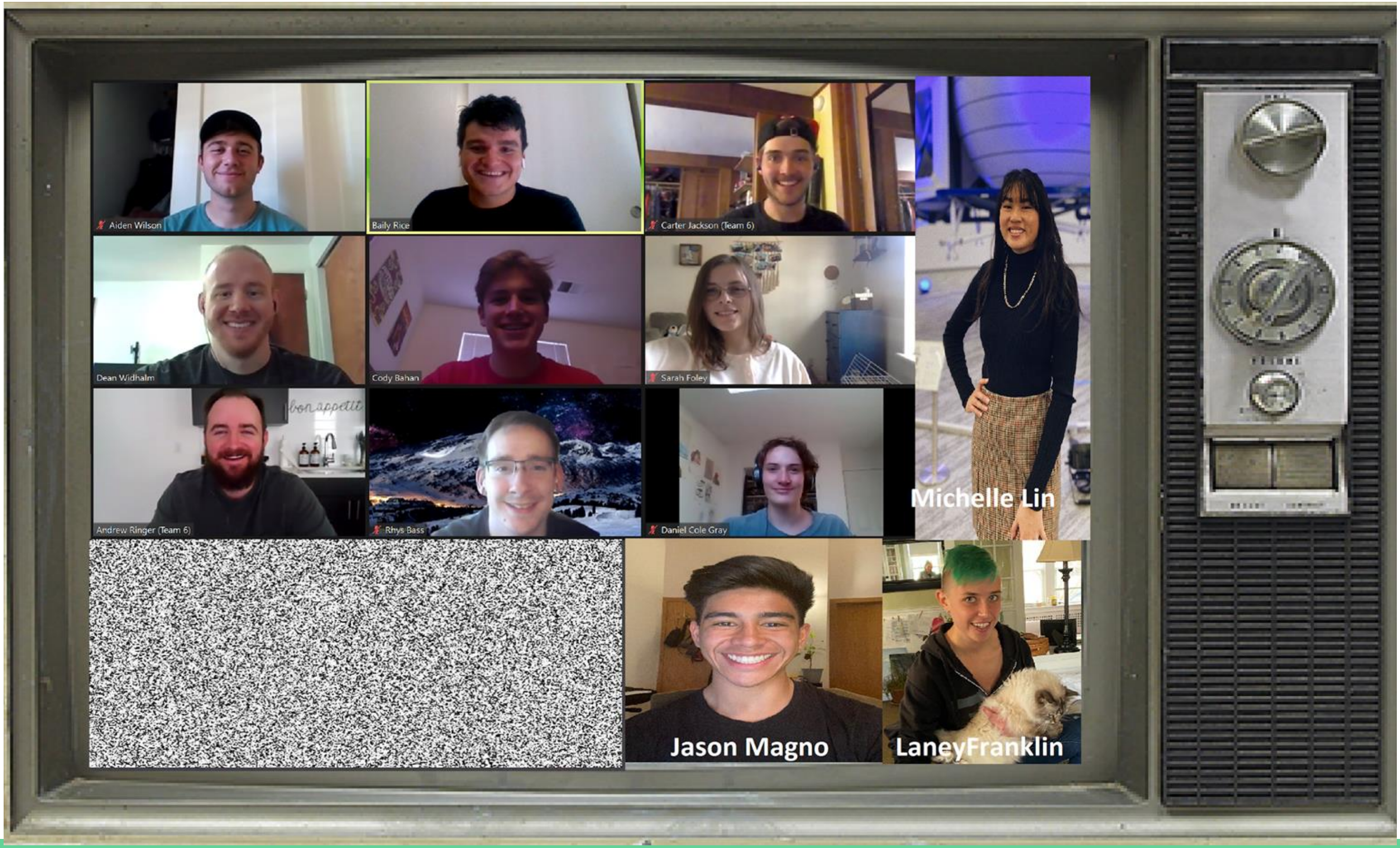
CHAIR

Cueing via Haptics And Inner-ear Responses

CHAIR Team Members



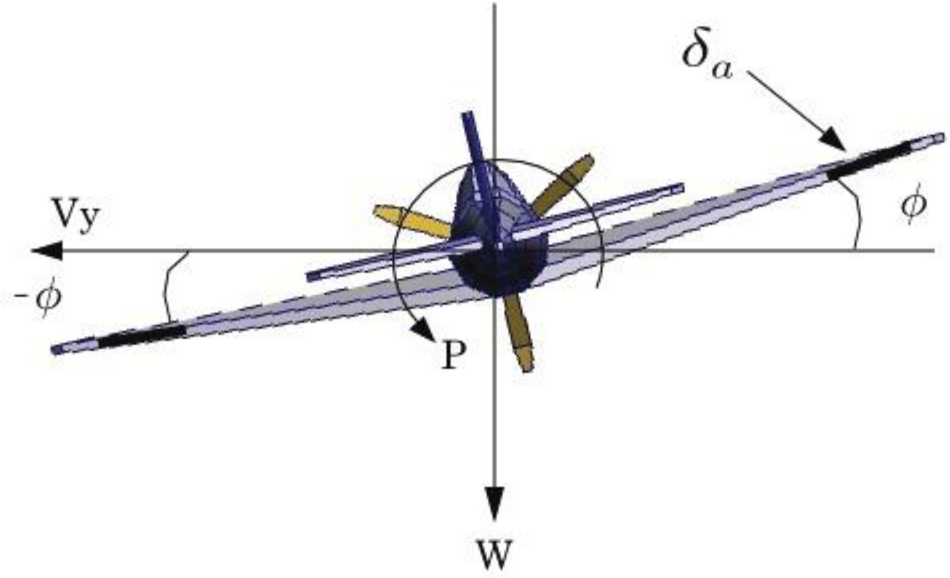
Project Motivation

- Create a cueing device capable of providing additional sensory information to remote pilots
- Provide our customer a research tool to validate this proof of concept before application to industry

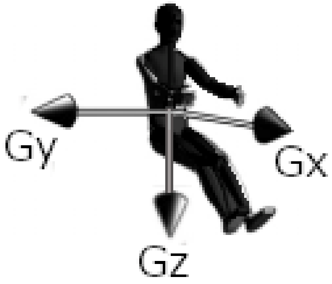
NBC News: https://www.nbcnews.com/technolog/virtual-cockpit-what-it-takes-fly-drone-1C9319684

General Overview

- The CHAIR project is focused on cueing a pure roll response



- Take advantage of two seperate sensory pathways
- Accurate cueing of pure roll still provides useful information



https://www.researchgate.net/figure/Pure-rolling-motion_fig1_235987139

Terms and Definitions

Test Subject: The person who is receiving cues from the CHAIR system

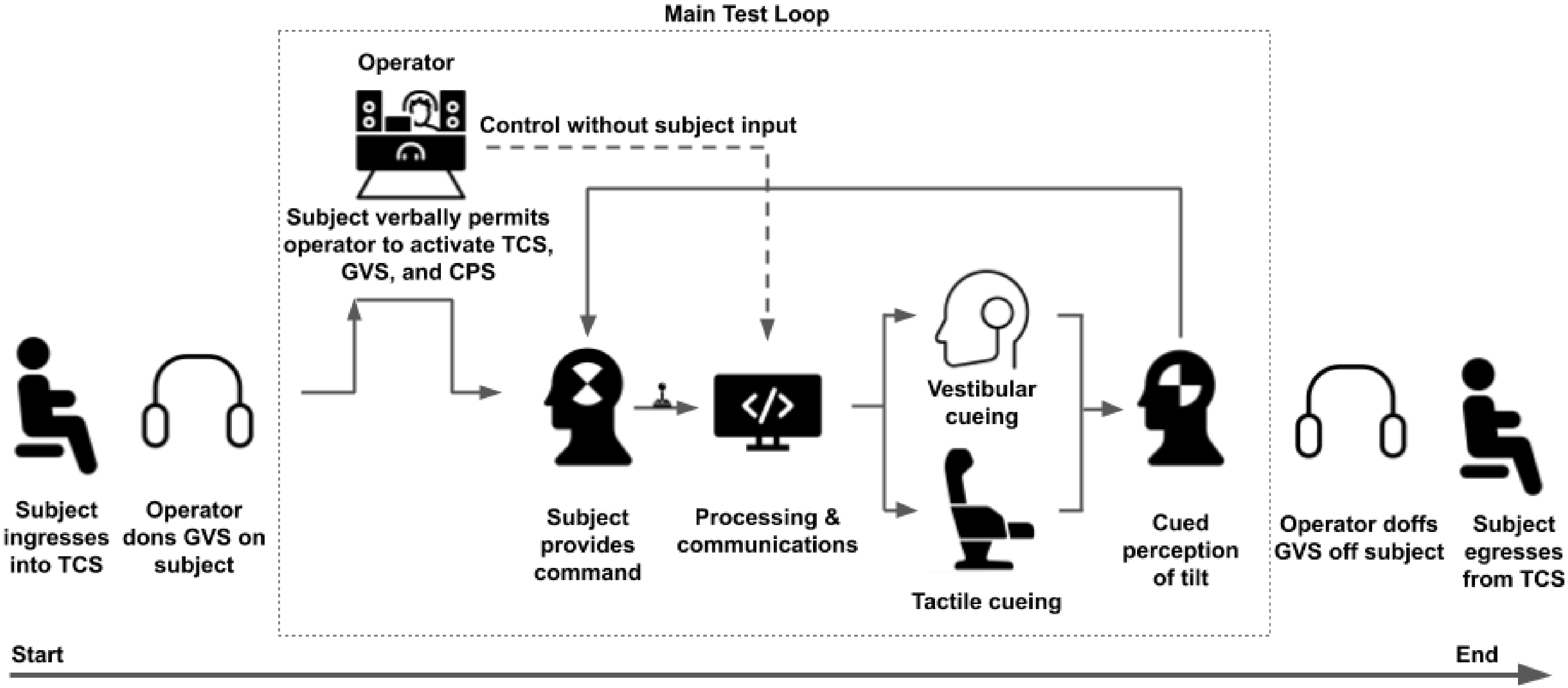
Test Operator: The person who is controlling input cues to the test subject

TCS: Tactile cueing system, applies pressure stimulation to subject

GVS: Galvanic vestibular stimulator, electrically stimulates the inner ear to elicit a feeling of tilt or motion in the subject

CPS: Central processing system, performs relevant computations, receives inputs from and sends outputs to subsystems

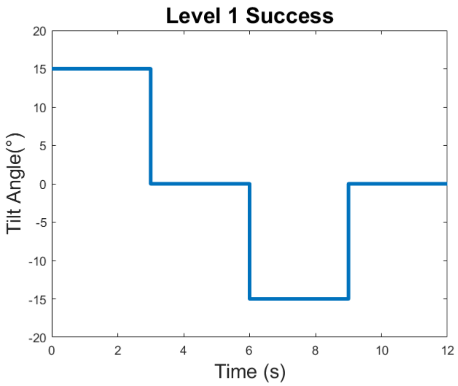
ConOps

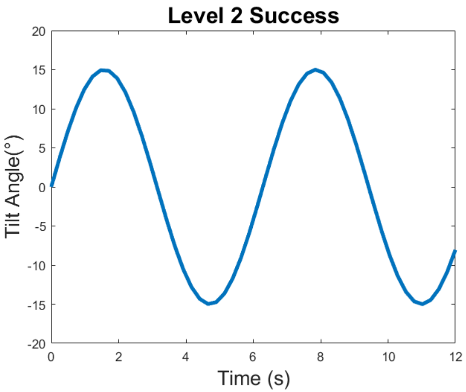


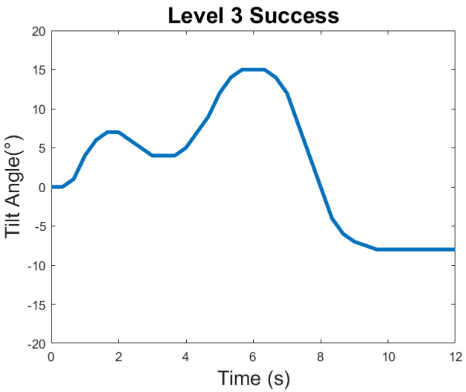
Main Test Loop
Operator
Control without subject input
Subject verbally permits operator to activate TCS, GVS, and CPS
Subject ingresses into TCS
Operator dons GVS on subject
Subject provides command
Processing & communications
Vestibular cueing
Tactile cueing
Cued perception of tilt
Operator doffs GVS off subject
Subject egresses from TCS
Start
End

Objectives

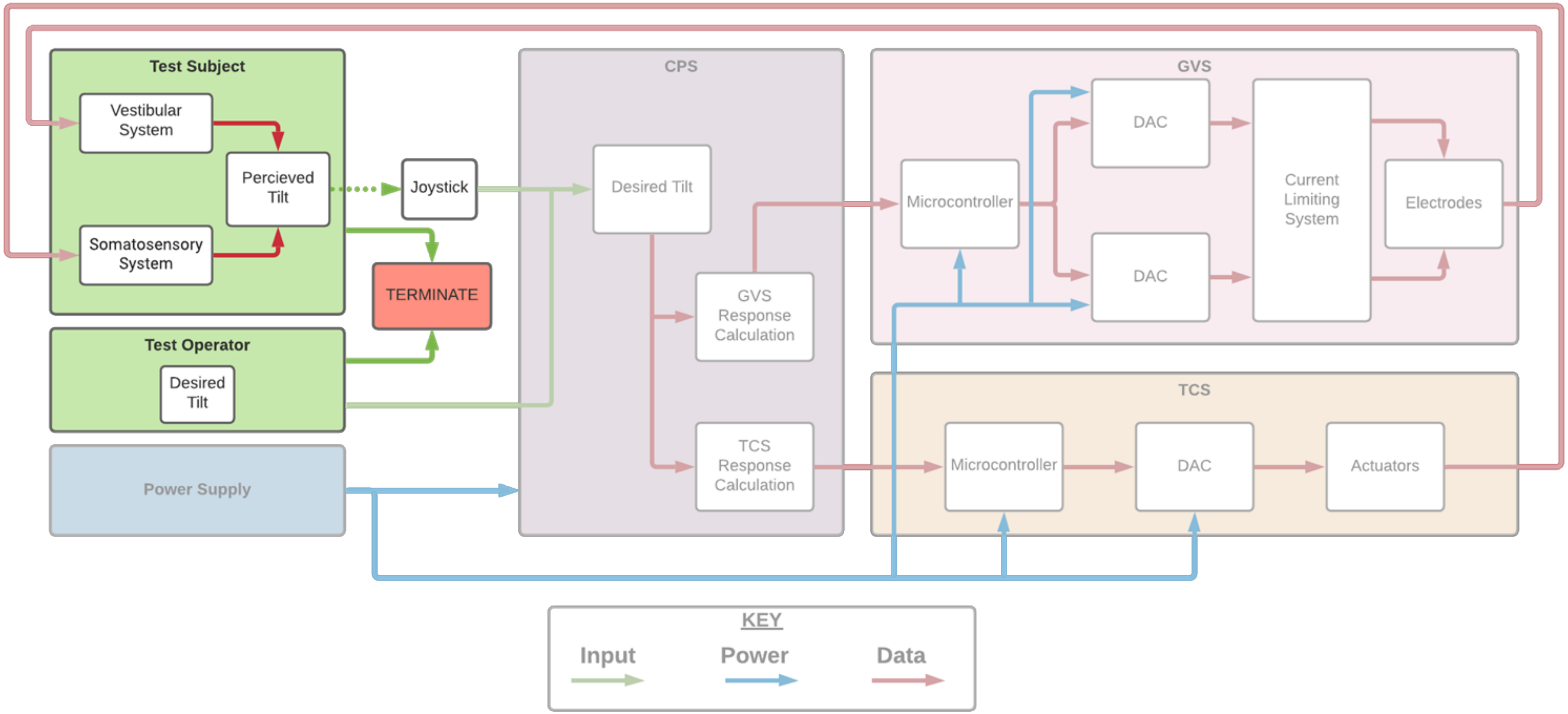
- Level 1
  - Cue static tilt angles of up to 15° in either direction
  - Implementation of joystick control from first level
- Level 2
  - Cue sinusoidal tilt profiles with maximum amplitude of 15°
- Level 3
  - Cue any tilt profile as commanded by the test subject up to 15°





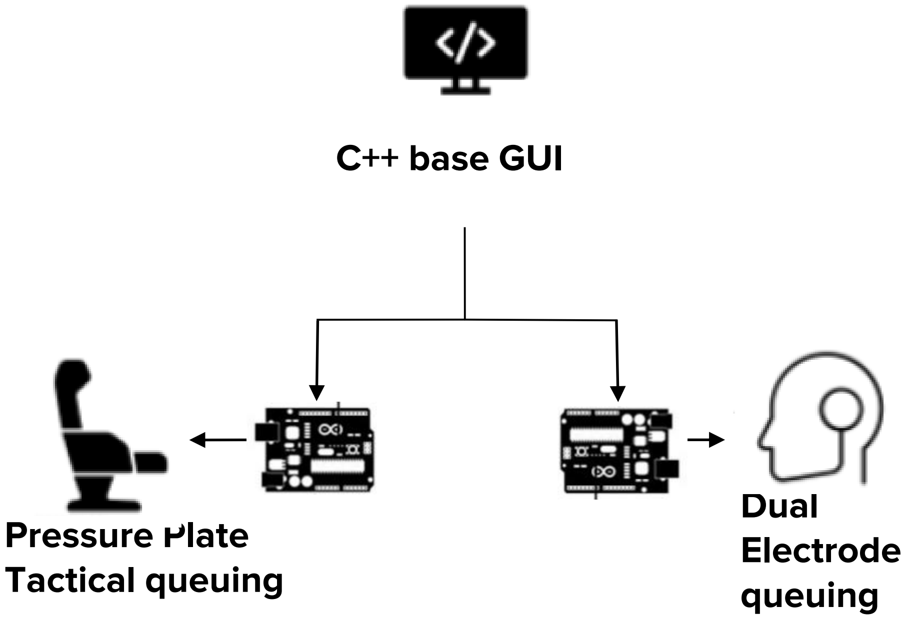


Functional Block Diagram



Baseline Design

- **TCS**: Physical pressure cueing performed by side and bottom actuators (8 total)
- **GVS**: Custom dual electrode system
- **CPS**: One processing unit (running code written in C++) that commands two microcontrollers
- **Microcontrollers**: Two microcontrollers, one for the TCS and one for the GVS



Applicable NASA Safety Standards

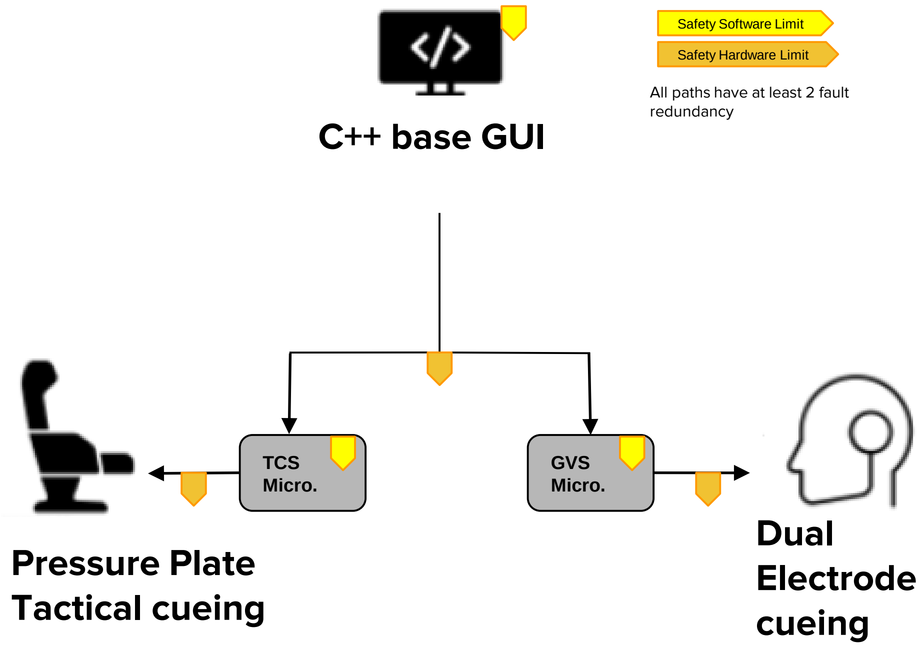
- Safety standards will be implemented with respect to NASA safety standard publications as our framework.

- For example we will be referencing the NASA standards for models and simulations (NASA-STD-7009A) along with NASA software safety guidebook (NASA-GB-8719.13).

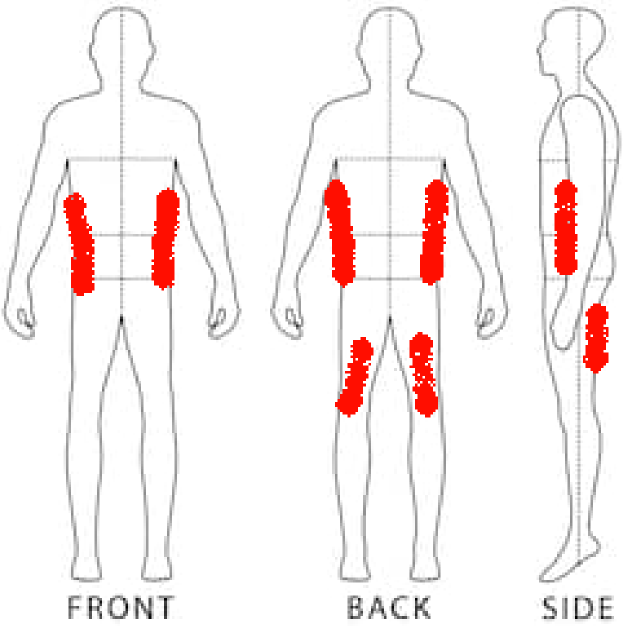
- 7 total documents referenced in appendix.

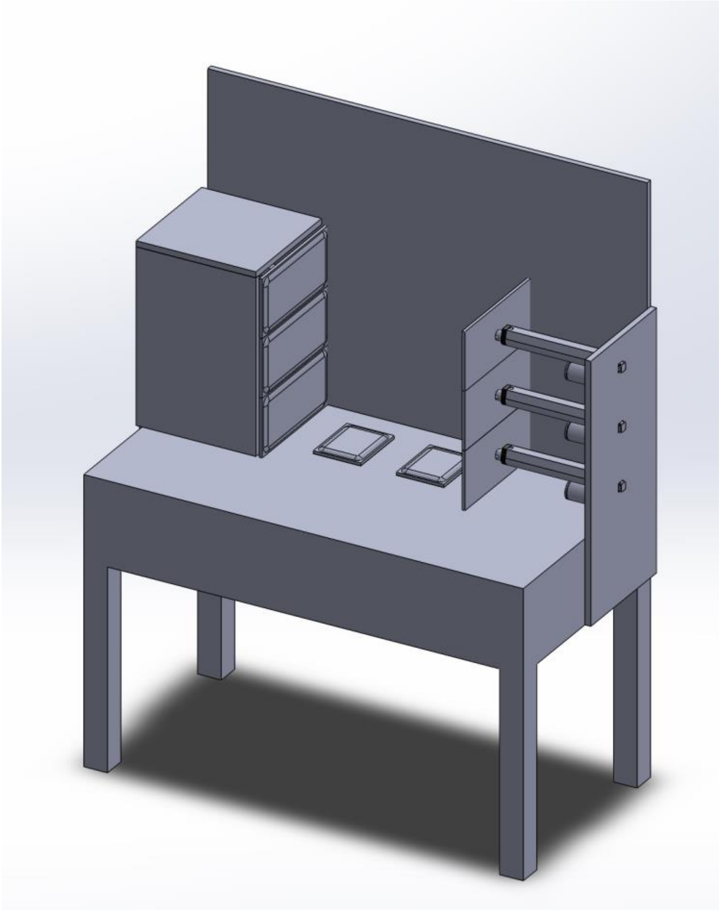
Safety Overview

- Hardware and software safety limits
- Both the GVS and TCS queuing 'paths' contain redundant (4 total) safety limits
- Test subject controls a system 'shutdown switch' that will stop all cueing



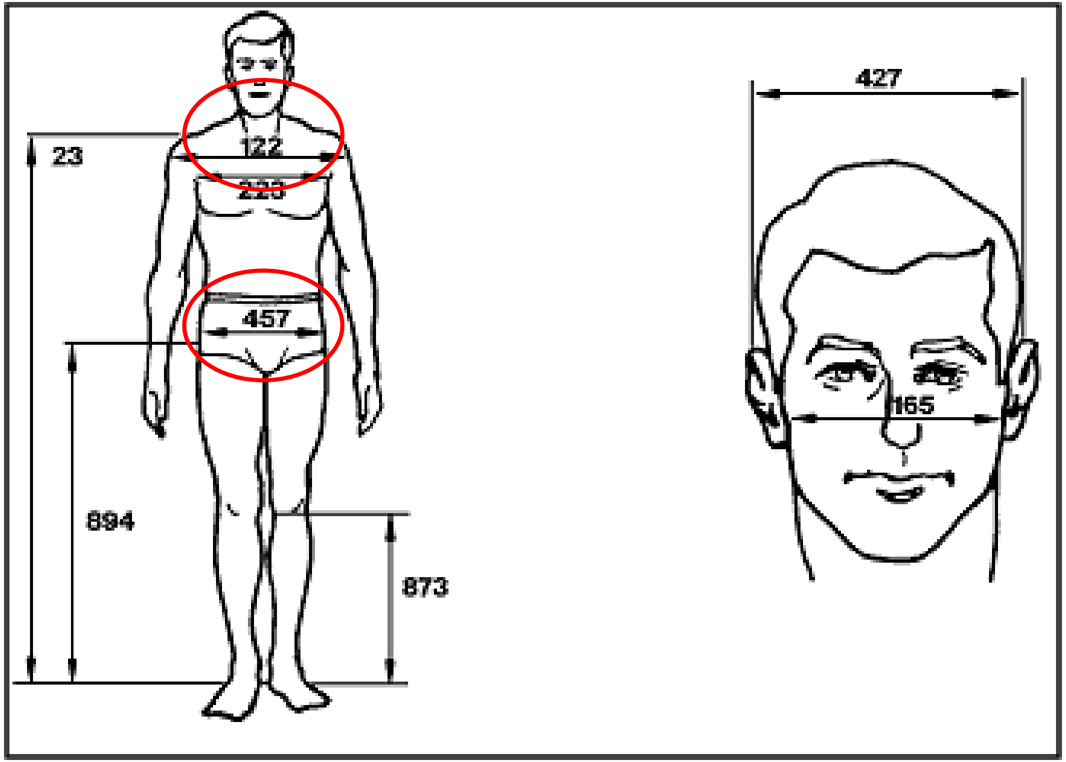
Tactile Cueing System (TCS) Feasibility





Note: Actuators not drawn to scale

Anthropometric considerations



Must accommodate customer (Dr. Clark)
Aim to accommodate 50th percentile male dimensions as well if these are larger

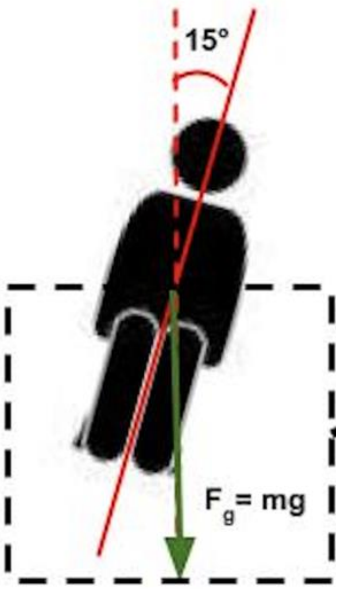
Shoulder breadth (19.3 in) [Dr. Clark's: 18.3 in]

Hip breadth (14.1 in) [Dr. Clark's: 14.4 in]

Addition anthropometric measurements must be considered for the GVS and joystick

NASA STD 3000 Anthropometry and Biomechanics

TCS Feasibility - Required Force Derivation



*representative

Primary focus is accommodating the customer

Anthropometric dimensions are independent

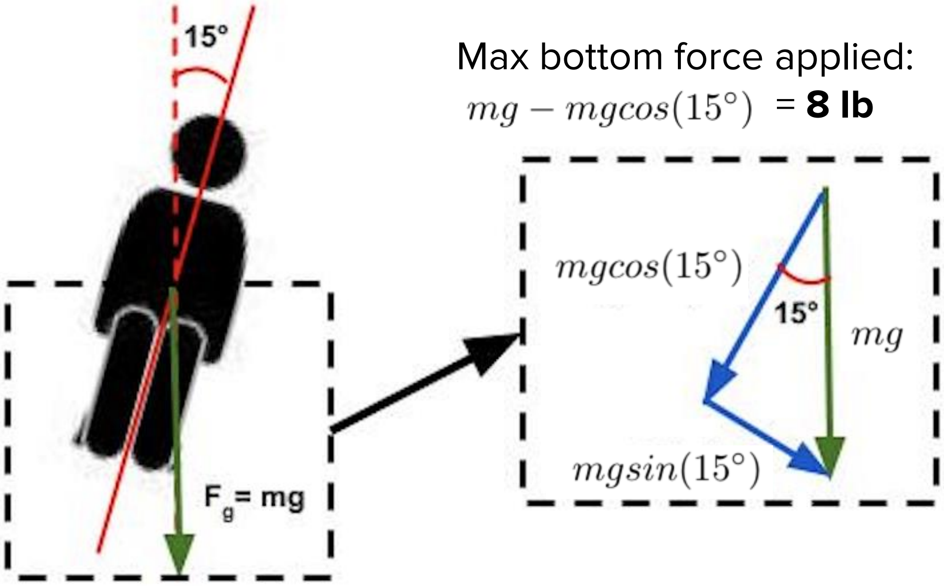
Increase capabilities and provide margin without impact to hardware selection (manufacturing)

TCS Feasibility - Required Force Derivation

Max test subject weight: **215 lb**

Max side force applied:
$mgsin(15°)$ = **55 lb**

Max bottom force applied:
$mg - mgcos(15°)$ = **8 lb**



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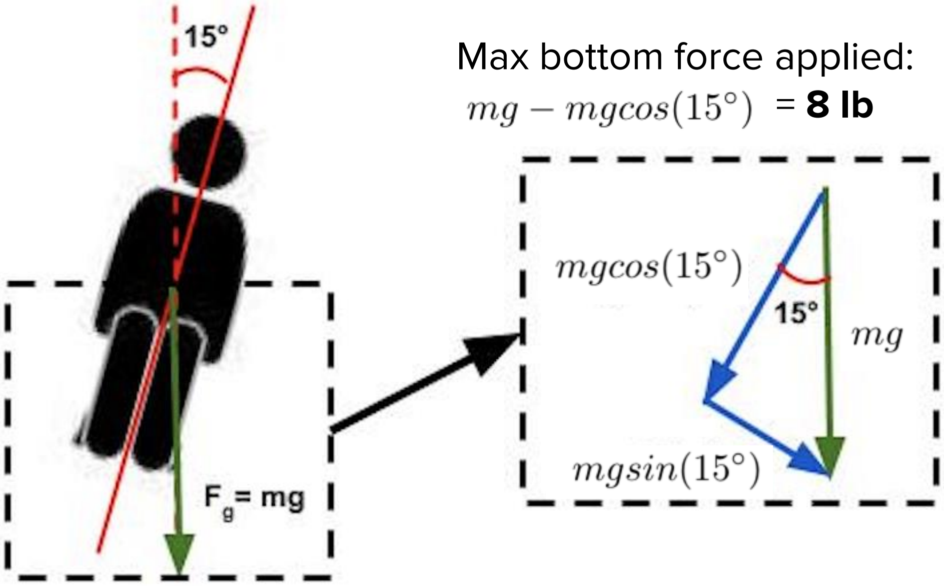


*representative

DR 1.1.3

Side actuators must apply a total of 55 lb to mimic horizontal gravitational force during 15° roll angle

Bottom actuators must apply a total of 8 lb to mimic vertical gravitational force during 15° roll angle

Weight is supported by the primary structure

TCS Feasibility - Stimulation Area + Force Per Actuator

50 lbf Progessive Automations Linear Actuator

Side Actuators per side:

Required min pressure	Force from 15° roll angle	Maximum stimulated area	# of modules	Force per actuator	Force margin
0.38 psi	55 lbf	145 sq in	3	19 lbf	31 lbf

Feasible

Bottom Actuators per side:

Required min pressure	Force from 15° roll angle	Maximum stimulated area	# of modules	Force per actuator	Force margin
0.38 psi	8 lbf	20 sq in	1	8 lbf	42 lbf

Feasible

TCS Feasibility - Stimulation Area + Force Per Actuator

50 lbf Progessive Automations Linear Actuator

Side Actuators per side: DR 1.1.1

Required min pressure	Force from 15° roll angle	Maximum stimulated area	# of modules	Force per actuator	Force margin
0.38 psi	55 lbf	145 sq in	3	19 lbf	31 lbf

Feasible

Bottom Actuators per side:

Required min pressure	Force from 15° roll angle	Maximum stimulated area	# of modules	Force per actuator	Force margin
0.38 psi	8 lbf	20 sq in	1	8 lbf	42 lbf

Feasible

Safety Limit: DR 2.1

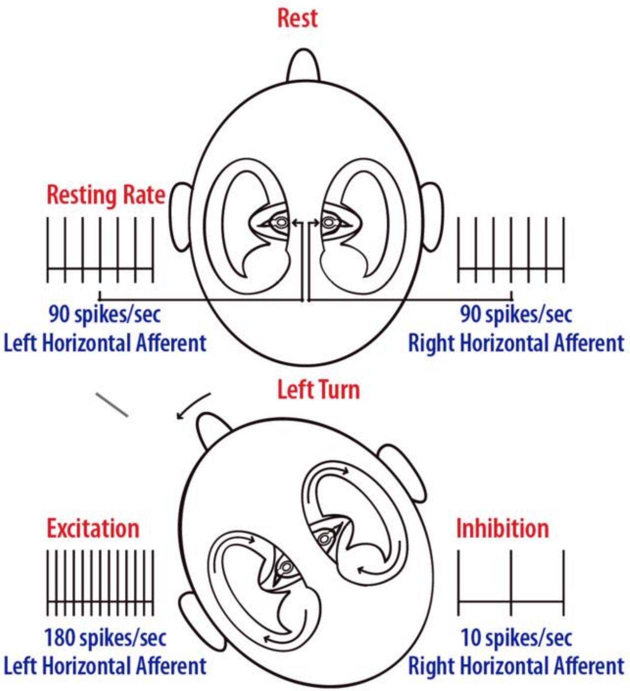
Actual force limit of actuator	# of modules	Maximum pressure capability	Pressure limit (requirement)	Factor of safety
50 lbf	8	1.03 psi	3.63 psi	3.5

Safe

Galvanic Vestibular Stimulator (GVS) Feasibility

- Vestibular nerves “spike” in voltage at regular intervals when at rest.
- Changes in this spike rate results in the perception of motion
- GVS alters the spike rate by applying currents across the vestibular nerves.

$$\Theta_{perceived} = f(A)$$



From nobaproject.com

GVS Feasibility

Design Requirement 1.2.1: The GVS shall be able to cue roll angles about the body x axis up to 15° from the nominal upright position.

- Customer identification that 15° can be cued within the 4mA provided.
- Customer also requested linear model of current vs angle with a TBD slope
- Current to angle transfer function will be worked on by customer as part of his research

Feasible, Customer (A GVS Expert) has provided a maximum current which will achieve his research goals

GVS Feasibility

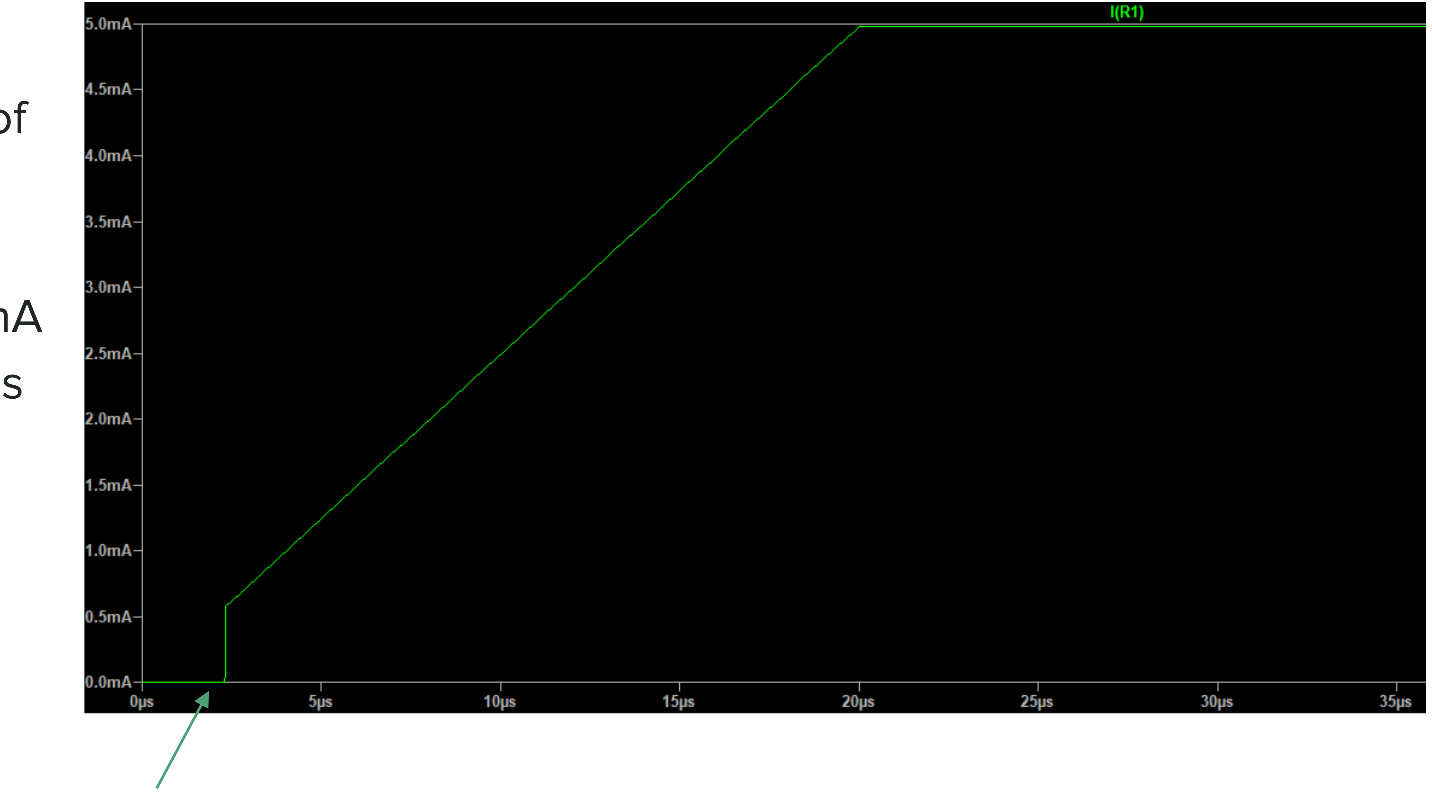
Design Requirement 2.3: The GVS will have a maximum output that will not exceed 4 mA of current

- The GVS will be designed as a two fault tolerant system
  - Software:
    - Software limitations prevent commands that draw more than 4 mA (DR 2.4).
    - DACs with built-in ammeters will be used to verify circuit conditions
  - Hardware:
    - Hardware current limiting circuitry will be installed for each electrode wire
    - The DACs maximum current can be set with resistors.

Feasible, Both Software and Hardware have two fault tolerance

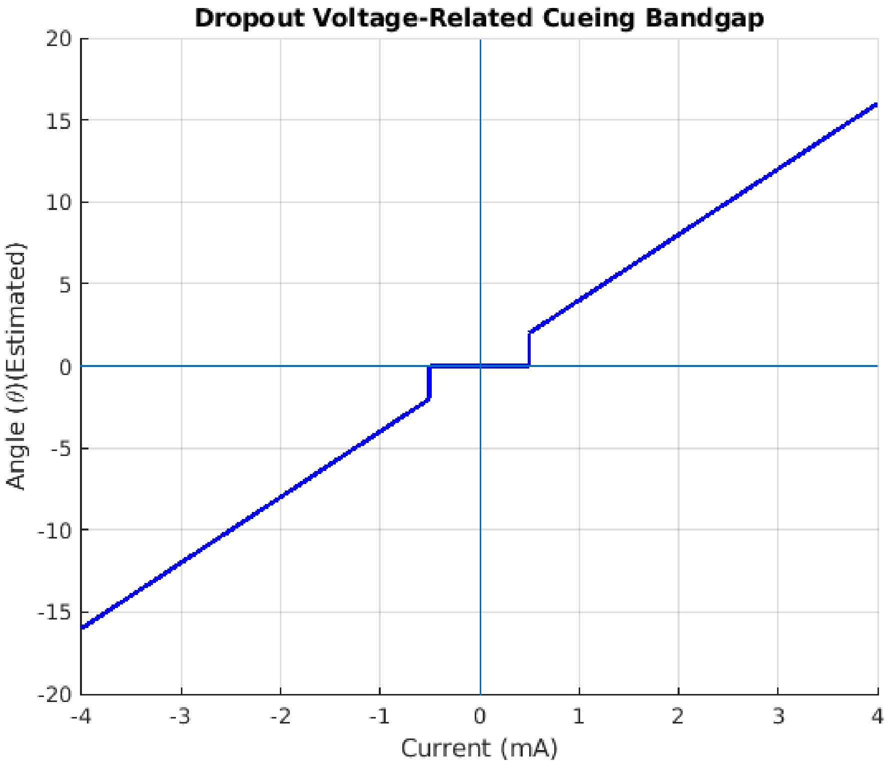
GVS Models

- LTspice Model of AD5770R DAC shows time response for 5mA command across a 1kΩ load



GVS Models

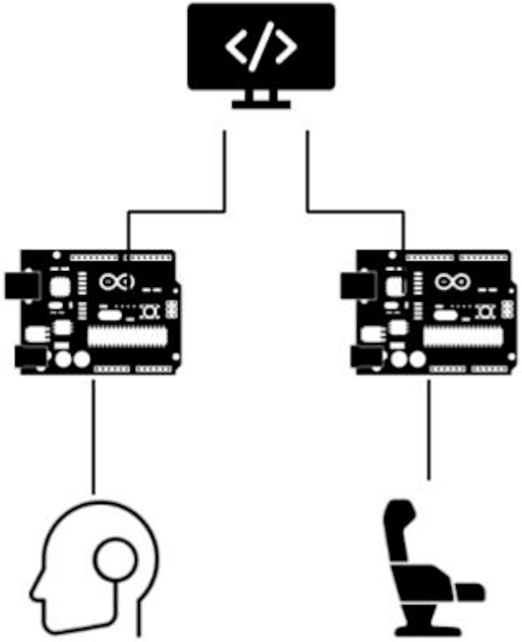
- A fixed dropout voltage means our system has a minimum current it can generate ($V_{min} = I_{min}R$)
- For a 1kΩ load, this would be around 0.5mA
- Navy Medical Research Institute study found that the minimum perception threshold for current is 1mA



Central Processing System (CPS) Feasibility

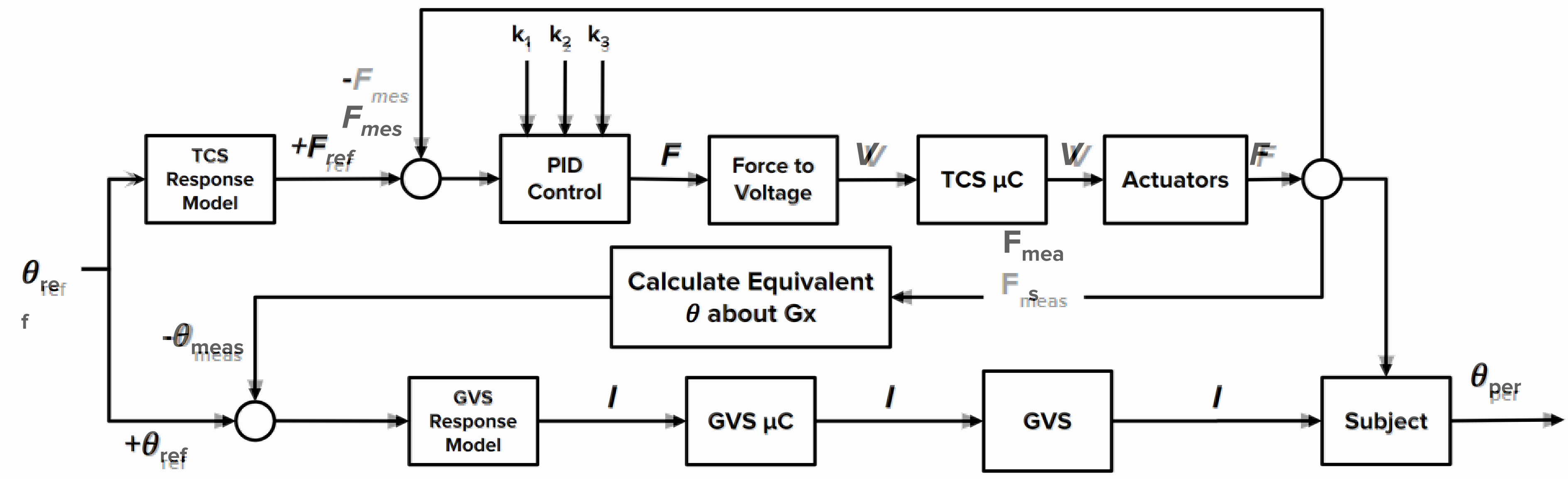
- Takes inputs from controller or subject
- Command Force/Current via TCS and GVS

DR 3.2 :
Time delay between the TCS and GVS cues as experienced by the test subject is less than 100 ms.

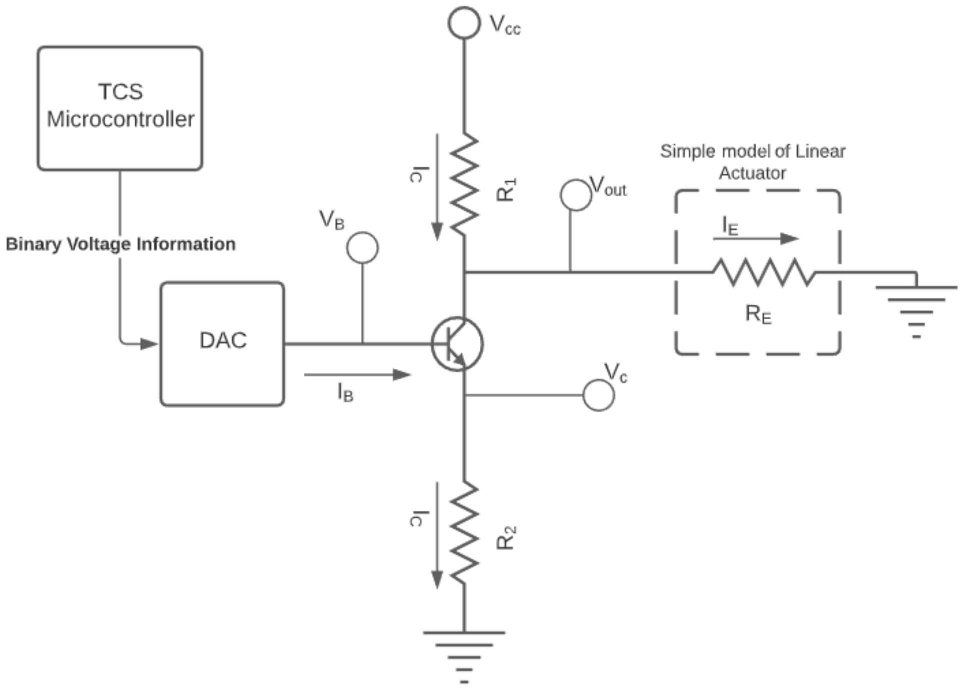


CPS Feasibility- TCS and GVS Control Logic

θ_{ref}: commanded angle about Gx
θ_{per}: angle about Gx subject perceives
θ_{meas}: equivalent cued angle about Gx by TCS



CPS Feasibility- Commanding Voltage to the TCS

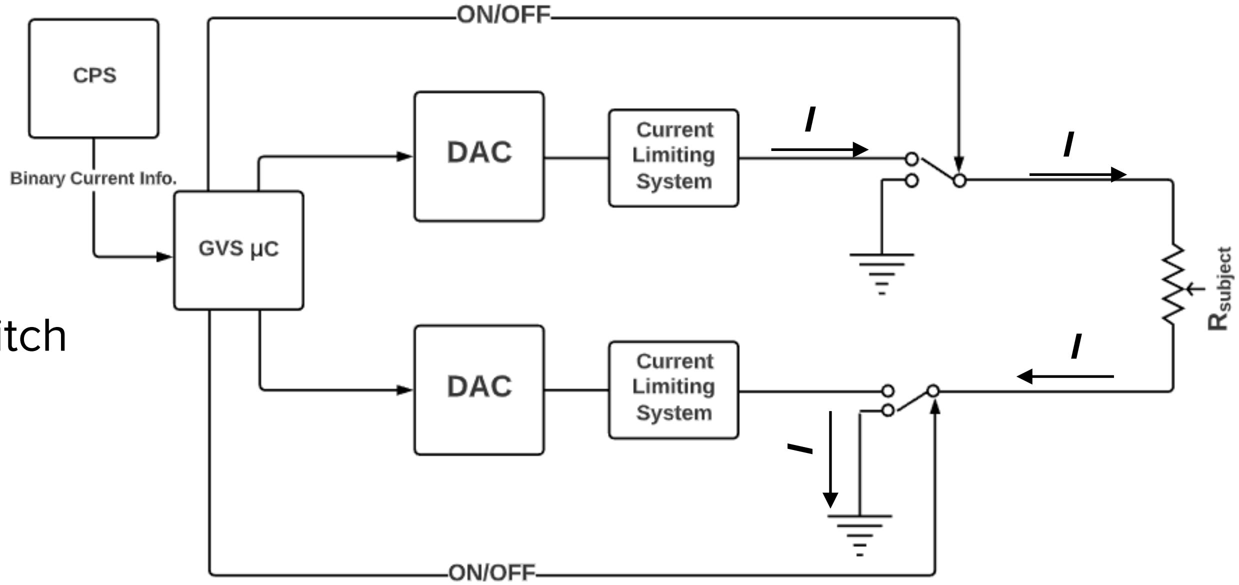


$$V_{out} = V_{cc} - (1 - \frac{1}{1+\beta})\frac{V_B - 0.6\mathbf{V}}{R_2}R_1$$

- CPS must be able to command any voltage to actuators
- Looking at a single actuator, voltage output can be controlled through *npn* BJT circuit
  - Equation derived in Appendix
- Scaleable to many actuators

Feasible, Power supplied to actuators (V_{out}) can be commanded at any value (limited by power source, circuit design)

CPS Feasibility- Commanding Current to GVS



- CPS must be able to switch which electrode is the cathode/anode

Feasible, a signal can be sent from CPS to GVS through a USB or similar connector to command the desired current. An inexpensive current source DAC will allow for this.

CPS Feasibility - Future Considerations

- Development of transfer functions for control logic
- Sensor placement and reliability
  - Forces felt by subject will change with their position in the seat and as they move
- Time response model development of Tactile Cueing System
- Validation of control system outputs concerning human perception

CHAIR Status Summary

Potential Problem Areas

- Acquiring Access to Facilities.
    - Provide detailed schematics to PILOT's staff for fabrication.
- Safely Conduct Meetings.
    - Follow CDC guidelines & utilize GitHub
- Acquisition of Components.
    - Start searching for parts early.

	CPS	TCS	GVS
Feasible	- Control Both MCU's - Software Logic	- Pressure Limit Safety - TCS Circuit Design - Required Actuator Force	- Current Limited to 4mA - GVS Current Control Model - GVS Circuit Design
Some Work Still Needed	- Cost - Component Selection	- Cost	- Cost
Excess Work Still Needed	- System Verification - UI Design	- Fabrication	- Fabrication
Status Summary	The CPS is yet to be fully proven feasible.	The TCS is mostly proven feasible.	The GVS is mostly proven feasible.

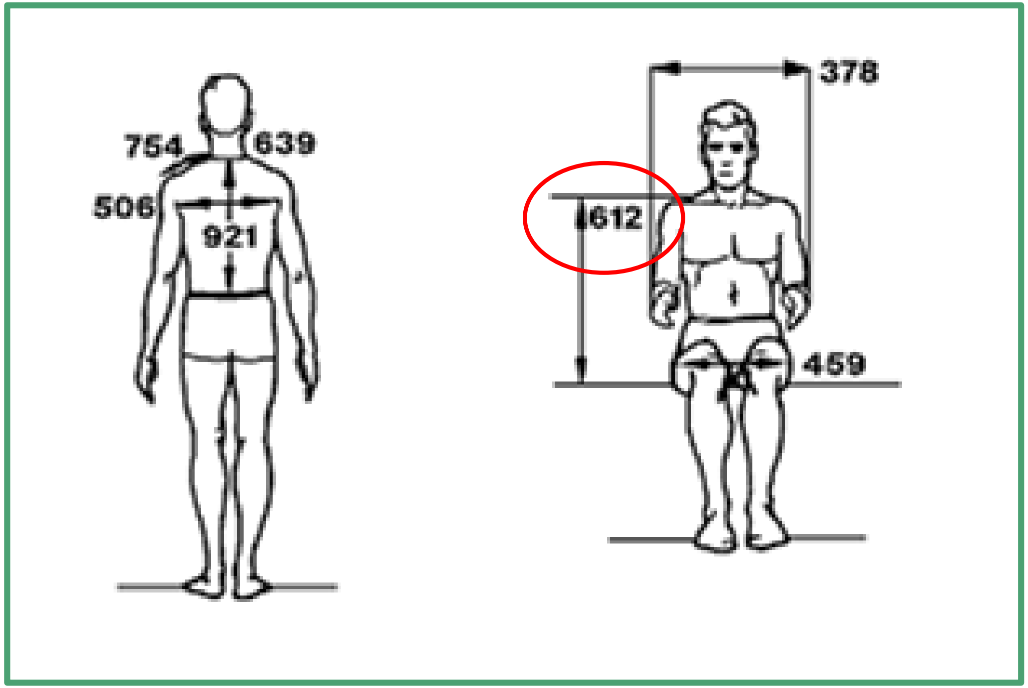
Thank you

Questions?

BACKUP SLIDES

Table of Appendices

Anthropometric considerations

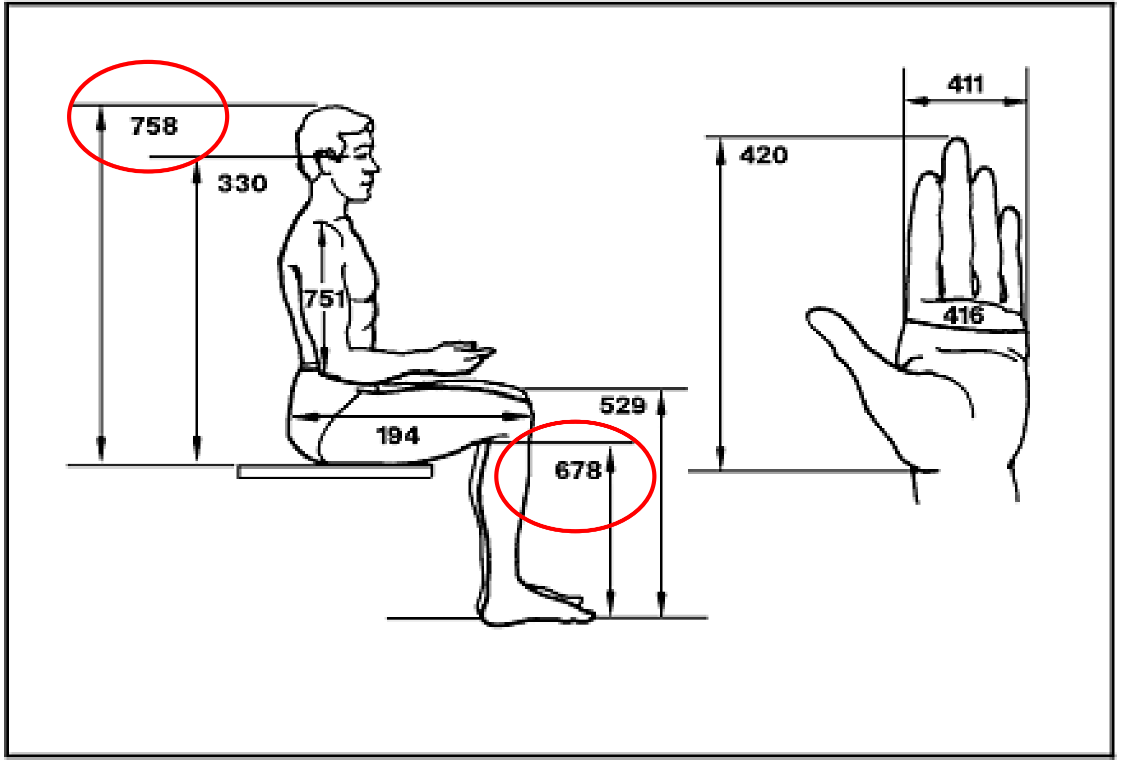


Must accommodate customer (Dr. Clark)
Aim to accommodate 50th percentile male dimensions as well if these are larger

Mid-shoulder height, sitting (25.7 in): effectiveness

NASA STD 3000 Anthropometry and Biomechanics

Anthropometric considerations



Sitting height (73.1 in) - effectiveness

Popliteal height (17.5) - comfort

NASA STD 3000 Anthropometry and Biomechanics

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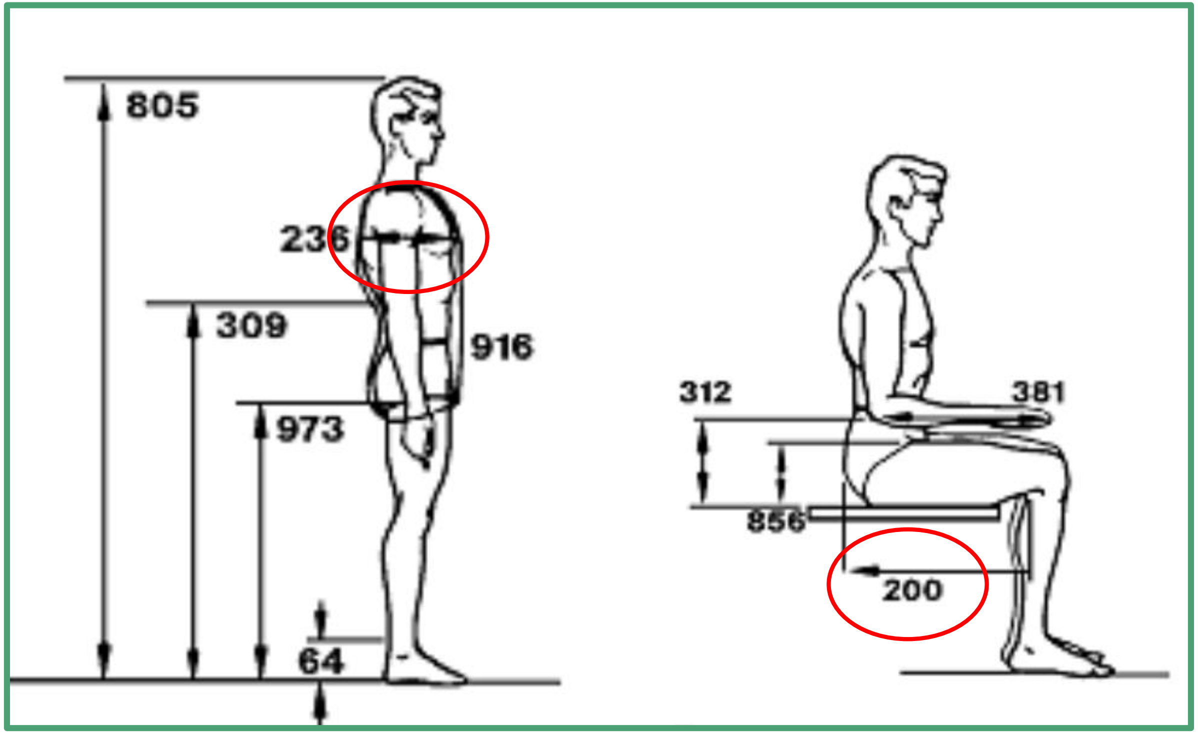
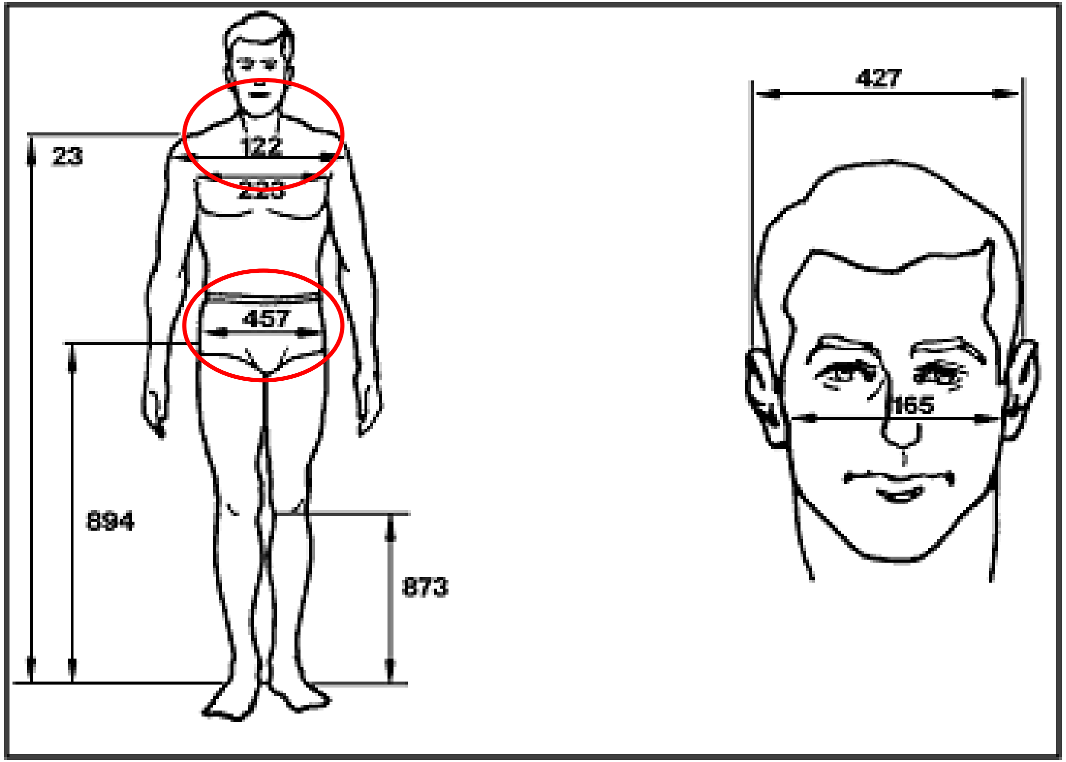


Bust depth (9.8 in): effectiveness

Buttock-popliteal length (20.2 in): comfort

NASA STD 3000 Anthropometry and Biomechanics

Anthropometric considerations



Shoulder breadth (19.3 in): effectiveness
[Dr. Clark's: 18.3 in]

Hip breadth (14.1 in): comfort
[Dr. Clark's: 14.4 in]

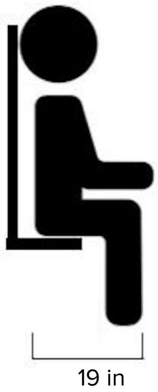
Addition anthropometric measurements must be considered for the GVS and joystick

NASA STD 3000 Anthropometry and Biomechanics

TCS Feasibility - Spatial Requirements

Design Requirement 4.1: “**The TCS shall operate within a space no larger than 6’ x 6’.**”

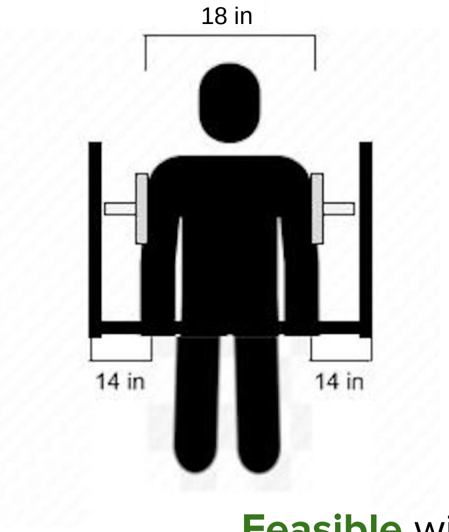
Back to Front:



- Customer femur length is 19”
- Total back to front length around **22”**

Feasible with 50” of margin

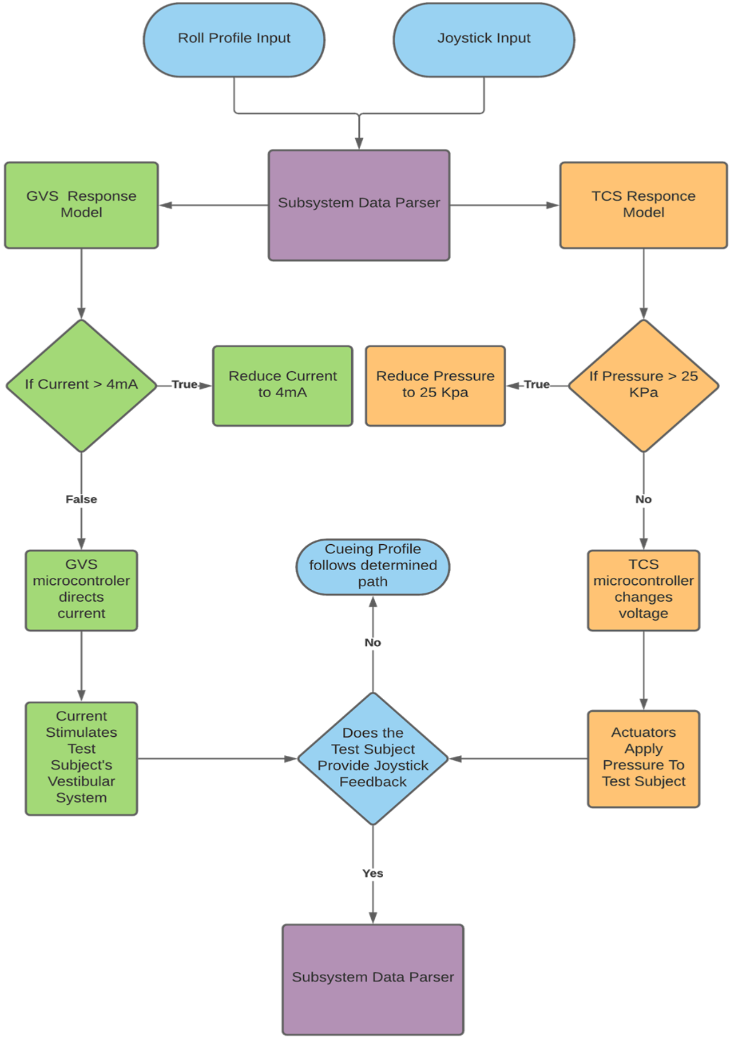
Side to Side:



- Customer shoulder width is 18”
- 150 lb actuators range from 10”- 14” extended
- PA actuator is 10”, plus about 4” for pressure plate and chair
- Total side to side length around **44”**

Feasible with 28” of margin

General Software Flowchart



Derivation of CPS to TCS Actuator Output

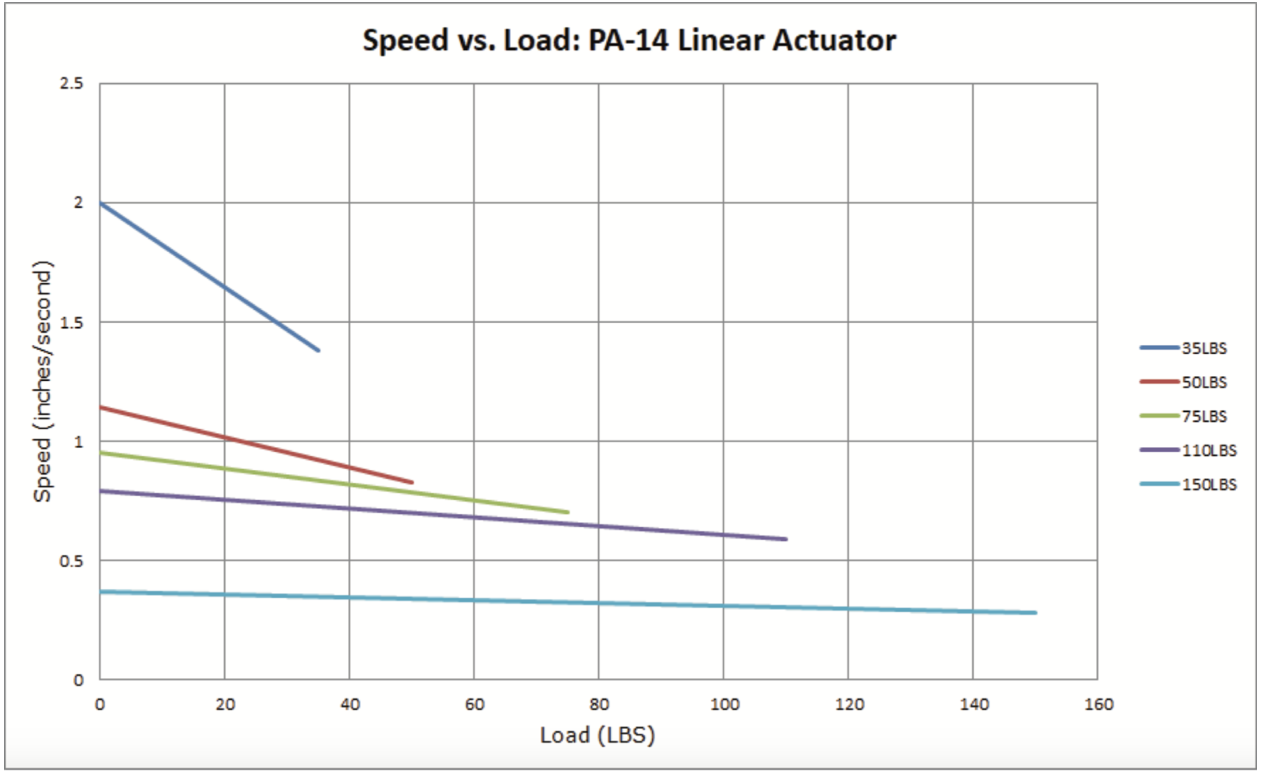
$$I_C = \beta I_B$$
$$V_E = V_B - 0.6\mathbf{V}$$
$$I_E = \frac{V_E}{R_2}$$
$$I_C = I_E - I_B$$
$$V_{out} = V_{cc} - I_c R_1$$

$$V_{out} = V_{cc} - I_c R_1$$
$$V_{out} = V_{cc} - (I_E - I_B)R1$$
$$V_{out} = V_{cc} - \left(1 - \frac{1}{1+\beta}\right) I_E R_1$$
$$V_{out} = V_{cc} - (1 - \frac{1}{1+\beta})\frac{V_B - 0.6\mathbf{V}}{R_2} R_1$$

Applicable NASA Safety Standards

NASA Safety Standard	Doc.
NASA SAFETY CULTURE HANDBOOK	NASA-HDBK-8709.24
NASA RELIABILITY AND MAINTAINABILITY (R&M) STANDARD FOR SPACEFLIGHT AND SUPPORT SYSTEMS	NASA-STD-8729.1A
STANDARD FOR MODELS AND SIMULATIONS	NASA-STD-7009A
ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL (EEE) PARTS ASSURANCE STANDARD	NASA-STD-8739.10
NASA SOFTWARE SAFETY GUIDEBOOK	NASA-GB-8719.13
SOFTWARE FORMAL INSPECTIONS STANDARD	NASA-STD-8739.9
SOFTWARE ASSURANCE AND SOFTWARE SAFETY STANDARD	NASA-STD-8739.8A

50 lb Actuator Speed vs. Load



50 lb Actuator Current vs. Load