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Launch of "Smallsats" Using Low-Cost Sounding Rocket Technologies, Methods, and Practices

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Abstract. A system study has been conducted to investigate the use of established sounding rocket technologies, methods, and practices to lower the cost of placing small lightweight satellites into low earth orbit. The cost savings gained in utilizing such technologies are largely due to the simplification of booster design and operations. Launching a 150 kilogram satellite into a 200 nautical mile, sun-synchronous orbit was selected as the target requirement. Designs and operating practices developed for Sandia National Laboratories' Strypi class suborbital sounding rockets have been applied to a vehicle configuration with sufficient boost performance to meet this target. The "Super-Strypi" spinning booster system is rail launched and flies an unguided, fin-stabilized ballistic trajectory while in the atmosphere. The exo-atmospheric upper stages use spin-stabilization to maintain a constant thrust direction during burn, eliminating the complication of an active thrust vector control system during powered flight. A "fail-safe" command enable philosophy for the ignition of upper stages eliminates the need for a command destruct flight termination system. Recurring cost per launch is expected to be approximately $5.0 million for the concept presented in this study, assuming a minimum launch rate of two flights per year.

Introduction

The development of low-cost access to space has been a high priority for those interested in flying "university-class" scientific payloads. Many payloads remain grounded due to the $15 million minimum cost of booking a small booster launch. Some small satellites have received rides as secondary payloads, using unbooked space on an existing mission. While this practice will likely continue, it necessarily compromises the objectives of some experiments, since the primary payload carries priority in mission planning, mission timelines, orbital targeting, launch windows, and overall scheduling. The National Aeronautics and Space Administration (NASA) established the Bantam Lift program to develop the technologies required to make launch of small satellites economically viable, but it remains to be seen when such efforts will actually bring forth a commercial capability for this class of launch vehicle.

Previous Study

The dilemma faced by experimenters interested in this class of payloads was initially brought to the attention of Sandia National Laboratories (SNL) by the Universities Space Research Association (USRA) in the

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spring/summer timeframe of 1992.[1] The USRA was interested in SNL rocket systems technologies and recommendations that could help alleviate this problem. This request was made in conjunction with the availability of Spartan rocket motors to the USRA for possible conversion as small satellite launchers. After a few months of study, SNL recommended that the Spartan assets be used in a configuration based on the application of basic sounding rocket technologies and practices. It represented a "keep it simple" and "keep it low cost" philosophy with all the technologies readily in hand. Although it still did not meet the $2 million per launch cost goal desired by the USRA, the concept represented a significant cost reduction (50%-70%) compared to the next best commercial option. A concept paper was presented informally to the USRA on November 9, 1992, which was later published as a formal SNL document in 1993.[2] For various reasons, the Spartan motor options were never pursued. The Spartan assets were finally destroyed in 1996-1997.

Current Study

The concept of using sounding rocket technologies, methods, and practices to launch university class payloads into orbit was revived by SNL after participating in NASA's "Hard Rocket" Conference[3] in January 1998. The issue of providing launch opportunities for such experiments seemed to still be largely unresolved. While the development of newer and cheaper technologies holds promise for the future of small commercial boosters, a concept based on the application of sounding rocket technologies could be a valuable interim step toward such goals.

This concept has its roots in the SNL experience base with its solid-fueled Strypi class suborbital launch vehicles. The designs and operating practices for the Strypi family of boosters have been well validated through the conduct of 44 missions to date. Scaling this technology base up to a vehicle size with sufficient performance to launch small satellites is presented in this paper. A number of configurations were studied, although only one is presented here. This larger family of vehicles has been generically termed "Super-Strypi".

The Super-Strypi satellite launcher concept represents a relatively modest increment to the existing Strypi sounding rocket technology base, thus minimizing development risk. The simplification of design and operation reduces parts count, testing procedures, software complexity, safety issues, and launch crew size, all of which contribute to reducing cost and enhancing reliability. Until a commercially viable booster is available to service this class of payloads, SNL envisions that the USRA could be the operator of this system, launching its own small research satellites into orbit. This could provide students and faculty with valuable experience in the launcher end of the business, similar to that currently being obtained in satellite technologies.

Concept Approach

The concept approach was to scale up existing SNL sounding rocket technology to the task of placing small payloads into orbit. The overall goals that guided this process were as follows:

- Define a rocket booster capable of placing a 150 kilogram satellite into a 200 nautical mile circular, sun-synchronous orbit. This is consistent with NASA's goal for the Bantam Lift program.
- Design a vehicle to be compatible with simple launch operation procedures.
- Build upon the SNL sounding rocket experience base and proven technologies to reduce risk, minimize both development and recurring cost, and permit an early demonstration of the concept.

These goals bring focus to the key design features to be extracted from the sounding rocket technology base for application to the small satellite launch problem. The impact of each of these design features on attaining the desired goals is summarized in Table 1.

Table 1. Impact of Design Features

Design Feature	Impact
Rail Launched	1. Vehicle buildup is simplified; no need for vertical stacking or missile erector. 2. Initial "guidance system" is a simple, reliable rail. 3. Depressed launch elevation angle accelerates the vehicle away from the launch area quickly, enhancing safety. 4. Can be launched from any site with a rail launcher of sufficient length and loading capacity.
Unguided Atmospheric Flight	1. Expense and risk of complex guidance system is eliminated. 2. Stability is provided passively through aerodynamics and aerodynamically induced roll rate. 3. Need for flight termination system is eliminated for the first stage.
Spinning Vehicle	1. Simple, proven method to minimize the effect of thrust asymmetries, limiting dispersions from intended flight path. 2. Spinning-vehicle cold gas attitude control system on second stage, reducing cost and complexity compared to thrust vector control systems. 3. Spin stabilization eliminates the need for any control system on the orbital insertion stage. 4. Permits the use of a "fail safe" command enable philosophy for flight safety, where each of the upper stages is only allowed to fire if it is properly oriented and stable; eliminates need for flight termination system on upper stages.

Vehicle Configuration and Operation

After a number of iterations, it was decided to base the Super-Strypi configuration on a scaled up version of the SNL Strypi XI three stage sounding rocket[4]. It was reasoned that anything more than three stages would add unwanted cost and complexity. Anything less than three stages would result in difficulties finding a large first stage rocket motor that could operate in the spinning environment. A comparison of the Strypi XI to the proposed Super-Strypi is shown in Figure 1.

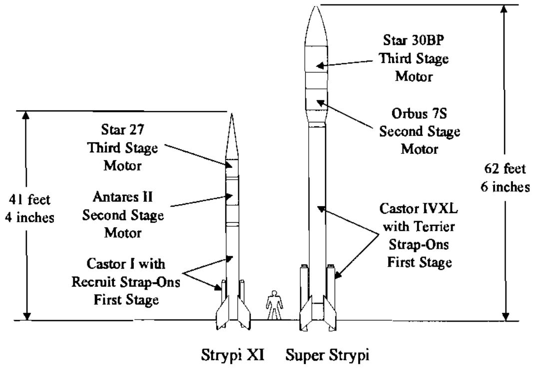

Figure 1. Configuration Comparison

The Super-Strypi consists of a Castor IVA-XL first stage motor, replacing the Castor I on the Strypi XI. Similarly, two strap-on Terrier Mk. 70 motors replace the Recruit motors. In both cases, the strap-on motors provide additional boost to ensure that a sufficiently high velocity is attained at the release point from the launch rail. For exoatmospheric flight, the Orbus 7S and Star 30BP replace the Antares II and Star 27, respectively. All motors have fixed nozzles without thrust vector control capability.

Figure 2 shows the internal configuration of the upper stages. Figure 3 shows the staging sequence for the vehicle. Most of the electronics are housed in the section between the second and third stage motors, including telemetry, guidance package, flight computer, and ordnance firing system. It remains with the second stage throughout the flight. The third stage and satellite payload are completely shrouded. Since the third stage is the spin stabilized orbital insertion motor, it carries very little in the way of electronics. A classical "yo-yo" despin system[5] can be included on this stage if the satellite requires despin prior to release.

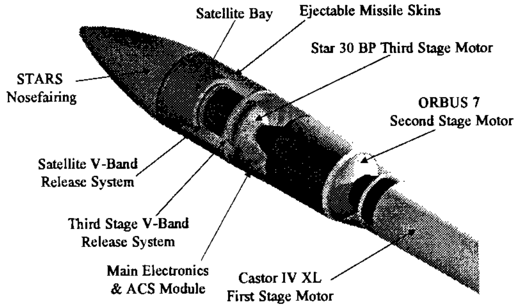

Figure 2. Upper Stage Cutaway View

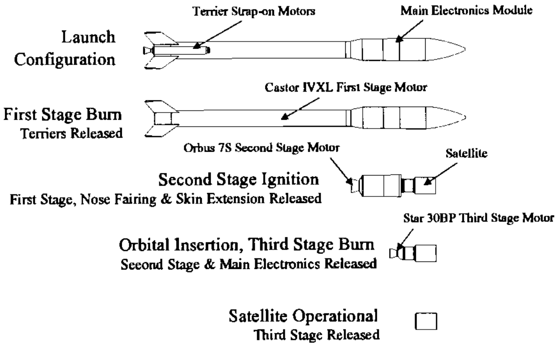

Figure 3. Staging Sequence

Flight Sequence

The proposed Super-Strypi flight sequence is illustrated in Figure 4. In sounding rocket fashion, the vehicle will be launched from a rail. The launcher elevation and azimuth settings are determined by the ascent profile required to reach the target orbit and the vehicle's predicted aerodynamic response to the measured wind profile at launch time. The core stage and strap-ons are ignited simultaneously. Nozzles on the Terrier strap-on boosters are oriented such that their thrust vectors are directed through the center-of-gravity of the entire vehicle. This minimizes overturning moments due to any residual thrust mismatch between the strap-on boosters during the first few seconds of flight. The expended Terriers are then jettisoned approximately 6 seconds after launch. The core vehicle continues on its flight path.

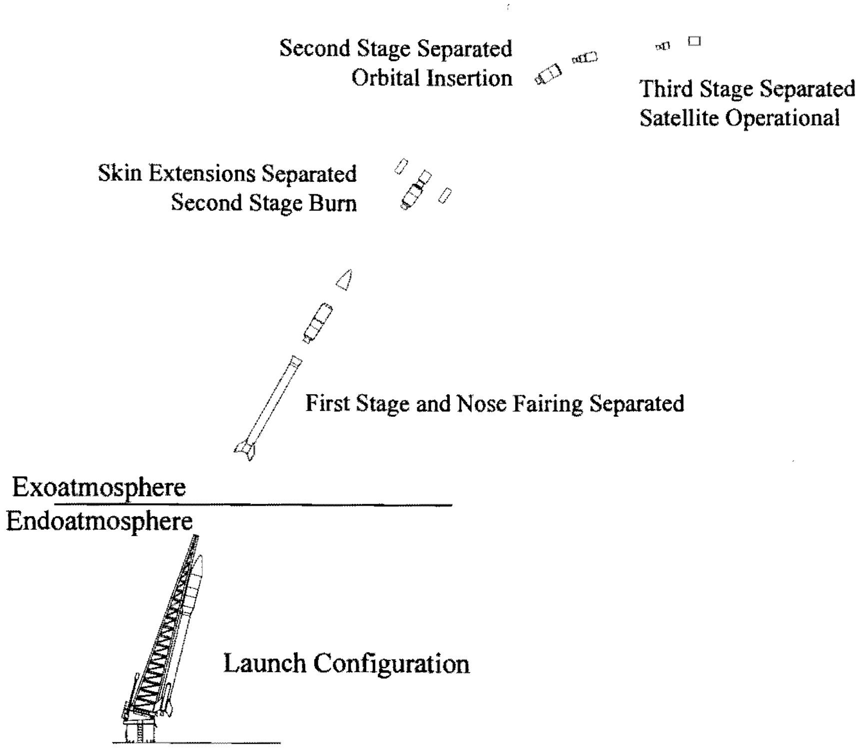

Figure 4. Super-Strypi Flight Sequence

The Super-Strypi flies through the atmosphere on an unguided trajectory. The fins provide passive stability for the vehicle as well as roll torque to average out any residual thrust asymmetries. As the first stage flies toward burnout, it reaches a maximum roll rate of approximately 900 degrees per second (2.5 rps). After burnout, the vehicle coasts up to an altitude where the dynamic pressure drops down to 1.0 pound per square foot. First stage separation occurs at that time, along with ascent shroud release, exposing the satellite payload and its third stage orbital insertion bus.

During the entire flight, the flight computer continuously keeps track of the vehicle's state vector using inputs from the inertial measurement unit (IMU) and a Global Positioning System (GPS) receiver. Upon assessing first stage performance, the flight computer adjusts the second stage ignition time and vehicle pointing vector such that residual dispersions in first stage performance and position are corrected as a result of second stage burn. A spinning-vehicle cold gas attitude control system (ACS),[6] located on the second stage, simultaneously adjusts the vehicle's body attitude to the commanded orientation while reducing the roll rate to 360 degrees per second (1 rps). The Orbus 7S second stage is then ignited at the prescribed time and flies in a spin stabilized mode to burnout.

The remaining stack, with the expended second stage still attached, coasts toward a ballistic apogee that is near the desired orbital insertion altitude. During that time, the flight computer repeats the state vector assessment process, and defines a body pointing vector and third stage ignition time that results in meeting the orbital target conditions at the end of the burn. Once again, the ACS performs the required orientation maneuver. The flight computer then starts a fireset sequencing timer located on the third stage bus and ejects the spinning third stage/satellite stack. Since the flight computer, IMU, GPS, ACS, telemetry, and all the other electronic systems remain with the second stage when it separates, event control for the remainder of the booster's flight is now in the hands of this fireset sequencing timer. The fireset ignites the Star 30BP third stage motor at the appropriate time and executes the spin stabilized orbital insertion. After burnout, the "yo-yo" despin system is activated, reducing the roll rate to near zero, and the satellite is released in its target orbit.

Performance

Trajectory simulations revealed that the Super-Strypi can carry a 400 pound satellite to a 200 nm circular sun-synchronous orbit, meeting the target requirement set forth in this study. Table 2 also shows other performance estimates to alternative orbits. Most of the simulations were run using Ascent 2.0 software,[7] although a number of simulations were benchmarked, with good agreement, against SNL's Trajectory Analysis and Optimization System (TAOS) code.[8] In order to ensure that the vehicle always has the ability to reach the target orbit insertion conditions (within an acceptable insertion accuracy), all simulations were conducted using -3σ low boost performance for the first and second stages, and nominal performance for the insertion stage. Rocket motor performance data from the individual motor manufacturers[9, 10, 11] and the CPIA Rocket Motor Manual[12] were used to construct the vehicle model.

Table 2. Super-Strypi Performance Estimates

Launch Site	Orbit nm (km)	Inclination deg.	Satellite Mass lbm (kg)
Vandenberg	200 (370)	97.1	400 (181)
Vandenberg	297 (550)	97.4	335 (152)
Wallops	200 (370)	38	506 (230)
Wallops	270 (500)	38	463 (210)
Wallops	540 (1,000)	38	295 (134)

For the Super-Strypi configuration, orbital insertion accuracy will be affected by such things as navigator knowledge of the vehicle state vector and attitude, the ability to determine and maintain commanded burn attitudes, the uncertainty in system mass, and motor performance uncertainty. Ballast for the vehicle is set based on the stage performance assumptions outlined above. Performance dispersions in first stage flight are removed by appropriate selection of second stage ignition time and pointing attitude. Similarly, on-board determination of the third stage ignition time and pointing attitude are intended to eliminate accumulated dispersions at the end of second stage flight. There is no mechanism, however, to correct for third stage performance dispersions. A preliminary estimate for 3σ orbital insertion velocity accuracy to the target orbit is ±49 feet per second. Further study is required to obtain better estimates for this as well as orbital inclination accuracy.

Vehicle Aerodynamics

A preliminary aerodynamic analysis was conducted for the Super-Strypi configuration. The use of the standard Strypi fin was considered a high priority in order to keep development costs down. Similarly, an existing ascent shroud used in SNL's Strategic Target System (STARS)[13] program was selected for use in this concept. Both decisions have significant aerodynamic effects on the vehicle.

The condition analyzed was the period of maximum dynamic pressure (max-Q). Body loading was computed using the MURACA code.[14] The TAD2 program[15] was used to compute fin loading. These results were then used as input data for the GUST[16] aeroelastic analysis code.

The computation has yielded a rigid body static margin of approximately 14% with a maximum bending moment of 580,000 inch-pounds for a 1° angle of attack at max-Q. This result is shown in Figure 5. The figures are promising, indicating that the configuration is well within the current technology to operate in a sounding rocket mode. The flexible body calculation, however, showed significant shifts in both answers (4% and 720,000 inch-pounds, respectively). Additional analysis, including computational fluid dynamics modeling, will be required to better quantify these results. A number of options are available to correct

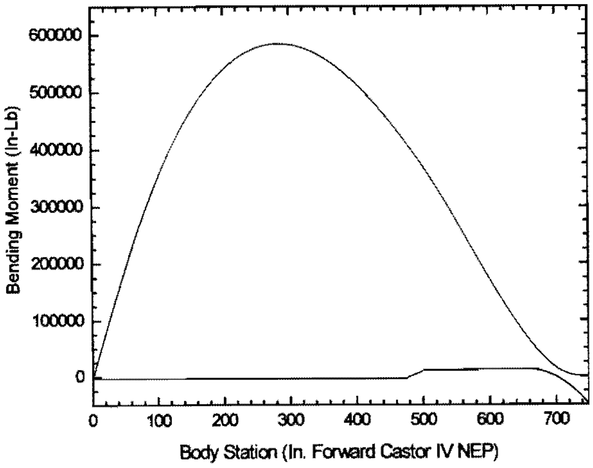

Figure 5. Super-Strypi Bending Moment

the problem if it proves to be real, such as scaling the fins to a larger size and changing the shape of the ascent shroud from an ogive to a cone.

A separate computation indicates that the Strypi fin cant angle will need to be reduced slightly for the Super-Strypi application, from 0.75° to 0.65°. This calculation is based on a steady state roll rate equation that can be used for scoping, but oversimplifies the actual vehicle response. Calculated spin rate as a function of time is shown in Figure 6.

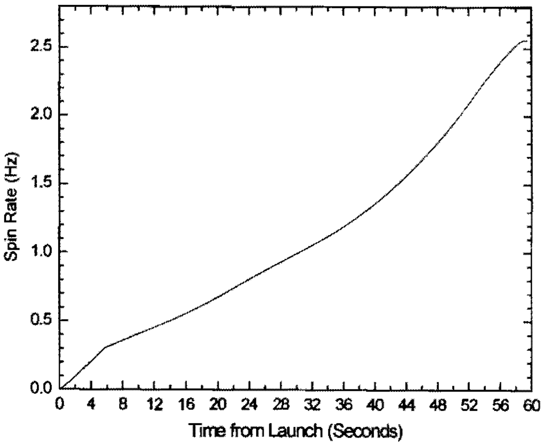

Figure 6. Super-Strypi Spin Rate

Flight Safety

The development, approval, and conduct of Super-Strypi flight safety operations are expected to be greatly simplified by adopting the philosophical approach used in the Strypi sounding rocket family of launch vehicles. This approach, which relies on the passive stability of the rocket and the "command enable" feature for authorizing upper stage ignition, has been used for Strypi launches from the Kauai Test Facility (KTF), located at the Pacific Missile Range Facility, and Wallops Island since 1972.[17] The key features that have allowed flight safety officers to approve this method of operation are outlined below:

- Rail launching of the vehicle at a depressed elevation angle, instead of vertically, rapidly establishes the direction of a velocity vector that causes the instantaneous impact point to move quickly out over the water away from the launch area.
- Vehicle stability and direction of travel are provided passively via aerodynamics and spin rate, which in turn are defined by the fins and overall geometry. Therefore, stability is dependent only upon fixed, robust structural elements that make the prediction of failure modes and off-nominal vehicle behavior relatively simple.
- Upper stage ignition is disabled until a specific command signal is sent from the ground by the flight safety officer. During the coast phases between stages, telemetry is used by the flight safety officer to determine if the spin-stabilized stack is pointing in the correct direction for the next stage motor burn and, consequently, whether the ignition enable signal should be sent.

The command enable procedure is considered to be "fail safe", since the loss of telemetry, radar, or the command system uplink results in termination of any further sequencing. The vehicle falls into the ocean at its current impact point prediction.

Rail Launcher

The 50K Launcher was designed and built by the Space Data Division of the Orbital Sciences Corporation for the BMDO Starbird program back in the early 1990's. One is currently installed on Pad 1 at the Wallops Flight Facility (WFF).[18] Another is planned for installation at Vandenberg Air Force Base (VAFB) at Space Launch Complex 5 (SLC-5)[19]. For the purposes of a Super-Strypi orbital launch, the WFF site could be used for easterly launches to low inclinations, while VAFB SLC-5 could serve as the launch site for high inclination or polar missions.

The launcher, shown in Figure 7, consists of three main component subassemblies; the boom support, the elevation drive, and the azimuth drive/pedestal. It has been designed to handle launch vehicles that generate a maximum overturning moment about the boom pivot point of 1 million foot-pounds.[20]

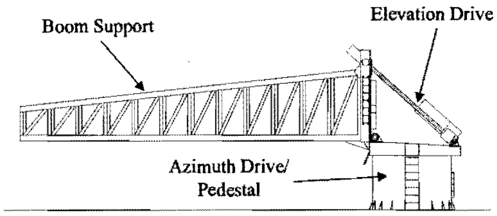

Figure 7. 50K Launcher

A simultaneous rail release system, used on SNL's Strypi sounding rockets, would be adapted to the boom support assembly. This system is illustrated in Figure 8. Both the forward and aft rail systems, along with the skyhook system, are shown in a single cross section.

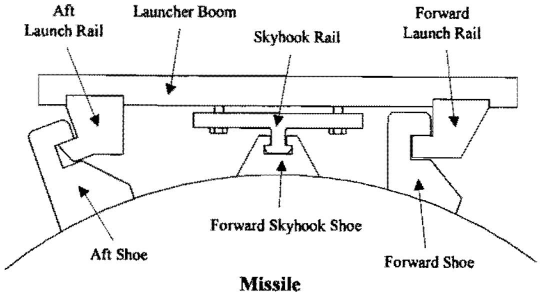

Figure 8. Simultaneous Rail Release System

The forward and aft shoes are attached to each end of the Castor IVA-XL first stage motor. Proper positioning of the rails on the boom support results in both the forward and aft shoes running off their respective rails at the same time. Simultaneous release provides a clean missile separation from the launch rail without a gravity induced tip-off torque. The skyhook supports the forward end of the second stage motor and releases after the first few inches of missile travel. It is spring loaded and retracts up into the boom assembly immediately thereafter.

Rail Release Velocity

One of the important parameters in controlling the dispersion of unguided rail launched rockets is the rail release velocity. This is why the Strypi sounding rockets have Recruit strap-on boosters. Similarly, the Super-Strypi configuration is proposed to have strap-on Terrier boosters for the same reason. Analysis and simulation, however, show that the Super-Strypi leaves the standard length 50K boom at a velocity of 30 feet per second, much slower than the normal 100 ft./sec. Strypi sounding rocket rail release velocity. While detailed analysis might ultimately indicate that the resulting 3σ first stage dispersion is acceptable, a launch rail boom extension was considered for the purposes of this study. Figure 9 shows the Super-Strypi on the 50K launcher with a 25 ft. rail extension. This extension yields a 70 ft./sec. rail release velocity, which is much closer to the Strypi sounding rocket experience base.

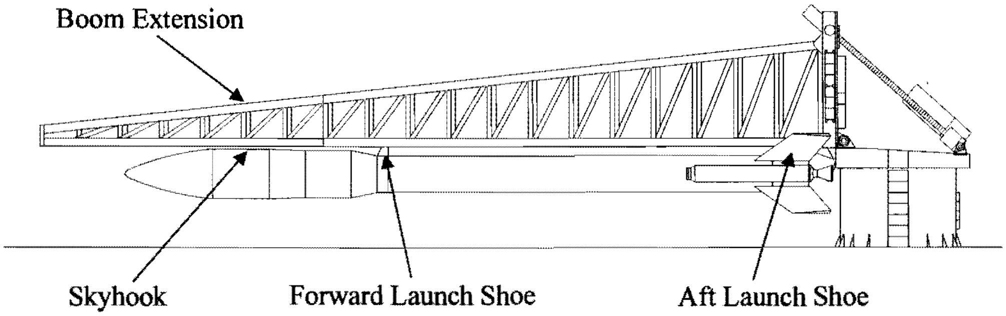

Figure 9. 50K Launcher with Boom Extension

Loading

The estimated moment loading applied by the Super-Strypi and the boom extension on the 50K launcher is 1.34 million ft.-lbs. This is 34% greater than the rated capacity of the 50K launcher. It is currently unknown whether there is sufficient design margin in the launcher to accept this loading condition. Similarly, further study would be required to determine what modifications, if any, are needed to accommodate the Super-Strypi. While this is an issue that requires resolution, it is not considered to be insurmountable.

Potential Alternative

One alternative suggested has been to convert the existing Scout launchers to Super-Strypi launchers through the addition of a rail system to the elevation boom. Since the Super-Strypi is of similar mass and length when compared to the Scout, the launcher's overturning moment capacity might be sufficient to meet the needs of this concept. The total azimuth travel capability would also need to be assessed. Scout launchers are located at Wallops Island on Launch Complex 3 and at SLC-5 at VAFB, which would theoretically allow the full range of orbital inclinations.

Launch Acoustics

The acoustic noise field generated by the exhaust flow of the rocket motors at launch has the capability of harming the satellite payload or the missile system. A brief study was conducted to evaluate this field for the Super-Strypi.

For this study, it was assumed that the 50K launcher was at a 90° elevation (vertical), resulting in the worst case reflection condition with the nozzle exit plane parallel to the flat launch pad surface. The acoustic environment was calculated using the RRAP (Reflective Rocket Acoustic Program) code. RRAP is a Sandia modification of the VAEPP (Vehicle Acoustic Environmental Prediction Program) developed by acoustic engineers at the NASA George C. Marshall Space Flight Center.[21] It was specifically developed to predict acoustic pressures and power levels of rocket systems given various motor parameters. The predicted sound levels from the RRAP code have been compared with actual experimental measurements taken during Sandia launch operations at KTF with excellent results.[22, 23, 24]

Figure 10 is a plot of the overall Sound Pressure Levels (SPL) as a function of missile station. Maximum SPL is 178 dB at the nozzle exit plane, and tapers off to 147.5 dB at the exterior of the satellite bay. The sound pressure level in this area as a function of frequency is shown in Figure 11. At these levels, it is likely that some form of acoustic absorption system will be required in this area.

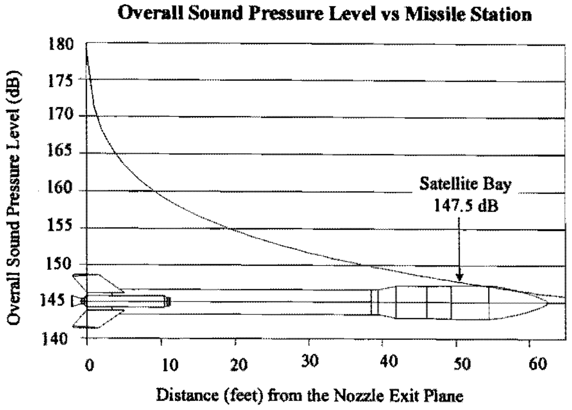

Figure 10. Sound Pressure Levels

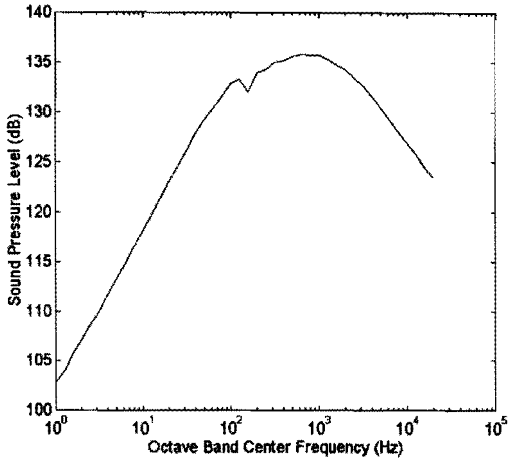

Figure 11. Satellite Bay Exterior SPL

Mechanical and Electronic Systems

It is envisioned that the mechanical and electronic systems for the Super-Strypi would trace their heritage to the Strypi sounding rocket experience base. Virtually all systems have reaped the benefits of evolutionary improvements since the inaugural Strypi mission in 1962, with their performance well validated in flight.

Joints

The most widely used joint design in the Strypi series of launch vehicles is the SNL developed "radax" joint.[25] Under cyclic loading, the radax joint maintains consistent elastic behavior and linearity, small hysteresis, and relatively high stiffness characteristics. It has already been scaled up from the Strypi size (31 inch diameter) to the Super-Strypi size (52 to 54 inches in diameter) as a result of SNL's Strategic Target System (STARS) program development.

Wherever possible, the mild detonating fuse (MDF) explosive separation joint will be used for staging and segment separation. It was developed for the STARS program, but has found application in Strypi vehicles in recent years. The MDF separation joint is the stiffest and lightest separation device used in the SNL rocket systems programs. It is likely, however, that the separation of the satellite from the third stage bus will be accomplished using a v-band joint to eliminate debris.

Terrier Strap-On Jettison

Conceptually, the jettison of the Terrier strap-on boosters after they burn out will be done with the same mechanisms currently used by the Strypi for Recruit jettison. This process will require more study, since the scaling effects up to the size needed for Super-Strypi are still unknown. The system uses slide rails mounted on the sides of the first stage tail can. Once the strap-on booster is expended and released, it simply slides axially down the rails while the core vehicle accelerates up through the center.

Electronic Flight Systems

In the interests of simplicity, single link telemetry for booster diagnostics is proposed for the Super-Strypi. Dual redundant ordnance firing systems, however, will likely be employed to ensure reliable staging and flight sequencing. Both philosophies represent typical Strypi practice.

Navigation systems will likely be upgraded to the latest technology SNL is developing for rocket and payload applications. The Litton LN200 fiber-optic gyro IMU combined with the Rockwell CMDT miniature GPS receiver represent the latest, lightest, and least costly option. Further study is required to determine if the IMU can be used in its strapdown configuration, or if the vehicle's maximum spin rate will require the roll-stabilized version currently under development at SNL. The flight will be controlled by a single board version of the modular Sandia Digital Airborne Computer (SANDAC), complete with its latest Motorola 68040 processor upgrade.

Technical Issues

Simulations indicate that the flight environment for the Super-Strypi include axial accelerations of up to 12.5 g's and spin rates of up to 2.5 revolutions per second. These are not typical launch environments for designers to consider in the development of their satellites. The question of whether "smallsat" designers could accommodate this environment without significant penalty needs to be investigated.

One other area of uncertainty is the development of a canted nozzle for the Terrier Mk. 70 strap-on boosters. Simply scaling up the existing Strypi design from the Recruit strap-ons is unlikely to yield satisfactory results. Development of this feature could be a strong cost driver. Canting the entire rocket motor on its rail mount might offer a less costly solution that is just as effective.

Finally, the Super-Strypi does leave up to three pieces of "space junk" in orbit. The spent third stage has no provisions for de-orbit, although it is unlikely to break apart since there are no residual propellants on board. A pair of despin weights with their tethers also fly freely near the spent third stage, assuming the satellite required despin prior to release. It is unclear whether leaving these items in orbit will be accepted as the standard mode of operation for this vehicle.

Cost and Schedule

The cost of the Super-Strypi system has been carefully considered based on the previous Strypi experience base. Most aspects of the cost modeling were built from the bottom up, using validated methods of estimation extracted from the historical database for identical or similar items. Development costs, along with any other non-recurring costs, have been included as part of the effort to execute the first flight. This model assumes that the technology to operate the Super-Strypi system is transferred to the USRA (or some other similar university consortium) in the course of the program. The proposed effort encompasses four flights, at the end of which the USRA would be able to conduct more missions without Sandia's assistance. Table 3 shows the breakdown of the flight costs and their associated schedules from the start of the program.

Table 3. Super-Strypi Cost and Schedule

Description	Cost	Schedule (month from start)
Development and First Flight	$10.25 million	18 months
Second Flight	$6.5 million	24 months
Third Flight	$5.5 million	30months
Fourth Flight	$5.0 million	36 months
Total	**$27.25 million**	**36 months**

Once the program gets into its recurring flight phase, the cost of a mission is dominated by the procurement of new motors (approx. $3.35 million of the per mission total). Manpower costs are minimized through the use of standardized interfaces between the booster and the satellite. Similarly, the application of flight software with explicitly defined inputs for targeting eliminates the need to customize software for each mission.

Table 3 does not include the range cost associated with a launch of the Super-Strypi. Whether the simplifications afforded by the use of sounding rocket technology translates to reduced range cost still needs to be investigated.

The Minuteman III Propellant Replacement Program (PRP) may provide an opportunity to reduce the motor cost for the Super-Strypi. Its SR-73 third stage motor is the military equivalent of the Orbus 7. The PRP is effectively discarding the SR-73 propellant loaded chambers, salvaging some of the equipment and attachment structure for use on new motors. The Pratt & Whitney Chemical Propulsion Group indicates that $0.5 million savings can be realized for each Orbus 7S motor if they are built from the PRP's residual SR-73 chambers. This represents a 10% reduction in the mature recurring cost of a Super-Strypi flight.

Undoubtedly, there will be other ideas and suggestions regarding how to further reduce costs if this concept was pursued. However, as long as the manufacture of new motors represents such a large fraction of the total cost, it is unlikely that the cost of a Super-Strypi will get any lower than the $5 million level. Obtaining motors as surplus from other programs, like the PRP, or a price cut from the motor manufacturers in the production of new motors, would be the only hope to further reduce the cost of a sounding rocket-like orbital launcher.

Summary

The Super-Strypi concept for launching "university class" scientific payloads into earth orbit has been presented. Utilizing sounding rocket technologies, methods, and practices, this booster can achieve the goal of placing a 330 pound (150 kilogram) satellite into a 200 nautical mile (370 kilometer) circular, sun-synchronous orbit. It represents an interim solution for a space access problem that the commercial launch industry has yet to satisfactorily address. The sounding rocket technologies are well developed, commensurate with a low risk approach to meeting the objective.

Simplification of design and operation, compared to traditional orbital rocket launch systems, is the key element that reduces cost and enhances reliability. It also enables the relatively easy transfer of the Super-Strypi concept to an organization like the USRA. As its own launch system operator, the USRA could fly numerous payloads, on dedicated launches, over the next three to five years while commercially viable, new technology, small boosters are being developed. Although it has its limitations, Super-Strypi launches can move this class of space experiment payloads forward, contributing to real scientific needs.

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Eric Schindwolf is currently the manager of Rocket Systems Technology Department II in the Aerospace Systems Development Center at Sandia National Laboratories. He has received degrees in Mechanical Engineering from Lowell Technological Institute, Lowell, Massachusetts (B.S.) and California State University at Long Beach (M.S.). During the last 14 years at Sandia, Eric has presided over virtually all aspects of the design, analysis, development, and operation of sounding rockets (including Strypi) and longer range ballistic missiles. Prior to joining Sandia, his experiences included research and development efforts for the Department of Energy's Clinch River Breeder Reactor and Uranium Gas Centrifuge programs, as well as aerospace engineering positions in commercial airliner programs at McDonnell Douglas and military fighter programs at Grumman Aerospace. Eric is the originator of the Super Strypi concept for orbiting small payloads, including the initial Spartan based Super Strypi studies in the early 1990's. His interest in space activities and rocket systems was inspired by his father's work at Grumman Aerospace in navigation, guidance, and control systems for the Apollo Lunar Module in the 1960's.

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Bruce Swanson is currently a Principal Member of Technical Staff in the Reentry Body Technology Department of the Aerospace Systems Development Center at Sandia National Laboratories. He has received Bachelor and Master Degrees in Mechanical Engineering from Kansas State University, Manhattan, Kansas. In the past 11 years at Sandia, Bruce's responsibilities have ranged from Lead Mechanical Designer to Project Manager of nine different rocket system variants (including 5 Strypi systems). Bruce was a Principal Investigator for the initial Spartan based Super Strypi study in the early 90's and continues to develop new advanced flight system concepts.

Biographical Information for William A. Millard

Bill Millard retired from Sandia National Laboratories in 1997. He began his career at Sandia in 1965 after graduating from the University of Michigan with a degree in aeronautical engineering. While at Sandia, Bill was involved in conducting aerodynamic and flight performance studies for a variety of missile and sounding rocket configurations. He is currently a consultant to High Technology Solutions, Inc., where he is involved in supporting testing activities at the Pacific Missile Range Facility.