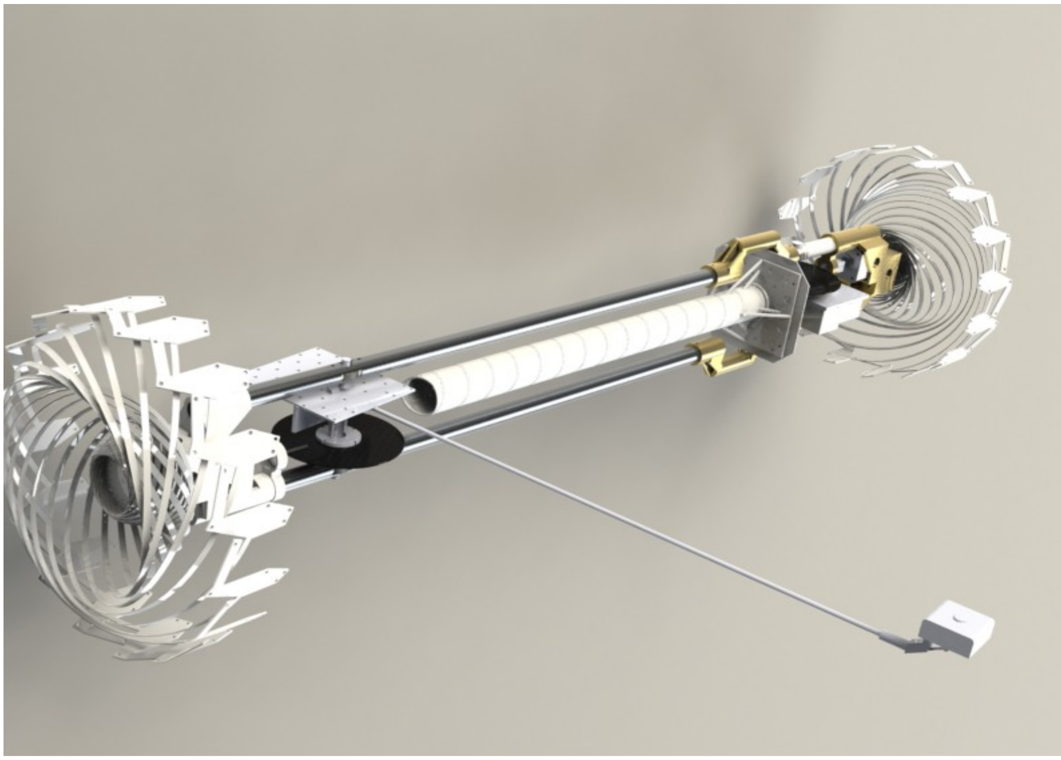
**Team PlanB, Mobility Subsystem, Technical Risk Assessment**



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## 1.0 Summary

Mobility subsystem includes rover weight of 4 kg, Consists of a frame made from carbon fiber. Two wheels mounted on a stepper motors. Antenna mount. Low resolution cameras box. Stand for low resolution camera box. Sealed HD camera box. Counterweight compartment for low resolution camera stand. Symmetrical gears for antenna, and low resolution camera's box. Two additional stepper motors to support movements of a antenna and low resolution camera stand. Gyro-platform with 2 gyro-sensors mounted inside frame, 2 accelerometers, and magnetometer. Additional gyro, and accelerometer sensors mounted on a antenna mount. Additional gyro and accelerometer mounted on low resolution cameras stand. Solar panels mounted on frame. Power energy storage capacitors inside tubes of the frame. Craft avionics inside HD camera box. Solar sensors mounted on a frame. Communication system electronics on reflector of the antenna. 3D printing test equipment for technological experiments on lunar surface includes lens mounted on HD camera box and indium metal dispensing holder.

Mobility of the system supported by two wheels powered by two stepper motors and low resolution camera stand used as sliding leg in 45 degree rotated position. For guidance used a gyro-platform, allowing to keep desired direction. By retracting antenna and leg/camera's stand mobility of a rover converted from 3 touching surface points of the rover to 2 wheel configurations. That allow fast travel down on slop of carter to get as much as possible imaging (HD video) information of a geological observation.

At stops low resolution camera stand moves to a position with best observation to take pictures. Pictures can be transferred at stops in communication session performed by orienting antenna to the earth by gyro-platform based on solar sensor detected sun's direction and center of the moon direction detected by accelerometer of gyro-platform.

Mobility session of the rover is separate from a communication sessions, autonomous, and accepts command from a mission control to support movement in desired direction, with desired distance.

Wheels of rover have springs to allow accumulate elastic potential energy of springs in motion's movements. Harmonic oscillation of individual springs holding loads of the rover

 

will be detected by gyro-platform and can be used to achieve desired direction move on lunar terrain. On tip of spring mounted rims with flat surface. Surface of the spring's rim used to form a molding cavity for 3D printing technological experiment. There are 16 spring in each wheel, which makes possible to form 32 possible molds, or messages can be printed on a lunar surface.

Communication subsystem of the rover is a communication subsystem of the craft. And it is equivalent of a ground station communication system uses 2.4GHz hopping frequency band.

## 1.1 Primary mobility actuators

Two stepper motors are the primary actuators for the subsystem. It can make 200 steps per one rotation, with torque 0.36Nm.

Two stepper motors for antenna mount and for low resolution camera box are capable to make 200 steps per one rotation with torque 0.21Nm.

Both stepper motors updated with ceramic bearings and rated for -70-125 wires.

To lift 4 kg rover by two stepper motors on lunar surface with distance from wheel's rotation axes to surface 0.108m it requires force of 3.26N. Chosen motors provide such torque in a case of deformation of springs of the wheel to 80% of original radius 0.134m of the wheel. That torque and deformation allows avoiding use of gears for main mobility movements. 80% deformation of the wheel applied to individual spring allows movements on slops with 11 degree of angle. To travel on slopes with bigger angles require more compression of the spring. For 45 degree slope it is 51% deformation, or 6.5cm deformation of the spring. One spring allows deformation of from axes on 6 cm under 120-160 gram of load.

To provide the same mobility (for simulation and tests) but on the earth surface need to have torque at least 19.6N. That require at least gear with 1:6 ratio.

To support rotation of the antenna and camera box stand (max mass for both in worse case =0.5kg) on lunar surface needs to have the ability to provide 0.8N force. Gear 1:5 for antenna/camera stand will provide such torque with chosen stepper motors. Gear 1:5 also allows to precise positioning antenna with 0.36 degree on a sky.

To provide rotation of the antenna and camera box stand on the earth (for tests and simulations) it will require force 4.9N. Gear with ration 1:5 allows doing simulation tests without special gear.

### 1.2 Mechanisms for pointing, driving, throttling the primary mobility actuators

Two symmetrical gears used for antenna mount rotation and for camera box stand rotation. Both are made from carbon fiber, steal and titanium. Two surfaces are meshed in gear, one is titanium - titanium which is formed bevel gear, and carbon fiber - steel which are formed crown gear.

For better terrain observation stand with a low resolution cameras can be lifted over lunar surface up to 0.5. In that position imagining subsystem can take make still picture. Stand can be moved to a 75 and 115 degree position in this case to picture will allows to have 4 stereoscopic still picture of a terrain with base distance from picture taking points of 25 cm. Image taking angle for a low resolution camera is 45 degree with 480 degree that allows to have 10 pixels per 1 degree. Assuming 0.25 degree of a precision that allows to measure distances up to 55 meters by processing pictures.

Solar sensor of a craft is embedded into a frame of the rover. In craft configuration it allows detect direction to the sun but rotation of an all craft. Shield of a solar sensor in “craft” configuration is an impact shied itself. After landing impact shield destroyed and holes in tube of a frame provides small shielding of sun light that will reduce precision of solar sensor to 1 degree. Movements of a frame of the rover during mobility sessions allow detecting plane with a sun object in the plane. Two planes detected by gyro-platform allow detecting direction of the sun with precision of 1 degree. Combining this direction with direction of lunar gravity allows calculating direction to the earth. Earth angular diameter is 1.9 degree, which will allow pointing antenna to the earth for communication session with precision of 1 degree.

Low resolution camera box stand in 45 degree position allow to use camera's stand as a third sliding leg for movements, this will allow to climb slopes with 20 degree inclination. In worse case scenario camera stand can rotate to 90 degrees position in this case max slope can be 45 degree.

On HD camera box located lens for technological experiment. In one focus of a lens placed indium metal holder. Orientation of a lens to the direction of a sun with focus on a holder will melt indium alloy and drop of the metal will form small part with "Google" logo on it. (That is in case if "Google" will like to use its logo associated to our lunar mission). HD camera mounted low to the surface can record first 3D printed part. Rotation mechanism of antenna allows having a precise view for lunar regolith. Planned to use rover on even area of a lunar surface to use tip of a camera box to draw the image using mobility of the rover. Formed image will be a used as mold for a second 3D printing test. In this case antenna mount will be rotate and oriented to allow sun light to be in focus of a indium metal holder. Second drop will produced second 3D printed part. Another test for 3D printing on the moon planned - in focus of the lens temperature will be around 1000C that will allow making attempt to "bake" lunar regolith by itself. In this case mount will rotate to a position to attempt to bake particles of a regolith together. Movements will be used to make a wire/line of a formed 3D part. All this can be recorded from closest position by HD camera.

## 1.3 Mechanisms for deployment from craft

Guidance system for lunar descent will include one laser range measurement device. After mission control determined the direction of a firing brake engine, sequence of commands will be send to the craft. First, task will to (a) find the sun, next will be to (b) find "center of moon direction. Based on time of finding the second direction, task (c) will be triggered to store the craft's rotate data, around the axis of firing of the brake engine. After the craft started to rotate with 5 rounds per sec, (d) laser range finder will start to measure the distance to the lunar surface. Attitude control device is no longer needed as a result (e) it will be separated by pyro bolts. When pre-set distance will be reached (f) brake engine will ignite. From that moment a counter will count for a time before fixed impulse will be done. It that moment (g) separation of the shell of the engine from the rover is still attached to the impact shield. Rover and impact shield after this separation will rotate around the center axis. To support the separation, a small "parachute" device (h) will be ignited. It will create tiny impulse to move out from the shell of the engine, and to keep orientation of the rover and impact shield toward lunar surface.

### 1.4 Avionics for surface navigation including sensors for the mobility system

Crafts avionics used on a rover. It is a gyro-platform with 2 gyro-sensors, 2 accelerometers, and magnetometer. Additionally one accelerometer and gyro-sensor mounted on rotation mounts of antenna and low resolution camera stand. Inside of the tube of the frame mounted solar sensor consists of 4 IR sensors. Gyro-platform allows keeping desired direction with precision of 0.5 degree per hour. Accelerometer allows detecting direction to the center of the moon with precision of 0.1 degree. Accelerometer of gyro platform allows to measure vector of force with precision of 2mg. Combined precision of a 4 accelerometers allows to measure 0.001g each 10ms. Error in distance measuring using accelerometers for 1 minute of a travel will be 1.8 m. That allow to detect speed of travel up to 3 meters per min.

Location of the earth on lunar sky is fixed. The angle of a direction to the earth and direction to the center of a moon to in north - south plane is constant. Determination of the location of the sun will be done by solar sensor. Two planes calculated in different frame position gives direction to the sun. Two vector of the direction to the sun and to center of the moon together with a time allow calculating vector of the direction to the earth and north-south direction. To make such measurements rover needs to be moved in two orthogonal positions. It can be done by rotation of the rover.

Movement of a rover set from a mission control as (a) direction from a current stop position (b) distance to be travel, and (c) max allowed time to travel to a position. Sequence of commands with a direction and distance each can be used to navigate over rough terrain. Also in autonomous mode general direction distance and time can be set. In both (detailed and auto) navigation modes gyro platform calculates position and in case of obstacle on the path two type of avoidance approached (i) path shifted to a left for 4 meters to bypass obstacle (ii) if time for all movement allows to try random paths.

When time for movement command passed or position reached the rover made full stop. Than gyro-platform check possibility to point antenna to the earth in stop position. If such move performed by wheel's stepper motors (rotation of the frame perpendicular to a wheels axes) and stepper motor by rotation antenna mount is possible. Than rotation preformed communication subsystem starts to listen to a communication sessions to the earth. If mission control via ground station sends "turning" commands to a rover, then gyro-platform starts to turning to the direction of the earth, by adjusting the direction of the antenna depended on an amount of errors detected in received packets. If in a communication session time window over will not receive "connect" message from ground station, then it will try to rotate itself in stop position. If rotation will be not achieved than rover will perform "random" movements to move into different than original stop position, detects a sun direction and points antenna to the earth for attempt to perform communication session.

### 1.5 Hardware and software for distance verification, including any on-ground processing steps

Mobility moments of the rover will be recorded in main memory storage. Size of the file will be 7K per 1 minute of the movement. Those records optionally/partly can be retrieved by mission control. Each aggregated movement record with just final position and orientation in much smaller size around 200bytes can be optionally retrieved by mission control.

Imagining subsystem perform snap-short picture taken "in stop" position and in "in-travel" cases of changing direction. That "in-travel" position includes changing direction to avoid obstacles, changing direction after passing segment of traveling pass, changing position in case of unavailability to point antenna to the earth. In communication session mission control can retrieve any of pictures from all travel path points to conform final position and to choose next direction. For conformation of a distance travel request to make stereoscopic still pictures can be done after 50 + 10 =60 meters of a travel from landing point, or previous measurement point. In this case analyses of a data stored in DB of a mission control server will be a source for conformation. Retrieved from received packets pictures will be visually conformed to be not "stereoscopic" visual landmarks around landing / previous traveled point. Conformation of non-stereoscopic means that rover travels more that imaging subsystem precision to measure directions, more than 50 meters. Direction to previous land mark / original landing point can be calculated by verification of a data from gyro-platform, accelerometers+ gyro-sensor of low resolution camera stand and image of a previous landmark. Placing on the map both points allows keeping a manual track of the total travel distance from a landing point. Because from a moment of launch till landing will be at least 1 week, in this period of time group of software developers can design implement and debug automatic system for tracing directions based on data stored in DB of mission control.

Other methods of verification of the distance of a travel can be based on landmarks on maps available from previous lunar observation. It is strongly desirable to travel not just for a case of to reach the distance, but for some another useful observation/ scientific data. HD camera's low position location is not good in matter to create nice images of observation of a boring terrain. But if travel will be performed new some geological formation the observation becomes scientific. Such structures are the craters on the moon. To reach and preform such observation with HD camera rolling needs to land on a tip of a big crater. Near (20-30km) prime landing location (S2E15), there are two carters Theon Senior and Theon Junior. Both have around 3 km dip from a tip the rim to a floor of the carter. Theon Senior has small carter on north part of the rim, it is 1000m in diameter and can allow not falling into a crater in case of bouncing of a rover during landing. Travel to a south tip of the crater will be less stiff because small carter is younger. And then travel downhill of a crater floor will allows recording valuable information about all geological formation from top of the crater till floor on the bottom. Final destination of the rover with high probability will be on the bottom of the crater. After conformation the stop location traveled distance can be verified precisely.

## 1.6 Lunar communication subsystem.

**Communication System**

For communication we chose a 2.4GHz frequency. That range is allowed to use (on earth) as long as the frequency channel is periodically switched in a 1 second interval. The core device used is a Blue Tooth front end Nordic semiconductor (nnnn). For power amplifiers was chosen (nnnn). These are the formulas used in communication analyses:

*Power Prx = Ae * S*

*Power Ptx = S * 4 * 3.1415 * R * R / Gt*

*Frequency f= C0 / A*

*Electric field Strength E = Z0 * H*

*Power Flux Density S = E * E/ Z0 = Z0* H * H*

 

*Distance A0 = G * lambda * lambda / (4 * 3.1415)*

*Distance R = Distance Rx - Tx*

| Variable/constant | Value/definition |
|---|---|
| C0 | 3e8 m/sec |
| Z | 120 *3.1415 = 377 Ohm |
| F | Frequency |
| Gt | antenna Gain of a transmitter |
| Gr | antenna gain receiver |
| R | Distance |
| Ptx | Transmitted power |
| Prx | receiver power |
| E | Electric field strength |
| H | magnetic flux strength |
| Z0 | characteristic impedance of free space |
| C0 | speed of light in vacuum |
| Lambda | Wavelength |
| Ae | effective area |

**Further Specs**

- Formulas output on frequency 2.45Ghz
- Transmitter antenna gain 16 dBi
- Receiver antenna gain 16 dBi
- Distance 400,000 km
- Transmitting power of 10Wt
- Electric field strength 273 V/m
- Magnetic field strength 724 A/m
- Power flux density 198 W/m*m
- Receiver amplifier with 140dBm gain is required.

**Blue Tooth Tech**

If core front end RF module is capable to pickup of -83 dBm signal than we'll need an additional N low noise amplifiers to achieve the gain on receiver (140-83+0.9*n)/12.5=n. With n = 5 (5 LNA) it shows a good outcome.  Additional gain is achieved by the antenna, using a "polarized-reduced-size" winding of antenna, or mounting instead of 1 receiver antenna for a ground station. The use of the "polarized" winding of antenna requires additional rotation of the antenna during communication session (antenna's angle position will be at an unpredictable position on the lunar surface).

Transmitter power needs to be at peak: 10Wt to support communication.

Transmitter element has efficiency of a 40% in the medium of 2.4GHz band. For thermal dissipation of communication transmitter will be used radiation ability of a reflector of the antenna and Peltier elements to re-harvest released thermal energy back. High efficiency of Peltier elements allows to recycle 70% of lost on heat (PAE 40% assumed 60% loses) Reflector of the antenna has patches of carbon fiber or/and graphene to increase infrared radiation ability of PCB's copper conductor.

**Communication Protocol**

The communication system uses a triple send packet over 3 different frequencies. Each packet is transmitting via Blue Tooth with a spec max 32 bytes long. On each packet instead of a "unit" address we use a byte as a preamble. Normally, BT device scans RF channel and searches for a "preamble‟ + ″unit address" sequence to start receiving the signal. If the preamble and unit address is matched than the BT receiver accepts the payload data and checks for CRC at the end of the packet. Correct CRC and correct unit triggers an interrupt in BT front end device to inform the receiving device that a message arrived.

Wrong CRC instead generates NAK transmitted by receiver. ACK/NAK is not a practical way to communicate on lunar distances.

**Checksum**

Approach is to skipping packet if something is wrong with the unit address. All packets must be accounted for, preamble, which is the sequence of 10101010 can be destroyed by noise. However, packet by itself can be fine that is why preamble sequence is used as "unit" address. CRC calculation can verify the packet's integrity but it should be done on a high level of network protocol. Packets with broken CRC needs to be accounted for the same way we account for good packets, session might never repeated with the same request (to retrieve HD video for example). The packets are repeated on 3 different frequencies channels. If all 3 packets contain broken CRCs, then an attempt will be made to restore the message by majority voting.  In this restoration process shifts of the data must be accounted for - preamble can loss the first bit and all messages will be shifted as it happens on modern city RF environments.

**Memory Sync**

Communication subsystem comes with an embedded FLASH memory synchronization capability.  Any device on the craft can store data in the exchange area of a FLASH memory. After establishing communication, two RF modules start to exchange data from each other's FLASH memory.  This process happens independently that can be verified by checking the session communication status.

**Communication Device Specs**

Communication system for Craft, nano-satellite is different in terms of a transmitted peak power.  For a craft it is 10Wt, for nano-satellite it is 1Wt.  Mechanically, ground station is equal to a rover.  All communication system on ground station, rover, nano-satellite are logically, and electronically equal each other.  The same goes for the functionality, from a moment of an established session till settings AT set of commands.

**Command Process**

Commands are processed based on a loop of serial communication between each unit on board.  Packets inside the loop transfers using the start and end unit address which logically allows to restore all "loop" data transfer functionality in case of lost/broken packets.  Each unit has its own "unit address".  Two "loops" - one on craft/nano-satellite and another on a ground station connects in time of communication session.  Both loops are equal logically (i.e. gyro-platform on both are perform logically the same way but with input data from different sensors).  Loop on ground station is "open".  Input to loop comes from mission control server from hub/connector software running on a PC based computer and an output is transfer by hub/connector to mission control.  The hub/connector by itself is also a server; it can receive HTTP requests from mission control and can send HTTP requests back to main mission control server.

 

**Additional Avionics Specifications:**

- Included back-up communication system, communicate with ORBITCOM commercial satellites
- Includes solar sensor which are 4 infrared sensors sensitive in 740nm. It consists of a mount with 4 holes on top and 2 orthogonal partitions, separates each sensors. Direction to a sun is an imaginary line of intersection of two partitions. Sensors are connected to balanced amplifier. Attitude control system rotates craft/nano-satellite to match value from all 4 sensors
- Includes infrared detection of the direction to a near celestial body device. It is a two group of IR sensors. Rotating craft/nano-satellite exposed each group to different measured directions
- Can include imaging sensors from mobile imaging subsystem using low resolution camera to determining direction to the nearest celestial body. Processing the picture from low resolution camera (compression to jpeg). This can be done simultaneously with edge detection of the nearest celestial body
- Includes encryption system to encode upload data from ground station.

## 1.7 Thermal control subsystem of a rover

Thermal control includes a combination of passive and active methods to keep the electronics and mechanisms within proper operational temperature boundaries. Passive thermal control measures include a layer of gold on the boxes of the low-resolution camera and the HD camera to reflect solar radiation. Temperature is further stabilized by including 6 water-filled containers, with a total of 0.01kg water, in the walls of the HD camera box. The containers are filled with water and sealed under a 5 mm/Hg vacuum. The passive thermal control system also includes thermal heat conductors for all of the surface mount electronic components. The components are thus thermally coupled with the copper layer on the PCB. Heat conduction is provided by a carbon fiber composite made with a thermally-conductive epoxy.

The active thermal control system of the HD camera has 2 temperature sensors located inside the box and the tip of the box is placed in contact to the ground. A temperature control processor checks the temperature value and signals the main microprocessor when there is an "about to be out of limit" condition. Logic for temperature control has 2 modes: an "on orbit" and an "on moon" mode. The "on orbit" temperature is monitored in the HD camera's power-off state and in each of the different craft orientation positions. Samples of temperature variations at 26 different points are for two conditions of a craft: (A) exposed to the sun, and (B) in the shadow of the earth. Derivatives are calculated on 26 recorded samples and these derivatives are stored as indicators of the cooled or heated state of the HD camera.

When the "on orbit" mode temperature rises to +80C, the power is switched off and a request is sent to the main microprocessor to rotate the craft to a more desirable orientation with respect to the calculated heat sources. An algorithm has been devised to best-fit the stored derivatives and calculate the direction of temperature flow within the box. Thus, the orientation of the craft will change to counteract rising temperatures. Also, when in "on orbit" mode and the temperature falls to -20C and a check for an available level of power returns an "OK to power on the HD camera" state, the HD camera is powered constantly. If the HD camera should be powered constantly, yet the sensors still experience a fall of the temperature to -25C, the power is switched off and a request to rotate craft to a position with high value of the derivatives of the temperature curve is sent to the main micro-controller. Thus, the orientation of the craft will change to counteract falling temperatures.

In the "on moon" mode, while the antenna is in a travel position, the temperature of HD camera is recorded for some period of time, and derivatives for the temperature sensor values are calculated and stored to predict the rise or fall of temperature of the HD camera. The same monitoring of the temperature is performed while in a communication session. At this moment, the HD camera box will be touching the lunar surface and the recorded temperature indications will depend on the heat exchange that is occurring with lunar regolith. This change of temperature is recorded and derivatives of the temperature values are stored to predict the temperature rise or fall when the HD camera box is in contact with the lunar regolith. When in "on moon" mode temperature rises up to +80C, the power is switched off. Touching the lunar regolith may lower the temperature and the effect of lowering the HD camera box will have been predicted by the last communication session. If all conditions are met, a request to touch the lunar regolith will be sent to the main microprocessor. While in "on moon" mode and the temperature has risen to +80C, the power has been switched off, and the HD camera box is already touching lunar regolith, the HD camera may not operate until the temperature within the box reaches operational conditions.

 

Similar logic is applied in a case of an "about to be out of limit" state detected near a low temperature of -20C in the "on moon" mode. If proper operating temperature can be maintained while powering the HD camera, then the HD camera can maintain the power-on state. If maintaining temperature within operational limits is not possible and the temperature can be raised by touching lunar regolith, a request to touch the lunar regolith is sent to the main microprocessor. If neither operation is possible, then the HD camera is maintained in the power-off state.

A special mode of the HD camera can override the temperature out of operational range condition. The HD camera can be switched on or off, it can make a video recording, or an image can be captured.

The camera box with 4 low-resolution sensors is also monitored for temperature in a similar manner as the HD camera box. There are also two modes of temperature regulation: an “on orbit” mode and an “on moon” mode.

In the "on orbit" mode, the power-off state of all cameras and the temperature within the boxes are monitored, recorded, and derivatives of temperature samples inside the boxes are calculated. The temperature derivatives are stored for the 26 possible orientations of the craft exposed to sun and 26 orientation positions of the craft in the earth’s shadow. If the temperature is out of operational limits, then based on the stored derivatives of the temperatures, a request is sent to change the orientation of the craft to cause a rise or fall of the temperature inside box.

Requests for different orientations are supported from each of the different subsystems onboard and are fulfilled by performing maneuvers in many directions as are requested by the different subsystems. Each orientation request is serviced in turn and after both achieving the commanded position to heat or cool a specific subsystem and reaching operational conditions for that subsystem, the gyro-platform accepts commands to orient the craft to each subsequent position. Orientation maneuvers continue to execute for all requests for temperature control. Time to maintain an orientation is calculated based on the temperature of the onboard subsystems; in this case, the low-resolution camera and the HD camera. When moving from the last orientation, the gyro-platform is able to switch off the solid-state gyroscopes without external command as the sequence to move and rotate back to the original position has been pre-recorded by the orientation system. The pre-recorded data may be used with precision and without analyzing data from the gyro-sensors for each specific maneuver. During each of these maneuvers, infrared detectors of the sun and infrared detectors of the edge of a nearby celestial body are switched on and the time between the peaks of these derivatives are calculated (*e.g.*, crossing the edge of the earth). The calculated data are stored and used to determine points within the orbit. The calculations detect the direction of the sun and earth edges while the gyro-platform is powered on and the directional data is used for corrections with respect to the sun and the center of the earth while the gyro-platform is powered off.

In the "on moon" mode of the low-resolution camera, the stand is used for travel assistance.  The temperature recorded inside the box is correlated to the temperature of the regolith.  This allows the prediction of the temperature of the regolith and the prediction of the operational temperature range within -20C to +100C.  When the low-resolution camera's box temperature is out of operational range, the subsystem either may wait for the temperature to come within range or the lunar regolith will be used to cool or heat the camera.

## 1.8 Interfaces to other subsystems

The imaging subsystem's interface includes a connection to the communication subsystem, and eventually, via a ground station, to mission control.  Mission control sends a sequence of commands to control the low-resolution cameras, the HD camera, and to control the mechanisms related to each subsystem's operation.  A sequence of commands will typically be: (A) commands to attitude control subsystem that orient the craft in a specific direction. These commands will be related to the direction of the sun and the earth.  When the attitude control subsystem finishes executing a command for orientation, it sends a command, and (B) to the camera to capture and image.  These typical commands could also happen in reverse order.  The command to capture images can be sent followed by a command to the attitude control subsystem to resume original orientation of the craft.

An inter-unit communication protocol for exchanging data as well as the specific commands designed in such a way that each micro-controller can send a particular sequence to each other without the involvement of mission control.  Each micro-controller has an independent "state machine" that has been designed to perform independent tasks.  The state machines are implemented in the software for the micro-controllers.

# 2.0 An assessment of the technical risk on the way to ensuring the mobility subsystem can successfully complete its part of the mission

## 2.1 Primary mobility actuators

Stepper motor is 17H118D10B.  Due to temperature conditions there is a risk that the stepper motor can lost its magnetic property and torque created by stepper motor will be less than originally anticipated.

There is a risk that under lunar conditions it will be not enough torque to perform mobility of a rover because of reduced performance of a stepper motors and more than 45 degree slope to be travel. Performance can be less than anticipated because of additional friction in bearings, more friction of a low resolution camera box, different performance of lunar soil, and etc.

There is a risk that rover can stack on a terrain because of long distance between wheels.

## 2.2 Mechanisms for pointing, driving, throttling the primary mobility actuators

Mechanisms for retracing low resolution cameras depends in functionality on stepper motor, gear with 1/5 ratio, gyro-sensor mounted on stand, accelerometers, power plant, electrical controls, software. Failure of each can jeopardize functionality of all mission because it do not has any backup.

Gear is 1/5 ratio. Bigger wheel made from carbon fiber. It is mounted on stand and is around rotation axis of the stand. Small wheel of the gear made from titanium -80% silver -19% graphene -1% composite. There is a risk that gear can be jammed by lunar soil, be broken, main wheels cogs as less strong can be broken. lunar soil, be broken, main wheels cogs as less strong can be broken.

There is a risk that in time of the movement low resolution camera stand can be broken, that will be not allow to retract box to high observational point, plus ability of the rover to move will be crippled.

There is a risk that solar sensor will be clogged with dust and will be not able to find direction to the sun.

There are risks that mount of the lens for technological experiment can be broken.

### 2.3 Mechanisms for deployment from craft

Guidance system for lunar descent will include one laser range measurement device. After mission control determined the direction of a firing brake engine, sequence of commands will be send to the craft. First, task will to (a) find the sun, next will be to (b) find "center of moon direction. Based on time of finding the second direction, task (c) will be triggered to store the craft's rotate data, around the axis of firing of the brake engine. After the craft started to rotate with 5 rounds per sec, (d) laser range finder will start to measure the distance to the lunar surface. Attitude control device is no longer needed as a result (e) it will be separated by pyro bolts. When pre-set distance will be reached (f) brake engine will ignite. From that moment a counter will count for a time before fixed impulse will be done. It that moment (g) separation of the shell of the engine from the rover is still attached to the impact shield. Rover and impact shield after this separation will rotate around the center axis. To support the separation, a small "parachute" device (h) will be ignited. It will create tiny impulse to move out from the shell of the engine, and to keep orientation of the rover and impact shield toward lunar surface.

### 2.4 Avionics for surface navigation including sensors for the mobility system

There is a risk that sensors and electronics for data processing can fail because of a temperature conditions and damage by high energy particles.

There is a risk that solar sensor will be clogged with dust and will be not able to find direction to the sun.

There is a risk solar sensor will be clogged by dust and will be not able to detect direction to the sun.

There is a risk that random path movements to avoid obstacles and left avoidance path both can fail to find a proper path.

## 2.5 Hardware and software for distance verification, including any on-ground processing steps

There is a risk that it will be not enough time to transfer all mobility recorded data in a communication session.

There is a risk that imaging subsystem will be broker and low resolution pictures will be not able to obtain to perform measurements of a travel distances..

## 2.6 Lunar communications

**Avionic Risks:**

- Weather condition on a ground station will not allow communication with the craft in critical moment of time
- Noise environment which can ruin the communication session
- LNA and power amplifiers will fail to operate under temperature conditions and vacuum environment
- Damage power amplifiers and LNA by high energy particles
- Calculations for communication subsystem are wrong and communication sessions will be not possible at lunar distances
- Not enough power to support communication
- Triple packets restoration will be not enough to support communication session
- Communication session will have more than expected errors in packets to transfer data with speed for delivery 15 minutes of HD video
- FLASH memory used in communication session will be damaged by high energy particles
- Coder front end RF device and communication micro-controller will be damaged by high energy particles
- Different temperature conditions on a crafts/nano-satellite and ground station can change channels frequencies
- Failure of algorithms and software bugs in on-board avionics
- Communication session ground station communication can be interrupted from mission control

 

## 2.7 Risk assessment of a thermal control.

Active and passive thermal control for both HD low resolution camera and electronics can fail. There is no doubt that can happen despite of all designed measures.

**Thermal Control Risks:**

- Higher than expected heat flow from sun radiation because of damage to the reflection gold layer
- Box with low resolution cameras and HD camera’s box will be not able to move to a position with less/more heat flow, as a result cameras will be not only out of temperature's operation conditions, but can be damaged
- Li-ion battery can be damaged by out of operation temperature conditions
- Failure in software algorithms to keep stable temperature condition. Risk is higher than any other. Reason is - heat transfer via radiation and contact passing between electronic equipment are commonly assumed to be described (heat equation) as a parabolic partial differential equation. That type of equations are described by non-stationary processes, which mean that heat transfer process changes its characteristics with time as time depended function's parameter. Even modern computation methods are available for finding numerical solution, are hard to apply with lot of unknown parameters belonged to real structure. Controlling that processes is hard, because long and hard calculations, delays between "control action" and temperature respond of the system. Best recommendation for control (functions describing process of thermo stabilization) are useless, unless thermal system have a big "heat flow", which are in contradiction with craft / rover condition when heat "expenses" can be "dropped" only by the heat radiation.

## 2.8 Interfaces to other subsystems

For exchange between microprocessor we developed special serial protocol. That protocol allows for the exchange of any data between each unit (micro-controller). HD Camera stores video and picture in the same storage as low resolution picture obtained by low resolution cameras.

**Risk of failure for interface are:**

- Failure, partial or total, of a micro SD FLASH memory because of external events
- Algorithms bugs/errors in implementation of data exchange between units, or between units allocated remotely from each other (mostly this is a failure in algorithms inside RF communication protocol).

## 3.0 scope of the subsystem being developed

### 3.1 Primary mobility actuators

Prototype of the rover was designed. All technological steps to manufacturing flight ready rover were investigated and materials were selected. For a carbon fiber epoxy was chosen epoxy AREMKO-Bond 526N. It allows working with temperature conditions -75C+300C. Curing steps were investigated to have low outgassing parameters for preforming in vacuum. Carbon fiber inserts was manufacturing from carbon fiber's thread. Method can be described as "manually-factoring" - it is a manual knotting technique. Molds for all parts of the rover were designed and 3D printed. For complicated part was chosen technique for manufacturing molds from water solvable material (PVA). Prototyping of wheels was 3D printed. For proving concept was adopted idea to design ground station the same as rover.

Stepper motors chosen in 2010. Particular model of stepper motors was chosen because a best torque performance that regular NEMA N17 motors. From that time model went obsolete. For model were upgraded bearings from steel to ceramic. Motors were tested under different temperatures conditions. Wires were upgraded to wires with insulation material rated for -70+125C temperature conditions.

Gear was designed for antenna mount and for low resolution camera stand with 1:5 ratio. Current version is a combination of a titanium, steel and carbon fiber. Prototype was made for a ground station version of the rover. In summer 2013 was made decision to produce stand for low resolution camera and for antenna mount from titanium instead from carbon fiber. Same 3D model instead from mold creation and manufacturing from carbon fiber can be 3D printed from titanium.

In 2011 it was expensive solution for manufacturing special light weight gear for vacuum and operation temperature conditions. That crates a problem for rover testing under earth gravity. In 2013 were designed 3d printable gears for ground test case. Because gear can be made in-house with titanium silver graphene alloy today, was decided that to reduce risk of inability of rover to travel over rough terrain it is possible to use such gear in main mission flight. Weight of main stepper motor is 260grams. Less torque stepper motor is 200 grams. It is possible to fit gear into 60 grams weight with ration 1.4.

### 3.2 Mechanisms for pointing, driving, throttling the primary mobility actuators

Mount for antenna and box for HD camera was prototyped and 3D printed. Low resolution camera stand was prototyped and 3D printed. Box for low resolution camera was prototyped and printed. Carbon fiber rode for a stand was prototyped. Process of manufacturing of the carbon fiber rood for low resolution camera stand with power and signal wires going throw was investigated and designed. Control of rotation mechanisms with stepper motors was tested in 2011.

Frame manufacturing from carbon fiber was investigated, divided to steps to compline with outgassing requirements. Molds was designed and manufactured. Carbon fiber frame was manufactured.

Rover was assembled in two ground station configurations as (a) two wheels and as (b) simplified ground station. Low resolution imagining system was prototyped in two configuration one with jpeg compression on Z-80 based micro-computer, and another as jpeg camera adjusted to work under vacuum conditions.

Gyro-platform was developed with capability for control craft/nano-satellite. Precision of prototyped gyro-platform was considered enough to support direction in mobility movements, orientation of the cameras and antennas.

For solar sensors was chosen and tested IR detectors. Was prototyped differential methods for detection moment of a crossing the sun light over two detectors.

Technological experiments were prototyped in thermal vacuum chamber.

 

### 3.3 Mechanisms for deployment from craft

Laser range finder was developed and prototyped. In prototyping was used 1mwt laser diode for transmission, also ultrasound transmitter and receiver for simulation of a 10 km laser range distances were tested. Investigating in 1Wt blue laser for possibility to use in laser range finder.

### 3.4 Avionics for surface navigation including sensors for the mobility system

Gyro-platform was developed. Algorithms to use quaternion mathematics was developed and debugged in 2011. Calculation of any vectors for desired direction based on calculated directions was optimized. Methods to work and improve precision of accelerometers magnetometers and gyro-sensors were investigated in 2011.

For mobility of the rover it is more than not really needs to have precision as for gyro-platform for a craft/nano-satellite. Ground (lunar) mobility can be depend on less accurate sensors but with cross-correction of the data between each other. Direction to the center of the moon can be detected by accelerometer. That device produces vector which is constant, and can be measured with desired precision by averaging process. Instead of magnetic field on the moon can be used direction to the sum and time to determine north-south line. Cross correction process named as Kalman filters, that in algorithms that process was optimized to use on low power consumptions micro-controllers.

Was developed all loop for commands processing for controlling rover on the lunar surface. Was developed mission control with DB storage of the all communication data. Mission control is a web server with a collection of all services required for craft/nano-satellite/rover operations. Commands from mission control travels over IP connection to ground stations. Each ground station controls by a ground station hub software which is a web server also. Hub transfer data to / from mission control web server to a ground station via serial comm. Output from ground stations serial communication sent by hub software back to mission control. Mission control and hub is a prime tools support mobility of the rover on lunar surface. Communication subsystem of the ground station is equivalent of a communication subsystem of the nano-satellite/ craft / rover. Commands initiated by mission control reaches rover and data from on-board storage can be retrieved back to mission control for analyses and decision making for next steps of mission.

### 3.5 Hardware and software for distance verification, including any on-ground processing steps

Mobility moments of the rover/nano- satellite/craft recorded by gyro-platform in local data storage. Size of the data around 7K per 1 minute of the movement. That records optionally/partly can be retrieved by mission control.

Imagining subsystem perform snap-short picture. Processing of a pictures can be done by visual analyses.

### 3.6 Lunar communications

Communication system was prototyped. Second hardware version is now in testing. System allows to communicate with 0dBm transmitter (1mWt) on distances of up to 25km. LNA was selected and tested, power amplifiers are selected. Software for cure RF transmitter debugged. Algorithms for error restoration with 20% artificial random error insertion, with all data packets CRC broken, were tested with outcome of restoring all data packets.

### 3.7 Being developed. Thermal control

Temperature sensor DS1822 was chosen to monitor the temperature. Accuracy of the measurement is +-2C from -55C +150C. Sensor has special interface to communicate with multiple device over the same power and data line. This makes it minimum power requirement to get digitized temperature readings. Two micro-controllers can read all temperature measurements for all rover.

Thermal control study for HD camera box and low resolution camera's box was done during experiments performed on extruder system of a workable 3D printer in 2012. In case of extruder task will be to keep temperature 185C as stable as possible. To control temperature extruder uses heating element which can add heat flow into a system. Passive (convention) outflow of a heat is done by cooling elements of extruder. The mechanical characteristics of the extruder provide different characteristics for heat flow in parts of the extruder. Additional airflow can be introduced to increase outflow of the heat from the extruder. 3D printing was chosen because that technology was already designed and implemented with different technique for temperature control.

Temperature sensor on extruder gives temperature readings with precision of 1C. All source code was available to analyze. First we analyzed "bang-bang" temperature control method - basically it is a type of control when temperature reached some level then heating element was switched off or on. This technique allows us to keep fluctuation of a temperature in +-10C range. That method was assumed as a "basic" starting point for the study. Then we used another technique, with accounting dynamics of the heat flow throw the extruder. That technique claimed to be +-1C degree accuracy, but in real tests with independent measurements it did not show any improvements better than +-5C. Logic of the formulas with the explanations of temperature control was clear but it did not reach claimed values. More experiments followed to improve/adapt/change control based on formulas, but without success. Finally an attempt was done to increase heat flow by applying additional cooling fan, and by increasing speed of extracted filament, that improved performance but fluctuation of a temperate still was +-5C. Testing technique with software controlling, used on 3D printers, was assumed to be the same for target HD camera box and/or for low resolution camera's box. Instead of cooling fan in the craft we will use the technique to rotate craft to position with biggest temperature derivative. This derivative will supply the "real" characteristics of a HD/low res camera's boxes. And "real" performance values will be in calculations to keep all cameras equipment under operation’s temperature conditions.

### 3.8 Being developed. Interfaces to other subsystems.

Schematics have been developed (two sequential versions was tested) for connection of a low resolution camera in multiplex mode to main micro-controller. The serial interface of a camera is multiplexed with GPS device serial interface, memory storage serial interface. Software for process the picture from low rec camera allow to be flexible in choose 3 different types of micro-controllers. JPEG compression / decompression developed and debugged on 2 types of processors. HD camera interface includes 6 switches allowed to make turn on/off HD camera, take picture, and a video. That interface was connected to main computer. Main microcontroller can be chosen from one of 3 different types of microprocessors.

Software was implemented to process data from gyro- sensor (ITG-3200) and accelerometer (ADXL345) to properly orient low resolution cameras and antenna with HD camera's box.

For alternatives for a FLASH memory was tested two type of memory – magneto-resistive and ferromagnetic. Both were found capable to substitute FLASH type. Similar footprint of serial FLASH memory surface mounted component. Same protocol of data exchange are used. Benefits - low write memory time, but better withstand of radiation levels. Disadvantage - low memory capacity. We decided that switch from FLASH to magneto-resistive or ferromagnetic memory type can be done even 1 month before flight, by re-soldering already assembled electronics' components.

## 4.0 scope of the subsystem being verified

### 4.1 Primary mobility actuators

For a carbon fiber epoxy AREMKO-Bond 526N was verified procedures of curing to produce low outgassing characteristics of parts of the rover. Thermal test 10 temperature cycles -75C + 125C with 20-30 degrees per minute was performed to verified property of a wheel's carbon fiber spring.

For stepper motors was verified it holding torque. Stepper motors was verified to work after 10 temperature cycles -75+125C.

Gear performance for antenna and camera stand was verified, changes was made in design to support proper gear work. Titanium, carbon fiber and steel were selected for second version of gears. 3D printing was selected as a main method to develop gears.

### 4.2 Mechanisms for pointing, driving, throttling the primary mobility actuators

Assembly of a rover/ground station and ground station in stand configurations was verified to support mobility and ground station orientation functionality.

Method of carbon fiber inserts waiving (knotting) was verified to produce wheel's springs with desired performance.

 

Algorithms for compressing jpeg still pictures were verified. Algorithms for detecting center of circle on a picture were verified.

IR detectors were verified to be use as solar sensors. Algorithms for compare signals from 2 IR sensors for verified.

Technological experiments were verified in thermal vacuum chamber.

### 4.3 Mechanisms for deployment from craft

Nothing was verified.

### 4.4 Avionics for surface navigation including sensors for the mobility system

Gyro-platform was able to detect earth rotation.

Algorithms for quaternion mathematics were ported, optimized, and verified.

Command control of main internal serial communication protocol is under daily verification process.

### 4.5 Hardware and software for distance verification, including any on-ground processing steps

One-sensor's accelerometer data readings used for inertial navigation in 2011 was verified 23m precision on a walk around one city block.

Imagining subsystem was verified to measure 10 pixels per 1 degree with standard lens.

### 4.6 Lunar distance communications

Communication system was verified on a range test with TX power of 0dBm (1mWt) for 1.7km, and 4.8 km in 2013.  Previous tests allowed for the calculation that 0dBm transmission power will allow the support of communication at a distance of up to 25km.

**Communication Verifications:**

- Restoration of a data with artificial introduced all damaged packets. Damage done by altering one random bit in each packet
- Procedure to restoring data with artificially introduced damaged packets.  Damage done by altering 20% of data.  In this case damage for sequential packets was in non-interchangeable place
- Procedure of restoration of the packet with noise damaged to preamble.  That was easy test in urban environment - 1 of 20 packets traveling over modern apartment building has that damage
- Procedure of the restoration of packets with noise damaged preamble when all message including CRC was shifted.  It was also simple test - around 1 from 100 packets in urban environment has that damage
- Procedure for antenna diagram measurements, and was confirmed antenna diagram for helical antenna
- Procedure for matching impact for all cascade of LNA, power amplifiers, and antennas.

## 4.7 Being verified. Thermal control

Temperature verified sensor reading software.  Temperature controlling techniques with applying heat, applying cool capability were confirmed.

## 4.8. Being verified. Interfaces to other subsystems.

The Technique to store data in separate 3 FLASH devices has been verified.  We have 2 solutions - software and hardware.  3 devices (with serial FLASH interface or micro-SD FLASH memory card) used one output data serial pin to store data, and majority voting (2-from-3) from 3 devices on read operation.  Software solution works on all 3 types of micro-controllers, and allows for flexibility to tailor power consumption of flight electronics.

Software can work in 2 different configurations - with 3 output pins for each FLASH device, or with one output pin. Majority voting implemented also is in software. Hardware solution is actually a software solution too. In this case additional micro-controller with small SMD footprint has to be added. In that case it will add an additional weight of 2g. Additional schematics with hardware implementation will include 1 micro-controller, which will require additional routing of a connection traces to FLASH memory. Hardware and software solutions allow work with max speed 25MHz with FLASH memory device.

## 5.0 List the key functional performance and interface requirements of the subsystem and the environments in which it must operate and survive.

### Mechanisms.

Assumption - operating temperature for all mechanism used in imagining system -70 + 125C.

Dust conditions for mechanisms - particles size 10% < 5mkm < 10% < 20mkm < 10%, < 50mkm < 30% < 0.5mm < 40%

Temperature operation conditions for electronics used in imagining temperature operation conditions for low resolution imagining sensors -20+85C.

Temperature operation conditions for HD camera -20+85C Temperature operation conditions for HD camera -20+85C.

Performance by mechanisms - stand for box with low resolution camera has dual use - as a sent to lift camera for high observation point, and as a leg for movements of all rover.

Resonance frequency for mechanics must not be equal to the frequencies of another part of the rover and craft's frame, or crafts engines. Low resonance frequency of a mechanism of imagining subsystem must be high than 30 Hz.

### 5.1 Primary mobility actuators

 

Torque holding stepper motors 0.36Nm and 0.21Nm
Gear for low resolution camera and antenna stand 1:3 minimum.
Gear for earth mobility simulation 1:8 and backup gear for lunar surface 1:4

### 5.4 Avionics for surface navigation including sensors for the mobility system

Gyro-platform from the craft/nano-satellite. Temperature -40+105C. Vacuum < 0.0001 Torr.

Solar sensor dust conditions - particles size 10% < 5mkm < 10% < 20mkm < 10%, < 50mkm < 30% < 0.5mm < 40%

### 5.5 Hardware and software for distance verification, including any on-ground processing steps

Two pair of a human GLAZAs to visual analysis stereoscopic picture, and big piece of paper to draw the path. Calibration picture of angles visible from each low resolution cameras.

### 5.6 Lunar communications

Communication subsystem - TX power in peak 10Wt, sensitivity -145 dBm.

Time precision of no board micro-controllers with 1 sec per 1 month..

### 5.7 Thermal control

Thermal control should keep temperature

- in a range of -20C+85C inside box with low resolution cameras

- in a range -20C +85C inside HD camera's box

### 5.8 Interfaces to other subsystems.

Interface with communication subsystem must have the capability to delivery (via ground station) pictures and video to the mission control, with the ability to restore received packets "on the fly", or ability to restore data later by analyzing stored data of communication packets. Restoration of broken packets is essential for all imagining system functionality. Usually that assumes each protocol layer has limited ability to know what is going on inside. Noisy environment around a ground station is not only main reason mostly that is because pictures and video needs to be delivered from the lunar surface. As a result the "standard" approach with separation of the communication to the layers can be expensive. Data from low level needs to be traced back to command processed, and from opposite side delivery of a video from micro SD FLASH storage needs to be traced as low as possible to broken/lost packets, in this case restoration can be done by applying brutal computer force to approximate payload data. In that case restoration can be done even days after communication session with retrieving video/pictures from rover/ craft.

## 6.0 detail the critical technical risks that must overcome to bring the subsystem to flight ready status.

We as a team do not have any experience in space flight. And we cannot buy any flight experience, because usually anything that we are doing is considered "restricted" information and technology. On the market there are available solutions, however after our initial investigation it shows that those solutions are useless to reduce main risk. Open source solutions do not contain key element require for risk reduction. One possible way to reduce risk is to stay closer to Space Agencies, which is probably the same dream as the dream of reaching the moon.

To overcome that technical risk logical step will be used to fly nano-satellite. Imagining system in this case can show it performance in flight. All mechanical parts for the imagining subsystem including rover can be tested. For such task we have taken steps to make that testing mission possible. We designed and manufactured frame of Nano satellite and designed and prototyped for all mechanics and electronics for Nano satellite mission. An arranged launch was made, which was unfortunately postponed numerous time. Planned time was a spring of 2014 the date was shifted because of technical challenges faced by the launch provider.

Special tests required for certification of the flight on launch vehicle.

 

Testing on vacuum outgassing test, for such test we need to place an assembled rover into a vacuum chamber and as vacuum level reached 8 mTor heat applied to structure till 70C, vacuum level in chamber measurements will be taken during 2 hours. Confirm the "good" outgassing of the rover will mean that there isn’t a "big" increase of pressure inside the vacuum chamber.

Second important test is a vibration test. It is done on full assembly of the craft. Lunch vehicle provider needs to make sure that craft, placed in cargo bay, will not be loose, broken, and mostly will not create problem to lunch vehicle itself. Basically, such testing is performed by lunch vehicle's provider. To prepare for "passing" such tests we need to know resonance frequencies of all parts / frames of the craft. Such study can be done today on CAD simulation software. Requirement is not only to have 3D model to have 3D assembly as one solid structure in CAD simulation software.

Testing, to confirm that manufactured hardware parts of the rover/imaging system are the same as they were in the design we’ll need to do a study on in-house vibration table and acoustic system to confirm resonance frequencies of manufactured parts.

Vibration testing requires regular access to vibration table with frequencies 0-200Hz. Furthermore, acoustic test equipment is able to detect resonance vibration on frequencies 200-1000Hz to detect resonance vibration on frequencies 200-1000Hz.

### 6.1 Primary mobility actuators (e.g. wheels, thrusters.)

It is a critical risk that under temperature conditions permanent magnet on a rotor of a stepper motor can lost its magnetic property and torque created by stepper motor will be less than originally anticipated.

It is a critical a risk that under lunar conditions it will be not enough torque to perform mobility of a rover.

There is a risk that rover can stack on a terrain because of long distance between wheels.

### 6.2 Mechanisms for pointing, driving, throttling the primary mobility actuators

It is a critical risk that in time of the movement low resolution camera stand can be broken.

### 6.3 Mechanisms for deployment from craft

It is a critical risk that after impact rover will be not able to separate itself from an impact shield

### 6.4 Avionics for surface navigation including sensors for the mobility system

It is a critical risk that sensors and electronics for data processing can fail because of a temperature conditions and damage by high energy particles.

It is a critical risk that solar sensor will be clogged with dust and will be not able to find direction to the sun.

It is a critical risk that random path movements to avoid obstacles and left avoidance path both can fail to find a proper path.

6.5 Hardware and software for distance verification, including any on-ground processing steps

It is a critical risk that it will be not enough time to transfer all mobility recorded data in a communication session.

It is a critical risk that imaging subsystem will be broker and low resolution pictures will be not able to obtain to perform measurements of a travel distances.

6.6 Lunar communications

**Challenges to Overcome:**

- Work in urban noisy environment on 2.4GHz frequency and to suppress noise
- Channels shifting under different temperature conditions
- Upgrading software on-board in time of flight

- IR sensors for solar sensor detection and for the system for determination the direction to the center of nearest celestial body

## 6.4 Interfaces to other subsystems

Standard automatic software testing technique used in software development.  Tests confirm the functionality of the inter-unit communication protocol.  That tests are a routine checks performed in development daily.  For double confirmation, we will be considering a list of test’s cases for all commands in imagining control.  That list will includes in main tests list for all functionality on Nano satellite and craft.  Mission control will be able to initiate test list for imagining subsystem.  The tests will be performed before flight.

Same automatic test’s sequences of a functionality of common FLASH memory storage will be incorporated into a mission control.  In time of Nano satellite flight tests for imagining subsystem will be performed by mission control request.

Risk for algorithm’s bugs/errors in data exchange between units, or between devices allocated remotely from each other (mostly those are bugs in algorithms inside RF communication protocol) can be reduced by heuristic process only.  Nothing can be done, except capability to upgrade software in-flight.  It is mandatory to reduce such risks.  Test in Nano satellite test flight will include of upload of software version of all available micro-controllers, with upgrade of all software on board.

## 7.0 Demonstrations planned to verify the flight-ready status of the subsystem.

- “Ground” demonstration with transmitting data over 100km distance in BC mountains, Ground demonstration rehearsal with reducing transmitting power and transmission data over noisy environment (city noise, with 1 mWt transmitter, over 25 km range). Both tests will be recorded and available over YouTube channel. Judges will be invited to attend.

- "Flight-to-Ground" demonstration, with Nano-satellite during communication session, that, most important test will include one communication session over ground station from mission control. Judges will be invited to attend ground station.

- "Flight-to-Ground" demonstration will include taking low resolution and high resolution pictures by low resolution and high resolution cameras on demand. Also for flight ground demonstration on demand will be recorded on Nano-satellite two 15 minutes video clips with 720p HD quality.

- in "ground" and "flight-to-ground" demonstrations, judges will have access to a mission control over web mission control web server.

- in "ground" demonstrations will be a transfer data with pictures and HD video data from Nano-satellite to mission control.

- another "ground" demonstration - low resolution pictures obtained by modified version of the rover (ground station) will be delivered to a mission control.

For a "ground" demonstration it is planned two events. First with pictures of a earth and moon exposed to a Nano satellite suspended by a wire. First demonstration will be combined with a long communication range 100km test. Rehearsal of a long communication range test (first "ground" demonstration) will be at 25km communication range test. Second "ground" demonstration event planned after Nano satellite flight (or instead of a "flight-to-ground" demonstration in a case of a delayed Nano-satellite flight test). That will be with build rover (exception- for a rover's frame - epoxy for carbon fiber will be different from originally chosen for a rover). Another adjustment for second "ground" demonstration event - on wheels' stepper motors will be additional gear boxes, 3D printed from titanium (ether in-house or from 3D factory), that is done to accommodate gravity difference of original rover and it's ground version.

- For the second "ground" demonstration will be short communication distance between ground station and a rover. Transmitting signal will be 1 mWt for ground station and rover.

- For second "ground" demonstration event the lunar regolith will be simulated by a ray flower - it gives the same texture and dusty conditions as on lunar surface will have realistic view.

- For second “ground” demonstration event, typical craters and rocks/boulders will be simulated by a mockup.

- The GLXP logo cluster will be mounted on top of impact shield placed under the rover for a second “ground” demonstration event.

- In second “ground” demonstration event the parts of the frame with mockup of a brake engine, and destroyed impact shield (from tests of impact shield) will be used.

- Illumination conditions - sunrise will be simulated by projector, pointing to solar panels.

- “flight-to-ground” demonstration with Nano-satellite test flight will include pictures obtained on demand from mission control:

- Earth low resolution (at least one picture)

- Moon low resolution picture (at least one picture)

- Earth HD resolution (at least one picture)

- Moon HD resolution (at least one picture)

- earth HD video 15 min, one clip

- moon HD video 15 min, one clip

Frame rate for HD video will be 30 frame per 1 second.

Before “flight-to-ground” (Nano satellite’s test flight) demonstration and “ground” demonstration will be produced and presented "Content Plan for the Moon-cast Ground Demonstration" document.

The low / high definition pictures HD video will available for view and download from mission control server. Password and log-on will be provided.