FREESPACE SOLUTIONS™

ARDUPILOT
Versatile, Trusted, Open

Advanced Guidance

(Guided Mode)

Leonard Hall

First a quick update

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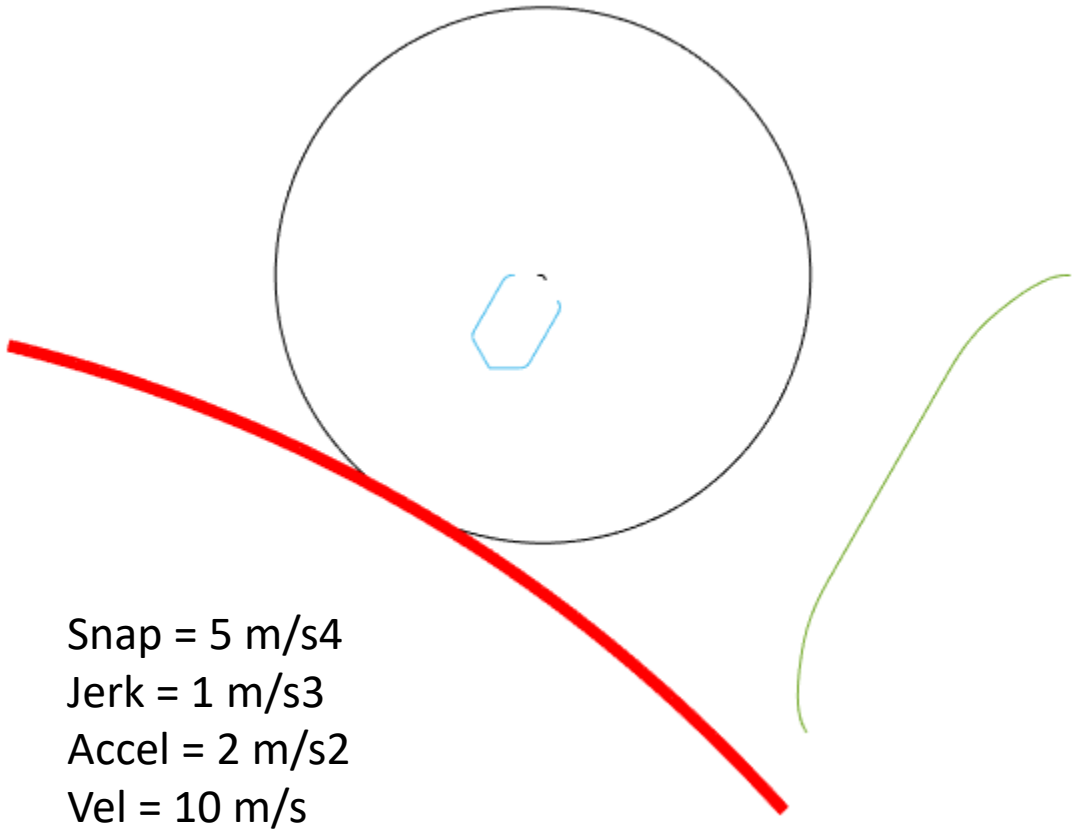
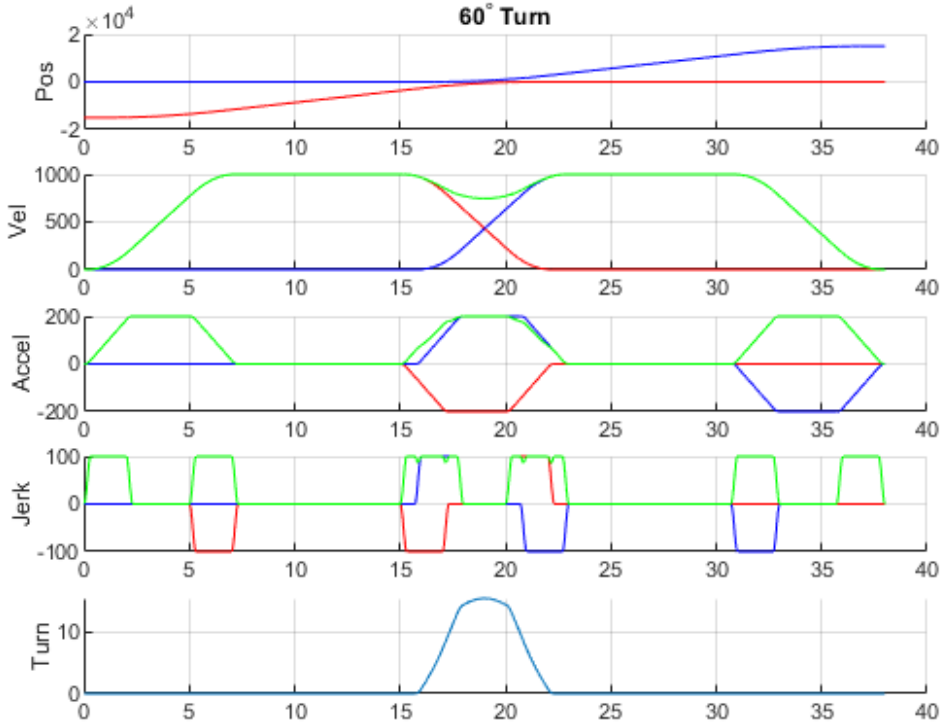
- Attitude control
  - thrust vector and heading control seems to be working well
- Separation of ACRO and PILOT parameters
  - Expo, Rate TC, Roll / Pitch / Yaw rates (no more Rate_P)
- S-Curves are in and operating well.
  - Fixed short waypoint problem in 4.2
  - Pause mission with calculation of tangential acceleration
  - Separate Corner acceleration – Should we have a parameter?
- Real time S-Curves
  - Reduce reaction time to small changes
  - Apply Real time S-Curves to Guided mode
- Position Control
  - Prioritize cross track error over tangential error
  - Removed override in precision landing (uses Real Time S-Curves)
- Remove Loiter from Takeoff and Landing

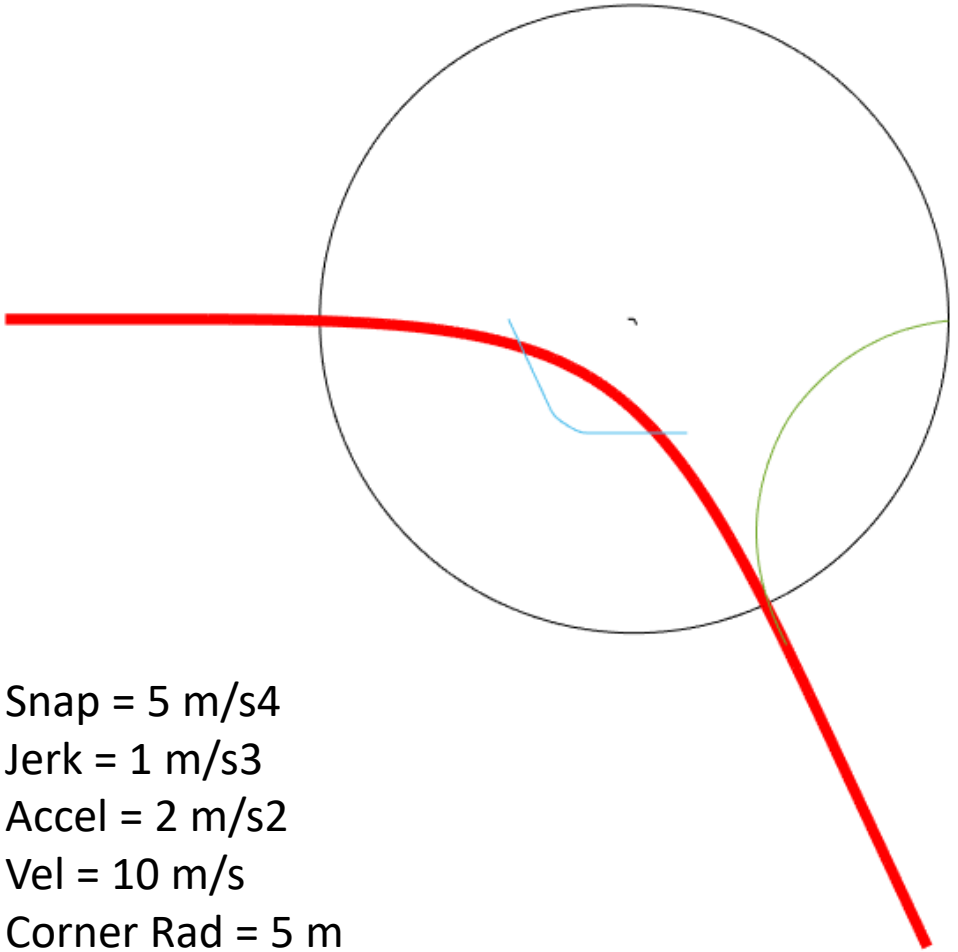
60° Turn



Snap = 5 m/s4
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 5 m
Corner Accel = 2 m/s2



65° Turn



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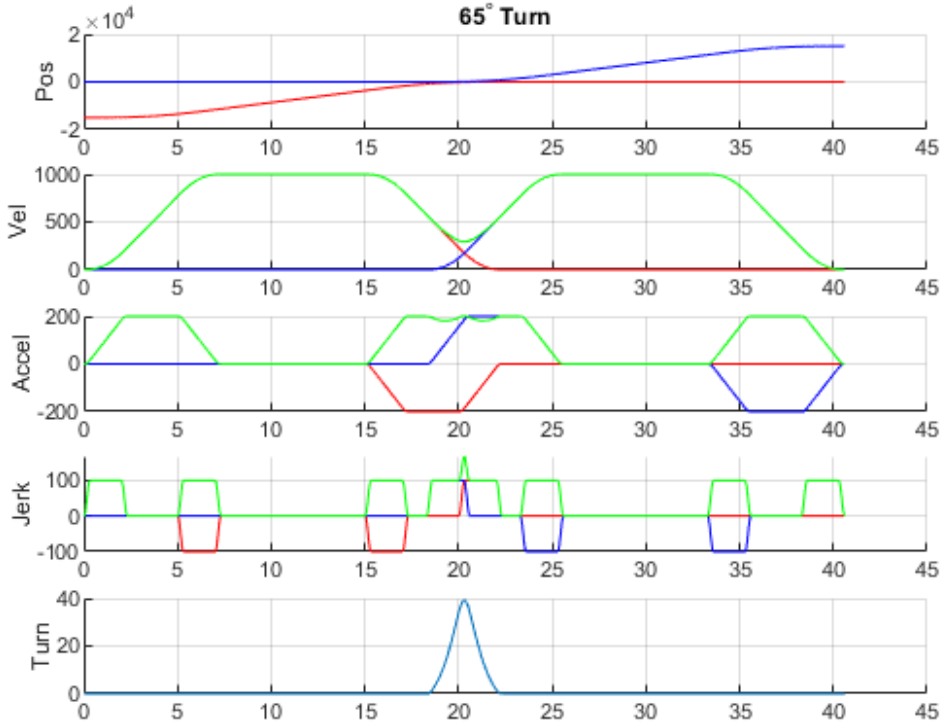
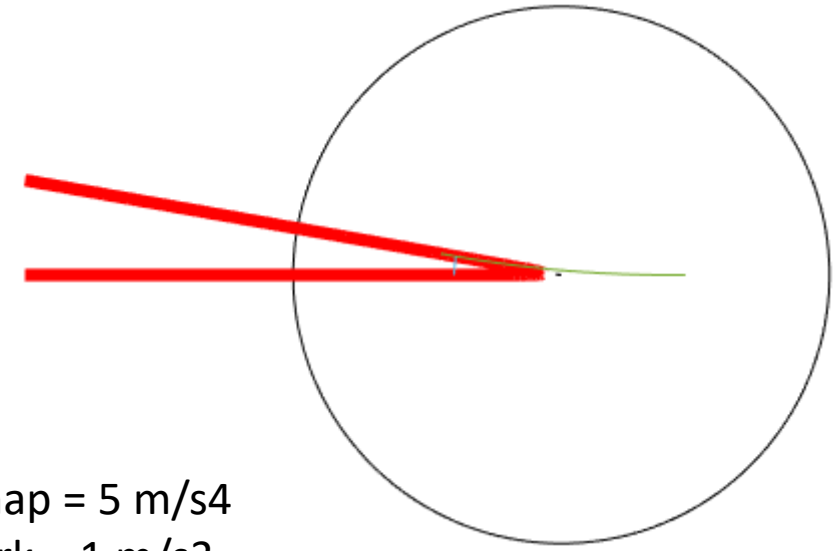


190° Turn



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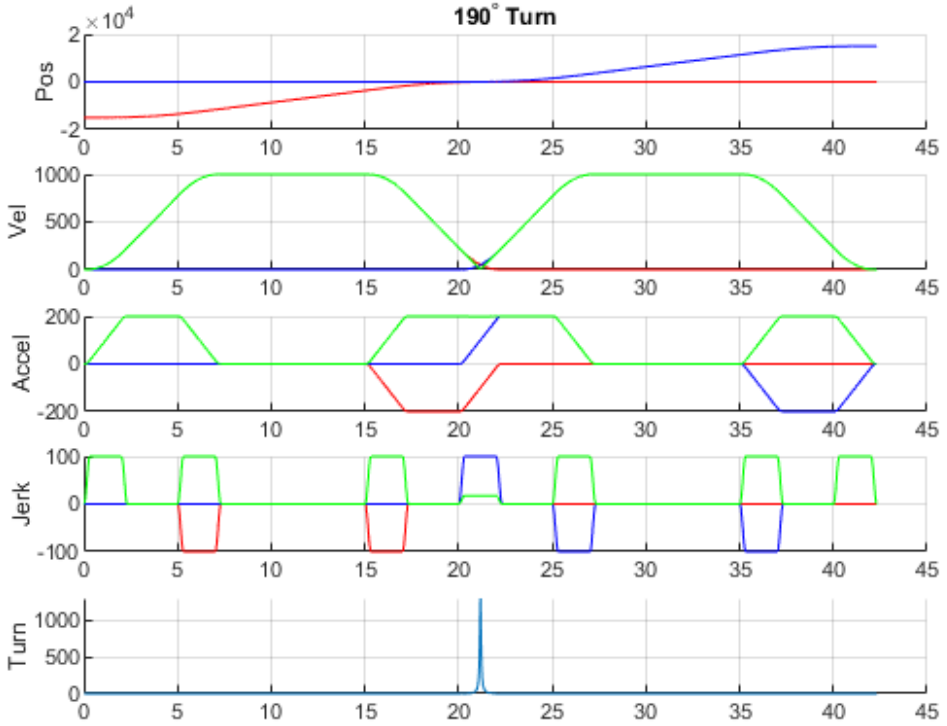
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 5 m
Corner Accel = 2 m/s2



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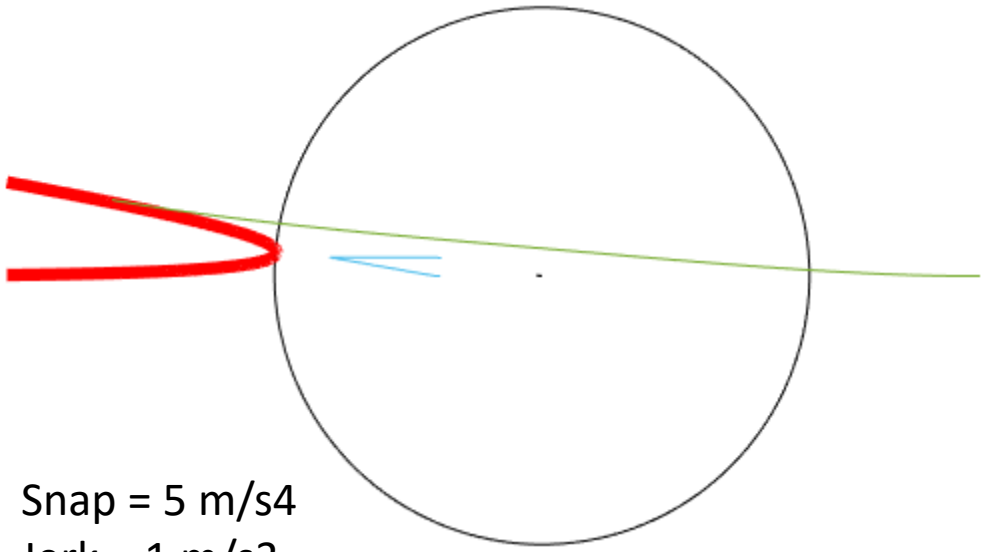
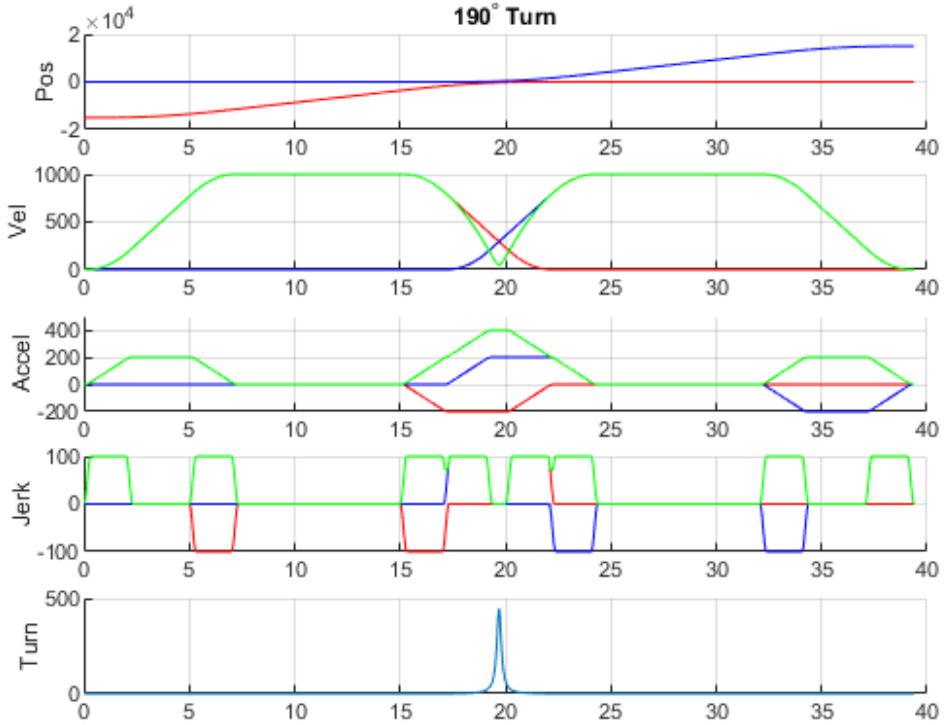
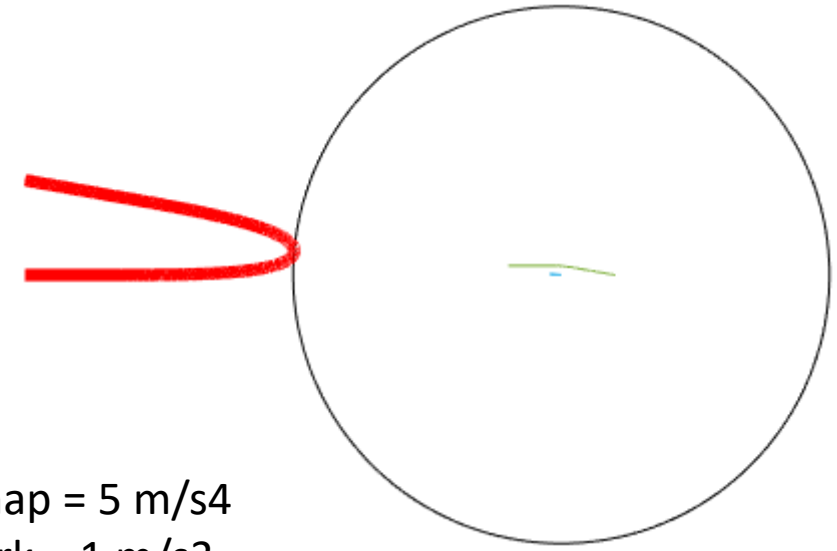


Snap = 5 m/s4
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 5 m
Corner Accel = 4 m/s2



190° Turn



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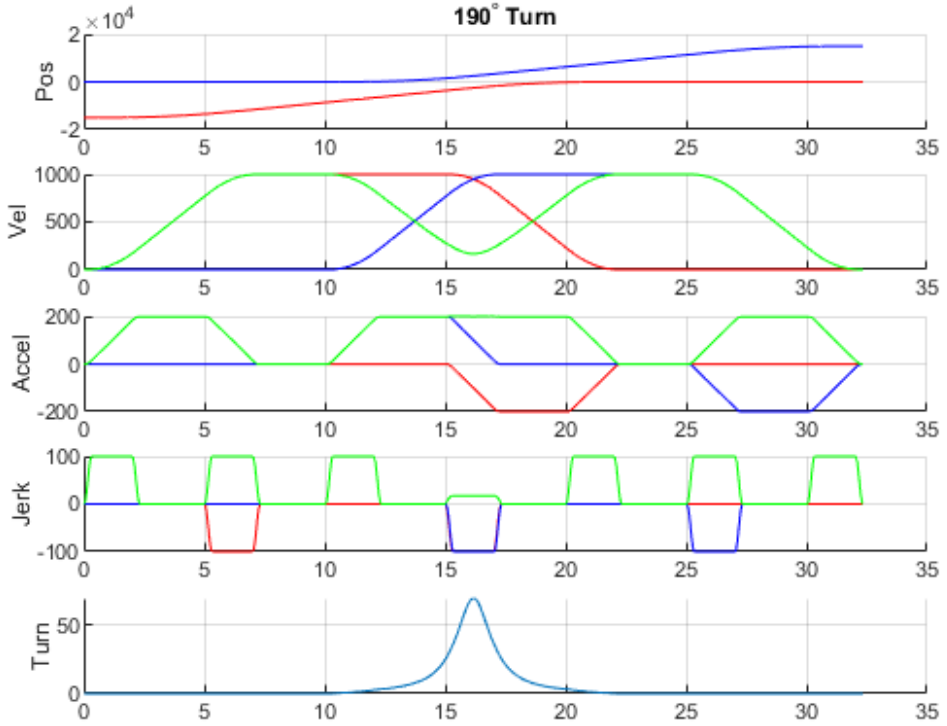
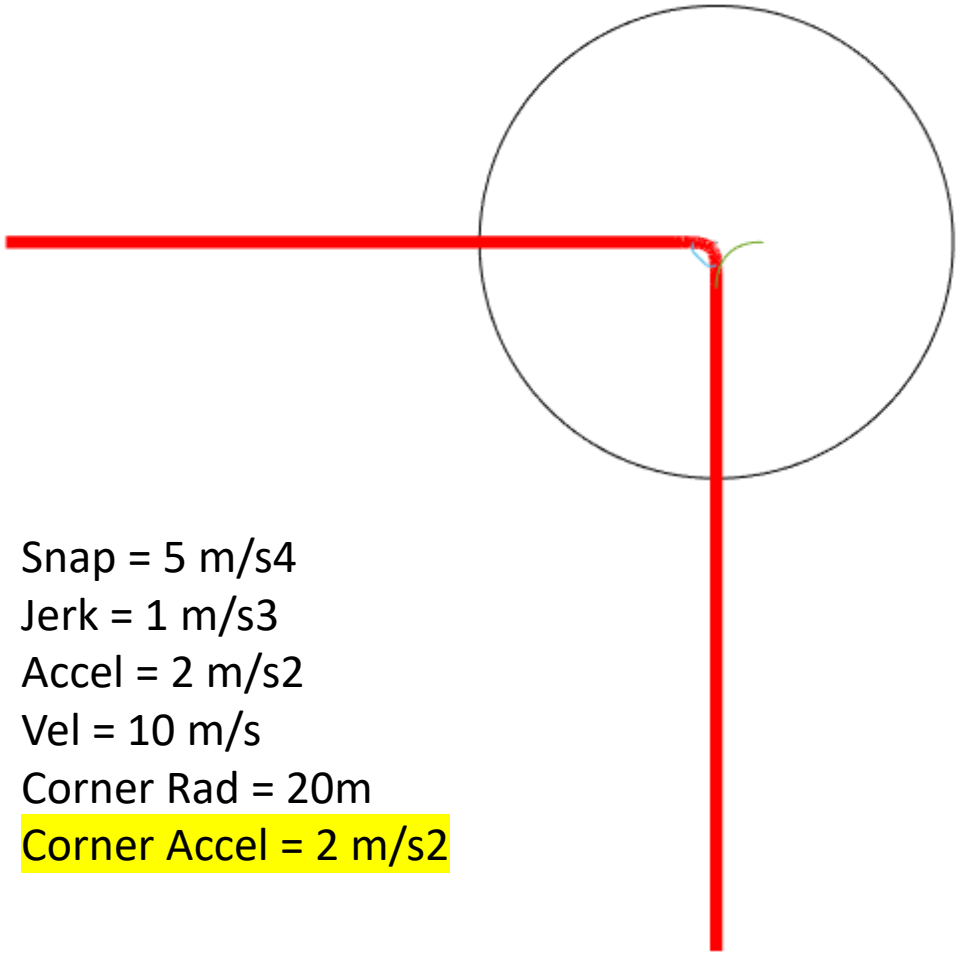
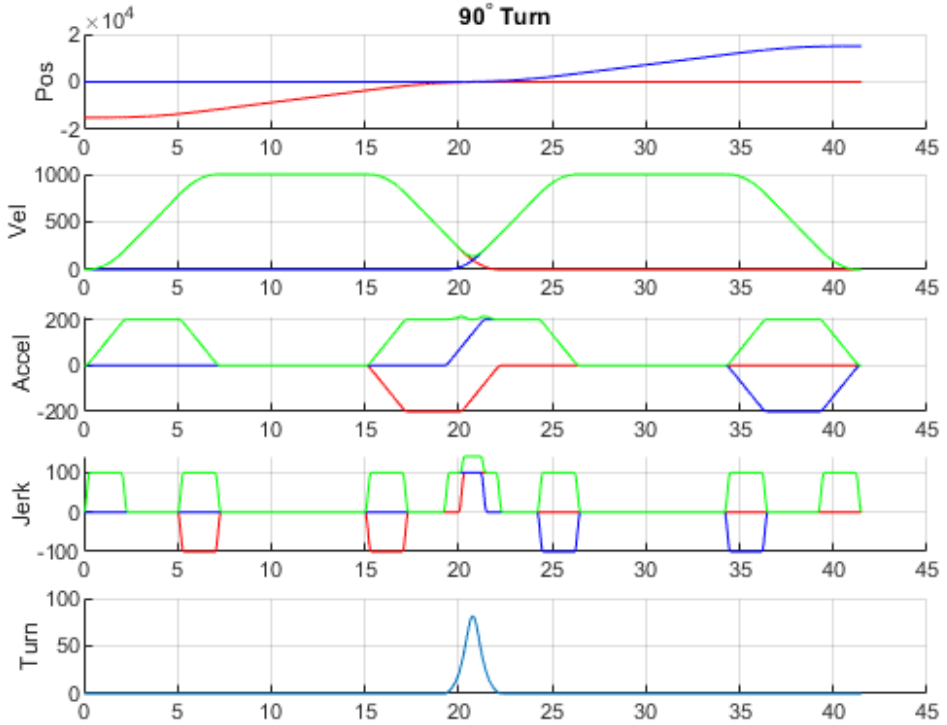
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 50m
Corner Accel = 4 m/s2



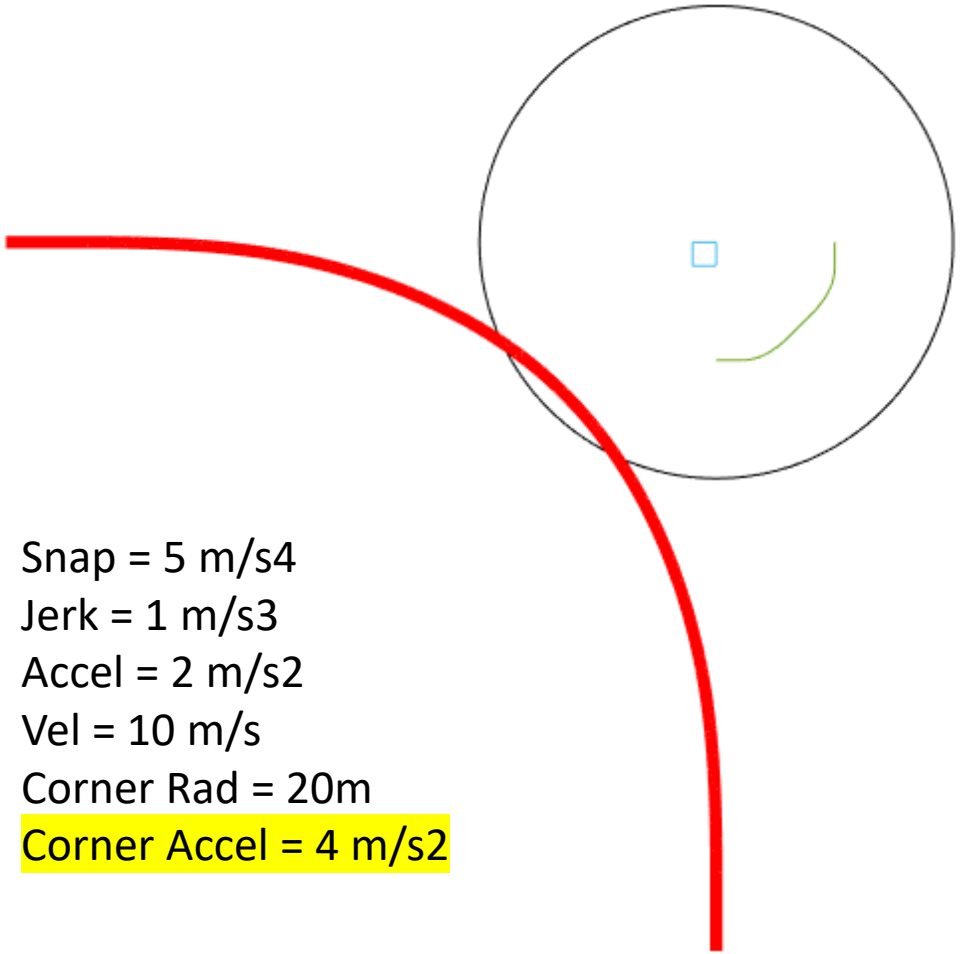
90° Turn



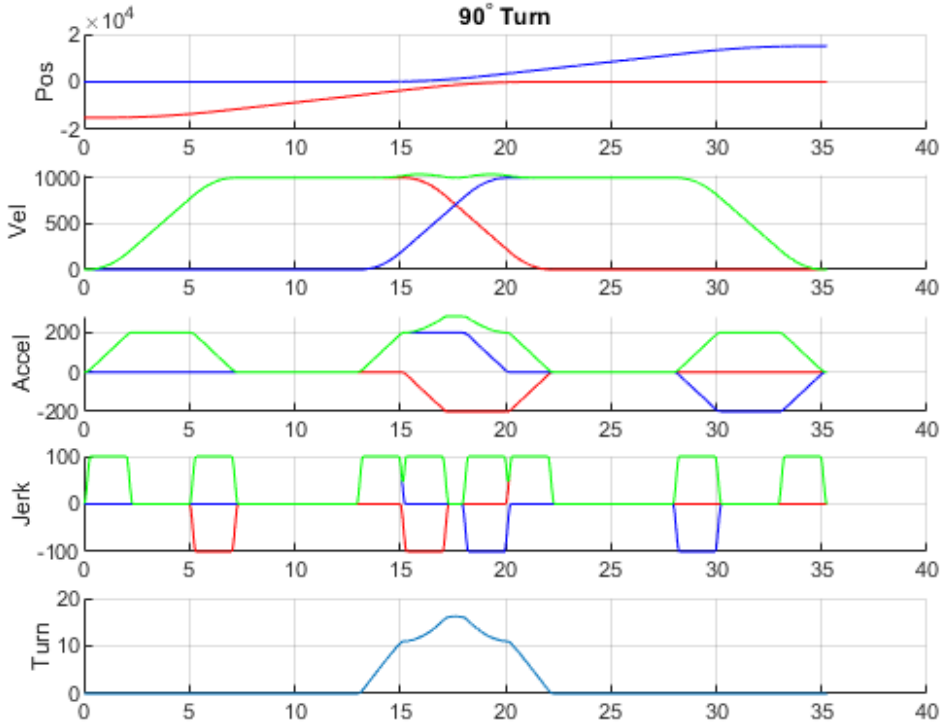
Snap = 5 m/s4
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 20m
Corner Accel = 2 m/s2



90° Turn



Snap = 5 m/s4
Jerk = 1 m/s3
Accel = 2 m/s2
Vel = 10 m/s
Corner Rad = 20m
Corner Accel = 4 m/s2



Max Corner Acceleration

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Is it worth an extra parameter?

How do we control an aircraft

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- We provide directions……
  - What directions?
- Are the directions complete?
  - How do we handle the ambiguities?
- Do we provide instructions on HOW to get there?
- Highly dependent on aircraft dynamics!

- Users tend to be Narcissistic
  - They want a command to be only just complicated enough to completely handle their current problem.
  - All unspecified behaviour should support their current problem.

How do we control an aircraft

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- Attitude
  - Roll, Pitch, Yaw
  - Roll, Pitch, Yaw Rate
  - Roll Rate, Pitch Rate, Yaw Rate
- Altitude
  - Throttle
  - Vertical Rate
  - Vertical Position
- What do we provide the User?
  - Users Answer: What I think I need before I work out that I need something else.

How do we control an aircraft

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How do people think about providing directions?

- Destination and limits
  - Go to this location with a maximum speed of X
  - Planning is done in the AutoPilot
  - Simple for User but inflexible
  - What limits should be defined in the message?

- Position, Velocity, Acceleration
  - This is exactly what I want you to be doing right now
  - Planning is done by the User
  - Complex for User but flexible

MAVLINK

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- The Micro Air Vehicle Link is a communication protocol for unmanned systems
- LGPL license
- Vehicle agnostic

- Three general control commands:
  - SET_POSITION_TARGET_LOCAL_NED
  - SET_POSITION_TARGET_GLOBAL_INT
  - SET_ATTITUDE_TARGET

- Matching reply or status commands
- Potential to add additional commands

SET_ATTITUDE_TARGET (#82)

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- Attitude quaternion (w, x, y, z order, zero-rotation is 1, 0, 0, 0)
- Body roll rate rad/s
- Body pitch rate rad/s
- Body yaw rate rad/s
- Collective thrust ArduCopter also supports vertical velocity
- 3D thrust setpoint in the body NED frame, normalized to -1 .. 1

- ATTITUDE_TARGET_TYPEMASK
  - Ignore body roll rate
  - Ignore body pitch rate
  - Ignore body yaw rate
  - Use 3D body thrust setpoint instead of throttle
  - Ignore throttle (could be used to select climb rate)
  - Ignore attitude

SET_ATTITUDE_TARGET (#82)

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- Attitude + Throttle
- Attitude + Angular Velocity + Throttle
- Angular Velocity + Throttle
- Attitude + Vertical Velocity
- Attitude + Angular Velocity + Vertical Velocity
- Angular Velocity + Vertical Velocity

- What limits should the autopilot apply?
  - Vertical Velocity requires an angle limit
  - Throttle does not require an angle limit

- 6 Control Combinations

Attitude + Angular Velocity

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- How can we specify both an attitude and an angular velocity?
  - The command specifies what the current state should be.
  - The command does not specify HOW to achieve the commanded state.
- Example: A person is facing north
  - Attitude only:
    - Face South
  - Attitude + Rate:
    - Face North turning CW at 10 deg/s
    - Wait 18 seconds
    - Face South turning 0 deg/s

SET_ATTITUDE_TARGET (#82)

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Control input NOT supported by this Message:

- Partial attitude specifications:
  - Roll, Pitch + Rate Yaw
- Relative attitude changes:
  - Yaw by X degrees
- Altitude (Vertical control is not formally part of the message)
- Single axis rate commands (others must assume zero)

- Stabilize and Alt_Hold control is not possible with this message alone

SET_ATTITUDE_TARGET (#82)

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- Provides a complete attitude control solution
- Provides a FAST response when angular velocity is provided
- Any attitude interface can be replicated with the right transformations.

- People keep discussing some sort of Stabilize or Alt_Hold instruction.
  - Is this simply the first thing people think of because it is how they control the aircraft?
  - Is there some real advantage for a companion computer, something I am missing?

SET_POSITION_TARGET

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- SET_POSITION_TARGET_LOCAL_NED (#84)
  - X m X Position in NED frame
  - Y m Y Position in NED frame
  - Z m Z Position in NED frame
- SET_POSITION_TARGET_GLOBAL_INT (#86)
  - lat_int X Position in WGS84 frame
  - lon_int Y Position in WGS84 frame
- Common
  - vx m/s X velocity in NED frame
  - vy m/s Y velocity in NED frame
  - vz m/s Z velocity in NED frame
  - afx m/s/s X acceleration or force
  - afy m/s/s Y acceleration or force
  - afz m/s/s Z acceleration or force
  - yaw rad yaw setpoint
  - yaw_rate rad/s yaw rate setpoint

- POSITION_TARGET_TYPEMASK
  - Ignore position x
  - Ignore position y
  - Ignore position z
  - Ignore velocity x
  - Ignore velocity y
  - Ignore velocity z
  - Ignore acceleration x
  - Ignore acceleration y
  - Ignore acceleration z
  - Use force instead of acceleration
  - Ignore yaw
  - Ignore yaw rate
- MAV_FRAME - LOCAL_NED
  - MAV_FRAME_LOCAL_NED = 1,
  - MAV_FRAME_LOCAL_OFFSET_NED = 7,
  - MAV_FRAME_BODY_NED = 8,
  - MAV_FRAME_BODY_OFFSET_NED = 9
- MAV_FRAME - GLOBAL_INT
  - MAV_FRAME_GLOBAL = 0 or 5,
  - MAV_FRAME_GLOBAL_RELATIVE_ALT = 3 or 6,
  - MAV_FRAME_GLOBAL_TERRAIN_ALT = 10 or 11

SET_POSITION_TARGET

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Navigation Control:

- Position, Velocity, Acceleration
- Position, Velocity
- Position
- Velocity, Acceleration
- Velocity
- Acceleration

Heading Control:

- Heading, Heading Rate
- Heading
- Heading Rate

- Separation of X,Y and Z axis may be achieved using the ignore flags
  - 108 combinations – 756 with frames
- No way to enable or disable stabilization of ignored axis
  - Stop Position Stabilization
  - Stop Position and Velocity Stabilization
  - 300 control combinations – 2100 with frames
- Does not specify limits or path when velocity and acceleration are ignored
  - Fastest?
  - Straight line?
- ArduCopter supports
  - 18 Basic Combinations
  - 36 including disabling XY Stabilization
  - 2 straight line options

SET_POSITION_TARGET

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Oh, I forgot to mention:

- We should be able to swap seamlessly between control systems!
- We want to be able to control yaw manually!
- Collision avoidance should work!
- We should not breach the fence!
- Should the reply message be:
  - What we sent,
  - Our current state?
  - Our current target state?

“But I think it should be……”

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SET_POSITION_TARGET

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- We should be able to swap seamlessly between control systems! ✓
- We want to be able to control yaw manually! ✓
- Collision avoidance should work!
- We should not breach the fence!

- Handle collision avoidance at the position controller level
  - Bendy ruler algorithm may work effectively based only on the information in the position controller.
  - Fence limits may also be implemented at the Pos Control level.
  - This may generalise and extend these features to all Position controller-based modes. (Loiter, Follow, Pos Control …..)

GET_POSITION_TARGET

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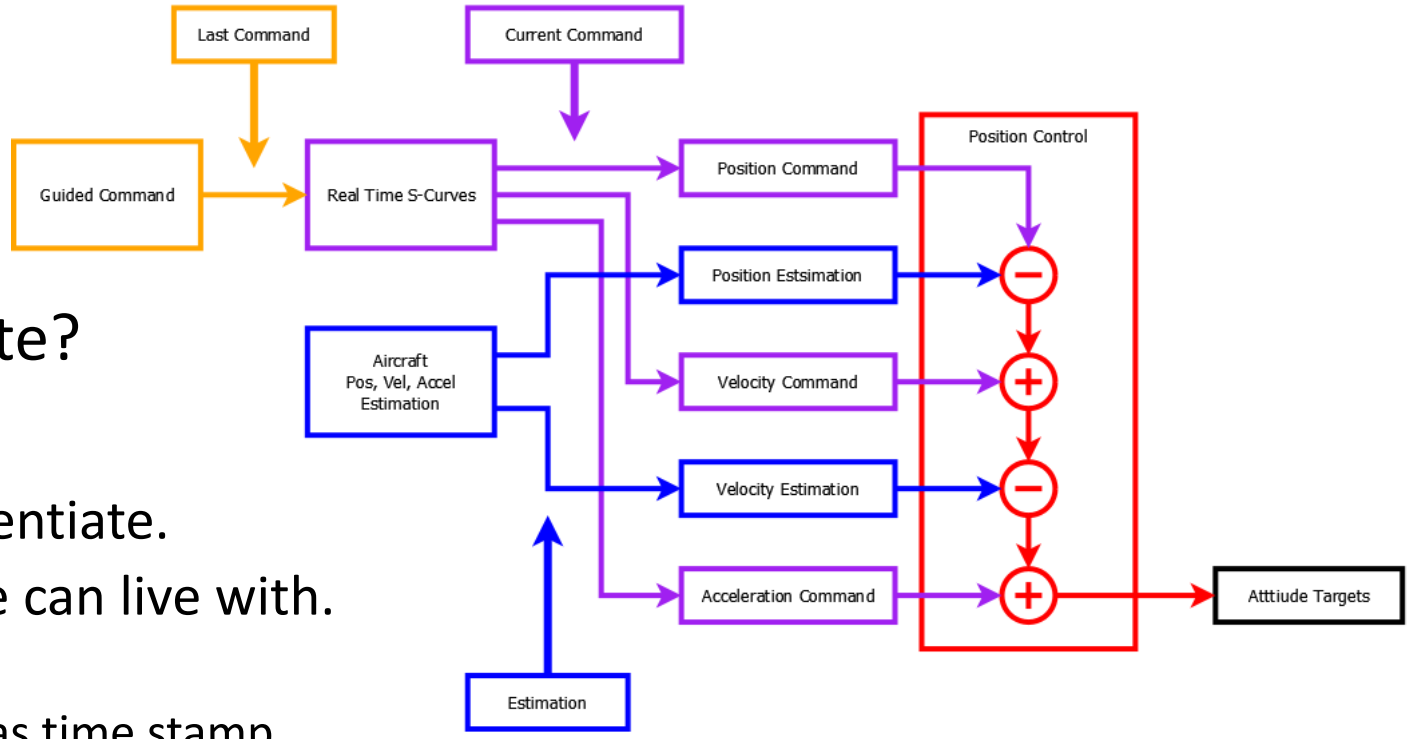
- Should the reply message be:
  - What we sent,

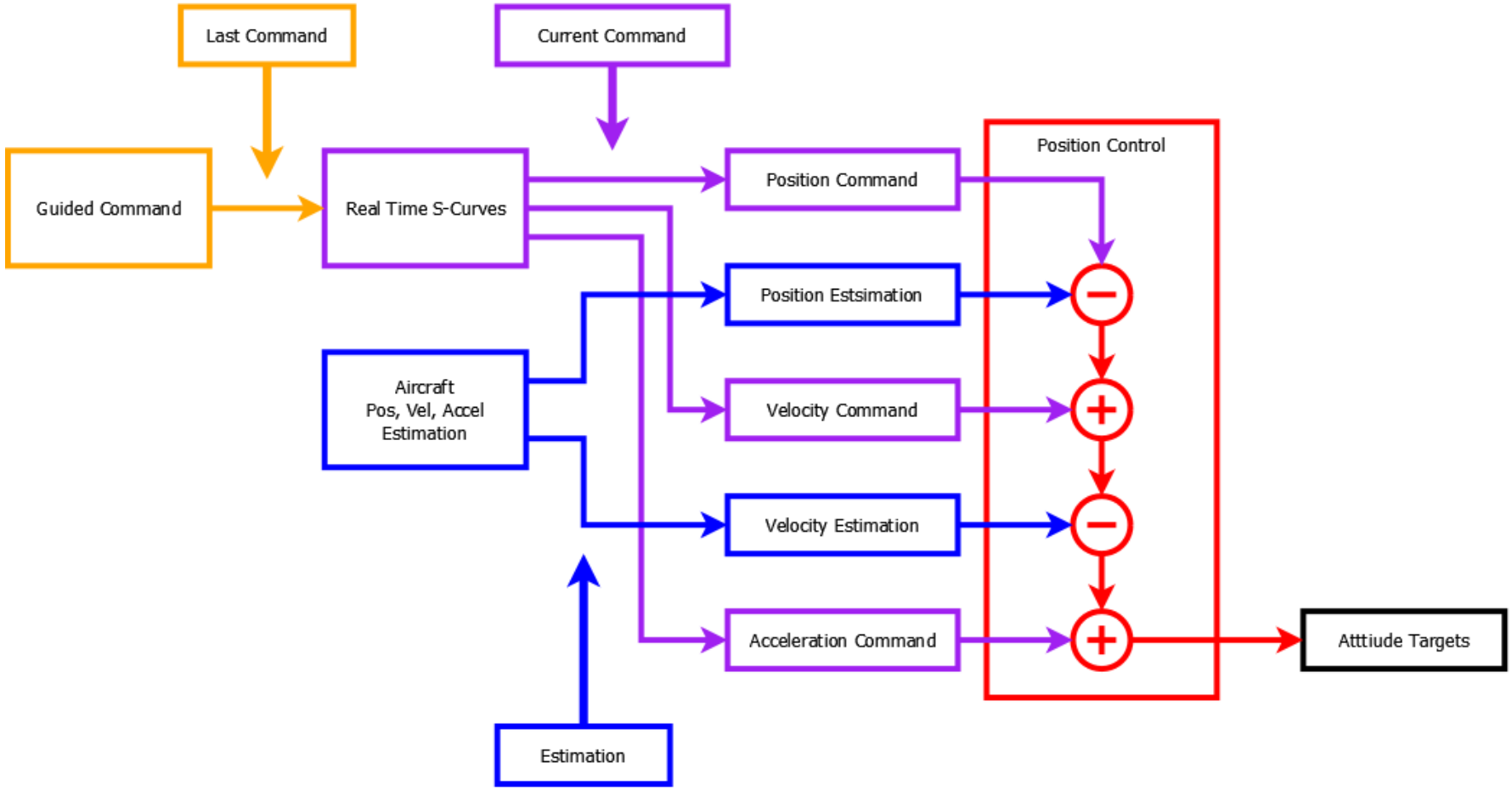
  OR
  - Our current state?

  OR
  - Our current target state?



- Time stamp may be used to differentiate.
- We need some formal decision we can live with.
- I would suggest
  - what was sent with received time as time stamp
  - Full message with current time stamp representing current target (not current state)

GET_POSITION_TARGET



GET_POSITION_TARGET

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- Guided command
  - Last instruction from the companion computer
- Real Time S-Curves
  - Project last instruction forward in time
  - Remove integration errors
  - Generate a Jerk limited “Target” trajectory following the command
- Estimation
  - Combine sensor data to generate Pos, Vel, Accel
- Position Controller
  - Make the Estimation as close as possible to the Target

Guided mode

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Pos Control Tools:

- input_pos_xyz
- input_pos_vel_accel (xy / z)
- input_vel_accel (xy / z)
- input_accel (xy / z)
- stop_pos_xy_stabilisation
- stop_vel_xy_stabilisation

Waypoint Navigation

- set_wp_destination

Pos Control Tools:

- Real time S-Curve trajectory
- Natural blending between commands
- Mix and match without discontinuity
- Path depends on state and limits

- Waypoint Navigation
  - Trigonometric S-Curve path
  - Strict path following
  - Initialised using stopping point
  - Discontinuous if called when moving

Real Time S-Curves

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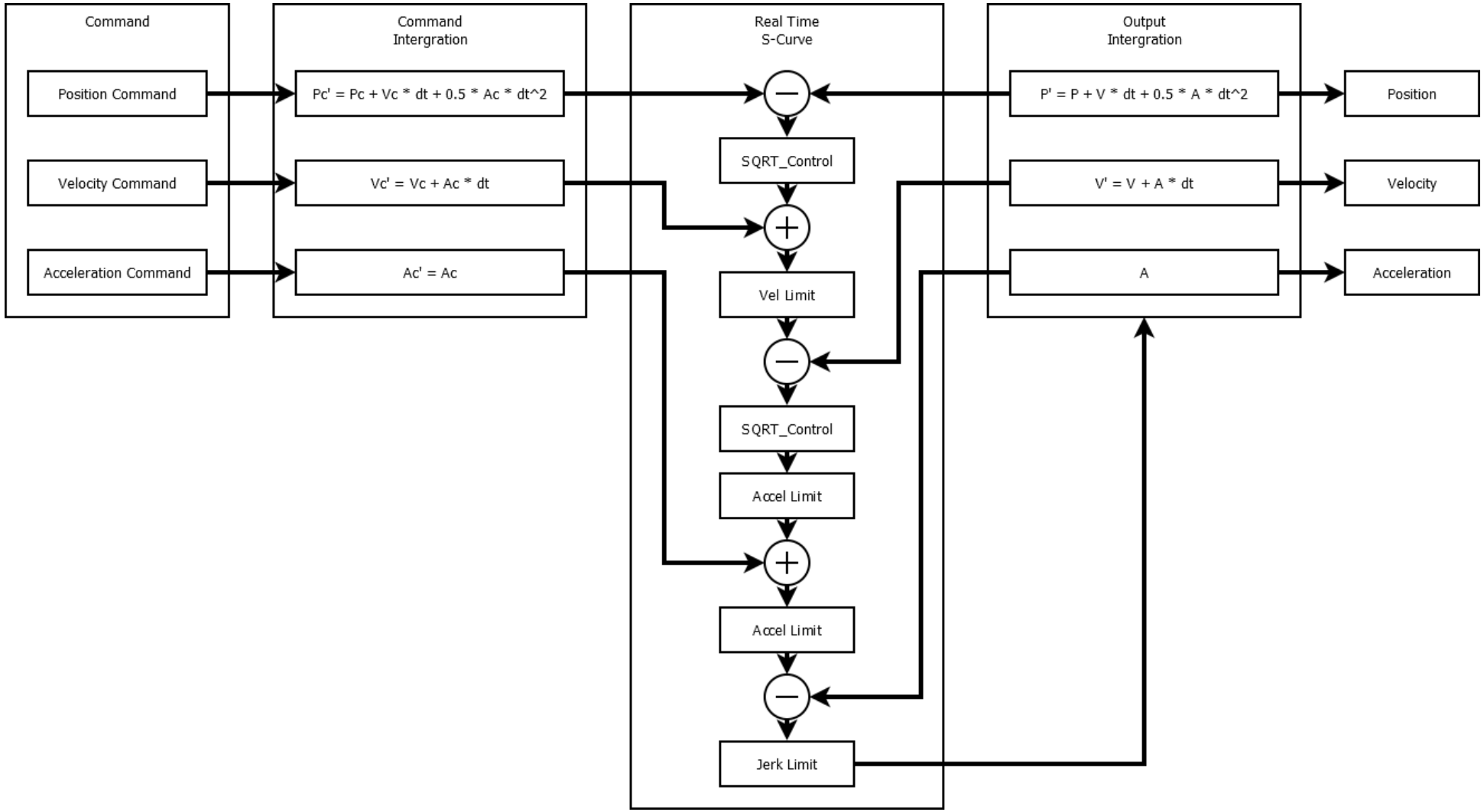
- Accepts Commanded
  - Position
  - Velocity
  - Acceleration
- Given Limits
  - Velocity
  - Acceleration
  - Jerk
- Move Pos, Vel, Accel towards commanded Pos, Vel, Accel using a Kinematically consistent, Jerk limited path.
- Output is an Acceleration

Real Time S-Curves



Guided Mode Future Development

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- Structure Guided mode handling of SET_POSITION_TARGET into vertical and horizontal functions
- Could we use SET_ATTITUDE_TARGET and SET_POSITION_TARGET together:
  - Attitude for thrust vector control.
  - Pos, Vel, Accel Z to control altitude.
  - Is it worth the complexity?
- Add a new message based on Destination + Limits
  - SET_ATTITUDE_LIMITS – Probably won't help users
  - SET_POSITION_LIMITS – Potentially useful for users
  - Stabilize / Alt Hold equivalent command – hard to justify when SET_ATTITUDE_TARGET is so complete.
- LUA scripting
  - Great care needs to be used when defining interface functions.
  - Guided mode interface is limited by the Mavlink commands.
  - Direct access to AC_PosControl and AC_AttitudeControl is desirable
  - Custom LUA flight mode may be required for safe operation.

Looking forward to 4.3

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- Ground / Air transition handling
  - Throttle time constant
  - Ground separation detection
- Complete Guided Mode implementation
  - Finalize and implement “GET” messages
- S-Curves
  - Add function to implement fast stop to assist WP based guided
- Follow Mode
  - Use Real time S-Curves to generate high-rate trajectory data
- Collision Avoidance Structure development
  - Support natively as some sort of Position Controller integration

Questions