

Lockheed Martin: Low-Cost Hands-on Throttle and Stick (H.O.T.A.S)

Operations Manual

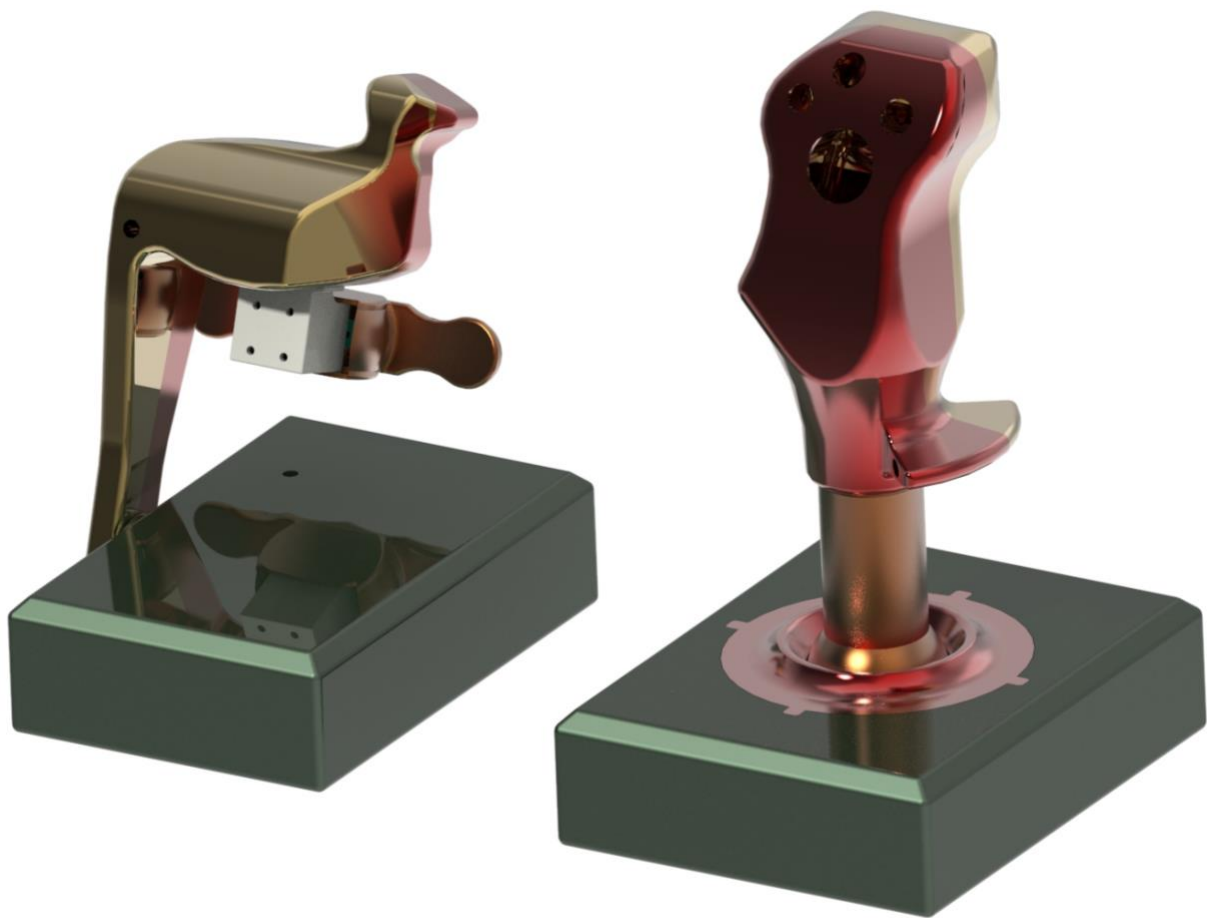


Table of Contents

1. Product overview 2
2. Required tools (2-3)
3. Component description (3-26)
 - Throttle components (3-17)
 - Buttons (4-6)
 - Mechanical components (6-12)
 - Electrical components (13-17)
 - Stick component
 - Buttons (17-19)
 - Mechanical components (19-25)
 - Electrical components (26-27)
4. Integration (26-27)
5. Operation (34-38)
6. Trouble Shooting(39)

Product Overview

The Operations Manual provides a detailed operational description of the Low-Cost H.O.T.A.S system's associated assembly, performance, and procedures.

Our Low-Cost H.O.T.A.S system will be used to help train pilots in Lockheed Martin's Pilot Training Devices (PTD) product line. The H.O.T.A.S has been created with modularity and low

cost in mind. This product allows the usage of multiple styles of throttle and stick from various fighter crafts.

Required Tools for Usage and Assembly

- Software
 - Computer or laptop with flight simulator software such as:
 - Prepar3-D Lockheed Martin's in house simulator
 - Microsoft flight simulator
 - Digital combat simulator
- Hardware for Usage and Assembly
 - M3 metric wrench (overall assembly)
 - M4 metric wrench (usage)
 - Glue (permanent assembly of mechanical components if desired)
 - Pliers (assembly of springs)
 - Wire cutters (assembly/repair of electrical)
 - Soldering iron, and solder (assembly/repair of electrical)
 - Heat gun (assembly/repair of electrical)
 - Wire crimping tool (assembly/repair of electrical)
 - Multimeter (assembly/repair of electrical)

Component Descriptions

Throttle Components

The following is a list of all the buttons on the throttle and their corresponding functions.

1. Single Push Button

- a. Cage/Uncage
- b. APC/SSS/Auto-STO
- c. Polarity Control
- d. MPO



2. 2-Position Switch

- a. Speed Brake



3. 3-Position Switch

- a. Speed Hold
- b. External Lights
- c. Chaff/Flare



4. 5-Way Push Button Switch
 - a. Weapons Management Switch
 - b. Communications Control



5. Radial Dial with Z-Axis Push Button
 - a. Management Switch



6. X & Y Axis Cursor with Z Axis Push Button
 - a. Cursor Slew Control

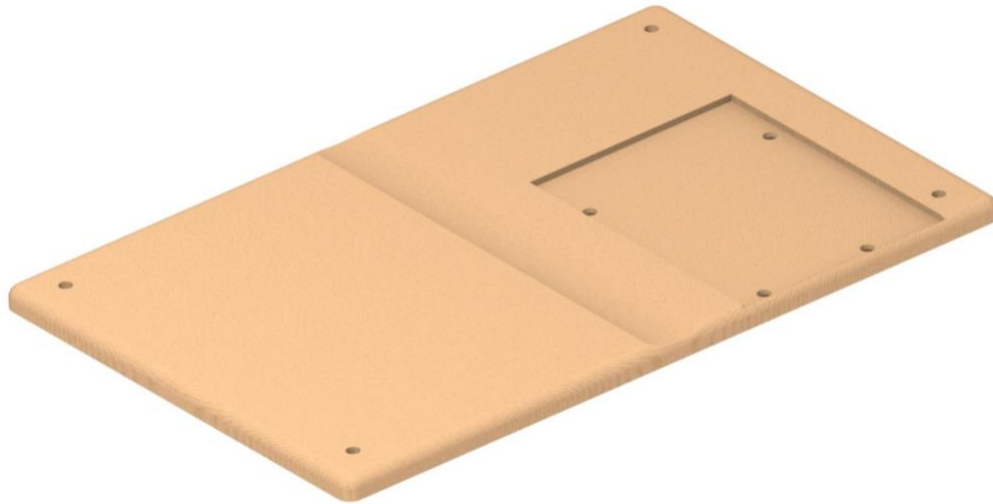


The following list consists of the components that make up the mechanical throttle assembly.

1. **Throttle Base** – Shown below, houses the electronic and other mechanical components for the throttle, all other throttle components mount onto or into this unit, 3-D printed part originally, can be reproduced by using the Throttle_Base file.



2. **Throttle Base Panel** – shown below, used to mount the Arduino Leonardo board and hold other components inside of the throttle base. 3-D printed part originally, can be reproduced by using the Throttle_Base_Panel file.



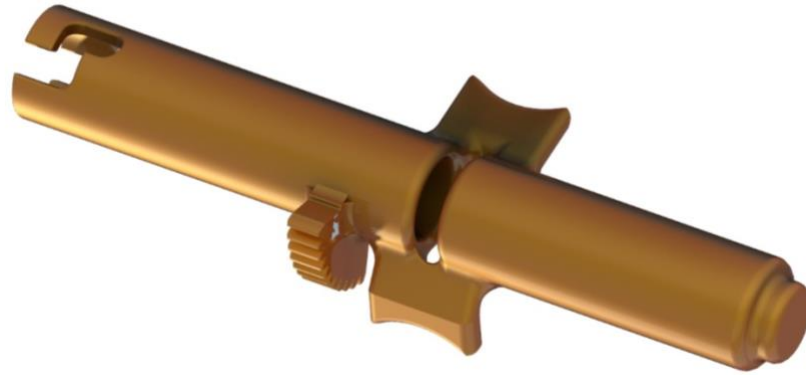
3. **Potentiometer Mount** – shown below, attached to the base when flipped via one M3 screw and nut, the mount will hold the electronic sensor (potentiometer) that detects rotation of the throttle on its main axis of rotation. 3-D printed part originally, can be reproduced by using the Potentiometer_Mount file.



4. **Small gear** – shown below, attached to the potentiometer and in mesh with the big gear to produce the output of the throttle through the potentiometer. The gear itself is a KHK SSAY0.8-28/K6, Module 0.8, 28 Tooth, Hub-less Gears with K-Clamps that has been modified to be 3-D printed and also to attach onto the potentiometer. Can be remade by using the Gear28Mod file.



5. **Throttle shaft** – shown below, the throttle shaft is mechanically attached to the base using bearings, and mechanically attached to the throttle using a slotted mechanism and the fit connection between DIN pins, it has large gear integrated onto it and houses the female DIN pin. The large gear is the KHK SSAY0.8-45/K8, Module 0.8, 45 Tooth, Hub-less Gears with K-Clamps, that has been modified by cutting it down to the range of motion needed as well as being prepared for 3-D printing purposes. This part can be reproduced via 3-D printing and is the Throttle_Shaft file.



6. **Throttle bearings** – shown below, mechanical ball bearings (part #/link to Grainger).

Used to attach the throttle shaft mechanically to the throttle base and allow for a smoother operation.



7. **Throttle front** – shown below, houses electronic buttons and the male DIN pin. The throttle front is attached to the throttle back using M3 screws and nuts. The full throttle is attached via the connection of the hole of the throttle base, and the throttle shaft, this component is both 3-D printed reproducible using the Thottle_Front file.



8. **Throttle back** – shown below, houses electronic buttons. The throttle back is attached to the throttle front using M3 screws and nuts. The full throttle is attached via the connection of the hole of the throttle base, and the throttle shaft, this component is both 3-D printed reproducible using the Thottle_Back file.

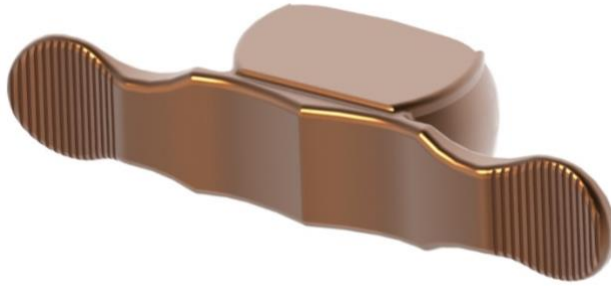


image not fully representative of final assembly, missing button holes.

9. **Yaw potentiometer mount** – shown below, holds the joystick potentiometer for the yaw paddle to attach on to, is placed between both the throttle front and back. 3-D printed and reproducible via the Yaw_potentiometer_mount file.



10. **Yaw paddle** – shown below, will be mounted on the throttle via the yaw potentiometer mount. This will house a joystick potentiometer that will only be able to rotate about one axis. This paddle will control the yaw of the vehicle. This component is 3-D printed and reproducible using the Yaw_paddle file.



11. **M3 nuts** – 8 needed for the throttle assembly. 4 nuts will be used to join the throttle base with the baseplate, 1 nut will join the throttle front to the throttle back and 3 will be used to join the PCBs together.



12. **M3 bolts** – 8 needed. These bolts will be used with the 5 M3 nuts mentioned above.

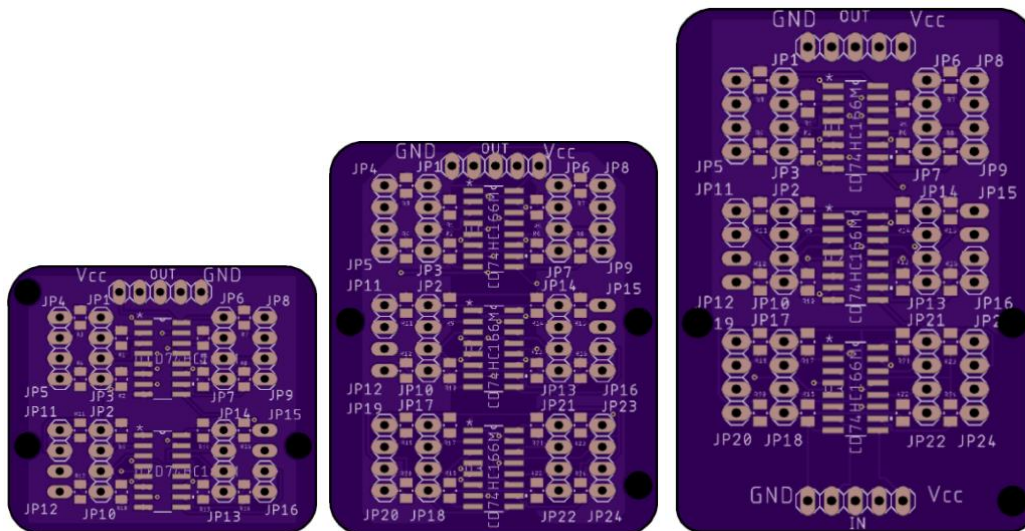


13. **Standoff screws** – 3 needed, to be used to join the PCBs together.



Electronic Components

14. **Three Printed circuit boards (PCBs)** - shown below,



15. **One male DIN pin** – shown below, will be housed in the throttle front and will have 5 of the pins connected to the PCB to communicate button outputs. This will connect to a female DIN pin housed in the bases to allow for modularity.



16. **One female DIN pin** – shown below, will be housed in the throttle base and will connect to the male DIN pin. Also, will be connected to the circuit board to communicate the button inputs to the Arduino.



17. **One Arduino Leonardo** – shown below, will be housed in the throttle base and will be the microcontroller used to turn the button inputs from the female DIN pin into outputs to be displayed in the simulator.



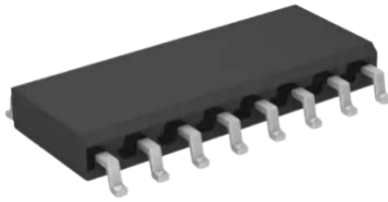
18. **One Micro USB cable** – shown below, will be used to connect the Arduino Leonardo to the computer



19. **One precision potentiometer** – used to measure the location of the throttle to determine the power output of the vehicle. Will be connected to a gear system to allow for the movement of the throttle to correlate to the full range of the potentiometer.



20. **Five Shift registers** – shown below, attached to each PCB in its corresponding location to allow for more buttons to be used.



21. **Joystick potentiometer** – shown below, used to read the movement of the yaw paddle button to yaw the vehicle left or right.



22. **Wires** – shown below, will be used for most of the electrical connections.



23. **Molex connectors** – shown below, attached to some of the buttons to allow the wires to connect from the PCB to the buttons.



24. **Heat Shrink** –used to keep the internals of the H.O.T.A.S neat and organized.



25. **Solder** – used in most of the electronic connections.



Stick Components

The following is a list of all the buttons found on the stick and their corresponding functions.

1. Single Push Button
 - a. Weapons Release Switch
 - b. Weapons Release Sub Mode

c. Nose Wheel Steering



2. 4-Way Hat Switch

- a. Target Management Switch
- b. Display Management Switch
- c. Expand Zoom FOV switch



3. 5-Way Hat Switch

- a. Trim Switch
- b. Countermeasures Management Switch



4. 2-Position Depress Switch

a. Trigger



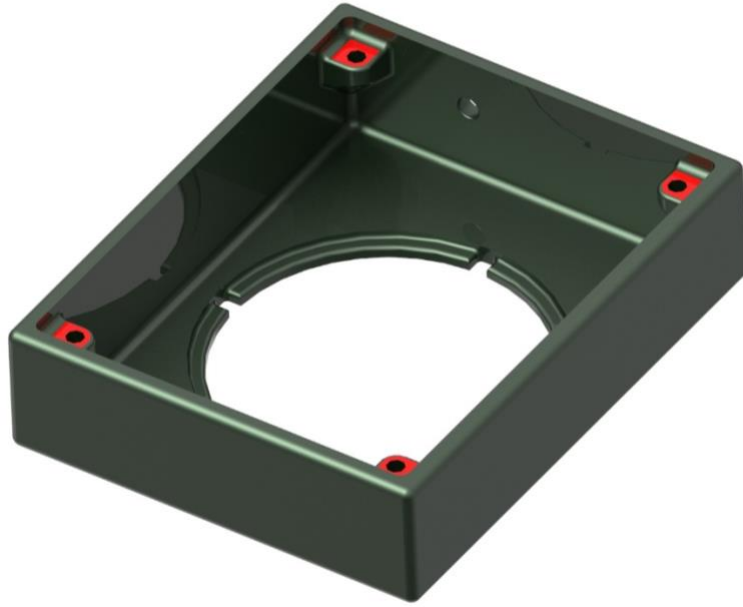
5. Single Push Button w/ Paddle Lever

a. Paddle Switch



The following is a list of the mechanical components that make up the stick.

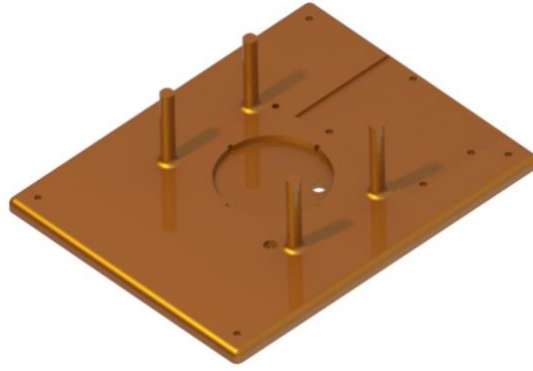
1. **Stick base** - Shown below, houses the electronic and other mechanical components for the stick, all other throttle components mount onto or into this unit, 3-D printed part originally, can be reproduced by using the `Stick_Base` file.



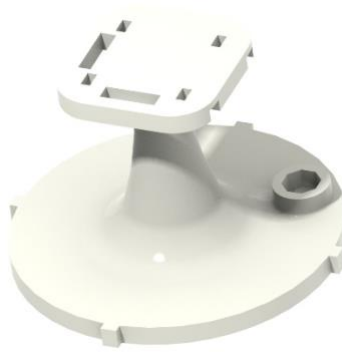
- 2. Stick base flange** – shown below, will house the stick ball and will be used for the attachment of the M4 nut as well as the 1/8th inch rod.



- 3. Stick base panel** - shown below, used to hold other components inside of the stick base.
3-D printed part originally, can be reproduced by using the `Stick_Base_Panel` file.



4. **Stick joystick mount** – used to connect the joystick potentiometer to the stick.



5. **Spring tensioner** – device used to control the amount of resistance the stick will provide to the user.



6. **Springs** – 6 springs used to attach to the spring tensioner, springs are what will provide the resistance to the user.



7. **Stick ball** – will house the stick and the joystick mount. The movement of the stick will be translated to the stick ball and in turn to the joystick mount to allow the stick movement to be turned into pitch and roll output to the simulator. The stick ball also has the female side of the locking mechanism to secure the stick to the base.



8. **Stick front** – the front half of the stick, where the user will grab the stick to control the vehicle and where the buttons will be mounted. Will combine with the stick back to make the full stick assembly.



9. **Stick back** – the back half of the stick where the trigger and other buttons will be located, will combine the stick front to make the full assembly of the stick.



10. **Trigger mount** – mount located inside the stick front shell, used to mount the trigger to the stick.



11. **1/8" rod** – shown below, will be fit into the spring tensioner to keep it level when it is being raised or lowered.



12. M3 screws and nuts – shown below, there will be 8 M3 screws and nuts, 4 will be used for the base to baseplate connection, 1 will be used for the throttle front to throttle back connection and 3 will be used to connect the PCBs together.



13. M4 screw and nut – similar shape and size to the ones shown above, there will be one M4 screw and nut to be used to tighten or loosen the spring tensioner to control the amount of resistance in the stick.

Electronic Throttle Components

1. **Two Printed Circuit Boards** – shown above, will be housed the throttle and have all of the buttons connected to it. It will be connected to the Arduino Leonardo through the DIN connector.
2. **One Arduino Leonardo** - shown above, will be housed in the throttle base and will be the microcontroller used to turn the button inputs from the female DIN pin into outputs to be displayed in the simulator.
3. **One Micro USB cable** – shown above, for Arduino Leonardo connection to computer.

4. **3 Shift Registers** – shown above, used to increase the number of outputs available to allow for more buttons to be used with only one circuit board.
5. **One Male DIN Pin** - shown above, will be housed in the stick front and will have 5 of the pins connected to the PCB to communicate button outputs. This will connect to a female DIN pin housed in the stick ball to allow for modularity.
6. **One Female DIN Pin** - shown above, will be housed in the stick ball and will connect to the male DIN pin. Also, will be connected to the circuit board to communicate the button inputs to the Arduino.
7. **Joystick Potentiometer** – shown above, mounted inside the stick, used to detect the movement of the stick in two axes to correspond to pitch and roll of the vehicle.
8. **Wires** – shown above, will be used in most electrical connections.
9. **Molex Connectors** – shown above, attached to the buttons to allow the wires to connect from the PCB to the buttons.
10. **Heat Shrink** – shown above, used to keep the internals of the H.O.T.A.S neat and organized.
11. **Solder** – shown above, used in most of the electrical connections.

Integration

Mechanical Assembly of Stick:

1. Gather stick components (electrical and mechanical)

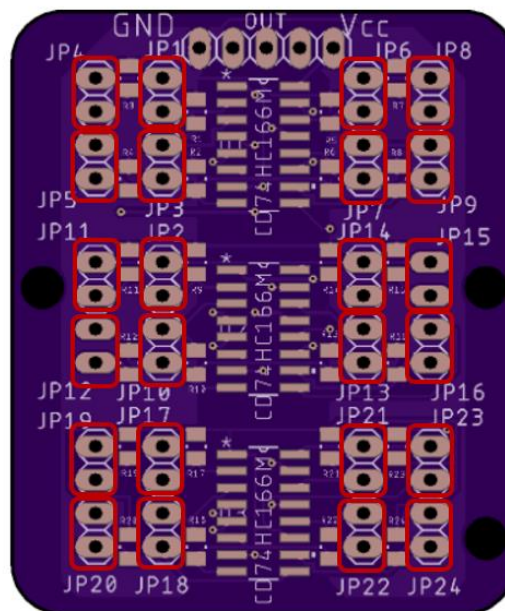
2. Start with stick base panel, attach Arduino board using M3 screws, placing screws from the bottom upward.
3. With stick ball pieces, place female din pin into its corresponding slot in the stick ball's shaft, and glue or screw closed, note this must be done after wiring of din is completed.(see electrical assembly below).
4. Joystick potentiometer and potentiometer mount, place potentiometer onto its mount and fold teeth using pliers, attach mount into stick base panel using m3 screw and nut.
5. Stick ball, spring tensioner, 1/8" rod and springs, attach springs onto each of the four corresponding sides of both components(ball and tensioner, make sure tensioner holes are upward facing). Place M4 nut into spring tensioner, slide the spring tensioner onto the stick base panel and stick ball onto the joystick potentiometer, when in place with tensioner all the way down, screw m4 from bottom of panel to hold tension on the tensioner while placing the 1/8" rod into the tensioner's opposite side and seating it in the base panel opposite of the m4 screw.
6. Place stick base flange onto stick ball, orient the flange cardinally, place M3 nuts into stick base, slide stick base onto the base panel, the fit should be good, insert M3 screws on all four corners and begin to slowly tighten as to not dislodge the M3 nuts inside the base.
7. Base complete. Stick Assembly.
8. Fit buttons into corresponding holes, attach PCB board via M3 screws, fit male din pin into slot position in stick shaft. Glue trigger mount with trigger in place on stick back. Next close the two shells together and using M3 screws and nuts tighten the two shells together.

Electronic Assembly of Stick:

1. Solder wires from the buttons to the appropriate male connectors
2. Solder wires from the female connectors to the PCB in a
3. Attach the hot wire from the button into the hot wire in the button input pair on the PCB.

Check the continuity with the Vcc terminal in the OUT channel to know which button input pin is connected to it

- a. Each vertical pair of inputs on the PCB corresponds to one button signal in the program. The figure below shows 24 vertical pairs boxed in red.



4. Solder the other wire from the button to the other pin in the button input pair on the PCB.
5. To ensure modularity, make these connections with the connector between the wires so that they can be separated easily
6. For buttons with more than one output signal, such as the trim switch, begin with step 3

7. Connect one of the output signals to the other pin in the button input pair
8. Connect the other output wires from the button to the signal pin in separate button input pairs. A 5-way switch will have a total of 6 connections and should take up 5 separate button signal input pins.
9. Solder the output wires from the PCB into the DIN connector
10. Solder the wires from the DIN connector to the appropriate pins on the Arduino. The connections are down below from left to right
 - a. GND connects to GND
 - b. The second output pin is the Clock, and it connects to a digital output pin
 - c. The third output pin is the serial data, and it connects to a digital input pin
 - d. The fourth output pin is the latch, and it connects to a digital output pin
 - e. The fifth output pin is the Vcc and it connects to 5V
11. Connect the analog parts to the Gnd and Vcc wires from the DIN
12. Each output from the analog parts connects to their own pin in the DIN connector
13. Connect these signals to the analog input pins on the Arduino

Mechanical assembly of throttle:

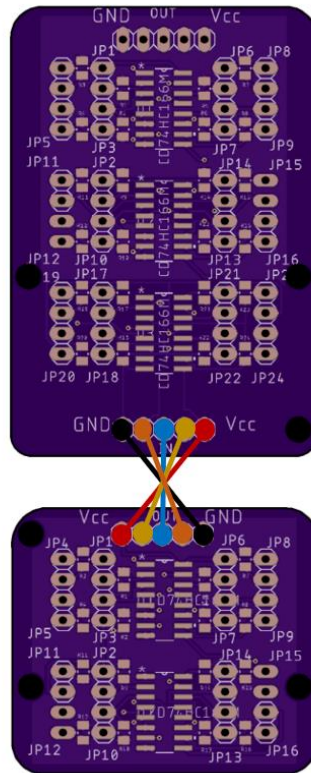
1. Gather throttle unit components (electrical and mechanical)
2. Starting with throttle base panel, attach Arduino board using M3 screws.
3. Insert female DIN pin into the throttle shaft, (with the larger gear on it for reference) seal shaft together.

4. Slide the two bearings onto the throttle shaft one on each end, insert the shaft into the throttle base and press fit bearings into place on each end of the throttle base.
5. Attach the potentiometer mount into the base using a M3 screw and nut.
6. Insert the potentiometer into the potentiometer mount screw into place, and attach the small gear onto the potentiometer so it meshes with the throttle shaft gear.
7. Connect the baseplate to the throttle base using 4 M3 screws, one in each corner of the base, similar to above be sure to place nuts into the base first, then slowly tighten the assembly together..
8. Insert the buttons into their corresponding holes on the throttle back. This is done by inserting the button through the outside of the throttle and screwing the corresponding nut to the threaded section of the button through the inside of the throttle, most buttons will be attached in this manner however some will be pulled through and glued on the inside.
9. Attach the yaw joystick to the yaw joystick mount, folding teeth from the back of the unit, wire the joystick before this step otherwise it must be redone..
10. Connect the yaw paddle to yaw potentiometer mount by attaching onto the yaw joystick potentiometer this will create the yaw assembly.
11. Insert the male DIN pin and yaw assembly into the throttle front and attach the throttle back to the throttle front using a M3 screw and nut.
12. Inserting the assembled throttle into the hole on the throttle base will simultaneously connect the male DIN pin to the female DIN pin, this must be done by inserting the throttle, rotating 45 degrees and pushing further inward.

Electronic assembly of throttle:

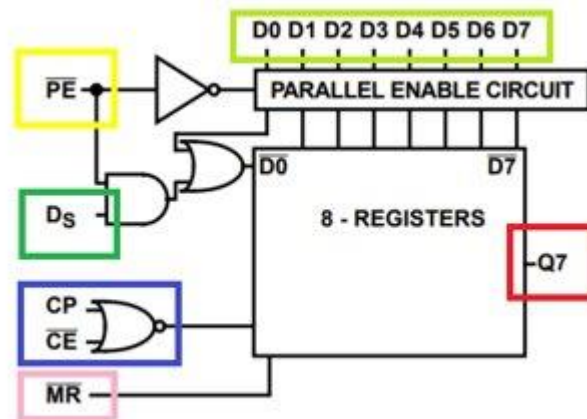
1. Do the same process as the electrical assembly of the stick

2. Use the standoff screws to attach the small throttle PCB onto the large throttle PCB
3. Solder wires to connect the output of the small PCB into the input of the Large PCB
 - a. The connections should go straight down from the small PCB to the large one



The PCB's are set up so that all the inputs do not need to be filled for them to work. Those pins will simply read LOW in the program. The buttons are set up with pull down resistors, so they read LOW until the button connects the circuit to HIGH. Holding the PCB so that the letters are read upright, the button connections are vertical. They were set up for SPST buttons but can be adapted for use with more types. For SPST push buttons, it doesn't matter which wire goes to which pin as long as they correspond to the same button. Each vertical pair of input pins correspond to the same button. You need to do a continuity test between the pair see which one goes to Vcc and which one is connected to GND/Shift Register. This is important when you need to connect buttons with more than one output like the hat switches.

The function diagram below shows how the shift register works. When the latch pin (PE) is LOW and the clock pin goes from LOW to HIGH, the shift registers shift in data in parallel (individual wires) from the buttons. Then when the latch pin is changed to HIGH, the shift registers prepare to send the data in serial (one wire). When the clock is pulled from LOW to HIGH, the shift registers send in one bit (either 1 or 0) to the Arduino. The Arduino keeps shifting in data by turning the clock from LOW to HIGH and sends that bit into the computer as a joystick button value. When the Arduino is done with reading all the data from the shift registers, it reads the analog values from the joysticks, encoder, and other potentiometers and assigns these numbers to parameters in the joystick. After everything has been sent to the computer, the Arduino resets the latch pin and starts the process over again.



Pseudo Code for the shift registers is shown below:

Loop

{

Latch = 0; //Set the shift registers up to input the data from the all the buttons at once

Clock = 0;

Clock = 1; //Set the clock from low to high to input all of the button values

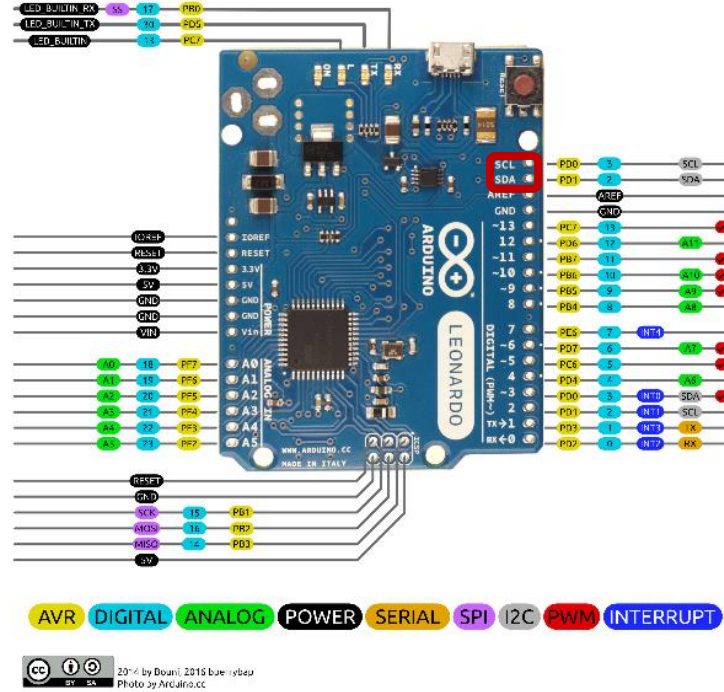

```

Latch = 1; //Set the shift registers up to output the data in serial
Clock = 0;
Clock = 1; //Set the clock from low to high to shift in one bit
While(Loop Through The Buttons in the Shift registers)
{
JoystickButton = ShiftRegisterData;
Clock = 0; //Shift in the next value from the shift register
Clock = 1;
}
}

```

This pseudo code will be in both Arduino boards in the throttle and stick bases. In order to send information from the Arduino in stick base to the one in the throttle base, we use an inter-integrated circuit (i2c). This sends serial data from one board at the speed of the clock. The serial data are bits, so integer values that are larger than 255 need to be mapped down using the map function in Arduino. The connection between the boards is through a DIN connector and it sends the Vcc, ground, clock, and serial data for a total of 4 signals. The slave sends data the master through the SDA pin and the master reads the value. For this project, the stick Arduino is the slave, and the throttle Arduino is the master. The throttle Arduino then assigns the values that it receives from the stick to the joystick buttons. The S

Arduino Leonardo Pinout



The pseudo-code for the slave serial communication is below

Loop

```
{
    //Get data from the shift registers as above
    While(data being sent from slave to master)
    {
        Wire.write(Button and analog values);
    }
}
```

The pseudo-code for the master serial communication is below

Loop

```
{
    //Get data from the shift registers as above
    While(data being sent from slave to master)
    {
```

```
JoystickButton = Wire.read(Button and analog values);  
  }  
}
```

Operation

Modularity

Stick – unit

To remove the stick attached to the base, grab the stick at the midpoint lift it upward till a stop, twist the stick clockwise 45 degrees followed by lifting the stick straight up out of the base.

To attach the new stick to the base, first insert the stick into the base ensuring the din pins are oriented correctly, press the stick downward till a stop, rotate stick 45 degrees counterclockwise till stop, then down again. This will fully mate the male and female din pin connectors. Ready to play

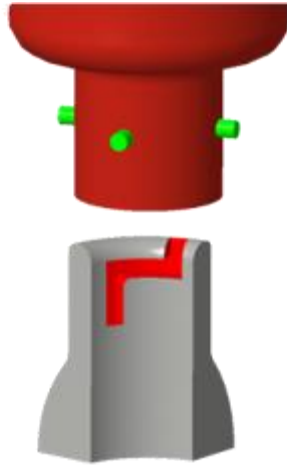


image not fully representative of final assembly, missing din pins, and sizing may vary

Throttle – unit

To remove the throttle attached to the base, grab the throttle at the midpoint pull it away from the base till a stop, twist the stick clockwise 45 degrees till stop, followed by pulling the throttle out of the base.

To attach the new throttle to the base, first insert the throttle into the base ensuring the din pins are oriented correctly, press the throttle downward till a stop, rotate throttle 45 degrees counterclockwise till stop and then down again. This will fully mate the male and female din pin connectors. Ready to play

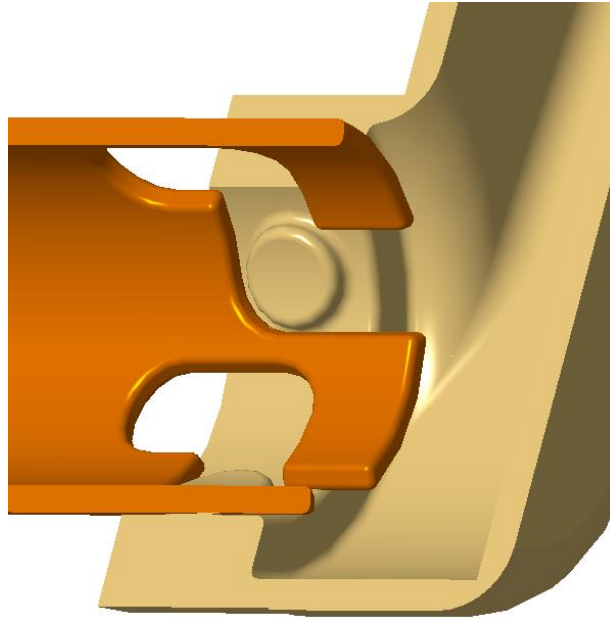


Image not fully representative of final assembly, missing din pins, and sizing may vary

Usage

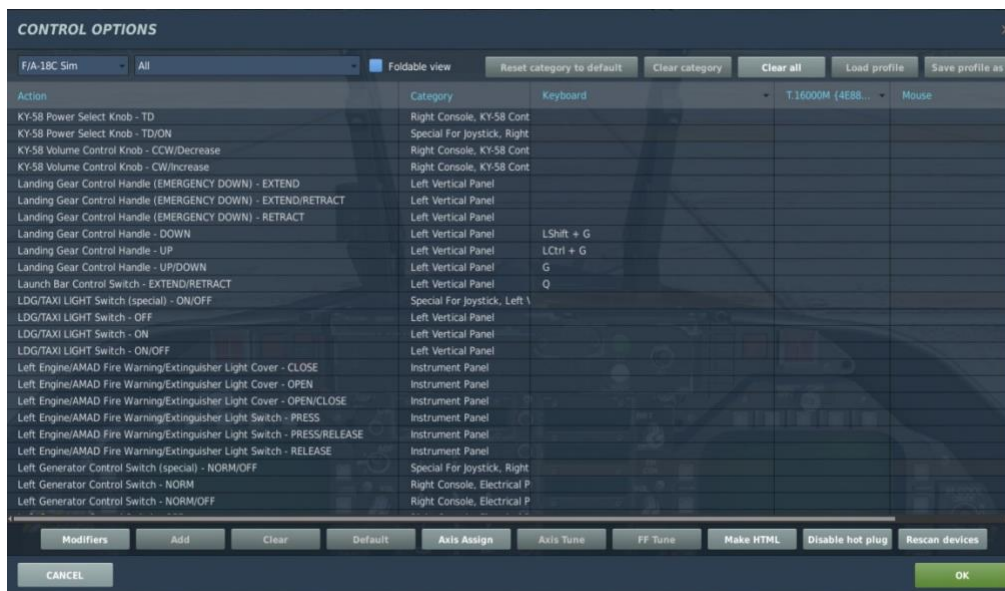
Using the H.O.T.A.S with a laptop or computer is a remarkably straightforward process. Simply plug in the USB coming out of the H.O.T.A.S into the computer or laptop that you would like to use the H.O.T.A.S with and the connection is complete. If the user would like to adjust the resistance the stick provides, using an Allen key turn the bolt underneath the stick clockwise to tighten the bolt and simultaneously increase the resistance of the stick, or loosen the bolt to decrease the resistance of the stick.

To operate the plane in the flight simulator, move the stick forward or aft (backwards) to pitch the aircraft up or down and move the stick left or right to roll the aircraft left or right. To

accelerate the aircraft, push the throttle forward, and to slow down the aircraft pull the throttle aft.

Simulator Pairing

Once the stick is connected to the device it is being used with, open the flight simulator software the H.O.T.A.S is going to be used with, be sure to only open the software after the H.O.T.A.S has been connected. In the flight simulator software initialize a flight. Once in a flight, open the settings for the software to begin mapping buttons to the H.O.T.A.S. Note: depending on which software you use will depend on how you map the buttons. To map the button, click on the output you would like the button to perform from the software then physically click the button you would like to map the output too. Repeat this process for all the buttons you would like to map. The process for mapping the axis of rotation for the stick and throttle is the same as mapping a button. For the pitch, click on the pitch output in the simulator then move the stick forward or aft. Repeat this for the roll, yaw, and throttle.



Troubleshooting

If a button breaks or is faulty, that individual button can be replaced. The process for every button is essentially the same, first disconnect the throttle or stick, depending on where the button is located, using the technique found in the usage section. From there the shell needs to be opened by loosening the screws found on the outside of the stick or throttle to gain access to the internals of the H.O.T.A.S. Locate the button that needs to be replaced and remove the wires connecting to the button and then disconnect the button from the throttle or stick, depending on the button will determine how the button is removed. Once the old button is removed, insert the new button into the hole and connect the wires to the button once it is secured in the stick or throttle. Insert the same screws into the stick or throttle to re-attach the two shells back together and re-insert the stick or throttle into the base.