FlightCoach Calibration

1. Purpose

The purpose of this document is to provide a set of instructions how to calibrate a Flight Coach system.

The material presented here is a collection of excerpts from various publicly available sources, including Ardupilot documents. Selected passages has been adopted to suit FlightCoach characteristics and needs.

We acknowledge Ardupilot team leadership and knowledge in the area. Almost entire information in this document comes from various Ardupilot documents and has been adopted for FlightCoach application.

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3. Summary

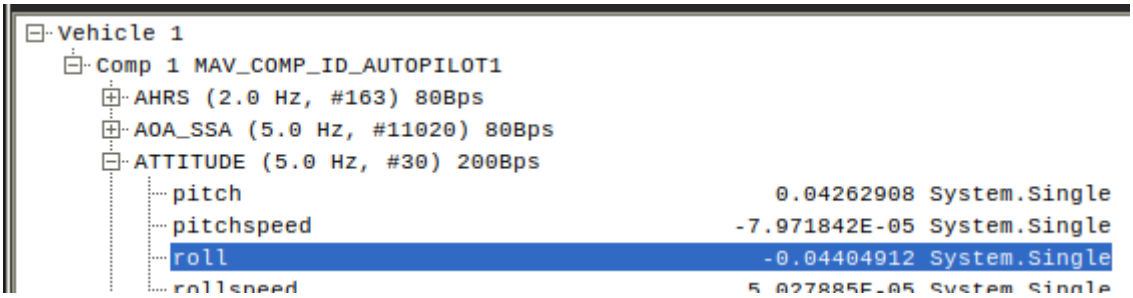
Step 1 - Magnetometer calibration. Take the FC Unit with GPS module and connect to a device capable running the Mission Planner. Unit must be disarmed and have the 3D GPS lock. Perform calibration in Setup > Mandatory Hardware > Compass > Onboard Mag Calibration > Start. Rotate the FC Unit in various 3D attitudes. Observe the progress until it completes.

Option – do the same with flying batteries attached in a similar relative position as in the model

Option – do the same with the module installed in the model fuselage (no wings)

You may also choose to enable in flight compass offsets learning by setting COMPASS_LEARN parameter to 3

Step 2 - Accelerometer levels calibration. With FC Unit in the normal position in the model, place the model in a flying attitude (wings level using spirit level, pitch 0 to 1.5 deg up. The angles must not be more than 10 deg of level. Connect the FC Unit to a device capable running the Mission Planner. Make sure the unit is disarmed (ARMING _REQUIRE set to 1 or disconnect the GPS unit). Go to Setup > Mandatory Hardware > Accel Calibration. Perform 1 axis calibration (middle button). Remember to reset ARMING _REQUIRE set to 0 or re-connect the GPS unit. Calibration result can be observed in Setup > Mandatory Hardware > Advanced > MAVLink Inspector > Vehicle 1 > Comp 1 > ATTITUDE.
Resulting roll should at or less than +/- 0.0175 rad (~ 1 deg).



Step 3 – Gyroscope calibration. This calibration is performed automatically at each FC Unit startup. Make sure that the model is in stable position and does not vibrate. Shelter the model from the wind, do not move it for 10-20s after the FC Unit boot.

4. Why do we need calibration

4.1 FlightCoach components

Flight Coach systems use a standard Ardupilot plane firmware that may be installed installed on a variety of hardware platforms.

Each of the platforms contains as a minimum:
- 3 sets of accelerometers, one for each axis
- 3 sets of one-axis gyroscope sensors, one for each axis
- 1 magnetometer (compass)
- 1 GPS unit (usually external)
- 1 IMU unit (combines a number of sensors into one unit)

In ArduPilot, the IMU (with all the sensors) is the primary sensor suite that provides the raw data that the flight controller uses to determine the aircraft's current attitude, position and other parameters.

Accelerometers: These measure linear acceleration, including gravity.

Gyroscopes: These measure angular velocity (the rate of rotation).

AHRS (Attitude and Heading Reference System): This is the internal software algorithm (often using an EKF - Extended Kalman Filter) that fuses data from the accelerometers, gyroscopes, GPS and Magnetometers to create a stable estimate of the plane's orientation in 3D space.

4.2 Sensor imperfections and impacts

Sensors in low-cost Inertial Measurement Units (IMUs) have inherent errors and noise. They are micro electro-mechanical devices and experience various issues that need to be managed (like mounting errors, bias, drift over time and temperature, etc). Calibration provides the critical input how to correct these issues necessary to achieve accurate and true representation of the model’s flight path. Some sensors need to be calibrated once (per mount) and some on daily basis.

ArduPilot performs a gyroscope (gyro) calibration at each startup to establish the correct baseline for the sensor readings, ensuring accurate measurement of the vehicle's angular velocity. The startup calibration estimates this specific bias by assuming the vehicle is perfectly still (zero angular velocity) and averaging the sensor readings.
Sensor performance can vary with temperature changes. The startup calibration accounts for the current ambient temperature conditions, providing a more reliable calibration than a one-time factory setting.

A precise baseline is critical for the flight controller to correctly interpret movement and orientation changes during flight. Without proper calibration, the recorded flight path will deviate from the true path by a larger margin and in

severe cases the log may experience visible errors (“jumps”). These in turn will impact the FCScore result.

The most typical example of miss-calibration is the wing level (accelerometer) calibration error. This error is almost always present as very few pilots calibrate the accelerometers after (usually imperfectly) installing an FC in a model. The outcome is a constant X degrees tilt to one side, and the whole flight will be presented with this tilt, even if the model was flown perfect level. FCScore will allocate penalty points for flying off-level.

Required calibration precision varies between the sensors. The only precision that a pilot can measure and confirm is the pitch and wing level. Anything within the range of 1-2 deg would be satisfactory but careful calibration allows reaching the precision below 1 deg.

The required level of calibration can only be maintained if the FC Unit is securely mounted into the airframe. The unit needs to sit firmly, in the same position relative to the airframe and it can only be achieved via a permanent mount or using a precise sit/socket where the unit could be placed and secured. Any vibration dumping material (foam, etc) needs to be designed in a way that under the load does not allow for angular movement of more than the desired calibration target. Installing the unit strapped on top of the batteries will rarely be sufficient to maintain the calibration targets.

4.3 Parameters

Sensor calibration values are stored in each Ardupilot’s unit memory in relevant parameters. After calibration each unit will have its own unique calibration parameters therefore copying (calibration) parameters between the units is not recommended.

Note – Fligthcoach, in Settings allows export of all parameters from a bin file so they can be viewed without the need to connect MissionPlanner

Calibration parameters of interest to FlightCoach are (d in X,Y,Z n in 1,2,3):

Accelerometers (*INS_ACCSCAL_d, INS_ACCOFFS_d, INS_ACCEL_FILTER, INS_ACCn_CALTEMP*)

Magnetometers (*COMPASS_OFSn_d, COMPASS_SCALEn*)

Gyroscopes (*INS_GYRnOFFS_d, INS_GYRn_CALTEMP, INS_GYR_CAL*) – note: gyroscope calibration (controlled with INS_GYR_CAL parameter) is by default performed at the startup so the values may change each flight

Each instance of a sensor (e.g. two magnetometers) will have its own copy of the parameters.

4.4 FC Units sharing

It is possible to share the same FC Unit between several models and maintain the calibration precision targets, if certain conditions are met.

Remembering that the calibration is sensitive to the model's magnetic field and the mount levels, sharing can be achieved in two ways:

1 - FC Unit is installed in an identical, leveled universal mount or
2 – model specific calibration parameters are set upon installing the unit

1. If both of the models have the same type of an universal FC mount installed within the calibration targets accuracy, we can assume that the there is no need to adjust the calibration parameters. This removes the need of calibrating the Unit levels each time it is swapped between the models.

In order to achieve the desired universal mount installation precision in the second model, the already calibrated FC Unit from the first model could be placed within the second model and the mount position adjusted/secured while monitoring the wing and pitch levels.
Additionally, it is recommended that the mounts in all models are installed within similar distance and position to the motor and the batteries. Assuming that the magnetic fields are similar, this removes the need of compass re-calibration.

2. If the achieved results are not satisfactory or when the magnetic fields or the mount positions do vary, it is still possible to share the FC Unit. In this case we need to perform full calibration of the Unit in both models and store the resulting parameters in separate files. Each time the Unit is swapped, we need to restore the calibration parameters specific to the model. This can be done using either the MissionPlanner or lua scripts stored on the SDCard. Lua scripts are an attractive option as it allows to quickly change the FC Unit configuration only by inserting another SD Card that contains the configuration data in the lua scripts stored on the SD Card.

Level angles perceived by the FC Unit can be monitored using MissionPlanner's Mavlink Inspector and displaying the ATT message parameters (pitch, roll). The levels are displayed in radians (1 deg corresponds to 0.0174533 rad). Accuracy at 1 deg or better can be relatively easy to achieve and is sufficient for FCScore.

Lua scripts execution must be enabled using the SCR_ENABLE parameter (set to 1) and will be supported only on some the boards (check the HW specifications). The scripts must be placed in SCRIPTS directory under APM at the SDcard. Lua scripts examples will be provided later.

5. FlightCoach calibration

FlightCoach unit calibration is a small subset of a standard Ardupilot calibration process, described here https://ardupilot.org/plane/docs/starting-up-and-calibrating-arduplane.html.

FlightCoach unit installation does not use radio channels, servos, ESC and other sensors (airspeed, lidar, etc) so there is no need to calibrate these. The FC does not control the plane flight path therefore there is no need to perform the whole tuning process.

The only calibration required is the accelerometers, magnetometer and gyroscope sensors.

5.1 Magnetometer calibration

The calibration purpose is to accurately map the Earth’s magnetic field while accounting for magnetic interference generated by the vehicle itself, ensuring reliable yaw (heading) data for stable flight.

Generally, the magnetometer calibration needs to be performed once per model. If the model key metal(ic) elements do not change (motor, main battery position, etc), the FC unit position is the same and the initial calibration has been done well, there is no need for repeated calibration.

The best way to calibrate the magnetometer involves rotating ready to fly (with batteries) model. It is however highly impractical and the alternative is to only rotate the unit itself. If the FC Unit is strapped to the batteries, the unit could be rotated while attached to the batteries alone.

It is not strictly necessary to recalibrate the magnetometer (compass) every time you move to a new, distant location. ArduPilot firmware utilizes a World Magnetic Model database, which allows it to calculate the magnetic deviation for a new location automatically using GPS data, provided the initial calibration was performed correctly.

The calibration needs to be repeated only if the log shows signs of incorrect model attitude or jumps or we suspect that the new location may have some magnetic anomalies.

Best Practices
Initial Calibration: perform the calibration in an open space, preferably outdoors, away from magnetic fields (computers), metal structures or concrete with embedded rebar/iron.

Field Calibration: Although not required, it is good practice to perform a quick "live" calibration at a new flying field, away from metal structures or concrete with embedded rebar/iron.

GPS Lock: Ensure your vehicle has a solid 3D GPS lock before starting calibration to ensure the magnetic database data is accurate.

In-Flight Learning: ArduPilot can learn new offsets during flight if COMPASS_LEARN is set to 3, which helps adapt to subtle magnetic changes without a full manual recalibration.

5.2 Gyroscope calibration

ArduPilot gyroscope calibration occurs automatically a few seconds after startup, indicated by flashing red/blue LEDs, and requires the vehicle to be held perfectly still. If the platform is moving, calibration fails after 30 seconds.

In case of a model, set the model in a stable position, it needs to be on a stand or sitting on the ground, shielded from wind so it does not vibrate. Precise level attitude is not required, the critical aspect is the lack of vibrations.

In case of strong wind conditions and if the model can not be held in a stable position during the FC startup, the first startup on the day may be performed in a sheltered spot (with wings off) and then the INS_GYR_CAL parameter set to 0. In that case the subsequent startups will use already stored values.

5.3 Accelerometer calibration

Core Calibration Methods include full, simple and level calibration methods. Full 3-Axis Calibration needs to be performed once per the FC module installation. The vehicle must be placed in six specific orientations: Level, Left Side, Right Side, Nose Down, Nose Up, and Back.

In lieu of Full 3-Axis Calibration, the Simple Accel Cal may be performed that has been designed for very large vehicles where a full rotation is impractical. It only calibrates main offsets by holding the vehicle still in a level attitude.
Level Calibration is an auxiliary calibration applied after a full or simple calibration to fine-tune the exact "level" flight attitude. It only corrects pitch and roll offsets up to 10 degrees. It needs to be performed once per the FC module installation or when we suspect that the module could’ve moved in the plane. This calibration fine tunes the wing level offsets. The model should be placed in the upright flying attitude (pitch and wing level using spirit levels). For the perfect wing level, a long spirit level could be placed across both of the wings at some support.