Report on Project “Phase One” Findings

October 1, 2005

Introduction

The Phase One “Initial Feasibility Study” of the Sugar Shot to Space (SS2S) project was comprised of the following key topics of investigation**:**

a) Trajectory simulations
b) Basic configuration (1 or 2 stage rocket, etc.)
c) Motor thermal issues
d) Nose Cone Thermal Issues
e) Materials study (composite, metallic, etc.)
f) Aerodynamic assessment
g) Payload instrumentation studies
h) Large grain production techniques
i) Regulatory issues
j) Launch locations
k) Cost estimation
l) Fund raising methods

Findings on each of these topics are discussed in this report. The report is concluded with a “Directors’ Statement” on these findings, and consequential next course of action for the Project.

a) Trajectory simulations
b) Basic configuration

These two topics are intrinsically linked and are discussed as one.

Simulations (SIMs) constituted one of the earliest efforts undertaken in support of our Project. It was necessary to know if there existed a hypothetical possibility of achieving the goal of lofting a rocket powered by “sugar propellant” to the threshold of space Several individuals were involved in running SIMs using different simulation software. The results of the SIMs were encouraging, being both positive and consistent. It was therefore demonstrated that theoretically the goal was attainable, based on scaling up the performance of existing “sugar” motor designs.

Various configurations were studied including single stage and multistage designs. Two things soon became apparent. First off, an exceptionally high “propellant mass fraction”, in the order of 0.80 minimum, was a requirement. This is a direct result of the relatively low specific impulse of the “sugar propellant”. The value of 130 seconds used in the analyses, which is close to half the specific impulse of commercial rockets, all of which are powered by Ammonium Perchlorate composite propellant. And secondly, there was a large drag-loss penalty to be paid by traversing the denser, lower atmosphere at high velocity.

The challenge of a high mass fraction means that any design would require careful attention to keeping mass of all rocket components to an absolute minimum.

SIMs indicated that it would be impractical to achieve the goal with a single-stage design. A two-stage vehicle, however, provided a solution to overcome these challenges. A respectable mass fraction could be attained by dropping the first stage upon burnout, followed by coasting through the denser part of the atmosphere prior to lighting up the second stage.

Unfortunately, the two-stage approach posed certain risks to the Project success that were deemed to be unacceptable. These risks were partly technical, however, the more significant risk stemmed from a regulatory concern (see Regulatory Issues).

An interesting design solution was borne out of this dilemma. A design concept which was deemed “dual-phase”, involving operation resembling that of a two-stage rocket, melded into a single-stage vehicle. With a dual-phase configuration, two separate propellant charges would be contained in separate compartments in a single motor casing. The first charge (phase) is fired initially. A time delay is invoked prior to the second phase firing, allowing the vehicle to coast through much of the dense lower atmosphere (identical to the two-stage approach). The two compartments would be isolated initially by a frangible bulkhead which is breeched prior to second phase firing. It was recognized that certain technical risks were associated with this untried concept; however, it was felt that sufficient ground testing (possibly augmented by flight testing) could be done to prove the concept and alleviate the chief concerns.

A sizeable number of SIMs were subsequently run on the dual-phase concept to optimize the design, which involved minimizing the overall vehicle size while providing decent payload mass.

Another important set of parameters that played a key role in the SIM investigations involved specific regulatory restrictions. According to 14 CFR (Aeronautics & Space) section 401.5, an "amateur rocket" must have:

1) Total impulse of 200,000 lb-sec (890 kN-sec) or less
2) Burn time of 15 seconds or less
3) Ballistic coefficient of 12 lb/in^2 (83 kN/m^2) or less

It was found that the first two restrictions were fairly simple to deal with. However, it was found that meeting the ballistic coefficient restriction was extremely challenging, if not impractical, and only could be met with a two-stage or dual-phase design (a direct consequence of the propellant's low specific impulse). Fortunately, a way around this dilemma was arrived upon in discussions with the regulatory agencies (see Regulatory Issues for details). Nevertheless, it has been considered prudent to keep these parameters for the proposed vehicle close to those specified limits.

A brief synopsis of the most current proposed vehicle configuration is given below:

- Number of stages: 1 (dual-phase operation)
- Vehicle size: 10" (25.5 cm) diameter by 26' (7.9 m) overall length
- Liftoff mass 1100 lbs (495 kg).
- Allotted payload mass 15 lbs (6.8 kg).
- Full vehicle recovery
- Propellant mass fraction 0.82
- Propellant type, cast Potassium Nitrate/Sorbitol (KNSB)
- Propellant mass 885 lbs (402 kg), consisting of 6 BATES segments per phase, for a total of 12 segments.
- Burn time 8.5 seconds each phase (17 sec. total)
- Motor average thrust, 6665 lbf (29.6 kN)
- Coast time between firings, 16 seconds

Preliminary mass targets for all significant vehicle components have been established.

c) Motor thermal issues

The primary concern with regard to thermal loading and consequential structural degradation was recognized to be the first-phase motor casing. This section of the casing would see thermal loading from both phase firings. Suitable casing wall insulation will need to be investigated as a solution. Other thermal concerns are with regard to the nozzle, which will similarly be subjected to heating over the dual operating duration. A graphite throat insert was considered to prudent, despite a successful history of all-steel nozzles used in existing “sugar propellant” motors. Whatever the material that would be used for the bulk of the nozzle body, various insulation options will need be studied (such as ablative coatings).

d) Nosecone Thermal Issues

At Mach 5, at an altitude still within the denser layers of the atmosphere, heating effects on a nosecone can be severe. In actual flights to Mach 5, but at lower altitudes, nosecone surface temperatures of approximately 1000 ^{o} F (500 ^{o} C.) were experienced in early NACA flights. That represents an outside limit for our design; we may have to withstand a similar temperature for a few seconds, less than 10. This estimate is based on experience and information derived from NACA reports and will be updated as actual thermal analyses are made. It appears, though, that either a composite or a metal nosecone will survive this environment. Some attention must be paid to insulation of the internal electronics. The very tip of the nosecone may have to be refractory or nearly so.

e) Materials study

The bulk of the rocket vehicle airframe will be comprised of the motor casing. Both metallic and composite solutions will be pursued as viable choices. Since a good fraction of the vehicle “dead mass” is the motor casing, choice of a material with a low mass density combined with high strength is paramount. Composite material has a number of intrinsic challenges, including a greater susceptibility to thermal strength degradation. Aluminum alloys have not been ruled out, but the prime candidate is currently titanium alloy. Alloy steel, such as 4130 has been considered, but indications are that the mass penalty may be unacceptably high.

The other major materials study, which is on-going, is with regard to the nosecone. Again, low mass combined with high strength and stiffness are important considerations. Thermal heating due to hypersonic velocity is being currently investigated to aid in the selection of a suitable material. Both composite and metallic materials are currently under consideration. Since the payload will be housed inside the nosecone, RF transparency is another desirable property. Another issue is the possible need to protect the payload from heat buildup, perhaps through the use of insulation.

Fin material is another issue that has been initially investigated and will be further studied in detail in the near future. Stiffness, strength, and resistance to thermal loading are the prime concerns with regard to materials selection. Thermal loading is both aerodynamic in nature (as with the nosecone) but is also a result of the need to attach the fins to the first-phase motor casing, which could subject the fins to serious heating at the interface location, particularly is if a metallic motor casing is chosen.

Material selection for the fairing (which will house the recovery system) has not been investigated in detail, but is not considered to pose any particular challenge, with the exception of the interface to the motor. Thermal concerns will need to be addressed.

f) Aerodynamic assessment

As part of the trajectory simulation process, vehicle aerodynamic features had been considered early on in the feasibility study. In particular, the variation of drag with respect to vehicle Mach number, as the vehicle will spend a majority of flight time in either supersonic or hypersonic velocity regime. Nosecone drag will have a profound effect upon overall vehicle drag losses. As such, the nosecone shape (profile and fineness ratio) has been studied to choose an optimum nosecone shape. The current shapes that are being pursued as a result of this study are conical and ¾ power of a fineness ratio of 5 or 6. Details of this investigation will be detailed in a separate report that will be released in the near future.

The pressure coefficient applying to a conical nosecone of 5:1- 6:1 aspect ratio and at Mach 5 is approximately 0.02. This figure is derived from NACA studies in the 40’s and 50’s. This greatly lessens concerns about dynamic pressure loading on the nosecone during the mission profile.

Fin shapes have been briefly investigated and will be studied more closely in the near future. Aerodynamic related concerns with the fins center around drag minimization and resistance to flutter. Other identified fin related issues include the inducement of vehicle roll to minimize trajectory dispersion.

Another aerodynamic concern is the effect of launch lugs. The possibility of going “lugless” is being considered, if studies indicate that drag losses are significant. Lugless designs under consideration entail devising a launch tower to support and guide the vehicle without the use of lugs, or the lugless solution could entail detachable lugs.

Use of a boat-tail is another drag-reduction option that has been proposed, and will be further investigated. Due to the diameter of the proposed nozzle exit cone being nearly equal to the vehicle diameter, the advantage may prove to be minimal.

Preliminary investigations into the beneficial effect of base drag reduction during motor operation suggest that a sizeable gain may be realized, and that this should be taken into account in refined SIMs.

g) Payload instrumentation studies

A great deal of discussion of potential payload items took place on the discussion forum early on in the feasibility study. The need for a flight computer which would continually sense and record parameters such as vehicle altitude, velocity and orientation was recognized as a key payload requirement. It was proposed that the computer would also perform key tasks such as:

- ignition of the second-phase motor including lockout if required
- vehicle abort (destruct) system
- de-roll system activation
- sense and record motor chamber pressure (and possibly temperature)

Other payload suggestions that will be studied and developed as deemed necessary include:

- Recovery beacons and other devices for aiding recovery of the rocket after touchdown (including visual and audible aids).
- Transmitter(s) to convey key vehicle information to a ground station on a real-time basis
- Nosecone temperature sensing and recording
- Sponsor scientific payload
- On-board videocamera (including so-called “lipstick cameras”) and still-camera photos to be taken throughout the ascent and descent. De-roll would be beneficial for video imaging during descent

The mass target of 15 lbs (6.8 kg) was deemed to be reasonable by members of the Payload Team.

The need for full redundancy of all key systems was recognized.

h) Large grain production techniques

A significant challenge presents itself with regard to the exceptionally large mass and sheer physical size of the propellant grain(s) required for the proposed vehicle. Each of the twelve BATES segments is projected to have a mass of 74 lbs (34 kg), which is a full order of magnitude larger than the biggest of those historically made from “sugar” propellant. Discussions on the topic of large grain casting techniques have highlighted several issues

- New preparation and fabrication techniques will need to be developed.
- Large amounts of raw ingredients will need to be processed in a timely, efficient, and safe manner “on site”

- Casting of such large segments will likely require a new class of heating vessels.
- Safety concerns will need to be addressed, as well, so that the processing of the propellant would be done without hazard to the participants.
- Acceptable quality of the resulting cast propellant segments will need to be ensured through suitable inspection methods.
- Storage and possible time-related degradation of the propellant will need to be studied.

None of the above issues are considered to be show-stoppers. It is anticipated that "scaling up" of current grain preparation methods could suffice. Nevertheless, a sizeable research and development program is clearly needed to be initiated in the near future.

To date, a large grinding mill (100 lb/hour) has been pledged by a team member for use in our Project. Suggestions have been made with regard to methods of pressing the propellant during cool-down and cure stage to ensure maximum density, adhesion (to the casting tube) and structural soundness. Physical and mechanical testing will need to be performed on representative propellant specimens in order to gain full insight and subsequent assurance of structural capabilities of large grains under conditions of flight loading.

i) Regulatory issues

This is another topic that was investigated early on in the feasibility study. Contact was made with FAA/AST by a Team member and discussions ensued about how best to obtain a waiver for the flight. The pressing matter concerning the official definition of an "amateur rocket" and associated restrictions was clarified. Information about which particulars of the rocket vehicle, trajectory, etc. that would need to be submitted to FAA/AST (should the flight take place in the USA) in order to obtain a launch permit has been either clarified or discussed. An open dialogue is being maintained to help avoid any hitches in the critical path to eventual flight clearance.

It was revealed early on that a two-stage rocket would likely pose a problem in attempting to obtain a launch permit. The concerns apparently related to the possibility of an unclean staging, and the possibility that the resulting deviant trajectory of the vehicle after staging could result in unacceptable dispersion

A document detailing the regulatory issues facing the flight of the SS2S rocket vehicle and the pathway to obtaining clearance is currently being prepared by a Project team member and will be released in the near future.

j) Launch locations

This topic was discussed at length early on in the discussions between project participants and other interested parties. A number of possible locations in the USA were suggested, as well as a number of non-USA sites. The current consensus is that a USA launch site is preferred, simply because of the logistics involved otherwise, and because the majority of project members (and available component manufacturing/assembly facilities) are in the USA. Other locations will nevertheless continue to be considered.

k) Cost estimation

Some “guesstimations” of total costs were put forth during discussions relating to this important topic. Part of the difficulty in cost estimation is the reliance on (and as it turns out, generous) support in the form of outright donations of both goods and services.

Due to a lack of meaningful cost data at this early stage of our Project, the Project Directors have made the decision that this topic will be deferred to Phase 2 of the Project. Priority will nevertheless be placed on Cost Estimation and as such, this topic is to be dealt with imminently.

l) Fund raising methods

This issue was discussed and ideas put forth on the discussion forum. To date, a number of modest fund-raising schemes have been implemented. This includes the selling of “Sugar Shot to Space” merchandise such as tee-shirts, trucker caps and coffee mugs. The main intent with this campaign is more directly related to publicizing our Project, which it is hoped, will lead to enhanced sponsorship and donations. Another scheme involves direct project member solicitation of individual contributions. This has been arranged such that contributors are now listed on the SS2S website. Contributors are placed on “tier” levels (i.e. bronze, silver, gold, etc.) corresponding to escalating levels of monetary support.

As fund raising is of crucial nature in the on-going support and continuance of our Project, the Project Directors have made the decision that the topic of Fund Raising be carried over to Phase 2 of our Project

Project Directors’ Statement

The Phase One Feasibility Study has now been concluded. The Project Directors have determined that all topics have been satisfactorily addressed (with noted exceptions) and that the decision has been made to <u>proceed with Phase Two</u> “<u>Research and Design</u>” effective immediately.

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