Papers on the Lunar Settlement

Logistics 1 : Space Transportation

0. Summary Access to cislunar space is clearly a critical issue for lunar settlement. Means of placing the initial settlement are examined, as are possible lunar contributions to broader space activity.

1. Initial Requirements The first expedition has to be fully described before detailed planning can take place. In general, we anticipate that the original settlement will consist of 60 to 120 members, who will go in parties of two to six, at intervals based on the progress made by preceding parties.

Aside from the settlers themselves, a considerable quantity of supplies will be needed. As the Luna Project aims to achieve the greatest degree of self-sufficiency in the least time, the supplies will be principally tools, especially tools for building tools and machinery, rather than finished products or raw materials. Clearly, considerable supplies will have to be pre-positioned at the settlement site before the first party arrives, in order to permit them to commence work when they arrive.

2. Direct Ascent The most straightforward approach to achieving Luna is direct ascent, a single maneuver launching from Terra and landing on Luna without orbits, rendezvous, or intermediate stops. Direct ascent was rejected by the Apollo planners because it would have required an enormous rocket known as the *Nova*, but for the mission profile which does not contemplate a return trip, requirements are less severe.

Current commercial launch vehicles could be used to deliver relatively small lunar payloads, such as orbiters, survey landers, or homing beacons. There are, however, no available rockets capable of delivering the required large payloads, even in the direct-ascent non-return configuration. The Saturn V rocket would be entirely suitable, but it is forty years obsolete ; rather than devote a year to reverse-engineering the unit being used as a lawn ornament at Johnson Space Center, the members of the Project would be well advised to develop a new vehicle for the purpose. If the design could be worked out soon enough, the components could well be fabricated and the assembly tested within the available time.

To illustrate the characteristics of the one-way lunar mission, let us examine a hypothetical rocket of 1000 tonnnes, one third the mass of the Saturn V. Taking the velocity needed for direct ascent as 13.6 km/s, the sum of the escape velocities of Terra and Luna, assuming a constant exhaust velocity of 4000 m/s and an empty mass for the first two stages equal to 0.1 the fuel mass, with three stages of mass ratios 2, 3, and 5 such a rocket could land 24 t on Luna.

This 24 t figure includes all the dead-weight of the final stage, but for vehicles not intended to return, and especially the cargo carriers, the *L59* principle can be applied. That is to say, the whole rocket would be designed for a maximum of reusability. For example, a cylindrical outer shell could be made to be rapidly cut into large strips of unequal width, with fittings built in to allow ready assembly into Quonset huts.

Even those parts which could not be reused could be recycled. For example, given a choice between copper and aluminum tubing in the fuel system, the designer would choose copper. The increased mass of the ship would be balanced by less need to carry copper (a substance not known on Luna) as payload, effectively saving the mass of the aluminum. Similarly, fuel tanks might be made of carbon composites.

The short time available for developing such a rocket would require treating the initial cargo launches as test firings. A suitable course might be to fire a specimen of each stage as it became available, with a dummy load, followed by a test launch of the complete rocket including a specimen of the manned lunar stage. All three stages could be fired to put the upper stage in a trajectory to pass behind Luna and return to Terra. In such a test, the guidance system, the restart capability of the upper stage, and the ability of the personnel capsule to withstand emergency reentry following an aborted launch, could all be proven.

Upon successful completion of the true test firings, a series of unmanned operational launches with extensive telemetry (and backups standing by in case of failure) would serve to validate the design for manned flight. The first might be a launch into lunar orbit, to serve as the nucleus of a future lunar orbital station. Subsequent launches would pre-position cargo required by the first party of settlers.

3. Terra Orbit Rendezvous Using the smaller expendable launch vehicles presently available would require Terra-orbit rendezvous to fuel, and possibly to assemble, the lunar stage. This poses certain difficulties. First, it would drastically increase the number of individual rockets required, raising the overhead expenses of fabrication, &c, and reducing the overall mission mass ratio. Secondly, particularly if cryogenic propellants are to be used for the lunar stage, Terra-orbit rendezvous requires numerous launches, with close coordination, within a short period of time. Considerable difficulty may be expected in this regard, as the problem of access to space today seems to be, not the cost of launches, but their infrequency and their interminable delays. It is reported that the largest number of a single type of expendable rocket launched in one year is 60 units of the Russian Soyuz booster, some years ago. Reckoning three to five boosters per lunar stage, the Terra-orbit rendezvous configuration might require that many in two or three months of the first phase.

This problem could be addressed with a reusable launch vehicle. A man-carrying fully-reusable orbiter, a true space ship, could be built today as a two-stage-to-orbit combination. Without the need to wait for expendable rockets to be produced and tested, a vehicle based on aircraft principles could enable more frequent launches.

The lower stage would be a large delta-wing aeroplane, generally similar to the North American B-70, using ramjets or hybrid engines, and possibly launched from a catapult. The upper stage would be basically a lifting body propellant tank, the compact form providing structural efficiency. The low density of the empty craft contributing to a gentle reentry, the broad, flat ventral surface might well withstand thermal loads without special shielding if made from titanium. Whatever the details, it seems likely that the first such ships would not have a significant payload capacity.

For cargo lifting, the best hope may be a semi-reusable configuration. The current NASA Space Shuttle is semi-reusable, but in effect it is the bottom stage which is discarded, and the Space Shuttle has the infrequent launches and high per-launch costs of typical expendable rockets. The combination of a reusable lower stage and an expendable upper stage, resembling the commercial Pegasus launch vehicle, bears examination. The rapid turnaround possible with an aircraft lower stage should increase the possible launch frequency, which will still be limited by the supply of upper stages and the time required for loading and checkout.

Further advantage might be gained by making the upper stage itself partially reusable. For example, the rocket engine might be built into a spherical heat-resistant shell which would be cast off the rocket, once in orbit, and reenter in the manner of a Vostok capsule. In this way, although the propellant tanks and body of the rocket would be lost, the engine, guidance system, and ancillary equipment could be saved. Different configurations of the disposable upper stage would be produced for different applications. For fuelling the lunar stage, the upper stage could be all tank, and its payload would be the residual fuel in the tank upon reaching orbit.

4. Launch Site Whatever type of spacecraft is used, in whatever mission configuration, must be launched somewhere, and a reusable system will also require a landing facility. Existing launch complexes which might be large enough for the necessary volume of traffic are owned by governments. This suggests that the Luna Project will need to develop its own launch facilities, at the cost of considerable effort. In compensation, these facilities would remain available for future use.

It seems reasonable that a lunar-launch facility should be located in an area where Luna passes directly overhead, confining possible sites to a certain band of lower latitudes. As the rotation of Terra contributes velocity to the rocket, locations closest to the Equator are most favourable, as the circumference, and hence tangential velocity, is largest there. For direct ascent, this advantage is available once daily, approximately when Luna is rising in the East. Since the atmosphere reduces the effectiveness of rocket engines and resists the passage of air- and spacecraft, a location at high altitude where the air is rarefied seems preferable. On this basis, the high basins near Quito, Ecuador, seem almost ideal.

Aside from the issue of coming to terms with the Ecuadorian government, however, the choice of Quito presents various problems. The first is that of transportation. Large rockets in large quantities demand large-scale transportation, typically by water, and Quito is isolated from the sea and poorly furnished with transport facilities. This objection might be met by assembling the rockets on site using parts brought in separately, including sheets for fabrication into tank sections. Secondly, a large if sparsely populated stretch of South America lies to the east, posing liability problems in case of a failed launch. A third consideration is that reusable stages or sections, especially the very large aeroplane type, might require a water landing. These factors suggest that an island, accessible to large ships and situate where possible crashes would fall in the sea, might be preferable.

The Atlantic and Indian oceans are poorly supplied with remote equatorial islands of sufficient size for a spaceport complex. This leaves the islands of the Pacific. Christmas, in the Gilbert Islands, the largest of all coral atolls, already possesses airfields and a Japanese satellite-tracking station ; the populace and local authorities might be receptive to the establishment of a space port. Alternatively, there are islands vacant due to nuclear testing, which would be suitable for medium-term occupation given suitable facilities. Unfortunately, Johnston, which has been used for rocket launches (and was briefly offered for sale by the U.S. government) lies above 15° North latitude, and Bikini lies above 10°, while the small French test islands lie above 20° South latitude.

5. Lunar Developments Once established, the lunar settlement will become highly relevant to issues of space transportation. Beyond the settlement effort itself, a collateral expansion of space activity in general is anticipated, as described elsewhere. The lunar settlement will be in an excellent position to contribute materially to this activity.

In the airless lunar environment, space launching "guns" become entirely practicable. The Northrup induction machine, which uses high-frequency three-phase current, is especially suitable because it acts on any object with a conductive surface, rather than requiring the magnetic buckets of some designs. Such a machine, arranged in the East-West direction at 45° North latitude in Mare Imbrium, with the muzzle end elevated and the breech end depressed, should be capable of putting objects into a high-inclination lunar orbit suitable for transferring to terrestrial orbits of various inclinations.

Rocket assemblies could be fabricated on Luna for use in lunar space, between Luna and Terra, and even in terrestrial orbit. The available materials dictate a hybrid design using liquid oxygen, presumably in large excess, and a metal fuel such as aluminum or calcium, probably in the form of sintered powder to reduce heat conductivity and the problem of melting. While the efficiency of such a unit would be low, its very availability would cover a multitude of sins. Mass production of a small range of sizes is likely, to be used in combination as each application requires.

6. Conclusion Space launch capability for the settlement expedition is certainly the most pressing issue confronting the Luna Project, and also perhaps the worst defined. Mutually compatible solutions must be found to each of the component problems. The choices made will play a major role in shaping the development of the solar system.

revision 0
submitted for comment by ***publius***
2007-196