AIMGRO

Aerial-Insertion Micro Ground Robot

It works so well!!!

ENGS 90 Final Design Review
March 6, 2017

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Physical Sciences Inc.

1867

Problem Overview

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Problem Statement

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Utilize the **InstantEye** to deploy a **micro-ground robot** to explore **ground-based operations** and perform **discrete** reconnaissance in otherwise **inaccessible** areas.

Project Goal & Impact

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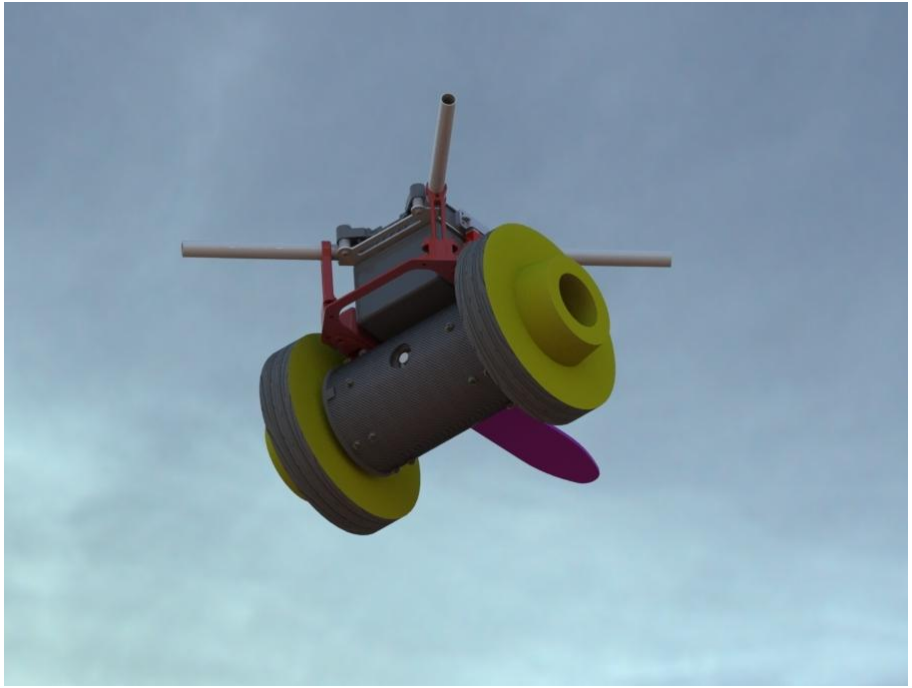
- Improves:
  - Surveillance capabilities
  - Range of applications
  - Personnel Safety
- Target Users:
  - Department of Defense
  - Law Enforcement
  - First Responders
  - NATO Allies
  - Professionals



Requirements and Objectives

- Proof of Concept Demo
- Deployable from InstantEye
- Low-Angle Perspective
- Ground-Based Mobility
- Maintains Tactical Flight

89/90 Deliverables

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- **Four Proof-of-Concepts:**
  - Three Mk 2 prototypes
  - One Mk 1 prototype
- **Documentation:**
  - BOM and Vendor information
  - Final CAD
  - Drawings, files, and G code
  - Software library, flow chart
  - Electronic schematic
  - Assembly documentation
  - Testing data

Design Methodology

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Specifications

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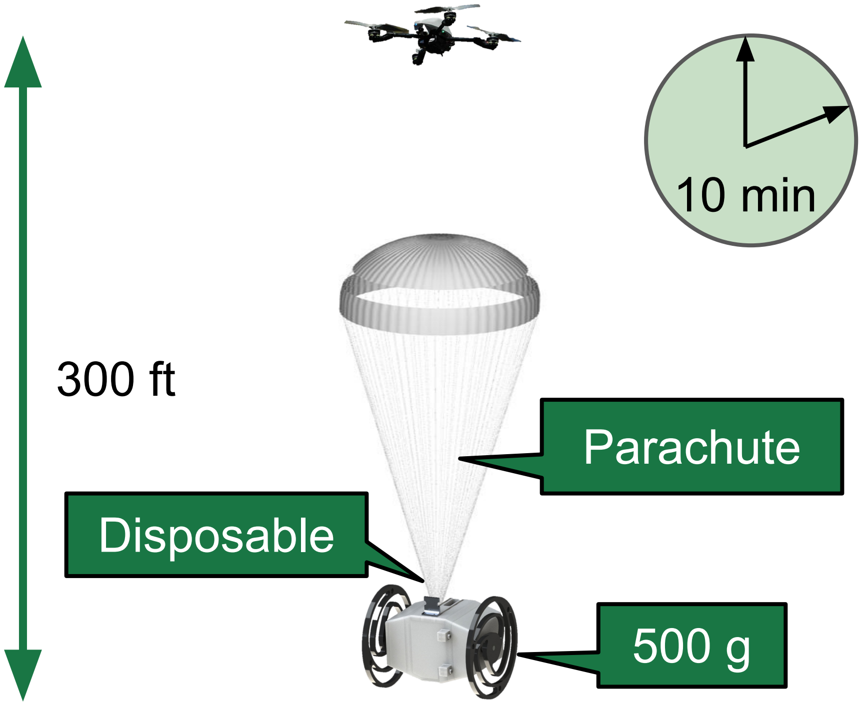
Description	PDR Specifications	FDR Threshold Specifications	PSI Product Specifications
Survivable Fall Height	300 ft	30 ft	300 ft
Reusability	1 drop	1 drop	10 drops
InstantEye Attachment	Rigid attachment. No dangling components prior to release.	Rigid attachment. No dangling components prior to release.	Rigid attachment. No dangling components prior to release.
System Mass	500 gm	680 gm	226 gm
System Size	150 in^3	150 in^3	45 in^3
Drive Time	10 min	5 min	> 15 min
Mobility	Navigate on flat hard ground and packed dirt	Navigate on flat hard ground and packed dirt	Navigate on grass, sand, as well as small obstacles up to 2 inches
Accuracy of Drop	No requirement	No requirement	Land within a 20 degree cone
Noise Emission	No requirement	No requirement	65-85 dB
Cost	A manufactured product should cost under $500	Prototype fabrication under $3000	A manufactured product should cost under $500
Transmits Video	Must continually relay video via the InstantEye System.	Must continually transmit video.	Must continually relay video via the InstantEye System.
Remotely Operable	Communicate over Xbee radios via InstantEye system.	Communicate over Xbee radios.	Communicate over Xbee radios via InstantEye system.

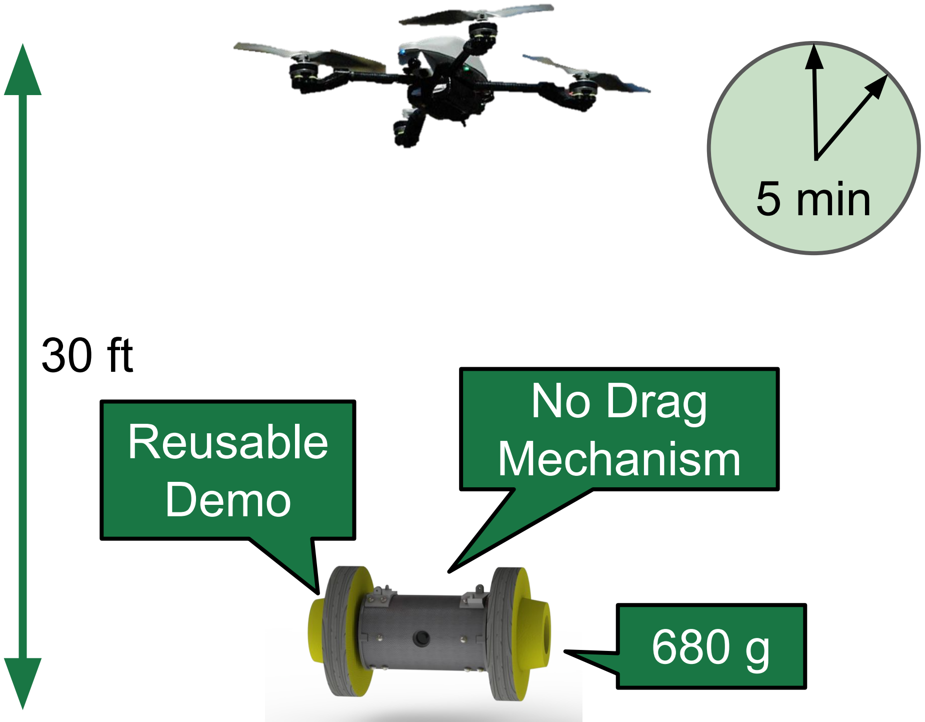
Specification Categories

	FDR Threshold Specifications	*PSI Product Specifications*
Fall Height	• 30 ft	• 300 ft
Reusability	• 1 Drop	• 10 Drops
Mass	• 680 g	• 226 g
Drive Time	• 5 min	• > 15 min
Accuracy	• N/A	• < 20 degree cone

Specification Changes



PDR Specifications



FDR Threshold Specifications

Wheels

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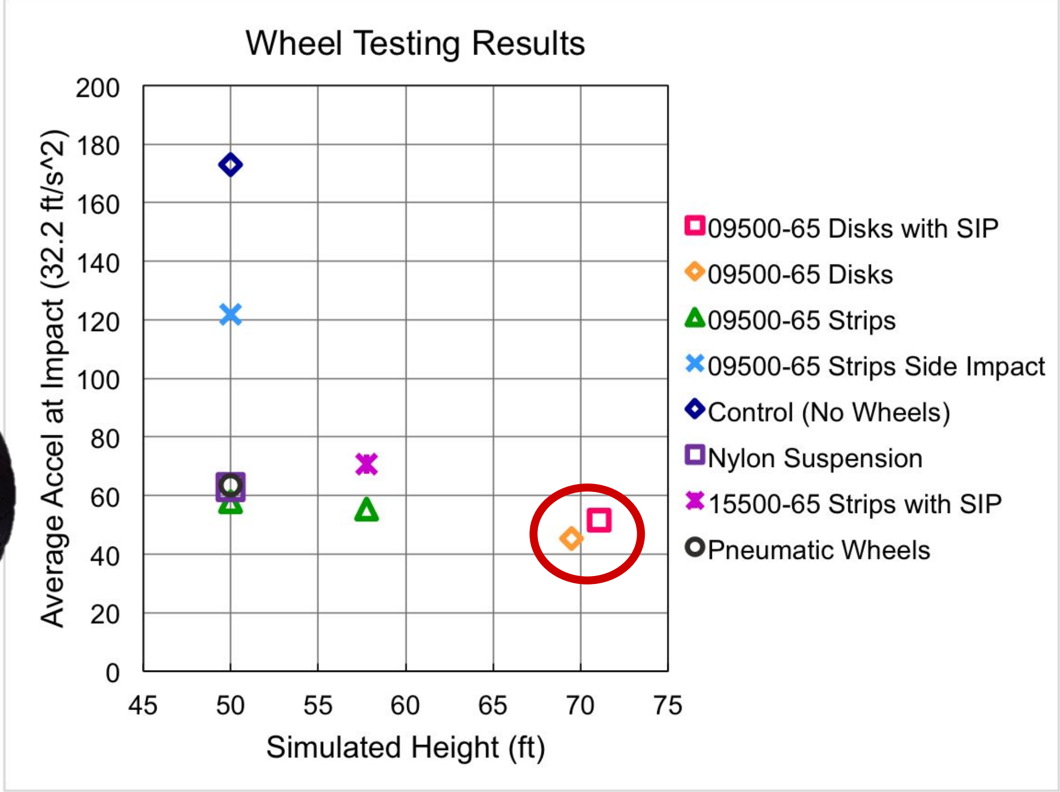

Wheels

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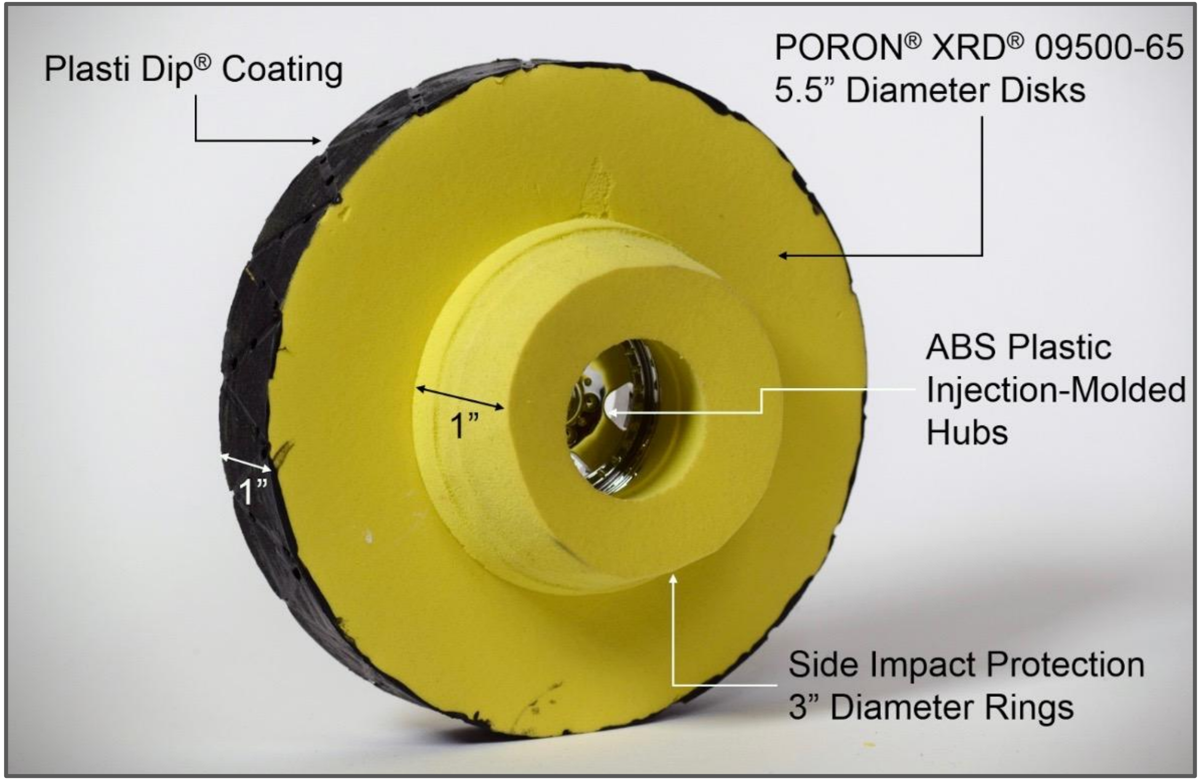

Chassis

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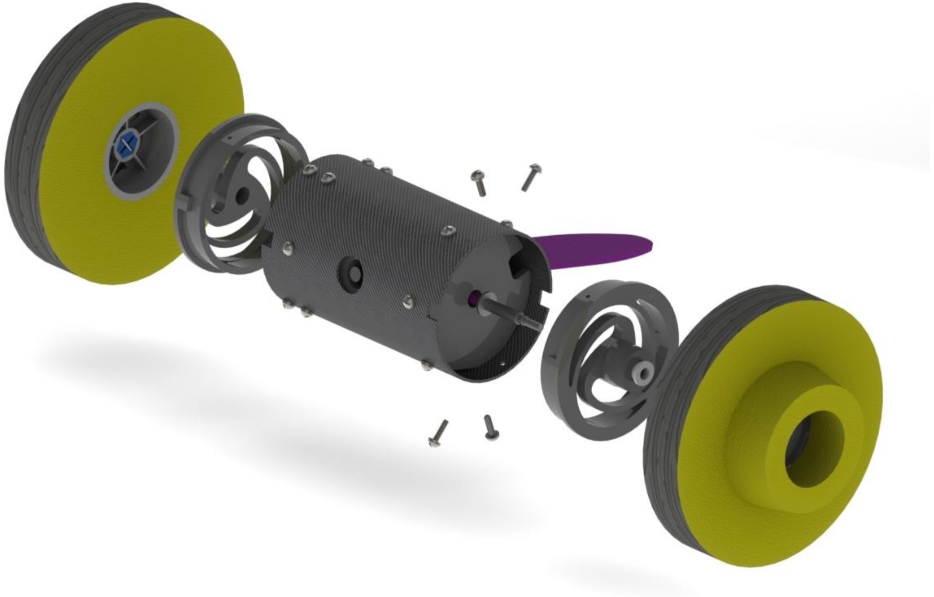
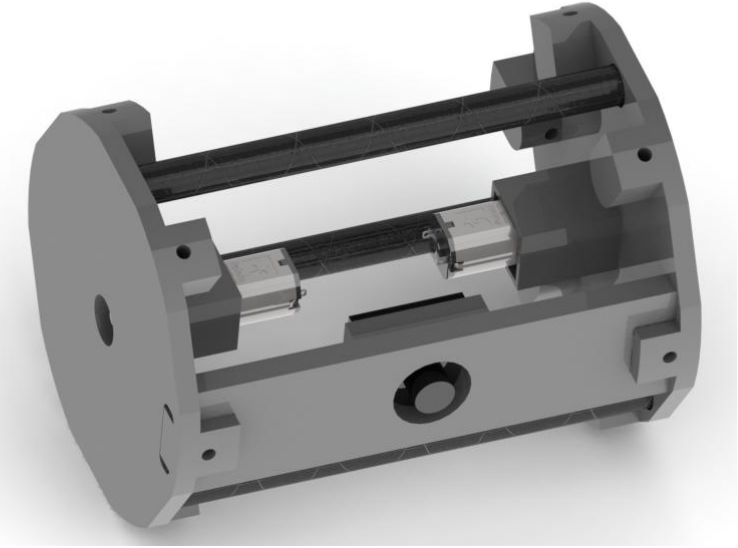
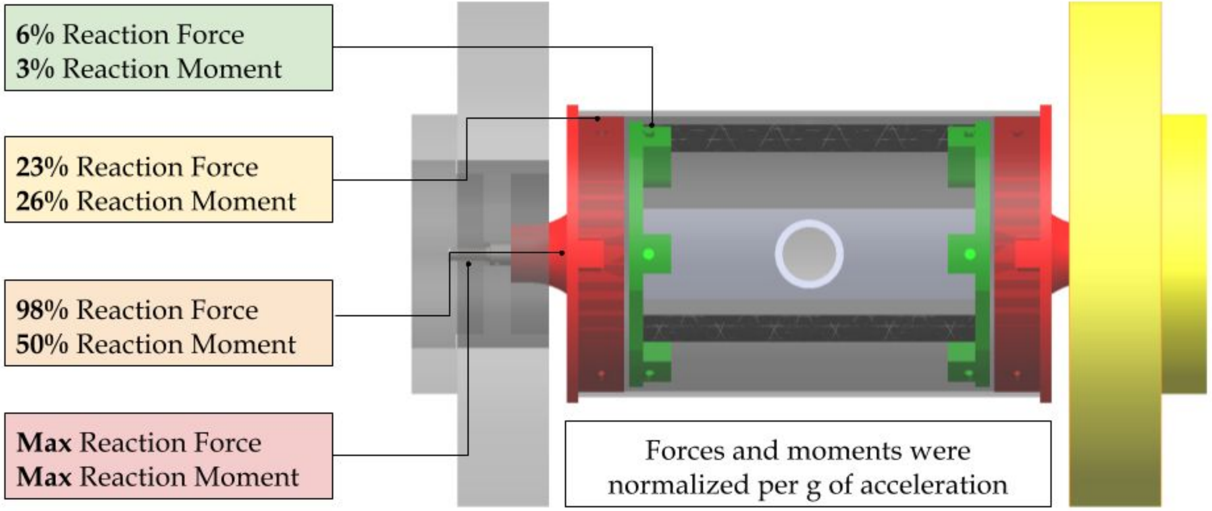




Drivetrain


6% Reaction Force
3% Reaction Moment
23% Reaction Force
26% Reaction Moment
98% Reaction Force
50% Reaction Moment
Max Reaction Force
Max Reaction Moment
Forces and moments were normalized per g of acceleration

Tail

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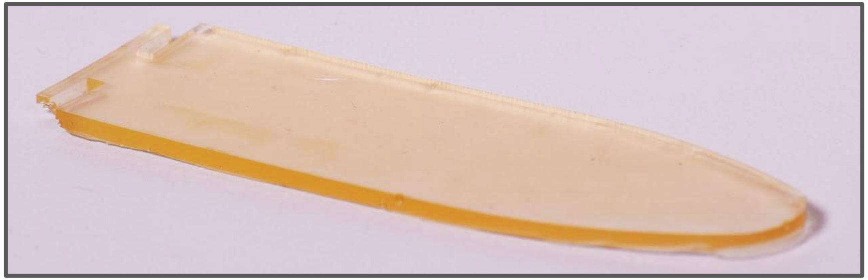
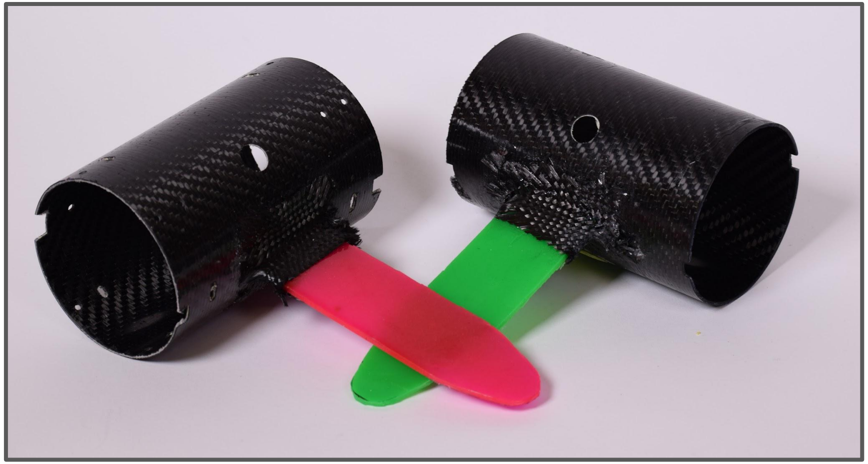
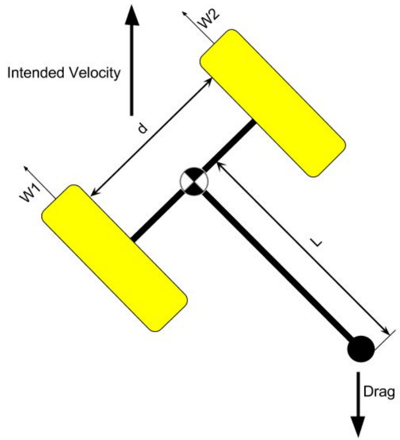
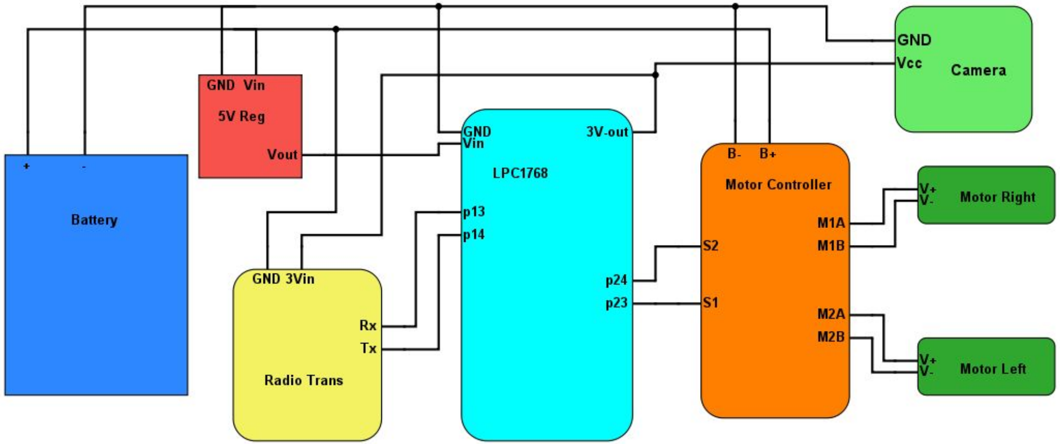


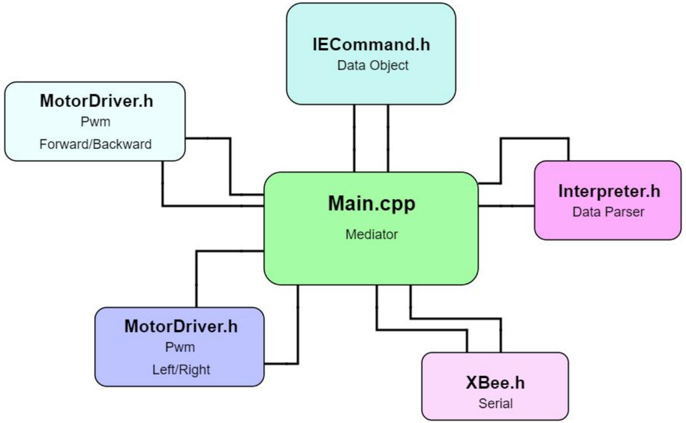


Tail Design	Drives Well	Lightweight	Survives Impact
Rigid Stick Tail	Yes	Yes	No
Flexible Flat Tail	Yes	No	Yes
Composite	Yes	Yes	No
Poron Tail	No	Yes	Yes

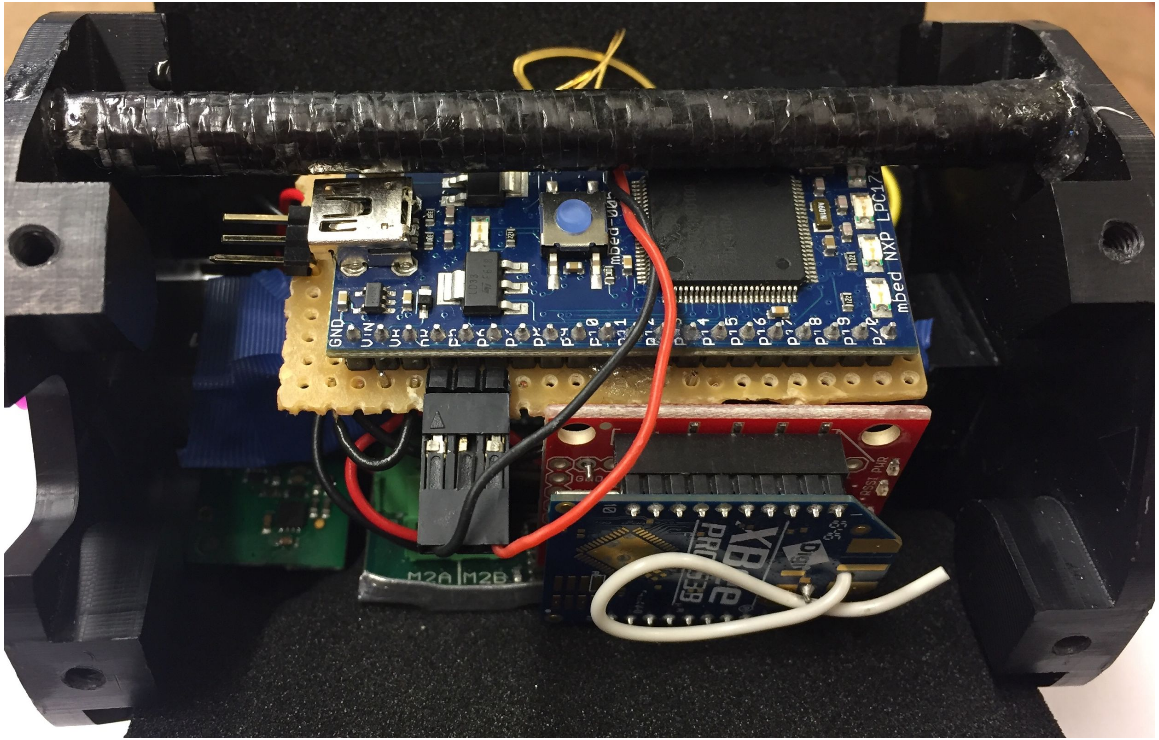


Electronics and Software





Electronics



Deliverables

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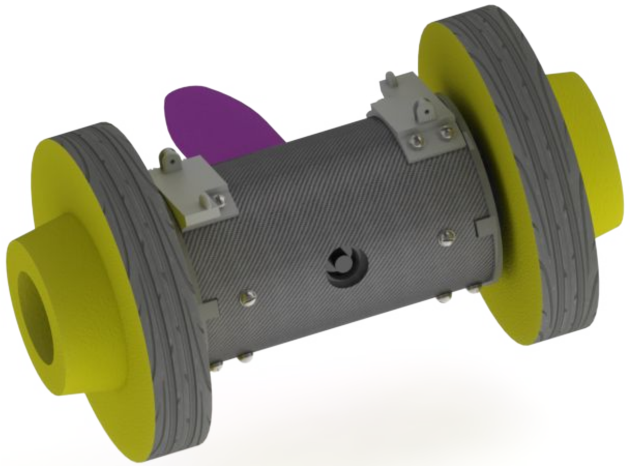
Deliverables Produced

- **Four Proof-of-Concepts:**
  - Two Mk 2 full prototypes
  - One Mk 2 mechanical only
  - One Mk 1 prototype



- **Documentation:**
  - BOM and Vendor information
  - Final CAD
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  - Software library, flow chart
  - Electronic schematic
  - Assembly documentation
  - Testing data

Testing Results for Overall System

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Description	Mk 2 PoC Prototype	Satisfied
Survivable Fall Height	35 ft	Threshold
Reusability	5 drops	Threshold
InstantEye Attachment	Rigid attachment, untested	Partial Threshold
System Mass	673.7 g	Threshold
System Size	100 in^3	Threshold
Drive Time	21 min	Product
Mobility	Navigate on flat hard ground and sand	Threshold
Accuracy of Drop	9 degree cone	Product
Noise Emission	79.5 dB	Product
Cost	$552 estimated prototype fabrication	Threshold
Transmits Video	Transmitted at 5.8 GHz	Threshold
Remotely Operable	Controlled via Xbee radio at 900 MHz	Threshold

Dropping

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Procedure

1. Increasing Height by 5’ Increments
2. Test *Mechanical Success Rate (Mk 2-1)*
3. Test *System Success Rate*
4. Record:
   a. Impact Noise
   b. Distance from target
   c. Failure Mode (if any)
5. Continue dropping until failure

Testing Results for Overall System

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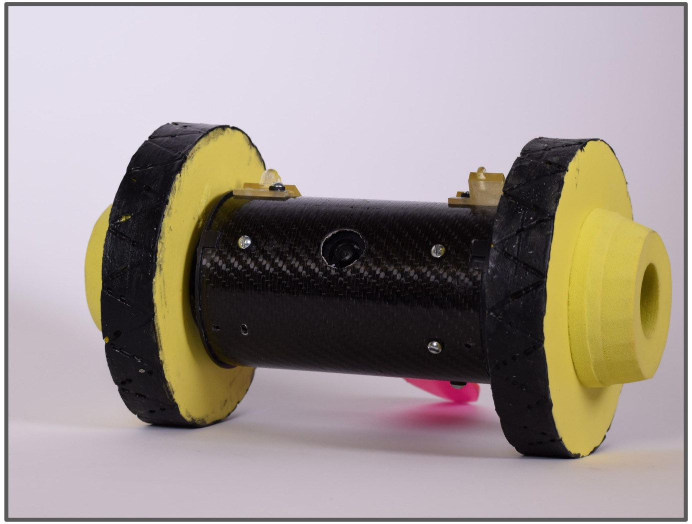
Drop Height	10-15 ft	20-25 ft	30-35 ft	40 ft
# of Drops	9	9	22	3
Mechanical Success Rate	100%	100%	81.8%	100%
System Success Rate	100%	100%	77.8%	N/A
Distance of Bounce (in)	3	17	32	23
Impact Noise (dB)	71.0	79.9	78.6	83.0
Tail Position	Upright	Upright	Upright	Upright

Failure Modes	Electronic Component	Pin Connection	Drive Axle	Wheel Hub	Tail Detachment
Over all 43 Drops	1	1	2	1	2
Rate of Failure	2.3%	2.3%	4.7%	2.3%	4.7%

Passed Threshold Specifications

Fall Height	35 ft
Reusability	5 Drops
Mass	673.7 g
Size	100 in^3
Cost	$552
Video & Operation	Controlled Via XBee Radio
Mobility	Drives on Flat Ground



Passed Product Specifications

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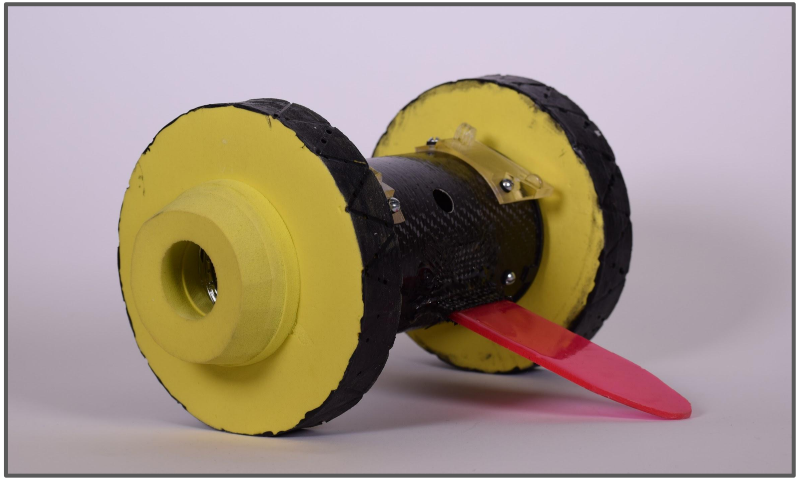
Drive Time	• 21 mins
Noise Emission	• 79.5 dB
Accuracy	• 9 degree cone
Attachment Mechanism	• Undetermined



Changing Assumptions

Assumption	Result
A wide tail will improve landing orientation	**Upright Tails**
A drag mechanism is needed for fall orientation and impact	**Single-wheel landing majority**
Force will be absorbed from wheels to prevent axle bending	**Several axles with minor bending**

State of the Art

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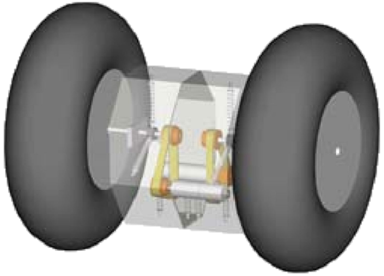
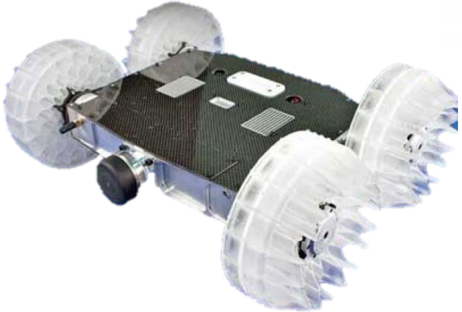
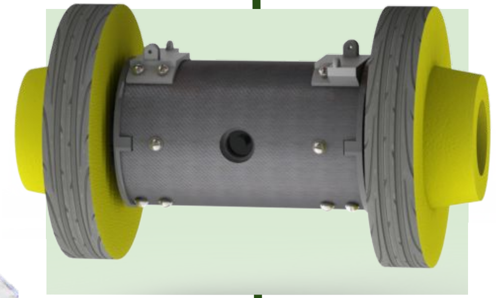
High Impact Survival







Size & Weight Class

Risk Assessment

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Function	Failure Mode	Effects	Control Method	RPN
Attaches to the IE Drop Mechanism	• Does not interface • Cannot fit under the IE	• Vehicle cannot attach • IE cannot take off	• Design an interface • Keep overall size within specs • Design new drop mechanism	72
Lifted by the IE	• Vehicle is too heavy • Interferes with IE airflow	• IE cannot take off • IE cannot safely fly	• Light components • PCB electronics • Lighter drop mechanism	160
Impacting the landing surface	• Tumbling • Non-ground impact	• Vehicle crashes • Side impact damage	• Deploy from stationary UAV	160
Survives the drop	• Vehicle shatters • Electronics damaged • Shaft shearing	• Vehicle cannot drive • Vehicle is not controlled • Vehicle cannot relay video	• Wheels are largest diameter • Impact forces to the chassis • Create a wide tail	144

Risk Assessment

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	Risk	*Strategy*
FLYING	• Weight • Size • Attachment	• Mass BOM • Dimension Limits • Centered Attachment
FALLING	• Electronics • Alternative Impacts • Impact Force Control	• Damping • Side Cushioning • Drivetrain Flexibility

Economic Analysis

Market Analysis

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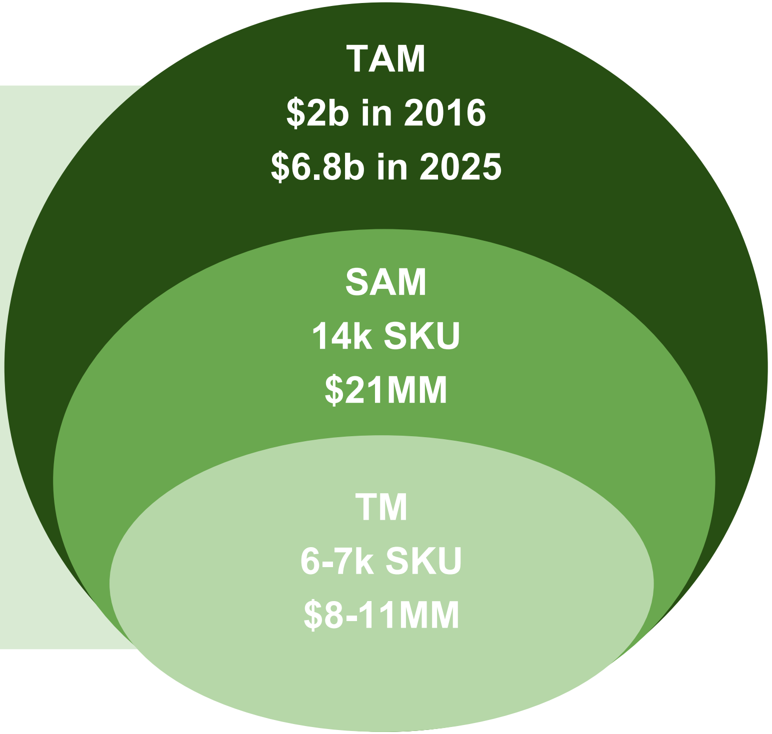
Key Clients:

US Department of Defense (DoD)

NATO Allies & Professionals

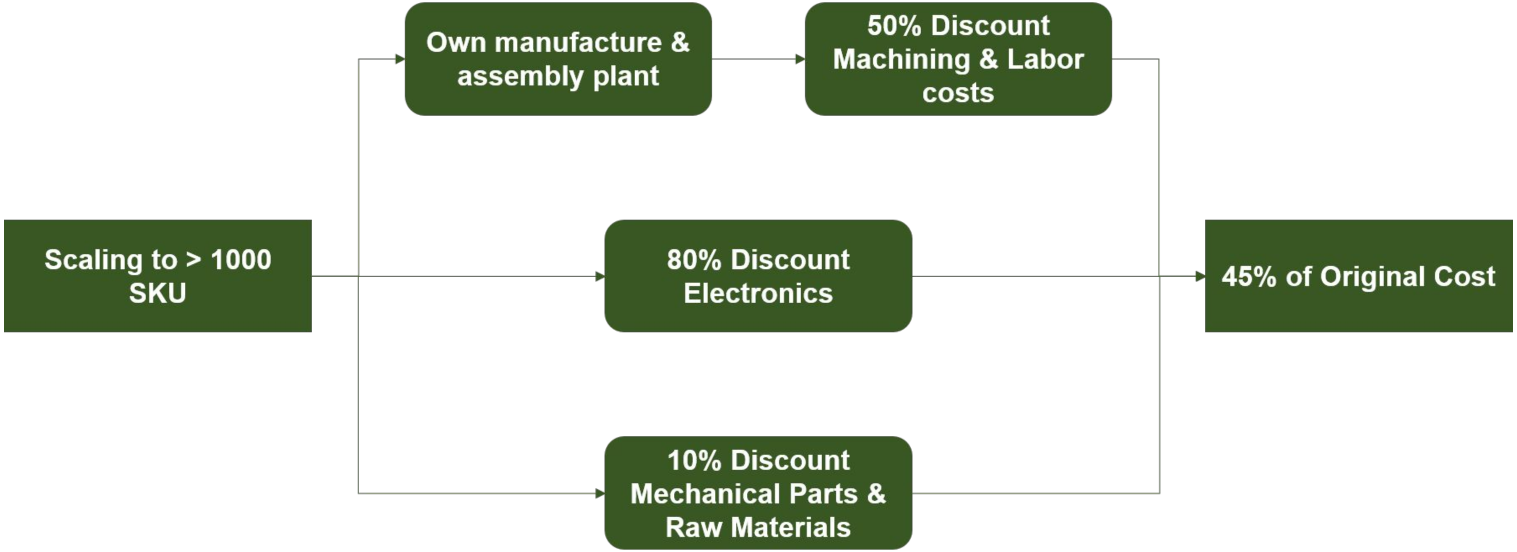
1 US Sale = 1 International/Professional Sale

5 InstantEye Sales = 1 AIMGRO Sale



Costs

	Individual Mk 2 Prototype	>1000 SKU
Raw Materials & Mechanical Parts	107	96
Electronics	220	44
Machining & Labor	225	113
Total	$ 552	$ 253



Future Recommendations

System Interface

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- Interface needs to be tested
- Dropper is 15% of overall mass

Other Electrical & Mechanical

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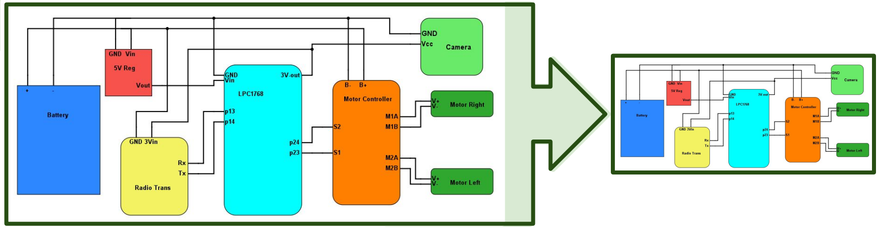
1



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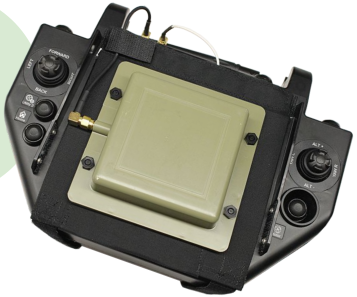

Summary

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$552

21 min battery with video

30-35’ drop

Met, or exceeded, every specification

9 deg cone
79 dB

673 g
100 in^3

Acknowledgements

Our Advisors:

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Our Sponsors:

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Thayer Faculty & Staff: Prof. Douglas Van Citters, Jason Downs, Callen Votzke, Kevin Baron

Corporate Aid: The Rogers Corporation

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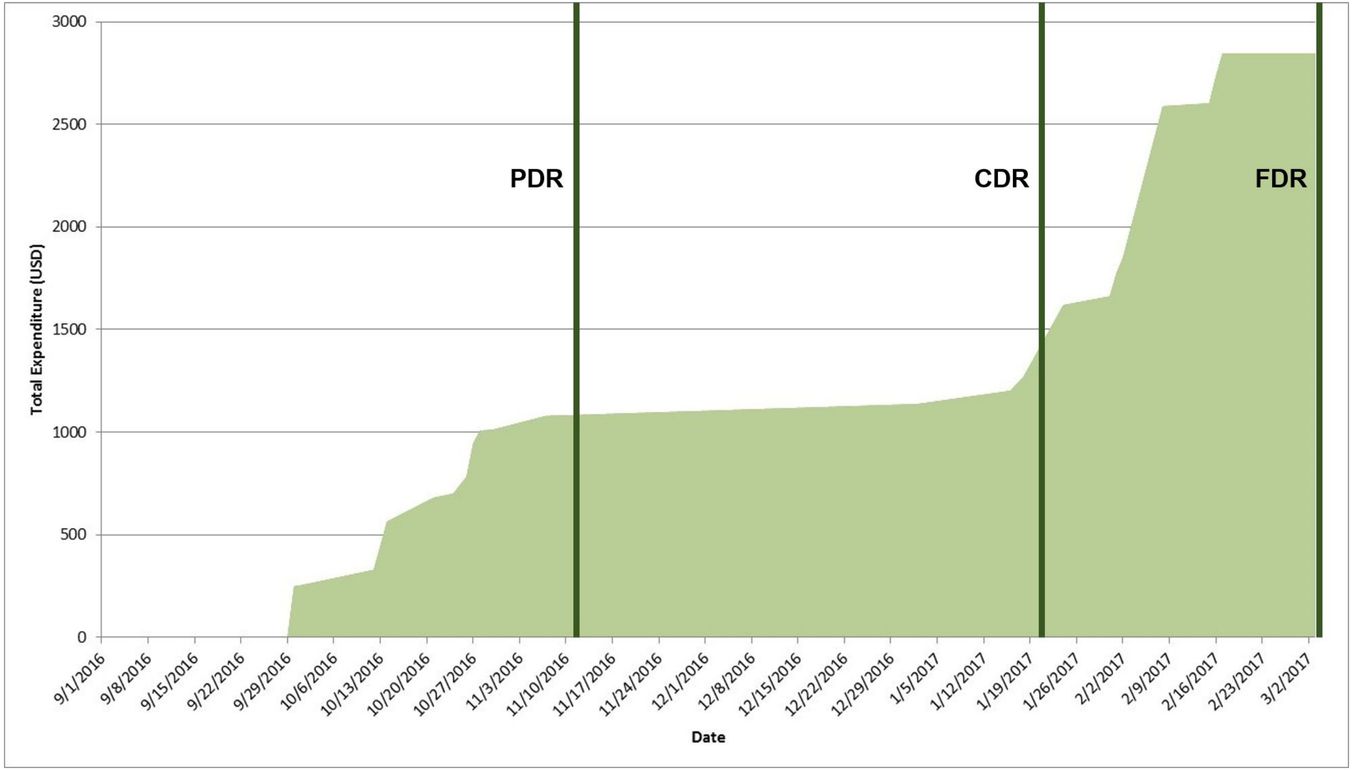
Appendices

Appendix - Dropping Video

Appendix - Budget



Appendix - BOM

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	Component	Material	Mass (g)	Quantity	Mass Total (g)	Cost ($)	Vendor
Chassis	Suspension Walls	Nylon	36.4	2	72.8	0.35	McMaster
	Sleeve Bearing 0.375" OD; 0.25" ID; 0.125" Long	Plastic	1	4	4	16.00	OilLite
	Socket Head Screw 6-32 Thread Size, .5" Long	Stainless Steel	1	20	20	0.26	Grainger
	6-32 Lock Washers	Stainless Steel	0.2	20	4	0.50	McMaster
	Chassis Body	Carbon Fiber	61.3	1	61.3	28.00	DragonPlate
	Inner Wall	Nylon 6	35.2	2	70.4	0.17	McMaster
	Support Bars	Carbon Fiber	2.5	3	7.5	6.38	DragonPlate
	Padding	Neoprene	2.3	1	2.3	0.36	Amazon
	Tail	PMC-790	13.5	1	13.5	0.35	Reynold's Advanced Materials
	Camera Holder	Nylon 6	11.9	1	11.9	0.06	McMaster

Appendix - BOM

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	Component	Material	Mass (g)	Quantity	Mass Total (g)	Cost ($)	Vendor
Wheels and Shafts	M4mmx0.7 Lock Nuts	Steel	1.3	2	2.6	0.16	McMaster
	.25" OD Drive Shaft	Steel	8.8	2	17.6	3.62	McMaster
	Hubs	ABS Plastic	11	2	22	15.00	Tamiya
	Steel Pin	Steel	0	2	0	0.03	Tamiya
	Plastic Hex Insert	ABS Plastic	0	2	0	0.03	Tamiya
	Tubing	Silicon	0.1	2	0.2	1.39	McMaster
	Poron Wheels	Poron	71	2	142	30.00	Rogers Corporation
		PlastiDip	0.04	2	0.08	0.00	United States Plastic Corporation

Appendix - BOM

	Component	Material	Mass (g)	Quantity	Mass Total (g)	Cost ($)	Vendor
Electronics	Pololu 30:1 Micro Metal Gearmotor MP 6V		9.467	2	18.934	15.59	Pololu
	Lithium Ion Battery		40	1	40	20.00	All-battery
	FPV Combo 3-In-1 600TVL Mini Camera 5.8GHz 40CH 25mW Wireless Transmitter		5	1	5	29.17	Range Video
	mbed LPC1768 Microcontroller		7	1	7	54.95	SparkFun
	Sabertooth Dual 5A Motor Driver		15	1	15	59.99	Dimension Engineering
	900 MHz Xbee Radio		7	1	7	39.99	Master Electronics
	Perfboard		10	1	10	5.00	Amazon
Dropper	Deployment Payload	From PSI	97.88	1	97.88	--	--
				Mass Total:	652.99	327.35	

Appendix - Tail Comparison

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Type	Length	Steps	Flat Drive	Flat Turn	Dirt Drive	Dirt Turn	Sand Drive	Sand Turn	Total Score
Flat Sheet	2"	0	3	3	1	3	0	3	13
	3"	1	3	3	2	3	1	2	15
	4"	2	3	3	3	2	2	1	16
Wire Loop	2"	0	3	3	2	1	1	3	13
	3"	2	3	3	3	2	3	1	17
	4"	2	3	3	3	1	3	0	15
Wire Stick	2"	1	3	3	2	1	1	2	13
	3"	1	3	3	1	2	3	3	16
	4"	2	3	3	2	1	3	2	16

Appendix - Force Path Analysis

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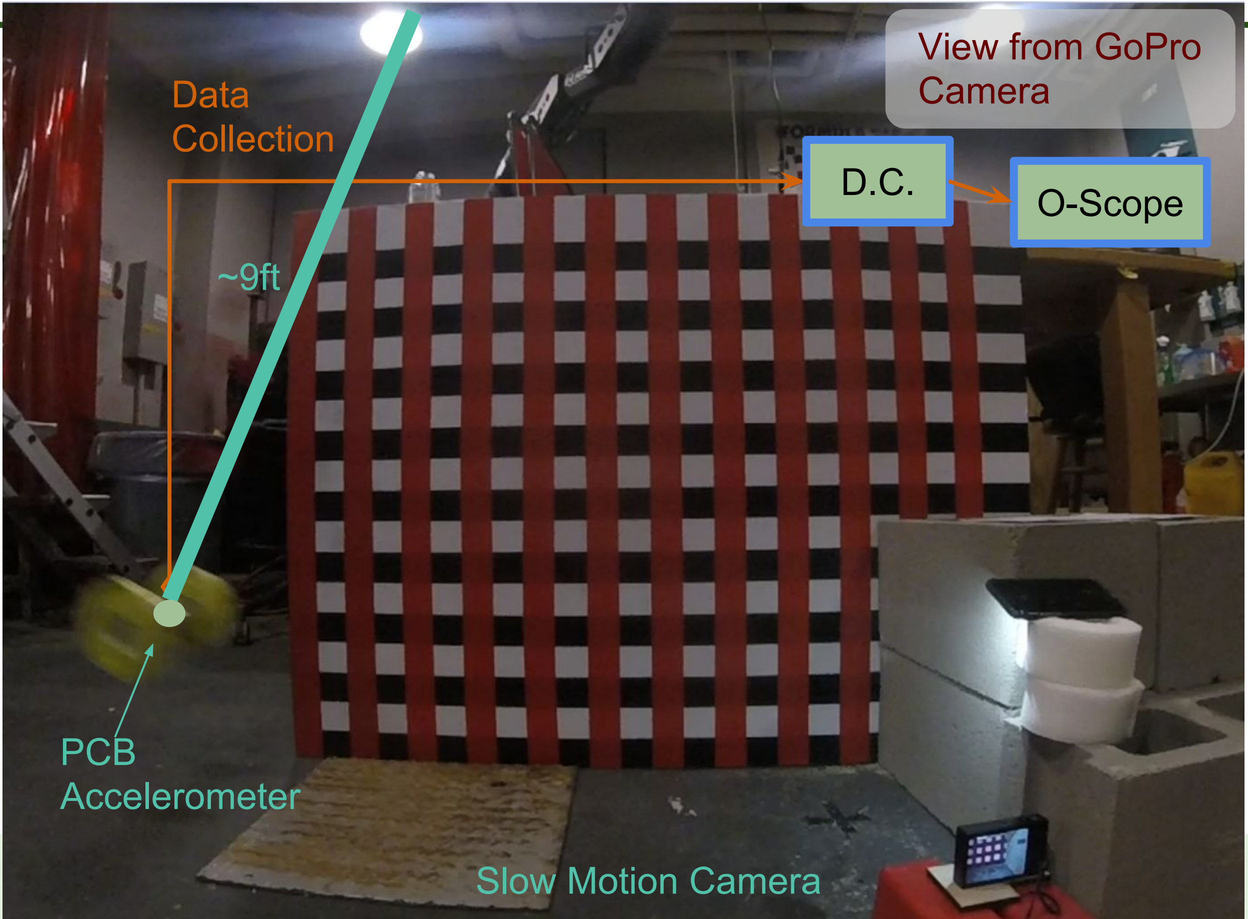
	Force per g (N/(m/s^2))			Moment per g (N-mm/(m/s^2))		
Orientation:	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Wheel-Shaft	0	5.2	0	180	0	0
Shaft-Outer Wall	0	5.1	0	91	0	0
Outer Wall to Chassis	0	1.2	0	47	0	0
Chassis to Inner Wall	0	0.33	0	7	0	0

Pendulum



View from GoPro Camera
Data Collection
D.C.
O-Scope
~9ft
PCB Accelerometer
Slow Motion Camera

PCB Accelerometer
Weights Attached on Bottom: For Variable Mass

Appendix - CMU High-Impact Survivable Robot

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"two-wheeled low-cost mobile robot platform that has high survivability when subjected to large impact forces and general rough handling."

- Large
- 20' Drop Capability
- No video functionality

Appendix - Parrot

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