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Mars Robotic Global Exploration Network

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Abstract

This paper proposes and develops a Mars Robotic Global Exploration Network(MARGEN) to explore Mars on a global range in the air and on the ground at low cost. MARGEN is composed of five robotic crafts that can fly in Martian atmosphere and vertically land/takeoff anywhere on Martian surface. The network is supported by a parent craft, Mars Aerial Nuclear Global Landing Explorer(MANGLE). The rest of the four crafts are the offspring craft, Mars Aerial and Surface Terrain Electric Robots(MASTER) powered by Li-ion batteries at low cost. The MANGLE powered by nuclear fission reactor is also a mobile power station to charge the batteries of the MASTER. The robotic network will move together on Martian atmosphere and land on any location of interest. Each robot will carry instrumentation for atmospheric survey, high resolution cameras for topographical survey, and deep drill for soil sample deeper than 1m. The whole mission period is four Martian years. MANGLE can work all seasons on Mars. However, due to the operating temperature limitation of the batteries, MASTER will only operate during the summer season of Mars, hibernate in the winter, and operate again in the next summer. For the whole mission, the MARGEN will survey a total area coverage of 13,210,675.808 km2 (9.12% of Mars surface). The cost of one MASTER is about 1/1000 of the MANGLE, but a MASTER can almost perform the same exploration missions as the MANGLE system. The MARGEN is hence a system that massively increases the Mars exploration scale at low cost.

1 Introduction

One of NASA's major strategic goals is to expand the frontiers of knowledge, capability, and opportunity in space. Mars exploration has the high priority with the motivation to discover the possible existence of extraterrestrial life.

In 1999, NRC published the guideline for essential capabilities of space exploration[1]. The most important conclusion from their study is that "mobility is not just important for solar system exploration–it is essential. The case is exemplified for Mars, where spacecraft mobility would enable major advances in understanding climate change and geologic history and in searching for direct evidence of past life"[1]. The second conclusion from the NRC study is that the diversity of planetary environments to be explored requires simultaneous development of some combination of wheeled rovers, aerobots(balloons), aircraft, and touch-and-go orbiters. The NRC study requires the platform mobility to have extensive range and long lifetime. Furthermore, for soil sample acquisition and examination, it is necessary to remove the thin rind of weathered materials on the planet soil surface. Even though the compositions of the rinds are of great interest, they will not

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provide a reliable inventory of the elements present in the fresh material. The NRC study points out that it is extremely important to develop the capability to drill deep into the soil up to depth of one meter or more instead of just micrometers to a few center meters. The high mobility and deep drilling capability pose extreme challenges to the spacecraft, which is limited by their weight, size, power, and energy available. Current spacecraft still have not met the requirements outlined by the NRC study[1].

As the efforts of deep space exploration, NASA has sent landers, rovers, and orbiters to Mars to perform various scientific missions, including the recent Curiosity rover and MAVEN orbiter. These rovers have the ability to examine surface samples, but the range is at a "point" scale. The orbiters do have a global scale range, but the high altitude limits the observation resolution and there is no capability to examine near surface atmosphere, such as crustal magnetization, spatial variability, potential biogenic gases, volcanic gases, and Martian atmosphere's boundary layer, etc.

To bridge the gap between rovers and orbiters for science missions with high resolution survey from 1-2km kilometer range, many efforts have been made to develop Martian aircraft. There are two challenges in designing an aircraft for Mars: 1) low atmospheric density and low Reynolds number, which causes conventional airplanes to have low wing loading(i.e. large planform area); 2) the carbon-dioxide dominant atmosphere can not be used as an oxidizer for air-breathing engines to generate high thrust.

In the late 70's, comprehensive Mars airplane concepts were studied by DSI with NASA[2]. The "Mini-Sniffer", developed by Akkerman, proposes a hydrazine fuel engine with a propeller and made it to the final concept list. However, its scientific mission is limited due to the small payload and short range. Other power systems considered included battery and fuel cell systems, which were not feasible due to low power density.

The ARES(Aerial Regional-scale Environmental Survey of Mars)[3] airplane was a rigorous effort made by NASA in the early 2000's to achieve an advanced science mission. It cruises at Mach number 0.65, with an altitude of 1.5km and CL=0.5-0.7. ARES is powered by a rocket engine with a fuel payload of 48kg. ARES has a total mass of 175kg, flight range of 500km to 600km, flight time of 4.2 hours, and endurance time of 60-70 minutes.

Another potentially useful airborne system for Mars exploration is balloons, which either use the gases lighter than the ambient atmosphere or heat the enclosed ambient atmosphere gas. A balloon with the autonomous position, altitude control capability, and landing capability is termed an "aerobot". The balloons share many of the advantages of Martian aircraft. However, they have some serious disadvantages: 1) the payload is very limited due to the thin atmosphere on Mars and the large size of the balloons; 2) it is very difficult to control navigation, altitude changes, and landing in the Mars environment.

The battery powered electric aircraft or robotic systems are potential low cost platforms for Mars exploration if they can be recharged. However, the current Lithium based battery still has very low power and energy density. It can also only work in the summer season on Mars due to the charging temperature requirement. Battery technology progress is slow and uncertain. The promising Li-air battery being developed on Earth can not be used on Mars due to the scarcity of oxygen molecules in the atmosphere. Even based on the advanced long range electric aircraft recently developed[4], to cover the whole Martian surface, it is estimated that at least several hundreds distributed power stations are needed to charge the batteries. This would be extremely costly. A feasible and economic way to make electric aircraft work is to have mobile power stations that can move freely on Mars to recharge the batteries wherever the aircraft need.

In general, the existing platforms have a single mission. For example, the rovers can only examine a very small designated land area and can not survey the atmosphere. The low power radioisotope thermoelectric generator used to power rovers are not able to conduct deep sample drilling. The airborne systems of aircraft and balloons may have a regional scale range, but have no or very limited capability to examine the soil on Mars surface.

Since it is very costly to send any mass to Mars due to the long distance and travel time, it is appealing to send a robotic system with minimal weight that is able to perform multiple scientific missions to explore both the surface and atmosphere of Mars with global scale mobility. Such a system will revolutionize our venture to understand Mars and the ability to explore this neighboring planet. This paper proposes and studies such a robotic network system.

Figure 1: MANGLE at cruise.

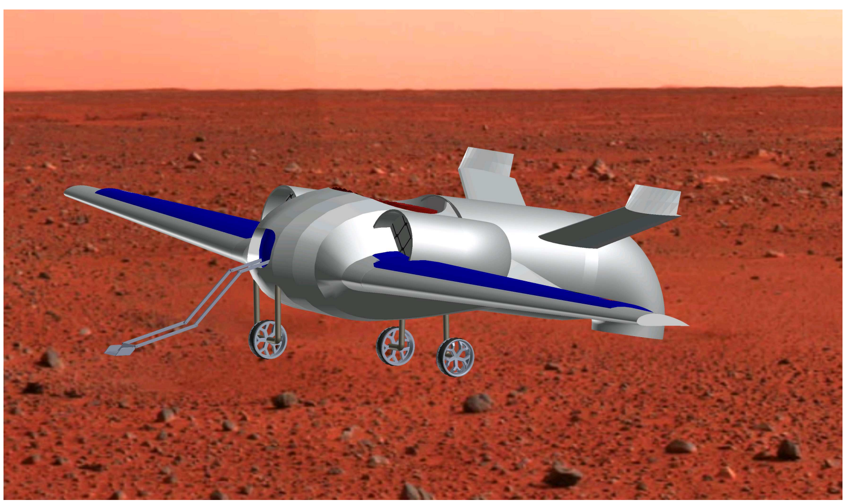

Figure 2: MANGLE vertical landing to take soil sample.

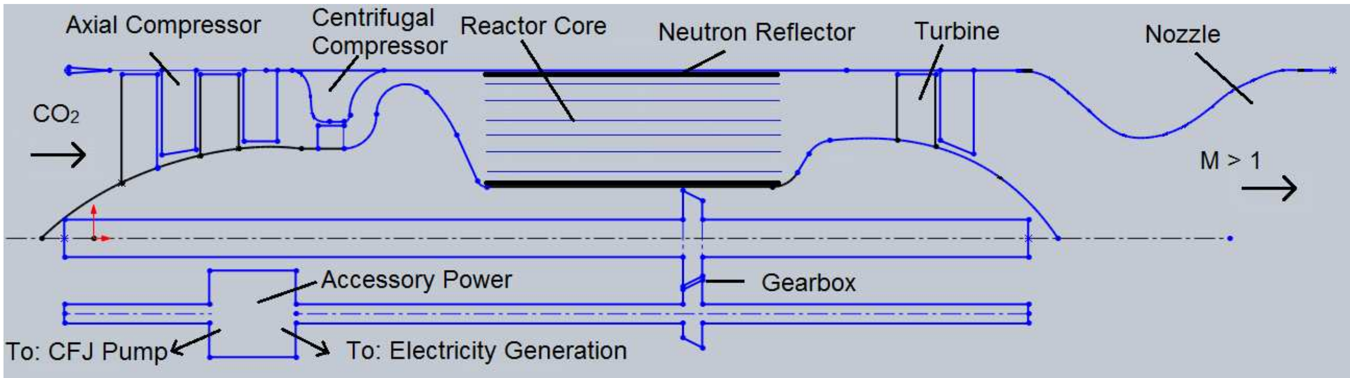

Figure 3: Carbon-Dioxide air-breathing engine sketch.

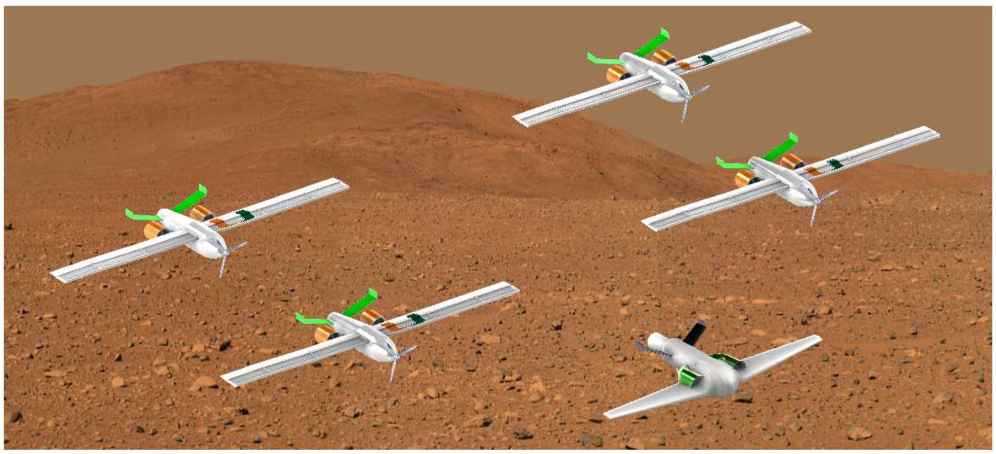

Figure 4: Mars Robotic Global Exploration Network fleet in flight.

2 Mars Robotic Global Exploration Network

The Mars Robotic Global Exploration Network(MARGEN) is to explore Mars in a massive scale on a global range in the air and on the ground. MARGEN will be composed of five robotic crafts that can fly in Martian atmosphere and vertically land/takeoff anywhere on Martian surface. The network is supported by the parent craft, Mars Aerial Nuclear Global Landing Explorer(MANGLE). The rest of the four crafts are the offspring craft, Mars Aerial and Surface Terrain Electric Robots(MASTER) powered by Li-ion batteries. Fig. 4 shows the network fleet in flight. The MANGLE powered by nuclear fission reactor is also a mobile power station to charge the batteries of the MASTER. The robotic network will move together on Martian atmosphere and land on any location of interest. Each robot will carry instrumentation for atmospheric survey, high resolution cameras, and deep drill for soil sample deeper than 1m. The cost of one MASTER is about 1/1000 of the cost of MANGLE, but a MASTER can perform about the same exploration missions as the MANGLE. Such a network can hence massively expand the exploration scale on Mars at a very low cost.

3 The Mission

MARGEN is a multi-mission robotic network system. It will not only perform a science mission to conduct topographical survey and investigate Martian atmosphere on crustal magnetization, spatial variability, potential biogenic gases, volcanic gases, and Martian atmosphere's boundary layer, but also land collect and examine soil samples at the locations of interest determined from the aerial survey. The whole mission period is four Martian years to investigate the seasonal variation of the atmosphere and surface soil. MANGLE can work all seasons on Mars. However, due to the operating temperature limitation of the batteries, MASTER will only operate during the summer season of Mars, hibernate in the winter, and operate again in the next summer. For the whole mission, the MARGEN will survey a total area coverage of 13,210,675.808 km2 (9.12% of Mars surface).

4 Mars Aerial Nuclear Global Landing Explorer

Zha et al [5] proposed a multi-mission Martian explorer platform with global mobility, the Mars Aerial Nuclear Global Landing Explorer(MANGLE). MANGLE is an aerial and ground system powered by nuclear propulsion to fly in Martian atmosphere as shown in Fig. 1 and 2. MANGLE has the vertical takeoff/landing capability realized by a lifting fan in the front and a vectored nozzle at the end of the engine. It is able to roam within a very short range on Martian surface to adjust its position for sample acquisition and examination. The 95.3% carbon-dioxide based Martian atmosphere will be used as propellant for an air-breathing engine heated by a fission nuclear reactor based on an open Brayton cycle as sketched in Fig. 3. The engine will generate both thrust and accessory power. The minimized weight of the vehicle is attributed to no carried on propellant and radiator as well as the extremely high power and energy density of nuclear fission. The ultra-high lift co-flow jet (CFJ) flow control airfoil, shown in Fig. 5, will be implemented on the blended wing-body configuration to achieve a cruise lift coefficient of 3.5, which is 5 to 10 times higher than that of a conventional airfoil. The multi-mission system requires a large amount of energy consumption, which is satisfied by the enormous energy capacity of the nuclear propulsion system. Due to its excessive capacity of power from nuclear fission, MANGLE can be also used as mobile power station to charge other robotic systems. The details of the feasibility study and design of MANGLE can be seen in[5].

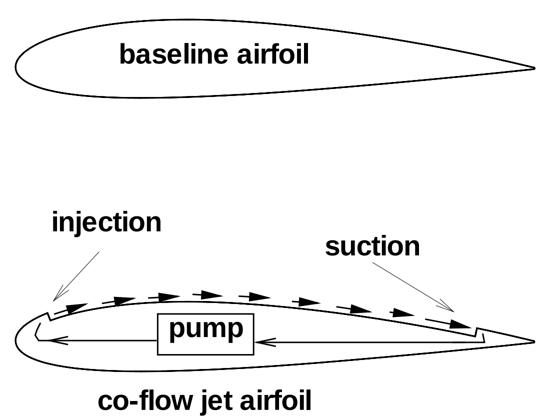

Figure 5: Co-flow jet flow control airfoil.

5 Mars Aerial and Surface Terrain Electric Robots

Mars Aerial and Surface Terrain Electric Robot(MASTER) has the same features as MANGLE except that it is powered by Li-ion batteries to reduce the cost. It is a flying robot with vertical takeoff/landing capability. The aerodynamic design is different from MANGLE since the propulsion system is different. MASTER is propelled by a front propeller and two rear ducted fans as shown in Fig. 6. The front propeller and ducted fans can rotate 90° for vertical takeoff and landing.

The wings are designed to fold into a "Z" shape so that there would be enough room to put at least three MASTERs in a single payload in the aeroshell, see figure below. The "Z" fold limits the Co-flow implementation to approximately 2/3 of the wing for a pump system. Table 1 shows the aerodynamic parameter list of MASTER.

The internal components are separated into sections. The front contains the motor for the propeller and the mechanisms for moving it. The middle of the aircraft will contain majority of the battery, the design is chosen so that the center of gravity is more in front of the neutral point of the aircraft. The back will either contain the drill or a laboratory. Each MASTER will have a camera system for surveying the surface. The batteries cannot work in extreme cold of the Martian atmosphere, so a summer mission should be done. Once the batteries are active, the heat they emit will help keep each other at operating temperatures. MANGLE will recharge the MASTERs depending on their flight plan.

Proper analysis of MASTER's weight is necessary for design of the vehicle and determining the amount of battery carried. Taking the components of the MANGLE design[5] and replacing the weight with the NCA lithium-ion battery cells gives the first approximation of total and battery weight. The breakdown of weights is given in Table 2.

Initial battery sizing is determined by using the volume left open in MANGLE after the removal of the nuclear engine. Using a diameter of 0.98 m and a length of 1.7 m gives a total available volume of 0.41 m3 or 408 L. The total mass of the batteries would have to fit in the available volume, preferably by a large amount in order to leave room for air circulation. Using the 630 Wh/L energy density, a total energy available was calculated as 547,147 watt hours for the available volume. Using the 233 Wh/kg specific energy gives an available battery weight of 1,103 kg, which more than doubles our initial design weight. Further calculations will continue to use 474.17 kg. of NCA lithium-ion batteries.

Fig. 7, 8, 9 are the 3 projection view with dimensions of MASTER.

5.1 Power Requirements/Usage

The total energy of the carried battery is 416,883,600.00 J. The energy required for drilling, climb to cruise, and takeoff and landing is subtracted from the total to give the power available for cruise. Energy required for drilling for one hour is calculated as 5,401,440 joules. This is determined from the power relation: $P = VA$, with the current and voltage supplied from manufacturer specifications located in the optimization section. The power used for climb and cruise requires the calculation of the drag, D. Since the MASTER system is powered by propellers it can use the relation

$$P = \frac{DV}{\eta} \tag{1}$$

where η is the propeller efficiency and V is the cruise velocity. The initial MASTER aircraft properties are given in Table 1.

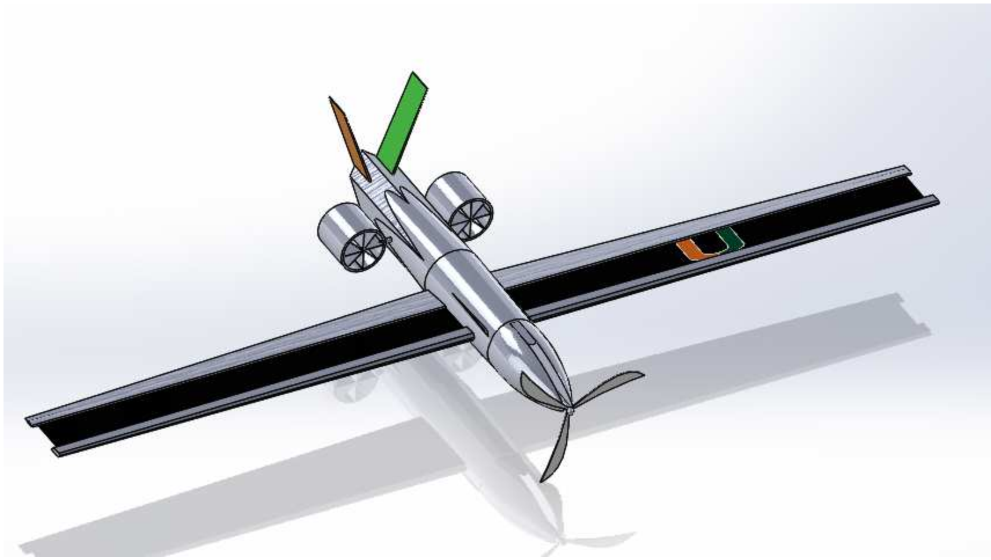

Figure 6: MASTER Configuration.

Inputs		
Mass of system (m_s)	899.31	kg
Platform Area (S)	12.00	m^2
Propellor efficiency (n)	0.80	
L/D (L_D)	12.00	
Cruise Mach (M)	0.38	M
Outputs		
Mass of battery (m_b)	474.17	kg
Weight of System (W)	3,351.10	N
Velocity Cruise (V_c)	91.66	m/s
Drag at Cruise (D_c)	279.26	N
Lift (L_c)	3,351.10	N
Coeff of Lift (CL)	3.5	
Coeff of Drag (CD)	0.2917	

Table 1: Aerodynamic parameters of MASTER.

Instrument/Item		Mass (kg)	Weight (N)
Instrumentation Suite	Magnetometer (x2)	10	37.3
	Panoramic Camera (x2)		
	Point Spectrometer		
	Mass Spectrometer		
	Air Data System		
	Barometer		
	Radar Altimeter		
Computer and Data Collection System		5	18.65
Communication Components	UHF Antenna	5.85	21.8205
Landing Gear		12.2	45.506
Aircraft Skin		30.88	115.1824
Aircraft Structural Support		100.73	375.7229
Battery System	Battery	474.17	1768.6541
Drill	BlueRock: Z-1WS Coring	18.2	67.886
Propellor Motor	Pratt & Whitney PT6	122	455.06
Lifting Fan		15	55.95
Co-Flow Jet System		5	18.65
Radioisotope Heater Units (12)		17.28	64.4544
Miscellaneous Weights		30	111.9
CheMin		10	37.3
SAM		40	149.2
iXA 180		3	11.19
Weight Totals:		899.31	3354.4263

Table 2: Component weight list.

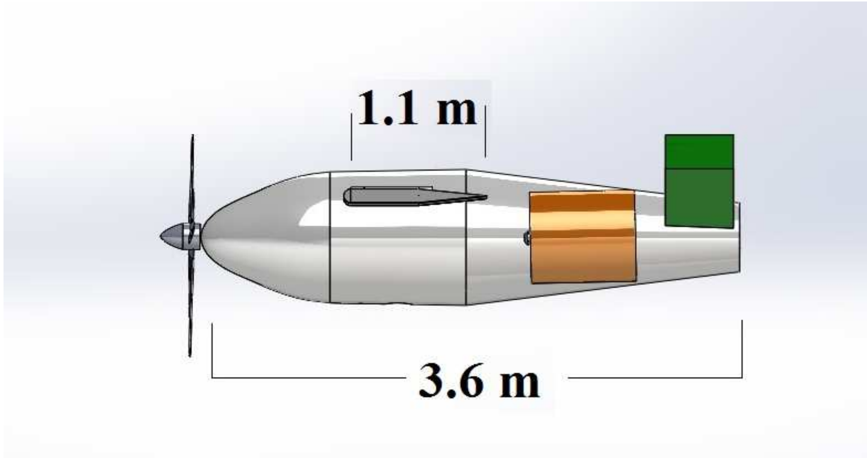

Figure 7: MASTER Configuration.

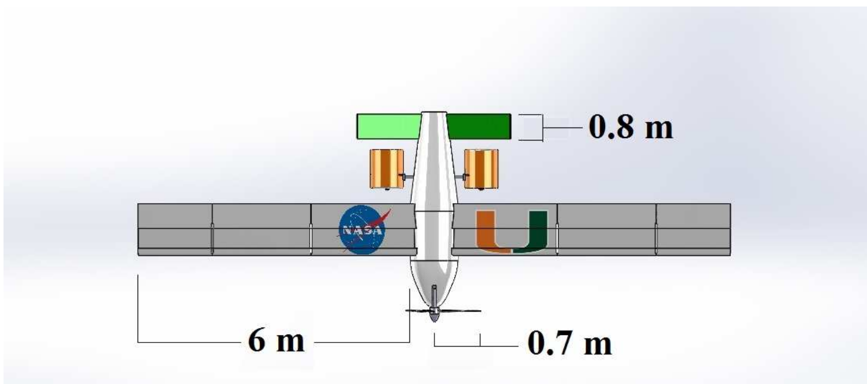

Figure 8: MASTER Configuration.

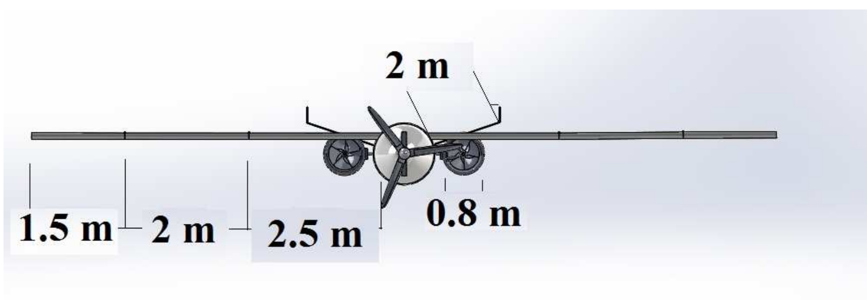

Figure 9: MASTER Configuration.

5.2 Range Calculations

Using the power and drag relation from the previous section gives a power used during cruise value of 31,987.91 J/s,

$$R = Vt \tag{2}$$

where R is the range, V the cruise velocity and t the cruise time of the aircraft. The cruise time is equal to the time to drain the battery, which under ideal conditions is

$$t = \frac{W_b E}{P_b} \tag{3}$$

where W_b is the mass of the battery, P_b the power drawn from the battery, and E is the energy available for flight.. Substituting t to the range equation yields

$$R = \frac{W_b E}{P_b} V \tag{4}$$

The time was calculated to be an average of 11,235.85 seconds (3.12 hours) and a range of 1,029.93 km for the first summer, 8,465.88 seconds (2.35 hours) and a range of 776.02 km for the second summer, 5,723.06 seconds (1.59 hours) and a range of 524.60 km for the third summer, and 3,044.96 seconds (0.85 hours) and a range of 279.11 km for the fourth summer.

5.3 Battery Charging

MASTERs batteries will be charged by the excess power available from the MANGLE engine while stationary. The energy of MASTERs batteries is equivalent to 257,147.10 watt hours. Using a max charge voltage of 375 V, and the relation:

$$Ah = \frac{E}{V} \tag{5}$$

where A is the max current in amp-hours, E is maximum energy in watt-hours, and V is maximum charging voltage. Using the same relation as above with the same voltage and using engine available power instead of energy, the relation is:

$$A = \frac{P}{V} \tag{6}$$

and dividing the maximum charging current by the current required for power available gives

$$t_{charging} = \frac{Ah}{A} \tag{7}$$

This gives the charging current for MASTER's batteries at 295 amp hours. MANGLE's engine can provide 200 kW of power. Using the power relation along with the max charge voltage of 375 V results in a charging current from MANGLE as 533 amps. These values give a charge time of 0.58 hours, or roughly 35 minutes. MANGLE also has the capability of charging two MASTERs simultaneously at 200 kW.

5.4 Time Limitations

Lithium-ion batteries suffer a loss per charge of 0.036%. Based on the maximum flight time of 3.12 hours and the 0.58 hour charge time

$$C = \frac{178 t_s}{t + t_{charging}} \tag{8}$$

Where C is the charges needed for 1 Martian summer, t_s is the daytime hours of a Sol, 178 is the Sols in a summer, t is the average flight time, and $t_{charging}$ is the time it takes to charge. MASTER will need 593 charges over the first Martian summer day- long mission. 748 for the second, 1,011 for the third, and 1534 for the fourth summer.

$$E_{min} = E(1 - (0.00036C)) \tag{9}$$

Where is the energy capacity after 1 Martian summer and 0.00036 is the loss of 0.036% loss per charge. Therefore, after 1 summer of continuous flight in the day and charging MASTER's battery capacity will have decreased from 404 MJ to 315MJ. The battery decay drops the flight time and range down to 2.74 hours and 902.57 km respectively. This same method is applied to calculate future summers but using E_{min} as the new E. After 4 Martian summers, MASTER will only be able to fly for 0.48 hours and thus would no longer be able to fly long enough to be able to produce significant results.

From here on out, the averages for time of flight, range, and number of charges will be used over the the four summers. For the network as a whole the different averages for the 4 summers will be averaged together so that the network is covering the same area each summer. This allows for a simpler mission design.

5.5 Topographical Survey

The basis of the topographical survey is strongly linked with how much ground the MASTERs cameras capture at 1.5 km cruise altitude. Mission parameters for photo flights with digital cameras are determined by the ground sampling distance. The ground sampling distance is explained in the following equation and figure:

$$GSD = \frac{h_g}{C_k} pixel \tag{10}$$

where h_g is the flying height above ground and C_k is the camera's focal length.

The IXA 180 has a focal length of 0.07 m, a camera sensor size of 10325 by 7760 pixels, and a pixel size of 5.2 micron. Converting pixels into meters and using the equation for GSD gives a ground coverage of 1.15 km by 0.86 km. The distance between the center of two adjacent pixels can also be calculated as 11.1 cm from the GSD equation. This is a remarkable improvement from the ground sampling distance of 30 cm from images taken by orbital satellite cameras such as the half meter long HiRISE camera currently in use on the Mars Reconnaissance Orbiter.

6 The Network

The use of MANGLE as a mobile charging station allows multiple MASTERs flying while one is being charged. This reduces downtime and eliminates any traveling to charging stations. Based on the 0.58 hour charge time. Therefore, a network of 4 MASTERs with one MANGLE would guarantee continuous flight of three MASTERs, with enough time for MANGLE to travel between the vehicles that need charged, as long as the aircraft are staggered appropriately.

Each MASTER will cover a 2.3 km wide strip from bottom of a square area up to half the range and then move over to create another 2.3 km wide strip back. The rectangle shape is more efficient than circular patterns and allows MANGLE to stay on a central axis that the MASTERs fly out

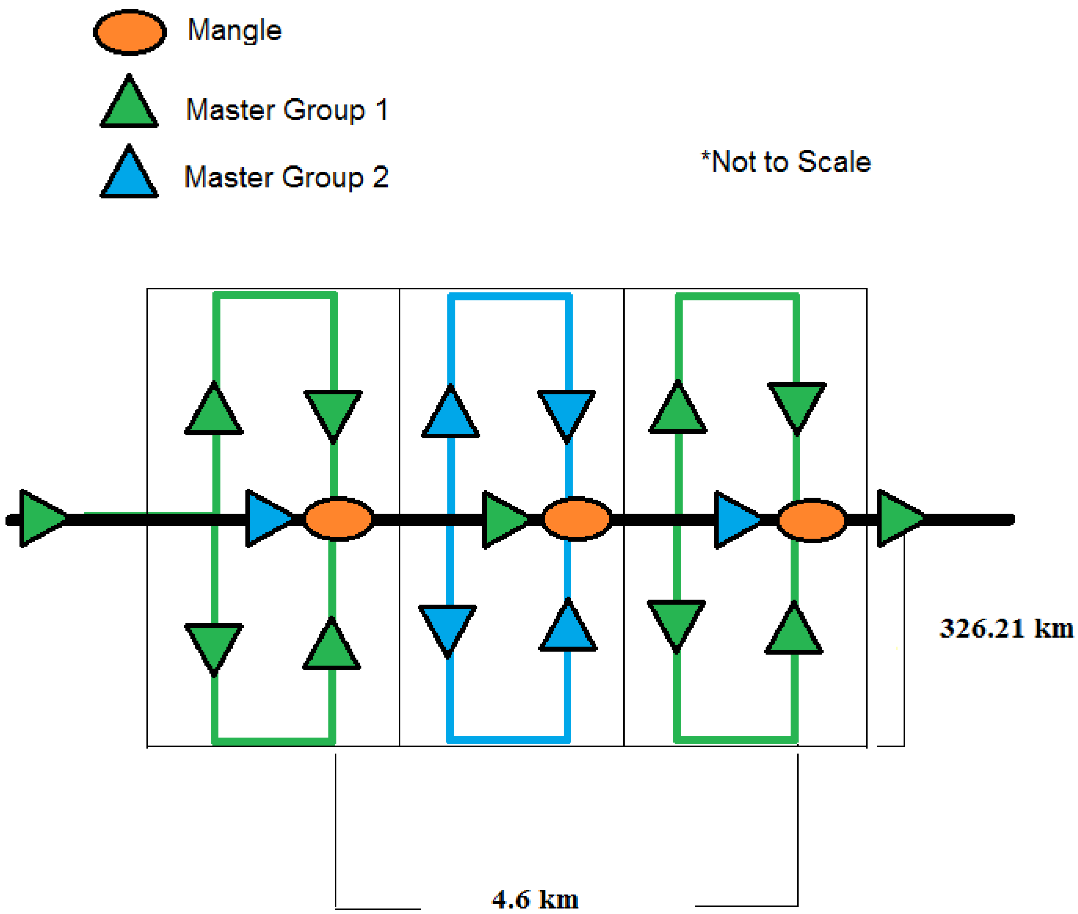

Figure 10: Mars Robotic Global Exploration Network fleet in flight.

and back. For simplicity in visual representation, the following figure shows the flight path of 2 groups of 2 MASTERs and one MANGLE.

The horizontal distance is scaled up to visualize the pattern better, however, MANGLE only needs to travel 2.6 km every 0.58 hours in order to get from the charging point of the first MASTER to the charging point of the second. This should only take MANGLE around 90 seconds after each charge, giving it over half an hour to conduct other missions between charges.

MANGLE will charge two MASTERs at the same time at one location and then the other two MASTERs at the next landing location. The 4 MASTERs depart perpendicular to MANGLEs flight path. MASTER 1 travels upwards;MASTER 2 travels down around half an hour after the first. This trend continues with the third and fourth, so that by the time the first lands and is charged the second will be landing. Then MANGLE moves to the next charging station to charge 3 and 4, while MASTERs 1 and 2 leapfrog to cover the next area. Distance out is half the average range minus the distance traveled parallel between charge.

6.1 Area Coverage

Based on the square area captured by the IXA 180,

$$A_c = A_f F \tag{11}$$

Where A_c is the area covered by 1 MASTER, A_f is the area covered in one flight, and F is the number of flights.

$$A_f = 2pw(\frac{R}{2} - 3pw) \tag{12}$$

Where pw is the picture width determined by Eq. 10, R is the range.

$$F = \frac{178t_s}{t_{avg}} \tag{13}$$

Where t_s is the daytime hours of a Sol, 178 is the Sols in a summer, t_{avg} is the average flight time for that summer.

The area covered in four summers is 13,134,284.765km^2 (9.07% of Mars' surface) before batteries need replaced, if the MASTER spends the whole time taking pictures. If MASTER only took pictures for 2/3 of the summer, it would cover 8,780,785.882 km^2 (6.06% of Mars' surface). Per summer, MASTER would cover 1.52% if only working for 2/3 of the summer and 2.27% if working the entire summer. The reason for the 2/3 summers would be to focus on collecting soil samples during the remaining 1/3 of the summer.

7 Launch System

A flight network of 4 MASTERs and 1 MANGLE will all need to be transported to Mars in the Falcon Heavy rocket. Using the following figure, the payload space available was determined.

The Falcon Heavy has a 109.7 m3 volume at the widest point, using a 4.5 m diameter and 6.6 m length for calculation. It is possible to use up to 11 m in length with a sacrifice to diameter available. This rocket is capable of fitting three MASTERs into a single launch. The aircraft will be configured as an equilateral triangle, nose to tail, while the wings fold in.

This equilateral triangle will run along the diameter of the fairing so that the folded wings go up into the excess space at the top and bottom. The nose to tail distance cannot exceed 4 meters for the 4.6 meter diameter. The 3.6 meter fuselage length gives room for the propeller and the tail. The three MASTERs will be connected to a central pole running the vertical length of the payload fairing. The last MASTER and MANGLE will be in a second Falcon Heavy rocket, configured the same way but with excess space available.

8 Entry and MASTER Deployment

The entry and deployment process of MASTER is similar to the one used for ARES[3]. There are three conditions that need to be satisfied during the entry, descent and deployment (EDD) process of MASTER. In the entry, the MASTERs must be protected from the heat of Mars atmospheric. The entry system must be slowed down enough to deploy the folded wings of MASTER. The deployment will be completed at a safe altitude, at which MASTER is able to reach level flight. The EDD process of MASTER will be completed in six steps. First, the entry system from interplanetary transit has to be slowed down enough to deploy the wings that are folded inside of the entry body. A main parachute is used to slow down the entry system y to the predetermined velocity. The

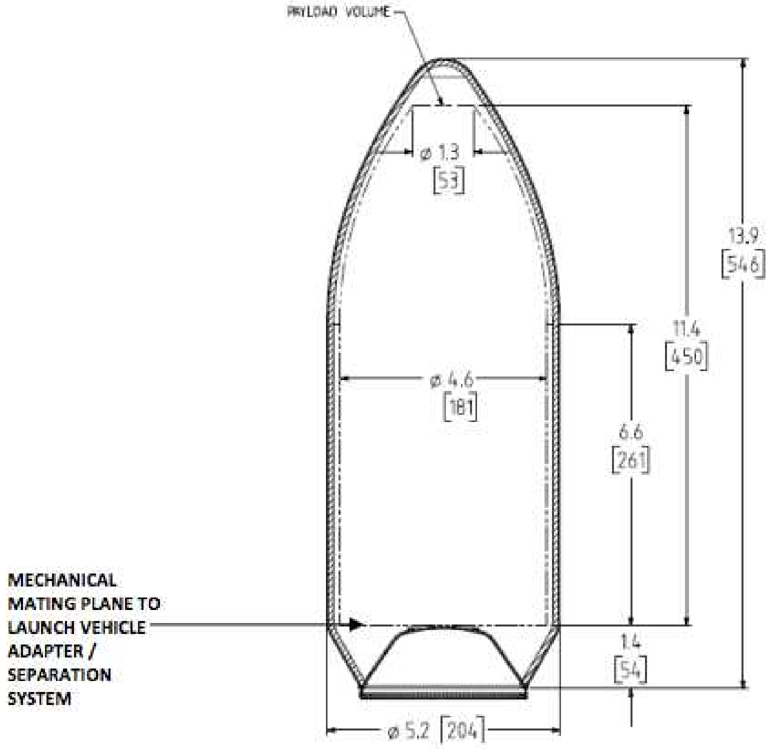

Figure 11: Cargo pod dimensions.

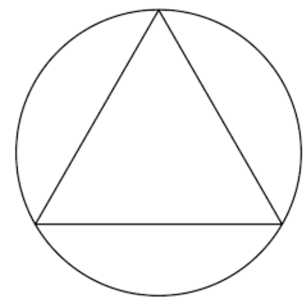

Figure 12: Equilateral formation.

heat-shield will then be released to complete the further deployment (The heat-shield separation distance must be long enough to avoid the collision to MASTER). Since the heat-shield is removed, the three MASTERs will be extracted from the entry system to clear the back aero-shell side. The three MASTERs will then be released in three directions following the geometry pattern (separated by 60 degree). When the three MASTERs are separated far enough, the tails of the MASTERs will be unfolded from the stored positions by the drag of the drogue parachutes. After the tails deployment, the wings of each MASTER will be deployed. The drogue parachutes will then be disconnected from the MASTER. After these six steps, the three MASTERs will reach level flight and form the fleet with MANGLE.

The following figures show the deployment process.

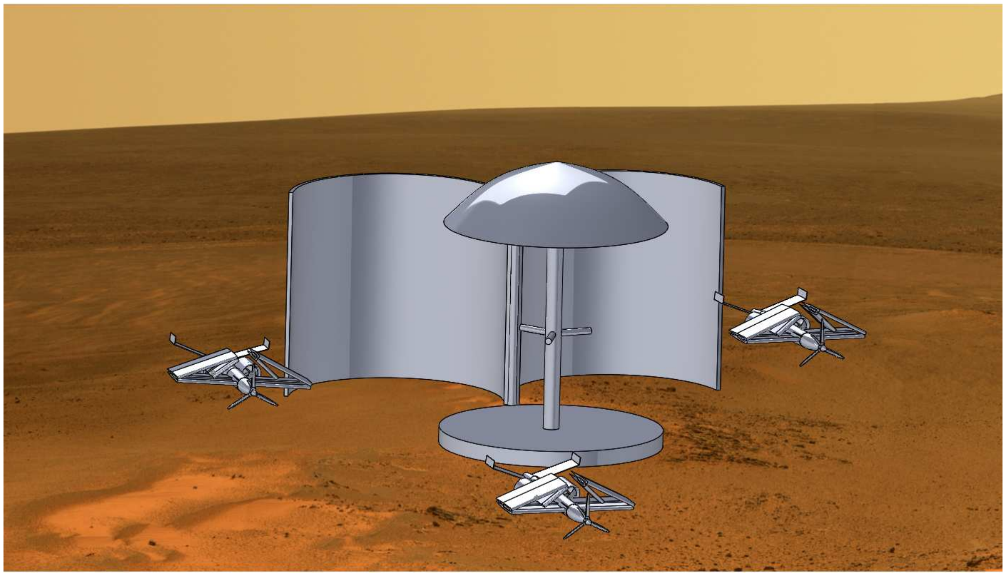

Figure 13: Initial deployment from the aeroshell.

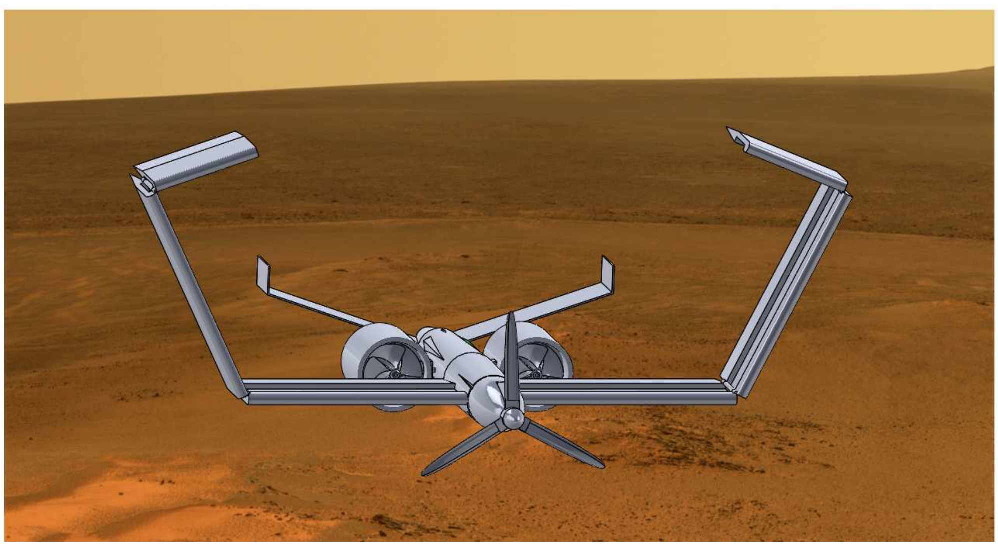

Figure 14: Unfolding the wing at deployment.

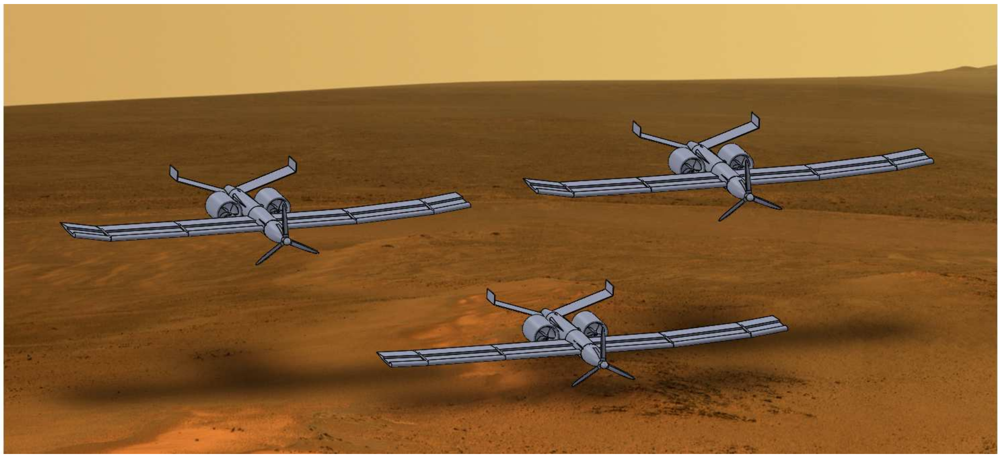

Figure 15: Initial development completed.

9 Conclusions

The Mars Robotic Global Exploration Network is proposed to explore Mars on a global range in the air and on the ground at low cost. MARGEN is composed of five robotic crafts that can fly in Martian atmosphere and vertically land/takeoff anywhere on Martian surface. The network is supported by a parent craft, MANGLE. The rest of the four crafts are the offspring craft, MASTERs powered by Li-ion batteries at low cost. The MANGLE powered by nuclear fission reactor is also a mobile power station to charge the batteries of the MASTER. The robotic network will move together on Martian atmosphere and land on any location of interest. Each robot will carry instrumentation for atmospheric survey, high resolution cameras for topographical survey, and deep drill for soil sample deeper than 1m. The whole mission period is four Martian years. MANGLE can work all seasons on Mars. However, due to the operating temperature limitation of the batteries, MASTER will only operate during the summer season of Mars, hibernate in the winter, and operate again in the next summer. For the whole mission, the MARGEN will survey a total area coverage of 13,210,675.808 km^2 (9.12% of Mars surface). The cost of one MASTER is about 1/1000 of the MANGLE, but a MASTER can almost perform the same exploration missions as the MANGLE system. The MARGEN is hence a system that massively increases the Mars exploration scale at low cost.

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