Quantitative Analysis of Velocity Curves

17.02.2023 / Week 13

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Few Gotchas discovered

Nominal Velocity shouldn’t be 0 for Multicopter

1. We already have **V_min** set to 0
2. It should consistently refer to **‘cruise** speed’
3. **V_path** is giving information about the desired speed on path already
    a. V_nom should rather be used for calculating wind triangle / nominal speed target

Solution: V_nom != 0

Track keeping shouldn’t be used for generating ground velocity curve

1. Track keeping, in its original formulation was explicitly developed for handling excess wind (when vehicle has risk of diverging from path)
2. Calculating Ground Velocity vector field shouldn’t have to care about wind for now (All other algorithms didn’t)
3. Due to effect of bearing feasibility, it complicates the formulation as well

Solution: $V_{tk} = 0$

Minimum approach speed isn’t needed

1. V_min_approach was originally added to handle case where nominal velocity of Multicopter was 0 (to ensure sane approach speed)
   a. **V_approach = max(V_min_approach, V_nom, V_path)**
2. V_min_approach was set as V_nom for FW already (disabling the feature)
3. But, as V_nom != 0 now, and since V_nom (‘cruise speed’) already sufficiently describes sane approach speed lower bound, it isn’t needed.

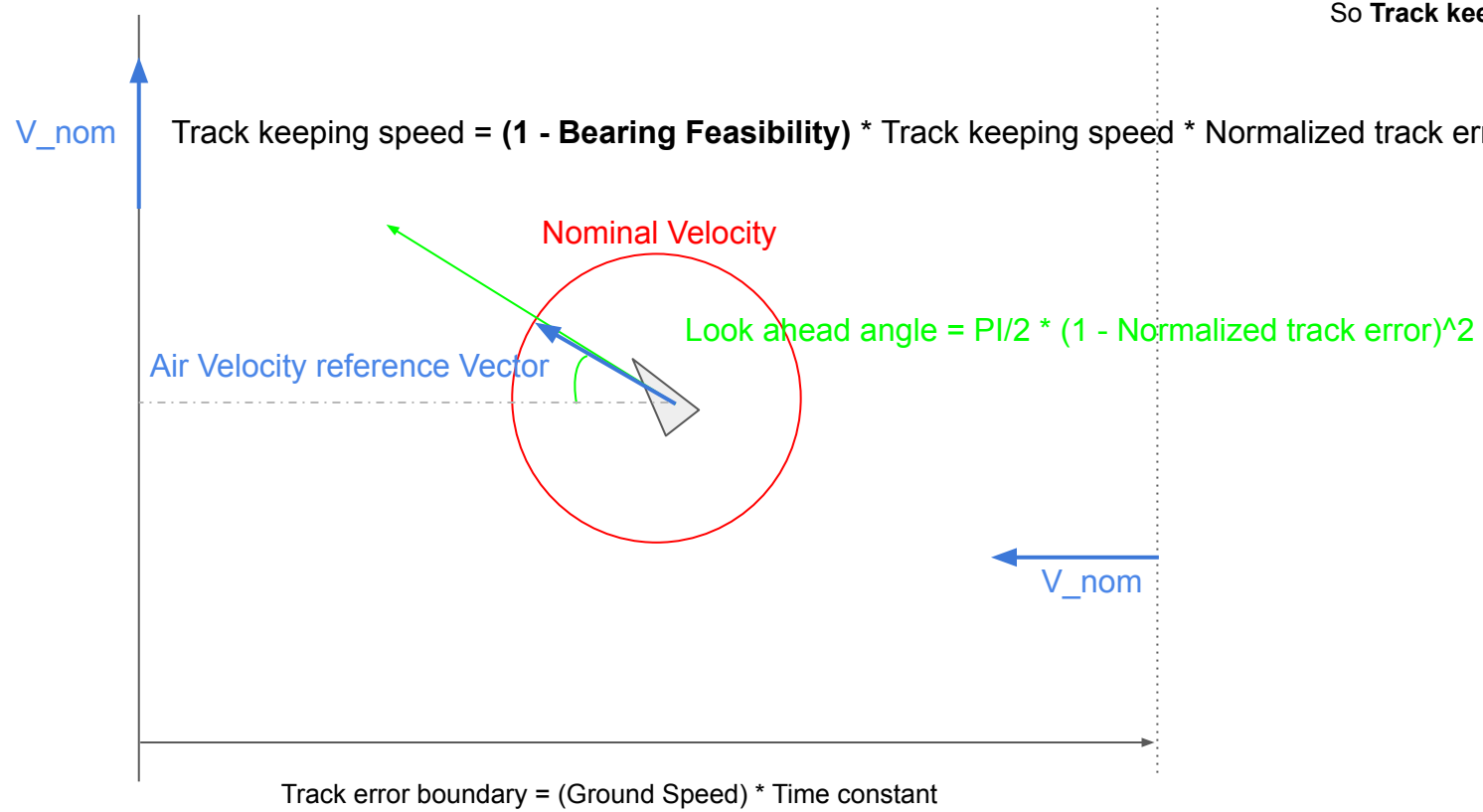
Solution: V_min_approach = 0

Description of Velocity Curves

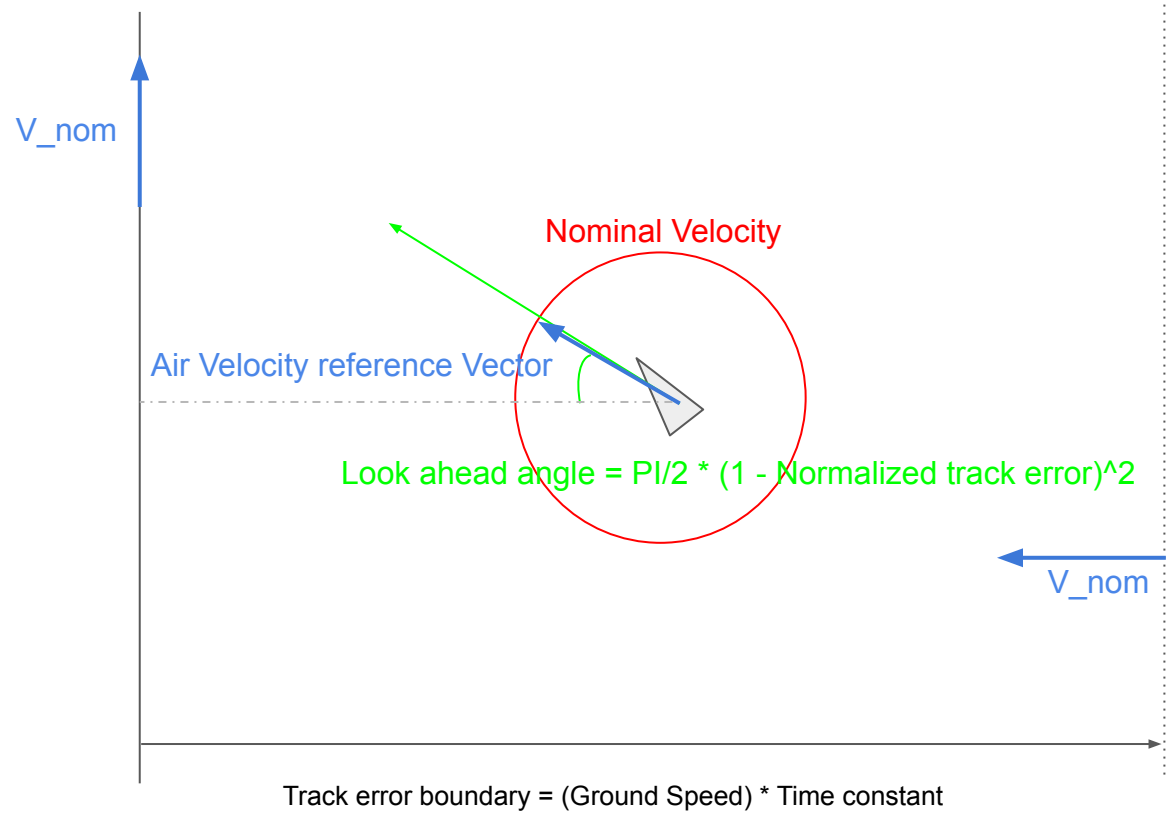
TJ NPFG

Unless Nominal Velocity is very small, bearing feasibility = 1 for all bearings (in no wind).

So **Track keeping speed = 0**



TJ NPFG (BF Stripped)



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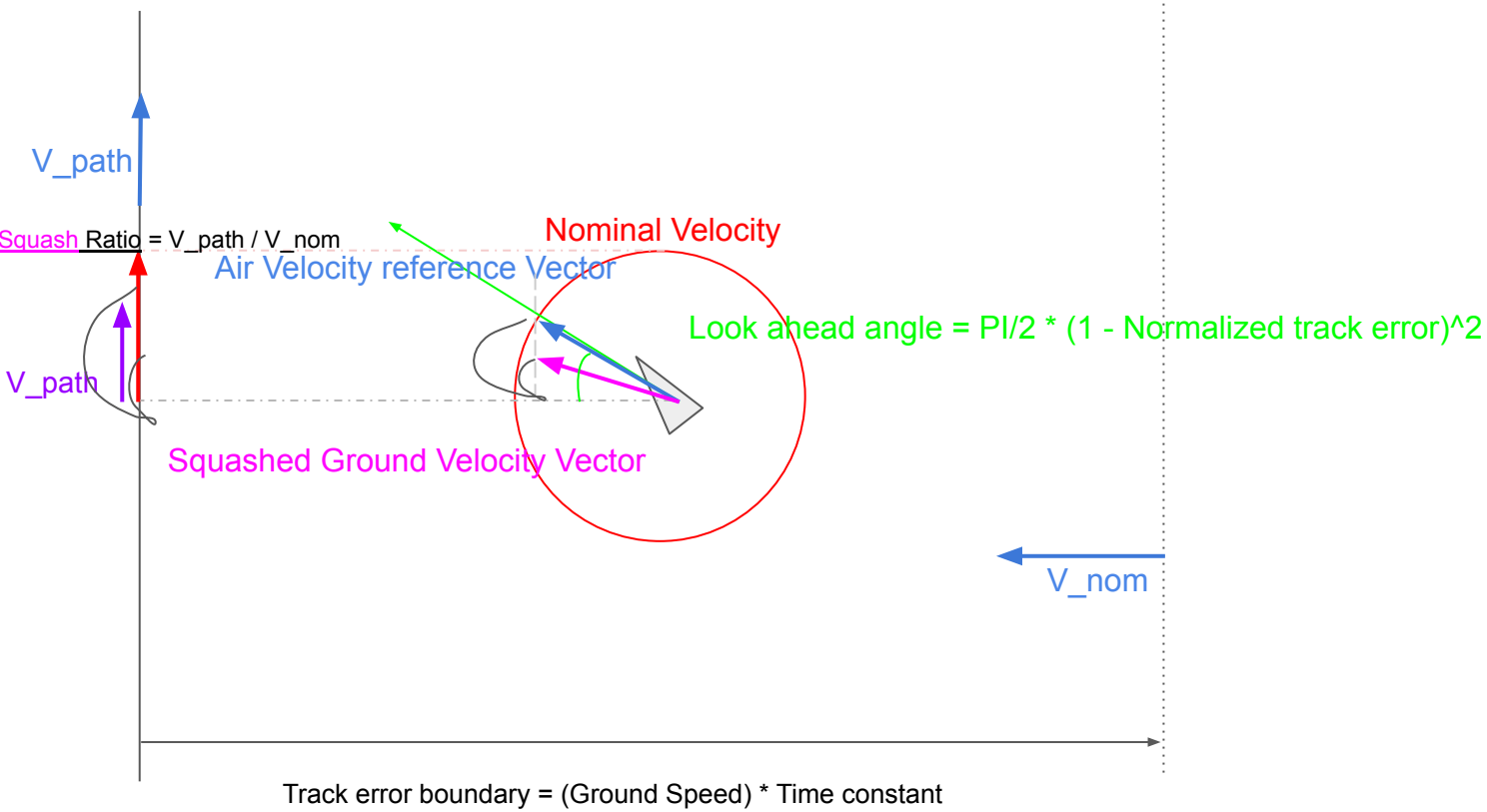
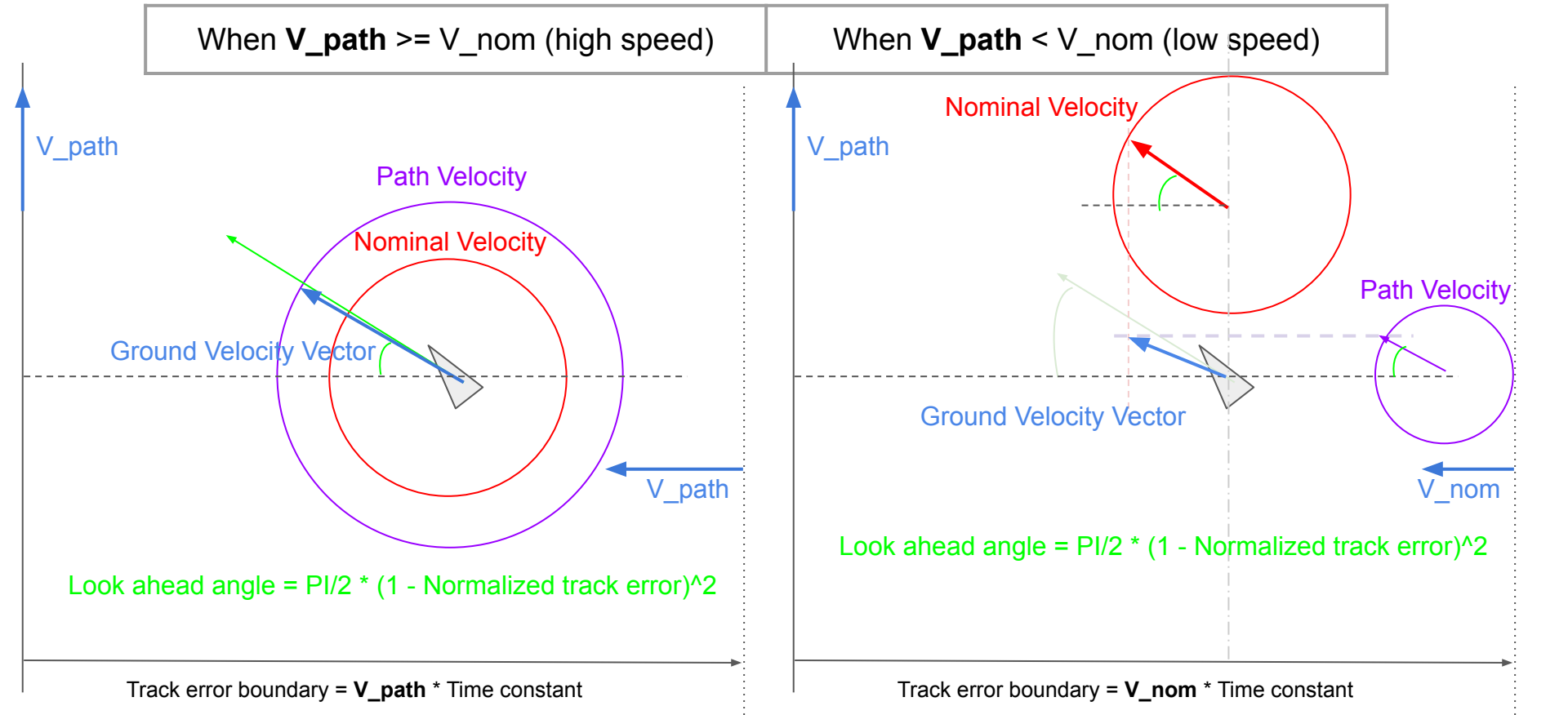
TJ NPFG squashed



Cartesian decoupling is completely equivalent to Squashed in **low V_path** case!

TJ NPFG Squashed extended (former ‘Cartesian’)



Vehicle constraints / Algorithm parameters

Vehicle Constraints

Constraints	Fixed Wing	Multicopter
Yaw rate	FW_YAW_R_MAX = 2 rad/s (FW_V_NOM / FW_ACC_LAT_MAX)	x
Acceleration	FW_ACC_LAT_MAX = 5 m/s^2 FW_ACC_LON_MAX = 0.5 m/s^2	MC_ACC_XY_MAX = 10 m/s^2
Velocity	FW_V_MIN = 6 m/s (flap) FW_V_NOM = 10 m/s **FW_V_MAX = 15 m/s (full throttle)**	MC_V_XY_MIN = 0 m/s **MC_V_NOM = 6 m/s (sane cruise speed)** **MC_V_XY_MAX = 15 m/s**

Testing Conditions

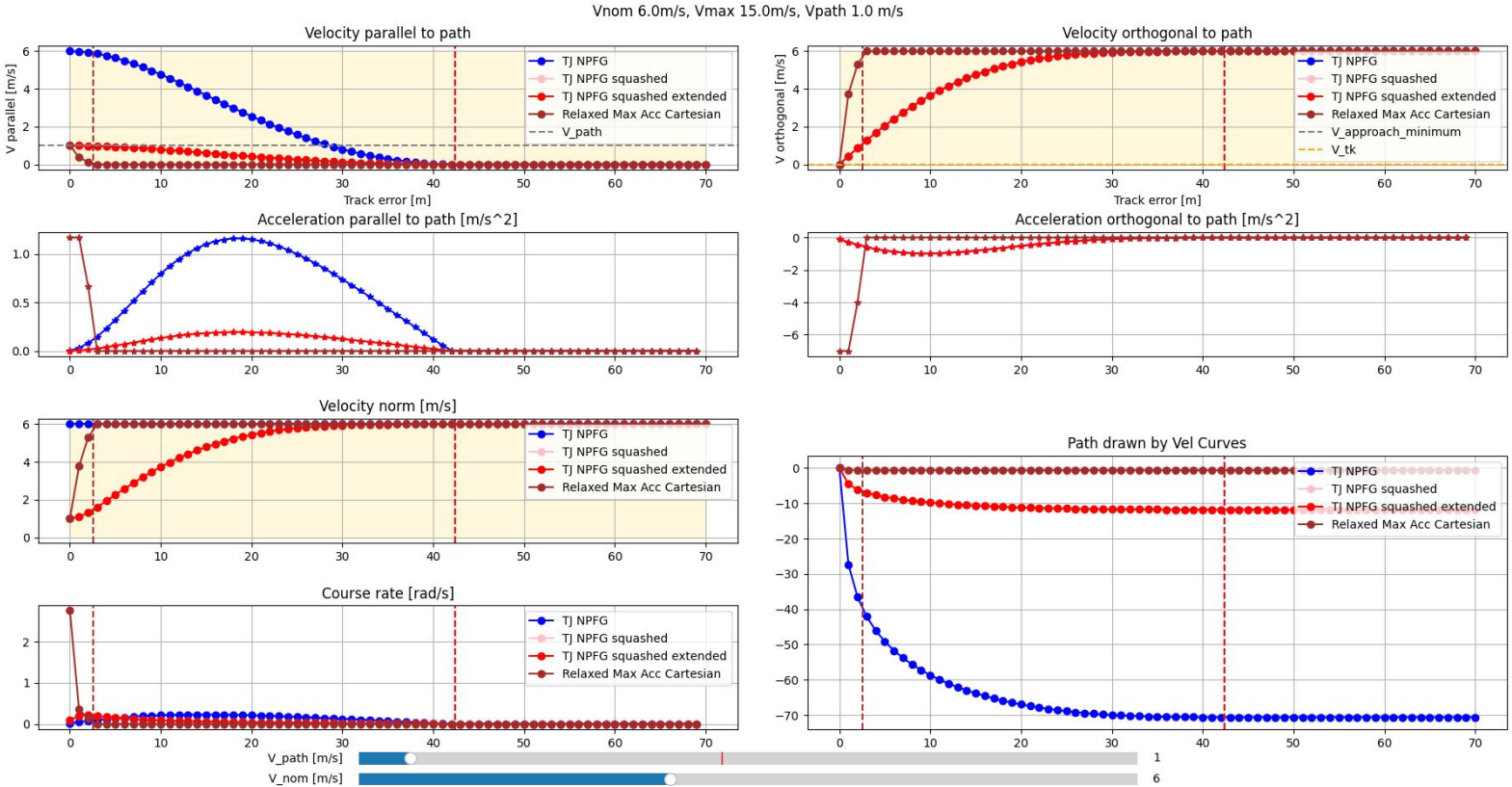
Case	V_nom	V_path	Description
Multicopter on fast path, but slower than FW (V_path < FW_V_MIN)	6	5	MC approaching and following path at high (but lower than FW speed range) speed
Multicopter on slow path	6	1	MC approaching and following path at slow speed
+ Multicopter on very fast path	6	12	MC approaching and following path at fast speed (without transition to FW)
Fixed Wing on fast path (V_path >= FW_V_MIN, V_path <= FW_V_MAX)	10	13	FW accelerating and following path at high speed
FW on slow path	10	7	FW braking and following path at minimum speed (near stall)
FW approaching slow path (transitioning to MC, V_path < FW_V_MIN)	10 -> 6	5	Fixed-Wing transitioning in the curve, and reaching on path as MC

Algorithm Parameters

Parameter	Value	Description
V_approach_min	0	As V_nom != 0 now, this isn't necessary
V_track_keeping	0	As described in below section, track-keeping should be decoupled from ground course/velocity vector field as it's for excess wind case only. Set to 0.
Current ground speed	V_nom	Used for track error boundary calculation on TJ NPFG derived models, reasonable speed (roughly) is V_nom
Path orthogonal acceleration limit	MC: 7 FW: undefined	MC: MC_ACC_XY_MAX/sqrt(2)
Path parallel acceleration limit	MC: 7 FW: undefined	MC: MC_ACC_XY_MAX/sqrt(2)

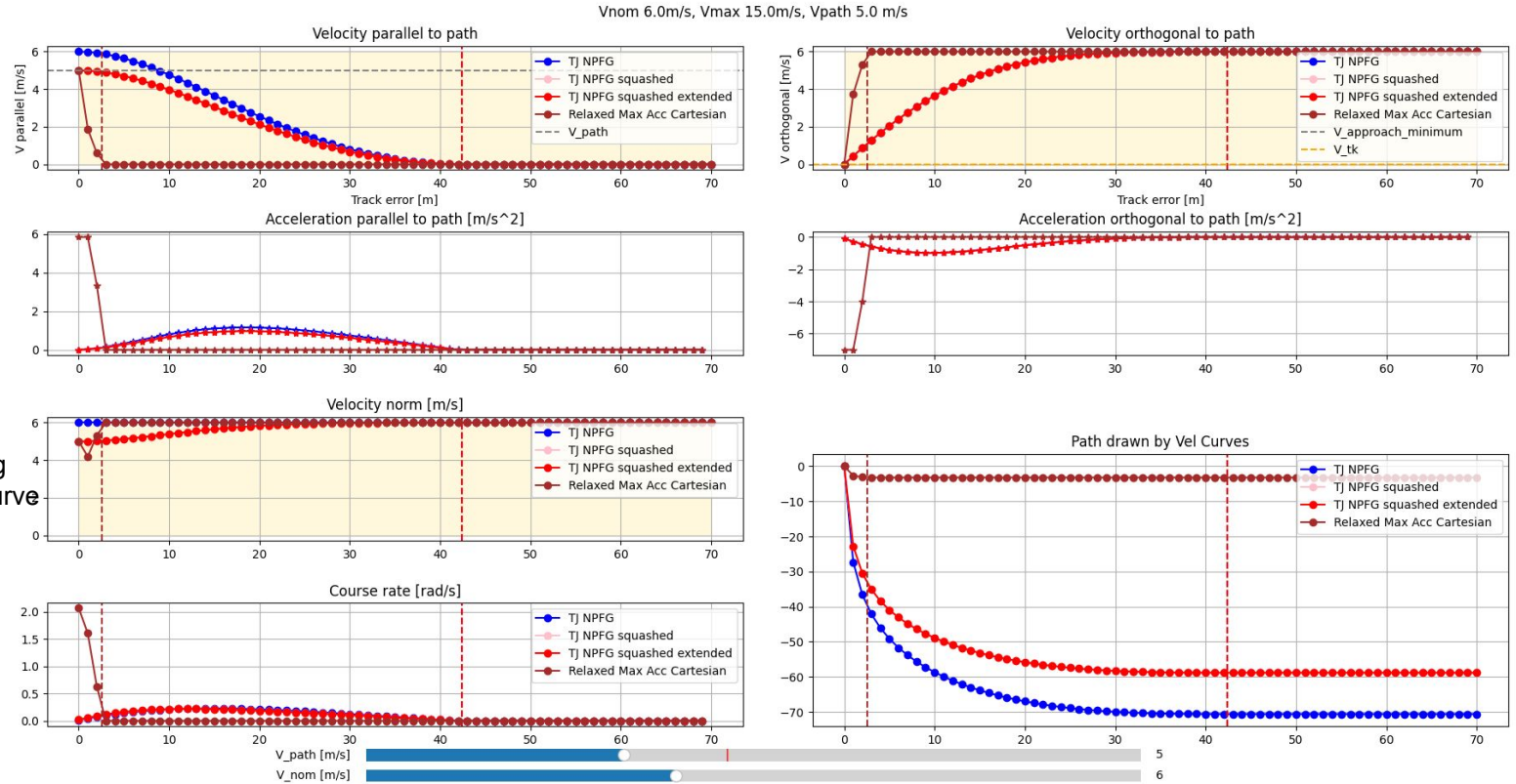
Analysis

Case	V_nom	V_path	Description
Multicopter on slow path	6	1	MC approaching and following path at slow speed

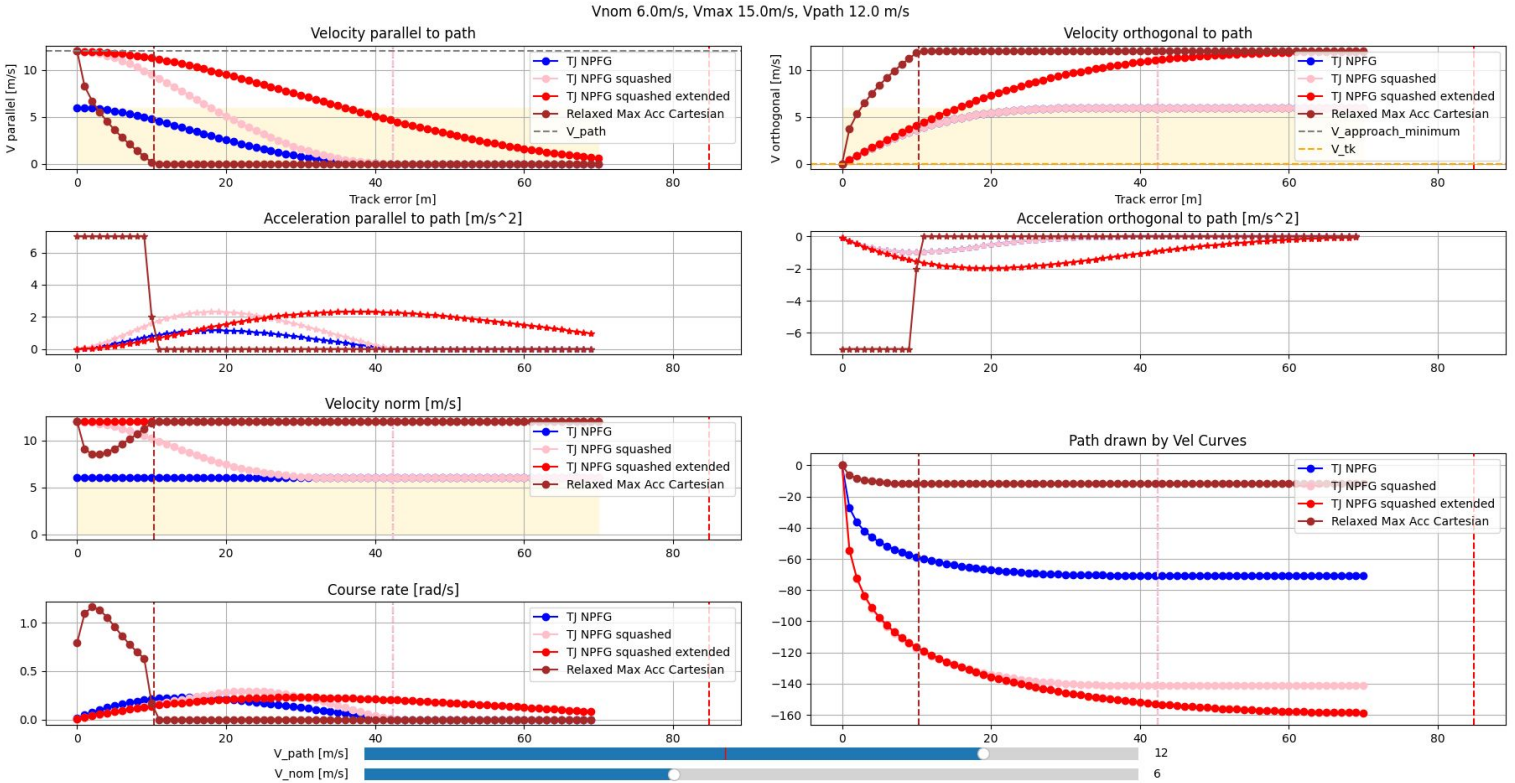


Case	V_nom	V_path	Description
Multicopter on fast path, but slower than FW (V_path < FW_V_MIN)	6	5	MC approaching and following path at high (but lower than FW speed range) speed

V_nom dipping for Max Acc curve



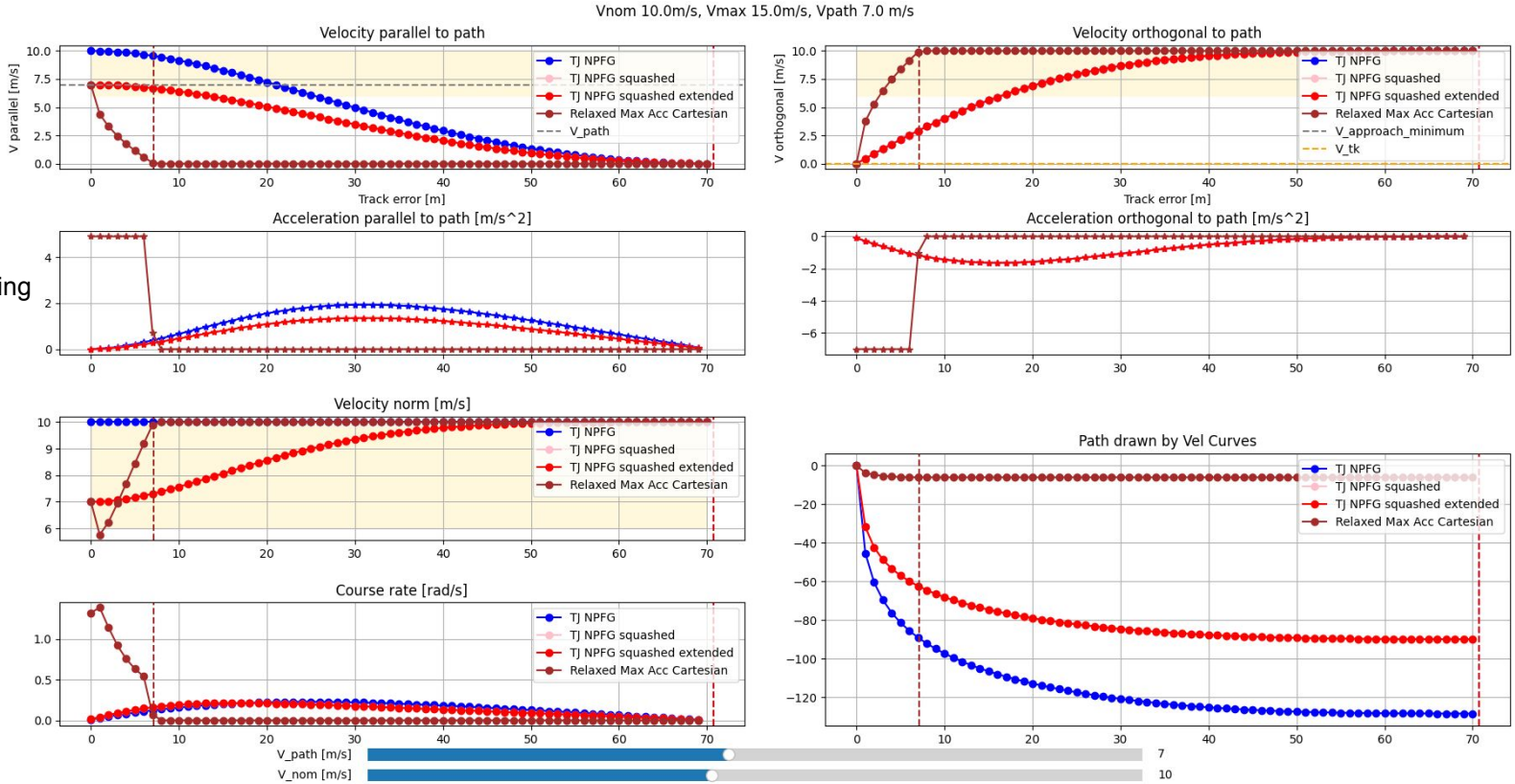
Case	V_nom	V_path	Description
+ Multicopter on very fast path	6	12	MC approaching and following path at fast speed (without transition to FW)



Case	V_nom	V_path	Description
FW on slow path	10	7	FW braking and following path at minimum speed (near stall)

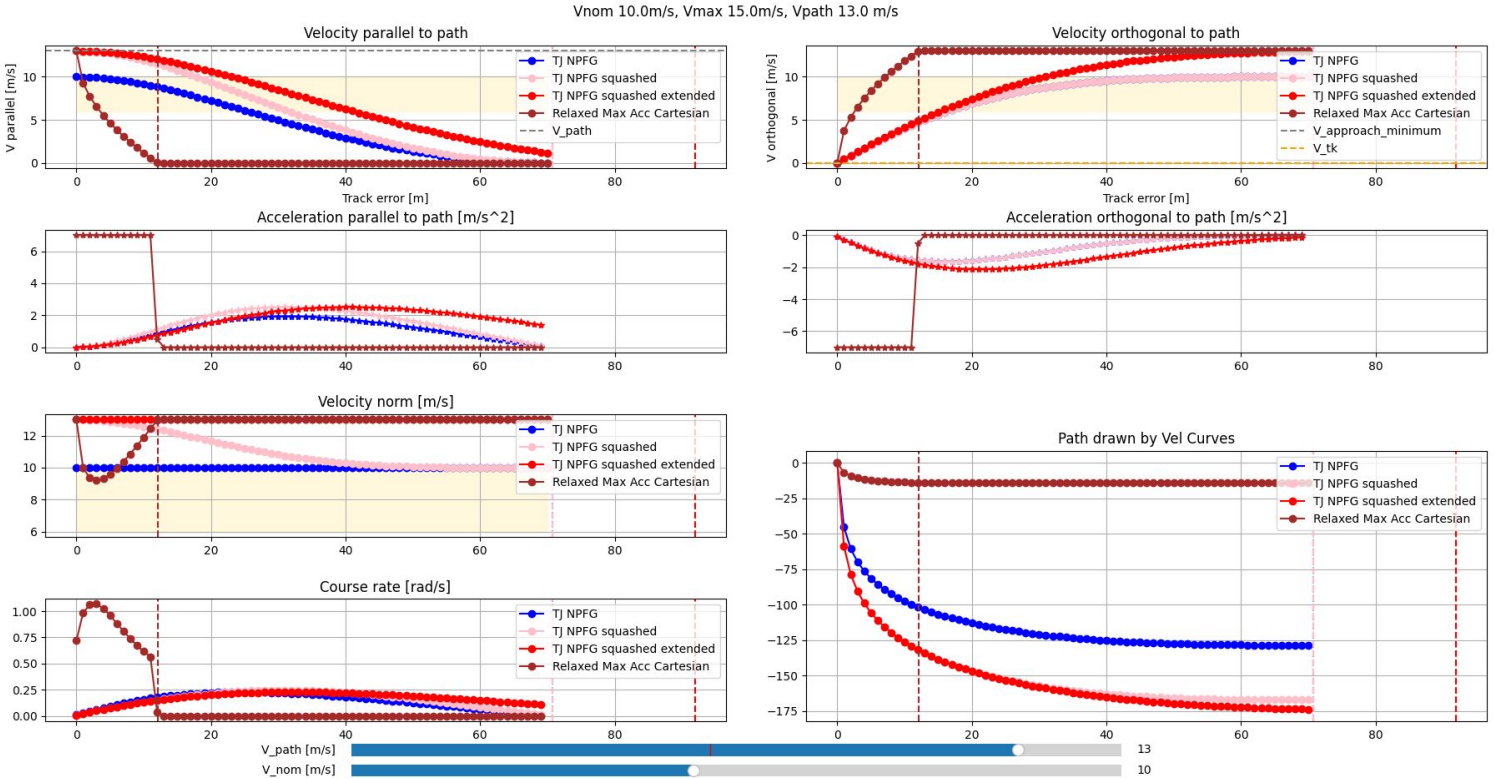
V_nom dipping (Max Acc)

Aggressive course rate (Max Acc)



Case	V_nom	V_path	Description
Fixed Wing on fast path (V_path >= FW_V_MIN, V_path <= FW_V_MAX)	10	13	FW accelerating and following path at high speed

Squashed extended is more aggressive (Acc/Vel magnitude) than Squashed one, **when V_path > V_nom (high speed)**, as it performs unicyclic motion using V_path as nominal speed.



Q: FW > MC Transition

Case	V_nom	V_path	Description
FW approaching slow path (transitioning to MC, V_path < FW_V_MIN)	10 -> 6	5	Fixed-Wing transitioning in the curve, and reaching on path as MC

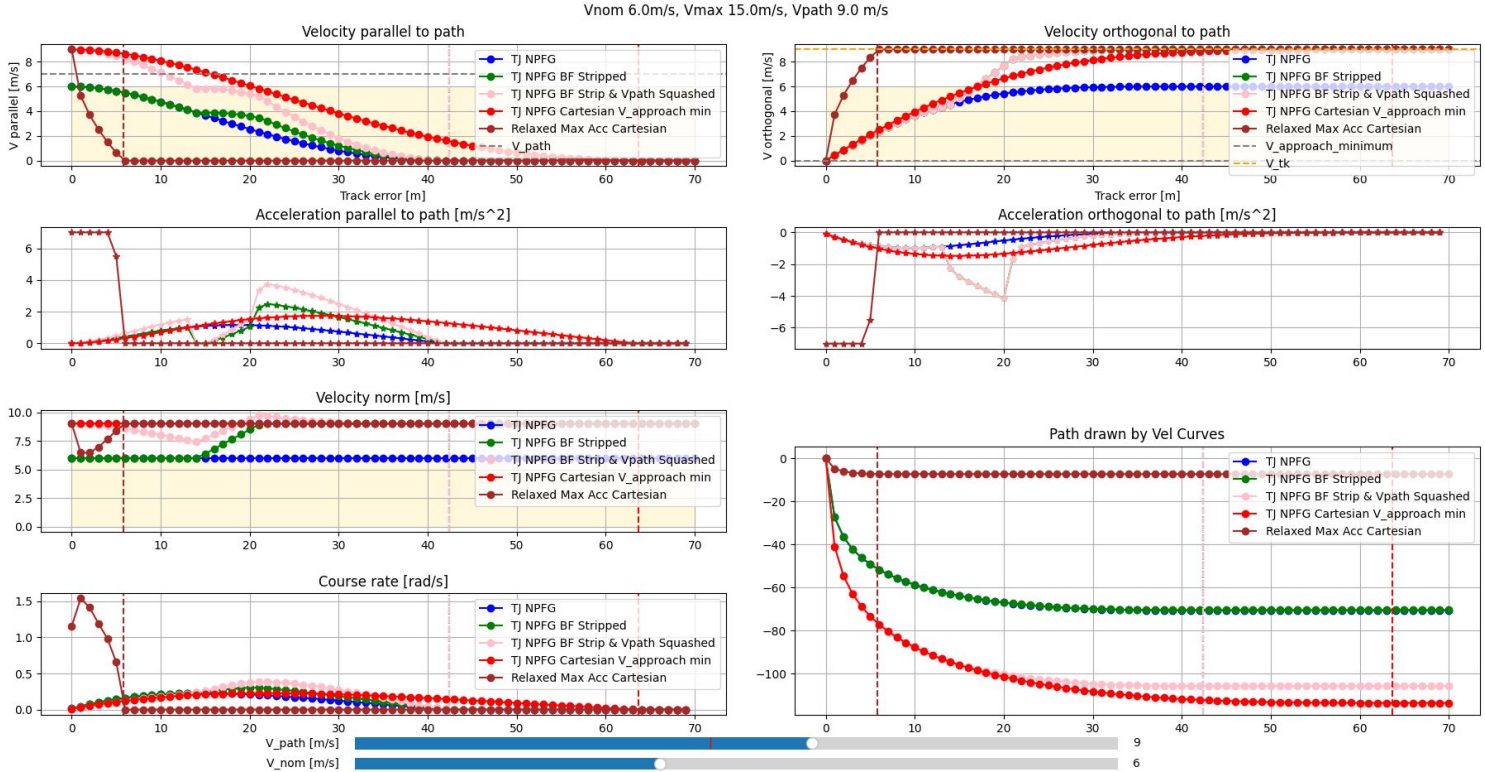
Q: Extending to Curved Path

Appendix: Showcasing side-effect of V_track_keeping

V_nom	V_path	V_tk
6	9	9

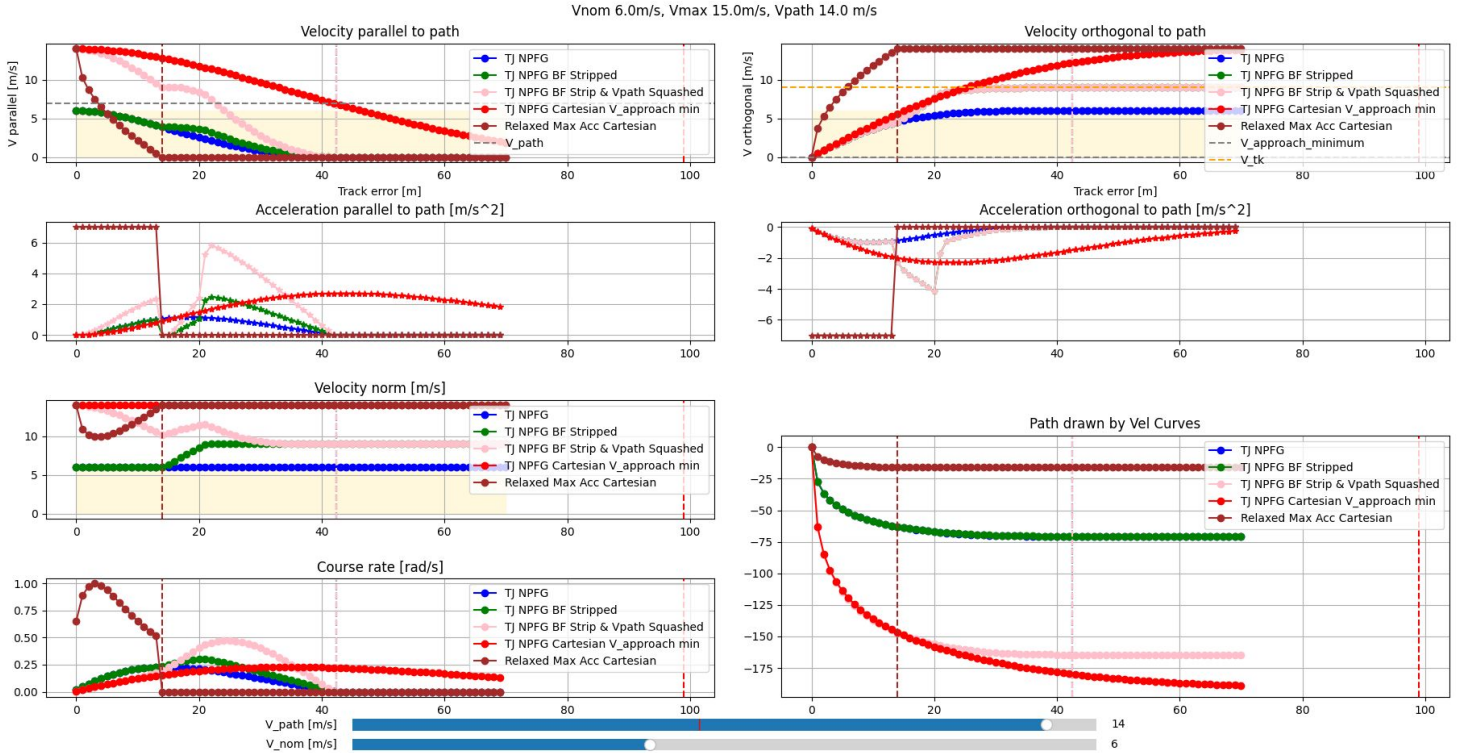
As track-keeping essentially modifies the air velocity reference vector's magnitude (becomes bigger than V_nom), applying **squashing** (pink-curve) results in **weird shape in Velocity norm curve**

Here, cartesian formulation (red) is simpler / doesn't suffer from this problem, compared to squashed formulation



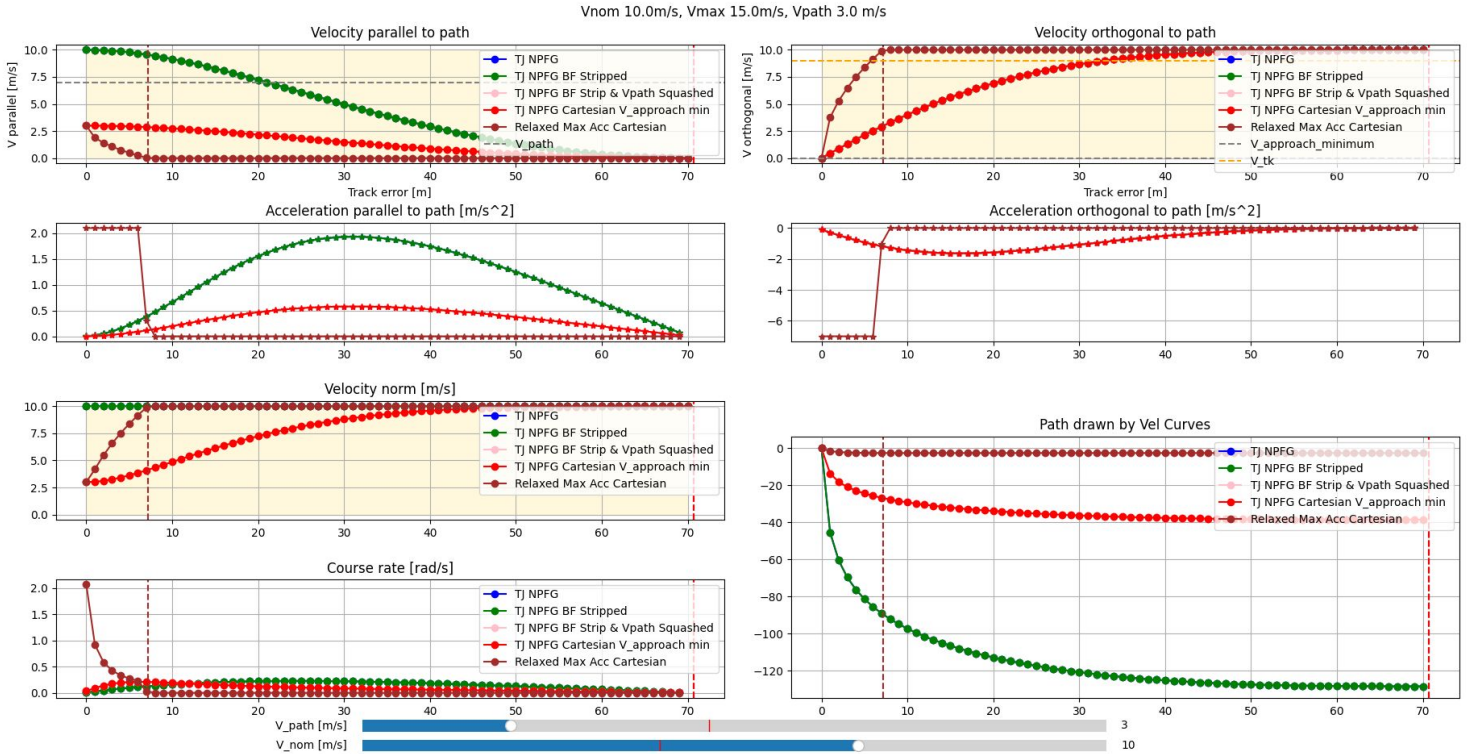
V_nom	V_path	V_tk
6	14	9

At **higher path velocity cases, distortion is even more severe**, as scaling factor (V_path/V_nom) is not correct for squashing formulation



V_nom	V_path	V_tk
10	15	9

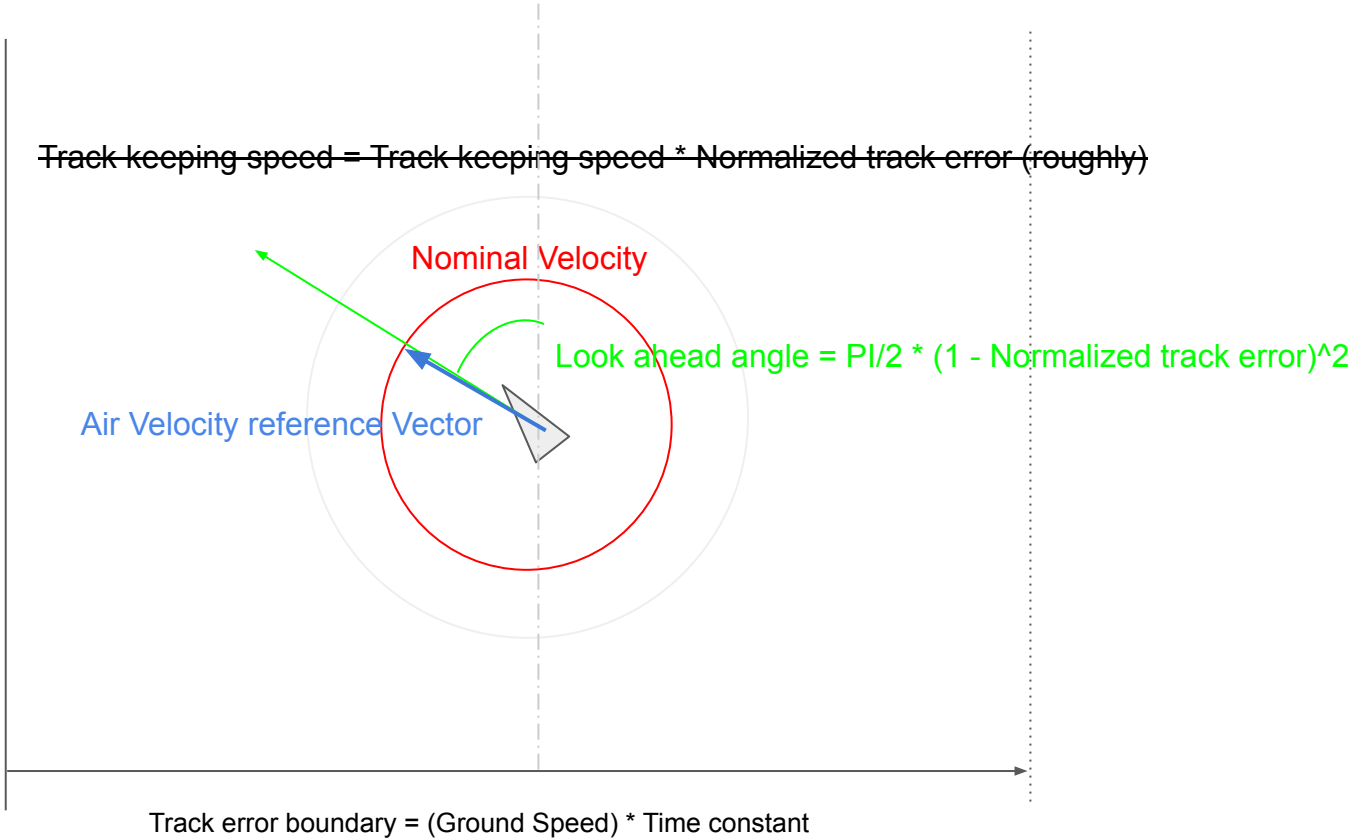
However, of course this **effect diminishes when V_nom > V_tk**, as the track-keeping feature won't elongate the reference air velocity anymore (as already it is satisfying minimum ground speed of 9 (V_tk)).



Appendix: Old plots

~~TJ NPFG BF Stripped~~

This case is showing **track keeping speed set to 0 (disabled)**



TK and Min approach speed enabled

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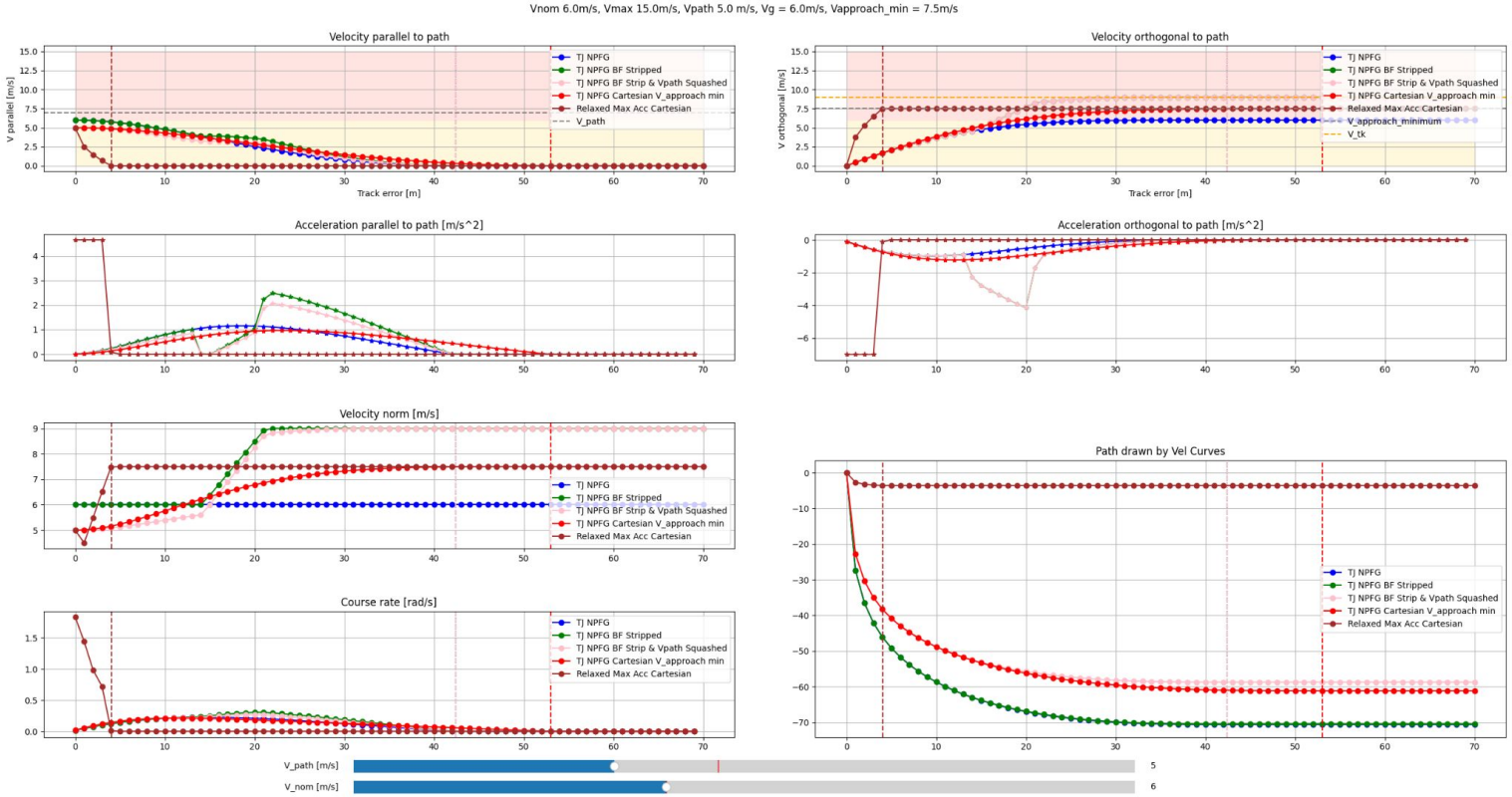

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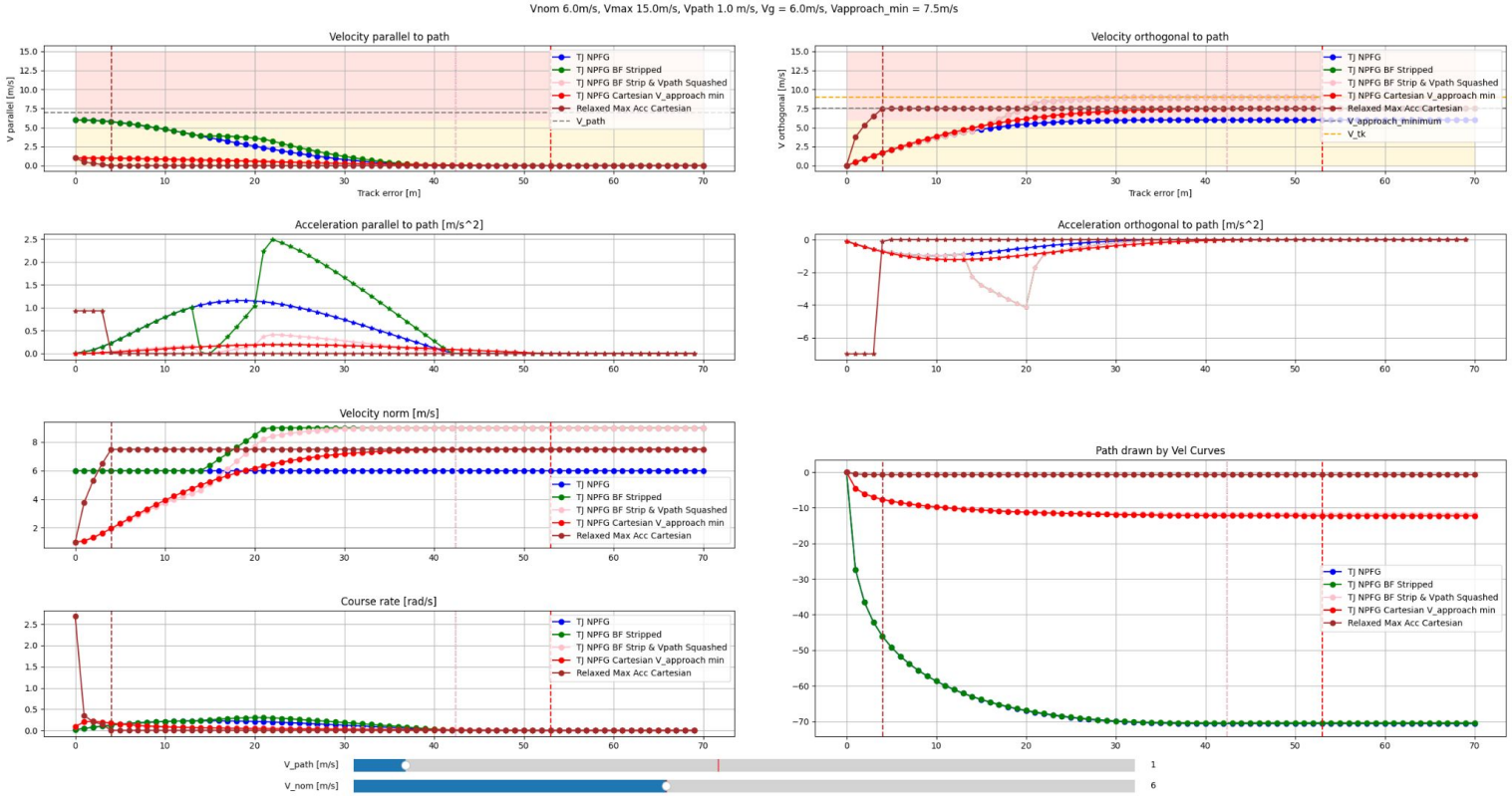

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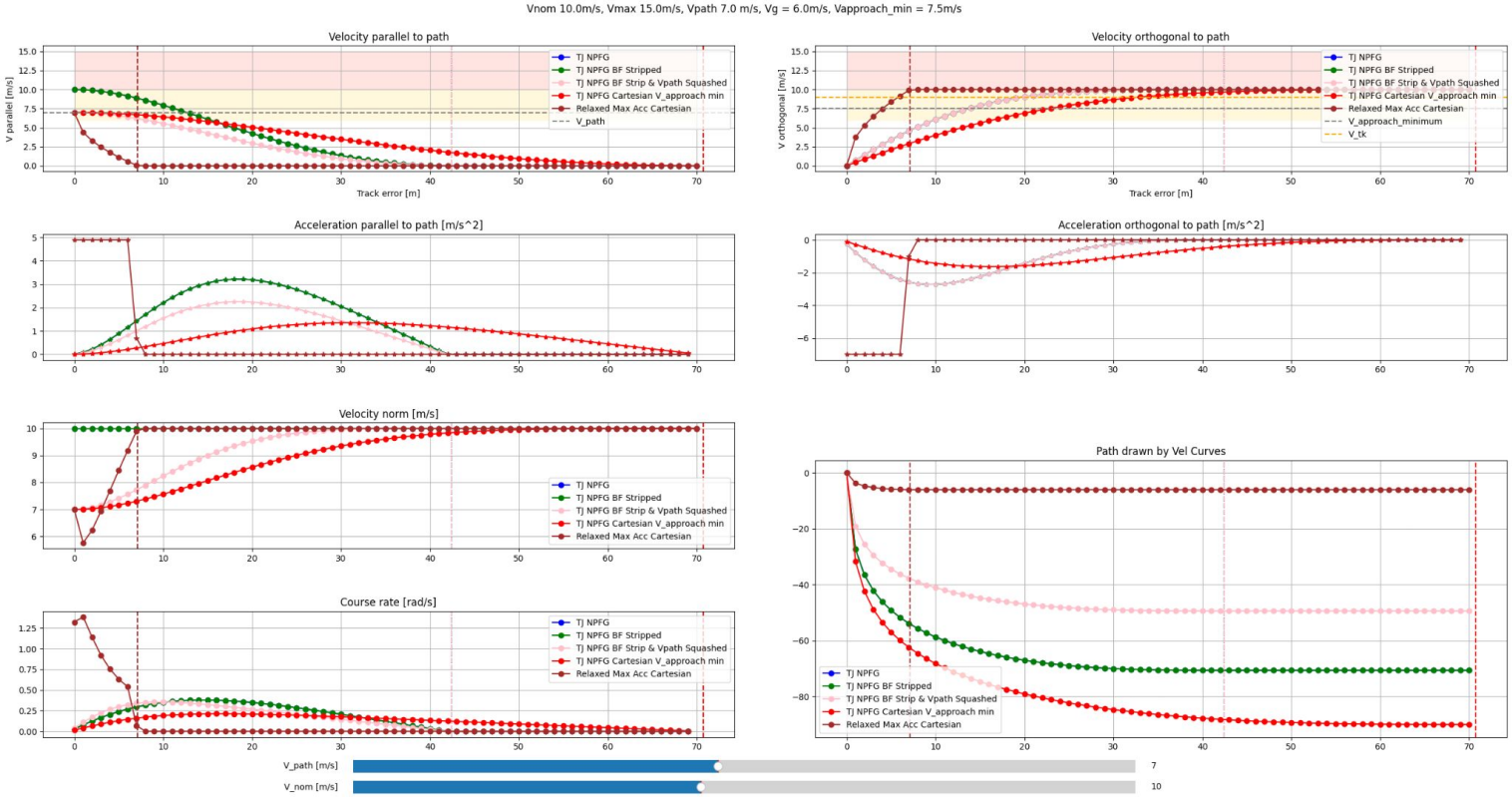

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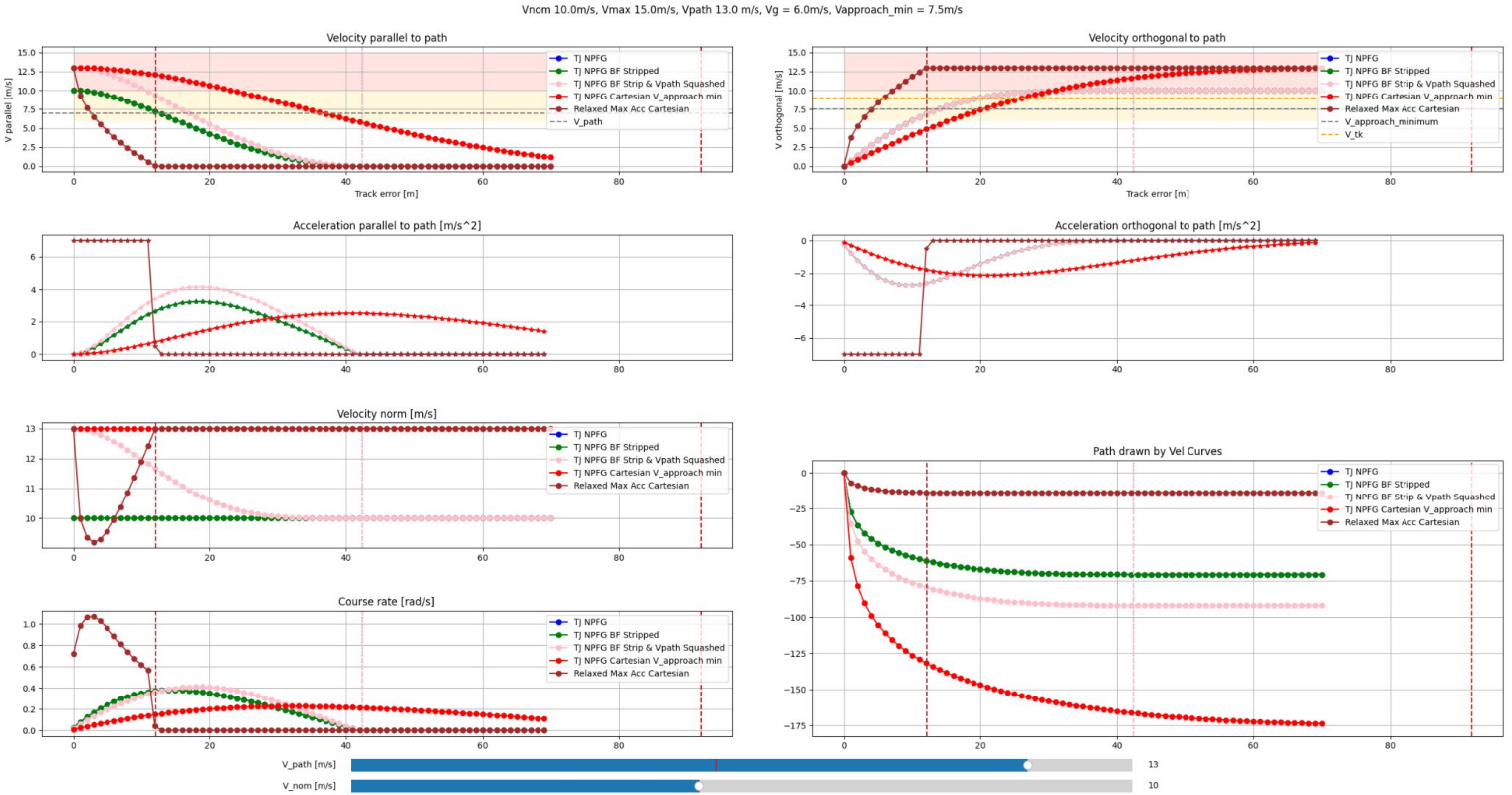

TK disabled / Min Approach Speed en

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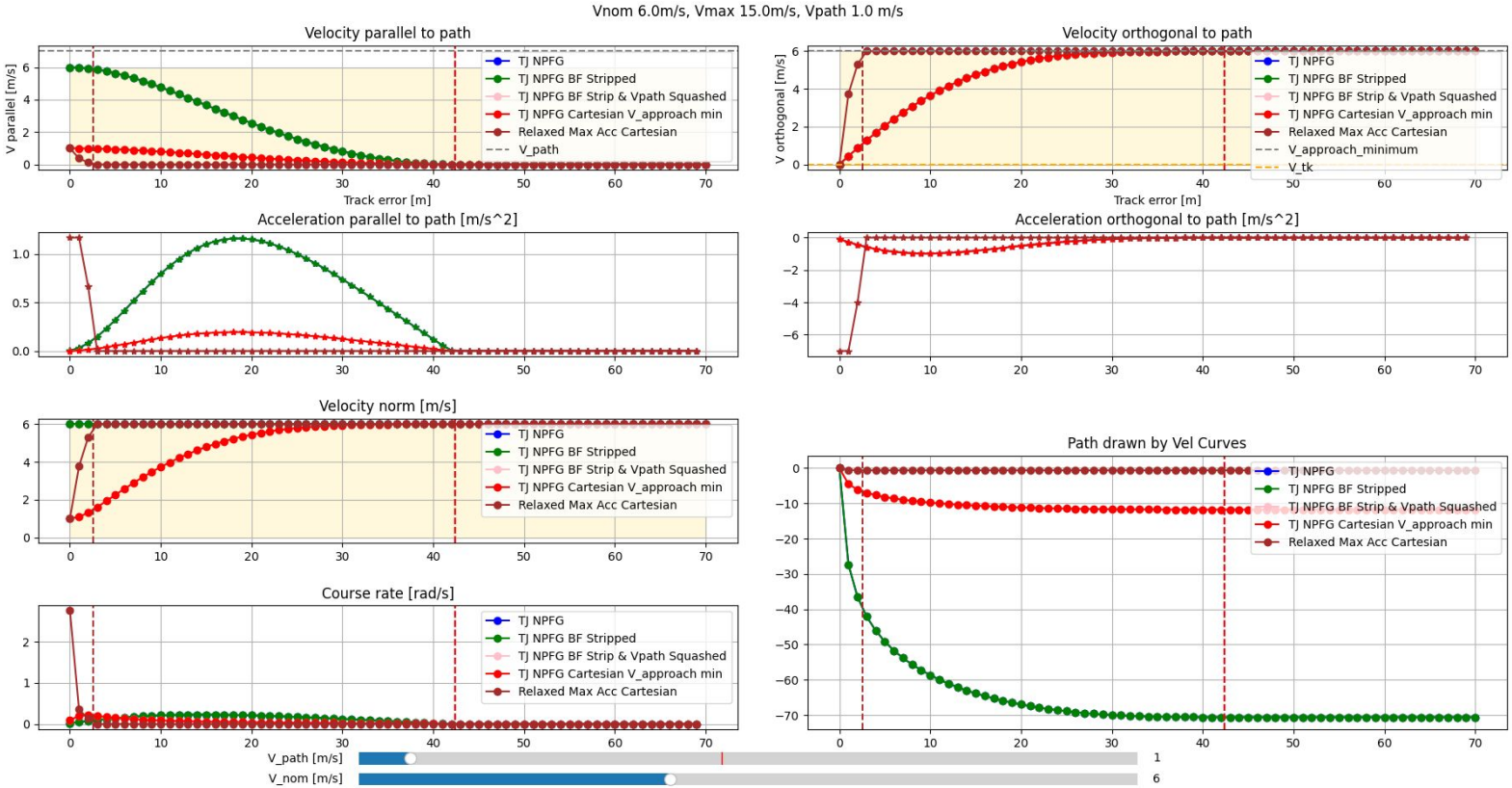

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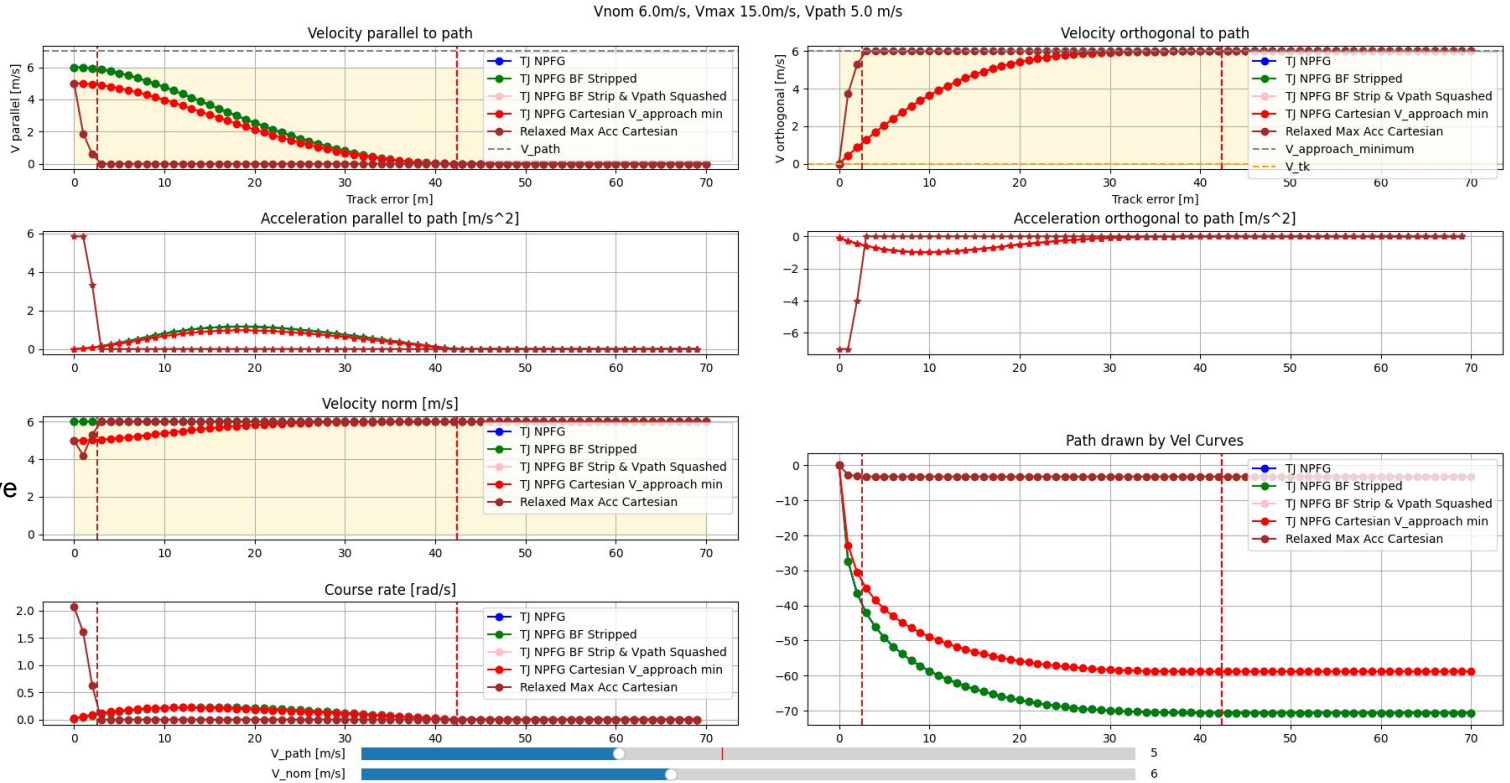

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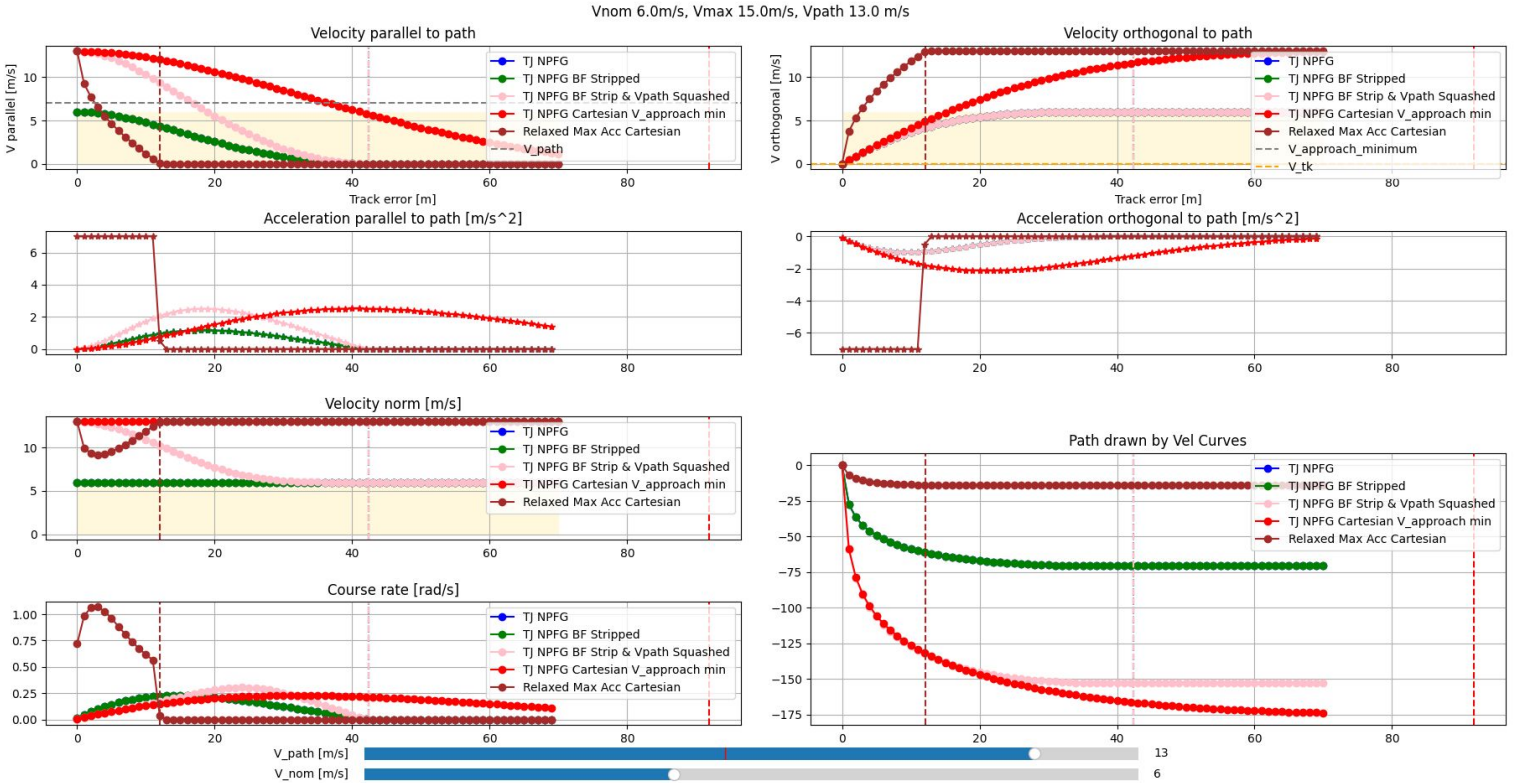

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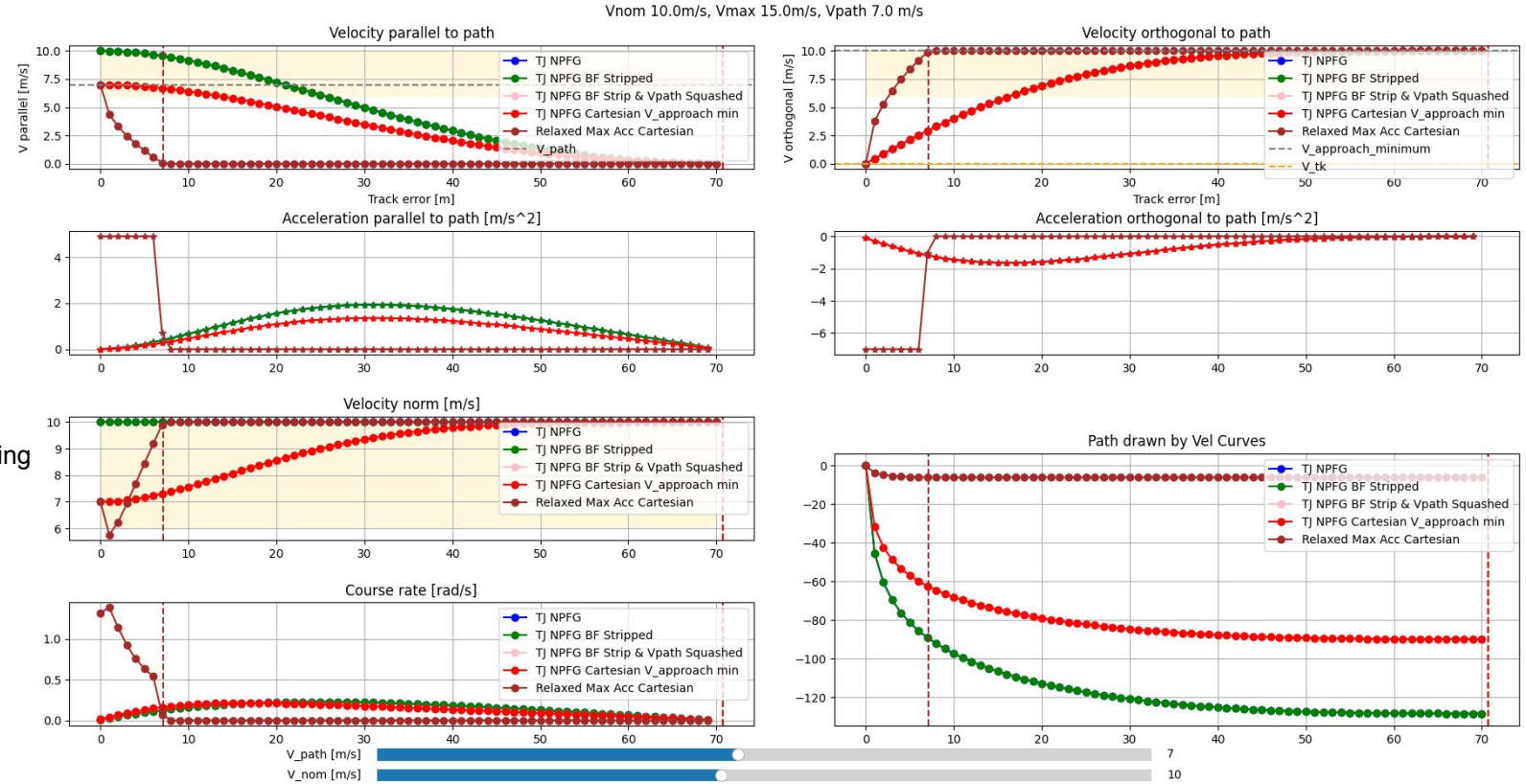

V_nom dipping (Max Acc)

Aggressive course rate (Max Acc)

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