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

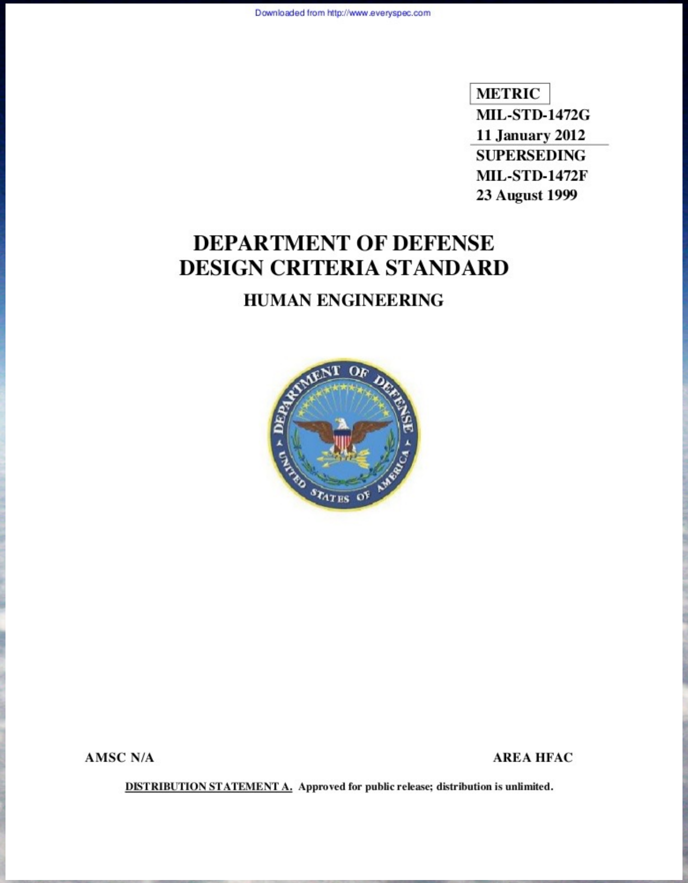
Key Functions

Ergonomics	Electronics	Mechanical
Support Multiple Modular Grips	Filter & Process I/O Data	Provide Feedback
Integrate with Lockheed System	Detect Aircraft Control Intent	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


Downloaded from http://www.everyspec.com

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

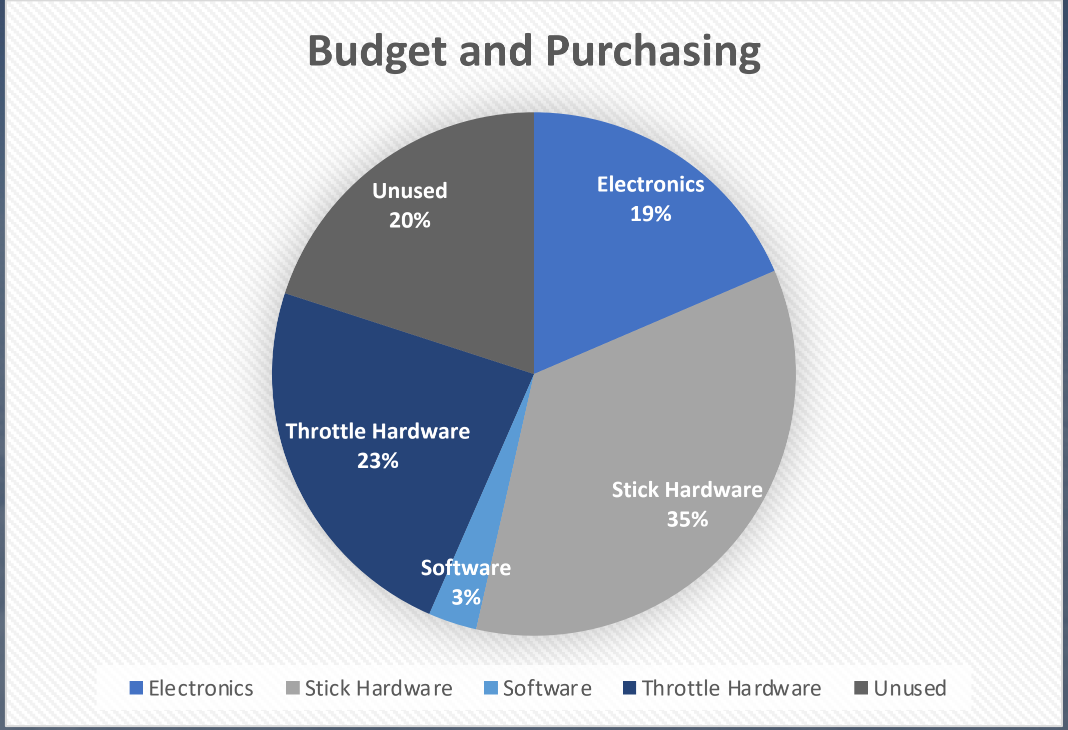
- Concepts generated: 100
- Standard Concept Selection: Narrowed down to 3
- Final Concept Selected: Concept 3 shown below

- 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

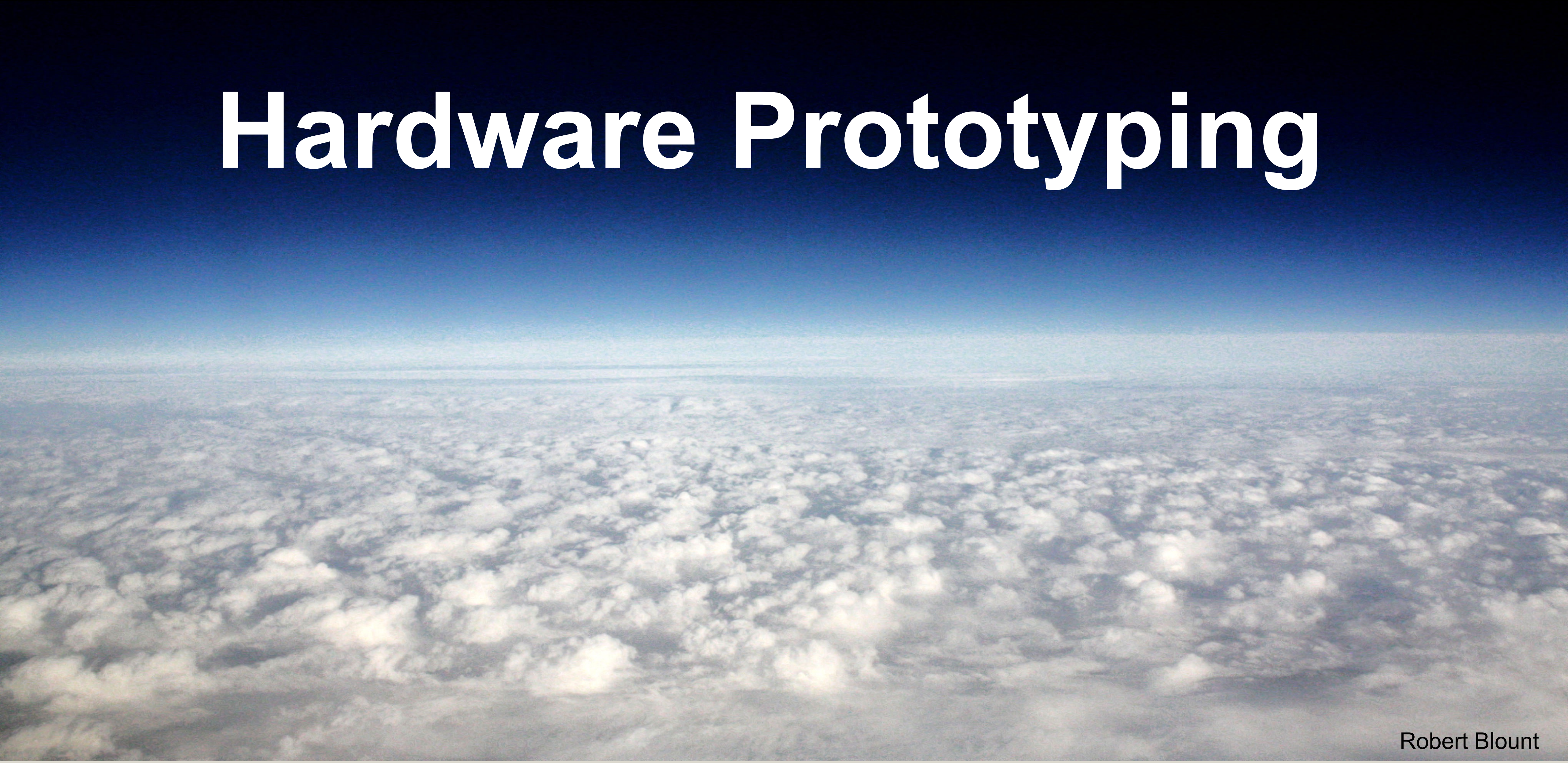
Budget and Purchasing

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



Patrick Dixon

Hardware Prototyping



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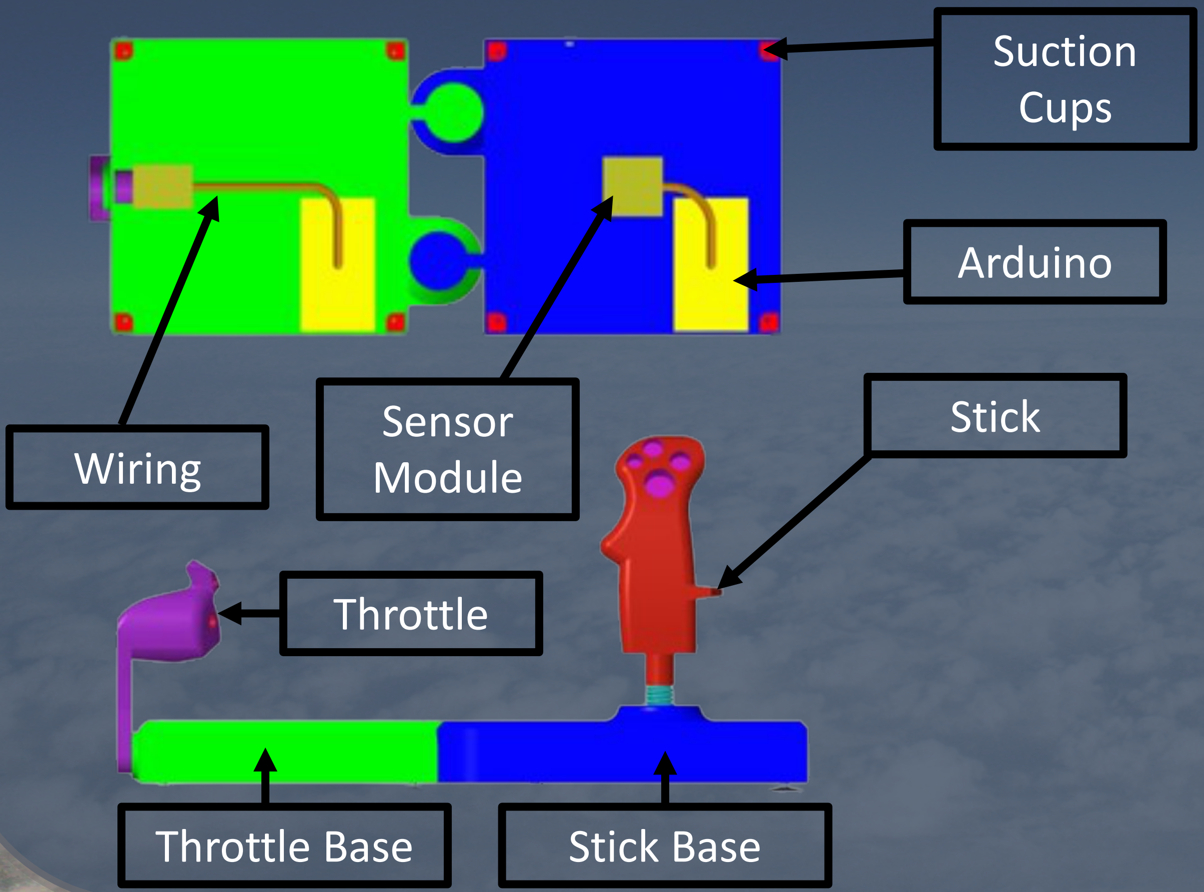
Initial 3D Model



- Things Assessed
  - Making the stick circumference smaller

Robert Blount

Initial Printed Design

Throttle

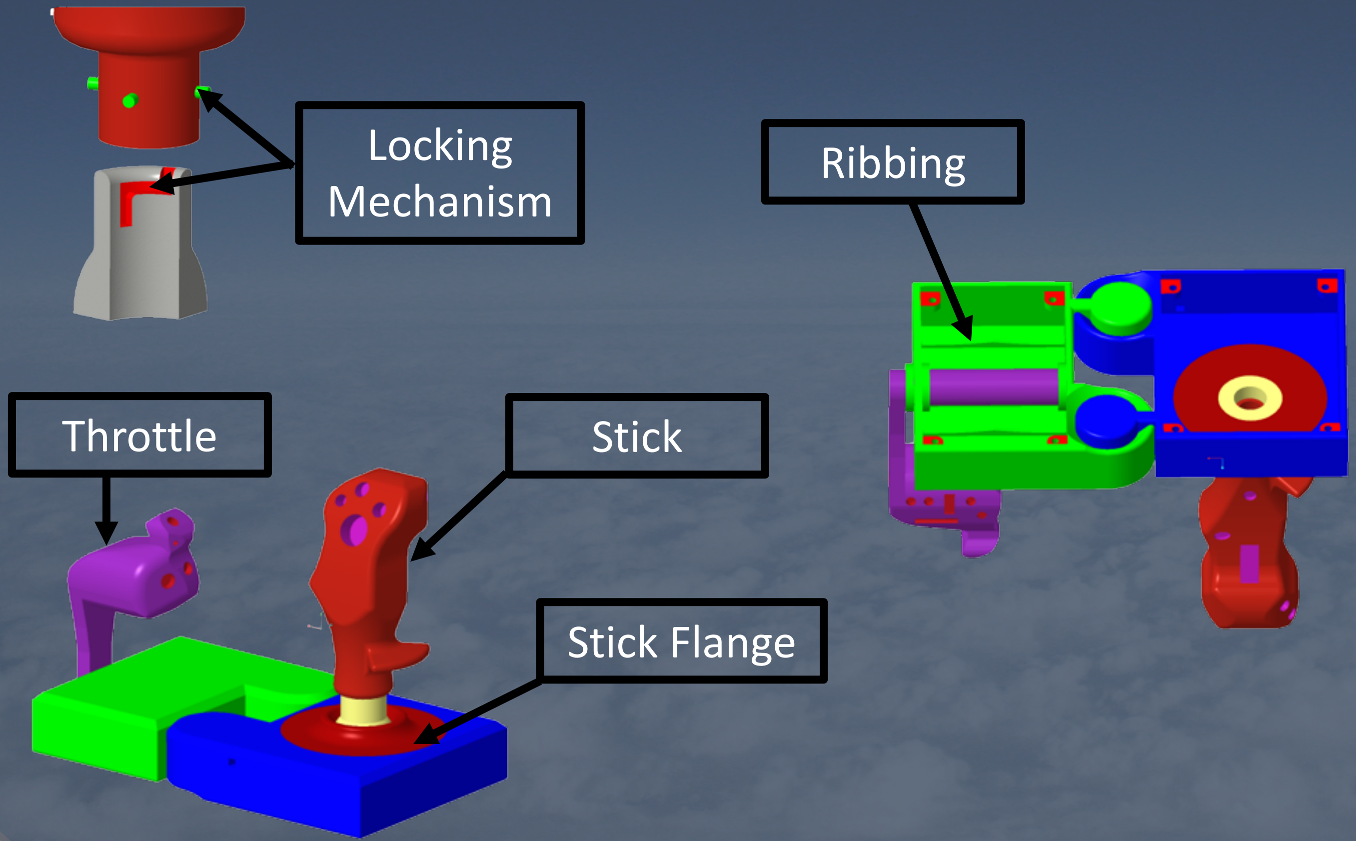
Stick

Initial Issues

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

Robert Blount

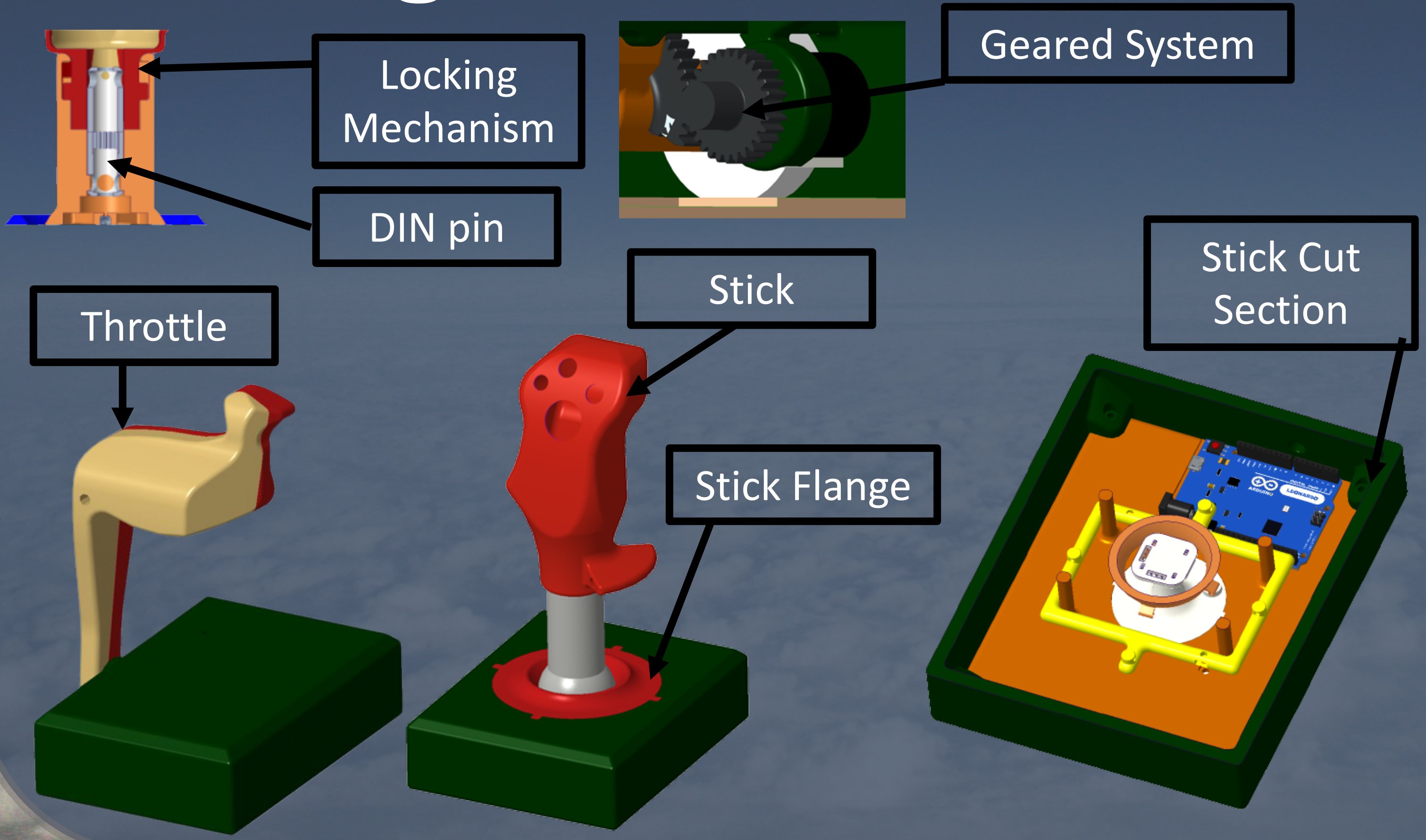
Design Update 1



- 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 Iteration 2

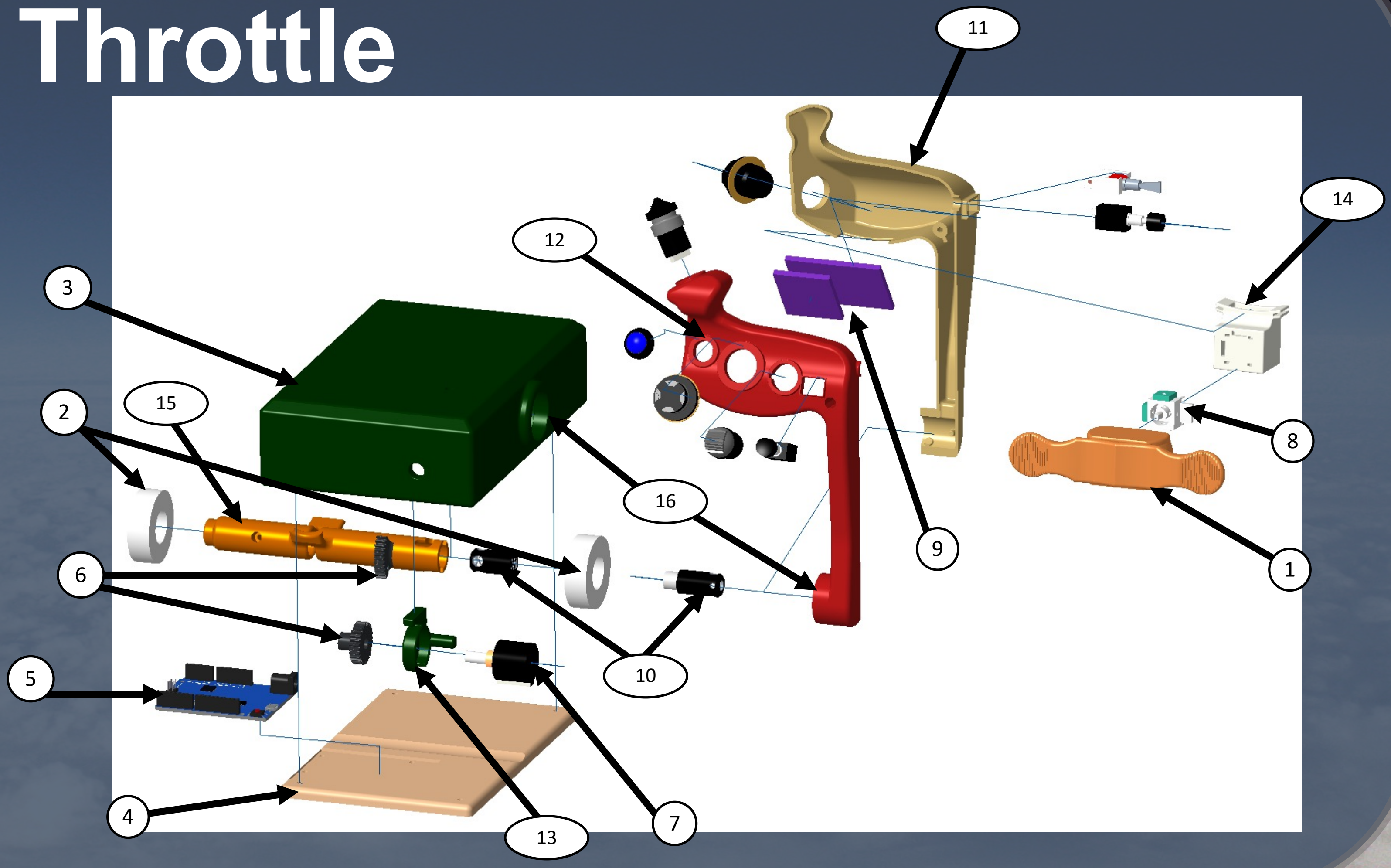


- Things changed
  - Added a gear system connected to the potentiometer
  - Reduced locking mechanism to two slots
  - Added space for the DIN pin connectors
  - Removed modular bases

Patrick Dixon

Exploded 3D Throttle

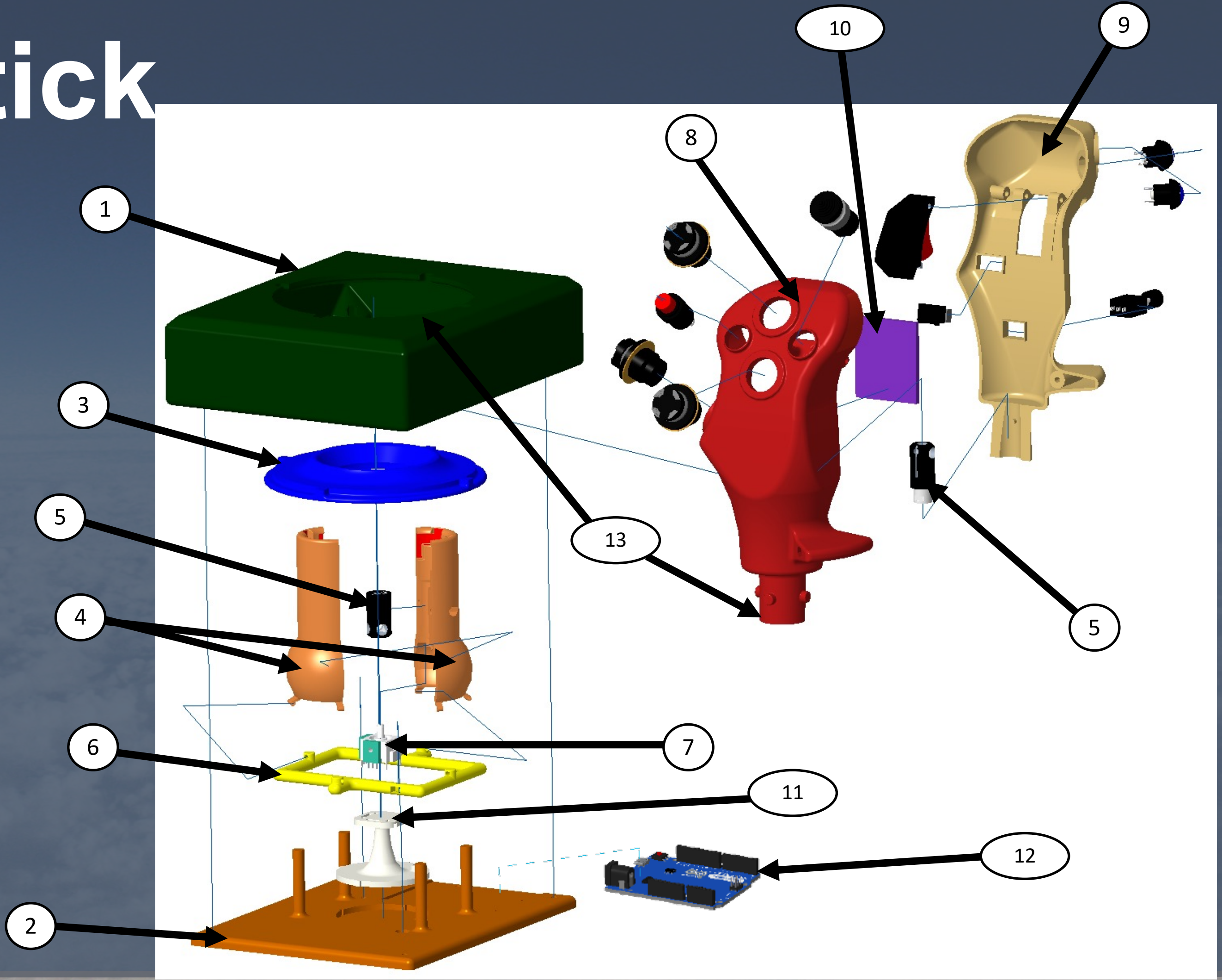
1) Yaw paddle
2) Bearings
3) Throttle Base
4) Baseplate
5) Arduino
6) Gears
7) Rotary Potentiometer
8) Joystick Potentiometer
9) PCB
10) DIN pin
11) Throttle Back
12) Throttle Front
13) Rotary Potentiometer Mount
14) Joystick Potentiometer Mount
15) Gear Shaft
16) Modular connection



Patrick Dixon

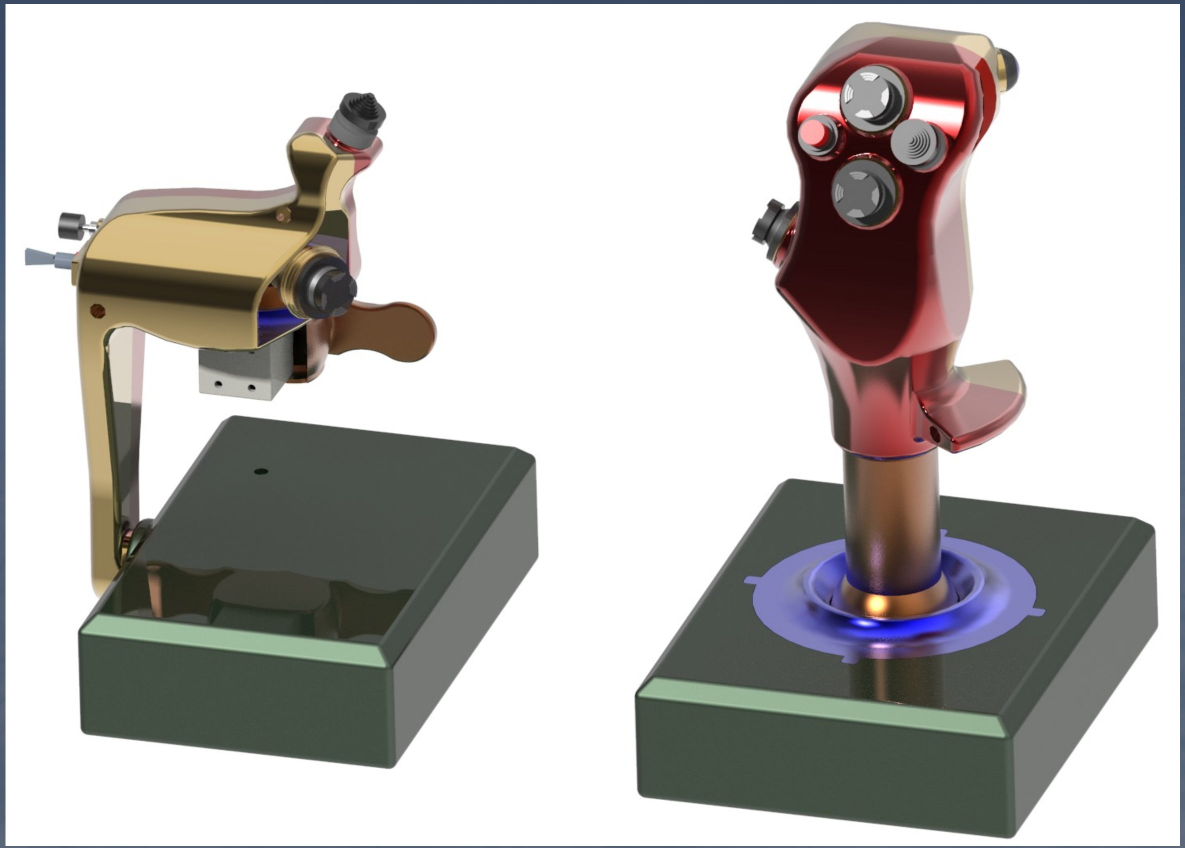
Exploded 3D Stick

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
13) Modular connection

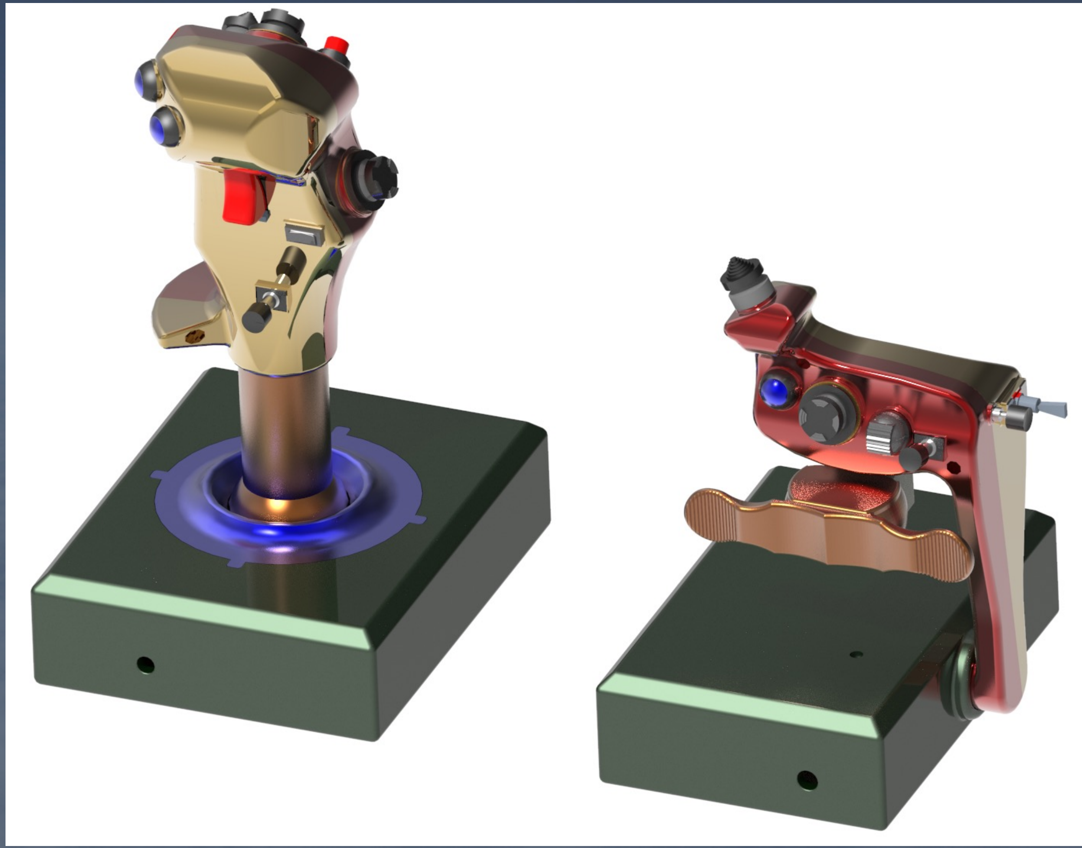


Patrick Dixon

Final Assembly of 3D Model



HOTAS Front View Isometric



HOTAS Rear View Isometric

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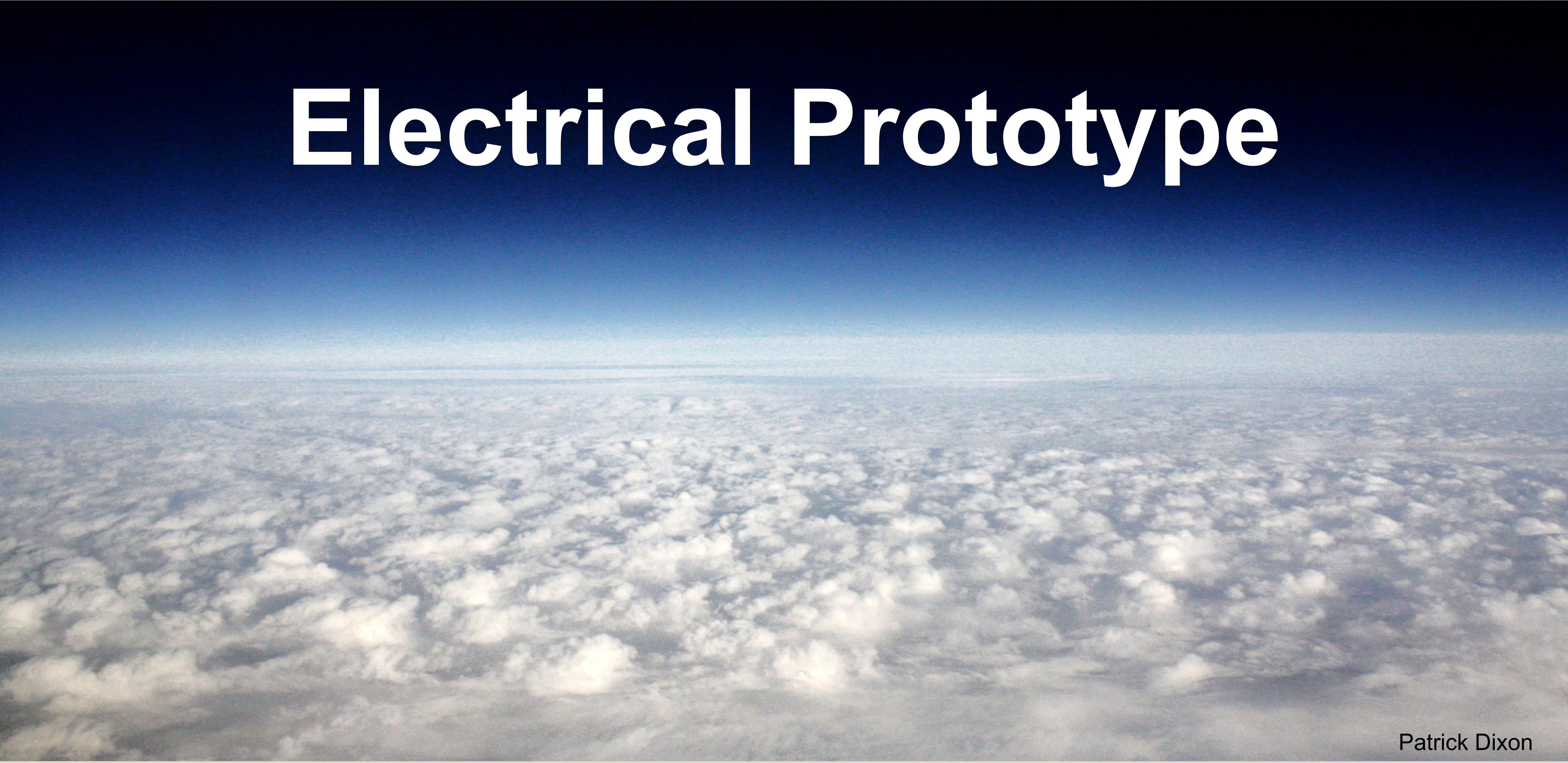
Electrical Prototype



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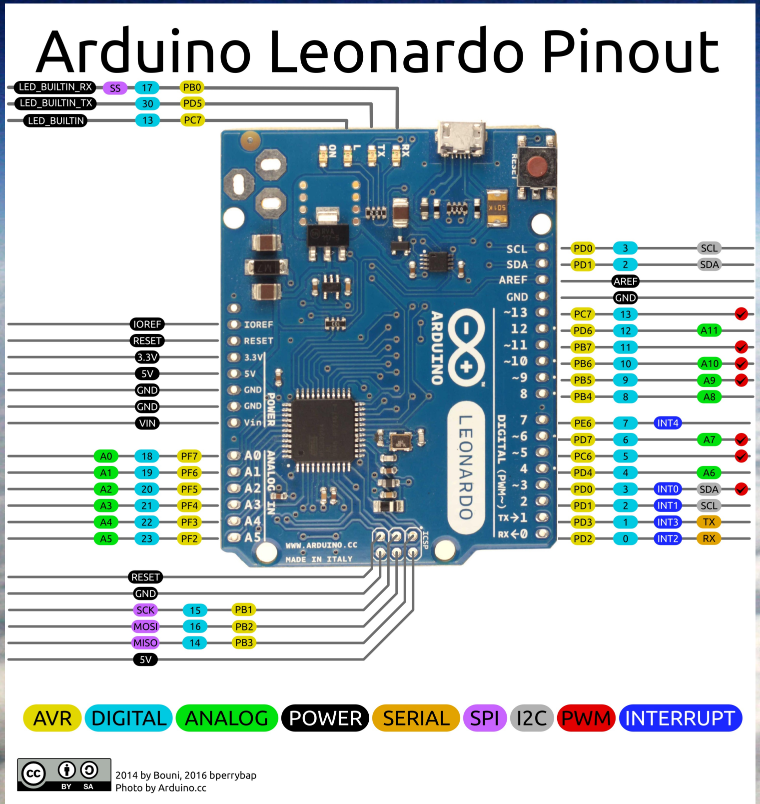
Software and Packaging



- 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

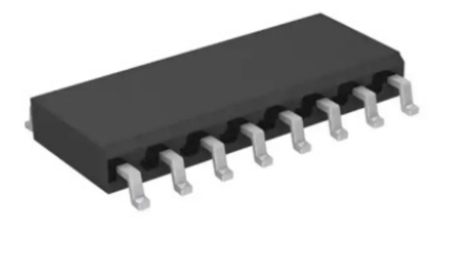
Female Din Pin

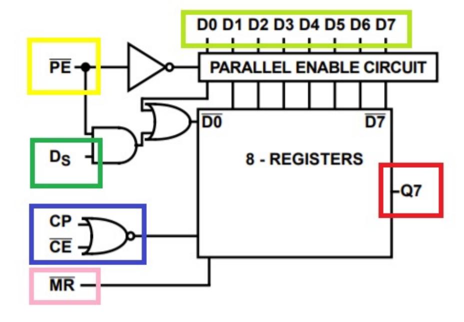
- 9 pin mini-DIN connector used for modular connection
  - 2 pins for input voltage and Ground
- Using three pins for all digital buttons in each pair
- Up to 4 analog signals through connection in each pair
- One male in each throttle, and stick
- One female in each base

Robert Craig

Shift Registers and Buttons

PISO Shift Register





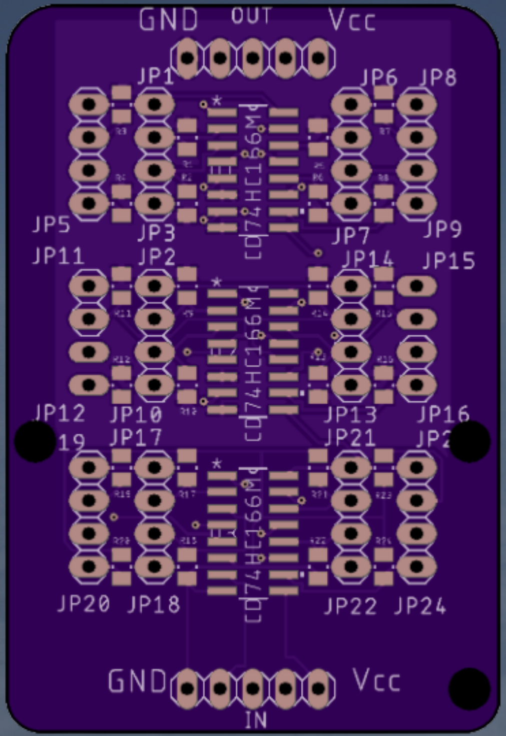
PISO Functional Diagram

- 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

2.20 in



1.50 in

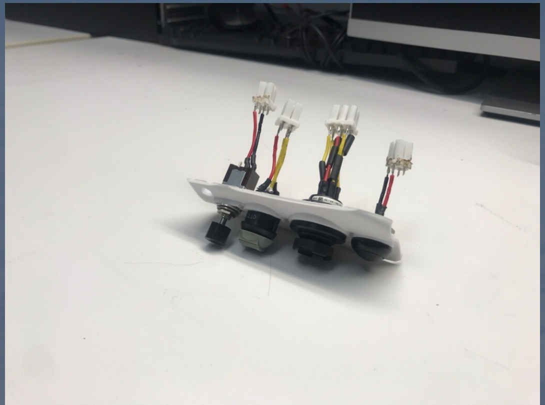
0.955 in

- 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

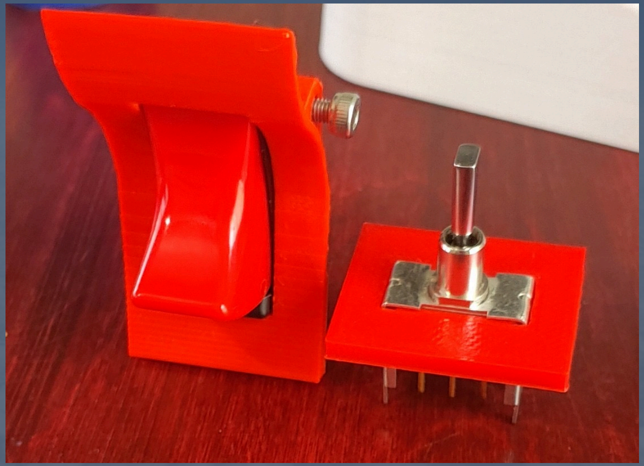
Robert Craig

Button Mount Prototyping

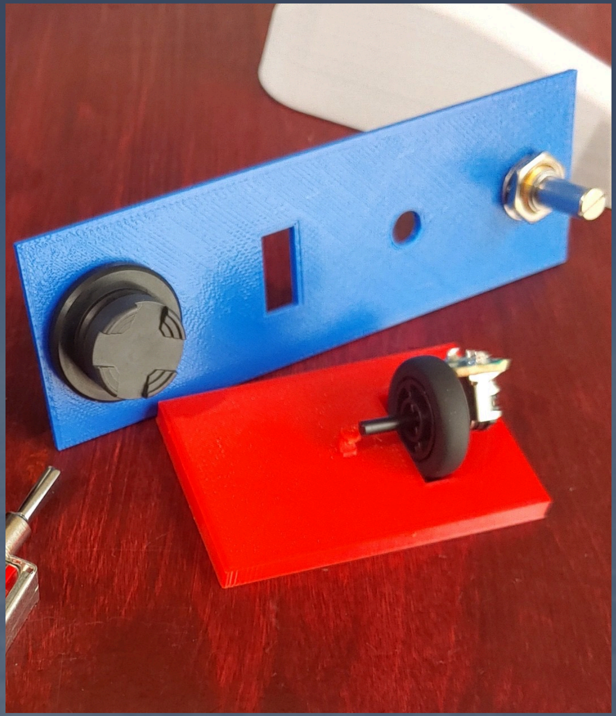
Throttle Buttons in Mount



Buttons with Connectors



Buttons in Mounts



Buttons in Mounts

Robert Craig

Integration

Robert Craig

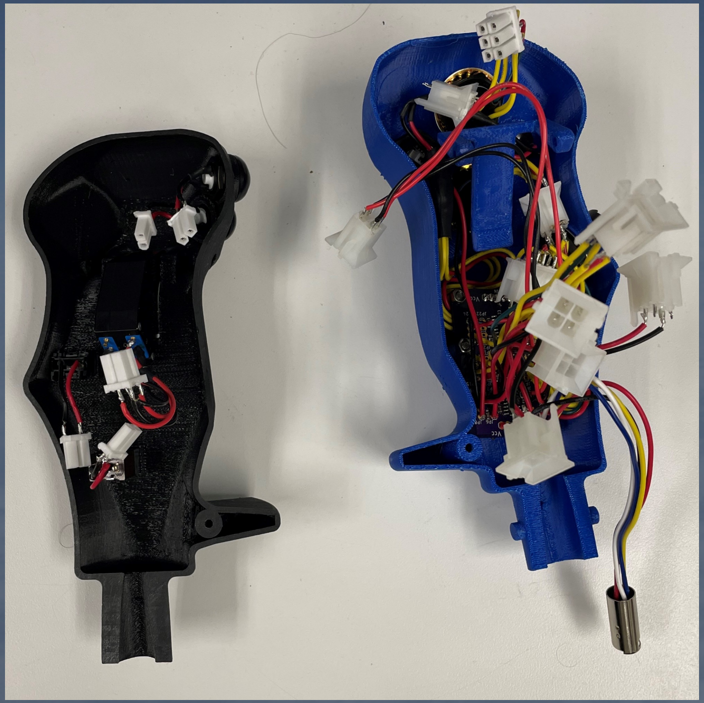
Throttle Integration

Throttle Front & Back

- Difficulties assembling the throttle
  - Housing was initially too small to fit the connectors and wiring harness
  - Cutting and re-soldering connections to improve spacing issues
  - Did not expect so much mass and space issues due to wires and Molex connectors

Robert Craig

Stick Integration



Stick Front & Back

Stick Assembly

Robert Craig

Testing

Robert Craig

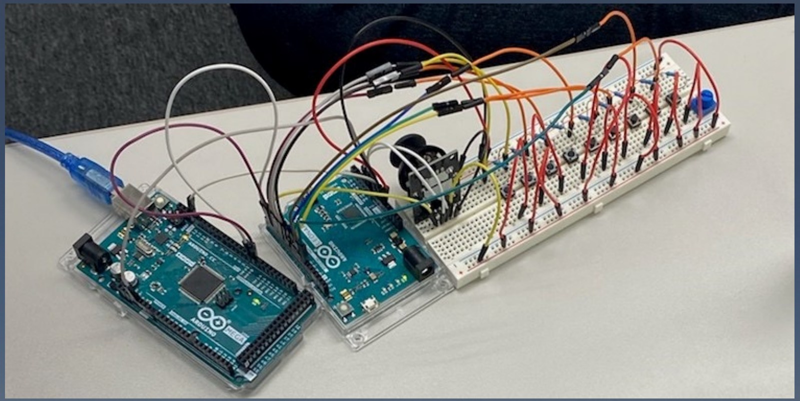
Initial Testing Goals

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

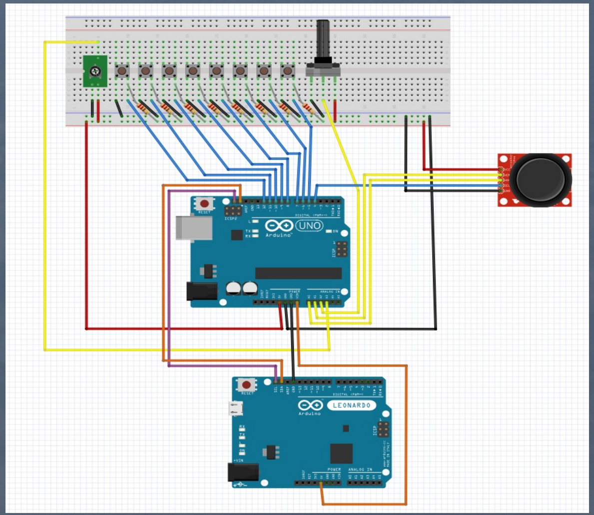
Connor Chuppe

Initial 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

- 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

F-16 Cockpit View During Test

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

Final Testing Goals

- Function with Prepar3D software
- Have all buttons display an output
- Have a realistic feeling throttle and stick

Connor Chuppe

Final Testing Takeaways

Accomplishments	Issues
Able to fly with Prepar3D	Throttle was not able to be used
Buttons could be registered with Prepar3D	Stick would not re-center when released

Testing using F-35 in Prepar3D

Connor Chuppe

Project Recap

Connor Chuppe

Future Work

- Finalizing assembly of stick and throttle
- Testing and validation of 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
  - Using a higher gauge wire would help with fitting
- Waiting for budget to be allocated must be considered when planning
- Integrating electronic and mechanical components is very tedious

Connor Chuppe

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Connor Chuppe

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Connor Chuppe

Questions and Comments

Robert Blount
Connor Chuppe
Robert Craig
Patrick Dixon

Come Fly With Us.

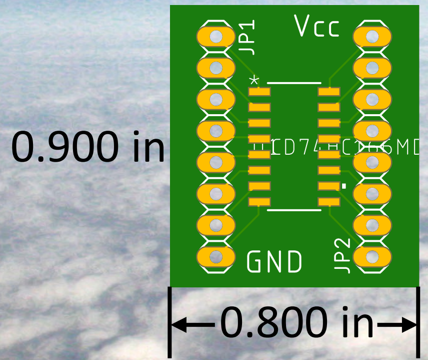
Robert Blount
Connor Chuppe
Robert Craig
Patrick Dixon

Backup Slides

Throttle integration

Stick integration

Final Assembly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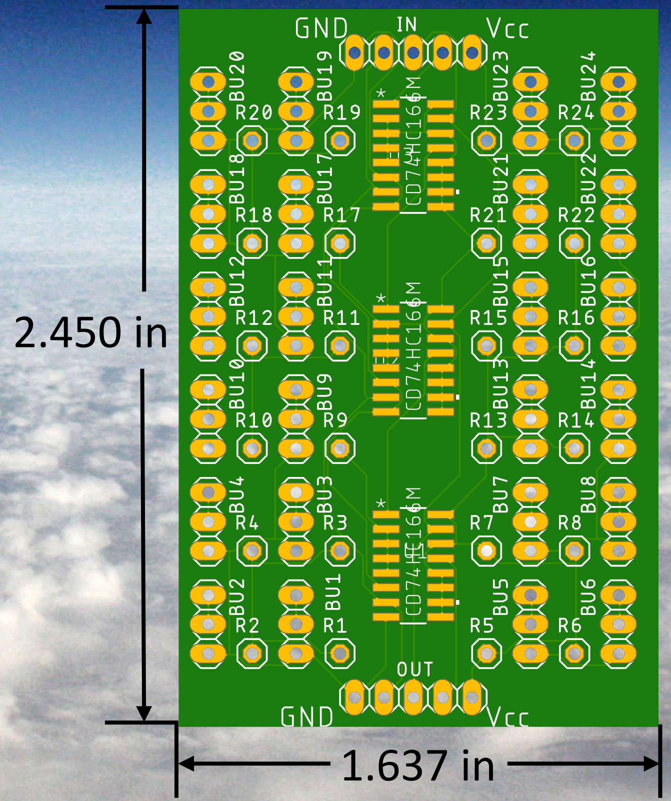

2.450 in
GND
IN
Vcc
OUT
GND
Vcc
1.637 in

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	mbined, 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	Datum	S	-	S	-	S	S	S
Cost		-	+	-	+	-	+	+
Latency/Transfer Speed		S	-	S	S	S	-	S
Frequency		S	S	S	S	S	S	S
Material Strength		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

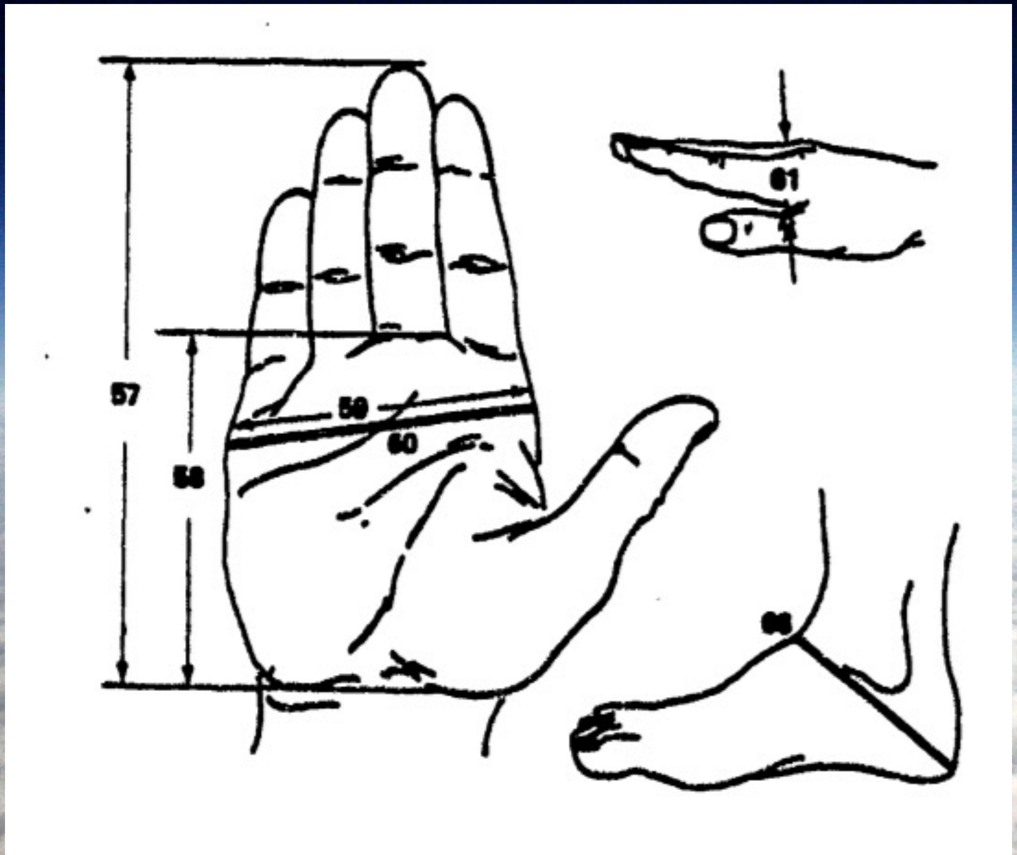
weighted total	weighted sum total	consistency vector	average consistency	4.2607
0.104	0.415	3.976	n value lookup	4
0.052	0.218	4.158	Consistency Index	0.0869
0.676	3.055	4.519	Random index value	0.89
0.167	0.734	4.390	Consistency Ratio	0.0976
1				

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

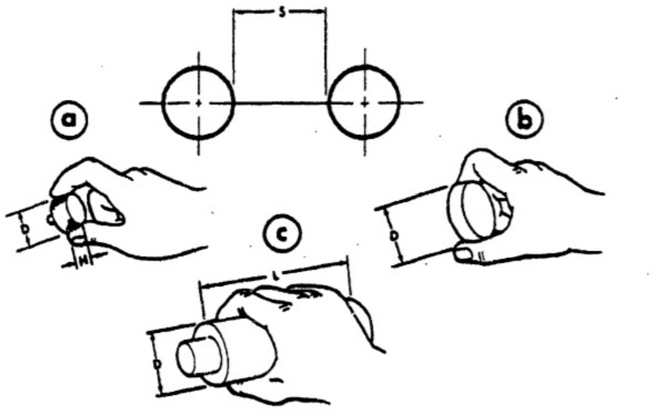
Frequency(resolution) N AHP	Concept 1	Concept 2	Concept 3	Concept 4
Concept 1	0.427	0.427	0.446	0.351
Concept 2	0.427	0.427	0.446	0.351
Concept 3	0.085	0.085	0.089	0.249
Concept 4	0.061	0.061	0.018	0.050
Total	1	1	1	1

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	9.8	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	6.88	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	12.08	11.21	14.57	14.30	13.11

MIL-STD-1472D

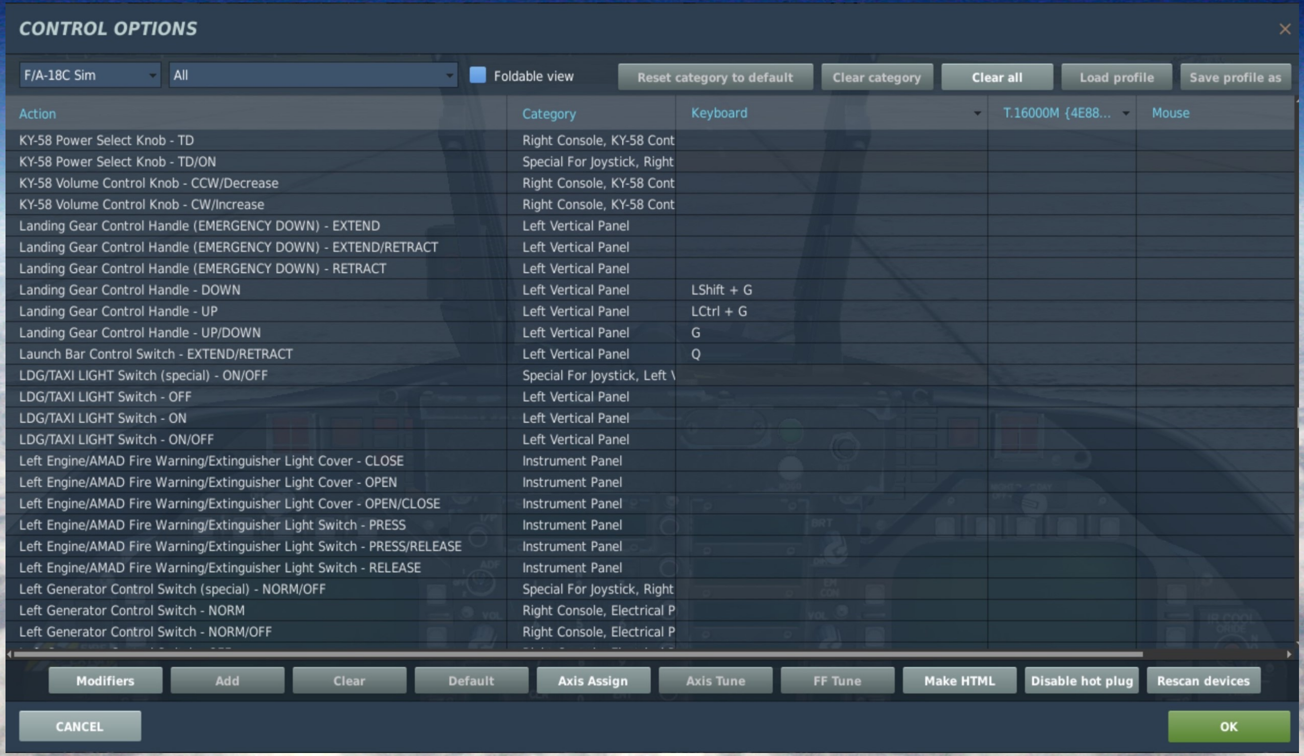


	DIMENSIONS				
	(a) Fingertip Grasp		(b) Thumb and Finger Encircled	(c) Palm Grasp	
	H Height	D Diameter	D Diameter	D Diameter	L Length
Minimum	13 mm (1/2 in.)	10 mm (3/8 in.)	25 mm (1 in.)	38 mm (1-1/2 in.)	75 mm (3 in.)
Maximum	25 mm (1 in.)	100 mm (4 in.)	75 mm (3 in.)	75 mm (3 in.)	-

	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
}
```