THE ONSPEED ANGLE-OF-ATTACK SYSTEM USER'S MANUAL

Waiex "One Week Wonder" Version

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Purpose

This manual supplements the ONSPEED System Pilot's Operating Handbook (POH) Supplement and System Software Maintenance, Set-up and Calibration Checklists. It provides detailed operational guidance for use of the ONSPEED angle-of-attack, overload, and airspeed warning systems. Operation of the WiFi Gateway, data acquisition system and optional visual display are detailed. Expanded software set-up and programming instructions are included in the Checklists and Appendices. Initial programming of the ESP 32 Pico WiFi Chip in the ONSPEED box and the optional modified M5 visual display is beyond the scope of this manual. Initial programming instructions for those components are included in the Builder's Manual.

This document contains internal and external hyperlinks. An internet connection is required for external hyperlinks to function properly. The Table of Contents is hyperlinked to assist with navigation. Appendices contain checklists designed for cockpit use.

Assumptions

The ONSPEED system is ergonomic and easy to use, but the current hardware requires some effort to initially program and calibrate. Once calibrated, the system has only one rotary switch used for normal operation: twist it to adjust volume, push it to enable or disable the system or insert a data mark. If the system has the optional modified M5Stack visual display, push the center button to cycle to the desired display. We have tried to make calibration as "pilot proof" as possible. We assume sufficient study this manual, or the POH Supplement and Maintenance Checklists, and pre-flight preparation.

This manual assumes the user is familiar with the use of a smart phone or tablet and laptop computer, knows how to connect to a WiFi network and log in with a password. It assumes the user can use an internet browser (Safari, Chrome, etc.) and knows what a USB and micro-USB port are. Software management and programming instructions are written at a "pilot level." Advanced users may find the checklists in the Appendices sufficient. If you are not comfortable using a laptop computer or smart phone, we recommend getting assistance from someone who is to assist with initial ONSPEED system set-up and calibration. Advanced users will find the system highly adaptable with many flight test features, including high-speed data integration and recording.

Please contact us at team@flyonspeed.org with questions, comments, or errors. We welcome the feedback as we constantly strive to improve.

Legal Warning

Pilot's Version. The ONSPEED system, logic and hardware are experimental. Hardware design is publicly available and may be downloaded from the internet. Although thoroughly tested, no warranty is made or implied as to its efficacy when it's used in your airplane. The hardware described in this manual is designed by volunteers to be assembled by hobbyists. The decision to install it is made by the aircraft owner, who assumes all risk and responsibility for suitability and use. The open-source software is written, and flight tested by volunteers, publicly available and may be downloaded from the internet. No provision is made to ensure software integrity when downloaded. Read the manual. Ask questions if there is something you don't understand (team@flyonspeed.org). Get flight instruction from a current and qualified instructor that understands angle of attack and energy management. **The system must be properly programmed, configured, and calibrated prior to use.** The pilot-in-command (PIC) makes the determination to turn the system on and use it in flight. It is NOT pilot proof and cannot compensate for lack of knowledge, training, proficiency, or aircraft handling skills. The airplane will stall and spin if the pilot mishandles the controls and exceeds critical angle of attack with sufficient yaw present. This will likely result in injury and/or death and property damage. Respect the angle of attack and energy cues and don't stall. **The PIC assumes all risk for using the system in flight**. If you find the tone distracting, turn the volume down.

Lawyer's Version.

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Definitions

NOTE: Item of interest.

CAUTION: Could result in damage to the system or aircraft.

WARNING: Could result in loss of aircraft and/or fatal injury to occupants.

Items in red font apply specifically to the Waiex (One Week Wonder) aircraft.

Hardware

ONSPEED (Version 3 [v3]) System. The ONSPEED system has two hardware components: the ONSPEED box and an LED equipped rotary switch on the instrument panel. The ONSPEED box measures approximately 4 x 3 x 1 inch and weighs 10 ounces. The front of the box has an ONSPEED label and a micro-USB connector. The back of the box has three ¼" OD quick disconnects for pitot, static and AOA pressure tubing and a 15-pin female DSUB connector. The system uses a PRJC Teensy 3.6 processor equipped with a 32 or 64 GB micro-SD card. The micro-SD card is utilized for recording flight data from the ONSPEED system as well as the EFIS or other flight test instrumentation systems (e.g., air data boom or reference gyro). All data is integrated into a single file and may be downloaded post-flight via WiFi. The WiFi system utilizes an Espressif Systems ESP32-Pico-D4 chip set. There are three pressure transducers: two TE Connectivity MS54525DO differential types for AOA and pitot pressure (<1% error), and a third Honeywell SSCSRNN1.6BA7A3 static pressure sensor (.25% accuracy). The system has a 6-DOF STMicroelectronics TSM330DHCX inertial measurement unit (IMU) to provide data for calibration.

NOTES

1. GPS is not required for system calibration or operation.
2. The system may be installed in any airplane. EFIS is not required.

The ONSPEED v3 through-hole hardware is designed to be built by hobbyists using off-the-shelf components. Specific hardware information including parts list, assembly instructions and initial system programming instructions can be obtained from the DOCUMENTS folder at www.github/flyonspeed/OnSpeed-Gen2.

WARNING

1. The onboard IMU generates an attitude display on the optional M5 visual display. **This display is not safe for use in flight as an attitude reference.** This display is intended for test purposes only.

Waiex Installation. The system is installed under the glare shield behind the instrument panel with 4 #6 screws and nylock nuts. It is mounted with the box top DOWN and the connectors facing RIGHT. Box orientation must be set correctly in the SYSTEM CONFIGURATION. A USB cable is attached to unit and tied up below the instrument panel to allow access to power the unit with battery (any USB type phone charger will work) or to connect the unit to a computer for software programming.

NOTE

1. The system is powered by the AVIONICS RELAY switch on the right side of the instrument panel and is equipped with a 1 AMP dedicated circuit breaker. The system may be disabled by pulling the circuit breaker.

Quick Pressure Connectors. To attach tubing, ensure a clean 90 degree cut and insert tubing approximately ¼" until it can no longer be pushed in. Check for a proper connection by pulling on the tube. To release the tube, push in the surrounding collar while pulling on the tubing.

Rotary Switch. The rotary switch on the instrument panel is the primary system control. This switch controls volume, enables and disables the system, and inserts a data marks. The LED in the switch functions as a "heartbeat" display: flashing on and off to let the pilot know that the system is operating properly.

NOTES

1. The system functions any time power is available. A short push of the rotary switch disables the tone. "ONSPEED DISABLED" voice warning is provided. The LED extinguishes when the tone is disabled. This mode silences aural AOA cues but does not impede data collection or auxiliary visual display indications. A subsequent short push of the switch enables the tones and is accompanied by an "ONSPEED ENABLED" voice warning. The LED flashes to indicate normal system operation.
2. Push and hold the switch to insert a data mark. "DATA MARK" voice warning is provided. Release the switch after "DATA MARK" warning.
3. The pilot can also turn the volume down. No tone or voice cues are heard with the volume turned down, but the DATA MARK function operates normally with a long push.

Optional M5 Visual Display. The visual display is an M5Stack development display modified with a custom power supply and back shell, an anti-glare hood and mount that attaches to the display with a single #8 screw. The modified M5 display is equipped with a four-pin plug on the back of the unit that provides data in, out, power and ground. The display operates on 10-36v DC.

NOTE

1. The #8 screw that secures the display to the mount may loosen if the unit is rotated and may occasionally require tightening. Use caution not to over-tighten.

Optional anti-glare hood configurations are available for the display. Hoods are printed, and snap in place. To change hoods, hold the M5 in place with two fingers placed on the inside of the hood pushing gently on the face of the display edges while pulling gently on the hood. The hood may be changed without disconnecting the display. Use caution not to use excessive force, which could damage the display.

Waiex Installation. The M5 mount is secured to glare shield with 2 #6 screws and nylock nuts. A grommet is installed for the small harness adjacent to the mount. The ½" hole is required to accommodate the 4-pin connector. Remove the grommet if it's necessary to pull the connector down through the glare shield.

Optional Audio Mixer. An external audio mixer is available for airplanes with a mono intercom or insufficient stereo inputs. Installation of the audio mixer provides 3D (stereo) tone capability in those airplanes. It also provides amplification for the ONSPEED audio input and increases available volume.

Flap Position Sensor. To accurately compute angle of attack, a flap position sensor is required. The system can accommodate up to five different flap settings.

Power Requirements. The system requires 10-36 volts DC, .5 amp power for proper operation.

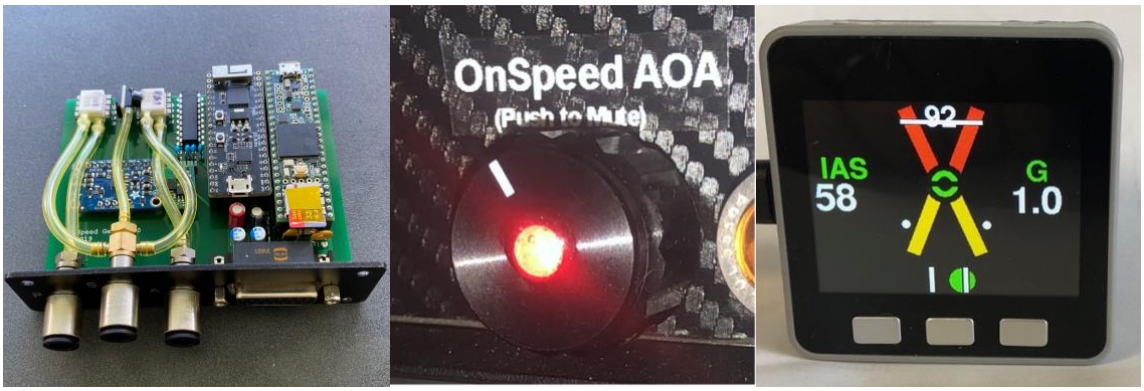


Figure 1. System Hardware. Box cover removed to show system components. PRJC Teensy 3.6 processor board is on right, ESP32-PICO-D4 Pico WiFi board is to the immediate left of the Teensy, pressure sensors are left rear, and IMU is located under the pressure tubing. Center picture is rotary knob with LED fitted to instrument panel. Right picture is optional M5 visual display with "energy display" selected.

Software and Firmware

Arduino Integrated Development Environment (IDE). The Arduino IDE is an open-source electronics platform intended for developing interactive projects. The V3 hardware and software are developmental and optimized for ease of assembly, flexibility, and capability. ONSPEED code is written in the Arduino programming language using version 1.8.16 of the Arduino IDE. The

ONSPEED code requires installing Teensyduino 1.55 software after the Arduino software is installed. This results in modifying the Arduino IDE to "Arduino/Teensyduino" IDE configuration. This software adds PRJC Teensy 3.6 board support and loader components to the basic Arduino IDE. Newer versions of Arduino and Teensyduino software have not been tested and may or may not be compatible with ONSPEED code.

Users must install the Arduino/Teensyduino IDE on a laptop computer (Windows or Mac) to update and maintain the ONSPEED system software.

ONSPEED Software and Firmware. This manual refers to "software" if code must be compiled prior to loading. "Firmware" is code is loaded via WiFi using a binary file. ONSPEED software (with user selectable settings) is provided for the PRJC Teensy 3.6 board. ONSPEED firmware is provided for the ESP32-PICO-D4 WiFi board and the optional modified M5 visual display. The PRJC Teensy 3.6 software is updated using a cable connected to the micro-USB port on the ONSPEED box. If the ONSPEED box is mounted in a remote location, fit an extension cable that is easily accessible. Other than initial programming during hardware build-up, the ESP32-PICO-D4 WiFi board and the optional M5 visual display are updated over WiFi. Update files are maintained in the ONSPEED software folder downloaded from our GitHub site. The version of PRJC Teensy 3.6 software and ESP32-PICO-D4 Pico WiFi board firmware installed are displayed on the top line of the home page of the ONSPEED WiFi Gateway. The firmware installed on the optional M5 visual display is shown on the "Firmware Upgrade Server" screen.

Appendices F and G are written at a "pilot level" for casual computer users and contain detailed instructions and figures to assist with setting up the Arduino IDE and system programming. See Arduino 101 and ONSPEED Software Management Big Picture sections for background on software basics. The checklists in Appendix E are written for users that do not require extensive detail.

Pressure-derived Angle of Attack

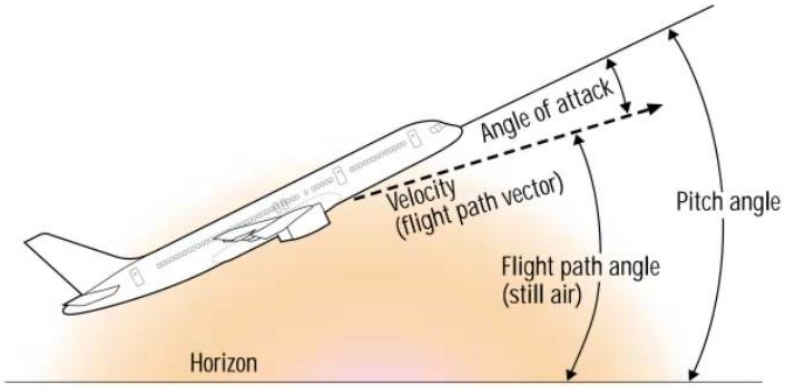


Figure 2. Angle of Attack

Angle of attack derived from coefficient of pressure. A coefficient of pressure AOA sensor measures two pressures. There is an angular difference between the two orifices. As angle of attack changes, the two pressures change. Pitot (dynamic) pressure is referred to as P_{FWD} and the offset pressure is referred to as P_{45} (approximate 45° offset angle). Coefficient of pressure is determined by dividing P_{45}/P_{FWD} to eight significant digits. Using dynamic pressure in the denominator avoids a divide by zero error for sensors that have a negative to positive coefficient of pressure transition across the AOA range of the airplane. During calibration, the onboard IMU (or EFIS, if equipped) measures pitch and computes flight path angle. Angle of attack is the difference between pitch and flight path angles. This is shown in Figure 2.

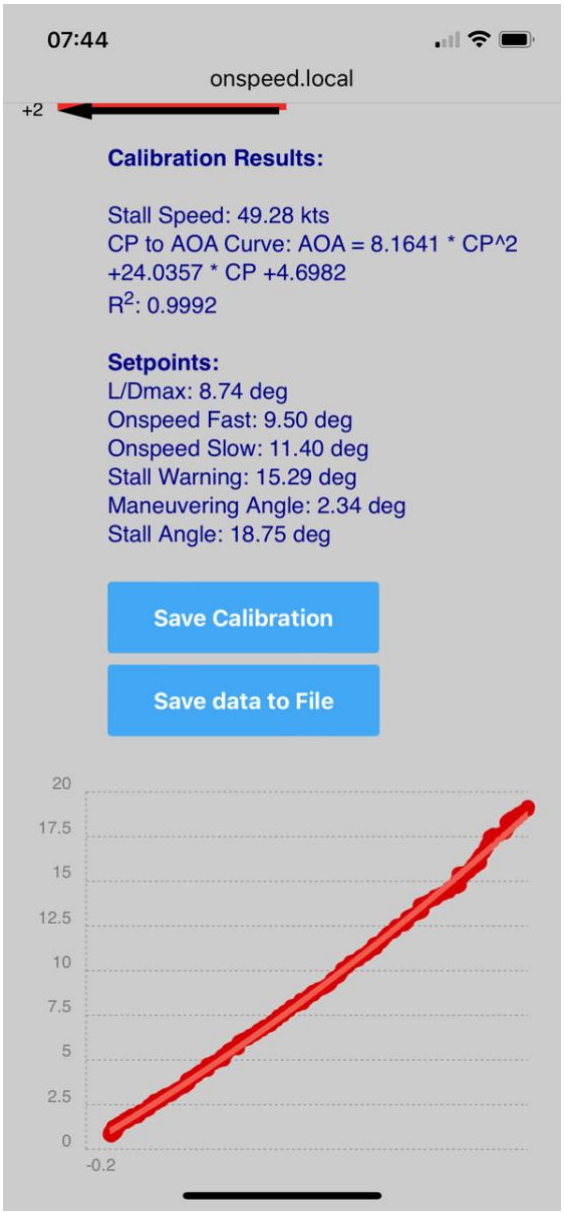


Figure 3. iPhone screen shot of automatic calibration display.

Calibration. During calibration, coefficient of pressure is compared to IMU or EFIS (if equipped) derived AOA at 10 Hz. The calibration source (IMU or EFIS) is pilot selectable. Coefficient of pressure data are inherently noisy, so smoothing techniques are applied to the data real-time. Coefficient of pressure vs derived AOA are plotted, and a polynomial regression is automatically performed by the system during calibration. The quality of the regression is determined using an "R^2" test. This is a statistical technique for measuring the quality of the resulting equation, i.e., how well the derived line reflects the data scattered around it. An R^2 value of 1 is perfect correlation. A high R^2 is desired during calibration. A typical calibration plot is shown in the lower portion Figure 3. 10 data points per second are captured from maximum structural cruising speed (or maximum level forward speed at wide open throttle) to stall. Depending on aircraft performance, this will result in 500-1000 data points that accurately define the entire aircraft curve. The resulting equation is the algorithm used for computing AOA. There is one curve for each flap setting. The airplane must be equipped with a flap position sensor for full functionality.

Set Points. A "set point" is an AOA associated with L/D_{MAX}, ONSPEED or stall. They are automatically computed during calibration. The ONSPEED band is approximately $\pm$ 1° wide, so two AOAs define the ONSPEED band: ONSPEED "fast" and ONSPEED "slow." Set points are described in further detail in the calibration section. Automatically derived set points may be manually adjusted by the pilot using the SYSTEM CONFIGURATION option on the SETTINGS menu on the WiFi Gateway home page, if desired. Adjustment procedures are described in the calibration section and checklists.

Waiex Installation. The ONSPEED V3 hardware installed has a modified IMU. EFIS AOA calibration is recommended: selectable via SYSTEM CONFIGURATION option on SETTINGS menu on the WiFi Gateway home page (See AOA Calibration Wizard Section or AOA In-flight Calibration Checklist in Appendix D).

Normal System Operation

WARNINGS

1. **The system must be properly calibrated prior to use.**
2. If the system is installed in an experimental airplane conducting initial Phase 1 flight test, it should be disabled until sufficient envelope expansion flight test has been conducted to allow for performance of automatic calibration sequence (See AOA Calibration Wizard section). Pull the 1-amp power circuit breaker until ready to calibrate.

AOA Tone. The LED flashes when power is applied. The LED is a "heartbeat" signal that tells the pilot the system is working normally even when AOA tone is not present. Rotate the switch clockwise to increase volume and counterclockwise to decrease volume.

Enable/Disable Function. The system is ENABLED when power is turned on. A quick push of the button DISABLES the tone. "ONSPEED DISABLED" voice warning is heard, and the LED extinguishes. Only the tone is disabled. The system remains powered up, data collection

continues and, if equipped, the optional visual display operates normally. A short push of the rotary switch re-enables the AOA tone. "ONSPEED ENABLED" voice warning and flashing LED indicate normal system operation.

Data Mark Function. A long push and hold of the rotary switch inserts a data mark in recorded data. "DATA MARK" voice warning is heard.

Optional M5 Visual Display Operation. The optional visual display offers multiple screens: primary energy display (AOA with IAS/CAS and G), AOA only display, attitude display, acceleration/deceleration display with instantaneous vertical velocity (for calibration and flight test) and historic G display (for flight test). **Cycle through the options by pushing the middle switch on the front of the display. The left switch dims the display and right switch increases brightness.**

WARNINGS

1. **The M5 AOA display is only accurate after system calibration.**
2. The M5 artificial horizon display is intended for test and calibration use only**. It is not safe for use as a flight reference.**

NOTE

1. The M5 display has limited sunlight readability. A hood is required for daytime operation to reduce glare. Full bright is recommended for daytime operations. The deepest hood with the narrowest field of view practical for the installation should be used.

Waiex Installation. Three different hoods are provided. The "wide field of view" (FOV) type was fitted during initial installation. A narrower hood may be required. A shallow and deep narrow hood are provided for that purpose.

Theory of Operation: Using AOA Cues in Flight

A series of tones provide AOA and energy information to the pilot. An intermittent 400 Hz tone starts as the airplane reaches L/D_{MAX} (maximum lift to drag ratio) AOA flaps up. As AOA increases, the pulse rate of the tone increases until the airplane achieves an ONSPEED condition (1G V_{REF}, minimum power required, 0 P_s throughout the flight envelope). A solid 400 Hz tone is heard when the airplane is ONSPEED. The ONSPEED band is approximately ± ½ to 1° actual AOA and 5 knots wide at 1G (i.e., ± 2.5 knots either side of optimum AOA). As AOA increases, the solid tone transitions to an intermittent 1600 Hz tone. Pulse rate increases as AOA increases. A 22 pulse per second stall warning is provided. (Figure 4)

Energy Management. "Energy" is power from the engine converted into some combination of airspeed and altitude. There are three energy states: positive, neutral, and negative. Energy is

positive if thrust exceeds drag for a given condition (G times weight, or "G weight"). No tone, or fast tone correlates with a positive energy condition. When energy is positive, the airplane can go up, speed up or some combination of both. If thrust and drag are balanced for a given G weight, the airplane is ONSPEED. If drag exceeds thrust for a given G weight, energy is negative; and the airplane will go down, slow down or some combination of both. In the event of engine failure, maximum sustained turn rate and maximum endurance glide will occur ONSPEED.

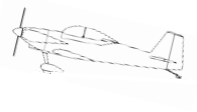
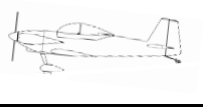
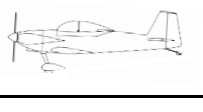
Energy Display AOA Cue	AOA % V_S	AOA % Lift	Aural Cue	Attitude
	<1.10 V_S	90	Stall Warning	
	1.11-1.2 V_S	56-90	Slow	
	1.2-1.25 V_S	55	Slightly Slow	
	1.25-1.35 V_S	60	ONSPEED	
	1.36-1.4 V_S	65	Slightly Fast	
	>1.4 V_S	51-64	Fast	
	N/A	50	L/D_{MAX}	

Figure 4. Basic System Operation.

AOA. AOA is not affected by G load, gross weight, or density altitude. The AOA for L/D_{MAX} is designed into the airplane. Like L/D_{MAX} AOA, stall and ONSPEED angle of attack are constant. Since the tone is based on AOA, it automatically accounts for changes in G, gross weight, and density altitude. The angle of attack for ONSPEED is equal to 1.73 x L/D_{MAX} AOA, adjusted to correlate with 1.3 V_S at one G (i.e., a normal approach AOA). Airspeed for ONSPEED will vary with G throughout the flight envelope since it automatically correlates with a neutral energy condition. This is shown in Figure 5. In the Figure, you can see that an ONSPEED tone occurs at about 75 IAS at 1 G, but at about 150 IAS at 4 G's.

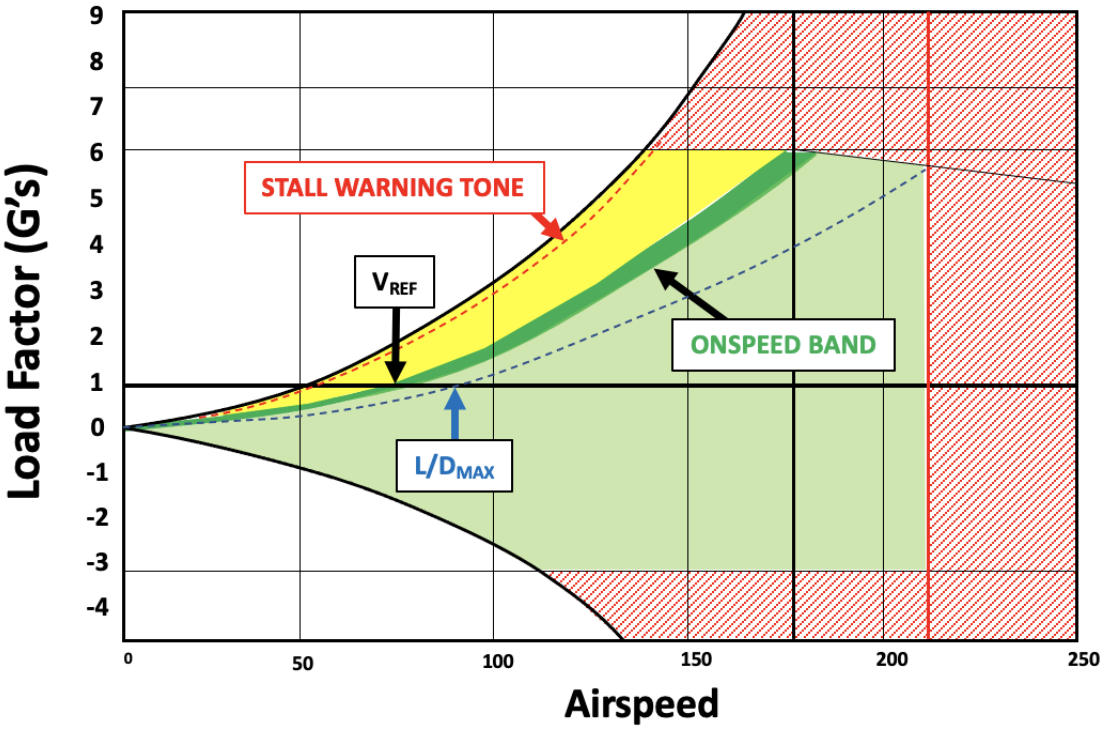


Figure 5. ONSPEED, L/DMAX and stall warning AOA superimposed on the flight envelope. ONPSEED AOA coincident with 1G V_{REF}. The yellow zone shows slow tone. Fast tone occurs between the ONSPEED band and blue dashed L/D_{MAX} line.

Flap Effects. As flaps are deployed, L/D_{MAX} AOA approaches ONSPEED AOA. Slotted flaps have a greater effect on shifting the lift curve than plain or split flaps. With full flaps deployed, L/D_{MAX} AOA is close to ONSPEED AOA. For this reason, the start of the fast tone is not a true L/D_{MAX} condition with flaps deployed. This is done so there is sufficient range of fast tone to provide trend information.

AOA Tone Cues. An ONSPEED condition should be used for approach and landing. During maneuvering flight, it corresponds to a neutral energy condition (0 P_S). **Generally, the pilot shouldn't pull harder than ONSPEED unless a negative energy state is desired** (i.e., they want the airplane to slow down and enter the yellow area [slow tone] in the flight envelope in Figure 5). Maximum **sustained** turn rate is achieved when maneuvering ONPSEED, since thrust and drag

are balanced. For a given weight, ONSPEED correlates with the minimum airspeed required to **maintain** a given G load. In Figure 5, you can see a minimum IAS of approximately 100 is required to maintain 2 G's, and an IAS of approximately 150 is required to maintain 4 G's. If the pilot pulls harder without increasing power, turn rate will increase, but energy will be negative as more drag is produced. An ONSPEED condition also correlates with maximum climb angle on takeoff and maximum endurance glide. Best rate of climb occurs at approximately L/D_{MAX} AOA for initial climb segment. L/D_{MAX} AOA may also be flown for maximum range under power or maximum range glide. A video of the basic tone pattern may be viewed here https://youtu.be/sHYG3pJNpJ8. A video of how to use the AOA logic throughout the flight envelope may be viewed here https://youtu.be/r8XcXDHLIIM. This tone logic was initially developed for and used successfully in McDonnell F-4 Phantom II.

Visual AOA Indications. If the optional visual display is fitted, AOA information is provided to the pilot graphically (Figure 6). The basic AOA display uses two chevrons and a doughnut. The lower (yellow) chevron lights with the fast tone present. The green doughnut lights up when the airplane is ONSPEED. The upper (red) chevron lights when slow tone is present and flashes when stall warning occurs. The AOA display includes a trend indicator that moves up and down as AOA increases and decreases. When the AOA trend indicator is aligned with the two balls adjacent to the lower chevron, the airplane is at L/D_{MAX} AOA. The numbers in the upper chevron are % lift. L/D_{MAX} occurs at 50% lift and ONSPEED occurs at 60% lift. Two AOA displays are available: AOA only, and the "energy display" that adds indicated airspeed and G.

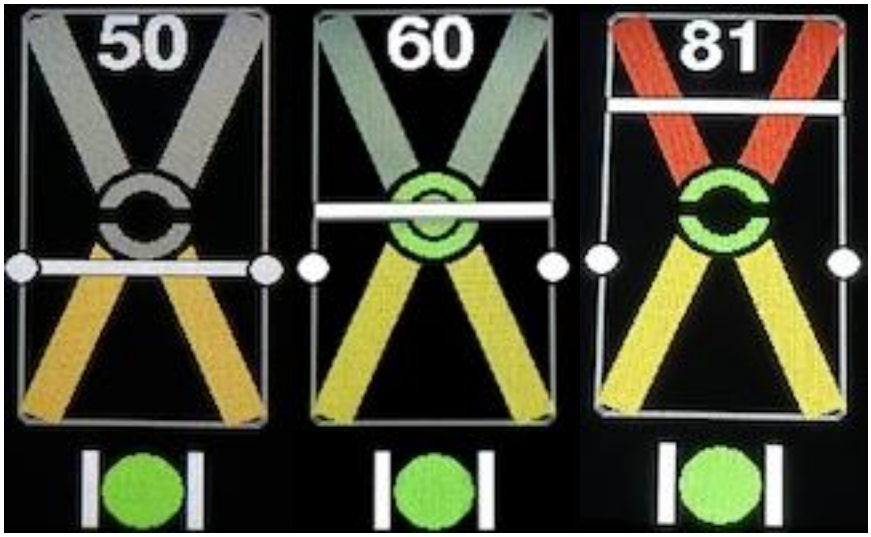


Figure 6. Optional visual display. L/D_{MAX} condition on left, ONSPEED condition, slow condition (negative energy state) on right. % Lift shown at top of display.

Application. The most basic application of an ONSPEED condition is approach and landing. The pilot slows the aircraft, establishes landing configuration, and maintains an ONSPEED condition until the flare is begun. During approach, AOA can be controlled with pitch and glideslope adjusted with power. This is the same technique utilized by the Navy to land aboard an aircraft

carrier. A simple "push/pull" model is shown in Figure 7. If the pilot encounters any slow tone on the desired glide path, they must "push" something: either the stick/yoke to reduce AOA, the throttle to increase power, or both. Similarly, if "fast," then they must "pull" something: either the stick/yoke to increase AOA, the throttle to reduce power or both. A video of a normal overhead pattern and landing may be viewed here https://youtu.be/h8_JAtdMKWg. The overhead pattern is designed to allow a constant AOA approach from base turn through touchdown. A smooth, descending 180° base turn is flown, eliminating square corners in the pattern.

The basic push/pull matrix applies during maneuvering flight as well. AOA is adjusted using pitch inputs. The pilot should maintain an ONSPEED condition or faster unless a negative energy state is desired. The push/pull matrix can also be applied to L/D_{MAX} AOA. If the pilot desires to maintain an L/D_{MAX} condition, they should reference the start of the fast tone, adjusting pitch input as required to establish L/D_{MAX} tone and align the AOA trend indicator with the pips on the optional visual display (if equipped).

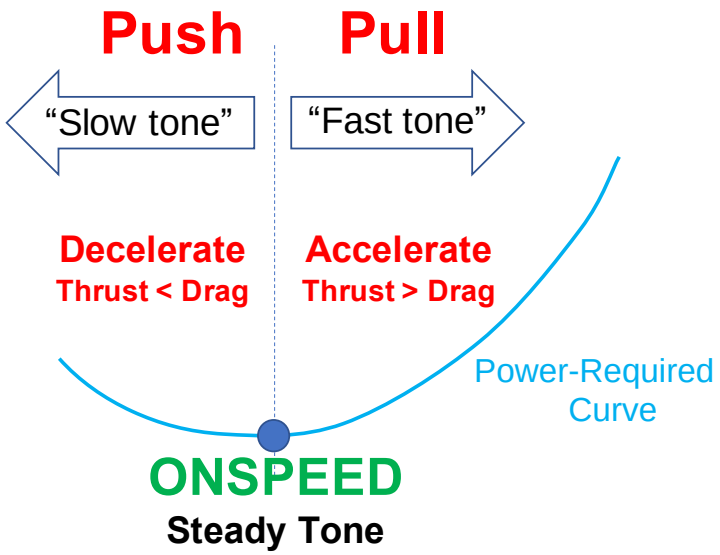


Figure 7. "Push/Pull" diagram

Stall Warning. The system provides outstanding AOA awareness from L/D_{MAX} through stall. A minimum of 1.5 to 2° actual AOA stall warning is desired. This is depicted by the dashed red line in Figure 5. This correlates with FAR 23 design criteria of "not less than 5 knots of warning." Stall warning is a 22 pulse per second 1600 Hz tone designed to mimic the sound of a stick or pedal shaker. Volume automatically increases as the airplane decelerates into the slow tone and approaches stall. The red chevron on the AOA display on the optional M5 visual display flashes during stall warning. A video of a base to final overshoot with a low-altitude stall and recovery to landing may be viewed here https://youtu.be/BPD5xk1wgOw. This video is only intended to

demonstrate system capability. It depicts flight test conducted under controlled conditions. A go-around would be appropriate under operational conditions.

Summary of AOA/Energy Performance Cues.

L/D_{MAX} (Start of 400Hz Fast Tone)
Yellow chevron lit. Trend indicator aligned with pips on visual display. 50% lift. 1.5 pulse per second, increases to 8.2 PPS as AOA increases. **Energy is positive: thrust exceeds drag.**

L/D_{MAX} is used for:
Best Range
Best Range Glide
Best Rate of Climb (approximate)

ONSPEED (Solid 400Hz Tone)
Green doughnut lit. Trend indicator in green doughnut. 60% lift. **Energy is neutral: thrust and drag are balanced**

ONSPEED is used for:
Approach and Landing
Optimum maneuvering (0 P_S/maximum sustained turn rate)
Maximum Endurance Glide
Best Angle of Climb

Slow Tone (1600Hz Tone)
Red chevron lit. 1.5 to 6.2 PPS as AOA increases. **Energy is negative: drag exceeds thrust. Reduce AOA, add power or both.**

Stall Warning (22 PPS 1600Hz Tone)
Red chevron flashes. >90% lift. Within 1.5-2° of stall (5 kts at 1G): **reduce AOA → DON'T STALL**

AOA System Performance

To provide a "flyable" cue, the AOA system must be accurate, responsive, and sufficiently smoothed to provide ergonomic cuing. The system measures AOA throughout the flight envelope using coefficient of pressure to accuracy of .1 - .25 degrees actual at 2 G's or less and within .5 to <1° degree actual at 6 G's. It is capable of handling G onset rates of at least 2 G's per second (≥ 64 FPS gust load). Damping is provided as a function of digital to analog conversion, system logic, and pilot adjustable smoothing. The pilot can adjust the system smoothness, making it more, or less responsive, as desired. The proper combination of responsiveness and damping is required for system performance during maximum performance maneuvering or in turbulent flight conditions. Absolute AOA (difference between zero lift line and relative wind), geometric AOA (difference between chord line and relative wind) or body angle (difference

between fuselage reference line and relative wind) may be measured. Automatic calibration utilizes body angle. Manual calibration is required to obtain absolute or geometric AOA. Manual calibration requires use of advanced flight test techniques and post flight data analysis. That discussion is beyond the scope of this document. If manual calibration is required, please contact us at team@flyonspeed.org for more information.

Overload Warning System (OWS)

The system provides overload (G) warning in the form of voice warning. "G LIMIT" is heard when the airplane reaches programmed limits. Warning varies with roll rate. If the airplane is rolling under G, allowable G is reduced by 33%. This is referred to as "asymmetric maneuvering" or "rolling G." Asymmetric G limits are not usually published by the manufacturer. 33% is the maximum reduction in allowable G permitted by FAR 23 design criteria. If roll rate is low or stable, "symmetric" (published) G limits are applied. The system measures roll rate and G and adjusts limits automatically. It is recommended programmed limits be reduced by ½ G to allow for a margin of handling error at high G onset rates. G limits are programmed via WiFi using the SYSTEM CONFIGURATION option under the SETTINGS menu. Asymmetric roll rate is a software setting (default 15°/sec). Do not exceed 20% of maximum roll rate when adjusting this setting. This OWS logic is used in the McDonnell-Douglas (now Boeing) F-15.

Waiex Installation. G limits are set to + 4.4 and – 2.0.

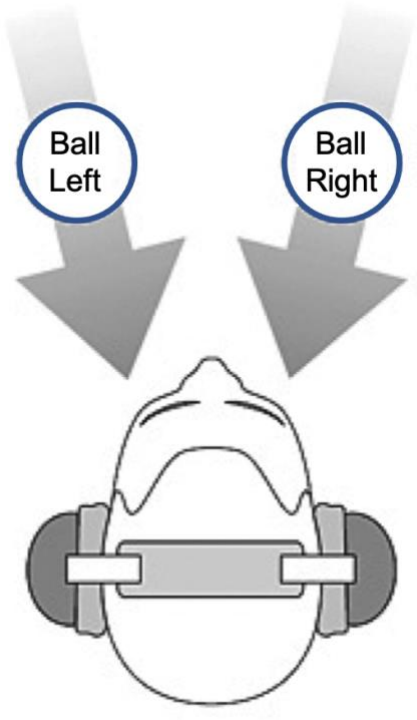


Figure 8. 3D Audio.

3D (Stereo) Audio

If equipped with a stereo intercom system or the optional audio mixer, optional "3D audio" may be utilized to provide slip/skid feedback to the pilot using the tone. When this mode is enabled, the tone moves left and right in the sound field with the slip/skid ball. If the tone moves left, the pilot "steps on the tone" to properly coordinate rudder use (Figure 8).

Airspeed Warning

Airspeed warning is provided for maximum structural cruising speed (V_{NO}). V_{NO} is a structural limit that corresponds with the top of the green arc on a properly marked airspeed indicator. It is the maximum indicated speed at which a 50 FPS gust load can be sustained. A chime is heard when the aircraft reaches or exceeds V_{NO}. V_{NO} is programmed in KIAS and the chime interval is pilot selectable. Both settings are accessed via WiFi using the SYSTEM CONFIGURATION option under the SETTINGS menu.

Waiex Installation. Airspeed warning set to 170 KIAS and chime interval is set to 5 seconds. There is no V_{NO} specified. V_{NE} is 171 knots. The designer does not specify whether this is indicated or true airspeed.

WiFi Gateway

The WiFi Gateway is the primary method to interface with the ONSPEED system for setup, calibration or changing a setting. The ONSPEED network (SSID) may be accessed using any smart phone, tablet, or laptop any time the system is powered up. Network password is "angleofattack" (one word, all lower case). WiFi signal strength is software adjustable and set for 2dB for normal installation. The WiFi Gateway home page is shown in Figure 9.

CAUTION

1. Only one device should be connected to the ONSPEED network at a time. Disable WiFi on other proximate devices.

Data Acquisition System (DAS) Capability

The PRJC Teensy 3.6 CPU is equipped with a 32 or 64 GB micro-SD card to record flight data. Recording rate of onboard pressure sensors, IMU and associated derived data is 50 Hz. If EFIS data is recorded, it is transmitted at manufacturer's clock speed (e.g., Garmin 10 Hz) and integrated into the 50 Hz file. The system can integrate data received at varying clock speeds. Currently, Dynon DY-series and SkyView, AFS, MGL, Garmin G3X and G5 data outputs are supported. The software also supports the VectorNav VN-100/200/300 reference gyros and the SpinGarage Featherweight Wireless Air Data Boom (20Hz CHECKSUM and NONCHECKSUM firmware configurations). A log file is created any time the system is powered up. Data are saved

in .csv format and may be downloaded post-flight utilizing Wifi. The LOG FILES function may be accessed via the TOOLS menu on the WiFi Gateway. Depending on system configuration and flight time, data files can be large. Data will download over WiFi at approximately 5 MB per minute. For example, a 70MB file will take approximately 14 minutes to download.

Data may also be downloaded via cable using a serial interface, if desired. The system recognizes the following serial commands:

STOP!	Stops SD Logging
LIST!	Lists log files
DELETE log_#.csv!	Deletes individual files
PRINT log_#.csv!	Displays file contents
FORMAT!	Reformats SD card and deletes all files
NOLOAD!	Shows pressure sensor bias
START!	Starts logging
REBOOT!	Reboots system
WIREFLASH!	Allows reflash of WiFi chip via USB cable
FLAPS!	Shows current flap position potentiometer value
VOLUME!	Shows current volume potentiometer value

SD Card Management. A Log files is automatically created when the system is powered on or reboots. Files are saved in log_#.csv format. Files may be accessed post flight using the LOG FILES option on the TOOLS menu. The FORMAT SD option on the TOOLS menu erases log files.

NOTES

1. All recorded data are integrated into a single file that can be downloaded post-flight.
2. Press and hold the rotary knob to create a data mark. A "DATA MARK" voice warning is heard. Release the button after the voice warning.
3. **A new log file is created if the system reboots in flight.** Data Marks begin at 0 when a new log file is created.
4. Only click the file once when downloading a file over WiFi post-flight. A double click will result in downloading the file twice. Files are saved in the browser downloads.
5. **Disable SD RECORDING if data recording is not desired** (WiFi Gateway: SETTINGS > SYSTEM CONFIGURATION). Testing with a full SD card has not been conducted. It is not known if the system will work properly with a full card.
6. A system configuration file (onspeed.cfg) is a created every time the system configuration is updated. There is only one system configuration file. It is over-written if a configuration change is made, or sensor calibration performed. The onspeed.cfg file is stored on the micro-SD card and may be accessed using the WiFi Gateway (LOG FILES > TOOLS). **The system configuration file is NOT erased when the SD card is formatted.**
7. The system may be powered by an external battery for post-flight data download. Any phone charging battery and USB to micro-USB chord will work.

System Setup and Calibration using the WiFi Gateway

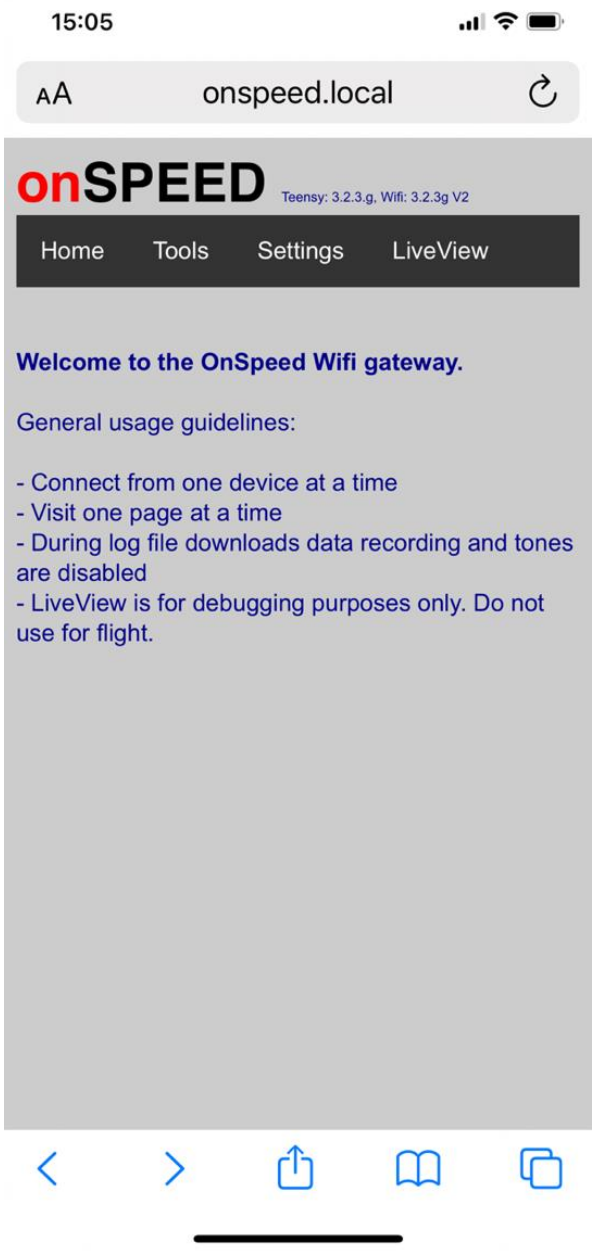


Figure 9. WiFi home page (iPhone).

WiFi Gateway Home Page. Connect to the ONSPEED network using a smart phone, tablet or laptop, password "angleofattack." Open browser: enter onspeed.local in the address line. The WiFi homepage is shown in Figure 9. The current version of Teensy software and WiFi firmware are shown on the top line. There are four menus available: Home, Tools, Settings and LiveView. This menu bar is always visible. The Home page contains general usage guidelines for navigating the WiFi gateway.

WARNING

1. The LiveView AHRS display is intended for calibration and test purposes only and should not be used as a flight reference.

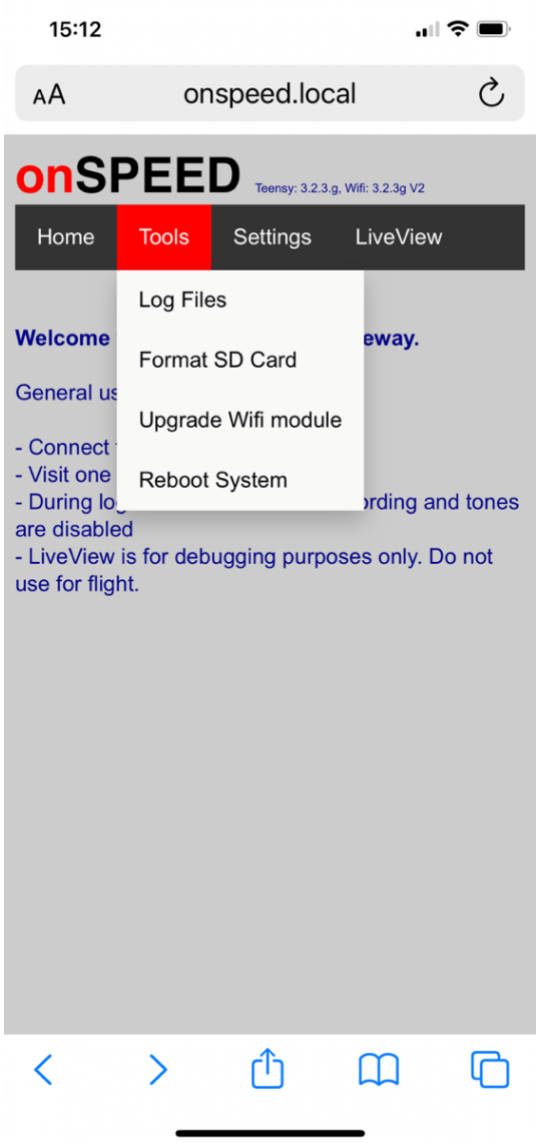


Figure 10. Tools menu (iPhone).

Tools Menu

The following options are available under the Tools menu: Log Files (used for file management), Format SD Card, Upgrade WiFi Module and Reboot System. The Tools menu is shown in Figure 10.

Log Files. Selecting the log files option will display stored files. The onspeed.cfg file contains system settings and is automatically updated with each SYSTEM CONFIGURATION or SENSOR CALIBRATION update. **A new log file is created every time the system is powered up** or reboots. Log files are created in "log_#.csv" format (Figure 11). Log files may be downloaded via WiFi. To download a file, click on the file once, and the file will be downloaded to the web browser. Data is downloaded at a rate of approximately 5 MB per minute, so large files will take some time to download post flight. The 56MB log_2.csv shown in Figure 11 will take approximately 11 minutes to download via WiFi.

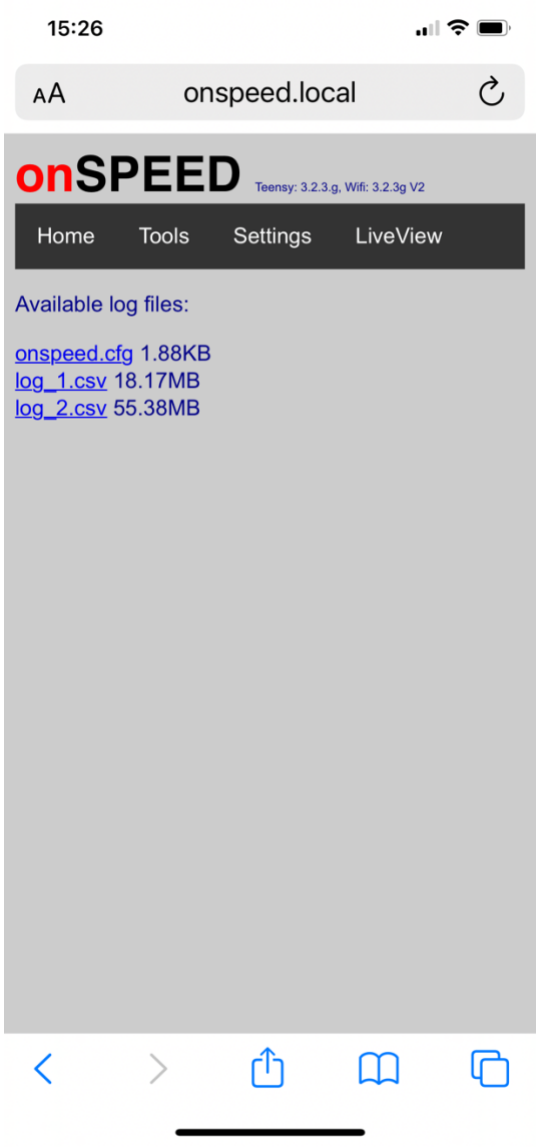


Figure 11. Log files page (iPhone).

Format SD Card. Use the FORMAT SD card option to remove old/unwanted data files. The onspeed.cfg file is maintained during re-format.

Waiex Installation. Because of the remote mounting of the box under the glareshield, a cable is plugged into the micro-USB port and tied off under the instrument panel. If battery power is desired for WiFi data download, plug it into this cable.

Upgrade WiFi Module. This option is used for upgrading WiFi firmware. See WiFi Firmware Update section below.

Reboot System. Self-explanatory.

NOTE

1. To perform a hard boot, cycle circuit breaker or remove/restore power to the system.

Settings Menu

SYSTEM CONFIGURATION

This option is used to manage system configuration. WiFi Gateway Home Page: SETTINGS > SYSTEM CONFIGURATION (Figure 12). Settings are saved in the onspeed.cfg log file (TOOLS > LOG FILES).

NOTE

1. Changes to the settings only take effect if the red SAVE button is pressed on the bottom of the page.

AOA Smoothing. Value from 0-30. A higher value should be selected if more damping is desired. Select a lower value for a faster response, but nosier signal. A setting of 10 has been flight tested at G onset rates of 2G/sec up to 6G's and has shown to provide good accuracy and response while delivering a flyable cue throughout the flight envelope.

NOTE

1. Natural pressure damping is provided by the tubing connecting the pitot/AOA sensor to the box. The longer the tubing run, the more the natural damping. Thus, an installation with a short tubing run may require more smoothing than an installation with long tubing runs.

Pressure Smoothing. Value from 0-30. Simple moving average. A setting of 15 has been flight tested at G onset rates of 2G/sec up to 6G's and has shown to provide good accuracy and response while delivering a flyable cue throughout the flight envelope.

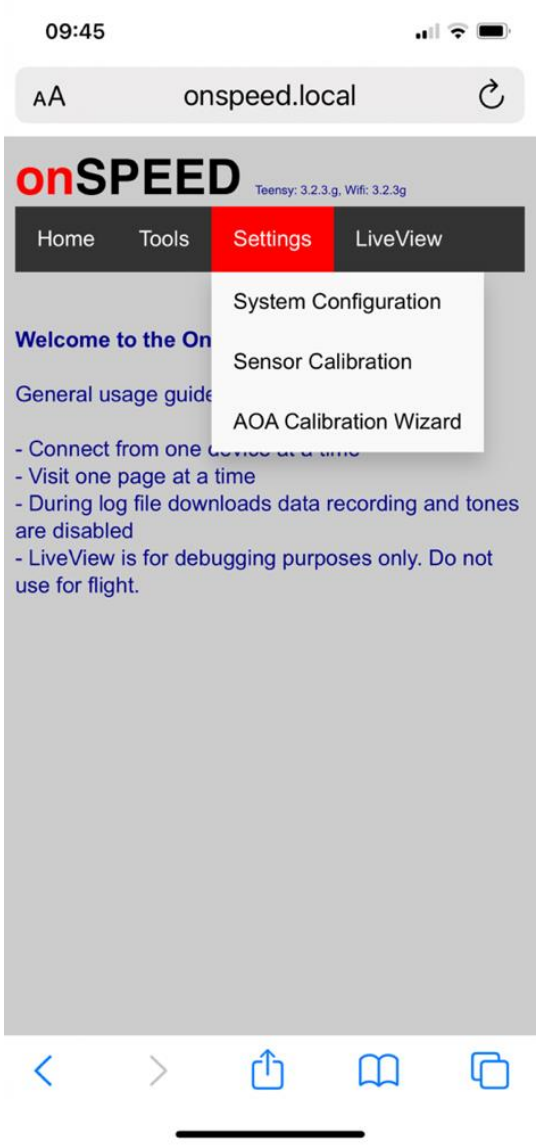


Figure 12. SETTINGS menu (iPhone).

Data Source. This should normally be set to SENSORS (default). This means that the CPU is processing onboard pressure sensor and IMU data. This option also adds additional capabilities that are used for diagnostic and test purposes:

1. **Test Potentiometer.** Not used.
2. **Range Sweep.** Generates the AOA tone pattern from low AOA to high AOA and back down.
3. **Replay Log File.** Replays a log file. Reads a recorded log file, calculates AOA, plays tones, drives the M5 display and generates LIVE VIEW exactly as it would in flight.

Flap Curves. The system can store up to 5 calibration curves. A different calibration is required for each flight setting to accurately compute AOA. Flap position information is received from the flap position sensor. Each curve contains the following information:

1. Flap setting (deg).
2. Flap sensor value (ohms resistance).
3. L/Dmax AOA (deg, fast tone begins).
4. Onspeed Fast AOA (deg, tone goes solid).
5. Onspeed Slow AOA (deg, slow tone begins).
6. Stall Warning (deg, 22 PPS warning tone begins).
7. AOA Curve Type:
    a. Polynomial (default)
    b. Logarithmic
    c. Exponential
8. AOA Curve Formula (maximum 3rd order polynomial).

The READ button captures flap sensor value (ohms resistance). The USE LIVE AOA captures actual AOA when selected.

NOTES

1. DELETE FLAP POSITION and ADD NEW FLAP POSITION buttons are provided to manage flap curves.
2. Flap curves are set up using the WiFi Gateway > SETTINGS > SYSTEM CONFIGURATION menu prior to calibration. A flap curve for each flap setting is required. The READ function is used to measure flap position sensor readings. This is best accomplished under air loads in flight. **Scroll to the bottom of the page and select the red SAVE button any time a change is made to the SYSTEM CONFIGURATION.** A "configuration saved successfully" page opens after a SAVE.
3. The AOA curve is calculated automatically during calibration.
4. AOA setpoints are calculated automatically during calibration. Set points are based on stall speed detected during calibration. ONSPEED slow is 1.25 x stall speed, ONSPEED fast is 1.35 x stall speed. Stall warning is set at stall + 5 knots. Flaps up L/D_{MAX} is weight adjusted. After calibration, setpoints may be manually adjusted, if desired.

Flight Test Boom. The system supports the SpinGarage Featherweight air data test boom, if installed. Software settings allow use of boom firmware with or without the CHECKSUM feature. Settings allow use of algorithms to translate vane data to degrees and pressure data to millibars or simply record raw data (vane and pressure sensor potentiometer readings) for post-flight analysis.

Airspeed Calibration. Applies an airspeed correction to IAS. Generally used to correct IAS to CAS. This is the airspeed displayed on the optional M5 visual display. Supports polynomial,

logarithmic, or exponential regression curve (same logic use for calibration curves). It's necessary to have accurate IAS and CAS data from flight test to develop a correction curve. GPS speed runs with appropriate post-flight analysis will generally produce good data. CAS derived from analysis is plotted against IAS and appropriate regression is performed. The resulting equation may be programmed into the software to correct IAS displayed on the optional visual display and recorded in data to CAS, if desired.

Pressure Ports Orientation. The direction the pressure ports (back of the ONSPEED V3 box) are pointing. Options:

1. Up
2. Down
3. Left
4. Right
5. Forward
6. Aft

Box Top Orientation. The direction the top of the ONSPEED V3 box is pointing. Options:

1. Up
2. Down
3. Left
4. Right
5. Forward
6. Aft

Serial EFIS Data. This option allows data from the EFIS to be transmitted and recorded.

EFIS Type. The following EFIS types are supported:

1. Dynon D10/D100
2. Dynon SkyView/Advanced Flight Systems
3. Garmin G5
4. Garmin G3X
5. VectorNav VN-100 IMU/AHRS
6. VectorNav VN-200/300 GNSS/INS
7. MGL iEFIS

Calibration Data Source. Selects onboard IMU or EFIS (if equipped) to be used for AOA calibration.

Volume Potentiometer. Calibrates the volume knob (rotary switch). A TEST AUDIO function is provided. READ capability is provided for switch calibration:

1. Low Volume Value (ohms resistance)

2. High Volume Value (ohms resistance)

Mute Below IAS (kts). Pilot selects the IAS at which the tone will activate during takeoff and deactivate during landing. A speed that is at least 10 knots below rotation speed is recommended.

3D Audio. Turns 3D audio off and on.

*OverG Audio Warning***.** Enables OWS capability. The pilot programs positive and negative G limits.

Vno Warning Chime. Enables airspeed warning. The pilot programs V_{NO} (or desired ***indicated*** airspeed) and chime interval (in seconds). A test function is provided.

SD Card Logging. Turns data logging on or off.

NOTE

1. It is recommended that SD Card Logging be disabled for normal use after the system has been calibrated if data logging is not desired. No testing has been conducted with a full SD card and system performance with a full card is not known.

Serial Out Format. This is the format that serial data is transmitted FROM the ONSPEED system. Options are:

1. ONSPEED format
2. Garmin G3X format

Serial Out Port. This selects the ONSPEED serial out port number and configuration (TTL or RS-232).

Load File Button. This option allows you to load a stored configuration file (onspeed.cfg) from your mobile device file manager.

Load Default Button. The Arduino/Teensduino software has a default configuration tab (Figure 13). This tab stores the settings as a back-up to the automatic onspeed.cfg file stored in the log files directory on the SD card. It is recommended that after the system is set up and calibrated, the default_config.h tab in the AHRS Arduino code be updated to provide this back-up function. **After the tab is updated, it will be necessary to reload software**. To access the default configuration file, click on the inverted triangle on the right side of the green Arduino tab display. This will open a drop-down menu. Select default_config.h to open the default configuration tab.

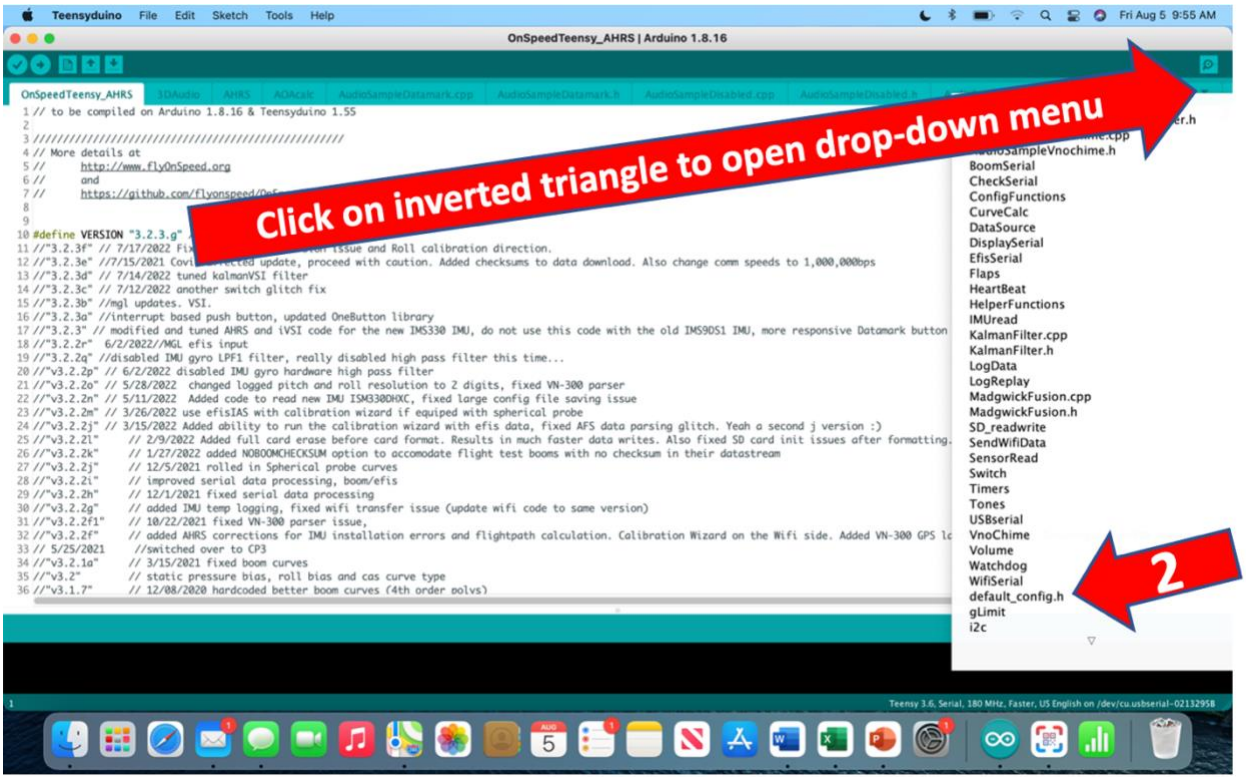


Figure 13. Navigate to config.h in the OnSpeedTeensy_AHRS.ino software.

An example default file is shown in Figure 14. The default tab will be populated with the file for a test airplane when software is downloaded from our GitHub site. **This must be replaced with a text file copied from the onspeed.cfg after the system is set-up and properly calibrated in your airplane.** It will be necessary to update this tab every time software is updated (or a sensor calibration is performed) on a calibrated system, since each aircraft calibration is unique. If this is not accomplished the LOAD DEFAULT button will load incorrect data.

NOTES

1. A complete configuration file can only be created after the system has been fully calibrated.
2. When copying and pasting, be sure to preserve header and footer lines on the default_config.h tab. Rename Line 1, as desired.
3. Changes can be manually typed into the default_config.h tab, however cut/paste is recommended to reduce potential for error.
4. Software must be reloaded any time the default_config.h tab is updated for LOAD DEFAULT option to work correctly.

CAUTION

1. The default_config.h tab must be updated if a new sensor calibration is performed.

Figure 14. Default configuration tab (default_config.h).

SENSOR CALIBRATION

Sensor calibration is required when a system is installed in the airplane. It is performed on the ground, under no wind conditions—preferably in a closed hangar. A digital level is required. It is necessary to know aircraft pitch (fuselage reference line used for weight and balance), aircraft roll and pressure altitude. Left roll is NEGATIVE and right roll is POSITIVE. Pressure altitude is displayed on the altimeter when it is set to 29.92 inches or 1013 mb. The sensor calibration page is shown in Figure 15.

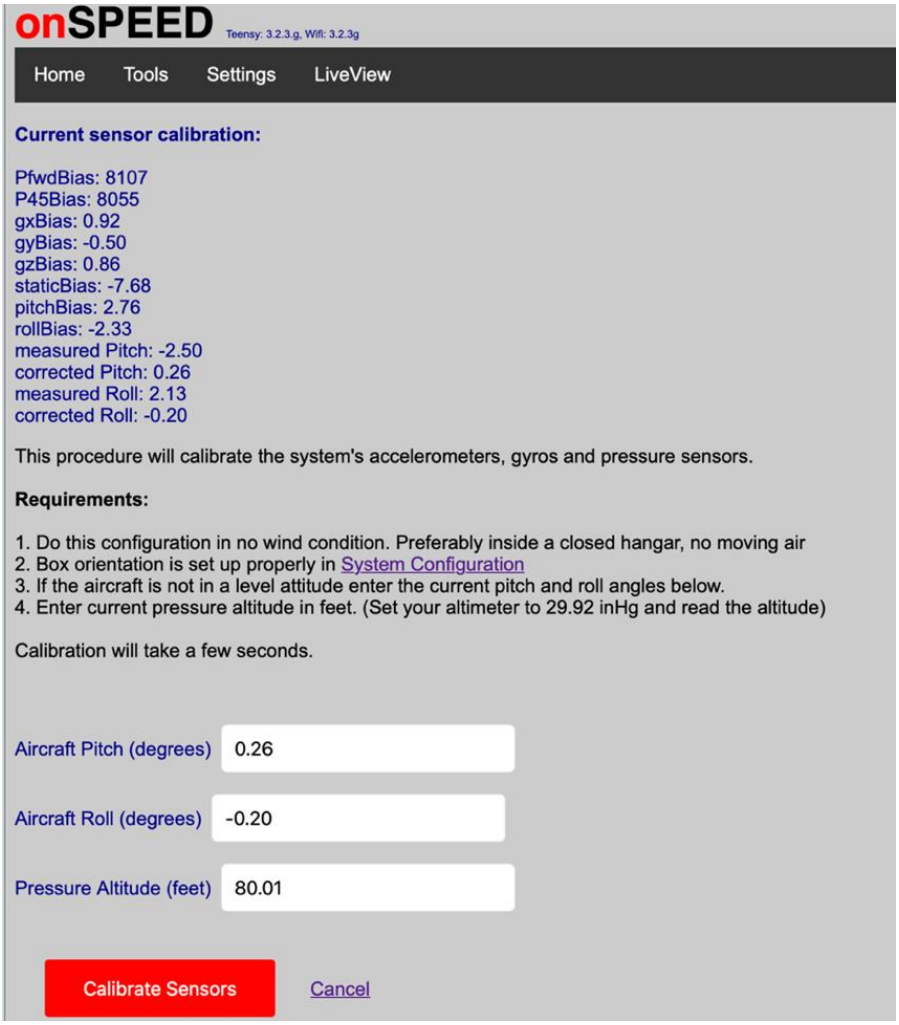


Figure 15. Sensor calibration page.

This function calibrates accelerometers, gyros, and pressure sensors. Regular update is not required. As a technique, sensor calibration quality should be checked any time system software is updated by comparing displayed pitch, roll and pressure altitude against measured pitch, roll and pressure altitude. Re-calibrate, as desired. If the system is used for flight test, more frequent calibration may be desired. The default_config.h tab in the software should be updated any time a calibration is performed. Software must be reloaded after updating this file.

NOTES

1. A checklist for sensor calibration is provided in the Appendix C.
2. Allow the system to warm up for at least 10 minutes prior to calibrating sensors for best results.
3. Align the EFIS 0° pitch with the fuselage reference line (if equipped).

After entering pitch, roll and pressure altitude, press the red CALIBRATE SENSORS button. A successful calibration result is shown in Figure 15. "Measured Pitch" and "measured Roll" on the output display (Figure 16) should match or be very close to values input in the white boxes on the input page (Figure 15).

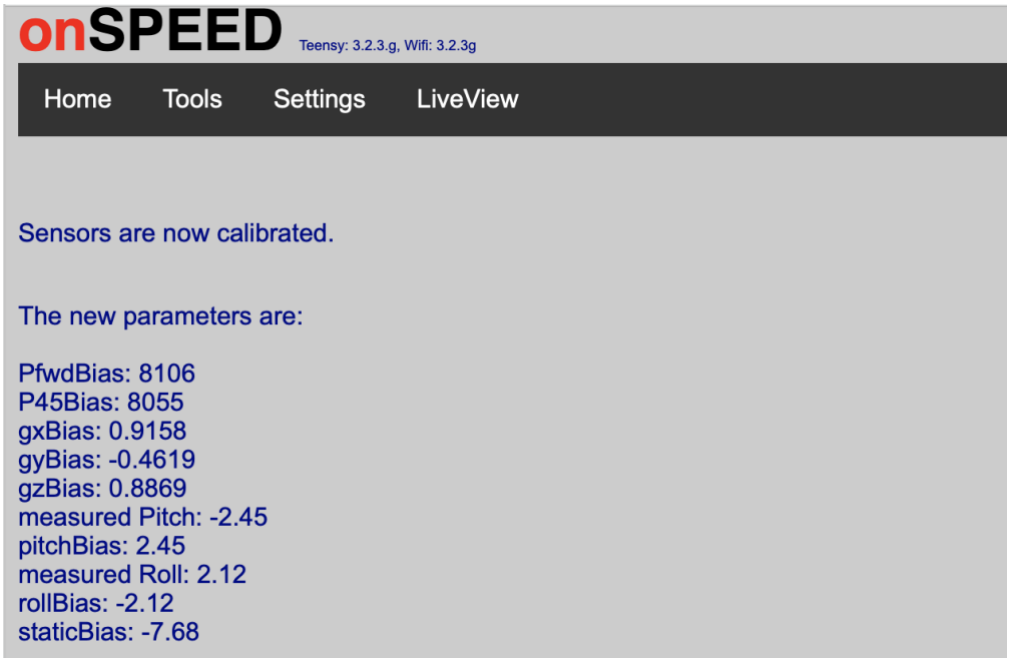


Figure 16. Post calibration page.

AOA CALIBRATION WIZARD

WARNINGS

1. Consider use of an assistant for calibration. The assistant can operate the smart phone, tablet or laptop allowing the pilot to concentrate on flying and maintaining a safe flight path.
2. A full stall is required to calibrate the system. The airplane must be loaded within weight and CG limits to ensure proper stall recovery. The calibration profile should be flown at an altitude high enough to allow stall recovery at or above 1500' AGL.

Calibration physics are discussed in the "Pressure Derived Angle-of-Attack" section above. The AOA calibration wizard assists the pilot with in-flight AOA calibration. The calibration wizard is accessed through the WiFi Gateway (SETTINGS > AOA CALIBRATION WIZARD) and consists of three pages.

The first page of the calibration wizard is shown in Figure 17. The pilot (or assistant) inputs maximum aircraft gross weight, aircraft weight during calibration, best glide speed flaps UP (1G

L/D_{MAX}) and G limit. These parameters are used to calculate the initial AOA set points. After inputting parameters, select CONTINUE.

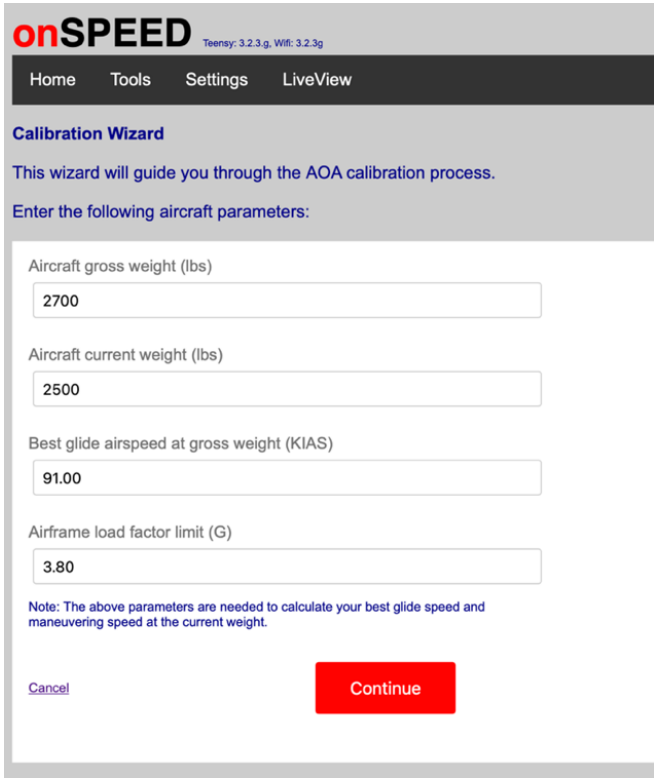


Figure 17. AOA Calibration Wizard first page.

The second page of the AOA Calibration Wizard contains instructions for the conduct of the calibration. This is shown in Figure 18. After reviewing instructions, select CONTINUE.

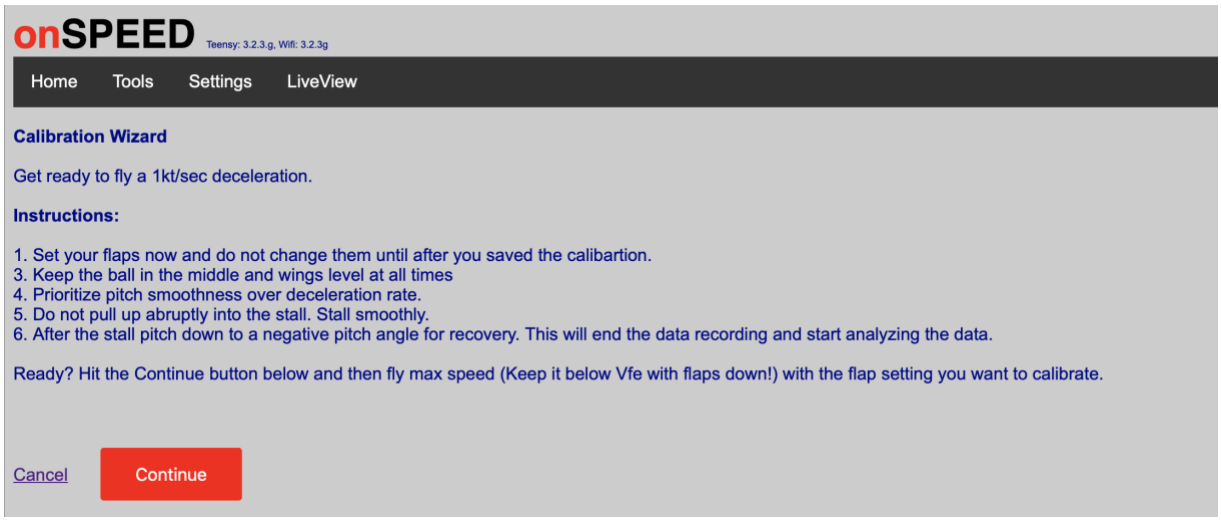


Figure 18. AOA Calibration Wizard second page.

The third page of the Calibration Wizard is shown in Figure 19.

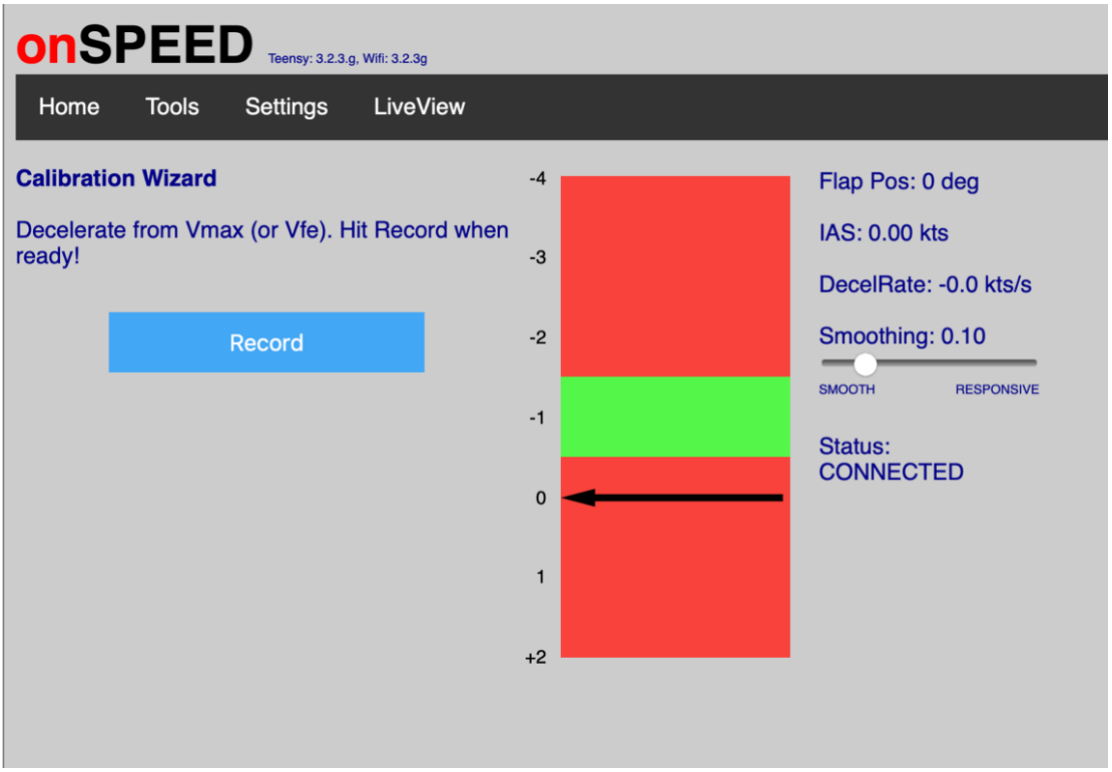


Figure 19. AOA Calibration Wizard page 3, deceleration display.

The blue RECORD button starts the automatic calibration sequence. The arrow on the deceleration display moves up and down to show deceleration or acceleration in knots per second. A slider is provided to adjust arrow smoothing. A relatively smooth setting (as shown in Figure 19) is recommended. Flap position and IAS are also displayed. **If flap position read-out does not match actual flap position, the flap curve has not been correctly set-up** (SETTINGS > SYSTEM CONFIGURATION).

To calibrate, the pilot climbs to a safe altitude, accelerates to V_{MAX} Flaps UP, not to exceed maximum structural cruising speed [V_{NO}]) or V_{FE} Flaps DOWN, presses the blue record button, reduces power, and decelerates to a stall remaining within ± 500 feet of start altitude. The system automatically detects stall and generates a calibration curve for the flap setting.

During the calibration sequence, the blue RECORD button changes to a red STOP! button. This is normal. When the system senses stall, the button changes back to a blue RECORD button and calibration results are displayed (Figure 20). The pilot may choose to SAVE DATA and/or to SAVE CALIBRATION after a calibration run. The SAVE DATA function will save a 10Hz .csv file to the device (smart phone, tablet, or laptop). The SAVE CALIBRATION function populates the flap curve and generates a "Calibration Saved Successfully" message. **If the calibration is not saved and another run is desired, refresh the page prior to beginning the next run.**

NOTE

1. It is recommended that the pilot take a screen shot of the calibration curve (Figure 20) and SAVE DATA after every calibration attempt, even if the calibration is not saved. This information is helpful for technical support.

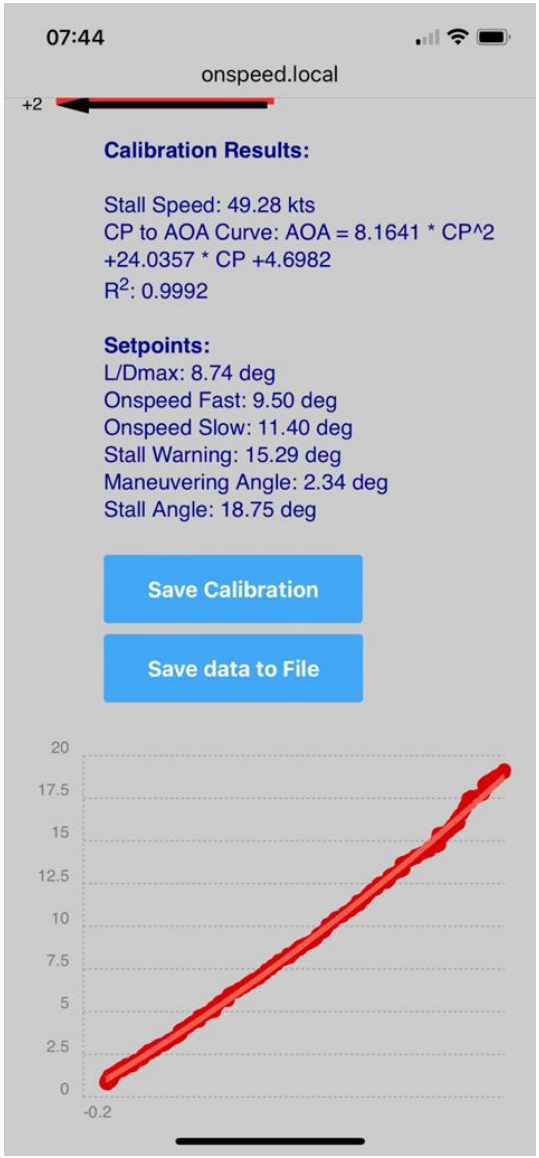


Figure 20. Post-calibration display (EFIS Calibration Source).

The best calibration will be obtained in smooth air. Calibrations should be hand flown, do not use an autopilot. Think of the calibration as one long, smooth *pull* into the stall. During the calibration run, precise deceleration rate is not critical. **Do not chase the arrow on the deceleration display.** Precise altitude control, or the altitude used for calibration is not critical.

Stall within ± 500 feet of start altitude is fine. The green band on the calibration display is centered around 1Kt per second. During deceleration, the airplane will naturally fall into this band. Figure 21 Shows a level deceleration to a stall. The green band is 1 kt/sec ± ½ knot. Note that in area A, the deceleration rate is going to be outside of the green band. In this example, about halfway through the run, the deceleration rate settles into the green band. This run was accomplished just looking out the window and gradually increasing back pressure as the airplane slowed. The blue line depicts AOA increase during the calibration. Note the smooth, geometric increase. This means that initially, a very slow pull is required; but as the airplane decelerates, the rate at which back pressure is applied increases. In other words, as you slow down, you need to pull back faster—not fast, just faster. Think "smooth." Be patient and make as many runs as you'd like.

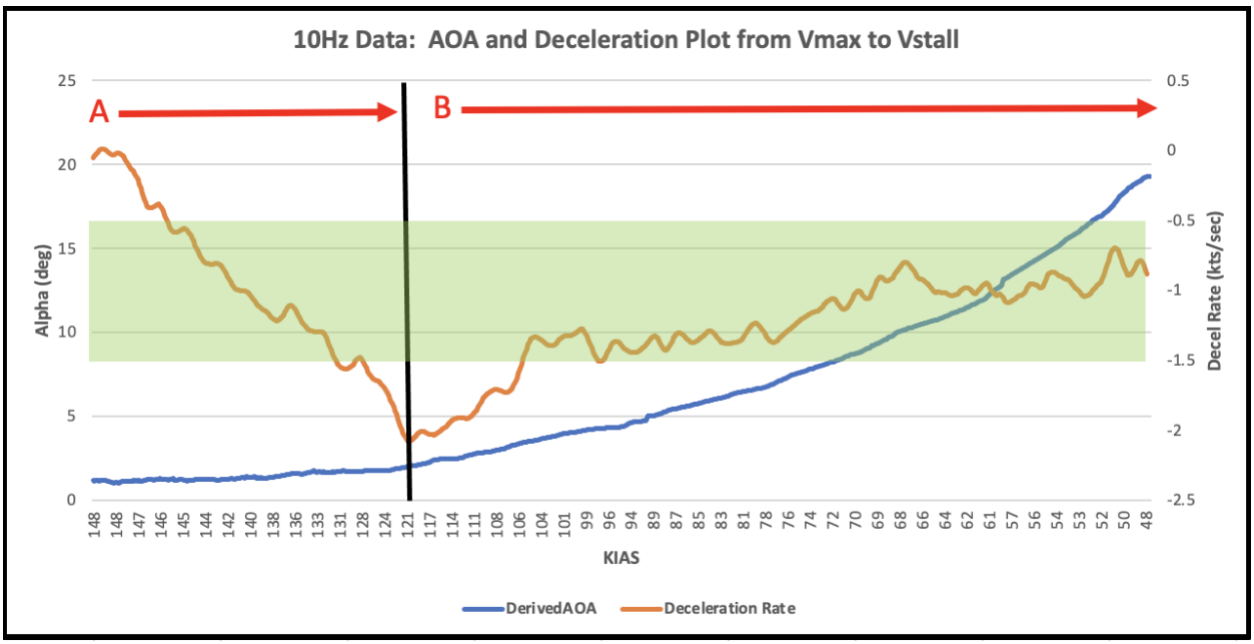


Figure 21. 10 Hz Automatic calibration data downloaded from iPhone and plotted in Excel.

WARNING

1. Trim may be applied during deceleration to assist with smooth control, however, do not trim full nose up to ensure normal stall recovery.

If difficulty is encountered getting a smooth calibration curve, try a smooth, steady pull aft, accepting some climb approaching the stall.

A "how to" calibration video can be viewed here: https://youtu.be/4ZN5XmLhtl0.

CAUTION

1. Do not exceed V_{FE} with flaps deployed.

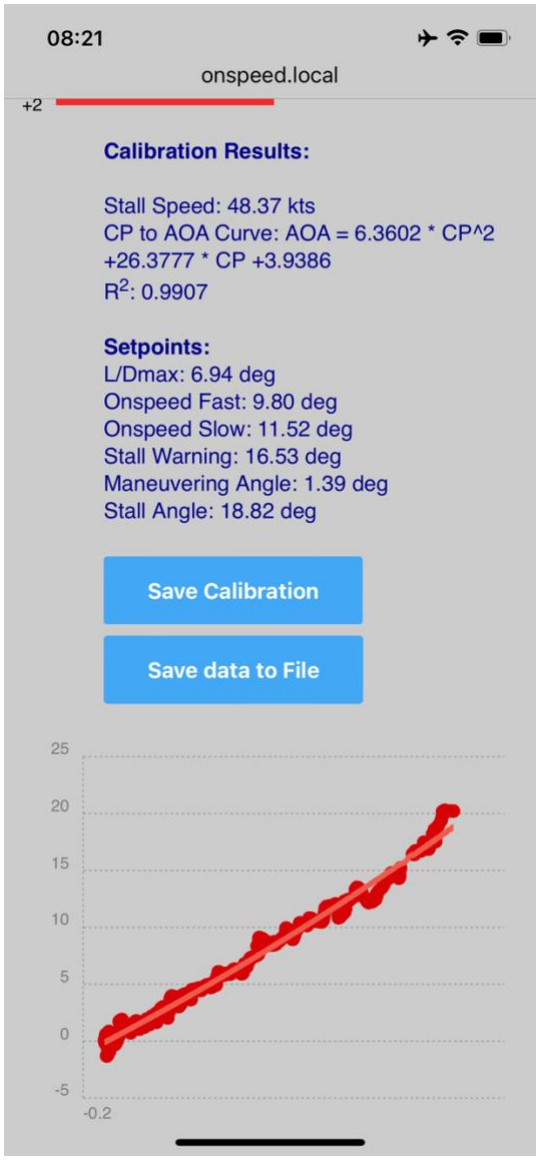


Figure 22. Post-calibration display (IMU Calibration Source).

NOTES

1. A checklist for in-flight calibration is contained in Appendix D.
1. Fly a calibration profile in each flap setting normally used. Flaps must be set prior to starting the run and remain deployed until calibration results are shown.

2. Prior to calibration, insert a flap curve for each flap position and READ the flap position sensor. Use the ADD CURVE button as required and SAVE after any configuration updates. Up to five curves are supported.
3. Flap position should be checked in flight under air loads. The value varies slightly each time the position is read. This is normal.
4. The pitch change to reduce AOA should be sufficient to end the run and enable the automatic calibration sequence. This is indicated by the red STOP! button above the deceleration tape changed back to a blue RECORD button and there are set points and a curve plot at the bottom of the display**. If the red STOP! button remains displayed after stall, the system did not sense a stall.** Press the STOP! button. If the airplane "mushes" at stall, try some climb in the calibration run to achieve a higher pitch angle, and ensure a smooth unload (reduction in AOA by pushing forward on the stick or yoke) at stall.

Quality of the calibration. Three things should be considered when assessing the quality of a calibration attempt: the R^2 value, the shape of the regression line (curve) and the shape of the data plot. The R^2 value should be .98 or higher. The regression line curve should be concave to linear (NOT convex), and the data plot should be relatively smooth. A good calibration is shown in Figure 20. The key to this quality is the smooth AOA/pitch rate increase to the stall. Figure 22 shows a good automatic calibration using the internal IMU as the calibration source. This figure was derived using software version 3.2.3.g3 with first generation Kalman filtering.

Assessing Set Points. A set point is automatically calculated for L/D_{MAX}, ONSPEED fast (where the tone transitions from 400Hz beeps to 400Hz solid) and ONSPEED slow (where the solid tone transitions to 1600Hz beeps) and stall warning (where the tone transitions to 1600Hz 22 pulses per second). After a successful calibration, the set points should be verified and adjusted if necessary. Setpoints are calculated for each flap curve. They should be checked in each flap configuration.

To check a setpoint, very slowly decelerate to assess quality. Slow below desired setpoint and very slowly accelerate to check the quality from both directions.

Setpoints may be manually adjusted. To adjust a set point, first establish the desired flap configuration and desired speed at 1G (trimmed). Then use the USE LIVE AOA button next to the AOA for the setpoint being adjusted (SETTINGS > SYSTEM CONFIGURATION menu) to capture the desired AOA. Use the SAVE button at the bottom of the SYSTEM CONFIGURATION page to save the new setting(s). An alternative method is to simply change the AOA and then decelerate to check the setpoint speed at 1G: adjust AOA lower for faster or higher for slower. Try .25-.35° adjustments if tweaking L/D_{MAX} (start of fast tone), .1-.2° for ONSPEED fast or slow, and .1° for stall warning. Stall warning of less than 5 MPH/KTS at 1G is not recommended.

Live View. Two live view options are available for diagnostic and test purposes: AOA (Figure 23) and AHRS (Figure 24).

WARNING

1. Live view is intended for diagnostic and test use only. **The Live View AHRS display is NOT SAFE FOR FLIGHT.**

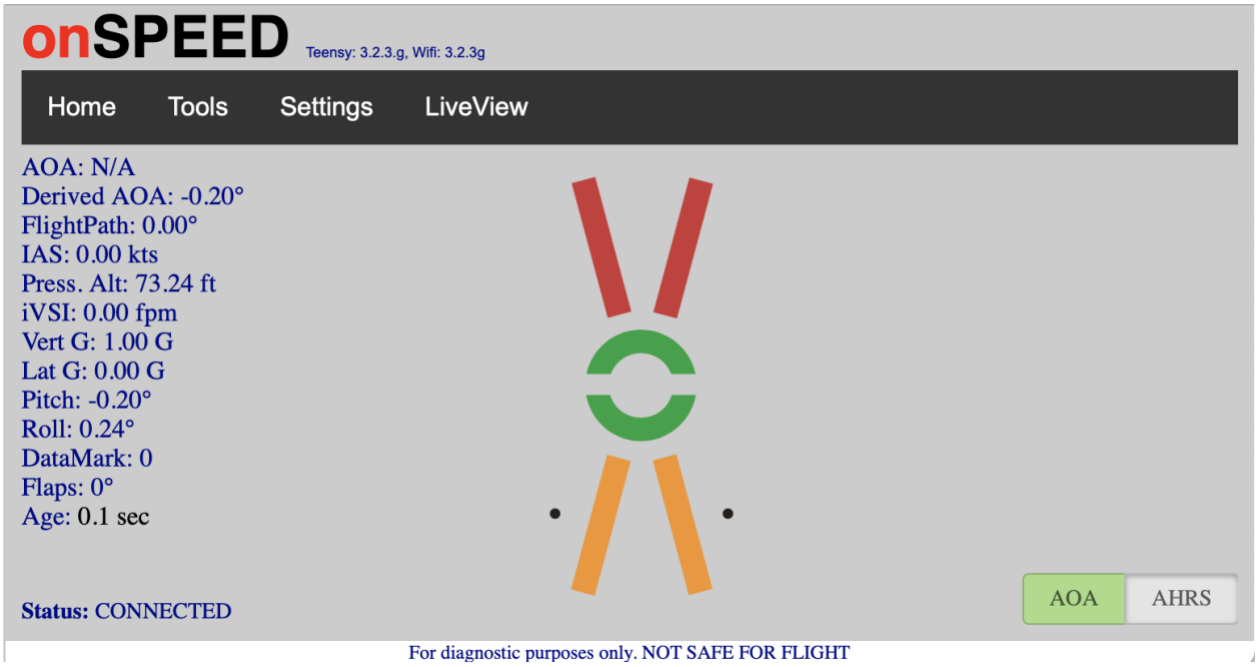


Figure 23. Live view AOA display.

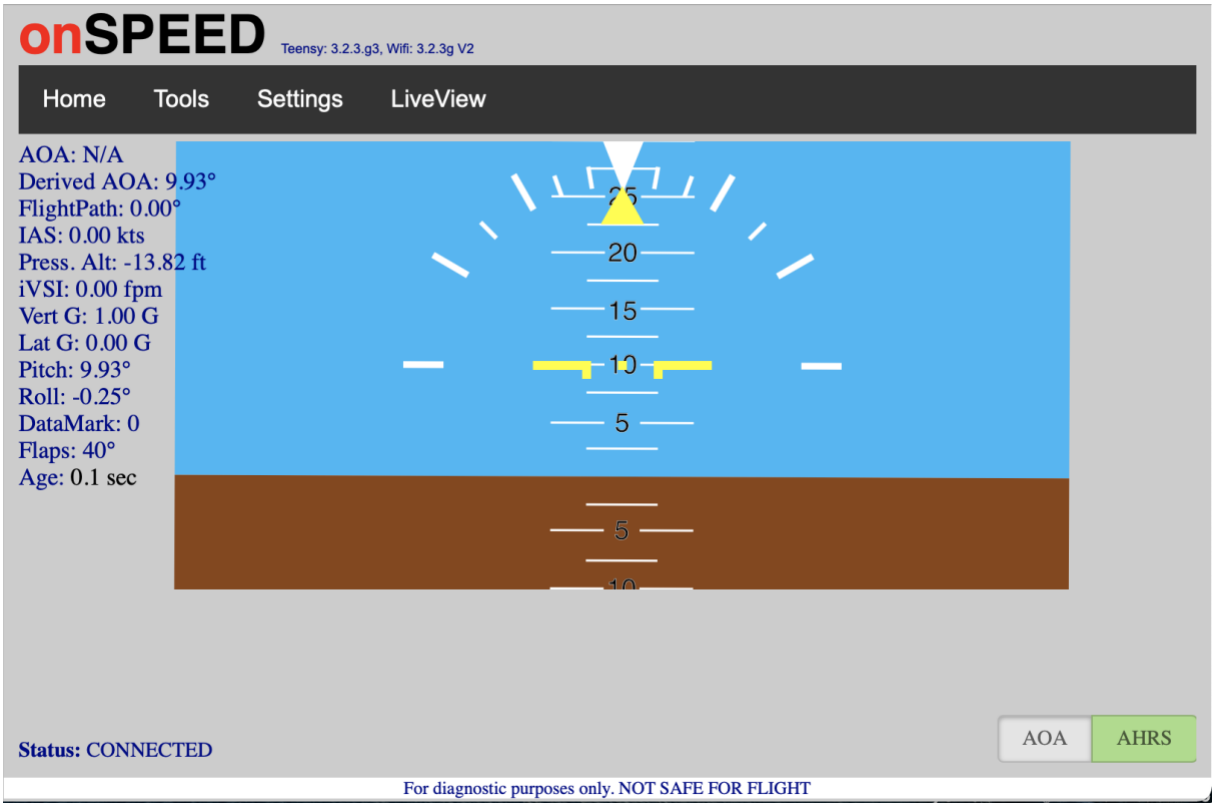


Figure 24. Live view AHRS display (tailwheel equipped aircraft on the ground shown).

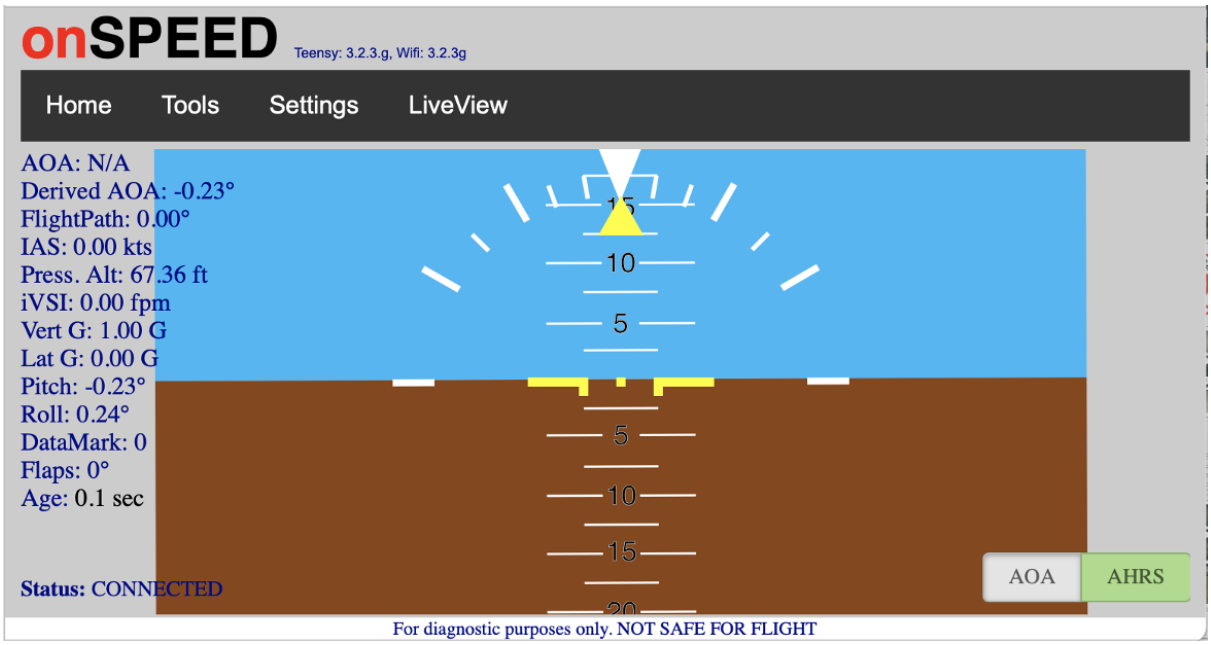


Figure 25. Live View AHRS display with EFIS selected as calibration source and box powered by external battery connected to micro-USB port.

NOTES

1. The optional M5 visual display always shows attitude data from the on-board IMU. The Live View AHRS display shows either IMU or EFIS data (if equipped) depending on the calibration source selected in the SETTINGS > SYSTEMS CONFIGURATION menu. (Figure 24). **The optional M5 cannot display EFIS data.**
2. If the system is powered by a battery connected to the micro-USB port, and the calibration source is set to EFIS (i.e., the EFIS is not powered up), the Live View AHRS display will display zero pitch and roll (Figure 25). Change the calibration source to ONSPEED IMU to display current attitude using SETTINGS > SYSTEM CONFIGURATION menu.

Appendix A: Normal and Abnormal Checklist

AOA Tone Normal Operation

1. Appropriate bus switch – ON
2. Volume – ADJUST
    a. Flashing LED normal
3. Disable tone – SHORT PUSH
    a. "ONSPEED DISABLED" warning
    b. LED extinguishes
4. Enable tone – SHORT PUSH
    a. "ONSPEED ENABLED" warning
    b. LED flashes
5. Insert Data Mark – LONG PUSH
    a. "DATA MARK" warning

AOA Quick Reference

L/D_{MAX} (Start of 400Hz Fast Tone)
Yellow chevron lit. Trend indicator aligned with pips on visual display. 50% lift. 1.5 pulse per second, increases to 8.2 PPS as AOA increases. **Energy is positive: thrust exceeds drag.**

L/D_{MAX} is used for:
Best Range
Best Range Glide
Best Rate of Climb (approximate)

ONSPEED (Solid 400Hz Tone)
Green doughnut lit. Trend indicator in green doughnut. 60% lift. **Energy is neutral: thrust and drag are balanced**

ONSPEED is used for:
Approach and Landing
Optimum maneuvering (0 P_S/maximum sustained turn rate)
Maximum Endurance Glide
Best Angle of Climb

Slow Tone (1600Hz Tone)
Red chevron lit. 1.5 to 6.2 PPS as AOA increases. **Energy is negative: drag exceeds thrust. Reduce AOA, add power or both.**

Stall Warning (22 PPS 1600Hz Tone)
Red chevron flashes. >90% lift. Within 1.5-2° of stall (5 kts at 1G): **reduce AOA → DON'T STALL**

M5 Visual Display Normal Operation (if installed)

1. Brightness – AS DESIRED
    a. Bright – Right button PRESS
    b. Dim – Left button PRESS
2. Display – SELECT
    a. Center button – PRESS to cycle

Connect to WiFi Gateway

1. Power – APPLY
    a. Appropriate bus switch – ON, or
    b. Battery or USB port on a laptop computer – CONNECT to micro-USB port on the FlyONSPEED box
2. Connect to ONSPEED network
    a. Password – angleofattack
3. Open browser
    a. Address: Onspeed.local

WiFi Post Flight Data Download

1. Connect to WiFi Gateway
2. Select TOOLS > LOG FILES
3. **SINGLE CLICK** on file to download
    a. File downloads to browser at 5 MB/min

Delete Log Files

1. Connect to WiFi Gateway
2. Select TOOLS > FORMAT SD CARD

Turn Data Logging ON/OFF

1. Connect to WiFi Gateway
2. Select SETTINGS > SYSTEM CONFIGURATION
    a. Scroll to "SD Card Logging"
    b. ENABLE or DISABLE
3. Red SAVE Button at bottom of page – SELECT

Abnormal Procedures

HARD REBOOT

1. 1 Amp Circuit breaker - CYCLE

SOFT REBOOT

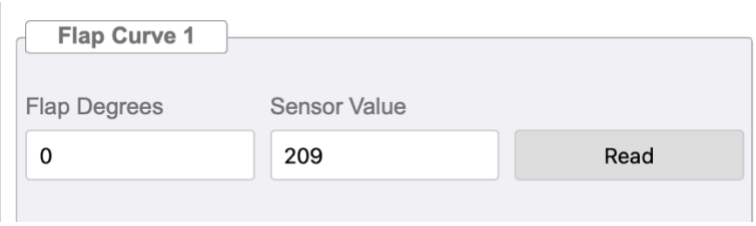
1. Connect to ONSPEED network
    a. Password – angleofattack
2. Open browser
    a. Address: Onspeed.local
3. TOOLS > REBOOT

Appendix B: SYSTEM CONFIGURATION SETUP CHECKLIST

1. Connect to WiFi Gateway
    a. Master Switch – ON
    b. Appropriate bus switch – ON, or
    c. Battery or laptop – CONNECT to micro-USB port on FlyONSPEED box
2. Connect to ONSPEED network
    a. Password: angleofattack
3. Open browser
    a. Address: onspeed.local (Apple) or 192.168.0.1 (Windows/android)
4. Select SETTINGS
5. Select SYSTEM CONFIGURATION
    a. AOA Smoothing: 10
    b. Pressure Smoothing: 15
    c. Data source: Sensors (default)

    NOTE
    - Build a flap curve for each flap setting used. The system accommodates up to five flap positions.

    d. Flap Curve 1
        i. Flaps UP, enter degrees (value may be negative for reflexed flaps)
        ii. Simulate air load on flaps by lifting the trailing edge of flaps
        iii. Sensor Value READ
            1. System reads flap sensor (ohms resistance)
        iv. Verify SENSOR VALUE window populates
            1. Specific value varies



    NOTES
    - When you read a sensor value, the result will be slightly different each time. This is normal.
    - **It is best to read flap sensor values in flight under actual air loads.** Some flaps have significant hysteresis (slop) when extended. **This procedure is also included in the in-flight AOA Calibration Checklist for that reason.**

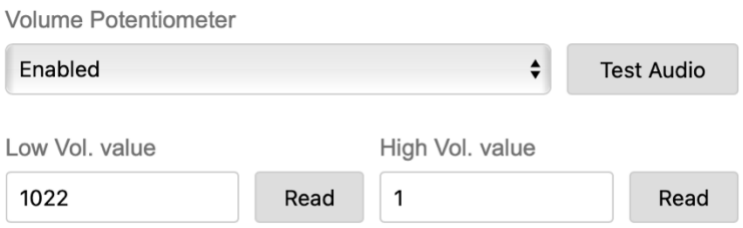
    e. ADD NEW FLAP POSITION, as required
    f. Repeat procedure in (d) above, as required

g. Flight Test Boom: DISABLED (unless equipped)
h. Airspeed Calibration: DISABLED
    i. This is an advanced function used for flight test or to adjust IAS on the optional visual display.
    ii. Enabling airspeed calibration will open correction curve windows.
i. Pressure Ports Orientation (direction the quick release pressure ports are pointing)
    i. UP, DOWN, LEFT, RIGHT, FORWARD, AFT, as appropriate
j. Box Top Orientation (direction the top of the box is pointing)
    i. UP, DOWN, LEFT, RIGHT, FORWARD, AFT, as appropriate
k. Serial EFIS Data: AS DESIRED

NOTE

- If EFIS data recording isn't required/desired for flight test, recording should be DISABLED since the SD card will eventually fill up and testing with a full card hasn't been conducted.

l. EFIS TYPE: SELECT
m. Calibration Data Source: AS DESIRED
    i. EFIS Recommended, if equipped
n. Volume Potentiometer: ENABLED
    i. Low Vol. Value
        1. Twist knob full counterclockwise and READ
    ii. High Vol. Value
        1. Twist knob full clockwise and READ



o. Mute Below IAS (KTS): AS DESIRED
    i. Not more than V_R (rotation speed) -10 KTS recommended
p. 3D Audio: AS DESIRED
q. Positive G Limit: AS DESIRED
    i. Positive G limit -0.5 G recommended
r. Negative G Limit: AS DESIRED
    i. Negative G limit +0.5 G recommended
s. V_{NO} Warning Chime (KTS): AS DESIRED
t. Serial Out Format: ONSPEED
u. Serial Out Port: AS DESIRED

i. Optional modified M5 Visual Display requires output from Serial 3 in RS-232 format
ii. Serial 1 is a unique configuration for program test aircraft. It is not applicable for V3 hardware.

v. SAVE settings

Appendix C: SENSOR CALIBRATION CHECKLIST

CAUTION

- **Prior to performing sensor calibration, confirm ONSPEED box orientation settings in the SYSTEMS CONFIGURATION menu are correct** (See Appendix B Steps 5[i] and [j]).

NOTE

- Allow system (IMU) to warm up for 10 minutes prior to sensor calibration for best results.
- Update default_config.h tab in OnSpeedTeensy_AHRS.ino file after sensor calibration (SEE LOAD DEFAULT BUTTON).

SENSOR CALIBRATION CHECKLIST

A sensor calibration is required when the system is installed in an aircraft for the first time. It may be updated at any time. The airplane should be in a closed hangar during sensor calibration (i.e., free of movement), if practical. If calibration is conducted on the ramp, it should be done in calm, no wind conditions. The airplane should be unoccupied for calibration. The IMU and pressure sensors are calibrated during this process.

The following measurements are necessary:

Pitch	_____	(deg)
Roll	_____	(deg, - for left, + for right)
Pressure altitude	_____	(ft)

- To obtain pitch angle, place a digital level longitudinally on the fuselage reference line (FRL) used for leveling when weighing the aircraft.
- Align EFIS with FRL (set EFIS pitch to equal FRL reading, in degrees)
- To obtain roll angle, place a level or other stiff piece of metal (e.g., aluminum angle stock) laterally across the cockpit and measure roll angle with a digital level.
- To obtain pressure altitude, set the altimeter to 29.92.

1. Connect to WiFi Gateway
    a. Master Switch – ON
    b. Appropriate bus switch – ON, or
    c. Battery or laptop – CONNECT to micro-USB port on FlyONSPEED box
2. Connect to ONSPEED network
    a. Password: angleofattack
3. Open browser
    a. Address: onspeed.local
4. Select SETTINGS
5. Select SENSOR CALIBRATION

   a. Enter Pitch
   b. Enter Roll
   c. Enter Pressure Altitude
6. Red Calibrate Sensors Button – SELECT
   a. System will calibrate sensors and output bias data. To verify new calibration, select SETTINGS again, then select SENSOR CALIBRATION and verify pitch, roll, and pressure altitude are nearly identical to what was input during calibration. This is simply a verification. Exit the page when complete.

Appendix D: AOA CALIBRATION CHECKLIST

CAUTION

- **The ground sensor calibration must be completed before in-flight calibration** (see SENSOR CALIBRATION CHECKLIST in APPENDIX C).

ONSPEED AOA CALIBRATION PRE-FLIGHT PREPARATION

NOTES

- The calibration profile is a wings level deceleration from V_{NO} (top of the green arc or maximum level speed at wide-open throttle) to V_S flaps up and V_{FE} (top of the white arc) to Vs flaps down in each normally used flap configuration. A full stall is required. Plan a safe altitude to use for calibration that will allow for stall recovery at or above 1500 feet AGL.
- The GROUND PREPARATION checklist should be completed prior to attempting in-flight calibration. Time spent becoming familiar with the WiFi Gateway and "chair flying" the profile will result in a more expeditious and accurate calibration.

Ground Preparation

1. Determine aircraft maximum gross weight, test weight, best glide speed (L/D_{MAX}) and positive G limit.
2. Confirm SYSTEM CONFIGURATION settings are correct, the required number of flap curves have been added and flap position sensor readings are correct (See Appendix B SYSTEM CONFIGURATION SETUP CHECKLIST).

Ground Familiarization with the Calibration Wizard

1. Connect to WiFi Gateway
    a. Master Switch – ON
    b. Appropriate bus switch – ON, or
    c. Battery or laptop – CONNECT to micro-USB port on FlyONSPEED box
2. Connect to ONSPEED network
    a. Password: angleofattack
3. Open browser
    a. Address: onspeed.local (Apple) or 192.168.0.1 (Windows/android)
4. Select SETTINGS
5. Select AOA CALIBRATION WIZARD
    a. Input the maximum allowable gross weight, test weight, best glide speed (L/D_{MAX}) at maximum gross weight and positive G limit into the white data fields.
    b. Numbers correct? Select the red CONTINUE button at the bottom of the page.
    c. The second AOA Calibration Wizard Window opens. This page contains instructions for the conduct of the calibration profile. **A calibration must be conducted for each flap position.** After reviewing calibration instructions, select the red CONTINUE button.

d. The third AOA Calibration Wizard Window opens. A red and green deceleration tape is provided to assist the pilot with calibration. The display has a black arrow that moves up and down to show deceleration or acceleration in kts per second. A green band is provided at a deceleration rate of 1 kt/sec ± ½ knot.
    i. A sensitivity adjustment slider for the arrow is provided. A smoother setting is recommended.
e. To begin calibration, press the blue RECORD button. At the conclusion of the calibration run (automatically detected stall), the lower portion of the page will populate with calibration results.

NOTE

- Pressing the RECORD button on the ground will have no effect. A "simulated" calibration cannot be performed on the ground.

f. During in-flight calibration, two additional options will populate after the stall:
    1. SAVE CALIBRATION. This blue option saves the calibration to the SYSTEM CONFIGURATION settings.
    2. SAVE DATA TO FILE. The blue option saves the 10Hz data to a file that may be downloaded post-flight. Multiple files may be saved.

ONSPEED AOA IN-FLIGHT CALIBRATION PROCEDURE

WARNINGS

- Calibration requires a stall. It must be performed at a safe altitude that allows recovery at or above 1500' AGL.
- Ensure aircraft is operated at or below maximum allowable gross weight and the CG is within the allowable flight envelope.

CAUTION

- Ensure a full battery charge.
- Place phone or tablet in AIRPLANE MODE, WiFi ON, Bluetooth and data OFF. Disable auto screen lock. This prevents notifications from interfering with calibration wizard, saves battery, and prevents screen lock during calibration.

NOTES

- The calibration should be flown in smooth air for best results.
- Consider using an additional pilot or assistant.
- It is not necessary to maintain altitude during the calibration run: ± 500 feet of start altitude.
- **The calibration run should be hand-flown.** Prioritize a smooth increase in pitch over deceleration rate. **Do not chase the deceleration arrow with pitch.** Use visual references: single, smooth pull from V_{MAX} to stall. Be patient. Anticipate the need for increased pitch input as the airplane slows.

- EFIS calibration is recommended, if equipped.
- If using the IMU as calibration source, check for a good attitude display prior to calibrating (WiFi Gateway > LIVE VIEW > AHRS or select attitude display on optional M5 visual display). If attitude display is incorrect, do not perform IMU-based calibration. An EFIS calibration will bypass the IMU and may be performed if EFIS-equipped.

Calibration Procedure

1. Climb to test altitude
2. If optional M5 visual indicator is fitted, use center button to select DECELERATION display.
3. Connect to ONSPEED WiFi Gateway
    a. Phone/Tablet set-up: Airplane mode, Bluetooth OFF, WiFi ON, screen lock DISABLE
    b. Network: ONSPEED
    c. Password: angleofattack
    d. Open Browser
        i. Address: onspeed.local
4. Select SETTINGS
5. Select SYSTEM CONFIGURATION
    a. Scroll to Flap Curve 1
    b. Set Flaps 0
    c. Flap position READ
    d. Slow to V_{FE} or less and **repeat for each flap setting**
    e. Scroll to bottom of SYSTEM CONFIGURATION page and hit red SAVE button
    f. Verify Configuration Saved
6. Select SETTINGS
7. Select AOA CALIBRATION WIZARD
    a. Enter max allowable gross weight
    b. Enter test weight
    c. Enter flaps up best glide speed (KIAS) at maximum allowable gross weight
    d. Enter positive G limit
    e. Select CONTINUE
8. Review calibration instructions
    a. Select CONTINUE
9. Establish a trimmed condition at V_{NO}.
    a. If airplane cannot achieve V_{NO} in level flight, accelerate to V_{MAX} (level maximum speed, wide-open-throttle)
10. Select RECORD
    a. Button changes to red and says STOP! When calibration logic is active.
11. Smoothly reduce throttle to IDLE
12. Smoothly increase pitch as airplane decelerates to stall, trimming as desired.
    a. Using primarily visual references.
    b. It is NOT necessary to maintain altitude.

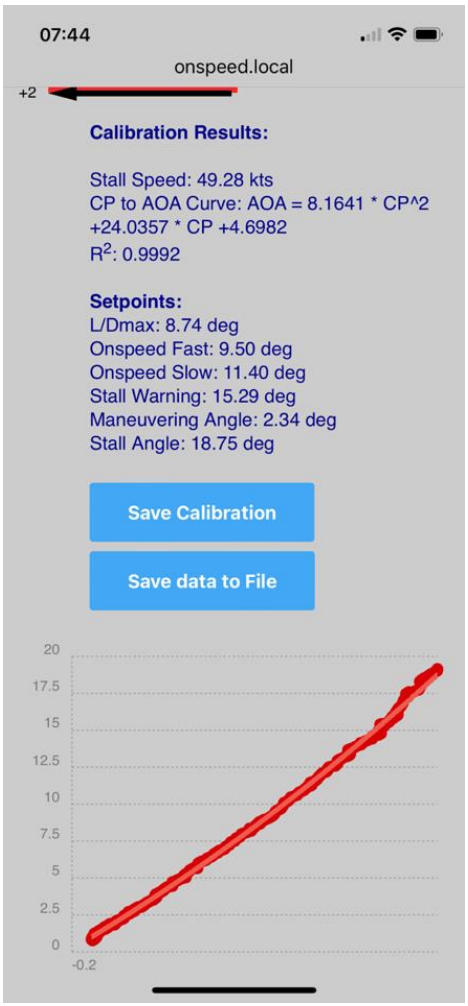
        i. ± 500 feet of start altitude is sufficient
    c. Do NOT over-control pitch. Do not chase deceleration rate. Avoid forward (down) pitch inputs. Steadily increase back pressure as airplane slows. Be patient.
        i. The **rate** at which you pull back will increase as the airplane slows down
        ii. Airplane should be fairly level at stall (+ 5-10^{o} nose up)
    d. If using trim, stop trimming no later than 1.3 x V_S and use back pressure to stall.
        i. Do NOT use full nose up trim
    e. If having difficulty using visual references, simply strive to hold altitude using steadily increase back pressure.
13. When stall is detected, the red STOP! Button will change back to a blue RECORD button and lower portion of page will populate.
    a. Screenshot calibration results
    b. SAVE DATA TO FILE
    c. SAVE CALIBRATION, as desired after assessment

NOTES

- Initiate recovery at the stall by reducing AOA (pitch).
- The criteria used to detect stall is a change in pitch rate (breakdown in longitudinal stability). A "mushy stall" or insufficient reduction in AOA at stall may result in the red STOP! Button remaining in view and no calibration results shown (i.e., system is still in auto calibration mode). Selecting STOP! will exit calibration mode and generate a calibration curve.
- A better calibration can be achieved with natural stall recovery behavior that using the STOP! button. Try climbing into the stall if system does not automatically detect stall. Use smooth forward pressure to break the stall.
- It is recommended that you use SAVE DATA feature to save 10Hz data calibration files to your phone/tablet/laptop during calibration as well as taking a screenshot of each calibration run. This will be helpful for tech support if you encounter problems calibrating.

Assessing quality of Calibration

1. R^2 value .98 or higher.
2. Relatively smooth line on graph.
3. Concave curve or linear trend line.
4. Calibration sequence may be repeated as often as desired.



CALIBRATION RESULTS DISPLAY

Assessing Quality of Set Points

1. Ensure fast tone begins at Flaps UP L/D_{MAX}
2. Ensure stall warning provides at least 5 kts/mph warning at 1G
3. Ensure ONSPEED band captures 1.3 x stall speed
4. Repeat assessment for each flap curve
5. To assess the quality of a set point
    a. Slowly decelerate to set point (start of fast tone, ONSPEED fast, ONSPEED slow or stall warning)
        i. Use very slow declaration rate (1/2 kt per second or less)
        ii. Compare tone change with IAS
    b. Slow below set point and slowly accelerate to check tone changes at desired airspeed.
        i. Compare tone change with IAS
    c. Repeat, as desired

NOTE

- L/D_{MAX} velocity will decrease as flaps are deployed. If L/D_{MAX} speed is not known for each flap setting, consider starting the fast tone at flaps UP L/D_{MAX} speed to ensure sufficient range of fast tone to provide trend information. With full flaps deployed, L/D_{MAX} and ONSPEED are nearly coincident.

Manually Adjusting Set Points

NOTE

- If desired, a set point (Fast tone start [L/D_{MAX}], ONSPEED fast, ONSPEED slow or Stall Warning) may be manually adjusted after a successful calibration. To do this, the airplane is flown to the desired condition (flap configured, power set, aircraft trimmed, speed and altitude stable) and the "Live AOA" function is used to read current AOA which is then input into settings.

Method 1: Establishing Trim Condition and Using LIVE AOA READ

1. Connect to ONSPEED WiFi Gateway
    a. Network: ONSPEED
    b. Password: angleofattack
    c. Open browser, Address: onspeed.local
2. Select SETTINGS
3. Select SYSTEM CONFIGURATION
4. Scroll to flap curve appropriate for configuration
5. Establish trim condition
    a. Desired airspeed at 1G, aircraft trimmed, speed, altitude and power stable
6. Press USE LIVE AOA button
    a. System will input measured AOA at trim condition
7. Scroll down to bottom of SYSTEM CONFIGURATION page and press SAVE

Method 2: Adjusting Angle and Assessing

1. Connect to ONSPEED WiFi Gateway
    a. Network: ONSPEED
    b. Password: angleofattack
    c. Open browser, Address: onspeed.local
2. Select SETTINGS
3. Select SYSTEM CONFIGURATION
4. Scroll to flap curve appropriate for configuration
    a. Adjust angle down for faster or up for slower for desired set point
        i. Try .1 deg adjustment per KT at L/D_{MAX} and .2-.3° ONSPEED or STALL WARNING
            1. Decrease angle for faster

2. Increase angle for slower
3. As speed approaches ONSPEED/stall, AOA increases rapidly, so a larger change may be required

ii. Stall warning of less than 5 KTS/MPH is not recommended

b. Repeat as desired

5. Scroll down to bottom of SYSTEM CONFIGURATION page and press SAVE

Appendix E: Software Installation and Update Checklist

NOTE

- First time users should review the expanded procedures in Appendix F and G prior to utilizing this checklist. **Older versions of Arduino and Teensyduino software are used. Newer versions have not been tested.**

Setting up the Arduino/Teensyduino IDE (Required before first-time use)

1. Install Arduino version 1.8.16 software: www.arduino.cc/en/software/OldSoftwareReleases.
2. Open Arduino software, SAVE FILE and close Arduino software.
3. Install Teensyduino version 1.55 software.
    a. Click on hyperlinks and software will automatically download to your browser:
        i. For Windows: www.pjrc.com/teensy/td_155/TeensyduinoInstall.exe
        ii. For Mac: www.pjrc.com/teensy/td_155/TeensyduinoInstall.dmg
4. Increase RX (receive) buffer size available to the PRJC Teensy 3.6 to 8192.

NOTES

- Only change the RECEIVE buffer size. Transmit buffer size remains 64 for serial1.c, and 40 for serial2.c through serial4.c.
- When Arduino IDE software installation is complete, Windows laptops will display the window title as "Arduino." MacBooks will display the window title as "Teensyduino."

Windows:

a. In File Explorer
    i. C:\ProgramFiles(x86)\Arduino\hardware\teensy\avr\cores\teensy3\serial1.c
    ii. Scroll down to serial1
    iii. Change permissions. Right click on file name. Select PROPERTIES. Select SECURITY. Select USER. Select EDIT. Add checkmarks in all Permissions. Select OK.
    iv. Change
    v. #define SERIAL1_RX_BUFFER_SIZE 64
    vi. To
    vii. #define SERIAL1_RX_BUFFER_SIZE 8192
    viii. Save
    ix. Repeat for serial2.c, serial3.c and serial4.c files

Mac:

a. In Finder
    i. Applications > Teensyduino, right click > Show Package Contents

ii. Contents > Java > hardware > teensy > avr > cores > teensy3
iii. Scroll down to serial1.c
iv. Right click on serial 1.c
v. Select OPEN WITH TextEdit
vi. Change
vii. #define SERIAL1_RX_BUFFER_SIZE 64
viii. To
ix. #define SERIAL1_RX_BUFFER_SIZE 8192
x. Save file
xi. Repeat for serial2.c, serial3.c and serial4.c files

5. The basic Arduino/Teensyduino (modified Arduino IDE) software installation is now complete.

ONSPEED Software Updates

NOTES

- The ONSPEED V3 box has two programmable boards: The PRJC Teensy 3.6 and the ESP32-PICO-D4 WiFi.
- The optional M5 visual display has its own ESP32 Wifi board (M5Stack-Core-ESP32).
- The PRJC Teensy 3.6 software (OnSpeedTeensy_AHRS.ino) is *always* updated (compiled and loaded) using a laptop and cable connection to the micro-USB port on the box (or an extension cable if box is mounted in remote location).
- Aside from initial hardware assembly and programming, the ONSPEED WiFi and the optional M5 visual display are updated using WiFi.
- The two Wifi boards (ESP32-PICO-D4 in the ONSPEED box and M5Stack-Core-ESP32 in the optional M5 visual display) use different versions of the ESP32 library and must be configured IAW with the steps below to compile correctly. **Compiling WiFi .ino files is not normally required.** Instructions are included for advanced users.

Download ONSPEED Software from GitHub

NOTES

- **Libraries must be up to date before configuring boards and loading software.**
- The delete/replace technique in steps 5 and 6 ensures duplicate file copies aren't created (Mac). Duplicate library files will prevent PRJC Teensy 3.6 (OnSpeed_AHRS.ino) from compiling.

1. www.github.com/flyonspeed/OnSpeed-Gen2
2. Click on green CODE button
3. Download zipped file
4. Move downloaded file to desired location and unzip
    a. Folder named OnSpeed-Gen2-master will be created.
5. Open the SOFTWARE folder inside the OnSpeed-Gen2-master folder

   a. Open the ARDUINO folder
6. Navigate to DOCUMENTS using File Explorer (Windows) or Finder (Mac)
   a. Open the ARDUINO folder
   b. Find the LIBRARES folder
      i. Delete the current LIBRARIES folder
      ii. Move new LIBRARIES folder from the SOFTWARE folder into the ARDUINO folder in Documents

PRJC Teensy 3.6 Update Using Cable

1. Open the OnSpeed-Gen2-master folder
   a. Open the SOFTWARE folder
   b. Open the OnSpeedTeensy_AHRS folder
   c. Scroll down to OnSpeedTeensy_AHRS.ino file
   d. Click on the file: The Arduino/Teensyduino IDE opens
      i. Software settings may be changed prior to upload, as desired. This is not normally required (See Appendix H).
2. Set board to Teensy 3.6
   a. Select Tools
   b. BOARDS > Teensyduino > Teensy 3.6
   c. USB TYPE > Serial
   d. CPU SPEED > 180 MHz
   e. OPTIMIZE > Faster
3. Connect the laptop to the ONSPEED micro-USB port using appropriate cable
   a. LED will begin to flash
4. Select UPLOAD (Green circled arrow button on the left-hand side of the green bar at the top of the Teensyduino window)
   a. Software COMPILES and then UPLOADS: there is a progress bar in the lower green bar at the bottom of the Teensyduino window. Compiling and uploading may take up to two minutes. Be patient.
   b. The Teensy boot loader icon appears during load in a separate window. It also shows load progress.

CAUTION

- **DO NOT DISCONNECT cable during upload.** If the cable is disconnected during upload, it will be necessary to remove the ONSPEED box, disassemble and use the reset button on the PRJC Teensy 3.6 to restore normal system operation.

NOTE

- During upload, the LED "freezes." It may freeze on or off. This is normal. LED operation will resume after reboot following load.

5. **PRJC Teensy 3.6 software upload is complete when "Done Uploading" appears on the left side of the lower green band in the Teensyduino window, Reboot OK appears on the Teensy boot loader app window and normal pulsing LED operation resumes.**
6. Disconnect cable

OnSpeed_AHRS.ino Fails to Compile

1. If first compile/upload fails, try again. Occasionally a glitch will occur, and a second attempt is all that is required.
2. Check board type is set correctly.
3. Verify Libraries folder in Documents was updated (using remove/replace NOT copy/paste).

ONSPEED WiFi Gateway Firmware Update Using WiFi

NOTES

- WiFi updates use binary files (.bin) downloaded from GitHub in the ONSPEED SOFTWARE folder.
- **It is *not* necessary to use the Arduino/Teensyduino IDE to update.**
- On Macs, .bin files have a zip file icon. This is normal.

CAUTION

- Only one device should be connected to the ONSPEED network at a time. If you have multiple devices in range, disable WiFi (e.g., phones, tablets, laptops, etc.).

1. Power up the ONSPEED system using ship's power, a laptop or battery connected to the micro-USB port.
2. Connect to the ONSPEED network
    a. Password: angleofattack (one word, all lower case)
3. Open internet browser on laptop
    a. Type onspeed.local in the address line
4. The ONSPEED WiFi Gateway home page opens
5. Select TOOLS
    a. Select UPGRADE WiFi
    b. Select CHOOSE FILE

i. Navigate to OnSpeed-Gen2-master folder
ii. Open SOFTWARE folder
iii. Open OnSpeedWiFi folder
iv. Select OnSpeedWiFi.ino.pico32.bin file

c. Select UPLOAD
i. Upload may take up to 60 seconds. A progress bar will appear. Be patient.

6. After upgrade is complete, verify firmware load
   a. Teensy and WiFi firmware version numbers appear on the top line of the ONSPEED WiFi Gateway home page.
7. Reboot system by powering off and on

Optional M5 Visual Display WiFi Update

NOTES

1. WiFi updates use binary files (.bin) downloaded from GitHub in the ONSPEED SOFTWARE folder.
2. **It is *not* necessary to use the Arduino/Teensyduino IDE to update.**
3. On Macs, .bin files have a zip file icon. This is normal.

1. Power up the M5 Display using ship's power, a laptop or battery connected to the USB-C port on the left side of the display.
2. Momentarily press the red reset button on the left side of the display
   a. System reboots
   b. Fly ONSPEED Display opens for 3 seconds
3. Press center button within 3 seconds
   a. The FIRMWARE UPGRADE SERVER display opens
   b. Software version displayed in lower left screen
4. Connect the laptop to the OnSpeedDisplay network
   a. Password: angleofattack
5. Open internet browser on laptop
   a. For Windows: Type 192.168.0.2 in the address line
   b. For Mac: Type display.local/upgrade in the address line
6. The M5 Display WiFi upgrade page opens
   a. Select CHOOSE FILE
      i. Navigate to OnSpeed-Gen2-master folder
      ii. Open SOFTWARE folder
      iii. Open OnSpeed_M5_display folder
      iv. Select OnSpeed_M5_display.ino.m5stack_core_esp32.bin file
   b. Select UPLOAD
      i. Monitor upload progress on M5 display. Upload takes approximately 30-40 seconds. Be patient.

ii. Display automatically reboots when upload is complete. If the ONSPEED box is also powered, a normal display will appear. If only the M5 display is powered, a "NO DATA" with red X display will appear.

7. Reboot by turning system power off then on

ONSPEED Software/Firmware File, Board and Library Configuration Quick Reference			
Board	**Folder**	**File**	**Library**
v3 Teensy 3.6 (CPU)	OnSpeedTeensy_AHRS	OnSpeedTeensy_AHRS.ino	Downloaded from GitHub
v3 ESP32-PICO-D4 (WiFi)	OnSpeedWifi	OnSpeedWifi.ino	esp32 Espressif Systems Version 1.0.6
M5Stack-Core-ESP32 (WiFi)	OSoeed_M5_display	OnSpeed_M5_display.ino	esp32 Espressif Systems Version 2.0.0
Note: All software and firmware use version **1.8.16** of the Arduino IDE and **1.55** of the PRJC Teensyduino software. Newer versions have not been tested and may not work correctly.			

Appendix F: PRJC Teensy 3.6, WiFi Board and M5 Firmware Updates (Expanded Discussion)

The Arduino software must be set-up on a laptop (Windows or Mac) before loading or managing ONSPEED system software and firmware (See Appendix G: Setting up the Arduino IDE).

Arduino 101

Downloading and setting up the Arduino/Teensyduino IDE is not easy for non-experienced users. It's covered in Appendix G. Using the Arduino/Teensyduino IDE to program and update the ONSPEED system can also be difficult. This software provides a tremendous amount of system adaptability and capability. These instructions are written for first-time users with no programming experience.

What is "compiling?" A "compiler" is a program that translates the Arduino programming code into language that the CPU and WiFi chips understand. The ONSPEED code is written using the Arduino/Teensyduino IDE, compiled, and THEN uploaded. Any time the software fails to compile, it will not upload, usually because a board type or library isn't set properly. The Arduino/Teensyduino IDE has a compile function that allows you to check software prior to uploading. That is the round, check mark icon in the upper left of the command bar at the top of the display (Figure 26). If you click on this icon, the software will compile but not upload. As implied by the design of the icon, the purpose of this function is to simply check to see everything is set correctly.

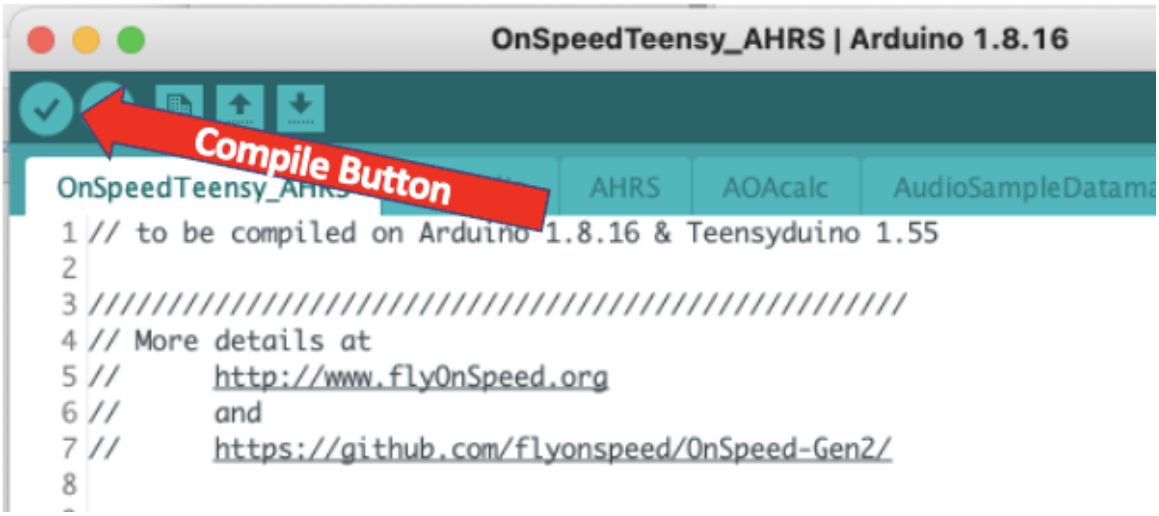


Figure 26. The compile icon in the Arduino IDE.

NOTES

1. It is not necessary to compile software prior to uploading. If you select the upload button (round arrow icon immediately to the right of the compile "check" icon), software will compile and then upload.
2. **Compiling and uploading are not instantaneous and may take up to a minute.** Progress information is provided in the lower green bar. Be patient.

What is a "Board?" A board is a device that requires software or firmware to run. The ONSPEED system has two programmable boards in the V3 box and a third in the optional M5 visual display. Boards may be colloquially referred to as "chips." The Arduino IDE uses a "boards manager" to set the type of board the software is programming. A common error is having the wrong type of board selected when trying to compile. The Onspeed System uses three different boards: the PRJC Teensy 3.6 (main processor); the ESP32-PICO-D4 WiFi (WiFi board in the ONSPEED box) and the M5Stack-Core-ESP32 in the optional visual display. To change a board type, use a TOOLS > BOARD > BOARD MANAGER flow. This works on either a Windows computer or Mac—the difference is where you find the TOOLS menu. On Windows machines, the main menu is on the top line of the open window, on a Mac it's at the top of your screen. The Arduino/teensyduino IDE always displays the current board selected in the lower right portion of the window. (Figure 27)

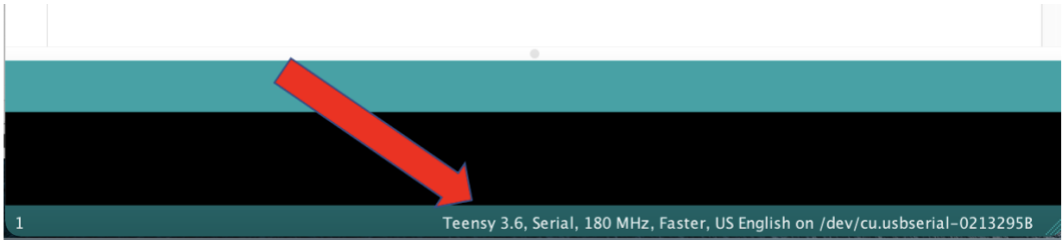


Figure 27. Arduino/Teensyduino Window, board configuration, lower right corner.

NOTES

1. The Arduino IDE automatically saves the last board type programmed. Prior to compiling software, it is good practice to ensure board type is set correctly.
2. It is only necessary to change board type from Teensy 3.6 if it's necessary to export a compiled binary file to update the v3 or optional M5 visual display WiFi boards. Current binary files are available for download from the ONSPEED GitHub site, so it shouldn't normally be necessary to perform this function.

What is a "library?" The easiest way to understand a library is to think of it as a chunk of code that performs a specific function. This saves the software engineer time—they don't have to write the code for that function, just cross-reference the library to perform the task. It's dependent on the correct library being available for cross-reference. If it's not, the code will not compile. Libraries are constantly being updated, so version control is important. There is only

one library that we must actively manage when programming the ONSPEED system: The ESP32 library used for compiling WiFi code. The WiFi board in the v3 box uses a different version of the library than the optional M5 visual display.

NOTES

1. The Arduino IDE automatically saves the last library programmed. When changing board type, it is good practice to ensure library version is set correctly.
2. It is only necessary to change the ESP library if it's necessary to export a compiled binary file to update the v3 or optional M5 visual display WiFi boards. Current binary files are available for download from the ONSPEED GitHub site, so it shouldn't normally be necessary to perform this function.

Compiling Instructions. Each ONSPEED software or firmware .ino file downloaded from GitHub has instructions for compiling on the first line. These instructions can be confusing. The following table shows the version settings required for compiling. Detailed instructions for downloading software, changing boards and libraries follows below.

ONSPEED Software/Firmware File, Board and Library Configuration Quick Reference			
Board	**Folder**	**File**	**Library**
v3 Teensy 3.6 (CPU)	OnSpeedTeensy_AHRS	OnSpeedTeensy_AHRS.ino	Downloaded from GitHub
v3 ESP32-PICO-D4 (WiFi)	OnSpeedWifi	OnSpeedWifi.ino	esp32 Espressif Systems Version 1.0.6
M5Stack-Core-ESP32 (WiFi)	OSoeed_M5_display	OnSpeed_M5_display.ino	esp32 Espressif Systems Version 2.0.0
Note: All software and firmware use version **1.8.16** of the Arduino IDE and **1.55** of the PRJC Teensyduino software. Newer versions have not been tested and may not work correctly.			

Table 1. ONSPEED Software and Firmware Board and Library Configurations.

Deselect the push notification option in the Arduino IDE preferences (Figure 28). Once the Arduino/Teensyduino software is set up in accordance with Appendix G, it is not necessary to accept updates. To access preferences on a Windows computer, select FILE, then PREFERENCES. To access the preference on a Mac, click on "Teensyduino" in the main command line at the top of the screen and select PREFERENCES.

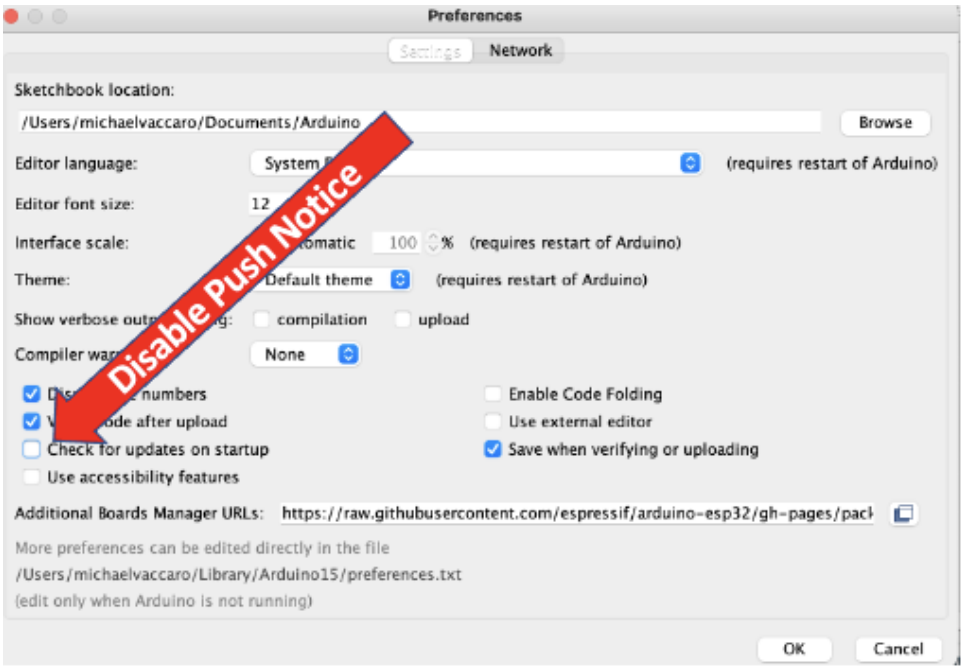


Figure 28. Do not accept Arduino updates after everything is set-up.

What is the difference between "software" and "firmware?" Our engineers consider the Teensy code (OnSpeed_AHRS.ino) to be software, since it must be compiled and uploaded to the box using the Arduino IDE and a cable. WiFi upgrades are performed using binary files uploaded via WiFi. A binary file is only readable by a computer and contains executable code. The Arduino IDE can compile and export binary files. Our engineers consider a binary update to be "firmware" since the user simply uploads the file. Unless it's necessary to customize a firmware setting, binary files can be downloaded directly from the ONSPEED GitHub site and used without modification.

Why don't we update to the latest version of Arduino and Teensyduino IDE? It hasn't been tested and may not work correctly. Think of the development environment as "frozen in time." The ONSPEED software and firmware may work with newer code, but we simply don't know. If you use newer versions, we cannot provide support, but would appreciate knowing what you learned at team@flyonspeed.org.

ONSPEED Software Management Big Picture

ONSPEED software (OnSpeed_AHRS.ino) is provided for the PRJC Teensy 3.6 CPU and software (binary files) are provided for the ESP-Pico WiFi chip and optional M5 visual display. PRJC Teensy 3.6 software upgrade is always accomplished using the Arduino/Teensyduino IDE software and a cable from a laptop to the micro-USB connector on the front face of the ONSPEED box. After initial programming (newly built hardware only) with a cable, the ESP-Pico WiFi board in the ONSPEED box is updated using the ONSPEED WiFi Gateway and the optional M5 visual display

firmware updates are accomplished using a simplified WiFi gateway. Advanced users may change a setting in the WiFi code, set up boards and libraries appropriately and export a revised binary file, as required. Normal users simply update the WiFi firmware using binary files provided on GitHub.

Waiex Installation. Due to remote mounting of the ONSPEED box under the glare shield, a USB cable is provided and tied up underneath the instrument panel. This cable should be used for PRJC Teensy 3.6 software update. It may also be used to power the system via Laptop or battery, if desired.

STEP 1: Download Software Update from GitHub.com (Windows and Mac)

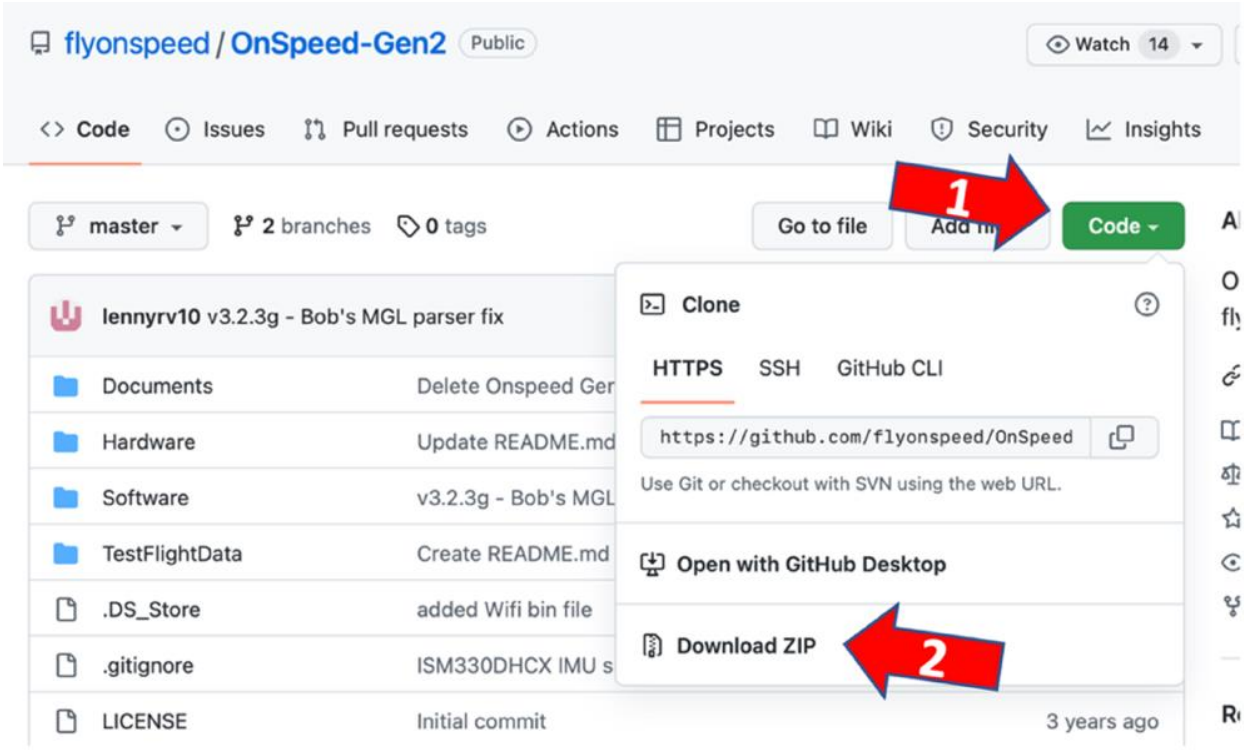


Figure 29. Downloading current software and firmware from GitHub.

All required software and firmware are distributed via GitHub. Software and firmware are updated from time to time. Navigate to https://github.com/flyonspeed/OnSpeed-Gen2 to download software. To download software, click on the green CODE button, then click on the DOWNLOAD Zip option (Figure 29). A zip file will be downloaded into the browser. Transfer the zip file from the browser download to the desired location and unzip it. A video of how to download the software from GitHub may be viewed here: https://youtu.be/FETsl_BXYEs.
When unzipped, a folder named OnSpeed-Gen2-master will be created. Move the folder to the desired directory and open it (Figure 30 Mac Finder View and Figure 31 Windows File Explorer View). Only the sub-folder named "Software" is required for update.

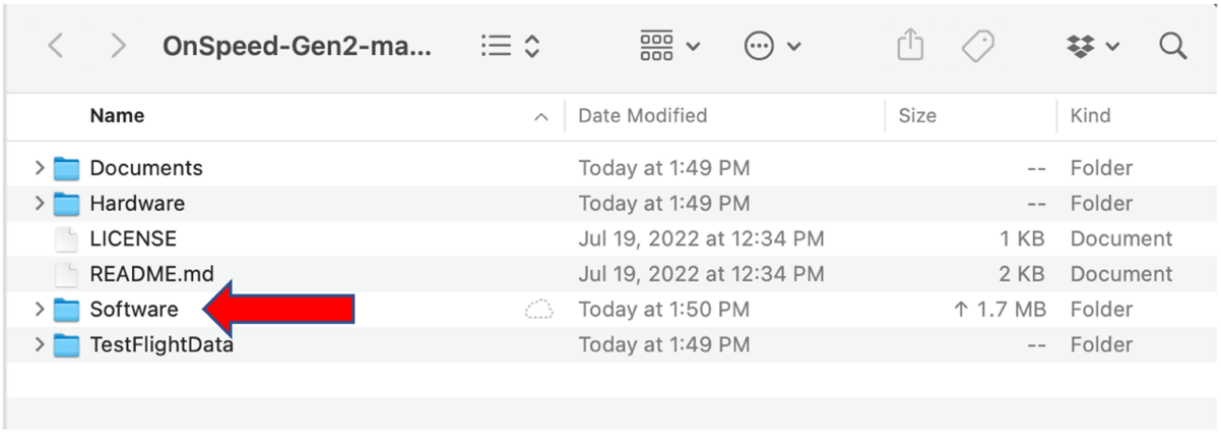


Figure 30. Downloaded, unzipped OnSpeed-Gen2-master folder (Mac).

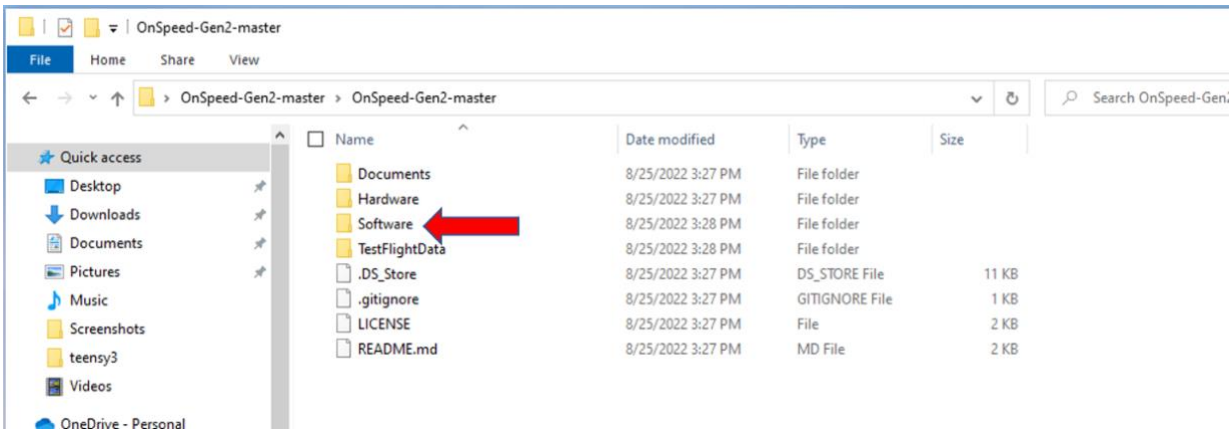


Figure 31. Downloaded, unzipped OnSpeed-Gen2-master folder (Windows).

STEP 2: Arduino Library Update Mac

Before updating Teensy software, it is necessary to ensure libraries are up to date. If libraries are not current, the software won't compile. To update libraries, locate and remove the old LIBRARIES folder move the new LIBRARIES folder from the downloaded SOFTWARE folder to replace it:

1. Open Finder
2. Select Documents
3. Open Arduino folder
4. Find "libraries" folder, right click, and send to trash
5. Open new SOFTWARE folder
6. Move new "libraries" folder into the Arduino folder in Documents

This procedure is shown graphically in Figures 32 and 33. Libraries are now up to date. This procedure is used in lieu of a copy/paste to avoid possible file duplication on Apple computers. If duplicate files are present in the folder, the software will not compile correctly.

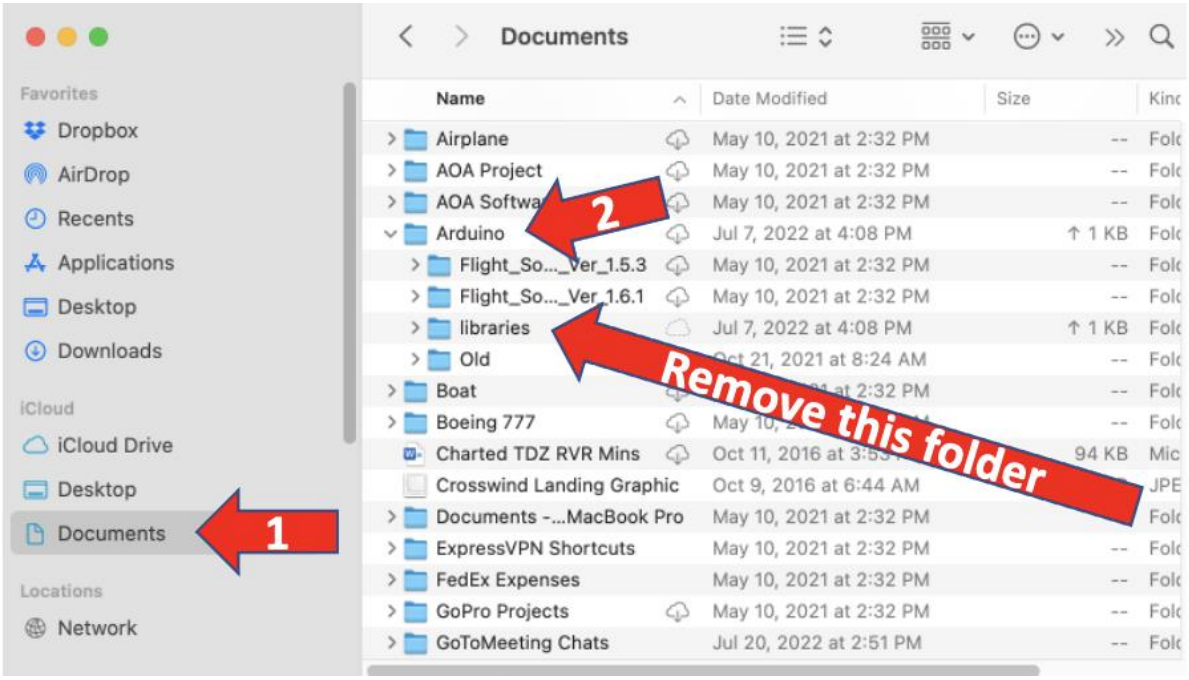


Figure 32. Locate and remove old "libraries" folder (Mac): Documents > Arduino > right click on libraries folder and send to trash (Mac Finder).

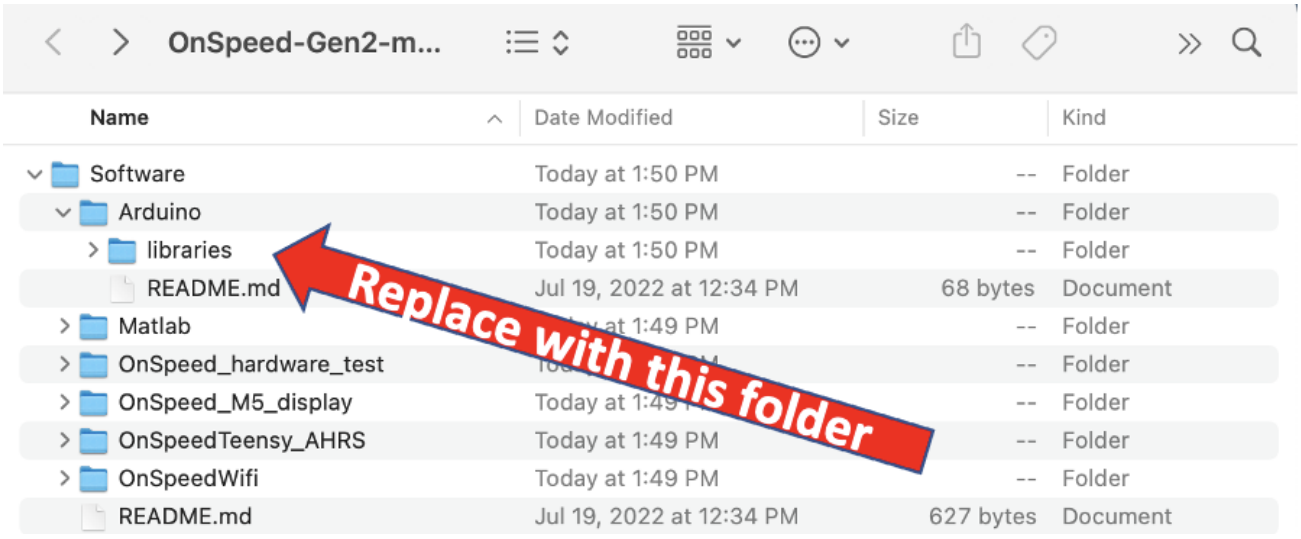


Figure 33. Move the new "libraries" folder into the Arduino folder in Documents (Mac Finder).

STEP 2: Arduino Library Update Windows

Before updating Teensy software, it is necessary to ensure libraries are up to date. If libraries are not current, the software may fail to compile. To update libraries, locate and remove the old LIBRARIES folder move the new LIBRARIES folder from the downloaded SOFTWARE folder to replace it:

1. Open File Explorer
2. Select Documents
3. Open Arduino folder
4. Find "libraries" folder, right click, and delete
5. Right click on OnSpeed-Gen2-master folder downloaded from GitHub
6. Open SOFTWARE folder
7. Find new "libraries" folder
8. Move new "libraries" folder to the Arduino folder in Documents

This procedure is shown in Figure 34. Libraries are now up to date. While not strictly necessary in Windows to remove/replace the "libraries" folder, this technique allows a common procedure for Windows and Mac laptops utilized in the Software Update Checklist in Appendix E.

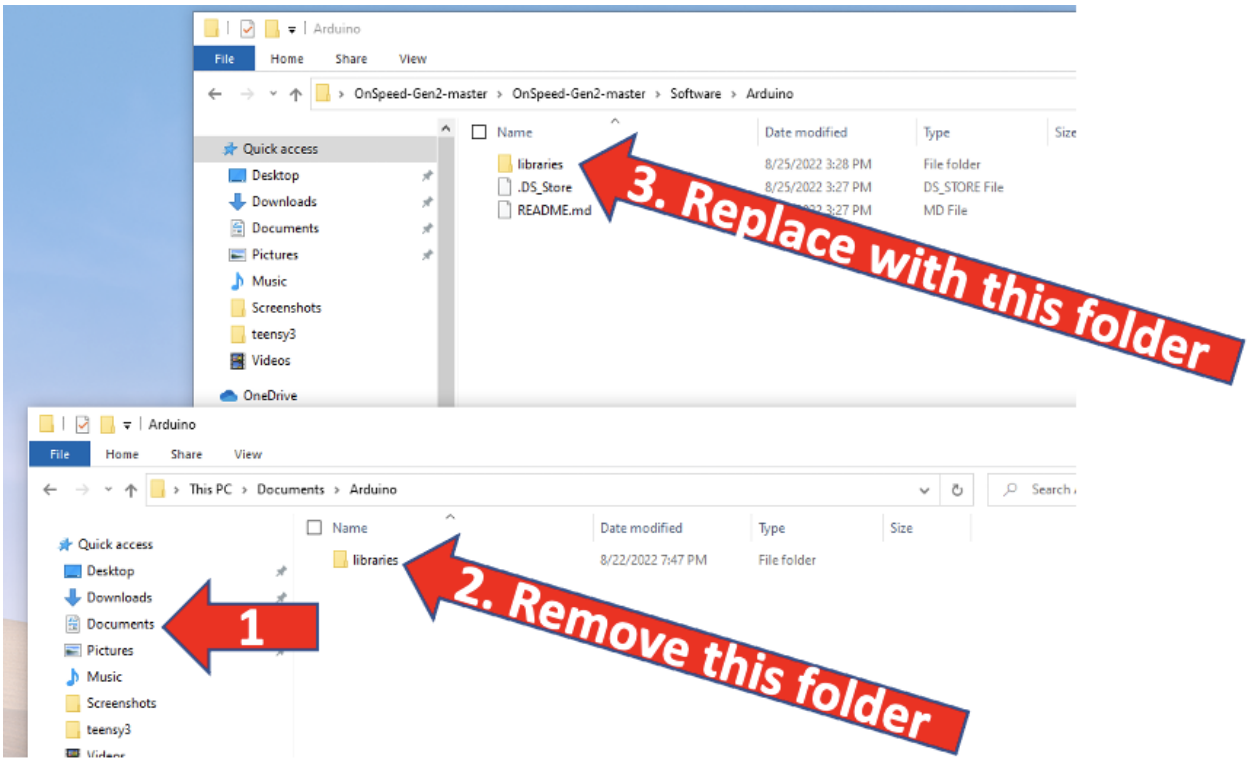


Figure 34. Delete old "libraries" folder and move new "libraries" folder to Documents (Windows File Explorer).

PRJC Teensy 3.6 Software Update (Windows and Mac)

Software for the PRJC Teensy 3.6 CPU is contained in the "OnSpeedTeensy_AHRS" sub-folder. To begin the Teensy software update process, open the OnSpeedTeensy_AHRS folder. Figure 35 shows OnSpeed-Gen2-master > Software > OnSpeedTeensy_AHRS in Finder (Mac). Figure 36 shows OnSpeed-Gen2-master > Software > OnSpeedTeensy_AHRS in File Explorer (Windows). **There are many files in the OnSpeedTeensy_AHRS folder, scroll down to find the OnSpeedTeensy_AHRS.ino file** (Figures 37 and 38).

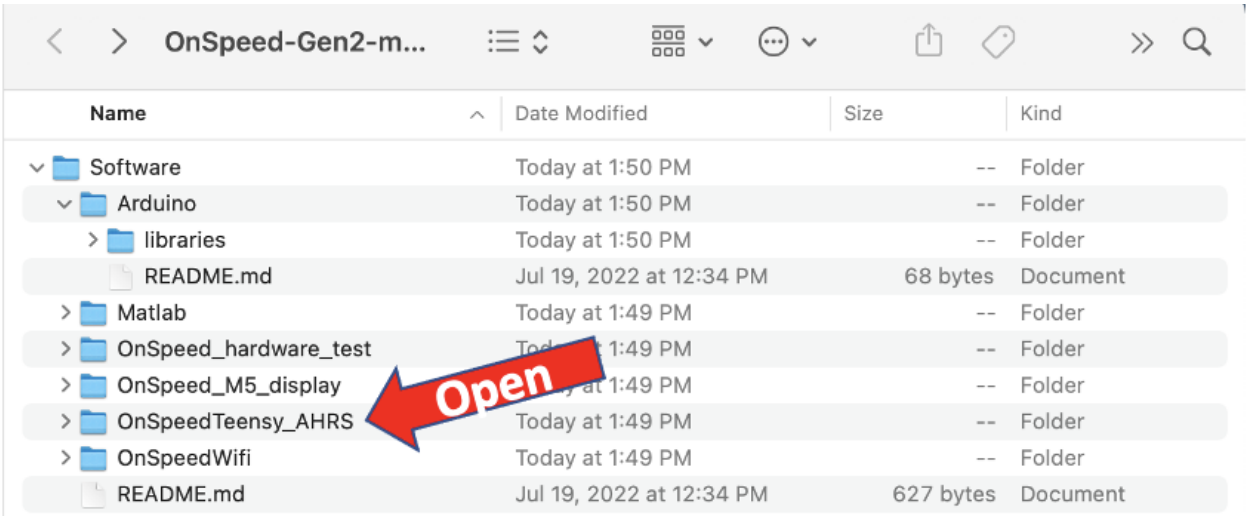


Figure 35. Open the OnSpeedTeensy_AHRS folder in Finder (Mac Finder).

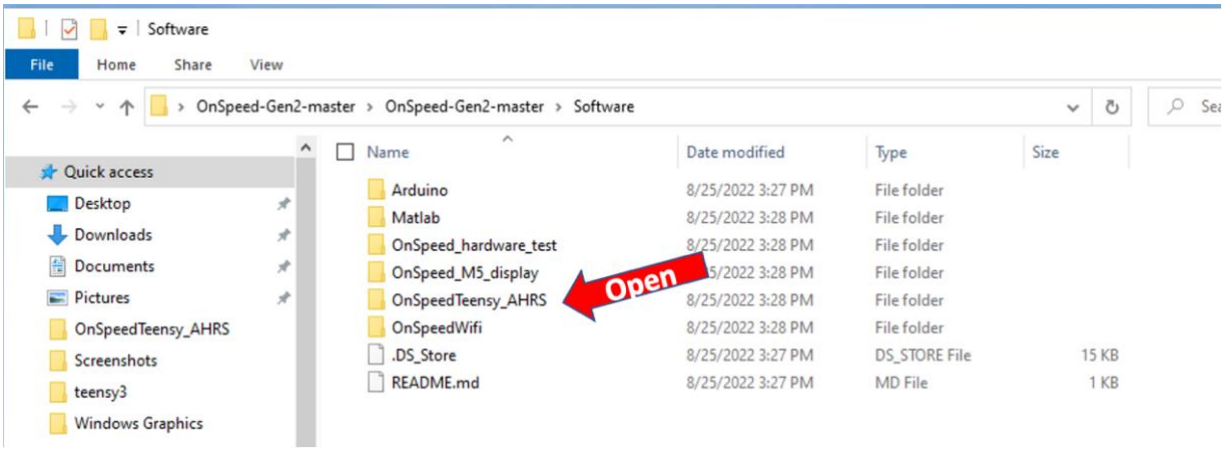


Figure 36. Open the OnSpeedTeensy_AHRS folder in File Explorer (Windows File Explorer).

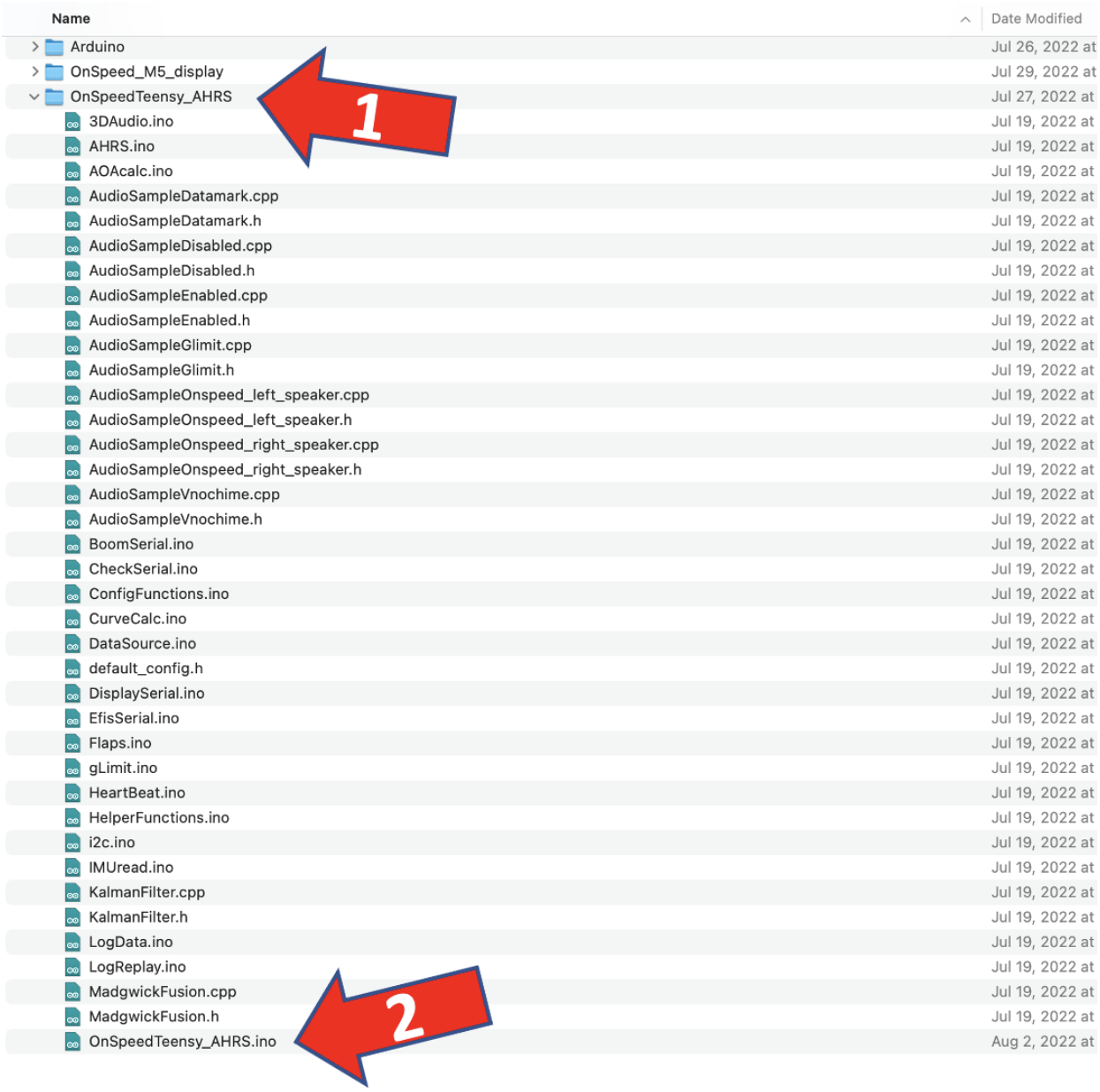


Figure 37. The OnSpeedTeensy_AHRS.ino in the OnSpeedTeensy_AHRS folder (Mac Finder). This folder contains many files.

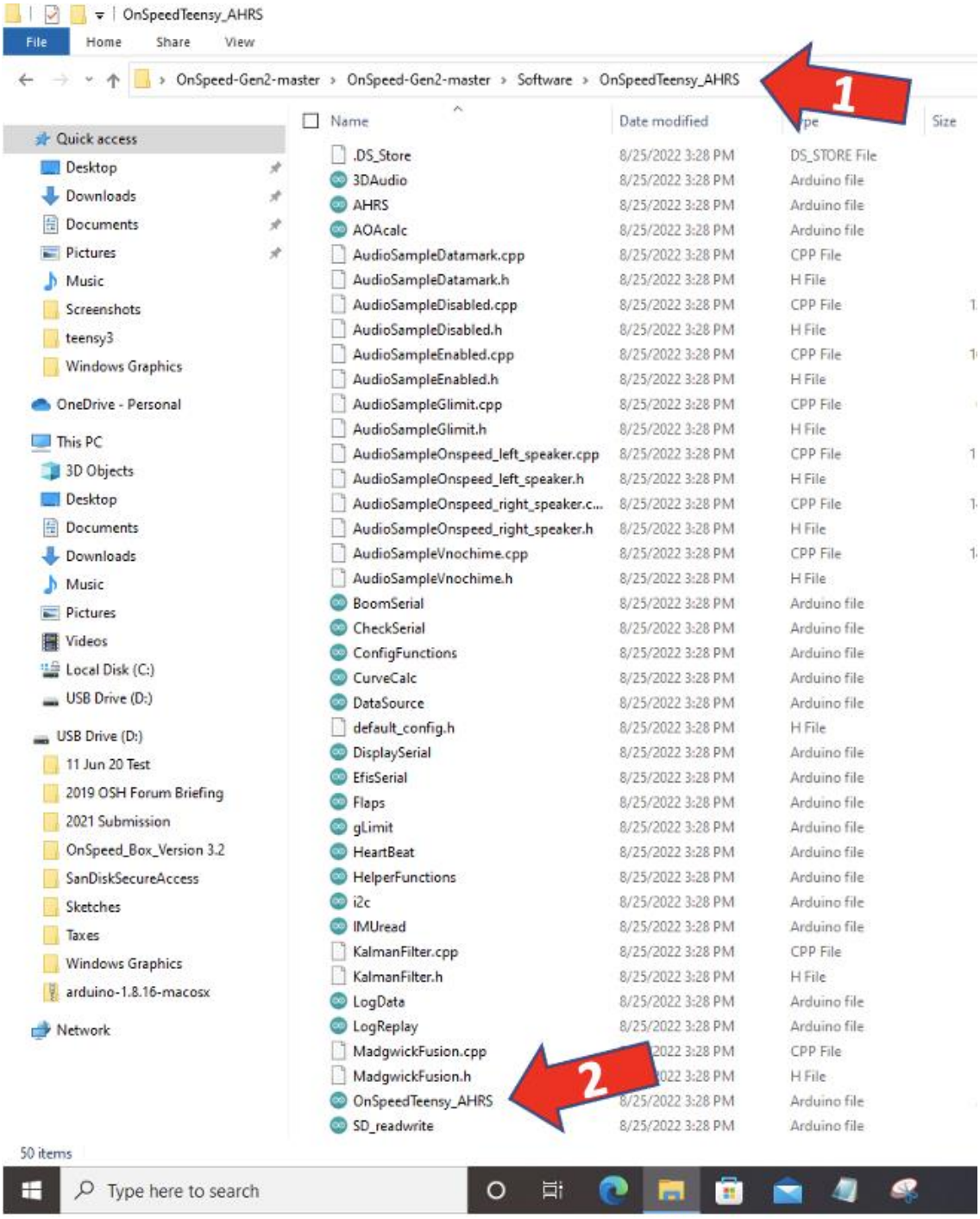


Figure 38. The OnSpeedTeensy_AHRS.ino in the OnSpeedTeensy_AHRS folder (Windows). This folder contains many files.

Open the OnSpeedTeensy_AHRS.ino file. The Arduino software will boot, and the OnSpeedTeensy_AHRS tab will open (Figure 39).

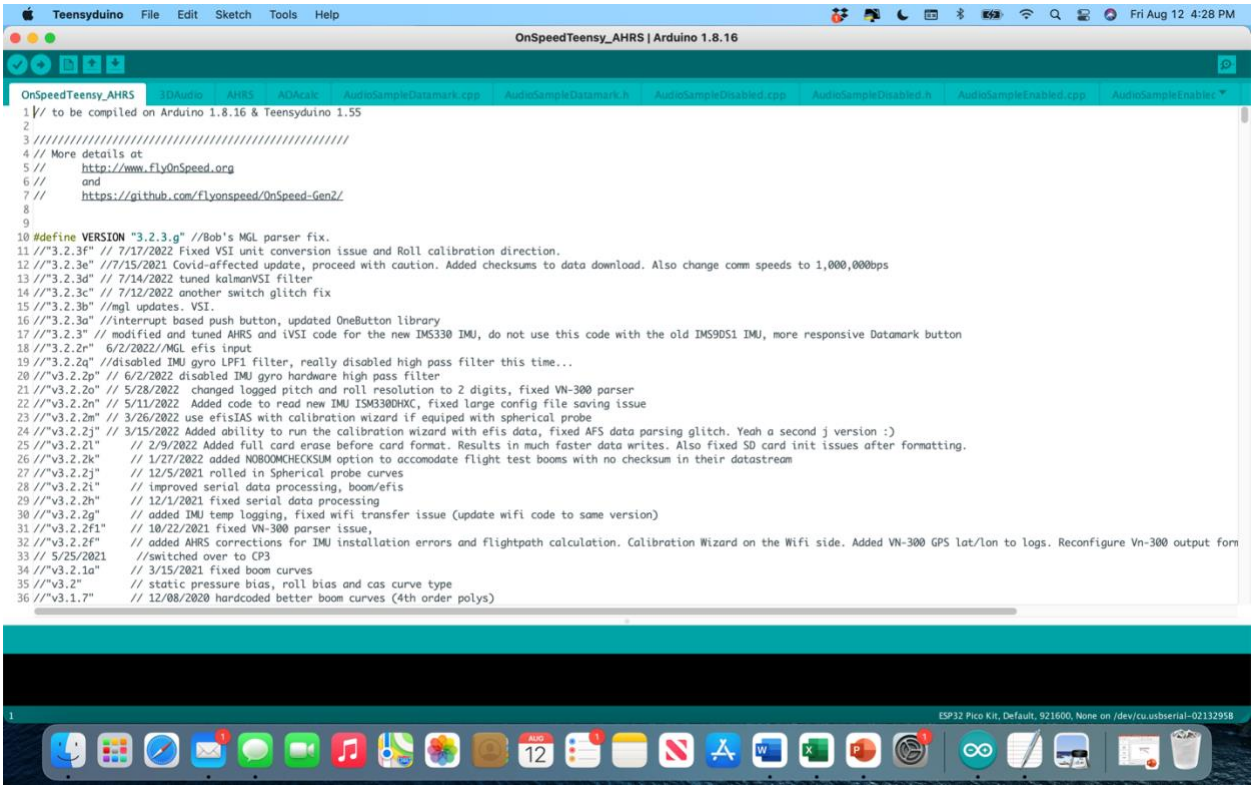


Figure 39. OnSpeedTeensy_AHRS.ino open, OnSpeedTeensy_AHRS Tab.

NOTES

1. The Arduino/teensyduino IDE is the same on a Mac or Windows computer except for the command line. On a Mac, the command line is at the top of the home screen, and correctly installed software is titled "Teensyduino." On a Windows computer, the command line is at the top of the window and is titled "Arduino."
2. **When using the Arduino/teensyduino IDE, the top line of the first tab in the OnSpeedTeensy_AHRS.ino always contains the versions of software and/or libraries to be used for compiling.**
3. Don't see line numbers on the left?
    a. Mac: Click on Teensduino in command line on the top of the screen. Select PREFERENCES. When PREFERENCE window opens, select DISPLAY LINE NUMBERS.
    b. Windows: Open the Arduino software. Select FILES. Select Preferences. When PREFERENCE window opens, select DISPLAY LINE NUMBERS.
    c. **The line numbers will change with each version of the code.**
4. The ONSPEED software is very versatile and is designed to support flight test operations in addition to normal AOA functionality. It has many advanced user selectable settings.

These are detailed in Appendix H. It is not normally necessary to adjust software settings, however, **any desired adjustments must be made prior to compiling and uploading software**.

Before uploading software, adjust any software settings desired (not common) and edit the default_config.h tab (recommended for all aircraft/uploads). See LOAD DEFAULT BUTTON section for details on how to access and update the default_config.h tab in the Teensy software. It will be necessary to update this tab every time software is updated on a calibrated system, since each aircraft calibration is unique, and software downloaded from GitHub.com will have data for a program test airplane in the default_config.h tab that must be over-written. It is also necessary to update this tab any time a sensor calibration is performed. If this is not accomplished the LOAD DEFAULT BUTTON on the SETTINGS > SYSTEM CONFIGURATION in the WiFi Gateway will not function correctly.

NOTE:

1. The default_config.h tab cannot be updated until an initial calibration is performed and an onspeed.cfg file is created.

Before attempting to upload software, be sure that board is set correctly to Teensy 3.6 (Figure 40).

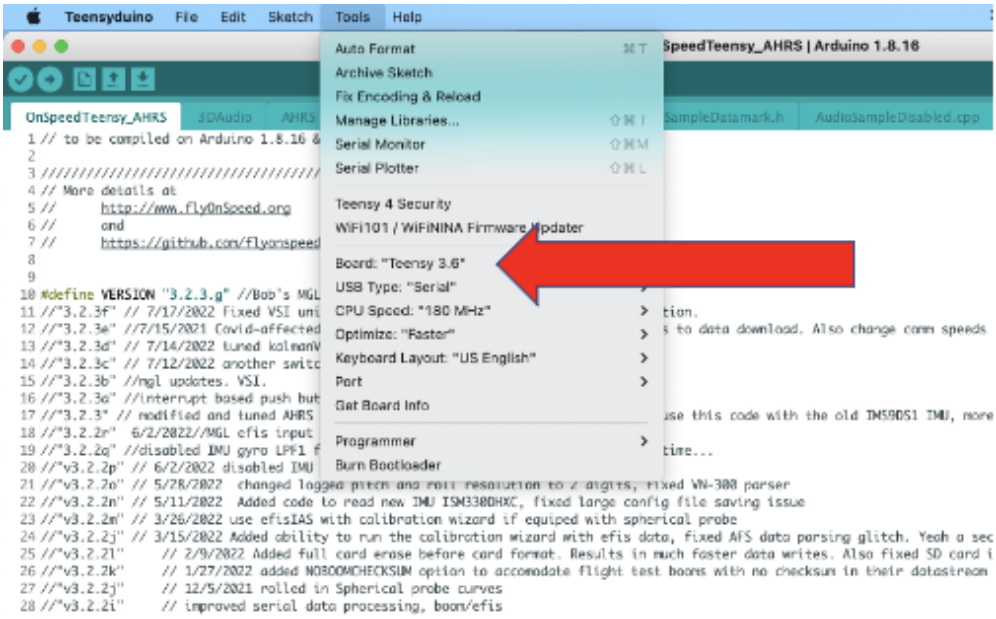


Figure 40. Ensure board is set to Teensy 3.6 prior to upload.

To upload Teensy Software, connect the laptop to the ONSPEED box using a micro-USB cable. The LED on the rotary switch will light and begin pulsing. **Select the green circled arrow in the upper left corner of the Arduino window** (Figure 41) **to upload software. When upload**

sequence is complete, "Done Uploading" will appear on the left side of lower green band in the Arduino window.

CAUTION:

1. **Do not disconnect micro-USB chord during program update.** If the chord is disconnected during upload, it will be necessary to remove the ONSPEED box, open it and push the reset button on the PRJC Teensy 3.6 CPU.

NOTES:

1. Before uploading, the software will compile. This will take approximately 30-60 seconds. There is a progress bar on the lower green band, right hand side of the Arduino window.
2. When upload begins, a small Teensy window opens to show upload progress (Figure 42).
3. During upload, there is also a progress bar on the lower green band, right hand side of the Arduino window.

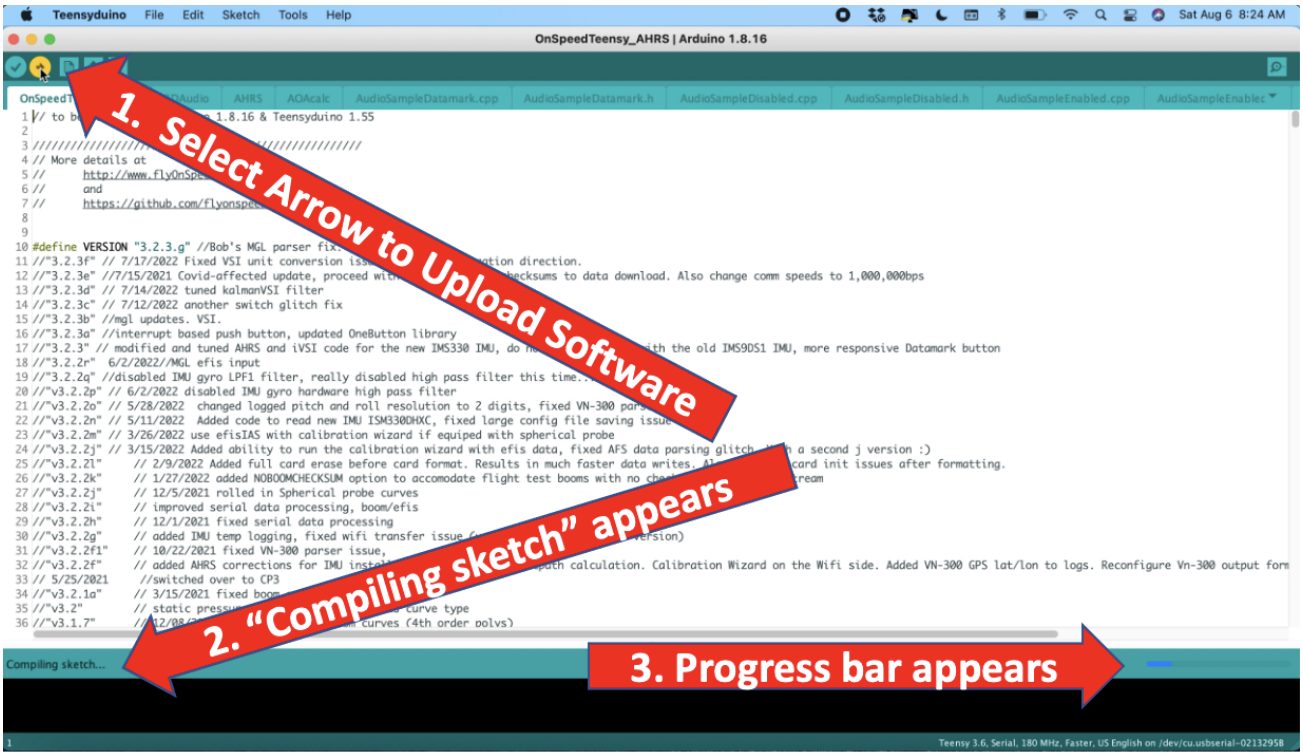


Figure 41. Select green circle arrow to upload Teensy software.

Upload is complete when "Done Uploading" (Figure 43) **appears in lower green band in Arduino window and Teensy boot window displays "Reboot OK"** (Right-hand portion of Figure 42).

Figure 42. Teensy boot window. Opens after file is compiled, prior to upload sequence.

NOTES

1. If software fails to upload on first attempt (lower bar of Arduino turns orange and displays warning), try a second time.
2. If software fails to upload after two or three attempts, check to ensure board is set correctly to Teensy 3.6 and libraries are up to date.

Figure 43. Software upload complete ("Done Uploading" displayed).

WiFi Firmware Update

WiFi firmware is updated using the WiFi Gateway. To connect to the WiFi Gateway, power up the ONSPEED system using ship's power or connect a battery to the micro-USB port. Use a smart

phone, tablet or laptop to connect to the ONSPEED WiFi network (password: angleofattack, one word, all lower case). Open the internet browser and type onspeed.local in the address line. The ONSPEED WiFi Gateway home page will open. To update WiFi firmware, select the UPGRADE WIFI MODULE option on the TOOLS menu. This will open the window shown in Figure 44.

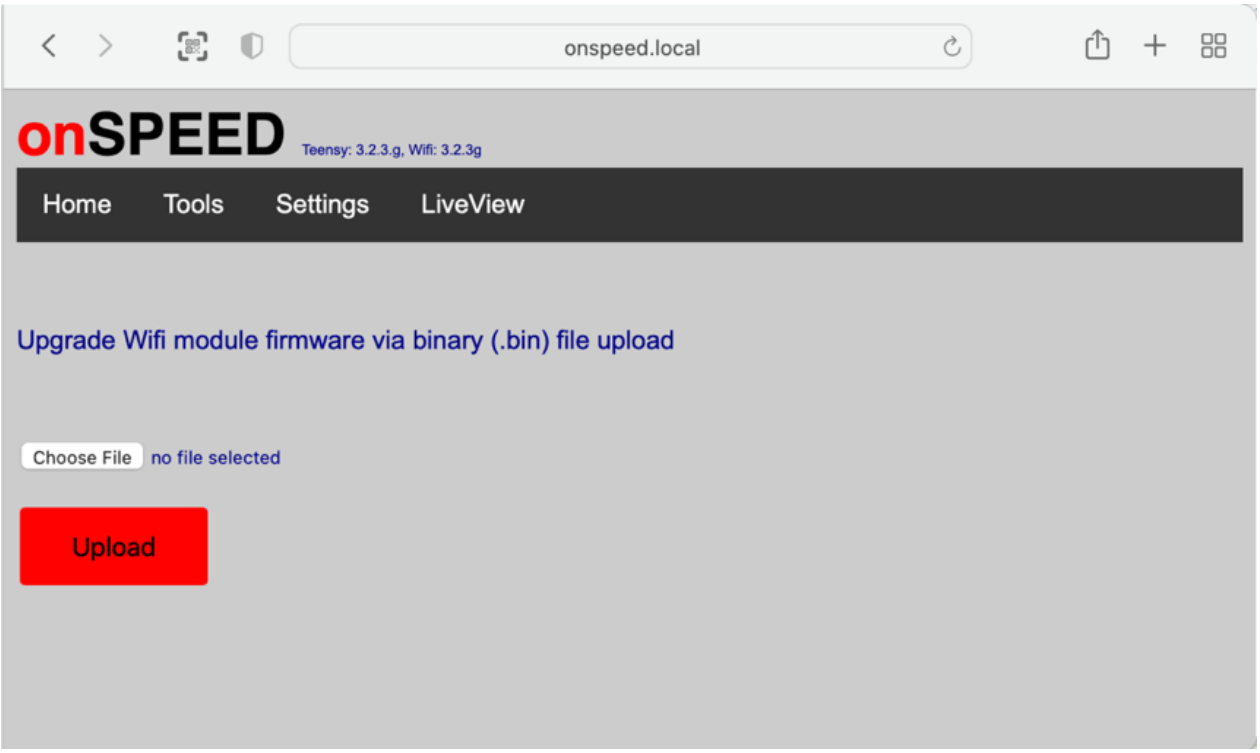


Figure 44. Upgrade wifi module window, browser view.

Open the downloaded OnSpeedWiFi folder (Figure 45 for Mac and Figure 46 for Windows).

CAUTION

1. Be sure to navigate to the "OnSpeedWiFi" folder to find the correct binary file for update (Figures 45 and 46). If the optional M5 visual display binary file is installed accidently (by navigating to the wrong folder), call for tech support.

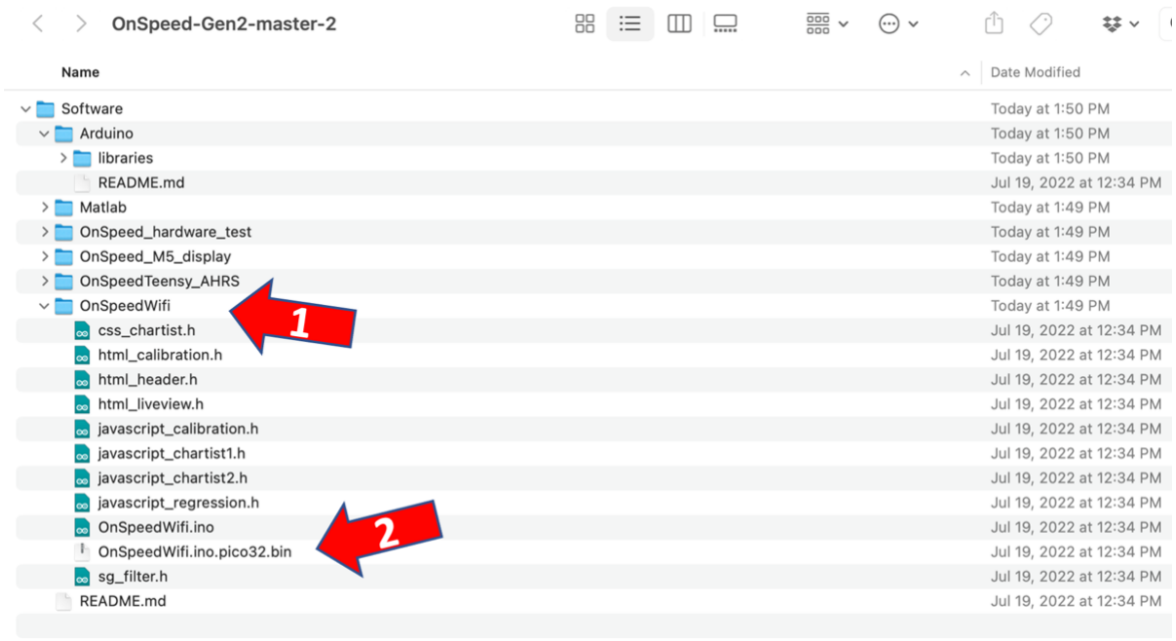


Figure 45. OnSpeedWiFi folder contents (Mac Finder).

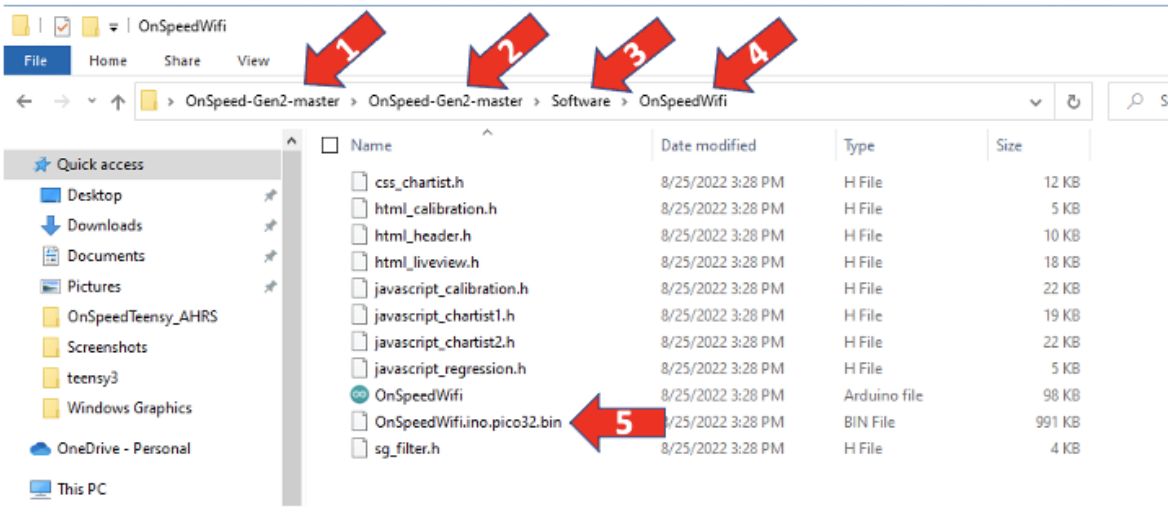


Figure 46. OnSpeedWifi folder contents (Windows File Explorer).

Drag and drop the OnSpeedWiFi.ino.pico32.bin file over the "Choose File" button or click the CHOOSE FILE button to select the .bin file or navigate to the SOFTWARE > ONSPEEDWIFI and select the .bin (binary) file and double click. If you have done this correctly, "no file selected" will change to the name of the .bin (binary) file selected.

NOTE

1. If using a Mac, the OnSpeedWiFi.ino.pico32.bin file will have a zip file icon. This is normal.

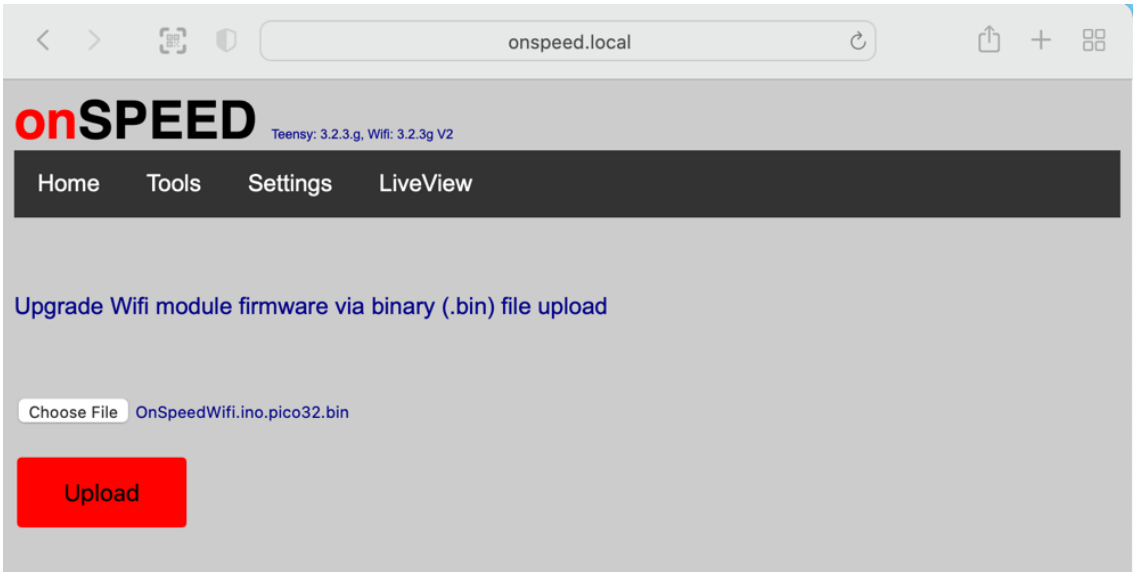


Figure 47. New firmware (.bin file) ready to upload.

Push the UPLOAD button (Figure 47) to begin the upload process. A progress bar will appear during the upload (Figure 48). When upload is complete, the home page will appear and the new version of WiFi firmware will be shown on the top line, right side (Figure 49).

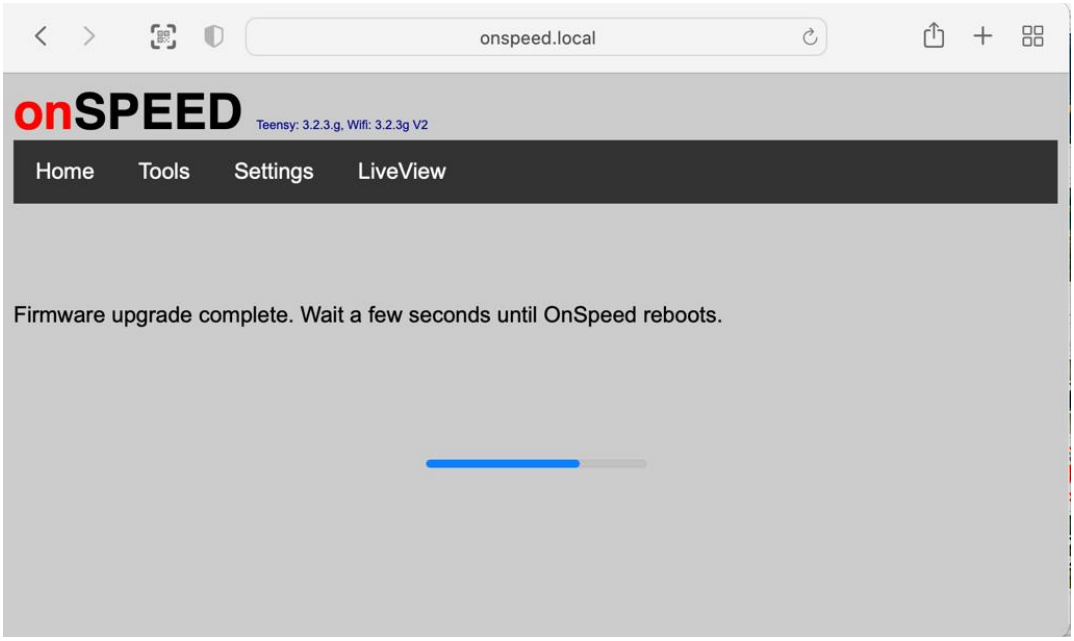


Figure 48. WiFi firmware uploading.

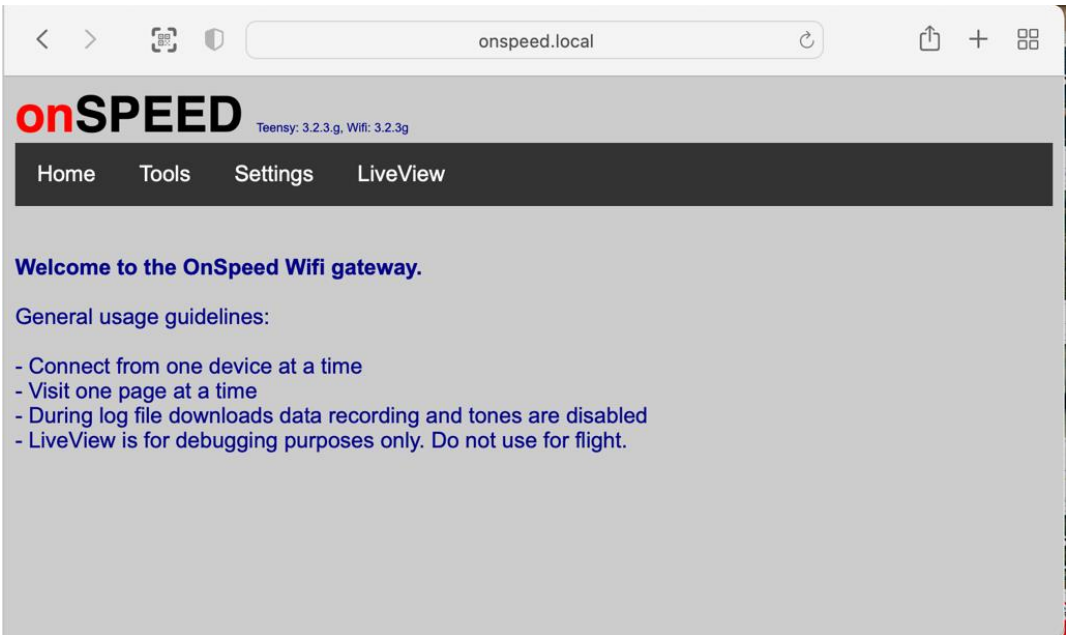


Figure 49. WiFi firm upload complete. New Version number displayed on the right side of the top line.

M5 Visual Display Firmware Update Using WiFi (Not First-time Set-up of New Hardware)

Basic Firmware Update via WiFi. Updating the optional M5 display firmware is like updating the WiFi firmware but is NOT performed using the ONSPEED WiFi Gateway. A simple, stand-alone gateway is used. Other than initial firmware installation (new modified M5 visual display installation), WiFi is the preferred method for upgrading M5 firmware.

To update the optional M5 display firmware, power up the optional M5 display using ship's power, or a laptop or battery connected to the USB-C port on the left side of the unit. Once powered up, momentarily press the red reset button on the left side of the unit. This will force a reboot and the screen in Figure X will appear. Press the center button within 3 seconds. The Firmware Update Server display will open (Figure 50).

NOTE

1. See the next section for initial M5 programming instructions.

Figure 50. Optional M5 Visual Display Reboot Screen.

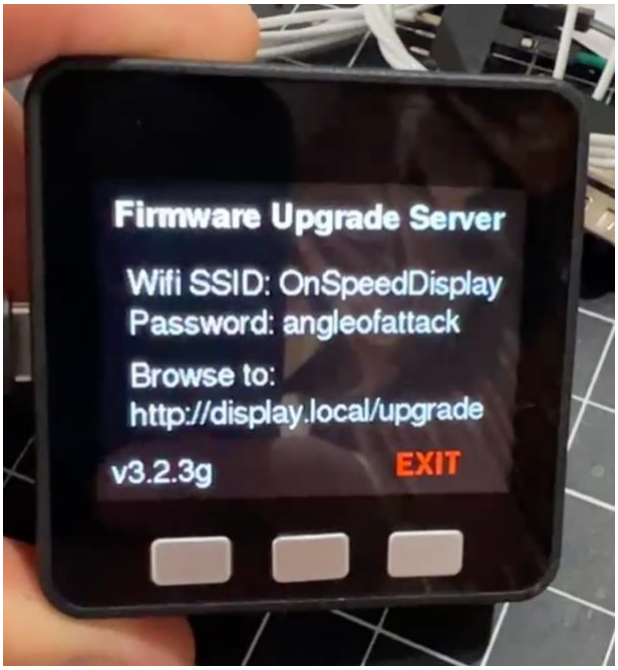


Figure 51. Optional M5 Display Firmware Upgrade Server display. Currently, the browser address shown in the display only works on a Mac. In Windows, type 192.168.0.2.

Use a laptop to connect to the OnSpeedDisplay WiFi network. The password is angleofattack (one word, all lower case). Open the internet browser on the laptop and type "display.local/upgrade" in the address line on a Mac. **On a Windows computer, type 192.168.0.2**

in the address line. A simple window will open on the browser. Figure 52 shows the gateway window on a Mac. On a Windows computer, when the first widow opens (Figure 53), select UPDATE NOW and a second window will open (Figure 54) that looks just like the Mac version in Figure 52.

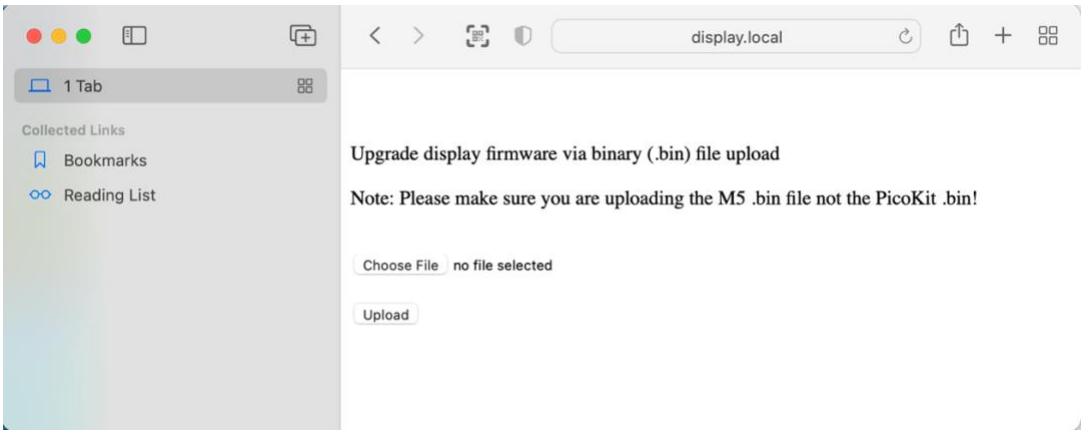


Figure 52. M5 Simplified WiFi Gateway used for firmware upgrade (Mac).

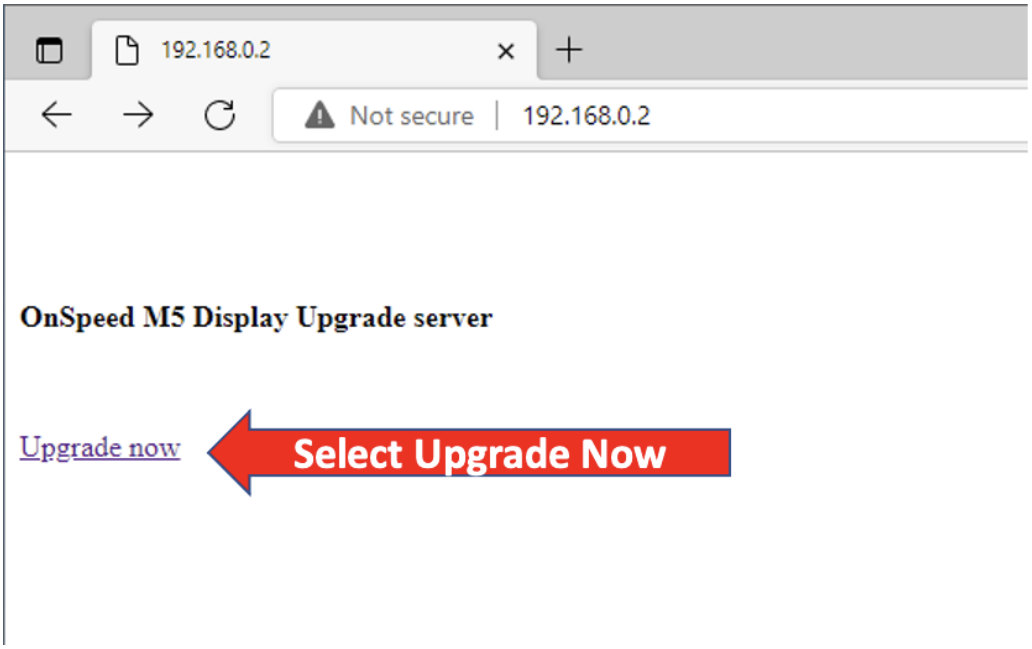


Figure 53. Page 1 of the M5 Simplified WiFi gateway used for firmware upgrade (Windows File Explorer). Select Upgrade now to open page 2.

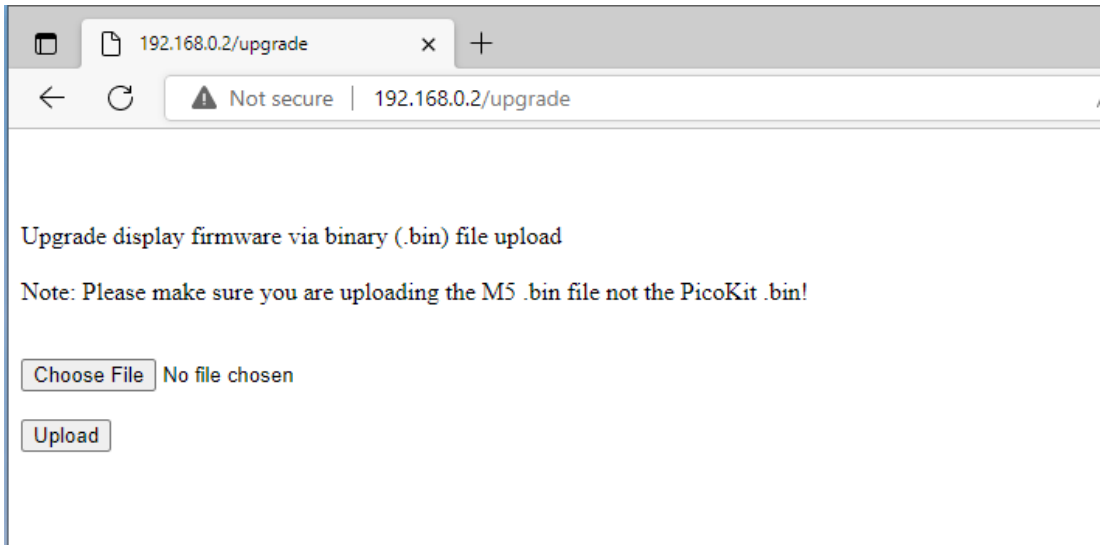


Figure 54. Page 2 of the Windows M5 simplified WiFi gateway (Windows File Explorer).

CAUTION

1. Navigate to the correct "ONSPEED_M5_display" folder to find the binary file for update (Figures 55 and 56). If you accidently upload the OnSpeedWiFi binary update file, call for technical support.

Select the CHOOSE FILE button and navigate to the desired firmware file downloaded from the ONSPEED GitHub site (Figure 55 for Mac and Figure 56 for Windows File Explorer). UPLOAD the OnSpeed_M5_display.ino.M5stack_core_ ESP32.bin file. During upload, the screen will display "Upgrading Firmware, please wait" (Figure 57). Firmware upgrade will take approximately 30-45 seconds. Be patient.

NOTE

1. On a Mac, the .bin file will show a zip file icon. This is normal.

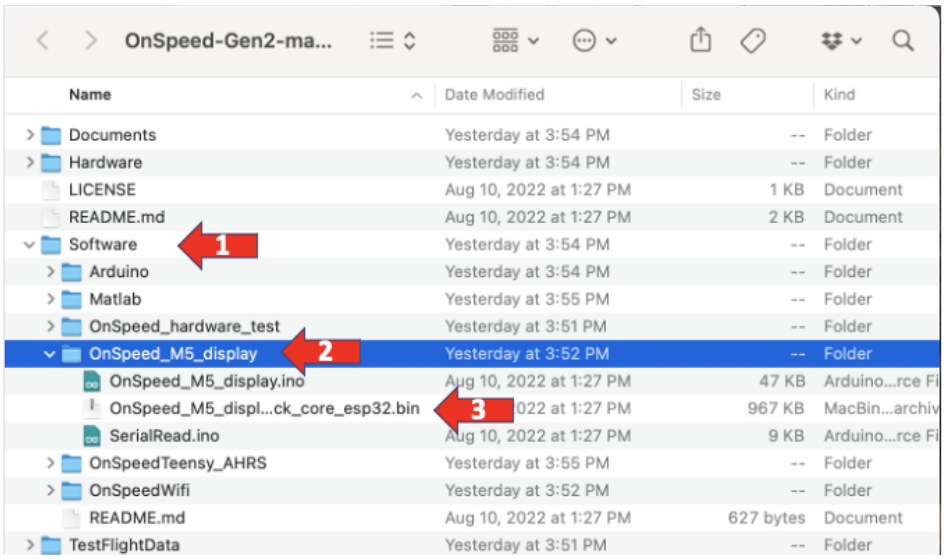


Figure 55. Navigating to optional M5 display firmware update file (Mac Finder).

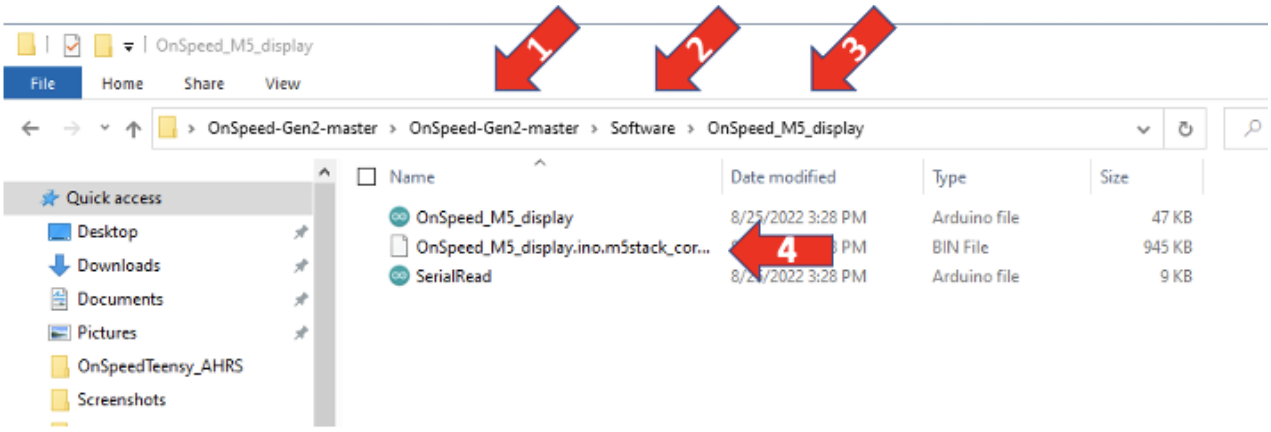


Figure 56. Navigating to optional M5 display firmware update file (Windows File Explorer).

Figure 57. Updating optional M5 display firmware.

M5 Visual Display Firmware Update Using a USB-C Cable (First Time Set-up for Newly Built Hardware)

Initial Set-up. If the optional M5 display is added to an existing system, it must be programmed using a cable for initial programming using the procedure in this section. All subsequent updates may be performed using WiFi as described in the previous section. WiFi update is easier and is recommended for that reason. If WiFi update is not practical, any update may be performed using a USB-C cable using this procedure.

It is necessary to properly configure the Arduino/teensyduino IDE when using the USB-C port to update the display. First, open the Arduino/teensyduino IDE. Select TOOLS from the main menu bar, then select board and BOARDS MANAGER (Figure 58).

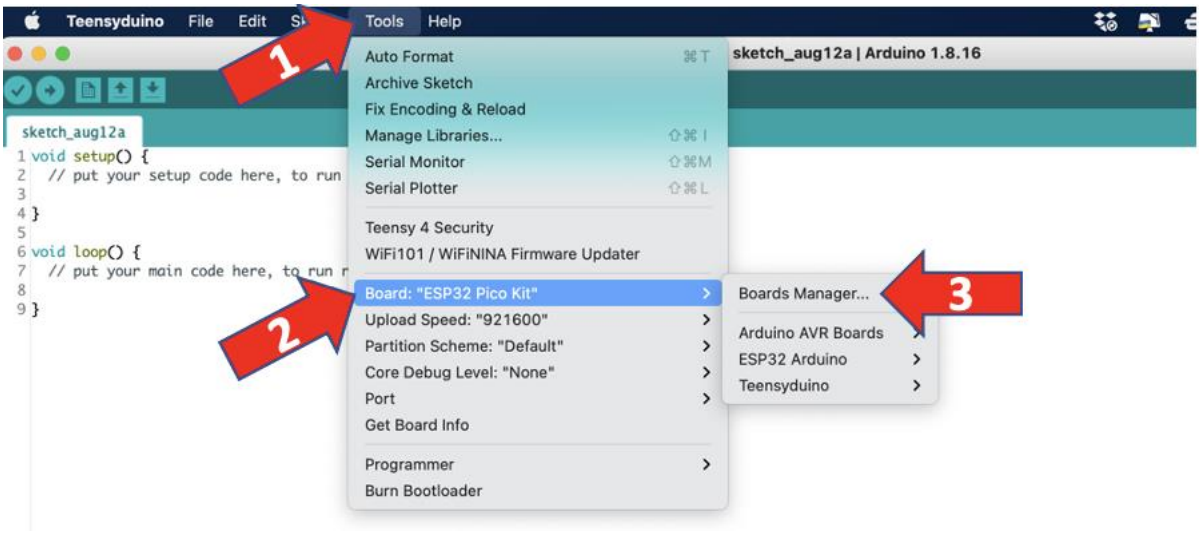


Figure 58. Accessing the BOARDS MANAGER in Arduino/teensyduino IDE.

The Boards Manager Library Window opens (Figure 59). Type "esp32" in the search window. The ESP library will open (look for "Expressif Systems"). Open SELECT VERSION window and select version 2.0.0. Select INSTALL. Verify version number after installation (Figure 60) and CLOSE the boards manager window using the button in the lower right.

CAUTION

1. **The optional M5 Display and the ESP32 WiFi board in the ONSPEED box use DIFFERENT versions of the SAME library.** This can be confusing. Ensure the proper library is set. **If the wrong library is selected, the software for the M5 will not compile correctly.**

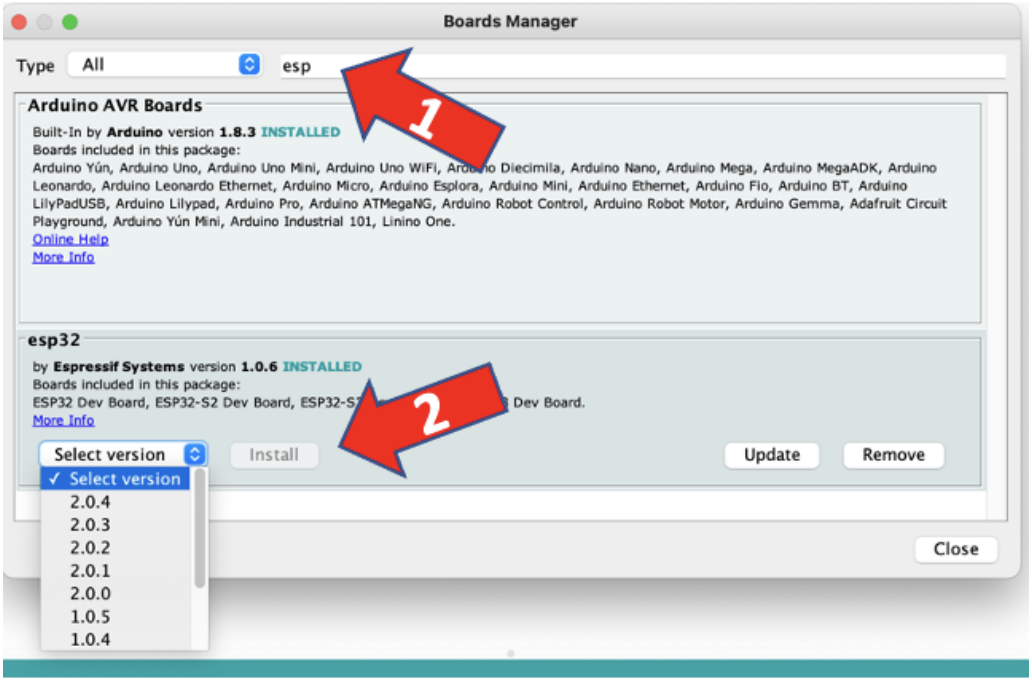


Figure 59. Changing ESP32 board library to Version 2.0.0.

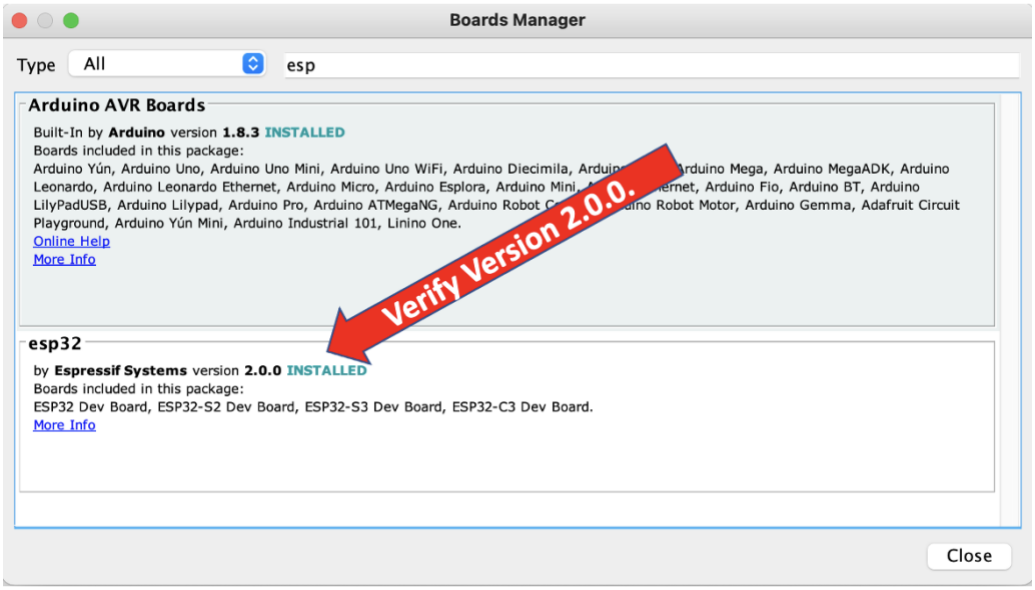


Figure 60. Verify Version 2.0.0.

Once the ESP32 boards manager library has been updated, change the board type to M5Stack-Core-ESP32 (Figure 61). The Arduino/teensyduino IDE is now properly configured to compile and upload the OnSpeed_M5_display.ino file. To load the file, select the green arrow circle on the upper left of the window. The software will compile and then upload. This process will take approximately one minute. A blue progress bar will appear in the lower right. Upload is complete

with "Done Uploading" appears on the left side of the lower green bar in the Arduino/Teensyduino window**. After programming the optional M5 visual display using a USB-C cable, it is recommended that the boards manager ESP32 library be reset to version 1.0.6 and board type be reset to Teensy 3.6 using the procedures shown in Figure 62.** This will ensure the Arduino/teensyduino IDE is properly configured for the next PRJC Teensy 3.6 updates, which occur more frequently than M5 display updates.

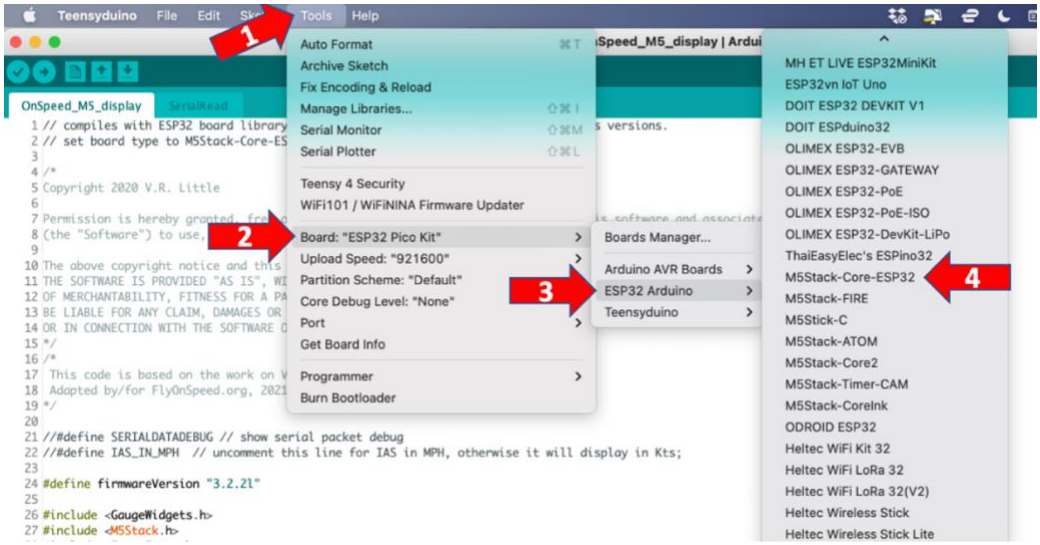


Figure 61. Prior to programming the optional M5 display using a USB-C cable, change the board type to M5Stack-Core-ESP32.

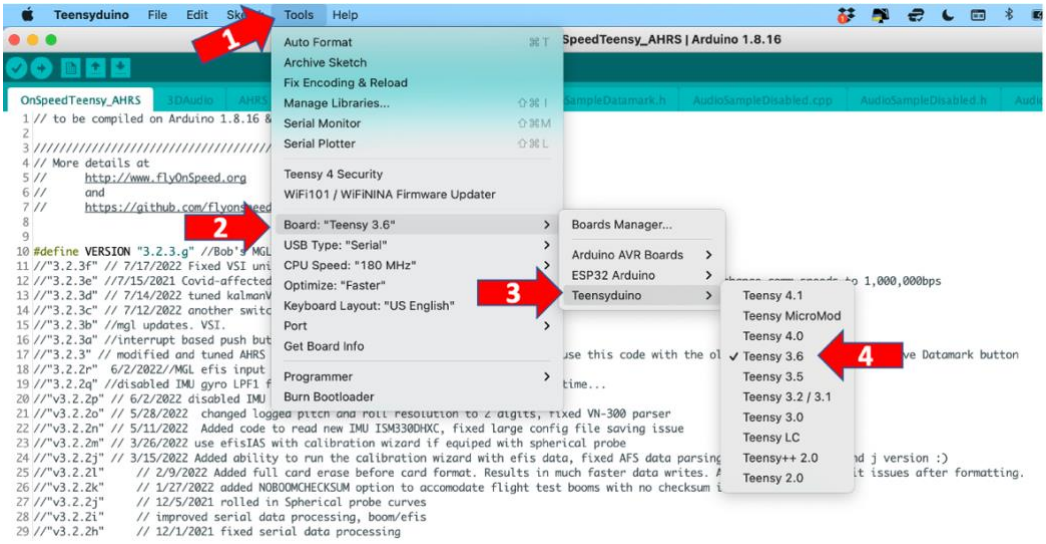


Figure 62. Re-configuring board back to Teensy 3.6 after completing M5 programming.

Appendix G: Setting up the Arduino IDE Prior to First Use (Expanded Discussion)

Prior to programming or updating the ONSPEED software, it is necessary to set up a laptop (Windows or Mac) with the appropriate Arduino and Teensyduino software.

Arduino is open-source electronics prototyping platform. The Arduino/teensyduino IDE is referred to as an integrated development environment (IDE). Code for the ONSPEED system is written in the Arduino IDE. The Arudino/Teensyduino IDE is the primary programming user interface with the ONSPEED system.

CAUTION:

1. **ONSPEED intentionally uses older versions of Arduino (1.8.16) and Teensyduino (1.55) software to ensure system stability.** This software must be downloaded from the internet. These versions work correctly on Windows's and Macs. Testing has not been accomplished with newer versions of Arduino/teensyduino IDE.
    a. Download Arduino version 1.8.16 here: https://www.arduino.cc/en/software/OldSoftwareReleases.
    b. Download Teensyduino version 1.55 here
        i. For Mac: https://www.pjrc.com/teensy/td_155/TeensyduinoInstall.dmg
        ii. For Windows: https://www.pjrc.com/teensy/td_155/TeensyduinoInstall.exe
2. **It is necessary to increase the buffer memory available to serial ports on the Teensy for both Windows machines and Macs.** This procedure is explained in detail below.

First, download the CODE package from our GitHub site: https://github.com/flyonspeed. A video of how to download the software from GitHub may be viewed here: https://youtu.be/FETsl_BXYEs

STEP 1: Download the Arduino software version 1.8.16 and install.

STEP 2: Install Teensyduino 1.55.

NOTE

1. This software customizes the baseline Arduino software for Teensy compatibility. Mac views are shown in figures. Windows installation similar except individual windows will open during installation. Ensure all example files/libraries are selected (check marked).

STEP 3: Open Arduino application.

STEP 4: Set up preferences in Arduino IDE.

1. Open PREFERENCES (Figure 63 and Figure 64)
2. Check DISPLAY LINE NUMBERS option
3. Check VERIFY CODE AFTER UPLOAD option
4. Check SAVE WHEN VERIFYING OR UPLOADING
5. Leave all other options un-checked
6. Copy and paste this address into the "Additional Boards Manager URL" box:
    a. https://raw.githubusercontent.com/expressif/arduino-esp32/gh-pages/package_esp32_index.json
7. Save PREFERENCES and close PREFERENCES window

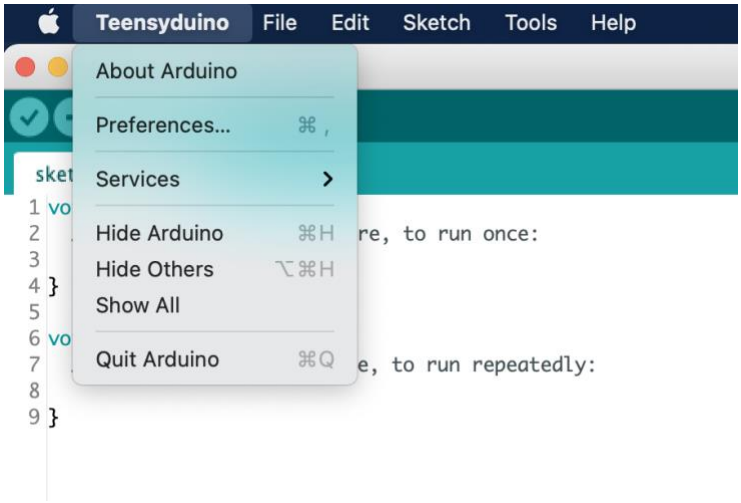


Figure 63. Open Preferences.

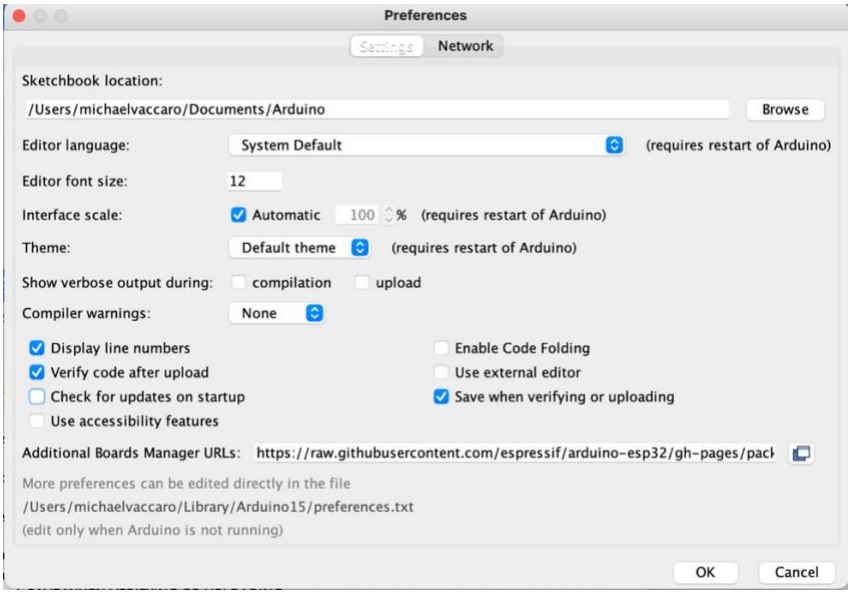


Figure 64. Arduino PREFERENCES window.

STEP 5: Set up the ESP 32 WiFi board in Arduino IDE (Figure 65).

1. Open the TOOLS menu
2. Select BOARD
3. Select BOARD MANAGER

CAUTION

1. **Two different versions of the same ESP library are used. One version (1.0.6) is used when programming the ESP 32 Pico WiFi chip in the ONSPEED box and another version (2.0) is used when programming the optional M5 display.** Wifi software updates are published more frequently than M5 updates, so it is recommended that version 1.0.6 be maintained as the baseline Teensyduino configuration. If ONSPEED WiFi software is accidently compiled using version 2.0.0, post-flight WiFi data download will be much slower.

NOTES

1. Proper set-up of the ESP 32 board manager is ONLY required if you modify the settings and export a new binary (.bin) file. E.g., change WiFi network signal strength or SSID. **This is not necessary for a typical firmware update.**

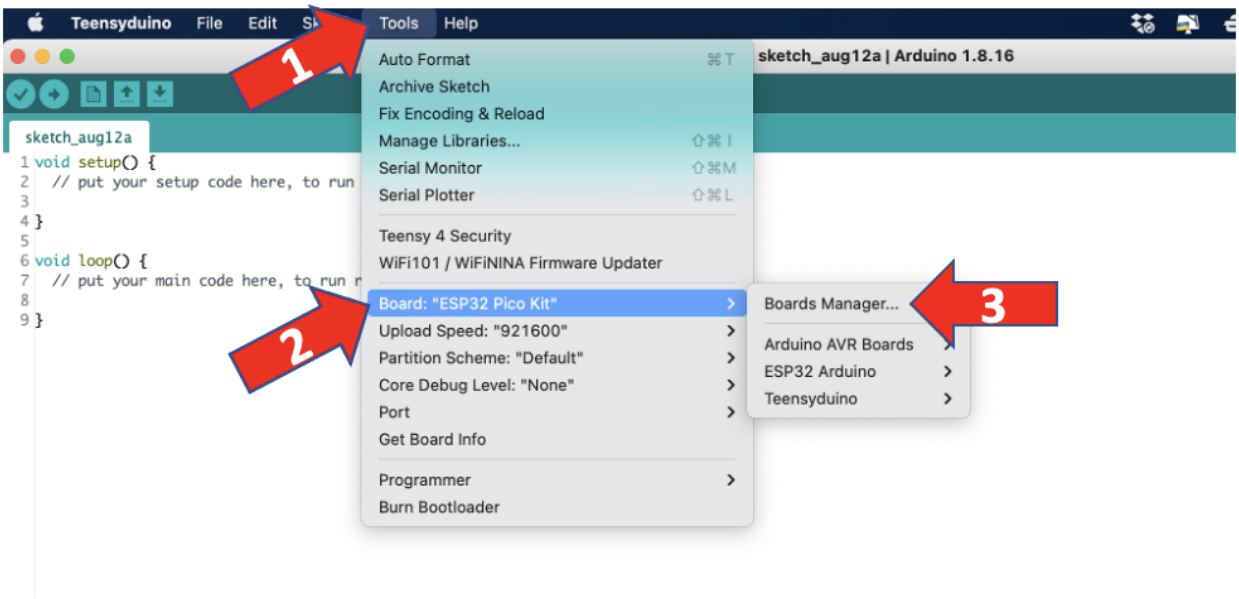


Figure 65. Navigating to the Boards Manager in the Arduino Software.

4. Boards Manager Box Opens (Figure 66)
5. Type "ESP" in search box
6. Go into box labeled ESP32
    a. Look for "Expressif Systems"
7. Select version 1.0.6 from drop down menu for ESP 32 WiFi chip in ONSPEED box

8. Select INSTALL

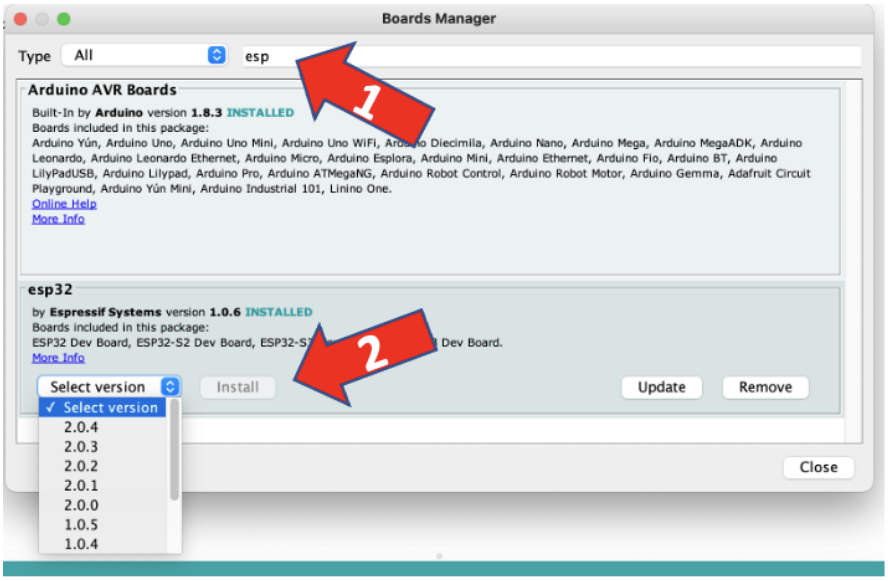


Figure 66. Arduino Boards Manager Selection Window.

NOTE

1. Arduino AVR Boards is automatically installed when the Arduino software is installed. The ONSPEED system does not use any boards on this menu. The only boards used by the ONSPEED system are the "Teensy 3.6," "ESP32 Pico Kit" and optional "M5Stack-core-ESP32" (Version 1.0.6 for the ESP 32 WiFi chip in the ONSPEED box and Version 2.0 for the optional M5 display).

STEP 6: Close Arduino application.

STEP 7 (For Mac): Increase buffer memory available to serial ports on Teensy. This task requires the user to modify text files serial1.c through serial4.c. First, we'll describe the procedure for Mac users, then we'll describe it for Windows users (See STEP 7 for Windows below)

1. In FINDER, click on APPLICATIONS
2. When applications window opens, right click on Teensyduino (Figure 67)
    a. Select SHOW PACKAGE CONTENTS

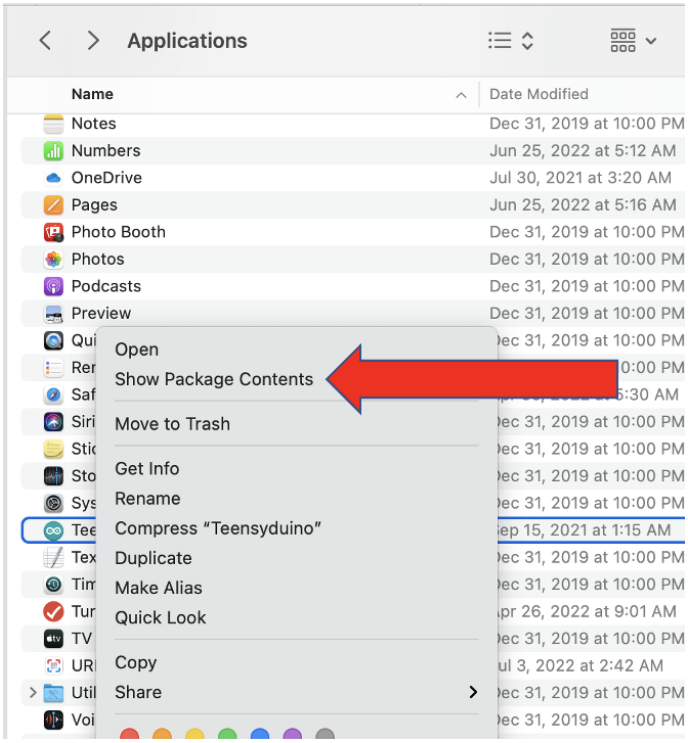


Figure 67. "Show Package Contents" option.

3. Open CONTENTS folder
4. Open JAVA folder
5. Open HARDWARE folder
6. Open TEENSY folder
7. Open AVR folder
8. Open CORES folder
9. Open TEENSY 3 folder
10. Scroll down to serial1.c (Figure 68)
11. Right click on serial1.c (Figure 69)
    a. Click on OPEN WITH
    b. Click on TEXTEDIT. A Text File window will open (Figure 70)

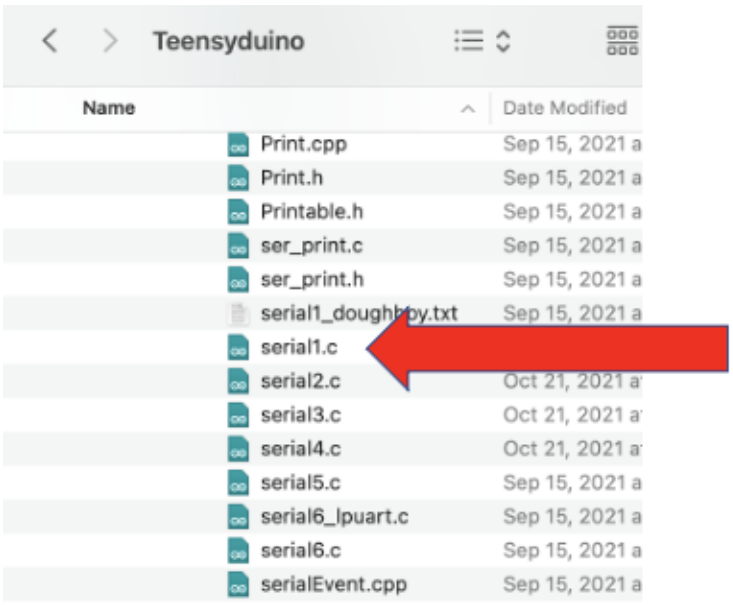


Figure 68. Right click on serial1.c

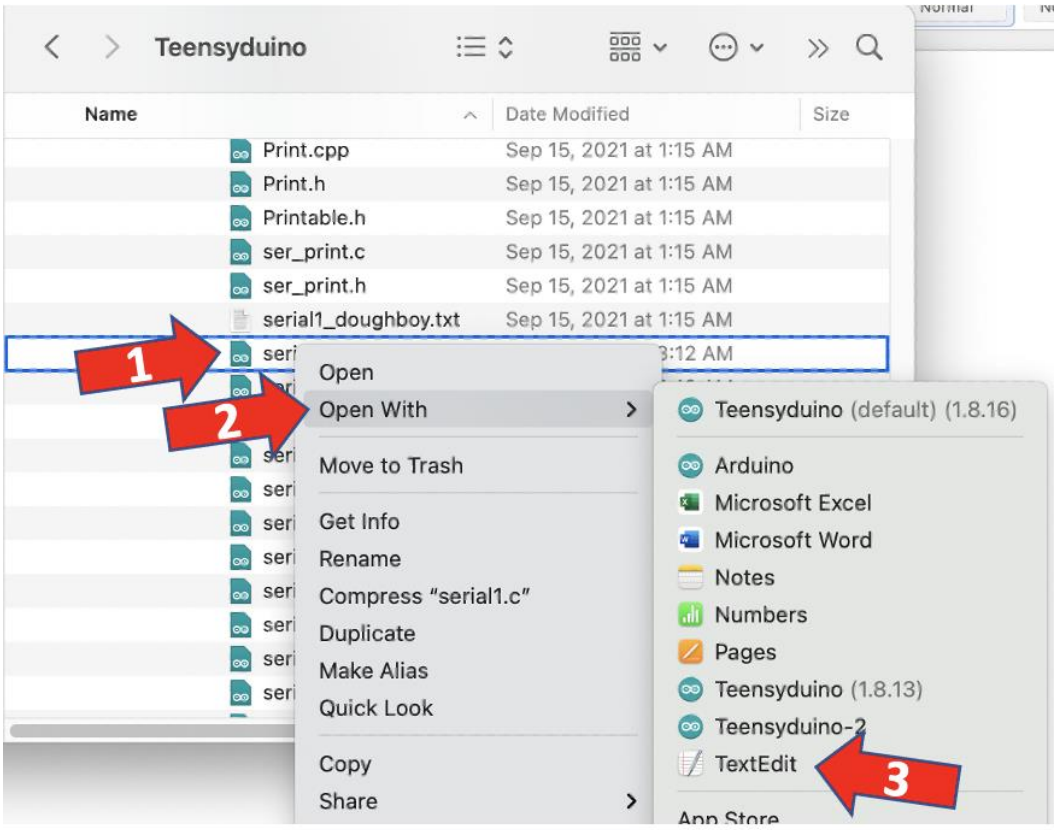


Figure 69. Accessing the serialX.c text file.

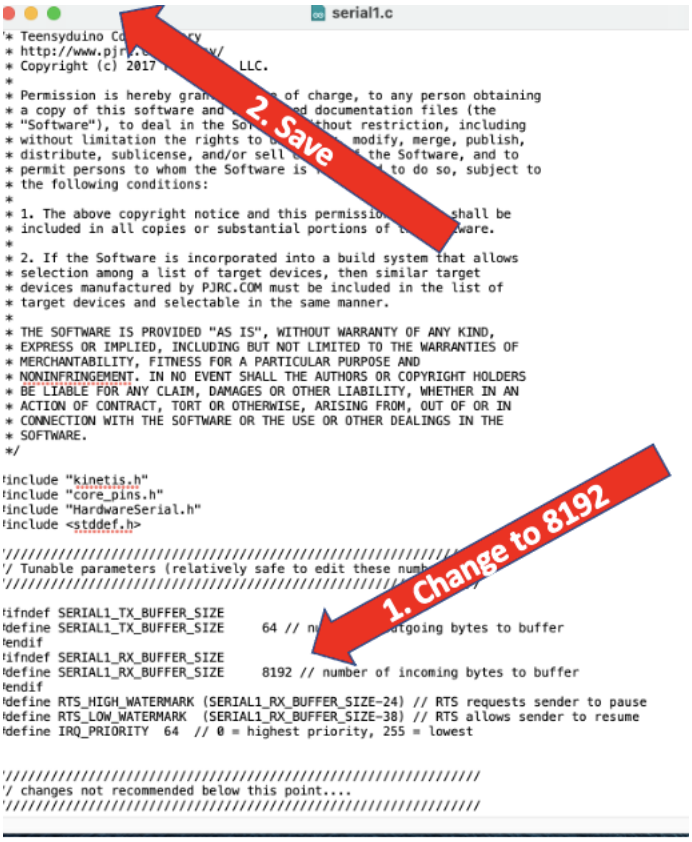


Figure 70. Modifying RX buffer size in text file. Do NOT modify TX buffer size.

c. Change the receive buffer size from 64 to 8192.

CAUTION: Only change the receive buffer. DO NOT change the transmit buffer size. The transmit buffer size is 64 for serial1.c and 40 for serial2.c through serial4.c.

d. **SAVE the file**

12. Repeat this procedure for serial2.c, serial3.c and serial4.c

STEP 7 (For Windows): Increase receive buffer size for serial1.c through serial4.c using text editor.

1. In FILE EXPLORER, select THIS PC
2. Select LOCAL DISK
3. Select PROGRAM FILES (x86)
4. Select ARDUINO
5. Select "hardware"
6. Select "teensy"
7. Select "avr"
8. Select "cores"

9. Select "teensy3"
    a. You will see serial1, serial2, serial3 and serial 4 files in this folder. These are the files you will open with text editor.
10. Select serial1 (Figure 71)

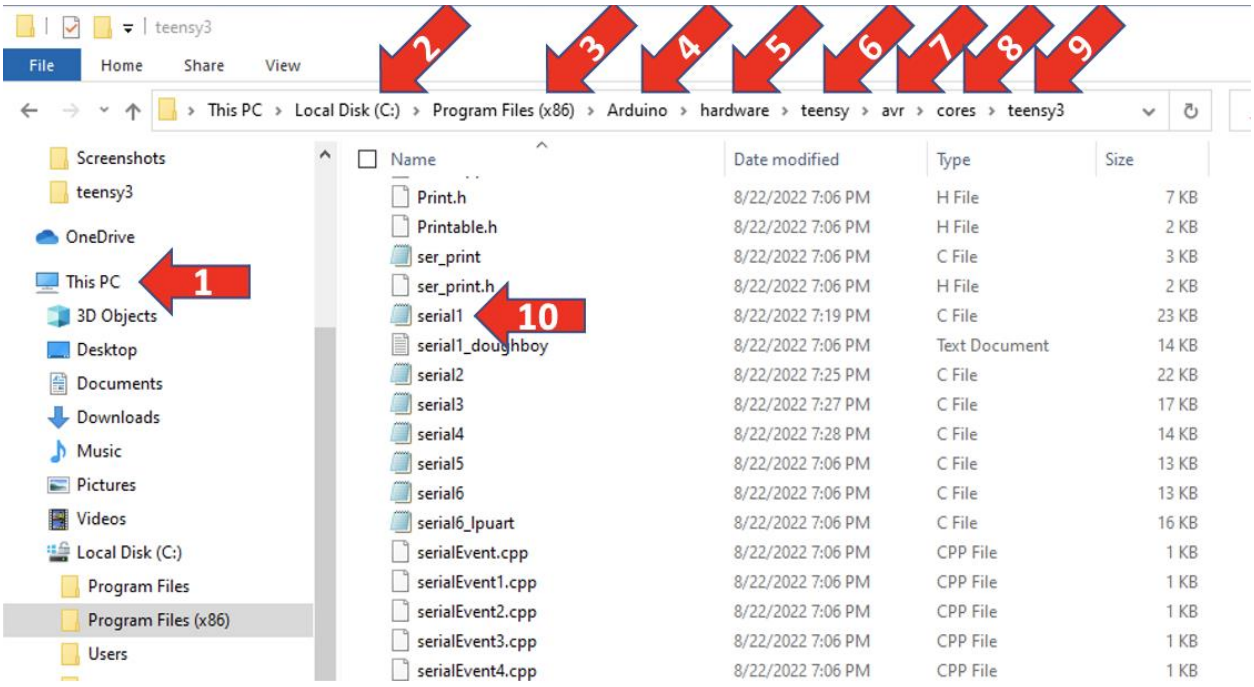


Figure 71. Navigating to the serial1-serial4 files in File Explorer. Files may be displayed alphabetically. There are many files in this folder. You will need to scroll down to find the serial1 file.

11. Right click on serial1 to modify write permission.
    a. A window will open
    b. Select PROPERTIES (Figure 72)

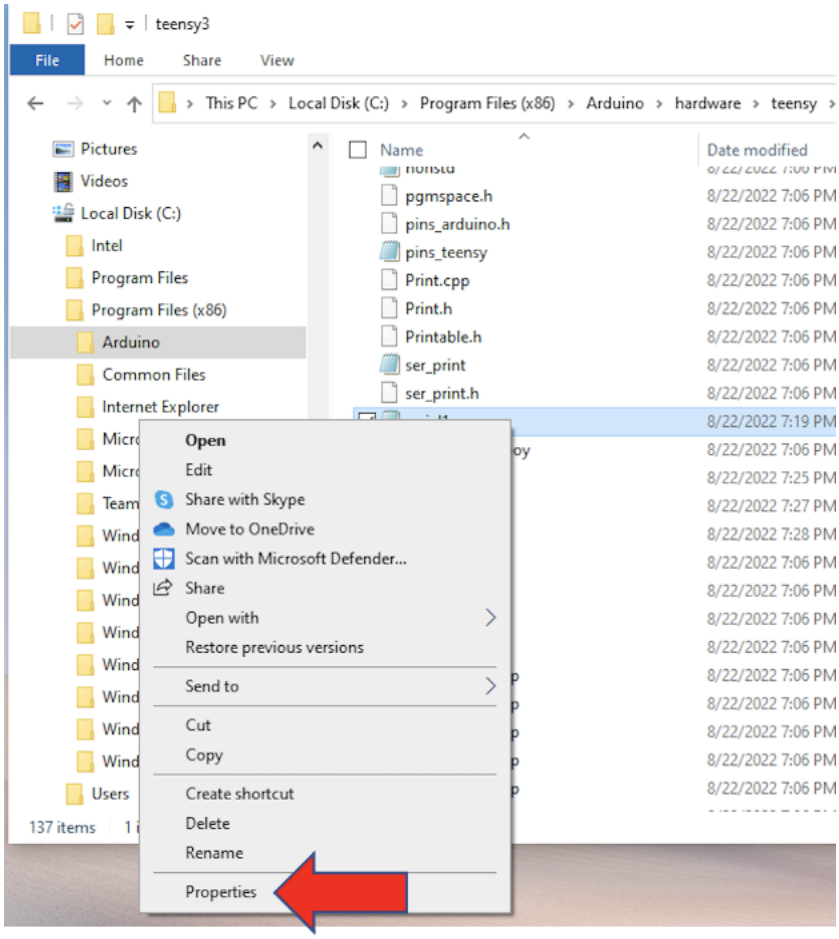


Figure 72. Right click on serial1. Window opens, select PROPERTIES

12. After selecting properties, the window in Figure 73 will open. Select SECURITY tab.

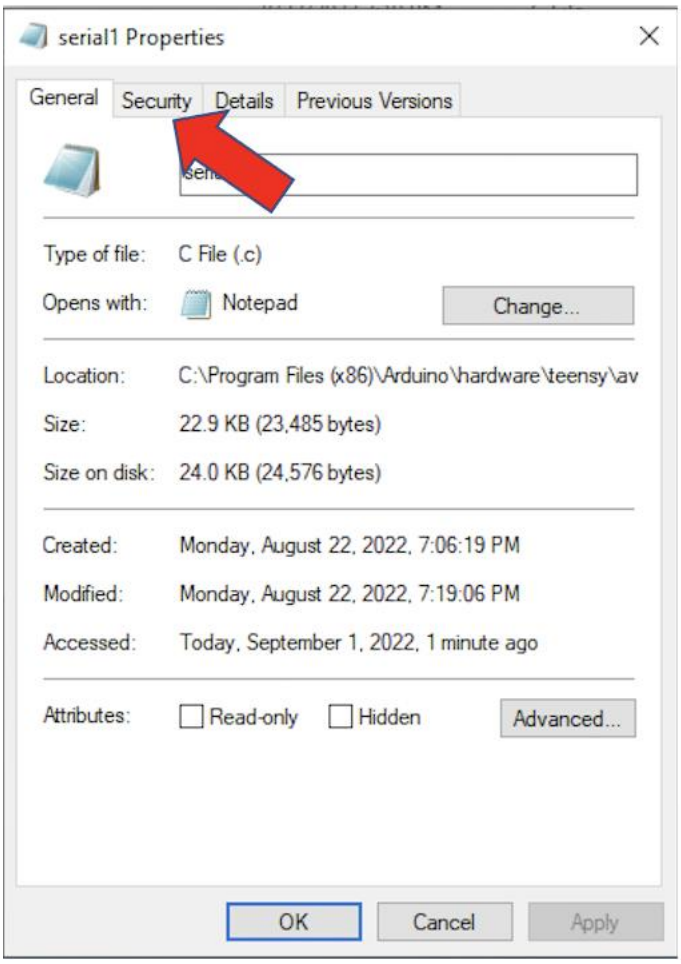


Figure 73. Serial1 File Properties Window

13. Security Tab opens (Figure 74).
    a. Select Users (LAPTOP-PBJCOP\users)
    b. Select EDIT
14. Permissions for Serial1 File window opens (Figure 75).
    a. Place a check mark in
        i. FULL CONTROL
        ii. MODIFY
        iii. WRITE
    b. Select APPLY
    c. Select OK
15. Repeat this procedure for Serial2 through Serial 3 files

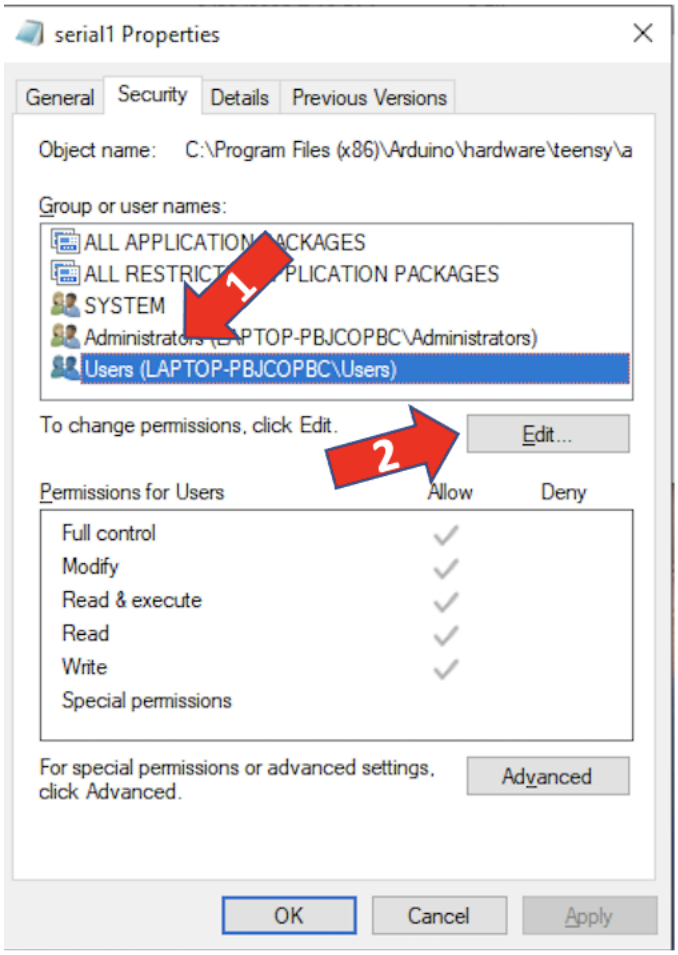


Figure 74. Serial1 Properties Security Tab.

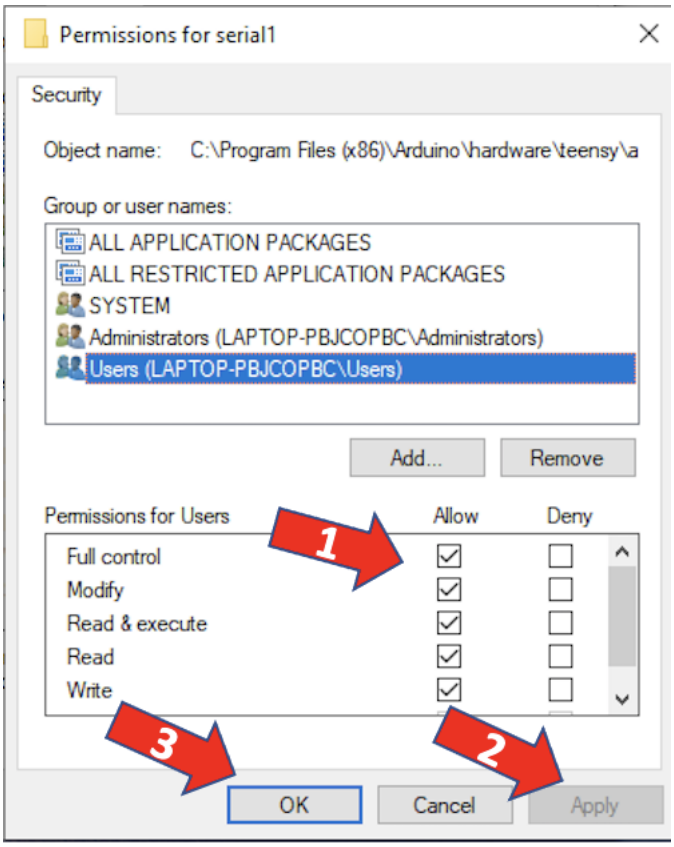


Figure 75. Changing write permissions for serial1 file. This procedure must be accomplished for serial2 through serial4.

16. Modify text file to change RX (receive) buffer to 8192 from 64 (Figure 76).
    a. Open serial1 file in Notepad
    b. Scroll down slightly to find TUNABLE PARAMETERS section
    c. Find line #define SERIAL1_RX_BUFFER_SIZE from 64 to 8192

CAUTION

- **Do not change the TX (transmit) buffer size.** It should be 64 for serial1 and 40 for serial2 through serial4.

    d. Save the file
    e. Repeat this procedure for serial2, serial3 and serial4 files

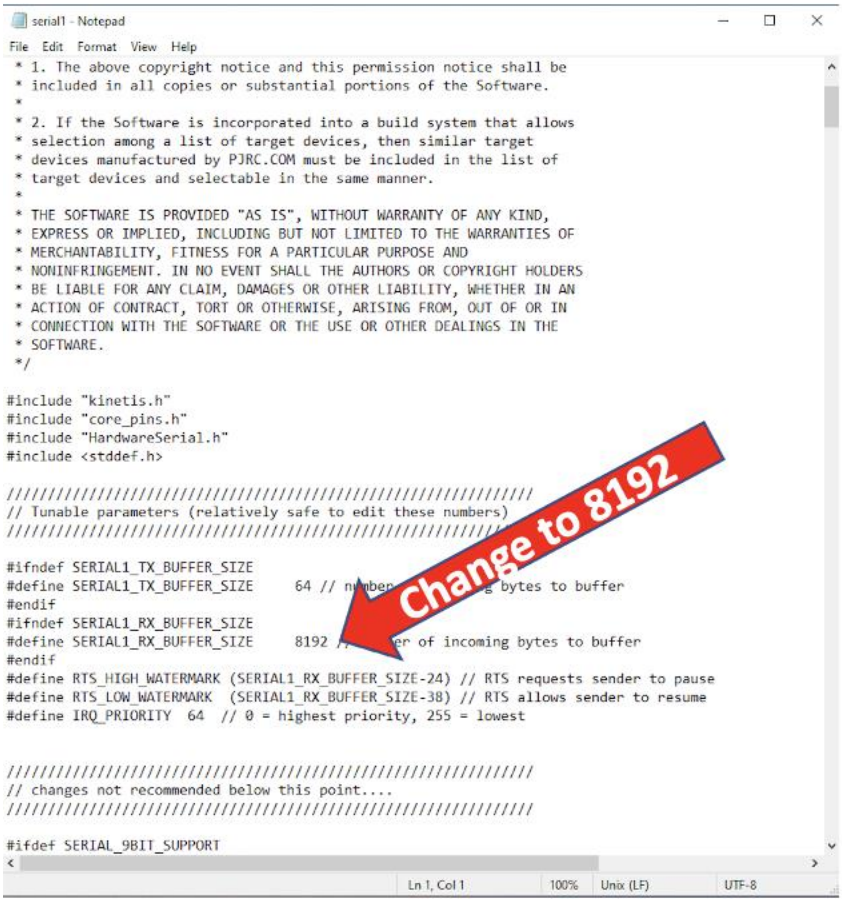


Figure 76. Change receive (RX) buffer size to 8192. Do NOT change transmit (TX) buffer.

The Arduino IDE Software installation is now complete.

Appendix H: Software Settings

NOTE:

1. Line numbers will change with each update.
2. **It is not normally necessary to update software settings prior to upload.** Advanced users may change a setting for flight test or de-bugging.
3. // Two backslashes are used to "comment out" (de-select) a line of code.
4. Any change in software settings requires reloading of software to take effect.

Definable settings of interest:

OnSpeed_AHRS.ino (Teensy Software)

OnSpeed_AHRS Tab

LOGDATA_PRESSURE_RATE	50Hz (normal) data recording rate
LOGDATA_IMU_RATE	208Hz (high-speed) data recording rate. Used for IMU development.
IMUTYPE_LSM9DS1	Original 9-DOF IMU (not suitable for IMU-based auto calibration)
IMUTYPE_ISM330DHCX	New 6-DOF IMU (required for IMU-based auto calibration)
NOBOOMCHECKSUM	Required for SpinGarage Featherweight Air Data Boom with unmodified software (as delivered from factory)
MAX_AOA_CURVES	Max AOA curves (flap positions) available (default 5)
MAX_CURVE_COEFF	4 coefficients = 3rd order polynomial regression (default)
GLIMIT_REPEAT_TIMEOUT	"G Limit" voice warning interval, in milliseconds
ASYMMETRIC_GYRO_LIMIT	Roll rate in deg/sec to establish an asymmetric G condition
//coefficient of pressure formula	This section contains the formula used to compute coefficient of pressure. Default for Dynon, Garmin, Alpha Systems and bent tube sensors is P45/Pfwd.
//boom curves	This section contains calibration curves for the air data boom. A curve is required for alpha, beta, dynamic and static pressure. If a formula is included and the line is commented in, the system will compute and record alpha and beta in degrees and dynamic and static pressure in mB.

//log raw counts for boom	If these lines are commented in, alpha, beta, dynamic and static pressure are recorded as raw counts.
BOOM_PACKET_SIZE	Self-explanatory
EFIS_PACKET_SIZE	Self-explanatory
//debug capability	Provides real-time serial monitoring capability of various functions.
SENSORDEBUG	Shows pressure sensor serial data
EFISDATADEBUG	Shows EFIS serial data (if connected)
BOOMDATADEBUG	Shows air data boom serial data (if equipped)
TONEDEBUG	Shows tone related debug info
SDCARDDEBUG	Shows SD card write debug info
VOLUMEDEBUG	Shows audio volume info
VNDEBUG	Shows VectorNav VN-100/-200/-300 serial data
AXISDEBUG	Shows accelerometer axis configuration
IMUTEMPDEBUG	Shows IMU temperature
AGEDEBUG	Shows boom and EFIS data age (ms)
//box functionality config	Allows testing of various functions
TESTPOT	Used to test potentiometer positions (volume/flap position)
RANGESWEEP	Plays AOA tones
SENSORS	Default setting for normal operation
REPLAYLOGFILE	Allows system to replay a log file and generate tones and visual display
AUDIO_3D_CURVE	Moves tone with ball to provide slip/skid information. Scaled at 0.08 lateral G's/ball width
//smoothing Windows	Smoothing settings
aoaSmoothing	AOA smoothing window (number of samples to lag). Pilot selectable via WiFi Gateway.
pressureSmoothing	Median filter window for pressure smoothing (de-spiking). Pilot selectable via WiFi Gateway.
accSmoothing	Accelerometer smoothing, simple moving average
imuTempSmoothing	IMU temperature smoothing, simple moving average
gyroSmoothing	Gyro smoothing, simple moving average
compSmoothing	Linear and centripetal acceleration compensation
iasSmoothing	Indicated airspeed smoothing. 314 sample moving average, optimized for 208Hz IMU clock speed
ahrsSmoothing	Exponential AHRS smoothing
serialDisplaySmoothing	IAS and Lateral G smoothing for optional visual display

AOA_MAX_VALUE	Maximum computed AOA (default 40 degrees)
AOA_MIN_VALUE	Minimum computed AOA (default -20 degrees)
//Tone Pulse Per Second (PPS)	This section defines the AOA tone patterns. Settings are taken from USAF TO-1-F4-1.
HIGH_TONE_STALL_PPS	20
HIGH_TONE_PPS_MAX	6.2
HIGH_TONE_PPS_MIN	1.5
HIGH_TONE_HZ	1600 (frequency of slow tone)
LOW_TONE_PPS_MAX	8.2
LOW_TONE_PPS_MIN	1.5
LOW_TONE_HZ	400 (frequency of fast tone)
//serial baud rates	
BAUDRATE_CONSOLE	921600 (for wired serial connection)
BAUDRATE_BOOM	115200 (air data boom WiFi)
BAUDRATE_EFIS	115200 (EFIS recording serial data rate)
BAUDRATE_WIFI	1000000 (WiFi Gateway log file download rate

DB15 Pinout

//DB15 pinout (Gen2 v3 hardware)
//1 - 14V +PWR
//2 - EFIS Serial RX
//3 - PANEL SWITCH
//4 - GPS Serial RX
//5 - LED+ Digital/PWM
//6 - AUDIO RIGHT
//7 - FLAPS Analog IN
//8 - AUDIO LEFT
//9 - OAT Analog IN (or Display Serial out)
//10 - VOLUME Analog IN
//11 - SENSOR PWR 3.3V
//12 - EFIS Serial TX
//13 - BOOM TTL RX
//14 – GND
//15 - AUDIO GND

OnSpeed_M5_display.ino (Optional M5 Visual Display Firmware)

NOTE

1. Changing any software settings requires exporting a compiled binary file that is used for firmware update.

//#define IAS_IN_MPH // uncomment this line for IAS in MPH, otherwise it will display in Kts

OnSpeedWiFi.ino (WiFi Firmware)

NOTE

1. Changing any software settings requires exporting a compiled binary file that is used for firmware update.

const char* ssid = "OnSpeed" // change SSID. Only recommended if multiple units are installed in the same airplane for flight test.

WiFi.setTxPower(WIFI_POWER_2dBm) //change WiFi signal strength. 2db recommended for normal cockpit installation. 15 db max.