Altitude Hold and Speed Control – Installation, Setup and Operation

Control modes

The MatrixPilot altitude hold function adjusts the throttle and elevator to maintain a target altitude and airspeed, with the following options and modes of operation:

In manual mode, the pilot has complete and sole control over elevator and throttle. In manual mode, all pilot inputs are passed directly through to the servos.

In stabilized mode, altitude/speed control behavior depends on the value of the ALTITUDEHOLD_STABILIZED parameter in the options file:

- AH_NONE ï MatrixPilot augments the pilot's elevator input to stabilize aircraft pitch only. No effort is made to control altitude or speed, that is entirely up to the pilot.
- AH_PITCH_ONLY ï MatrixPilot augments the pilot's elevator input to stabilize pitch and to control altitude. Airspeed is also included in the control, if the SPEED_CONTROL parameter in the options file is set to 1. Throttle control is a direct pass through. The pilot must be alert to adjust the throttle as needed, because elevator alone is not adequate to control both altitude and airspeed. The target altitude is whatever altitude the plane is flying at when stabilized control mode is engaged. The target airspeed is specified in meters per second by the parameter DESIRED_SPEED in the options file.
- AH_FULL ï MatrixPilot augments the pilot's elevator input, and completely takes over throttle control, to stabilize pitch and control altitude. Airspeed is also controlled, if the SPEED_CONTROL parameter in the options file is set to 1. The target altitude is set by the pilot throttle input. When the throttle stick is at its completely off position, MatrixPilot shuts the motor off, turns off speed control, and stabilizes pitch, typically used for stabilized gliding. Otherwise, when the throttle stick is somewhere in its normal range, MatrixPilot computes a target altitude that is proportional to the throttle stick input, with a maximum target altitude in meters equal to HEIGHT_TARGET_MAX. The target airspeed is specified in meters per second by the parameter DESIRED_SPEED in the options file.

During stabilized mode with the AH_FULL option, the target altitude is set according to the throttle stick on the transmitter. This achieves a similar feel to the controls in both manual and stabilized mode. You can still control the elevator and the throttle from the transmitter with altitude hold turned on. The only difference is that altitude hold will control the throttle and augment the elevator signal to maintain altitude. Stabilized mode with the AH_FULL altitude hold option can be used during takeoff and landing. For takeoff, you use maximum throttle. For landing, you use a low throttle setting.

In waypoint mode, the altitude control options are set by the ALTITUDEHOLD_WAYPOINT parameter in the options file:

- AH_NONE ï The option makes no sense in waypoint mode.
- AH_PITCH_ONLY ï MatrixPilot augments the pilot's elevator input to stabilize pitch and control altitude. Airspeed is also controlled, if the SPEED_CONTROL parameter in the options file is set to 1. Throttle control is a direct pass through. The pilot must be alert to adjust the throttle as needed, because elevator alone is not adequate to control both altitude and airspeed. The target altitude is computed by the MatrixPilot navigation controls, either by a list of waypoints or via LOGO. The target airspeed is specified in meters per second by the parameter DESIRED_SPEED if waypoints are being used, or by the LOGO navigation specification.
- AH_FULL ï MatrixPilot augments the pilot's elevator input, and completely takes over throttle control, to stabilize pitch and control altitude. Airspeed is also controlled, if the SPEED_CONTROL parameter in the options file is set to 1. The target altitude is computed by the MatrixPilot navigation controls, either by a list of waypoints or via LOGO. The target airspeed is specified in meters per second by the parameter DESIRED_SPEED if waypoints are being used, or by the LOGO navigation specification. When the throttle stick is at its completely off position, MatrixPilot shuts the motor off, turns off speed control, and stabilizes pitch. No attempt is made to control altitude or speed, but navigation continues to operate to reach the waypoints.

MatrixPilot includes a fail-safe feature. If valid pulses stop arriving on the fail-safe channel, it goes into a fail-safe return to launch mode in which it executes a separate list of waypoints. The same altitude control options apply as for waypoint mode, except the pilot will not have any control over any of the plane's control surfaces, and no control over the throttle.

Setting the control parameters

Altitude control works by comparing the actual altitude with the target altitude, and adjusts the throttle and elevator to provide negative feedback to drive the altitude and speed toward the target values.

The details of the control actions in response to altitude error depend on whether or not the speed control option has been selected. If speed control is not selected, control of both the throttle and the elevator is based on the actual altitude error:

$$Error = Height_{desired} - Height_{actual}$$

However, if speed control is selected, adjustments are made to the error signals used for throttle and elevator control that account for the equivalent height of the speed of the plane:

$$Error_{throttle} = Height_{desired} - Height_{actual} + \left(\frac{Velocity^2_{desired} - Velocity^2_{actual}}{2 \cdot gravity} \right)$$

Including the equivalent height of the energy associated with the velocity of the plane in the throttle control helps suppress the phugoid response that you might get if you based throttle control on only the actual height.

For the velocity, the smaller of ground speed or air speed is used, to enable the plane to make progress when flying into the wind, and to prevent the plane from stalling when flying with the wind.

A similar adjustment is made in the error signal for the elevator, with the opposite sign for the velocity contribution:

$$Error_{throttle} = Height_{desired} - Height_{actual} - \left(\frac{Velocity^2_{desired} - Velocity^2_{actual}}{2 \cdot gravity} \right)$$

The following are the parameters that you use to set up altitude and speed control.

- SPEED_CONTROL ï Define this to be 1 if you want speed control, otherwise set it to zero.
- DESIRED_SPEED ï If you are using speed control, define this to be the target speed, in meters per second.
- HEIGHT_TARGET_MIN ï If you are using altitude control in stabilized mode, define this to be the target altitude in meters that you want to correspond to the lowest throttle setting that engages altitude control. Typical value is 25 meters. *If you set the minimum height to a positive number and are using AH_FULL, you will wind up landing dead-stick. If you use a negative value of height minimum, throttle control will continue all the way through landing*.
- HEIGHT_TARGET_MAX ï If you are using altitude control in stabilized mode, define this to be the target altitude in meters that you want to correspond to the highest throttle setting. Typical value is 100 meters.
- HEIGHT_MARGIN ï This defines the linear range of operation of the altitude controls in any control mode that engages altitude control. When the actual height is equal to the target height minus HEIGHT_MARGIN, throttle and pitch go to their maximum values. When the actual height is equal to the target height plus HEIGHT_MARGIN, throttle and pitch go to their minimum values. Typical value is 10 meters. Using a smaller value for this parameter

- ALT_HOLD_THROTTLE_MIN ï The minimum amount of throttle to be used, when the height is equal to the target value plus the margin.
- ALT_HOLD_THROTTLE_MAX ï The maximum amount of throttle to be used, when the height is less than or equal to the target value minus the margin.
- ALT_HOLD_PITCH_MIN ï This is the minimum pitch angle, in degrees, that the control will attempt to hold the plane's pitch, when the height is equal to the target value plus the margin. Typical value is -15 degrees.
- ALT_HOLD_PITCH_MAX ï This is the maximum pitch angle, in degrees, that the control will attempt to hold the plane's pitch, when the height is less than or equal to the target value plus the margin. Typical value is +15 degrees.
- ALT_HOLD_PITCH_HIGH ï This is the pitch angle, in degrees, that the control will attempt to hold the plane's pitch, when the height is greater than the target value plus the margin. Use a negative value if you want the controls to seek the target altitude, use zero if you want the plane to glide and take advantage of lift. Typical values are -15 degrees or 0 degrees.

Note that when the height of the plane is greater than the target value plus the margin, the throttle will turn off and the pitch target will be set to the "pitch_high" value.

Here are some suggestions for selecting values.

First, before you adjust altitude control, get the pitch stabilization controls working to your liking by adjusting the pitch feedback gain. That is because the net altitude control gain is equal to the pitch stabilization gain divided by the height margin.

When setting the minimum and maximum throttle values, keep in mind that the way the software computes the throttle is by starting with whatever pulse width the Tx was sending 10 seconds after power up, and adding 1 millisecond times the throttle setting parameter. For example, suppose the initial, "trim" setting on the throttle channel was 1 millisecond, and the minimum and maximum throttle settings are 0.35 and 1.0. Then the pulse width of the PWM throttle control will be between 1.35 and 2.0 milliseconds.

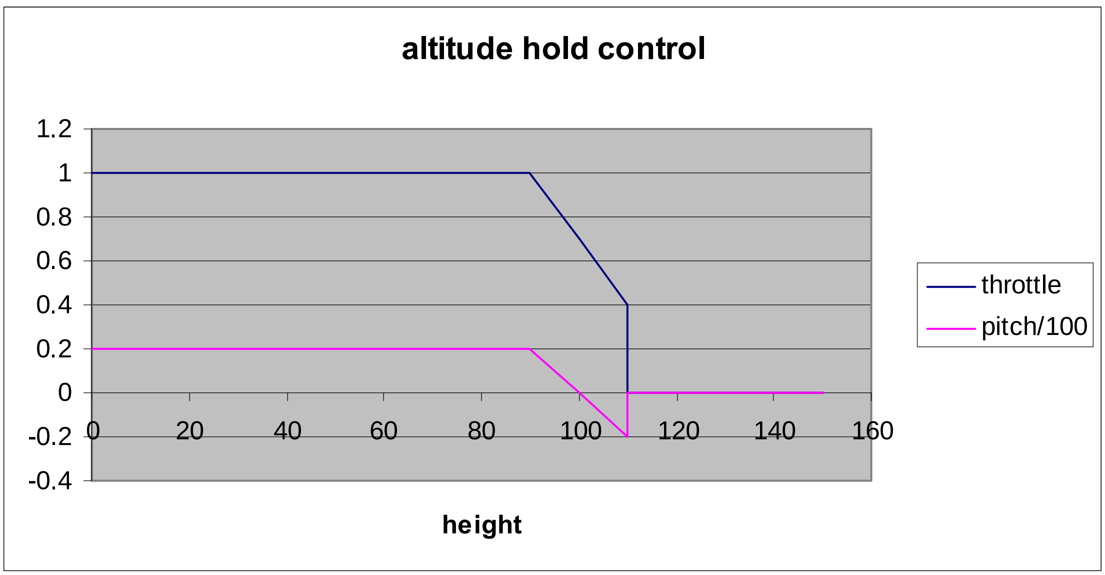
If you use speed control, set the desired speed to be the cruising air speed of your plane. You can either estimate what that is, or measure it from the telemetry data. The desired speed is not a critical setting.

The height margin is a critical setting. Basically, it is the inverse of a gain. If you set it for a very small value, such as 2 meters for example, the gain will be very high. Although the control will then hold the altitude to within a tight margin, the throttle will be turning on and off, and the plane will pitch up and down. If you set a very large value, such as 20 meter for example, the gain will be very low. This means the response will be very smooth, but the plane will wander up and down a bit. So, adjust the height margin accordingly.

Keep in mind that lift and downdrafts play a very important role in the altitude controls. Strong lift will cause the altitude controls to pitch the plane down in an effort to maintain altitude, and the speed will increase as a result. Similarly, downdrafts will slow the plane down as it may struggle to gain altitude.

When setting the throttle and pitch parameters, it is best if the minimum pitch is equal to minus the maximum pitch, and if the average of the maximum and minimum throttle setting is the cruising value of the throttle. The reason for that is when the plane is flying at the target altitude at the desired speed, the pitch and throttle controls will be at the average of the minimum and maximum settings.

The following figure shows how the throttle and pitch will vary with altitude for a typical collection of settings:



Minimum pitch is -20 degree, maximum pitch is 20 degrees, and pitch high is 0, so the plane can glide. Target height is 100 meters. Height margin is 10 meters. Throttle minimum is .4, maximum is 1.0.

Installation and connections

Refer to the MatrixPilot Wiki instructions for installing and connecting the UDB. If you are using the AH_FULL altitude control option, then both the elevator and throttle control must pass through the UDB.

Power up and manual checkout

Power everything up. Turn on your transmitter first, and then your plane. If you are using an electronic speed control, make very sure that the throttle stick is set for minimum throttle and the mode control is set for manual.

Otherwise your motor could come on during the initialization sequence. *It might be a good idea to prepare for the possibility that the motor will come on during initialization, until you go through the setup process once.*

Hold the plane level and steady during the first 10 seconds of power up. At the end of 10 seconds, the gyro and accelerometer offsets are recorded, the rudder or elevator will waggle once, and you are then free to move the plane.

If you have an ESC that requires you to cycle the throttle to full and then back to off, you can do that either before or after the 10 second mark .

Check the directions of elevator and rudder or ailerons under manual control. If either of them is in the wrong direction, fix it by changing the servo reversing switch on your transmitter.

Now you need to wait for GPS lock, it may take a minute or two. After the GPS locks, the rudder or ailerons should "waggle" a few times. When they stop waggling, the controls are ready for further setup.

Stabilization checkout

Test the stabilization functions, including altitude hold, on the ground. *Make sure the throttle is in the off position. Put the controls in "stabilize mode", but be prepared for the possibility that the motor will come on.* Now is the time to check that the MatrixPilot throttle reversing is in the right position. Place the controls in the stabilize mode, and advance the throttle. If you have the throttle in the correct position, the throttle will ñsnapò on to the minimum throttle setting. If you have the throttle reversing in the wrong position, the altitude hold will not engage, and the motor will stay off. So, if the motor does not come on, then flip the throttle direction sense, either with the appropriate switch or in software. Once correct polarity, test out the altitude hold function by slowly increasing the throttle. What you are doing is changing the commanded altitude. At some point, the motor will turn on rather abruptly. Switch back and forth between manual and stabilized mode and notice the different throttle response in the two modes.

Next, set the throttle back to off, still in the stabilized mode, and then check pitch and roll response, when you pitch and roll the plane, the elevator and ailerons should respond. The elevator should respond to pitch, the ailerons to roll. If you are using rudder, it should not do anything.

Check that the direction of responses is correct. When the nose pitches down, the elevator should deflect up. The pitch control is proportional to the pitch error, so the elevator deflection should be approximately equal to the pitch angle, until it reaches the maximum deflection.

If either the elevator or the aileron control feedback polarity is reversed fix it. Once you get the correct feedback control directions for "stabilize mode", they will also be correct for return to launch.

Waypoint and/or return to launch checkout

Once you have stabilized mode checked out, test the waypoint and/or fail-safe return to launch functions, depending how the fail-safe behavior of your Rx.

For waypoint mode, walk around and see what the ailerons or rudder and elevator do. The elevator should continue pitch control. The ailerons should stabilize the roll, and the ailerons and/or rudder should try to turn the plane toward the next waypoint. Double check the direction of the deflection of the rudder, if it is in the wrong direction, fix it.

If everything looks good to you, then you are ready for flight.

Operation

Power up with the board level and motionless, and the throttle set for off for an ESC, or for low idle for a fueled engine. Hold the board level and motionless for 10 seconds while the gyros and accelerometers are zeroing. Offsets and trims are recorded just prior to the tail/aileron wag that signals the 10 second mark. So it is important that you hold the board motionless during the few seconds just prior to the wag.

If you have an ESC that requires calibration and/or arming by moving the throttle stick in some prescribed fashion, you can do that either immediately after power up, or any time after the first wag. The software records the "minimum throttle" position at the 10 second mark, so it is important that you have the throttle stick at that position at the 10 second mark.

After the first wag, all of the offsets and trims are recorded, so you can do anything you want with the plane and your Tx. At this point the software is waiting for the GPS to acquire a valid navigation solution. There will be a double wag at that point, indicating that the controls are ready for flight.

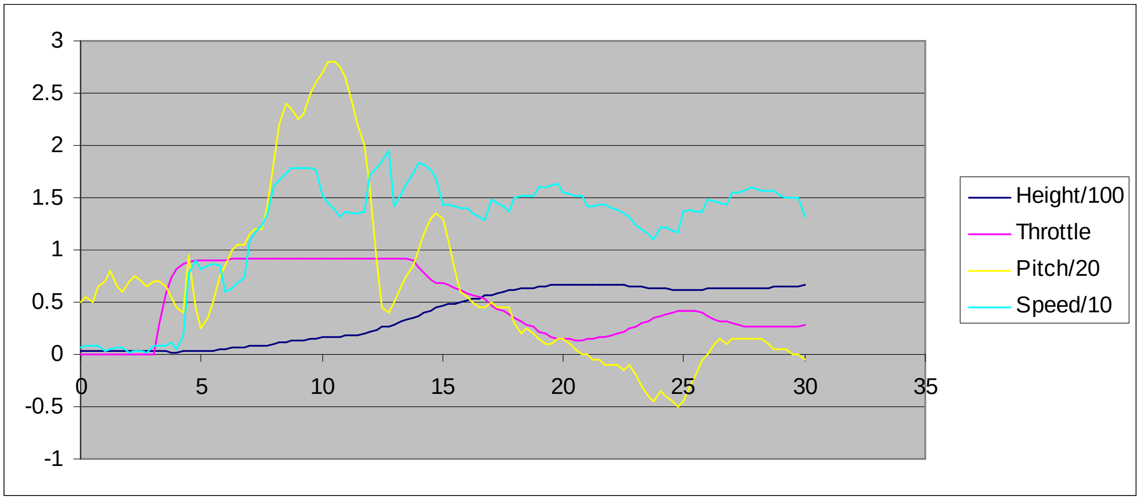
However, if you are using the option to specify the location of the origin, you should wait another minute before flying. The reason for that is if you are not located at the specified origin, there will be a transient generated in the IMU computations that takes a few seconds to decay.

Before you launch, it is best to check the deflection direction of ailerons and elevator one more time, for both manual and stabilized control. For stabilized control, the aileron off the higher wing should deflect upward, to push the wing back down.

Typical operation is to turn stabilized mode on prior to launch and do your takeoff and climb out in the usual fashion. When you get to the altitude that you want, turn the throttle down to what you think is cruising power, just enough power to hold altitude. The altitude hold function will then adjust throttle and pitch to maintain that altitude.

The following are plots of typical control response during climbout and cruising. The aircraft is a brushless EasyStar. Minimum and maximum throttle settings were 0.0 and 1.0. Minimum and maximum pitch was -20.0 and 20.0

degrees. Height margin was 10.0 meters. The target height was about 67 meters. Desired speed was 10 meters per second. The first plot is for launch and climbout. The pilot was supplying up elevator to increase the climb rate. A brushless EasyStar and climb quite briskly, it climbed 67 meters in less than 20 seconds. (600 feet per minute) As the plane approached target altitude, the throttle smoothly adjusted from 1.0 for climbout to 0.25 for cruising.



Below is the plot while the plane was cruising at 67 meters. The controls have throttled back to whatever is needed to maintain altitude: