# Team 512: Lockheed Martin Low-Cost HOTAS

**EML 4552C**

Robert Blount
Connor Chuppe
Robert Craig
Patrick Dixon

# Team Introductions

**Robert Blount**
*Systems Engineer*

**Connor Chuppe**
*Test Engineer*

**Robert Craig**
*Controls System Engineer*

**Patrick Dixon**
*Mechatronics and Geometric Design Engineer*

Robert Blount

# Sponsor and Advisor

**Project Sponsor**

Andrew Filiault

*Lockheed Martin F35 Training Systems Engineer*

**Professor**

Dr. Shayne McConomy

*Professor and Director of Mechanical Engineering Senior Design at the FAMU-FSU College of Engineering*

**Project Adviser**

Dr. Patrick Hollis

*Professor at the FAMU-FSU College of Engineering*

Robert Blount

# Project Background

Robert Blount

# Project Objective

Wraith Systems F-35 HOTAS

The objective of this project is to create a low-cost Hand-On Throttle and Stick (HOTAS) system to support the Pilot Training Devices (PTD) product line. The product will replicate the throttle control assembly and control stick of various Lockheed Martin vehicles. The bases will be modular to allow for use with multiple HOTAS sets.

Robert Blount

# Key Goals

- **Support multiple modular grips**
  - Allow different vehicle controllers to connect to the bases
- **Integrate with Lockheed's system**
  - HOTAS needs to work with Prepar3D, flight simulator software
- **Create a low-fidelity HOTAS**
  - HOTAS should have low manufacturing costs and be easily repairable
- **Shall be used with desktop simulators**
  - Not going to be implemented with full cockpit simulators
- **Provide same functionality as current models used**
  - Needs to have a similar number of outputs (buttons)
  - Does not have to be on the same tier of fidelity

Robert Blount

# Key Functions

## Ergonomics

- Support Multiple Modular Grips
- Integrate with Lockheed System

## Electronics

- Filter & Process I/O Data
- Detect Aircraft Control Intent

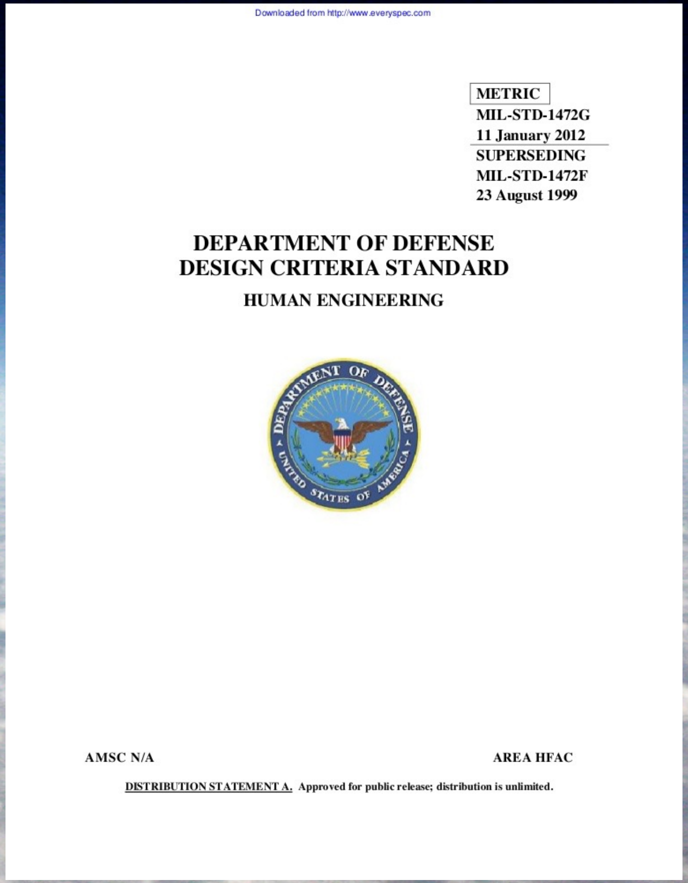
## Mechanical

- Provide Feedback
- Operate Throttle & Stick

Robert Blount

# Targets and Metrics

- Conform to Mil Standard 1472
  - Fits 95% of Aviators
- Implement with Various Craft Design
  - 55 Separate Signals




METRIC
MIL-STD-1472G
11 January 2012
SUPERSEDING
MIL-STD-1472F
23 August 1999

DEPARTMENT OF DEFENSE
DESIGN CRITERIA STANDARD

HUMAN ENGINEERING

AMSC N/A AREA HFAC

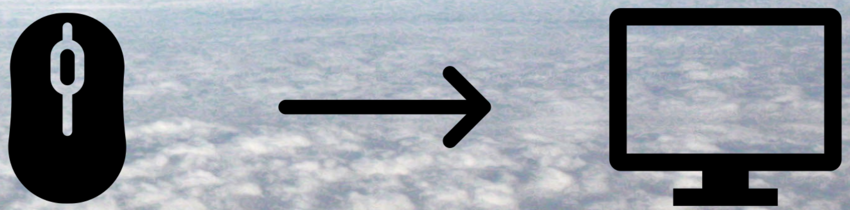
DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Mil Std. 1472 Doc. cover

Patrick Dixon

# Targets and Metrics

- **Output Signals**
  - Transfer less than 5 Gbps of data
  - Less than 10 Gbps @ 250 MHz between throttle and Stick
- **Detect Aircraft Control Intent/ Signal Activation**
  - Less than 20 ms latency



Patrick Dixon

# Targets and Metrics

- Operate Throttle and Stick
  - Buttons can be depressed
  - Plus or minus 35 degrees of stick rotation
  - Throttle travels 6” or 65 degrees
- Filter and Process I/O signals
  - Filter noise, process data into appropriate signal type, fast 0ms

HOTAS Motion Diagram

Patrick Dixon

# Concept Generation and Final Selection

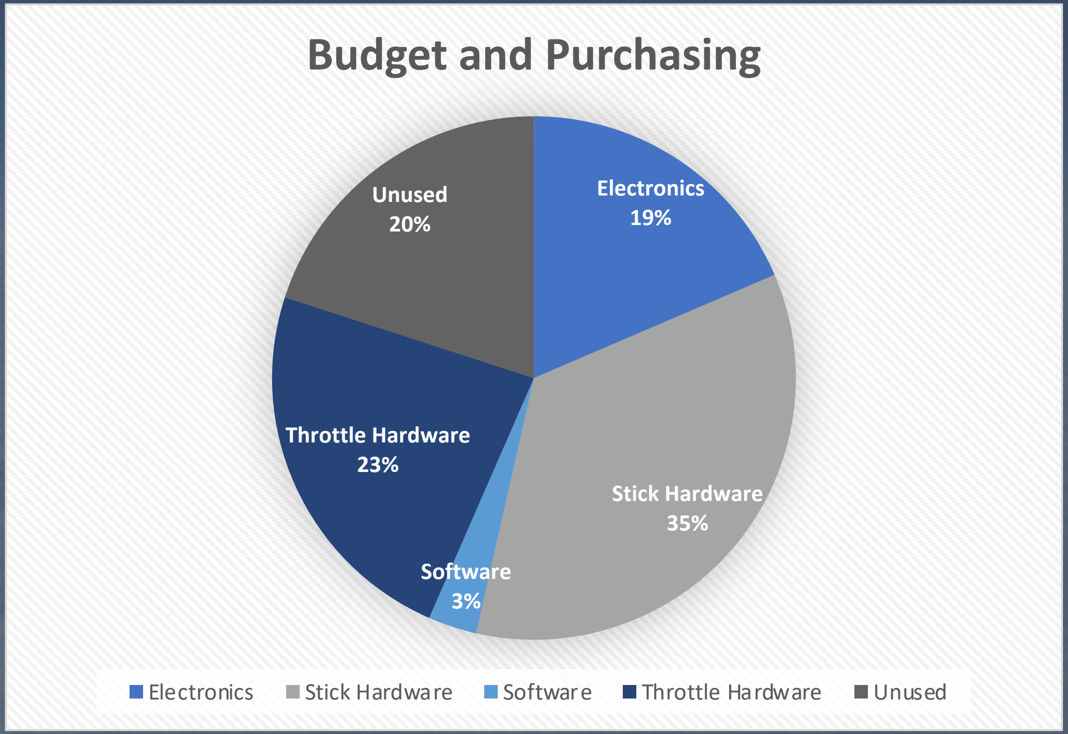
- Concepts generated: 100
- Standard Concept Selection: Narrowed down to 3
- Final Concept Selected: Concept 3 shown below

- Concept 1
  - Singular joysticks
  - Hall effect sensors
  - Python board
  - Yaw on stick
  - Sliding throttle
- Concept 2
  - Modular sticks
  - Hall effect sensors
  - Arduino board
  - Yaw on stick
  - Sliding throttle
- Concept 3
  - Modular sticks
  - Potentiometers
  - Arduino board
  - Yaw on throttle
  - Rotating throttle

Patrick Dixon

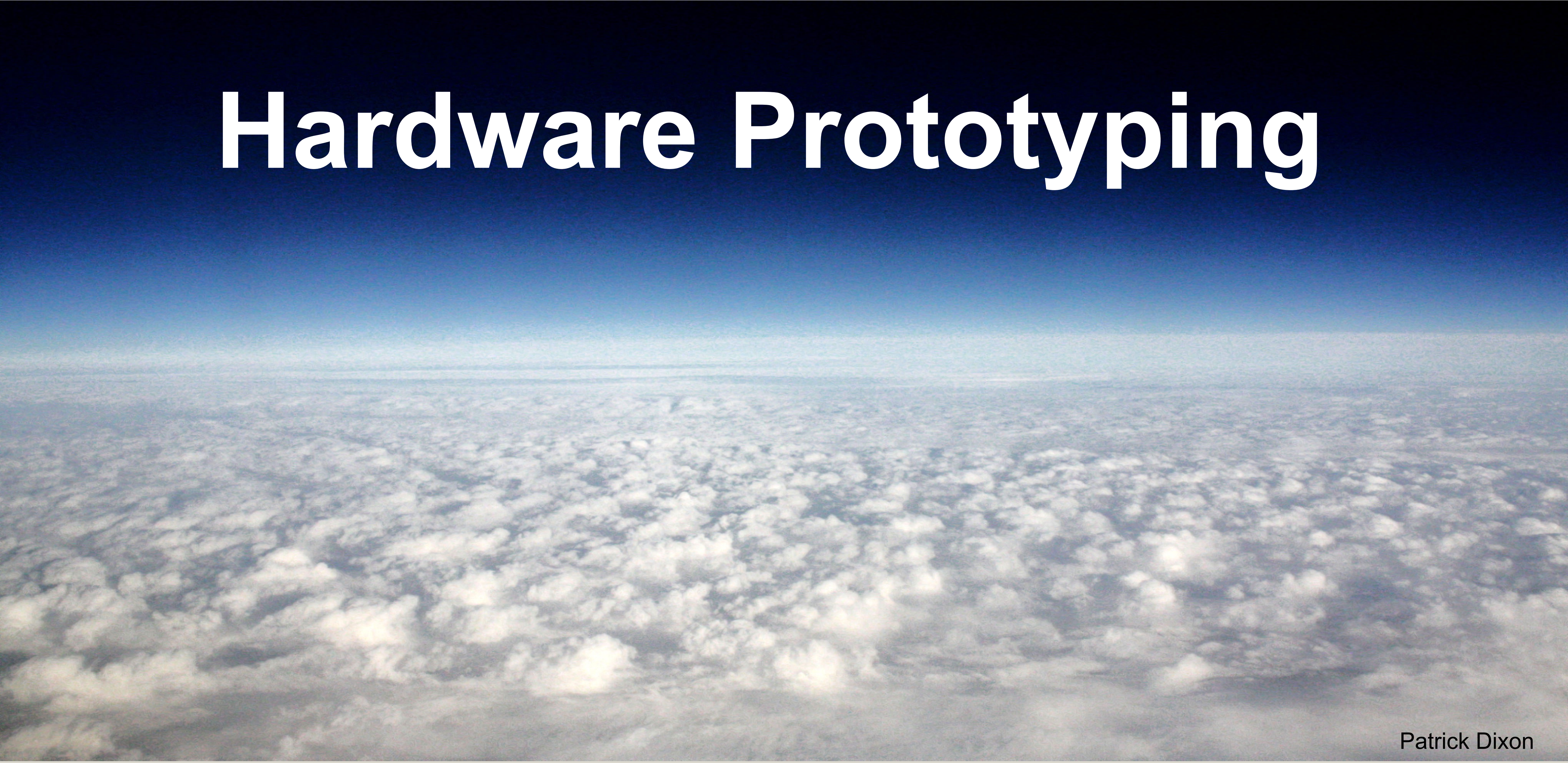
# Budget and Purchasing

- Allotted $2,000 total
- Allocated $1,600
  - Electronic Components
  - Hardware Components
  - Software Necessities



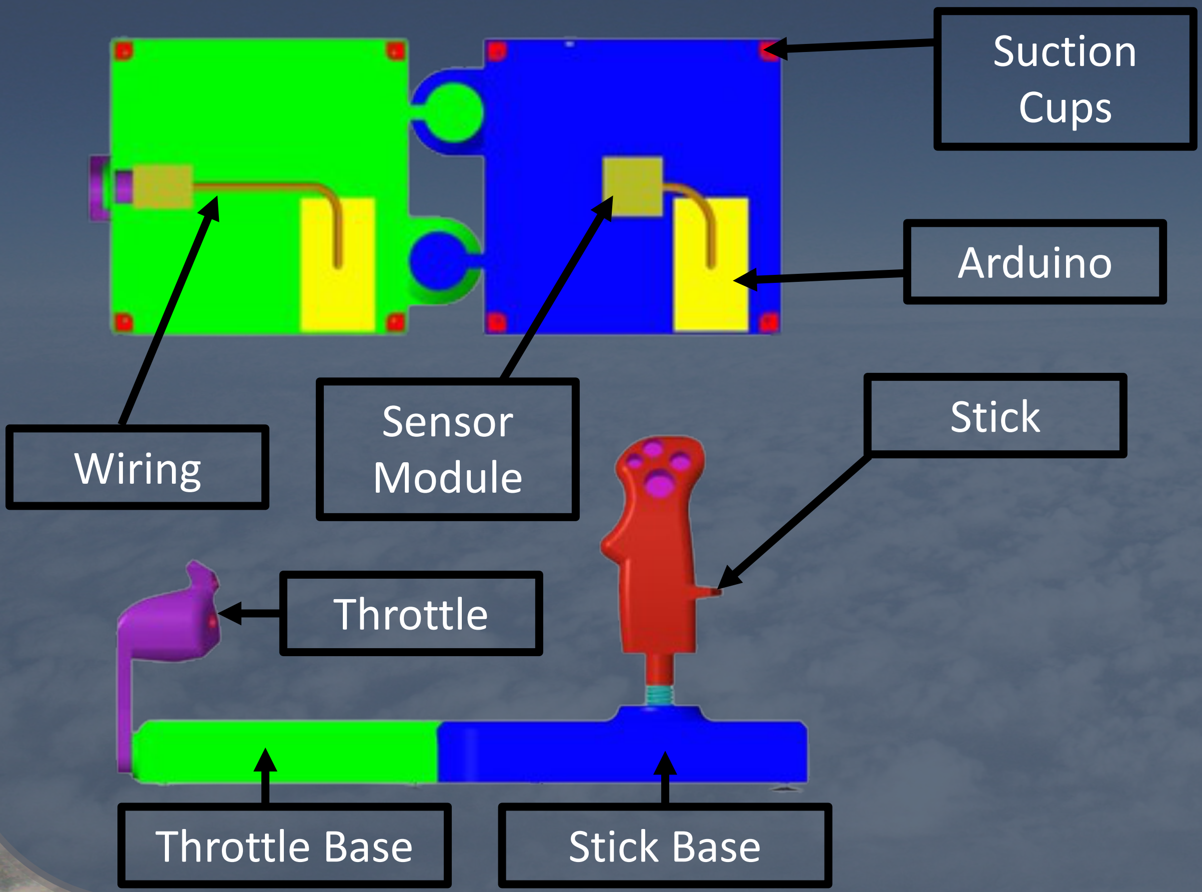

Patrick Dixon

# Hardware Prototyping



Patrick Dixon

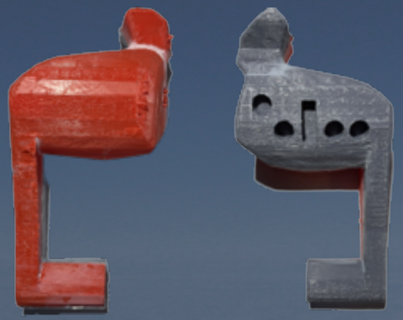
# Initial 3D Model




- Things Assessed
  - Making the stick circumference smaller

Robert Blount

# Initial Printed Design



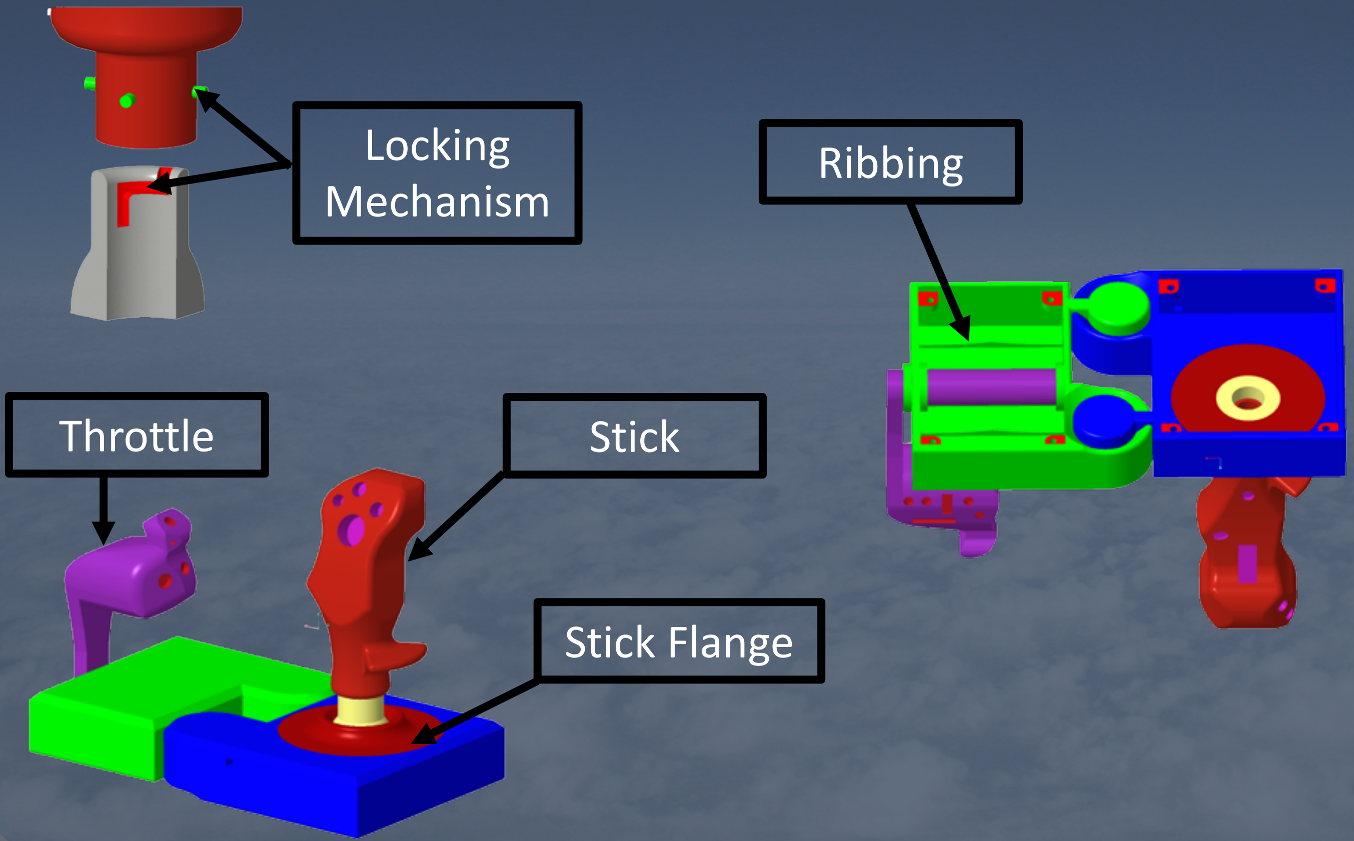
Throttle

Stick

- Initial Issues
  - Material finish is rough
  - Excess support material was printed
  - Stick wall thickness was too thin

Robert Blount

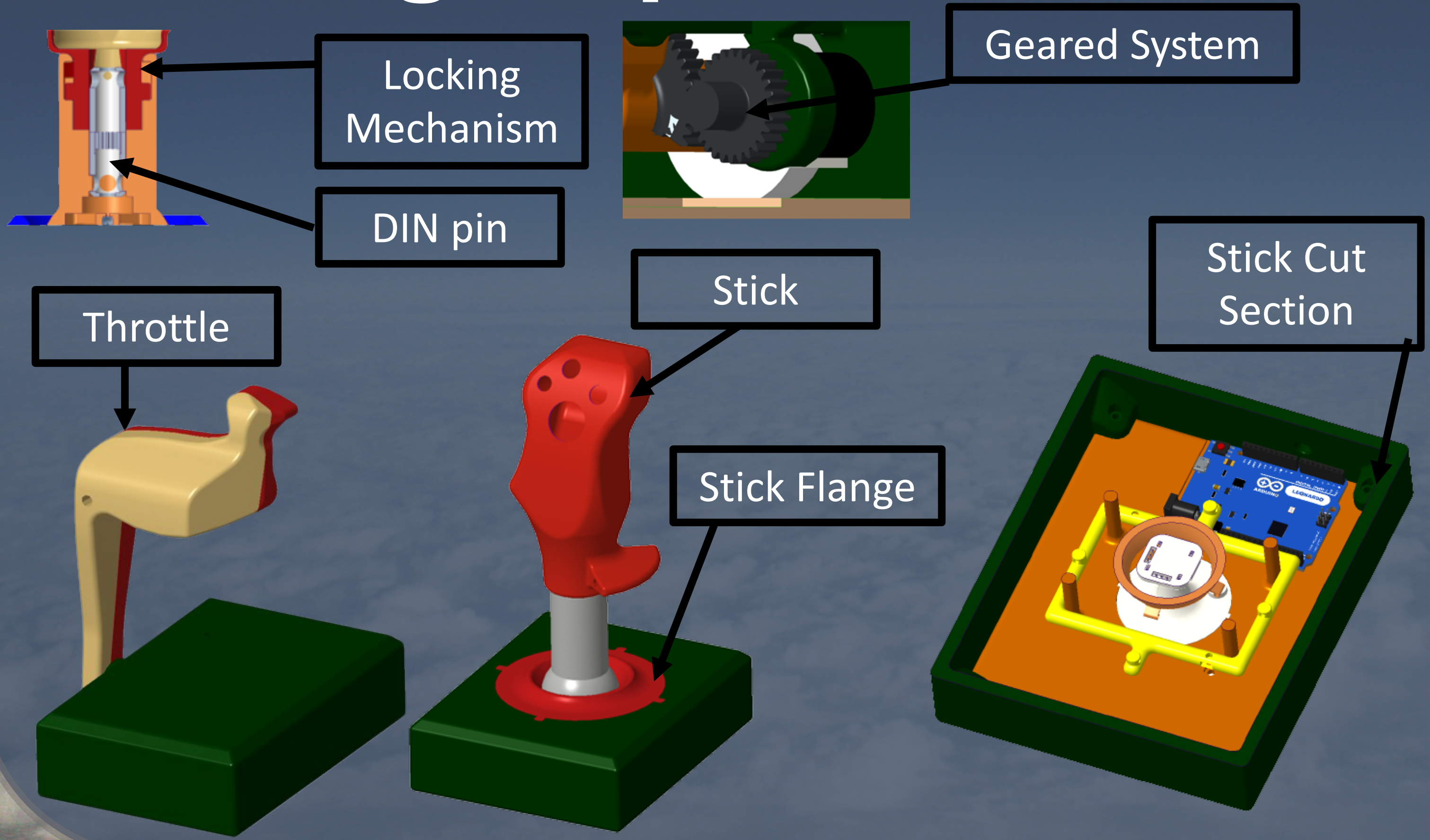
# Design Update 1




- Things changed
  - Removed threaded stick
  - Added flange on stick base to reduce material used
  - Added ribbing to the throttle base for increased strength

Robert Blount

# Design Update 2

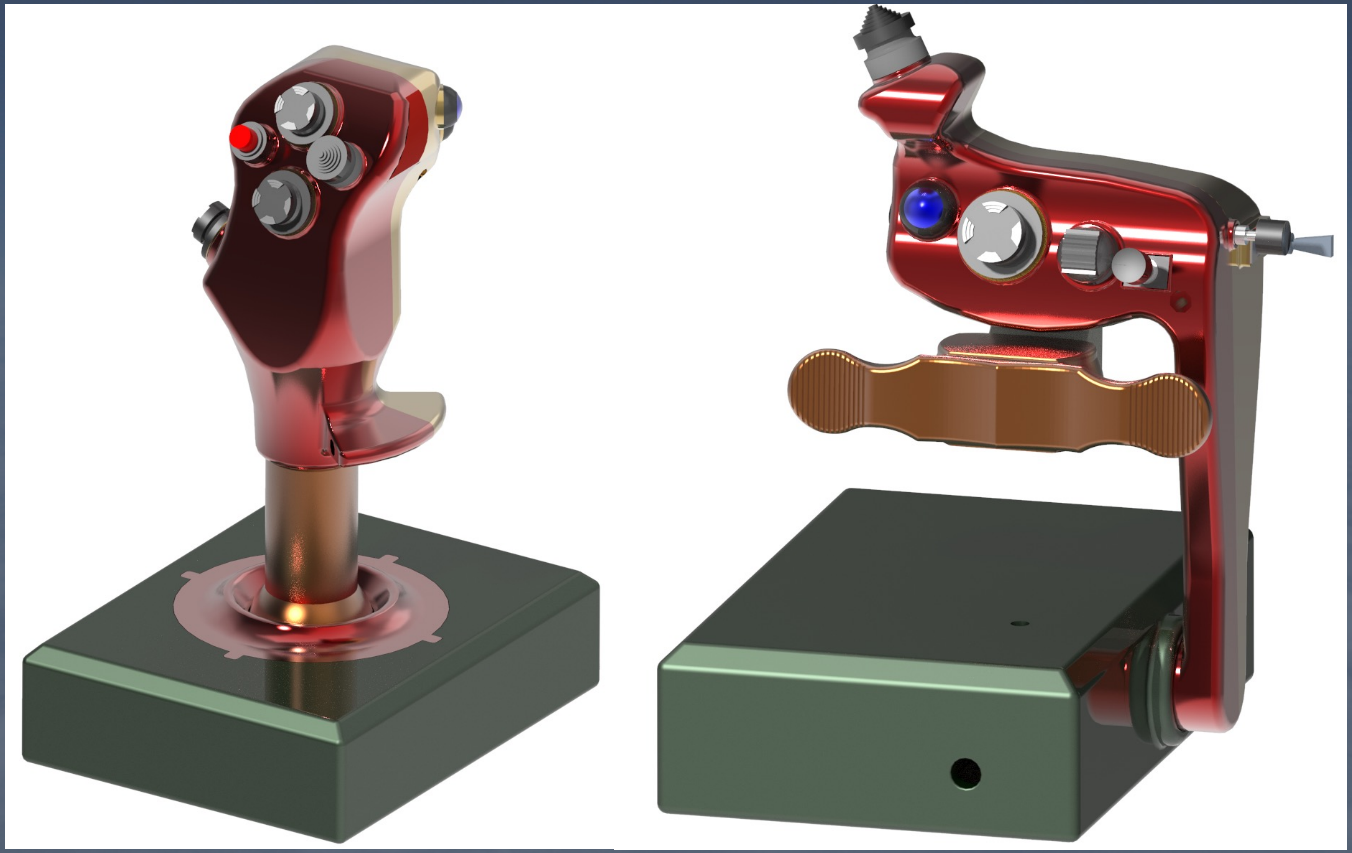



## Things changed

- Added a gear system connected to the potentiometer
- Reduced locking mechanism to two slots
- Added space for the DIN pin connectors
- Removed modular bases

Patrick Dixon

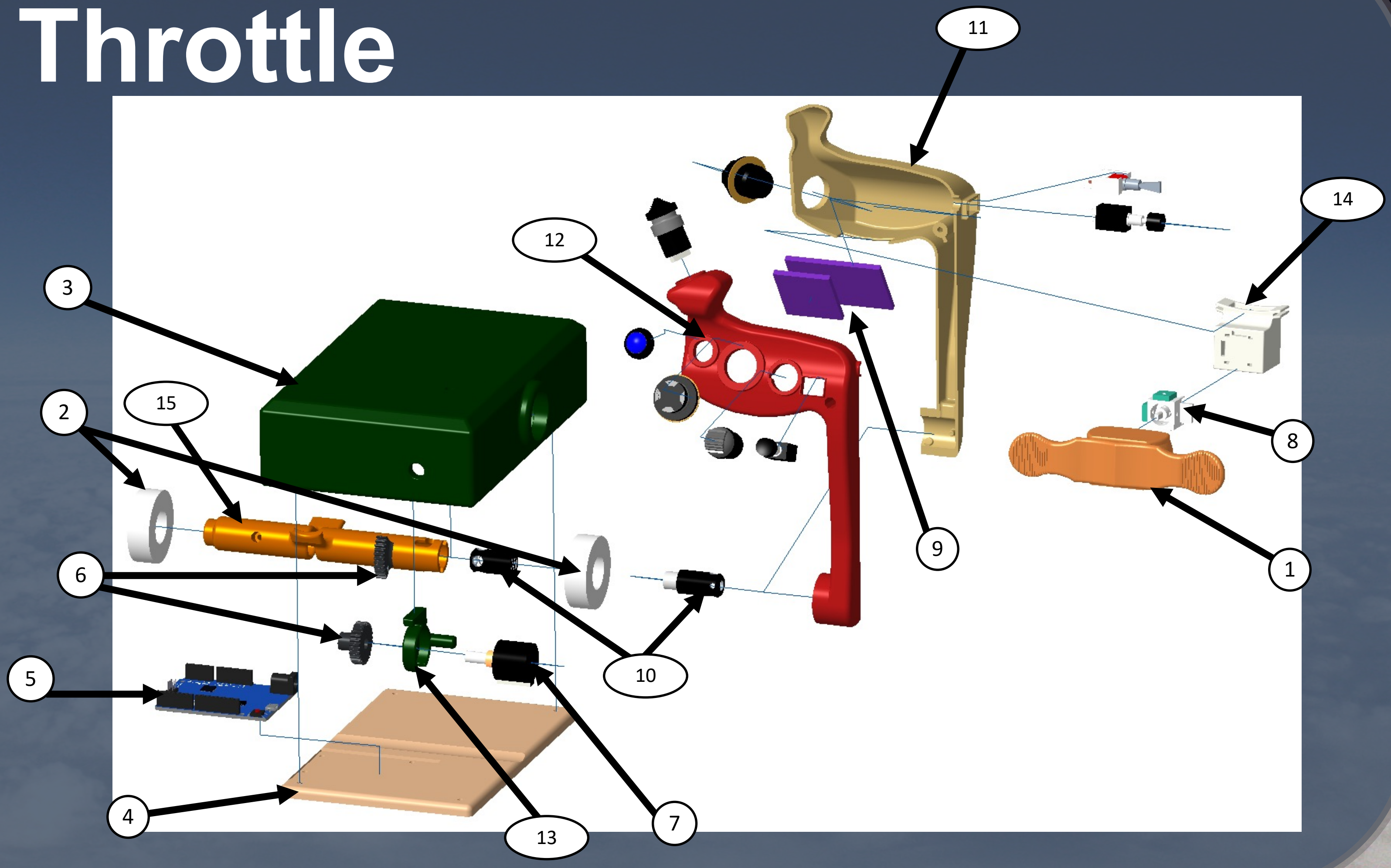
# Final Assembly 3D Model



Patrick Dixon

# Exploded 3D Throttle

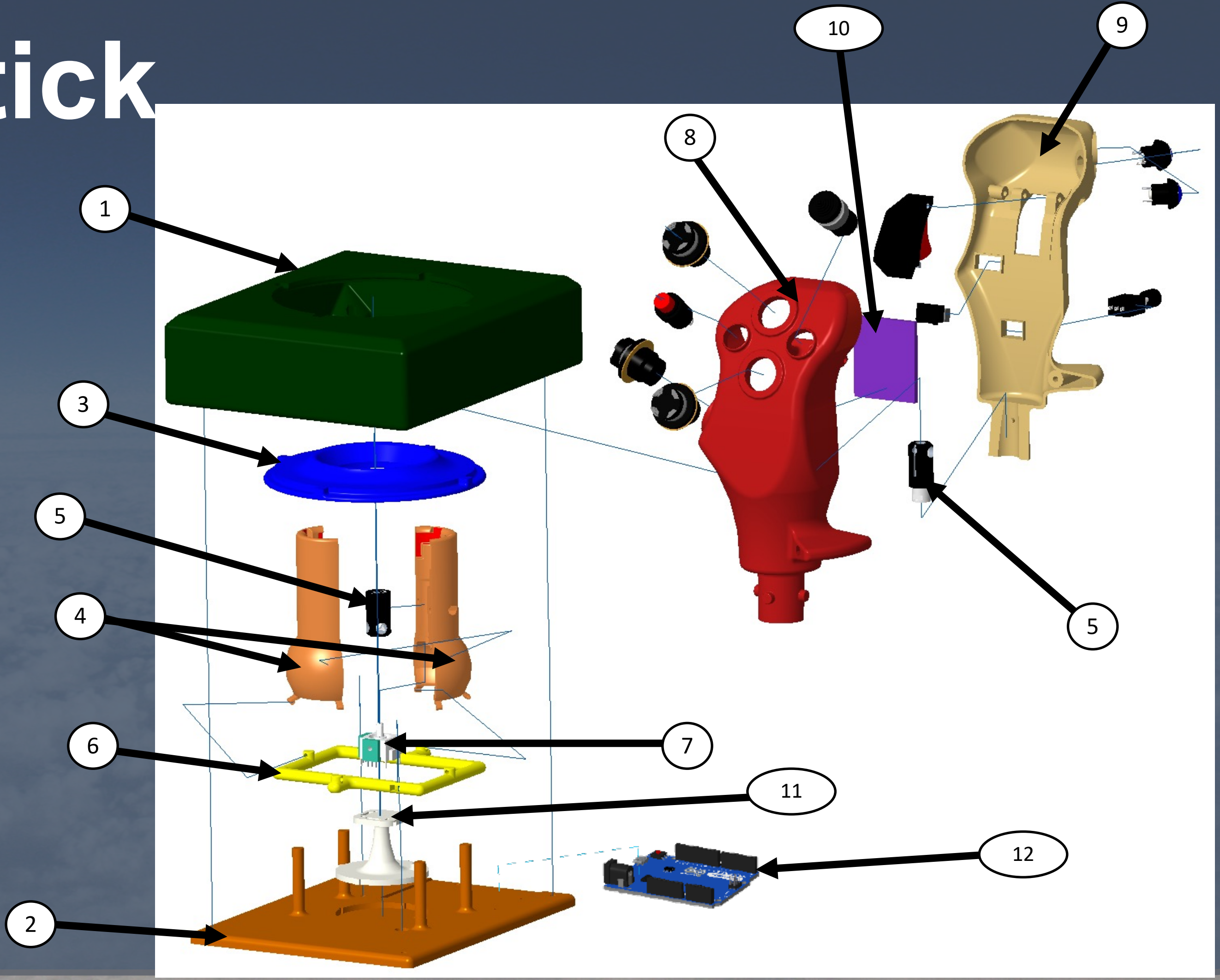
1) Yaw paddle
2) Bearings
3) Throttle Base
4) Baseplate
5) Arduino
6) Gears
7) Rotary Potentiometer
8) Joystick Potentiometer
9) PCB
10) DIN pin
11) Throttle Back
12) Throttle Front
13) Rotary Potentiometer Mount
14) Joystick Potentiometer Mount
15) Gear Shaft




Patrick Dixon

# Exploded 3D Stick

1) Stick Base
2) Baseplate
3) Stick flange
4) Stick Ball Left, and Right
5) DIN pin
6) Spring tensioner
7) Joystick Potentiometer
8) Stick Front
9) Stick Back
10) PCB
11) Potentiometer mount
12) Arduino

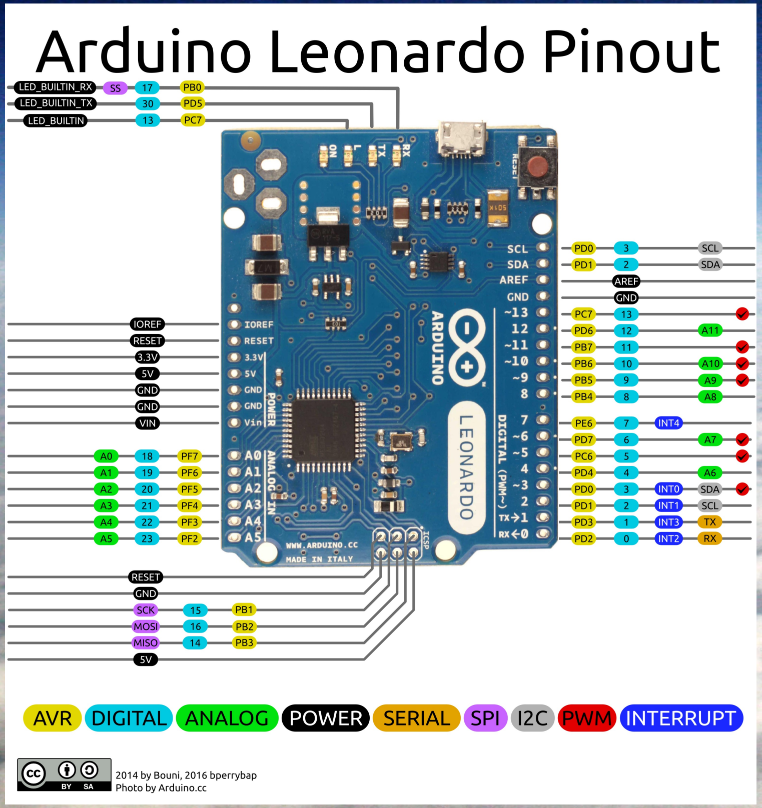



Patrick Dixon

# Electrical Prototype

Patrick Dixon

# Software and Packaging




- Using Arduino Leonardo boards in each base
- Arduino is programmed with Arduino ide in C
- ATmega32u4 chip set allows the computer to recognize the Arduino Leonardo as a game controller

Robert Craig

# Modularity and Connectivity

Male Din Pin

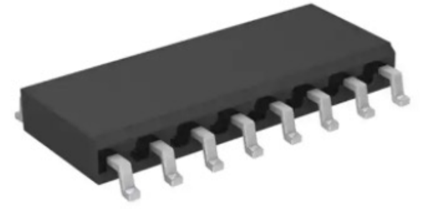
Female Din Pin

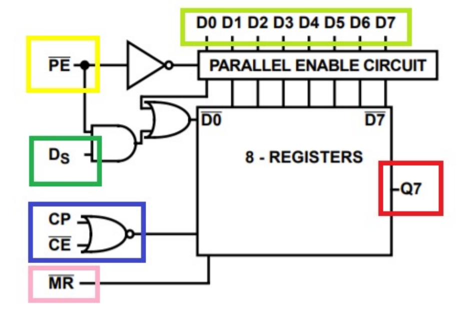
- 9 pin mini-DIN connector used for modular connection
  - 2 pins for input voltage and Ground
- Using three pins for all digital buttons in each pair
- Up to 4 analog signals through connection in each pair
- One male in each throttle, and stick
- One female in each base

Robert Craig

# Shift Registers and Buttons

PISO Shift Register



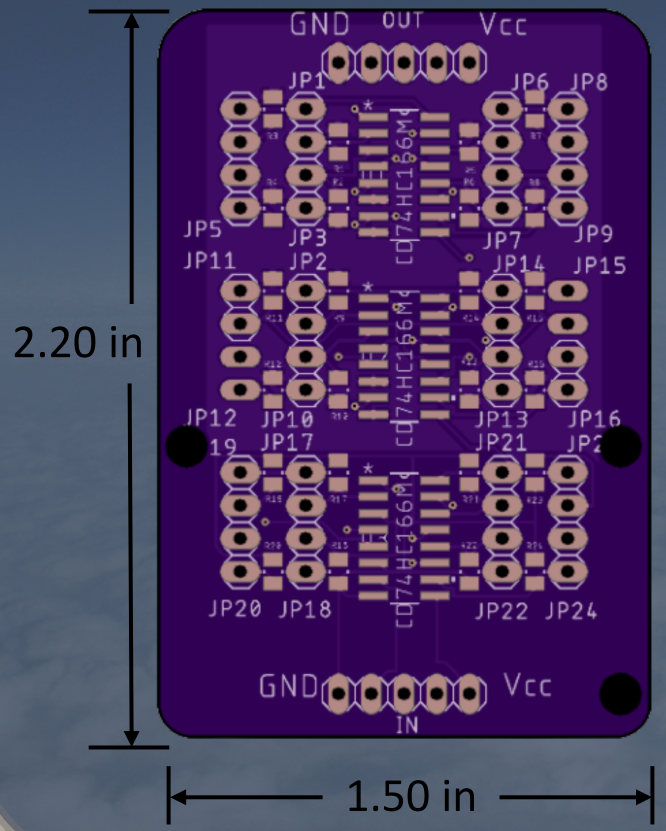



PISO Functional Diagram

- Each shift register allows the connection of 8 buttons
- Can be wired together in series with multiple registers to increase buttons, we use up to 5 in each set for 40 signals.
- Works by taking in a parallel set of data D0-D7(buttons)
- Each clock cycle shifts in the data to output through Q7 digitally as a singular value

Robert Craig

# Printed Circuit Board Design

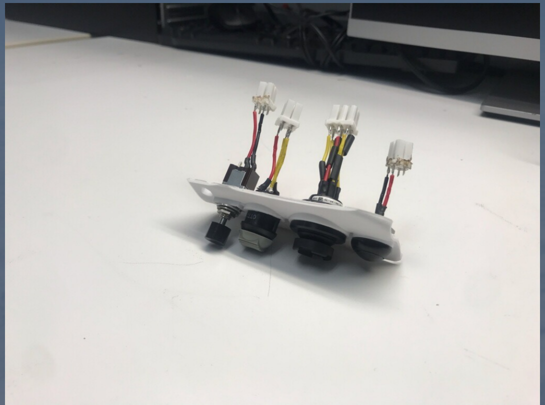



- PCBs allow for wiring to be more organized
- Made for 3 shift registers
  - Can be connected to each other to accommodate more
- More robust design
- Allows for ease of button replacement

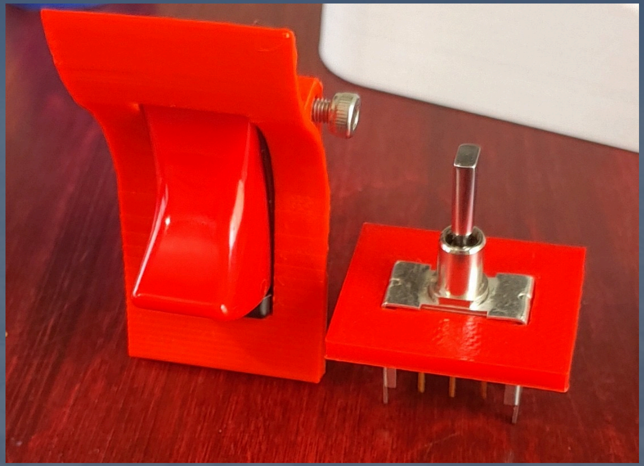

Robert Craig

# Electrical Connections

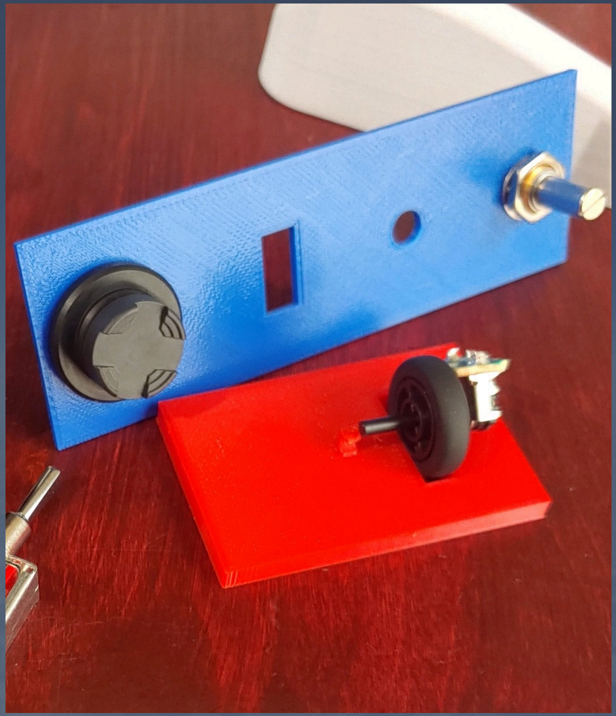
Throttle Buttons in Mount



Buttons with Connectors



Stick buttons in Mounts



Buttons in Mounts

Robert Craig

# Testing

Robert Craig

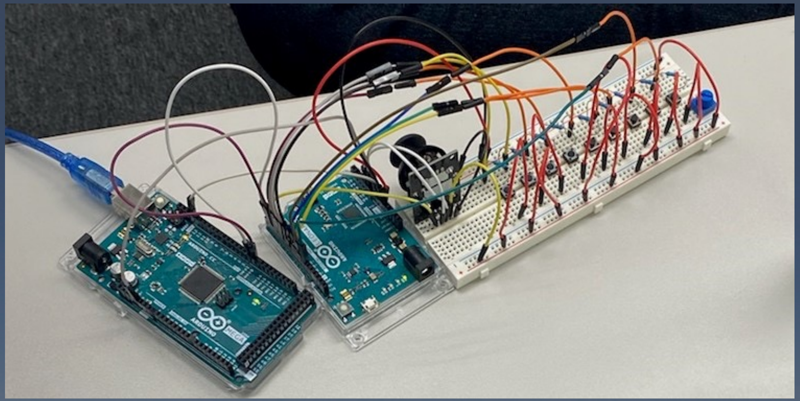
# Initial Testing Goals

- Communicate with the computer
- Control aircraft in Digital Combat Simulator
- Have less than 20ms of latency
- Attempt a successful takeoff and landing

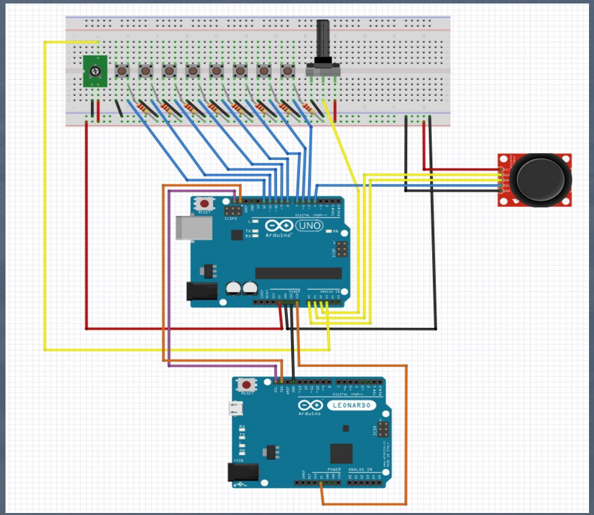
Connor Chuppe

# Testing Setup

- Connected Arduino to laptop to initialize buttons and potentiometers
  - Done using Microsoft Setup Game controller
- Verified outputs were correctly displayed for buttons
- Calibrated potentiometers
  - Ensured output was displayed across entire range



Initial Testing Wiring Setup



Initial Testing Wiring Diagram

Connor Chuppe

# Initial Software Testing


F-16 Cockpit View During Test

- Mapped in-game commands to our buttons
  - Done using the DCS software
  - Selected a command of our choice then clicked the button we wanted it mapped to
- Assigned potentiometers to corresponding axis
  - Axis for pitch, roll, yaw and throttle
- Fly the aircraft in the simulator

Connor Chuppe

# Initial Testing Takeaways

**Accomplishments**

- Able to fly aircraft
- Digital buttons worked 9/10 times
- Latency was under target of 20ms (12.5ms)

**Issues**

- Joystick movement did not always correspond to an output
  - Potentiometer did not fit into potentiometer mount
- Yaw potentiometer did not center when released
  - Switched to a joystick potentiometer
- Throttle wasn't linear across entire range
  - Switched to a high precision potentiometer

Testing Using F-16 in DCS

Connor Chuppe

# Project Recap

Connor Chuppe

# Future Work

- Final Assembly of Stick and Throttle
  - Waiting on parts to finish printing
- Testing Fully Assembled HOTAS with Prepar3D
- Implementing multiple sticks and throttles with bases
- Feedback proportional to the speed and angle of attack of aircraft

Connor Chuppe

# Lessons Learned

- Shift registers are a great way to gain large number of i/o
- Fitting electrical internals is much more difficult when done without the use of machines
- Waiting for budget to be allocated must be considered when planning
- Integrating electronic and mechanical components can be painfully tedious

Connor Chuppe

# References


1. *3D Lego Brick 2x4 Black Model*. (n.d.). Retrieved from Turbosquid: https://www.turbosquid.com/3d-models/3d-lego-brick-2x4-black-model-1409498
2. *Apem Series HF Joystick Finger Joystick*. (n.d.). Retrieved from Hawk Electronics: https://www.hawkusa.com/manufacturers/apem/switches/finger-joystick/hf22s10?gclid=CjwKCAiA17P9BRB2EiwAMvwNyDoLi0kiWbGFXKNDY317HFxCRfCyBWZIEJBDPD2clZMBO_0nsEmS3xoCRD8QAvD_BwE
3. *CH Products Eclipse Yoke*. (n.d.). Retrieved from Pilot Mall: https://www.pilotmall.com/products/ch-eclipse-yoke?variant=10887410909227&utm_medium=cpc&utm_source=google&utm_campaign=Google%20Shopping&gclid=CjwKCAiA17P9BRB2EiwAMvwNyDK6SGyUQPz_6ZoxU53jzyExnO0IKAULyTxFMkDQ7nT7Vl_jXQ4BpBoCrPwQAvD_BwE
4. *Compare* . (n.d.). Retrieved from Oculus: https://www.oculus.com/compare/
5. *Electronic Circuit Board Icon Simple Style*. (n.d.). Retrieved from Vector Stock: https://www.vectorstock.com/royalty-free-vector/electronic-circuit-board-icon-simple-style-vector-9884194
6. *Ergonomic Icon*. (n.d.). Retrieved from Free Icons Library: https://icon-library.com/icon/ergonomic-icon-20.html
7. *F-35 Joint Strike Fighter Sidestick Grip*. (n.d.). Retrieved from Essex Industries: https://www.essexindustries.com/products/f-35-joint-strike-fighter-sidestick-grip/
8. *FC2000 Series- F-35 High Fidelity Simulated Stick and Throttle*. (n.d.). Retrieved from Bugeye Technologies: https://www.bugeyetech.com/simulatedf-35controls


Connor Chuppe

# References


9. *Fully Threaded Rod, Steel,1/2"-20, 1ft Length*. (n.d.). Retrieved from Grainger: https://www.grainger.com/product/10P611?gclid=CjwKCAiA17P9BRB2EiwAMvwNyOGWcULrpShFmIAzrFZW4p_l3qAJnlcGB1Jn9NDWAB7BubJSB15nTxoCHVkQAvD_BwE&cm_mmc=PPC:+Google+PLA&ef_id=CjwKCAiA17P9BRB2EiwAMvwNyOGWcULrpShFmIAzrFZW4p_l3qAJnlcGB1Jn9NDWAB7BubJSB15nTxoCHVkQAvD_
10. Lockheed Martin. (n.d.). *Lockheed Martin*. Retrieved from Lockheed Martin: https://www.lockheedmartin.com/en-us/index.html
11. *Photos*. (n.d.). Retrieved from Luke Airforce Base: https://www.luke.af.mil/News/Photos/
12. *Remote Control AA59-00666A Replace for Samsung Smart TV*. (n.d.). Retrieved from ebay: https://www.ebay.com/i/132884810326?mkevt=1&mkcid=28&chn=ps
13. Thrustmaster. (n.d.). *US Airforce Joysticks*. Retrieved from Thrustmaster: http://www.thrustmaster.com/products/categories/joysticks-0&tid=25
14. *United States Military Logo Packs*. (n.d.). Retrieved from Muskegon Biker: https://muskegonbiker.com/military-logos-vector/


Connor Chuppe

# Questions and Comments

Robert Blount
Connor Chuppe
Robert Craig
Patrick Dixon

# Come Fly With Us.

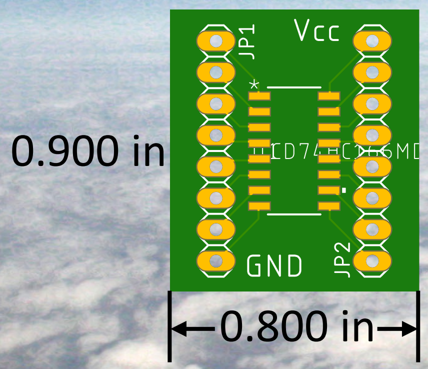
Robert Blount
Connor Chuppe
Robert Craig
Patrick Dixon

# Backup Slides

# Throttle integration

# Stick integration

# Final Assembly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0.800 in
JP1
Vcc
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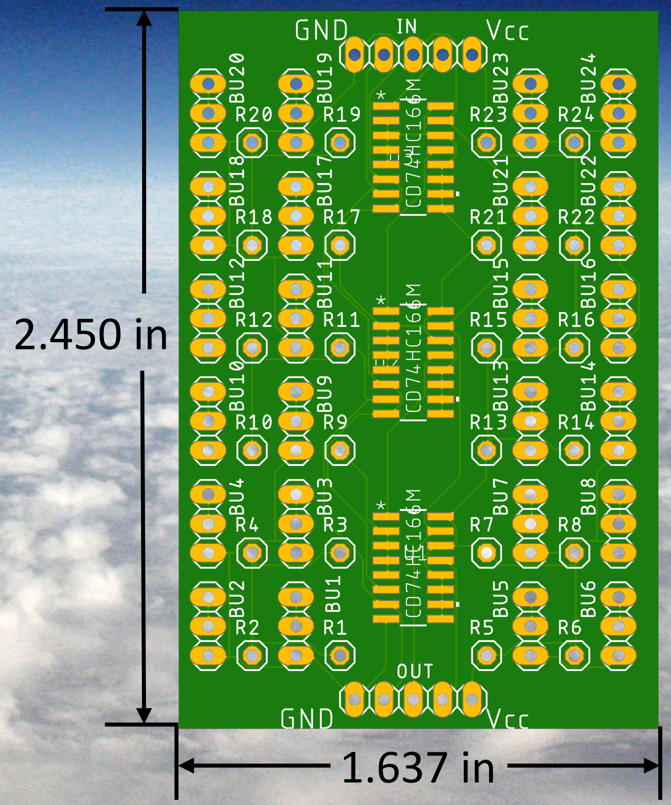
JP2


2.450 in
1.637 in
GND
IN
Vcc
OUT
GND
Vcc

# targets and metrics backup

| Function | Target | Metric |
|---|---|---|
| Integrate with Current Lockheed System | Yes | It works with the system |
| Support Multiple Modular Grips | Variable per each stick | Major diameter and threading of mounting section for the stick |
| | 1”-2" | Length of mounting section for the stick |
| | ¼"-20 | Pitch of the mounting threads for the stick |
| Integrate Buttons Within Specified Tolerances | ±0.078-0.25in (2-6mm) | Distance button can be displaced |
| Input Feedback Signals | Receive signal for AOA, and craft speed to send to process into feedback | Receive data through USB to USB-A |
| Provide Feedback | 1.12 ± 0.45 lbf (5 ± 2 N) of force | Provide an actuator force |
| This one and each below have no function to create a target and metric from | Less than $4000 to manufacture | Cost in $$ |
| | 10 lbs. (45 N) ≤ weight ≤ 15 lbs. (67 N) | Weight |
| | Can be dropped from a height of 29” (73.66 cm) ± 1” (2.54 cm) at any orientation without mechanical failure | Drop height until failure |
| | At least 2 Years | Component Lifetime |
| | At least 5 years | Product Lifetime |

# Concept Generation Backup

# Morphological Chart

| Subsytems | Fit | Form | Assembly | Process | Communicatio | Sense | Force | Throttle Displacement | Stick Displacement | Power | Mounting | Material |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generated Concepts | Thumbwheel Adjustment | Resemble F35 | Separate Throttle & Stick | Arduino | USB-A | | Torsional Spring | Sliding Throttle | Twistable Stick | Battery | Suction Cups | Plastics |
| | Pushbutton | Resemble F16 | Single Unit Throttle & Stick | Custom Circuit Board | USB-B 3.0 | Hall effect sensers | Stepper Motor | Rotating Throttle | Yaw on Throttle not Stick | From Computer | Clamp | Metals |
| | Toggle Switches | Resemble F22 | Combined, but Modular for Separation | Raspberry Pi | USB-C | Potentiometer | DC Motor | Slotted Throttle | | | Velcro | Combination |
| | Isotonic Joystick | Threaded Grips for multiple crafts | | Python Board | DV9 | Motor DC | | | | | Increased Base Weight | Silicone |
| | combination from above | multiple Grip Covers for single Stick | | | Ethernet | Encoder | | | | | Mighty Mug Bottoms | Polymers |
| | | | | | | | | | | | Full Chair Mount | Fiber Materials |

| Concepts | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Fit | combination of buttons/switches | Isotonic Joystick | combination of buttons/switches | combination of buttons/switches | combination of buttons/switches |
| Form | Threaded Grips for multiple crafts | Threaded Grips for multiple crafts | Resemble F35 | multiple Grip Covers for single Stick | Threaded Grips for multiple crafts |
| Assembly | combined, but modular for separation | Separate Throttle & Stick | combined, but modular for separation | Separate Throttle & Stick | combined, but modular for separation |
| Process | Arduino | Arduino | Arduino | Arduino | Arduino |
| Communication | USB-A | Ethernet | USB-A | DV9 | USB-A |
| Sense | Hall effect sensers | Hall effect sensers | Hall effect sensers | Potentiometer | Encoder |
| Force | DC Motor | DC Motor | DC Motor | Torsional Spring | DC Motor |
| Throttle Displacement | Rotating Throttle | Sliding Throttle | Rotating Throttle | Rotating Throttle | Slotted Throttle |
| Stick Displacement | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick |
| Power | from Computer | From Computer | from Computer | From Computer | From Computer |
| Mounting | Mighty Mug Bottoms | Increased Base Weight | Full Chair Mount | Suction Cups | Mighty Mug Bottoms |
| Material | Combination | Plastics | Combination | Plastics | Combination |

| Concepts | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Fit | combination of buttons/switches | combination of buttons/switches | combination of buttons/switches | combination of buttons/switches | combination of buttons/switches |
| Form | Resemble F35 | multiple Grip Covers for single Stick | Threaded Grips for multiple crafts | Threaded Grips for multiple crafts | Resemble F35 |
| Assembly | combined, but modular for separation | Separate Throttle & Stick | combined, but modular for separation | Separate Throttle & Stick | combined, but modular for separation |
| Process | Arduino | Arduino | Arduino | Arduino | Arduino |
| Communication | USB-A | USB-A | USB-A | USB-A | USB-A |
| Sense | Encoder | Potentiometer | Hall effect sensers | Potentiometer | Hall effect sensers |
| Force | DC Motor | Torsional Spring | DC Motor | DC Motor | Torsional Spring |
| Throttle Displacement | Rotating Throttle | Sliding Throttle | Rotating Throttle | Rotating Throttle | Rotating Throttle |
| Stick Displacement | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick |
| Power | From Computer | From Computer | From Computer | From Computer | From Computer |
| Mounting | Mighty Mug Bottoms | Suction Cups | Clamp | Full Chair Mount | Clamp |
| Material | Combination | Plastics | Plastics | Combination | Combination |

| Concepts | 11 | 12 | 13 | 14 | 15 |
| --- | --- | --- | --- | --- | --- |
| Fit | combination of buttons/switches | Push Button | combination | Toggle switches | Thumbwheel Adjustment |
| Form | Threaded Grips for multiple crafts | Resemble F35 | Resemble F16 | Resemble F35 | multiple Grip Covers for single Stick |
| Assembly | combined, but modular for separation | Separate Throttle & Stick | Single Unit Throttle & Stick | Separate Throttle & Stick | Single Unit Throttle & Stick |
| Process | Arduino | Python Board | Python Board | Python Board | Python Board |
| Communication | USB-A | USB-A | USB-B 3.0 | USB-C | USB-B 3.0 |
| Sense | Encoder | DC Motor | DC Motor | DC Motor | Potentiometer |
| Force | DC Motor | Torsional Spring | DC Motor | Torsional Spring | Stepper Motor |
| Throttle Displacement | Sliding Throttle | Sliding Throttle | Sliding Throttle | Rotating Throttle | Slotted Throttle |
| Stick Displacement | Twistable Stick | Twistable Stick | yaw on Throttle not Stick | Twistable Stick | yaw on Throttle not Stick |
| Power | From Computer | from Computer | from Computer | Battery | from Computer |
| Mounting | Full Chair Mount | Clamp | suction cups | Velcro | increased base weight |
| Material | Combination | Silicone | Plastics | combination | Polymers |

| Concepts | 16 | 17 | 18 | 19 | 20 |
| --- | --- | --- | --- | --- | --- |
| Fit | Push Button | combination | Thumbwheel Adjustment | Toggle switches | combination |
| Form | Resemble F22 | multiple Grip Covers for single Stick | Threaded Grips for multiple crafts | multiple Grip Covers for single Stick | Threaded Grips for multiple crafts |
| Assembly | Separate Throttle & Stick | Single Unit Throttle & Stick | Combined, but modular for separation | Combined, but modular for separation | Single Unit Throttle & Stick |
| Process | Python Board | Python Board | Python Board | Python Board | Python Board |
| Communication | USB-A | Ethernet | DV9 | USB-C | USB-B 3.0 |
| Sense | Encoder | Potentiometer | Hall effect sensers | Encoder | Hall effect sensers |
| Force | Torsional Spring | Stepper Motor | DC Motor | Stepper Motor | Torsional Spring |
| Throttle Displacement | Rotating Throttle | Slotted Throttle | Rotating Throttle | Sliding Throttle | Sliding Throttle |
| Stick Displacement | yaw on Throttle not Stick | Twistable Stick | yaw on Throttle not Stick | yaw on Throttle not Stick | Twistable Stick |
| Power | from Computer | Battery | Battery | from Computer | from Computer |
| Mounting | Full Chair Mount | increased base weight | Clamp | Mighty Mug Bottoms | suction cups |
| Material | Metals | combination | Metals | Fiber materials | Silicone |

| Concepts | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|
| Fit | Pushbutton | Isotonic Joystick | Thumbwheel Adjustment | Pushbutton | Thumbwheel Adjustment |
| Form | Resemble F16 | Resemble F35 | Resemble F22 | multiple Grip Covers for single Stick | Resemble F22 |
| Assembly | Single Unit Throttle & Stick | Separate Throttle & Stick | Separate Throttle & Stick | Combined, but Modular for Separation | Separate Throttle & Stick |
| Process | Raspberry Pi | Raspberry Pi | Raspberry Pi | Raspberry Pi | Raspberry Pi |
| Communication | DV9 | Ethernet | USB-A | USB-B 3.0 | Ethernet |
| Sense | Potentiometer | Hall effect sensers | Encoder | Hall effect sensers | Hall effect sensers |
| Force | Potentiometer | DC Motor | Stepper Motor | DC Motor | Stepper Motor |
| Throttle Displacement | Sliding Throttle | Rotating Throttle | Slotted Throttle | Sliding Throttle | Slotted Throttle |
| Stick Displacement | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick |
| Power | Battery | From Computer | From Computer | From Computer | Battery |
| Mounting | Suction Cups | Full Chair Mount | Clamp | Velcro | Mighty Mug Bottoms |
| Material | Plastics | Metals | Combination | Fiber Materials | Silicone |


| Concepts | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|
| Fit | Pushbutton | Isotonic Joystick | Thumbwheel Adjustment | Pushbutton | Thumbwheel Adjustment |
| Form | Resemble F16 | Resemble F35 | Resemble F22 | multiple Grip Covers for single Stick | Resemble F22 |
| Assembly | Single Unit Throttle & Stick | Separate Throttle & Stick | Separate Throttle & Stick | Combined, but Modular for Separation | Separate Throttle & Stick |
| Process | Raspberry Pi | Raspberry Pi | Raspberry Pi | Raspberry Pi | Raspberry Pi |
| Communication | DV9 | Ethernet | USB-A | USB-B 3.0 | Ethernet |
| Sense | Potentiometer | Hall effect sensers | Encoder | Hall effect sensers | Hall effect sensers |
| Force | Potentiometer | DC Motor | Stepper Motor | DC Motor | Stepper Motor |
| Throttle Displacement | Sliding Throttle | Rotating Throttle | Slotted Throttle | Sliding Throttle | Slotted Throttle |
| Stick Displacement | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick |
| Power | Battery | From Computer | From Computer | From Computer | Battery |
| Mounting | Suction Cups | Full Chair Mount | Clamp | Velcro | Mighty Mug Bottoms |
| Material | Plastics | Metals | Combination | Fiber Materials | Silicone |

| Concepts | 31 | 32 | 33 | 34 | 35 |
|---|---|---|---|---|---|
| Fit | combination from above | Thumbwheel Adjustment | combination from above | Pushbutton | combination from above |
| Form | Resemble F35 | Resemble F35 | Resemble F16 | Resemble F22 | Resemble F35 |
| Assembly | Separate Throttle & Stick | Separate Throttle & Stick | Combined, but Modular for Separation | Combined, but Modular for Separation | Combined, but Modular for Separation |
| Process | Raspberry Pi | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board |
| Communication | USB-C | USB-A | USB-A | USB-A | USB-A |
| Sense | Potentiometer | Encoders | Hall effect sensers | Motor DC | Motor DC |
| Force | Stepper Motor | Torsional Spring | Torsional Spring | Torsional Spring | Torsional Spring |
| Throttle Displacement | Rotating Throttle | Sliding Throttle | Sliding Throttle | Sliding Throttle | Rotating Throttle |
| Stick Displacement | Yaw on Throttle not Stick | Twistable Stick | Twistable Stick | Twistable Stick | Yaw on Throttle not Stick |
| Power | From Computer | Battery | Battery | From Computer | From Computer |
| Mounting | Suction Cups | Suction Cups | Increased Base Weight | Increased Base Weight | Clamp |
| Material | Plastics | Plastics | Combination | Combination | Metals |

| Concepts | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|
| Fit | Toggle Switches | Isotonic Joystick | combination from above | Toggle Switches | Toggle Switches |
| Form | Resemble F16 | Resemble F22 | Resemble F35 | Resemble F16 | Resemble F22 |
| Assembly | Combined, but Modular for Separation | ombined, but Modular for Separatic | Separate Throttle & Stick | Single Unit Throttle & Stick | Combined, but Modular for Separation |
| Process | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board |
| Communication | DV9 | USB-C | USB-A | Ethernet | USB-A |
| Sense | Potentiometer | Hall effect sensers | Hall effect sensers | Potentiometer | Encoder |
| Force | Stepper Motor | Stepper Motor | Torsional Spring | DC Motor | DC Motor |
| Throttle Displacement | Slotted Throttle | Slotted Throttle | Sliding Throttle | Slotted Throttle | Sliding Throttle |
| Stick Displacement | Twistable Stick | Twistable Stick | Twistable Stick | Yaw on Throttle not Stick | Yaw on Throttle not Stick |
| Power | From Computer | From Computer | From Computer | From Computer | From Computer |
| Mounting | Velcro | Velcro | Increased Base Weight | Increased Base Weight | Clamp |
| Material | Silicone | Silicone | Combination | Combination | Fiber Materials |

| Concepts | 41 | 42 | 43 | 44 | 45 |
| --- | --- | --- | --- | --- | --- |
| Fit | combination of buttons/switches | combination of buttons/switches | Isotonic Joystick | Push Button | Isotonic Joystick |
| Form | Threaded Grips for multiple crafts | multiple Grip Covers for single Stick | Threaded Grips for multiple crafts | Resemble F22 | Threaded Grips for multiple crafts |
| Assembly | Separate Throttle & Stick | Separate Throttle & Stick | Combined, but modular for separation | Combined, but modular for separation | Separate Throttle & Stick |
| Process | Arduino | Arduino | Python Board | Python Board | Raspberry Pi |
| Communication | USB-A | USB-A | DV9 | Ethernet | USB-B 3.0 |
| Sense | Encoder | Potentiometer | Encoder | Potentiometer | Motor DC |
| Force | DC Motor | Torsional Spring | DC Motor | Torsional Spring | Torsional Spring |
| Throttle Displacement | Slotted Throttle | Rotating Throttle | Sliding Throttle | Slotted Throttle | Rotating Throttle |
| Stick Displacement | Twistable Stick | Yaw on Throttle not Stick | Twistable Stick | Twistable Stick | Yaw on Throttle not Stick |
| Power | From Computer | From Computer | Battery | Battery | From Computer |
| Mounting | Mighty Mug Bottoms | Clamp | Mighty Mug Bottoms | Clamp | Mighty Mug Bottoms |
| Material | Combination | Plastics | Fiber materials | Plastics | Polymers |

| Concepts | 46 | 47 | 48 | 49 | 50 |
| --- | --- | --- | --- | --- | --- |
| Fit | Isotonic Joystick | combination from above | Pushbutton | Isotonic Joystick | Pushbutton |
| Form | Resemble F16 | Threaded Grips for multiple crafts | Resemble F22 | Resemble F22 | Resemble F22 |
| Assembly | Single Unit Throttle & Stick | Separate Throttle & Stick | Single Unit Throttle & Stick | Combined, but Modular for Separation | Separate Throttle & Stick |
| Process | Raspberry Pi | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board | Custom Circuit Board |
| Communication | USB-A | USB-B 3.0 | DV9 | USB-C | USB-C |
| Sense | Hall effect sensers | Motor DC | Potentiometer | Motor DC | Encoder |
| Force | DC Motor | Torsional Spring | Torsional Spring | DC Motor | Torsional Spring |
| Throttle Displacement | Sliding Throttle | Rotating Throttle | Rotating Throttle | Rotating Throttle | Slotted Throttle |
| Stick Displacement | Yaw on Throttle not Stick | Yaw on Throttle not Stick | Yaw on Throttle not Stick | Yaw on Throttle not Stick | Yaw on Throttle not Stick |
| Power | Battery | From Computer | From Computer | Battery | From Computer |
| Mounting | Velcro | Increased Base Weight | Clamp | Clamp | Increased Base Weight |
| Material | Metals | Silicone | Silicone | Fiber Materials | Combination |

- The throttle base has buttons but not on the throttle itself. The base for the stick has no buttons but the stick itself has all the necessary buttons. Separate base for throttle and stick
- The throttle base doesn't have buttons, all throttle buttons are on the throttle itself. Stick base has buttons and not on the stick itself. Separate base for throttle and stick
- The base has all the buttons on it and no buttons on the throttle or stick. Single base for throttle and stick
- The HOTAS becomes just a stick with throttle functionality, in example the stick rotates in 3 axis and move along one.
- Throttle with a detent to distinguish between various engine stages.
- Use lights with heat camera to determine location and placement of hands to operate the hotas, without a physical throttle or stick, just bases for either main subsystem.
- Use only COTS (Commercially off the Shelf) parts to make up the buttons
- Bee-Hive resembling throttle and stick to save money on amount of material
- 3-D print all the buttons, stick and throttle
- Disassemble a working keyboard to recreate a HOTAS by using switches and keys along with the rollers and sliders on some keyboards.

- Using a 3-d scanner and appropriate tech create the one stick and throttle to rule them all (like the one ring form lord of the rings), with functionality in key locations for each of the operable crafts chosen
- Destroy an existing HOTAS of low fidelity to create a new shell and reuse most of their electronics and components.
- Entire desk is the HOTAS, the stick and throttle built into the desk surface as well as all the buttons and switches
- Haptic HOTAS, gloves on the hand that recognize hand positions in space to detect control intent
- Chair with throttle and stick built into the armrests
- HOTAS that reacts to neural signals to detect aircraft intent
- Base made with foam core
- Have dual throttle that controls yaw when pushed in opposite directions
- Stick made from a used car gear shift
- Disassemble a computer mouse to use the scroll wheel and left and right click buttons

- Use a ball joint for the stick with variable resistance in all directions to detect the control intent.
- Electric signal could then be sent through the stick to sense the orientation of the stick
- Base housing made of LEGO's, could be painted and glued together to form a rigid structure
- Printed circuit boards to direct the signals instead of a lot of wires
- Oculus rift set up. Doesn't have to actually be virtual reality but both the stick and throttle could
- be floating controllers not mounted to a base and the user just has to manipulate the controllers in mid air
- Breaking down and using a video game controllers' components and board to provide some functionalities of the HOTAS.
- Stick that doesn't move but interprets the amount of force being applied
- Throttle that is able to be detached and replaced with a different style
- Buttons that sense force but don't physically depress

- Buttons that are rubber similar to a tv remote
- Stick base bolted to floor
- A yoke(flight steering wheel) with the HOTAS implemented into it, so that the right side has the stick with operable functions and the left side has the throttle with rotating functionality.
- Mirror the Atari 2600 system Joystick
- Replicate actual assembly of current military aircraft
- Glove like HOTAS controlled by hand gestures
- Use radio waves as a form of communication between the stick and throttle
- Strain gauges to sense input
- Filter the signals using various hardware rather than coding
- Foldable HOTAS with a hinge on where the shaft connects to the base for transformational purposes

- Instead of having a base to mount to the desk, you have it attached via a wrap around on your legs
- All leg functional HOTAS
- Bluetooth/WIFI HOTAS
- Magnetic interchangeable stick
- Tripod style base for stick instead of rectangular
- Ferro-magnetic fluid to create the different sticks to then operate with similar control
- Altering the shape of the HOTAS to conform to various sticks by changing an active frequency to be applied through sound waves.
- GPS sensor to determine pitch roll yaw of the HOTAS and throttle
- Use a belt system to actuate the throttle. There would theoretically be no backlash in the system
- 4-bar linkage mechanism for the throttle, it could either be a coupler or an output link
- Have the HOTAS in a booth and use lidar to detect the orientation of the stick and/or throttle
- Snap-fit throttle. If a material is pliable enough, then the end of the throttle it could be deformed to fit into a holder. Can work by either applying this concept to the throttle/stick or to the holder it mates into.

# HOQ backup

| Customer Requirement | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| Easily Repairable | – | 0 | 0 | 1 | 0 | 1 |
| Under $4,000 | 1 | – | 0 | 1 | 1 | 3 |
| Be able to integrate with Lockheeds software | 1 | 1 | | 1 | 1 | 4 |
| Provide Feedback | 0 | 0 | 0 | – | 0 | 0 |
| Similar Functionality to Current Products | 1 | 0 | 0 | 1 | – | 2 |
| Total | 3 | 1 | 0 | 4 | 2 | |

| | | Engineering Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Improvement Direction | | ↑ | ↓ | ↓ | ↓ | ↑ | ↑ | – | – | ↑ | ↑ |
| Units | | Years | $ | n/a | ms | MHz | Mpa | lbs | n/a | lbsf | n/a |
| Customer requirements | Importance Weight Factor | Lifespan | Cost | Design Complexity | Latency/Transfer Speed | Frequency | Material Strength | Weight | Shape | Force | Repairability |
| Easily Repairable | 1 | 1 | 3 | 3 | 1 | 0 | 3 | 0 | 9 | 0 | 9 |
| Under $4,000 | 3 | 0 | 9 | 9 | 3 | 3 | 3 | 3 | 1 | 3 | 3 |
| Be able to Integrate With Lockheeds Software | 4 | 0 | 1 | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| Provide Feedback | 1 | 0 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 9 | 1 |
| Similar Functionality to Current Products | 2 | 3 | 9 | 3 | 3 | 3 | 0 | 3 | 3 | 0 | 0 |
| Raw Score | 249 | 7 | 55 | 41 | 31 | 28 | 15 | 16 | 19 | 18 | 19 |
| Relative Weight % | | 2.81 | 22.09 | 16.47 | 12.45 | 11.24 | 6.02 | 6.43 | 7.63 | 7.23 | 7.63 |
| Rank Order | | 9 | 1 | 2 | 3 | 4 | 7 | 6 | 5 | 8 | 5 |

# pugh charts backup

| | Concepts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Engineering Chars | Wraith Systems | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Lifespan | Datum | + | + | + | + | + | + | + | + |
| Cost | | + | + | + | + | + | + | + | + |
| Latency/Transfer Speed | | - | - | - | - | - | - | - | - |
| Frequency | | - | - | - | - | - | - | - | - |
| Material Strength | | - | - | - | - | - | - | - | - |
| Weight | | - | - | - | - | - | - | - | - |
| Shape | | - | - | - | - | - | - | - | - |
| Force | | - | - | - | - | - | - | - | - |
| Repairability | | + | + | + | + | + | + | + | + |
| Pluses | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Minuses | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |

# pugh charts backup

| | Concepts | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Engineering Chars | Concept 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Lifespan | | S | - | S | - | S | S | S |
| Cost | | - | + | - | + | - | + | + |
| Latency/Transfer Speed | | S | - | S | S | S | - | S |
| Frequency | | S | S | S | S | S | S | S |
| Material Strength | Datum | S | S | S | - | S | - | S |
| Weight | | S | S | + | - | S | - | S |
| Shape | | S | + | - | S | S | S | - |
| Force | | S | S | S | - | + | - | S |
| Repairability | | S | + | - | + | - | S | + |
| Pluses | | 0 | 4 | 1 | 2 | 1 | 1 | 2 |
| Minuses | | 1 | 2 | 3 | 4 | 2 | 4 | 1 |

# pugh charts backup

| | Concepts | | | | | |
|---|---|---|---|---|---|---|
| **Engineering Chars** | Concept 3 | 1 | 2 | 4 | 5 | 8 |
| Lifespan | Datum | + | S | S | - | S |
| Cost | | - | + | - | + | + |
| Latency/Transfer Speed | | + | + | S | S | S |
| Frequency | | S | S | S | S | S |
| Material Strength | | S | S | S | - | S |
| Weight | | S | S | + | - | S |
| Shape | | - | S | - | S | - |
| Force | | - | - | S | - | S |
| Repairability | | - | - | - | + | + |
| Pluses | | 2 | 2 | 1 | 2 | 2 |
| Minuses | | 4 | 1 | 3 | 4 | 1 |

# pugh charts backup

| | Concepts | | | | |
|---|---|---|---|---|---|
| **Engineering Chars** | Concept 2 | 1 | 3 | 4 | 8 |
| Lifespan | Datum | S | - | S | S |
| Cost | | S | + | - | + |
| Latency/Transfer Speed | | S | S | S | S |
| Frequency | | S | - | S | S |
| Material Strength | | S | S | S | S |
| Weight | | S | S | + | S |
| Shape | | + | + | - | - |
| Force | | S | S | S | S |
| Repairability | | S | + | - | + |
| Pluses | | 1 | 3 | 1 | 2 |
| Minuses | | 0 | 2 | 3 | 1 |

# AHP charts backup

| Engineering Characteristics AHP | Lifespan | Cost | Transfer Speed/Latency | Frequency | Material Rigidity | Weight | Shape | Force | Repairability |
|---|---|---|---|---|---|---|---|---|---|
| Lifespan | 1 | 1/7 | 1/3 | 1/3 | 3 | 3 | 7 | 3 | 1/3 |
| Cost | 7 | 1 | 3 | 3 | 7 | 9 | 7 | 9 | 3 |
| Transfer Speed/Latency | 3 | 1/3 | 1 | 1/3 | 5 | 7 | 5 | 7 | 3 |
| Frequency | 3 | 1/3 | 3 | 1 | 5 | 5 | 5 | 7 | 1/5 |
| Material Rigidity | 1/3 | 1/7 | 1/5 | 1/5 | 1 | 1 | 3 | 1 | 1/7 |
| Weight | 1/3 | 1/9 | 1/7 | 1/5 | 1 | 1 | 1 | 1 | 1/7 |
| Shape | 1/7 | 1/7 | 1/5 | 1/5 | 1/3 | 1 | 1 | 1 | 1/5 |
| Force | 1/3 | 1/9 | 1/7 | 1/7 | 1 | 1 | 1 | 1 | 1/9 |
| Repairability | 3 | 1/3 | 1/3 | 5 | 7 | 7 | 5 | 9 | 1 |
| Total | 18.14 | 2.65 | 8.35 | 10.41 | 30.33 | 35.00 | 35.00 | 39.00 | 8.13 |

| Engineering Characteristics N AHP | Lifespan | Cost | Transfer Speed/Latency | Frequency | Material Rigidity | Weight | Shape | Force | Repairability |
|---|---|---|---|---|---|---|---|---|---|
| Lifespan | 0.055 | 0.054 | 0.040 | 0.032 | 0.099 | 0.086 | 0.200 | 0.077 | 0.041 |
| Cost | 0.386 | 0.377 | 0.359 | 0.288 | 0.231 | 0.257 | 0.200 | 0.231 | 0.369 |
| Transfer Speed/Latency | 0.165 | 0.126 | 0.120 | 0.032 | 0.165 | 0.200 | 0.143 | 0.179 | 0.369 |
| Frequency | 0.165 | 0.126 | 0.359 | 0.096 | 0.165 | 0.143 | 0.143 | 0.179 | 0.025 |
| Material Rigidity | 0.018 | 0.054 | 0.024 | 0.019 | 0.033 | 0.029 | 0.086 | 0.026 | 0.018 |
| Weight | 0.018 | 0.042 | 0.017 | 0.019 | 0.033 | 0.029 | 0.029 | 0.026 | 0.018 |
| Shape | 0.008 | 0.054 | 0.024 | 0.019 | 0.011 | 0.029 | 0.029 | 0.026 | 0.025 |
| Force | 0.018 | 0.042 | 0.017 | 0.014 | 0.033 | 0.029 | 0.029 | 0.026 | 0.014 |
| Repairability | 0.165 | 0.126 | 0.040 | 0.480 | 0.231 | 0.200 | 0.143 | 0.231 | 0.123 |
| Total | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| Weighted total | Weighted sum | Conistency vector | average consistency | 10.0820 |
|---|---|---|---|---|
| 0.076 | 0.716 | 9.433 | n value | 9 |
| 0.300 | 3.240 | 10.806 | Consistency index | 0.1353 |
| 0.167 | 1.770 | 10.628 | Ri (lookup value (n)) | 1.45 |
| 0.156 | 1.615 | 10.375 | Consistency Ratio | 0.0933 |
| 0.034 | 0.319 | 9.376 | | |
| 0.026 | 0.250 | 9.786 | | |
| 0.025 | 0.243 | 9.792 | | |
| 0.025 | 0.235 | 9.589 | | |
| 0.193 | 2.116 | 10.953 | | |

# AHP charts backup

| Cost AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 1 | 1/3 | 1/7 | 1/5 |
| Concept 2 | 3 | 1 | 1/7 | 1/3 |
| Concept 3 | 7 | 7 | 1 | 5 |
| Concept 4 | 5 | 3 | 1/5 | 1 |
| Total | 16.00 | 11.33 | 1.49 | 6.53 |

| Cost N AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 0.063 | 0.029 | 0.096 | 0.031 |
| Concept 2 | 0.188 | 0.088 | 0.096 | 0.051 |
| Concept 3 | 0.438 | 0.618 | 0.673 | 0.765 |
| Concept 4 | 0.313 | 0.265 | 0.135 | 0.153 |
| Total | 1 | 1 | 1 | 1 |

| weighted total | weighted sum total | consistency vector | average consistency | 4.2457 |
|---|---|---|---|---|
| 0.055 | 0.222 | 4.065 | n value lookup | 4 |
| 0.106 | 0.431 | 4.075 | Consistency Index | 0.0819 |
| 0.623 | 2.827 | 4.535 | Random index value | 0.89 |
| 0.216 | 0.931 | 4.308 | Consistency Ratio | 0.0920 |
| 1 | | | | |

# AHP charts backup

| Repairability AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 1 | 3 1/33 | 1/7 | 1/3 |
| Concept 2 | 1/3 | 1 | 1/9 | 1/3 |
| Concept 3 | 7 | 9 | 1 | 7 3/71 |
| Concept 4 | 3 | 3 | 1/7 | 1 |
| Total | 11.33 | 16.03 | 1.40 | 8.71 |

| Repairability N AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 0.088 | 0.189 | 0.102 | 0.038 |
| Concept 2 | 0.029 | 0.062 | 0.080 | 0.038 |
| Concept 3 | 0.618 | 0.561 | 0.716 | 0.809 |
| Concept 4 | 0.265 | 0.187 | 0.102 | 0.115 |
| Total | 1 | 1 | 1 | 1 |

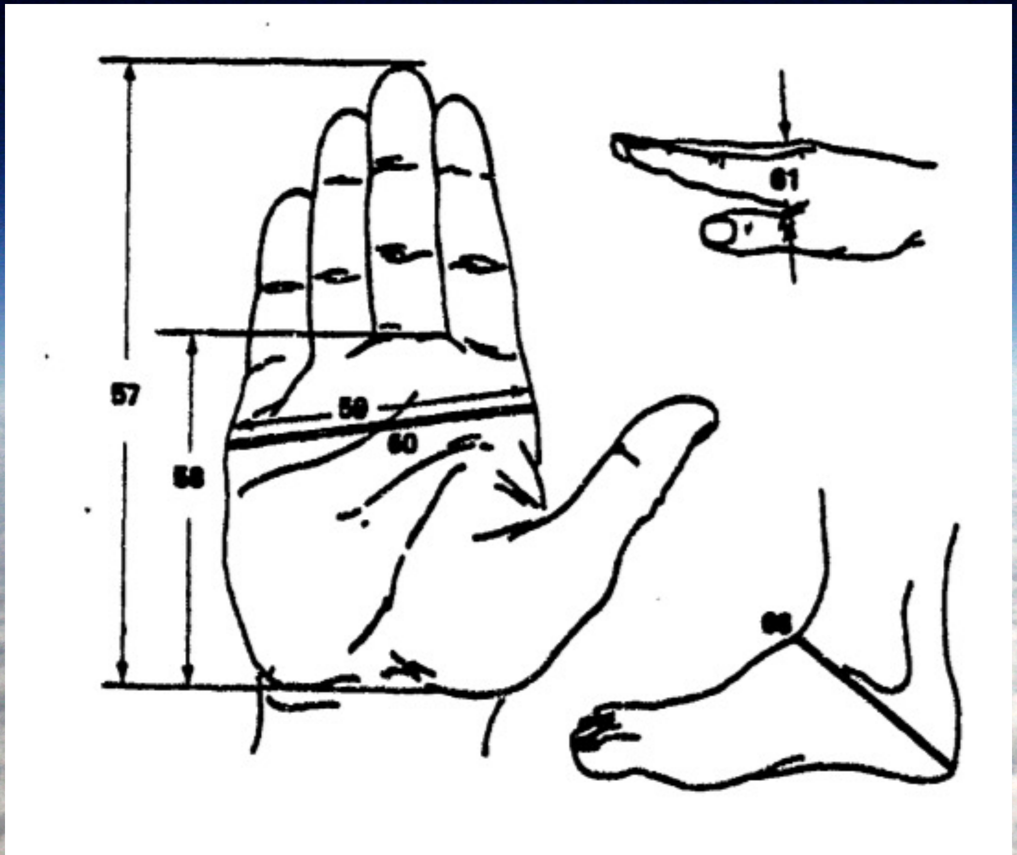
| weighted total | weighted sum total | consistency vector | average consistency | 4.2607 |
|---|---|---|---|---|
| 0.104 | 0.415 | 3.976 | n value lookup | 4 |
| 0.052 | 0.218 | 4.158 | Consistency Index | 0.0869 |
| 0.676 | 3.055 | 4.519 | Random index value | 0.89 |
| 0.167 | 0.734 | 4.390 | Consistency Ratio | 0.0976 |
| 1 | | | | |

# AHP charts backup

| Frequency(resolution) AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 1 | 1 | 5 | 7 3/71 |
| Concept 2 | 1 | 1 | 5 | 7 3/71 |
| Concept 3 | 1/5 | 1/5 | 1 | 5 |
| Concept 4 | 1/7 | 1/7 | 1/5 | 1 |
| Total | 2.34 | 2.34 | 11.20 | 20.08 |

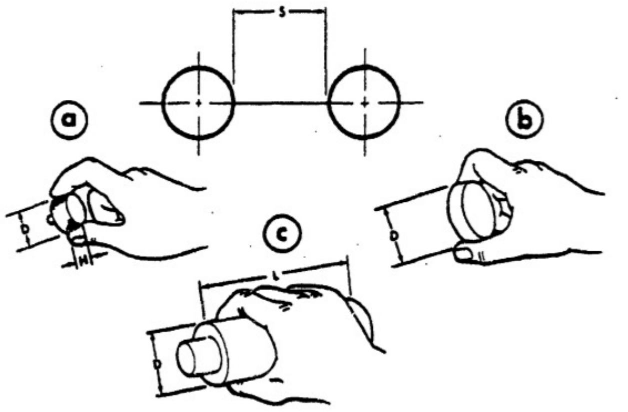
| Frequency(resolution) N AHP | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Concept 1 | 0.427 | 0.427 | 0.446 | 0.351 |
| Concept 2 | 0.427 | 0.427 | 0.446 | 0.351 |
| Concept 3 | 0.085 | 0.085 | 0.089 | 0.249 |
| Concept 4 | 0.061 | 0.061 | 0.018 | 0.050 |
| Total | 1 | 1 | 1 | 1 |

| weighted total | weighted sum total | consistency vector | average consistency | 4.2172 |
|---|---|---|---|---|
| 0.413 | 1.794 | 4.347 | n value lookup | 4 |
| 0.413 | 1.794 | 4.347 | Consistency Index | 0.0724 |
| 0.127 | 0.528 | 4.153 | Random index value | 0.89 |
| 0.047 | 0.190 | 4.021 | Consistency Ratio | 0.0813 |
| 1 | | | | |




| | Percentile Values in Centimeters | | | | | |
|---|---|---|---|---|---|---|
| | 5th Percentile | | | 95th Percentile | | |
| | Ground Troops | Aviators | Women | Ground Troops | Aviators | Women |
| **HAND DIMENSIONS** | | | | | | |
| 57 HAND LENGTH | 17.4 | 17.7 | 16.1 | 20.7 | 20.7 | 20.0 |
| 58 PALM LENGTH | 9.6 | 10.0 | 9.0 | 11.7 | 11.9 | 10.8 |
| 59 HAND BREADTH | 8.1 | 8.2 | 6.9 | 9.7 | 9.7 | 8.5 |
| 60 HAND CIRCUMFERENCE | 19.5 | 19.6 | 16.8 | 23.6 | 23.1 | 19.9 |
| 61 HAND THICKNESS | | 2.4 | | | 3.5 | |
| **FOOT DIMENSIONS** | | | | | | |
| 62 FOOT LENGTH | 24.5 | 24.4 | 22.2 | 29.0 | 29.0 | 26.5 |
| 63 INSTEP LENGTH | 17.7 | 17.5 | 16.3 | 21.7 | 21.4 | 19.6 |
| 64 FOOT BREADTH | 9.0 | 9.0 | 8.0 | 10.9 | 11.6 | 9.8 |
| 65 FOOT CIRCUMFERENCE | 22.5 | 22.6 | 20.8 | 27.4 | 27.0 | 24.5 |
| 66 HEEL—ANKLE CIRCUMFERENCE | 31.3 | 30.7 | 28.5 | 37.0 | 36.3 | 33.3 |

| | Percentile Values in Inches | | | | | |
|---|---|---|---|---|---|---|
| **HAND DIMENSIONS** | | | | | | |
| 57 HAND LENGTH | 6.85 | 6.98 | 6.32 | 8.13 | 8.14 | 7.89 |
| 58 PALM LENGTH | 3.77 | 3.92 | 3.56 | 4.61 | 4.69 | 4.24 |
| 59 HAND BREADTH | 3.20 | 3.22 | 2.72 | 3.83 | 3.80 | 3.33 |
| 60 HAND CIRCUMFERENCE | 7.68 | 7.71 | 6.62 | 9.28 | 9.11 | 7.82 |
| 61 HAND THICKNESS | | 0.95 | | | 1.37 | |
| **FOOT DIMENSIONS** | | | | | | |
| 62 FOOT LENGTH | 9.65 | 9.62 | 8.74 | 11.41 | 11.42 | 10.42 |
| 63 INSTEP LENGTH | 6.97 | 6.89 | 6.41 | 8.54 | 8.42 | 7.70 |
| 64 FOOT BREADTH | 3.53 | 3.54 | 3.16 | 4.29 | 4.58 | 3.84 |
| 65 FOOT CIRCUMFERENCE | 8.86 | 8.91 | 8.17 | 10.79 | 10.62 | 9.65 |
| 66 HEEL—ANGLE CIRCUMFERENCE | 12.32 | 12.09 | 11.21 | 14.57 | 14.30 | 13.11 |

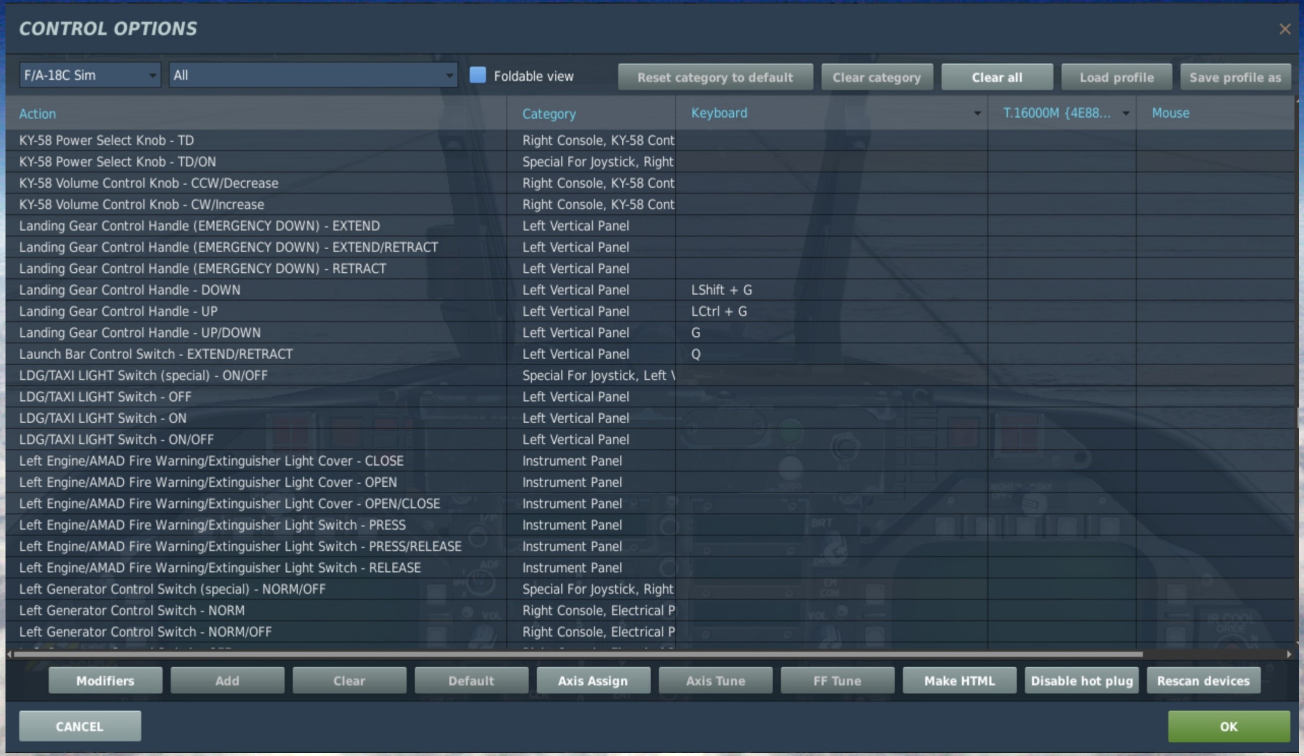



| | DIMENSIONS | | | | |
|---|---|---|---|---|---|
| | (a) Fingertip Grasp | | (b) Thumb and Finger Encircled | (c) Palm Grasp | |
| | H Height | D Diameter | D Diameter | D Diameter | L Length |
| Minimum | 13 mm (1/2 in.) | 10 mm (3/8 in.) | 25 mm (1 in.) | 38 mm (1-1/2 in.) | 75 mm (3 in.) |
| Maximum | 25 mm (1 in.) | 100 mm (4 in.) | 75 mm (3 in.) | 75 mm (3 in.) | - |

| | TORQUE | | SEPARATION | |
|---|---|---|---|---|
| | * | ** | S One Hand Individually | S Two Hands Simultaneously |
| Minimum | - | | 25 mm (1 in.) | 50 mm (2 in.) |
| Optimum | - | - | 50 mm (2 in.) | 125 mm (5 in.) |
| Maximum | 32 mN-m (4-1/2 in.-oz.) | 42 mN-m (6 in.-oz.) | - | - |

*To and including 25 mm (1.0 in.) diameter knobs
**Greater than 25 mm (1.0 in.) diameter knobs

FIGURE 7. KNOBS


CONTROL OPTIONS
F/A-18C Sim
All
Foldable view
Reset category to default
Clear category
Clear all
Load profile
Save profile as
Action
Category
Keyboard
T.16000M {4E88...
Mouse
KY-58 Power Select Knob - TD
Right Console, KY-58 Cont
KY-58 Power Select Knob - TD/ON
Special For Joystick, Right
KY-58 Volume Control Knob - CCW/Decrease
Right Console, KY-58 Cont
KY-58 Volume Control Knob - CW/Increase
Right Console, KY-58 Cont
Landing Gear Control Handle (EMERGENCY DOWN) - EXTEND
Left Vertical Panel
Landing Gear Control Handle (EMERGENCY DOWN) - EXTEND/RETRACT
Left Vertical Panel
Landing Gear Control Handle (EMERGENCY DOWN) - RETRACT
Left Vertical Panel
Landing Gear Control Handle - DOWN
Left Vertical Panel
LShift + G
Landing Gear Control Handle - UP
Left Vertical Panel
LCtrl + G
Landing Gear Control Handle - UP/DOWN
Left Vertical Panel
G
Launch Bar Control Switch - EXTEND/RETRACT
Left Vertical Panel
Q
LDG/TAXI LIGHT Switch (special) - ON/OFF
Special For Joystick, Left
LDG/TAXI LIGHT Switch - OFF
Left Vertical Panel
LDG/TAXI LIGHT Switch - ON
Left Vertical Panel
LDG/TAXI LIGHT Switch - ON/OFF
Left Vertical Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Cover - CLOSE
Instrument Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Cover - OPEN
Instrument Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Cover - OPEN/CLOSE
Instrument Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Switch - PRESS
Instrument Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Switch - PRESS/RELEASE
Instrument Panel
Left Engine/AMAD Fire Warning/Extinguisher Light Switch - RELEASE
Instrument Panel
Left Generator Control Switch (special) - NORM/OFF
Special For Joystick, Right
Left Generator Control Switch - NORM
Right Console, Electrical P
Left Generator Control Switch - NORM/OFF
Right Console, Electrical P
Modifiers
Add
Clear
Default
Axis Assign
Axis Tune
FF Tune
Make HTML
Disable hot plug
Rescan devices
CANCEL
OK

Shift_Register_Practice §

```
#include <Joystick.h>

//This code is set up to have the shift registers daisy chained together, if this method produces a latency that's too slow, then we'll change it so that the
#define JOYSTICK_IDENTIFIER 0x50         //This identifier will help the library recognize the joystick. It's in Hexidecimal for 80
int ioSelect = 2;                        //Shift register Pin 15, PE connected to digital pin 2 on the arduino
int clockPulse = 3;                      //Shift register Pin 7, CP connected to digital pin 3 on the arduino. The pins above are tied together on all shift registers in the PCB
int dataIn = 4;                          //Shift register Pin 13,  Q7 connected to digital pin 4 on the arduino
int j;                                   //Used in the loop to later to cycle through all of the buttons/bits
const int shiftRegisterNum = 5;          //This set up is currently made for 5 shift registers but it can be changed with this variable
const int bitNum = shiftRegisterNum*8;   //Number of bits being processed
int buttons[bitNum];                     //Array to store all of the values for each button


//Joystick_Joystick(JOYSTICK_IDENTIFIER,JOYSTICK TYPE,# of Buttons (55 max),#of hat swtiches(2 max),Include X,IncludeY,Include Z,
// Include RX, Include RY, Include RZ,Include Rudder, Include Throttle, Include Accelerometer, Include Brake, Include Steering)

//Initialize the joystick
Joystick_ Joystick(JOYSTICK_IDENTIFIER,JOYSTICK_TYPE_JOYSTICK,9,1,false,false,false,true,true,true,false,true,false,false,false);

const bool InitAutoSendState = true;      //initial the send state for the joystick. Makes sure the board isn't waiting for polling to be
                                          //requested from thecomputer, it will send values automatically

int xRot_ = 0;
int yRot_ = 1;
int zRot_ = 2;
int throt_ = 3;

void setup() {
  // put your setup code here, to run once:
pinMode(ioSelect, OUTPUT);
pinMode(clockPulse, OUTPUT);
pinMode(dataIn, INPUT);

Joystick.begin();
Serial.begin(9600);
}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(ioSelect, LOW);          // Shifts in all parallel inputs
  digitalWrite(clockPulse, LOW);        //start the clock pin low
  digitalWrite(clockPulse, HIGH);       //Set the clock pin high, now all of the data is in the shift registers
  digitalWrite(ioSelect, HIGH);         //Set the shift register to stop shifting in parallel inputs and start shifting out through the serial output
  for (j = 0;j < bitNum ;j++)           //The loop iterates until all of the buttons in the shift registers are read
  {
    buttons[j] = digitalRead(dataIn);
    Joystick.setButton(j,buttons[j]);   //Set the button up in the joystick library to be translated into the computer
    Serial.print("| ");                 //Print out the buttons as a table in the serial monitor
    Serial.print(buttons[j]);           //It isn't necessary but it is nice to see what is going on behind the scenes
    Serial.print(' ');
```

```
    digitalWrite(clockPulse,LOW);          // After the bit is stored in the button array, the clock is moved
    digitalWrite(clockPulse,HIGH);         //This shifts the next bit into place
  }
  Serial.println(' ');                     //Adds a new line to the serial monitor
  Joystick.setRxAxis(analogRead(xRot_));
  Joystick.setRyAxis(analogRead(yRot_));
  Joystick.setRzAxis(analogRead(zRot_));
  Joystick.setThrottle(analogRead(throt_));


  delay(5000);                             //This delay is for when we read the serial monitor, it will be removed once the joystick is added
}
```