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General Purpose Satellites: a concept for affordable low earth orbit vehicles

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GENERAL PURPOSE SATELLITES:
A CONCEPT FOR AFFORDABLE LOW EARTH ORBIT VEHICLES

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Abstract

A general purpose satellite has been designed which will be launched from the Space Shuttle using a NASA Get-Away-Special (GAS) canister. The design is based upon the use of a new extended GAS canister and a low profile launch mechanism. The satellite is cylindrical, measuring 19 inches in diameter and 35 inches long. The maximum vehicle weight is 250 pounds, of which 50 pounds is dedicated to user payloads. The remaining 200 pounds encompasses the satellite structure and support components, which include a hydrazine propulsion system, a 75 watt solar power system, an S-band telemetry transmitter and receiver, a 12 megabyte data storage unit, and a 16 bit system microprocessor. Active nutation control techniques are employed for spin stabilization about the longitudinal axis. Using the hydrazine propulsion system, circular orbits as high as 835 nm or elliptic orbits with an apogee of 2200 nm are attainable, departing a nominal Shuttle orbit of 135 nm. Pointing accuracies of +/- two degrees are possible. Total cost for the satellite and a GAS launch will be approximately $1 million dollars.

1. Introduction

No nation should structure its spacecraft fleet solely upon the use of high cost satellites and a single launch system. Without the balanced use of spacecraft which span a wide range of cost profiles, the development of space may be doomed to a flawed future. The present status quo of high cost satellites denies the general public,the business entrepreneur, and the military the widespread access to space that is required to ensure a vital and energetic development of space resources. Public access to space is effectively denied through the lack of low cost, competitive launch services and inexpensive but dependable low earth orbit spacecraft.

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Opening the realm of low earth orbit to a wider audience of space users requires that low cost, generic spacecraft be developed which are readily adapted to a variety of mission profiles. Such satellites would provide new opportunities for space based research, communication, and commercial access that are presently available to only a select group of government and industrial entities. For example, small communication transponders, miniature earth imaging systems and platforms for basic science research could all be profitably implemented on small satellites. The technology to develop such vehicles has existed for over ten years, yet the concept of inexpensive generic spacecraft has not been emphasized widely in the public space program or the US military. It is proposed, therefore, that a small general purpose spacecraft be designed to demonstrate the feasibility, reliability and marketability of inexpensive vehicles as effective workhorses in the exploitation of near Earth space. Such a spacecraft concept has reached the preliminary design phase at the Naval Postgraduate School. A small, spin stabilized satellite known as ORION has been designed to launch from the Space Shuttle as part of the "Get-Away-Special" (GAS) program. Pending final funding arrangements, it is anticipated that the first such vehicle will be ready for launch in 1990, carrying a military payload.

2. Small Satellites

Small satellite technology is made possible by the advent of the Space Shuttle "Get-Away-Special" satellite ejection concept, and the approval by NASA to deploy small satellites from open lid GAS canisters. This ejection concept was proven through the revolutionary success of the GAS launched NUSAT and GLOMR satellites in 1984 and 1985 respectively. These vehicles utilized a standard opening lid GAS canister (Fig. 1) and a Marmon band restraint/spring launch mechanism. The satellite launch unit was fitted in a 5.0 cubic foot GAS canister, having been designed by the NUSAT team in conjunction with NASA Goddard Space Flight Center GAS program managers. Recently, production-phase funding has been committed by the US Air Force to develop an extended GAS canister with a much improved launch mechanism. This will provide the opportunity to fly small satellites which are optimally configured to utilize a larger percentage of the GAS volume than was possible with the NUSAT or GLOMR vehicles

NUSAT and GLOMR proved the GAS satellite ejection concept, but lacked the volume required to transport medium (~ 0.25 ft^3) size payloads and propulsion systems. The inclusion of attitude control, propulsion, and a large payload volume were effectively prevented as a consequence of the large launch platform and correspondingly small satellite structure. However, the use of the new US Air Force launch mechanism and extended GAS canister will provide the potential for the inclusion of those satellite support services in a second generation GAS-launched vehicle. This paper will detail the new canister design and the concept of a satellite that is optimized for the new canister's geometry and structural capabilities. The ultimate goal of the authors' design effort is to provide a relatively low cost, general purpose satellite system that is easy and inexpensive to configure and deploy.

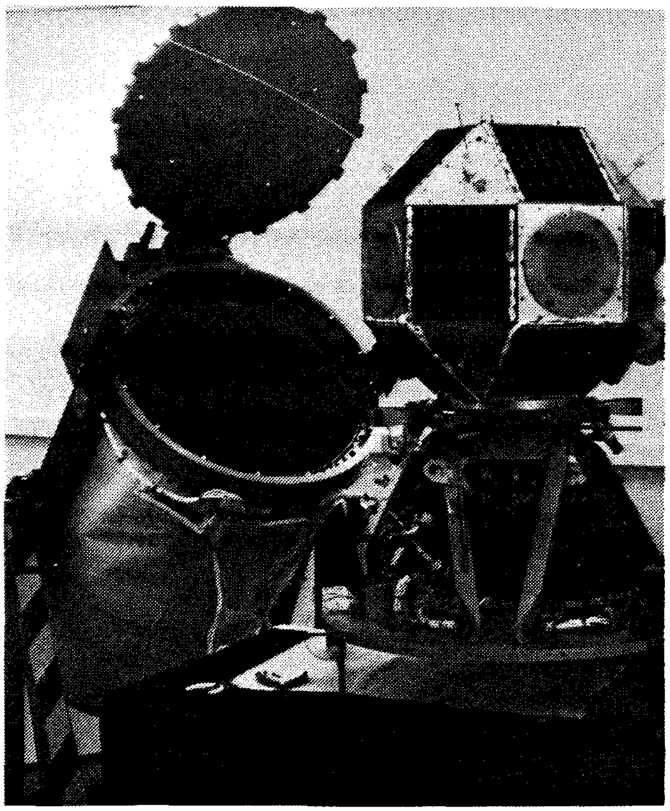

Fig. 1 Opening Lid GAS Canister with NUSAT Satellite and Launch Platform

3. Design Constraints

The general purpose satellite design is based upon four major design constraints. They are (1) the satellite should be affordable; (2) the satellite should conform to the volume limitations of the new extended GAS canister; (3) there should be a provision for satellite payloads of up to 50 pounds mass, occupying up to 2.0 cubic feet of payload space; (4) all satellite support services, including propulsion and attitude control, should be incorporated, providing circular orbits as high as 800 nm and pointing accuracies of +/- one degree. These constraints are based upon the specific requirements of a number of potential users, as surveyed during the past two years.

The first design constraint pertains to affordability from the perspective of military research laboratories, large corporations and some educational institutions. A preliminary cost goal of $1 million has been identified. In keeping with this constraint, the satellite design incorporates the use of simple, commercially available systems, avoiding redundancy where possible. Simplicity can often be equated with reliability, particularly in the design of propulsion systems. Hence, a simple design can be both reliable and affordable, when long life is not a critical requirement for the vehicle. This has been proven through the success of the simple but robust NUSAT satellite launched in 1984.

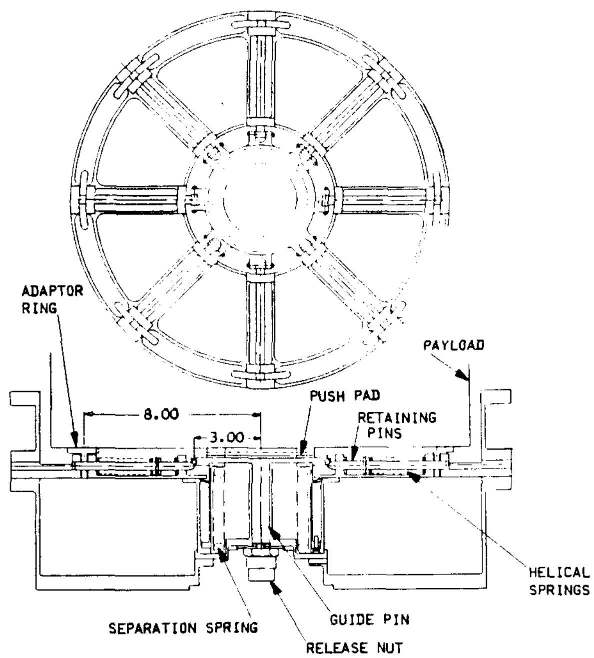

Fig. 2 GAS Canister Extension and Launch Mechanism Cross Section

The second design constraint reflects the choice of the Get-Away-Special canister and launch mechanism as the deployment method for the ORION spacecraft. The GAS program has a history of quality low cost engineering for spaceflight hardware and is considered to be well suited to the concept of low cost spacecraft. Using that program, the spacecraft must conform to the structural and geometric limitations of the new extended GAS canister being developed by the US Air Force. Figure 2 details the construction of a GAS canister extension which encases an integral launch and restraint mechanism in addition to the necessary GAS interface circuitry. This package attaches to the bottom of the GAS cylinder, and a servo operated opening lid is mounted to the top. The satellite is fastened within the canister by an apparatus in which eight spring loaded pins mechanically lock eight matching holes in an adaptor ring projecting down from the bottom of the satellite. In the center of the launch mechanism, a pyrotechnically actuated release nut holds a spring and pusher plate assembly in place until satellite ejection is commanded. At that time, the nut releases the spring and pusher plate, which permits the retaining pins to withdraw from the satellite adaptor ring. Shortly thereafter, the push plate contacts the satellite base and ejects it from the canister at a velocity of 2 to 4 feet per second. The launch mechanism and GAS canister will safely restrain up to 250 pounds of payload within a volume 19.25 inches in diameter by 35 inches long. Use of the new launch mechanism and canister extension concept provides additional payload volume not available in the original NUSAT design. The ORION design will specify a cylindrical structure 19 inches in diameter by 35 inches in length to maximize the use of the GAS volume.

Fig. 3 ORION General Purpose Satellite

The third design constraint specifies that up to 2 cubic feet of satellite volume and 50 pounds of mass be dedicated to the eventual payload of the vehicle. The decision to use these parameters was based upon surveys conducted by the Aerospace Corporation in 1976 and discussions between the authors and potential payloaders during the period 1984 - 1986. The Aerospace Corporation survey, in support of the NASA Standard Satellite Test Program (SSTP), indicated that many experimenters requesting payload manifests aboard US Air Force launch vehicles would require approximately 2 cubic feet of payload volume for payloads that averaged 50 pounds in mass, with the additional requirement for 15 watts of power and a data rate of 4000 bits per second. These "average requirements" were found by the authors to still be realistic for many potential payloads at the Aerospace Corporation, Naval Research Laboratory, and other military laboratories. Much of the internal volume of the ORION vehicle is dedicated to propulsion, attitude control, and data storage systems. Although the volume and geometry of each potential payload will vary, the preliminary design has proven that a payload space of approximately 1.5 cubic feet can be dedicated for payload use near the "upper" end of the vehicle structure. Figure 6 diagrams the internal layout of the satellite. While a specific mass placement has not been identified for the first ORION mission, the preliminary design has proven that it is feasible to reserve 50 pounds of mass and 1.5 ft^3 of volume for payload requirements. Surveys and informal discussions with satellite users indicate that these design constraints will permit the integration of a wide variety of small payloads.

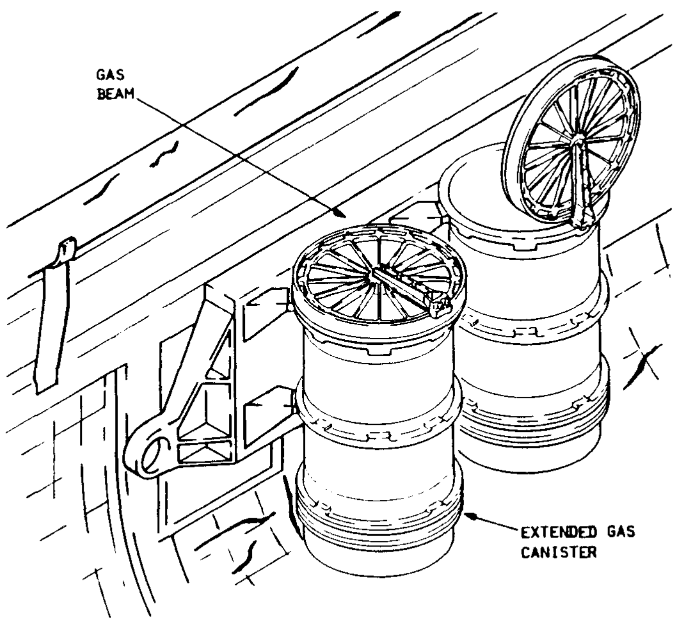

Fig. 4 Extended GAS Canister Mounted in Shuttle Bay

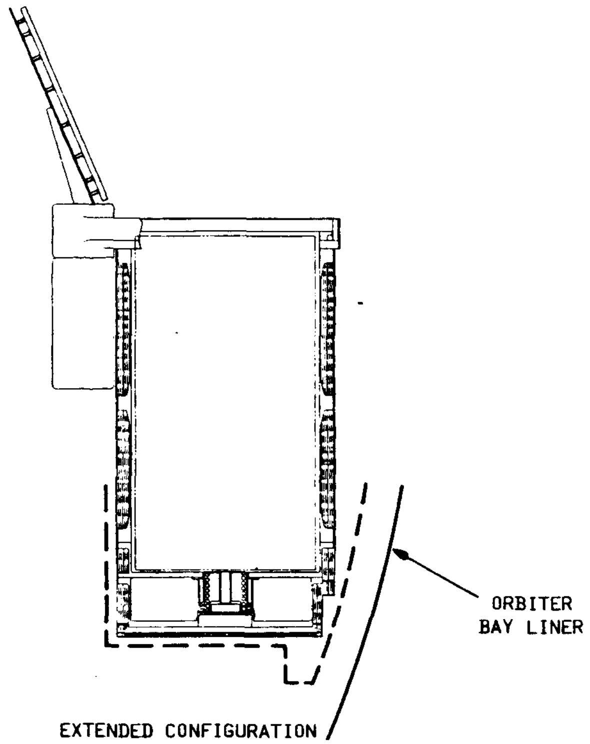

Fig. 5 Extended Canister and Payload Volume

The final design constraint, to incorporate propulsion and attitude control systems, was a response to the request of many potential users for orbits above Shuttle altitudes. The NUSAT, GLOMR, SPARTAN, and LDEF spacecraft all operate at their deployment (Shuttle) altitude. With the advent of the new Air Force extended canister, it is feasible to incorporate propulsive systems aboard GAS launched satellites. The NUSAT and GLOMR satellites do not utilize propulsion or attitude control as a consequence of their limited volume. However, many payloads for ORION will require pointing accuracies of +/- 1 to 3 degrees, and orbits as high as 800 nm (circular). To accomplish this, a hydrazine monopropellant thruster system has been proposed to enable orbit insertion, station keeping, spin maintenance and pointing control. Sufficient hydrazine will be transported in a 16 inch diameter positive expulsion tank to enable circular orbits of 835 nm or elliptic orbits of 2200 nm, departing a nominal shuttle orbit of 135 nm. An attitude control propellant reserve will enable spin stabilized attitude control. Using advanced sun/earth sensor packages, rate gyros, and magnetometers, a pointing accuracy of at least +/- 2 degrees is feasible. Commercially available thruster systems that are in production are utilized in lieu of costly, specialized systems. The seven thrusters are connected to a pressure fed positive expulsion (elastomeric diaphragm) tank, and operate over a blowdown ratio of 5:1. Six 0.1 lbf thrusters and one 5.0 lbf thruster are used.

Attitude stabilization of the vehicle may require active nutation control. When the satellite is spun about the longitudinal axis, the body will behave as a prolate spinner. Using the mass placement identified in the preliminary design, the vehicle possesses an inertia ratio of 0.305. Energy dissipation due to fuel motion in the spherical on-axis hydrazine tank will cause a rapid increase in the nutation angle. Hence, if the longitudinal axis is identified as the spin axis, active nutation control will be required to regularly reduce the nutation angle to manageable proportions. For example, at a spin rate of 20 rpm with a full fuel tank, the satellite will exhibit a time constant of 350 seconds. This time constant is reduced to less than 150 seconds at 60 rpm. As fuel is expended from the tank, the inertia ratio will change, varying from 0.305 to 0.325, and the time constant will also increase proportionately. Assuming a maximum angular

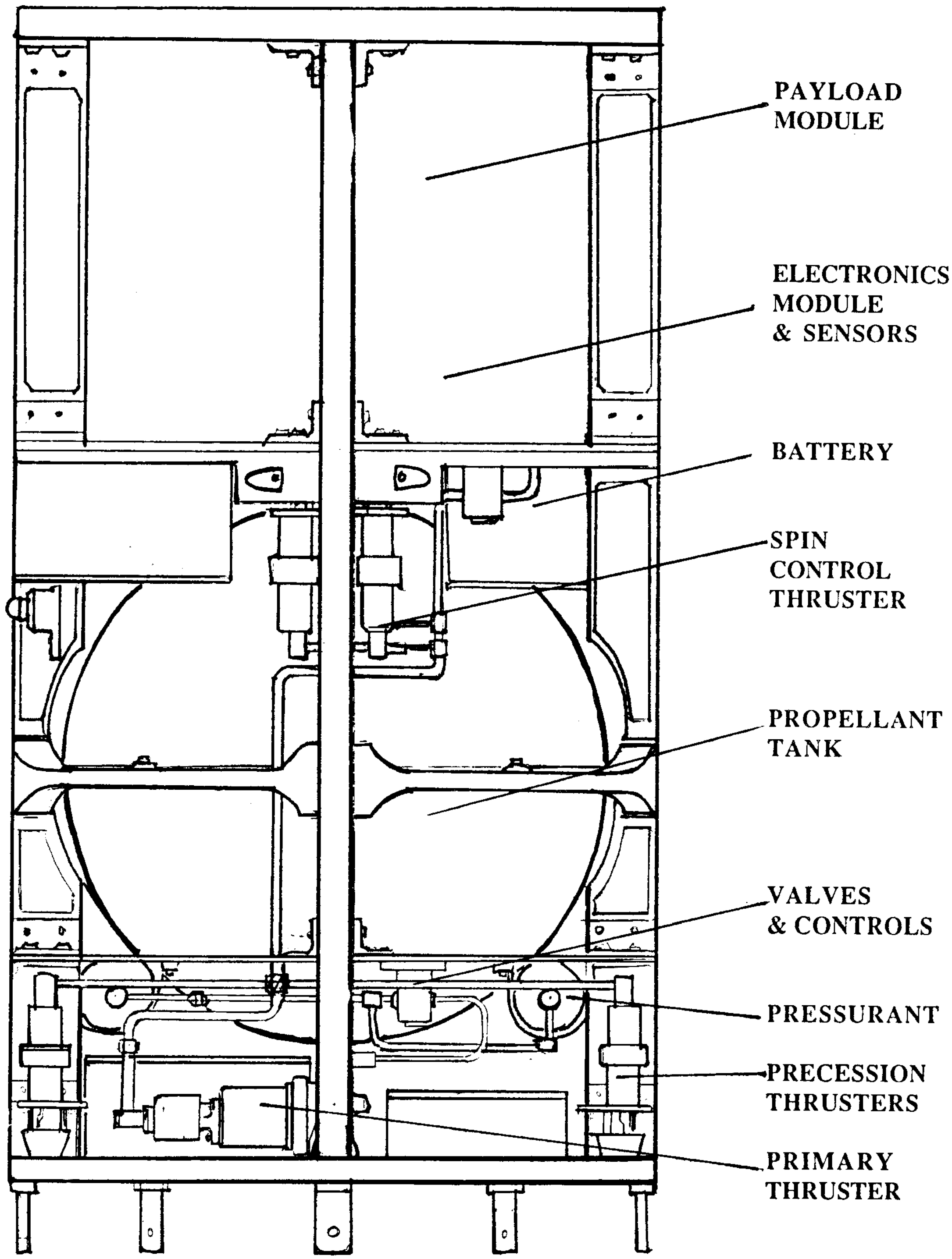

Fig. 6 Cross Section of ORION General Purpose Satellite

resolution of 0.5 degrees and a maximum nutation angle of 3.0 degrees, the thrusters will exhibit a limit cycle of 4.5 seconds. With such a limit cycle, the satellite will exhibit a lifetime of approximately 20 days per pound of fuel expended. The total system fuel capacity is 71.5 pounds. The preliminary design calls for an attitude control propellant reserve of 6 pounds at a circular orbit of 835 nm, and thus a 120 day lifetime. If the transverse axis is chosen as the spin axis, the vehicle behaves as an oblate, stable spinner. For this attitude control configuration no active nutation control is required, as the inertia ratio varies between 3.08 and 3.28, varying with fuel expenditure. With such a stable inertia ratio, the only fuel expended for attitude control will be for spin control and pointing changes. Lifetimes of up to three years are anticipated for this oblate spinner case.

4. General Purpose Architecture

Accommodating the needs of many different experimenters in a small satellite design requires that a general purpose system architecture be pursued to the maximum extent possible. The needs of many payloads have been considered in the development of ORION in an attempt to provide a complete spectrum of satellite services to the user while meeting the aforementioned design criteria. Based upon inputs from potential users, a design has been formulated which provides 75 watts of power, a 12 megabyte magnetic bubble memory data storage unit, a 16 bit microprocessor/controller, signal and data interfaces to the payload, and an S-band telemetry package. While no design can be "all things to all people", the ORION design has proven that it is possible to provide basic services in a small, low cost spacecraft.

Spacecraft power will be provided by silicon solar cells mounted on the periphery of the satellite cylinder, but not on the ends. The beginning of life (BOL) power output will be 75 watts, with approximately 20 watts available for the payload. The solar cells will be supplemented with a 15 volt, 90 watt-hour NiCad battery. The solar cell power output is based upon a spacecraft spin about the longitudinal axis, and the average power output will be 10% to 20% less for a stable spin about the transverse axis. Optimal orientation relative to the Sun is assumed.

The satellite will be controlled by a 16 bit system microprocessor, augmented by a 12 megabyte magnetic bubble memory (MBM) data storage system. Significant experience in MBM data systems at the Naval Postgraduate School has led to the choice of MBM for ORION. It is less expensive and capable of more rapid access than tape recorders. However, it is not yet competitive in terms of storage density. Small amounts of data (eg. 12 megabytes) can be stored inexpensively using MBM technology on ORION. The controller will interface with an S-Band telemetry transmitter and receiver pair, communicating with ground stations through an omnidirectional antenna. Data rates of at least 150 kilobits per second are anticipated. An option is also being investigated for a despun platform and a pointed, high gain antenna in a future vehicle.

5. Conclusion

The inception of the NASA "Get-Away-Special" (GAS) experiment program instituted a "spaceflight for all" capability. It has opened the field of space based experimentation to a multitude of public and private users. The NUSAT and GLOMR satellites launched in 1984 and 1985 demonstrated that small vehicles could be successfully transported and launched by the Space Shuttle using the GAS container. A second generation concept in low cost vehicles is now proposed, focused upon the use of a new, low profile, satellite ejection mechanism mounted within an extended GAS canister. This satellite design will maximize the potential of the GAS canister and demonstrate improvements over the proof of concept NUSAT/GLOMR design. A full array of satellite systems is proposed for new ORION vehicle, including propulsion, attitude control, S-band telemetry, and data storage. A payload capability of 50 pounds mass in a volume of 1.5 cubic feet is anticipated. The payload will be provided with at least 20 watts of continuous power, a 150 kilobits per second data rate and pointing accuracies of at least +/- 2 degrees. A flexible set of propulsion and attitude control options will be based upon the use of hydrazine monopropellant thrusters. Orbits as high as 835 nm circular will enable the user to access altitudes above Shuttle orbit . With its propulsion and payload capacity, ORION is capable of providing a valuable complement to the NASA fleet of free flyers such as NUSAT, SPARTAN and LDEF.

Spacecraft like ORION, SPARTAN and NUSAT possess the potential to revolutionize the use of low earth orbit. Innovative approaches to satellite design and deployment will continue to be required to reduce the high cost of space operations. The private development of space, and cost effective government utilization of low earth orbit are both critically linked to the continued development of low cost spacecraft which this paper promotes.