Unified Path Following Guidance for VTOL Vehicles

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Intermediate Presentation

Supervisors
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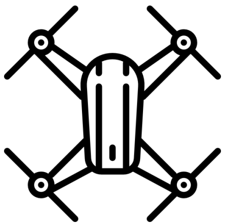
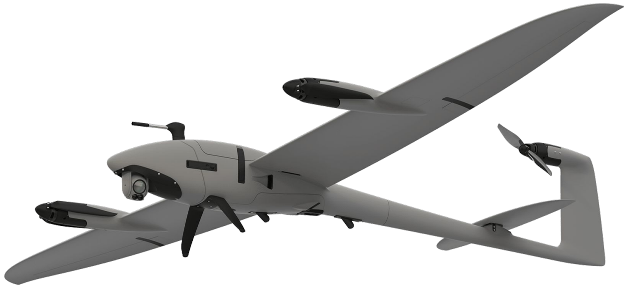
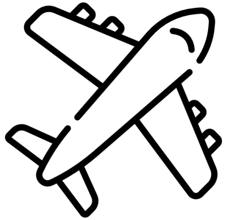
Autonomous Systems Lab
LEE J 205
12:20 pm

GOAL

- Unified Path Following Algorithm for both Multicopter & Fixed-Wing
- Wind-robust guidance



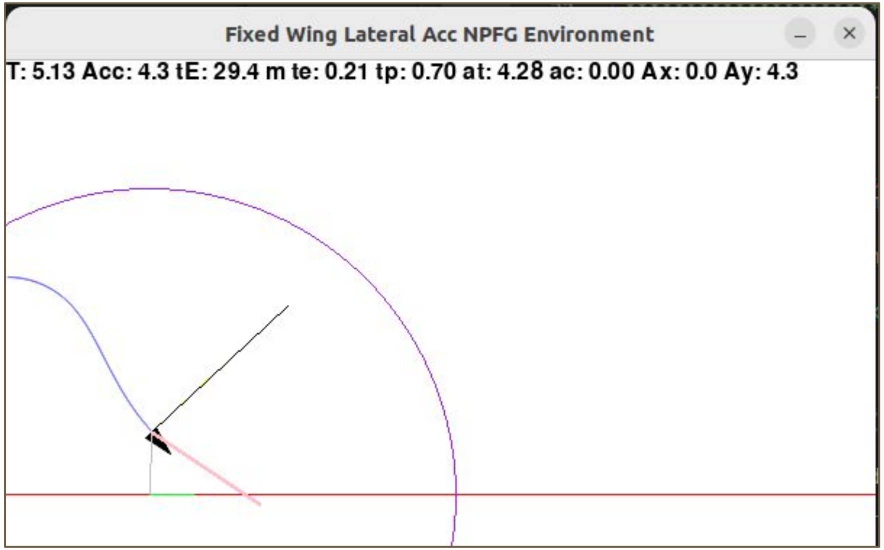


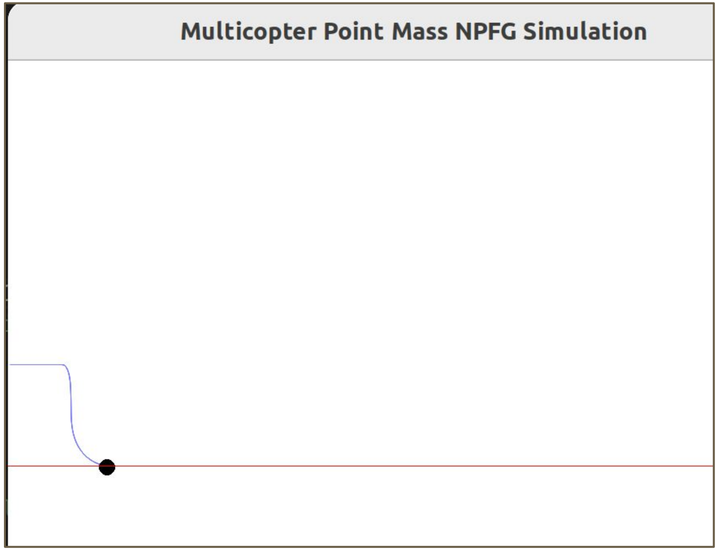


Current Status #1

Implementation of a NPFG Library in an OpenAI Gym Environment

- Multicopter Point-mass model
- Fixed-wing Lateral acceleration command model



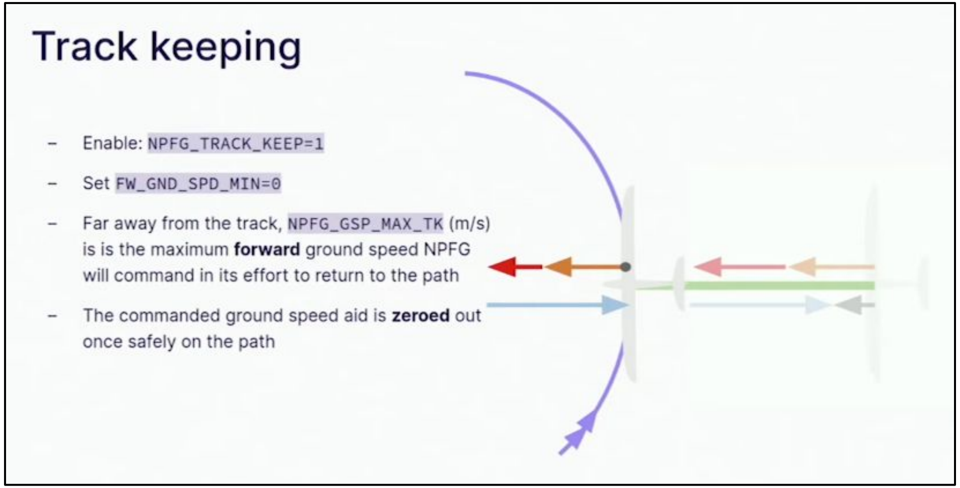


Current Status #2

Analysis of the limitations of NPFG

1. **Track keeping feature calculates a sub-optimal airspeed target (MC)**
    - Under-utilizes the multicopter's agility

2. **Vector Field doesn't consider jerk limit** required by the vehicle (especially Multicopter)



Current Status #3

1. Formulating **air-velocity reference vector calculation method**
    a. Respecting the Jerk constraint
2. Visualizing air-velocity reference vector around path

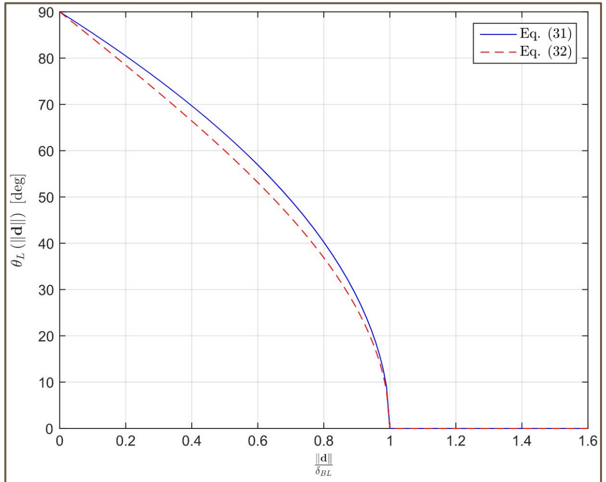
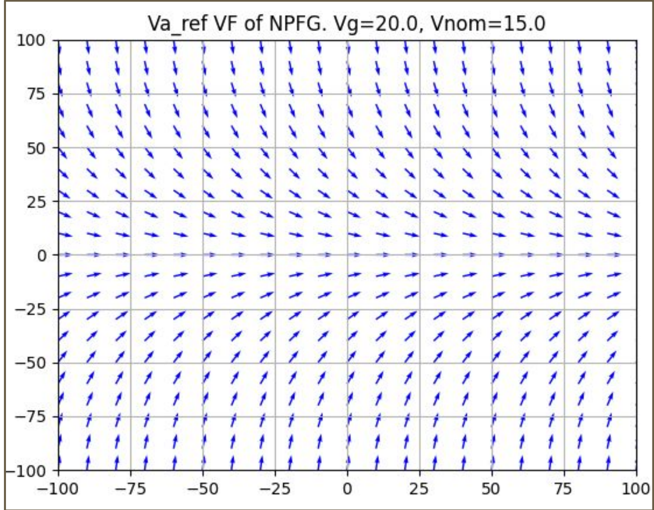
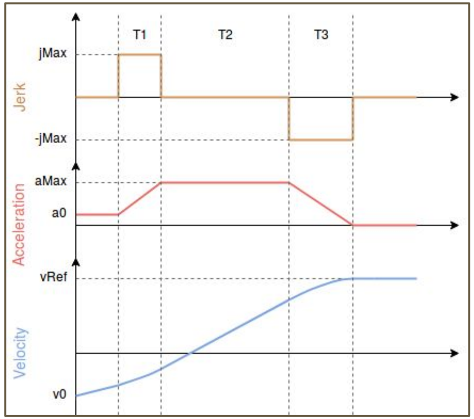


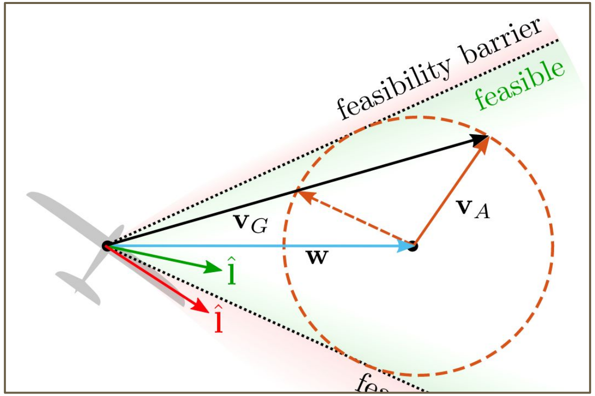
Fig. 4 Look-ahead angle function ($\epsilon = 0$).

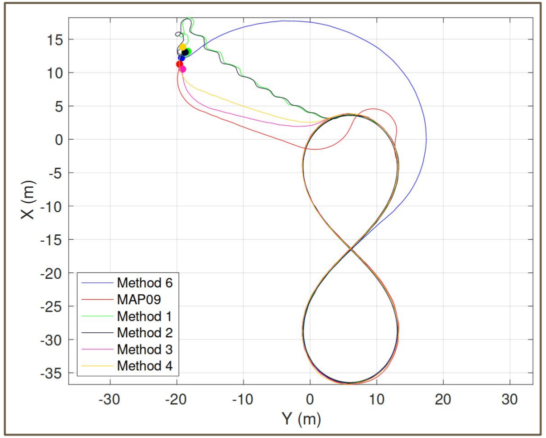


Future Work

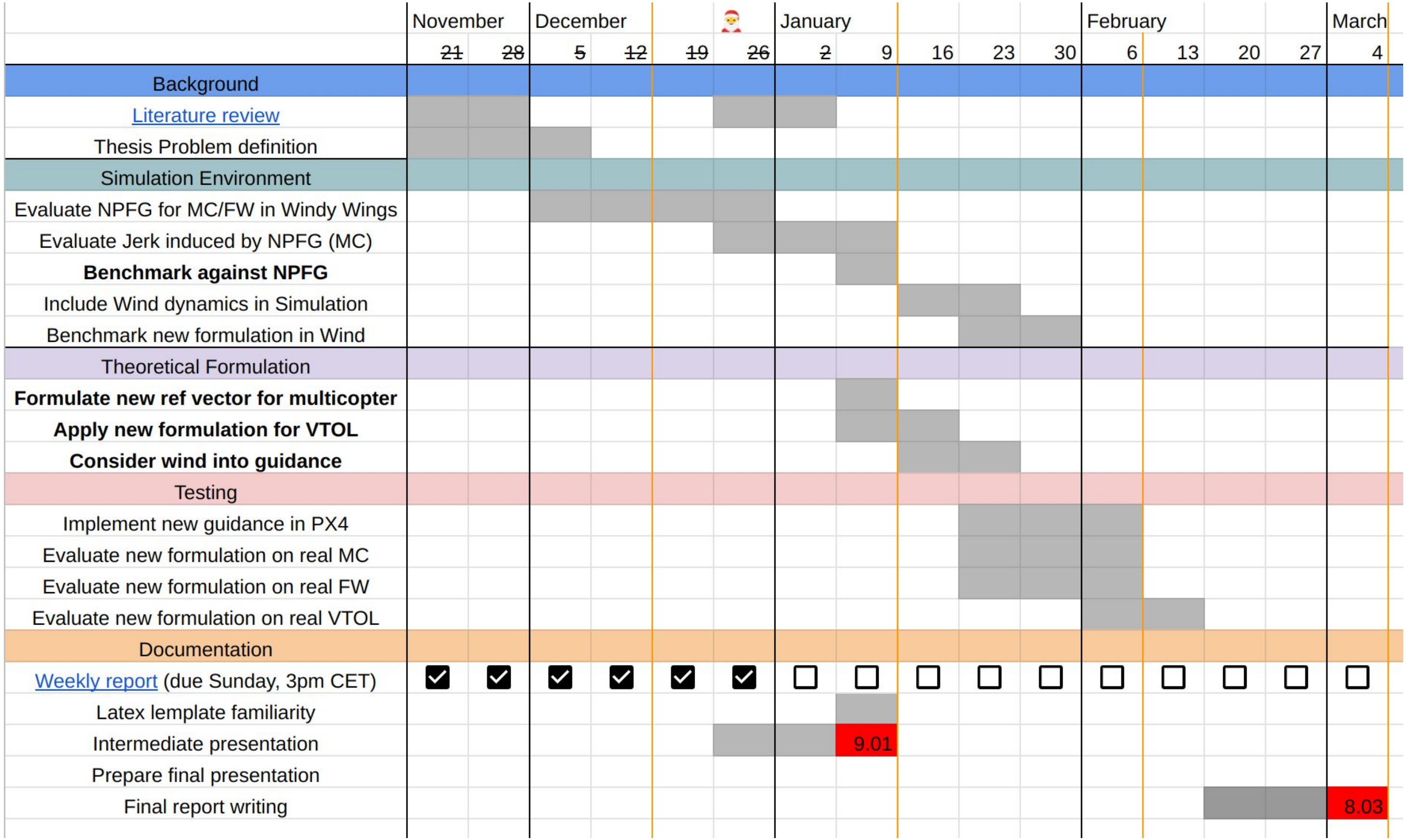
1. Formulating new velocity reference vector logic & track error boundary generation logic respecting vehicle's **jerk** limits (MC)
2. Incorporating **wind** into the guidance
3. Quantitative **analysis** on the new guidance law's PF capability







Timeline



November
December
January
February
March
21
28
5
12
19
26
2
9
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30
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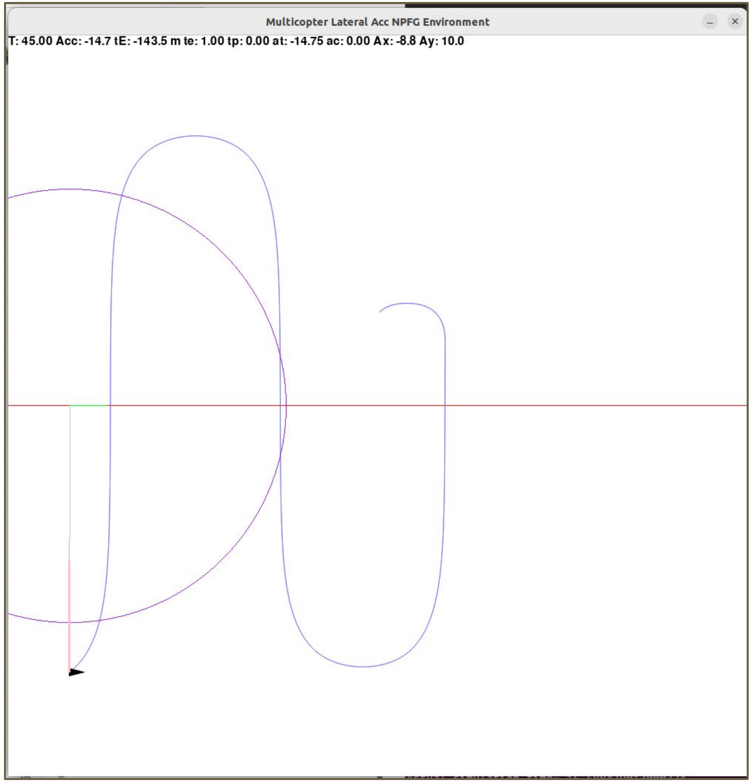
13
20
27
4
Background
Literature review
Thesis Problem definition
Simulation Environment
Evaluate NPFG for MC/FW in Windy Wings
Evaluate Jerk induced by NPFG (MC)
Benchmark against NPFG
Include Wind dynamics in Simulation
Benchmark new formulation in Wind
Theoretical Formulation
Formulate new ref vector for multicopter
Apply new formulation for VTOL
Consider wind into guidance
Testing
Implement new guidance in PX4
Evaluate new formulation on real MC
Evaluate new formulation on real FW
Evaluate new formulation on real VTOL
Documentation
Weekly report (due Sunday, 3pm CET)
Latex lemplate familiarity
Intermediate presentation
Prepare final presentation
Final report writing
9.01
8.03

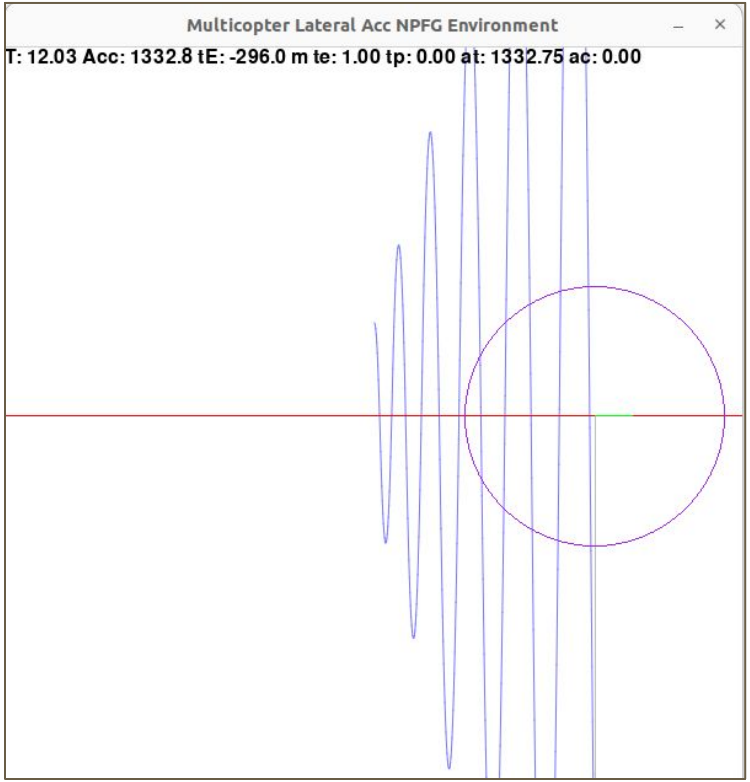
Thank you!

Reference

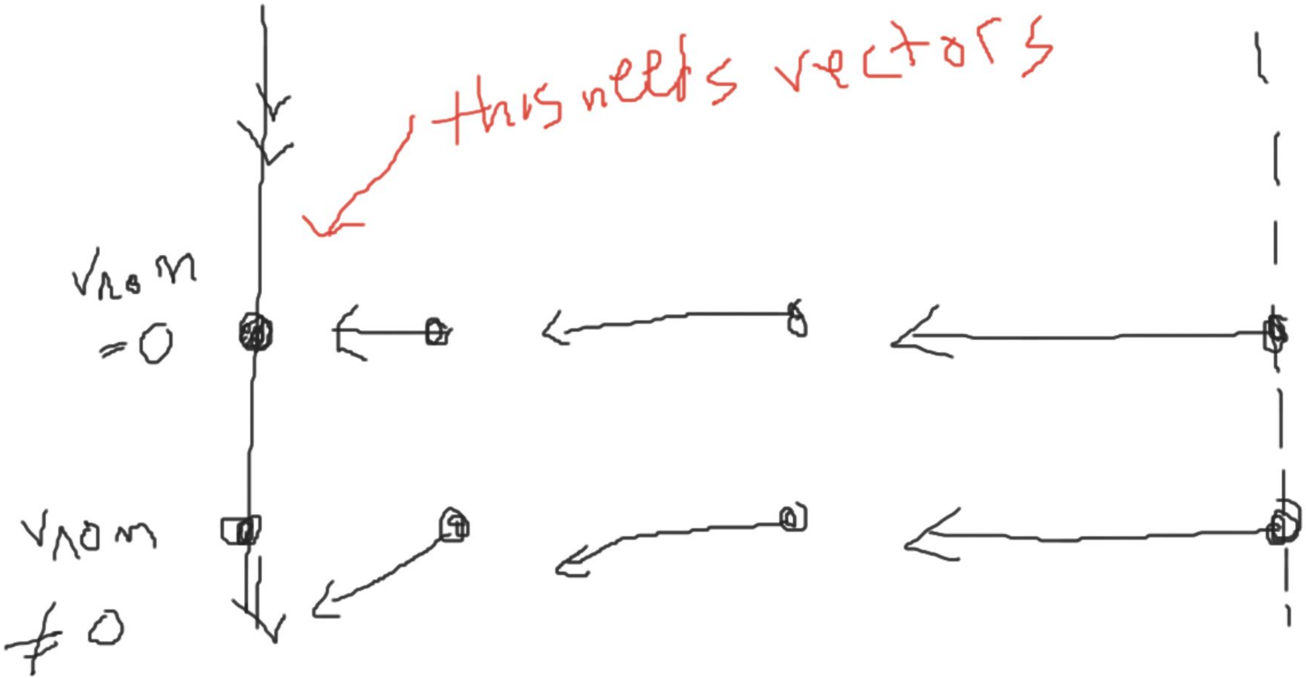
- Drone SVG
- Plane SVG
- Quantum Vector
- Quad PF Diagram: Fig 10 from ‘Rubi et al. 2020’
- Fixed Wing PF Diagram: Cover of ‘Sujit et al. 2014’
- Feasible Bearing directional guidance: TJ PhD Paper, Figure 4.4
- Path Following Simulation paths: Medusa Paper, Figure 7.6
- Mario Mystery Box PNG
- Feasibility Barrier diagram: TJ PhD Paper, Figure 4.2
- Wind Disturbance diagram: Fig 14 from ‘Rubi et al. 2020’
- 3D NPFG: Fig 3 from ‘Cho et al. 2015’
- All the vehicles: Video
- Look ahead angle diagram from 3D NPFG paper, Figure 4

Appendix A

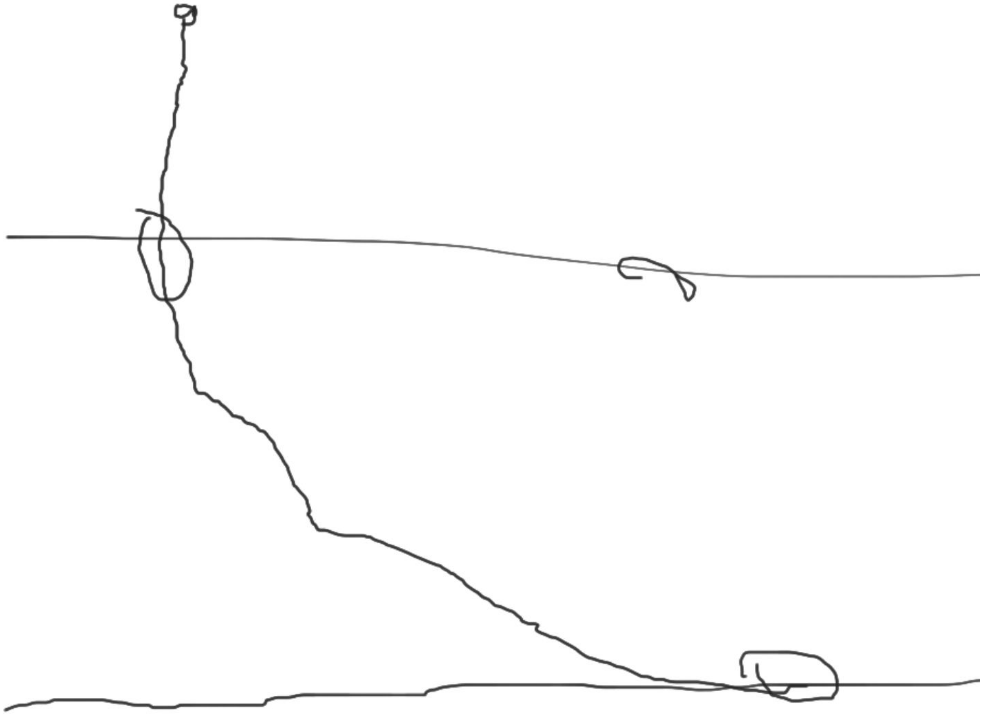

Multicopter Lateral Acc NPFG Environment
T: 45.00 Acc: -14.7 tE: -143.5 m te: 1.00 tp: 0.00 at: -14.75 ac: 0.00 Ax: -8.8 Ay: 10.0


Multicopter Lateral Acc NPFG Environment
T: 12.03 Acc: 1332.8 tE: -296.0 m te: 1.00 tp: 0.00 at: 1332.75 ac: 0.00

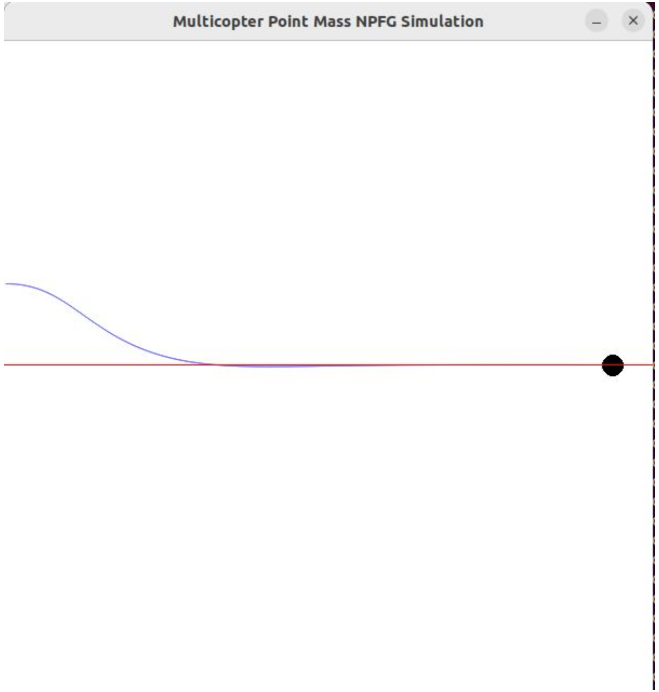
Appendix B



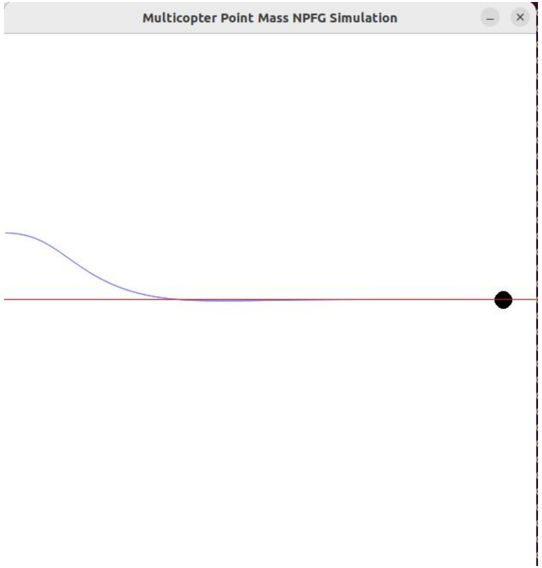
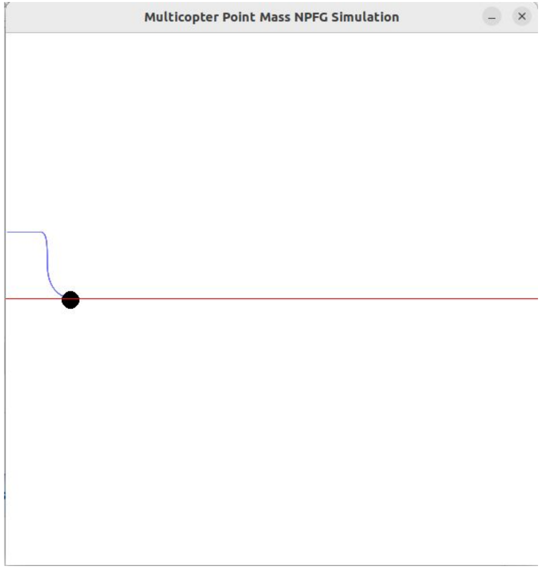
Appendix C



Multicopter Point-mass model



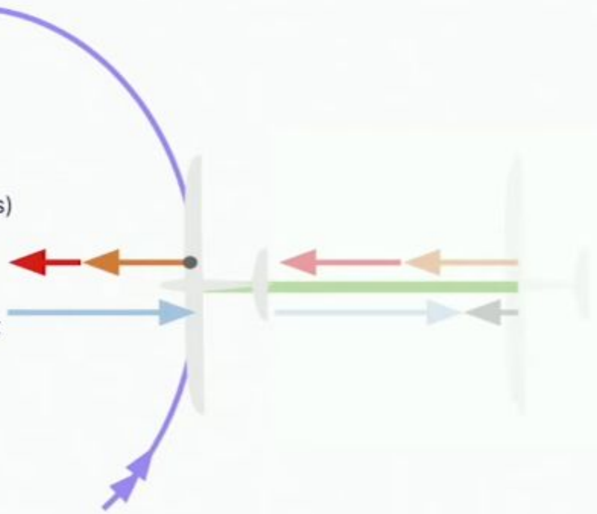
Track-keeping

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

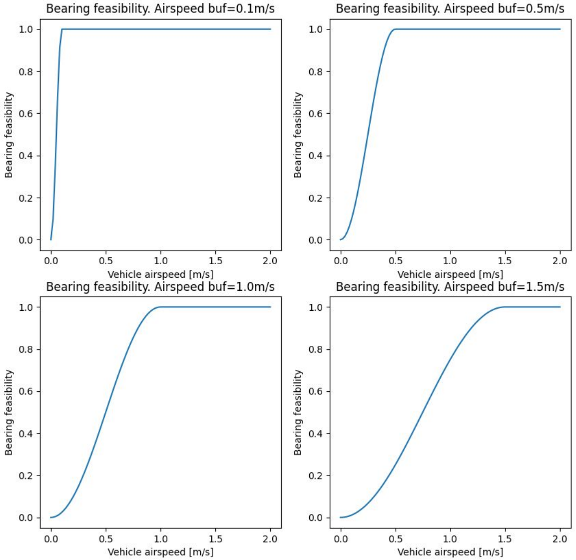
```
float NPFG::minGroundSpeed(const float normalized_track_error, const float feas)
{
	// minimum ground speed demand from track keeping logic
	min_gsp_track_keeping_ = 0.0f;

	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

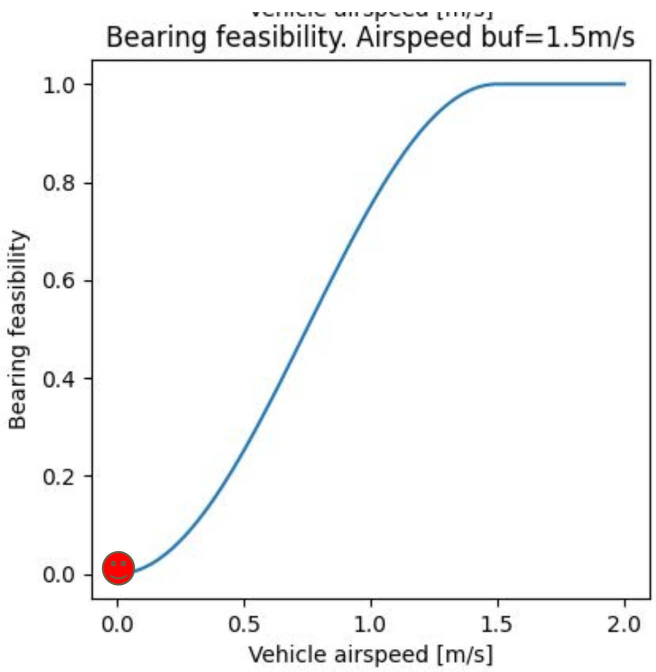
Minimum Ground Speed = 1 - feasibility X Minimum Ground Speed Track-Keeping

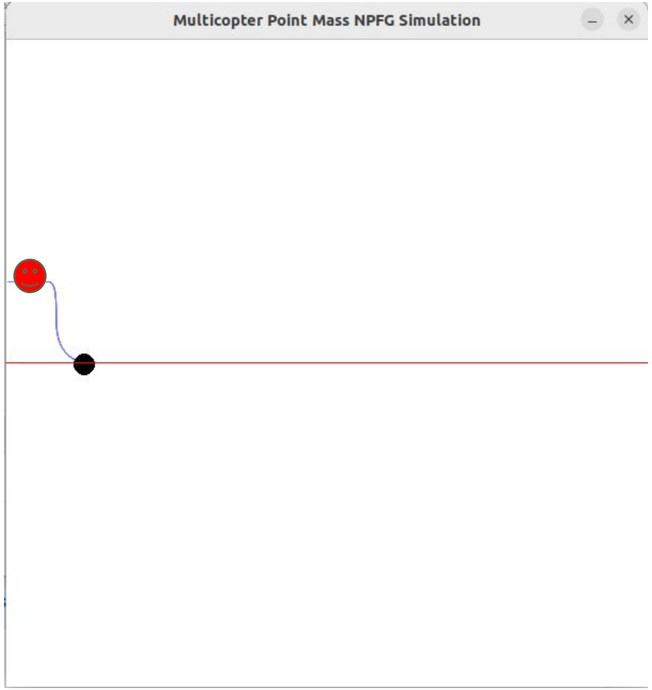
Bearing Feasibility

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

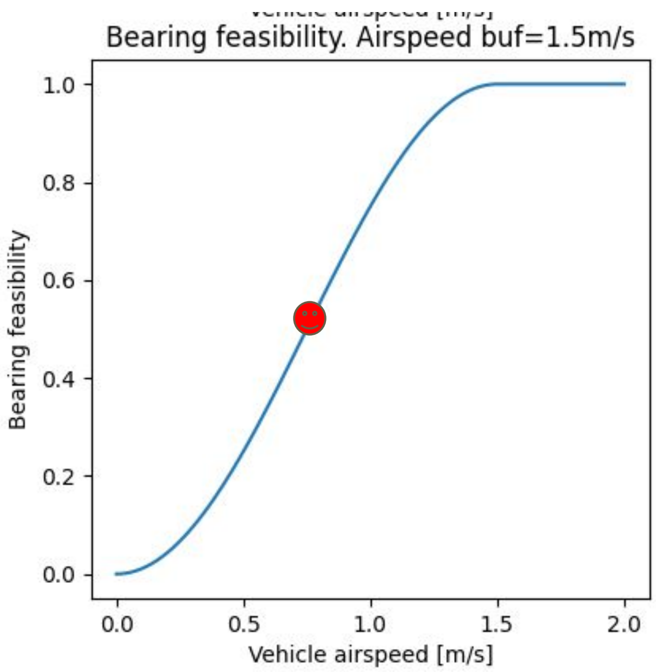


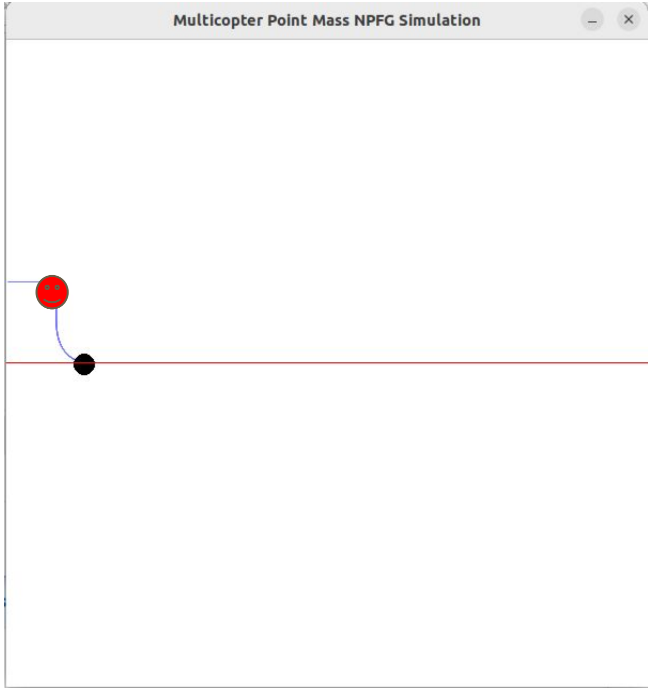
Bearing Feasibility



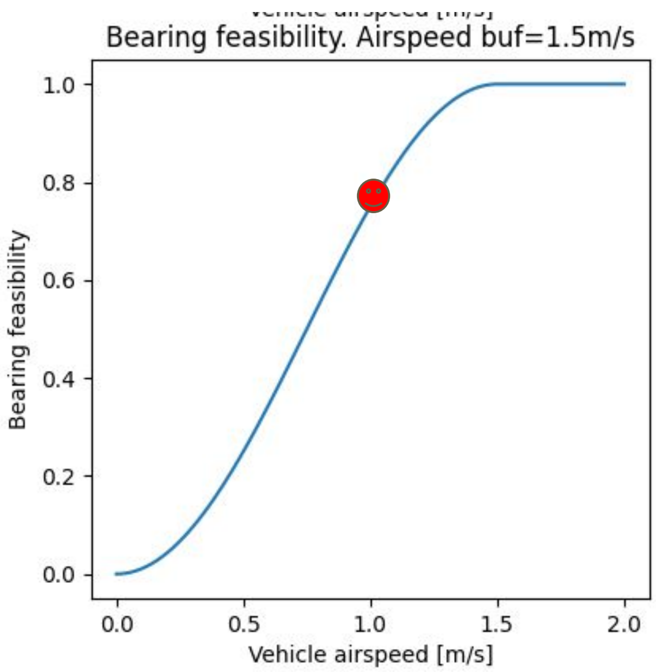


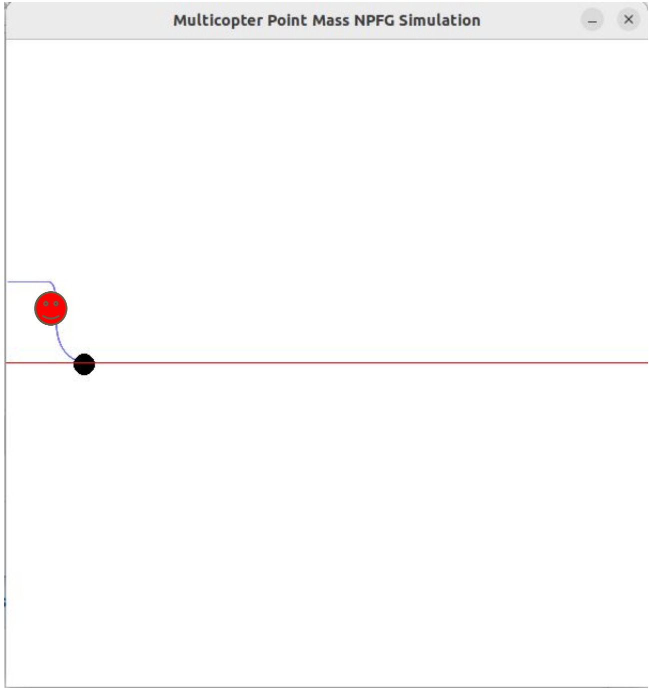
Bearing Feasibility



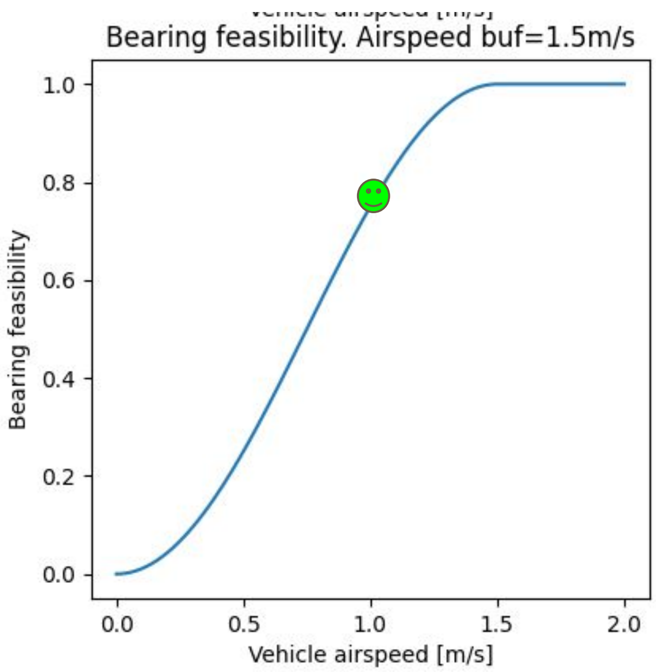


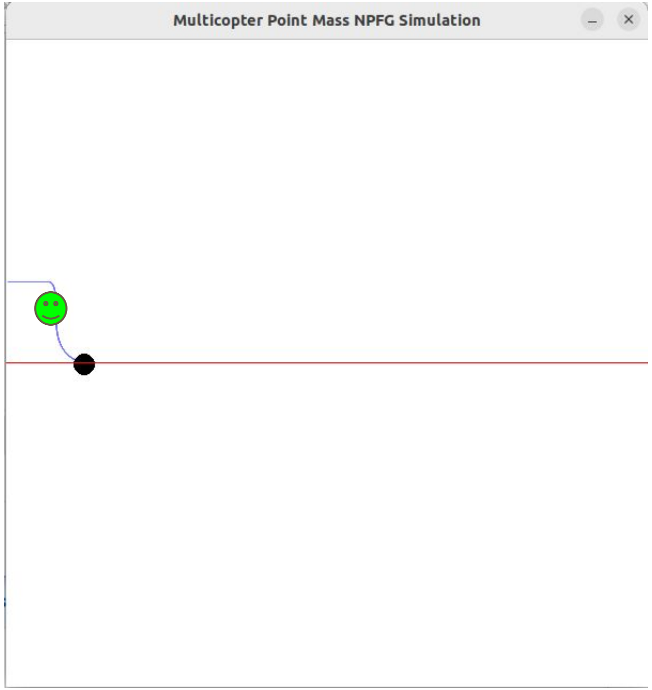
Bearing Feasibility





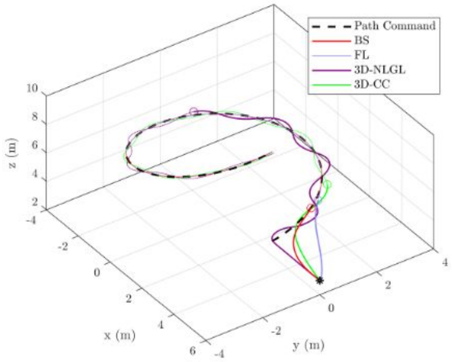
Bearing Feasibility



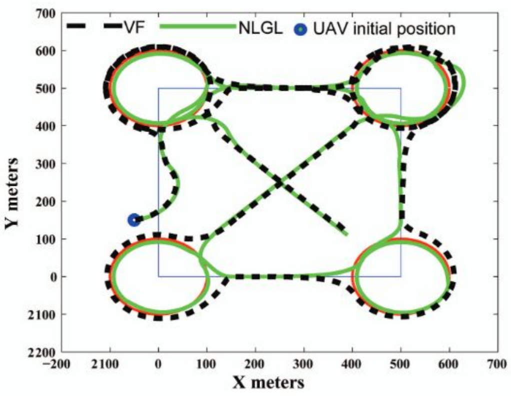


Disregard the Slides after this one

Other



Path Command
BS
FL
3D-NLGL
3D-CC
z (m)
x (m)
y (m)



VF
NLGL
UAV initial position
Y meters
X meters

Future Work

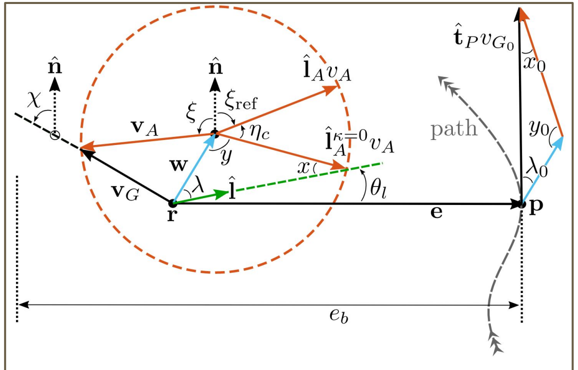


Figure 4.4: Directional guidance – geometry for feasible bearing.