

Tuning the Yaw Axis

Make sure the tail functions properly before proceeding with tuning pitch and roll.

Important Note - UAV helicopters, as opposed to sport helicopters, will usually be running low headspeed and higher disc loading. With a mechanically driven tail this also means lower than normal tail speed and reduced tail authority. If your helicopter meets this description, it is recommended to set **ATC_RAT_YAW_VFF** to **0.05** before the first test hover.

Below are the current default settings for yaw. Spool up the heli and hover it no more than .25 meters above ground in Stabilize flight mode and test the starting tail settings. If the tail seems "loose" and doesn't want to hold increase the **ATC_RAT_YAW_P**. If the tail rapidly shakes side to side reduce the **ATC_ANG_YAW_P**.

In all cases it is not recommended to adjust **ATC_ANG_YAW_P** below **3.5** or **ATC_RAT_YAW_P** above **0.38**. If your helicopter cannot seem to achieve a solid tail within those limits you likely have a mechanical problem with the tail - either excessive "slop" or play in the linkage, binding of the linkage or a servo problem. Correct the problem before proceeding with roll and pitch tuning.

Make **H_COL_YAW** zero. then mechanically adjust your tail rotor so that **PIDY.I** is near **0** for hover

Tuning ANG_P,RAT_D, RAT_I (Bill's way)

1 - Zero **RAT_P,I,D** gains input.

2 - sweep **ANG_P** for pitch and roll. Take it to at least **6** if without seeing more then 4-5 oscillatory overshoots behavior,after making a sharp stick input.

3 - sweep **RAT_D** until oscillation. Take that gain and use **50 %** of that as final value. Notice when adding the **RAT_D** gain that the oscillation seen with the **ANG_P** (if seen any) should subside before you start seeing an oscillation due to the **RAT_D** gain instability.
- if needed Tune **RAT_D** seperatly to eliminate Rate overshoot, if overshoot continues, take down **VFF**.

4 - sweep **RAT_P** until oscillation. Take that gain.

5 - After you have the **ANG_P** and **RAT_D** gains set then add **RAT_I** gain. I would not use any more that **0.15**.

Setting VFF and ACCEL_x_MAX Parameters for Desired Pitch and Roll Response

In both pitch and roll axes, the **VFF** gain is set so that the actual aircraft **rate** matches the **desired rate**. **RATE** message in the log is compared, **P.des** and **P** and **R.des** and **R**. With the **VFF** gains set to **0.15**, takeoff and establish a hover in Stabilize flight mode, make sharp stick inputs in both pitch and roll. pull the log and look at the signals. If the actual rate is more than the desired rate then decrease **VFF**. If it is less, increase **VFF**. If the desired and actual rates are offset by some amount it means that your swash was not properly leveled in the setup or the **CG** is not right. In this case, just make sure the change in rate is similar between desired and actual. If you get the rates to match and they feel like they are **too fast**, then reduce the **ATC_ACCEL_x_MAX** parameter and repeat the process above to match the desired and actual rates.

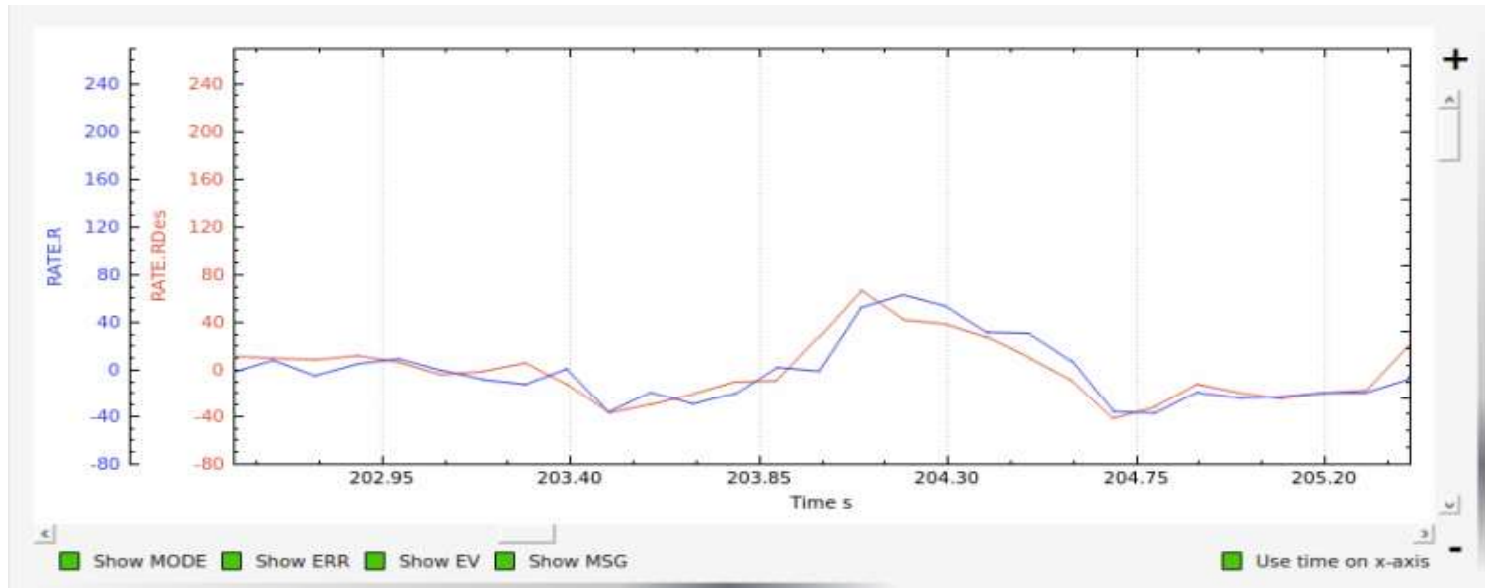
If while tuning the **VFF** gain the aircraft starts to oscillate, reduce the **ATC_ANG_XXX_P** gain for that axis until the oscillations stop. However for most helicopters the suggested values above should not cause this problem.

Flybar head: start with **0.22 VFF** for both pitch and roll, you will likely have to go higher with **VFF**.

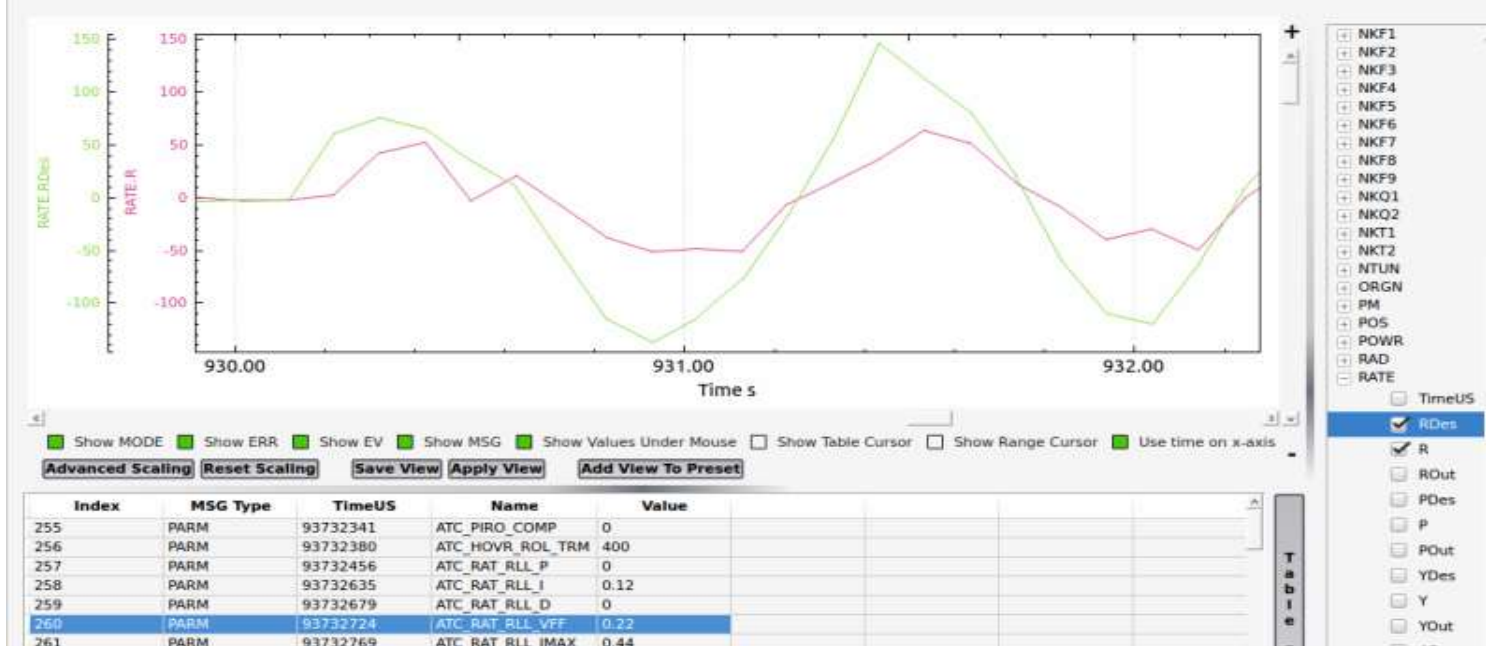
Flybarless head: **VFF** shouldn't be more than **0.22** unless you have slow servos or linkage rate. With all helicopters, the **VFF** gain compensates for differences in servo and linkage speed.

Final setting for **ATC_ACCEL_x_MAX** parameters will depend on the size of the helicopter. Large **800-900** class machines will typically be in the **36000-52000** range; smaller **450-500** class machines will typically be in the **90000-110000** range. You may want to experiment with the **ATC_INPUT_TC** parameter as well to get the initial aircraft response the way you like it. It is recommended to keep the **ATC_INPUT_TC** parameter between **0.15** and **0.25**. Once this process is complete, the aircraft should have the desired feel in snappiness and rate.

Below is a graph showing an example of Rate Roll Desired vs actual Rate Roll. The peak corresponds to a rapid stick input and the amplitude (height) of the peaks should be approximately the same with no more than 100 milliseconds offset.



Note on Tuning Flybar Helicopters: the flybar is a mechanical version of the rate PID loop. So flybar is tuned using only **VFF** in pitch and roll. The rate **D** and **P** gains mentioned in the next topic below are left set to **0** for flybar. **I**, **IMAX**, and **ILMI** are tuned just like **FBL**. Below is a plot of beginning a tune on a flybar helicopter using the starting setting of **ATC_RAT_RLL_VFF = 0.22**. The graph shows the aircraft's response to the rate request of the attitude controller is low, meaning the **VFF** value must be increased to achieve proper rate response. For all flybar helicopters be sure to set **H_FLYBAR_MODE = 1**.



Tuning the D and P gain (FBL)

Once you have the heli responding nicely with the rate **VFF** gain, now tune the PID gains. The rate PID controller provides stability to reject disturbances and keep the actual aircraft following the software predicted rates.

[Start with the D gain. Use the Transmitter based tuning feature of ArduCopter. Make the following parameter changes:](#)

TUNE -- 21
TUNE_MIN -- 0
TUNE_MAX -- 0.03

Adjust the tuning knob until the **ATC_RAT_RLL_D** and **ATC_RAT_PIT_D** gains are **0.001**. Hover and make some sharp stick inputs in roll. Most helicopters will see roll oscillations before they see pitch oscillations. That is why roll inputs are suggested. If it doesn't shake, increase the gain by **0.001** and try it again. At the value where you get the rapid shaking, cut that value in half and enter it as the final tuning value for **ATC_RAT_RLL_D** and **ATC_RAT_PIT_D**. Test hover the heli and make some rapid stick movements in both pitch and roll to make sure it's stable.

Now tune the **P** gains. Make the following tuning parameter changes:

TUNE -- 4
TUNE_MIN -- 0
TUNE_MAX -- 0.3

Adjust the tuning knob until the **ATC_RAT_RLL_P** and **ATC_RAT_PIT_P** gains are **0.05**. Lift into a hover and roll aggressively from side to side. If it doesn't shake, increase the gain by **0.01** and try it again. At the value where you get the rapid shaking, cut that value in half and enter it as the final tuning value for **ATC_RAT_RLL_P** and **ATC_RAT_PIT_P**. Test hover the heli and make some rapid stick movements in both pitch and roll to make sure it's stable.

After tuning the P and D gain the aircraft should feel much smoother.

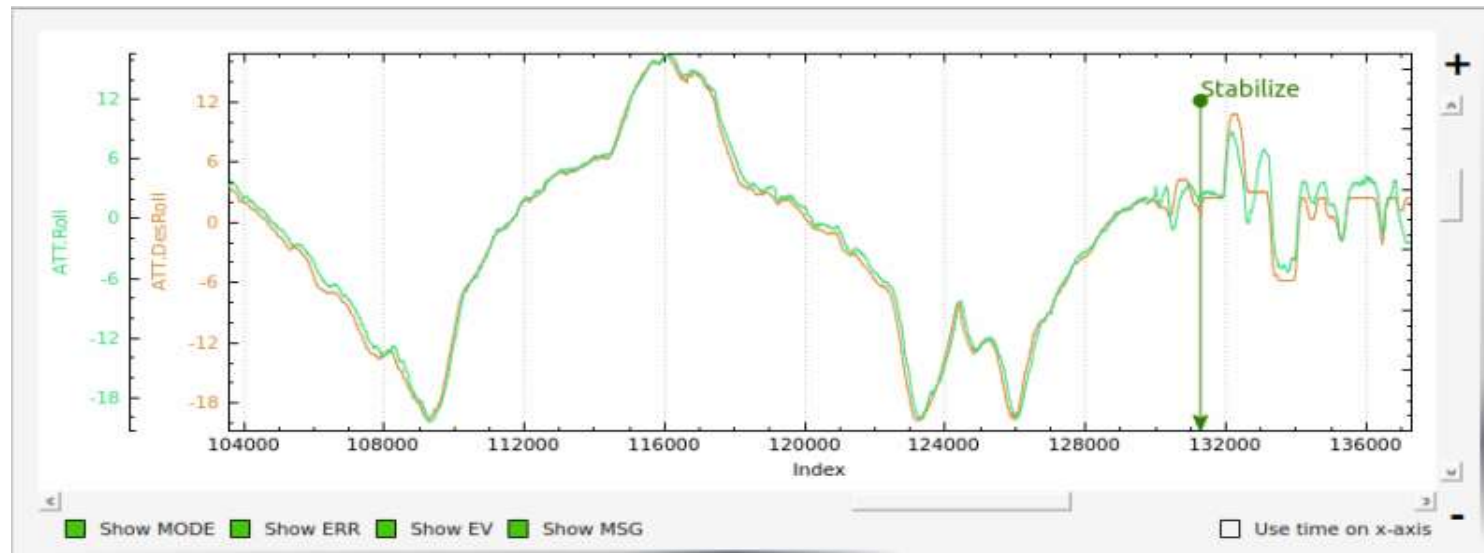
Setting the I gain, IMAX, and ILMI (FB @ FBL)

Set the **ATC_RAT_PIT_I** equal to the **ATC_RAT_PIT_VFF** and the **ATC_RAT_RLL_I** equal to the **ATC_RAT_RLL_VFF**.

The **IMAX** value limits amount of integrator error that can be stored to counter large disturbances in attitude. In the pitch axis this is set by the integrator error required to hold the aircraft attitude at high forward speeds. The starting value is **0.4**. To check this set the value to **IMAX = 1**, fly the aircraft at the maximum desired speed. Pull the log and look at what the maximum **I** value is in the PIDP message. Set **IMAX** for **0.1** above the maximum value. You could do the same for the roll axis but typically **0.4** should be sufficient.

ILMI is set for the maximum amount of integrator that you want to retain in a hover to help maintain attitude. It is recommended that this value is no larger than **0.1**

Below is a graph of desired roll attitude vs actual roll attitude for a helicopter in high-speed autonomous flight with the **ILMI** parameters set to **0**. The effect of the **I** gain and **IMAX** parameters, properly set, will make the helicopter track the desired attitude very closely at speed exceeding **5m/s** for more than 2 seconds (what we call "dynamic flight"). It should be within **1-2** degrees of desired in dynamic flight. Towards the right side of the graph the helicopter hover and the pilot switched to Stabilize flight mode. notice a discrepancy between the actual and desired roll attitude at that point. This is the effect of having **ILMI** set to **0**. The **ILMI** can be considered to be a sort of "auto trim" for hover that will reduce the discrepancy between desired and actual pitch and roll attitude when the helicopter is not in dynamic flight.



Advanced Tuning for Hover Trim, Loiter Flight Mode and Waypoint Flying

At this point you should have a helicopter that is responsive and yet stable. But we need to trim the helicopter so it hovers pretty much hands-off in Stabilize flight mode. And adjust the **I-gains** for Auto flight mode so it tracks attitude properly under full autopilot control.

Hover Trim

Trimming the helicopter in pitch and roll axes is an important step to keep the aircraft from drifting in modes like Stabilize and Althold. The trim attitude in the roll axis is affected by the tail rotor thrust. All conventional single- rotor helicopters with a torque-compensating tail rotor hover either right skid low or left skid low, depending on which way the main rotor turns. The ArduCopter software has a parameter, compensating tail rotor hover either right skid low or left skid low, depending on which way the main rotor turns. The ArduCopter software has a parameter **ATC_HOVR_ROL_TRM** to compensate for this phenomenon. Longitudinal CG location will affect the trim attitude in the pitch axis. There is no parameter to tell the autopilot what pitch attitude the aircraft hovers with no drift. It always targets **0** deg pitch as measured by the autopilot. Therefore the actual pitch attitude the aircraft hovers may be **5** deg nose high but the autopilot AHRS Trim value is set to make it think the attitude is **0** deg.

In order to trim the aircraft, set the **ATC_HOVR_ROL_TRM** parameter to **0**. During the initial setup of the autopilot, the **AHRS_TRIM_x** values are set during the accelerometer calibration on the last step that has you level the aircraft. For that step you should have made certain that the shaft was perfectly straight up in pitch and roll. For this trim procedure, it is recommended that you check it and using the method below.

Measure the actual frame angle (on a portion of the frame that is perpendicular to the mainshaft) in pitch and roll with your digital pitch gauge. Connected to your ground station software with MavLink, note the pitch and roll angle the autopilot is "seeing". Adjust the **AHRS_TRIM_X** and **AHRS_TRIM_Y** values so the autopilot "sees" the identical frame angle you measured with the digital pitch gauge. You can use the **Level Horizon function** in your ground station to level the horizon with the helicopter at actual level. That function will make the adjustments to the **AHRS_TRIM**'s for you.

Important Note : do not use the radio trims at all. Make sure they are centered.

After setting the **ATC_HOVR_ROL_TRM** now hover the helicopter again. If it still drifts make small adjustments to the **SERVO1_TRIM** , **SERVO2_TRIM** and **SERVO3_TRIM** . The chances of getting the swashplate perfectly level during bench setup is very low and this dynamic tuning is needed to trim the helicopter. If it requires large deviation from your original **SERVOx_TRIM** values it is likely you have a CG problem, or your initial setup when leveling the swashplate was not very accurate.

Your helicopter is now trimmed properly. This trimming procedure makes the difference between a helicopter that is difficult to handle vs one that flies with true scale quality and handling.

Adjusting I-gains For High-Speed Autonomous Flight

Prepare a mission with your ground station software that will fly the helicopter, preferably in a figure-8 pattern to make both right and left turns, at a speed of **6 m/s**. Fly the helicopter on this mission, look at the AHRS desired vs actual pitch, roll and yaw attitudes in dynamic flight. They should track within **1-2** degrees. If they do not, increase the **ATC_RAT_xxx_I** value for that axis until they do.

Fly the same mission, but at higher speed of **9-10 m/s**, and analyze the logs the same way. Make further adjustments to the **I** gains and **IMAX** values as required. It is not clear what **I** gain values will be required as no two helicopters are the same. But **I** gain values from **0.25 - 0.38** are common in pitch and roll, and **0.18 - 0.30** in yaw. **IMAX** values of **0.40 - 0.45** are common, however refer to the "Setting the **I** gain, **IMAX**, and **ILMI**" section above, on how to determine what the **IMAX** value should be.