INAV WING TUNING MASTERCLASS

by Marc Hoffmann
Editing and color commentary by Steve Schlesinger

TABLE OF CONTENT

FROM THE FACEBOOK INAV FIXED WING GROUP

The INAV Fixed Wing Group is a friendly support group for INAV fixed wing pilots. It's a place to go for answers, ideas and inspiration. When the group first started there were more questions than answers. People struggled with getting INAV setup properly for their planes and didn't understand how to tune the plane nor what all the modes did. We created a series of manuals to help people walk them through the process of basic setup, trouble-shooting, we covered all the flight modes including Nav Autolaunch and then Masterclass tuning of INAV.

By taking many surveys of the group we discovered that many members were using FrSky transmitters and receivers. Taking on OpenTX while learning INAV was a bit too much of a task to take on all at once. After many surveys with the group we created an FrSky radio setup that is simple, intuitive and covers all the INAV flight modes and enough features that you will not outgrow it quickly. Everything works exceptionally well and there are is a very complete manual that comes with it. This download is available to you in the files section INAV Fixed Wing Group's Facebook page.

The reason why the INAV Fixed Wing Group is so friendly and enthusiastic is because we get you. INAV fixed wing isn't plug and play and there is learning, reading, and failures along the way. The success is so strong, so sweet with INAV fixed wing that this is something you'll just love. In the end, it's all worth it. You'll want to keep going, to keep learning, to keep pushing yourself to do more. Read, learn from your mistakes, accept your failures and never, ever give up.

Because the INAV developers have supported the fixed-wing community so well (Thank you!) , we'll keep going with these manuals. A list of the most up to date resources can be found at www.bit.ly/INAVFWG

INTRODUCTION

As many of you already know, our INAV builds are not just plug and play. Like on multirotor, any wing model has its own behavior, characteristics and moods... Let's call it personality. To get a plane flying as well as possible, INAV needs to learn what to do in any situation. This tuning process is necessary to get a plane to fly in a way you are proud of and want to show to your friends.

Before starting with this tuning guide, you need to prepare a few things. First of all, you need a plane that is already completely set up. All final hardware needs to be installed, the correct battery in use, all your modes are configured, the mixer is set up correctly and you already did a maiden flight at least in manual mode to see if all works fine. If this is not the situation right now, look in our other guides first to get your plane ready. The best way is to start with the INAV Fixed Wing Setup Guide from Steve and Georgios. If you are able to understand German language, then you can also follow my First setup tutorial on YouTube.

This Guide will consist of three major phases. Phase one will be the initial tuning with Autotune to get a nice and stable flight in calm conditions. Phase two will be a manual fine-tuning tutorial, to get the plane ready for windy and gusty days and optimize it for different speed situations. In phase three we will go into some special features and optimizations to get automatic modes work perfectly.

So, let's get started!

PREPARATION

To get through the whole tuning process, the following conditions need to be met and some modes need to be set up on your transmitter and INAV. If you are new to INAV and use a Taranis Q7 or a X9D, it is recommend for you to use our Beginners Setup Profile from Darren Lines.

NEEDED HARDWARE

- Working GPS Module (Compass optional but not recommended)
- Active Blackbox with On-Board Flash/SD Card or alternatively FPV Recording

NEEDED MODES

- MANUAL (for maiden and emergency reasons in case of a failed or bad tune)
- ACRO / RATE MODE (active if no other fly mode is activated)
- ANGLE
- NAV CRUISE + NAV ALTHOLD (to easily tune board alignment and optimize navigation in phase three
- NAV RTH (optional)
- NAV POSHOLD (optional)
- AUTOTRIM
- AUTOTUNE

PHASE ONE: INITIAL TUNING

If you did not maiden the plane before this point, that's no problem. If your CG is correct and all hardware is tested on the bench before, you can do the maiden right now. Make sure you do the maiden with Manual Mode active via a switch and do not use Autolaunch. Get someone else to throw the plane so you have full control over the launch. If you have already maiden your craft, just skip the next step.

GETTING AIRBORNE AND TEST THE BASIC TUNE

After your plane is in the air in manual mode, make a few turns and see if all goes well. The next step is to see if the default PIFF values can keep the plane in the air without getting unresponsive or 'freaking out.' The best thing to do this is in FPV mode but Line of Sight is fine too.

Fly to a safe height and disable MANUAL mode and make sure no other mode is active (ANGLE, CRUISE, HORIZON etc.). Continue flying around and watch the plane and be ready to switch back to MANUAL if the plane behaves strangely. Maybe the plane will feel a bit sluggish now or it could also happen, that it starts to oscillate on one axis. In the second scenario, switch back to MANUAL and leave the stabilization disabled for now. The plane can stay in the air for the next step but after landing, lower the P and I values in PID Tuning Tab and try again before continuing. You can use the trim on your radio at this point but only if you stay in manual mode. Do never use radio trim on any stabilized flight mode!

DETERMINE THE PHYSICAL LIMITS OF THE PLANE

To be able to control the plane correctly, INAV needs to know the physical limits of the plane. Four values are essential: roll rate, pitch rate, yaw rate and stall throttle. The easiest way to get these values is, by recording your flight with an on-board camera or an FPV recording. If you only do LOS flights without camera equipment, you can also use Blackbox data to analyze the rates. To do the test, just follow these steps. If you are a beginner pilot, you should let a experienced pilot do this for you because it needs some extreme maneuvers. Activate the Roll and Pitch angle view in OSD to use them as a reference when calculating the rates later. Also, the Throttle Value should be activated in OSD.

ROLL rate	200	degrees per second
PITCH rate	200	degrees per second
YAW rate	200	degrees per second
Max. ROLL angle	30,0	degrees
Max. PITCH angle	30,0	degrees
Manual ROLL rate	100	%
Manual PITCH rate	100	%
Manual YAW rate	100	%
MagHold rate	90	degrees per second

It is essential, that this is done in manual mode and at medium to high airspeed.

ROLL RATE

Fly level at a high airspeed. Do some roll maneuvers at quick and full stick deflections. On agile planes you can even do a double roll to get best results. On big planes and cruiser builds like a Mini Talon or an S1100, you should not do full rolls but hard left and right banks to more than 45 degrees on each side.

PITCH RATE

Fly at the same airspeed as before. Then go into a short dive with about 45° nose down and instantly pull back on the pitch stick to maximum deflection and do a loop. On bigger wings or planes that are not able to do a loop, just do a nose up to 45° and then level out again. Do these two or three times to get an average.

YAW RATE

If you fly a plane with V-Tail, Rudder control or differential thrust the Yaw Rate needs to be measured too. Fly level first. Then input a full Yaw deflection and at the same time use your Ailerons in the opposite direction to keep your wings at only a slight bank angle. Do at least a 90° turn or better a full 360° Circle this way

STALL THROTTLE

Fly level again. Then lower the throttle very carefully, further and further, in small steps and try to keep the plane at the same height. If the plane becomes unstable, loses height or pitches nose down, raise the throttle again. This way you determine the minimum cruise throttle to keep the plane in the air and a value to set for automatic throttle modes. This needs to be redone if you build additional equipment into the craft, because stall throttle will raise with more weight.

CALCULATE THE RATES

After doing these maneuvers, land the plane and get to a PC. If you recorded your FPV feed with the active OSD elements, open the video file with VLC player or any media player that can do a frame by frame stepping of videos. For Pitch and Roll rates, look at your video and search a point, where your maneuver already has reached its maximum speed. Write down the angle shown in the OSD and skip frame by frame while counting them. If you did a full roll or loop, just count the frames of half of the maneuver. For rolls start counting the frames when the OSD shows 90° Bank Angle and stop counting the frames on -90°. For Pitch start at 0° pitch and stop at 180°. For Yaw you count the frames depending on compass position and a 180° turn. Then calculate each rate by the following formula.

((360° / measured angle) * counted frames) / FPV frames per second (24 PAL/30 NTSC)

The result is the rate in Degree per Second. Set these values in the PID TUNING tab in INAV configurator. Better set these slightly lower (by 10%) but never set them higher!

To get your safe cruise speed, look at your OSD during your stall test. Write down the throttle value when the plane starts to descent or pitch down or even stalls. Add 20% throttle to the shown value to get your minimum cruise throttle for lowest safe speed during navigation. If the shown throttle was 40%, your safe cruise throttle value would be 1480 in configurator. You can set this in the Advanced Tuning Tab.

AUTOTRIM

After setting these values, the next step will be trimming the control surfaces. If you used radio trim before, you must reset the trims to zero at this point. Never fly with active radio trim when in any stabilized mode. Also, this needs to be done in very calm wind conditions.

Launch your plane again. You can do the trim in ACRO mode, but I recommend using ANGLE mode at this point to let INAV stabilize the plane and determine the trims by itself. Fly with a comfortable cruise speed, but not close to stall and not at full throttle. Fly in a straight line and keep your fingers off the sticks, then activate AUTOTRIM via switch and keep it activated. Wait about 5s before taking over control of the plane again. Switch back to your desired flight mode, land and disarm the plane. Now the trim is saved.

In disarmed state, switch back to manual mode and look at the control surfaces. Measure the deflection of each surface or just take a picture. Go to configurator und switch to the Servo Tab. Look at the midpoints of each servo. If the midpoints are in a range between 1450 and 1550, you are done. If the values are lower or higher than these, you need a mechanical trim to avoid losing servo authority. To do this, reset the midpoints to 1500 and then mechanically move the pushrods to get the servos in the same position as you have noted before.

Then do another AUTOTRIM flight and check the midpoints again. All midpoints should now be close to 1500 and you are finished here.

AUTOTUNE

Now let's get into the serious stuff. After a lot of preparation, INAV will now finally learn how to control and stabilize the plane in a smooth and reliable way. For AUTOTUNE you need to fly in calm conditions with ideally no wind at all. For windy conditions, this needs some manual adjustments. We will do this in Phase Two.

Start flying around in ACRO mode. You could also use ANGLE mode, but this is not recommended because it is not possible to do very sharp maneuvers here to do a good tune. Alternatively, you could use HORIZON Mode to keep the security of self-leveling. If you don't want to do these maneuvers for yourself because you don't have enough experience, ask an experienced pilot to do this for you.

Turn on AUTOTUNE in flight via switch. When doing this the first time, the plane will likely become very sluggish. Immediately start doing hard roll and pitch maneuvers with full stick deflection in each direction and quick stick centering. The craft will become more stable quickly after a few maneuvers.

Do this always at a low speed, especially if your Motor setup is very powerful. This method will calculate the PIFF controller values depending on the airspeed and control authority you have. If fly too fast, the plane will become sluggish again at low speeds or at landings. So lower speed is better and high-speed tuning will be done in Phase Two.

Do the AUTOTUNE as long as you want. Tip: Add an OSD Layout with ROLL PID and PITCH PID activated to see how the values change in FPV, so you can see when the tuning is done.

As soon as the tuning is done, disable AUTOTUNE via switch and land the plane. DO NOT DISARM after landing. Turn on AUTOTUNE again. Then move both sticks down and outwards (left stick down and left, right stick down and right) for about 2 seconds to save the new values, then disarm the plane. You can then check with the configurator if the saving has worked.

PHASE ONE: CONCLUSION

Now we are done with the basic tuning of Phase One. The plane should now fly stable and smooth in calm conditions, NAV CRUISE, RTH and NAV POSHOLD modes should now work acceptable and your failsafe is ready. For new pilots it is now time to fly some batteries to get experience and confidence in your plane. After that, we can continue to PHASE TWO.

At this point I recommend you run through our Autolaunch Guide:

INAV AUTOLAUNCH

PHASE TWO: MANUAL FINE-TUNING

After finishing AUTOTUNE and flying around for some packs, maybe you are getting more confident and try to fly also in not that ideal conditions like gusty wind or fly with high speed, you will likely recognize that not everything is perfect. The plane is wobbling around in the wind or jittering on full throttle and fast dives and maybe also overshoots when stopping from fast rolls or loops. At this point this is absolutely normal because AUTOTUNE is only able to give you a basic PIFF controller tuning. But to get a real perfect tune, there are some more things to set up that cannot be determined automatically. This is the point where we need to look exactly how the plane behave to analyze what needs to be optimized in the tune.

PIFF OPTIMIZATION

As you might remember, the automatic tuning is done at very calm conditions. This is necessary to avoid wind turbulences influence the measurement of the overshoots causing wrong values. Therefore, the P-Value is set very low and there will be only minimal stabilization to counteract wind gusts. We need to optimize that manually and I'll explain how. Also, the I-Term is set relatively low to avoid backshoots but sometimes it can be too low and causing slight drift. We need to be careful with the I-Term and I'll explain you why.

Name	Proportional	Integral	Derivative
Basic/Acro			
Roll	40	30	23
Pitch	40	30	23
Yaw	85	45	0

P-TUNING

To get a good P-Value for descent stabilization, it is important to find the correct weather conditions. A slightly windy day with some gusts is perfect for this but be careful that the wind is not too strong so as to be able to land safely.

Start flying normally. Watch how much it is bumping around in the wind, while there is no stick input. Always fly at low speeds but fast enough to get a stable and responsive flight. Then do some hard maneuvers from left to right and pitch up and down and watch the oscillations. The plane should not swing back and forth fast or more than 3 times when stopping from a rapid roll or pitch movement. On flying wings, the pitch can oscillate a bit quicker and more often due to the short fuselage. This is to check if the P value is too high. In this case you will get multiple swings around each axis.

If the plane is too bumpy and sluggish on straight flight and not oscillating more than 2 or 3 times on each axis when doing hard rolls and pitches, land the plane and raise the P gain on the axis that is not stable enough by about 20% or 1 step. Then do the same again until the roll stop oscillation gets too strong on each axis (3 or 4 swings on each axis), then go back the last step and you have finished the P tuning. We will get rid of the last overshoot oscillation later.

I-TUNING

The I-Term tuning is a little bit delicate and usually not necessary. But if your plane has some strange aerodynamic properties, it can be useful though. Planes like the Dart XL from ZOHD tend to nose up on high throttle and here it makes sense to have a higher I-Term to compensate for that, because the I-Term counteracts on slow drifts of attitude. Also, if a plane is nose heavy, it would cause a 'nose up' on high speeds due to the reflex that is needed to counteract the nose weight, but the I-Term will compensate for that. Too high I value can cause a dangerous tip stall or even flat spin if the airspeed gets too low and the plane aggressively tries to keep the nose up instead of letting it fall and gain speed. It will also cause massive rollbacks when stopping long rolls or loops.

If the plane drifts slowly away on roll or pitch, without any stick input, raise the I value a little bit. Try 10% steps as a good start. Only raise the I-Term on the axis that drifts away and then fly again. Fly around at low and high speed and watch for roll or pitch overshoots on hard maneuvers. Then fly a slight nose up and lower the throttle slowly until plane reaches stall speed. If the plane does not nose down and instead goes into a tip-stall or flat spin (only do that at a safe height), throttle up and gain back control. Then lower the Pitch I value again and test again until the stall is more stable and the nose dips on low airspeed.

After that, the I-Term tuning is done too.

FF-TUNING

The last value should not be touched after autotune but can be checked if it is still fine after P and I optimization. The FF-Term does the most work when flying the wing and translates the user input into correct control surface movement. To keep some room for P and I to work, even on hard maneuvers, the FF value should not use the full servo throw. You can check this on the bench by doing the following.

Plug a battery in the plane and make sure you have no flight mode active (ACRO) and manual mode on a switch. Take your transmitter and give the plane a full pitch input and look at the control surfaces. While holding the stick at full deflection, switch into MANUAL mode. At this moment, the control surfaces should move slightly to give even a bit more throw. Disabling MANUAL mode should move the control surfaces back a little bit. The difference should be about 10-15% of the servo throw. If the difference is smaller, you need to lower the FF gain a bit. If the difference is too high, just raise the FF value a bit. Do the same with the Roll-Axis and you are done. FF is not necessary for Rudder.

TPA-TUNING FOR HIGH-SPEED

Now we will come to the point that is very interesting for race-wing pilots, especially if you do proximity flying. All the tuning we have done so far, was done at low speeds to get as much stabilization as possible on the plane. The issue now is that high airspeeds will cause much more aggressive reactions of the plane to any control surface movement. As INAV does not account for that by default, we need to tell the FC, when to lower the control movements. The system to do that is called TPA (Throttle PID Attenuation). The TPA system relies on two values: TPA Percentage and TPA Setpoint. The TPA setpoint will mark the throttle value, where INAV starts to lower the PIFF controller values. The percentage is the amount of value reduction at full throttle. The PIFF controller will get lower linear, starting at the setpoint up to full throttle. This will counteract the over correction at high speeds and keeps the stabilization at a constant level. This is how to determine these values.

First of all, we need to check what the TPA setpoint needs to be. For that you launch the plane again. Fly with FPV and do a recording if possible. Also activate the throttle value in your OSD. Start flying in any stabilized flight mode at low throttle and rise it slowly. Do slight maneuvers and rise the throttle further very slowly and watch how the plane behaves. If the plane starts to jitter a bit or if it oscillates quickly after small but rapid movements, lower the throttle until it flies stable again. Note the throttle value and now you have determined your TPA setpoint.

Getting the correct TPA percentage is more a series of trial and error adjustments. The higher your motor power, the higher the TPA percentage at full throttle. On low powered planes, if the setpoint is already above 50% throttle, you can start with 20-30%. Fly again and slowly go up to full throttle. If the plane still jitters or oscillates at full throttle, rise the percentage by 10% and repeat the test. Do this until the plane flies smooth and stable at full throttle but ignore the slight overshoots on hard rolls or pitch movements. We will account for that next. After that, the TPA setpoint is tuned and we can continue.

Roll/Pitch acceleration limit	0	dps^2
Yaw acceleration limit	10000	dps^2
TPA	0	%
TPA Breakpoint	1500	

RATE ACCELLERATION FOR SMOOTHER FLIGHTS

After your plane is now tuned very well and hopefully nicely locked in position during flight, it is time to make hard maneuvers a bit smoother. As you might remember during PIFF Optimization, we left some oscillations in favor to more intense stabilization, when coming out of fast rolls and loops. To counteract that, we will now physically limit the acceleration for starting and stopping roll and pitch movements.

In PID tuning TAB You will find a value called "Roll/Pitch acceleration limit" and the name tells you the function of this. By default, the limit is disabled. Limiting the rate acceleration forces the flight controller to incrementally raise the roll and pitch movement instead of trying to force the full speed instantly, what it physically not possible. Smaller builds can easily reach their maximum rates quickly, but larger planes need some time to gain their full axis rates. For starting a roll or pitch movement, this limit is more an optical benefit to have a smoother and more natural movement. But when stopping a rapid movement, this can massively increase the stabilization behavior, because it lowers the amount of overshoot and oscillation on high P-Gains.

On small builds like 600mm race wings, a value between 1500 and 2000°/s^2 is a good value to start with. Crafts up to 1000mm can use lower values like 1200-1500°/s^2. Large Long-range crafts like a Skyhawk can be set to 1000°/s^2 or even lower. As a side effect, this limit will also apply to automatic flight modes like waypoint and avoids the rapid and stiff direction changes that INAV usually does.

BE CAREFUL: Setting the rate limit lower, will also reduce your maneuverability in case of an obstacle avoidance situation. So double check what you set here before the flight to avoid a situation where you can barely control your craft. For proximity flying this rate limit should be kept very high because it can cause a slight delay in your controls.

PHASE TWO: CONCLUSION

At this point, you have a craft that can be flown well in any situation with good stabilization, optimal rates and smooth flight. This counts for flights not only in ACRO mode but also for ANGLE and HORIZON flight modes.

In the next phase we will further optimize some configurations that mainly accounts for automated flight modes like POSHOLD (loiter), RTH, CRUISE and NAV WAYPOINT. From here on you definitely need a working GPS module and also either black box recording or FPV recording of your OSD, because we will set up some values, that are hard to figure out just by your bare eyes, but still are important for the flight behavior.

PHASE THREE: NAVIGATION OPTIMIZATION

The PHASE THREE tuning part contains just a few additional things that seem to be unimportant but are strongly impacting the flight behavior of your plane in any automatic flight mode. This includes not only NAV WAYPOINT or RTH but also CRUISE and POSHOLD modes and is essential for a reliable FAILSAFE situation.

PITCH TO THROTTLE RATIO

Pitch2Throttle ratio is essential for a stable flight in modes, that have automatic throttle control and it is absolutely necessary to have this set up right when you are in a failsafe situation, where you can't take over control. If this value is set too low, it will likely cause a stall on every climb.

This value works in a very simple way but is extremely important. You can set it in the Advanced Tuning Tab below the max, min and cruise throttle setting. The throttle change is calculated by the following formula: Pitch Angle * P2T Ratio + Cruise Throttle. Let's assume you have a cruise throttle of 1400 and your plane pitches up at 10 degrees and a P2T Ration of 10, the motor will throttle up to 1500. If the plane is pitched down 20 degrees (-20) the throttle will go down to 1200. If the P2T ratio is too low, the plane will stall on climb because it cannot maintain enough airspeed. The throttle is limited to min and max throttle.

Tuning P2T is very easy with OSD but needs a bit trial and error and is best done in CRUISE mode with active ALTHOLD because cruise has automatic throttle control. Just fly in CRUISE mode on auto throttle and fly level to see your actual ground speed. Then pitch up to max climb rate and watch your ground speed. If the speed drops, your P2T ratio is too low and you need to set it a bit higher. Do this in small steps on high power setups and bigger steps like 5 on low power setups. If the speed is slightly increasing, that's totally fine and adds a bit more stall security.

Another way to tune this is in ANGLE mode with ALTHOLD active with manual throttle. For this you need throttle value and pitch angle activated in your OSD. Fly level first and set your cruise throttle with the throttle stick. Also note your average pitch angle (because it is not tuned yet). Then pitch up to maximum angle and rise throttle slightly until the plane is a bit faster than on level flight. Note the new pitch angle average and your actual throttle value. Then multiply your throttle percentage difference by 10 and divide this value by the pitch difference in degree. Now you have your correct P2T ratio.

CORRECT BOARD ALIGNMENT

After the plane can fly safe in automatic modes with correct throttle value, it is now possible to easy tune the board pitch alignment. You can do this the same way as tuning the P2T ratio before.

Fly in ANGLE mode with ALTHOLD active. Set your throttle manually to the configured cruise throttle value and don't move the throttle. The plane now tries to maintain altitude and controls pitch automatically. Therefore, INAV will hold a specific pitch angle to maintain height with minimal pitch correction. Watch your OSD pitch value and estimate an average if it is fluctuating a bit. Now just go to the Configuration Tab and set the Pitch Degrees to the noted value. Fly again and look at the pitch angle again. It should now be close to zero and you're done.

After that you will immediately recognize that ALTHOLD and POSHOLD will keep the altitude much more precise than before.

PHASE THREE: CONCLUSION

After these final things are set up the tuning is now finished, and your plane should fly as good as possible in any condition. Do some intensive testing of navigation modes, especially RTH with automatic climb and do some POSHOLD tests. The plane should be able to keep height very precisely on calm conditions and maintain its speed when climbing or descending. At this point you can be very confident on long-range flights too, as FAILSAFE should work flawlessly.