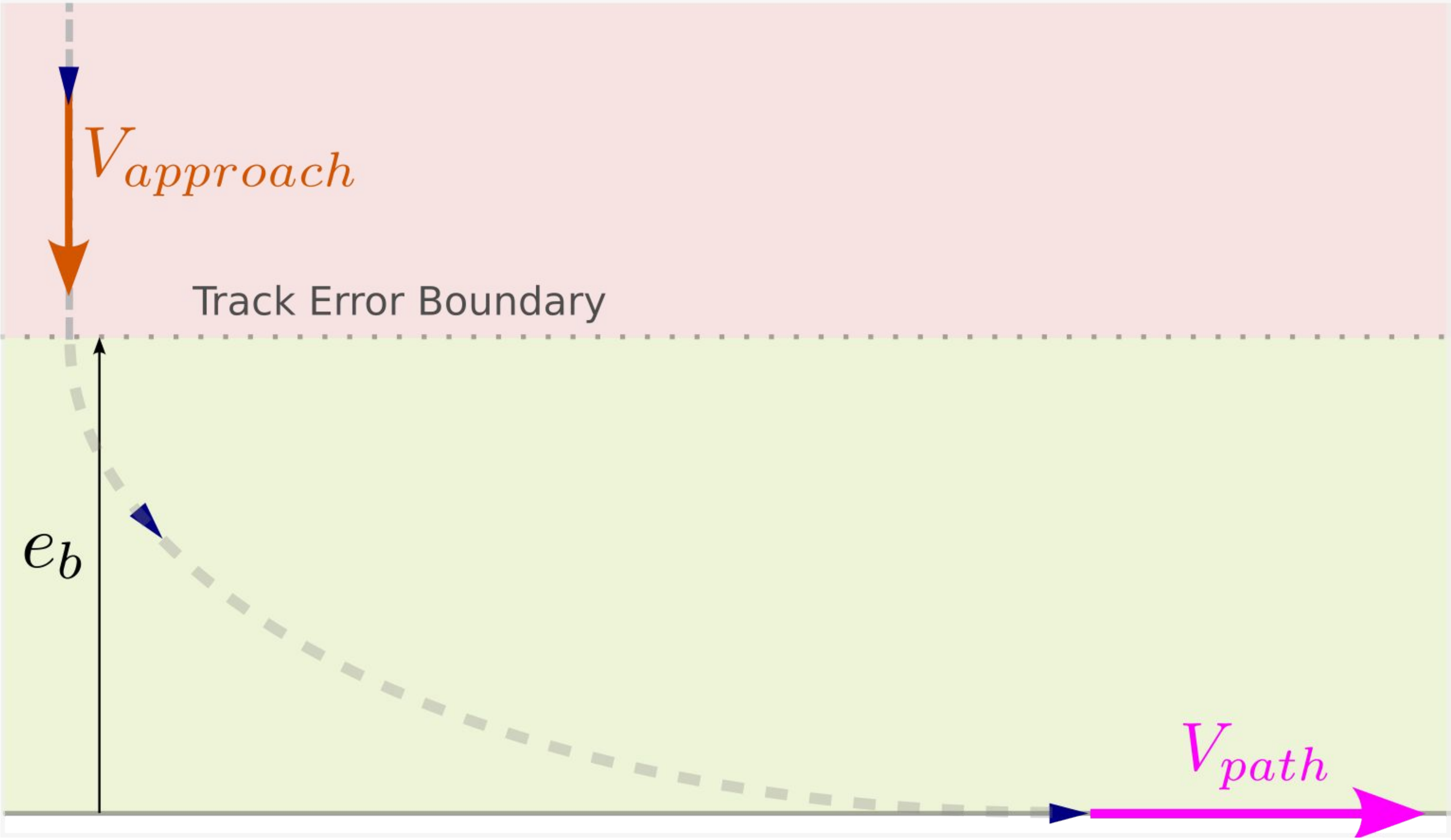
Hybrid Unicyclic Method



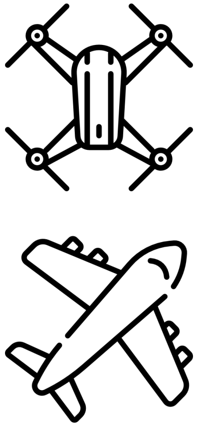
Proposed Method: Low speed on Path (Aggressive turning)

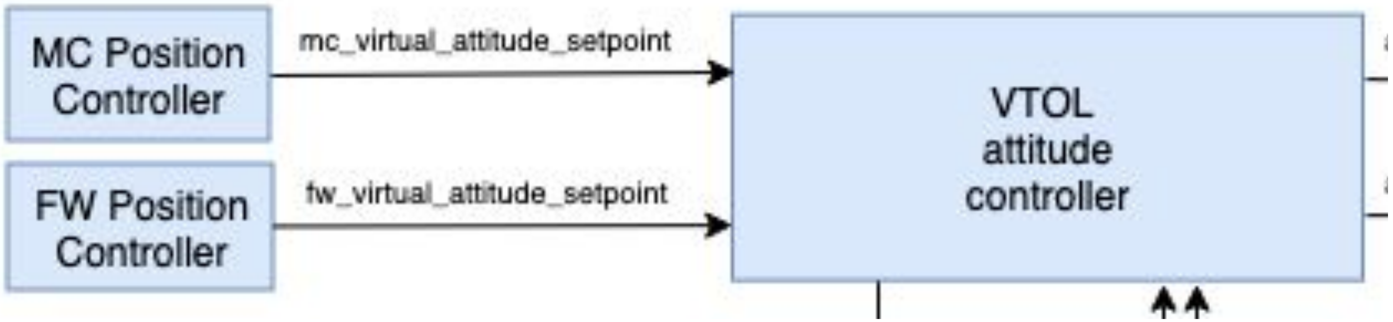


Proposed Method: High speed on Path (Smoother turning)



Path Following for VTOL: Current Status





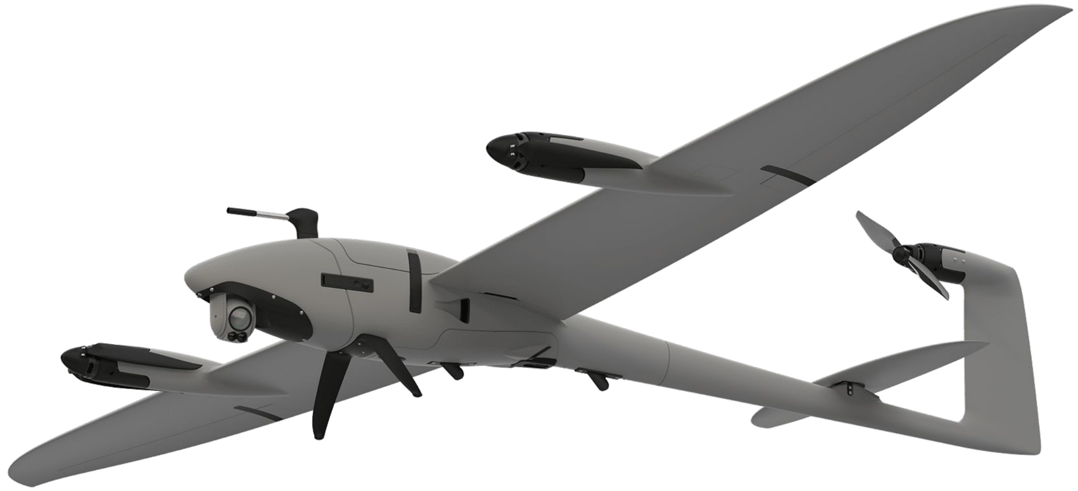
Decoupled between MC / FW

https://docs.px4.io/main/en/flight_stack/controller_diagrams.html

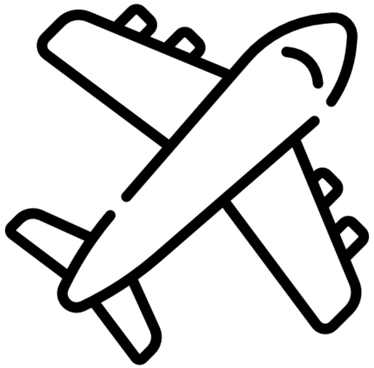
What is Path Following?

What is a Hybrid VTOL?

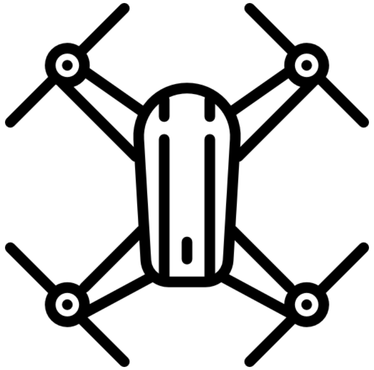
Modes of operation of Hybrid VTOL



Modes of operation of Hybrid VTOL

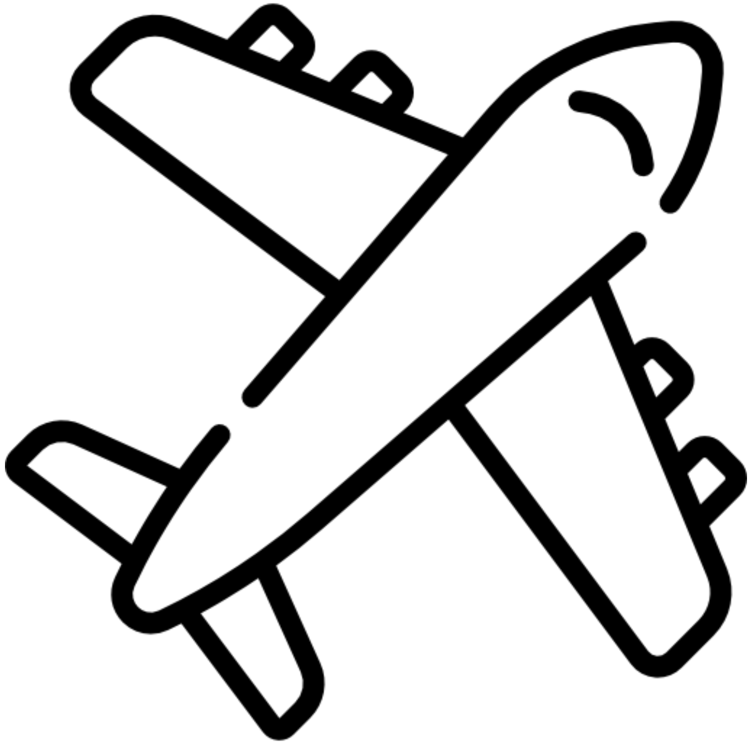


Fixed Wing



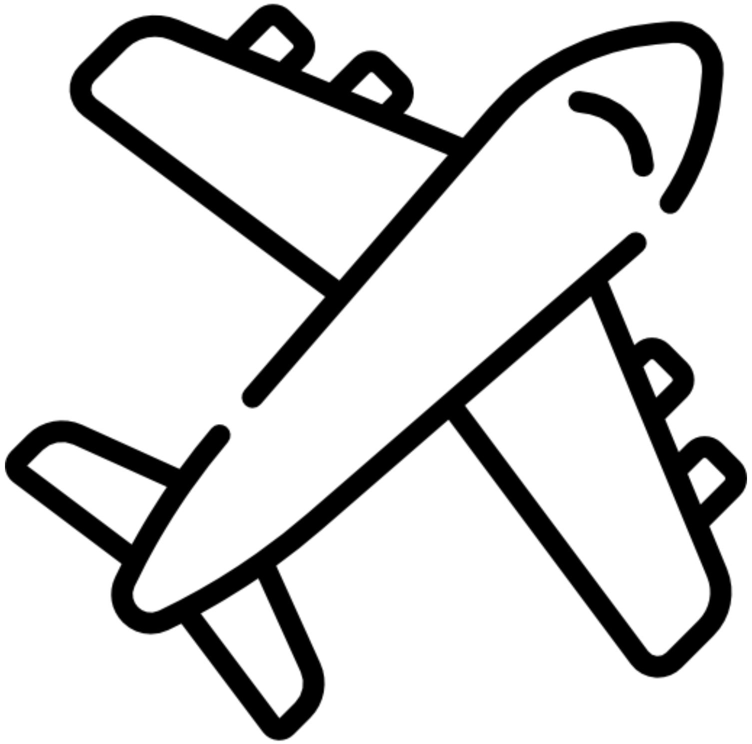
Multirotor

Modes of operation of Hybrid VTOL



Fixed Wing

Modes of operation of Hybrid VTOL



Fixed Wing

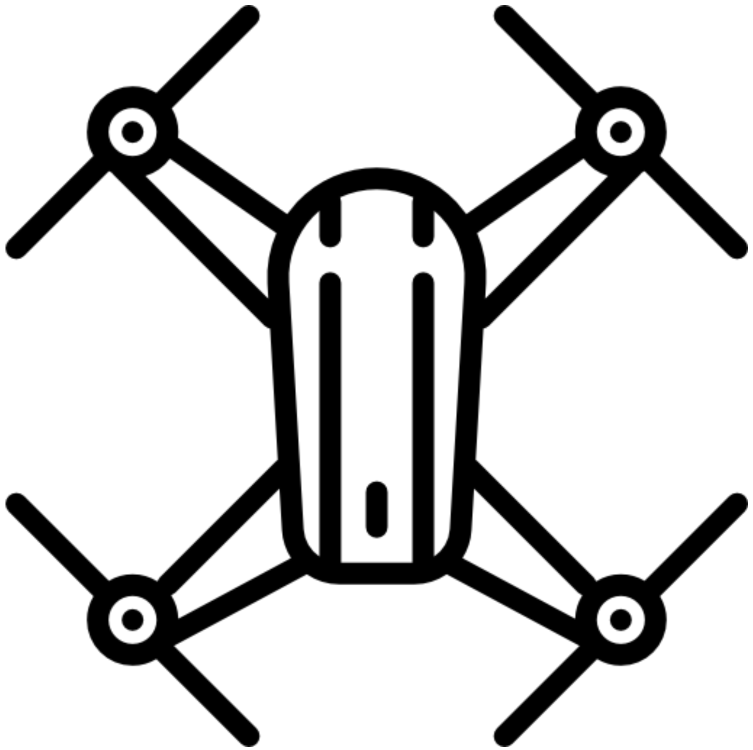
Acceleration

- **Lateral** (Rolling): **Coupled** with **yaw**
- **Longitudinal**: (almost) **None**
- Vertical (Pitching): Flexible

Velocity

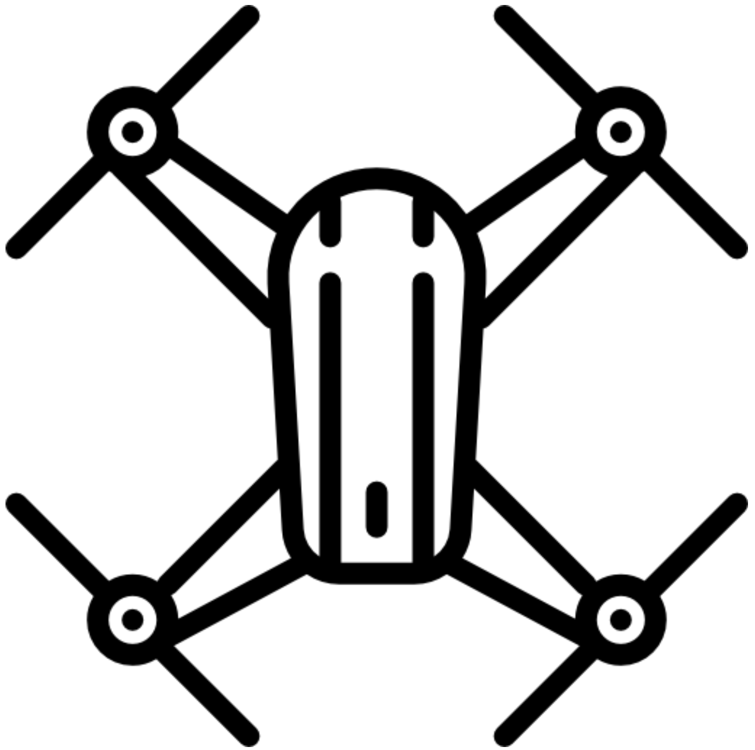
- **Airspeed**: (almost) **Constant**

Modes of operation of Hybrid VTOL



Multirotor

Modes of operation of Hybrid VTOL



Multirotor

Acceleration

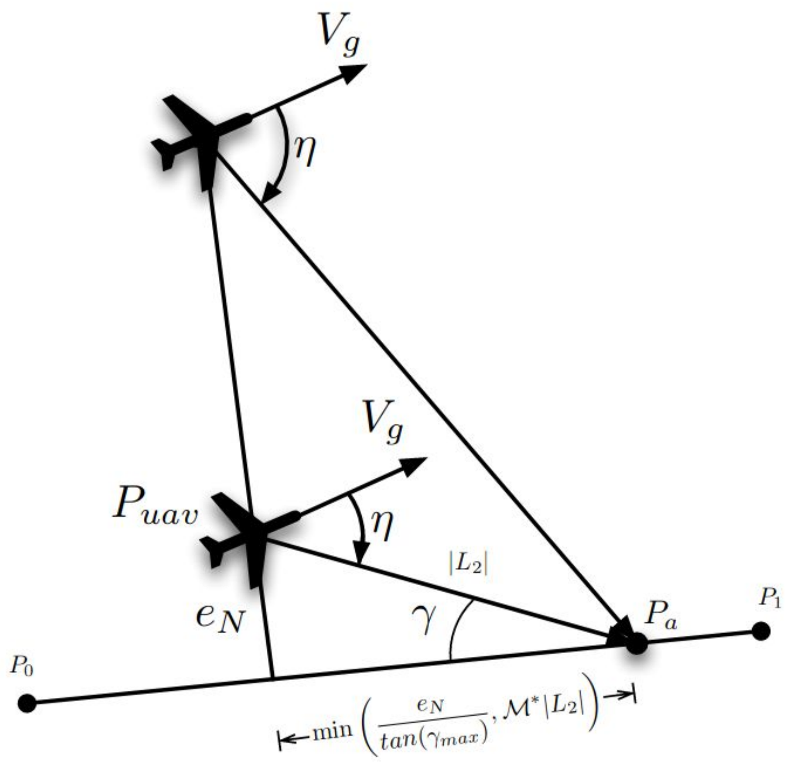
- **Lateral** (Rolling): **Full range**
- **Longitudinal** (Pitching): **Full range**
- **Vertical** (Throttle): (almost) Full range

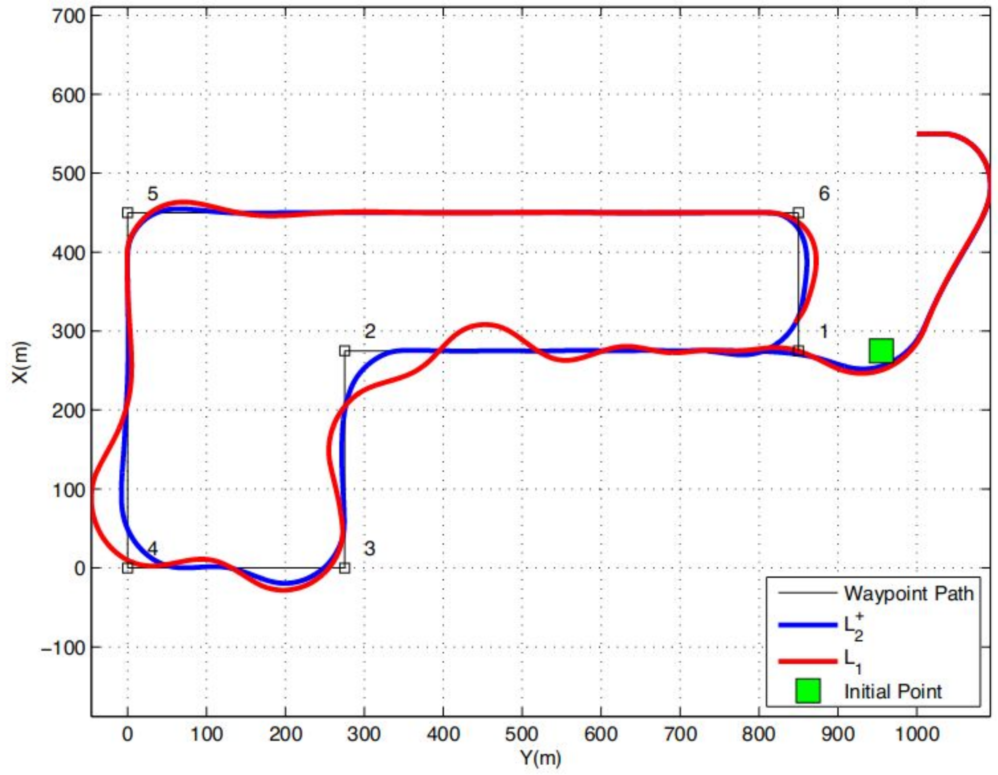
Velocity

- **Airspeed**: **Full range**

Related Work: Path Following on Fixed Wing

- Nonlinear Control [Stastny, IROS, 2019]
- **Line of Sight Control** [Curry, ACC, 2013]

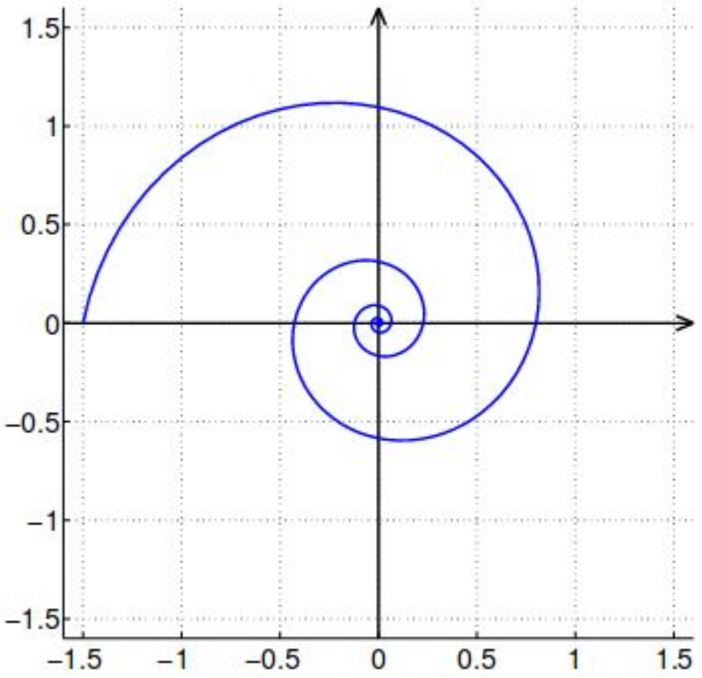


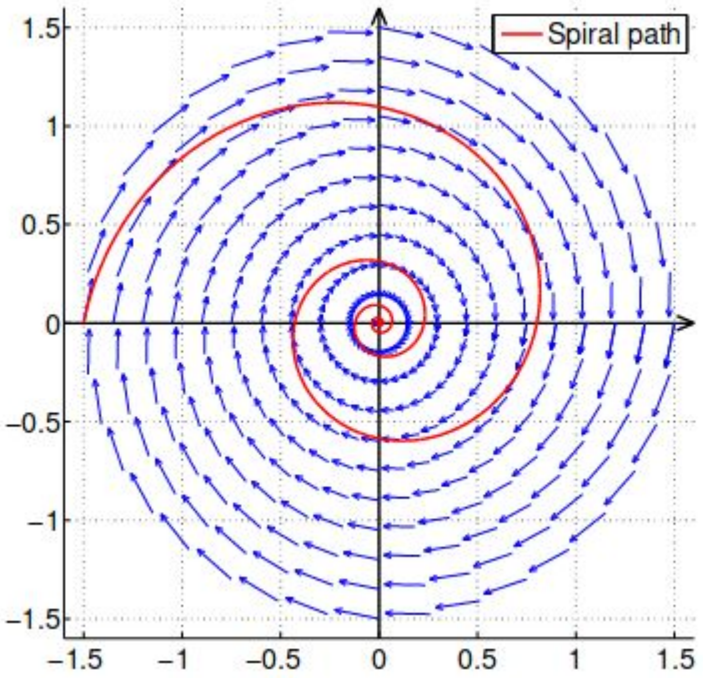


T. Stastny. "On Flying Backwards: Preventing Runaway of Small, Low-speed, Fixed-wing UAVs in Strong Winds". IROS, 2019
R. Curry. "L+2, an improved line of sight guidance law for UAVs". *American Control Conference*, 2013

Related Work: Path Following on Multirotor

- **Virtual Target Pursuit** [Manjunath, 2016]
- **Vector Field** [Zhou, 2014]

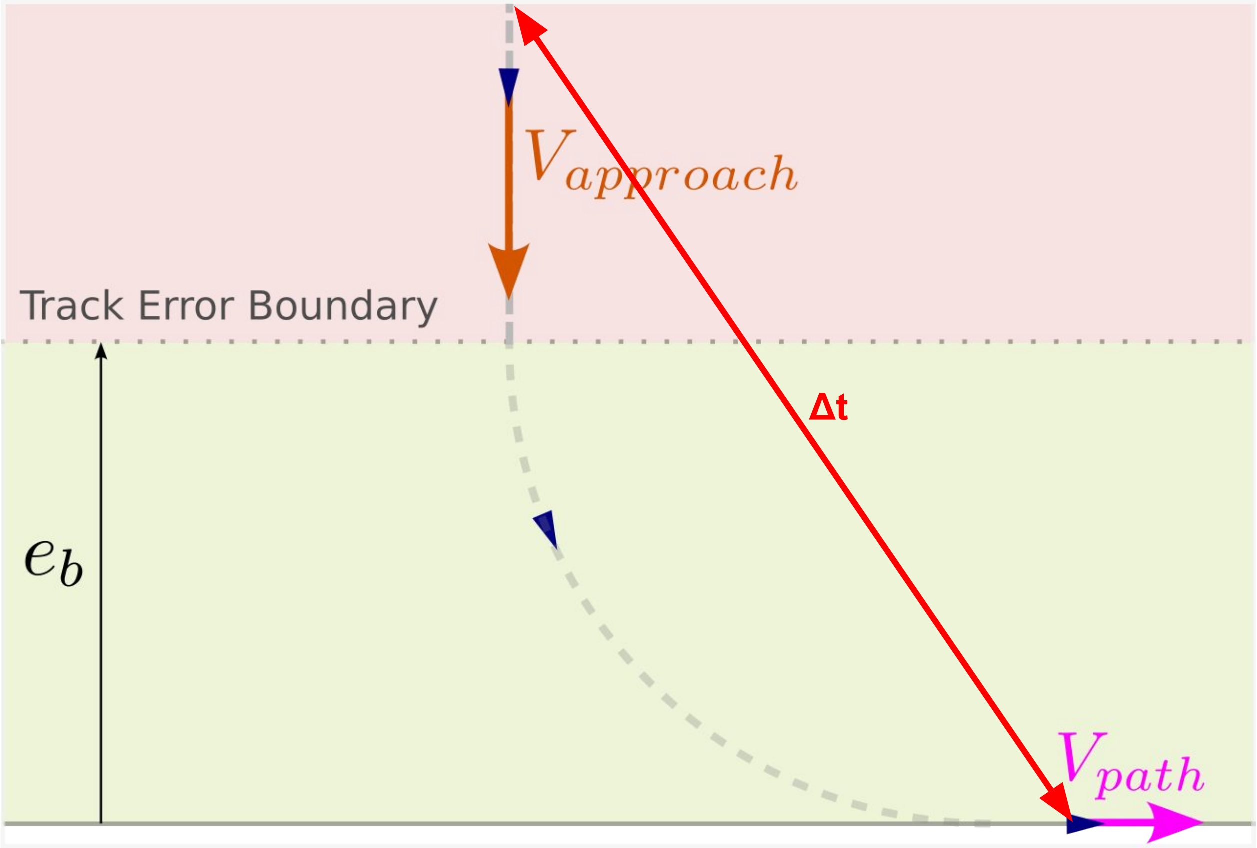




Manjunath, A. R.. “Path following by a quadrotor using virtual target pursuit guidance.” (2016).
D. Zhou, "Vector field following for quadrotors using differential flatness," ICRA (2014)

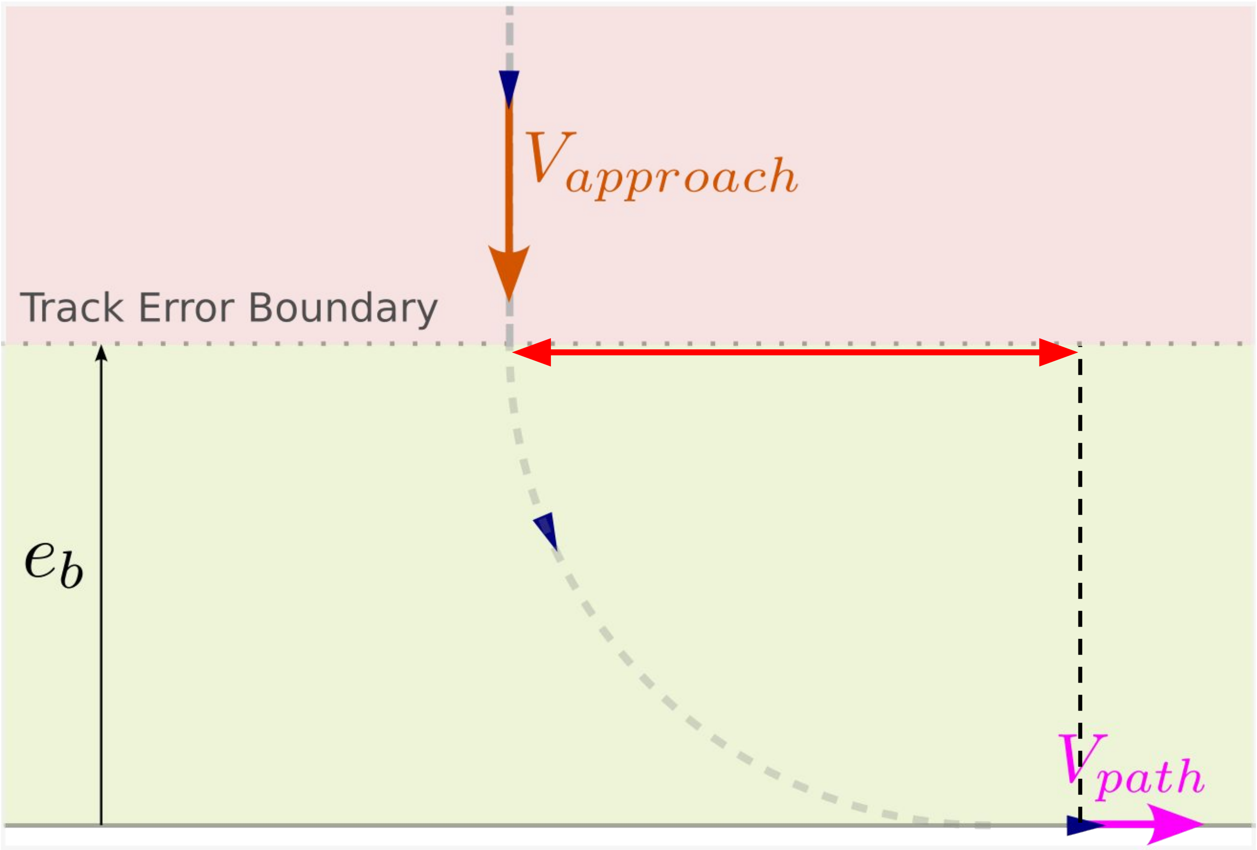
Evaluation Criteria

- **Time to Convergence**



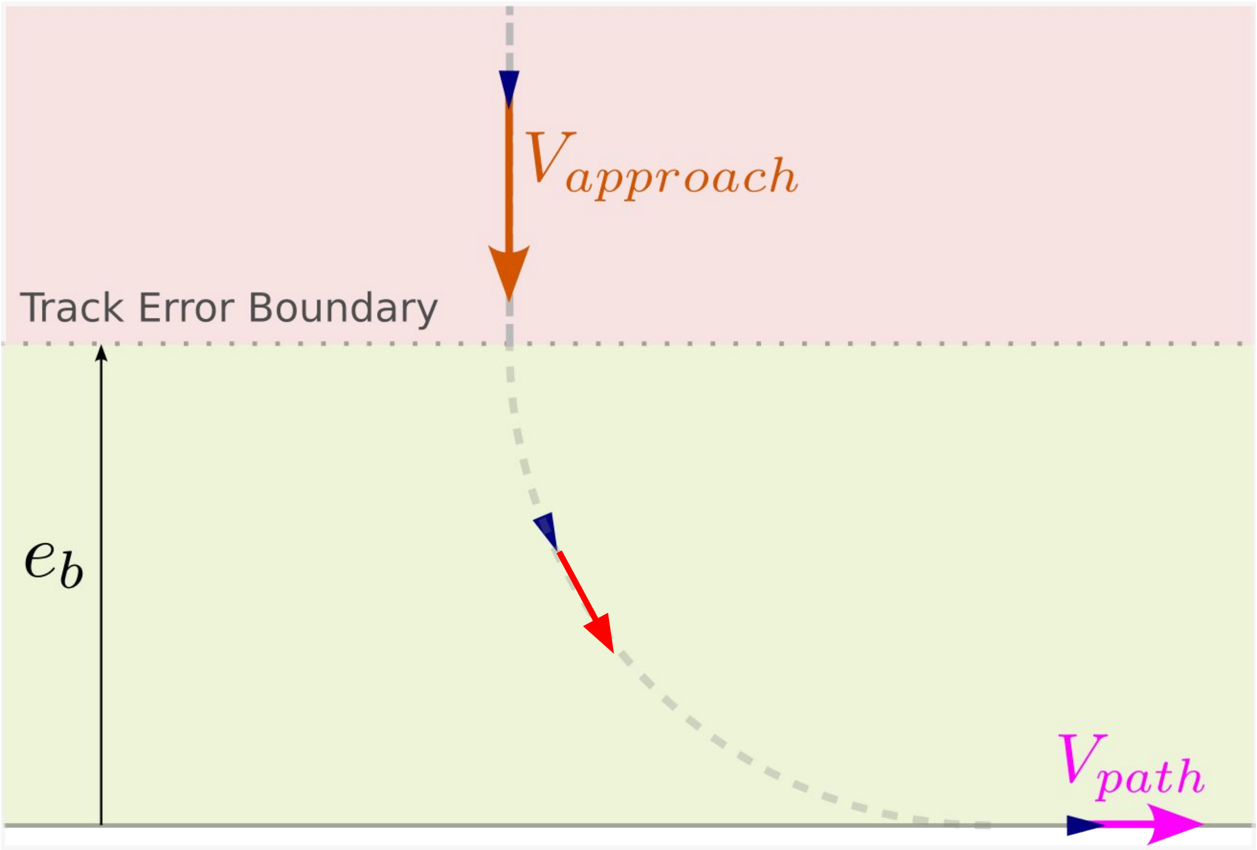
Evaluation Criteria

- **Time to Convergence**
- **Converging Path Parallel Distance**



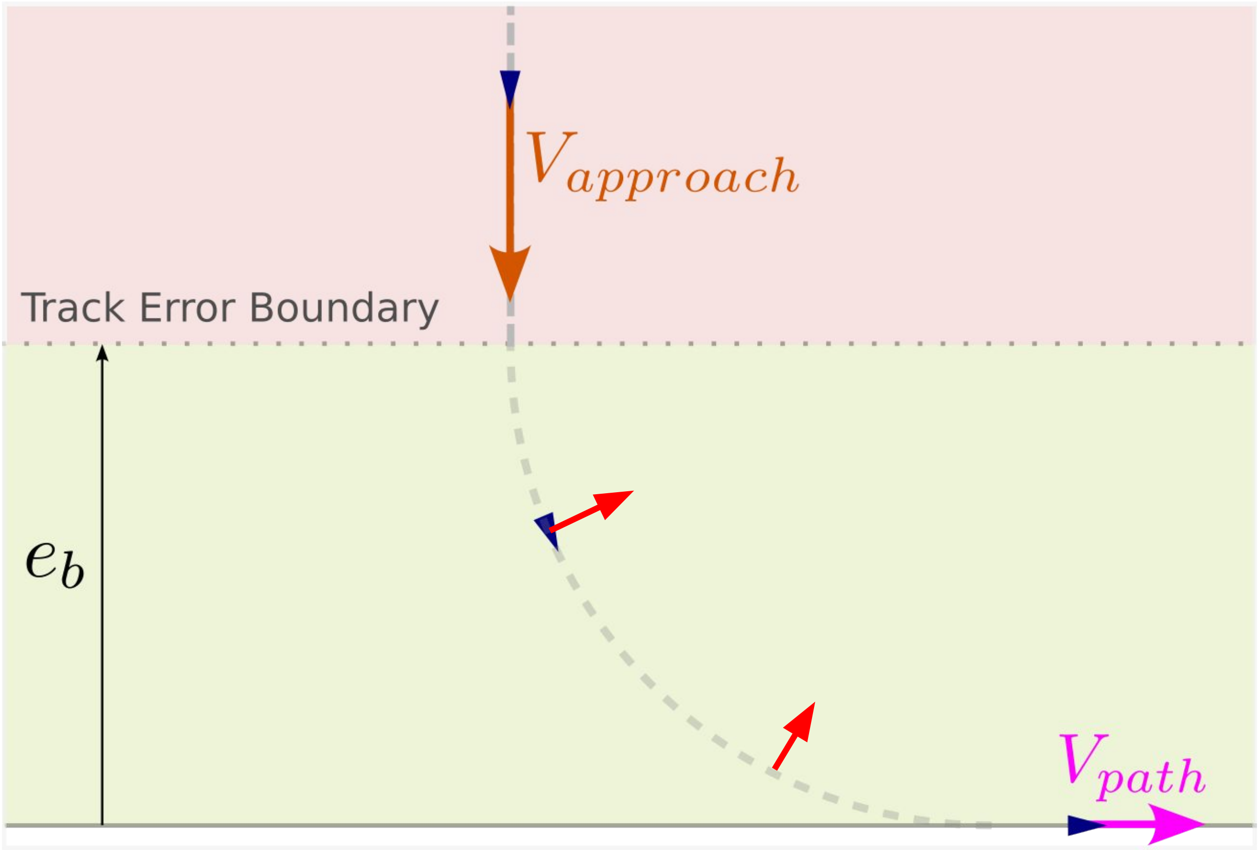
Evaluation Criteria

- Time to Convergence
- Converging Path Parallel Distance
- Monotonicity of Ground Speed

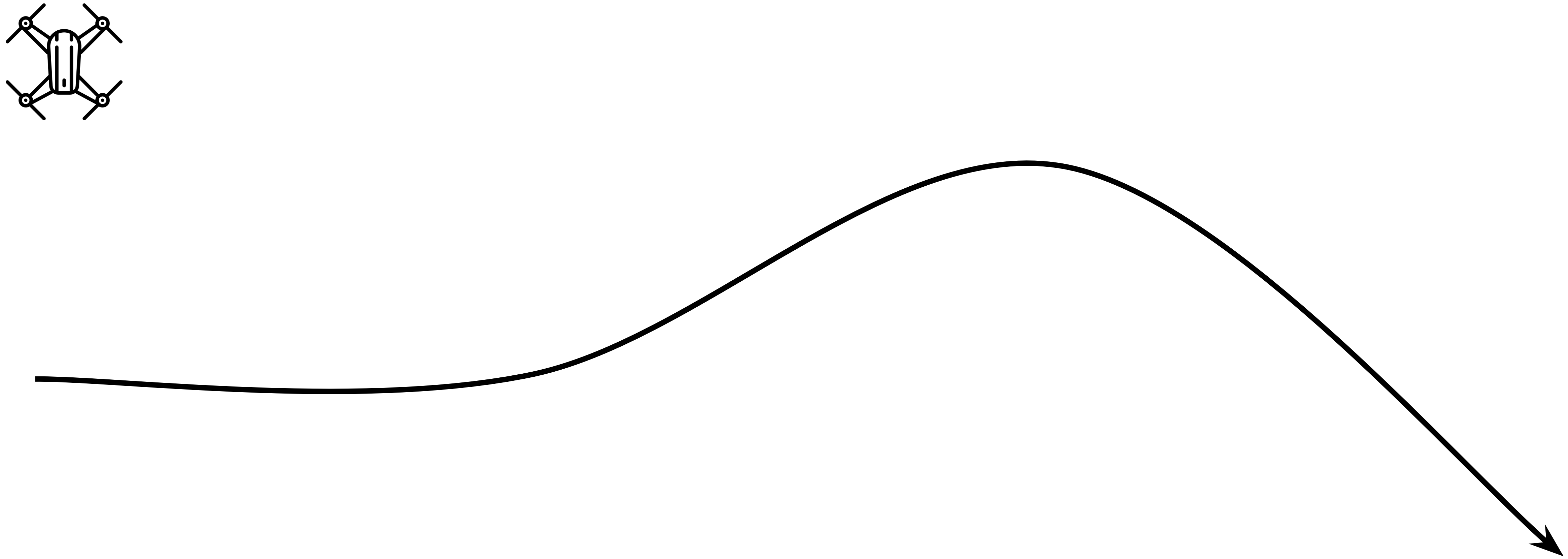


Evaluation Criteria

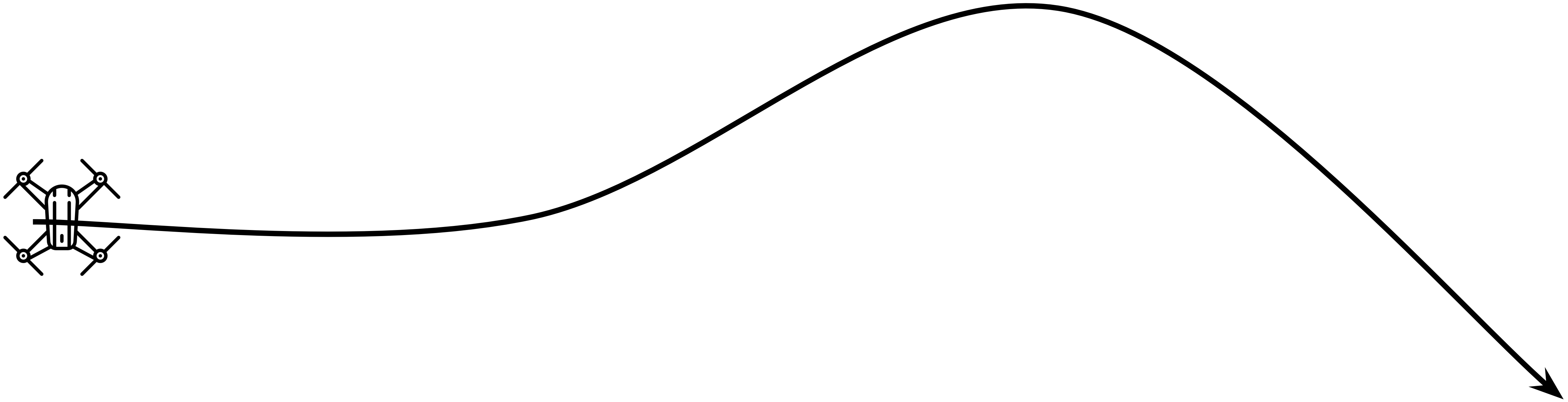
- Time to Convergence
- Converging Path Parallel Travel
- Monotonicity of Ground Speed
- Total Acceleration RMS



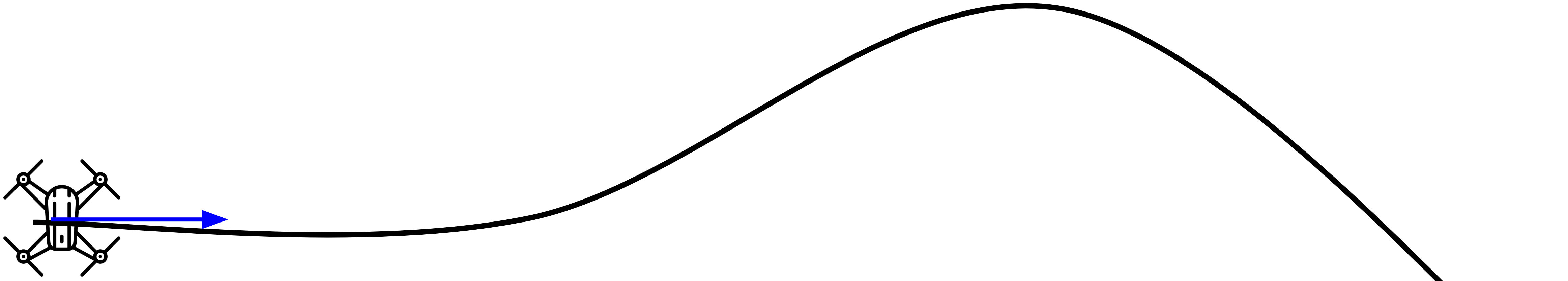
What is Path Following?



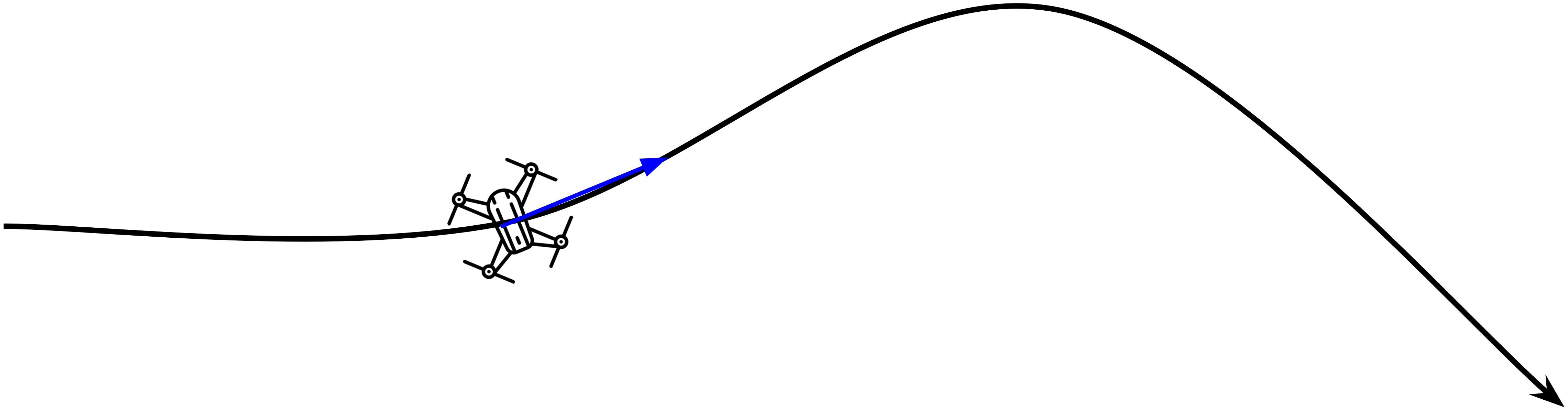
What is Path Following?



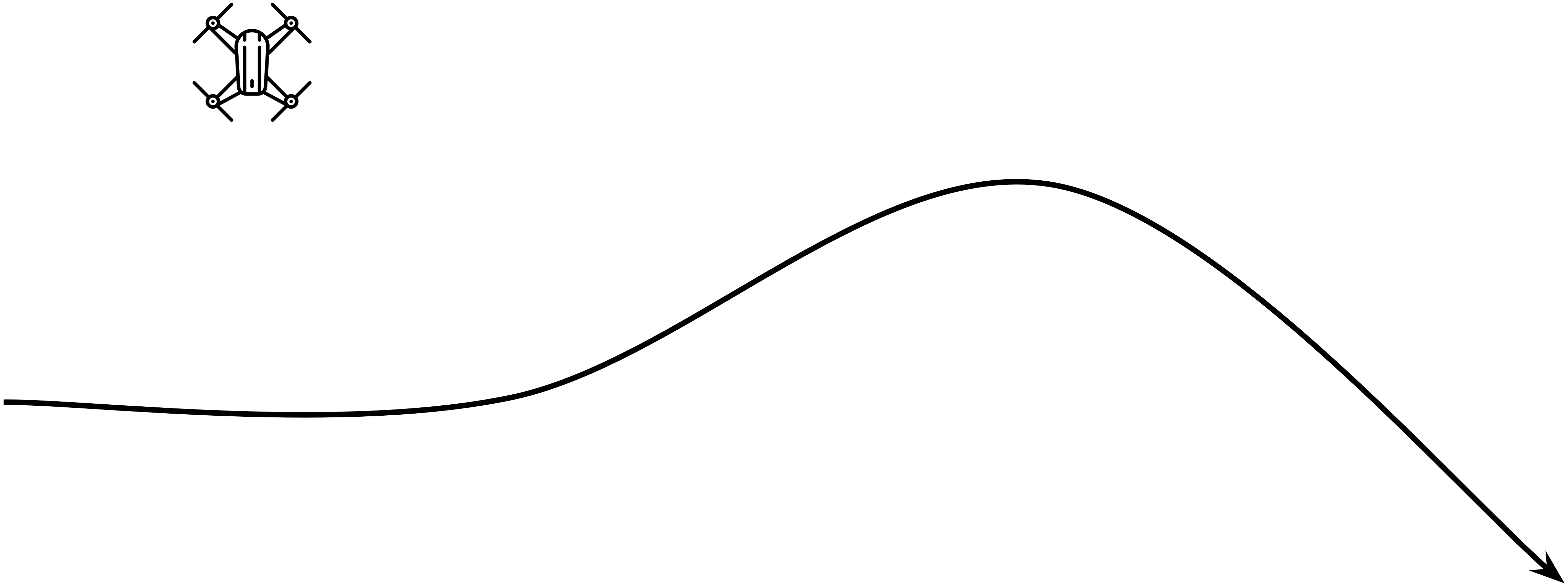
What is Path Following?



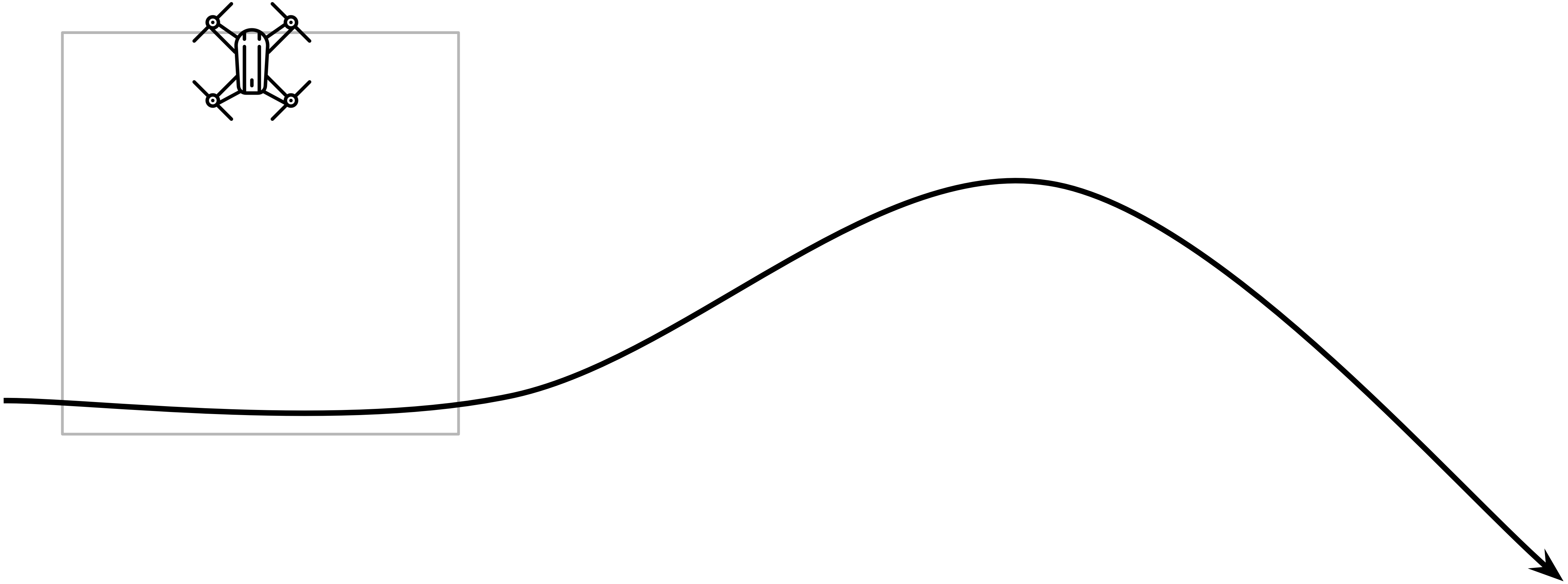
What is Path Following?



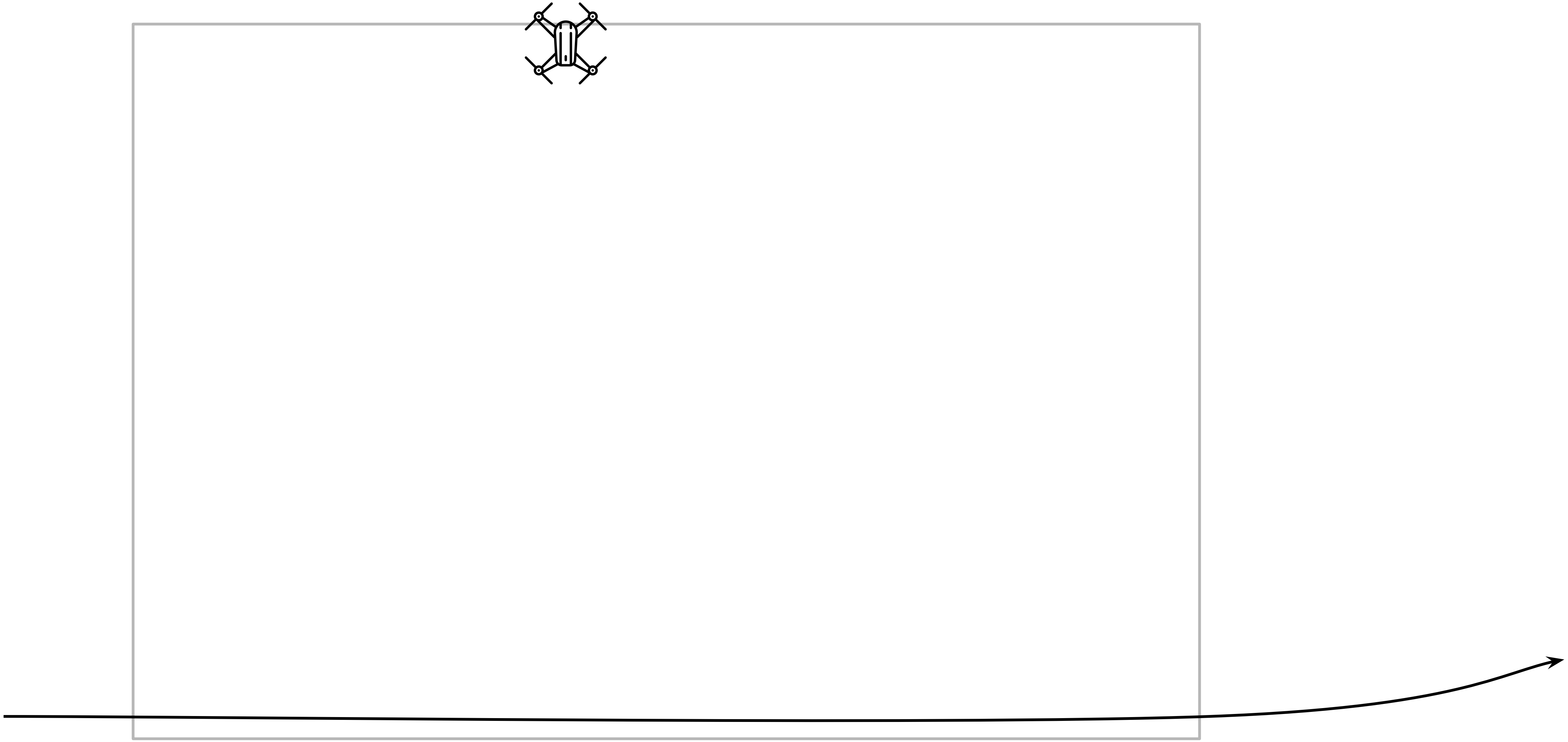
Problem Definition: Revisited



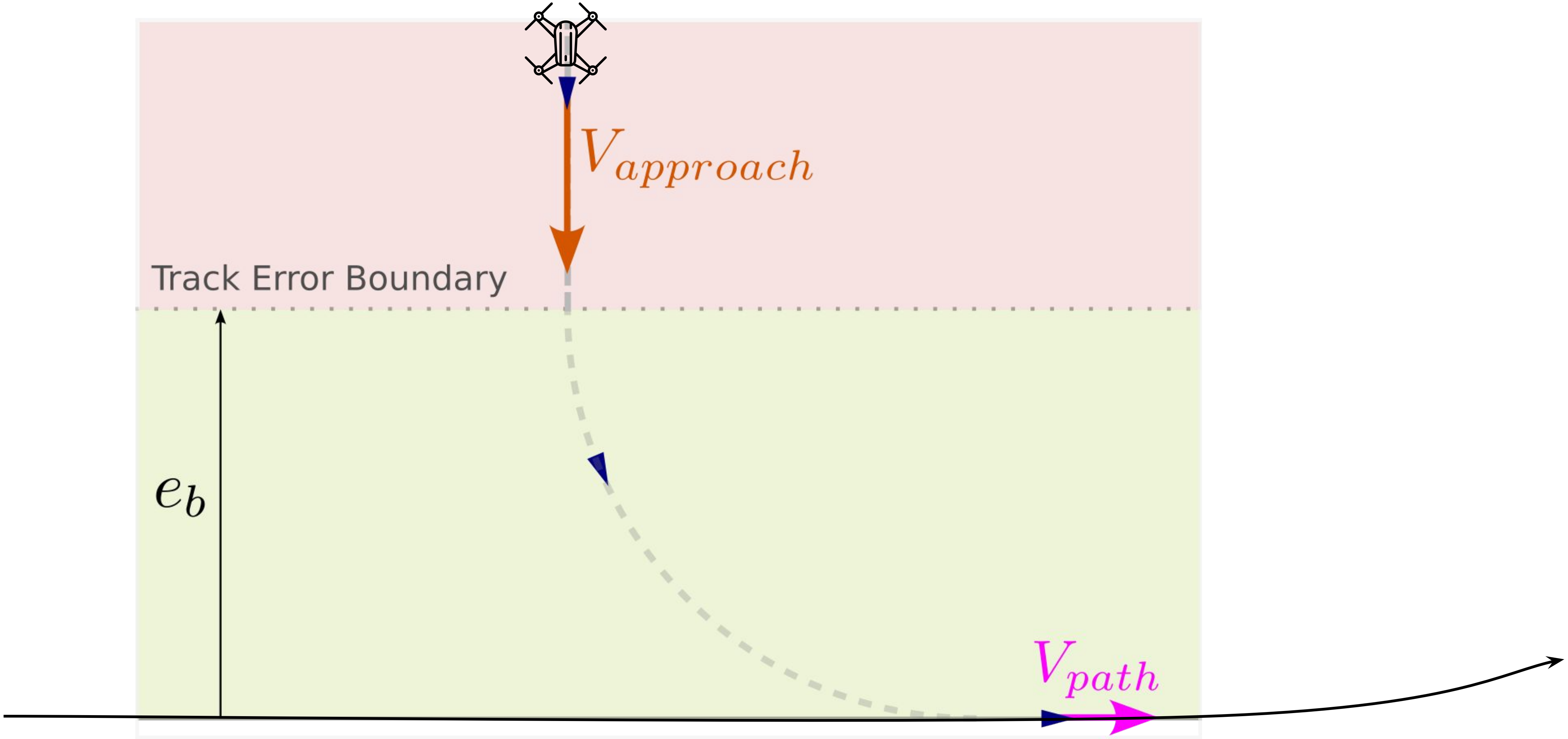
Problem Definition: Revisited



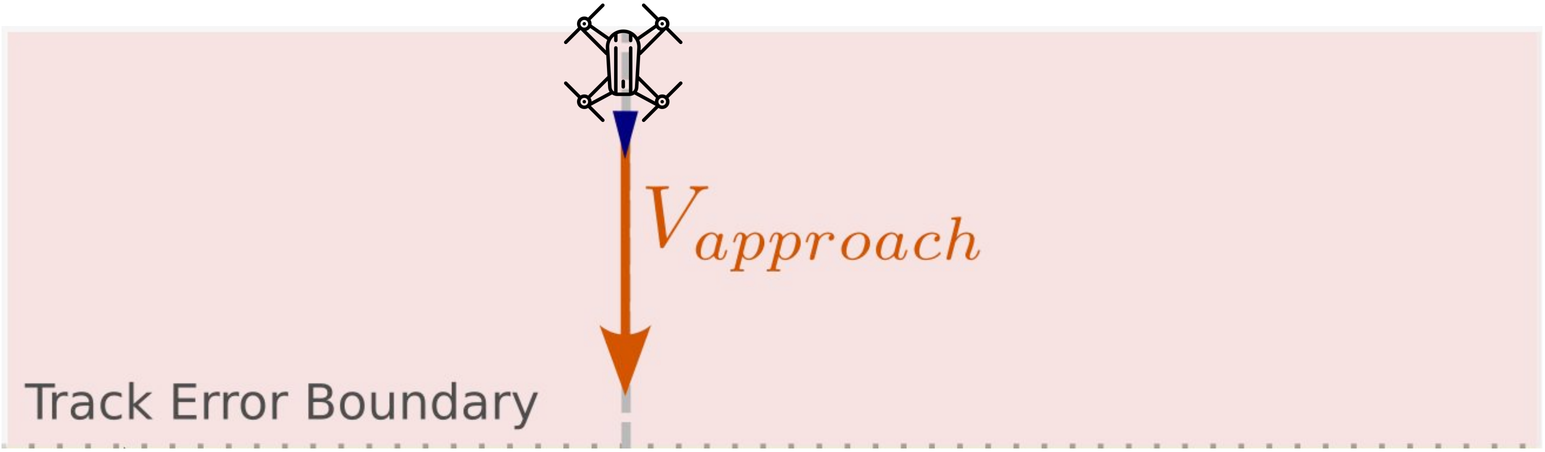
Problem Definition: Revisited



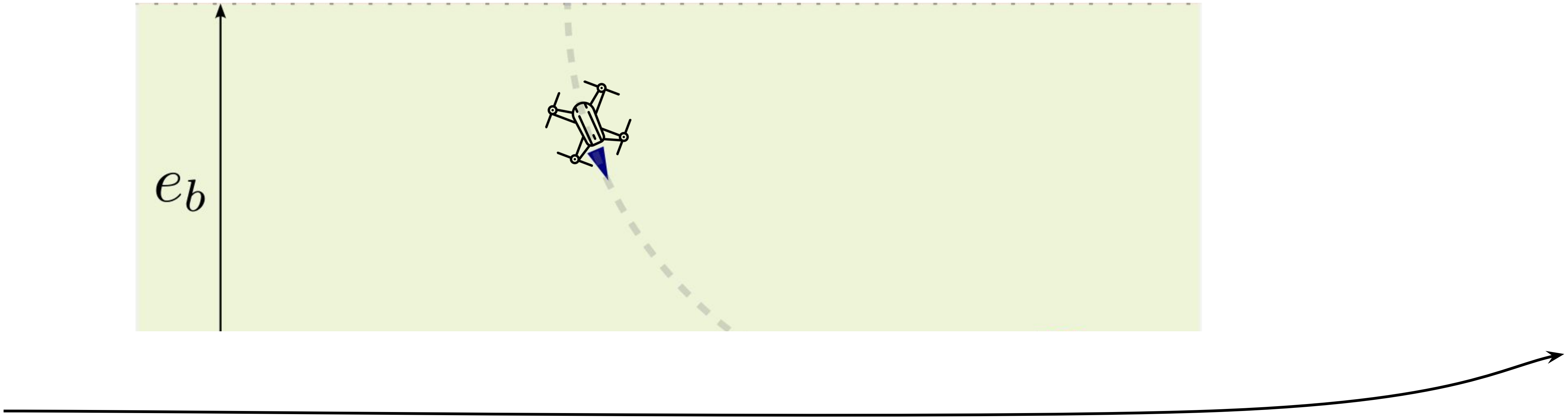
Problem Definition: 3 Phase breakdown



Problem Definition: Approach phase

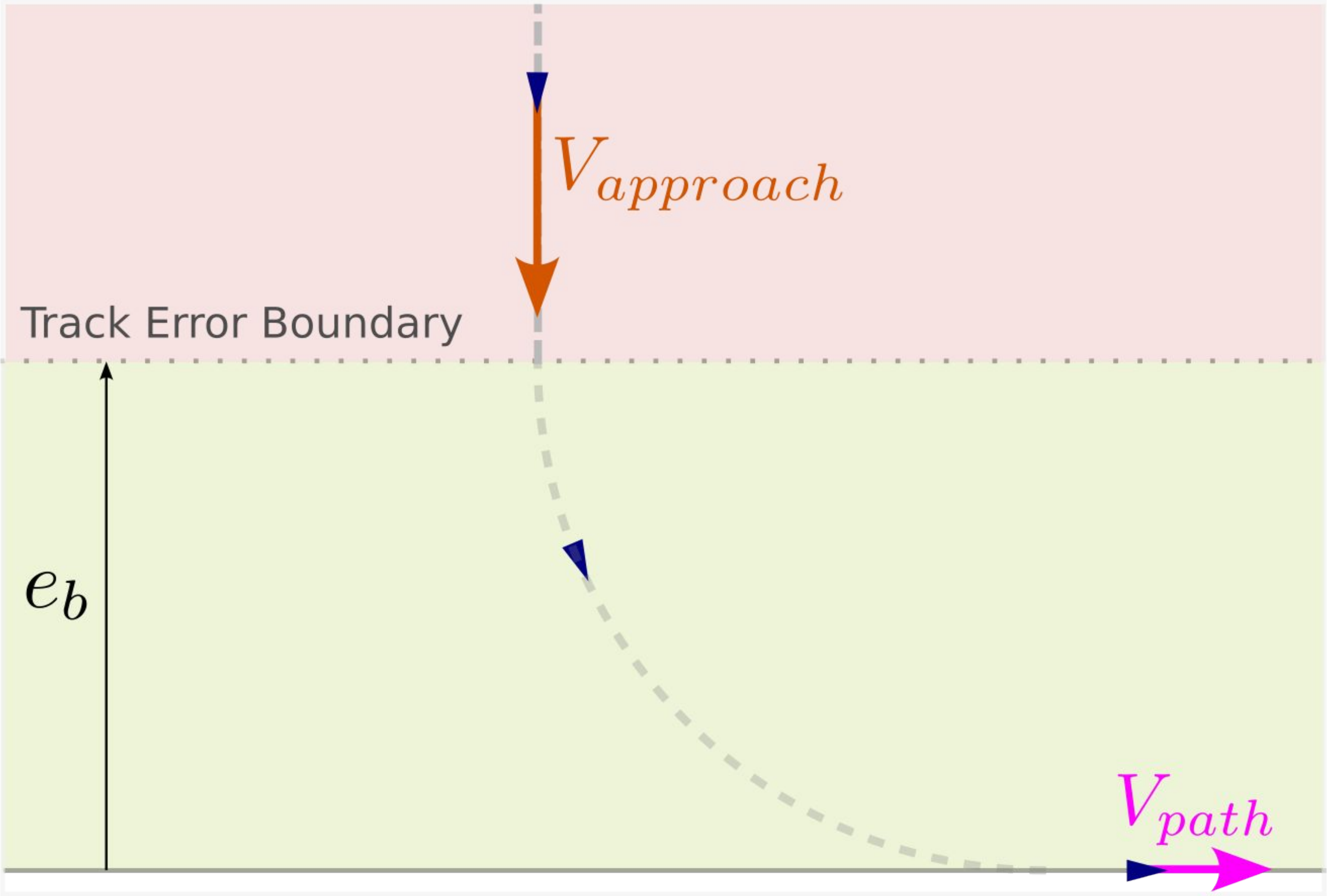


Problem Definition: Turning phase



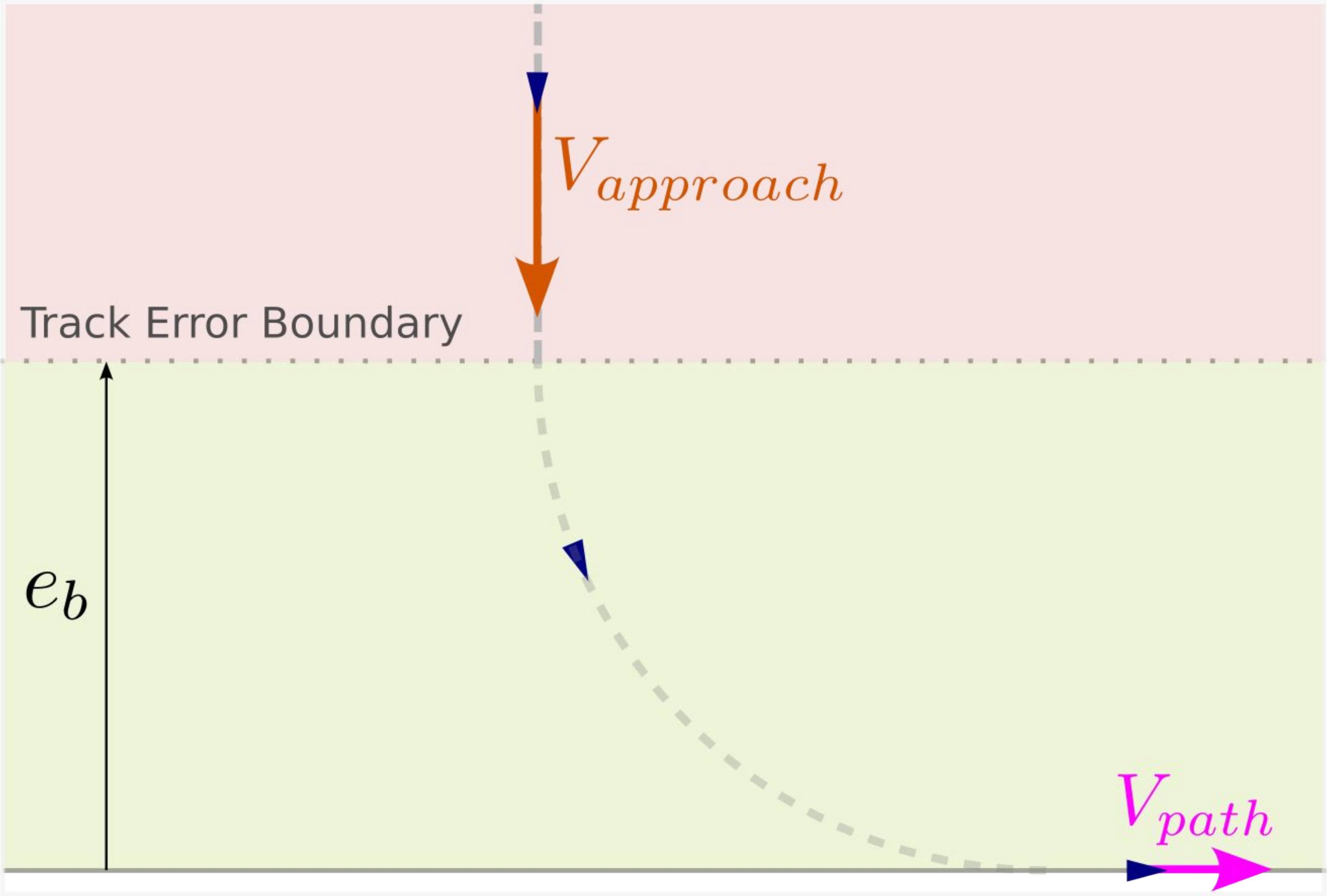
Problem Definition: On path phase

Problem Definition: Re-defined



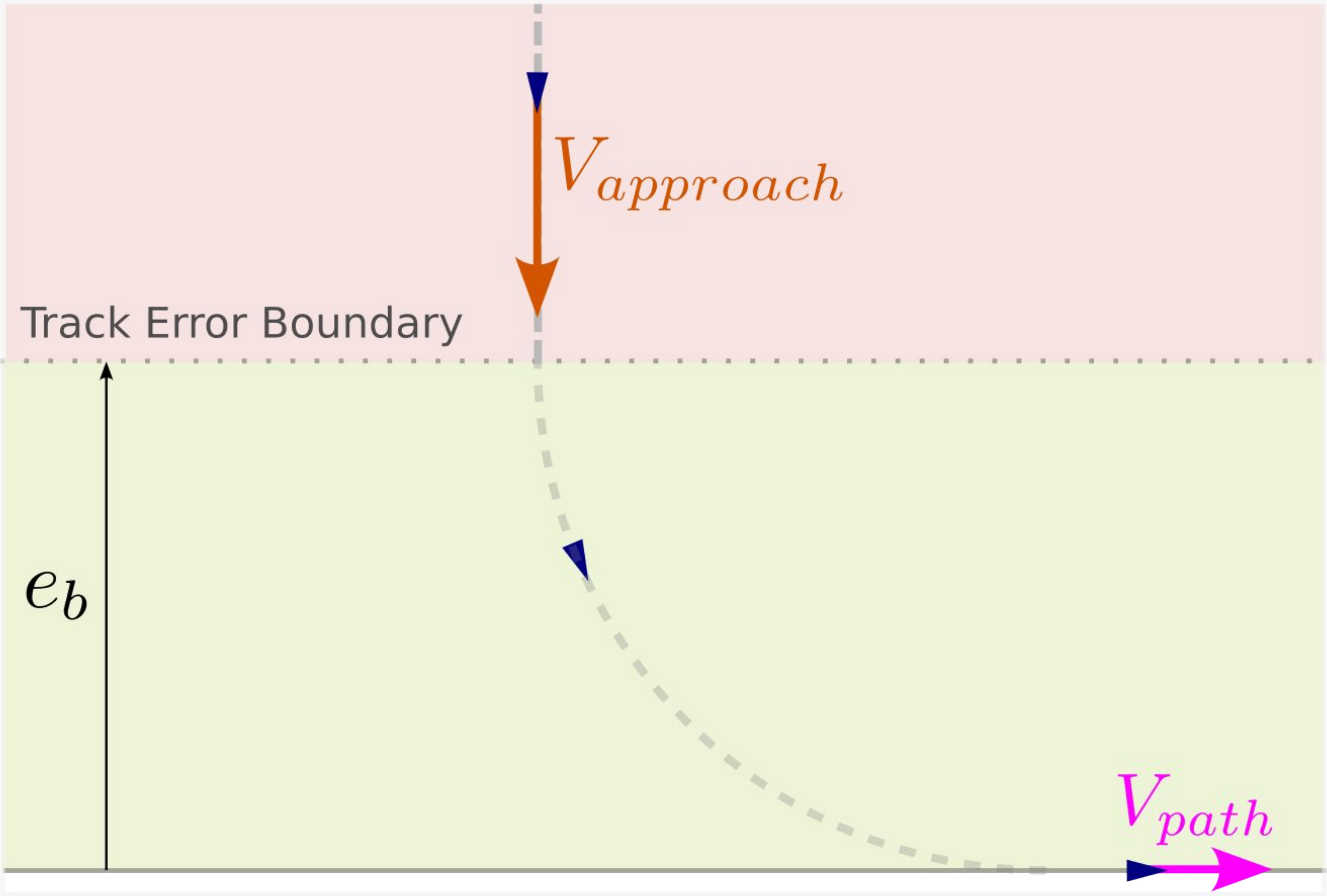
- **3 Phase sequence** (Velocity profile, Track error boundary)

Problem Definition: Re-defined



- **3 Phase sequence** (Velocity profile, Track error boundary)
- **Acceleration commands** to guide the vehicle

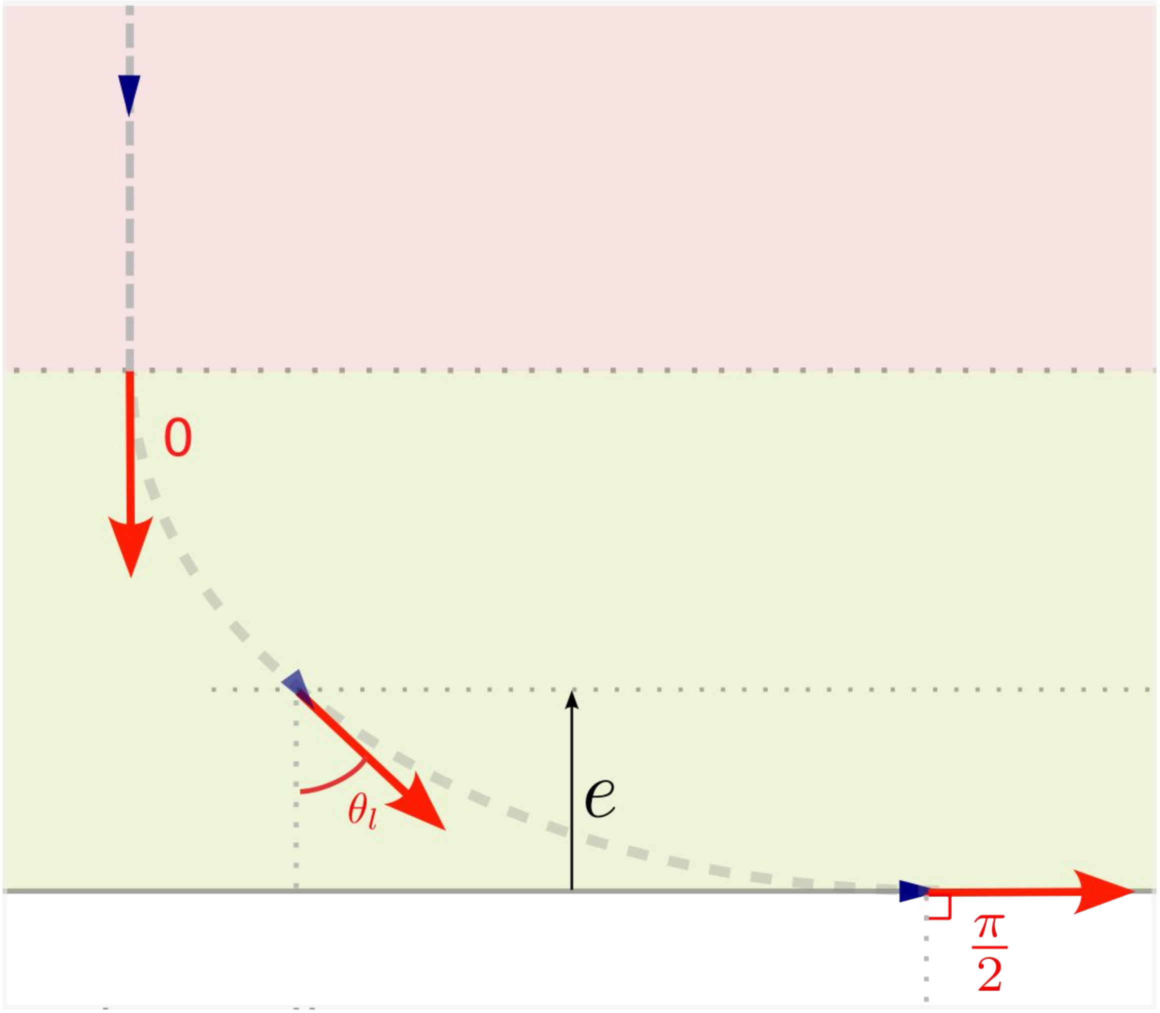
Problem Definition: Re-defined



- **3 Phase sequence** (Velocity profile, Track error boundary)
- **Acceleration commands** to guide the vehicle
- While respecting vehicle's **maneuverability**

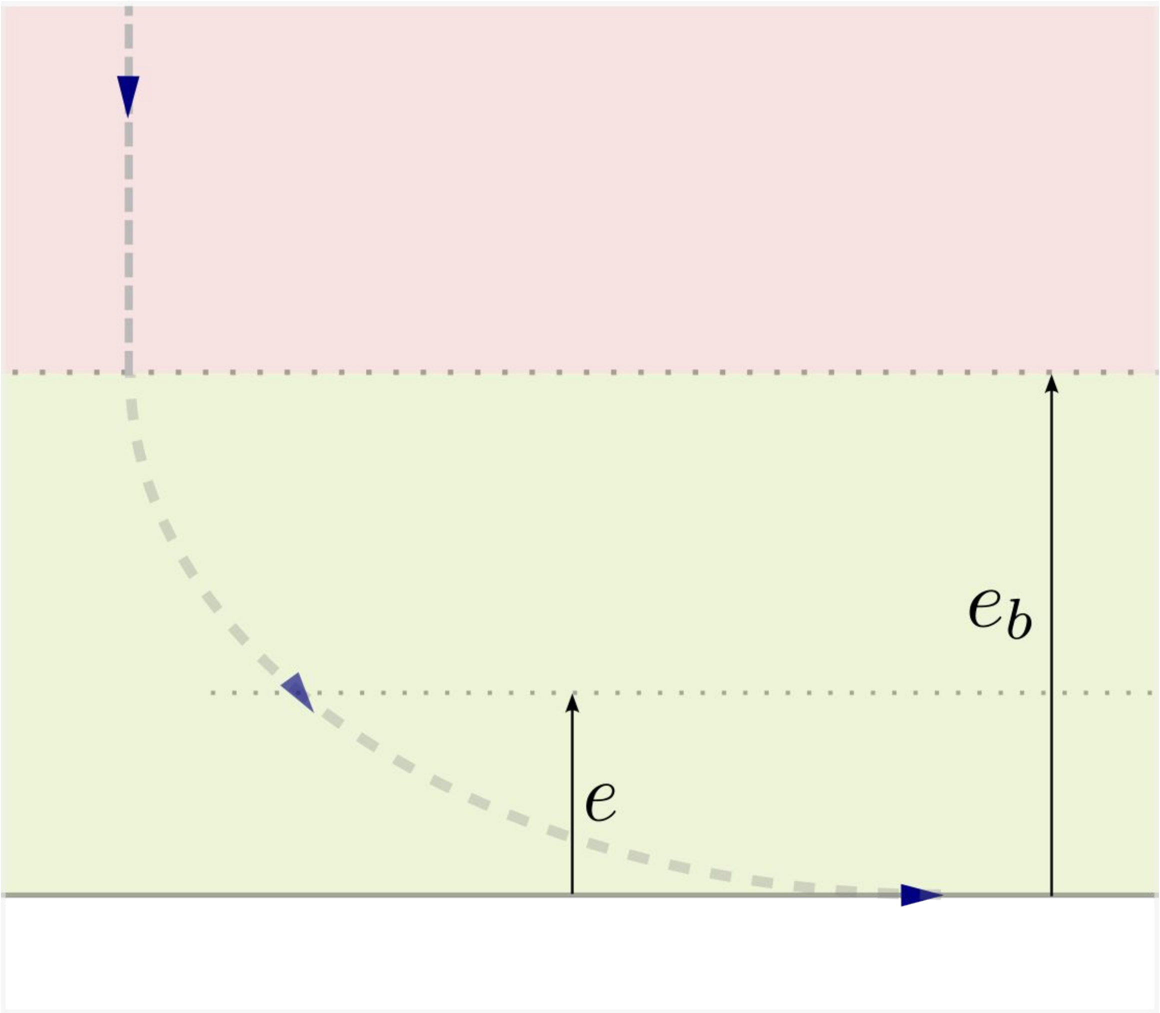
Problem Definition: Defining the Ground Velocity Curve

- **Look-ahead angle**



Problem Definition: Defining the Ground Velocity Curve

- Look-ahead angle
- Path parallel / orthogonal velocity
- Track error boundary



Evaluation

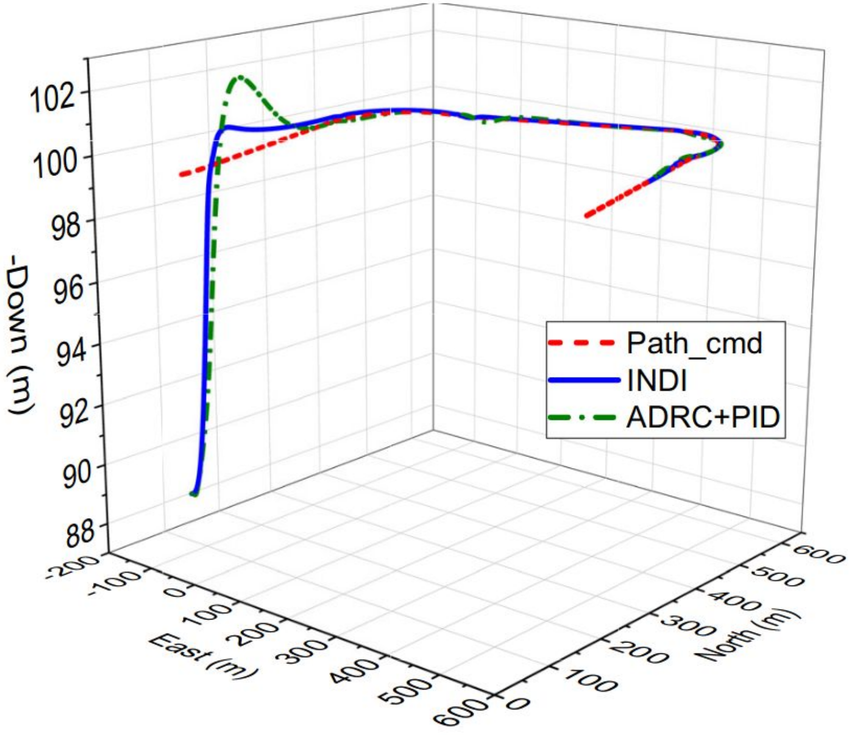
Conditions

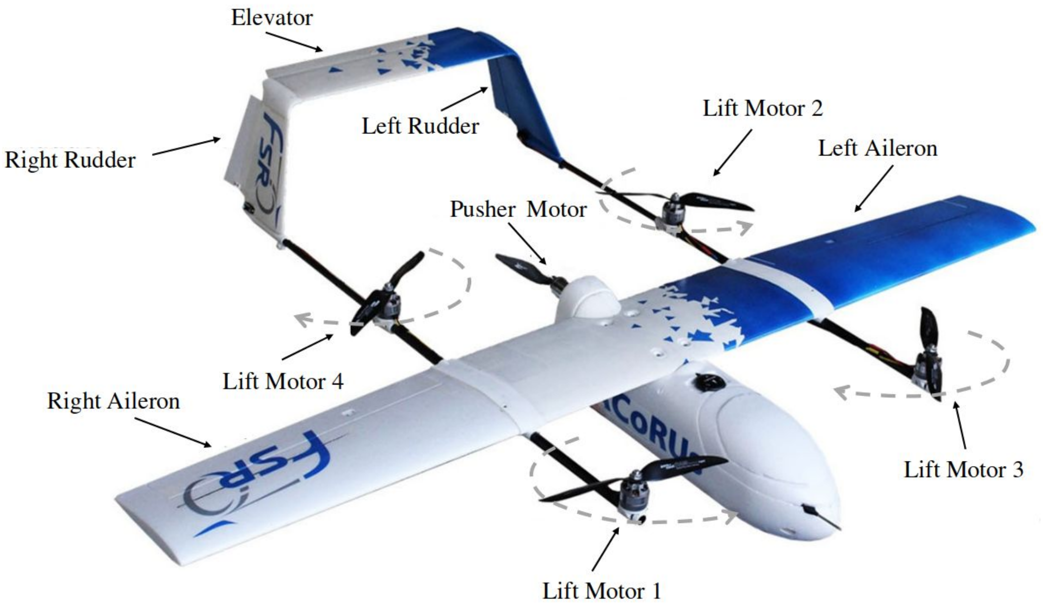
- Track error boundary: 70 m
- Approach speed: 10 m/s
- Speed on path: 15 m/s

Criteria	Unicyclic	Hybrid Unicyclic
Time to Converge	12.5 seconds	21.2 seconds
Converging path parallel travel	82 m	82 m
Ground speed monotonicity	True	True

Related Work: Path Following on Hybrid VTOL

- **INDI based Vector Field Path Following** [Zhou, 2022]





Li, Zhou. "Incremental nonlinear dynamic inversion based path-following control for a hybrid quad-plane unmanned aerial vehicle" (2022)

References

1. https://www.pix4d.com/blog/modelling-matterhorn/
2. https://tenor.com/view/who-cares-meme-gif-24186451
3.