Lockheed Martin Low-Cost F-35 Simulator

Senior Design Team 514

Laiken Kinsey

Meet the Team

Jonah Gibbons
Manufacturing & Electrical Engineer

Laiken Kinsey
Test and Analytical Engineer

Francisco Lopez
Control Systems Engineer

Branden Pacer
Mechanical Engineer & Web Design

Will Rickles
Mechatronics Engineer

Emelia Rodriguez
Project Manager & Research Engineer

Laiken Kinsey

Sponsor and Advisor

LOCKHEED MARTIN

Andrew Filiault

Mechanical Engineer, B.S.

JSF F-35 Pilot Training and Training Infrastructure Systems

FAMU-FSU College of Engineering

Brandon Krick

Mechanical Engineer, Ph.D.

Associate Professor

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Project Objective

The objective of this project is to create F-35 flight controls that integrate with Lockheed Martin's simulator software to be used in the pilot training program

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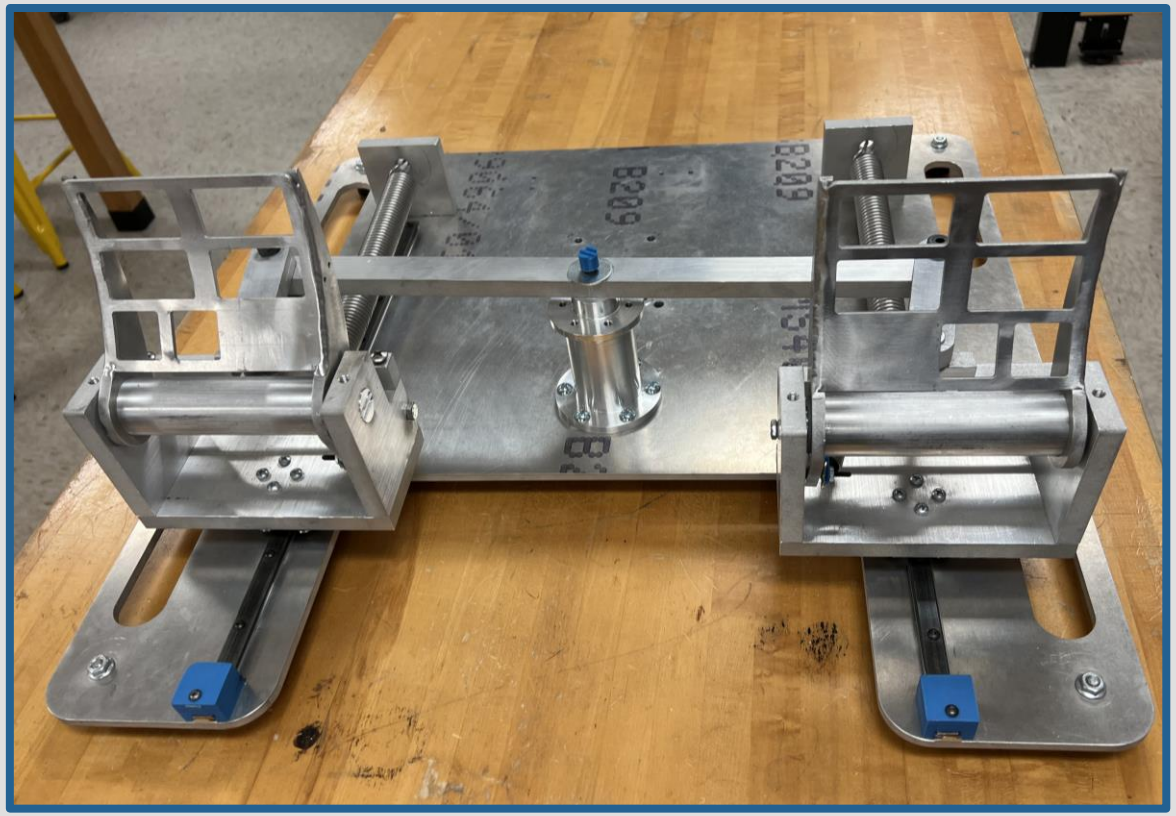
Rudder Pedal System



- Rudder Pedal System (RPS): Controls the rudders which change the yaw axis of the aircraft and also the wheel brakes
- Initially developed by a previous senior design team, we will incorporate this Rudder Pedal System with minor modification

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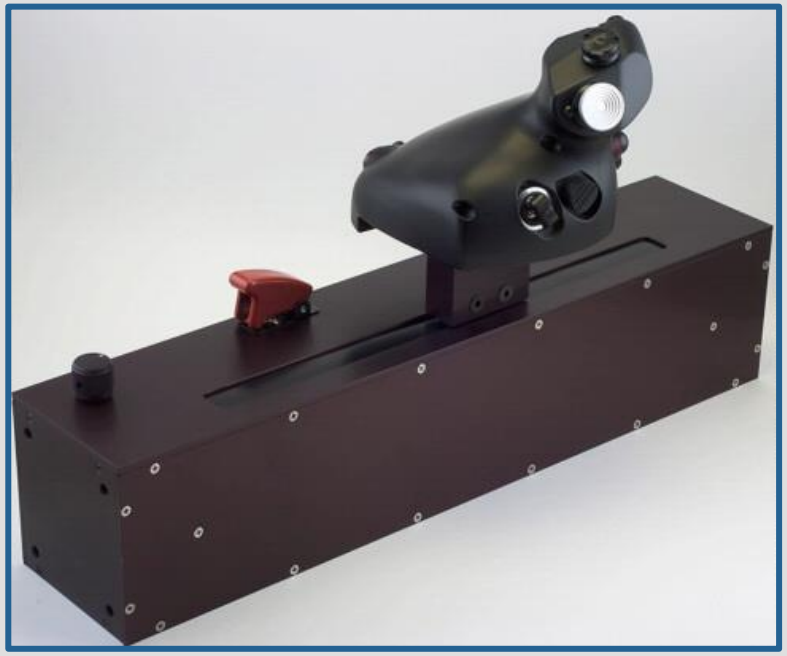
HOTAS System

- HOTAS: Hands on Throttle and Stick
- Throttle: Controls the thrust from the jet engine
- Stick: Controls the pitch and roll axes of the aircraft
- Initially developed by a previous senior design team, we will completely redesign the stick concept



Throttle

Stick

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3D Printed Cockpit and Desktop Simulator for Training

- Pilots train in simulators to develop muscle memory and learn the unique operating procedures of the aircraft

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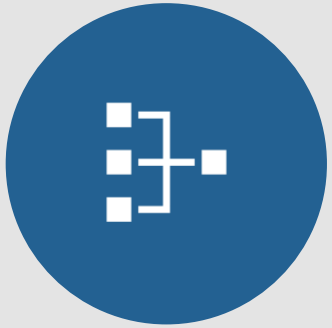
Key Goals

Create finished, working prototype



Integrate both physical sub-systems into the simulation software

Keep manufacturing costs low

Can be used in desktop or cockpit training models

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Flight Control Functions

Pilot Interface

- Controls closely mimic F-35 look and feel
- Mechanic parts will withstand repeated use

Communicate to software

- Controller position awareness
- Negligible input delay
- Inputs accurately affect simulated jet

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Critical Targets

- **Cost**
  - Each new sub-system less than $1000
- **Latency**
  - No more than 20ms delay from input
- **Compatibility**
  - 3D printed cockpit and standard desk

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Additional Targets

Individual Component < 35 lb	Joystick deflection 13 deg in all directions	Throttle travel 6 in
Operates 1 hour without defect	No more than 15 lbf required to move RPS	HOTAS withstands applied 7.5 lbf

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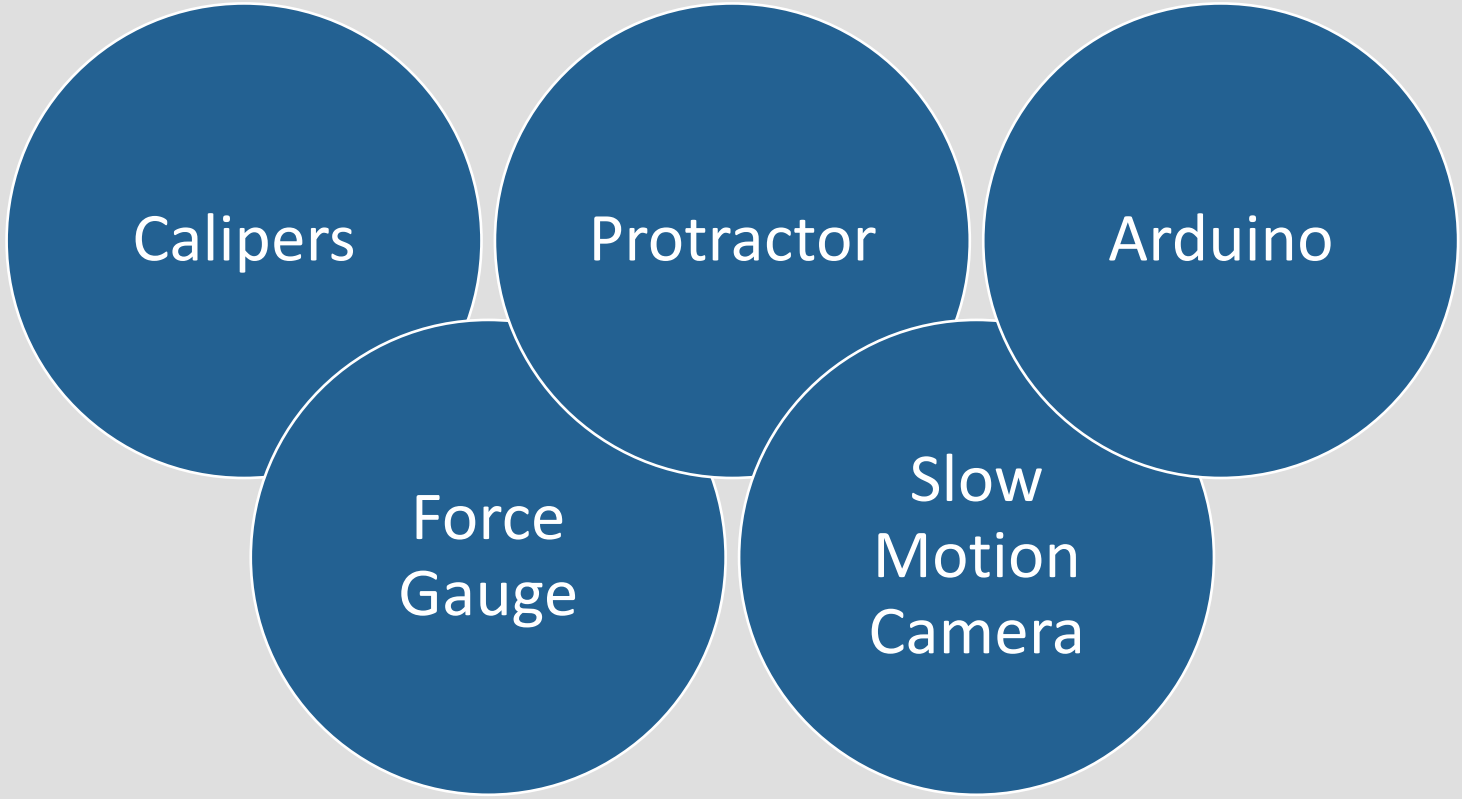
Methods of Validation



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Concept Generation

- 100 unique design concepts were generated
- Four components to consider:
  - Joystick
  - Throttle
  - Rudder Pedals
  - Electrical Integration
- Two or more high fidelity concepts selected per category
  - High fidelity concepts move forward to selection process

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Concept Generation

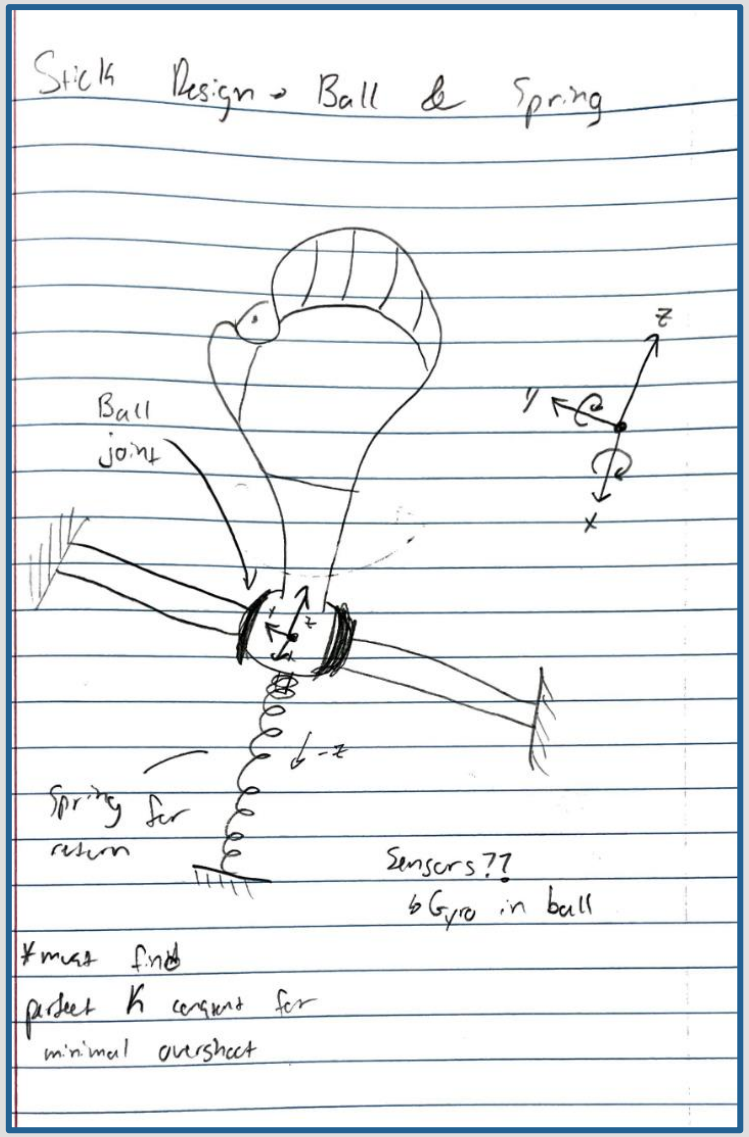
- Joystick High Fidelity Concepts
  - Single-spring, ball joint
  - Multi-plane gimbal

Concept Generation

Joystick High Fidelity Concepts:

Single-spring, ball joint— a ball in a socket with a single spring below to keep the neutral position upright

- The design is simpler to construct and easier to support from downward forces of pilot's hand
- Much harder to measure the joystick position with sensors



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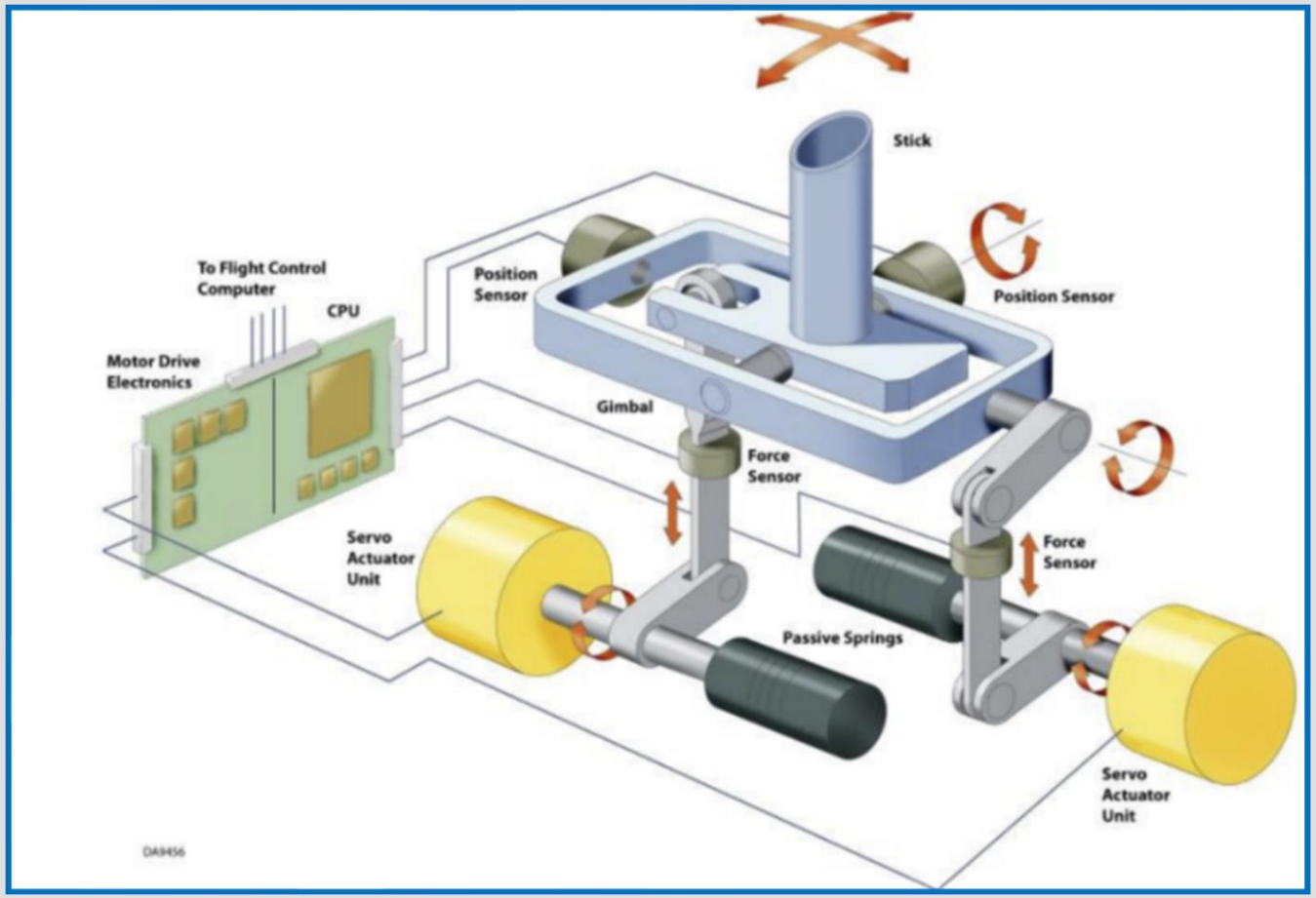
Concept Generation

Joystick High Fidelity Concepts:

Multi-plane gimbal— two-piece gimbal with axels connected to rotary sensors with individual springs to keep the neutral position upright

- This requires more intricate pieces to construct but is identical to the actual construction in an F-35 jet
- Linkages make it easier to measure position



NEEDS REFERENCE

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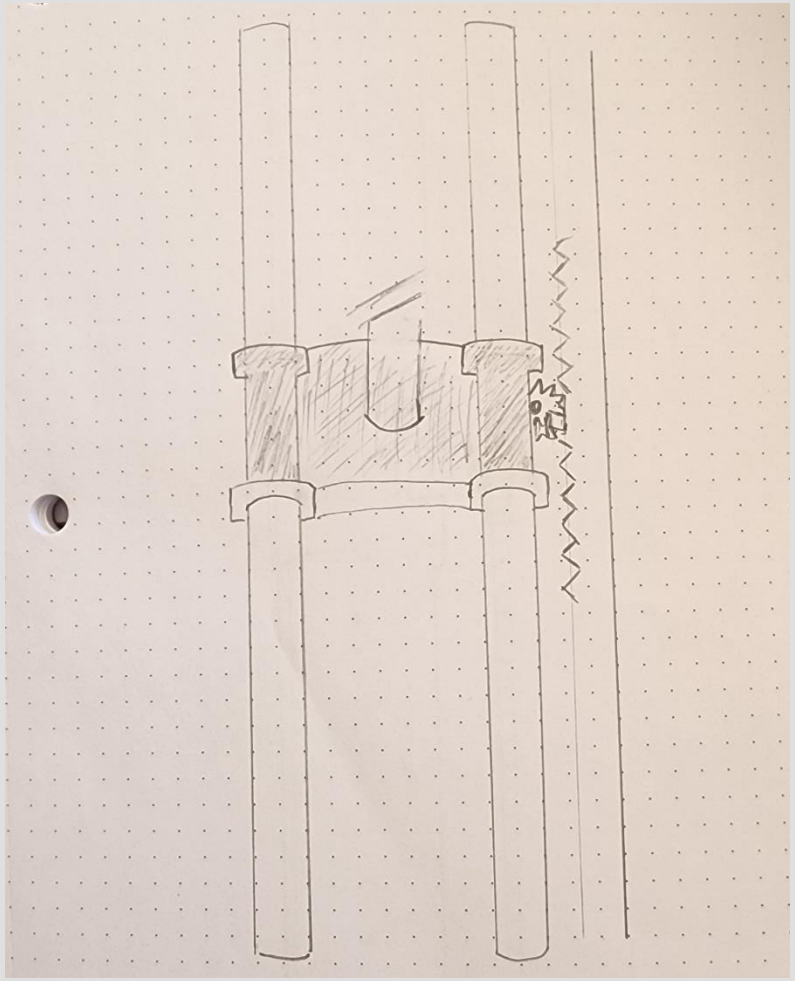
Concept Generation

Throttle High Fidelity Concepts:

Multiple, tube rails— the throttle handle will slide along two parallel rails

- This concept was considered in order to resist the risk of torque damage and instability that a single tube rail would have
- Requires a lot of “from-scratch” design work on the cart and its bearings



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Concept Generation

Throttle High Fidelity Concepts:

Single, rectangular rail— the throttle handle will slide along a single rail with ball bearings in the grooves

- This concept is very high-strength and the construction eliminates concerns of torque damage and excessive wear
- It is pre-manufactured and low cost

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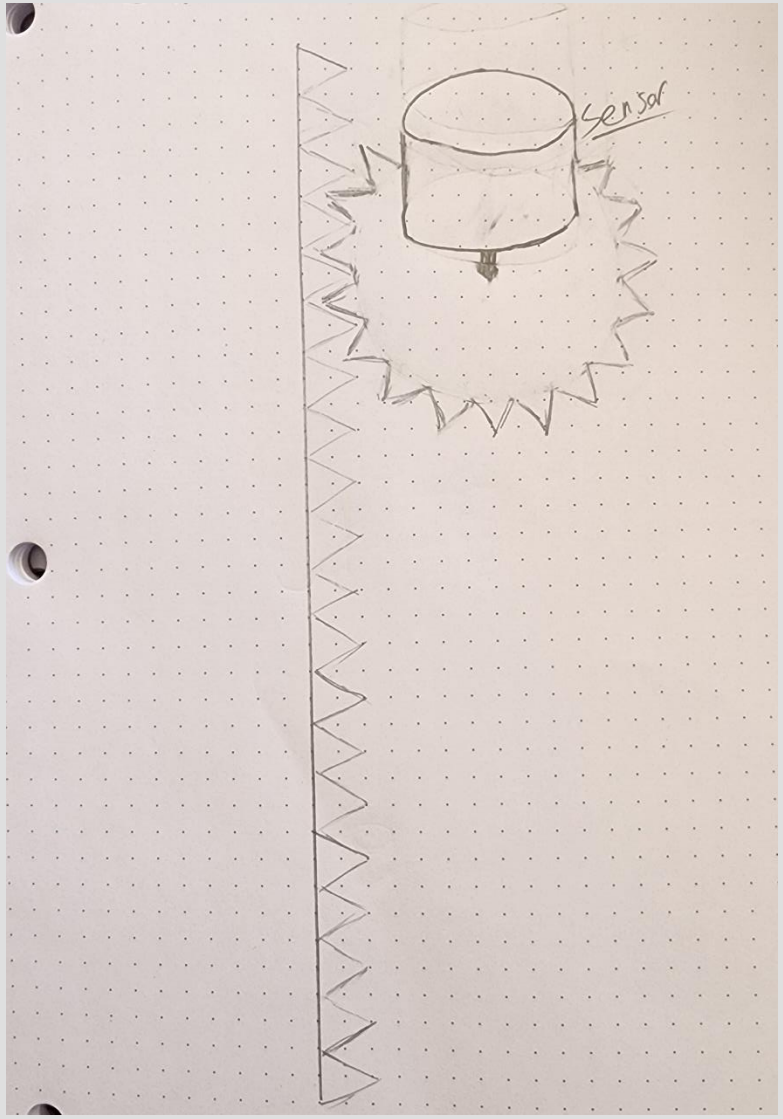
Concept Generation

Throttle Position Concepts:

Gears: rack and pinion— the sensor would be attached to a rack and pinion to actuate it when the throttle is moved

- This concept is very simple and durable



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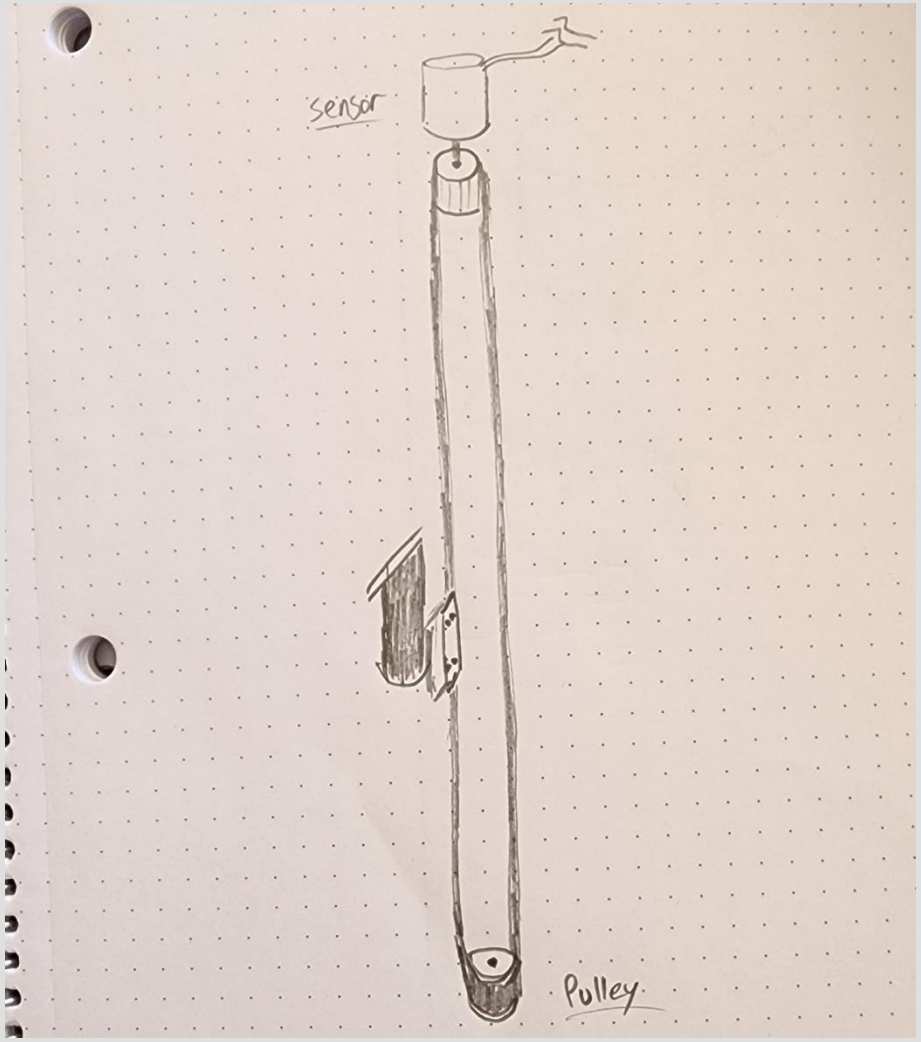
Concept Generation

Throttle Position Concepts:

Belt actuated— the sensor would be attached to a pulley with a belt around it which is fixed to the cart, moving with the throttle handle

- This concept is could be tricky to design from scratch and requires more maintenance and adjustable tensioning



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Concept Generation

Sensor High Fidelity Concepts:

Rotary Hall Effect— measures the strength of a magnetic field from a permanent magnet which moves inside

- Because the sensor doesn't rely on mechanical contact, it has a longer lifespan
- The sensors cost more

Rotary Hall Effect Sensor

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Concept Generation

Sensor High Fidelity Concepts:

Potentiometer— contains a wound resistive element and a wiper contact which moves along the element providing a variable level of resistance

- They are very cheap, standard, and easy to implement

Potentiometers

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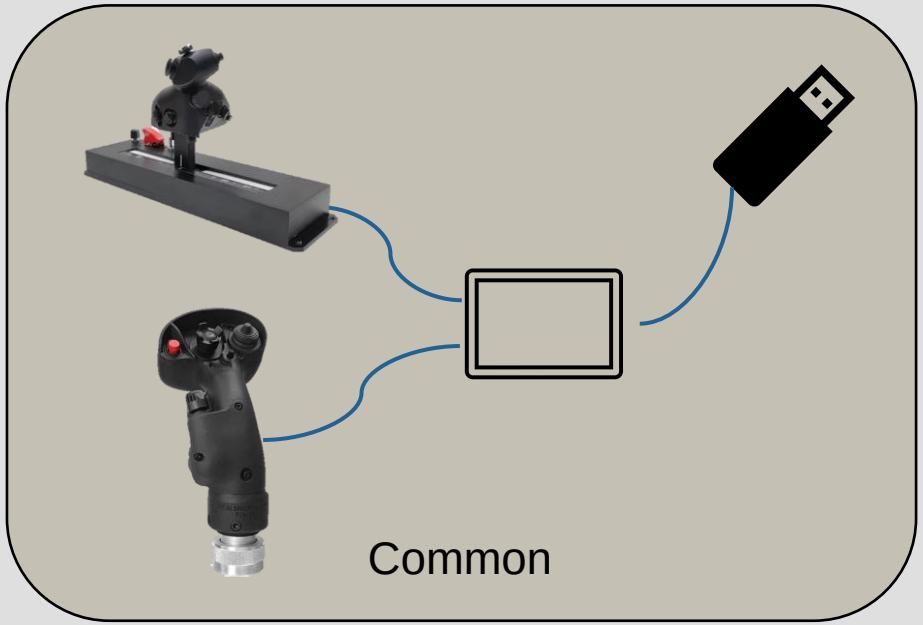
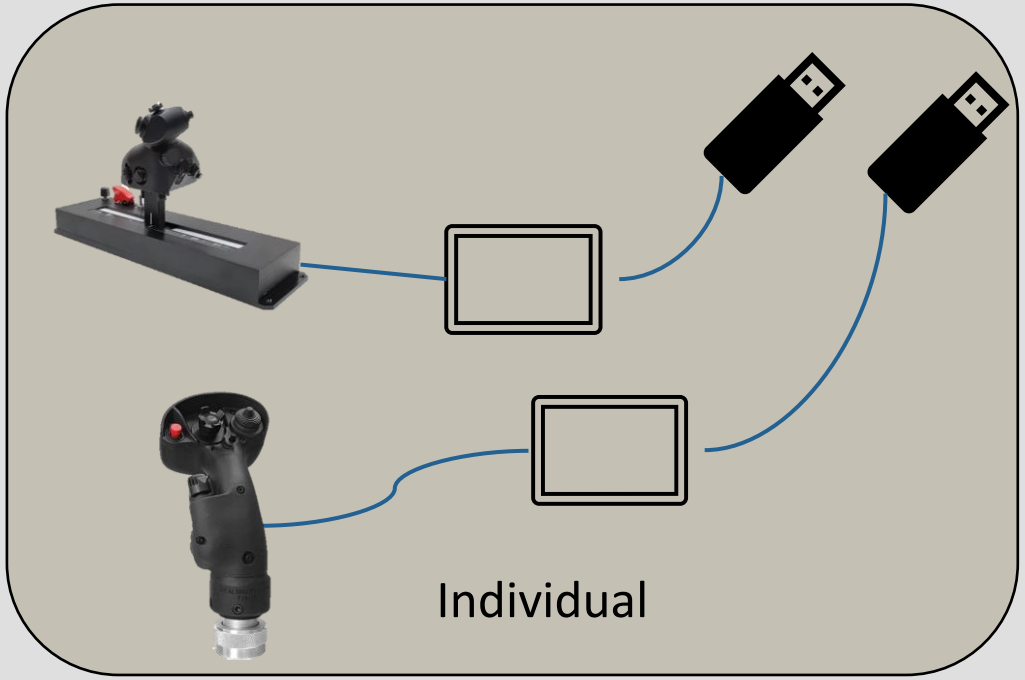
Concept Generation

- Microcontroller Options
  - Individual controllers
  - Common controller





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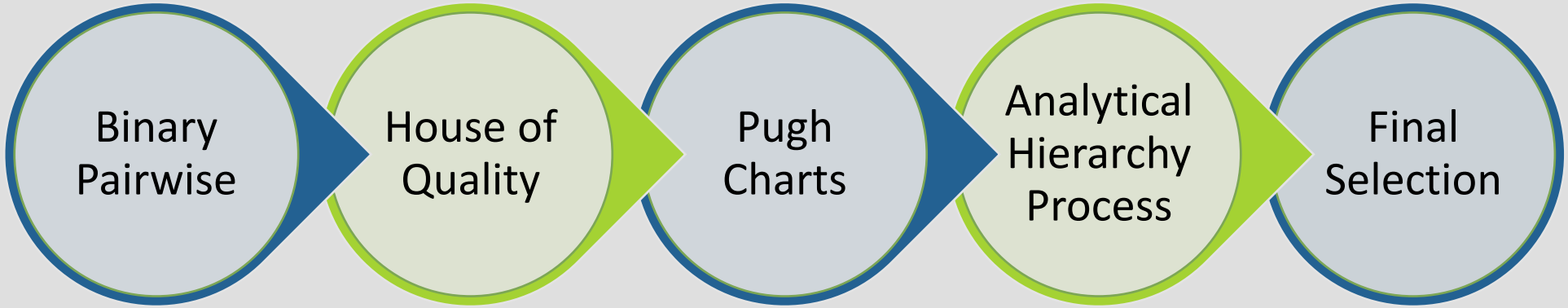
Concept Selection Process



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Binary Pairwise Comparison

	1	2	3	4	5	6	7	8	9	Total	IWF
1. Cheap to manufacture	-	1	0	1	0	1	0	1	1	5	4
2. Fits into desk and cockpit model	0	-	0	0	0	1	0	1	1	3	2
3. Equipment fully integrated with Prepar3D	1	1	-	1	0	1	1	1	1	7	5
4. Will be able to simulate flying a box	0	1	0	-	0	1	0	1	1	4	3
5. Complete, polished prototype	1	1	1	1	-	1	1	1	1	8	5
6. Components provide appropriate resistance	0	0	0	0	0	-	1	1	0	2	2
7. Provides accurate in-flight feel for F-35	1	1	0	1	0	0	-	1	0	4	3
8. Lower mechanical complexity	0	0	0	0	0	0	0	-	1	1	1
9. Withstand vigorous use	0	0	0	0	0	1	1	0	-	2	2
Total	3	5	1	4	0	6	4	7	6	n-1=8	

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House of Quality

HoQ	Improvement direction	↑	↓	↑		↓	↓	↓	↓	↑
	Units	psi	s		lbs	$	integer	in	hours	
Customer Requirements	IWF	Material stength	Latency	Accuracy of position sensing	Applied resistance	Cost of Materials	Number of parts	Deviation from given dimensions	Time to complete	Aesthetics
Cheap to manufacture	4	1				9			1	
Fits into desk and cockpit model	2						1	9		
Equipment fully integrated with Prepr3D	5		9	9						
Will be able to simulate flying a box	3		3	9						
Complete, polished prototype	5								3	9
Components provide appropriate resistance	2	3			9					
Provides accurate in-flight feel for F-35	3		3	9	9			1		
Lower mechanical complexity	1						9			
Withstand vigorous use	2	9			3					
Raw Score (373)		28	63	99	51	36	11	21	19	45
Relative Weight %		7.5	16.9	26.5	13.7	9.7	2.9	5.6	5.1	12.1
Rank Order		6	2	1	3	5	9	7	8	4

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Pugh Chart

Selection Criteria	Datum	Concepts							
	Current LM F35 Sim "Wraith"	1	2	3	4	5	6	7	8
Accuracy of Position Sensing		-	+	-	+	-	-	-	-
Latency		+	+	-	-	+	+	-	-
Applied Resistance		-	-	-	+	-	+	-	+
Aesthetics		+	-	S	S	+	-	S	S
Cost of Materials		+	+	+	+	+	+	+	+
Material Strength		-	-	-	-	-	-	-	-
# of pluses		3	3	1	3	3	3	1	2
# of minuses		4	3	4	2	4	3	4	3

Concept	electrical	throttle	joystick	rps
1	hall & individual	single	ball	use existing
2	hall & individual	single	gimbal	use existing
3	hall & common	single	ball	use existing
4	hall & common	multi	gimbal	use existing
5	pot & individual	single	gimbal	use existing
6	pot & individual	multi	gimbal	use existing
7	pot & common	single	gimbal	use existing
8	pot & common	multi	gimbal	use existing

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Pugh Chart

Selection Criteria	Datum	Concepts					
	Past year projects	1	2	4	5	6	8
Accuracy of Position Sensing		-	+	+	+	+	+
Latency		+	+	+	+	+	+
Applied Resistance		S	+	+	+	+	+
Aesthetics		-	-	+	-	-	+
Cost of Materials		-	-	-	-	-	-
Material Strength		+	+	+	+	+	+
# of pluses		2	4	5	4	4	5
# of minuses		3	2	1	2	2	1

Concept	electrical	throttle	joystick	rps
1	hall & individual	single	ball	use existing
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3	hall & common	single	ball	use existing
4	hall & common	multi	gimbal	use existing
5	pot & individual	single	gimbal	use existing
6	pot & individual	multi	gimbal	use existing
7	pot & common	single	gimbal	use existing
8	pot & common	multi	gimbal	use existing

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Pugh Chart

Selection Criteria	Datum	Concepts				
	Logitech pro flight	2	4	5	6	8
Accuracy of Position Sensing		+	+	S	S	S
Latency		S	-	S	S	-
Applied Resistance		+	+	+	+	+
Aesthetics		S	+	S	S	+
Cost of Materials		-	-	+	S	S
Material Strength		-	-	-	-	-
# of pluses		2	3	2	1	2
# of minuses		2	3	1	1	2

Concept	electrical	throttle	joystick	rps
1	hall & individual	single	ball	use existing
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7	pot & common	single	gimbal	use existing
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AHP

AHP for the targets resulted in the following data

Criteria	{W}	Rank
Accuracy of Position Sensing	0.319	1
Latency	0.229	2
Applied Resistance	0.121	4
Aesthetics	0.119	5
Cost of Materials	0.151	3
Material Strength	0.032	6
Deviation from Given Dimensions	0.029	7

CR=0.043

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AHP

Accuracy of position sensing AHP

Concept	{W}	Rank
2	0.71	1
5	0.14	2
8	0.14	2

CR=0

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AHP

Latency AHP

Concept	{W}	Rank
2	0.311	2
5	0.623	1
8	0.066	3

CR=0.133

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AHP

Cost of Materials AHP

[C]	{W}	Rank
2	0.074	3
5	0.643	1
8	0.283	2

CR=0.063

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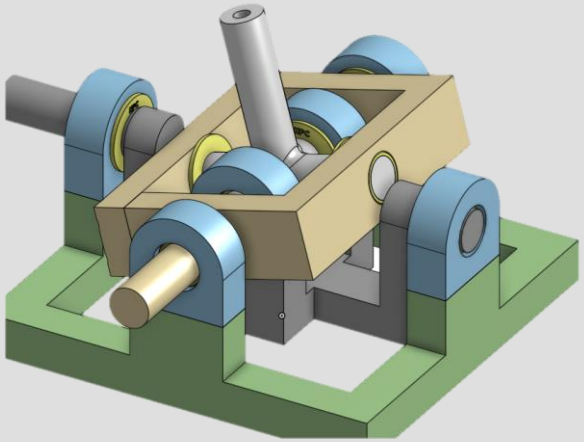
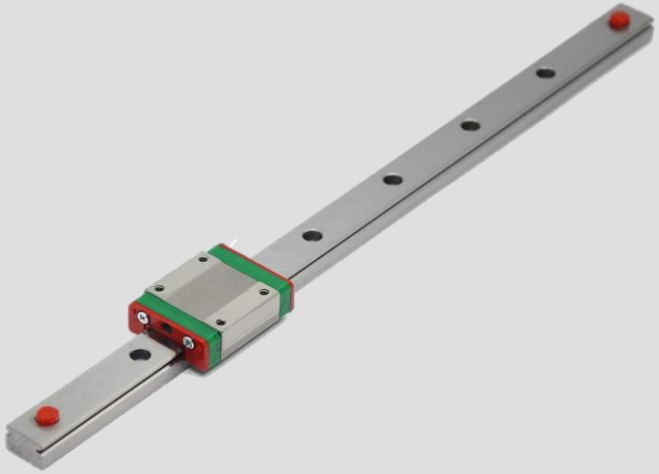
Final Selection

Concept 5: potentiometer to sense position, individual microcontroller for the RPS and throttle, separate microcontroller for the joystick, the throttle slides on a single rail, and the joystick is on a gimbal joint

Final Ranking			
	Concept		
	2	5	8
Accuracy	0.714	0.143	0.143
Latency	0.311	0.623	0.066
Cost	0.074	0.643	0.283
Average	0.366	0.470	0.164





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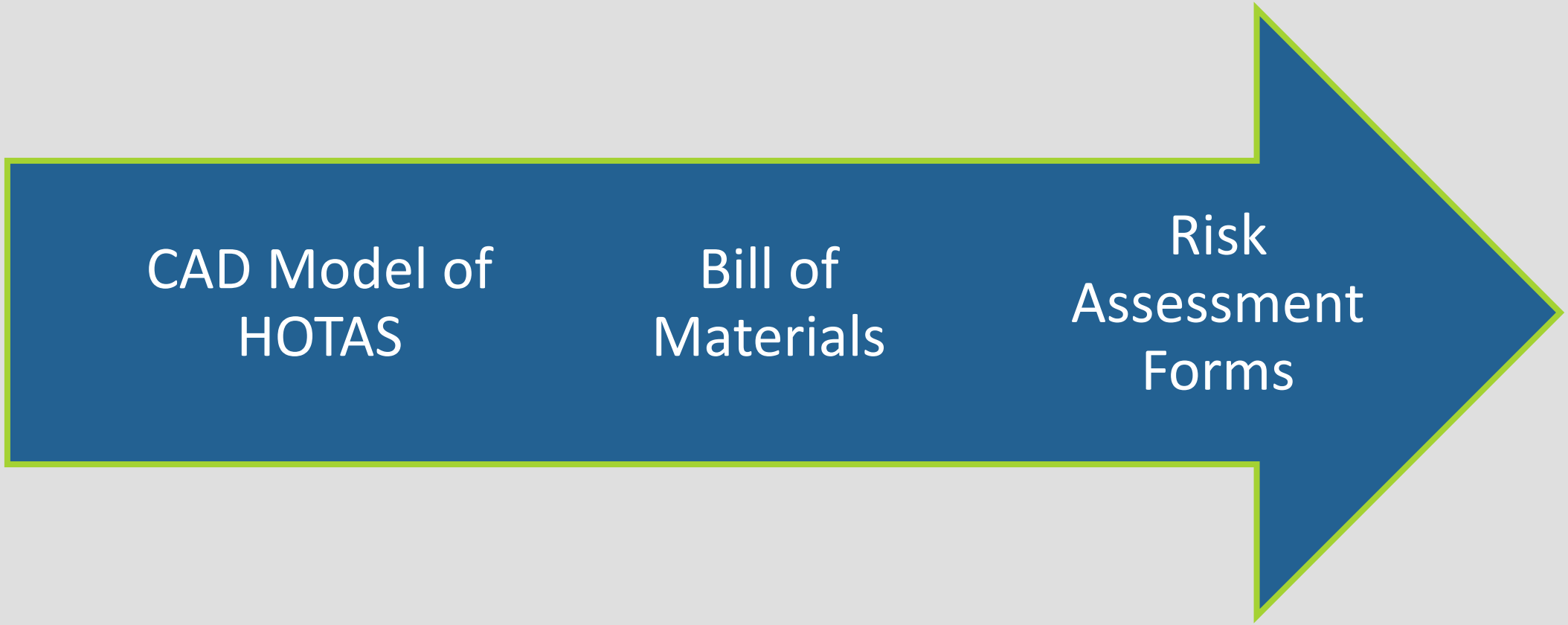
Future Work



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Questions?

- Design Team
- Sponsor
- Objective
- Background
- Functions
- Targets
- Concept Generation
- Concept Selection
- Future Work

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References

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