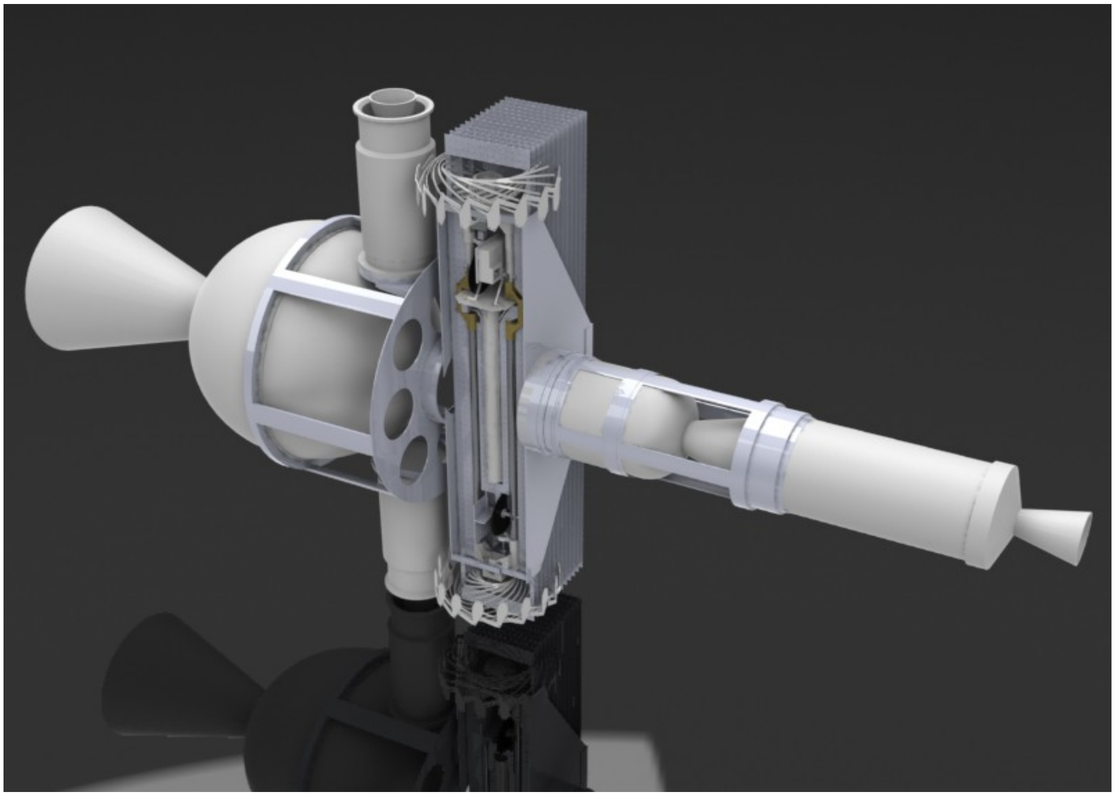
Team PlanB, Landing subsystem, Technical Risk Assessment



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1.0 Summary

The landing system included hardware and software that support a soft-landing of the craft to the lunar surface. Attitude control is achieved by all the devices, of the craft, working harmoniously together. The following outlines the technical design of all devices including antennas, cameras, gyro-sensors, software trajectory, avionics (Blue Tooth).

1.1 Attitude control en route to the Moon

Attitude control consists of gyro-platform, rotation mechanism, and microcontrollers processing all data from sensors, and movements/rotations performed by rotational mechanism.

The following rotational mechanism is used for the landing of the craft. Rotation mechanisms use 3 devices. First - located in nozzle of the brake impulse engine. That device is mounted to the frame stepper motor, with the shaft lying on the line crossing center of the craft. A cylindrical object with the mass of 0.185g and the dimensions 25.4mm x 76.2mm is mounted to that shaft. The other two devices are used to control attitude of the craft are wheels of the rover. These wheels rotate freely; the superposition of the movement of all 3 devices allow for rotation momentum applied to the craft. The device mounted inside is the brake impulse engine it is responsible for the rotation. The speed of the rotation is 5 rounds per second for main impulse burn and for the break impulse. That device is ejected after achieving a rotational speed of 30 rpm before ignition of a brake engine. After the ejection, wheels of the rover will not be used for such attitude control. Instead they will be used for their prime purpose.

Gyro-platform is a two solid state gryro sensors mounted on a frame of the rover, 1 solid state gyro sensor is mounted on antenna mount, 1 solid state gyro sensor mounted on a low resolution camera stand mount, 1 accelerometer mounted on a frame of the rover, 1 accelerometer mounted on antennas mount, 1 accelerometer on low resolution camera stand, one magnetometer mounted on frame of the rover.

Processing all the data from 7 sensors is done by 2 microprocessors located on two independent PCB board.

Attitude control controls antenna direction for communication session for the craft. It is done by separate stepper motor mounted on the antenna stand of the rover. For "on-orbit" configuration, an antenna is set to a fixed position that orient’s it to the ground station. This is performed by the rotation of the full craft. Nano-satellite antenna points to a fixed direction, all nono-satellite need to orient itself for communication session.

Attitude control also controls two low resolution camera fixtures on the rover. Low resolution pictures can be taken on "on-orbit" mode. In "on-orbit' mode the stand fix is opposite of the antenna direction. That is done to reduce the interference from electronics of the antenna and low the resolution cameras. On the nano-satellite, another low resolution camera is fixed. Attitude controls forces the rotation of all nano-satellite to make the desired orientation to take a picture.

1.2 Systems for tracking and orbit determination en route to the Moon

System Trajectory Software

This trajectory calculation software will be based on the ground stations. The stations will be strategically placed all around the globe to facilitate most constant communication. This trajectory software can simulate flights of any satellites while accounting for the gravitational pull of the sun and all celestial bodies.

For orbits near celestial body/bodies, software uses gravitational potential to calculate position orbit of satellites. The software utilizes gravity coefficients for its calculations note, that coefficients are limited by computer power.

Global positioning raw signals are used as input data for the trajectory calculation. Two tools are used in the system tracking software, regular GPS receiver SIRF protocol and raw front end GPS Galileo receiver.

Regular GPS

First tool, the regular GPS receiver is capable of outputting raw satellite date over its interface. GPS SIRF protocol normally reports record ID 29/30. By setting ID 29/30 to output, all raw data from a navigational satellite is sent over serial communication. It includes position, velocity (in geo stationary system), GST time, and internal time stamp of a receiver when the raw data is received. Usually, GPS receiver includes "on-board" calculations with the assumption that the device is located above the earth surface, and is not travelling faster than speed of sound at the altitude less than 10km.

To calculate the position of the satellite we make an assumption, the satellite is flying on the orbit around the earth, with the speed of about 8km/sec. Usually, that requires mathematical formulas to do orbit calculation. For our case we assume that the raw signal needs to be recorded and transferred to the earth mission control by backup communication. Than assuming that orbit's simulation software calculates position of a satellite with the precision within a couple meters. It will be possible to use brute force method to perform iteration steps with attempt to match all observer time stamps with GPS's positions and velocity. Five records will be needed to properly get the orbit. Additional raw data recorded later, can increase precision of orbit determination as long the orbit simulation software is precise.

Galileo GPS Receiver

Second tool, raw front end GPS Galileo receiver, is based on RF from end with the ability to digitize signal with 40MHz frequency. Digitizing is done by RF's front end device it is a 2 bit per sample that requires 10MB of data stored in ROM for 2 seconds of recorded data. Then the microcontroller needs to extract the signals from the raw 2-bits per sample data. Extracted data will equal the data from GPS system with SIRF protocol. Transferring over backup communication (or over main communication session) will make the second system (GPS Galileo receiver) a backup for a first.

Communication Subsystem

In orbit determination it is important to mention the communication subsystem. The communication subsystem allows for the measurement of time travel/distance from ground station to a nano-satellite/craft and back with a precision of 35m. In this case, time measurement will be available right away at ground station location and if the inclination of the orbit (plain) is known then it allows for calculating the orbit (position and velocity in moment of time) based on sequential measurements.

After the main impulse burn, on the route to the moon, global navigation system raw signal will be available only for a brief period of time. When the distance from the earth is far from navigation system satellites, it will be impossible to use GPS/Galileo signal. It is important to record as much raw signals as possible from the main impulse till decay of the signal. That data will be the base of orbit determination and correction impulse on the way to the moon.

Detection Systems

The worse situation will be after the third correction impulse. From this moment of on the only available way for orbit determination will be calculated for the direction to the sun, earth, and moon. It will be impossible to measure vectors simultaneously, but rather in some moment of time. **Two system will be used for this - solar sensor and infrared center of earth detection system**.

Solar Sensor

After turning on the gyro-platform and setting some orientation quaternion as the "zero" direction, solar sensor will search for the sun by the rotation of the craft; the direction where solar sensor points to the sun will be some quaternion from the zero direction. This way two quaternions are known "zero" and "sun" together with a time stamp when the "sun" was detected. Solar sensor consists of four infrared sensors with two separation partitions between them. When level of each of the IR sensors are equal then it will mean the line of intersection of two partitions is directed to the earth. Sequential measurement of the direction to the sun can give earth based trajectory calculation data to match orbit.

Infrared Detectors

Second system will be the infrared detectors. Craft/nano-satellite performed rotation to detect edge of the nearest celestial body. Two projection cones give the time of intersection of the edge of the earth/moon and sky. Based on this direction we can calculate the center of the celestial body. Infrared edge detector uses data from solar sensor and another 4 IR detector with the same functionality as solar sensors. In this case direction of 2 separation partitions will be none parallel to the intersection line of two partitions of a solar sensor.

1.3 Guidance Navigation and Control(GNC) for the lunar descent(including sensors)

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.

Those are all steps needed to be performed by the lunar descent guidance and control system.

1.4 Avionics

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 nRF24L01+. For power amplifiers was chosen standard WiFi power amplifier. These are the formulas used in communication analysis:

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.

Additional Solutions for Orbital Calculation

Communication subsystems have internal measurements from sending packet from ground station to a craft/nano-satellite and back to ground station. It is done to support measurements of a distance from one transmitter to another. Measurements will be used in trajectory simulation software running on a mission control server to determine orbit. That will allow to obtain time stamps (a) when data send to another communication device, (b) data received from another communication device, special "loop" packets travels over two communication devices loads dynamically with 4 historical time stamps. Two sequential "loop" packet will automatically be initiated by mission control and then delivered to the ground station. Later, transmitted to a craft's communication device, processed inside craft's control system, loaded with previous "time stamps" records, transmitted from craft to ground station, loaded on ground station with second sets of time stamps, delivered back to mission control, and stored in DB. Once the packet transmitting loop is consistence the session allows for time estimation of orbit determination.

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.

1.5 Propulsion

As once rocket engine designer said, "You can attach a good rocket engine to the fence and that fence will become a rocket." It was a joke but, we are trying to keep craft the same way, Simple and light.

A study was done in 2011 to investigate a good trajectory to the moon, these were the specs found for the impulse engines:

Part(s)	Description	Weight(kg)
Break impulse engine	weight of the engine, fastening bolts, frame connects to rover and impact shields	16.2
2 correction orbit's engines	weight of the engine, frame, fastening bolts, connected to a frame of a brake impulse engine	6.5
main impulse engine	weight of the engine, frame, fastening bolts, connected to a frame of the brake impulse engine	194.8
pre-main burn engine	weight of the engine, frame, fastening bolts, connected to a frame of a main impulse engine	3.2
1 LEO orbit correction	weight of the engine, frame, fastening bolts, connected to a frame of the main impulse engine	3.2

We are looking for any other opportunities to buy the different fixed impulse engines with same parameters. Price and availability are the same, but are not only the parameters to shop for. For a fixed engine performing brake burn, it is essential to know the precise impulse. This is possible to only get by measuring couple burns and take the average data. That makes brake engine expensive in time rather than in price.

1.6 Touchdown devices

The touch down devices is an impact shield, compensation spring, and small impulse 4 nozzle parachute device.

Impact shield consists from 13 layers of a carbon fiber sheets. Each sheet is designed to be crushed against each other and destroy the next layer. Destruction is supposed to suppress the kinetics energy of failing to the lunar surface rover, and reduce speed from worst case 35m/sec to 0m/sec. This makes acceleration on impact equal to 364g in bad case of a fall from 362m of the lunar surface. Descending with the speed of 25 m/s in a case of Luna-9 was around 260g on impact. Study performed in 2011 showed impact with a speed from 9-12m/sec makes the acceleration from 30 to 40g on impact.

Each layer of impact shield connects to each other and to the rover by the carbon fiber bridge. Impact destroys the bridges which separates the rover from the impact shield.

To compensate for the rotation of the rover and impact shield used carbon fiber spring designed to give rotation moment in time of separation of the brake engine frame and rover. Spring is mounted on the engine and will apply rotation momentum on the impact shield and rover.

1.7 Thermal control of subsystem a craft

Thermal control includes a combination of passive and active methods to keep electronics and mechanism under operation temperature. Passive measures include a layer of gold on a box of the low resolution cameras and on HD camera box to reflect solar radiation. Also, as a temperature stabilizer 6 water filed containers are used in walls of HD camera box with a total of 0.01kg of water. Containers filled with water and are sealed under 5 mmHg vacuum. Passive system includes thermal heat conductors for all electronics surface mount components to be thermally coupled with copper layer on PCB. Heat conduction provided by carbon fiber composite with thermally conductive epoxy.

For active thermal control HD camera has 2 temperature sensors located inside box and tip of the box in place of contact to the ground. Temperature control processor checks the temperature value and signals the main microprocessor "about to be out of limit" condition. Logic for temperature control has 2 modes, “On orbit" and "on moon" mode. In the case of "on orbit" temperature monitored in HD- camera's power off state in different craft's orientation position. It is recorded 26 functions of temperature variations in two conditions of a craft (a) exposed to the sun and (b) in shadow of the earth. On 26 recorded functions calculated derivatives and value of derivatives stored as information indication cool or heat ability of HD camera.

When in "on orbit" mode temperature rises to +80C power switched off, a request is sent to the main microprocessor to rotate the craft to a desired (best fitted derivative of stored temperature flow) direction. When in "on orbit" mode temperature falls to -20C a check for the available level of power returns "OK to power on HD camera" state, HD camera powered constantly. If powered constantly the HD camera still experiences a fall of temperature to minus 25C power switched off and request to rotate craft to position with high value of derivative of temperature curve send to main micro-controller.

In "on moon" mode, each time when the antenna is in travel position the temperature of HD camera recorded for some period of time and derivative for temperature function calculated and stored to predict rise or fall of temperature of the HD camera. The same monitoring of the temperature is performed in time of communication session. In that moment HD camera box touched lunar surface and depending on a lunar regolith temperature appears heat exchange. That change of temperature recorded and derivative of the temperature is stored to predict temperature rise or fall when HD camera box touched regolith. When in "on moon" mode temperature rises up to +80C, then power switched off, and if touching regolith will low temperature, then request to touch the ground send to main microprocessor. If in "on moon" mode temperature rise to +80C, then power switched off, and if touching regolith will rise the temperature, then nothing done until temperature will reach operational conditions.

The same logic is applied in the case of "about to be out of limit" conditions detected with low temperature -20C in "on moon" mode. If temperature can be kept by constantly powering HD camera, then HD camera keeps power on state. If not, and a rise of temperature can be done by touching lunar regolith, request for such operation send to main microprocessor. If both operations are impossible then HD camera is kept off.

Special mode can overdrive temperature out of operational conditions. HD camera can be switched on/off, video recording or picture can be taken, outside of the limits of operation temperature range.

Low resolution cameras (four of them) are located in a special box and in time of travel temperature is recorded inside the box. There are also two modes of temperature regulation "on orbit" and "on moon".

In "on orbit" mode, constantly, in power of state of all cameras, temperature monitored, recorded and derivative of temperature function inside a box is calculated. For 26 possible orientation of a craft exposed to sun and 26 orientation position of a craft in earth shadow stored temperature derivatives. If for some reason temperature is out of operation conditions, then based on stored derivatives of temperatures a request can be sent to change the orientation of the craft and to keep rising or lowering the temperature inside the box to reach operation conditions.

Request for different orientations from different devices on board can be fulfilled by performing orientation maneuver of two or many different direction preferable by different devices. After achieving one position to heat/cool one device and conforming heating/cooling gyro-platform issues orientation commands to turn craft in to second position (requested by another subsystem to be heated/cooled). The orientations maneuvers continue to execute all requests for temperature control from all requested subsystems on board. Time to stay still in each direction is calculated based on temperature of the on board devices (low resolution camera/HD camera). To move from last orientation gyro-platform can switch-off (by itself) solid state gyroscopes, because sequence to move /rotate back to the original position is pre-recorded by orientation system and can be used with precision without analyzing data from gyro-sensors. During each of this movements infrared detectors of the sun, infrared detectors of the edge of near celestial body switched a derivatives (crossing edge of the earth) time calculated, and stored for orbit determinations (in case of gyro-platform is working and detection of a direction of the sun is done). Or that data can be used for sun/center of the earth correction (in case of gyro-platform is switched off).

In "on moon" mode low resolution cameras stand used for travel assistance. Temperature recorded inside the box is correlated to the temperature of the regolith. That allows for the prediction of temperature and operation temperature conditions -20C +100C. Every time when the low resolution camera's box temperature is out of operational range ether it waits to come to range or uses the lunar regolith to cool/heat the camera.

1.8 Onboard autonomy

On board autonomous supported by command subsystem. It consists of a power plant automatic, thermal subsystem requests generation, gyro-platform automatics, nearest to celestial body center determination, sun direction determination, and orientation of the communication antenna to the earth ground station.

Power plant microcontroller controls switches connecting power harvesting devices with individual power storage capacitors. High volume capacitors are operational under designed temperature conditions. Power plant receives craft's orientation vectors from gyro-platform. Performance of separated groups of solar harvesting device under each direction will be prerecorded. Periodically power plant generate request for attitude control subsystem for desired orientation of the craft.

Thermal subsystem received from a gyro-platform orientation vectors of the craft. Thermal subsystem calculates temperature characteristics of key parts of the craft (basically everything is inside the rover). And based on thermal control algorithm in "on orbit" mode send orientation requests to an attitude control subsystem.

Gyro-platform automatics perform calculations to set orientation direction of the craft; usually this is done for communication session, active thermal control of the craft, and harvesting power best direction. Last sequences of commands are sends from gyro-platform to attitude control, prerecorded to be able to repeat on backward order with precise rotation torque performed by stepper motors.

Directions to the sun to the nearest celestial body changes with time. It happens, because of sun, earth, and the moon's rotation around of center of mass of the solar system. In communication sessions quaternions of rotations of that two directions delivered for an interval of time till next communication session. Periodically that "corrections" applied to store in gyro-platform directions. After each "correction" request to attitude control subsystem send to confirm sun and nearest celestial body direction.

At the time of the next communication session, and at periodical time set from mission control, gyro-platform sends request to orient the antenna.

1.9 Interfaces to other subsystems

HD Camera is picked from shelf and tested for functionality in different conditions. It is equipped with socket to micro SD FLASH card, Lithium-Ion battery and interface cable for connection to PC. All this connectors extended via additional mufti-wires cable. Cable can extend out of HD camera carbon fiber box. Lithium-ion battery is connected to the cable outside of the box. Lithium-ion battery is sealed inside epoxy and package is mounted outside of HD Camera box. Two wires from cable provide power +5V to the camera from rover power plant. Wires from micro SD FLASH connector connects to main microprocessor PCB.CB.

Interface of imagining subsystem includes connection to a communication subsystem, and eventually via ground station to the mission control. Mission control sends sequence of command to control low resolution cameras, HD camera, and to control mechanisms related to subsystem's operation. Sequence of commands typically can be - (A) command to attitude control subsystem to orient craft to a specific direction (related to the direction of the sun and the earth). When attitude control subsystem will finished to execute command for orientation, it (attitude control system) sends command (B) to the camera to make a picture. And vice versa - command for making picture after picture was made can send command to attitude control subsystem to resume original orientation of the craft. Inter-unit communication protocol for exchanging data and command is designed in such way that each micro-controller can set sequence to each other without the involvement of mission control. It is some sort of "state machine" in software development. Each micro-controller has independent "state machine" designed to perform independent tasks.

2.0 Risk assessment

2.1 Attitude control en route to the Moon

"Rotation wheels" (or "reaction wheels") can break because of mechanical failure by exposing to vacuum and temperature conditions.

- Stepper motor is 17H118D10B. There is a 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.

- Ejection of a "face off device" can fail at time of ignition of the break engine.

- Gyro-sensor ATG-3200 used in gyro-platform. There is a risk that gyro-sensor can fail because of out of temperature operation conditions, or because of high energy charged particles.

- Accelerometer ADXL342 mounted on a stand. There is a risk that the accelerometer can be fail because of the same reasons as gyro-sensor.

- Risk that configuration with retrieved and fixed position of low resolution cameras and antenna it will be the difference in performance of attitude control.

2.2 Systems for tracking and orbit determination en route to the Moon

System Tracking Risks:

- Trajectory calculations based on in-house developed system. There’s a risk that system can produced wrong values of the orbits
- First subsystem for determining low earth orbit determination based on GPS reciever with capability to output raw navigational satellite data in record ID 29 and 30. A risk that such a receiver will fail to produce ID records 29 and 30
- Distributed calculations of low earth orbit will fail to determine orbit in time
- Second subsystem for orbit determination based on front end global navigation receiver. There is a risk that it can fail because of thermal operation conditions and vacuum environment
- First and second subsystem for orbit termination has a risk of failure because of damage obtained from high energy particles
- Second subsystem for orbit determination, after main engine burn, will be not able to collect data for orbit determination
- Errors in orbit determination after correction impulse on the route to the moon
- Solar sensor will fail to detect sun direction because of damage from high charged particles
- Solar sensor will fail to detect sun direction, and system for detecting nearest center of celestial body because of errors in navigational software
- Nearest celestial body detectors to be damage from high charged particles
- Navigation micro-controller will be damaged on the route to the moon (out of earth's magnetic field protection).

2.3 Guidance Navigation and Control (GNC) for Lunar Descent

Guidance Navigation & Control Risks:

- Determination of the orbit and intersection path with the moon, and direction of the firing of a break engine will be wrongly calculated
- Determination of the direction to the sun before firing brake engine because of time limit
- Rotation will not reach the desired 30rpm before firing brake engine.
- Shock from separation of attitude control community favorite "face-off- hockey-puck" will change rotation vector of the craft
- Laser sensor will fail to determine distance from the lunar surface and command for ignition will fail to be in 10 mks time frame

- Laser emitting device will fail to perform under vacuum and temperature conditions
- Separation (from shell of the brake engine) rover with impact shield will continue to rotate, because of changed characteristics of loaded spring
- "Parachute" device/engine will not move out rover and impact shield from failing to the same spot as a brake engine
- Terrain will be not as predicted on the landing site as a result calculations on time to ignite and direction of firing of brake engine will be calculated wrongly

2.4 Avionics

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

- Failure of solar sensor and direction to the center of the nearest celestial body because of shortage of time
- In case of use imaging sensor capable to detect center of nearest celestial body by processing image from the image sensor, there is a risk of failure of algorithms for such determination.

2.5 Propulsion

Propulsion Risks:

- Failure to ignite any fixed impulse engines
- Ignition of fixed impulse engines at proper time
- Different performance of the fixed impulse engines in vacuum at temperature conditions than expected
- Failure of separation of any frame /engine shell, after impulse is performed.

2.6 touchdown devices

Touchdown Device Risks:

- Different performance than expected of the fixed impulse engine, because of vacuum and temperature conditions
- High than expected velocity at touchdown

2.7 Risk assessment. 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
- In "on orbit" mode it will not have enough power to orient craft in position to support balance of a heat flow to low resolution, HD camera
- 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 Onboard autonomy

Onboard Autonomy Risks:

- Power plant will be not able to harvest enough energy to perform any autonomy maneuvers
- Power plant data not reliable to perform active autonomy maneuvers
- Bugs and errors in algorithms imbedded into onboard autonomy subsystems.

2.9 Risk assessment. Interfaces to other subsystems.

For the exchange between microprocessor we developed special serial protocol. The protocol allows an 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 Attitude control en route to the Moon

Gyro-platform was developed for attitude control. It includes two solid state gyro sensors mounted on two sides of the PCB with axis Z sensitive lying on the same line with opposite polarity of rotation. Axis of sensitivity X will be on the same line of Y axis and polarity of rotation opposite of each other. This allows for compensation for the Z axis and each X-Y axis. Specification of the sensitivity of ITG-3200 allow to detect rotations 0.069 degree per sec, but forcing sensor to undocumented mode will increase sensitivity to 0.0089 degree per sec, and disable internal temperature compensation (which creates unpredictable results in measurements). Placing two sensors with cross compensation allow for the increase in sensitivity to 0.0043 degree (which is sensitivity enough to detect earth rotation 0.0041 degree /sec). Actually increasing amount of sensors to 4 will double that precision to 0.002 degree per/sec.

Quaternion

Next in gyro-platform we implemented quaternion mathematics to calculate rotations and integrate measured values. Quaternion mathematics was optimized to reduce times instruction cycles for targeted micro-controller. Temperature compensation (zero drift) was done by calculating zero drift quaternion function with t (time) as a parameter. It detected periods in compensation quaternion function, and found methods to account periodically for the period of periods of time.

Experiments in 2011 allowed detecting earth rotation in two experiments one with 1 hour test, and another with 6 hours test. In both cases direction to a polar start was equal to normalized vector of quaternion.

Another sensor for the gyro-platform is the accelerometer ADXL345. It allowed measuring the vector of acceleration with precision of 0.004 m/s2. Together with HMC5838 magnetometer both accelerometer and magnetometer allowed for the detection of zero drift of gyro-sensor. Signal of zero drift sets an adjustment for quaternion zero drift function. On orbit such method is not possible, because accelerometer is in free fall, but combination of solar sensor and magnetometer allowed for zero drift events to be registered. Prime device for gyro-platform on low earth orbit will be gyro-sensor and magnetometer, for lunar surface will be gyro-sensor, magnetometer and accelerometer and for lunar trajectory gyro and solar sensors.

In 2011 devices were tested on rotation support with stepper motor mounted and allowed to rotate in horizontal plane. Sending sequences for each step to the motor was visual confirmed. Sending backward sequence rotate back the amount to its original position.

In 2010 was ported source code for Z-80 based micro-controller for jpeg compression. In 2007, interface for retrieving raw image data from image sensor was tested and confirmed to work. In 2001 implemented algorithm of detection center of the circle object from the picture. Both efforts were done to use imaging device as tool to detect a direction to nearest celestial body. In 2011 such development was abandoned because of discontinued production of the sensor with visibility in near infrared (sensor was working for 720nm wavelength).

3.2 Systems for tracking and orbit determination en route to the Moon

Trajectory calculations software was developed in 2011. It allows to simulate all solar system based on JPL. Initial sets of positions retrieved from polynomial approximation. Then simulation runs for some period of time, final results was confirmed by comparing polynomial approximation from JPL. Some periods were found in different position from the calculated position and velocity of the planets and calculated position from JPL data polynomial approximation. Those periods were in position of the earth gives the error of 1 sec for the earth and the moon. Nature of the periods and error was not found but was assumed that error is in a range of required precision for 3 month of calculation time.

Next to simulation software was added capability to set satellite's orbit based on Kepler's elements, formulas was ported from Fortran source code. Some formulas in earth gravitation were hard to understand and assumed were made. To simulate satellite flight we used the same formulas assuming dot mass of each celestial body used in calculations. Additionally, assumption that impulse for fixed impulse engine can be fired based on some direction. That allowed for a method for trajectory reaching the moon. 5 engines burns was used in the Calculation. Two low orbit prepared some waiting orbit, second main burn was intend to reach 1.1 of the earth to moon distance, third lunar trajectory correction allowed to directly reach the moon in some desired landing point, and brake engine reduced speed of the rover and impact shield to speed from 0 to 15 m/s with precision allowed some restriction on the time of landing.

Next was implemented the calculation of a gravitation potential for low celestial body orbits. Available models of earth or moon approximated by lagrangian coefficients can be entered with decided amount to simulate gravitation of a satellite flying low to the on spherical body. Error measurements were done by comparing position of the satellite calculated via space track report 3 Fortran program, and simulations from the program.

GPS raw data was obtained from SIRF capable GPS receiver in 2012. Data was recorded conformation was made. Algorithms for orbit determination based on raw data was investigated. Available open source code was investigated for possible use.

GPS front end receiver was obtained. Raw data was sampled and investigated by math CAD software. Approximated time for implementation/porting code is 30 man-days. For implementing onboard data there's a need to store around 5MBit of data.

Communication subsystem was developed in 2012. To measure time travel between two devices special "loop" message was introduced. Normally, the message from one unit to another consists of an address at the beginning of the packet, command to be processed by unit and ending byte to close packet. "Loop" message immediately send itself back with modification of a payload inside message. Two consecutive "loop" messages introduced periodically from a mission control can have enough data to estimate the time travel of the signal from ground station. Development was finished, testing and adjustments are needed to be done.

3.3 Guidance Navigation and Control(GNC) for the lunar descent(including sensors)

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

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.

Backup communication used ORBITCOMM was verified in 2011.

Communication subsystem FLASH memory exchange is in development now.

Antenna with reduction size polarized antenna was designed. Antenna 3D printing for ground station was developed.

3.5 Propulsion

Model impulses for all fixed engines was calculated in 2011. Match for catalog (on-shelf) was done. Selection of engines was made, assuming only weight match. If match impulse instead of weight, thenconfiguration of the rover will become less that will categorize it as a mini-satellite (less 200kg). Matching by weight is less restrictive with a landing time.

3.6 Touchdown devices

Impact shield was designed. 3D printed molds was designed, waiting its manufacture and tests.

3.3 Being developed. Thermal Control

Temperature sensor DS1822 was chose to monitor temperature. Accuracy of the measurement is +-2C from -55C +150C. Sensor has special interface to communicate with multiple device over same power and data line. That makes it a minimum power requirement to get digitized temperature readings. Two micro-controllers can read all temperature measurements for the 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. 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 of 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. Source code contained description a formulas that are used for active temperature control. First was analyzed "bang-bang" temperature control method - basically it is type of control when temperature reached some level then heating element was switched off or on. That technique allowed stable fluctuation of 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 through 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 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, attempt was made 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, assumed to be the same for target HD camera box and/or for low resolution camera's box. Instead of cooling fan in craft we'll use the technique to rotate craft to position with biggest temperature derivative. That derivative will be 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 Onboard autonomy

Software was developed to support onboard autonomy. It is includes interrupt service routine for different families of micro-controllers, callback functions to process commands, and queues for to be processed data. Gyro-platform by itself allows the calculation difference in quaternions from "zero" direction to "required" direction. All automatics are assigned and verify the task performed.

3.9 Being developed. Interfaces to other subsystems.

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

Software was developed 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 are capable to substitute FLASH type. It can fit into a same footprint of serial FLASH memory surface mounted component. Same protocol of data exchange can be used. Benefits - low write memory time, 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 Attitude control en route to the Moon

In 2011 gyro-platform functionality was confirmed in two tests performed to detect earth rotation, measured for 1 hour (and 6 hours for second test) quaternion of rotation (without Kalman correction of the drifting zero direction) we conformed by using a normalized vector pointing to the north pole, and cosine of half of rotation angle showed match with earth rotation in both cases.

4.2 Systems for tracking and orbit determination en route to the Moon

Verification was based on JPL ephedermes DE410. Trajectory calculation software was inserted with initial values of position and velocity of celestial bodies. Than trajectory simulation was running for some period of time to simulate orbits of the planets for 3 month and then resulting values was compared from JPL ephedermies DE410. Error in simulation was around 1 sec of position of the earth. Nobody did explain that difference.

Verification for low earth orbit is based on ported FORTRAN source code from space track report 3. Code allowed to convert 3 punch cars (today name: Two Line Elements) with Kepler's elements of the satellite's orbit into a position and velocity of the satellite in specific epoch time. Trajectory calculations were verified while accounting for the lagrange coefficients of a gravitation potential of the earth. Initial position and velocity of some real satellite (ISS) was calculated by well known TLE available data. Then initial data was inserted into trajectory calculation software. After some orbit rounds position the velocity of the satellite was compared to the calculated Kepler's elements. Error was fluctuated around 7 km. Backward conversion of a speed and velocity to TLE performed by different algorithms based on open source, and allowed to do another comparison. Inclination of the orbit was matched, but error has periods. Attempt to get explanation was unsuccessful. On some private conversation we confirmed that explanation cannot be done for restrictions and regulations. Best explanation was obtained from available orbit determination lectures in Russian, - methods used in Space Track report 3 assuming some additional "matching" algorithms to statistically fit orbit to best possible observation.

Trans lunar orbit was not been verified independently. On the route to the Moon and on LEO was bunch of orbit's corrections, to verify it needs to know real data from orbit corrections from a real satellite. That information was not available in time of development.

An attempt was made to confirm calculation by software available for orbit determination, but any attempt to contact designers of the software was not successful.

In 2011 summit was announcement from NASA, that they will verify orbit and correction impulses, before flight. That process will require some resources to be dedicated to a NASA team, and verification will be in form of "Yes - orbit is ok". That announcement also explained that it is the best what NASA can do for our team and this will be a last resort for orbit verification.

4.3 Guidance Navigation and Control(GNC) for the lunar descent(including sensors)

Concept was developed; laser range finder was prototyped in 2011. Simulation by ultrasound transmitter and receiver was performed in 2012 and 2013. Commercial available system was developed and offered to a customer for certification.

Optical system for laser transmitter and receiver was investigated. Harness for the lenses was decided, originally to be made from carbon fiber mold, then we decided to have all harness be 3D printed from titanium. Two optical solutions were considered - one based on the lenses from modern DVD burner, another from commercially available laser range finder.

Laser 1Wt transmitter was chosen to be same as used in modern DVD writers.

For "parachute" device testing "solid" state rocket class A in 2010 was available commercially.

4.4 Avionics

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.

In 2012 GPS receiver was obtained records ID 29/30 to verify GPS satellite position. Satellite position was verified by 3 punch card's orbits elements (joking - TLE from real satellite).

4.5 Propulsion

Nothing was verified. Even data from catalogs cannot be verified. Need to trust engine manufacturers that it will perform as they have described.

4.6 Touchdown devices

In 2010, was verified "parachute" device as solid state rocked motor class C.

4.7 Being verified. Thermal Control

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

4.8 Onboard autonomy

Software algorithms for interrupt service routines, call back functions, and data queuing were verified.

4.4. 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 functional performance and interface requirements of the subsystem and the environments in which it must operate

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 Attitude control en route to the Moon

Attitude Control Specs:

- Temperature conditions for all mechanisms -70+125
- Orientation precision 0.1 degree for a craft, and 0.1 for a nano-satellite

5.2 Systems for tracking and orbit determination en route to the Moon

System Tracking Specs:

- On LEO it is 100 m in position, and 1 m /s in velocity
- On trans lunar trajectory 100m in position and 1 m/s in velocity.

5.3 Guidance Navigation and Control(GNC) for the lunar descent(including sensors)

Laser range measurements on descend 10 m in position, with 10 measurements per second.

5.4 Avionics

Avionics Specs:

- Communication subsystem - TX power in peak 10Wt, sensitivity -145 dBm
- GPS raw data orbit determination with precision of 100m in position and 1 m/s in velocity
- Time precision of no board micro-controllers with 1 sec per 1 month.

5.5 Propulsion

Propulsion Specs:

- At least 1% accuracy for impulses of all engines except brake engine
- At least 1% accuracy in profile of the performed trust of the brake engine.

5.6 Touchdown devices

Touchdown Specs:

- To support soft touchdown of the rover with max acceleration of 362g and expected acceleration of 40g
- To reduce rotation of the impact shield and rover from 5/sec to 1 per min after separation from burned brake engine
- To orient rover and impact shield by impact shield side before impact with lunar surface.

5.7 Thermal control

Thermal control should keep temperature:

- In the range of -20C+85C inside box with low resolution cameras
- In a range -20C +85C inside HD camera's box

5.8 Onboard autonomy

Requirements:

- Thermal system must operate autonomously
- To support communication session orientation must be automatic
- To support solar sun and center of nearest celestial body detection must be automatic
- To support time error determination by mission control.

5.9 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 the critical technical risks that the 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 Attitude control en route to the Moon

"Rotation wheels" (or "reaction wheels") must be tested vacuum and temperature conditions. Critical test will be nano-satellite test flight. Rotation wheels must perform its task calibrated HD camera can confirm precision of the orientation within 0.1 degree.

To reduce risks before test flight and main flight, all mechanical components of a rover and nano-satellite will be exposed to temperature limits of operation conditions on regular bases. Cycle is performed weekly - 6 hours -10C, 1 hour -75C, 30 minutes heating to +25C, then 1 hour under +125C with cooling to +25C. Heating test to +25C, then 1 hour under +125C with cooling to +25C.

To qualify for a flight on a launch vehicle vibration and acoustic study must be performed on the nano-satellite, which will include vibration table tests to confirm that resonance frequency is in a designed range for nano-satellite, same goes for the stand of the low resolution camera box, for antenna with HD camera box, and for gears.

Will be mandatory test require for certification of a Nano satellite and craft to fly on launch vehicle.

To qualify for a flight we'll be performed vibration and acoustic test to match vibration and acoustic profile of the launch vehicle. That requires two tests first one for Nano satellite test mission, and second test provided (probably) on the launch vehicle provider facility.

To qualify for a flight outgassing tests must be performed in a vacuum chamber. There also has to be two tests first for Nano satellite mission and second for frame and rover of a main mission. Outgassing parameters for the engines will be obtained from the engine manufacturer.

In case of failure in performance of the stepper motor we need to perform the same tests we performed for the "rotation wheels". We still need to choose proper stepper motors and replacement of the bearings.

Pyro devices are to be tested in vacuum and under required temperature conditions. That is the main objective of reducing the risk with ejection of the "face off device". Testing will be performed on mockup craft configuration. However, nothing can be done to account for the fact that pyro-device will be purchased from manufacturer. Manufacturer process and testing procedure performed by separate company will be the main risk reduced factor.

Risk for Gyro-sensor ATG-3200 accelerometer ADXL342, magnetometer must survive under high energy particle, but cannot be verified without proper equipment. That challenge has to be solved by applying design to reduce chances for primary and secondary high energy particles to be collided with sensors and all electronics on board.

6.2 Systems for tracking and orbit determination en route to the Moon

Challenges to Overcome:

- How to verify trajectory calculations. It can be done by verification of the data by independent methods. As a last resort for such verification it will be the flight itself, because of promise of orbit verification be performance by big Space Agencies before flight. Also, existing data must be found with known performed impulses to confirm impulse simulations in trajectory calculation software
- Raw navigational satellites orbit data determination. Both systems can be verified only on orbit, in test flight
- Distributed calculations of low earth orbit. Interface for such calculation has to be simple and allowed for rapid development of different methods for such calculations
- Raw global navigation system receiver as a fully GPS with ID29/30 record output and front end RF raw modules needs to be tested for vacuum and operation temperature conditions together with all electronics

- Risk of failure due to damage obtained from high energy particles of raw global navigation system devices has to be solved the same way as all electronics
- Risk about uncertainty and errors in orbit determination after correction impulse on the route to the moon can be overcome by allying multiple measurements by communication subsystem. For this risk elimination we need to use simulation software with introductions of errors in measurements of time and distances.

6.3 Guidance Navigation and Control(GNC) for the lunar descent(including sensors)

Challenges to Overcome:

- Impulse simulation software by introducing random error in performance of a fixed impulse engine
- 10-25km distance measurements using laser range finder
- Adjustments of a rotation momentum of the rotation compensation spring
- Simulation of "parachute" fixed impulse motor and its equivalent in drop test.

6.4 Avionics

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
- Additional independent system for detecting center of nearest celestial body.

6.5 Propulsion

Nothing can be done to propulsion system except to trust fixed engine manufacturers.

Separation methods of used engines parts based on pyro-devices. Nothing can be done to improve such devices except to trust manufacturer.

Challenge is to find a good manufacturer for fixed impulse engine and manufacturer for the pyro-devices.

6.6 Touchdown Devices

We need to overcome challenge of finding testing technique to simulate touchdown.

6.7 Thermal Control

To reduce risk of a failure planned to use special heat/cool, on/off tests/design technique - source of the heat capable to delivery heat flow over surface of the box (low res camera / HD camera) will be switched on /off and energy flow will be measured. Cooling will be provided with either 0C cooling reservoir, or with -75C cooling container. Camera's thermal control will be tested to produce on/off signal that will switch on/off heat source (capable to heat imagining system component up to +125C). In a real flight of a Nano satellite (or on a craft in main mission) thermal control subsystem will give recommended orientations command for a best heat/cool. To confirm proper processing / collection of a thermal data go through testing, when ground station is exposed to a heat radiation (with +125C) and cooling source with -75C, in this case software has to detect cooling and heating orientation (directions) for antenna/imagining subsystem mechanics and issued a commands, send over inter-unit serial communication to perform temperature stabilization.

6.8 Onboard autonomy

Testing techniques for software has to be embedded in planned demonstration/tests to reduce bugs and errors in software and on board autonomy. That is why each demonstration test is separated from each other by at least 1 week. Review performance is sharp after each demonstration test. This will help to solve the challenges in debugging process.

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

"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, this is the most important test which will include one communication session over the 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.

“Ground” and “flight-to-ground” demonstrations, judges will have access to a mission control over web mission control web server.

“Ground” demonstrations will have 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 the mission control.

For the “ground” demonstration we have planned two events. First, pictures of the 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 the 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 a short communication distance between ground station and a rover. Transmitting signal will be 0dBm (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 the brake engine, and destroyed impact shield (from tests of impact shield) will be used.

“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.

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.

Drop test will be planned for impact shield and rover, after drop test rover was to perform mobility movements and all system should show functionality. Drop tests will be with a 40g impact (12m/s) and with 362g.