OpenAero-VTOL Firmware for KK2.1x Boards (V1.5)

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Copyright and Disclaimer

OpenAero-VTOL (OAV) firmware is intended for use in radio controlled model aircraft. It provides flight control and stabilization as needed by Vertical Takeoff and Landing (VTOL) aircraft when used in combination with commercially available KK2 Flight Controller hardware. It is provided at no cost and no contractual obligation is created by its use.

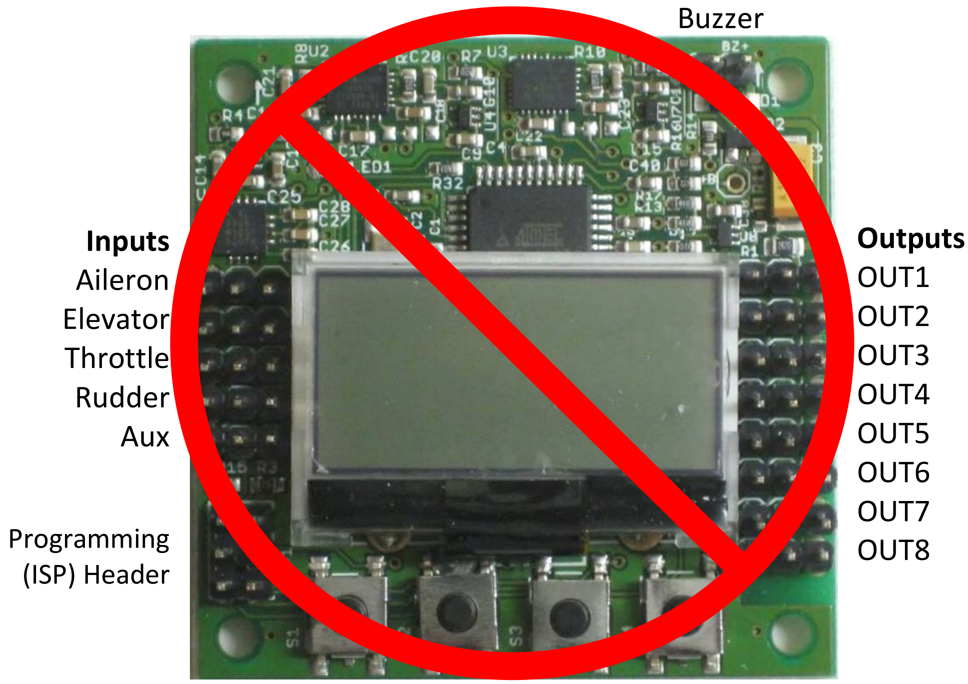
Features and Functions

OAV firmware is designed for use with the popular and relatively inexpensive KK2 line of Flight Controllers (FC). It has a unique set of features that make VTOL (Vertical Take Off and Landing) radio controlled aircraft possible for modelers without the need to write custom firmware. The major features of OAV include:

1. Transitional Mixers – If you have an application where aileron becomes rudder, or a similar sort of "axis translation" the OAV will get you smoothly and in control from one flight mode to the other.
2. Full Transition Control – You have full control of the transition with an analog input. You can transition at any speed, in any direction, at any time. You can also set up a 3 step timed transition with the flip of a switch.
3. 8 outputs, all with the same functional capabilities.
4. 5 inputs in PWM mode, 8 inputs in CPPM, SPPM, Xtreme, Mode B/UDI, S.Bus and SUMD modes.
5. 7 point curve for offset adjustment. You can separately trim Hover, Slow Forward Flight, and Fast Forward Flight on each output, and transition smoothly between them.
6. 2 point curve for P, I, and Auto-Level stability feedback adjustment. You can smoothly change stability feedback values as you transition between Hover and Fast Forward Flight on all 3 axis.
7. 2 point curve for Volume/gain adjustment. You can smoothly vary control throws as you transition between Hover and Fast Forward Flight.
8. 2 each 7 point throttle curves and 2 each 7 point collective pitch curves for separate tuning of helicopter based VTOL aircraft in Hover and Fast Forward Flight.
9. 2 each 7 point universal input curves applicable to all TX inputs, as well as Gyro, Accelerometer, and Auto-Level feedback.
10. Auto-Level that is effective both for hovering and in forward flight or as an emergency recovery mode.
11. 2 frames of reference for support of tilting aircraft such as tail sitters.
12. Safety Features – Arm and Disarm options that are compatible with all aircraft types.
13. Maximum Flexibility – This is not a "Tell me what kind of aircraft you have" type of interface. It is a "tell me what you want each output (servo/ESC/etc.) to do" type of interface.
14. Off the Shelf KK2 hardware, available for about $20 from HobbyKing.
15. No PC required (except for initially flashing the board). Full configurability via the included LCD interface.
16. No programming (code) required. Only configuration via the LCD display and the menu driven interface.
17. Gyro and Accelerometer based stability. No magnetometer, GPS, or pressure based altimeter.
18. Vibration meter for dynamic balancing of motors and propellers.
19. Battery low voltage alarm.
20. Optional Excel based GUI Interface for programming and saving user parameters and programming firmware.

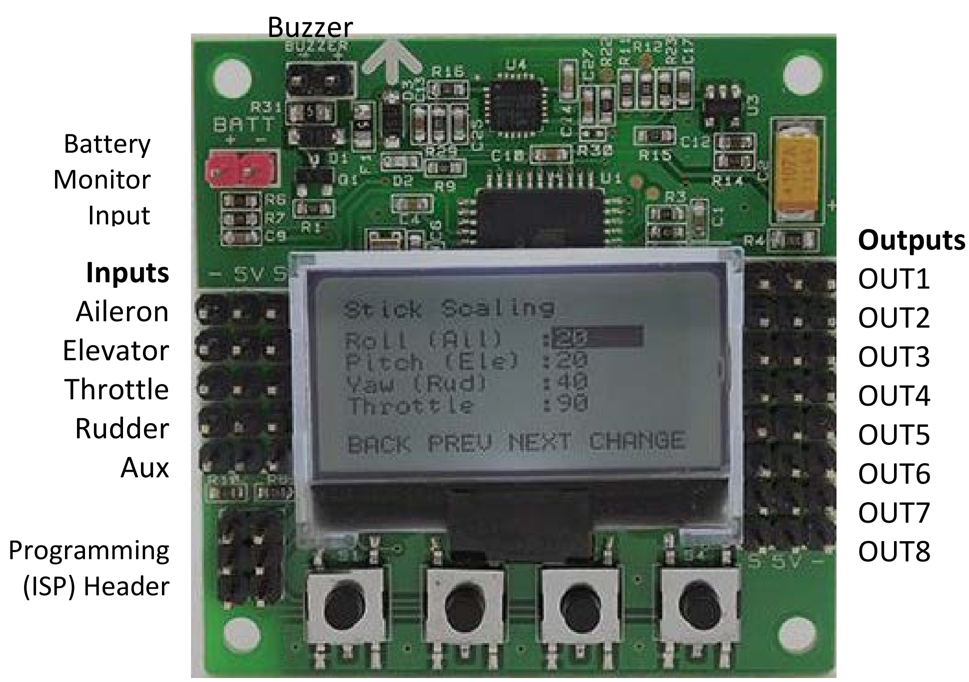
Board Pinout

KK2.0 Board



Note: The V1.4 and later firmware versions do not work on the KK2.0 board. KK2.0 boards are limited to V1.0 or earlier.

KK2.1.x Board

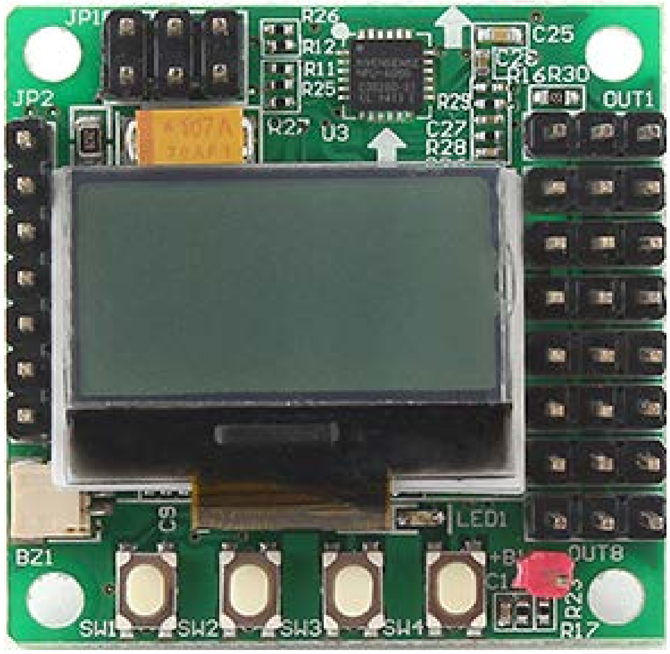


KK-Mini

Programming
(ISP) Header

Inputs
Aux
Rudder
Elevator
Aileron
Throttle
V+
Ground

Buzzer

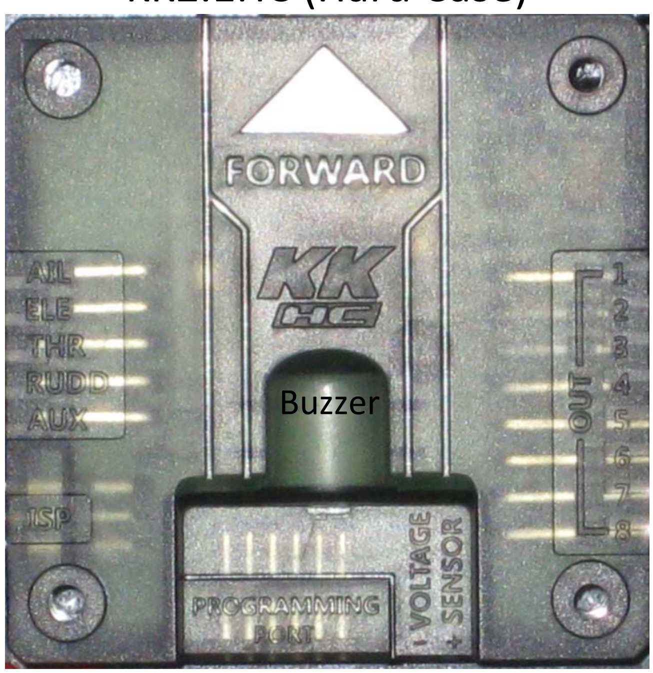


Outputs
OUT1
OUT2
OUT3
OUT4
OUT5
OUT6
OUT7
OUT8
Battery
Monitor Input

KK2.1HC (Hard Case)

Inputs
Aileron
Elevator
Throttle
Rudder
Aux

Programming
(ISP) Header



Outputs
OUT1
OUT2
OUT3
OUT4
OUT5
OUT6
OUT7
OUT8

Programming Port
Voltage Sensor

Safety Considerations

VTOL model aircraft can be quite dangerous. They often have multiple exposed propellers and it can be difficult to work on them, carry them, or even plug in the battery without being in range of one or more of the propellers. They also have the power to become airborne instantly and sometimes without warning. Even if you are holding them, the forces they generate can be quite amazing. Electric motors in general don't hit you once and stop, they keep turning and slicing. OAV has several safety features to mitigate these risks.

OAV has 2 safety modes, Armed and Armable. When in the Armed mode the FC is permanently armed and the motors can turn at any time. It is strongly recommended that you not use Armed mode for anything other than bench testing with servos or possibly well secured motors that have no propellers.

Armable mode allows you to arm and disarm the motors with the TX in a manner similar to many multi-copter flight controllers.

The FC (Flight Controller) is armed by moving both sticks "down and in" and holding for 1 second. Similarly the FC is disarmed by moving both sticks "down and out" and holding for 3 seconds. The 3 second hold is required to insure that you don't accidentally move the sticks to this position while in flight.

Arm

Disarm

OAV also has an auto-disarm timer that will disarm the motor outputs after a specified number of seconds if there is no activity on the control inputs and the throttle is set to full idle. The default for the disarm timer is 30 seconds. If you land and forget to disarm, after 30 seconds the FC will disarm for you.

Only motors are disarmed, not servos. It is important that you accurately designate which outputs will be driving motors or servos in the OUT1-8 Mixer menus.

When in the disarmed state, the motor outputs will output a minimum pulse width of 1ms. This pulse width should be well below the value required to cause any ESC (Electronic Speed Controller) to run the motor.

Regardless of the Armed or Disarmed state, the motor outputs will be driven to a minimum pulse width whenever the throttle is below 2.5%. This prevents the motors from starting unexpectedly due to stability feedback when the throttle is at full idle. It is important that you do not bump up the throttle trim or you will disable this important safety feature.

When entering the programming menu, the FC will not provide any pulse output to any motors or servo's. This will cause ESCs to remain off and servos to either go limp, or hold their last remaining value if they have some sort of a built in failsafe. It is normal to hear your ESCs beeping to indicate that they have no pulse input when programming the FC. OAV is always disarmed when exiting programming mode.

Supported Aircraft Types

When flashed with OAV, the KK2 becomes a general purpose Flight Controller (FC) capable of supporting almost any conceivable VTOL aircraft type. Because VTOL aircraft vary widely, the user interface is not based on the concept of “Tell me what kind of aircraft you have”. Instead the user configures the FC based on an understanding of what the individual motors and servos must do. This provides maximum flexibility and avoids the need to trick the FC into doing what you want.

While you could use OAV to fly a standard multi-copter, there would be no real point. The stock KK2 firmware is designed specifically for that, and you don’t need the special features of OAV to fly a multi-copter. Multi-copters are, however, very commonly the basis for VTOL aircraft, and OAV supports them easily.

OAV firmware is, however, still not a dedicated multi-copter firmware. The main difference is that dedicated multi-copter firmware typically provides control pulses to the ESCs and motors at around 400Hz, whereas the OAV firmware is limited to the pulse frequency less than 200Hz. This means that dedicated multi-copter firmware can provide stability feedback to the ESCs and motors with reduced latency, which implies that the PID gains can be increased without inducing oscillations. As a practical matter it means that the OAV firmware can be used to fly a multi-copter but it is not suitable for the most extreme multi-copter applications such as aerobatics.

None of this has any impact in most VTOL applications. VTOL aircraft tend to have wings, and sometimes a tail, which provide aerodynamic damping and allows the PID gains to be cranked as high as you would want. They are also typically not highly aerobatic in hover mode, nor are they particularly fast in hover mode. As they pick up speed they become airplanes and don’t depend on the stabilization from the lift motors much anyway.

Helicopters are a special class of VTOL aircraft that require collective and cyclic pitch for proper control. OAV has the necessary throttle, and collective pitch curves to support helicopter based VTOL Aircraft in 2 flight modes.

OAV is designed to support airplanes that can also hover, or at least take off and land in very short distances (VSTOL). The major classifications for these types of aircraft include:

1. Tilt Rotors (V-22 Osprey)
2. Tilt Wings (XC-142)
3. Separate Lift and Thrust (SLT, GE-Ryan XV-5A)
4. Tail Sitters (Pogo, Vertijet)
5. Vectored Thrust (Harrier)
6. Helicopters with Wings (Kamov Ka-22, Lockheed AH-56 Cheyenne)

There are also any number of combinations of these types, as well as many different methods for generating lift and thrust including rotors, propellers, fans, and jets. A more complete listing of the various VTOL types can be found here. Click on the various aircraft and aircraft categories for more detailed information:

http://vertipedia.vtol.org/vstol/wheel.htm

The diversity of VTOL aircraft is part of what makes them interesting, but until recently the technology required to make them fly in model form was either not available or very expensive. Successful builders of model VTOL aircraft often worked for years and spent many thousands of dollars to make their creations fly, and there were often many failures before achieving some kind of success.

VTOL aircraft are still not for beginners, but OAV is the last piece of the technology puzzle required to make them practical and relatively inexpensive for the average experienced modeler. If you can understand the physics of what makes these aircraft fly, and how they are controlled, then OAV is a general purpose tool that can make them stable so you can fly them.

Although OAV was designed specifically for VTOL aircraft, its broadly flexible design can be used for almost anything that needs to be balanced or stabilized. This includes not only hovering or fixed wing aircraft but also active stabilization for 4 and 2 wheeled vehicles as well as robotics applications.

General Concepts

OAV supports 2 "Profiles" also known as Flight Modes. Profile 1, (P1) is generally assumed to be for hover mode. Profile 2 (P2) is generally used for Fast Forward Flight (FFF) or airplane mode. The process of getting from P1 to P2 and back again is called a "transition". The transition from hover mode to FFF is called an "outbound transition". The reverse transition from FFF back to hover mode is called an "inbound transition". Various points on the transition curve between P1 and P2 are sometimes called "P1.n" where the "n" is sometimes replaced by a number. For example, P1.4 would be 40% from P1 and 60% from P2.

There is an intermediate flight mode sometimes called "Slow Forward Flight" (SFF). SFF does not imply any specific percentage of transition but is often in the general range of P1.2, or 20% from hover mode. Aircraft in SFF can often still hover with a nose high attitude, but SFF is generally not used for hovering, except possibly into a head wind. SFF is a fun and gentle mode of flying, as if on a low gravity planet, and is often used to perform a Short Takeoff or Landing (STOL). It can also be used to perform a hovering takeoff or landing into a headwind. The percentage of transition for SFF is often adjusted to match the current wind conditions.

Hover mode (P1) and FFF mode (P2) often involve very different flight characteristics and control systems. Hover mode usually requires active stabilization in two or all 3 axis. FFF mode, or airplane mode, generally does not require stabilization, but even fixed wing aircraft can sometimes benefit from some stabilization. The stability feedback parameters for P1 and P2 are often very different, and the transition between P1 and P2 benefits from a smooth transition of stability feedback parameters.

OAV uses the same PID feedback parameters as are commonly used for multi-copters, except that only P and I feedback are provided. If you are not familiar with PID feedback or are not already a multi-copter pilot, you would be well advised to purchase an inexpensive quad-copter and learn to fly it before attempting any sort of a VTOL aircraft.

The P, or Proportional, feedback term is based on the output of a solid state Gyro built into the KK2 board. It basically senses the rate of rotation on any axis and provides a corrective feedback response to the necessary motors or servos. The I feedback term is the integral of the P term and provides a relative sense of attitude. It is, however, an imperfect sense because it never knows where true level is, and the Gyros also drift over time. The D term is the differential of the P term and corresponds to the angular rate of acceleration. D feedback is not provided by OAV and is generally not necessary for good flight performance.

In addition to the Gyro based stability feedback, the KK2 board also has accelerometers that can measure acceleration in all 3 axis, X, Y, and Z. This includes the constant acceleration due to gravity. The accelerometers and gyros are combined to create an IMU (Inertial Measurement Unit) which provides what is sometimes called an "Auto-Level" function. The Z axis accelerometer can also be used for "altitude damping" which helps the pilot to hold a more constant altitude in a hover. Lateral acceleration can also be used to detect and compensate for an uncoordinated turn, also known as a "slip".

As VTOL aircraft transition between P1 (hover mode) and P2 (Fast Forward Flight or FFF) the control systems often vary dramatically. Hover control is often by direct control of various lift motors. It can also be accomplished by servos that drive collective or cyclic pitch on rotors and it also sometimes involves aerodynamic surfaces in the powered air stream. In FFF control often depends on aerodynamic surfaces, including elevator, rudder, and ailerons, as with any typical airplane. In intermediate flight modes like Slow Forward Flight (SFF), all the methods of control are often simultaneously somewhat effective.

The transition control often changes some important aspect of the aircraft configuration. Tilt rotors, or tilt propellers, often tilt motor pods to redirect the angle of thrust. Tilt wings, tilt the entire wing, motors and all. Vectored thrust aircraft like the Harrier redirect the thrust in a manner similar to a tilt rotor. Separate Lift and Thrust (SLT) types do not typically change configuration, but modulate the lift and thrust available from different motors to achieve transition. Tail sitters also do not change configuration but simply tilt the entire aircraft.

It is not uncommon for the frame of reference to change for VTOL aircraft during transition. Roll often becomes Yaw and Yaw becomes Roll. For example, for a tilt rotor in hover mode, increasing power to the right motor causes a left roll. When in forward flight mode, increasing power to the right motor causes a left yaw. Ideally this axis transition should be accomplished smoothly maintaining the proper frame of reference from the pilot’s point of view at any point in the transition.

Even for aircraft that do not change physical configuration there is often a marked change in the control system dynamics. Trim points will change, control throws need to change, and stability factors need to be modulated. The flight controller (FC) needs an input from the pilot telling it what flight mode, or percentage of transition is desired. The FC can then process the pilot’s real time inputs and provide the required control and stability feedback accordingly.

Helicopter based Aircraft have rotors, not just fixed pitch propellers. Rotors have some degree of cyclic and/or collective pitch capability. Collective pitch increases the blade angle throughout the rotation and is useful for generating more or less lift, or even negative lift. It can also be used to increase the pitch and make a more efficient propeller when in fast forward flight. Cyclic pitch varies the pitch of the blades dynamically as they rotate. It is typically used for roll and/or pitch control when hovering. A helicopter typically has a swash plate that converts the servo input from the fuselage into the dynamic rotary input required for collective and cyclic pitch control.

Collective pitch is often controlled in a non-linear manner based on input from the throttle stick. The mapping of throttle stick to collective pitch is accomplished by the collective pitch curve. A different non-linear curve is used to map the throttle stick to the rotor drive. For electric helicopters this throttle curve can control either the motor power or RPM directly. For helicopters driven by internal combustion engines the throttle curve controls the engine and attempts to balance the throttle against the different loads imposed by the main rotor and the tail rotor according to the pilots control inputs.

Menu Structure

OAV has a simple menu structure and navigation system that is obvious with little or no explanation.

An Excel file is provided that contains the entire menu structure including every selectable option on the "Menu Structure" tab. A brief explanation is offered for each option.

The file contains tabs for the 4 available "Presets". The presets load the menus with values suitable for common aircraft types including:

QuadX – X-Quad with the Left Front motor turning clockwise (CW)
QuadP – Plus-Quad with the Front motor turning CW
Tricopter – Standard tricopter configuration with 2 motors in front and one in the back.

A 4th preset called "Blank" zeroes all of the values to simplify programming a new model starting from a blank slate.

Several tabs include examples of configurations for common VTOL aircraft types.

A blank "User Template" tab allows users to record their specific configuration parameters.

The Excel file, along with this user manual, and the .hex files for flashing both the various KK2.1 boards, can be found at the end of the first post in the RCGroups Thread, "OpenAeroVTOL with transitional mixers perfect for VTOLs)" at this location:

http://www.rcgroups.com/forums/showthread.php?t=1972686

System Architecture

The data path for each of the 8 outputs is the same. Once you understand one output you understand them all.

Each output is a mix, or mathematical sum, of multiple inputs. These include a user defined percentage of Throttle, Aileron (Roll), Elevator (Pitch), Rudder (Yaw), the Gyro and Accelerometer based stability factors associated with Roll, Pitch, Yaw, and Altitude Damping, as well as 2 Universal Inputs designated A, and B. The universal inputs allow the user to select from a list of inputs including Throttle, Aileron, Elevator, Rudder, Gear, Aux1-3, AutoLevel feedback in pitch and roll, the filtered Acceleration in Pitch and Roll, Gyro feedback in Pitch, Roll and Yaw, collective pitch curve, as well as 2 universal input curves.

Conceptually, there are two such mixers for each output, one based on the user input parameters for P1 (Hover Mode) and the other based on the user input parameters for P2 (Fast Forward Flight Mode).

The output of these two mixers is combined in proportion to the percentage of transition. For example, at the 20% transition point the output is the sum of 20% of the P2 (Fast Forward Flight Mode) mixer, and 80% of the P1 (Hover Mode) mixer.

The output also includes a 7 point offset curve which allows the user to adjust the trim point for P1 (Hover Mode), P2 (Fast Forward Flight Mode), and P1.n (Slow Forward Flight Mode.

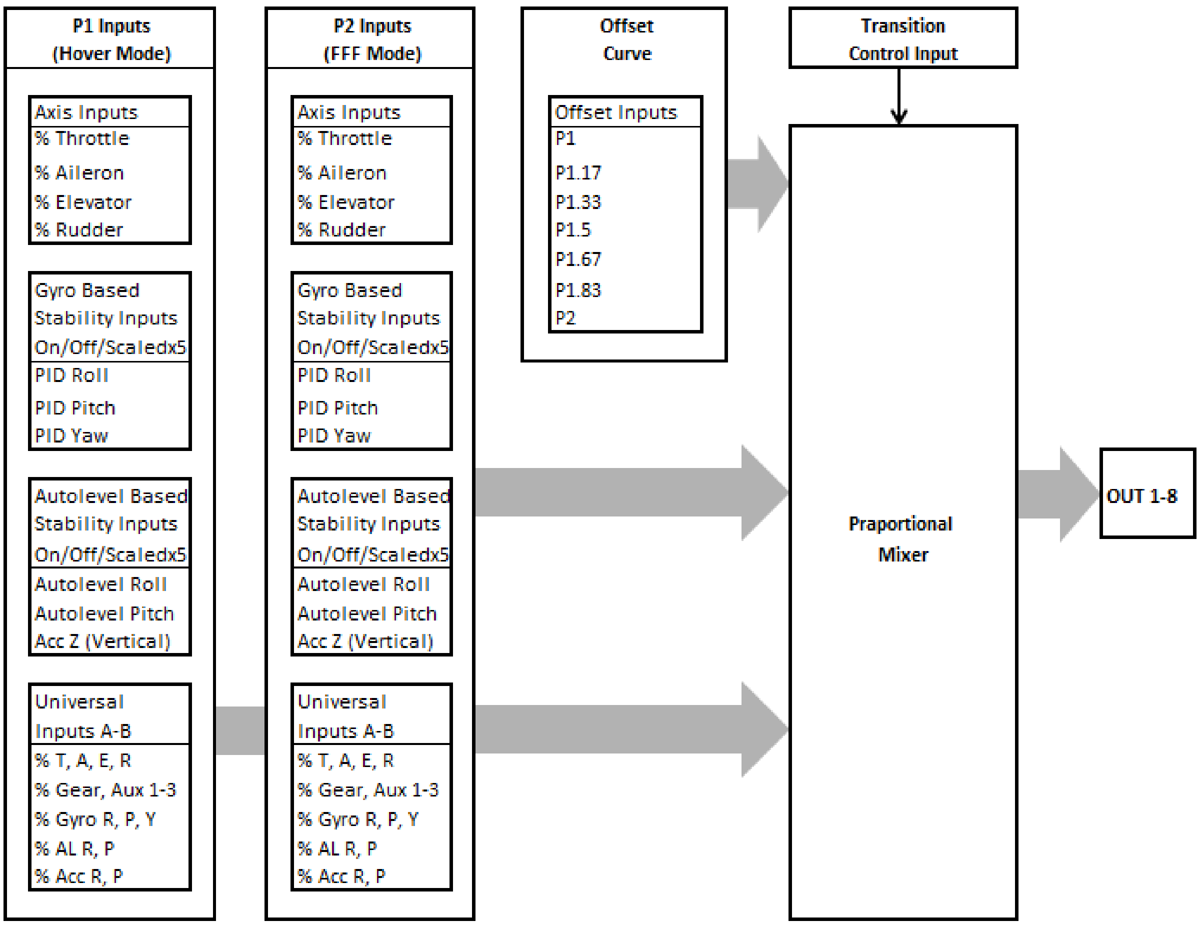
All of the stability parameters can be separately set for P1 and P2. These include the Gyro based P and I parameters for Pitch, Roll, and Yaw, the Auto-Level parameters for Pitch and Roll, altitude damping based on the Z axis accelerometer, and a trim value for the Gyro based feedback in pitch, roll, and yaw. The stability parameters vary linearly between P1 and P2 creating a 2 point transition curve.

Two 7 point throttle curves map the throttle stick input for P1 and P2. Two 7 point Collective Pitch curves map the throttle stick to the collective input which is selectable for any output. Two 7 point universal curves map any chosen input to any output.

The menu structure also includes options for reversing any of the outputs and limiting their positive and negative travel.

Data Path Block Diagram

OpenAero-VTOL V1.3 Data Path Block Diagram (KK2.1.x only)



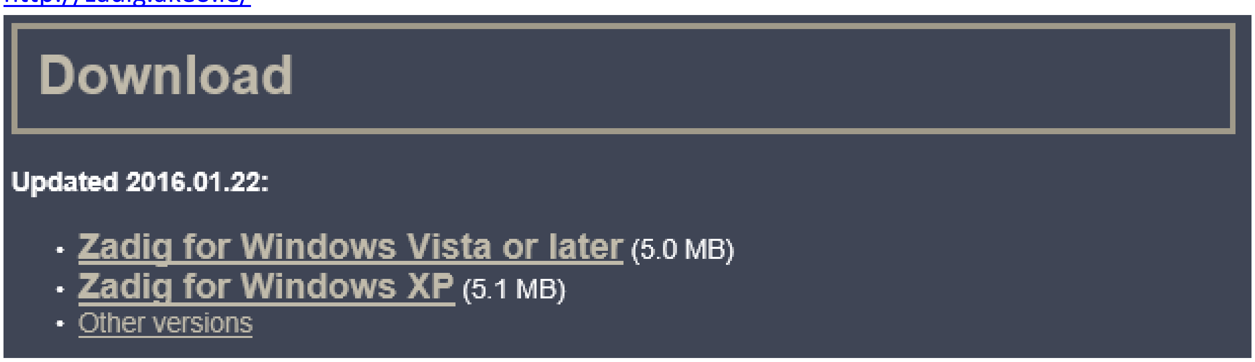
A more detailed block diagram is provided in the Excel file with the menu structure.

Reflashing the KK2.0 Board with OpenAero-VTOL Firmware

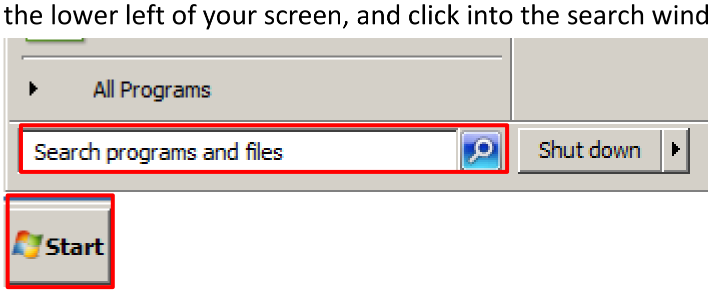
1. Buy a USBasp programming dongle. The one at this link will work:
   http://www.hobbyking.com/hobbyking/store/__27990__USBasp_AVR_Programming_Device_for_ATMEL_Processors.html?strSearch=USBasp
   or this one:
   http://www.ebay.de/itm/-/222186817568
2. Download the OAV Firmware. The files are located at the bottom of the first post in the RCGroups thread "OpenAeroVTOL with transitional mixers (perfect for VTOLs)" here:
   http://www.rcgroups.com/forums/showthread.php?t=1972686
   Open the ZIP file labeled "OPENAeroVTOL_Bxx" and save all of the .hex files to a convenient location on your computer, probably your desktop.
3. Download the latest KKMulticopter Flashtool for your computer. The file is located here:
   http://lazyzero.de/en/modellbau/kkmulticopterflashtool
   The file you want is 1/3rd of the way down the page in this section:

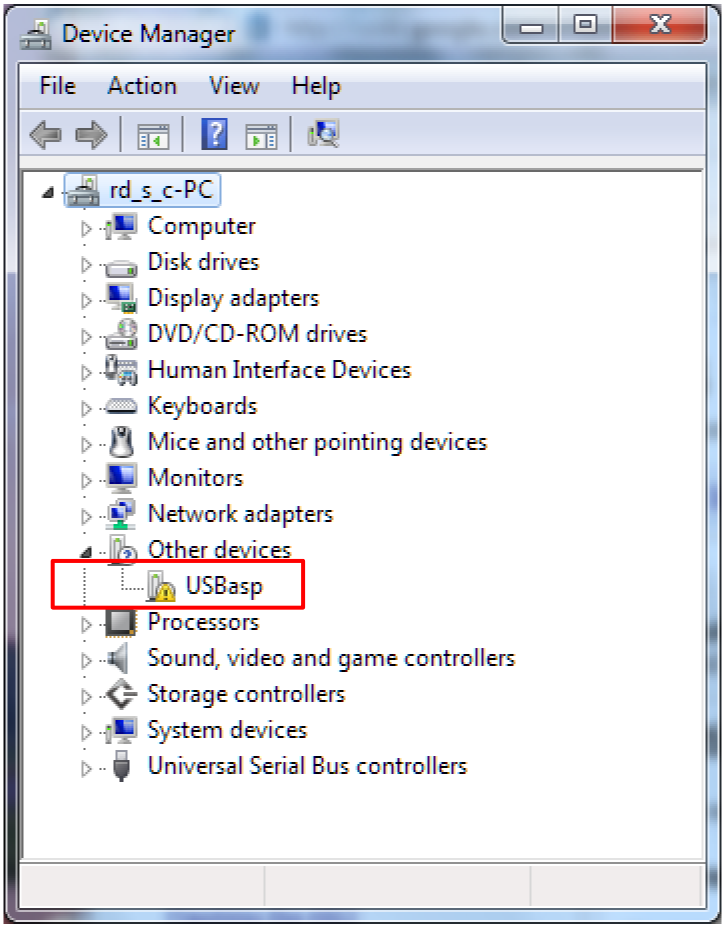
   Extract the contents of the zip file to a "Flash Tool" folder on your desktop.
4. If you are using a Windows based machine you will probably need to load the latest Windows driver that supports your USBasp programming dongle. On Linux and Mac OS X no kernel driver is needed. The executable file to load the driver is located here:
   http://zadig.akeo.ie/

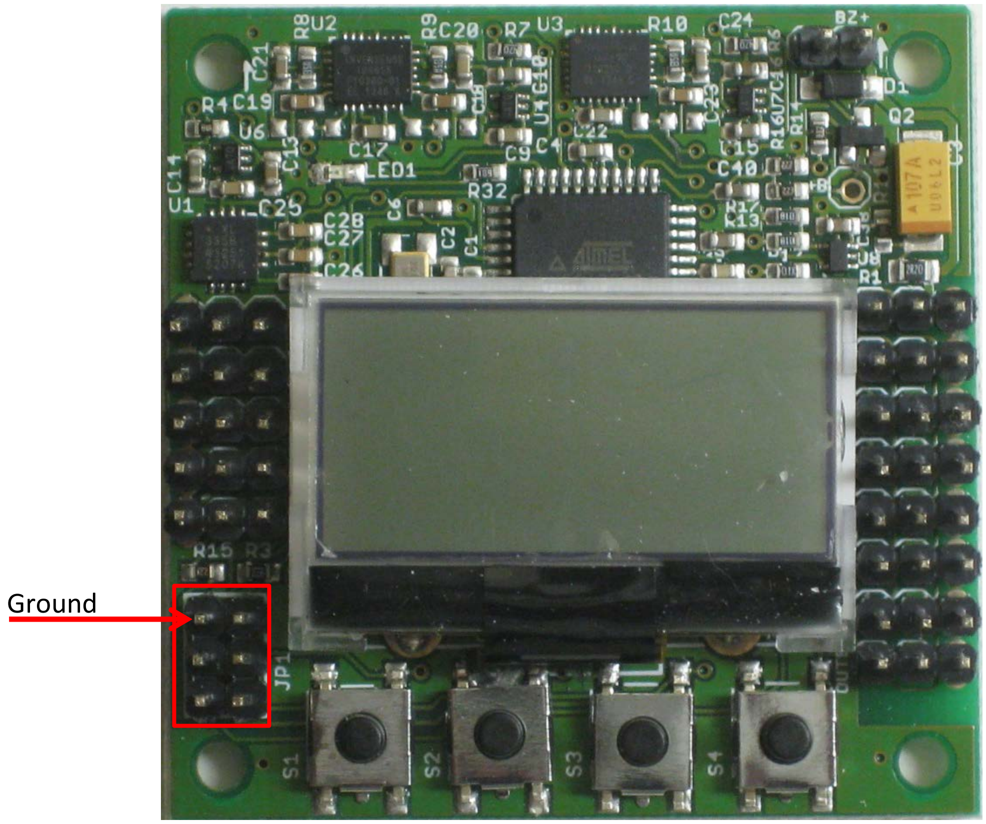
5. You can verify that your USBasp dongle is working properly as follows: Plug your USBasp programming dongle into an open USB port on your computer. Click the start button, usually in the lower left of your screen, and click into the search window.

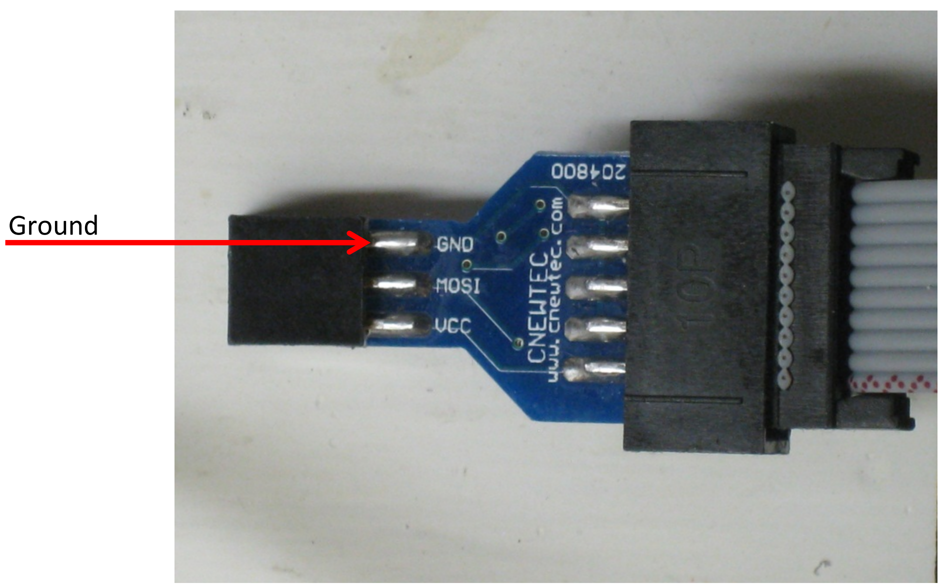
Type “device manager” into the search window and select it from the options that it finds.
If The device manatger shows the USBasp highlighted indicating that it is unhappy then your driver is not installed correctly.



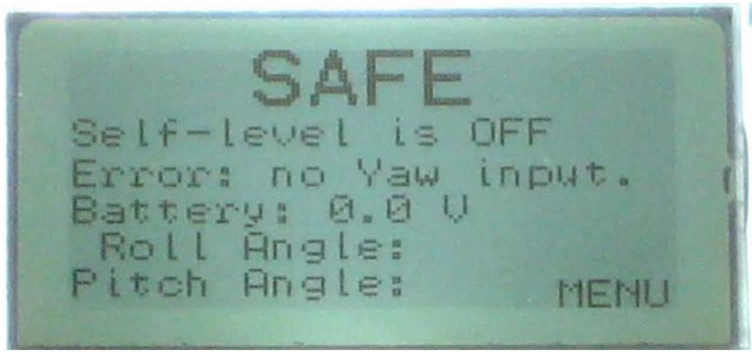
6. Disconnect everything from the KK2 board you wish to program, and connect the programming cable attached to the USBasp dongle to the KK2 board programming connector. The programming connector is on the lower left side of the board when viewed in the normal upright position with the buttons near you. The ground pin on the KK2 programming connector is in the upper left hand corner.



The corresponding ground connector on the USBasp dongle cable is labeled as well.

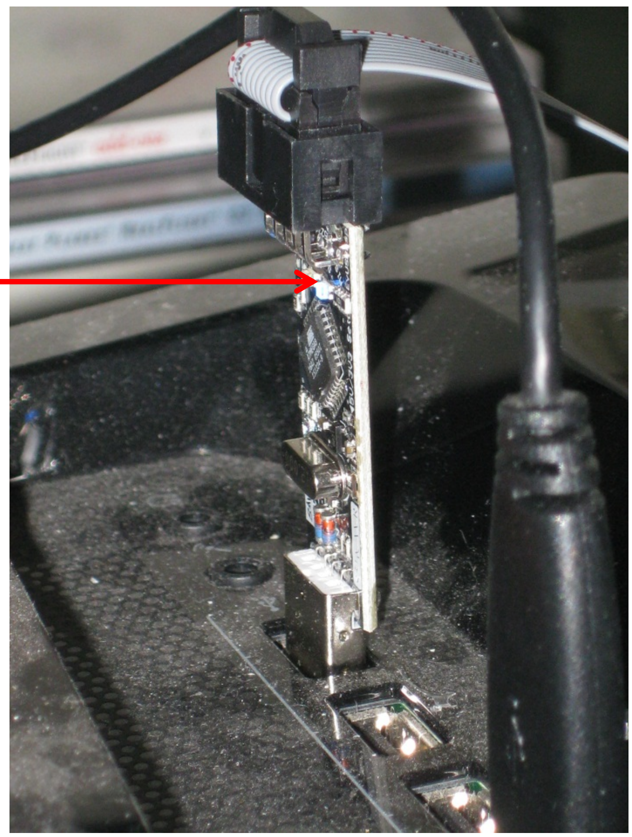


The KK2 board should power up and display the normal start up screen



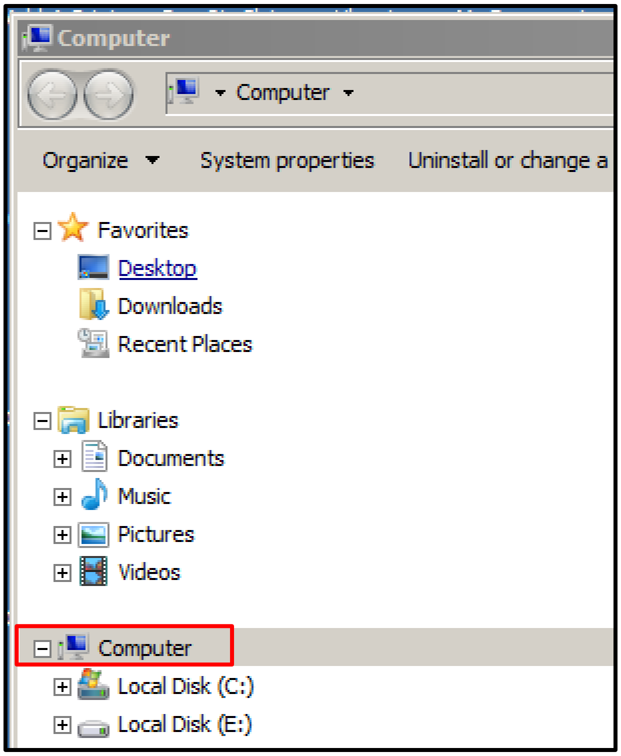
If the board does not power up normally, it may be defective, or you may have other things connected to it that should be disconnected.

Blue LED

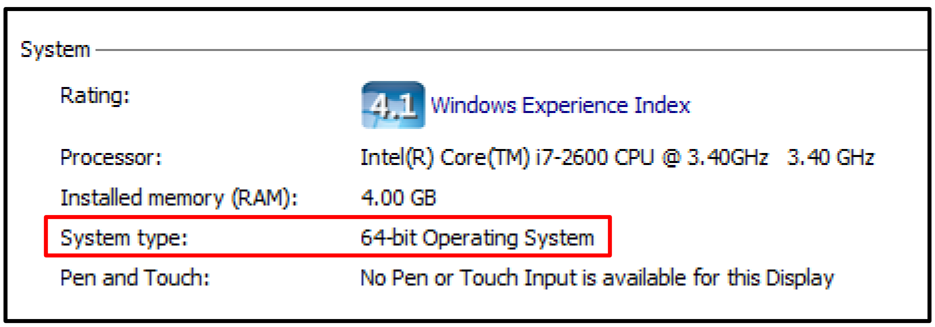


A blue LED should now be lit on the USBasp programming cable indicating that it is communicating to the KK2 board. Some programmers have LEDs with different colors.

7. If you have a 64 bit PC then double click the file “kkflashtool_win64.exe” within the “Flashtool” folder you previously created on your desktop. If you have a 32 bit PC then use the “kkflashtool_win32.exe” file instead. You may find it convenient to create a shortcut and place it on your desktop. If you don’t know what kind of PC you have then click the start button and type “computer” into the search window and select “computer” from the options it finds.



Then right click on the computer icon, select "properties" and look under "System Type:"

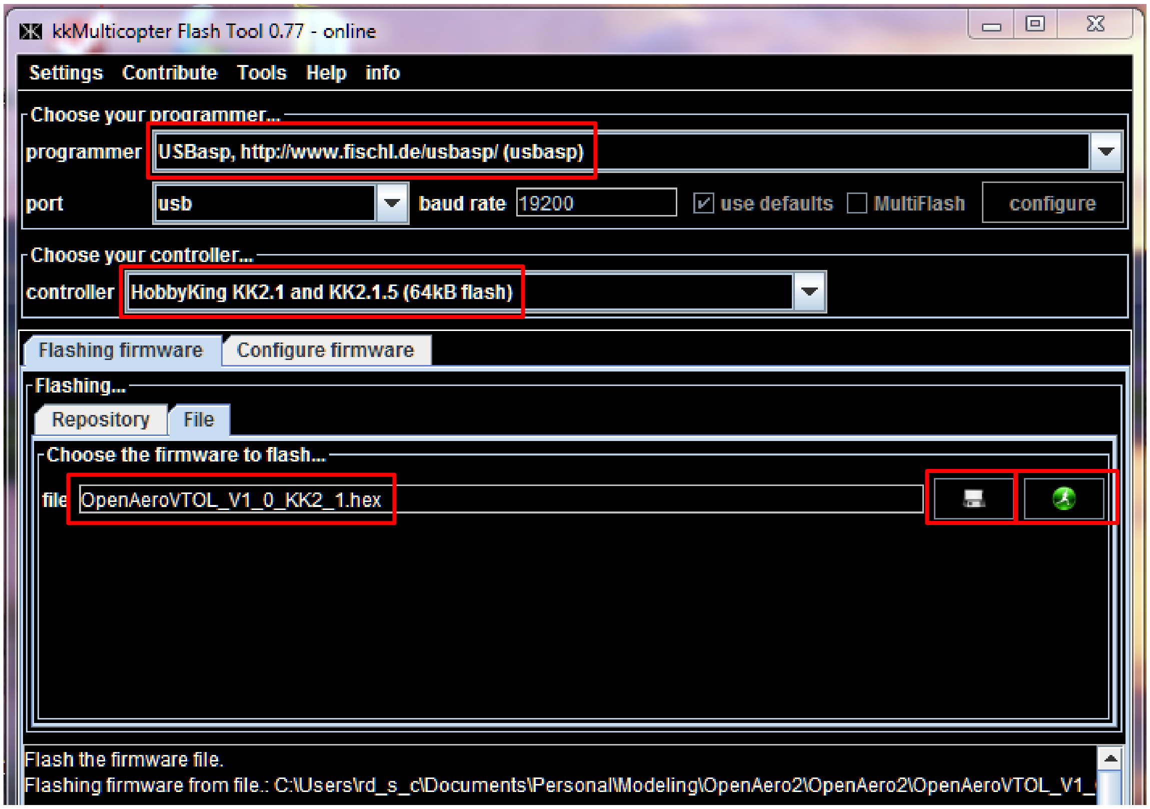


8. If at some point your computer complains that you do not have the proper version of Java loaded you will need to go here and get the latest update:

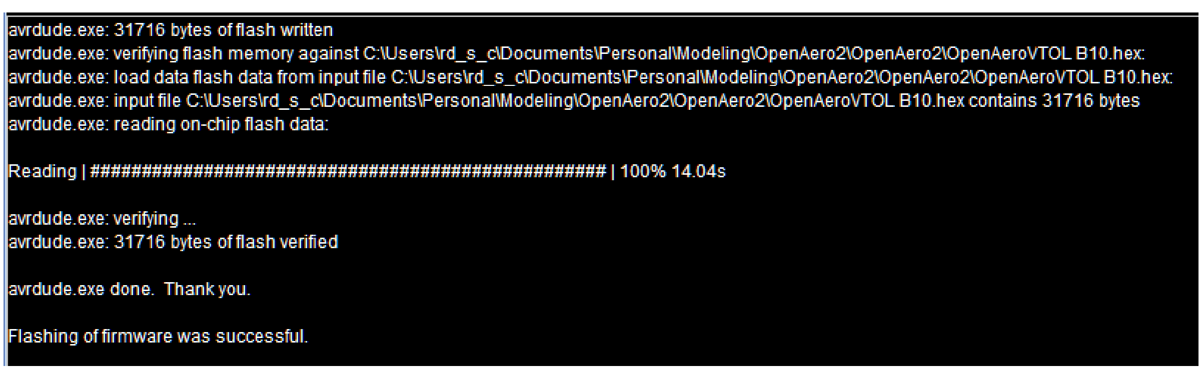
http://java.com/en/download/manual.jsp

Be sure to install the correct Java for your computer system, either 32 bit or 64 bit.

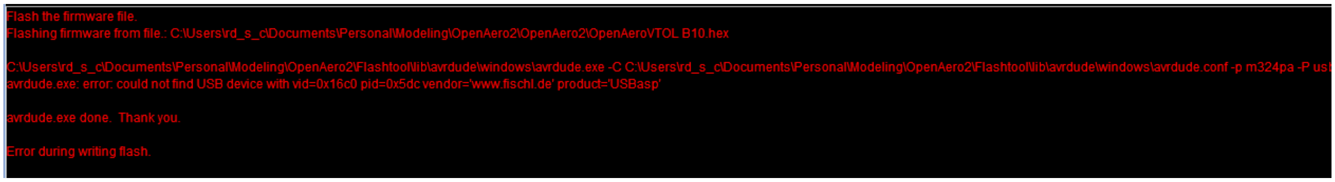
9. Select "USBasp" from the programmer drop-down menu.
10. Select "Hobbyking KK2.0 (32kB flash)" or "Hobbyking KK2.1 (64kB flash)" from the controller drop-down menu.
11. On the 'Flashing firmware' tab, click on the floppy disc icon.
12. Navigate to your desktop.
13. Select the "OpenAeroVTOL_V1.1.hex" file, to program a KK2.1x board, and click "open".



14. Maximize the application window to see the writing and reading progress in the next step.
15. Click the green icon next to the floppy disc to start the writing process.
16. The KKflashtool should write and read back the OAV code and indicate that the read process has a 100% success rate.



17. It is sometimes necessary to unplug the USB cable from the PC and plug it back in again to get the application to run properly. This is what it looks like when it fails.



18. Close the 'KKFlashtool' and remove the USBasp from the computer. Disconnect the KK2.0 board from the programming cable and power the KK2.0 board in the normal manner. See the “Power Distribution for the Receiver (RX) and Flight Controller (FC)” in this manual for information on how to power the board. Hold down buttons 2 and 3, the two middle buttons, when power is applied. This will perform a factory reset. The board will not operate properly until a factory reset is performed. When the board is powered up in this manner the word “Reset” will briefly appear on the LCD screen. A factory reset can be performed in this manner at any time, however all user parameters will be set to default and therefore lost.

Note: If you had previously programmed the board with OAV Version 1.0, 1.1, 1.2, or 1.3 then you can skip the factory reset after programming with Version 1.3. The previous parameters from V1.0, V1.1, V1.2 or V1.3 will remain in the board making firmware upgrade much easier. You still need to go through the basic Flight Controller Initialization procedures including calibrating the TX input and calibrating the sensors. You should also verify all programming parameters before powering up the aircraft with propellers installed. Also, verify all stick input and stability feedback functionality before flying. The transfer of parameters is a great convenience but it does not absolve the users’ responsibility to insure proper programming and safe operation of the aircraft.

Flashing of the board is complete.

GUI (Graphical User Interface)

The GUI is an alternate method for writing data to, and reading data from the KK2 board. It is in the form of an Excel spreadsheet and associated macros. The data is of two types:

1. User Parameters control the real time functions of the flight controller
2. Firmware is the basic code that allows OAV to function.

The GUI (Spreadsheet) provides the following functions:

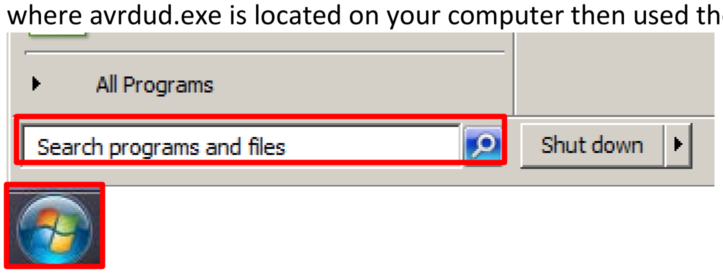
1. Manual entry of user parameters into the GUI (spreadsheet).
2. Read the user parameters from the GUI (spreadsheet) and write them into the KK2 hardware.
3. Read the user parameters from the KK2 hardware and write them into the GUI (spreadsheet).
4. Read the user parameters from the GUI (spreadsheet) and write them into a .txt (text) file for safe keeping.
5. Read the user parameters from a .txt (text) file and write them into the GUI (spreadsheet).
6. Load the KK2 with new firmware from a specified .hex file. This is an alternative to the kkflashtool method.

The GUI (Spreadsheet) has 3 tabs:

1. Settings – User configuration and reading and writing of data.
2. GUI – The spreadsheet where the user parameters are manually entered or viewed.
3. Printable – A copy of the user parameters that is formatted for convenient printing.

GUI (Spreadsheet) User Setup:

1. Select the programmer type using the drop down menu on the Settings tab. “usbasp” is the default and most commonly used programmer. The setup of the usbasp and its driver are described in a previous section of this manual.
2. Select the “Set path to AVRdude” button and navigate to the file avrdude.exe. If you don’t know where avrdud.exe is located on your computer then used the windows search facility to find it.



When you find avrdude.exe, right click and select properties. You can then find the “Location:” on the “General” tab and copy and paste the path to a convenient location like a note pad or word document. If you find avrdude.exe in more than one location, do not use the path that includes “usbtiny”.

GUI (Spreadsheet) Operation -The use of the GUI (Spreadsheet is mostly obvious. If you have difficulty reading or writing to the KK2 then un plug and reinstall the USBasp programming cable into the USB port on your computer.

Methods of Communication Between The Receiver (RX) And The Flight Controller (FC)

OAV supports 7 methods of data input.

- S.Bus (Serial Bus, Futaba, Orange) (Preferred)
- PWM (Pulse Width Modulation, All Brands)
- CPPM (Combined Pulse Position Modulation, FrSky)
- Spektrum Satellite (Spektrum, Orange)
- XTREME (Xtreme Link Serial Input)
- Mode B/UDI (Multiplex, Jeti)
- HoTT SUMD (Graupner)

The serial formats (S.bus, Xtreme, Mode B and SUMD) are the preferred method of data input. Serial data formats are both more precise and easier for the firmware to decode. It also requires only a single cable to make the connection. It also allows the use of the "High" PWM Rate: which updates the ESCs at up to 200Hz for improved hover stability.

OAV supports 5 methods of "serial" data input. These methods all require a single cable between the RX and the FC. In some cases these are special cables with active circuitry, and in some cases they connect to either the rudder or throttle input of the FC. These 5 "serial" methods allow up to 8 input channels instead of just 5.

When using any of the serial input methods, it is necessary to identify the sequence of input channels via the Ch. Order menu within the Receiver Setup menu. The sequence of input channels will vary depending on the brand of TX and does not typically relate to any off-brand modules that may be used in the TX. OAV supports 4 channel sequence options:

- JR/Spektrum - THR, AIL, ELE, RUD, GER, AX1*, AX2, AX3
- Futaba - AIL, ELE, THR, RUD, GER, FLP**, AX1, AX2.
  * Note: AX1 may be replaced by Flap in some TX configurations
  ** Note: FLP may be replaced by AIL2 in some TX configurations
- Multiplex - Aileron, Elevator, Rudder, AUX1, Throttle, Gear, AUX2, AUX3.
- Custom – Any order you like as specified in the Custom Channel Order Menu.

The Custom Channel Order Menu is the next to last menu within the main menu sequence. It selects the functionality for each input channel and only applies when Ch. Order: Custom is selected within the Receiver setup menu. If necessary you can determine the channel order for your TX and RX by trial and error. The In/Out Display menu, which is the last menu item in the main menu sequence, may be helpful in determining which control function is available on each channel. Do not select the same function for multiple input channels in the menu. It will only confuse you when you are trying to sort out which input function is on which channel.

Regardless of the method of communication, an input channel must be selected for transition control. This is done via the Profile Chan.: menu within the Receiver Setup menu. For PWM input you must select Gear, which corresponds to the 5th or bottom physical input on the FC. This input is also called the AUX input. The Gear/AUX input to the FC may be connected to any convenient output of the RX depending on how you have programmed your TX. For serial input you can specify any convenient RX output, the most common being Gear, AUX1, AUX2 or AUX3, depending on how you have programmed your TX.

S.Bus Example:

S.Bus is the recommended communication method, however, it requires a special adapter cable.

- RX: OrangeRx R720X V2 7Ch 2.4GHz DSM2/DSMX receiver
  HobbyKing page:
  http://www.hobbyking.com/hobbyking/store/__90619__OrangeRx_R720X_V2_7Ch_2_4GHz_DSM2_DSMX_Comp_Full_Range_Rx_w_Sat_Div_Ant_F_Safe_SBUS.html
- Cable: ZYX S.Bus adapter cable plugged into the Rx's S.Bus port and the 3rd or THR input of the KK2. The short end goes to the RX and the long end goes to the KK2 board.
  Manufacturers page: http://tarot-rc-heli.com/Gyros/%20ZYX-is-S-Futaba-S-Bus-receiver-cable
  HobbyKing page:
  http://www.hobbyking.com/hobbyking/store/__24523__ZYX_S_S_BUS_Connection_Cable.html

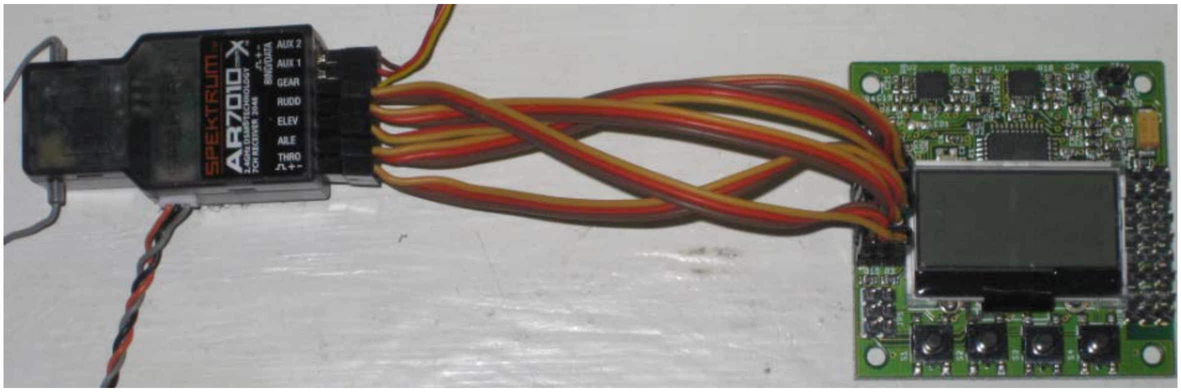
- RX type: S-Bus.
- Ch.Order: JR,/Spktm or Futaba based on TX
- Profile Chan.: Users Choice

PWM Example

While Pulse Width Modulation (PWM) is one of the most common methods of data input it is not the best. The PWM signals are the same as what would normally be used to drive a servo or ESC (Electronic Speed Controller). PWM is a "parallel" communication method requiring 5 separate cables for AIL, ELE, THR, RUD, and AUX. It is up to the user to correctly match the signals that are output from the RX to the input of the FC. This is rather obvious for the Aileron, Elevator, Throttle, and Rudder, but the AUX input to the FC can come from any convenient output channel of the users RX.

PWM input works fine for many models but it does not allow for the High PWM Rate option. This can make it difficult to achieve a stable hover for small heavily loaded aircraft or simple multi-copters.

- RX: Any standard receiver with PWM output.
- Cables:http://www.hobbyking.com/hobbyking/store/__61681__10CM_Male_to_Male_Servo_Lead_JR_26AWG_10pcs_set_.html



- RX type: PWM
- Ch.Order: Does not matter for PWM Input
- Profile Chan.: Gear

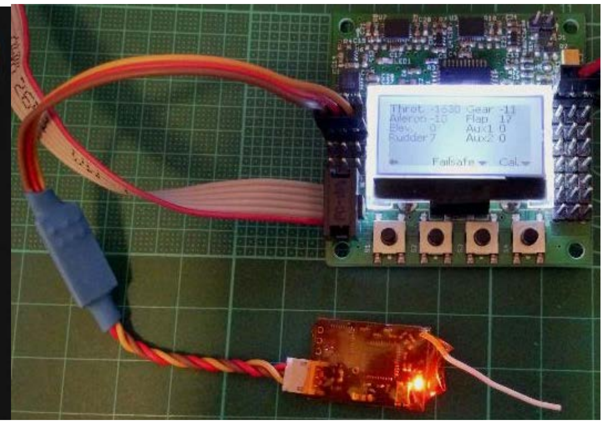
CPPM Example

- RX: FrSky D4R-II, configured for CPPM mode using this manual:
  http://www.hobbyking.com/hobbyking/store/uploads/736633136X172282X46.pdf
  Quote: "If CH3 and CH4 are connected by a jumper, CH1 will output CPPM for CH1-CH8"
  Manufacturer's page: http://www.frsky-rc.com/product/pro.php?pro_id=24
  HobbyKing page:
  http://www.hobbyking.com/hobbyking/store/__24788__FrSky_D4R_II_4ch_2_4GHz_ACCST_Receiver_w_telemetry_.html
- Cable: Use a normal female to female servo cable between CH1 of the receiver and the RUD input of the KK2.
  http://www.hobbyking.com/hobbyking/store/__61681__10CM_Male_to_Male_Servo_Lead_JR_26AWG_10pcs_set_.html
- RX type: CPPM.
- Ch.Order: JR,/Spktm or Futaba based on TX
- Profile Chan.: Users Choice

Spektrum Satellite Receiver Example:

This method allows the use of the “High” PWM Rate: which updates the ESCs at up to 200Hz for improved hover stability. However, due to a lack of RF path diversity, it is not recommended for anything but the smallest, lightest, and least dangerous aircraft. It is not possible to add a 2nd Spektrum Satellite RX to improve antenna diversity.

- RX: OrangeRx R110XL Satellite receiver
- http://www.hobbyking.com/hobbyking/store/__65902__OrangeRx_R110XL_DSMX_DSM2_Compatible_Satellite_Receiver_.html
- Cable: Connect between Satellite RX and the 3rd or THR input of the KK2.
  Manufacturer's page: http://tarot-rc-heli.com/Gyros/DSM2-DSMJ-satellite-receiver-cable
  HobbyKing page:
  http://www.hobbyking.com/hobbyking/store/__45214__ZYX_S_DSM2_DSMJ_Satellite_Receiver_Cable_US_Warehouse_.html



- RX type: Spektrum.
- Ch.Order: JR,/Spktm
- Profile Chan.: Users Choice

Binding Satellite Receivers

OpenAero makes it easy to bind Satellite receivers without the need for a separate host receiver. See the following video for a demonstration of the binding process:
https://www.youtube.com/watch?feature=player_embedded&v=c_x0GtdCm6o

Binding modes

Spektrum specify four different slave binding modes. The one that you choose is dependent on the model of receiver that you have. The binding mode is selected by holding down one of four buttons on the KK2 on power-up. The four modes and associated buttons are listed below.

Button 1: DSM2 1024/22ms
Button 2: DSM2 2048/11ms
Button 3: DSMX 2048/22ms
Button 4: DSMX 2048/11ms

Binding procedure

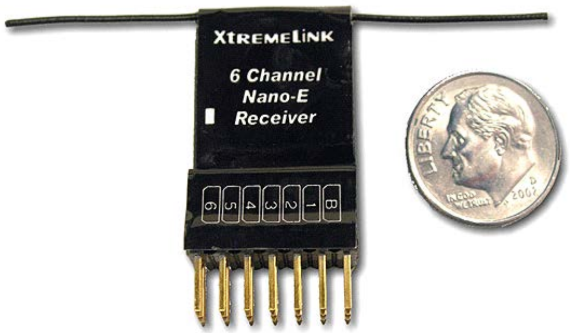
1. Ensure that the Satellite receiver is connected via the adapter cable.
2. Hold down the appropriate button of the KK2 board.
3. While holding down this button, apply power to the KK2 board. The attached Satellite receiver should start to blink rapidly. Release the button.
4. Switch on the TX in binding mode. This is usually done by holding down the Bind button on the TX module. The TX module should flash.
5. After a few seconds the Satellite will complete the binding process and will show a solid lit LED.

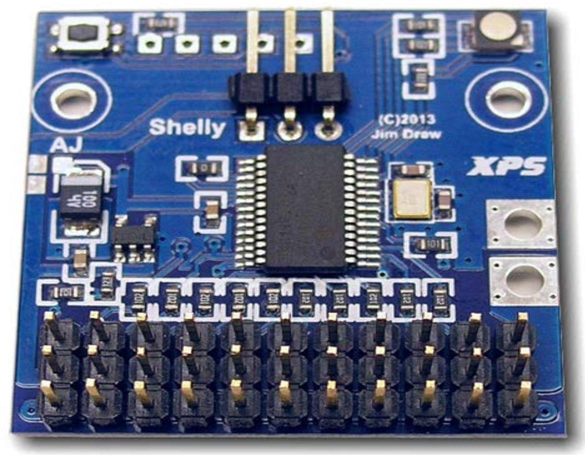
XtremeLink® Receiver Example:

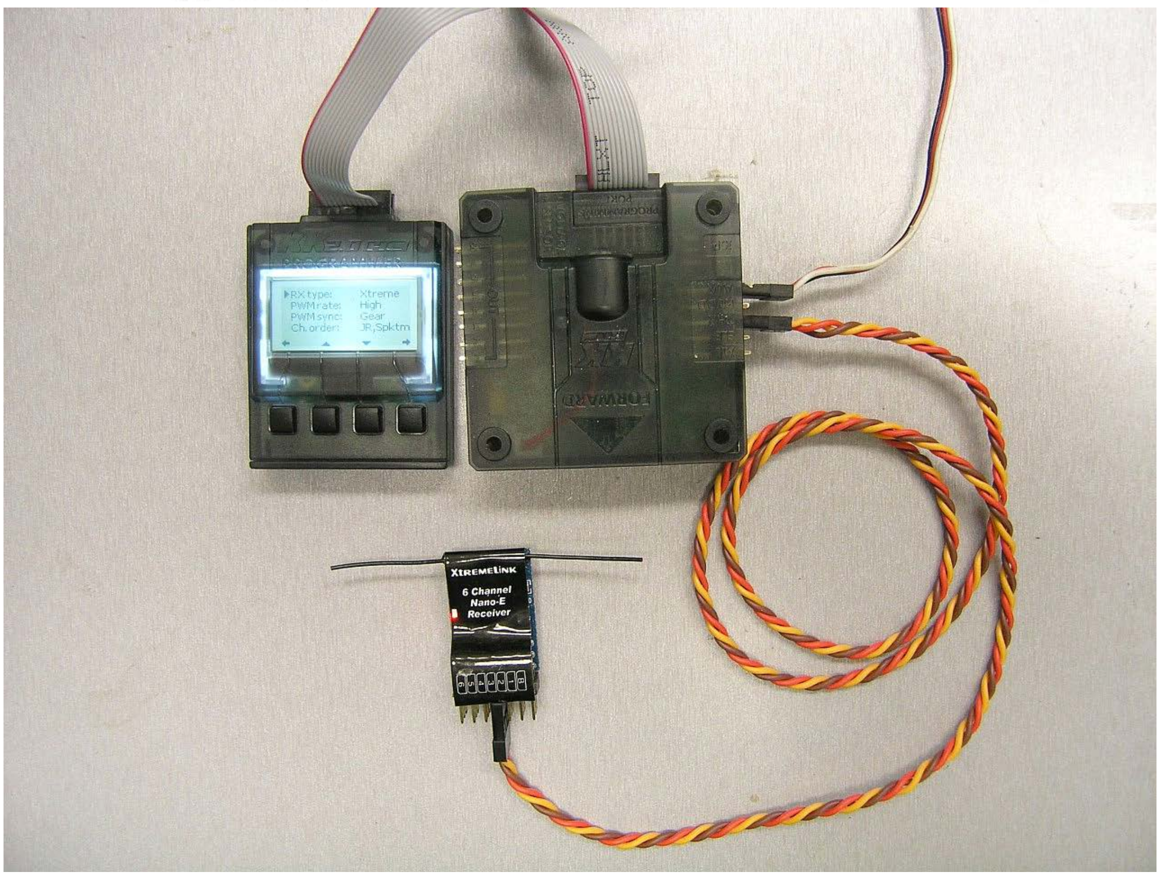
This method allows the use of the “High” PWM Rate: which updates the ESCs at up to 200Hz for improved hover stability

- RX: Nano-T, Nano-E, or RFU
  Manufacturer's page: www.xtremepowersystems.net/search.php?pg=1&stext=Nano+III, http://www.xtremepowersystems.net/proddetail.php?prod=XPS-RFU

- Product manual page: http://www.xtremepowersystems.net/manuals.php
- Cable: Connect between Nano or RFU and the 3rd or THR input of the KK2. Manufacturer's page: http://www.xtremepowersystems.net/search.php?pg=1&stext=ultra-twist





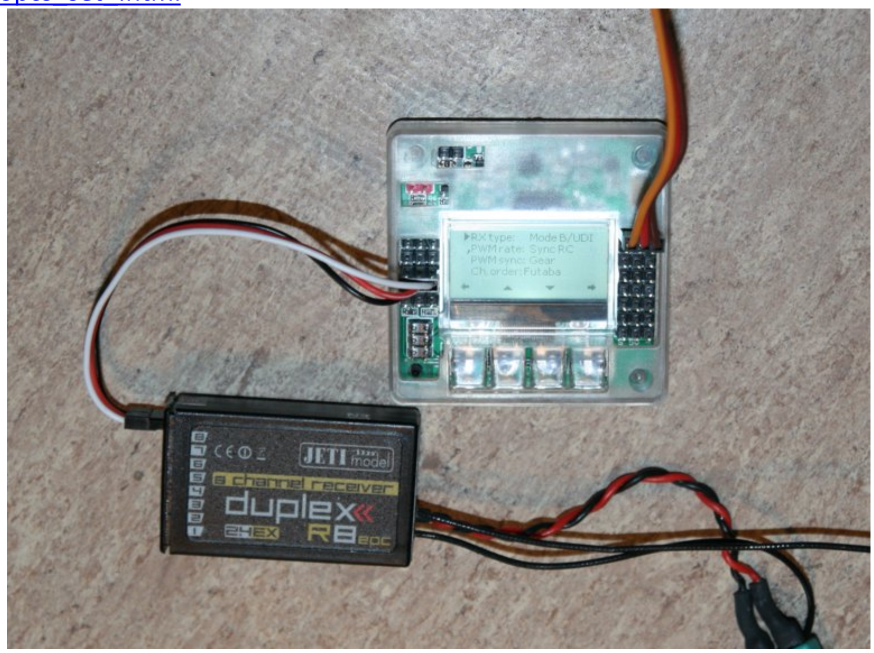


- RX type: Xtreme.
- Ch.Order: Based on type of transmitter
- Profile Chan.: Users Choice

Mode B/UDI Example:

Mode B/UDI is the Jeti-serial bus.

- RX: You can use any Jeti 2.4Ghz-RX with Firmware 3.13 or higher. UDI must be selectable via Jeti-Box/Jeti TX. Example:
  http://www.jetimodel.com/en/katalog/Discontinued-products/@produkt/Duplex-R8-EX/
- Cable: Use a normal female to female servo cable between the last channel of the receiver and the 3rd or THR input of the KK2.
  http://www.hobbyking.com/hobbyking/store/__61681__10CM_Male_to_Male_Servo_Lead_JR_26AWG_10pcs_set_.html

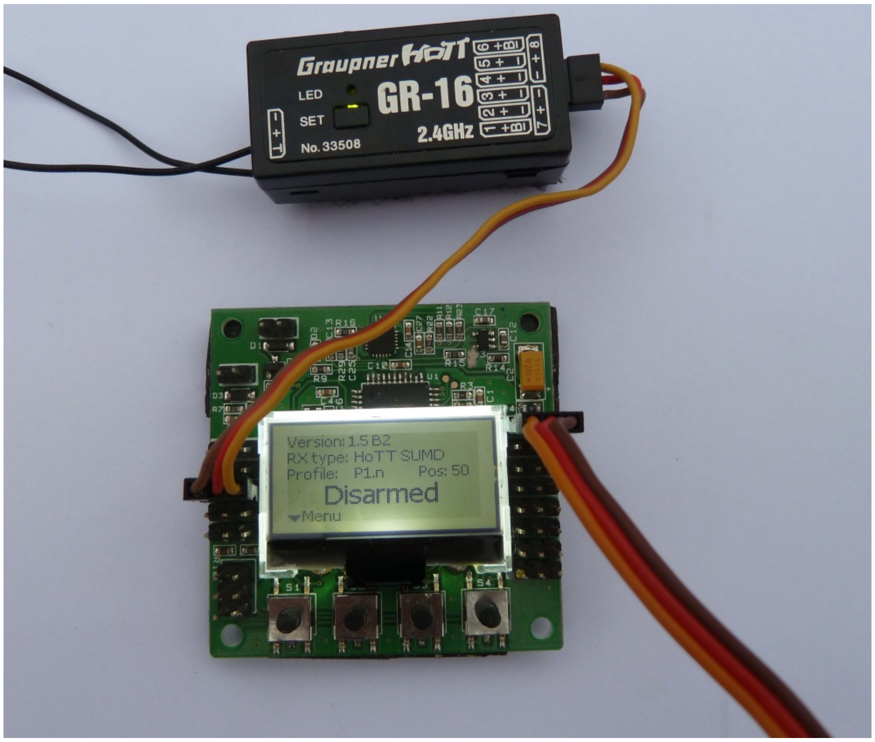


- RX type selected in the FC: ModeB/UDI
- Ch.Order: There are many possible combinations of TX and Jeti modules available resulting in many possible channel orders. The channel order may be selectable within the TX, or you can use the Custom Ch. Order: option within OAV. Use the Receiver inputs menu, or the In/OUT Display menu to verify which channels correspond to which stick input and adjust accordingly.
- Profile Chan.: Users Choice

Graupner HoTT SUMD Example:

SUMD is Graupner's serial bus protocol.

- Cable: Use a normal female to female servo cable between the last channel (8) of a receiver type GR-16 the 3rd or THR input of the KK2.
  http://www.hobbyking.com/hobbyking/store/__61681__10CM_Male_to_Male_Servo_Lead_JR_26AWG_10pcs_set_.html
- Manufacturer's page: https://www.graupner.de/Empfaenger-GR-16-HoTT2.4-GHz-8-Kanal/33508/
- Product manual page: https://www.**graupner**.de/mediaroot/files/33508_Kurzanleitung_en.pdf



- RX type selected in the FC: HoTT SUMD
- Ch.Order: The channel order may be selectable within the TX, or you can use the Custom Ch. Order: option within OAV. Use the Receiver inputs menu, or the In/OUT Display menu to verify which channels correspond to which stick input and adjust accordingly.
- Profile Chan.: Users Choice

OpenAero-VTOL Transmitter(TX) and Flight Controller (FC) Setup

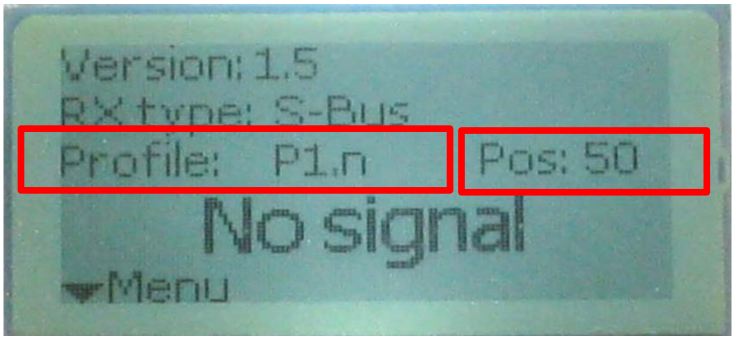
TX Initialization

1. Select a new model and configure the TX as a basic transmitter with at least 5 channels.
2. Turn off Dual rates, or set them to high rates.
3. Set all trims to neutral.
4. Set all sub-trims or offsets to neutral.
5. Eliminate all mixing and offsets related to mixing.
6. Turn off expo or any curves (for now).
7. Set all endpoint or travel adjustments to 100% or normal full travel (not extreme maximum travel).
8. Turn off any channel reversing or servo output reversing.
9. If you have a Futaba or other TX that produces a wide pulse width for low throttle, then reverse the throttle channel only. (Most TX brands produce a narrow pulse width for low throttle.)
10. Bind the TX to the Receiver (RX) as needed per the manufacturer's instructions.
11. Determine which RX outputs will be used for Rudder, Elevator, Aileron, and Throttle.
12. Determine which RX channel you will use for transition control and program the TX to use a knob, slider, or switch as you prefer. A three position flap switch controlling the flap output is one of the most common choices. Set the knob/slider/switch to a middle position and program the TX to produce a neutral (1.5ms) pulse output.
13. Connect the Receiver (RX) to the Flight Controller (FC). The S.Bus communication method is preferred.

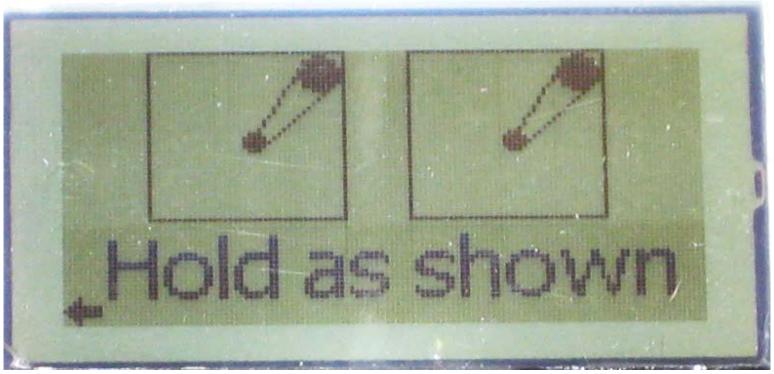
Flight Controller (FC) Initialization

1. Do a power up reset if you haven't already done so. This is done by pressing buttons 2 and 3, the two middle buttons, while applying power. The LCD screen will briefly display "Reset" before returning to the initial power on display. The FC may complain about "Throttle High" but that is only because the RX inputs haven't been calibrated yet. If you are not flashing the board for the first time, meaning you are upgrading the OAV firmware, and you already have a set of parameters loaded that you want to keep, you may want to skip the power up reset. If the upgraded firmware requires different input parameters the firmware will carry forward what it can and select appropriate defaults for what it can't. It is up to the user to verify all of the parameters before connecting motors with propellers attached.
2. Press any button followed by the Menu button and navigate to the "Receiver inputs" menu. Set the TX throttle stick to full idle and everything else to the center position, including the flap switch or whatever you are using for transition control. Press the "Cal." Button and all the displayed values should now read approximately zero.
3. Test each stick input on the TX one at a time and verify the corresponding numbers on the display. Adjust the travel or endpoint adjustment on your TX so that full stick input for rudder, elevator, and aileron produce display values of +-1,000 or slightly larger. Adjust the throttle to display values from 0 to 2,000 or slightly more. Take care to maintain throttle linearity when you do this. Adjust the transition control input for approximately +-1024.

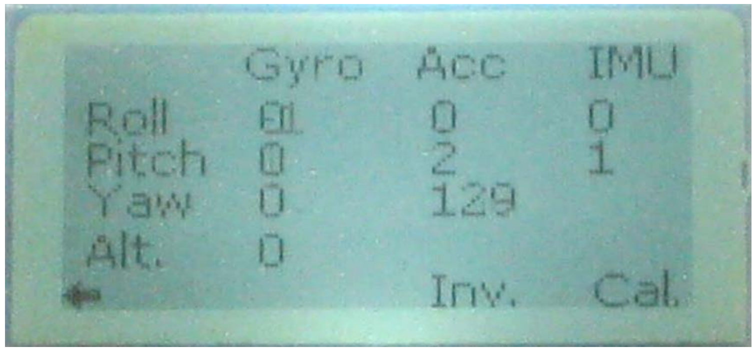
4. Exit to the status menu on the display. The status menu will only appear for 10 seconds at a time, so you may need to press the Menu button from time to time to make it reappear. With the flap switch, pot, slider, or whatever is controlling the transition point on the TX set to neutral, you should see “P1.n” in the “Profile:” display and “50” in the “Pos:” display.



5. “P1” or “Profile 1” is generally used for hover mode, and “P2” or “Profile 2” is generally used for Fast Forward Flight (FFF) mode. “P1.n” indicates that you are somewhere in between the thresholds for these two modes, and Pos: 50 indicates that you are exactly in the middle. Verify that the switch, pot, slider, etc. on your TX that controls the transition point results in P1 and P2 displayed with the desired input polarity. The Profile: will change from P1.n to P2 as the Pos: reaches 100. Likewise the Profile: will change from P1.n to P1 as the Pos: reaches 0.
6. Go to the Stick polarity menu and move the sticks on your TX as seen in the FC display.

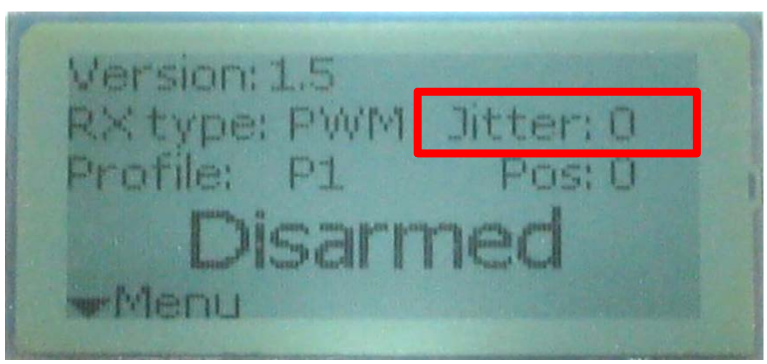


7. From this point forward you will not want to touch the TX trims, sub-trim, endpoint adjustment or anything else related to the channels going to the FC. All such adjustments will be made in the FC. The one exception to this rule is that you may want to apply some Expo to rudder, elevator, or ailerons.
8. Go to the “Sensor calibration” menu and with the FC level and stable press the “Cal.” Button. The displayed numbers should all now read close to zero with the exception of the number on the lower right which should be in the vicinity of 130. This is a measure of the Z axis or gravity vector. Hold the FC level, stable, and upside down (LCD screen facing the floor) and press the “Inv.” Button. It is very important that you also do the inverted calibration even if you do not intend to fly inverted.



If you have selected one of the tail sitter modes, either "Earth ref." or "Vert. AP ref." then you will need to do the above calibration twice. Do it once with the fuselage level while in P2 (FFF – Fast Forward Flight mode) and again when in P1 (Hover Mode). When in P1 the upright position is with the nose pointed straight up, and the inverted position is with the nose pointed straight down. Select the "Level meter" menu and verify that the bubble level works as you would expect in both P1 and P2. In some cases, depending on the polarity of your transmitter signals or the FC orientation option selected the bubble may appear to move in the wrong direction. As long as the bubble returns to the center when the FC is level it is working properly.

9. This step is only necessary when the multi-cable PWM (Pulse Width Modulation) method is used to provide data from the RX to the FC (Flight Controller). It does not apply when using the various single cable methods of serial communication such as CPPM, S.bus, Xtreme, Mode B/UD, SUMDI or Spektrum Satellite. Go to the "PWM sync:" menu within the "Receiver Setup" menu. The PWM sync: menu is used to synchronize the RX pulse outputs with the internal firmware loop. This insures jitter free operation by avoiding any delays in the measurement of incoming pulses, or the creation of outgoing pulses. One at a time, select each of the 5 PWM inputs as a synchronization pulse. It is then necessary to exit to the status menu to observe the jitter counter.



Select the PWM input that produces the smallest jitter count, preferably zero. Given the wide variation in RC equipment it is not possible to guarantee that a zero jitter option will always be available

10. The FC is now ready for application specific setup.

Gyro and Accelerometer Initialization

The accelerometers are calibrated when the Cal. button (button #4) and the Inv. (Inverted calibration button #3) are pressed within the Sensor Calibration menu. This only needs to be done once when the aircraft is first setup, but can be redone at any time. Just make sure that the aircraft is held stable in the desired attitude.

For Tail Sitters, don't forget to properly calibrate the sensors in both P1 (Hover) and P2 (FFF). The calibration instructions can be found in this manual under Flight Controller (FC) Initialization.

The Cal. button within the calibration menu also calibrates the Gyros. It is important that the Gyros read 0 or as close to 0 as possible when the aircraft is stable in order to minimize the "I" (Integral) feedback drift. For this reason the Gyros are also recalibrated at every power up and also whenever the FC is armed. It is important that the aircraft be held steady immediately after power up and when the FC is armed.

If you move the board excessively immediately after power up, the calibration may fail, in which case the board will reset and try again.

The Gyro calibration from within the calibration menu is a "fast calibration" which is also most accurate but depends on the aircraft being held very still for maximum accuracy. The Gyro calibration that is performed on power up and when the board is armed is an "averaging calibration". The averaging calibration method is used to increase tolerance to movement that might be caused by user handling or wind during the calibration process.

An averaging calibration basically averages the Gyro output until the resulting value stabilizes to within plus or minus 1 count. If the average value does not stabilize within 5 seconds the calibration will fail. It is unusual for the calibration to fail unless the aircraft is moving quite a lot. The solution is to simply hold the aircraft steady during the brief period after power up, or when arming. Failure to do so can result in random trim changes.

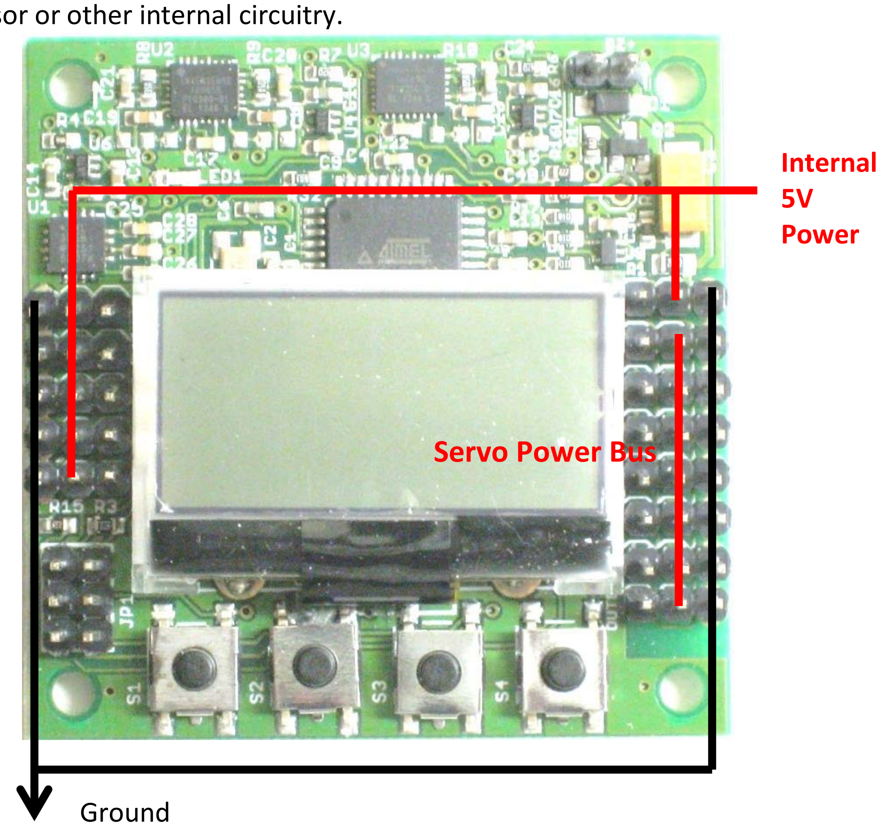
Power Distribution for the Receiver (RX) and Flight Controller (FC)

The KK2 board has two separate power supply inputs.

1. Power to the KK2 internal circuitry
2. Power to Servos on OUT2-8

The power bus for internal circuitry includes the power pins (center pins) for the connectors on the left side of the board that are used for Aileron, Elevator, Throttle, Rudder, and the Aux input. It also connects to the power pin (center pin) of the OUT1 connector, which is the top 3 pin connector on the right side of the board.

The power pins (center pins) on OUT2-8 are connected to each other and nothing else. They will not provide power to operate the KK2 internal circuitry. The power bus on these outputs is isolated from the rest of the KK2 board to prevent any noise that might be generated by servos from causing problems with the KK2 processor or other internal circuitry.



The various forms of the KK2 board, including the KK2.0, KK2.1, KK2.15, KK2-HC (Hard Case) and the KK2 Mini all have this same power structure.

VTOL applications typically involve a mix of servos and ESCs (Electronic Speed Controllers). Servos should not be connected to the power source that powers the internal circuitry of the KK2. Any deficiencies in the power that is provided to the KK2 internal circuitry could cause a processor reset which would almost certainly result in a crash.

The simplest recommended solution is to power the internal KK2 circuitry via the BEC (Battery Eliminator Circuit) that is part of an ESC that is connected to OUT1. The power required by the KK2 board is modest, about 35mA, and any reasonable BEC should be able to handle it without difficulty.

If the RX will be driving any servos directly then the cable or cables that connect the RX to the KK2 should have their power wires removed or disconnected in order to isolate the KK2 internal power from the RX (Receiver) power.

A separate BEC rated for 5V to 6V, depending on the specifications of your servos, should be used to provide power to OUT2-8. If you don't have an open connector for OUT2-8 then a Y-harness can be used to gain access. If the servo or servos you are using require any significant amount of current then it would be best to use a separate BEC that is not part of any ESC to drive OUT2-8. If the current requirements are high enough, it would be best to use a SBEC (Switching Battery Eliminator Circuit) for OUT2-8. Just be sure that any power source you use is rated to handle the expected load.

The power to your RX (Receiver) can be provided from the same BEC, or SBEC that is used to provide power to OUT2-8. You can also use a 3rd power source for your RX if you wish. Bear in mind that any servos that are connected directly to your RX will draw power from your RX, so your RX power source needs to be able to handle the load.

However many power sources you may have, they must all share a common ground connection.

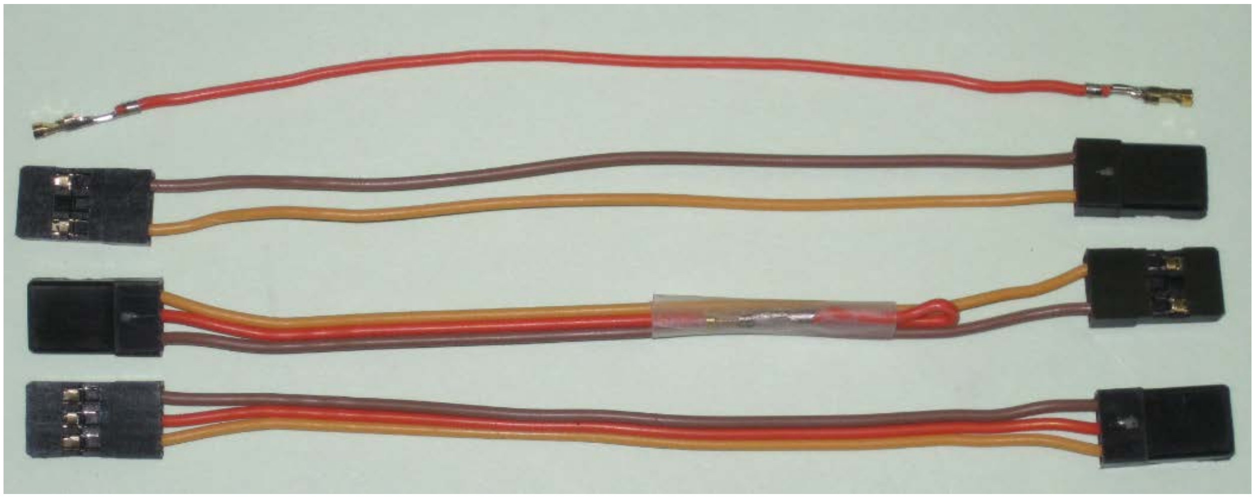
If you have an application that does not require any servos then you can use a single BEC connected to OUT1 to power both the KK2 board and also the RX through power wires between the KK2 and the RX. This is the typical configuration for a simple quad-copter.

If you have only ESCs connected to OUT2-8 then it is not usually necessary to provide power to OUT2-8. The ESCs will receive power from their connection to the main power battery.

If you have a servo or servos connected to OUT2-8, then it is acceptable to have an ESC that is also connected to OUT2-8 to provide the necessary power. Just make sure that the BEC inside the ESC is rated for the load.

If you have multiple ESCs connected to OUT2-8 then it is best to disconnect the power wire for all but one of them. It is possible that the multiple BECs in the multiple ESCs could fight over the exact voltage to be provided and damage the BECs/ESCs. Many smaller ESCs use linear BECs that will not be damaged if connected in parallel in this manner. Follow the manufacturer's recommendations for the specific BECs/ESCs you are using.

A simple method for disconnecting the power wire on a ESC/BEC is to gently lift the tab on the connector and remove the female contact. Fold it back against the wire and cover it with tape to prevent shorts. This process can easily be reversed by pushing the female connector back into the connector housing. You can use this same technique to disconnect power on the jumper cable(s) between the RX and the KK2, however it is neater to remove the female power connector from the connector housing on both ends of the cable and then strip out the entire power wire. The power wire can be replaced at a later date if needed, but the individual wires will no longer be joined as a ribbon. Twisting the wires will help to keep them close together when they are not joined as a ribbon.



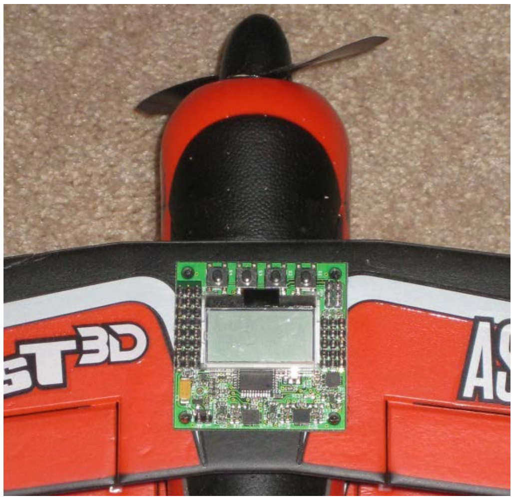
Board Mounting Positions

OpenAero-VTOL provides 24 board orientation options, which means that every possible option is supported to 90 degrees of resolution.

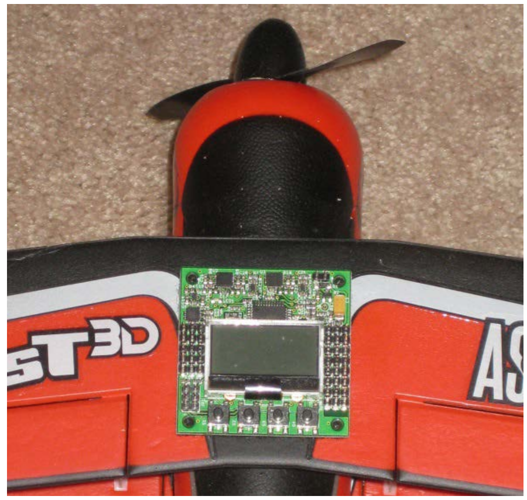
To understand the naming convention it is helpful to imagine a cube in the middle of your aircraft. You first place the FC (Flight Controller) board on one of the 6 cube faces, (Top, Bottom, Front, Back, Left, or Right). You then spin the board so the buttons are facing one of 6 possible directions, but only 4 for any given side (Up, Down, Left, Right, Front or Back).

For tail sitters, select the orientation corresponding to P2, or FFF (Fast Forward Flight). The P1 or hover mode orientation will automatically be assumed to be 90 degrees nose up from there.

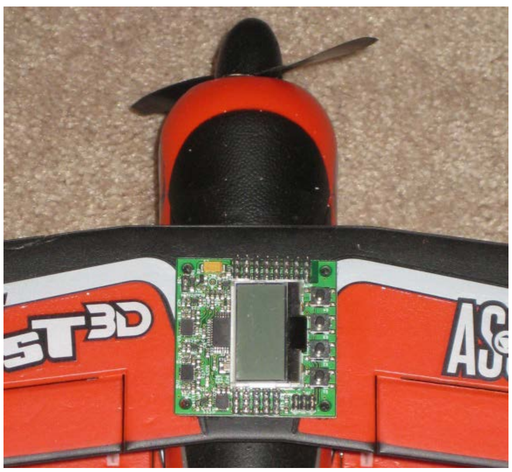
Orientation	Description
Top-Rear	Flat with the LCD facing Up and the buttons to the Rear of the model
Top-Left	Flat with the LCD facing Up and the buttons to the Left side of the model
Top-Front	Flat with the LCD facing Up and the buttons to the Front of the model
Top-Right	Flat with the LCD facing Up and the buttons to the Right side of the model
Back-Down	KK board on edge with the LCD facing the Back and the buttons at the Bottom
Back-Left	KK Board on edge with the LCD facing the Back and the buttons to the Left
Back-Up	KK Board on edge with the LCD facing the Back and the buttons on the Top
Back-Right	KK Board on edge with the LCD facing the Back and the buttons on the Right
Bott.-Back	Flat with the LCD facing Down and the buttons to the Rear of the model
Bott.-Right	Flat with the LCD facing Down and the buttons to the Right of the model
Bott.-Front	Flat with the LCD facing Down and the buttons to the Front of the model
Bott.-Left	Flat with the LCD facing Down and the buttons to the Left of the model
Front-Down	KK Board on edge with the LCD facing the Front and the buttons on the Bottom
Front-Right	KK Board on edge with the LCD facing the Front and the buttons on the Right
Front-Up	KK Board on edge with the LCD facing the Front and the buttons on the Top
Front-Left	KK Board on edge with the LCD facing the Front and the buttons on the Left
Left-Down	KK Board on edge with the LCD facing the Left and the buttons on the Bottom
Left-Front	KK Board on edge with the LCD facing the Left and the buttons in the Front
Left-Up	KK Board on edge with the LCD facing the Left and the buttons on the Top
Left-Back	KK Board on edge with the LCD facing the Left and the buttons in the Back
Right-Down	KK board on edge with the LCD screen facing Right and the buttons at the Bottom
Right-Back	KK board on edge with the LCD screen facing Right and the buttons at the Back
Right-Up	KK board on edge with the LCD screen facing Right and the buttons at the Top
Right-Front	KK board on edge with the LCD screen facing Right and the buttons at the Front



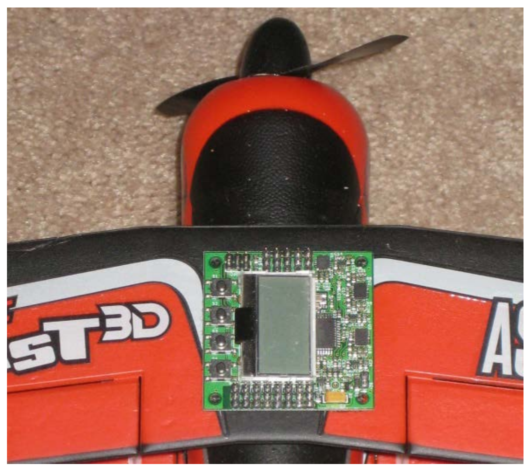
Top-Front



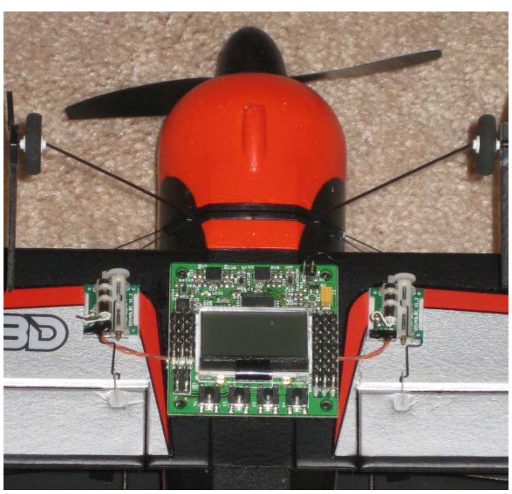
Top-Rear



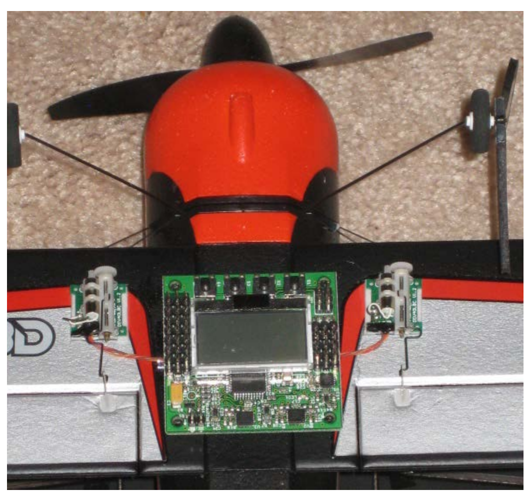
Top-Right



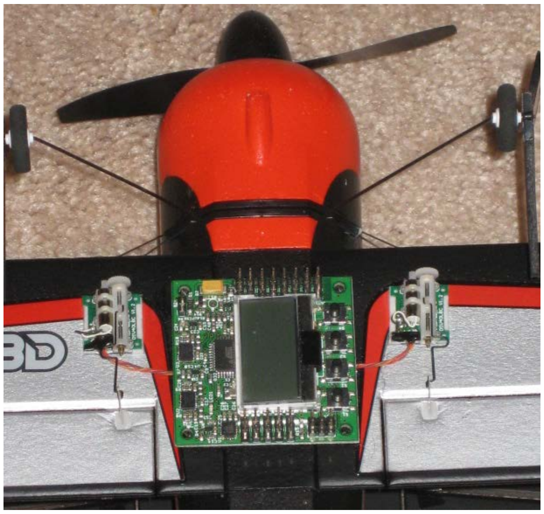
Top-Left



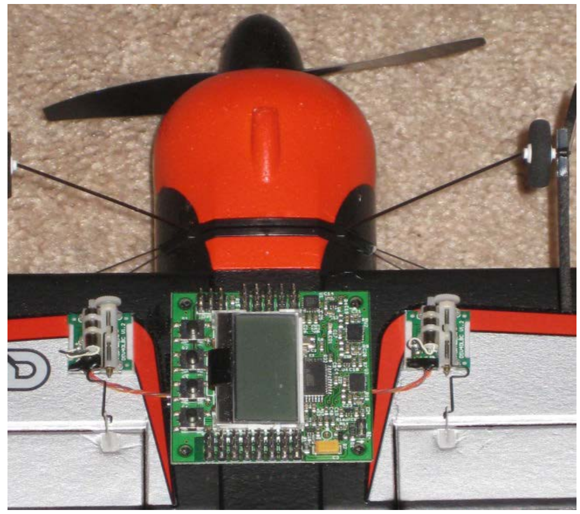
Bottom-Back



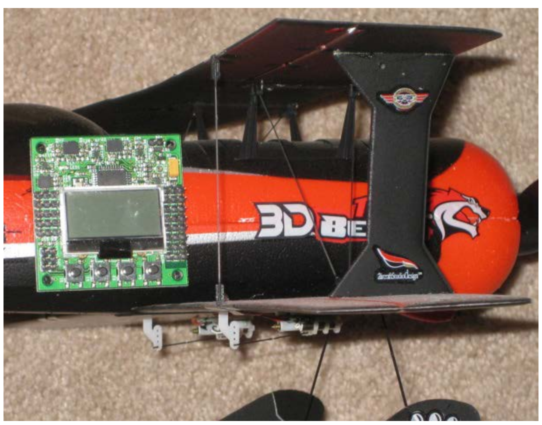
Bottom-Front



Bottom-Left



Bottom-Right

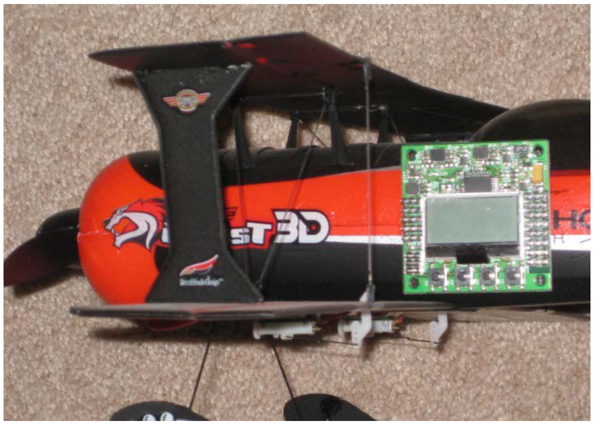


Right-Down

Right-Up

Right-Back

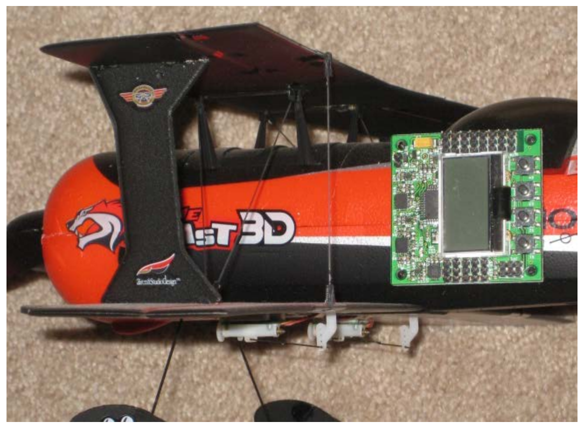
Right-Front



Left-Down

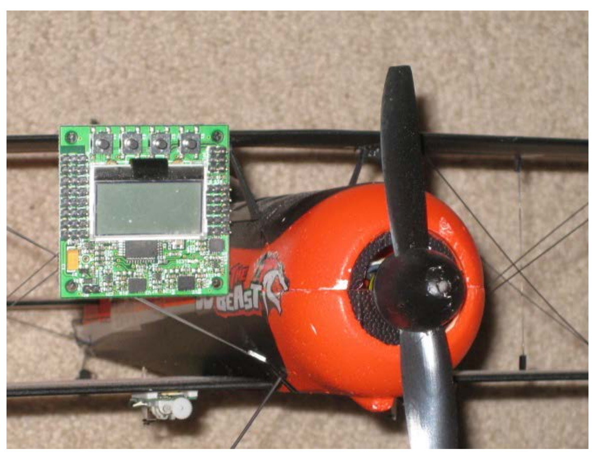
Left-Up

Left-Front



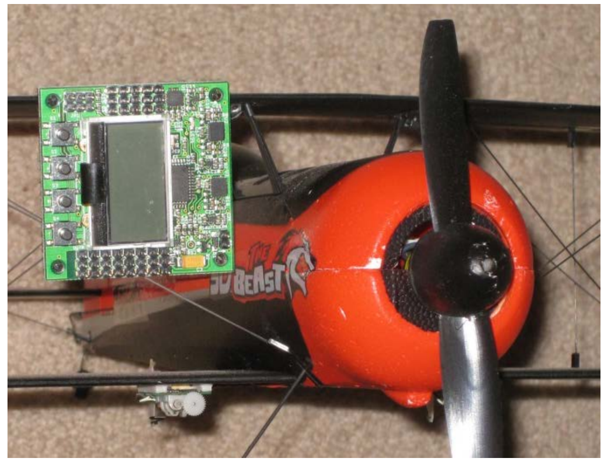
Left-Back

Front-Down

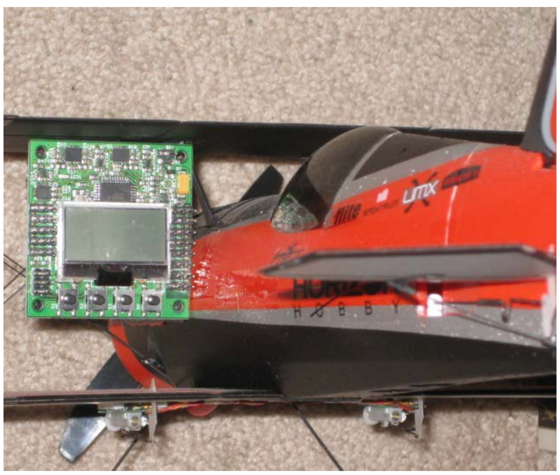


Front-Up

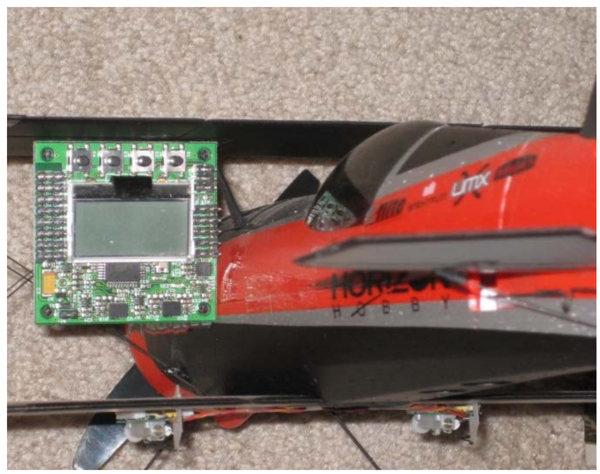
Front-Left



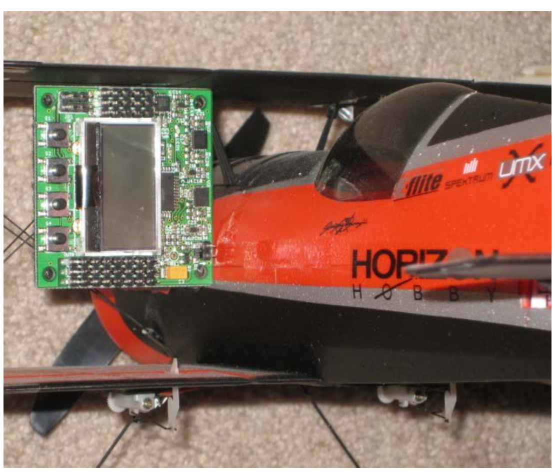
Front-Right



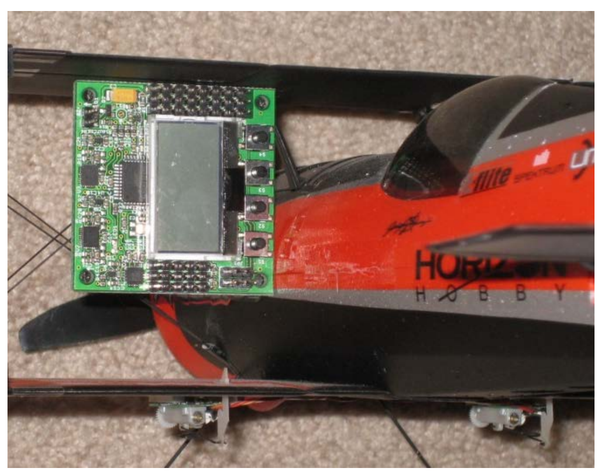
Back-Down



Back-Up



Back-Left



Back-Right

Transition Control Methods

Transition control is a matter of personal preference and is often dictated by the physical capabilities of your transmitter (TX). One of the more common techniques is to use a 3 position switch, often designated on the TX as the “Flap Switch”. Some transmitters have the ability to output a linear flap channel with a “slow” transition between 3 different flap states. This signal is often used as the “Profile Input” or “Profile Channel” to tell the FC what percentage of transition you want.

It is also possible to use this technique with a 2 position flap switch, however, in that case you would only have two flight modes, most likely hover mode and FFF (Fast Forward Flight).

OAV has a “slow function” that can be used with transmitters that do not have a built in slow function. The outbound transition is programmable from 1 to 40 seconds, and the inbound transition is separately programmable from 0 to 40 seconds. The slow function is needed because it generally takes an aircraft a few seconds to accelerate to flying speed from a hover, or likewise to decelerate from flying speed into a hover. If the transition were to happen instantly, many aircraft types would simply fall out of the sky.

When using the internal OAV “slow function” it is possible to separately select the “Transition low:”, “Transition mid:”, and “Transition high:” values. Normally Transition low: is set to 0 corresponding to P1 or Hover mode. Transition high: is set to 100 corresponding to P2 or FFF. Transition mid: is set to something between 15 and 50 corresponding to SFF. It is possible, however, to set the Transition low/mid/high to other values as is often convenient when testing a new aircraft.

It is also possible to control the percentage of transition directly using a pot or a slider. This gives full control of the transition in terms of both speed and direction, but is potentially dangerous. A too rapid transition can result in a loss of altitude and in some cases a crash. Not all transmitters have a pot or slider that is easily accessible while maintaining full control over both sticks. Also, the pilots attention is divided between flying the aircraft and operating the transition control at a point when flying the aircraft is most critical. Finally, good tactile feedback is often not available on the pot or slider, forcing the pilot to look at the controls, which further diverts attention from flying the aircraft. Despite these concerns, some pilots may prefer this method, and OAV fully supports it.

Some full scale VTOL aircraft use a “beep switch”. This is their terminology for the functionality that is commonly used for digital trims. If your TX has the ability to convert a spare digital trim for use as an analog output then you can use this technique with OAV. Bear in mind, that the TX trims are generally of no use when using a FC (Flight Controller) so you might as well use them for something else.

Some VTOLs, especially those with Separate Lift and Thrust motors (SLT) will have multiple throttles. In this case it is possible to put one throttle on the normal throttle stick, and the other throttle on a separate pot or slider. This brings us back to the issues with pots or sliders on most transmitters being difficult to access, having poor tactile feedback, and distracting from flying the aircraft. It is also possible to transition too quickly, or simply make a mistake and move the wrong throttle in the wrong direction. Never the less, some people prefer this technique, and with practice they can become quite good at it. OAV supports this technique but there is essentially nothing to support. The throttle to the forward thrust motor does not generally require any stability feedback and does not need to pass through the Flight Controller (FC).

Modern full scale VTOLs like the F-35B have sophisticated flight controllers and flight modes that are unlike anything we would recognize for traditional RC model aircraft. They often depend on various instrumentation, such as an airspeed sensor or GPS, that are not available in the KK2 board. In general, OAV is designed to provide the standard RC control experience with direct control over roll, pitch, yaw, and throttle in all flight modes.

ESC (Electronic Speed Controller) Calibration

Warning! ESC calibration is potentially dangerous and should only be done with all of the propellers removed and the aircraft safely secured.

Some ESCs that are designed for use with fixed wing aircraft will continuously adjust their input range based on any input signal they receive. This sort of ESC is generally not suitable for use with VTOL aircraft or any sort of multi-copter.

Most modern ESCs that are suitable for use in a VTOL aircraft come in two basic types. Those that have fixed endpoints and those that match their endpoints to a user provided signal range.

The fixed endpoint type are less common but can easily be used with OAV. There is nothing to calibrate in the ESC, but instead you must adjust the volume and offset of the signal feeding the ESC to obtain the desired results. Generally this means that the ESC range is matched to full throttle stick travel for a smooth linear throttle response.

ESCs that are calibrated to a user input range are the most common type. One option is to use an RX (Receiver) to calibrate the range unrelated to the FC. Once the range is calibrated you can treat the ESC like a fixed endpoint type.

It is common for VTOL aircraft to have several motors and it is often convenient to calibrate their ESCs in an identical manner. You can purchase a 4 output or even an 8 output Y cable to make this easier. The input to this Y cable can come from your RX if you so choose. This technique does not necessarily have anything to do with the FC.

The most common method is to calibrate the ESCs based on the actual output from the FC. Follow the ESC manufacturer's instructions, but most ESCs of this type are calibrated in the same general way. You apply a full throttle input and power up the ESC. After a moment the ESC will beep indicating that it recognizes the full throttle input as a calibration point. Then set the throttle to full idle and wait for the ESC to beep indicating that it accepts the full idle input as a calibration point. Power down the ESC and thereafter use it normally.

The OAV firmware uses this same calibration technique except that your transmitter is not required. As part of the Flight Controller setup procedures you should have calibrated the throttle input signal from the transmitter so the expected output from the Flight Controller for 100% throttle input and 100% throttle volume is already known.

With the ESCs connected to the Flight Controller in the normal manner, hold down buttons 1 and 4, the two outer buttons, and apply power to the ESCs and the Flight Controller in the normal manner. The board will output a 1.9ms or "full throttle" pulse to all outputs configured as "Motor".

Once the ESCs acknowledge the full throttle input, release buttons 1 and 4 and the Flight Controller will output a 1.1ms or "full idle" pulse to all outputs configured as "Motor". Once the ESCs acknowledge the full idle input, remove power. The ESC calibration is complete.

Throttle Transition Curves

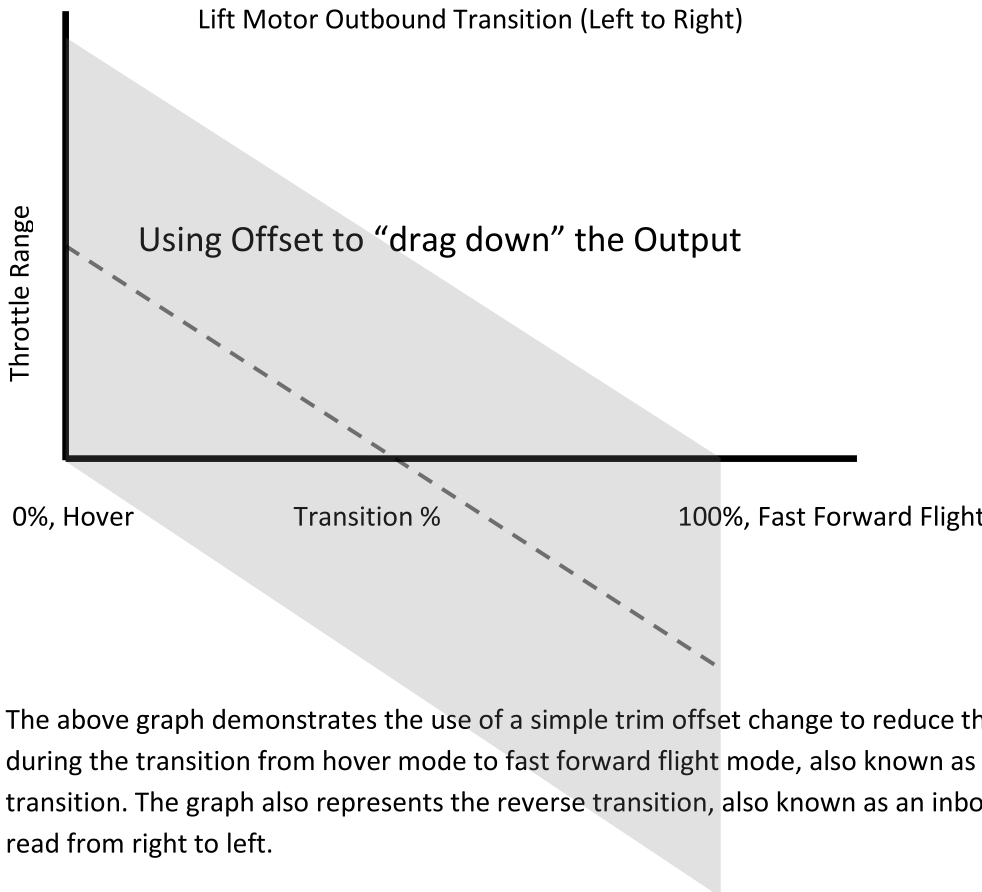
A throttle transition curve is not the same as a throttle curve. A Throttle curve maps the throttle stick input to the throttle output. A throttle transition curve manages the transition between the P1 throttle volume and the P2 throttle volume during transition.

Some VTOL aircraft types need to turn off one or more motors in various Flight Profiles (Flight Modes). This is especially true for SLT (Separate Lift and Thrust) type aircraft that use different motors to provide lift and thrust. In hover mode the thrust motor is typically turned off, and in FFF (Fast Forward Flight) mode the lift motors are typically turned off. This is also true for aircraft that have tail rotors, or other control type rotors that can be turned off in FFF.

The challenge is to make a smooth transition between hover mode and FFF. Ideally, if we flip the switch for an outbound transition, the aircraft will smoothly accelerate from a hover and enter FFF without gaining or losing any altitude. Reality is rarely that perfect, but the less the pilot has to do to make a smooth transition the better.

The exact requirements for a smooth transition will vary with aircraft type, but the general idea is that there needs to be some degree of “overlap” in time between the lift and thrust motors. For an outbound transition the thrust motor needs to come on and give the aircraft some time to accelerate before the lift motors shut off. The overlap for an inbound transition is generally less critical as the aircraft already has forward airspeed so the lift motors just need to come on before forward airspeed is lost.

This concept of overlap is further refined by applying a throttle transition curve. There are numerous ways to create a throttle transition curve, some better than others.

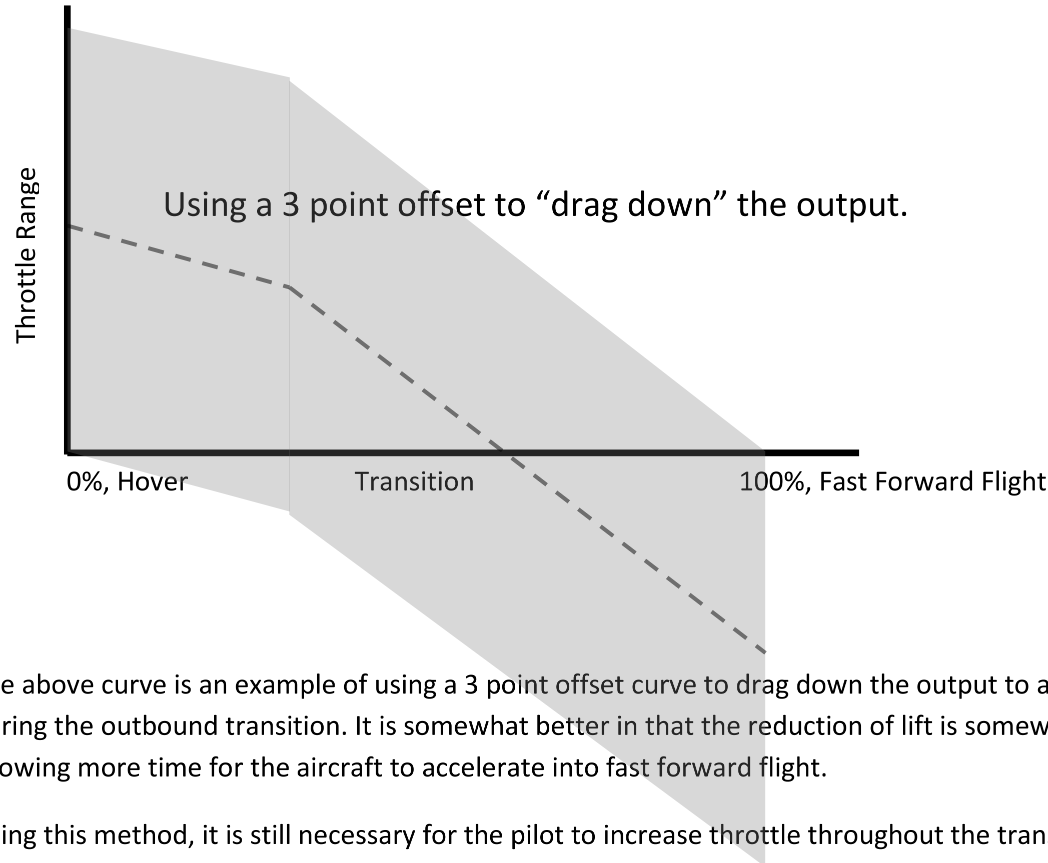


The above graph demonstrates the use of a simple trim offset change to reduce the output to a motor during the transition from hover mode to fast forward flight mode, also known as an outbound transition. The graph also represents the reverse transition, also known as an inbound transition, when read from right to left.

The vertical axis of the graph represents the throttle output sent to the ESC and hence to the motor. The grey zone represents the range of user throttle input from the TX. The top of the grey zone is for 100% throttle stick input. The bottom of the grey zone is for 0% throttle stick input, and the dashed line in the middle of the grey zone is for 50% throttle stick input which is also approximately the power level that is assumed to be required to hover.

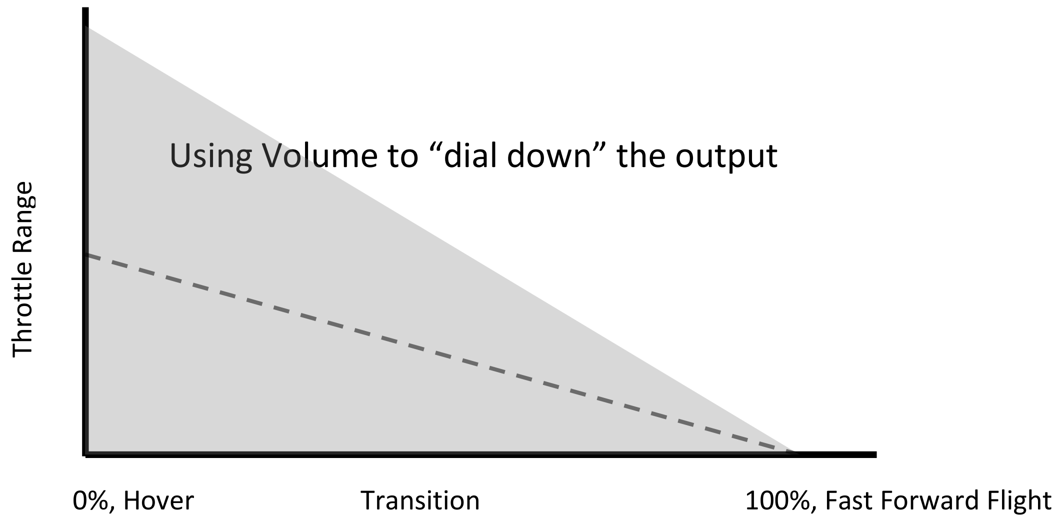
Using a trim offset to drag down the output to the motor is the simplest method for turning off a motor during a transition, but it is less than ideal in a number of ways. As the transition begins, the hover power immediately begins to drop, even before the aircraft has a chance to begin to accelerate horizontally. As the transition continues the pilot must apply more and more throttle input to maintain a reasonable amount of lift throughout the transition. If the throttle input is maintained at 50%, or nominal hover power, all lift is lost by the 50% transition point. Depending on the transition curve for the thrust motor, and the nature of the aircraft, and the speed of transition, the aircraft may not have achieved sufficient airspeed to fly by that point.

The graph shows a large grey area below the line because much of the range of throttle stick input will be below the minimum level to run the motor. As a practical matter this extreme low level input would be clipped, but it is shown here for clarity of the concept.



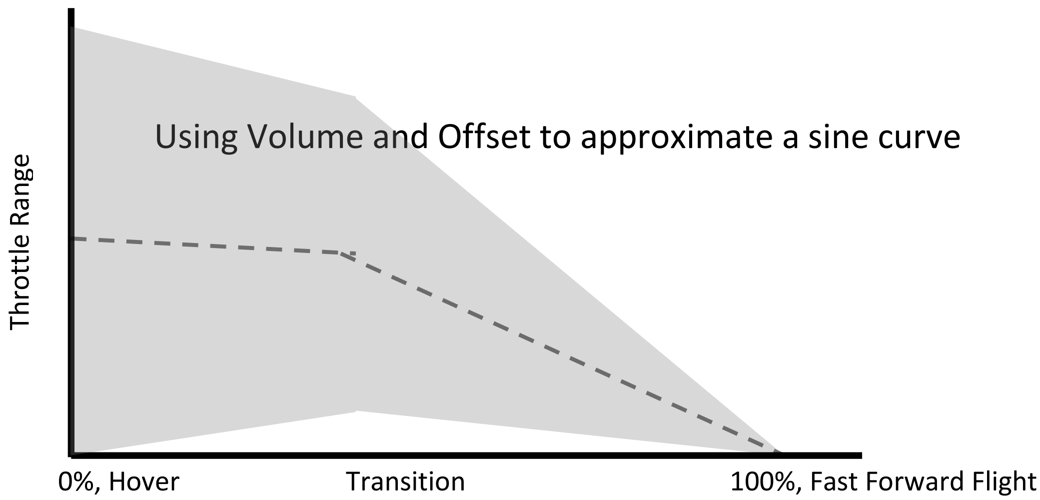
The above curve is an example of using a 3 point offset curve to drag down the output to a lift motor during the outbound transition. It is somewhat better in that the reduction of lift is somewhat delayed allowing more time for the aircraft to accelerate into fast forward flight.

Using this method, it is still necessary for the pilot to increase throttle throughout the transition in order to prevent the loss of lift before the transition is complete.



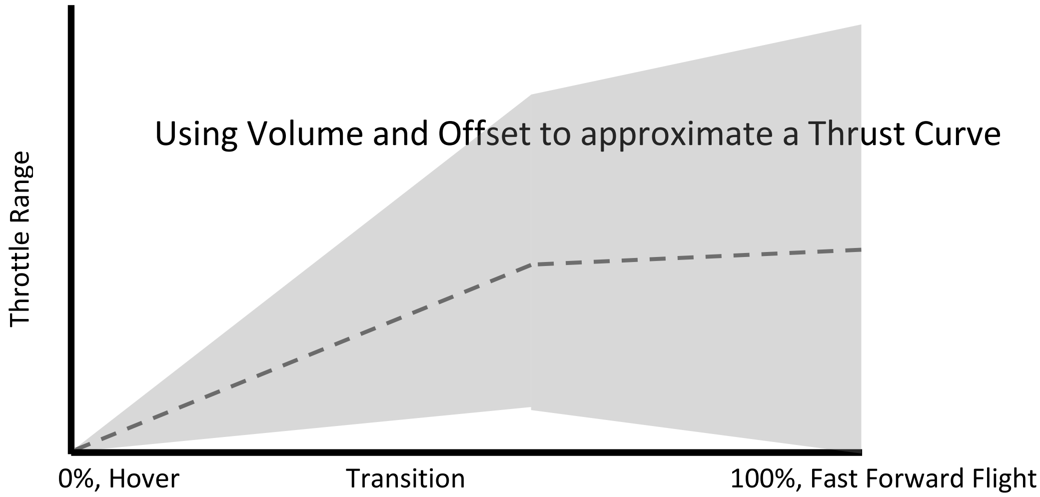
The above graph represents the use of a 2 point curve to dial down the throttle output to a lift motor during transition. Since the response is linear, the lift will immediately begin to drop at the beginning of the transition, it will not, however, go to zero until the transition is complete.

The pilot will likely need to increase throttle during the early stages of the outbound transition to maintain adequate lift until sufficient airspeed is achieved. This adjustment is, however, fairly minor, and something that a pilot can easily do.

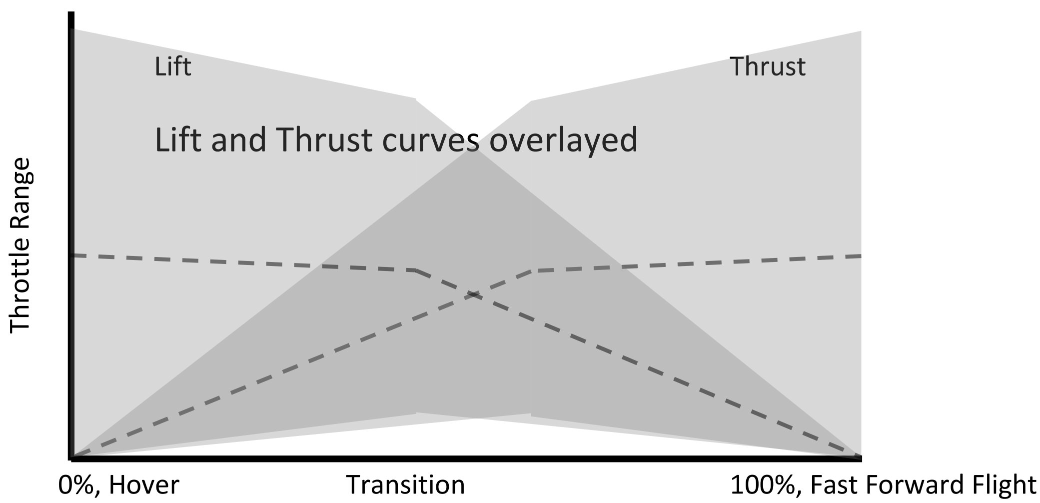


The above diagram represents the use of a 2 point volume curve in combination with a 3 point offset curve. The shape of the dashed line is intended to approximate 90 degrees of a sine wave**.** The kink in the middle of the curve is accomplished by increasing the P1.n offset by some amount.

You will note that there is a white space below the curve in the 50% transition region. This means that at 50% transition the pilot will be unable to completely shut the lift motors off. This would be true except for the safety feature that shuts off power to the motors for inputs below 2.5% throttle. The net result is that the pilot will be able to shut off all motors throughout the transition but in the middle of the transition curve the throttle will have a non-linear jump from off to a low throttle setting when the stick input crosses the 2.5% threshold. None of this is a problem in the air, nor is it a safety issue on the ground. It may cause some minor confusion when doing a STOL (Short Take Off and Landing) where the transition is already partially underway when power is applied.



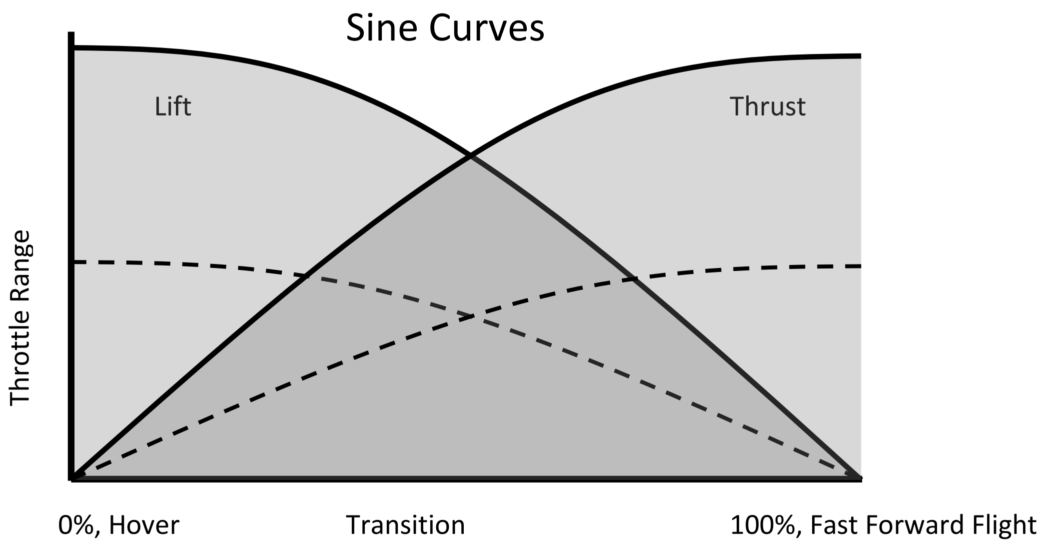
The curve for the forward thrust motor is the same as for the lift motor but flipped from left to right.



By placing the lift and thrust curves on top of one another we can show how they overlap. If these were ideal sine curves they would cross at the sine of 45 degrees or 70.7%, and the dashed lines representing 50% throttle would cross at half that or 35.4%.

In reality the shape of these curves only needs to be approximate. The pilot will make small corrections as needed throughout the transition and in most cases the transition does not need to be an extremely precise maneuver. For an outbound transition it is usually sufficient to apply enough throttle to maintain a positive rate of climb throughout the maneuver. For VTOLs that can glide reasonably well, the entire inbound transition is often non-existent. The conversion to hover mode is made with the throttles off or nearly off, and the plane simply glides to a location where the pilot wants to hover, at which point hover power is applied.

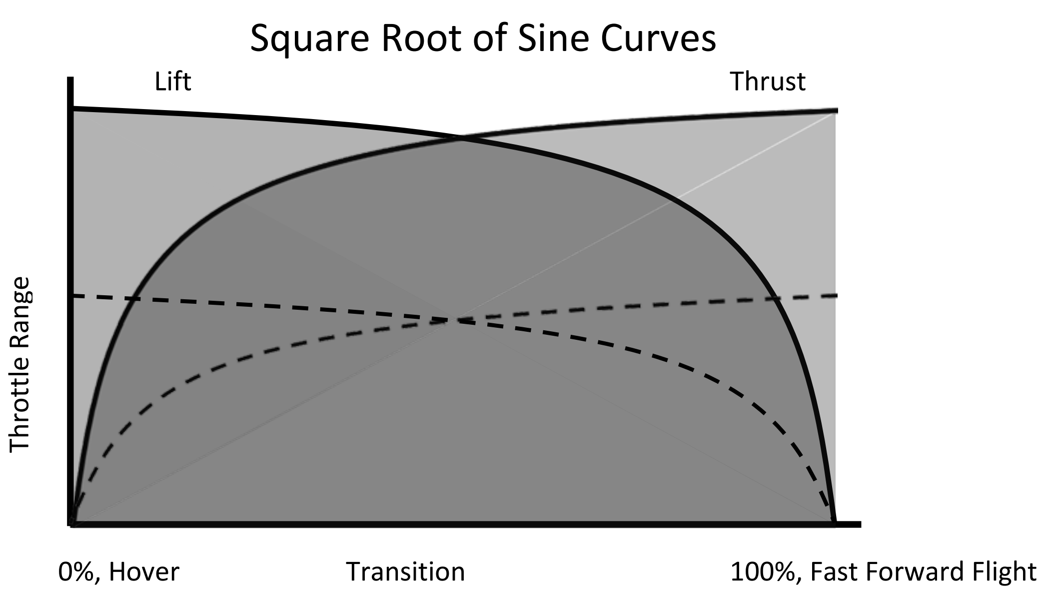
OAV makes all of this even easier by providing a sine curve function.



When you select the sine curve, OAV will automatically give you the correct curve shape based on whether Profile 1 (P1) or Profile 2 (P2) has the higher throttle volume setting. The above curves show the throttle going to zero, but the firmware allows you to transition from any throttle volume to any other throttle volume.

A sine curve is only a theoretical optimum for a grossly simplified case. The actual optimum depends on aircraft configuration, airspeed, and lots of other things, some of which will vary from one transition to the next.

OAV also has the option of a Square Root of Sign Curve. The Square Root of Sign curve provides additional overlap between the lift and thrust motors and allows for a more rapid outbound transition.



You can also modify the shape of these curves to some degree by using the P1.n offset point to shift the P1.n point up or down. This is the same technique as described earlier for a linear curve and it has the same minor difficulty of a non linear throttle response at the P1.n point.

When adjusting throttle transition curves it is difficult to just listen to the motors and know what is happening. It is a good idea to invest in a digital servo tester like this one with a pulse width readout so you can know exactly what is happening.

http://www.hobbyking.com/hobbyking/store/__17047__turnigy_digital_anolog_servo_tester_.html

Whatever curve shape you select, it will apply to both the outbound and inbound transition. This is not usually a problem as the curve shape is driven by the outbound transition.

You can observe how your aircraft responds during outbound and inbound transitions and make adjustments accordingly. Likewise you can fly your aircraft at various percentages of transition and make adjustments accordingly. Bear in mind that an outbound transition requires more energy input to accelerate the aircraft to flying speed as compared to SFF (Slow Forward Flight) that is more of a steady state condition. The difference is typically nothing more than a couple of clicks of throttle.

It is common to continuously fly VTOL aircraft at various percentages of transition. Most commonly this is done in SFF (Slow Forward Flight) mode at about 20% of transition. Regardless of the transition percentage, the aircraft should be fully in control throughout the transition. Some difficult aircraft may have regions within the transition where control or power are marginal. It may be necessary to push through these regions quickly to get to the safe zone on the other side. Better yet, make whatever adjustments are necessary to make the entire transition a safe zone.

Curves Menu

The curves within the Curves Menu are most commonly used for helicopter base VTOL aircraft, meaning aircraft with collective and/or cyclic pitch capability.

The curves are tuned via a graphical user interface (GUI). Exit the GUI by pressing either the left or right button repeatedly. Any changes are immediately saved.

Throttle Curves

A throttle curve is not the same as a throttle transition curve. A Throttle curve maps the throttle stick input to the throttle output. A throttle transition curve manages the transition between the P1 throttle volume and the P2 throttle volume during transition.

OAV has two 7 point throttle curves, one for P1 and the other for P2. The throttle curves are always in the data flow path, but the default mapping for these curves is “pass through”, meaning the output is identical to the input, or in other words it is like there is no curve.

Standard helicopters often have 2 throttle curves, one for takeoff and normal flying, and another for stunts, including inverted flight. For regular flying the throttle comes up gradually with throttle stick input and intends to hold a constant head speed from about mid stick to full throttle. The stunt mode maintains a constant head speed (RPM) regardless of the throttle stick input.

Helicopter based VTOL aircraft are unlikely to hover while inverted, but the P1 and P2 flight profiles could be used as a normal flight and stunt mode. More likely the P2 or FFF mode will involve some sort of constant RPM variable pitch scenario with a much higher collective pitch than would normally be used for hovering.

The P1 and P2 throttle volume parameter in the OUT1-8 menus work regardless of whether the throttle curves are used or set to the default pass through values.

There is only one P1 throttle curve, and only one P2 throttle curve for use by all 8 outputs.

Collective Pitch Curves

OAV has two 7 point collective pitch curves, one for P1 and the other for P2. The collective pitch curves are mapped from the throttle stick input just like the throttle curves. The collective curve output is included as an input when “Collective” is selected via the P1 or P2 Source A or B menus within the OUT1-8 mixer menus.

Standard helicopters often have 2 collective curves, one for normal flight and one for stunt mode. The normal flight mode uses minimal negative collective except possibly for autorotation. The stunt mode often allows for up to 10 degrees of positive and negative pitch.

VTOL aircraft are unlikely to use negative pitch except possibly for reverse thrust in STOL applications. They may, however, control airspeed in FFF using collective in combination with fixed rotor RPM.

The bipolar volume parameter associated with the P1 or P2 Source A or B inputs to the OUT1-8 mixer menus can be used to limit the curve amplitude in addition to the curve values themselves.

There is only 1 P1 collective pitch curve, and only 1 P2 collective pitch curve for use by all 8 outputs. The associated volume parameter can be varied separately for each output.

Universal Input Curves

OAV has two 7 point universal input curves known as Generic Curve C and D. These curves are not associated with P1 or P2, nor are they related to the P1 or P2 Source A or B menus except that they are available as input selections on those menus.

The possible inputs to the generic curves include None (Default), AL Pitch, AL Roll, AccY, AccX, GyroYaw, GyroPitch, GyroRoll, Aux3, Aux2, Aux1, Gear, RUD, ELE, AIL, and THR.

The bipolar volume parameter associated with the P1 or P2 Source A or B inputs to the OUT1-8 mixer menus can be used to limit the curve amplitude in addition to the curve values themselves.

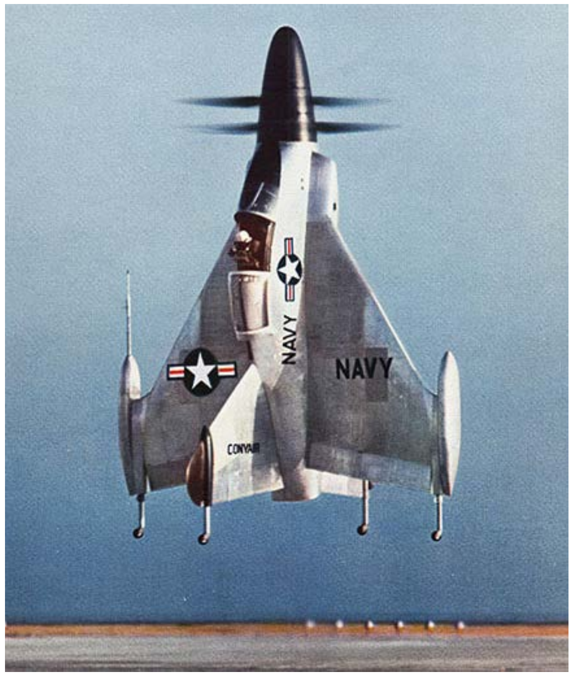
Swash Plate Programming

OAV does not have a menu where you select the type of swash plate you are using. Each of the outputs that drives a servo that controls the swash plate must be separately programmed in terms of the aileron, elevator, and collective pitch volume needed for that servo. The values must be calculated using sines and cosines according to the geometry of your specific swash plate. A simple volume calculation spreadsheet is provided on the “Swash” tab of the provided Menu Structure Spreadsheet.

The Swash calculator assumes that your servos and mechanical linkages are matched. It is also unable to determine the correct polarity for the elevator and aileron volumes because it does not know your specific linkages. If the servo motion is backwards then either reverse the elevator and aileron input volumes or reverse the servo using the servo direction menu.

If the Altitude Damping motion is reversed then reverse the servo using the servo direction menu and reverse all the volume inputs to that servo so they are correct as well. Alternatively you can select Alt. damp: as in input via P1 or P2 Source A or B in the OUT1-8 mixer menu, and then set its polarity and volume however you like.

Tail Sitters



Tail sitters like the Pogo, or Vertijet pose an interesting control issue for the RC modeler. Traditionally they have been flown and hovered using standard airplane controls. Vertical hovering is a skill that many airplane pilots are already comfortable with, so hovering to a landing is not a problem.

An alternate control scheme is to “flip a switch” and have the aircraft control axes change for hovering. This allows the aircraft to be hovered using the same control inputs as a helicopter or multi-copter. When in hover mode rudder input controls the ailerons, and aileron input controls the rudder.

OpenAero-VTOL supports both of these control modes. It can also provide different stability parameters for hover and forward flight mode. This includes the possibility of AutoLevel in both hover and FFF (Fast Forward Flight) as well as throughout the transition.

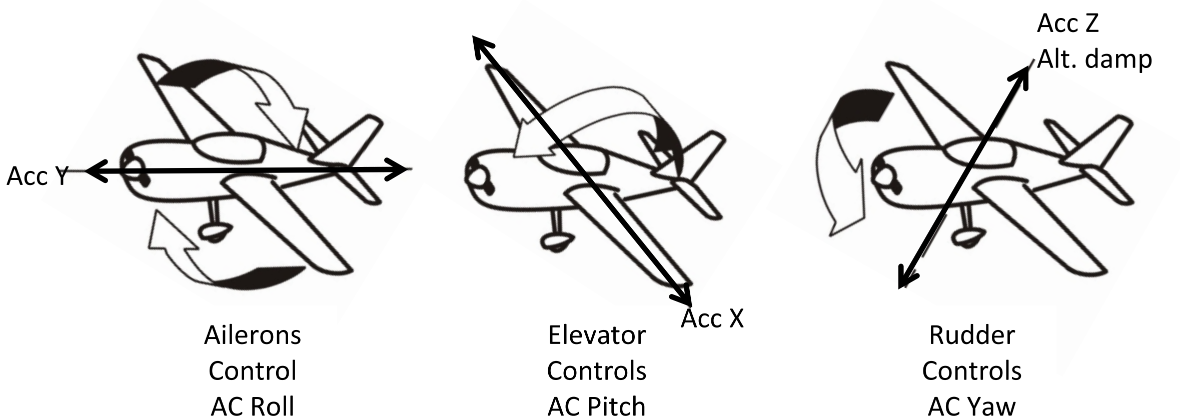
The techniques used for Auto-Level stabilization of “Tail Sitters” work equally well for hover stabilization of aircraft that don’t actually take off or land vertically. For example, you can use OAV to create a fully stabilized hover mode with your favorite 3D model.

In general, P1 and P2 can be used for any 2 flight modes you want, but for tail sitters P1 must be used for hover mode, and P2 must be used for FFF. Failure to follow this rule will result in incorrect stability feedback polarity.

Due to the different control modes and aircraft orientations the normal terminology of Roll, Pitch, and Yaw can become confusing. For aircraft that fly and hover with the fuselage approximately level, in other words aircraft that are not tail sitters, the normal definitions of Roll, Pitch, and Yaw apply at all times, whether in P1 (hover mode), P2 (FFF) or anywhere in between.

The axes for Accelerometer (Acc) feedback are Acc X – Lateral Acceleration, Acc Y – Longitudinal Acceleration, and Acc Z – Vertical Acceleration, also known as “Alt. damp” or altitude damping.

Fuselage Level Type Aircraft (AC), Both P1 and P2

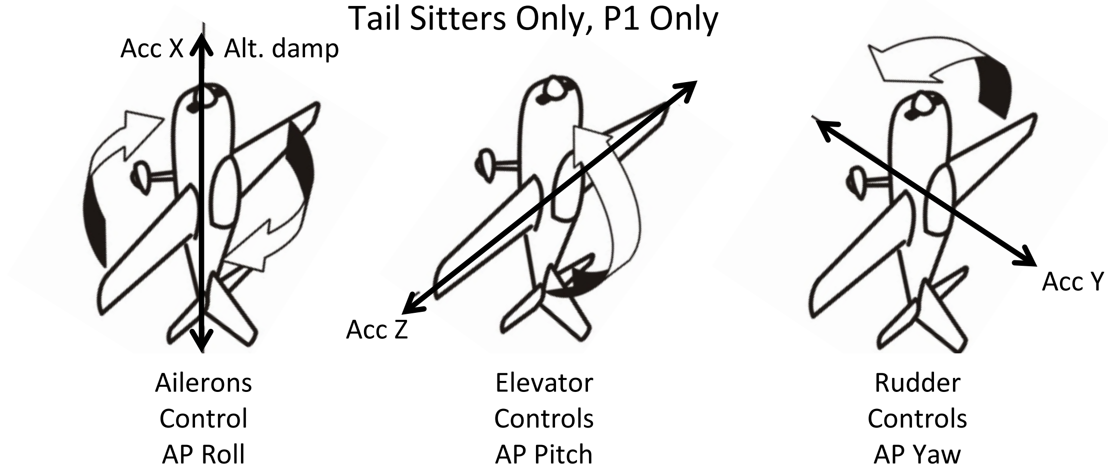


For aircraft that rotate 90 degrees nose up to hover, or in other words tail sitters, while in P2 (FFF) with the fuselage approximately level, the terminology is the same as non-tail sitters, and Roll, Pitch, and Yaw have the normally accepted meanings.

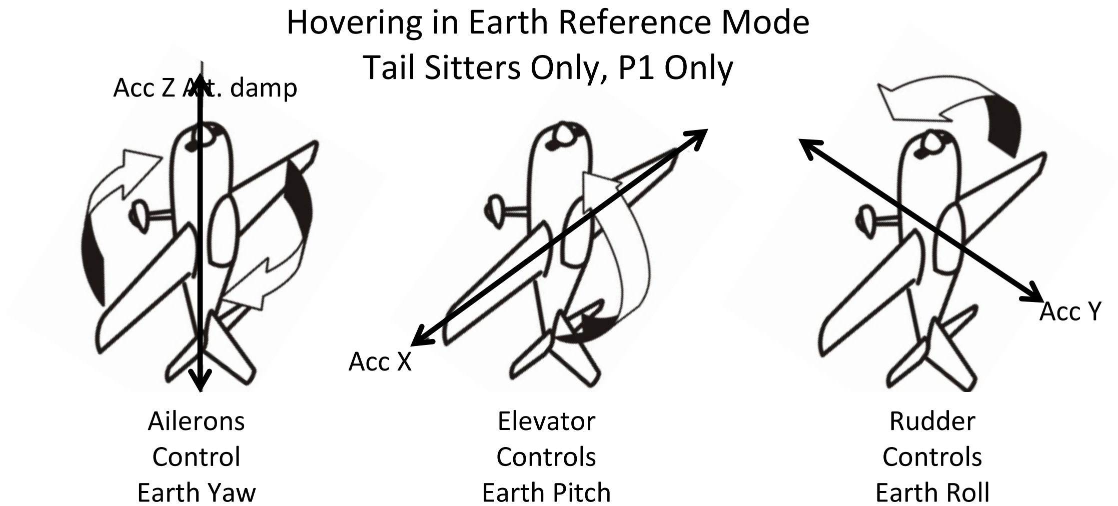
For tail sitters in P1 (Hover Mode), with the nose pointing straight up, there are two possible control schemes, corresponding to two possible frames of reference, that the user may choose:

Vert AP Ref. – Vertical Airplane Reference – Roll, Pitch, and Yaw are defined relative to the aircraft, not the earth. Roll is controlled by the ailerons (or equivalent functionality), Pitch by the elevator, and yaw by the rudder. This implies that the AL (AutoLevel) function applies to Pitch and Yaw in this mode.

Hovering in Vertical Airplane (AP) Reference Mode
Tail Sitters Only, P1 Only



Earth Ref. – Earth Reference – Roll, Pitch, and Yaw are defined relative to the earth, not the aircraft. For a vertical airplane this implies that the ailerons control Yaw and the Rudder controls roll. In this mode AL applies to Pitch and Roll. The axes for accelerometer feedback remain unchanged relative to the Earth.



When programming the FC (Flight Controller) it is important to remember whether you have chosen Vert AP Ref. or Earth Ref. When turning ON/OFF the Gyros or AL for a specific output (OUTn), you must determine whether Roll or Yaw is controlled by that output per your chosen frame of reference.

For example, when hovering a tail sitter in VERT AP Ref. mode, the Rudder stick input will drive the rudder output controlling Yaw so any desired Gyro or AL stability feedback on that output will be selected as Yaw. Likewise, the P, I, I-limit, and AL values in the P1 Profile Menu for Yaw will control that output.

For the same aircraft when hovered in Earth Ref. mode, The Aileron stick input will control the rudder, and the stability feedback to the rudder output will be Roll for both the Gyros and the AL. The values in the P1 Profile Menu for Roll will control that output.

Don't forget to properly calibrate the sensors in both P1 (Hover) and P2 (FFF). The calibration instructions can be found in this manual under Flight Controller (FC) Initialization.

Tail Sitter Transitions

The piloting technique for inbound transitions from FFF (P2 -Fast Forward Flight) to hover (P1) is a matter of pilot preference. Many pilots may prefer to fly the aircraft into a hover or near hover and then "flip the switch" into hover mode (P1). An alternate technique is to "flip the switch" while in FFF and let the FC (Flight Controller) perform the transition. The pilot still has control during this form of semi-automated transition and throttle management is required to make a more or less "level transition" or a "zoom climb transition". A level transition is usually preferred as it avoids the need to back down a large distance which is often problematic for tail sitters.

The piloting technique for outbound transitions, from hover (P1) to FFF (P2) is usually for the Pilot to "flip the switch" into FFF (P2) and then fly the plane. If the pilot is holding a lot of down elevator stick, as often occurs when in AL (Auto Level) mode and leaning into a headwind, the aircraft can immediately rotate nose down when the switch is flipped. This can also occur if the aircraft is set up to hover with a combination of AL and I feedback. The I feedback will have “wound up” due to continuous down elevator stick input. Once in P2, with the AL feedback gone, the wound up I feedback will push the plane’s nose down rapidly requiring up elevator stick input to counter.

All of these potential transition issues can be solved with a combination of pilot technique and parameter selection.

The solution to I feedback windup on the outbound transition is to avoid using I feedback in P1, or if it must be used then set the I-limit value fairly low so it can’t wind up very far. I feedback is rarely used in FFF (P2) so there is generally no I feedback windup problem for the inbound transition from FFF (P2) to hover (P1).

There are 2 ways to control the speed of transition.

If you are in FFF (P2) then you generally have full control of the aircraft. If you fly the transition, either outbound or inbound, while in P2 then you directly control the speed and form of the transition by your control inputs. In this case an “AL Correct:” value of 2 is recommended for a most rapid change of control mode.

If you “flip the switch” from P2 to P1 while in level flight and allow the FC to perform a semi-automated transition then you can adjust the “AL Correct:” parameter to control the speed of transition. The range of values is 2 to 11 roughly corresponding to as many seconds. You will still need to modulate the throttle to control the amount of climb, if any, during the transition.

Using a slow function in the TX to control the speed of transitions is not recommended for tail sitters. It works, but can have some slight unexpected consequences when doing an inbound transition from P2 to P1 where the plane has already been flown into a hover. The plane will nose over slightly before returning to a hover. This does not happen if you flip a switch to make a “snap transition” in the TX and then use the AL Correct: parameter to control the speed of transition.

It is not recommended to use a “Outbound tran:” value other than zero in the Receiver setup menu, for the same reason that a slow function in the TX is not recommended.

Using the Vibration Display

The vibration display is an option within the Receiver Setup menu. It is a built in tool to assist with dynamic balancing of motors or propellers. It is NOT intended to be used in flight as it is difficult or dangerous to read the resulting values while hovering. The special code required to update the display also creates a small degree of in-flight instability. Do not leave the vibration display turned on when you are not using it.

Vibration is usually the result of a rotational imbalance of motors or propellers. For aircraft with multiple motors this can result in various beat frequencies which can often be felt when holding the aircraft while the motors are running. When excessive, the vibration can feed back through the gyros resulting in a seemingly random instability. This instability has a different character from the typical sinusoidal instability related to excessive feedback gain. Vibration can excite or aggravate gain based instability and therefore force the use of less than optimal stability feedback values.

The negative impact of vibration can be mitigated by setting the MPU and Gyro LPFs (Low Pass Filters) to a lower frequency but this has a negative impact on stability feedback latency and can also force the use of lower stability feedback gains. The net result is a less stable aircraft.

The first and primary recommendation is to perform a static balance on the propellers, and when possible spinners, collets and motors. In many cases this will be sufficient to eliminate any vibration related problems. It is not always convenient or possible to perform a static balance on motors or spinners due to the lack of a proper tool. Also certain aircraft have structural vibration modes which are unusually sensitive to certain frequencies and effectively amplify the noise.

Place the aircraft on a stable surface. It can be a firm surface like a table top, or a compliant surface like a bed, but the surface needs to be consistent for consistent readings. Disconnect power to all but the 1 motor that you intend to test. Temporarily program your TX (Transmitter) to produce a reduced full throttle output that is modestly below that necessary for flight. It is important that you achieve a consistent full throttle setting. You can also add a small amount of weight to the aircraft to insure that it doesn’t significantly move or begin to fly. Temporarily turn off all I feedback as gyro drift will cause the motors to speed up or slow down over time. When balancing motors without propellers choose a throttle setting that produces an RPM that is similar to what you might expect when hovering. Turn on the vibration display mode and arm the aircraft in the normal manner.

Dynamic balancing can be done on motors without propellers, or it can be done with both motors and propellers at the same time. When motors, propellers, collets and spinners, etc. are balanced together it is important that they remain firmly and consistently configured. Removing a propeller and replacing it on the motor in a different orientation can impact the resulting balance.

It is best to first balance motors without propellers or collets. A common technique is to wrap a cable tie around the bell housing. The head of the cable tie can then be moved around the bell housing to find the maximum and minimum point of vibration. This can help to identify the best location for balancing tape. For motors this is often copper tape as various plastic or paper tapes may not be heavy enough to do the job, and the adhesive may not be strong enough to hold at full RPM. It is also possible to use 2 cable ties wrapped around the bell housing. Two cable ties can be positioned so their heads are on opposite sides of the motor which means that they can produce any reasonable level of balance in any direction. The down side is that they can shift or catch on things when the motor is spinning.

Propellers are typically balanced with some form of tape. Small pieces of standard plastic office tape are often sufficient. You can also buy special balancing tape though it is not clear that it works any better.

Regardless of what you are balancing, or what you are using for weight, the technique is always the same. Add weight, see if it makes the balance better or worse, and then add, remove, or shift weight accordingly. Try to get the lowest possible vibration number. You should not expect to get the vibration down to zero. There are many sources of vibration that you can't easily control. Motor bearings are not perfect, propellers don't run perfectly in plane, etc. Just do the best you can.

After balancing each motor/propeller separately, you can run them all together, but there is nothing you can do with or about the number. It is only a relative number based on your specific test conditions. We cannot tell you if a particular combined reading is good or bad, it depends on your test conditions. Ultimately good or bad is determined by whether you have vibration based instability issues. If your aircraft isn't bouncing around randomly then you don't have a vibration problem.

In/Out Display

The In/Out Display is provided as a convenient means to monitor all 8 inputs and all 8 outputs on a single screen in real time. There is no PWM output to motors or servos when using this screen. Exit the screen by pressing either button #1 or button #4.

```
THR: 50 AX2: 50 4: 100
AIL: -100 AX3: -50 5: -100
ELE: 0 OUT: 6: 0
RUD: 100 1: 50 7: 50
GER: 0 2: 100 8: -50
AX1: 0 3: -100 Pn: 1.50
```

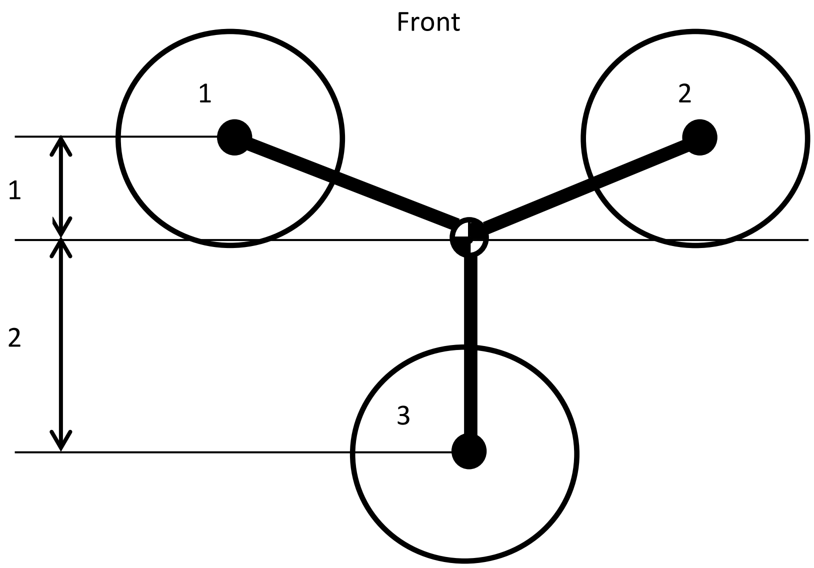
For technical reasons, the outputs will not be properly updated when using the internal slow function to set the transition speed. When the Outbound transition is set to 0, meaning the TX is in control of the transition speed, the outputs will be updated correctly.

Parameter Selection by Aircraft Configuration

VTOL aircraft come in many unusual configurations, and while they are often based on quad-copters or tri-copters, they often have asymmetric proportions. This can make it interesting to determine the proper control and stability parameters.

The overriding principle is that we want to keep Pitch (Elevator), Roll (Aileron), Yaw (Rudder) and the Z axis (Throttle) as independent as possible. For example, when we apply throttle, we don't want to introduce roll, pitch, or yaw, we want the aircraft to go straight up. Likewise, if we apply a pitch (elevator) input, we don't want the aircraft to climb or descend.

Consider the case of a simple tri-copter. The two rotors in the front are one unit of measure ahead of the CG (Center of Gravity). The one motor in the rear is 2 units of measure behind the center of gravity.



If we want the aircraft to pitch up, then we need to increase the power to the front rotors, and decrease the power to the rear rotor. If we do this equally then we will have 2 positive increments of power and one negative, for a total of plus one increment, which will cause the aircraft to rise.

The solution is to apply ½ increment to each of the front rotors and a full increment to the rear. This applies not only to stick input from the pilot, but also to pitch stability feedback from the Gyro or Accelerometers. OAV has provisions to make this easy.

It is up to the user to determine the proper value of the stick inputs. In this case the outputs that drive motors #1 and #2 might be set to include +10% Elevator, while the output that drives motor #3 might include -20% elevator. This establishes the proper ratio and polarity for proper user input control.

The P, I, I-Limit, I-Rate, and AL for pitch would all be set to reasonable values in the Flight Profile menu. For example, the P value might be set to 80. The Pitch Gyro and Pitch Acc fields would then be set to "Scaled" for the outputs related to all 3 motors.

The effective P value applied to the two front motors would be (80 x 10% x 5 = 40).
The effective P value applied to the rear motor would be (80 x -20% x 5 = -80).

The negative P value of -80 does not imply negative stability, only that the stability is being applied in the correct polarity the same as the user stick input.

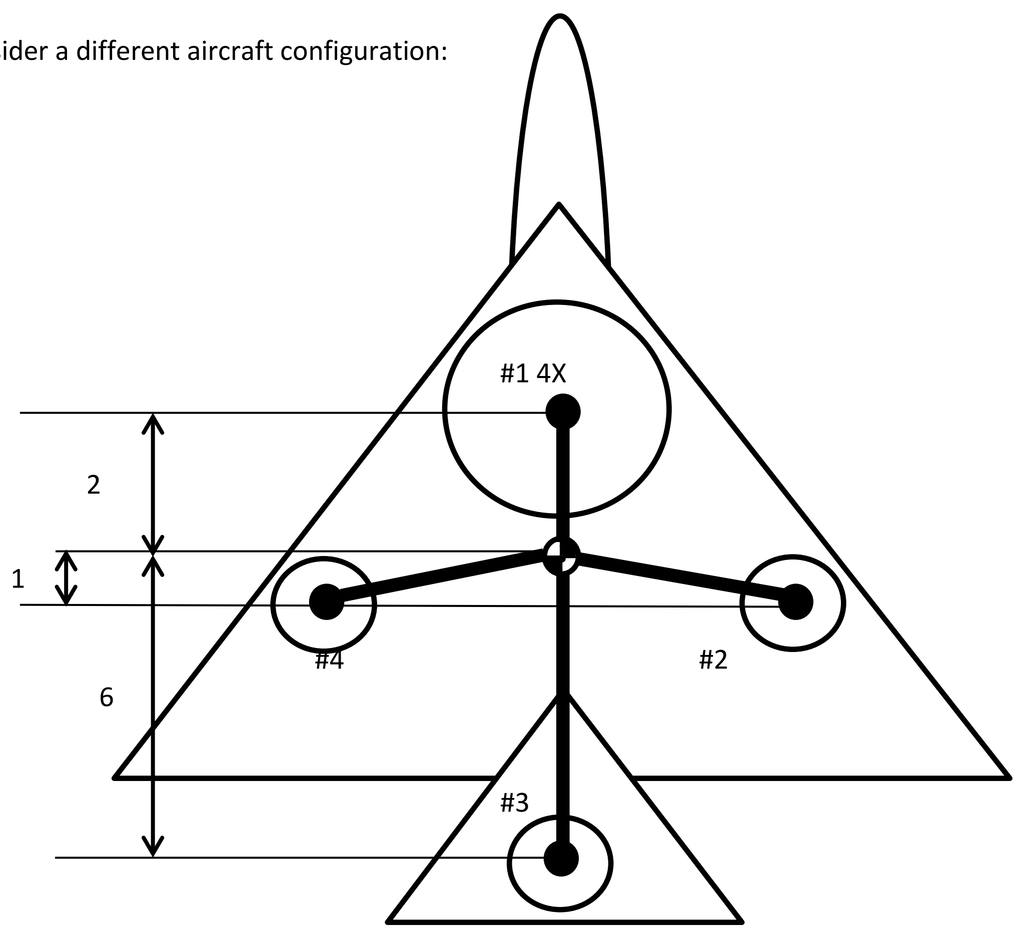
The additional multiplier of “x 5” is automatically applied whenever you use the “Scaled” option as a convenience. Since control input values are typically in the range of 20% the “x 5” factor results in 20% x 5 = 100% which means 100% of the defined P value will be used. If, for example, the P value in the active Profile Menu is 80 then 20% x 5 x 80 = 80. This avoids the need for the user to set extremely large P values which are limited to a range of 0 to 127.

If you want to change the P value then you only need to change it in the flight profile menu. The correct ratio and polarity of the stability factors will still be applied to each of the motors.

If you had selected “ON” rather than “Scaled” then the effective P value applied to the front motors would be 80, and the rear motor would be -80. Note that the correct polarity is still determined based on the user input for Elevator (Pitch) but the P value is not scaled. This would cause the Tri-copter to climb every time the Gyro or Auto-Level tried to pull the nose up. This sort of unwanted climb or descent is called “Surge”.

A tri-copter is symmetrical from left to right, so the Roll (Aileron) stick input values will be the same magnitude but opposite polarity. It is not necessary to use the Scaled option when providing the Roll (Aileron) stability input to the left and right motors. You can use it if you want, but the “ON” selection will work just as well. If you use the “ON” selection then the effective P values will be the same as set in the Fligh Profile Menu. There is no need to do any sort of calculation to figure it out.

Now let’s consider a different aircraft configuration:



For this configuration, the front fan is 4 times more powerful than each of the other 3 fans. The total lift is, however, balanced about the CG. The front fan has 4 units of lift and 2 units of lever arm for a positive pitch torque of 8. The two side fans have one unit of lift each, and one unit of lever arm for a total negative pitch torque of 2. The tail fan has 1 unit of lift and 6 units of lever arm for a negative pitch torque of 6. (8 – 2 – 6 = 0).

Motor	**Lever Arm**	**Power (Lift)**	**Pitch Torque**	**Elevator Volume**	**Pitch Lift**	**Effective P**
Motor #1	2	4	8	15%	60	60
Motor #2	-1	1	-1	-20%	-20	-80
Motor #3	-6	1	-6	-20%	-20	-80
Motor #4	-1	1	-1	-20%	-20	-80
Totals	**N/A**	**7**	**0**	**N/A**	**0**	**-80**

When determining the appropriate Elevator (Pitch) volume for each fan, we need to remember that our goal is zero surge when pitch inputs are applied. Since we have 4 units of lift ahead of the CG, and 3 units of lift behind, the control input ratio needs to be 4:3, except that the larger number applies to the weaker fans. We pick a somewhat arbitrary but reasonable number of -20% for fans 2 through 4, which implies a value of 15% for fan #1.

We can double check our numbers by calculating the change in total lift when a 100% up Elevator input is applied. We multiply the Lift for each fan by the Elevator Volume for the corresponding motor to get the Pitch Lift. (4 x 15% = 60 for the front motor) (1 x -20% x 3 = -60 for the other 3 motors). (60 – 60 = 0 so the lift remains unchanged).

You might ask, why not apply more elevator volume to the #3 motor since it has more lever arm? The answer is that you could, but then the #3 motor would saturate more quickly and you would lose pitch authority more quickly as you approached 100% throttle.

So now if we set the P to a reasonable starting value of 80, and set the Pitch Gyro for all 4 motors to Scaled, we get (80 x 15% x 5 = 60 for Motor #1), and (80 x -20% x 5 = -80 for motors 2 through 4).

Since the aircraft is symmetrical left to right the roll control parameters are simple. The left fan is set to 20% Ailerons (Roll) and the right fan is set for -20% Ailerons (Roll). The Roll P is set to a reasonable value like 80, and the Roll Gyro and Auto-Level feedback is set to ON.

The ultimate P, I, I-Limit, I-Rate, and AL values will be tuned by observing the aircraft in flight, but at least we are starting in a reasonable range with plenty of room for tuning.

Now let's consider a 3rd application. Let's say you have a twin engine seaplane that is hard to steer on the water, and tends not to go straight on takeoff. You might wish to use differential throttle to control Yaw (Rudder), and you might want to use the Yaw Gyro to stabilize yaw through both differential throttle control and also with the rudder.

The differential throttle steering is easy. We simply mix 10% rudder into the left motor and -10% rudder into the right motor. Now we set the Yaw P value to 20 to start and set they Yaw Gyro feedback to ON for the two motor outputs. We will probably want to gradually increase the P value after flight testing but we are starting with a modest value to avoid any oscillations.

For the rudder output we have the rudder input volume set to 100%. We set the Yaw Gyro feedback to ON and we have an effective P feedback value of 20. The problem is, we have to be very careful because too much Gyro feedback on rudder could easily cause oscillations. Even 20 might be too high.

Warning, do not use the "Scaled" option in a case like this or you will get (20 x 100% x 5 = 100 and that would probably be way too much feedback on the rudder).

Warning, do not use I (Integral) feedback on the rudder for an airplane or it will not want to turn unless you actively fly the rudder all the time.

The yaw stability due to differential throttle is probably more effective on the water, and less likely to cause an oscillation in the air, so it can probably be cranked up as high as 60, but 60 would be way too much for the rudder, so what do we do? The simplest solution would be to turn off the Yaw Gyro to the rudder and crank up the Yaw Gyro on the differential throttle, however there are other options.

OAV provides two universal inputs per output, Source A and Source B. You can go to the Rudder channel in the Output Mixer Menu and select Source A, then select GyroYaw, and dial in a small amount of Yaw Gyro stability. 100% will be based on the P value in the active Flight Profile menu, so if it is set to 60 as needed by the motors, then you can set it to 10% and get an effective P value of 6.

One last application note based on this same seaplane. Let's say that this aircraft has a tendency towards adverse yaw and you would like some help coordinating the turns. Go to the Rudder channel in the Output Mixer Menu and select Source B. Select the AccX input and set it to a modest volume like 25. Now test the functionality on the ground by tilting the plane to one side and make sure the rudder moves towards the low wing (bottom rudder). You can also use this technique with the motors to increase the throttle to the high side motor and decrease the low side motor.

You may need to reverse the polarity from 25 to -25 in the Output Mixer Menu depending on the rudder linkage. Take care and increase this value slowly to avoid unwanted side effects or oscillations. Note that the “AccX” feedback available via Source A or Source B in the Output Mixer Menu is based directly on the accelerometer output. It is not the same as Auto-Level.

Warning, do not use the Roll AL: (Roll Auto-Level) in the profile menu, which is set to ON/OFF/Scaled in the OUT1-8 Mixer menu, for automatic turn coordination. It is based on the IMU (Inertial Measurement Unit) which calculates a level estimate based on the Gyro and then trims the drift on that estimate using the accelerometers. You should not use the IMU based “Roll AL:” for automatic turn coordination as it will apply “bottom rudder” whenever the plane is tilted in roll, even if the turn is coordinated. This will result in positive feedback and spiral instability.

Explanation of Selected Parameters

Most of the menu options are sufficiently explained in the provided spreadsheet, the User's manual only explains selected functionality in greater detail.

Low V. Alarm: - Battery Low Voltage Alarm – Off disables the alarm. On power up the voltage is measured and used to determine the cell count. The battery voltage is compared with the number of detected cells multiplied by the selected cell voltage. 2-cell to 6-cell LiPo batteries are supported. The lowest input voltage threshold is 2 cells at 3.2V each or 6.4V. An input voltage of over 26V will damage the KK2 board.

MPU6050 LPF: - The MPU6050 is the chip that provides both accelerometer and Gyro output. This LPF (Low Pass Filter) is built into the chip and slows and smooths both the accelerometer and Gyro output prior to processing by the FC firmware. The range of values is 5 Hz, 10Hz, 21Hz, 44Hz, 94Hz, 184Hz, and 260Hz with 44Hz being the default. Higher frequencies can sometimes be used in combination with higher P, I, and AL values for a more "locked in" feel. Lower values are sometimes necessary to filter vibration induced noise.

Acc. LPF: - The Accelerometer Low Pass Filter – Filters the accelerometer outputs in addition to the MPU6050 LPF. The range of values is 5 Hz, 10Hz, 21Hz, 44Hz, 74Hz and None with 21Hz being the default. The bubble level in the level meter menu reflects the action of the Acc. LPF.

Gyro LPF: - The Gyro Low Pass Filter – Filters the gyro outputs in addition to the MPU6050 LPF. The range of values is 5 Hz, 10Hz, 21Hz, 44Hz, 74Hz and None with None being the default.

AL Correct: - Auto-Level Correct – Controls the rate at which the accelerometers are used to correct Auto-level drift. The Auto-Level feedback is primarily created by integrating the gyros, and is secondarily based on feedback from the accelerometers in Pitch and Roll. This makes it relatively insensitive to short term lateral acceleration. The Gyros "remember" level but drift slowly over time. The accelerometers trim the level estimate to counteract Gyro drift but are subject to noise and random fluctuations due to flight conditions. The range is from 2 to 11 with 6 being the default. For gross changes in AL orientation, such as when switching flight modes for a tail sitter, the AL Correct value roughly corresponds to the number of seconds required to correct the orientation.

Preset: - Parameter initialization for common aircraft types. – The Preset menu option offers 4 parameter sets called Quad X, Quad P, Tricopter, and Blank. The Quad X preset is for a basic X-Quad configuration where the left front motor turns clockwise. The Quad P preset is for a basic Plus-Quad configuration where the front motor turns clockwise. The Tricopter preset is for a typical Tricopter with two motors in front and a tilting motor in the back. All 3 of these presets also provide Elevator, Aileron, Rudder, and a Tilt Servo output on OUT5-8. The Blank preset provides a blank slate to simplify entry of custom values. The detailed values for these presets are included in the Menu Structure spreadsheet. It is the users responsibility to verify that these presets have the desired effect on their aircraft.

Outbound Trans: - Transition Speed.- A user input of "0" (Analog mode) results in an immediate transition based on the analog value of the Profile Channel. Analog mode is used when the user wants to control the transition directly with an analog input like a pot or slider. It is also used when the users TX has a switch based output, like a flap switch, that can be programmed to make a slow transition between preset values.

A user input of "1-40" (Switched Mode) results in a slowed outbound transition by 1 to 40 seconds for the full transition. Switched mode is provided for users that do not have the slow function in their TX. In Switched Mode the transition state is based on the Profile Channel input relative to two thresholds that are preset at -50% and +50%. It is assumed that the user will set up a three position switch in their TX to output approximately -100%, 0% and +100% . If they only have a 2 position switch then they would output -100% and +100%. When setup in this manner the TX switch can be set to any position at any time and the transition percentage will proceed to the designated state at the defined rate.

Switched Mode Transition Control

State Name	Approximate User Input	Thresholds	Profile State
High	+100% (1.9 ms)		Profile 2 (Fast Forward Flight Mode)
		+50% (1.7 ms)	
Med	0% (1.5ms)		Profile 1.n (Slow Forward Flight Mode)
		-50% (1.3ms)	
Low	-100% (1.1ms)		Profile 1 (Hover Mode)

Inbound trans: - Inbound Transition speed. Has no effect if the Outbound Trans.: is set to 0. If Outbound trans.: is set to 1-40 then a value of 0-40 for the Inbound trans.: results in a slow inbound transition of 0 to 40 seconds for the full transition when the P2 to P1.n threshold (+50%) and the P1.n to P1 threshold (-50%) are crossed.

Transition low: - Defines the percentage of transition for the low position in Switched Mode. It only applies if the Transition: value is set to 1-20, but not 0. "Transition low:" is typically set to a value of around 0% corresponding to P1 or hover mode. It is sometimes set to a higher value like 5% or 10% to allow the aircraft to more easily maintain station when hovering in a headwind.

Transition mid: - Defines the percentage of transition for the center position in Switched Mode. It only applies if the Transition: value is set to 1-20, but not 0. "Transition mid:" is typically set to a value of around 15% to 40% corresponding to a comfortable SFF (Slow Forward Flight) mode.

Transition high: - Defines the percentage of transition for the high position in Switched Mode. It only applies if the Transition: value is set to 1-20, but not 0. "Transition high:" is typically set to 100% corresponding to P2 or FFF (Fast Forward Flight) mode. When aircraft are first being flight tested and tuned it is common to set Transition high: to a value only slightly above Transition mid: and then slowly increment it to higher values on subsequent flights while making any necessary tuning adjustments along the way.

AccVert Filter: - High pass filter setting for the Z axis accelerometer I feedback (Z velocity). Larger numbers "wash out" the feedback more quickly. The integral of acceleration, as measured by the Z axis accelerometer is vertical velocity. Since the actual vertical velocity is unknown it is necessary to assume that on average the vertical velocity will be zero. Also, over time, small errors in the accelerometer output would integrate to a very large velocity. Therefore it is necessary to "wash out" or filter the integrated velocity back to a long term value of zero. Larger values of I feedback (Z velocity) will require larger AccVert Filter: values otherwise the throttle offsets will become too large and the vertical responsiveness of the aircraft will be too slow.

Profile Menu Related Parameters

Roll/Pitch/Yaw P: - Primary feedback gain based on the angular rate of change from the gyros.

Roll/Pitch/Yaw I: - Integral feedback gain based on the integrated Gyro output.

Roll/Pitch/Yaw I Limit: - Limits the maximum I feedback in order to prevent excessive integrator "windup".

Roll/Pitch/Yaw I Rate: - Sets the speed of response for the "I" feedback loop. 0 responds most slowly and 7 most quickly. I rate controls the ratio of the stick integral to the Gyro integral. Depending on this ratio, the stick integral and the Gyro integral will be in balance at a certain rate of rotation for full stick deflection. Ideally the forward stick volume will drive a rate of rotation that keeps the stick integral and Gyro integral in balance. If, when hovering and not using Auto-Level, you find the aircraft tends to return to level rather than holding attitude after returning the stick to neutral, try increasing the I Rate. Slower values like 2 will often feel more comfortable.

User Value	Rate of Rotation
7	1,920 deg/sec (5.33 rev/sec)
6	960 deg/sec (2.67 rev/sec)
5	480 deg/sec (1.33 rev/sec)
4	240 deg/sec (1.5 sec/rev)
3	120 deg/sec (3 sec/rev)
2	60 deg/sec (6 sec/rev)
1	30 deg/sec (12 sec/rev)
0	15 deg/sec (24 sec/rev)

Roll/Pitch Trim: - Trims the level position for Auto-Level only. Has no impact on gyro based P or I feedback.

Yaw Trim: - Trims the output of the yaw Gyro. Technically the Yaw Gyro does not require trim as it will be zeroed by the sensor calibration process, however, aircraft often need a small amount of yaw trim in hover due to slight imperfections in the aircraft itself. This could be resolved by fixing the imperfection, or making multiple adjustments in the output menus, but the trim option is offered here as a convenience.

Z-axis P: - The P or Primary feedback based on the Z axis accelerometer. It acts to try to hold the vertical acceleration at zero. In practice it is a weak form of altitude damping. Not recommended for use in forward flight.

Z-axis I: - The I or Intigral feedback based on the Z axis accelerometer. The integral of acceleration is velocity. It acts to try to hold the vertical velocity at zero. In practice it is a much stronger form of altitude damping. Large values of Z axis I: will result in a very slow vertical or throttle response. Large values of Z-axis I: will also require large values of AccVert Filter: to prevent the accumulated offsets from slowly pushing the aircraft to the ground. Z-axis I: is not recommended for use in forward flight.

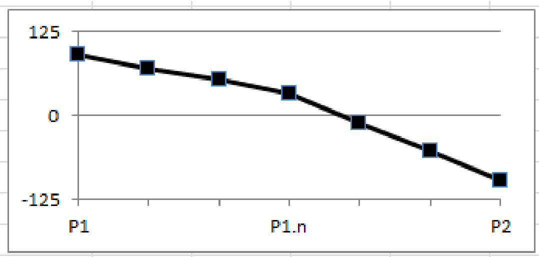
Z-axis I Limit: - Prevents excessive windup of the Z-axis I:. It also limits how much altitude damping the Z-axis I: can provide.

OUT1-8 Mixer Menu Related Parameters

Output Offset Curves 1-8 - A 7 point offset curve ranging from P1 (0%) to P2 (100%). The percentage of transition values for each of the 7 points are not adjustable, only the corresponding offsets. The offset curve is not only used as a variable trim value but is also often used as a primary control function. For example. When tilting a wing during transition between P1 and P2 large offsets may be used. This provides much greater control over the wing tilt function as compared to using the transition control input directly to control the tilt servo.

The P1.n designation in the middle of the curve is not meant to imply that P1.n, or the middle switch position occurs at 50% of transition. The middle switch position can be set to any percentage of transition, and P1.n is a generic term for any percentage of transition between P1 and P2.

	Transition % (Fixed)	Offset
P1	0	90
	17	71
	33	53
P1.n	50	34
	67	-10
	83	-53
P2	100	-97



OFF, ON, and Scaled options for Gyro and Acc stability feedback

"**ON**" enables the feedback according to the parameters in the Profile menu that is in force at that time. The correct polarity of the stability feedback is based on the polarity of the associated user input. It is understood that Rudder is associated with Yaw, Elevator is associated with Pitch, Aileron is associated with Roll, and Throttle is associated with Z axis acceleration. When in the tail sitter "Earth ref." mode, and only when in P1 (hover mode) Rudder is associated with roll and Aileron is associated with yaw.

"**Scaled**" Turns the Gyro or Acc on in proportion to the volume of the associated input. Scaled mode is used when you have an asymmetrical configuration where you need to use different volume levels to achieve the desired Roll, Pitch, Yaw, or level Z-axis acceleration. See the "Parameter Selection by Aircraft Configuration" section in the manual for proper use of the scaled option.

The Scaled option is also sometimes used when you need stronger P, I, AL, or Alt. damp: feedback than is offered in the Flight Profiles menu. The scaled option multiplies these values X5. Typically the stick input volumes are around 20% so multiplying X5 results in feedback values similar to those in the Flight Profile Menus. If the Stick Input volume is set to 100% then the feedback values will be X5 larger than the values in the Flight Profiles menus.

Universal Inputs within the OUT1-8 Mixer Menu Related Parameters

The universal inputs are rarely used but provide additional flexibility for less common situations.

AL Pitch, AL Roll –AutoLevel (AL) Pitch and Roll – Setting these to 100% is the same as turning AL ON in the OUT1-8 Mixer menus. The difference is that the volume and polarity can be set from -125% to

+125% and that the polarity is independent of the associated stick input volume, elevator for pitch, and aileron for roll. AL Roll will be replaced by AL Yaw for the Vert AP ref. mode in P1 only.

AccY, AccX - These are pure filtered outputs from the accelerometers with the Acc LPF (Accelerometer Low Pass Filter) applied. They differ from the more commonly used P1 and P2 Roll AL: and Pitch AL: (Auto-Level) inputs in that they do not involve the IMU (Inertial Management Unit). The IMU calculates a level estimate, combining the accelerometer output with an Integral (I) output from the Gyro. AccX is most commonly used as an input to control rudder for automatic turn coordination.

GyroYaw, GyroPitch, GyroRoll – These are the same as the P1 and P2 Roll Gyro:, Pitch Gyro:, and Yaw Gyro: except that you have direct control over the volume and polarity unrelated to any user input for Rudder, Elevator, or Aileron. They are most commonly used when you want to stabilize one axis by making an input to a different axis. For example, you might correct an aircraft that is tilted in roll by applying rudder.

Gear, Aux1-3 – Gear is most commonly used as a transition control input, but can also be used as a general control input. For example, you might use Gear as an input to drive a rotor tilt servo. Aux1-3 are additional inputs that are available when in one of the serial input modes and can be used for whatever you want.

Rudder, Elevator, Aileron – These are the same as the P1 and P2 Rud. Volume, Ele. Volume, and Ail Volume except that you have direct control over their amplitude and polarity without having any impact on the associated Gyro and Acc. based stability feedback.

Throttle – This is a bipolar throttle input as opposed to the standard unipolar throttle input provided by the P1 and P2 Thr. Volume. The unipolar throttle input range is 0 to 2000. The bipolar throttle input range is -1000 to +1000. The unipolar throttle is normally used to control motors where a negative input is not possible. The bipolar throttle is most commonly used as a trimming input. For example, if you wanted to apply a small amount of down elevator with increasing throttle you would use the bipolar throttle as an input to the elevator servo.

Collective – This is the output of the collective curve in the Curves Menu. The P1 Source inputs automatically select the P1 collective curve and the P2 source inputs select the P2 collective curve.

Curve C/D – This is the output of the generic curves C and D in the Curves Menu. These two curves can be used for any output and either P1 or P2 Source A or B inputs

Servo and ESC Control Options

VTOL aircraft can be very complicated with lots of servos or ESCs to control. Some thought should be given to the resources available to control them.

The servos and ESCs can be divided into two groups, those that must be driven from the KK2 and those that can be driven direct from the RX (Receiver).

If a motor or servo requires stability feedback then it must be driven from the KK2. For example, all of the motors in a multi-copter will require stability feedback to hover. Control surfaces in the powered airstream will probably require stability feedback to hover.

If a motor or servo requires an axis translation, then it should probably be driven from the KK2. For example, a tilt rotor with motors on each wing tip will use differential throttle to control roll in hover mode, and yaw in FFF (Fast Forward Flight) mode. It is theoretically possible that a very capable TX (Transmitter) could do the necessary smooth flight mode transition, but this is what OAV is made for.

If you need different gain/travel/volume in the different flight modes, or you need different trim settings in different flight modes, then you may be able to do this in your TX, but the KK2 is probably easier. OAV can smoothly transition between flight modes, whereas your TX may only be capable of a switched transition.

If you need safety features, like the ability to arm and disarm multiple motors, then you may be able to do this with your TX (Transmitter), but it is probably easier and safer to do with the KK2 outputs.

If you need to turn a motor or servo off/on in different flight modes then it is probably most convenient to do this with a KK2 output. Your TX may be able to do it, but once again it may not make a smooth transition, and it probably doesn't offer a transition curve to create the necessary overlap between lift and thrust motors.

Conventional control surfaces like elevator, ailerons and rudder will probably not require stability feedback, but it is good to have the option. Likewise, the tilt function on a tilt wing or tilt rotor probably does not require stability feedback, but it is good to have the option.

Once you have identified all of the servos and ESCs you can decide if they all need separate control. For example, two aileron servos can be driven by a single output and a Y harness. Likewise, multiple motors on the same side of a multi-engine aircraft can often be driven by the same output. In some cases this might require a tradeoff. For example, 2 ailerons can be driven by one output, but 2 flapperons cannot, so if you save an output channel you will lose the ability to have flaps.

If you ultimately need 8 outputs or less it is probably easiest to drive them all from the KK2. That way you maximize your flexibility.

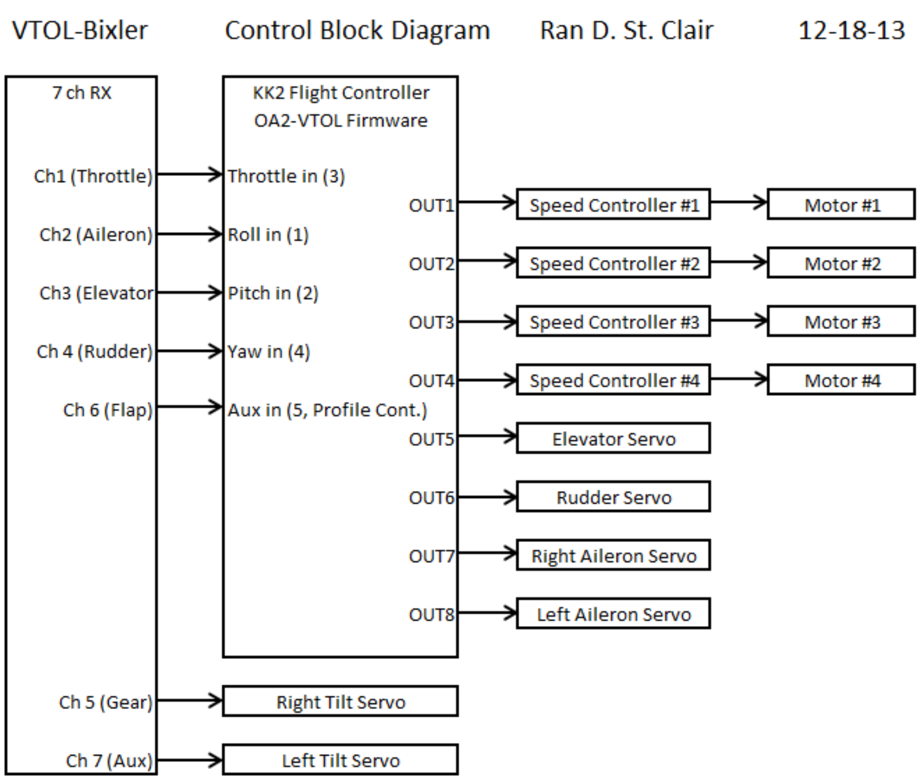
If you need more than 8 outputs then you can decide if any of them are suitable to be driven direct from the RX. You should assume that the KK2 requires the first 5 input channels, Ailerons, Elevator, Rudder, Throttle, and some sort of transition control input like Flap or Aux1. If you have a 7 channel RX then that leaves 2 channels for other things.

It is not usually necessary or recommended, but it is possible to use a Y harness to drive a servo or motor with the signals that are also an input to the KK2. Except for throttle, OAV is generally flexible on the signal input polarity so you can give it whatever is required by the servo or motor. OAV does have specific requirements for the input signal range, so you can't adjust the TX to match the needs of the servo or motor.

If you need more than 8 outputs, it is possible to drive more than one KK2 board in parallel with Y harnesses from the RX. This would be a very unusual and advanced technique so I need not explain it to the experts that would be inclined to do something like this. I recommend against it, if only because it is inconvenient. There would be twice as many things to be calibrated and tuned and there is no guarantee that the resulting outputs would be identical in every way.

If you use one of the serial communication techniques between the RX and the KK2, then the PWM outputs are generally still available from the RX. It depends on the specific make and model of the RX. You will need to test your specific RX to find out how it works.

Ultimately you need to make yourself a list, or better yet a simple control system block diagram. The following example is for the VTOL-Trainer. It uses two channels direct from the RX to control the two tilt servos. Programming in the TX uses differential motor tilt to enhance yaw authority, but there is no stability feedback involved. The yaw stability feedback is via differential throttle in the manner of a typical quad-copter.



Aircraft Specific Programming

The provided programming examples are not a recipe. It is important that you understand the physics of your aircraft and then program the individual motors and servos accordingly. If you are not sure where to begin I recommend the following:

1. Start from a "Blank" preset in the FC. Do not program it with a full set of parameters based on one of the example models. Your model will almost certainly be different in some way, and it won't work. You will then have so many things happening at the same time that you won't be able to figure out what is wrong.
2. Pick a single surface or motor to begin. OUT1 is as good a place to start as any. It is usually a motor. Remove all propellers for safety. You will be testing each parameter as you enter it so you need the aircraft powered up and ready for test.
3. Enter the volume values one at a time and then verify that they work as expected. For a motor you usually want to enter the throttle volume first. The motor should run up and down smoothly with the full throttle range over the full stick range. If not, either calibrate the ESCs, or adjust the throttle volume and offset the match the ESC requirements.
4. If the output is a servo, adjust the offset values so the servo output arm is in the proper position and the control surface centered. The mechanical linkages need to be geometrically correct before you do this. The offset is not properly used to make up for an incorrect linkage.
5. Add as many input volumes as you need. A typical quad-copter motor will require throttle, elevator, aileron, and rudder. Check each one to make sure the polarity is correct. For motors, this is easily done by raising the throttle until the motor is running slowly, and then verifying that the motor stops when you move each stick in the correct direction.
6. A typical control surface will require one or more volume inputs. Elevons, for example will require elevator and aileron. If the surface doesn't move in the correct direction, simply reverse the polarity of the input volume. The polarity of the elevator won't impact the ailerons or any other volume.
7. Set up the stick volume for all of OUT1-8 one at a time. The changes you make to one output will never affect another so you can be confident that once you get an output working the way you want it will stay that way.
8. The next step is programming gyro stability feedback, so you need to set up some initial values in the Profile1 and Profile 2 menus. Set the Profile menus to all zeros except for the I Rate values which you can leave at defaults. Set the P feedback for Roll only to 100. This large value is only used to make the impact more obvious and will probably need to be tuned down later for flight.
9. Go through your outputs one at a time and turn on the P1 Roll Gyro where it is needed. Wiggle the plane in Roll and verify that the servo or motor responds correctly. Servos should move the control surface to stop any motion in roll, but will go back to neutral when the motion stops. Motors will do the same, but you have to look and listen for when they speed up or slow down. Once again, running them at a very low throttle setting makes this easier. It is also common to use a Y harness to put a servo in parallel with the motor so you can see the servo move. The same can be done with a servo tester with a numerical pulse width display.
10. The polarity of the gyro feedback should be correct if the polarity of the stick volume is correct. Likewise if the polarity of the gyro P feedback is correct, the polarity of the I and AL feedback will also be correct. If not, you have set the orientation incorrectly.
11. After you get the P feedback working in Roll, do Pitch and Yaw in the same way.
12. In the Profile menu, set the I feedback to a large value, like 50 or greater, and set the I limit value to the maximum of 125. You can test the I feedback just one axis at a time, or do all 3 at

once if you are comfortable with the process. You can also set the P feedback to zero when testing the I feedback, or you can leave the P feedback on once you understand what to expect. Remember, when testing I feedback, you must raise the throttle above 2.5% otherwise the integrators will be held at zero.

13. Move the plane and verify that the servos and motors respond correctly. For I feedback the control surfaces will move to fight any movement of the aircraft, and will continue to fight to return the aircraft to its original attitude. It is normal for the I feedback to drift slowly. If the drift is excessive then perform both the sensor calibration and the RX input calibration. If you want, you can use one or two clicks of trim to stop any drift, but this is really a waste of time as your TX and RX probably aren't consistent enough to reproduce these exact values over time and temperature. It is usually better to leave the trims alone.
14. After the P and I feedback are verified on all outputs it is time to turn on the AL (Autolevel). Once again, turn off the P and I feedback if you want a clear view of the AL impact. Likewise do just one axis at a time unless you are comfortable with the interactions between axes. Go through the outputs one at a time and verify the proper response. For AL, the control surface or motor should act to return the aircraft to level. You may need to disarm and re-arm the aircraft in the level position to initialize everything correctly.
15. Once you know what to look for you can turn on the P, I, and AL all at once for the motors and servos as appropriate to their function. You will be able to distinctly see each separate effect without difficulty. Likewise, you will be able to hold the aircraft in your hand and verify that it responds correctly to motions in all 3 axis. The propellers are still removed at this point.
16. Now is the time to load the Profile menus with actual flight values. You can use the provided examples for guidance. These values will need to be tuned based on the response of your specific aircraft. For now we are just trying to get reasonably close.
17. Install the propellers and verify the correct direction of rotation at very low throttle settings. It is best to tie the aircraft down, or at least hold it firmly at this point. Propellers are dangerous!
18. Very carefully, because this is potentially dangerous, perform a "hand maiden". This is usually done by holding the aircraft near the CG (Center of Gravity) and then powering up the motors to a low setting. Wiggle the aircraft in all axis and verify that the motors and control surfaces are responding as expected. Increase to hover power and you should be able to feel the various forms of stability. Once again, it is normal for the gyros to slowly drift if you are using I feedback, so bring the throttle back to full idle from time to time to reset the integrators.
19. For aircraft that hover, the lift during the "hand maiden" should be well balanced. If the aircraft is twisting or tilting in your hand, then something is wrong and needs to be fixed. If you can't hold the aircraft near the CG then it will be difficult to feel if the balance is correct.
20. This is a good time to check for vibration. A small amount of vibration is almost unavoidable but less is better. Make sure your propellers and motors are as well balanced as they can possibly be. Excessive vibration will cause flight control difficulties later.
21. Apply small stick inputs while doing the "hand maiden" and re-verify that the surfaces move in the correct direction. For aircraft that hover you should be able to feel the aircraft roll, pitch, or yaw in your hand. Yaw in particular is often weak and harder to feel, but you can often verify that the correct propellers are speeding up or slowing down.
22. It is difficult to feel, but you want to look for any tendency to oscillate. This would be an indication that you need to reduce the P, I or AL feedback values.
23. Be sure to check all functionality in both P1 and P2. Also verify that the transition occurs according to any "slow" function you have programmed.
24. Place the aircraft on the ground, step away, and arm it as if to fly. This can be done in your home if you take reasonable care. Raise the throttle to a minimum level and check the stick input

response for all control surfaces and motors. Raise the throttle carefully until the aircraft begins to become light on the landing gear and gently test the control response. The object is not to fly, only to verify that you have control as expected. You should not expect the aircraft to be stable at this point. It might show signs of stability, but so long as it is in contact with the ground you won’t really be able to tell much.

25. You are now ready for flight testing.

Hover Testing

The flight test program will vary depending on the aircraft type and pilot temperament. I recommend the following for a typical VTOL aircraft assuming you want to spend a minimum of time rebuilding after crashing:

1. Begin with indoor hover testing. A living room is minimally adequate, but a larger space is better. For aircraft with compliant landing gear a hard smooth surface is best. For aircraft with hard gear, or no gear, carpet is nice. Grass works as well, but little or no wind is recommended.
2. Initial flights are usually for less than a second, at an altitude of just a few inches. The goal is to verify that you have control, verify hover trim, and look for any sign of oscillation. Fast oscillations suggest that the P values need to be lowered. Slightly slower oscillations suggest that the I or AL values needs to be lowered. Very slow oscillations often benefit from more P and especially more I or AL. Do not use I feedback without P or it will oscillate.
3. If the aircraft seems to wander in pitch roll or yaw, then increase the stability feedback values. Tune P first, then I, and finally AL. When I say “wander” I am not talking about horizontal translation but a change in attitude. In general, aircraft will hover with nothing but P feedback. I feedback will make them fly better. Likewise, AL(Auto Level) and Alt. damp: (Altitude Damping) will make them fly better, especially if you don’t have the automatic reflexes of an experienced pilot.
4. If the aircraft bounces around randomly, then you probably have a vibration problem that needs to be fixed.
5. Doing initial test hops with nothing but P feedback is actually helpful to determine if your aircraft is properly balanced and mechanically trimmed. It is better to fix these issues rather than cover them up with I or AL feedback.
6. Any trim issues need to be resolved with CG changes or throttle volume changes on the individual motors. Trim can also be entered via the Profile menus, but only for AL in pitch and roll or gyro in yaw. Any significant yaw trim issue suggests a motor alignment problem that needs to be fixed.
7. Once you are confident that you have control you can climb to 3 feet and observe the aircraft more carefully. You should expect to see some minor bouncing around due to air recirculation in a small room.
8. The general tuning strategy is to increase the P feedback separately in pitch and roll until you begin to see oscillations and then back off a bit. You can apply a quick pulse input to the stick and look for any tendency to ring.
9. Once the P feedback is close, increase the I feedback until you see a tendency to oscillate or ring after a pulse input and then back off. This assumes you want to use I feedback at all. I is not always recommended, especially for yaw on VTOL aircraft.
10. AL (AutoLevel) is tuned last and is typically not limited by oscillations or ringing but by the amount of “stiffness” you want. You should expect to reduce the I feedback by about the same amount as you increase the AL feedback to avoid oscillations.
11. In extreme cases you can use AL in place of I feedback for maximum “stiffness”.
12. Alt. damp: (Altitude Damping) is tuned by personal preference. You should not expect it to hold altitude for you, only to dampen changes in altitude.
13. Once you have reasonable stability you can concentrate on the level of control. If the control is sluggish then increase the stick input volume. If the control is too sensitive then reduce it.
14. You should expect the various parameters to interact. In general, stability fights control. This is not true for all flight controllers, but it is for OAV.

15. If you are using I feedback and the control is too sluggish you can try increasing the I rate. For pitch and roll the default value is 2. Increasing the I Rate to 3 is a pretty big change, so take it one step at a time. The default I Rate for yaw is 2. You can increase it to 3 or even 4. Yaw is often sluggish by the nature of the aircraft, so the FC can only do so much to improve it.
16. If you have a vibration problem, and have done all you can to eliminate it at its source, then you can lower the MPU6050 LPF (Low Pass Filter) frequency to 10Hz. This will likely require that you reduce the P, I, and AL feedback to avoid oscillations. Likewise, if you can raise the MPU6050 LPF frequency without vibration problems, you may be able to increase the P, I, and AL feedback for a more crisp response. If you are using a KK2.0 you can use the Gyro LPF instead.
17. Hover testing should continue outdoors, preferably with little or no wind, but later in wind. You should find that hovering with no air recirculation and no walls to run into is easy. You can also do more control testing including translating horizontally, usually forward. Be careful about translating backwards very quickly as some aircraft will “catch their tail” and do a flop loop.
18. You may not need AL to hover, and you may not even like to use AL when hovering, but it is often handy once you begin transition testing. AL can save you if the aircraft tumbles. It can also save you if you lose visual orientation, which is easy to do when the aircraft is far away and hard to see.
19. You are now ready to begin transition testing.

Transition Testing

Some aircraft like the VTOL-FunCub can confidently make their first flight with a conventional takeoff, and landing. If they have already been shown to hover well then an inbound transition, to hover from FFF (Fast Forward Flight), is probably not difficult, but it still represents a minor leap of faith. Even if you make the inbound transition successfully, it doesn't mean you can safely do an outbound transition.

Other aircraft are far less forgiving, and an initial attempt at an outbound transition will likely result in a crash. In general, I recommend an incremental process from hover to FFF. This will give you a chance to make any necessary trim adjustments and hopefully find any small problems before they become large ones.

For this discussion I will assume you are using a 3 position flap switch and a "slow" function. P1 is hover mode, P1.n is, or will be, SFF (Slow Forward Flight), and P2 is FFF. I will assume you are already hovering confidently.

1. Set your middle flap switch position to just 5% (P1.05), meaning 5% from hover and 95% from FFF. While in hover mode, climb to a safety altitude of at least 1 mistake high and flip to P1.05. The aircraft should begin to move forward slowly, but otherwise very little should happen. If you notice any trim changes land and adjust the offset curve as necessary.
2. When P1.05 is working well, increase your middle flap position to 10% (P1.1) and repeat the process. Many aircraft will want to hover with a nose up attitude at this point. You will need to adjust the offset curve to keep the aircraft level so it can begin to move forward.
3. From P1.1 go to P1.15. Depending on the aircraft type you will find a comfortable SFF (Slow Forward Flight) somewhere between 15% and 40% of transition. At 15% of transition it is probably still possible to hover if you pull the nose up, but mostly you want to explore the control and flight characteristics over the available speed range.
4. If at any point you become uncomfortable, flip back into hover, which is your "safe mode" and land. Try not to land a very long ways away because RC radio systems do not have their full range when the plane is on the ground.
5. Once you find your comfortable SFF percentage of transition, it becomes a new safe mode in addition to hover.
6. If, for example, SFF is at 20% of transition (P1.2) then set the upper position of your flap switch to 25% (P1.25). Make your transition from P1.2 to P1.25 with the necessary safety altitude. Continue increasing the percentage of transition in 5% increments with each flight, making any necessary adjustments as you go.
7. By the time you get to P1.5 most aircraft will be flying fairly fast and the aerodynamic control surfaces will be effective. At this point you are rapidly approaching success. If all is going well you can increase the remaining steps to 10%, meaning P1.6, P1.7, P1.8, P1.9, and of course P2.
8. It helps if you have a plan for the unexpected. If at any point in the process something bad happens be ready to flip into your "safe mode" either hover or SFF. If you are using AL it is often sufficient to go to ¾ throttle and let the AL save the plane. The main point is to not freeze with indecision while watching your plane crash. You have just a couple of seconds to do something, even if it is wrong.
9. Once you have made full transitions, you still need to explore the flight envelope. You can test high speed flight, stall characteristics while in FFF mode, high banked turns, maximum performance transitions, aerobatics, etc. I like to think of it as defining a space where you can

safely fly. Push the boundaries to either find them or insure that they are far enough away that you will never need to cross them.

10. Be sure to get some flight video. These complex aircraft tend to have a limited life.

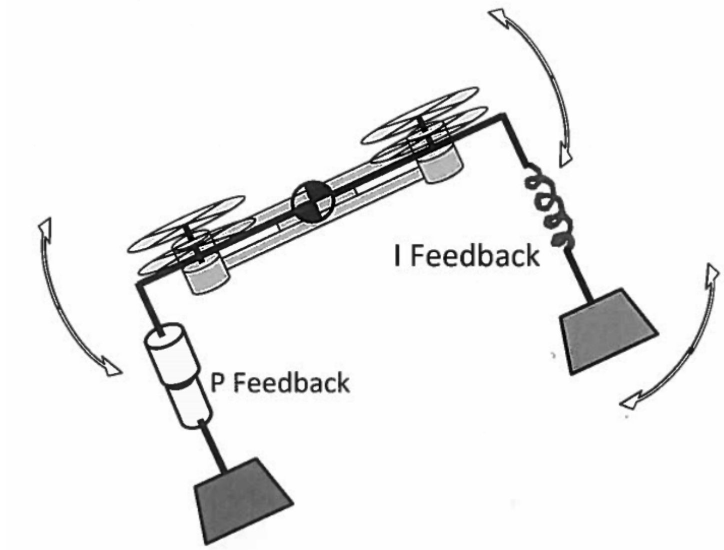
Understanding the Flight Controller (Short Version)

“P” feedback is like a shock absorber that resists rotation. The larger the number, the stiffer the shock. P feedback applies to Roll, Pitch, and Yaw.

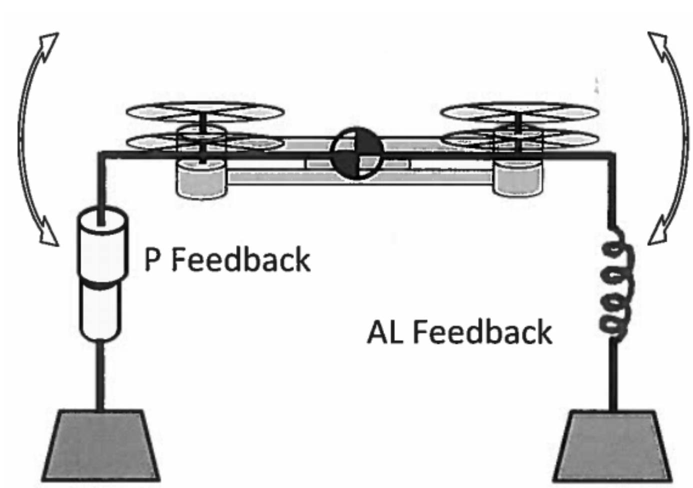
“I” feedback is like a spring that tries to hold the aircraft in the commanded attitude. The larger the number, the stiffer the spring. I feedback applies to Roll, Pitch, and Yaw.

“I Limit” only allows the spring to stretch or compress so far before dragging the anchor point of the spring to a new position. The larger the number the more the spring is allowed to stretch or compress.

“I Rate” determines how rapidly the springs anchor point moves in proportion to stick deflection. Larger numbers move the anchor point more quickly for a given amount of stick deflection.



AutoLevel (AL) is like a spring that tries to hold the aircraft in a level attitude. The larger the number the stiffer the spring. AL only applies to Roll and Pitch.



OUT1-8 Mixer menus

Mixing is nothing more than the addition of multiple inputs to create an output. The possible inputs include not only pilot stick inputs but various forms of stability feedback.

Volume is nothing more than a multiplication factor applied to an input. More volume means that input has more effect on the output.

Changing the parameters for a given output will never effect any other output.

P1 and P2 are two end points on a mixing curve. P1 corresponds to Hover Mode and P2 Corresponds to Fast Forward Flight Mode. Flight operation is possible at any point along this curve.

There are 3 axis of rotation for stability feedback, Roll, Pitch, and Yaw, as well as the Z axis (vertical acceleration) for Altitude Damping.

Gyro feedback includes P, and I feedback. The mixer menu only turns gyro feedback ON/OFF. The volumes for gyro feedback are in the Profile1 and Profile2 menus.

The mixer menu only turns AutoLevel feedback ON/OFF. The volumes for AutoLevel feedback are in the Profile1 and Profile2 menus.

The universal inputs, Source A and B, for both P1 and P2, provide additional less commonly used inputs along with volume control.

The following applies to Altitude damping:

“Z-Axis P:” feedback resists vertical acceleration. Larger numbers provide more resistance.

“Z-Axis I:” feedback resists vertical velocity. Larger numbers provide more resistance.

“Z-Axis I limit:” defines the maximum resistance to vertical velocity. Larger numbers allow more resistance.

“AccVert Filter:” reduces the resistance to vertical velocity over time. Larger numbers reduce the resistance more rapidly.

Understanding the Flight Controller (Longer Version)

Hover stability is built on a base of “P” feedback. P feedback or “Proportional” feedback is also sometimes called a “rate gyro” where the term rate refers to the rate of rotation. P feedback acts to resist rotation. This slowing effect is sometimes called rate damping or just damping. P feedback alone is enough to make a multi-copter flyable, although it does not technically make it stable. It just slows the rate of rotation enough so the pilot can control it. P feedback is typically used for all 3 axes, Roll, Pitch, and Yaw.

“I” feedback (pronounced “eye”) is based on the “Integral” of the angular rate of rotation, which is to say the angular position. I feedback cannot be used alone, but must be combined with P feedback or it will oscillate. I feedback has no concept of level, but only attempts to hold whatever angular position the pilot has commanded. I feedback “remembers” a certain angular position and will always fight to hold it, or return to it.

I feedback is subject to “windup” which is the cumulative difference between the commanded angular position and the actual angular position. In flight this difference is typically very small, as the aircraft is able to achieve the commanded angular position. In some cases, such as when the aircraft is on the ground, it is unable to move as commanded and the windup can be quite large. If the aircraft later has the ability to move, this windup can unwind unexpectedly leaving the pilot to wonder why the aircraft seemed to move on its own. In fact the movement was commanded, but previously and cumulatively, without the pilots understanding. This leads to the use of an “I Limit” which limits the maximum allowable windup. The I Limit sets a maximum angle that the aircraft will remember and attempt to return to.

Windup comes from 2 sources. One is un-commanded movement of the aircraft, typically due to some external force. The other is pilot stick input which cumulatively commands a movement even if the aircraft is unable to comply.

Pilot stick input causes the motors to speed up or slow down in proportion to the assigned volume. The same concept applies to the motion of servos. In flight, the physics of the aircraft and the P feedback, which resists the resulting angular rate of rotation, all combine to produce a certain angular rate of rotation in proportion to stick input. Ideally, this stick input causes an integral windup which is dynamically balanced or “unwound” by the physical movement of the aircraft. If the stick windup is too small for the aircraft movement then the aircraft will “kick-back” meaning the movement will partially reverse when the stick is neutralized. If the stick windup is too large for the aircraft movement, then the aircraft will continue to move after the stick is neutralized. The resulting “kick-forward” can be hard to see because it happens quickly, but it makes it difficult to fly precisely. The “I Rate” adjusts the rate of stick input windup. Kick-back suggests the need for a higher I Rate, while kick-forward suggests the need for a lower I Rate.

I feedback is imperfect due to cumulative errors in the angular position calculation. In other words, the gyros drift slowly over time. In flight, this generally happens so slowly that it is unnoticeable. Excessive drift can occur while the aircraft is sitting on the ground, which is why the integral windup is held at zero whenever the throttle is off. The gyros are calibrated for drift after power up and when arming, which is why it is important that the aircraft be held very still at these times.

When using I feedback it is important to never use the TX trims or sub trims as this will cause rapid gyro drift or windup. Likewise, holding stick input when the aircraft cannot respond will cause rapid windup unless the throttle is off.

AutoLevel or AL is similar to I feedback in many ways. Like I feedback it should not be used without P feedback or it will oscillate. Like I feedback it remembers the desired angular position and will keep fighting to achieve it. Unlike I feedback there is no stick input involved, and no stick windup. AL remembers level, not some arbitrary angular position that the pilot has commanded. AL requires a bunch of complex calculations which are based on input primarily from the gyros, and secondarily from the accelerometers. The gyros slowly drift so the accelerometers are used to gently remind them what level is.

I feedback and AL are somewhat interchangeable depending on the desired response. One common technique is to use mostly AL with a small amount of I feedback and a very small I limit. In this case the I feedback acts as an “auto-trim” function over a narrow range of angles around level. The same concept can compensate for an out of balance CG (Center of Gravity) but only to a point.

The simplified strategy for stability feedback tuning is to increase the P feedback until the aircraft begins to oscillate, and then back off a bit.

The strategy for I feedback is similar, however I feedback is not absolutely necessary. It is often desirable to fly initially without I feedback to insure that the I feedback is not masking an out of trim condition. Thereafter I feedback can be used to make the aircraft fly “better” depending on what the pilot considers better.

AL can be added up to a point of oscillation the same as I feedback, but is usually limited by the desired “stiffness” of the spring that pulls the aircraft back to level. Excessive stability can limit the pilots ability to make the aircraft do what he wants. AL and I feedback can be traded against one another in roughly equal proportions up to the oscillation limit.

Ultimately words cannot fully express the feel of an aircraft. Users are encouraged to play with all the values and develop their own visceral understanding of what they do. The physics of different aircraft will obviously have an impact on all of this so users should not expect that there would be one ideal set of values for all aircraft. The different axes will often require different values for the best results. Aircraft are rarely symmetrical in all respects, and yaw is frequently very different than pitch or roll.

Different pilots can have very different ideas about what they like and different applications suggest different values as well. An aircraft tuned for FPV (First Person View) is likely to be more gentle than one intended to be flown “line of sight”. The use of stability feedback does not necessarily imply stable, boring, or something only suitable for a beginner. The proper tuning of stability feedback can enhance aircraft performance allowing for extreme aerobatics.

Pulse Width Notes

There is no standard for the Pulse Width Modulation (PWM) used to control servos or ESC's, or as an output from the many different brands of receivers. Pulse widths are nominally 1.5ms plus or minus 0.5ms, or 1ms to 2ms, but that is only a rough approximation. The center pulse width varies from about 1.5ms to 1.52ms. The pulse width range varies from about 1.1ms to 1.9ms on the low end to 0.875ms to 2.125ms on the high end.

The calibration procedure for OE2-VTOL assumes that you have programmed your TX to a center pulse width of approximately 1.5ms plus or minus 0.4ms. The actual values of "sub-trim" or "offset" and "endpoint", "travel", "volume" or "gain" required to achieve this will depend on your specific brand of TX and RX.

The pulse width outputs from OE2-VTOL vary depending on whether that output is designated as "Motor" or "Servo" in the OUT1-8 Mixer menus. They also vary depending on whether the throttle volume is set to a non-zero value for both P1 and P2.

	Motor Output	**Servo Output**
Throttle Volume 0% for both P1 and P2	• Bipolar referenced to 1.5ms • 1.1ms to 1.9ms for 100% input • Throttle Cut Active	• Bipolar referenced to 1.5ms • 1.0ms to 2.0ms for 100% input • No Throttle Cut
Throttle Volume not 0% for either P1 or P2	• Unipolar referenced to 1.1ms • 1.1ms to 1.9ms for 100% input • Throttle Cut Active	• Unipolar, referenced to 1.0ms • 1.0ms to 2.0ms for 100% input • No Throttle Cut

For outputs designated as "Servo" the nominal pulse width for an input volume of 100% is 1.0ms to 2.0ms with neutral stick input being 1.5ms.

Stick Input	Servo Out at 80% Volume	Servo Out at 100% Volume	Servo Out at 125% volume
-100%	1.1ms	1.0ms	.875ms
0%	1.5ms	1.5ms	1.5ms
100%	1.9ms	2.0ms	2.125ms

For outputs designated as "Motor" where the Throttle Volume is set to 0% for both P1 and P2, the nominal pulse width for an input volume of 100% is 1.1ms to 1.9ms with neutral stick input being 1.5ms.

Stick Input	Motor Out at 80% Volume	Motor Out at 100% Volume	Motor Out at 125% volume
-100%	1.18ms	1.1ms	1.0ms
0%	1.5ms	1.5ms	1.5ms
100%	1.82ms	1.9ms	2.0ms

The smaller pulse width range for "Motor" outputs is to ensure compatibility with various brands of ESCs. The larger pulse width range for "Servo" outputs is to allow servos to be driven as far as possible for the greatest mechanical advantage.

Any output designated as “motor” will go to 1.0ms when the throttle stick is below 2.5%. This is a safety feature that prevents motors from being turned on by stability feedback or other control inputs when the throttle is at idle. When an output is driven to 1.0ms in this manner it is called “throttle cut”.

A motor output with non zero throttle volume in either P1 or P2 will be unipolar with a nominal minimum pulse width of 1.1ms. However, it will never reach 1.1ms because the throttle cut will activate at 2.5%.

Throttle Stick Input	Motor Out at 80% Volume	Motor Out at 100% Volume	Motor Out at 125% volume
Nominal 0%	1.1ms	1.1ms	1.1ms
Actual 0%	1.0ms	1.0ms	1.0ms
<2.5%	1.0ms	1.0ms	1.0ms
2.5%	1.116ms	1.12ms	1.125ms
50%	1.42ms	1.5ms	1.6ms
100%	1.74ms	1.9ms	2.1ms

A servo output with non-zero throttle volume in either P1 or P2 will be unipolar with a nominal minimum pulse width of 1.0ms. However, it will never reach 1.0ms because the throttle cut will activate at 2.5%.

Throttle Stick Input	Servo Out at 80% Volume	Servo Out at 100% Volume	Servo Out at 125% volume
Nominal 0%	1.0ms	1.0ms	1.0ms
Actual 0%	1.0ms	1.0ms	1.0ms
<2.5%	1.0ms	1.0ms	1.0ms
2.5%	1.02ms	1.025ms	1.028ms
50%	1.4ms	1.5ms	1.5625ms
100%	1.8ms	2.0ms	2.125ms

The exact pulse width center or range does not typically matter for most servos. If you need to adjust the center you can adjust the P1, P1.n, and P2 Offset values within the OUT1-8 Mixer menus.

The exact pulse width center or range does not typically matter for most ESCs either. Some ESCs will be calibrated to use whatever reasonable range you supply them. Other ESCs have a fixed input range and you will need to adjust the Volume and Offset within OAV to give them what they need.

For both servos and ESCs it is generally best to provide them with an input range of at least 0.8ms. For servos, this ensures adequate servo travel and when combined with a properly designed linkage should produce a reasonable combination of speed and torque at the control surface. For ESCs a reasonably broad input range makes the best use of the available pulse width measurement resolution within the ESC and provides finer control of the output throttle setting.

The “negative servo travel” and “positive servo travel” menus limit the minimum and maximum pulse widths as seen at the output.

Negative Pulse Width Limits

Input Values	Pulse Width Limit
0	1.5ms
-50	1.25ms
-100	1.0ms
-125	0.875ms

Positive Pulse Width Limits

Input Values	Pulse Width Limit
0	1.5ms
50	1.75ms
100	2.0ms
125	2.125ms

When entering values into these menus the output will be driven to the set value so that servos may be observed as they are driven up to any mechanical hard stop. This feature is disabled when an output is designated as a “Motor” as it would immediately drive motors to 50% throttle.

The negative pulse width limit does not block the “throttle cut” feature. “Motor” outputs will still go to 1.0ms when the throttle is below 2.5%.

Auto-Level vs. Accelerometers Explained

The Auto-Level functionality is based on both the Gyros and the Accelerometers. The IMU (Inertial Measurement Unit) integrates the Gyros in a manner similar to the I feedback loop. The accelerometers are filtered and used to gently "trim" the level estimate from the integrated Gyros. This is accomplished via the CF (Complementary Filter). All of this makes the Auto-Level relatively insensitive to short term lateral acceleration as well as the confusion that results from modest maneuvering.

The CF (Complementary Filter) is tuned by the "AL Correct:" parameter in the General menu. The "AL Correct" - Auto-Level Correct – sets the approximate time in seconds for the accelerometers to correct Auto-level drift. The range is from 2 to 11 with 6 being the default.

The Auto-Level is tuned via the "AutoLvl:" values in the Profile menus, and is applied via the ON/OFF/Scaled values in the OUT1-8 Mixer menus.

The filtered Accelerometer data is not the same as Auto-Level. It is only based on the accelerometers and has no Gyro based component. The accelerometer signals available from the hardware are in X, Y, Z, format and are very noisy, responding to every bump and vibration. They are filtered to slow and smooth the signal. This process has nothing to do with the Gyros, IMU, or CF.

Filtered lateral acceleration data is referred to as "Acc X" and can be used for automatic turn coordination and can also be used to provide a simplified form of stability feedback. Filtered longitudinal acceleration, or "Acc Y" can also be used to provide a simplified form of stability feedback. The Filtered accelerometer data is available via the universal inputs, Source A and Source B within the OUT1-8 Mixer menus.

The filtered Z axis, or vertical axis accelerometer is used for height damping. This also has nothing to do with the Gyros, IMU, or CF. The height damping functionality is not recommended for use with fixed wing aircraft in forward flight.

PWM Rate Selection Explained

The PWM Frame rate selection in the General menu has an impact on the average frequency or period of the PWM outputs from OUT1-8.

There is no standard for PWM (Pulse Width Modulation) frequency that is used to drive servos or ESCs. Originally it was intended to be around 50Hz or 20ms, but various brands of equipment have ranged from about 45Hz or 22ms to as high as 300Hz or 3.33ms. The higher frequencies were not necessary when control responses were limited by human reflexes, but once Gyros and other forms of electronic feedback became possible then 50Hz was no longer fast enough. Some ESCs can accept even higher PWM frequencies up to around 400Hz.

For many VTOLs a relatively slow PWM output of 22ms or 45Hz results in a very nice hover with good control and damping. Some smaller or heavier VTOLs that lack wings or a tail will benefit greatly from a higher frame rate. Using Sync RC mode with 91Hz PWM output can make a big difference. Frame rates up to almost 200Hz available in Fast mode will make a further improvement. Beyond a certain point the frame rate doesn't matter because the physics of the aircraft sets a limit to what is possible.

Higher frame rates allow larger values of P, I, AL and Alt. damp: (Altitude Damping) without inducing oscillations. The result is a more "crisp" or "locked in" feel when hovering. The higher frame rates may also make the FC less susceptible to the vibrations that inevitably occur with a multi-copter.

S.Bus is the recommended method of data input. The digital data format is more precise and compact, allowing more time for the KK2 hardware to process the data. Depending on your specific TX and RX it may not be possible to achieve 91Hz in Sync RC mode unless you use a digital data input format like S.bus or Satellite. For Fast mode to work, with PWM outputs of up to 200Hz, you must use S.bus.

Regardless of the "PWM Rate:" selected in the General menu, outputs designated "AServo" (Analog Servo) in the OUT1-8 Mixer menus will be limited to a frame rate of 55Hz or less. Outputs designated "DServo" (Digital Servo) or "Motor" will not be so limited.

Warning: Analog servos may be damaged by frame rates in excess of about 55Hz. Follow the manufacturer's recommendations for your specific servos.

A "PWM Rate:" of "Low" in the General Menu results in a frame rate on all outputs of 50Hz or less. If the input data rate from the RX is faster than 50Hz the firmware will divide the input frequency by an integer value to bring it below 50Hz. For example, an input data rate from the RX of 90Hz will be divided by 2 for an output frame rate from the KK2 of 45Hz.

The "Sync RC" option will take the input data rate from the RX and pass it directly to DServo and Motor outputs. In some cases, if the input data rate from the RX is too fast for the KK2 hardware to keep up, the output data rate will be divided by an integer value as necessary.

The "Fast" option will produce output pulses as fast as possible, and will fit as many output pulses as possible in between incoming S.bus data packets. This can result in PWM output frame rates of almost 200Hz. The actual frame rate will vary and the timing between individual output pulses will vary as necessary. All frame rate figures provided are average and approximate. The actual frame rates will vary depending on the user parameters selected which can change between P1, P1.n, and P2.

The “Fast” option is optimized to minimize the latency between the gyro and accelerometer data and the outputs. This is done at the cost of some delays in user stick input data with an effective data rate of up to 30Hz. This is still well faster than any human pilot could notice.

PWM Frame Rates

Modes	Stick Input	AServo	DServo	Motor
Slow	<50Hz	<50Hz	<50Hz	<50Hz
Sync RC	45Hz-91Hz	<50Hz	45Hz-91Hz	45Hz-91Hz
Fast	Up to 30Hz	<55Hz	Up to 200Hz	Up to 200 Hz

KK2 Hardware Variants

As of 2014 the KK2.0 is in the process of being replaced by the KK2.1. The update is being driven by component availability, primarily the chip responsible for Gyro and Accelerometer feedback. The two boards are intended to be functionally equivalent, however, the KK2.1x boards have more memory. As a result the OAV firmware for the KK2.0 has been frozen at Version 1.0.

The Version 1.1 firmware and beyond only works on the various KK2.1 boards.

The KK2.1.5 is essentially the same as the KK2.1 board.

The hard case version of the KK2.1.5 has the same functionality as the regular KK2.1.5.

The KK2.1 mini board has the same functionality as the KK2.1.5.

Solutions to Common Problems

- **OUT1 works but OUT2-8 do nothing** – You don't have power applied to the servo output power bus. Review the manual section on how to properly power the board.
- **The "P" Gyro stability feedback works but the "I" does not** – You forgot to set the I Limit value in the Profile menu to something other than 0. Or… The throttle stick input is at full idle and the I feedback loop is being held at neutral to eliminate Gyro drift. Move the throttle stick up.
- **A servo that uses throttle as one of the inputs is not centered** –Set that output as a servo and not as a motor.
- **The KK2 powers up but nothing seems to work properly** – Execute a factory reset and then carefully follow the setup procedures as described in this manual.
- **Everything was working fine but now the trims are all messed up** – Power cycle the board and hold the aircraft reasonably steady when you power it up.
- **The LCD screen blinks off and the board keeps resetting** – You are losing power. Review the section of the manual on how to power the board. Find a more stable power source.
- **Your ESCs beep constantly when the throttle is at idle** – This is a normal side effect of the safety features programmed into the firmware. The ESCs are complaining about the 1ms input pulse being too narrow.
- **Your ESCs beep constantly when the FC is in programming mode** - This is a normal side effect of the safety features programmed into the firmware. The ESCs are complaining about the lack of an input pulse.
- **Some servos run to the limit when the aircraft is on the ground** – This is normal if that servo is using "I" feedback. The servos will drift very slowly due to Gyro drift or more quickly due to stick input. If the drift is excessive when the stick is at neutral then you may have adjusted your TX trim input which is not allowed. Set your trims and stick to neutral and perform the Receiver inputs calibration procedure per the manual.
- **The manual Arm or Disarm process isn't working** – Make sure you are in the "Armable" mode. If your TX has low rates, switch to high rates. Check the Receiver Inputs menu and verify that your RX inputs are properly calibrated, near zero for neutral stick and full low throttle. Slightly more than +-1,000 for full stick input and +2,000 for full throttle. Perform the stick polarity calibration in the stick polarity menu.
- **The battery voltage error message is blocking your view of the status screen** – Set the "Bat. LVA x10:" to "0" if you have no battery voltage input to the board.
- **The servos move in steps when the status screen is displayed** – This is normal. The servos will move smoothly when the status display screen disappears in 10 seconds.
- **The servos jitter** – Verify that the jitter counter in the status screen is zero. If not, then follow the setup procedure to set the PWM sync: input correctly. If you still have jitter, then check the RX input values in the Receiver Inputs menu and make sure they are stable. If you still have jitter then make sure the board is mechanically stable and turn off any stability feedback to isolate the problem.
- **Everything was working, but now it is working differently** – Make sure you are in the correct Profile, P1, P1.n, or P2. Check the status screen for the "Profile:" and "Pos:" readout, and verify that your TX switch, knob, or other input is correct.
- **You are having too much fun and can't believe that the OAV Firmware is free** – Make a donation at the OpenAero Project Page: https://sites.google.com/site/openaerowiki/home

Preset, QuadX

The QuadX preset provides an initial set of values that is proven to fly well for a basic X-Quad configuration. The optimum values for your X-Quad may vary due to differences in size or equipment.

The QuadX preset assumes you have S.Bus input and a High PWM Rate. The use of PWM input will require different P, I, and AL parameters and will not result in as stable a hover.

The QuadX preset provides for Elevator, Aileron, Rudder, and Tilt Servo output on OUT5-8. They are not used but are provided as examples and servos can be plugged into those outputs for demonstration purposes.

The QuadX preset is essentially the same as the factory default values achieved by doing a power up reset by pushing buttons 2 and 3 on power up. Select the QuadX preset after doing a power up reset to update a few minor values.

The detailed values used for the QuadX preset can be found in the menu structure spreadsheet in the tab labeled QuadX.

As with all basic multicopters, carefully balance the motors and propellers for best performance. Excessive vibration will confuse the flight controller and cause random “bouncing” which cannot be resolved with simple parameter changes.

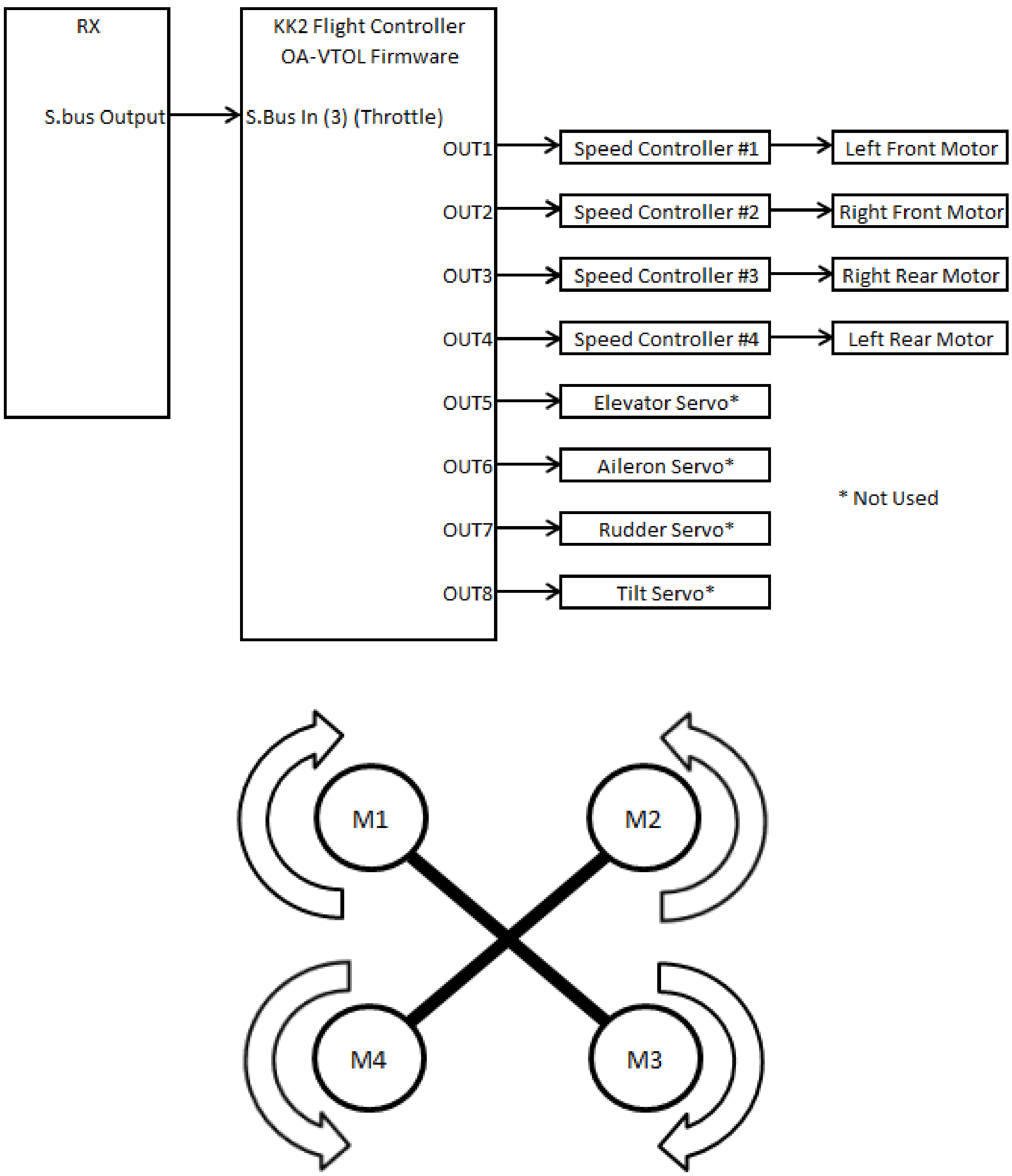
Profile 1 (P1) is set up with Auto-Level (AL) and mild controls for a nice beginner mode. Profile 2 (P2) has more aggressive controls and a very slight amount of AL for more advanced flyers. Any percentage of transition by be used between P1 and P2. Neither of these modes is intended for aerobatics. If you wish to do aerobatics with a multi-copter you would be better served to use dedicated multi-copter firmware.

The Z-Axis parameters in the P1 menu, along with the AccVert Filter: in the Receiver setup menu are set for fairly soft altitude damping in P1. There is no altitude damping in P2.

The MPU6050 LPF: is set to 44Hz. It can be lowered to 21Hz if you have vibration problems.

The Curves menu is not used and is set to defaults. The 7 point curves in the Output Offsets menu are all set to 0 except for OUT8 which is set up to demonstrate a tilt servo.

QuadX Control Block Diagram Ran D. St. Clair 3-29-15



Preset, QuadP

The QuadP preset provides an initial set of values that is proven to fly well for a basic Plus-Quad configuration. The optimum values for your Plus-Quad may vary due to differences in size or equipment.

The QuadP preset assumes you have S.Bus input and a High PWM Rate. The use of PWM input will require different P, I, and AL parameters and will not result in as stable a hover.

The QuadP preset provides for Elevator, Aileron, Rudder, and Tilt Servo output on OUT5-8. They are not used but are provided as examples and servos can be plugged into those outputs for demonstration purposes.

The detailed values used for the QuadP preset can be found in the menu structure spreadsheet in the tab labeled QuadP.

As with all basic multicopters, carefully balance the motors and propellers for best performance. Excessive vibration will confuse the flight controller and cause random “bouncing” which cannot be resolved with simple parameter changes.

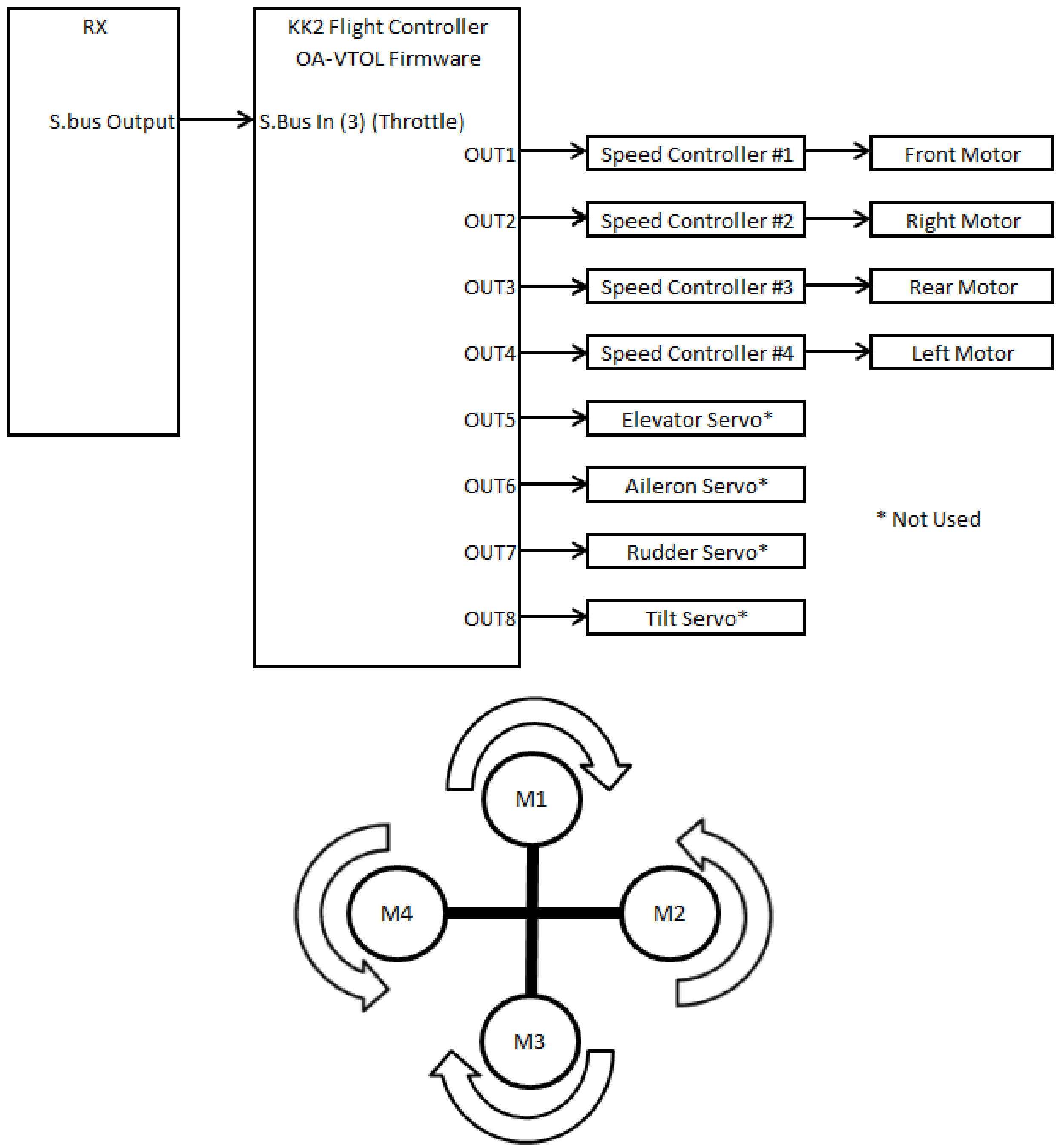
Profile 1 (P1) is set up with Auto-Level (AL) and mild controls for a nice beginner mode. Profile 2 (P2) has more aggressive controls and a very slight amount of AL for more advanced flyers. Any percentage of transition may be used between P1 and P2. Neither of these modes is intended for aerobatics. If you wish to do aerobatics with a multi-copter you would be better served to use dedicated multi-copter firmware.

The Z-Axis parameters in the P1 menu, along with the AccVert Filter: in the Receiver setup menu are set for fairly soft altitude damping in P1. There is no altitude damping in P2.

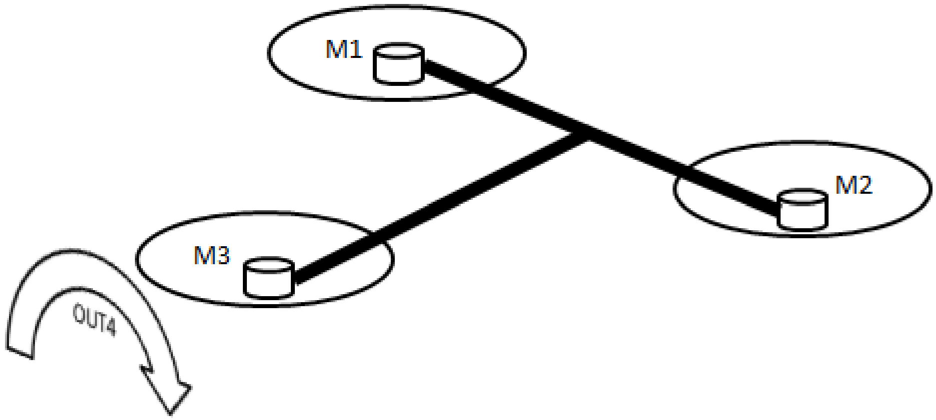
The MPU6050 LPF: is set to 44Hz. It can be lowered to 21Hz if you have vibration problems.

The Curves menu is not used and is set to defaults. The 7 point curves in the Output Offsets menu are all set to 0 except for OUT8 which is set up to demonstrate a tilt servo.

QuadP Control Block Diagram Ran D. St. Clair 3-29-15



Preset, Tricopter



The Tricopter preset provides an initial set of values that are assumed to fly well for a basic Tricopter configuration but they have not been tested in an actual aircraft. The optimum values for your Tricopter may vary due to differences in size or equipment. The direction of motor rotation does not matter except that M1 and M2 must be opposite. M3 will be tilted to compensate for its torque contribution.

The Tricopter preset assumes you have S.Bus input and a High PWM Rate. The use of PWM input will require different P, I, and AL parameters and will not result in as stable a hover.

The Tricopter preset provides for Elevator, Aileron, Rudder, and Tilt Servo output on OUT5-8. They are not used but are provided as examples and servos can be plugged into those outputs for demonstration purposes.

The detailed values used for the Tricopter preset can be found in the menu structure spreadsheet in the tab labeled Tricopter.

As with all basic multicopters, carefully balance the motors and propellers for best performance. Excessive vibration will confuse the flight controller and cause random “bouncing” which cannot be resolved with simple parameter changes.

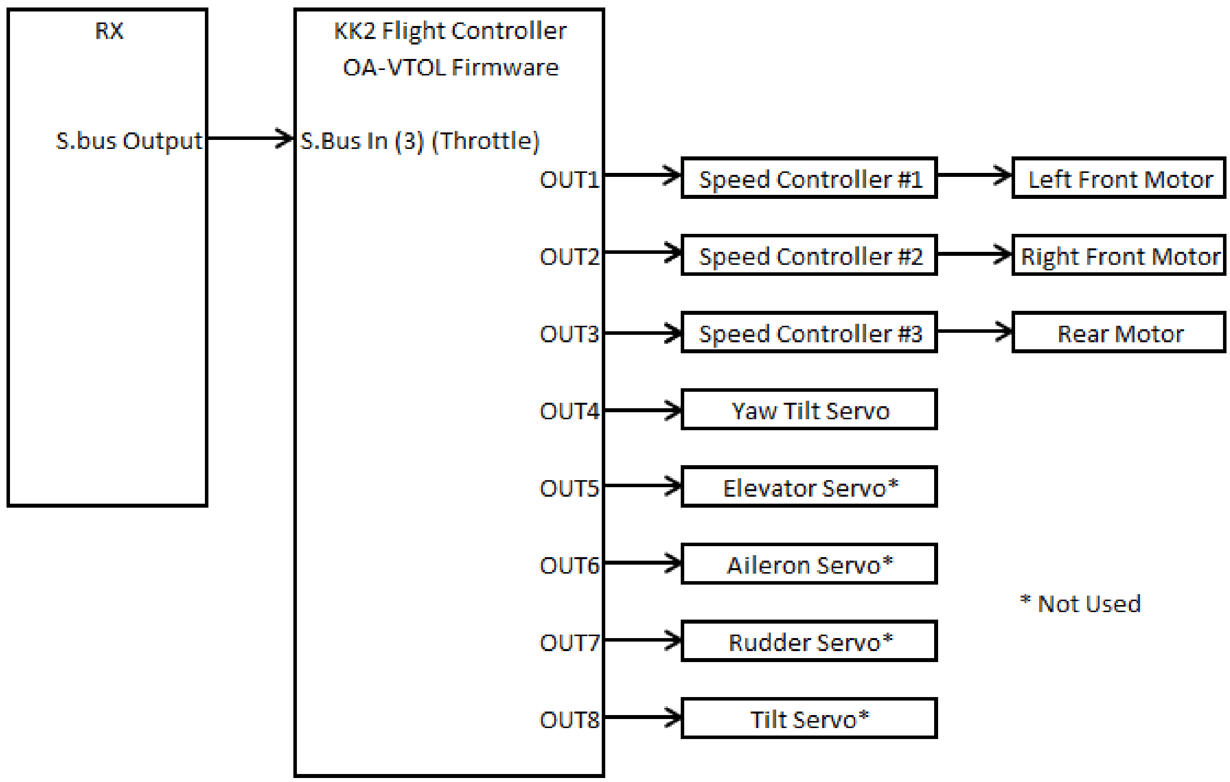
Profile 1 (P1) is set up with Auto-Level (AL) and mild controls for a nice beginner mode. Profile 2 (P2) has more aggressive controls and a very slight amount of AL for more advanced flyers. Any percentage of transition may be used between P1 and P2. Neither of these modes is intended for aerobatics. If you wish to do aerobatics with a multi-copter you would be better served to use dedicated multi-copter firmware.

The Z-Axis parameters in the P1 menu, along with the AccVert Filter: in the Receiver setup menu are set for fairly soft altitude damping in P1. There is no altitude damping in P2.

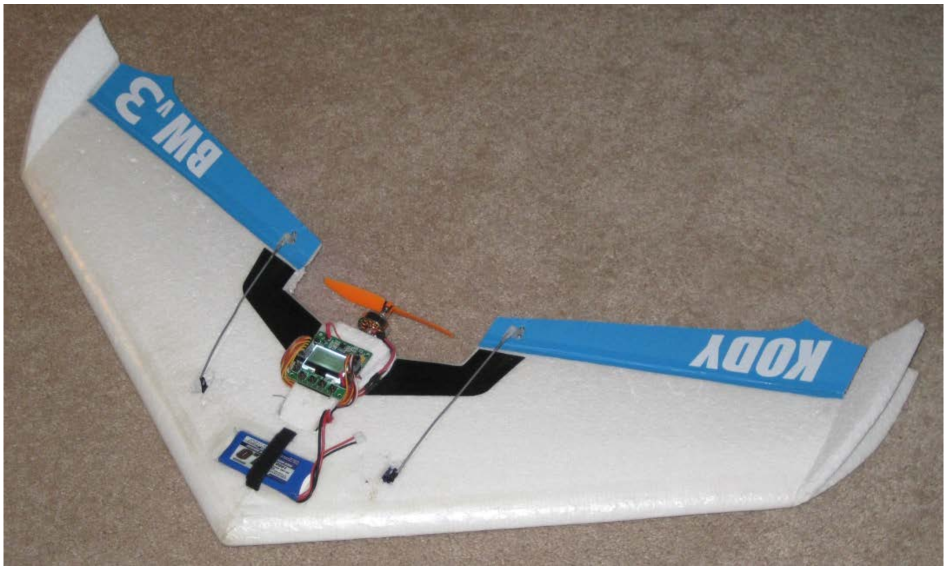
The MPU6050 LPF: is set to 44Hz. It can be lowered to 21Hz if you have vibration problems.

The Curves menu is not used and is set to defaults. The 7 point curves in the Output Offsets menu are all set to 0 except for OUT8 which is set up to demonstrate a tilt servo.

Tricopter Control Block Diagram Ran D. St. Clair 3-29-15

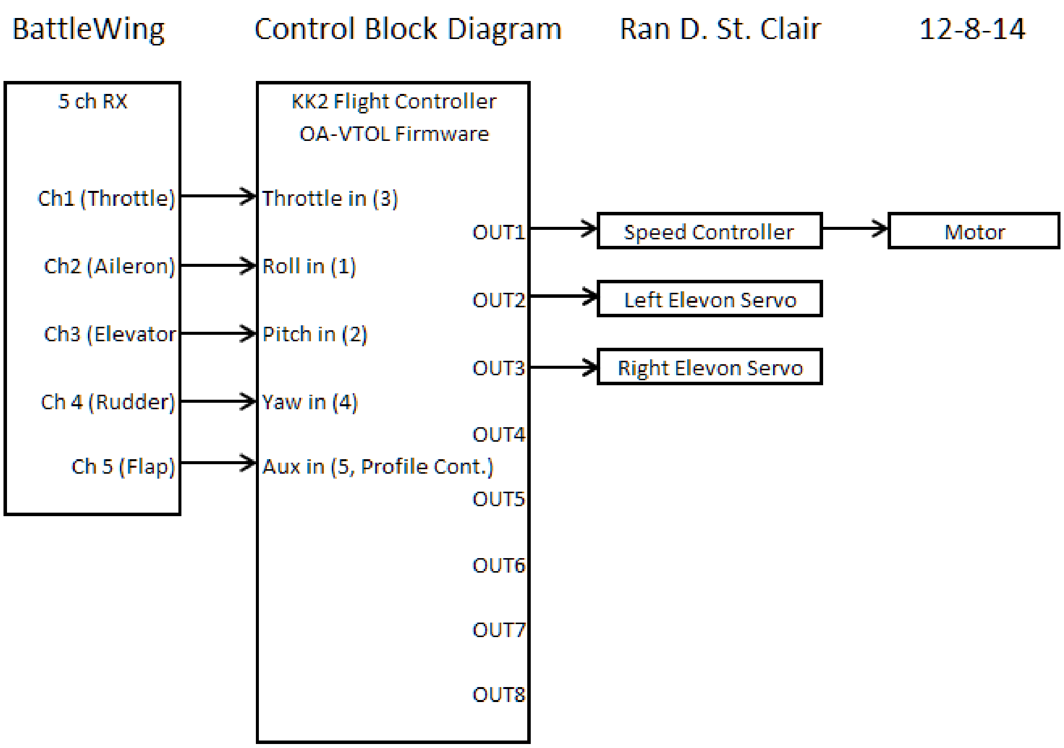


Example, BattleWing



The BattleWing is not a VTOL, but it serves to demonstrate a simple setup that includes elevons, and the use of AL (AutoLevel) as an automatic recovery mode in FFF (Fast Forward Flight)

Profile 1 (P1) is set up for normal flight with no stability feedback. Profile 2 (P2) is set up to use a fairly mild degree of AL that makes the BattleWing fly like a gentle trainer. The middle position of the flap switch on the TX is used for P1.5 which provides a reduced level of stability.



The General menu is set to defaults except that the Orientation: is Top Front and the Safety: is Armable.

The Profile 1 (P1) menu is set to all zeroes except for the I Rate values which are left at default. The I Rate values don't matter because no I feedback is being used.

The Profile 2 (P2) menu is also all zeroes except that the roll and pitch AutoLevel are set to 10 and the I Rate values are left at default. The AutoLevel value of 10 is strong enough that the aircraft cannot be forced to fly inverted, even with full stick input. This makes it an ideal training mode.

The curves menu is set to defaults and not used.

The output offsets menus are set to a fixed value on OUT1 to accommodate the ESC that drives the motor. Out2-3 are set to center the control surfaces in P1. In P2 they provide a few counts of up elevator to help hold the nose up in trainer mode.

OUT1 is used to drive the motor. The values of throttle volume and offset were chosen to match the needs of the simple auto calibrating ESC.

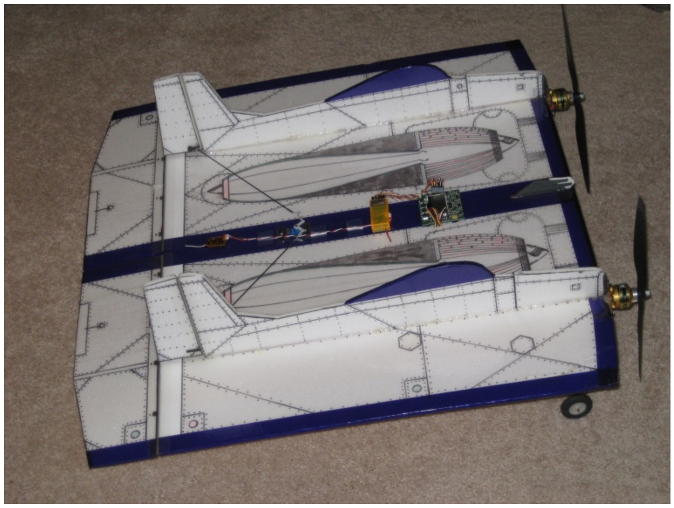
Both elevens have -40% Aileron volume in both P1 and P2. The ailerons move in opposite directions as they should because the mechanical linkages are symmetrical. In practice the sign of these values is arbitrary. You simply chose them to make the surfaces move in the correct direction.

Both elevons have 24% Elevator volume for both P1 and P2, but different polarity as required by the linkages. The smaller elevator volume is chosen to maximize maneuverability without causing unwanted snap roll characteristics. It's a matter of personal tuning preference.

The combination of elevator and ailerons is what makes the surfaces act as elevons. This method of mixing various stick inputs and stability feedback is the central idea behind OAV.

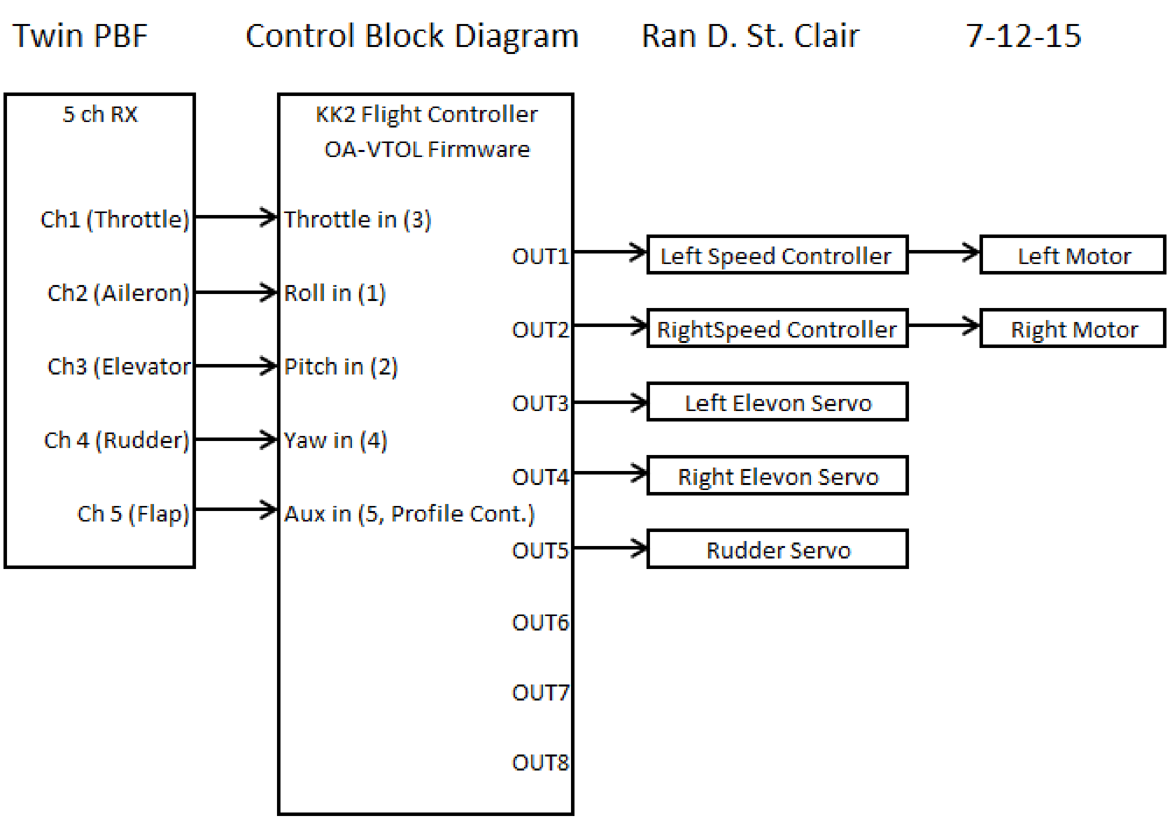
All of the ON/OFF values for OUT2 and OUT3 are set to ON. This was done because it is simple and easy to remember and program. The various Gyro, AL, and Z acc capabilities are all enabled but the controlling values in the P1 and P2 menus are still in force.

Example, Twin PBF (Pizza Box Flyer)

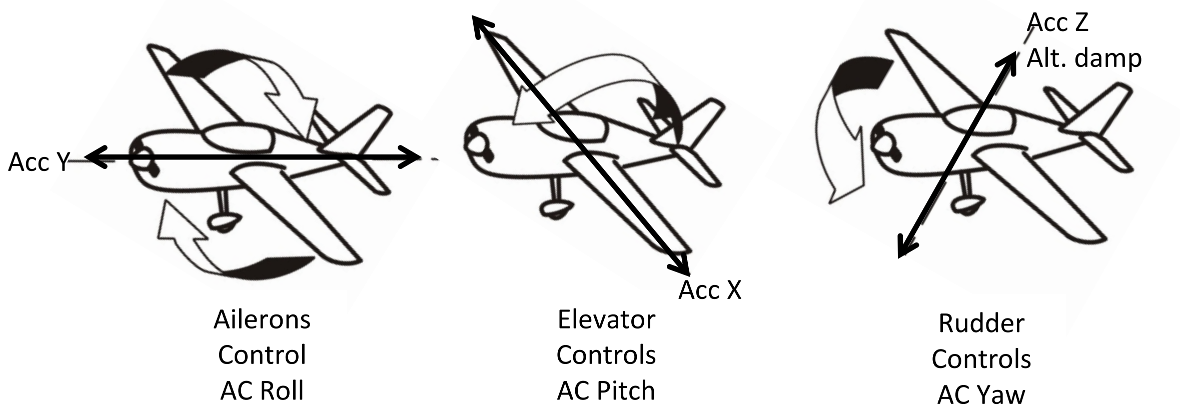


The Twin PBF is not a VTOL because it doesn't have landing gear to land vertically, but it flies and hovers in the manner of a VTOL "Tail Sitter". The control system can be configured so it hovers in the manner of a multi-copter or as an airplane.

Profile 1 (P1) is set up for hovering with strong AutoLevel (AL) feedback. Profile 2 (P2) is set to fly as a normal flying wing with elevons and rudder. Differential throttle is used to enhance yaw authority. A small amount of P feedback is used in all 3 axes to make the airplane fly more smoothly.



Remember, when in P2 (FFF – Fast Forward Flight) the normal airplane frame of reference applies.



The General menu is set to defaults except that “Tail Sitter:” is set to either “Earth ref.” or “Vert AP ref.” and the “AL Correct: is set to the fastest value of 2 or about 2 seconds.

The provided Excel spreadsheet shows two alternate configurations. When in “Earth ref.” mode it hovers like a quad-copter where aileron stick input controls the rudder and Rudder stick input controls the ailerons. When in “Vert. AP ref.” mode it hovers like a vertical airplane where the Aileron stick input controls the ailerons and Rudder stick input controls the rudder. Either method will work, so it comes down to pilot preference.

The spreadsheet has 2 values listed in some cells which are also highlighted in yellow. The left value is for “Earth ref.” mode and the right value is for “Vert AP ref.” mode.

The Receiver Setup menu is typical for PWM input from a standard Spektrum RX. The various polarity values are set automatically via the stick polarity menu.

The transition speed is set to zero meaning any slow transition must be programmed into the TX. Since this is a Tail Sitter, it does not benefit from a slow transition. The outbound transition only requires adding a little throttle to climb out of a hover. The inbound transition can be made from level flight, or the pilot can fly the aircraft into a hover and then flip the switch. Flipping the switch while in FFF (Fast Forward Flight) will result in a zoom climb if the throttle is not reduced appropriately.

The mid flap position on the TX is used to fly at a forward lean angle of about 30 degrees. This is done by setting the transition control input from the TX to about 25% from hover, 75% from FFF. This is sometimes convenient when there is a little wind and it is necessary to lean into the wind substantially to maintain station.

The Profile 1 (P1), hover mode, menu is set with fairly high P feedback values for Pitch, Roll, and Yaw which provides a high degree of damping in all axes. A small amount of I feedback is used in all axes, but is not really necessary for this aircraft. The I-limit values are also fairly small to minimize any potential for integrator “windup”. The I rate values are left at the default value of 2 resulting in a fairly gentle response.

The AutoLevel (AL) in P1 is set to 10 for Roll and 30 for Pitch. The difference in value is because differential throttle has a very powerful roll effect in hover, while the elevon control surfaces have somewhat less control authority in pitch. This is true even though the control surfaces and control throws are both very large. When in “Vert AP ref.” mode the “Roll AutoLvl:” menu item is renamed “Yaw AutoLvl:”.

The Z-Axis P: is set to 40, Z-Axis I: to 20, Z-Axis I Limit: to 10 and the AccVert filter: is set to 20. Taken together these provide a fairly soft altitude damping function in P1 only. No altitude damping is used in P2.

In Profile 2 (P2) Fast Forward Flight (FFF) mode all stability is turned off except for a modest amount of P feedback in all axes. The P feedback helps the plane to fly more smoothly, especially in wind, and also reduces a tendency for the wings to rock.

OUT1 is used to drive the left motor and OUT2 is used to drive the right motor. The choice of outputs is mostly arbitrary except that the power to the KK2 and RX comes from the ESC connected to OUT1.

The Curves menu is left and defaults and is not used.

The offset curves in the Output Offsets menu are all flat and the values are set to satisfy the fixed endpoints of the ESCs that were used, or are set to center the servo arms from the nearest spline on the output shaft.

The P2 throttle volume on the left motor is slightly reduced by 3%, as compared to the P2 throttle volume on the right motor. This was done to eliminate a tendency for the aircraft to pull to the right in FFF which might have come from a slight difference in the ESCs, motors, or propellers.

Both motors use 10% rudder stick input volume in P2, but the polarity is different. This provides enhanced yaw authority when in Fast Forward Flight (FFF).

When in “Vert AP ref.” mode the “P1 Roll AutoLvl:” menu item is renamed “P1 Yaw AutoLvl:”, but either way the P1 Roll/Yaw AL is turned on for both motors.

The P2 Yaw Gyro and the P1 Alt. damp:”is turned on for both motors.

OUT3 is the left elevon and OUT4 is the right elevon. Different offset values are used for the two elevons as necessary to center the control surfaces with neutral stick input.

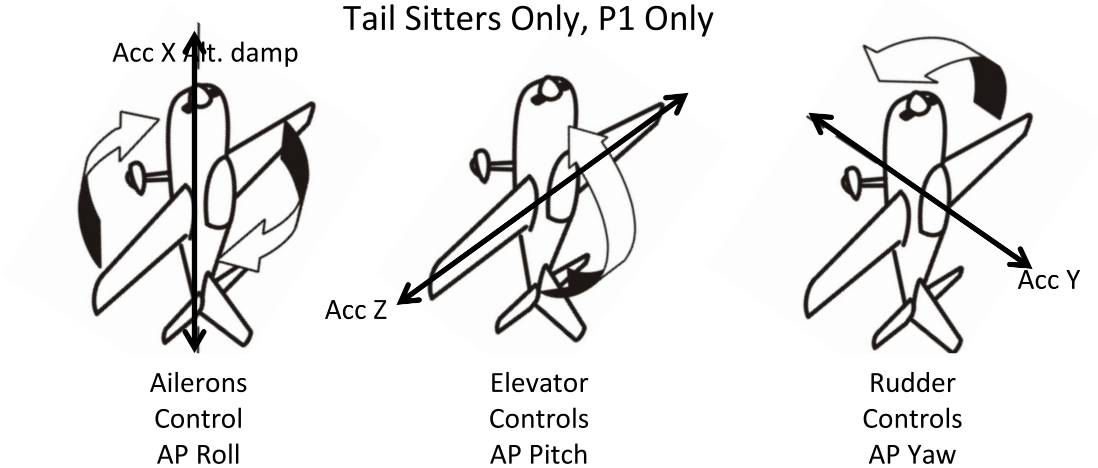
The P2 Aileron volume is set to -60%. The P1 Elevator volume is set to 75% though the signs are opposite for the two elevens. The P2 Elevator volume is set to 50%, though once again the signs are opposite. These values merely reflect the desired amount of surface movement and direction.

The P1 Pitch Gyro and the P1 and P2 Roll Gyros are all ON for both elevons. The P2 Roll AL is set to on, but the Roll AL value in the Profile 2 menu is set to zero so it doesn’t matter. The P1 and P2 Pitch AL are set to ON but only the P1 Pitch AL is activated in the Profile menus.

OUT 5 is used to drive the twin rudders using a single servo. The offset is set as required to center the control surfaces.

The P2 Rudder volume is 80 and the P2 Yaw Gyro is ON. .When in “Vert AP ref.” mode the “P1 Roll AutoLvl:” menu item is renamed “P1 Yaw AutoLvl:”, but either way the P1 Roll/Yaw AL is turned on for the rudder.

Hovering in Vertical Airplane (AP) Reference Mode
Tail Sitters Only, P1 Only

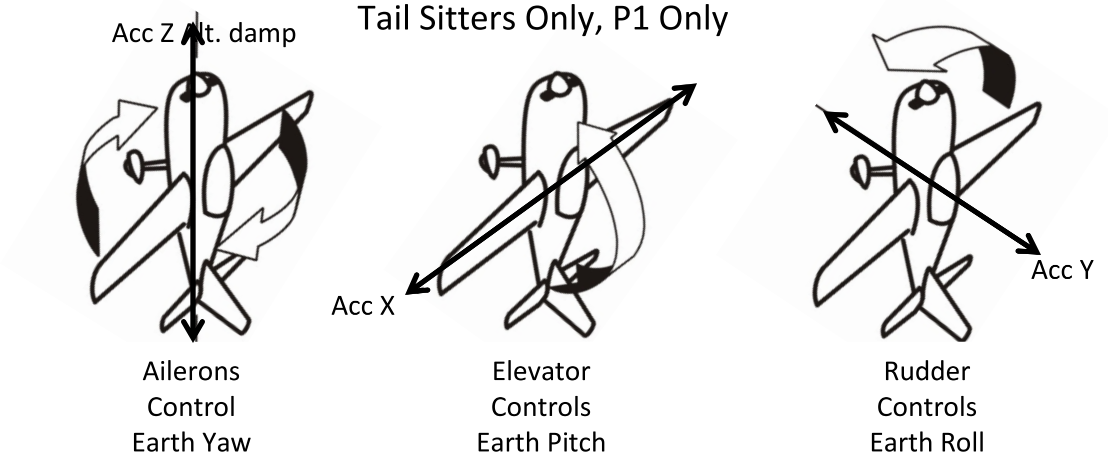


For “Vert AP ref.” mode hovering, both motors have a P1 rudder volume of 30% . This allows the rudder stick input to control AP Yaw. The P1 Yaw Gyro is ON for the motors. The “P1 Roll AL:” menu item is renamed “P1 Yaw AL:” and is turned ON for both motors.

The elevons have a P1 aileron volume of -60% and the P1 roll Gyro is ON.

The Rudder has a P1 rudder volume of 100 and the P1 Yaw gyro and P1 Yaw AL is ON.

Hovering in Earth Reference Mode
Tail Sitters Only, P1 Only



For “Earth ref.” mode hovering, the motors have a P1 rudder volume of 30%. This allows the Rudder stick input to control Earth Yaw. The P1 Roll Gyro and the P1 Roll AL is ON for the motors.

The elevons have a P1 aileron volume of -60% and the P1 Yaw Gyro is ON.

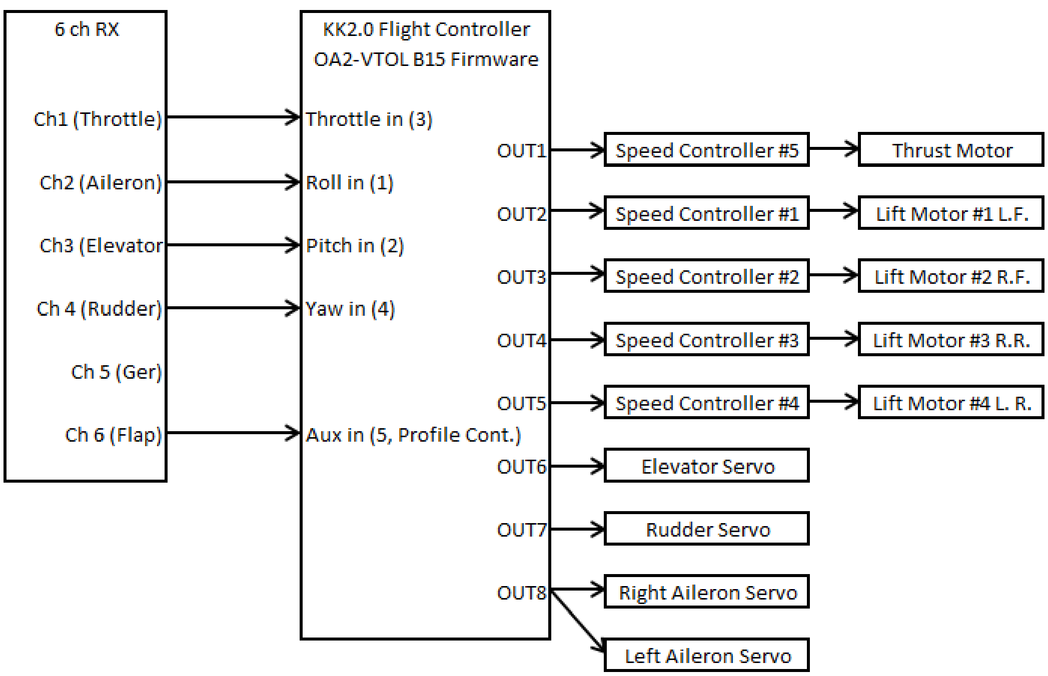
The Rudder has a P1 Aileron volume of 100 and the P1 Roll gyro and P1 Roll AL is ON.

Example, VTOL-FunCub, Quad-copter, SLT (Separate Lift and Thrust)

The VTOL-FunCub is one of the simplest types of VTOL. It is basically an airplane with a quad-copter attached. Nothing tilts or moves except for the spinning propellers.

In hover mode it is a normal quad-copter with the forward thrust motor turned off. When flying as an airplane the lift motors are turned off.

VTOL-FunCub   Control Block Diagram   Ran D. St. Clair   12-17-13



The choice of what FC (Flight Controller) board outputs are connected to what servos or ESCs is mostly arbitrary. In this case the BEC (Battery Eliminator Circuit) for ESC #5 (OUT1) can be used to power the FC as well as the RX (receiver) via the cables between the FC and the RX. A BEC in one of the ESCs connected to OUT2-5 can be used to power the servos connected to OUT6-8. In this case, since there are no servos connected to the RX, it is not necessary to use a separate BEC or SBEC (Switching Battery Eliminator Circuit) to power the RX.

The Profile 1 menu (hover mode) is loaded with values suitable for a basic quad copter. The “P” values are set to about 60 for roll pitch and yaw. The “I” values for roll and pitch are set to 40, and the I limit to 10 as a matter of personal preference. The I-Rate values are set to a value of 1. The Auto-Level for pitch and roll are set to 5 as a matter of personal preference, but you could choose to set them to a larger value like 10 if you wanted to. As a matter of personal preference no Z-Axis feedback is used for altitude damping. The various trim values are set to minimize any drift in no wind conditions. The truth is that there is a huge range of acceptable values for hover stabilization. The VTOL-FunCub, like most VTOLs of this type hovers very easily.

The Profile 2 menu “FFF or Fast Forward Flight mode) is set to all zeros since there is no need for any flight stabilization in FFF. You could program in flight stabilization if you wanted to but the “P”, “I”, and AL values would generally be much smaller than for hover mode in order to avoid oscillations. Alt. damp: is not recommended for FFF. Be careful about using “I” in FFF as it can “wind up” and produce unexpected results in some situations.

The Curves menu is not used and is left at defaults.

The Outputs Offset curve for OUT1 is set to a fixed value of 40 to accommodate the fixed endpoint ESC that is used on this particular aircraft. For the more commonly used type of ESC that is calibrated to match the throttle input, the offset would be set to 0.

The offset curves for OUT2-5 are set to compensate for a mild pitch up that occurs during outbound transitions. The downwash from the lift rotors pushes down on the horizontal stabilizer causing the pitch up. The two front motors are offset downward by up to 20 at a transition of 33%. Likewise the two rear motors are offset upward by the same amount. These values were determined through observation of the flight performance in P1.n or Slow Forward Flight (SFF) mode.

The output offset for OUT6, elevator is set to smooth the outbound transition. Basically a small amount of down elevator is used in FFF to keep the plane from climbing. Similarly the output offset for OUT7 trims the rudder during transition. This could have been accomplished with a little right thrust but was easily done in the flight controller.

The Thrust motor on OUT1 is set up with 0% throttle volume in P1 (Hover Mode) and 65% throttle volume in P2 (FFF or Fast Forward Flight mode), with a SqrtSine transition curve. The 65% throttle figure is based on the requirements for a specific ESC with fixed endpoints. When using an ESC that is calibrated to the signal from the FC (Flight Controller) then a value of 100% would probably be used. There is no Gyro or Auto-Level feedback required.

The lift motors on OUT2-5 are set up in the manner of a normal quad copter. Each has throttle as an input at 100% in P1 and 0% in P2 with a SqrtSine transition curve.

Each of the 4 lift motors on OUT2-5 has control inputs for Rudder (yaw), Elevator (pitch), and Ailerons (roll). The rudder and elevator inputs are 20% and the Yaw input is 30%. The signs of these inputs will vary for each individual motor depending on their location and direction of rotation. This is most easily determined by simple experimentation with the propellers removed from the aircraft.

Each of the 4 lift motors on the OUT2-5 also has Gyro and Auto-Level feedback on Roll, Pitch, and Yaw. The correct polarity of this feedback is set by the respective control input volume. In this application we will simply turn the Gyro and Auto-Level feedback On/Off as needed. If we had needed different amounts of Gyro or Auto-Level feedback in proportion to the respective control input volume, we would have used the “Scaled” mode.

The Elevator servo is driven from OUT6 with -80% input from the Elevator stick input. No stability feedback is used for elevator.

The Rudder servo is driven from OUT7 with -65% input from the Rudder stick input. No stability feedback is used for rudder.

The Aileron servos are driven from OUT8 with 65% volume on the Aileron input. Both aileron servos are driven from a single output using a Y harness. The offset values for P1, P1.n, and P2 are set to trim roll in all flight modes.

The individual offset and volume can be set based on any desired control sensitivity or aircraft trim requirements. You want to make any necessary trim adjustments first mechanically in the linkages, then in the FC parameters, and almost never in the TX (transmitter).

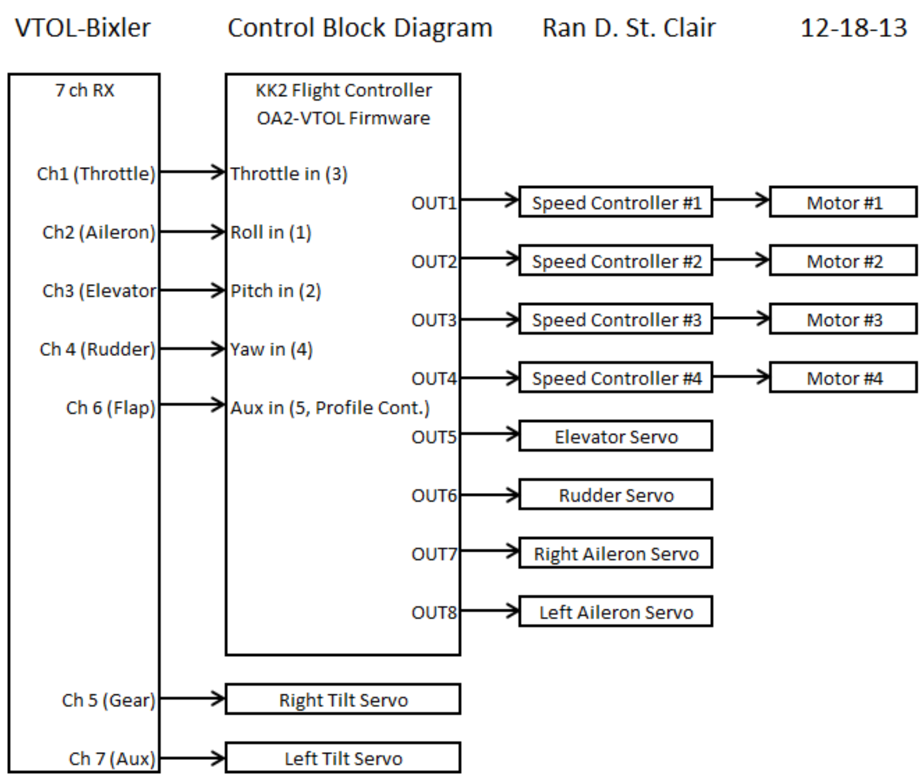
The TX for this aircraft is set up as a very basic 6 channel TX. The only programming in the TX is Expo (Exponential) and that is optional. See the section on TX initialization for details on the proper setup of the flap switch and flap output which is used to control the transition. The transition speed in the TX is set to 5 seconds.

Always test all functionality on the ground with the propellers removed, then again with the propellers installed and the aircraft safely constrained. The VTOL-FunCub is very easy to fly in all flight modes when setup properly.

Example, VTOL-Trainer, Quad-copter, Tilt Rotor

The VTOL-Trainer is a Bixler with a quad-copter attached, but the rotors tilt for forward flight.

In hover mode it is a normal quad copter. When the rotors (propellers) tilt to vertical it becomes a normal airplane.



The choice of what FC (Flight Controller) board outputs are connected to what servos or ESCs is mostly arbitrary. The BEC (Battery Eliminator Circuit) for ESC #1 (OUT1) is used to power the FC but not the RX (receiver). A separate Switching BEC (SBEC) provides power to the RX and the servos on OUT5-8. The power wires are removed from the plugs on ESC2-4 (OUT2-4) to avoid any conflict between their internal BEC and the SBEC providing power to OUT2-8.

The simplest programming is to set the “P” values in Profile 1 (hover mode) to 80 for Pitch, Roll, and Yaw. The Profile 2 (Fast Forward Flight) can be set to all zeros. While this works fine, it doesn’t take full advantage of what OAV is capable of, so let’s explore some other options.

The Profile 1 menu (hover mode) is loaded with values suitable for a basic quad copter. The “P” values are set to 60 for Roll and Pitch and 80 for yaw. The “I” values for Roll and Pitch are set to 40 with the “I limit” values set to 10. The “I” and “I limit” for yaw are set to zero. The I-rate values are left at the default of 1. The Auto-Level is set to 5 for both Pitch and Roll. This combination of values results in reasonably crisp control and makes hovering very easy. The Z-Axis values are set to provide some altitude damping in P1 only, which makes it a little easier to hold a fixed altitude. The various trim values are set to minimize any drift in no wind conditions. The truth is that there is a very broad acceptable range for all of these values.

The Profile 2 (Fast Forward Flight) menu is set to all zeroes except for a Yaw P: value of 30. This is used to smooth any yaw wobble. You could program in flight stabilization if you wanted to but the “P” and “I” values for aerodynamic surfaces would generally be much smaller than for hover mode in order to avoid oscillations. Alt. damp: (Altitude Damping) is not recommended for FFF. Be careful about using “I” in FFF as it can “wind up” and produce unexpected results in some situations.

The “Curves” menu is not needed and is set to defaults.

The Output Offsets Menu has a slight curve for the motors on OUT1-4. This aircraft will experience a very mild pitch up when entering SFF due to downwash from the lift rotors pushing down on the horizontal stabilizer. To compensate for this the two front motors, Motor #1 and #2, have a -2% offset at 17% of transition and the two rear motors, motor #3 and #4 have a corresponding +2% offset.

The lift motors on OUT1-4 are set up in the manner of a normal quad copter. Each has throttle as an input at 100% in P1 and 100% in P2 with a Linear transition curve. The transition curve shape does not matter since the P1 and P2 values are the same.

In P1 (Hover Mode), each of the 4 lift motors on OUT1-4 has control inputs for Rudder (yaw), Elevator (pitch), and Ailerons (roll) of 30%. The signs of these inputs will vary for each individual motor depending on their location and direction of rotation. This is most easily determined by simple experimentation with the propellers removed from the aircraft.

In P1, each of the 4 lift motors on the OUT1-4 also has Gyro, and Auto-Level feedback turned on based on the values in force from the active flight Profile. The correct polarity of this feedback is set by the respective control input volume. In this application we will simply turn the Gyro and Auto-Level feedback On/Off as needed. If we had needed different amounts of Gyro or Auto-Level feedback in proportion to the respective control input volume, we would have used the “Scaled” mode.

The P1 Source A: is set to AccX with a value of 30% on the left front and right rear motors, and a value of -30% on the right front and left rear motors. The idea is to cause the plane to yaw in the direction of a low wing when in hover mode. This allows the plane to be flown in hover and slow forward flight mode by using only ailerons. The plane will automatically coordinate the turns even when the airspeed is too low for the vertical stabilizer to be effective.

The P2 Source A: is set to -20% for the left motors and 20% for the right motors. This provides automatic turn coordination using differential throttle when in fast forward flight mode. If you hold the plane tilted to the left with the motors running while in P2, the right motors will run faster, and the left motors slower. This will yaw the plane into the turn in a manner similar to “bottom rudder”.

In P2 (FFF) the motors are driven based on 10% rudder. This is not really necessary but is handy to demonstrate the capability. Also the rudder input polarity sets the polarity of the P feedback in yaw so plus or minus 1% rudder input would have been required as a minimum.

The 4 servos on OUT5-8 are driven with a 80% input from their respective axis for both P1 and P2. The individual offset and volume can be set based on any desired control sensitivity or aircraft trim requirements. You want to make any necessary trim adjustments first mechanically in the linkages, then in the FC parameters, and almost never in the TX.

There is no need for any Gyro or Auto-Level stability feedback on any of the servos in P2 (FFF). You could use a small amount of P feedback if you wanted, but “I” feedback is not recommended.

The P1 Pitch and Roll Auto-Level can be turned on for the Elevator and Rudder if you want some help smoothing the transitions.

The P1 Pitch, Roll, and Yaw Gyro can be turned on for the Elevator, Ailerons, and Rudder if you want to be able to see visual evidence of the stability feedback in the surfaces. This has no impact on hovering flight, and minimal impact on SFF (Slow Forward Flight) but it is sometimes convenient to be able to see when the “I” feedback has “wound up” before you take off.

The P1 Source A: and the P2 Source A: can be programmed to -25% Acc X on Rudder. This is another demonstration of automatic turn coordination but using rudder this time. The P1 Source A: programming has no effect in hover mode and minimal effect in SFF but is programmed the same as P2 for consistency and for ease of visual verification.

The TX for this aircraft is set up as a very basic 7 channel TX. Other than Expo (Exponential) which is optional on Elevator, Ailerons, and Rudder, the only programming in the TX is related to the Flap Switch and the two tilt servos. The flap output is mixed to the two tilt servos to insure that they tilt together and don’t hit the mechanical stops. The transition time is set in the TX to 4 seconds, but it could be set longer. It is also possible, and optional, to program the TX for a small amount of differential motor tilt to enhance yaw authority.

Always test all functionality on the ground with the propellers removed, then again with the propellers installed and the aircraft safely constrained. The VTOL-Trainer (AKA VTOL-Bixler) is very easy to fly in all flight modes when setup properly.

Do not dive the VTOL-Trainer when doing an outbound transition. High airspeed can generate a pitch up torque on the rotors that can overcome the torque of the tilt servo. The motor tilt can be delayed or the motors can tilt unevenly from left to right, resulting in a flat spin and possibly a crash. Once the motors have completed the transition to FFF (Fast Forward Flight) mode, you can dive all you want.

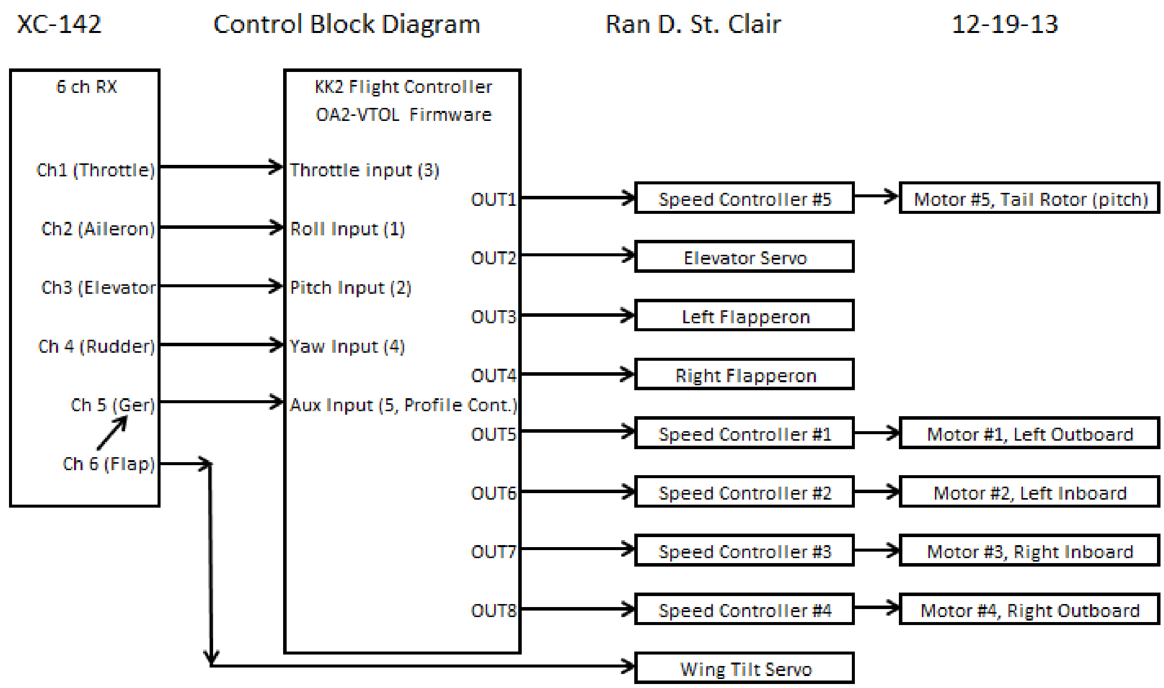
Detailed build instructions for the VTOL-Trainer based on the original KK2.0 board with stock firmware are available here.

https://www.dropbox.com/s/tlncv7ymuw4q1my/Combined%20VTOLT%20Build%20Instructions%205-14-14.pdf?dl=0

Example, XC-142, Scale Tilt Wing

The XC-142 is a stand-off scale model of a full scale VTOL transport. Five FS (Full Scale) aircraft were built in the 1960s and evaluated in various roles. Despite meeting most of the requirements it was never developed further. It had poor lateral stability in FFF (Fast Forward Flight) and a tendency towards a long period pitch oscillation in hover that eventually resulted in a crash that ended the program. The model faithfully reproduces those flaws and it is only through the capability of the OAV firmware that the model can be made to fly reasonably.

Unlike the full scale aircraft, which had variable pitch propellers for control, the model uses fixed pitch propellers for simplicity, including the tail rotor. In hover mode it is similar to a tri-copter except that there are 4 motors up front instead of 2, and the tail rotor is very small, lightly loaded, and doesn't tilt to control yaw. Instead the ailerons are used to control yaw. In FFF it is a normal airplane except that it uses differential motor thrust instead of rudder. Unlike many VTOL aircraft, stabilization feedback is required in FFF mode.



The choice of what FC (Flight Controller) board outputs are connected to what servos or ESCs is mostly arbitrary. In this case the BEC (Battery Eliminator Circuit) for the tail rotor ESC #5 (OUT1) is used to power the FC but not the RX (receiver). Since the RX is directly driving a large powerful servo, it has a separate SBEC (Switching Battery Eliminator Circuit) which also provides power to the servos on OUT2-4.

The FC orientation is set to “Top Front” for convenient access to the buttons. The MPU6060 LPF is set to 44Hz. The Acc. LPF: is set to 21Hz and the AL Correct: to 6, all of which are the default values. The “Outbound trans.:” is set to zero assuming a slowed input from the TX based on a 3 position flap switch.

The Profile 1 menu (hover mode) has the Roll P: set to 50, a Roll I: of 20, Roll I Limit: of 5, Roll I Rate: of 1, and a Roll AutoLvl: of 5. The Roll I: is needed because the wing, when vertical, provides very little aerodynamic damping and adds to the roll inertia. In Roll, the settings are most similar to a multi-copter.

The Profile 1 menu (hover mode) has the Pitch P: set to 35, a Pitch I: of 30, Pitch I Limit: of 15, Pitch I Rate: of 1, and a Pitch AutoLvl: of 2. The P and I values would seem to be on the low side, but the “Scaled” function multiplies them by the control input value and also by 5. For example, The tail rotor is very lightly loaded and needs an unusually large “P1 Ele. Volume” of 100. As a result the effective stability feedback values are Pitch P: 175, Pitch I: 150, Pitch I Limit: 75, and Pitch AutoLvl: 10.

The YawP: in Profile 1 is set to 80, but there is no Yaw I:. It is best to allow VTOL aircraft to weathervane into any relative wind. Airplane pilots are also often not comfortable having to constantly control yaw the way that helicopter or multi-copter pilots do. In general, the yaw response from the ailerons is small enough and slow enough that no stabilization is really required or is all that effective.

The Z axis values are set to provide some altitude damping but only in P1, hover mode.

The Profile 2 Menu (Fast Forward Flight mode) is mostly set to zero, but an unusually large value of 60 is entered for “P” on Roll and 80 in Yaw. This is to enhance stability in FFF. Failure to use this stability would most likely result in a crash. The larger value of 80 in yaw also helps to reduce yaw wobble in SFF, which is at 35% of transition from hover, which means the effective P on yaw in SFF is 80 x 35% = 28.

The P2 Pitch P: feedback is set to a very modest value of 3 to help smooth pitch in FFF. This is probably not necessary but is a slight precaution since the aircraft is being flow near the rear limit for a safe center of gravity.

The “Curves” menu is not needed for the XC-142 and is set to defaults.

Output Offsets Menu

The tail Rotor (OUT1) and the fully flying elevator (OUT2) have output offset curves as necessary to maintain proper pitch trim from hover to FFF. The full flying Elevator (OUT2) has a large amount of down elevator when in hover mode and most of the way through the transition. As the aircraft reaches FFF the elevator flattens out to match the wing,

OUT1-8 Mixer Menu

The Tail Rotor (OUT1) uses a combination of the 7 point offset curve and the 2 point throttle volume curve to maintain proper pitch control through the transition and turn off the tail rotor for FFF. The P1 Throttle volume is set to 50 to match the input range of the specific ESC that was used. The P1 elevator volume is 100% but the P2 elevator volume is zero. The P1 Pitch Gyro: and P1 Pitch AL (Auto-Level) are set to “Scaled”. The Scaled option is being used due to the large 16:1 asymmetry ratio between the lifting power of the front rotors and the tail rotor.

The P1 elevator volume is set to 48% and the P2 elevator volume is set to 40%. These values are based on personal preference and perceived control response in the various flight modes. The elevator has no aerodynamic control in hover, but begins to become effective from the earliest stages of the outbound transition. The P1 Pitch Gyro: and P1 Pitch AL (AutoLevel) are set to Scaled. The P2 pitch Gyro is set to ON to provide a small amount of Pitch stability feedback in FFF.

The Ailerons (OUT3-4) are set up identically and could have been driven from a single output with a Y harness. Driving them from 2 separate outputs makes it possible to program in “flaps” during the middle phase of the transition but for various reasons that was not done. The ailerons are set to -80% volume for Yaw on P1, and 80% volume for Roll in P2. The transition is smooth and linear between the two. The yaw Gyro is turned on in P1, and the Roll Gyro is turned on in P2.

The 4 motors on OUT5-8 are all programmed the same except for polarity. The throttle volume is set to 100% for both P1 and P2 so the curve doesn’t matter. The P1, P1.n, and P2 Offset are all set to 0% because these particular ESCs were calibrated to match the FC output. If the ESCs had been the type with fixed endpoints then different values would have been required.

The P1 Roll Gyro and P1 Auto-Level are set to ON for Roll stabilization in hover mode. The P1 Aileron volume is set to 20% to provide roll control. The signs for the left and right motors are opposite.

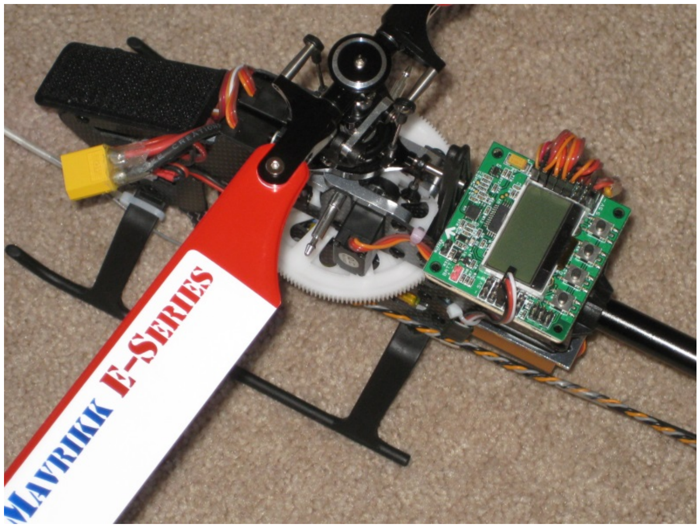
The P1 Pitch Gyro and Auto-Level are set to “Scaled” so their volume is scaled according to the P1 Elevator volume of -7%. This means that only 7% of the Pitch stability feedback, as defined in the Profile 1 menu, times 5, will be applied to the main motors. The reason is that the 9” main propellers are twice the diameter of the 4.5” tail rotor. That gives them each 4 times the area, times 4 propellers, or 16 times more area, or roughly 16 times the lifting power of the tail rotor. The tail rotor elevator volume is 100% so 100%/16 = 6.25%, which is rounded up to 7%. The point of all this is to ensure that when we apply a pitch input we do not also cause the aircraft to rise or fall, which is called “surge”. Likewise, we don’t want any surge when the stability feedback applies a pitch input. The sign of the elevator volume for the tail rotor is opposite the sign for the main rotors.

The P2 Yaw Gyro is set to ON to improve the lateral stability of the model in forward flight. The P2 Rudder Volume is set to 15%. The signs for the left and right motors are opposite.

Always test all functionality on the ground with the propellers removed, then again with the propellers installed and the aircraft safely constrained. The XC-142 is an advanced model and flies reasonably well in all flight modes, but proper tuning of the FC requires an in depth understanding of the physics and aerodynamics involved.

The XC-142 is not recommended for aerobatics or inverted flight. In some extreme flight conditions it can tumble and the only known recovery technique is neutral stick input and full throttle in SFF or hover mode, where the FC will recover it for you.

Example, 450 Helicopter (HC)



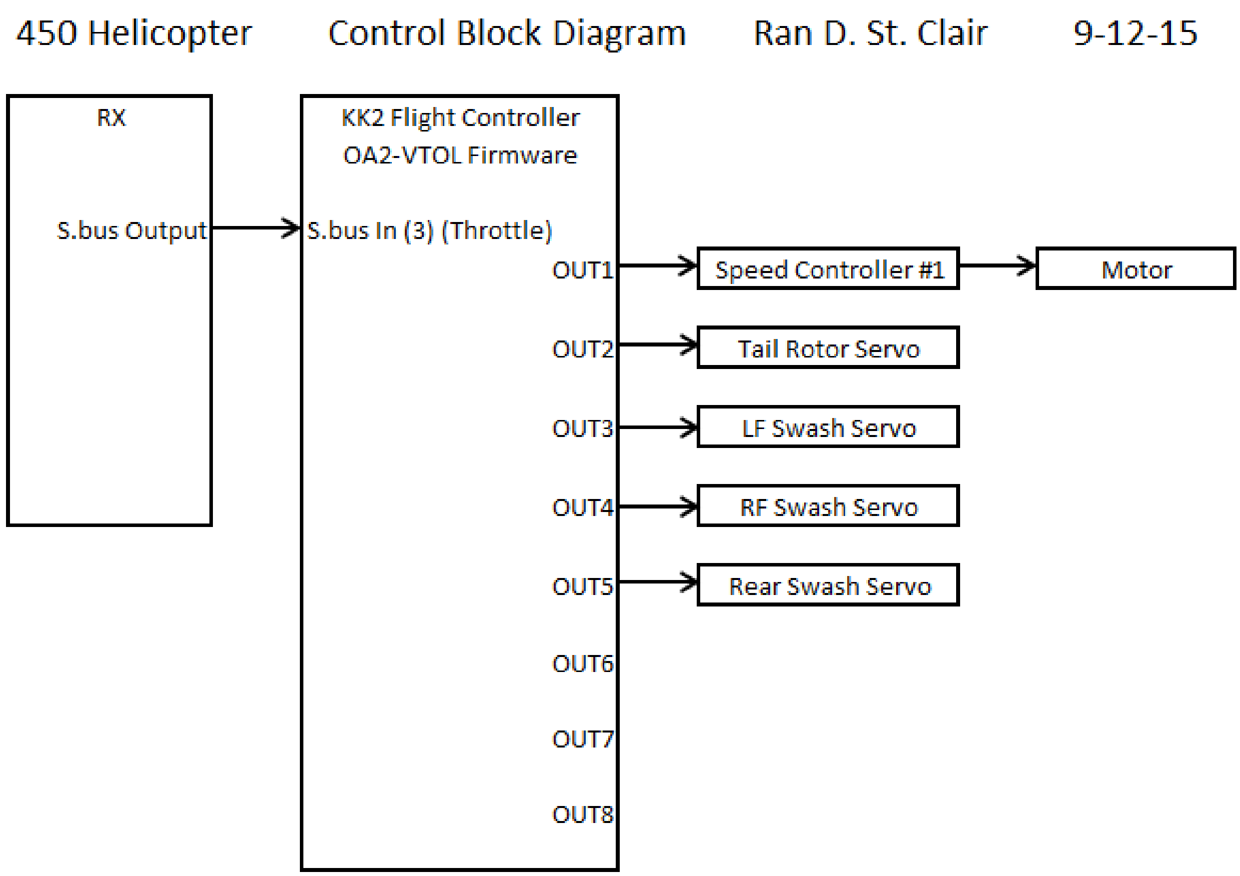
The Align T-rex 450 Pro clone, HK-450TT PRO V2 Flybarless 3D Torque-Tube Helicopter (HC) demonstrates the ability of OAV to be used as a flybarless flight controller (FC), and more generally as a FC for helicopter based VTOL aircraft that use collective and cyclic pitch for control.

The ESC is a Phoenix edge Lite 50A from Castle Creations. While the ESC has a governor mode which could have been used, this particular configuration demonstrates an “Open Loop” setup where the throttle and collective pitch curves are set up to maintain a head speed of approximately 2,400 RPM.

The flight modes (Profiles) are programmed to make helicopter flight reasonably easy and safe for an inexperienced helicopter pilot who is more familiar with multi-copters or airplanes. An aerobatic flight mode is theoretically possible, however, the intent is to support helicopter based VTOL, not to compete with helicopter specific flybarless flight controllers.

P1 (Profile 1) is configured for a very stable and easy to fly hover and SFF (Slow Forward Flight) mode. Pitch and Roll are set for “attitude control” meaning the HC tilts when the stick is tilted, and the HC immediately returns to level when the stick is released. The tail rotor is set for “heading hold” which means the pilot has to actively fly the rudder in order to turn the nose in the direction of travel.

P2 is configured as a stable forward flight mode. The HC can still hover easily but is optimized for non-aerobatic FFF. Roll is set for “attitude control” while pitch is set for “rate control” with “attitude hold”. I feedback is used to hold the pitch angle as set by the pilot. The tail rotor is stabilized as a “rate gyro”, not “heading hold” and roll AutoLevel feedback is used for automatic turn coordination. This allows the HC to be flown somewhat like an airplane without having to constantly fly the rudder.



The choice of what FC (Flight Controller) board outputs are connected to what servos or ESCs is mostly arbitrary. The BEC (Battery Eliminator Circuit) in the ESC (OUT1) is used to power the FC and RX (receiver). A separate switching BEC was used to provide power to the servos via OUT2-8.

The FC orientation is set to “Top Rear” for convenient access to the buttons. The MPU6060 LPF is set to 21Hz, not the default 44Hz, in order to better filter out vibration. “Outbound trans.” is set to zero assuming input from the TX based on a 3 position flap switch.

The AL Correct: is set to 11 not the default 6 seconds. This is important to allow the AutoLevel to work correctly. If left at the default value the helicopter will never fully stabilize when flown “hands off” but instead will fly in a large left hand circle. This is due to inherent asymmetry of a single rotor helicopter.

The Profile 1 menu (hover and SFF mode) has the Roll and Pitch P values set to 9. The “Scaled” option is used to turn on the gyros and AL (Auto Level in the OUT1-8 Mixer menus so the effective stability feedback values are multiplied by the control input volume and by 5. The largest control input volume for any of the swash plate servos is 48, so the effective P value is 0.48 x 5 x 9 = 21.6.

No I feedback is used in P1 for Pitch and Roll so the I Limit and I Rate values don’t matter. The Pitch and Roll AL (Auto Level) is set to 6 but the Scaled option is used so the effective AL value is up to 11.25. By using AL feedback and no I feedback, the helicopter is flown in “attitude mode” for pitch and roll. This means that the helicopter will tilt when the stick is tilted and will automatically return to level when the stick is centered. Attitude mode control allows for very precise hovering and is a relatively safe beginner mode.

In P1, Yaw P is set to 60, I to 40, the I limit to 25, and the I rate to 3, providing a solid heading hold. Alt. damp: is set to 15 which makes it easier to hold a constant altitude in hover.

The Profile 2 menu also uses a value of 9 for P feedback in pitch and roll. The yaw values for P, I, I limit and I rate are the same as for P1, but the Alt. damp: is set to 0.

For roll, the I, I limit, and I rate values are the same as in P1. This provides attitude control in roll for P2 which makes it easier to fly the helicopter at a distance where it can be difficult to see the exact roll attitude.

For pitch in P2, the helicopter is flown in rate mode with attitude hold. The Pitch P feedback is set to 9, I to 67, I limit to 6 and I rate to 3. This allows the helicopter to be set at a comfortable pitch angle and it will maintain that pitch angle subject to new pilot input. This is possible since pitch is easily seen even at a distance. It also allows the helicopter to more easily maintain a steady forward airspeed when flown like an airplane.

Curves Menu

The P1 and P2 throttle curves are both set to gently ramp up the rotor RPM when the throttle stick is raised above idle. Since both the P1 and P2 flight modes are intended for upright hovering and forward flight, not inverted flight, and not aerobatics, the throttle ramps up to provide the necessary power to hover at the mid throttle stick position. This corresponds to roughly 5 degrees of rotor pitch at 2,400 RPM. The rest of the throttle curve is intended to roughly maintain 2,400 RPM as the blade pitch is raised up to about 9 degrees at 100% throttle stick input. This means that the ESC is driving the motor at full throttle at about 84% stick input.

This “Open Loop” method is only one possible way to set up a helicopter. It is also possible to set up a helicopter in governor mode, where the ESC provides whatever power is necessary to the motor to attempt to hold a constant head speed or RPM. In that case the throttle curve would probably be flat, at the desired head speed, and the slow spool up function within the ESC would be used to prevent damage to the motor or gear train.

The P1 and P2 collective curves are set to provide zero blade pitch up to 33% throttle stick input, and then up to 9 degrees of blade pitch at 100% throttle input. If the helicopter had been set up for aerobatics then negative blade pitch would have been possible. In that case zero blade pitch would have been set at 50% throttle stick instead of 33% throttle stick. It also would have been important to make sure the P1 and P2 curves matched at around hover power so the helicopter would not immediately climb or descend when switching between modes. In this case the P1 and P2 collective pitch curves are identical, so they match at all throttle stick input values.

The “Generic Curve C” is being used as a “tail rotor curve”, and provides additional counter torque when the collective pitch is increased. In this case the tail rotor curve is identical to the collective pitch curve and the “Collective” option could have been selected as the “P1 Source A:” and “P2 Source A:” inputs in the OUT2 menu. If, however, the helicopter had been set up in a stunt mode with negative collective pitch then the tail rotor curve would have been a different shape, which is why “Curve C” is used in this example.

It is not strictly necessary to use a tail rotor curve as the tail rotor gyro, in either rate or heading hold mode would try to hold the tail steady anyway, however, it is common practice to try and keep the entire helicopter in balance even before relying on closed loop stability feedback to hold it steady.

Output Offsets menu

The output offsets are primarily set to achieve the proper linkage geometry with the servo arm at the nearest spline location. The OUT2, tail rotor offset was set during flight testing using only P feedback to achieve optimum yaw trim. All offset curves are flat from P1 to P2.

OUT1-8 Mixer Menu

OUT1, the motor, is set to a volume of 100 in both P1 and P2. The actual throttle values as required by the fixed endpoint ESC were set in the throttle curve. The rudder volume is set to 5%. This provides a small increase in motor power when turning right, and a decrease when turning left, which compensates for the extra power absorbed by the tail rotor when fighting torque. No stability feedback is required for motor power control, however, altitude damping could have been used to provide more or less power along with the increase or decrease in collective pitch that is also used for altitude damping.

Since the ESC and motor are being controlled by an output that is set to “Motor”, that output will provide a 1ms pulse when the throttle stick is below 2.5%. This is a desirable safety feature and compatible with the programmed flight modes for hovering and general upright flight. If the helicopter were set up in a stunt mode, where 0% throttle stick was meant to provide full negative pitch, cutting the motor power would be bad. In that case it would be necessary to set OUT1 to Dservo instead of Motor. This would, however, defeat the safety feature and make it impossible to cut the power to the motor without switching to P1 or hover mode. It would also mean that the motor is always armed even on initial power up.

OUT2, the tail rotor, is set to 50% rudder volume in both P1 and P2. The P1 and P2 Yaw Gyro are both set to ON but the actual effect of the Yaw gyro is defined in the Profile 1 and Profile 2 menus. The P1 and P2 Source A: are set to “Curve C” with a volume of 30. This adjusts the tail rotor pitch to provide the counter torque required when the motor power is increased as a result of increased collective pitch.

The P2 Source B: input is set to AL Roll with a volume of 100 for the tail rotor. This provides automatic turn coordination in P2 or “airplane mode”. It allows the helicopter to be flown roughly like an airplane where the tail automatically follows the nose so the rudder can be mostly ignored. It is unusual for AL Roll to be used in this way, and it only works because roll is controlled in attitude mode, not rate mode. Basically whenever the helicopter ls leaned to the left, it also yaws to the left. It is roughly equivalent to mixing ailerons into rudder.

OUT3-5 are the Cyclic control servos. This helicopter HC has a 120 degree swash plate with OUT3 controlling the left front (LF)servo, OUT4 the right front (RF) servo, and OUT5 the rear servo. All of these servos must work together for proper control, so the ratio of the various control volumes is important. The ratios would be different for different swash plate configurations.

The sign for all of these volumes is somewhat arbitrary as it depends on the specific helicopter servo and linkage layout. In this case, OUT4, the RF servo happened to be mechanically reversed compared to the other two. Therefore OUT4 was reversed in the servo direction menu. This was not really necessary but was done as a convenience to make the polarity of the input volumes for all 3 servos more understandable. For example, the Collective volume for all 3 servos is set to +39. If OUT4 had not been reversed the collective would have been set to -39. In fact all of the various values for OUT4, including the offset, would have been set to the opposite polarity. Having the polarity for all 3 servos the same was also a convenience when implementing altitude damping which has an assumed polarity relative to the accelerometer input. If reverse polarity altitude damping had been required for OUT4 it would have been necessary to select it as P1 Source B and then set the sign of the volume accordingly.

The volume values for aileron and elevator on the 3 cyclic servos can be calculated using signs and cosines. It is not a difficult calculation if you understand the geometry, however it is easy to make mistakes. Therefore a swash plate calculator is provided in the menu structure spreadsheet on the tab labeled “Swash”.

The overall control volume for pitch and roll cannot be known until you actually fly the HC. It depends on a number of factors including linkage geometry, stability feedback values, and pilot preference. The important thing to remember is that if, for example, you want more aileron control, you can’t just increase the aileron volume on one servo, or even on all servos. The volumes have to be adjusted in the proper proportions for all 3 servos, and with consideration for the impact on stability feedback values.

The “Scaled” option is selected for Pitch and Roll, on P1 and P2, for Gyro and AL feedback on all 3 swash plate servos. This would normally only be necessary in cases where there is left to right or front to back asymmetry. For example, the elevator volume is different for the rear servo as compared to the 2 front servos. Since all of the stability feedback must be in the same proportion as the control input volume, the scaled option must be used for pitch related feedback on all 3 servos. The LF and RF servos are symmetrical in terms of aileron volume so it would be possible to just set the roll feedback to ON instead of Scaled, however, for the sake of consistency the scaled option is used for all pitch and roll related feedback.

The use of the Scaled option for all Pitch and Roll feedback means that any increase/decrease in control volume will result in a corresponding increase/decrease in stability feedback. This can easily result in too much or too little stability feedback, making the HC unstable or causing it to develop an oscillation. If, for example, you decide to double the Elevator volume then you need to cut the stability feed back in half in order to keep the same effective stability feedback. The stability feedback volume is set in the Profile 1 and Profile 2 menus. When making volume adjustments, consider which profile, P1 or P2, and which Axis, Pitch or Roll, you are changing, and adjust the stability feedback for that same Profile and Axis in the Profile menus.

The altitude damp function is set to ON for all 3 swash plate servos in P1 but not in P2. I do not usually recommend the use of altitude damping in forward flight modes as it would reduce the power, or in this case the lift, when pulling Gs in a turn. Altitude damping is used in P1 as it is mostly used for hovering and gentile forward flight where it helps to hold a constant altitude.

It is not necessary to fly or even “spin up” the HC to verify that the swash plate servos are working properly. You can move the elevator and aileron stick and verify that the swash plate tilts properly, and that there is no vertical movement of the swash plate. You can also test the collective pitch by moving the throttle so long as the FC is disarmed. If you are concerned about the HC starting unexpectedly then disconnect at least 1 motor wire.

It is also possible to visually test the various feedback functions by looking at the swash plate and moving the HC. The polarity of all feedback should be correct if the stick input polarity is correct. The separate effects of P, I, and AL feedback can be observed if you know what to look for.

The Alt. damp: (altitude damping) function can also be tested in this manner, but it will probably be necessary to temporarily set the volume to 100 in the Profile 1 menu to be able to see it well. The swash plate should go down when you accelerate the HC upward. Do not attempt to fly with such a large volume or the HC will oscillate violently.

It is a good idea to carefully measure everything with a pitch gauge for proper control throws and blade tracking. When doing so you should temporarily turn off any I or AL feedback to avoid any impact on the measurements. The values provided herein are not a fixed recipe. They are values that worked on this specific HC. Your HC or HC based VTOL will almost certainly be different.

Positive and Negative Servo Travel Menus

Normally these values are left at defaults, however, helicopters often have mechanical limits that can jam a servo. In this case OUT2, the tail rotor servo, can only move to a count of 44 in the positive direction before the linkage jams. Simply enter the menu and slowly drive the servo to the limit while monitoring the linkage and listening to the servo for any buzz that would indicate that it is jammed. Once you find the point of jamming, then back off a couple of counts. The servo will never be driven beyond this point in operation.

Change History

V1.1 Changes

- No support for KK2.0. Just KK2.1 and above from here on.
- FAST PWM mode when S.Bus, Satellite, or Xtreme input is used. Up to 200Hz PWM.
- Universal mixers extended to allow selection of AutoLevel Roll/Pitch.
- Automated update of users' settings when reflashing from V1.0 to V1.1
- Low-voltage alarm changed to "Min. cell (V)" with presets. Handles up to 6S.
- The LED on the KK2 is now lit to indicate the armed state.
- Preset functionality was added including QuadX, QuadP, Tricopter and Blank.
- Support for Xtreme receiver input.

V1.2 Changes

- Support for 24 possible board orientations.
- Support for Auto Level in both P1 (Hover) and P2 (FFF)
- Simplified setup for Tail Sitters including Vertical Airplane Reference and Earth Reference.
- Vibration meter for dynamic balancing of motors and propellers.
- AL Correct (Auto level Correct) range linearized and scaled to read in seconds.
- Can now bind with all DSM2 and DSMX receivers in 1024/2048 resolution and 11ms/22ms rates.
- Now properly supports SBUS2 protocol. (To date it would have ignored 3 out of 4 packets).
- Added Multiplex channel order.
- Alt. damp: and IMU outputs now shown on the sensor display.

V1.3 Changes

- Added 7 point Throttle curves for P1 and P2 including GUI
- Added 7 point Collective Pitch curves for P1 and P2 including GUI
- Added 7 point Universal input curves, Generic Curve C and D Including GUI
- Support for Mode B/UDI serial input as used by Jeti
- Separate control for inbound and outbound transition rate when using internal switched transition control
- Added percentage of transition control for Low, Med, and High state when using internal switched transition control
- Added I/O Display (Monitor)
- Added 7 point offset curve in place of the previous 3 point curve with movable center point
- Increased Roll Trim: and Pitch Trim: power in Profile menus by 10X.
- Added Alt. damp: as an input selection in P1 and P2 Source A and B.
- Changed AccRoll and AccPitch to AccX and AccY in P1 and P2 Source A and B.
- Added custom channel order menu
- Increased the I-Rate range from 4 – 240 degrees/sec. to 7 – 1,840 degrees/sec.

V1.4 Changes

- Enhanced altitude hold
- Excel based GUI (Graphical User Interface)
- Buzzer ON/OFF feature added

V1.5 Changes

- Added HoTT SUMD serial protocol
- Fixed DSMX reception format bug
- Fixed compatibility issue with EMAX ESCs