The University of Texas at Austin
Cockrell School of Engineering

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USRC - Hardware Design Review 1

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Need Statement

The overall need of this project is to develop drones capable of sensing and avoiding obstacles with a minimized risk of collision or damage to property in GPS denied environments.

TABLE OF CONTENTS

HERITAGE

TAR DRONE

Development of an Autonomous Quadcopter at Murray State University

- Modify a manually flown quadcopter to enable autonomous flight including obstacle detection and avoidance
- Determine performance characteristics such as maximum speed and flight time at different weights
- Examine the considerations and modifications made by the students in this mission to better estimate the considerations and modifications which will need to be made to our own drone

Considerations

- Mass, wind impact, inter-swarm communication
- Stopping distance dependent on speed
- Max speed dependent on weight, thrust, motor output, and sensor range
- Larger systems can run for longer because sensors take up a lower percentage of weight

Modifications

- The drone needed to be able to maintain altitude, so a downward-facing ultrasound sensor was added to measure height
- This sensor was very noisy- it needed to average the elevation values before taking derivative, then averaged again before being put into controller
- Manually omitted outlier velocity values (>100 m/s)
- For obstacle avoidance, a distance sensor which used an infrared (IR) beam was employed
- The drone’s search algorithm was supported by a phototransistor sensor to find brightest light in the room
- Students cut off unnecessary weight because weight is more of a limiting factor for small drones. The sensors generally do not need to change in size, so they make up a larger percentage of mass for small drones

MISSION SCOPING

GOALS

1. Incrementally modify TAR replica drone to acquire baseline data and inform future designs.
2. Ensure efficient and effective cross-team communication/precise integration of different subsystems into the drone hardware.
3. Understand drone support equipment and consider open-sourced drones.
4. Create a preliminary design for our in-house drone capable of lifting all required sensors.
5. Develop a flight test plan and test modified drones to simulate real air space.

Incrementally modify TAR replica drone to acquire baseline data and inform future designs

- Work with the communications team to determine which sensors to implement
- Create mass budget based on sensor requirements in order to track that the flight hardware has enough lift to accommodate the necessary mass
- Select and purchase drone based on the previous TAR design and mass budget so that we will be able to quickly begin modifying the hardware and software
- Attach sensors in a balanced way gradually as they are procured and the software allows
- Analyze the aspects of the design that work well and those that do not to prepare to explain how to design the in-house drone

Ensure efficient and effective cross-team communication/precise integration of different subsystems into the drone hardware.

- Host 30-minute weekly tag-up meetings and maintain a burndown list of hardware related action items.
- Maintain ample documentation through the design process, detailing requirements, design choices, and change notices.
- Complete reiterative testing on hardware designs through prototyping.
- Host internal design reviews in each phase of the process, from criteria to critical, with other USRC teams.

Understand drone support equipment and consider open-sourced drones.

- Determine if open source drones are feasible option for drone control
- What equipment needed for maintaining of drone swarm
- Understand battery charging and storage

Create a preliminary design for our in-house drone capable of lifting all required sensors.

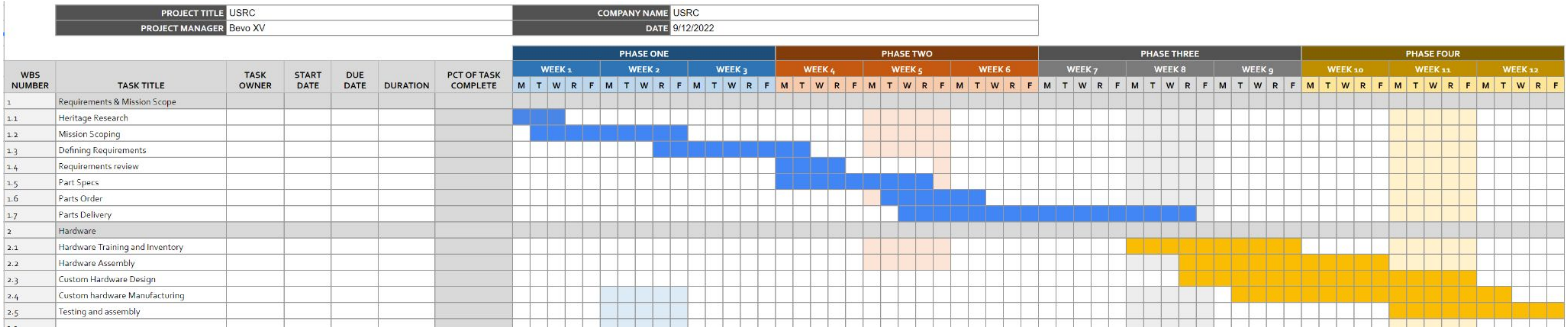
- Determine the requirements
- Determine weights of the components
- Select frame and motors
- Finalize the components that are needed for the in house drone

Develop a flight test plan and test modified/in house drones to simulate real air space.

- Develop valid testing points for a flight test plan
- Reserve drone cage and complete training
- Conduct pre/post flight check
- Evaluate future test areas and ideas

TEXAS ENGINEERING

Semester Gantt Chart



PROJECT TITLE	USRC	COMPANY NAME	USRC
PROJECT MANAGER	Bevo XV	DATE	9/12/2022

PHASE ONE			PHASE TWO			PHASE THREE			PHASE FOUR		
WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F	M T W R F

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	Requirements & Mission Scope					
1.1	Heritage Research					
1.2	Mission Scoping					
1.3	Defining Requirements					
1.4	Requirements review					
1.5	Part Specs					
1.6	Parts Order					
1.7	Parts Delivery					
2	Hardware					
2.1	Hardware Training and Inventory					
2.2	Hardware Assembly					
2.3	Custom Hardware Design					
2.4	Custom hardware Manufacturing					
2.5	Testing and assembly					

REQUIREMENTS

DERIVED REQUIREMENTS

- The project shall not exceed Budget (less than $60,000)
- The project shall follow NASA guidelines
- The project shall follow proposal specifications
- The project shall address safe, efficient growth in global operations and in-time system-wide safety assurance

HIGH LEVEL REQUIREMENTS

- Drone shall operate with a power source of no more than 14.8 V
- Drone shall be capable of being modeled in CAD program
- Drone shall be capable of open sourced collision avoidance programming
- Drone shall be able to function in swarms of 5
- Drone shall be able to avoid static obstacles
- Drone shall be able to avoid dynamic obstacles

INTERFACING REQUIREMENTS

- Drone blades shall be capable of X amount of thrust
- Drone shall be able to land at a downward speed of X m/s without breaking
- Drone performance shall not be impeded by FOD
- Drone shall be able to operate in X weather conditions
- Drone shall be able to communicate with other drones in flight

INTERNAL REQUIREMENTS

- Drone shall be capable of moving omnidirectionally
- Drone shall be robust enough to have reused capabilities
- The hardware shall be compatible with FAA standards
- Drone shall have a flight endurance of X minutes
- The hardware shall be compatible with FAA standards

PARTS LIST

TEXAS ENGINEERING

PARTS PROCURED

Amazon Basics 20 Pack AA High-Performance Alkaline Batteries, 10-Year Shelf Life, Easy to Open Value Pack 2 comments	Amazon ALK AA20FFP-U AMZ UT Market →	$14.24 1 × 20 Pack
TAROT 650 Carbon Fiber 4-Axis Aircraft Fully Folding FPV Drone UAV Quadcopter Frame Kit for DIY Aircraft Helicopter TL65B01 1 comment	Amazon B00O0NGT8A UT Market →	$158.88 1 × 1
Tiger Motors T-Motor Polymer Straight Propellers - MS1302 (Pair) - 13" - Black 1 comment	Amazon B07V3N74WV UT Market →	$22.43 1 × 4
Cable Zip Ties,400 Pack Black Zip Ties Assorted Sizes 12+8+6+4 Inch,Multi-Purpose Self-Locking Nylon Cable Ties Cord Management Ties,Plastic Wire Ties for Home,Office,Garden,Workshop. By HAVE ME TD	Amazon B08TVLYB3Q UT Market →	$6.99 1 × 1
Ethix Quad-Builder Cable Set 1 comment	Amazon B07NKN9G1H UT Market →	$27.08 1 × 1
oGoDeal 155 in 1 Precision Screwdriver Set Professional Electronic Repair Tool Kit for Computer, Eyeglasses, iPhone, Laptop, PC, Tablet,PS3,PS4,Xbox,Macbook,Camera,Watch,Toy,Jewelers,Drone Blue	Amazon B08BRJPWRN UT Market →	$27.99 1 × 1
Amass AS150 Male and Female Anti Spark Connector Plug Set for Battery, ESC, and Charge Lead	Amazon B00RVM93YO UT Market →	$9.95 1 × 1

PARTS PROCURED

Tarot 4006 / 620KV Multiaxial Brushless Motor TL68P02 for RC DIY Quadcopters Multicopters Drone, Tarot FY680 Pro Spare Parts (1 Pcs) 1 comment	Amazon B00W93P7TU UT Market →	$39.98 1 × 5
TAROT 650 Carbon Fiber 4-Axis Aircraft Fully Folding FPV Drone UAV Quadcopter Frame Kit for DIY Aircraft Helicopter TL65B01 3 comments	Amazon B00O0NGT8A UT Market →	$158.88 1 × 1
4S Lipo Battery 14.8V 5200mAh 120C RC Battery SoftCase for Traxxas/RC Car/Truck/Plane/Quadcopter/Helicopter/Jet/UAV Drone/FPV(2PCS)	Amazon B09V45YWGR UT Market →	$91.23 1 × 1
Lumenier Elite PRO 60A 2-6S BLHeli_32 4-in-1 ESC - 60 Amps 2 comments	Amazon B09KMHN3ZR UT Market →	$112.19 1 × 3
APD PDB500[X] 12S 52V 500A Power Distribution Board	Amazon B07R6P66YZ UT Market →	$106.91 1 × 1
Lumenier Elite PRO 60A 2-6S BLHeli_32 4-in-1 ESC - 60 Amps	Amazon B09KMHN3ZR UT Market →	$112.19 1 × 3

Propeller

- Overall requirements (heritage from TAR drone):
  - Shall be 13”
  - Shall be two bladed
  - Preferably carbon
- Tiger Motors T-Motor Polymer Straight Propellers
  - 13”
  - 107g
  - Carbon
  - 0.25mm trailing edge for better airflow

Motor

- Overall requirements:
  - Shall be compatible with 13” propellers
  - Shall be 4s or 6s compatible
  - Shall provide at least 1400g of thrust
  - Shall not exceed 15A current draw
- Tarot 4006 620KV Multi-copter Brushless
  - 4s (14.8 Volt) compatible
  - KV 620
  - 14 A load current draw
  - 13 inch prop compatibility

MOTOR TRADE STUDY/DECISION MATRIX

- Order of importance: Amazon availability, max thrust, mass, price per unit, cell compatibility, max current draw.

Motor	Cell Compatibility	Max Current Draw	Mass	Max Thrust w/ 13” Prop	Price per Unit	Available on Amazon?
Tarot 4006 KV620	4s	14A	82g	1580g	$39.88	✔
MN4010 KV580	4s	13.2A	112g	1420g	$86.90	□
MN4010 KV475	6s	14.1A	112g	1870g	$86.90	□

ESC

- Overall requirements
    - Shall be 4s compatible (based on motor selection)
    - Shall provide continuous current/motor of at least 10A
    - Shall provide peak current/motor of at least 15A
    - Preferably 4-in-1
- Lumenier ELITE PRO 60A
    - 2s-6s compatibility (we are using 4s)
    - 60A continuous current, 100A burst current
    - 4-in-1, only one ESC needed for 4 motors
    - 32bit architecture for lower latency
    - Programmable PWM

ESC STUDY/DECISION MATRIX

- Order of importance: Availability, cell compatibility, continuous current/motor, peak current/motor, mass, price per drone

ESC	Cell Compatibility	Continuous Current/Motor	Peak Current/Motor	Mass	Price per Drone	Available on Amazon?
Lumenier ELITE PRO 60A	2s-6s	15A	25A	27g	$112.19	✔
Lumenier Razor LED 55A	2s-6s	13.75A	16.25A	15g	$98.99	✔
T-Motor V45A V2	3s-6s	11.25A	13.75A	21g	$55.90	✔

Battery

- All batteries: must be 4S, 5200 mAh with XT90 connectors
- Motors are 4 cells in series, so battery must be 4S
  - All 4s batteries are 14.8 V
- 5200 mAh from heritage
- XT90s are stronger than EC5 connectors
  - More resistant to crushing or bending
- XT90s are easier to solder to a PDB than bullet connectors
- XT90s are more accessible than the other connectors (T, TR)
  - We have those connectors in BASIL

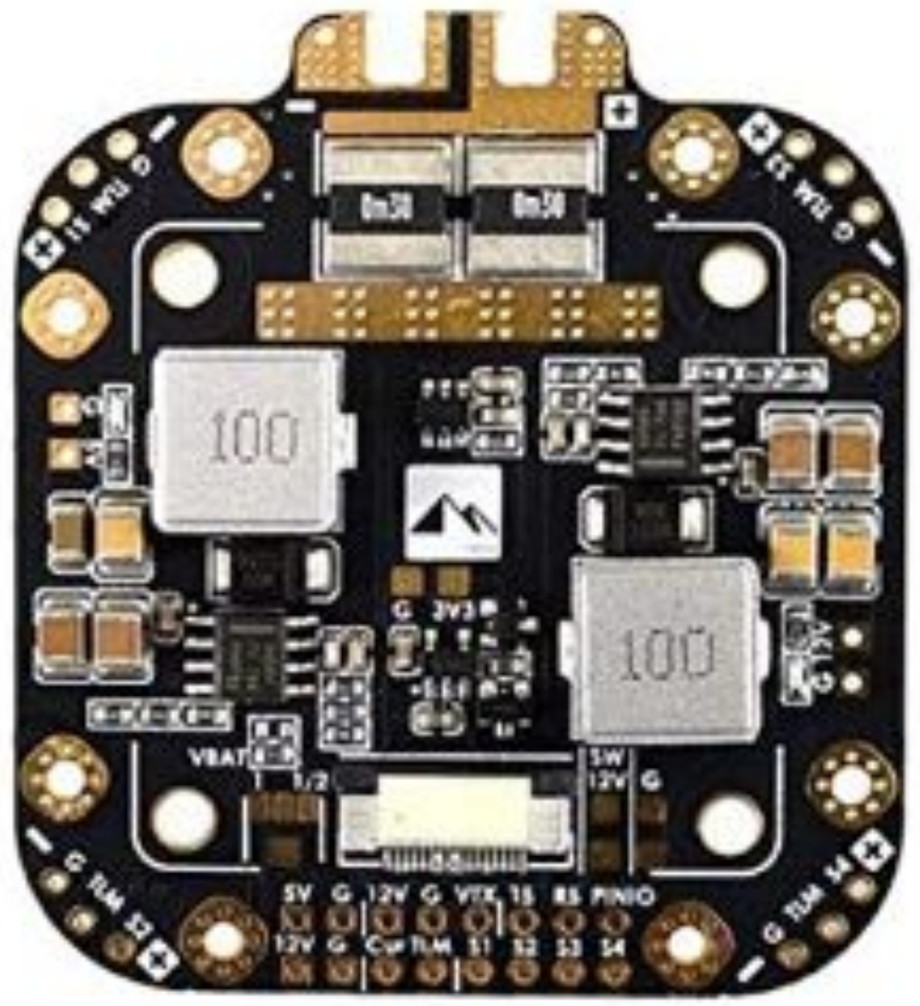
BATTERY TRADE STUDY/DECISION MATRIX

- Order of importance: Amazon availability, discharge rate, mass, price, dimensions
- Mass importance is further illustrated in Monte Carlo analysis

Battery Type	Discharge Rate	Dimensions	Mass	Price per unit	Available on Amazon
RCLIPO via Amazon	120C	5.75 x 1.89 x 1.5 inches	600g	$43.72	✔
Powerhobby via Amazon	50C	5.24 x 1.73 x 1.40 inches	476g	$129.95	✔
Powerhobby	50C	5.43 x 1.85 x 1.50 inches	468g	$72.95	☐

Power Distribution Board

- Heritage data: TAR used the upper PDB with success, so for the drone's first iteration we will as well.
- APD PDB500[X] 12S 52V 500A Power Distribution Board. $106.91
- Additional, smaller, cheaper PDBs may be experimented with in the future
- Matek X Class 12S PDB Power Distribution Board FCHUB-12S



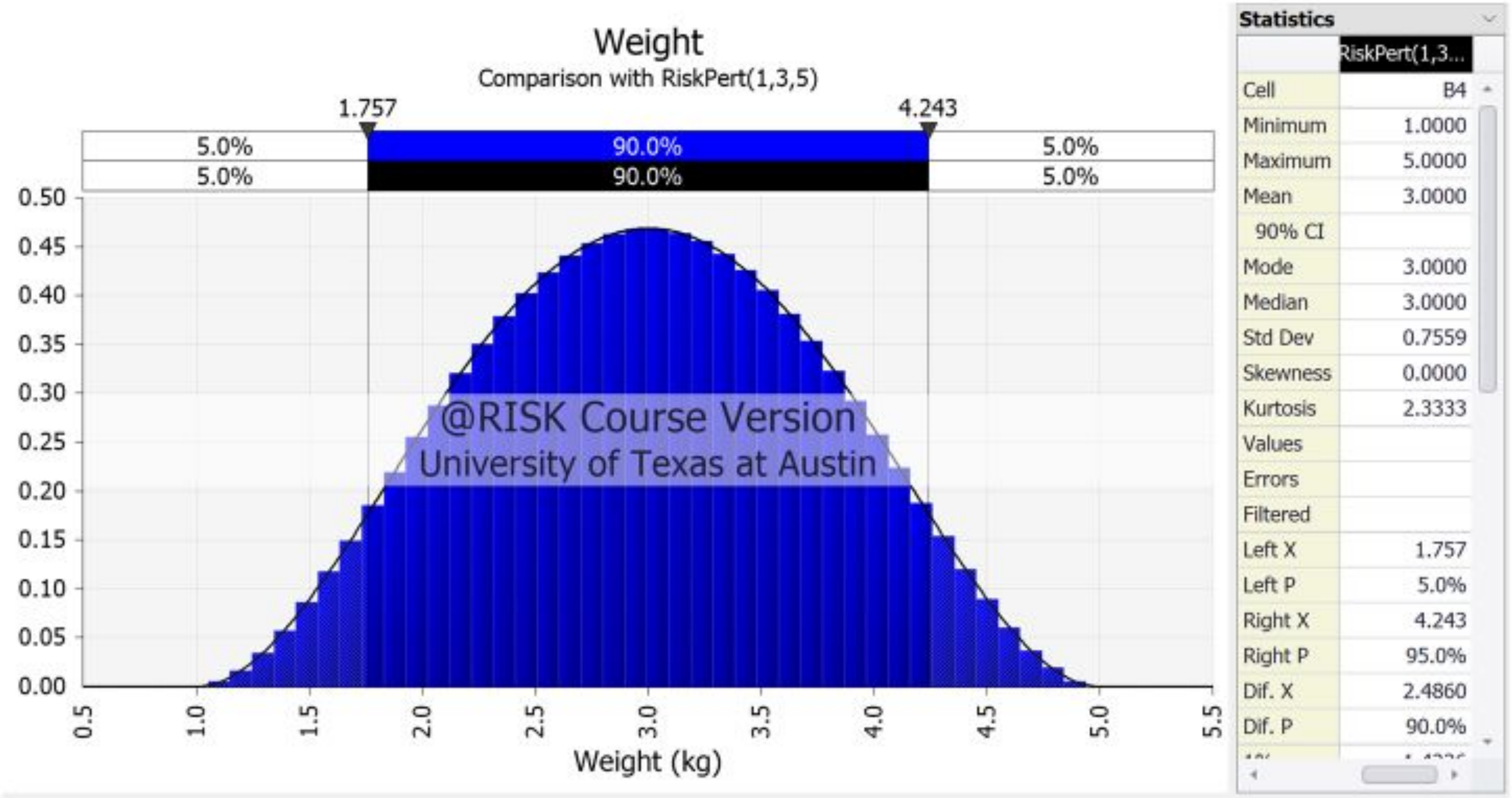
FLIGHT TIME
MONTE CARLO ANALYSIS

FLIGHT TIME

- Monte Carlo analysis was conducted on the resulting flight time with varying distributions.
  - Weight - various payloads
  - Power Supply - many different power supply options
  - Flight performance - different flight movements draw differing amounts of power

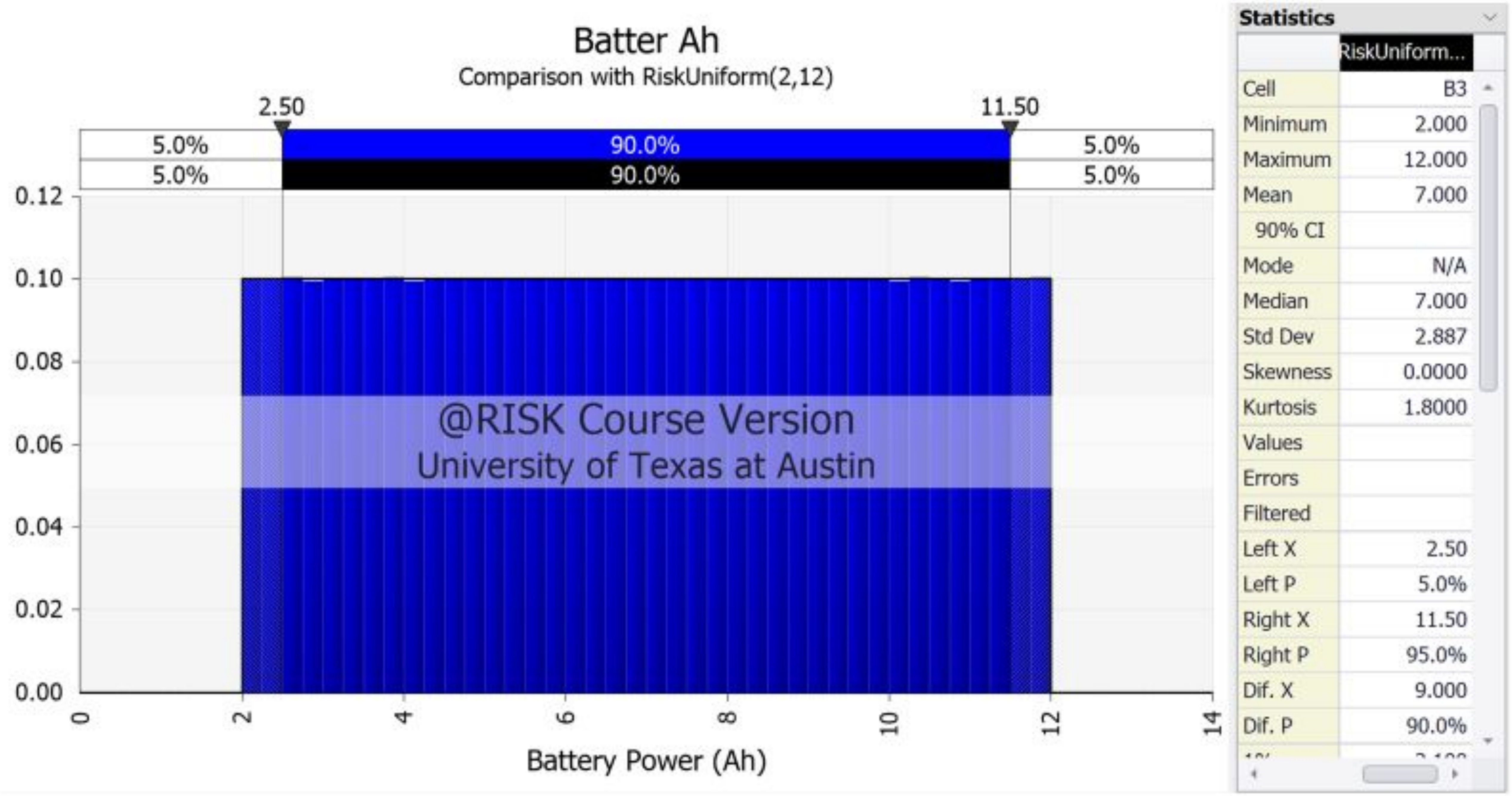
Input - Weight

- Pert distribution
- This distribution was selected as the weight cannot exceed the max flight capacity, but it also will not be zero or close to zero. Likely to be around 3 kg.
- The max was set to 5 kg and the min was set to 1 kg based on heritage research.
- This accounts for variable weight with varying payloads.



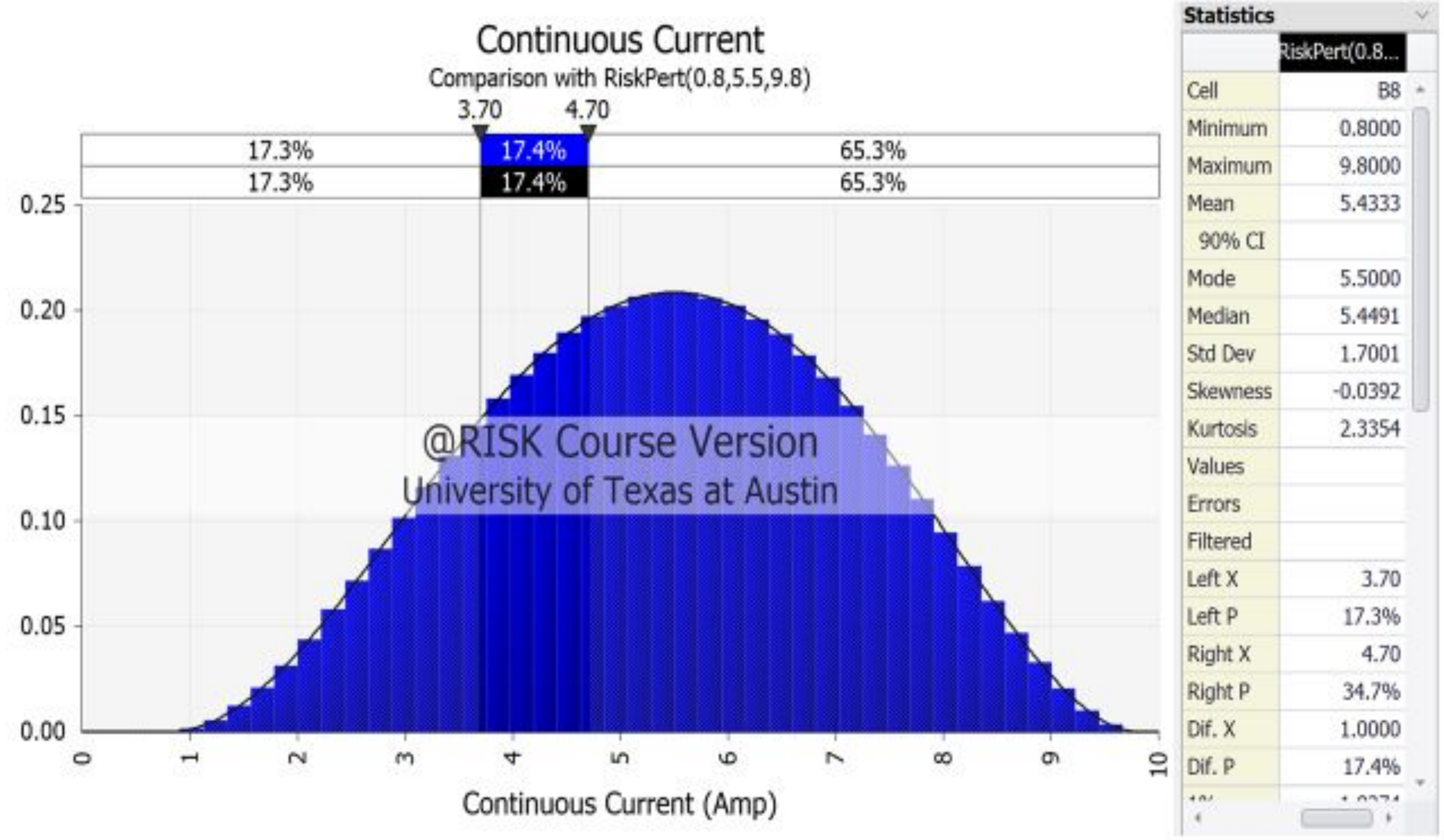
Input – Power Supply

- Uniform distribution
- This distribution was selected as the power supply from the battery is directly chosen by the designer, therefore no battery has statistical advantage.
- Common battery power supplies for 14.8 V range from 2 to 12 Ah.
- Beyond 12 Ah the batteries become too large and heavy.
- Increasing battery size results in diminishing returns.



Input – Power Consumption

- Pert distribution
- This distribution was selected as the power draw cannot exceed a minimum or maximum.
- The most likely value was set to 5.5 Amps. Max is 9.8 amps; minimum is 0.8 amps.
- This results in a distribution with the goal of modeling a flight plan where 17% of flight time is hovering (3.7 - 4.7 amps results in a hover) , 66% of flight time is increased throttle, and 17% of flight time is decreased throttle.

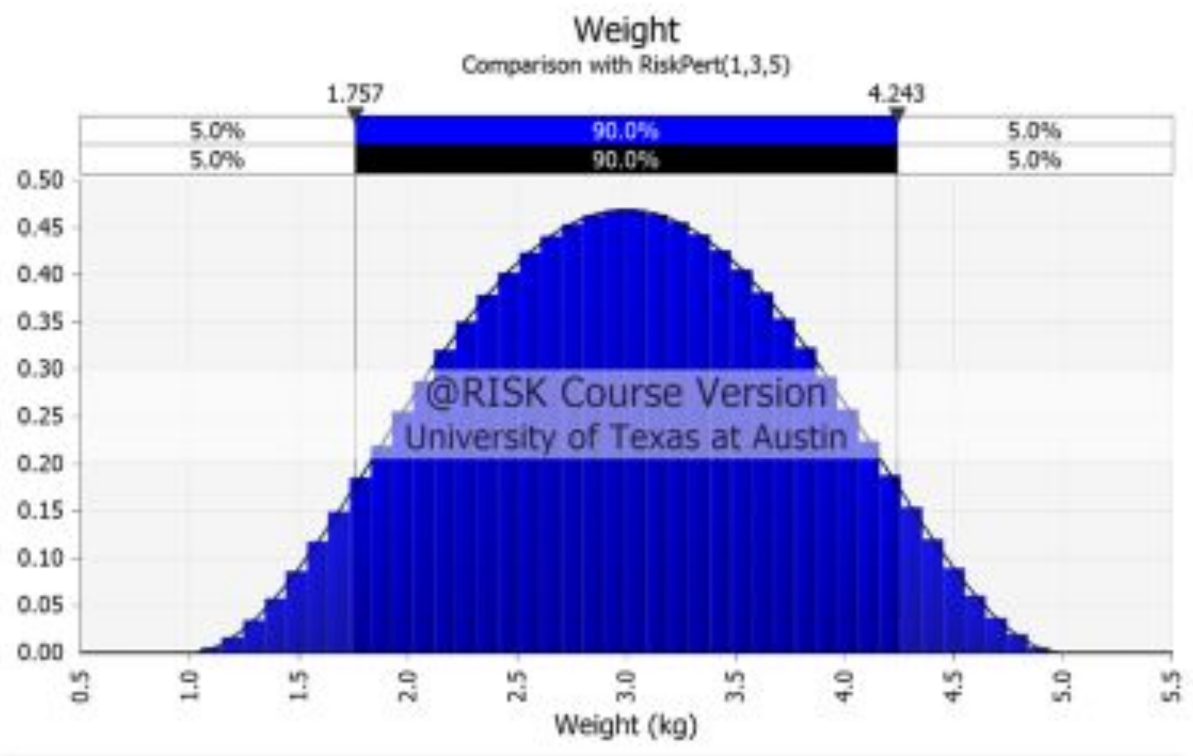


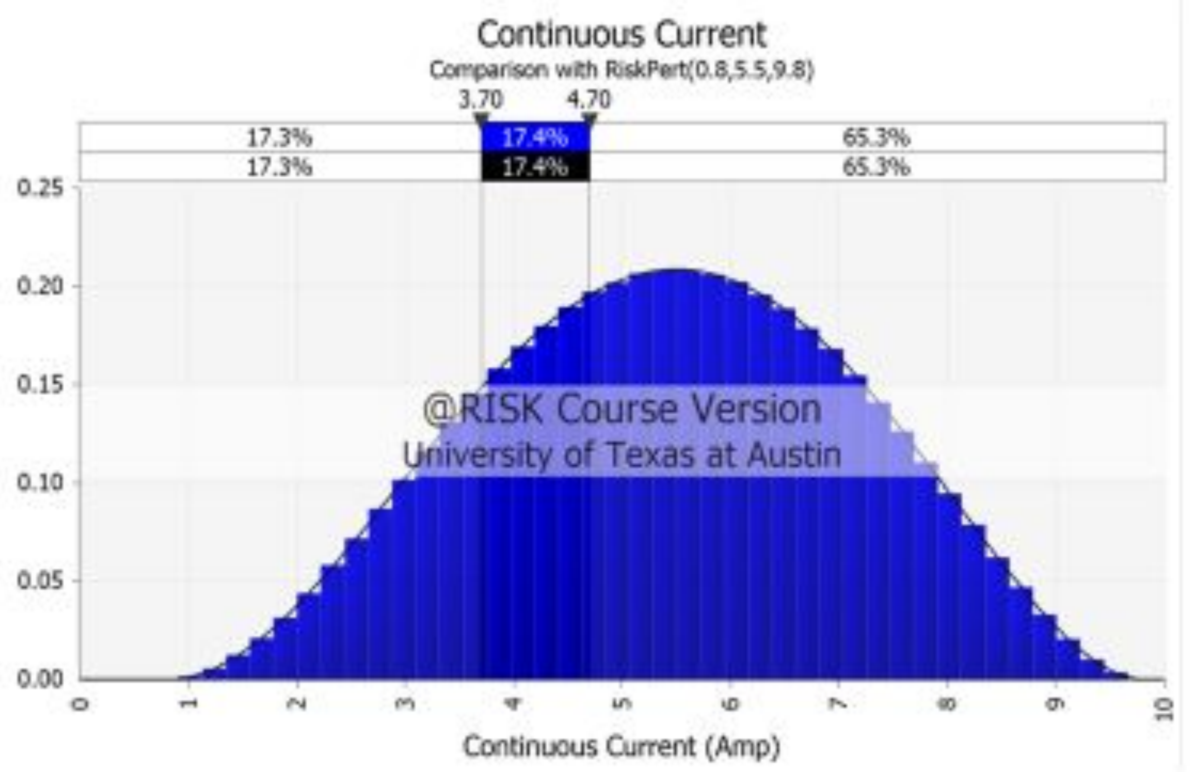
Prop	Throttle	Amps(A)	Watts(W)	Thrust(G)
13*4 carbon prop	25%	0.8	17.8	250
	50%	2	44.4	490
	65%	4.2	93.2	850
	75%	6	133.2	1180
	85%	8.5	188.7	1560
	100%	9.8	217.6	1780

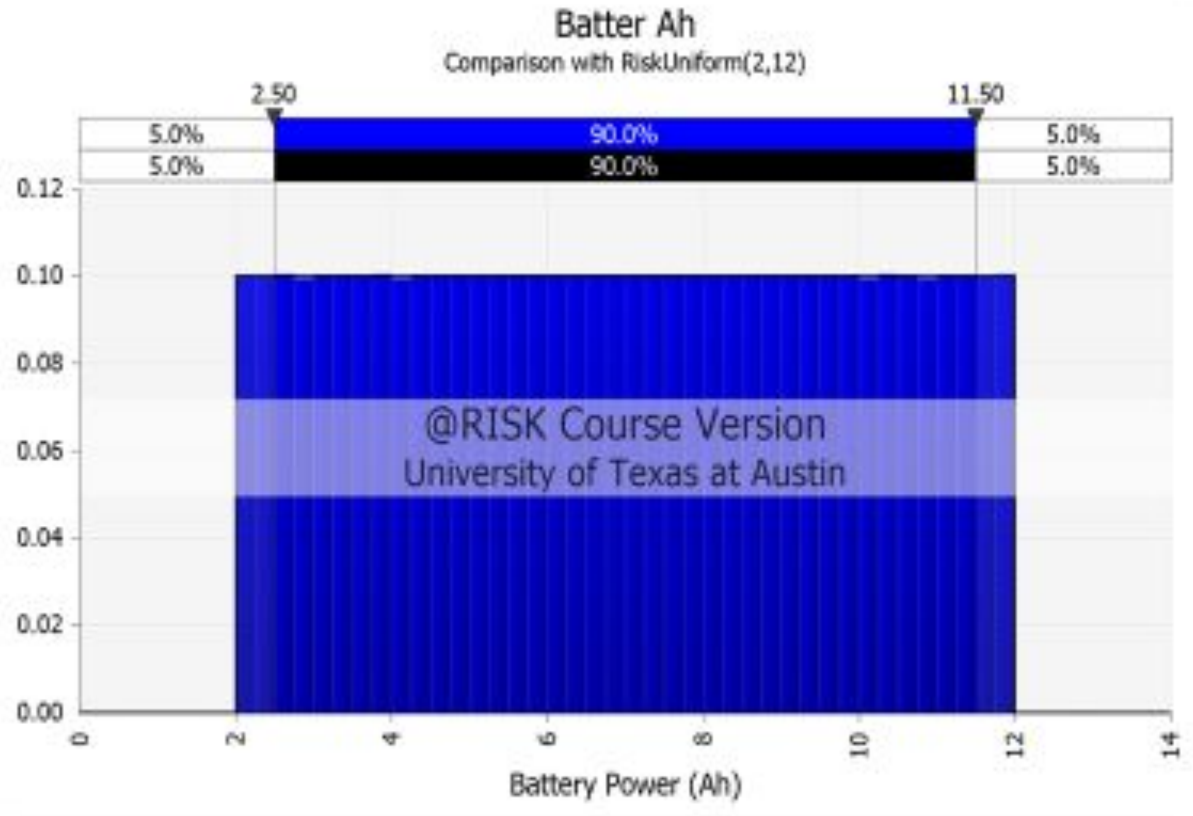
Thrust and electrical power data for a 380 kV motor from testing.

Results – Flight Time

TEXAS AEROSPACE ENGINEERING AND ENGINEERING MECHANICS







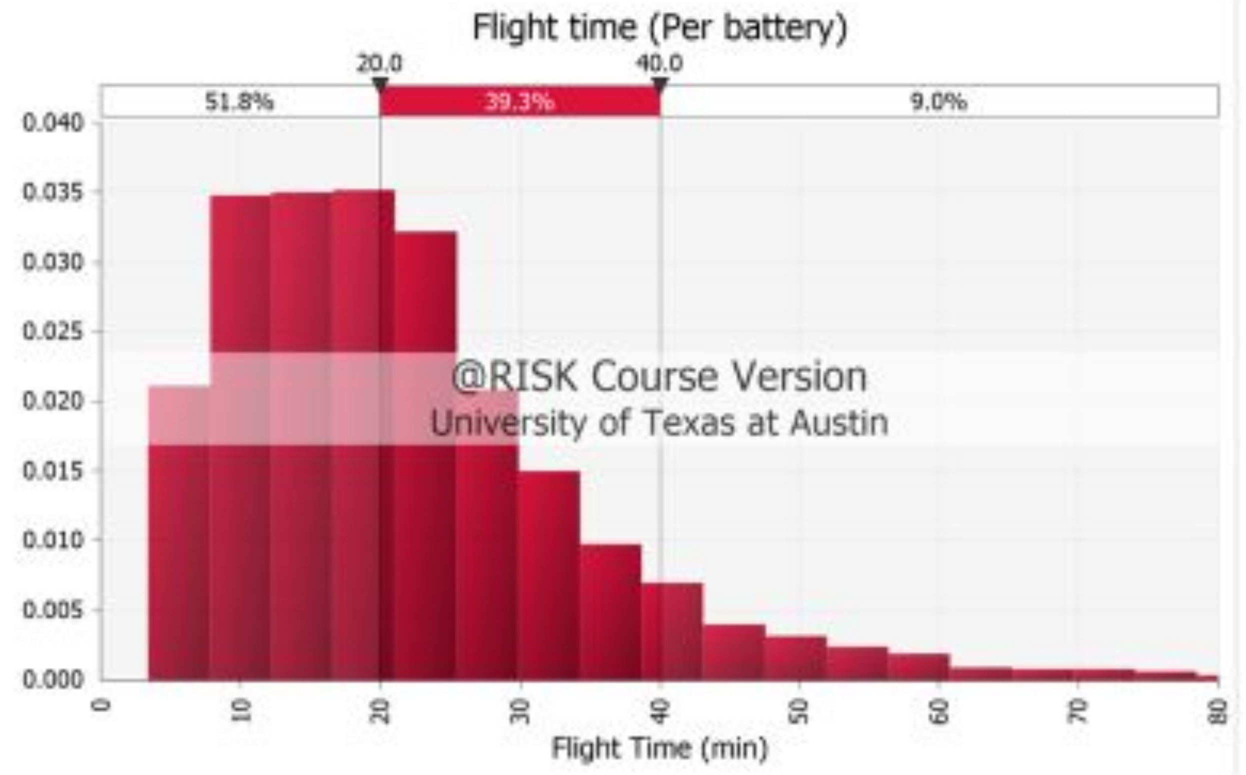
Equations

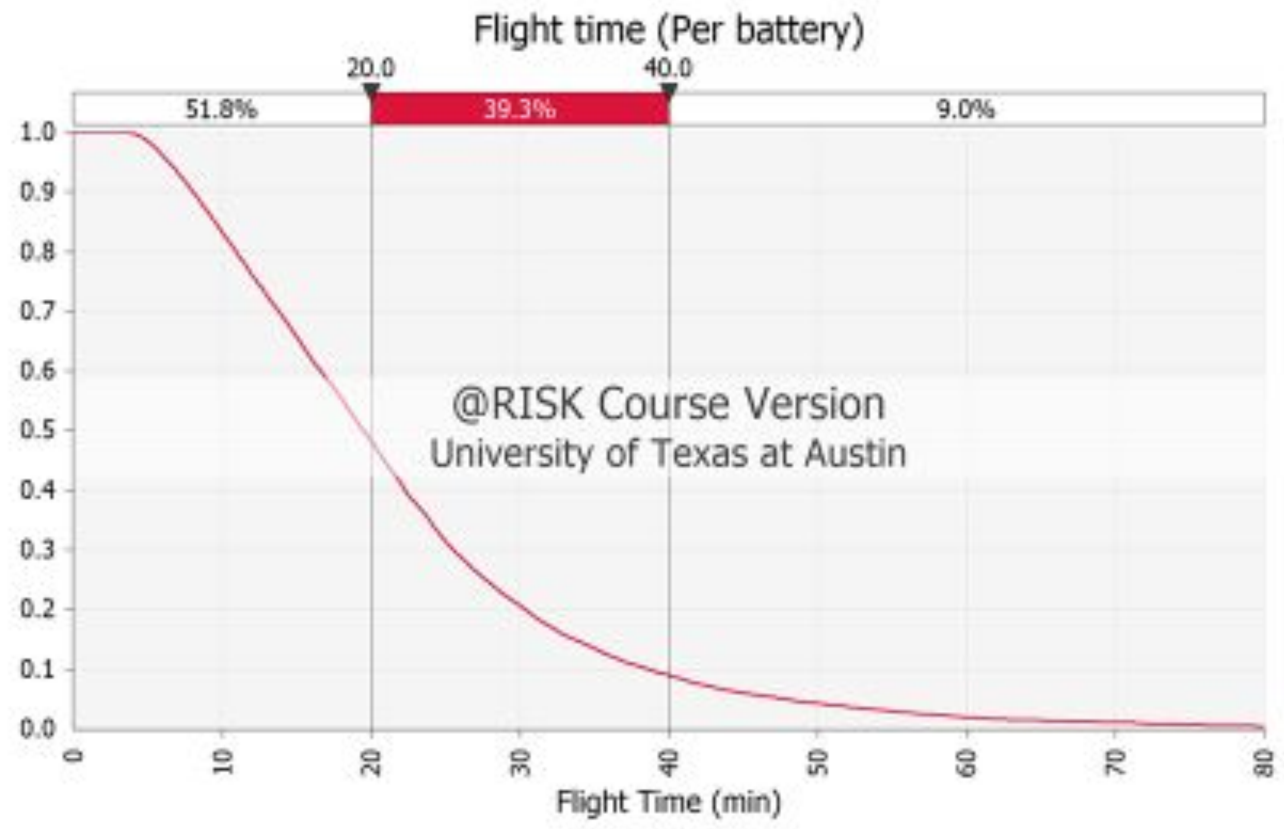
Thrust = Weight (kg)

Power Consumption (W) = V * I * 4 motors

Power Supply (Wh) = V * I * hour

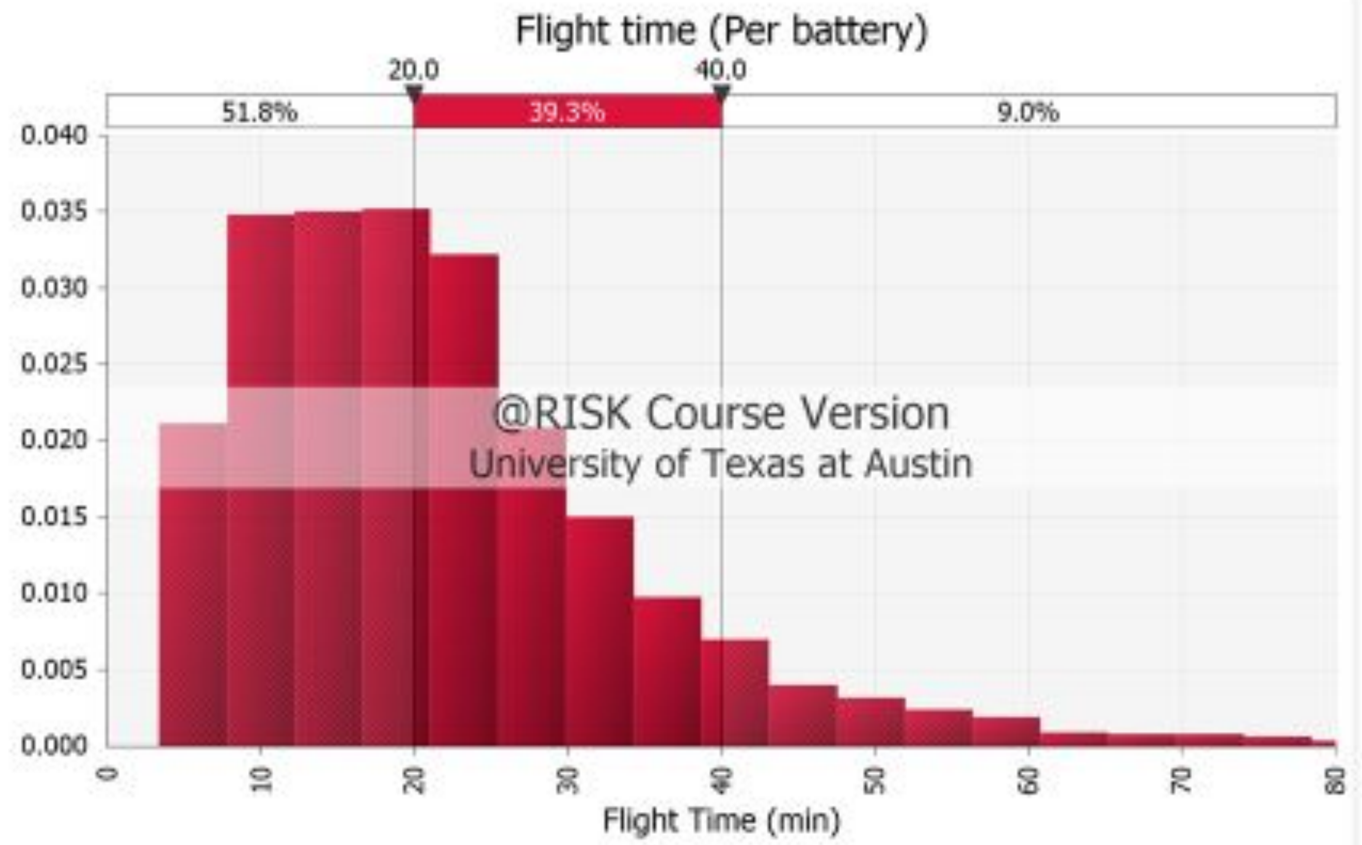
Flight Time (min) = Power Supply (Wh) / Power Consumption (W) *60

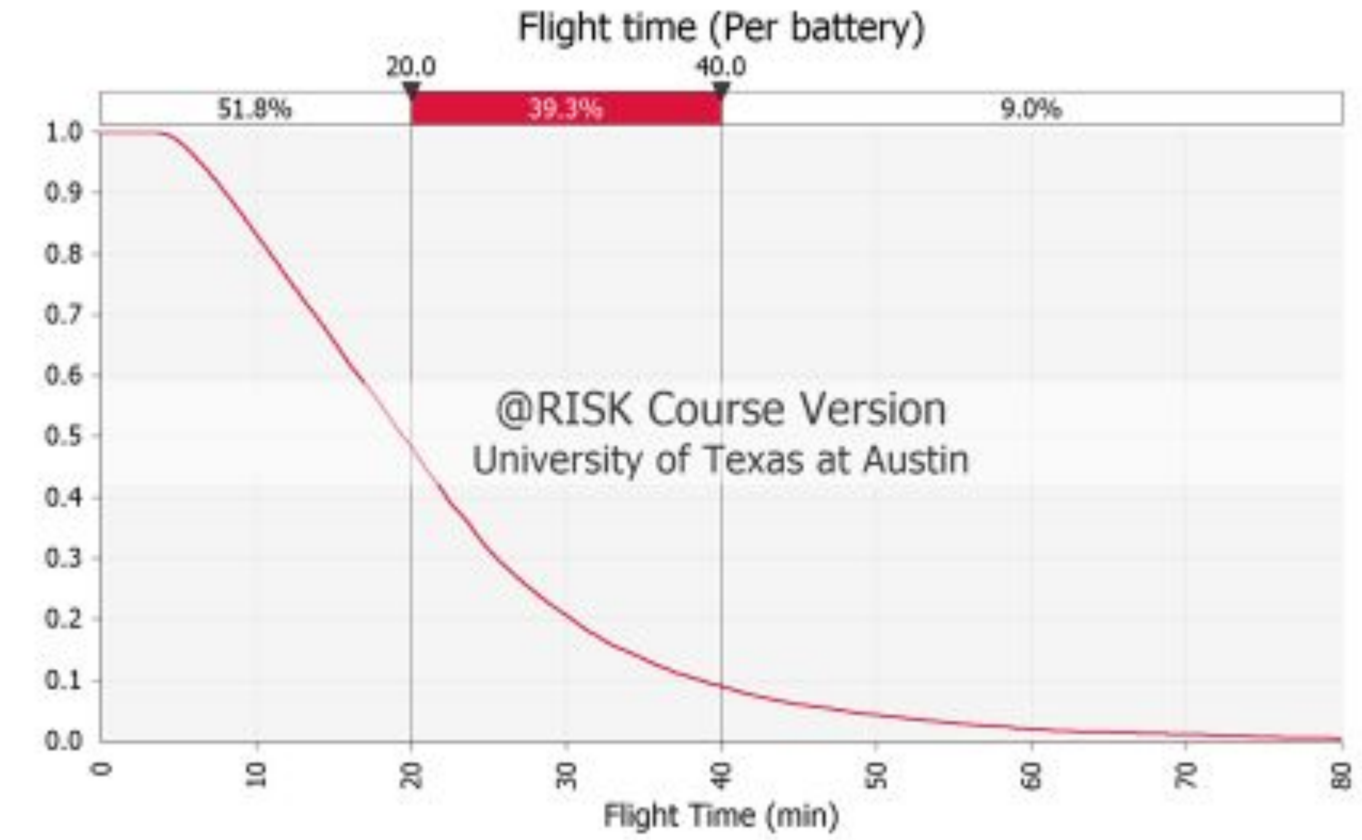




Results - Flight Time

- Flight time:
  - 51.8% likely to be < 20 min
  - 39.3% likely to be 20-40 min
  - 9% likely to be > 40 min.
- It is most likely that the flight time will be below 20 minutes.
- This is on par with similar drones on the market. This flight time can be increased by adding additional battery capacity.
- These confidence intervals were chosen because 20 and 40 minutes represent common desired flight times.
- The models accuracy can be increased by modeling the individual component weight distributions and adding the power consumption of other components.





FRAME ASSEMBLY

Frame

- Missing screws, ordering more backups
- Modularity
- T-connector cracks
- Improvements:
  - Potentially retractable landing gear
- Problems:
  - The carbon fiber/plastic was unthreaded, made screwing things in difficult

SAFETY AND RISK

LAB SAFETY

- Wear protective gloves.
- Wear safety glasses.
- Wear closed-toed shoes and pants.
- No horseplay in the lab.
- When sanding carbon fiber, wear respirators and alert other people in the lab to either exit or wear them as well.
- No food or drink in the lab in order to not contaminate the workspace.
- Completion of OH 101 and OH 500 training

Sourced from https://www.labmanager.com/lab-health-and-safety/science-laboratory-safety-rules-guidelines-5727

FAA SAFETY STANDARDS

Per FAA Regulations Part 107 Subpart B Operating Requirements [1]:

- Always avoid manned aircraft.
- Never operate in a reckless manner.
- Always keep your drone within unaided sight.
- Do not fly drone over people unless they are directly participating in the operation.
- Do not operate drones from a moving vehicle unless flying over a sparsely populated area.
- Operations in Class G airspace are allowed without air traffic control permission.
- Operations in Class B, C, D and E airspace need authorization.

FAA SAFETY STANDARDS CONTINUED

Per FAA Regulations Part 107 Subpart B Environmental/Physical Constraints [1]:

- Fly during daylight hours (30 minutes before sunrise/after sunset) OR in twilight if the drone has anti-collision lighting.
- Minimum weather visibility is 3 miles from the control station.
- A maximum allowable altitude of 400 feet above ground or a structure.
- Maximum speed allowed is 100 mph.
- Drones can carry cargo as long as they are securely fastened and do not affect the flight characteristics and controllability of the drone.
- Drone must not exceed 55 pounds including payload.

EXTERNAL SAFETY THREATS

- Transporting Hazardous Materials

  This is not allowed under any circumstances per FAA Part 107 regulations. It would require the development of special dangerous goods training programs that follow the Part 135 Certification Process as well as collaboration with the Office of Hazardous Materials Safety [2].

- The Weaponization of Drones

  Collision avoidance capabilities can be extremely beneficial in a warfare context. As a result, our drone would need to develop a secure software system that is not susceptible to hijacking or dangerous alterations.

EXTERNAL SAFETY THREATS

- Bird Strikes

  Probability of Impact: 3.5x10^-5 (100 drones in flight for 30 minutes)

  While the probability is extremely low, it is still something to be aware of, especially at certain times of the day and migration periods.

- Adverse Weather Conditions

  The ability for our drone to fly in more extreme conditions is dependent on developing measures that increase drone robustness in differing climates, informed by wind speed, temperature, and precipitation data.

RISK

Based on the FMECA, it was evaluated that there are only a few high level risks with high severity or probability, however majority of them are highly detectable.

Risk	Severity	Probability	Detectability
Landing Gear Failure	7	5	3
Motor Failure	9	3	3
Electrical Wiring Dislodged	6	2	2

FUTURE WORK

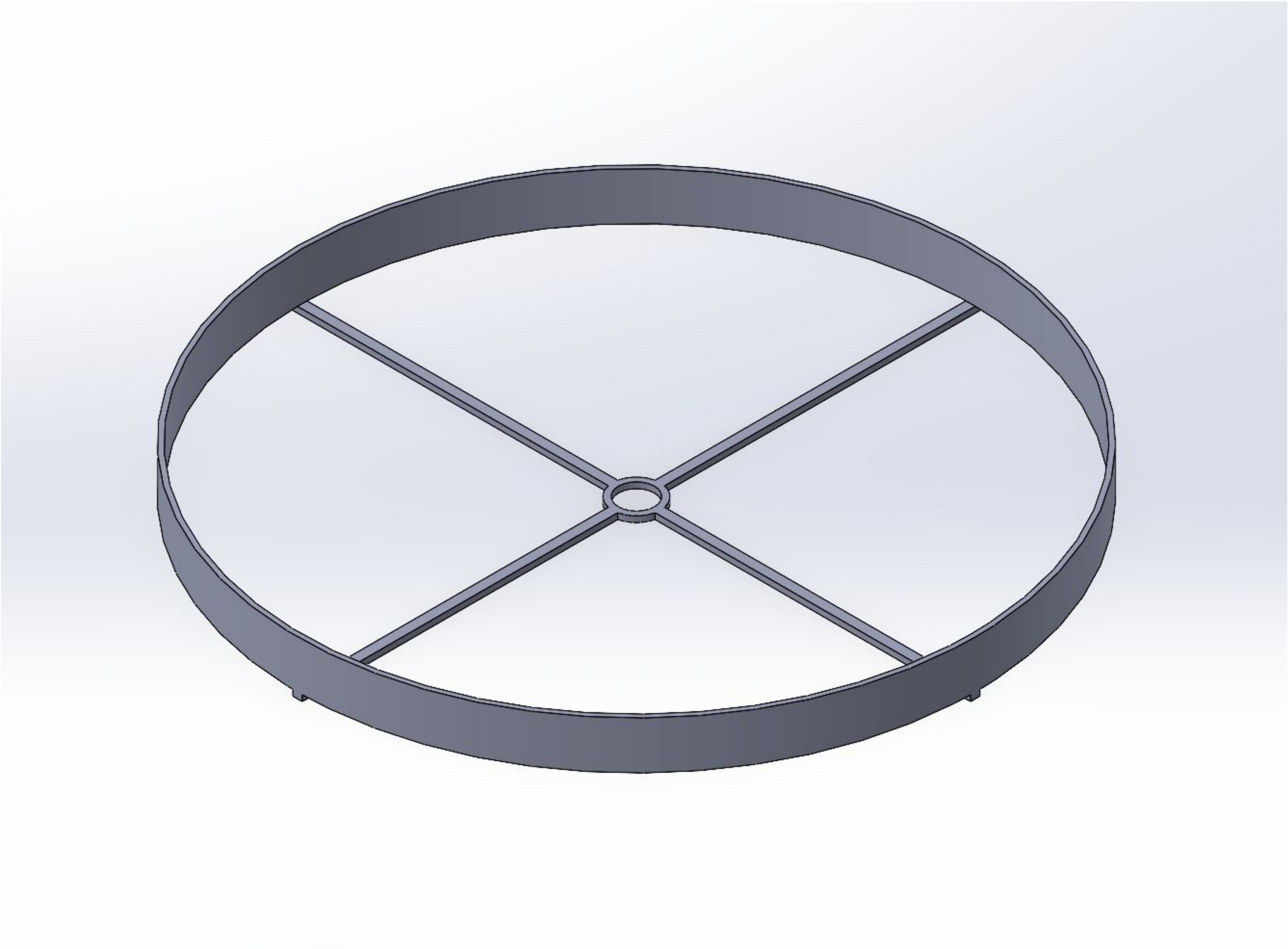
Short Term Planning

In order to continue to make progress through this and next semester, the following plans have been made:

- Complete building up the first drone
- Complete building up a secondary drone
- Complete initial hardware tests
- Complete initial bring-up with sensors and software team
- Complete preliminary testing
- Complete initial prototype testing with sensors and software team

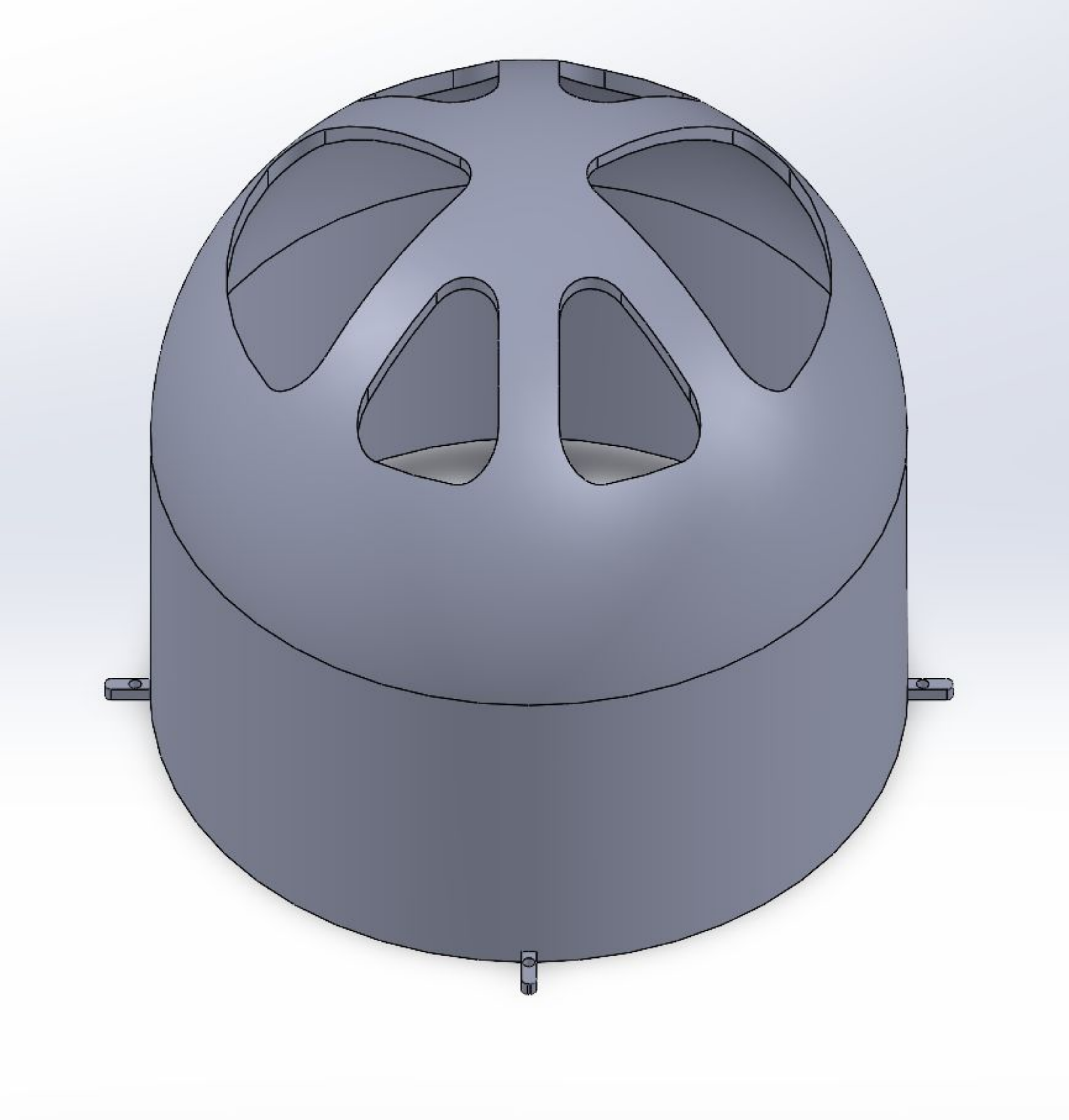
TEXAS ENGINEERING

Rotor Guard



TEXAS ENGINEERING

Drone Cover



Long Term Planning

When looking ahead there are several plans which will drive actions forward, such as:

- Evaluate the prior design and move forward with redesign if necessary
- Building up a new drone
  - Procure new hardware
  - Rewire sensors in order to optimize the drone
- Develop long lasting hardware plans for optimizing upon developmental testing drones

THANK YOU.

QUESTIONS?

The University of Texas at Austin
Cockrell School of Engineering