A Sounding Rocket Launch Technique For Pico Satellite Payloads

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ABSTRACT

A sounding rocket pico satellite launch technique to a highly elliptical orbit is described. With this scheme, a conventional multistage sounding rocket first launches the payload to a very high apogee. At apogee a small second impulse kick motor injects the payload into a highly elliptical orbit. It is shown that the sounding rocket launch technique for pico satellite payloads has a number of important advantages over the conventional low earth orbit satellite launch method, including a direct progression from simple sounding rocket programs, low cost, and the avoidance of strategic ICBM technologies. The method is particularly attractive to the launch of small national prestige payloads by small countries and as alternative commercial space access for corporations to larger national carrier launch vehicles.

INTRODUCTION

In the mechanics of orbital launch vehicles Bigger IS Better. Economies of scale dominate. As the launch vehicle gets larger, ancillary equipment is a smaller fraction of payload, larger budgets mean that advanced structural materials become available to enhance the mass ratio, engine efficiency increases, and aerodynamic drag is less of a problem. A large launch vehicle can carry multiple payloads including “piggyback” micro, nano, and pico satellites, to a precise efficient low earth orbit using a controlled zero angle of attack flight path trajectory. Yet, while there is no economic or technological justification for building a smaller launch vehicle, even in a world of excess launch capacity, there still remains a need for a small orbital launch vehicle, enough so that NASA has funded a two million dollar Centennial Challenge for back to back 1 kg satellite launches.[1] A large launch vehicle is an incredibly expensive national program far beyond the finances of commercial enterprise, which also generates problematic Weapons of Mass Destruction proliferation “dual use” ICBM technologies, of the current space fairing nations, only one does not have a nuclear warhead delivery capability. There is an obvious need for a small, low budget, low technology, simple space access vehicle for small nation national prestige satellite payloads, and to lower the space access threshold for innovative commercial satellite payloads which do not have access to national carrier launch vehicles.

The key to this scheme of low budget access to space is to turn the orbital launch problem on its head. Instead of trying to “hit” a precise low earth orbit injection point, the focus is on “missing” planet earth. Being farther away from the planet immediately helps. A very high first apogee is favored. The launch is now a two impulse maneuver, one, straight up to a very high apogee, two, an insertion kick into a highly elliptical orbit. The orbital injection impulse is easily calculated by equation no. 1 for elliptical orbital velocity at apogee from Eisele.[2]

REFERENCES

[1]http://www.nasa.gov/offices/oct/early_stage_innovation/centennial_challenges/nano_satellite/index.html

$$Vapogee = \sqrt{(Vescape^2/(1+R/r)) * (R/r)^2}$$

Equation no. 1 Velocity at apogee for an elliptical orbit
where V apogee = Velocity at apogee
V escape = Escape velocity at Earth's surface
R = Radius of earth
r = Orbit radius at apogee

Figure no. 1 below (not to scale), illustrates the spacecraft orbital injection technique as from a precisely vertical launch. Since this would require a launch in a westerly direction, the most probable trajectory would include some component of the easterly rotation of the earth and would be a transfer from a sounding rocket earth intersecting elliptical trajectory to a non earth intersecting orbital ellipse. The required launch boost deltavee would of course be dependent on the launch latitude, azimuth, and elevation and mostly dependent on the restrictions to the impact area of the booster stages.

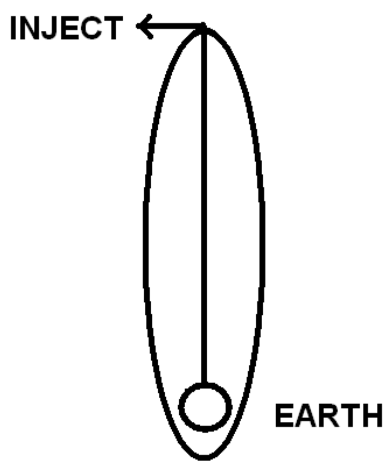

figure no. 1, Injection at apogee into elliptical orbit.

Figure no. 2, illustrates the increased tolerance to spacecraft injection velocity and attitude at high apogee orbital injection. For a Low Earth Orbit the injection burn has almost zero tolerance in pitch, yaw being a waste of energy, but having considerable tolerance in positive velocity from the required 7856 m/s horizontal velocity. At a very high apogee of 205720 Km, the required horizontal velocity is much less, about 340 m/s, and a wide range of pitch and yaw attitudes are allowed for the spacecraft. A circular orbit injection could be attained with a 1378 m/s injection and an escape parabola above 1951 m/s. Short of attaining escape velocity, excess injection velocity reduces the need for precise attitude control. Apogee being the best place to add to perigee altitude and the worst possible place to attain escape velocity.

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[2] Astrodynamics, rockets, satellites, and space travel; an introduction to space science, by John A Eisele, Washington, National Book Co. of America, 1967.

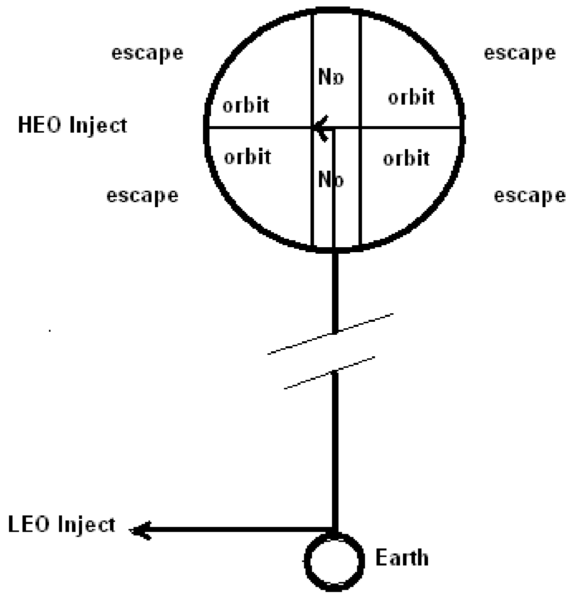

Figure no. 2, Tolerance to injection deltavee and attitude at apogee. (not to scale)

MISSION EXAMPLE

The proposed Texas Spacelines Inc. Sol Cazador launch vehicle[3] is a simple multistage sounding rocket, well within reach of amateur level technology. Each stage has a mass ratio of 0.75 and a working mass ratio 0f 0.5625.[4] The stage growth factor would be three. With an average stage ISP of 230 this results in a six stage launch vehicle using hybrid motors in the lower three stages and solids for the three spun upper stages. The sounding rocket needs to be capable of lofting its payload to 205,720 Km, half way to the Moon. A launch velocity of 11200 km/s which is normally considered escape velocity is required to overcome drag and gravity losses. Burn durations should be short and accelerations high. At apogee the spin stabilized payload comes to a virtual stop approximately 48 hours after launch with some remaining velocity due to easterly rotation of the launch site. Using low resolution sun and earth image sensors and a single attitude thruster, the spinning spacecraft orients itself for an orbital insertion kick of about 340 m/s and at 90 degrees to the earth spacecraft line. The resulting orbit would be of 96 hours duration. Most of the inspiration and the math for this type of orbit can be attributed to John A. Eisele's book.[5]

The technology is of course very simple, and precedents can be taken from historical sources. In the early days of sounding rocket spaceflight the Trailblazer project actually used six stages to attain the required velocities for its mission, although not all in the upward direction.[6] The

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[3] http://web.wt.net/~markgoll/rse54.htm and the advice and assistance of Arthur Schnitt.
[4] http://web.wt.net/~markgoll/rse49.htm
the stage mass ratio, equal to the propellant divided by the propellant plus the stage structural mass (MR=PR/(PR+ST)
the working mass ratio, which includes the mass of the payload (PL) which the stage is pushing, (MR=PR/(PR+ST+PL)
[5] ibid. pg. 458.
[6] A Wind-Compensation Method and Results of Its Application to Flight Tests of Twelve Trailblazer Rocket Vehicles, by Allen B. Henning, Reginald R. Lundstrum, and Jean C. Keating, National Aeronautics and Space Administration, 1964

Syncom Project used simple photo sensors and a single thruster for attitude control.[7] Of course today a simple low resolution CCD camera with a microprocessor could greatly enhance the spacecraft's navigation capabilities. This launch method was actually used by the STEREO mission. The injection of the spacecraft into a highly elliptical orbit at high apogee (a little beyond the lunar orbit) was done with standard techniques with a Delta 2 rocket, an expensive vehicle fully capable of Low Earth Orbit missions, and a second maneuver was needed at apogee to "miss the Earth", to prevent re-entry, the high apogee orbital injection maneuver being required for the mission to survive.[8]

ADVANTAGES

- Small, cheap, low technology. Possibly within the reach of a weekend volunteer type launch project.
- A direct progression from sounding rocket hardware to an orbital payload program.
- No IMU (Inertial Measurement Unit), no GPS, no RADAR needed.
- Not an ICBM development vehicle.
- No gimbal system or TVC (Thrust Vector Control), fin and spin stabilization of the launch vehicle.
- One site operation.
- For high angle sounding rocket type launches, the vehicle is in view during the entire launch booster stages burn duration from the single site.
- Failure to inject results in a nearly vertical reentry and payload debris disposal by burnup.
- The window for the orbital injection maneuver is measured in hours, not seconds.
- The orbital injection maneuver is in direct line of sight radio contact, when using a multiple of 24 hours for the first apogee.
- Each apogee is relatively fixed in celestial position, with hours available to establish radio contact with the payload.
- The spacecraft spends most of its time at apogee well above the low earth orbit and geostationary satellite belts, away from spacecraft collision hazards.
- Spinning payload with sun sensor and single thruster attitude control.
- Minor In plane changes in the major axis available at perigee, Major Out of plane changes in the minor axis at apogee.
- Works extremely well with Robert W. Farquar's and David W. Dunham's Indirect Launch Mode technique for lunar and interplanetary missions. This technique was used with the NASA CONTOUR mission giving increased time to "clean up" the orbit to hit the perigee injection state accurately.[9]

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[7] Attitude determination and control of SYNCOM, Early Bird, and applications technology satellites, by Sierrer, W. H.; Snyder, W. A., Journal of Spacecraft and Rockets, vol. 6, issue 2, pp. 162-166

[8] Ossing, D. A., Dunham, D. W., Guzmán, J. J., Heyler, G. A., Eichstedt, J. E., and Friessen, H. D., "STEREO First Orbit and Early Operations," in Advances in the Astronautical Sciences, Volume 129: Astrodynamics 2007, Proulx et al. (eds.), Proceedings of the AAS/AIAA Astrodynamics Specialist Conf., 1923 Aug. 2007, Mackinac, MI, Paper AAS 07-377, pp. 19751989 (2008).

[9] The Indirect Launch Mode: A new Launch Technique for Interplanetary Missions, by Robert W. Farquhar and David W. Dunham, Acta Astronautica, Vol. 45, Nos. 4-9, pp. 491-497, 1999.

Dunham, D. W., Muhonen, D. P., Farquhar, R. W., Holdridge, M. and Reynolds, E., "Design and implementation of CONTOUR's phasing orbits", in "Spaceflight Mechanics 2003", Advances in the Astronautical Sciences, Paper AAS 03-2008, Vol. 114, Part III, pp. 1535-1548 (Univelt, San Diego), 2003.

- For lunar, solar, or interplanetary missions, most of the escape velocity is acquired during the first launch impulse.
- With the emphasis now on required orbital debris removal, lunar perturbations will remove the satellite from earth orbit at the end of its useful lifetime without operator intervention.
- Low earth orbit is accessible by circularizing at perigee with the same spacecraft attitude as orbital injection, although this requires a large change in velocity.

DISADVANTAGES

- Not an efficient launch vehicle! Actually 100 times less efficient than the Saturn V.
- Not suited to delicate, large, or heavy payloads.
- Lunar perturbations limit orbital lifespan.
- Node rotation, each apogee is of long duration, but at a different celestial position, unless a 63° major axis orbital angle to Earth's rotational axis is attained.
- Manned operation of this launch technique is extremely dangerous due to the vertical reentry on failure to inject. It is NOT suitable for space tourism operations.
- Requires a certain level of spacecraft navigation capability to attain the orbital injection attitude at apogee, although almost any direction but directly towards Earth or directly away from Earth will work if enough impulse, but less than escape, is used.

CONCLUDING REMARKS

The results is a launch vehicle that literally cannot hit the broad side of a barn, yet is capable of orbital, lunar, solar, and interplanetary missions. After a national prestige orbital mission is achieved by a small country, the decision to continue development of a heavy launch capability or to utilize the subsidized carrier vehicles of other nations becomes an economic decision not involving national prestige. With this technique available in the literature, any country that develops a dual use (ICBM type) low earth orbit capable launch vehicle using the excuse that it is the only way of getting a national prestige payload into orbit must now admit to a nuclear capable ICBM development program. The technique is also available to any small private group with an innovative payload not considered legitimate or appropriate enough for the piggyback transport services of a national carrier vehicle.