Concept Generation

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Introduction

The goal of concept generation is to produce as many ideas as possible. Several systematic methods exist to aid in this process, including brainstorming, the most common method. Successful brainstorming occurs with an enthusiastic session of rapid, free-flowing ideas, where the SCAMPER checklist can be used as an aid. The six key questions, along with checklists and wishful thinking, can also help improve the brainstorming process.

Additional systematic approaches can also be used. Random input technique is grounded in lateral thinking, which focuses on thought provocation that illcits different thinking patterns. Synetics is a concept generation tool based on reasoning by analogy. The four types of analogies are direct analogy, fantasy analogy, personal analogy, and symbolic analogy. Biomimcry is a type of direct analogy that draws design inspiration from biological systems. A concept map can also be used for concept generation. It is useful for organizing information, generating ideas through connections, and recording ideas during brainstorming.

The design team used morphological methods to organize ideas developed in brainstorming. Morphological methods are useful in representing and analyzing multi-dimensional problems. The adopted morphological approach produced a morphological chart that generates solution concepts for each subproblem.

Morphological Chart

Morphological Chart							
Energy Conversion	**Signal Type**	**Enclosure Geometry**	**Visual Detection**	**Physical Detection**	**Locomotion**	**Locomotion Style**	**Traction Type**
Electrical to Mechanical	Radio Frequency	Rectangular	Go-Pro	Lidar	Hover	Plain Wheels	Tread
Solar Thermal to Mechanical	Wi-Fi Connection	Domical	Cell Phone	Radar	Roll	Omnidirectional Wheels	Spoke
Solar Photovoltaic to Mechanical	Bluetooth	Hexagonal	Point-and-Shoot Camera	Bumper	Jump	Diaphragm	Magnetic
Mechanical to Electrical	USB 2.0	Polygonal	Disposable Camera		Walk	Retractable Legs	
	USB 3.0	Square	DSLR Camera			Tracks	
	Satellite		360-Degree Camera			Stationary Legs	
	Infrared					Thrusters	
	RFID						
	GSM						
	GPS						

Table 1 - Morphological Chart

Selection of Subproblem Categories

A total of 103 concept components pertaining to subproblem categories were generated, Appendix D. Critical targets and metrics, Appendix E, were referenced to aid in the subproblem category selection process for the morphological chart, Table 1. The selected categories, located in column 1, were energy conversion, signal type, enclosure geometry, visual and physical detection, locomotion and locomotion style, and traction type.

Energy conversion relates to the critical target and metric of storing and converting energy. Signal type relates to the critical target and metric of sending and receiving signals. Enclosure geometry relates to the critical target and metric of housing equipment. Visual and physical detection both relate to the critical target and metric of detecting obstacles. Locomotion,

locomotion style, and traction type relate to the three critical targets and metrics of maneuvering terrain, navigating obstacles, and maintaining stability.

Durability was the only critical target and metric not addressed in the morphological chart. The design team deemed the inclusion of durability as it relates to material selection as unnecessary for comprehensive concept generation. The critical target and metric of durability, along with other unaddressed subproblem categories, will be explored and incorporated in later stages of the design process.

Medium-Fidelity Concepts

A concept's fidelity is based on the level of detail in its description. Medium fidelity concepts are distinguished by their accompanying hand drawn sketches and explanation of key features.

Medium Fidelity Concepts								
Concept Number	**Energy Conversion**	**Signal Type**	**Enclosure Geometry**	**Visual Detection**	**Physical Detection**	**Locomotion**	**Locomotion Style**	**Traction Type**
1	Solar Thermal	Radio Frequency	Domical	360-Degree	Lidar	Walk	Retractable Legs	Spokes
2	Electrical to Mechanical	Wi-Fi Connection	Rectangular	Go-Pro	Lidar	Walk	Retractable Legs	-
3	Solar Photovoltaic	Bluetooth Wi-fi Connection	Square	Cell Phone	Bumper	Roll	Omnidirectional Wheels	Magnetic
4	Solar Photovoltaic	Wi-Fi Connection	Rectangular	360-Degree	Lidar	Roll	Omnidirectional Wheels	Tread
5	Electrical to Mechanical	Radio Frequency	Domical	360-Degree	Lidar Bumper	Walk Jump	Diaphragm	-

Table 2 - Medium Fidelity Concept Table

Concept 1

Concept 1 has a domical enclosure where the lidar and other relevant data acquisition equipment can be housed, satisfying the customer need "The robotic explorer detects obstacles". This concept also has a walking style of locomotion paired with spokes as the form of tread. This allows the rover to easily maneuver various terrain types while still remaining on the surface of the asteroid. Concept 1 uses solar thermal energy which may be insufficient for a rover on the surface of Psyche. Psyche is a very cold asteroid and may not offer an appropriate amount of energy for a rover.

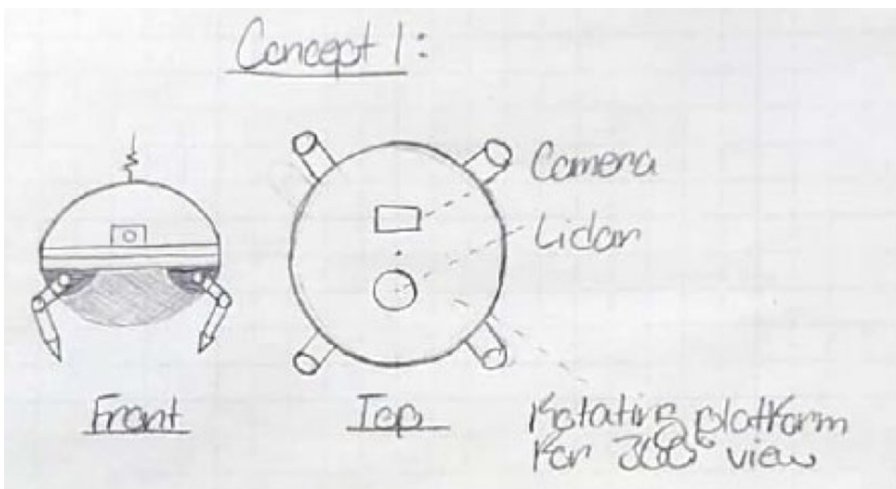

Figure 1 - Concept 1

Concept 2

Concept 2 would function using electrical to mechanical energy conversion, having access to its battery from the rover's rear. It will communicate via Wi-Fi connection, with a receiver positioned on the top of the rover. It will have a tripod that can hold a go-pro device for visual detection, as well as a lidar sensor positioned in front for physical detection. Its rectangular body gives the rover room for implementation of retractable walking legs and room to house electrical components.

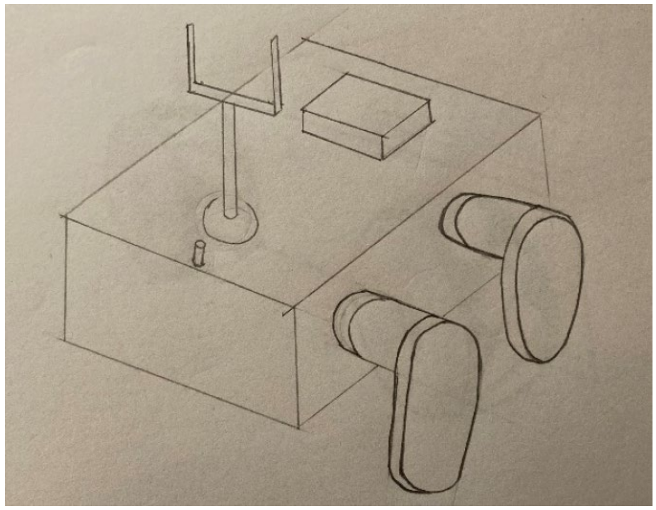

Figure 2 - Concept 2

Concept 3

Concept 3 has a square body that stores electrical components and creates a large surface area for mounting solar photovoltaic cells. The rover will have Bluetooth and Wi-Fi communication capabilities that will be signaled from the computer positioned inside the rover. It will have a tripod located on top of the rover to mount a cell phone for visual detection. Bumpers will be located at the front and rear of the rover for physical detection. It will have omnidirectional wheels for locomotion that are equipped with magnets for traction.

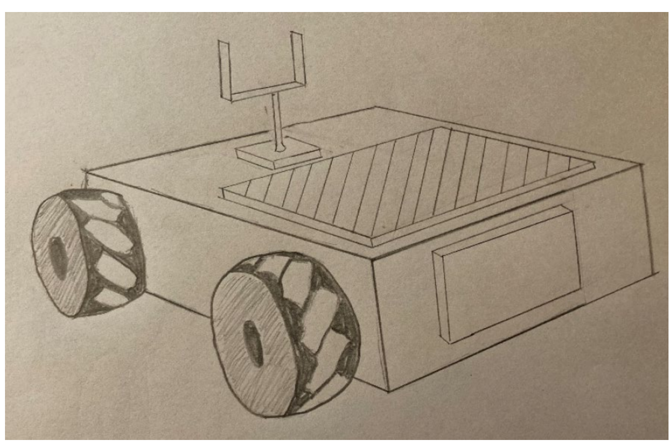

Figure 3 - Concept 3

Concept 4

Solar photovoltaic cells are desired for their increased reliability and are widely used in space applications (The European Space Agency, 2014). Extensive research relating to photovoltaic cells exist, yielding easy implementation because of their familiarity in the space industry. Wi-Fi signals produce high rates of data dispatch and receival. Mission success is highly correlated to efficient data management; therefore, quick data relay and recovery plays a pivotal role (Williams, 2019). The combination of rolling locomotion and omnidirectional wheels allow for a unique range of motion, suitable for traversing a range of terrains. Discontinuities in the tread provide sufficient traction for maneuverability.

A rectangular enclosure geometry accommodates a standard battery shape, as well as other required electrical components. Closely relating to signal exchange, visual detection is a critical factor in providing the necessary information about the environment. 360-degree visual detection allows the explorer to provide comprehensive visual details of its surroundings. Along with visual detection, physical detections of the explorer's environment provides an additional dimension of detail about the surrounding environment. The lidar's active sensor allows it to make choices regarding the location and timing of data acquisition, regardless of environmental lighting ("LITE: Measuring the Atmosphere With Laser Precision", 1994). Laser beams are able to travel far distances, while still providing concise detection. Additionally, lidars are capable of locating water droplets and ice particles, making their application particularly advantageous for the Psyche mission ("LITE: Measuring the Atmosphere With Laser Precision", 1994).

Use of Wi-Fi for signal exchange from far away planetary objects may require the addition or upgrade of components, such as software and digital ground architecture, resulting in increased costs and extensive testing (Williams, 2019). Although the rectangular enclosure is appropriate for traditionally shaped batteries, they may not be adequate for housing non-traditional battery or power source dimensions, whose final selection has not been made.

Lidars are an effective choice for physical detection on Earth; however, adjustments for space applications would be necessary. Some concerns include the limitation of a very small sampling region (“LITE: Measuring the Atmosphere With Laser Precision”, 1994), and sensitivity to high sun angles and reflections (“Pros and cons of LIDAR”, n.d.). Tread provides good traction; however, their easy wear may be unsuitable for repetitious usage on unknown terrain composition.

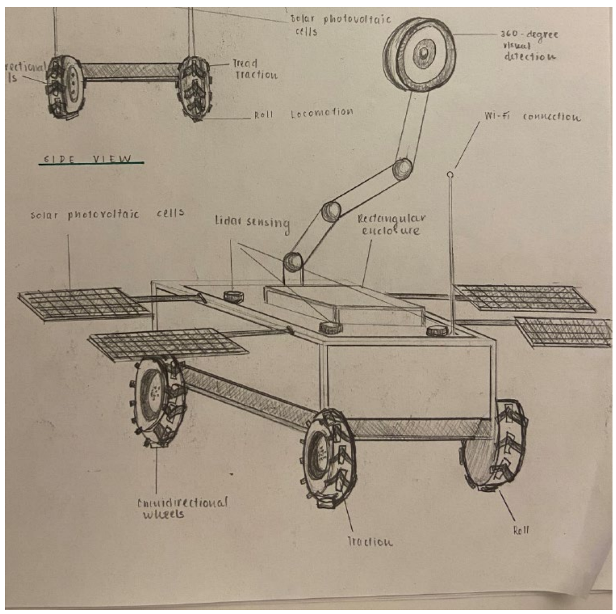

Figure 4 - Concept 4

Concept 5

Concept 5 converts electrical energy in the form of a battery to mechanical energy in the form of walking and jumping locomotion. The type of locomotion generated by this concept is centered around the use of a rover base housing batches of air voids that are repeatedly inflated and deflated with a diaphragm to produce desired movements. Concept 5 uses a domical enclosure shape to house necessary components, which rests on top of the rover’s base. For physical detection, Concept 5 employs a lidar and physical bumper, with visual detection being provided by a 360-degree camera. Radio frequency was chosen as the method of exchanging signals for this concept.

The use of a diaphragm provides increased stability, as the operator chooses which voids to fill during mission performance; however, the achievable velocities and durability of the diaphragm on unknown terrains are concerning. The selection of radio frequencies to exchange signals also requires further investigation, as transmission interruptions could significantly hamper operation.

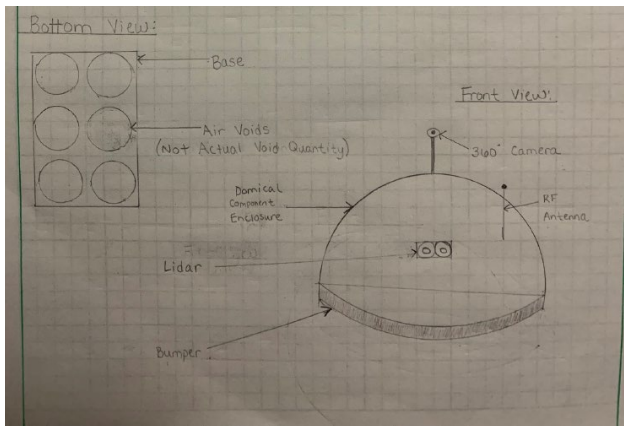

Figure 5 - Concept 5

Conclusion

The design team used morphological methods to generate robotic explorer concepts that can traverse a variety of different terrains. The team's functional decomposition and customer needs were used in developing criteria for the morphological chart, and research was performed to aid in brainstorming categorical options. Pros and cons were detailed for several medium-fidelity concepts, with concept drawings being located in Appendix C.

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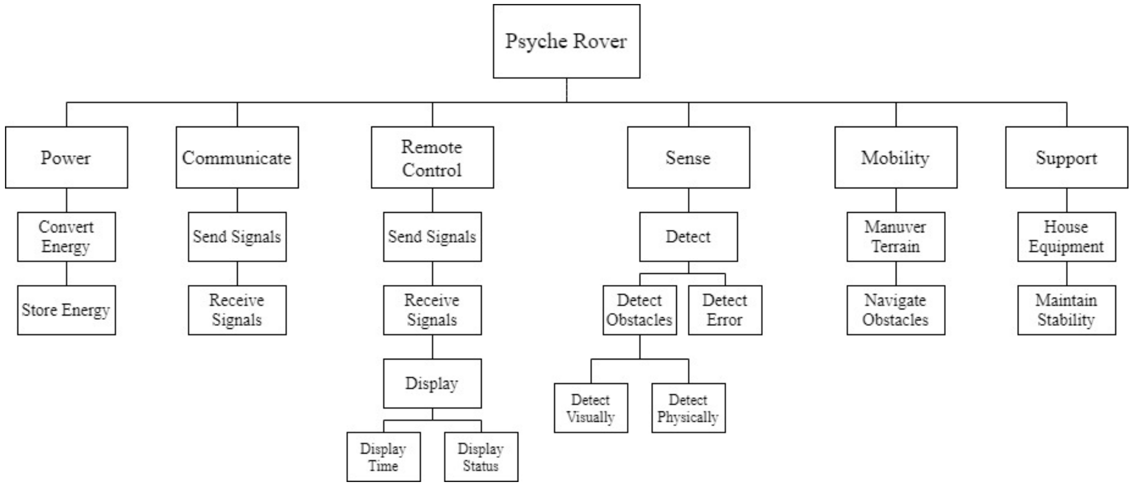
Appendix A – Functional Decomposition



Appendix B – Customer Needs Table

Question	Customer Statement	Interpreted Need
What types of terrains have been encountered on previous missions?	Asteroids have been shown to be covered in craters.	The robotic explorer manuevers through various changes in surface topography, depression, and curvature.
	Boulder rocks and big stones have been seen on asteroid surfaces.	The robotic explorer detects obstacles.
	Different rock types with varying characteristics have been detected.	The robotic explorer works on varying material compositions.
	Basaltic materials were expected, but surfaces similar to hard snow were encountered.	The robotic explorer can travel on surfaces with variable hardness and roughness.
	Comet terrains were mostly flat with some steep cliffs.	The robotic explorer detects and avoids sudden changes in surface elevation.
	The surfaces were non-magnetic, contrary to what was expected.	The robotic explorer functions independent of a planetary body's magnetic characteristics.
What is the budget for this project?	The school has allowed for a $2,000 budget for Senior Design projects.	The prototype for the robotic explorer is designed and implemented for $2,000 or less.
What type of environment is expected on Psyche?	Psyche is expected to have a low gravity, approximately 0.144m/s^2.	The robotic explorer remains on the planetary body after landing.
	Psyche has no atmosphere.	The robotic explorer operates on an airless body.
	The temperatures on Psyche are expected to be extremely cold.	The robotic explorer withstands low temperatures.
What types of terrain are expected to be encountered on Psyche?	Fractures and porous space, possibly hidden under regolith.	The robotic explorer traverses both metal and rock surfaces.
	Metal tektites and blocks, but possibly no persistent or deep metal regolith.	
How long will the robotic explorer need to operate at a time?	Spirit and Opportunity robotic explorers were designed to operate for 90 days.	The robotic explorer functions for the duration needed to gather data samples.
	MASCOT was designed to last two asteroid rotations.	The robotic explorer withstands two asteroid orbits.
How will the robotic explorer be deployed?	The robotic explorer will be deployed from the Psyche spacecraft.	The robotic explorer can be housed on the Psyche spacecraft.
Should the robotic explorer be autonomous or remote operated?	Explorers on previous missions have been hybrids.	The robotic explorer has controlled and autonomous functionality.
Who is going to operate the robotic explorer?	The robotic explorer will be operated by NASA personnel.	The robotic explorer is capable of being operated by human personnel.
Are there sizing requirements (i.e. dimensions, weight)?	The Curiosity rover was as large an as SUV.	The robotic explorer is sized to fit its deployment apparatus.
	Previous robotic explorers were sized based on the equipment needed for the mission.	The robotic explorer capably carries mission-essential equipment.

Appendix C – Concept Drawings

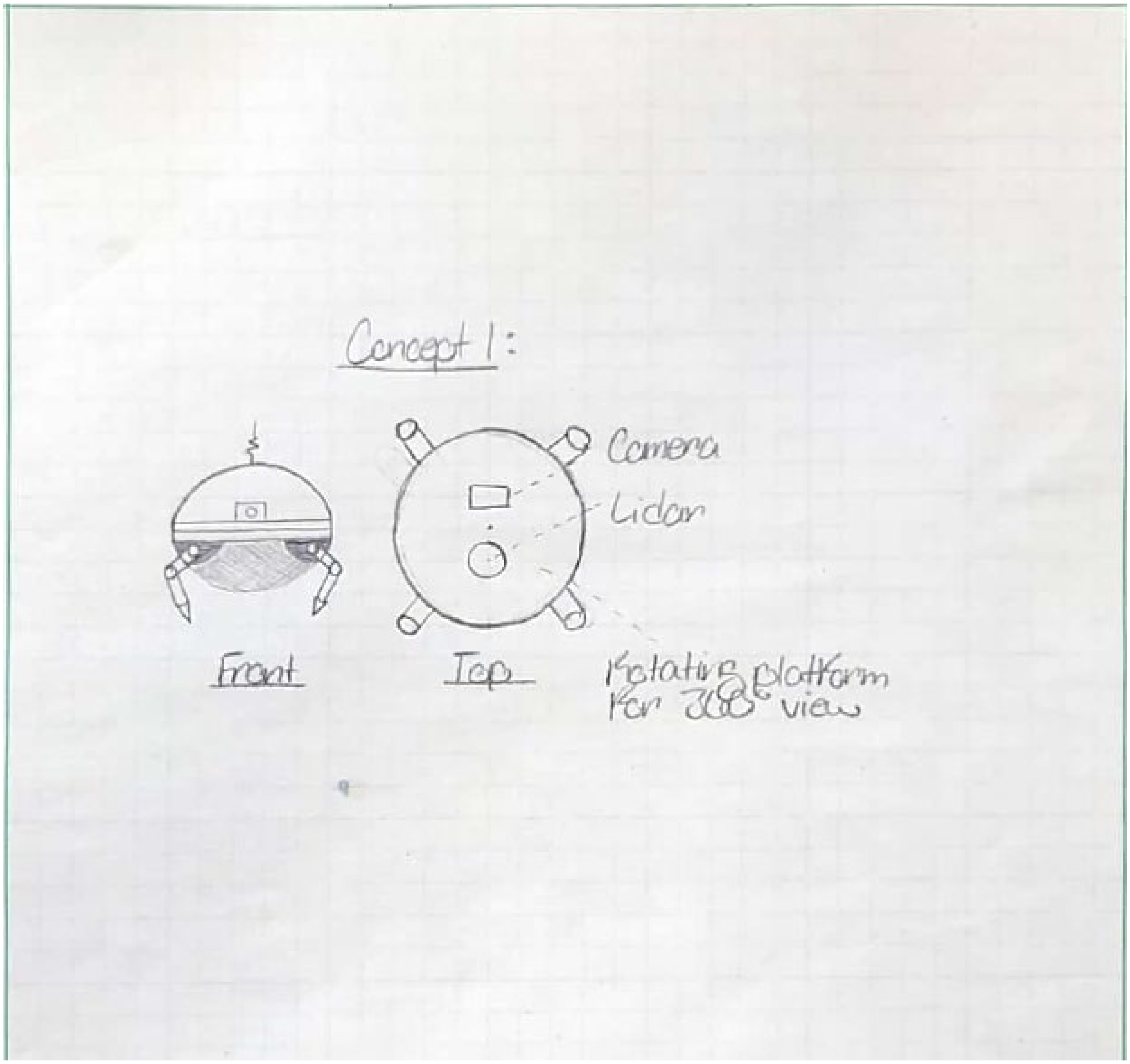


Figure 6 - Concept 1

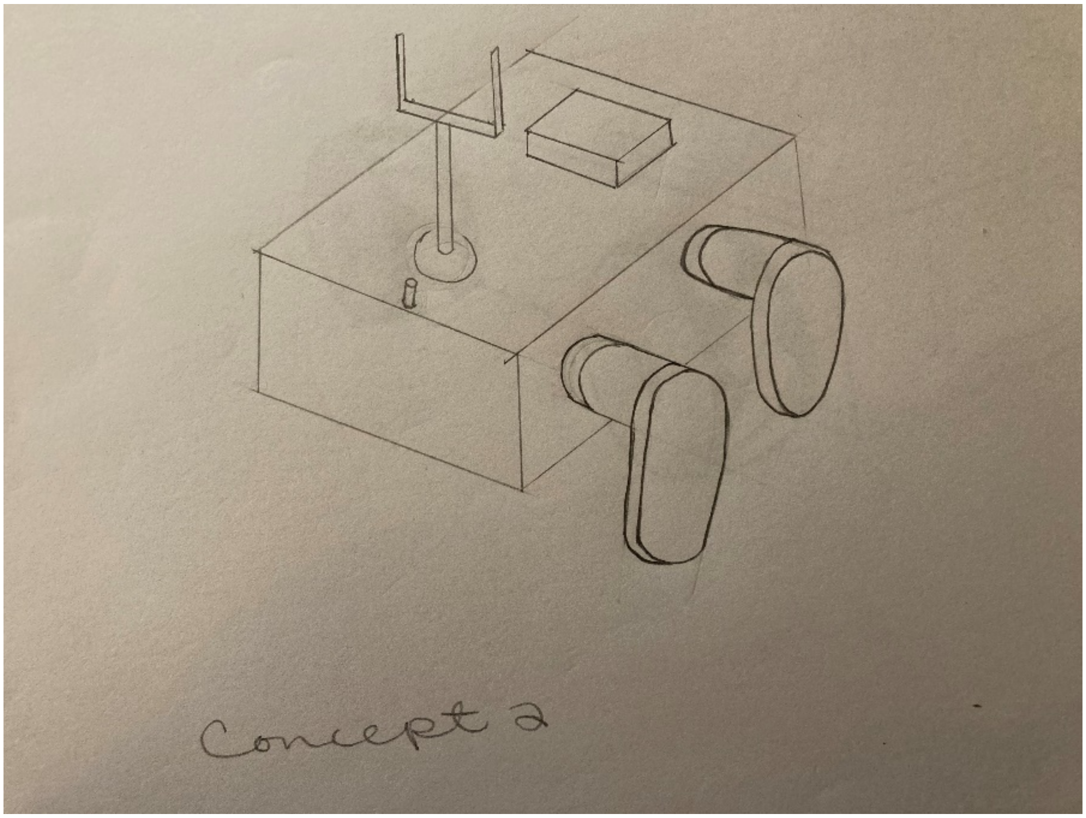


Figure 7 - Concept 2

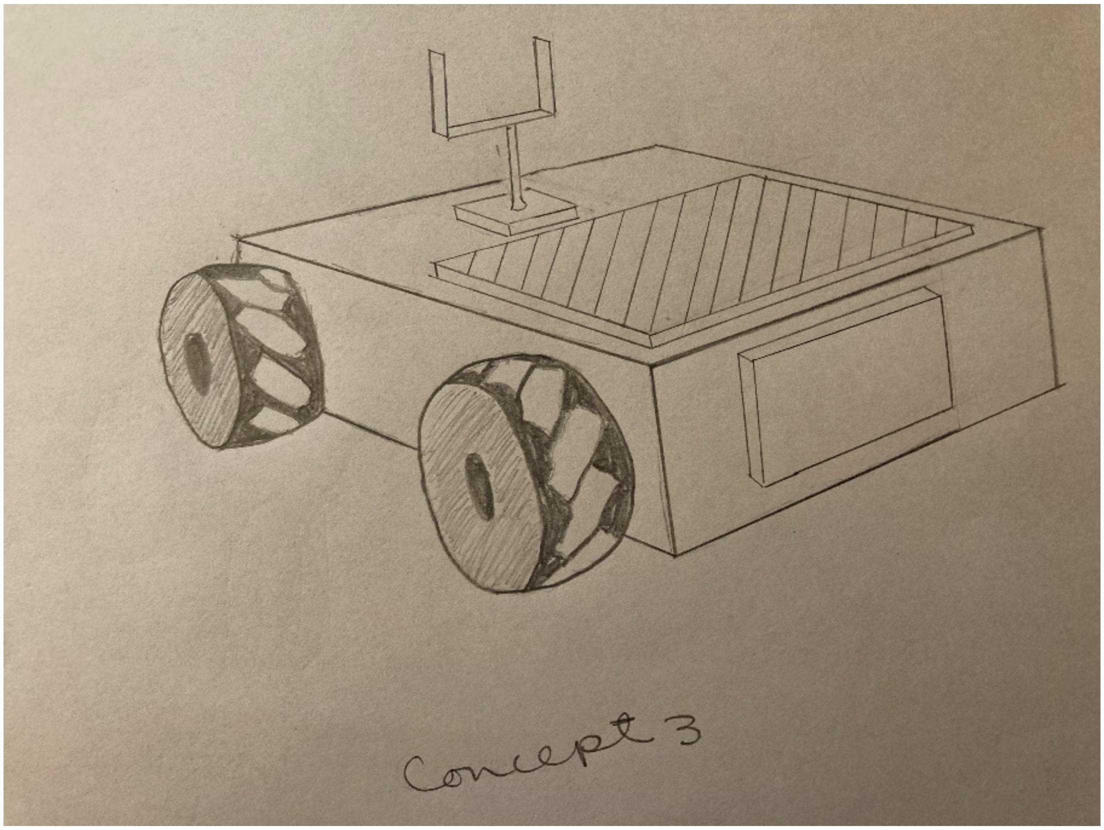


Figure 8 - Concept 3

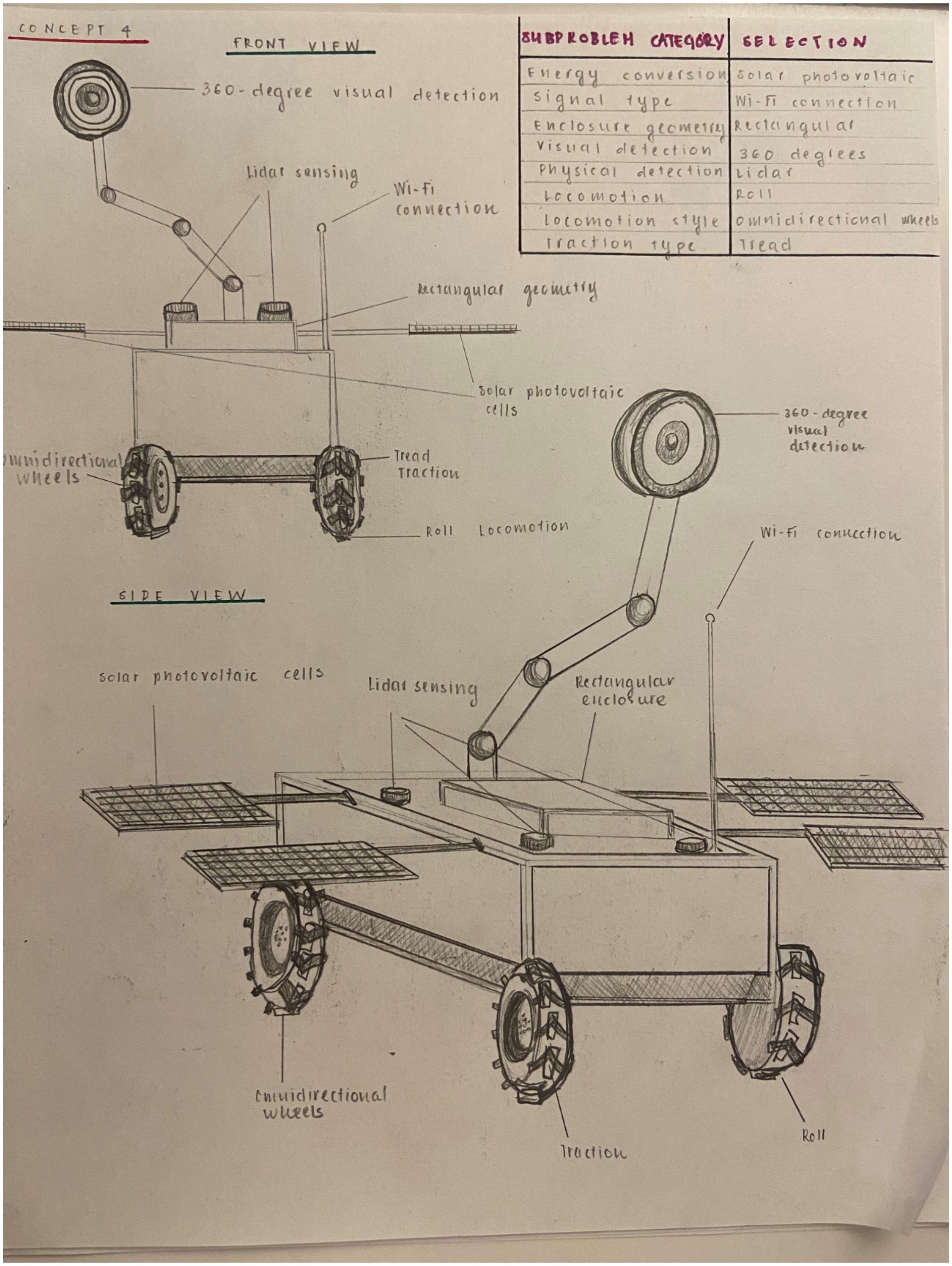


Figure 9 - Concept 4

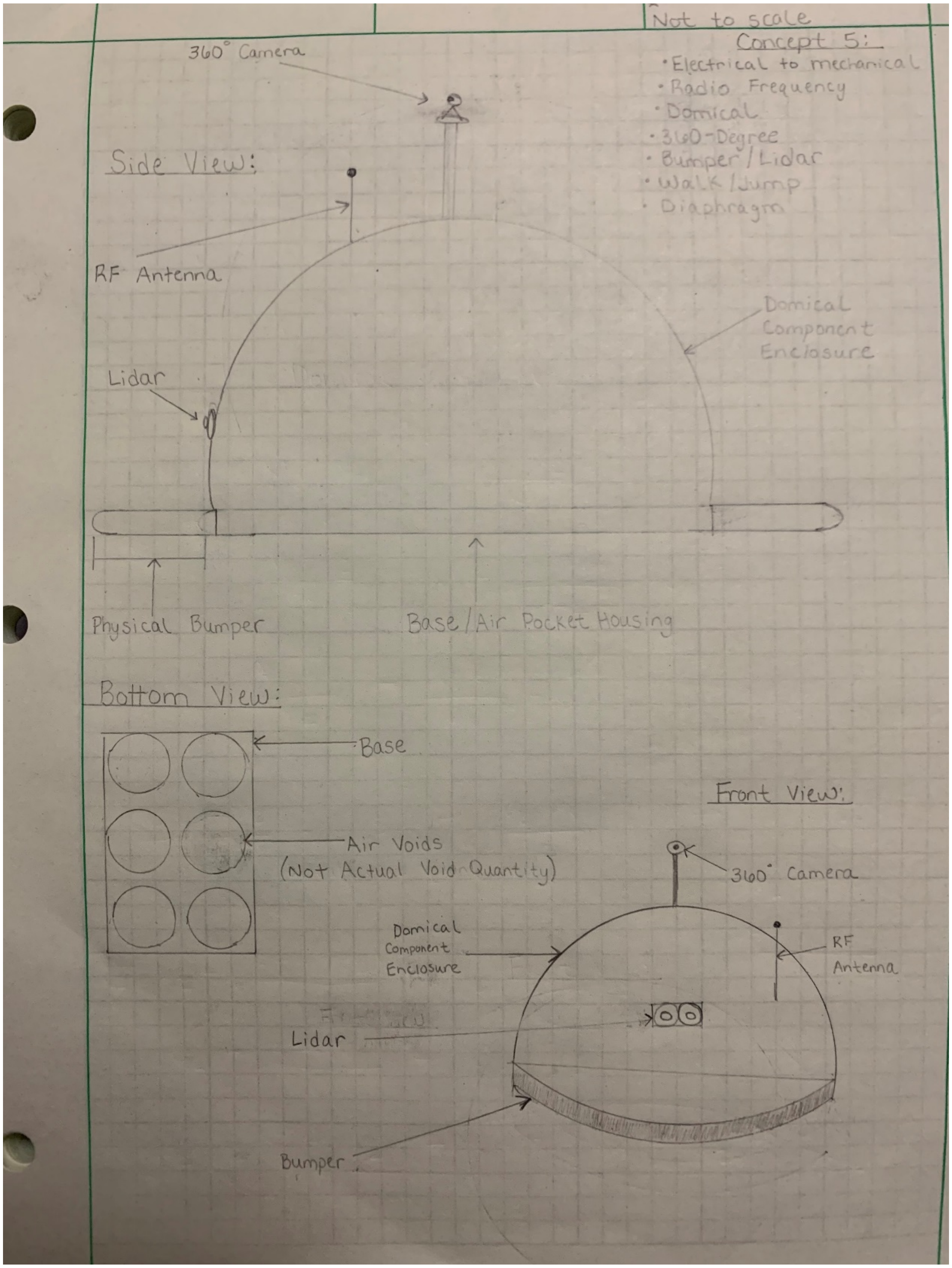


Figure 10 - Concept 5

Appendix D – Concept Variable List

- Energy Conversion

1. Electrical to Mechanical
2. Solar Thermal to Mechanical
3. Solar Photovoltaic to Mechanical
4. Mechanical to Electrical

- Battery Type

5. Lithium-Ion
6. Lithium Polymer
7. Nickel-Metal Hydride
8. Alkaline
9. Lead Acid
10. Sodium-Ion
11. Nickel-Cadmium
12. Silver-Oxide
13. Valve-Regulated Lead Acid

- Battery Capacity (V)

14. 9v
15. 12v
16. 24v

- Battery Connection

17. Series
18. Parallel

19. Combination

- Battery Amp Hours

20. 2

21. 4

22. 6+

- Battery Shape

23. Pouch

24. Cylinder

25. Prismatic

26. Rectangular

27. AA

28. AAA

29. Coin Cell

30. C

31. D

- Signal Type

32. Radio Frequency

33. Wi-Fi Connection

34. Bluetooth

35. USB 2.0

36. USB 3.0

37. Satellite

38. Infrared

39. RFID
40. GSM
41. GPS

- Enclosure Geometry

42. Rectangular
43. Dome
44. Hexagon
45. Polygon
46. Square

- Enclosure Opacity

47. Transparent
48. Opaque
49. Semi-Transparent

- Remote Control

50. Computer
51. PS4
52. Xbox
53. Universal Remote
54. Smart phone

- Visual Detection

55. Go-Pro
56. Cell Phone
57. Disposable Camera

58. DSLR Camera

59. Point-and-Shoot Camera

60. 360-Degree Camera

- Physical Detection

61. Lidar

62. Radar

63. Bumper

- Locomotion

64. Hover

65. Roll

66. Jump

67. Walk

- Locomotion Style

68. Plain Wheel

69. Omnidirectional Wheels

70. Stationary Legs

71. Diaphragm

72. Retractable Legs

73. Tracks

74. Thruster

- Traction Type

75. Tread

76. Spoke

77. Magnetic

- Body Material

78. Fiberglass

79. Aluminum

80. Titanium

81. Carbon Fiber

82. Polymer

- Enclosure Material

83. Plexiglass

84. Fiberglass

85. Aluminum

86. Acrylic

- Display Type

87. LCD

88. QLED

89. LED

90. Plasma

- Motor Quantity

91. 1

92. 2

93. 3

94. 4+

- Motor Type

95. Belt-Drive
96. Stepper
97. AC Brushless
98. DC Brushless
99. Servo
100. Direct Drive

- Traction Material

101. Rubber
102. Polymer
103. Metallic

Appendix E – Targets & Metrics Table

Psyche Rover - Targets & Metrics Catalog				
Function	**Metric**	**Target**	**Critical**	**Notes**
Power				
Convert Energy	Percentage Converted to Useful Work	80+%	Yes	Thermal to Mechanical Electrical to Mechanical
Store Energy	Operational Longevity	60-90 days	Yes	
	Driving Duty Cycle	20%	Yes	Expected driving capacity
Communicate				
Send Signals	Wi-fi Connection	802.11 2.4 GHz or 5 GHz	Yes	
Receive Signals	Wi-fi Connection	802.11 2.4 GHz or 5 GHz	Yes	
Remote Control				
Send Signals	Output Lag	0.5 seconds	Yes	
Receive Signals	Input Lag	0.5 seconds	Yes	
Display				
Display Time	Seconds	Accurate within 2.5%	No	
Display Status	Text	Successfully display text	No	
Sense				
Detect				
Detect Obstacles	Terrain Slope	20^{o} + incline 20^{o} + decline	Yes	
	Obstacle Size	Diameter: 8 in Length/Width/Height: 6 in	Yes	
Detect Visually	Pixel Quantity	8 megapixels	No	
	Video Quality	2,500 to 4,000 kbps	No	HD Quality
Detect Physically	Detection Radius	12 in	No	
Detect Error	Sudden Acceleration or Deceleration	20% increase/s 20% decrease/s	No	
	Sudden Descent	1 in/s	No	
	Reporting Time	1 s >	No	
Mobility				
Maneuver Terrain	Velocity	0.10 ft/s	Yes	Curiosity Rover achieved 0.127 ft/s
	Turn Radius	1 ft	No	
Navigate Obstacles	Terrain Slope	20^{o} > incline 20^{o} > decline	Yes	
	Obstacle Size	Diameter: 8 in > Length/Width/Height: 6 in >	Yes	
Support				
House Equipment	Enclosure Volume	$0.5ft^3$ (8"x10"x12")	Yes	Size estimated through similar rover designs
	Charging Surface Area	$10in^2$	No	Amazon AMX3d
Maintain Stability	Center of Gravity	Low (CG < H/2)	Yes	
***Additional Non-Function Needs**				
Durable	Withstands Environmental Conditions	Yes	Yes	Gravity = 0.144 m/s^2
Economic	Budget Adherence	≤ $2,000.00	No	
Original	Locomotion Style	Distinct from Standard Rovers	No	Wheels commonly used