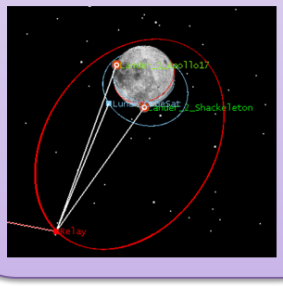
Lunar Mission Flight Opportunity for Small Missions and Payloads

Space Segment
Pathfinder mission transfer from GTO to Cis-Lunar space
- Data relay spacecraft offering passenger & payload transportation
- Commercial Comms & Nav services beyond Earth Orbit
- First launch 2019, Moon

Features:
- £0.8 -£1.5 M per kg
- Simple interfaces
- Enabler for low-cost, high-value small missions

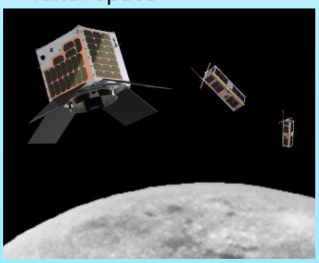


Ground Segment
Goonhilly Earth Station
- Utilises existing 32m antenna dish, GHY-6
- Utilises existing Goonhilly world wide connectivity
- Planned capabilities for Cis-Lunar missions
- >8 hours per day visibility of data relay orbiter

Internet based distribution
- Users will be able to command and receive data from their spacecraft via a web based interface

User Segment
Passenger Payload Delivery
- Small passenger missions and hosted payloads delivered to Low Lunar Orbit(s)
- Data relay satellite transfers to highly elliptical operating orbit

Commercial Services
- UHF baseline, S-band, X-band options between passengers to mothership
- Available to other orbiter and lander missions in cis-lunar space



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1 LUNAR MISSION OPPORTUNITY FOR SMALL MISSIONS AND PAYLOADS

1.1 Overview

Surrey Satellite Technology Limited (SSTL) and Goonhilly Earth Station (GES) are pleased to announce this exciting and enabling mission flight opportunity for small lunar missions and payloads.

SSTL and GES have entered into a partnership to deliver a Lunar Communications Pathfinder Mission as the first step in a plan to establish infrastructure in cis-lunar space which will provide a transportation service to lunar orbit for small payloads, and will then also provide command, telemetry, and payload data relay functionality to these missions (and any assets such as landers). This will enable a variety of low-cost, high-value small missions to the Moon.

In addition SSTL and GES are also currently engaged in a pilot phase activity with the European Space Agency (ESA), exploring the possibility of an industry-agency partnership for space exploration purposes. The mission described in this document, would be one of the key first steps in this partnership, bringing industry and ESA together to provide a mutually beneficial solution that provides value for all sides.

The first launch is targeted for launch in late 2019 and will carry small spacecraft and payloads to the Moon, as well as providing commercial communications services. Subsequent launches, which will also offer passenger and payload transportation, communications and navigation services, are planned on a two yearly basis.

For ease of reference, the term “mothership” will be used in the document to describe the communications relay orbiter, which will provide the transfer and delivery into lunar orbit for users, as well as the communications services for users in cis-lunar space.

This document provides an overview of the mission opportunity, details on the process for expressing interest in joining the mission manifest and an appendix containing background on the mission prime contractors and the mission.

Further information on the mission design and the expected space environment during the mission are provided in two supporting documents (see section 4 of this document for details).

1.2 THE OPPORTUNITY

The Lunar Communications Pathfinder Mission offers customers the opportunity to purchase a ‘ticket’ for their small missions and payloads, to be delivered and deployed in-orbit around the Moon, as well as providing command and control links and payload data relay in cis-lunar space.

The pathfinder mission offers the following services for small lunar missions and payloads:

1. Delivery of small spacecraft into Lunar orbit
2. Communications services between Earth and the Moon via a communications relay orbiter
   - Provision of Telecommand and Telemetry links between customer lunar assets and Earth
   - Provision of payload data relay from customer assets in lunar orbit or the Moon’s surface
3. Hosted payloads residing on the communications relay orbiter

In addition, if shown to be feasible it is envisaged that some form of experimental navigation service may be provided to customers, but this will be experimental in nature and is subject to later confirmation.

The high-level concept of operations for the mission is shown at Figure 1-1, whilst an overview of the mission architecture is shown at Appendix A1. More details are provided in RD-2.

This mission flight opportunity aims to open up lunar exploration to a wider user community than has been typical in the past by bringing lunar missions into the price range of national agencies and institutes, small private firms and even university budgets. This will enable new science, exploration and demonstration missions to be defined and undertaken, and increases the potential for deep space exploration to be performed in new and innovative ways.

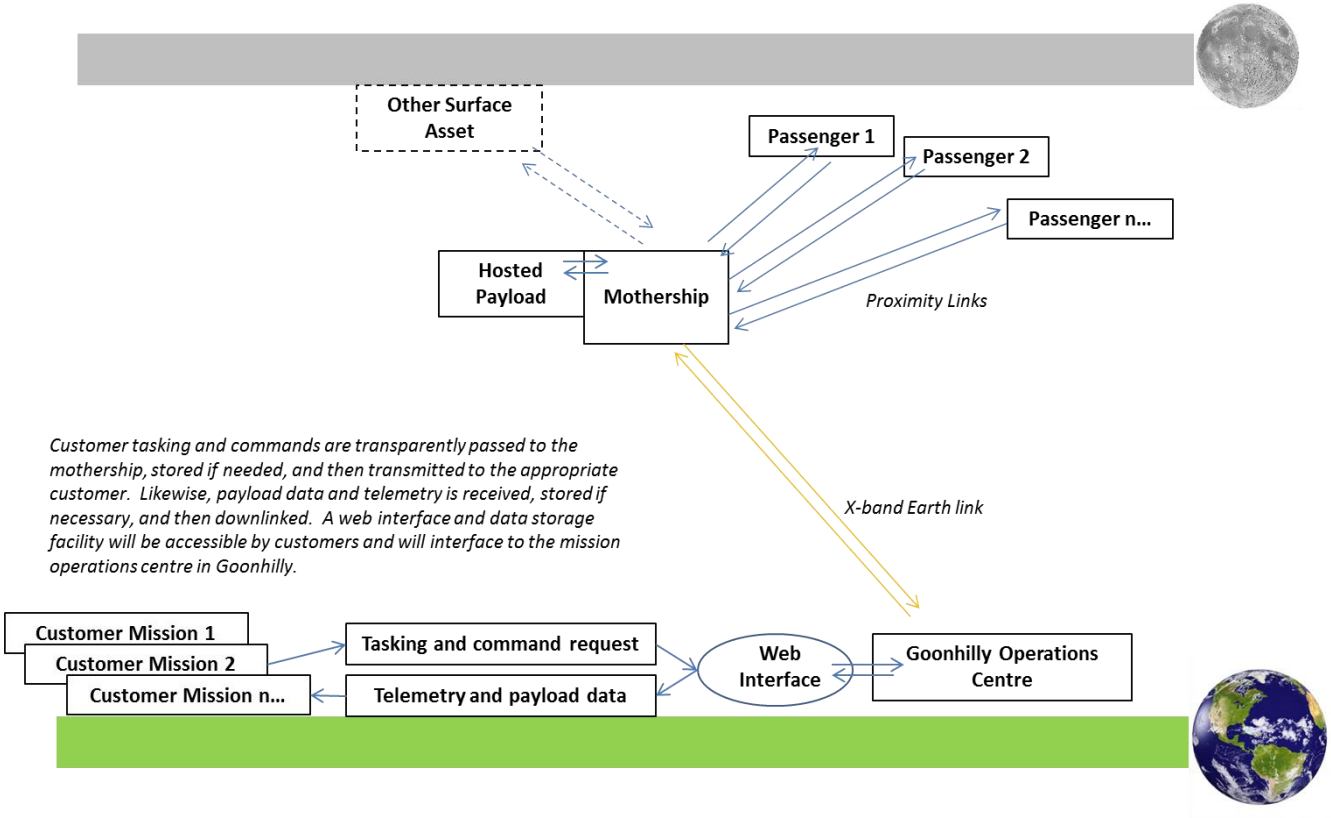


Figure 1-1: The Mission Concept of Operations.

1.3 Expressions of Interest

Customers interested in joining the mission manifest are requested to express interest in this call by providing the following information in no more than 4 pages:

1. **Organisation:**
2. **Named Contact:**
3. **Contact Details:** *email; address; phone*
4. **Passenger payload application:** *e.g. science orbiter, educational & inspiration, tech demo & innovation, commercial business application, microlander etc*
5. **Passenger payload:** *e.g. cubesat, nanosat, microsat, hosted payload (stays on mothership)*
6. **Passenger payload indicative characteristics:** *mass (kg), power (w), volume (cm2), data rate (bps)*
7. **Preferred operational orbit:**
    a. *Low circular*
    b. *High lunar elliptical orbit*
    c. *Inclination – polar, near polar, other, no preference*
    d. *Areas of special interest e.g. Lunar South pole, North pole etc. Please indicate other interests if applicable.*
    e. *Other orbits, please specify*
8. **Preferred communications frequencies to mothership if other than UHF**
    a. *For pathfinder mission - UHF, S-band, X-band, no preference etc*
    b. *For subsequent missions – UHF, S-band, X-band, no preference etc*
9. **Data rate expectations/ requirements**
    a. *For pathfinder mission e.g. minimum, ideal*
    b. *For subsequent missions e.g. minimum, ideal*
10. **Anticipated special provisions:** *e.g. accommodation preferences, power interfaces, ground support equipment, spacecraft level testing etc*
11. **Programmatics:** *Schedule and financial considerations in relation to the proposed engagement schedule*

Any questions about the response can be sent to **lunar@sstl.co.uk**.

The electronic copies (in PDF format) of the Proposal should be sent to lunar@sstl.co.uk.

2 ENGAGEMENT SCHEDULE

The planned engagement schedule for the Lunar Communications Pathfinder Mission is given in Table 2-1.

Date	Milestone
12 July 2016	Formal Call for Lunar Missions and Payloads Available from: **http://www.goonhilly.org/lunar**
Sep-Oct 2016 (TBC)	Workshop between customers and SSTL and GES Letters of Intent[1]
Sep-Nov 2016	Technical and Programmatic iteration between SSTL, GES and customers[2]
Dec 2016	Memorandum of Understanding signed with customers
Feb 2017	Final mission manifest decision. ESA partnership selection decision[3]
March 2017	Formal mission Kick Off Binding agreement signed with customers.
2017 - 2018 (dates TBC)	Mission and payment milestones to be agreed with customers
Jun 2019	Latest delivery of flight models to SSTL integration facilities, Guildford, UK[4]
Nov 2019 (TBC)	Launch Readiness Review
Launch + 3 months	Transfer & Deployment Phase
Deployment + 6 months	Communications Service Provision Phase
2021 onwards	Extended Services

Table 2-1 Lunar Communications Pathfinder Mission – Customer Engagement Milestones

[1]The schedule is demanding so customers are advised to consider their development schedules.

[2]The price and performance values provided in this document are indicative and will be consolidated during interaction with the customer base.

[3]Customers are advised that SSTL and GES are also exploring (under MoU) the possibility of a partnership with the European Space Agency (ESA) under the Partnerships for Exploration Initiative ("Space exploration as a driver for growth and competitiveness: opportunities for the private sector Issue Date 01/03/2015"). SSTL, GES and ESA are working on a pilot phase until February 2017 to explore the collective benefits and enhancements to the first and subsequent missions arising from such a Partnership. The status of this Partnership will be reported as it progresses.

[4]All payloads will be integrated onto the Lunar Communications Pathfinder Mission spacecraft at the SSTL facilities in Guildford, UK.

3 INDICATIVE PERFORMANCE AND PRICING

3.1 Indicative Delivery Capability

The mission aims to accommodate three main classes of customer:

- Orbital passengers e.g. nanosatellites and CubeSats which will be deployed from the Mothership and which will operate in lunar orbit
- Surface passengers e.g. Micro-landers/penetrators which will be deployed from the Mothership and go on to land on the surface of the Moon
- Hosted payloads, which will remain attached to the Mothership

This mass allocation can be split to suit the customer base e.g. multiple 3U or 6U Cubesats, a 12U CubeSat or nanosatellite etc.

- If the payload requires an additional dispenser mechanism, then the mass of this dispenser should also be included in the total mass purchased.

A target of 50 kg of customer payload mass will be available for delivery to lunar orbit on the first mission. This is based upon the following assumptions regarding the customer deployment orbit:

- Low lunar elliptical orbit with pericenter altitude 200 km and apocenter from 3000 km to 7000 km
- Inclination near polar (~ 90°)
- Passengers are invited to suggest other drop off orbit preferences for consideration
- *Note: The final altitude, eccentricity and degree of circularisation of the passenger drop off orbit will be iterated as part of the overall final mission design to deliver the best balance between overall mission performance, passenger manifest preferences, pricing and schedule.*

Post-passenger deployment, the Mothership will transfer to a high altitude elliptical data relay orbit of ~800 x 8000 km altitude, ensuring long duration coverage to lower altitude orbiting assets, or those on the lunar surface.

3.2 Communications

The current Mothership baseline is to transmit and receive data from customer assets over a UHF physical layer, to allow for high degree of flexibility in antenna pointing, spacecraft attitude and gain patterns. In addition, this band is already used by CubeSat and Nanosat missions and so is an established norm. However, we are interested to hear from customers with other requirements. This link is planned to be the CCSDS Proximity-1 UHF protocols for interoperability and cross-link opportunities [RD-1]. Users can be provided with CCSDS Proximity-1 Software Defined Radio (SDR) cards conforming to the CubeSat form factor, to interface between the user payload computer and any antenna system. Further information on the expected performance and capacity of the system is shown at 0.

The mothership will utilise an X-band link for communications with the Earth, using the 32m Goonhilly-6 station as the primary data downlink station and operations centre.

The mission operations centre will provide a secure internet based connectivity to users, allowing customers to interface to their asset, via the GES ground segment and the Mothership.

3.3 Interfacing

Interfacing to the system is designed to be as simple and user friendly as possible. Key characteristics include:

- Simple and flexible passenger accommodation and interfacing for transfer to Lunar Orbit
- Sizes from 1U to 12U accommodated in industry standard containers (such as P-POD) can interface directly to the Lunar Communications Pathfinder Mission spacecraft.
- Bespoke and larger form factors can be addressed on a case by case basis
- Passengers are provided with power connections for battery charging during transfer
- Passengers can be provided with telemetry and telecommand functionality during transfer
- Passengers can be thermally controlled during transfer
- Special provisions for passengers can be addressed on a case by case basis

3.4 Indicative Pricing

The total indicative price of the ticket is expected to be between £800,000 and £1,500,000 per kg of payload (Eight Hundred Thousand Pounds and One Million, Five Hundred Thousand Pounds Sterling per kg).

This indicative price is provided for budgetary planning purposes and for initial engagement discussions.

This ticket price includes:

- Interfacing of customer flight models to the Lunar Communications Pathfinder Mission at SSTL integration facilities, Guildford, UK
- Launch Fees and Transfer to agreed lunar orbit
- A plug-in communications subsystem card interface
- First 6 months in-orbit communications services
- A secure internet based service communicate with their lunar assets

Assumptions:

- The final price and performance will be confirmed following consideration and integration of customer needs into the mission and system design.
- Export licensing and national space licensing will be the responsibility of the customer.
- P-POD or other such space qualified deployment devices will be provided by the customer.
- Customers will deliver their flight payloads/ passenger spacecraft against jointly agreed delivery milestones.
- Deployed users (e.g. orbital or surface) may define and using their own ground segment in addition to the services offered by the mission. However, all users agree to use the communications services bundled into the ticket price for the first 6 months of the mission as it forms an essential part of the service validation.
- Beyond the first 6 months of included communications services, follow-on communications services will be available to purchase on either pay-as-you-go or fixed time period service agreements, should these be required.

4 REFERENCE DOCUMENTS

RD#	Title	Revision	Date
RD-1	PROXIMITY-1 Space Link Protocol—Data Link Layer, CCSDS 211.0-B-5	2	12/2013
RD-2	Lunar Communications Pathfinder Mission – Mission Analysis Guidelines	1	11/7/2016
RD-3	Lunar Communications Pathfinder Mission Radiation Environment Draft Guideline	1	11/7/2016

A1. MISSION ARCHITECTURE AND PHASES

Further details on the mission analysis and mission design are provided in RD-2, but a brief summary of the mission phases is given at Figure 4-1.

- Phase 1: Mothership launch into a highly elliptical Earth orbit
- Phase 2: Orbit raising manoeuvre(s) performed to place the spacecraft onto a lunar intercept trajectory
- Phase 3: Lunar Orbit Insertion (LOI) manoeuvre and initial capture into lunar orbit
- Phase 4: Mothership manoeuvres to lower altitude orbit(s)
- Phase 5: Passenger delivered into lunar orbit
- Phase 6: Mothership transfers to an elliptical orbit for service provision.
- Phase 7: Provide communications services
- Phase 8: End of Mission

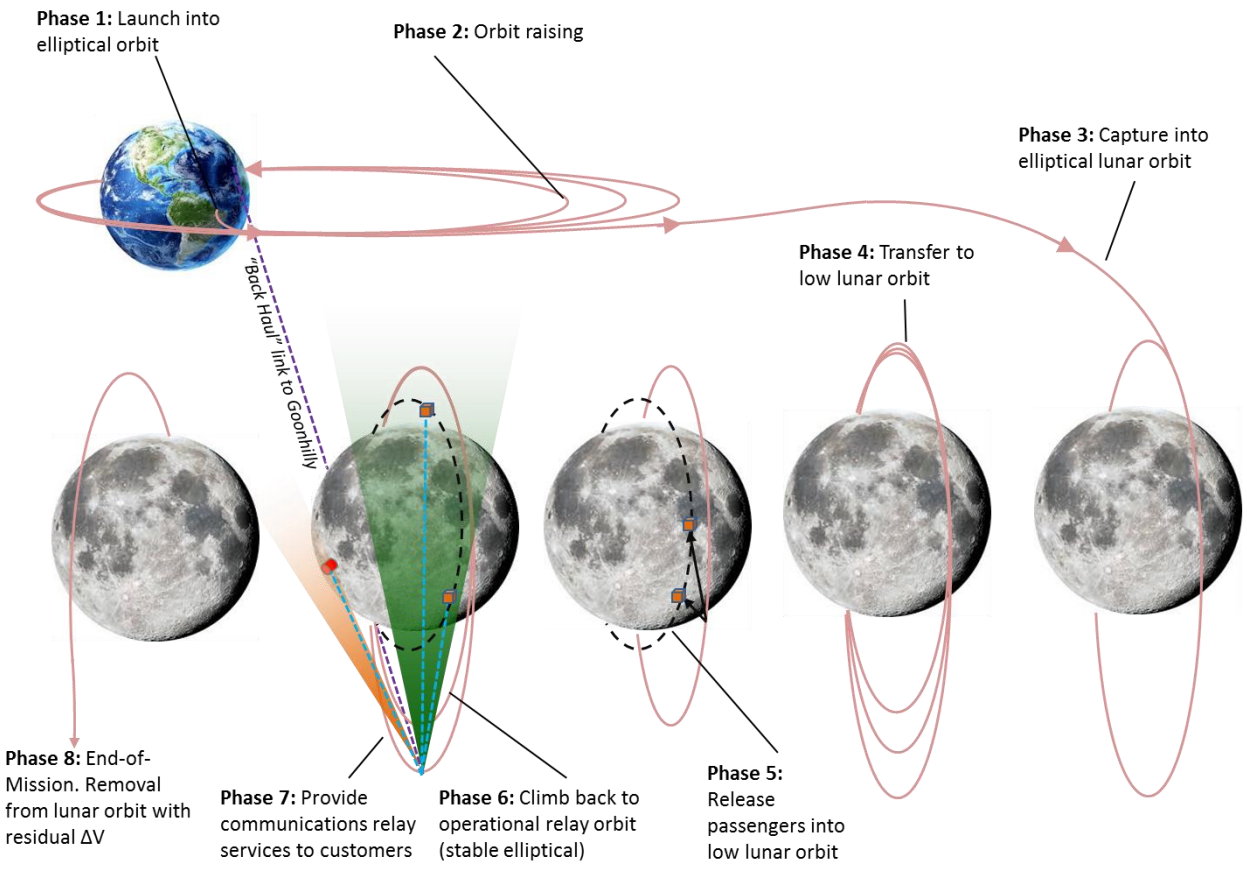


Figure 4-1: Lunar Communications Pathfinder Mission Architecture

A2. COMMUNICATIONS

(A) CAPACITY

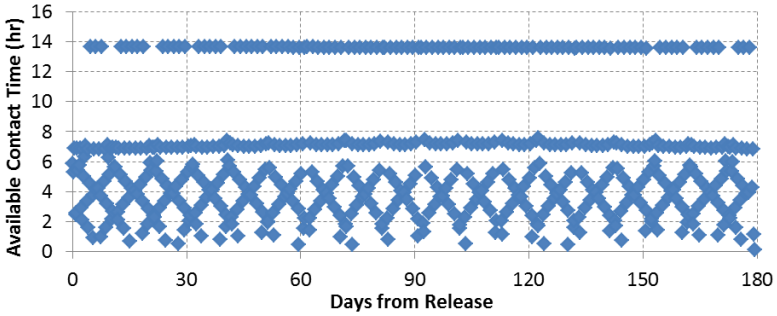
For a mission with multiple customers, it is envisaged that link times between the Mothership and customer assets will be time-sliced, with each customer given time allocations for sending or receiving data to or from the Lunar Communications Pathfinder Mission spacecraft (in a similar way to an Earth orbiting mission has defined overflight times of a ground station when communications with the spacecraft is possible). This time sharing will be done in as equitable way as possible, to ensure all payloads can benefit from the service. However, although each customer will be provided with an allocation of communications services, there will be the possibility of negotiating priority services for time critical events.

Achievable data rates will very much depend on the capability of the customer's communications subsystems. Preliminary link calculations assuming a 'basic' customer satellite with a linearly polarised whip antenna and a 2 W RF output using an ideal BPSK modulation are summarised in Table **4-1**.

RF Power	2 W	
Antenna	Whip	
Gain	0 dBi	
Modulation	Ideal BPSK	
Polarisation	Linear	Circular
Data rate	**32kbps**	**64kbps**

Table 4-1: Customer communications subsystem assumptions summary

Figure 4-2 shows an example of the total contact time available between a passenger spacecraft in a 300 x 5000 km lunar orbit, and the Mothership in a higher relay orbit. As shown, the total available contact time per day is high. For a mission with multiple customers, as envisaged here, this total would be divided between the total customer base, but it can be seen that there is the potential for long periods of contact time between the Mothership and a given payload, allowing for high data throughput, even if the actual date rate employed is relatively modest. For example a 32 kbps link will transfer ~115 Mbit of data if maintained for an hour.



Passenger Orbit 300 x 5000 km 91 deg	Time (hrs)
Average Contact	6.28
Max Contact	13.67
Min Contact	0.10
Average Gap	1.40
Max Gap	3.89
Min Gap	0.10

Figure 4-2: Example of total contact time available between a passenger in a 300 x 5000 km lunar orbit and the Mothership.

It should be noted that this data rate is based on a) assumptions on the customer spacecraft transmitter characteristics as shown in the table, and b) the inter-satellite range between the Mothership and the customer spacecraft. Both of these aspects could change as the design of the mission evolves, and so should be considered as an initial (conservative) baseline.

The primary link to ground will be at X-band offering 10 Mbit/s link rate for data downlink. It is expected that in excess of 10 Gbytes of data per day total throughput will be available for customer use.

Hosted payloads will interface directly to the Lunar Communications Pathfinder Mission spacecraft and will be provided with a data rate and data storage allocation.

Data from all customers will be stored on-board the Mothership and later downlinked to ground when the Goonhilly site is in visibility of the spacecraft. Uplinked data, such as telecommands and software patches, can also be stored on-board the Mothership to be forwarded to the customer payloads at a later time.

(B) SOFTWARE DEFINED RADIO PROVISION

The card will be size of CubeSat form factor, will reside on one single PCB, and is responsible for the physical, coding and link layer of the Proximity-1 protocol. This protocol requires that a Spacecraft ID (SCID) is registered with CCSDS. This will be organised through GES and each SCID will be programmed into the flight card before delivery to the hosted spacecraft manufacturer. The data interface to the spacecraft will be a packet interface running over RS422. This packet interface can either be CCSDS Space Packet or IP v4 packets (TBC).

The card will require power at a regulated 5V (TBC). The default state of the card is for it to be configured into listen mode (receiver on). The card will only transmit once requested to do so by the master controller of the channel. In this case it will be the relay unit on-board the Mothership. For the purposes of ground based testing the hosted spacecraft, detailed instructions will be delivered to create a Mothership simulator based on terrestrial COTS Software Defined Radio solution, such as GNU Radio.

A3. WHO ARE WE?

The Lunar Communications Pathfinder Mission will be implemented as a partnership between SSTL and GES, bringing the best aspects of both organisations together for maximum effect.

SSTL

SSTL is a medium sized prime contractor based in Guildford UK and has been delivering small satellite missions for 30 years - longer than anyone else in the world. SSTL covers all aspects of space missions including conceptual design, manufacturing, operations, service delivery and launch procurement. SSTL has also delivered many successful training programmes with a variety of customers, and regularly works with a range of customers from large institutions, commercial enterprises, start-ups, universities and space agencies. SSTL is an independent British company within the Airbus Defence & Space group.

For the mission described in this document, SSTL will be the space segment prime and will be responsible for the development, and manufacture of the Mothership spacecraft, as well as procurement of the mission launch vehicle.

More information about SSTL can be found at: **www.sstl.co.uk**

SSTL manufacturing facilities in Guildford

GES

GES is a private company that was established to transform the Goonhilly teleport site in Cornwall UK, once British Telecom announced, in 2008, its plans to cease commercial operations there. GES activities include commercial satellite communications, satellite operations (such as telecommand and control), deep space communications, radio astronomy services, training and education, a public visitor centre, data centre and an advanced electronics and communications manufacturing centre. The Goonhilly site includes a number of large agile antennas, as well as excellent line of sight visibility and good terrestrial internet connectivity.

For the Lunar Communications Pathfinder Mission, GES will be the ground segment prime, and will be responsible for the mission ground equipment and spacecraft operations.

More information about GES can be found at: **www.goonhilly.org**

Antenna Farm at Goonhilly