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ABSTRACT

A low cost general purpose mini-satellite bus has been designed to support a wide variety of small scientific and commercial payloads. The design provides a number of launch options, including the new NASA extended Get-Away-Special (GAS) canister and several small expendable launch vehicles. The satellite is 19 inches in diameter, 35 inches high and weighs approximately 270 lbs. The satellite bus provides telemetry, attitude control, orbital boost/station keeping, electrical power, microprocessor and data storage for up to 50 lbs. of user payload. The satellite has a hydrazine propulsion system, with up to 2600 ft/sec delta-V capability. On-board propulsion reduces launcher orbital insertion accuracy requirements and is sufficient to allow the satellite to independently achieve 800 nm circular or 2200 nm elliptic orbits from an initial orbit of 135 nm. The design stresses simplicity and utilization of previously proven components. Manufacturing costs are reduced by using high quality commercial components, good design practices and simplified test procedures. Total cost for the satellite is projected to be less than $1.5 million.

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BACKGROUND

The mission of the Naval Postgraduate School, Space Systems Academic Group is to educate and prepare military officers to assume positions of responsibility in the specification, design and operation of military space assets. Flight experiments are considered an essential part of the educational program. The complexity and thoroughness of design required in a satellite development program offers an excellent opportunity to reinforce and expand upon students academic education. Exposure to the many interrelated and complex aspects of space missions, through constructive hands on projects such as ORION, broaden the students education and provide insight in many ways that traditional academic approaches can not. This perspective makes the students better military officers and better prepares them for future space related assignments. Both the students and the faculty benefit from the experience, while making a valuable contribution to the available space assets of the United States.

INTRODUCTION

This nation's space program is caught in an upward cost spiral. Spacecraft have historically been designed for each application. The design and optimization of satellites for specific missions, while achieving an optimum design, does not allow the economies of scale available in a continuous production environment to be realized. Limited budgets, high costs and long development times result in limited flight opportunities. Limited flight opportunities and long development times foster a "reliability at any cost" approach which further serves to increase program costs. As a result, satellites have become more and more complex, larger and heavier. The requirement to launch larger and heavier satellites, combined with the apparent economies of scale in launch vehicle costs, based on a myopic dollars per pound on orbit criteria, has resulted in an emphasis on the development of ever larger and more complex launch vehicles. Small innovative payloads and experiments, which historically have been the source of many major scientific discoveries (such as the satellite that lead to the discovery of the Van Allen belt), have gotten lost in the dust of this cost spiral.

The ORION concept is an outgrowth of a belief that the spiralling costs and focus on "traditional" custom spacecraft development has placed access to space beyond the reach of most small users and experimenters. A broad approach is needed, which includes low cost satellites and low cost launch alternatives. A means is needed to provide economical access for small innovative payloads on a quick reaction basis. The choices available to experimenters and other low budget users have typically been limited to flying as a secondary payload on larger satellites or taking advantage of the shuttle

Get-Away-Special (GAS) program. Flight opportunities as a secondary payload on larger satellites are limited and provide the user with little or no orbit and attitude flexibility. The Shuttle Get-Away-Special program has provided a means of economical access to space, but flight opportunities are also limited. Development and availability of low-cost generic spacecraft and low cost launch vehicles is essential if the realm of low earth orbit is to be opened to a wider audience of space users. Considerable interest has been generated in small low cost satellites (Lightsats) by a current DARPA program to develop low cost space systems. (Ref. 1) This program offers significant opportunities for commercial and civilian applications. (Ref. 2) Low cost satellites provide new opportunities for space-based research, advancement of space technology, communications, and commercial activities which are presently available only to a select group of government and industrial firms. (Ref. 3)

DESIGN CONCEPT

Interest in small, low cost satellites has increased as a result of the Space Shuttle GAS program and the approval by NASA to deploy "free-flyers" from GAS canisters. (Ref. 4) The ejection concept has been demonstrated by the successful launch of NUSAT in 1984 and GLOMR in 1985. (Ref. 5) Both satellites used the standard NASA GAS canister and a launch mechanism designed to fit inside the canister. While proving the viability of launching small satellites from GAS canisters the available satellite volume using the original configuration was too small to allow the satellites to have propulsion or attitude control capability. Recently the USAF has funded the development of an extended GAS canister with an improved launch mechanism in the base. Figure 1 compares the available satellite volume of the new design with the canister and launch mechanism used for NUSAT and GLOMR. The use of the USAF extended GAS canister provides sufficient volume to allow the development of a small satellite with propulsion and attitude control capability. (Ref. 6)

While satellite launch using the space shuttle provides an economical means of access to space the number of launch opportunities that will be available using GAS canisters on the redesigned Space Shuttle is in doubt. The DARPA Lightsat program recognizes the need for lower cost launch alternatives and includes an emphasis on the development of lightweight lower cost launch alternatives. (Ref. 1)
Table 1 is a summary of several proposed small launch vehicles. Reducing launch costs is a critical element in providing economical access to space for small satellites.

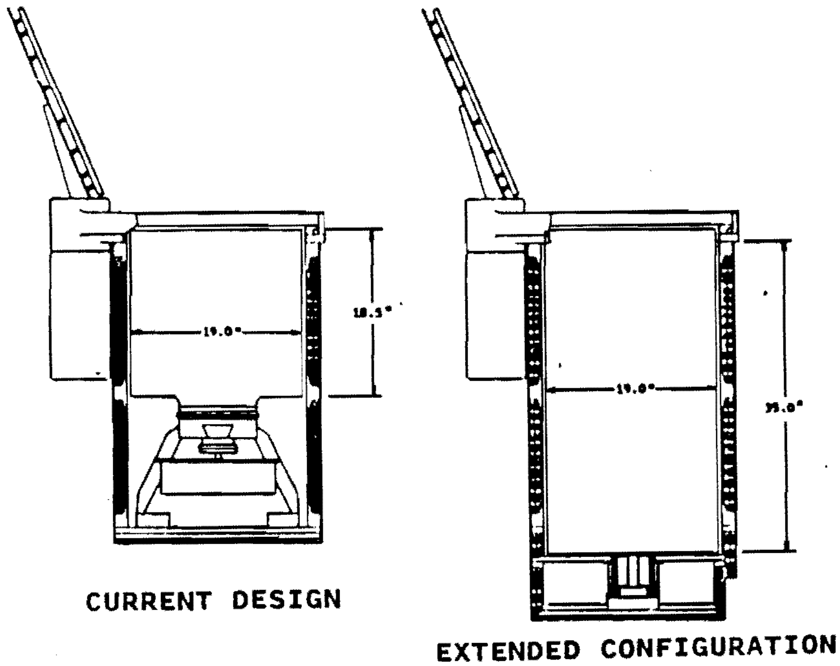

Figure 1
Volume Comparison of GAS Canister Configurations

DESIGN OBJECTIVES

The Naval Postgraduate School general purpose mini-satellite, ORION, was designed four basic objectives: (Ref. 7)

1. Support a payload weight and volume of at least 50 pounds and 2 cubic feet.
2. Provide maximum launch option flexibility.
3. Provide full satellite support capability such as attitude control, propulsion, continuous electrical power, computer and data storage, and telemetry.
4. Minimize manufacturing costs.

The first objective is based on surveys conducted by Aerospace Corporation (Ref. 8) and discussions with potential users during 1984-1986. The surveys indicated that a satellite bus providing 2 cubic feet of user volume, 50 pounds, 15 watts of continuous power, and a data rate of at least 4 kbits/sec would be sufficient to support a large percentage of small payload requirements. The concept of providing a general purpose vehicle with specified capabilities might require the user to modify experiment design but flexibility is

Table 1
Sample of Proposed Launch Vehicles

Vehicle Name	Company	Number of Orions (350 lb.)	Altitude Equatorial KSC	Altitude Polar VAFB
Super Starbird				
(Castor 4A)	SDC	1	360 NM	125 NM
(Algol 3A)	SDC	1	470 NM	220 NM
SDC Scout (STAR 20)	SDC	1	620 NM	340 NM
C-3A (STAR 20)	SDC	1	630 NM	350 NM
(STAR 30)		1 (2)	300 NM	960 NM
Pioneer (31)	SDC	1	740 NM	470 NM
LEO	ECR	1	800+NM	460+NM
		2	280+NM	--
Liberty 1	PAL	1	750 NM	155+NM

SDC = Space Data Corporation (602) 966-1440
ECR = Eagle Canyon Research (916) 644-1171
PAL = Pacific American Launch Systems (415) 595-6500

significantly better than that available as a secondary payload or Shuttle cargo bay experiment. In some cases the satellite might provide capabilities in excess of that required for a particular mission, however economies of scale should reduce total cost below that required to design and produce a lesser capability custom satellite.

Minimizing launch costs and maximizing launch opportunities means that the design must be compatible with as many launch alternatives as possible. To this end, the Shuttle extended GAS canister was selected as a configuration baseline for the ORION. The extended GAS canister will support a user volume 19 inches in diameter and 35 inches tall. Figure 2 presents a cross sectional view of the ORION satellite. This configuration is also compatible with a wide variety of existing and proposed small launch vehicles.

To support a wide variety of potential users the satellite must provide all typical satellite support functions. These functions include orbital boost/ station keeping, attitude control, electrical power, computer and data storage, and telemetry. With these services provided by the satellite bus the experimenter is free to focus attention and resources on experiment design.

The satellite must be simple and economical to manufacture. By using currently available components and creative design approaches a cost goal for satellite components of $1.0 to $1.5 million should be achievable. The design also focuses on simple manufacturing techniques so that potential users can fabricate the satellite with a minimum requirements for tooling and manufacturing equipment. Simplicity of design, when combined with good design practices, will also serve to enhance overall system reliability.

Table 2 provides a summary of the ORION satellite capabilities.

DESIGN FEATURES

Structural Design

The satellite is cylindrical, measuring 19 inches in diameter and 35 inches in length. This size is based on the envelope restrictions of the new NASA extended Get-Away- Special (GAS) canister. A satellite of this size will easily adapt to a number of the currently proposed lightweight and low cost launch vehicles. Using the currently available SCOUT launch vehicle two ORION satellites could be stacked and launched at the same time.

The structural design of ORION stresses simplicity and ease of manufacture. It is anticipated that most of the structural elements will be made of aluminum with the use of composites for critical elements. The basic structure is shown in Figures 3, 4 and 5. The design consists of four longerons and several circular equipment mounting plates. Structural rigidity is increased by the external skin quarter panels which are also used to hold the silicon solar cells. Launch loads are transmitted to the vehicle via the eight retaining lugs on the adapter ring attached to the satellite base. The satellite is thus supported in a cantilever fashion during launch and a major structural design constraint is ensuring adequate rigidity to keep the satellite from contacting the inner surface of the GAS canister or flexing sufficiently to damage to attached solar cells. Satellite components are mounted to the circular mounting plates which may be moved axially to change the volumes available for the various components and to insure proper location of the center of gravity.

Table 2.
SUMMARY OF ORION SPECIFICATIONS

VEHICLE
- 19 inch diameter; 35 inches Tall; 5.7 cubic feet total volume
- Total weight of 170 pounds

PAYLOAD

- 1.5 to 2.5 cubic feet
- 50 to 100 pounds

PROPULSION
- Monopropellant hydrazine
  - 5.0 pound thruster for orbital insertion and station keeping
- 0.1 pound thrusters for attitude control
- Total impulse of 15,720 lbf-sec; 2625 ft/sec delta-V
- Circular orbits to 800 nm (from 135 nm)
- Elliptical orbits to 2200 nm apogee

ELECTRICAL POWER
- Silicon solar cells attached to cylindrical surface
- 50 watts total power; 15 watts continuous power to payload
- Common power supply with regulated voltage bus
- Redundant Ni-Cad batteries; 150 Watt-hour capacity

TELEMETRY
- Several telemetry options
  - SGLS; UHF; S-Band
- Two antennas provide omnidirectional coverage

MICROPROCESSOR AND DATA STORAGE
- General purpose 16 bit microprocessor
- Non-volatile bubble memory data recorder
  - Up to 12 megabytes using NPS design
- Data rates up to 2.0 Mega-bits per second

The skin and attached solar cells serve to shield the internal components from direct exposure to the sun or deep space. This simplifies thermal control.

Propulsion and Attitude Control

Propulsion permits changes in orbit and reduces launch vehicle orbital insertion accuracy requirements. Figure 6 shows the operating envelope of the ORION satellite bus, assuming orbital insertion at

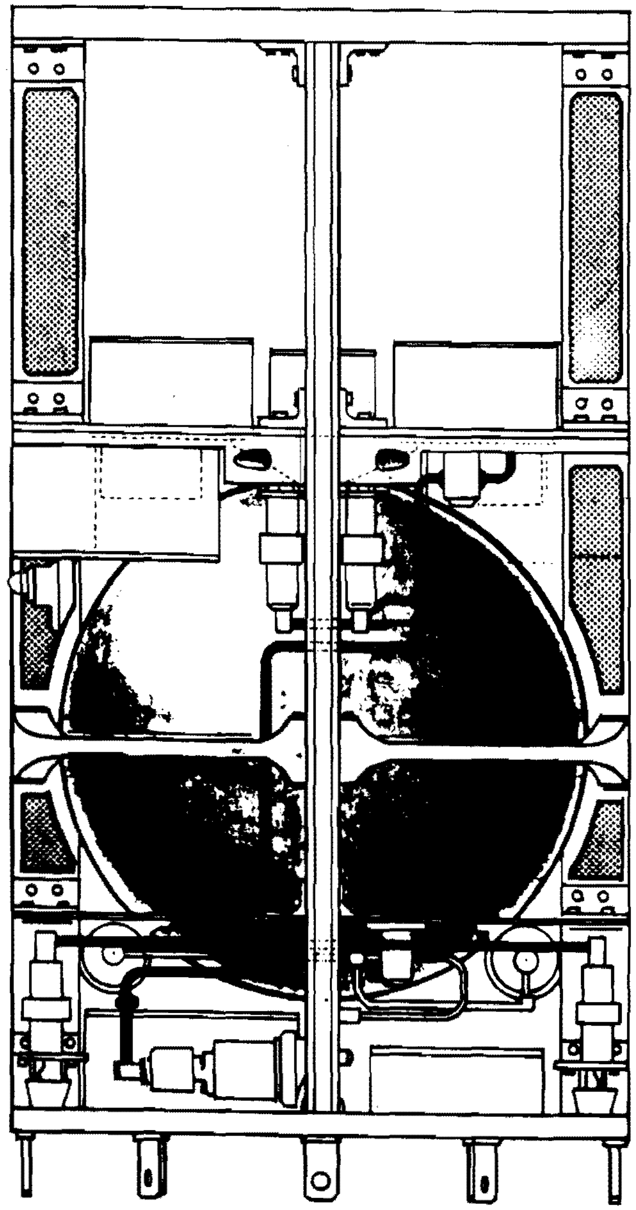

Figure 2
ORION Internal Layout

135 nm. The ability to change orbital parameters and control the satellite's attitude are critical elements in the ORION design. This capability gives the user the option of placing the payload in the optimum orbit and maintaining the optimum orientation for a particular mission. The hydrazine tank contains sufficient hydrazine

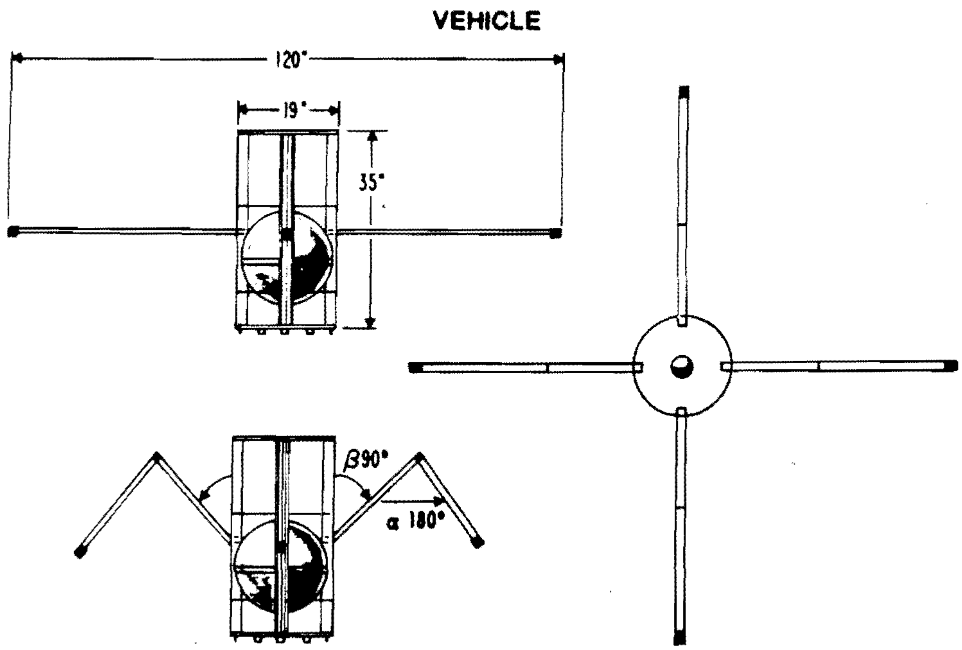

Figure 3
ORION Structural Design

to allow the satellite to achieve circular orbits of up to 835 nm and elliptical orbits with an apogee of up to 2200 nm starting from a initial nominal orbit of 135 nm.

The satellite is spin stabilized using 0.1 pound thrusters. Thrusters have been selected that are currently available. Because of the geometry imposed by the GAS canister, the satellite is unstable in spin about the cylindrical axis. To achieve stability simple folding booms, with friction extension dampers have been provided. With tip mass of 2 pounds the satellite is stable with a boom radius of 70 inches or more. Boom radius of 80 inches can be easily achieved by simple three section folding booms and will provide a ratio of spin to transverse moment of inertia of 1.18. Without the booms the spin to transverse moment ratio is 0.31 and active nutation control would be required to maintain spin about the cylindrical axis. For nutation angles bounded by 0.5 and 3.0 degrees active nutation control would require a propellant consumption of one pound for every two days on orbit. (Ref. 6).

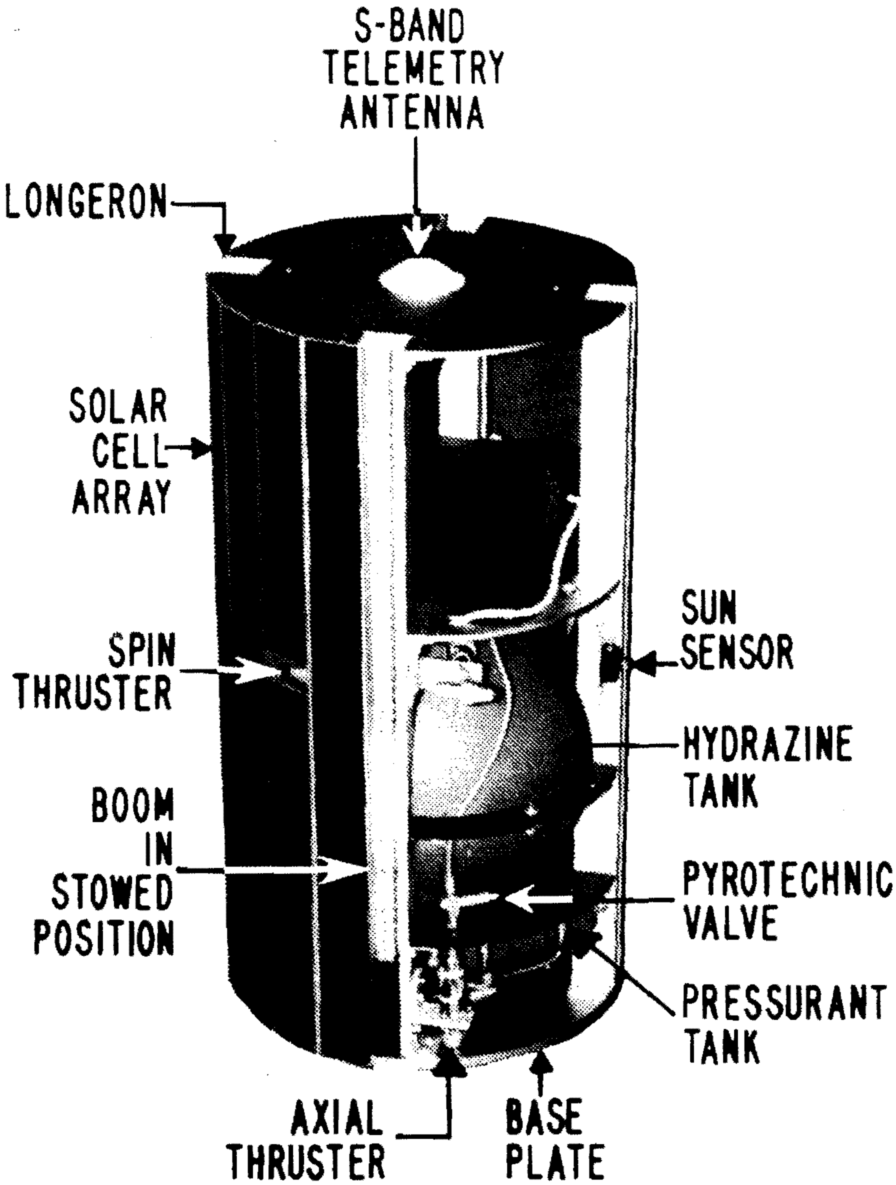

Figure 4
ORION Mock-up Internal Details

Electrical Power

Spacecraft power is provided by silicon solar cells mounted to the exterior surfaces of the skin quarter panels. This configuration provided 50 watts of power when the satellite is oriented normal to the sun at the beginning of life. To provide continuous operation during eclipse 150 watt-hours of Ni-Cad battery capacity is provided. 150 watt-hours of battery capacity is sufficient to support the

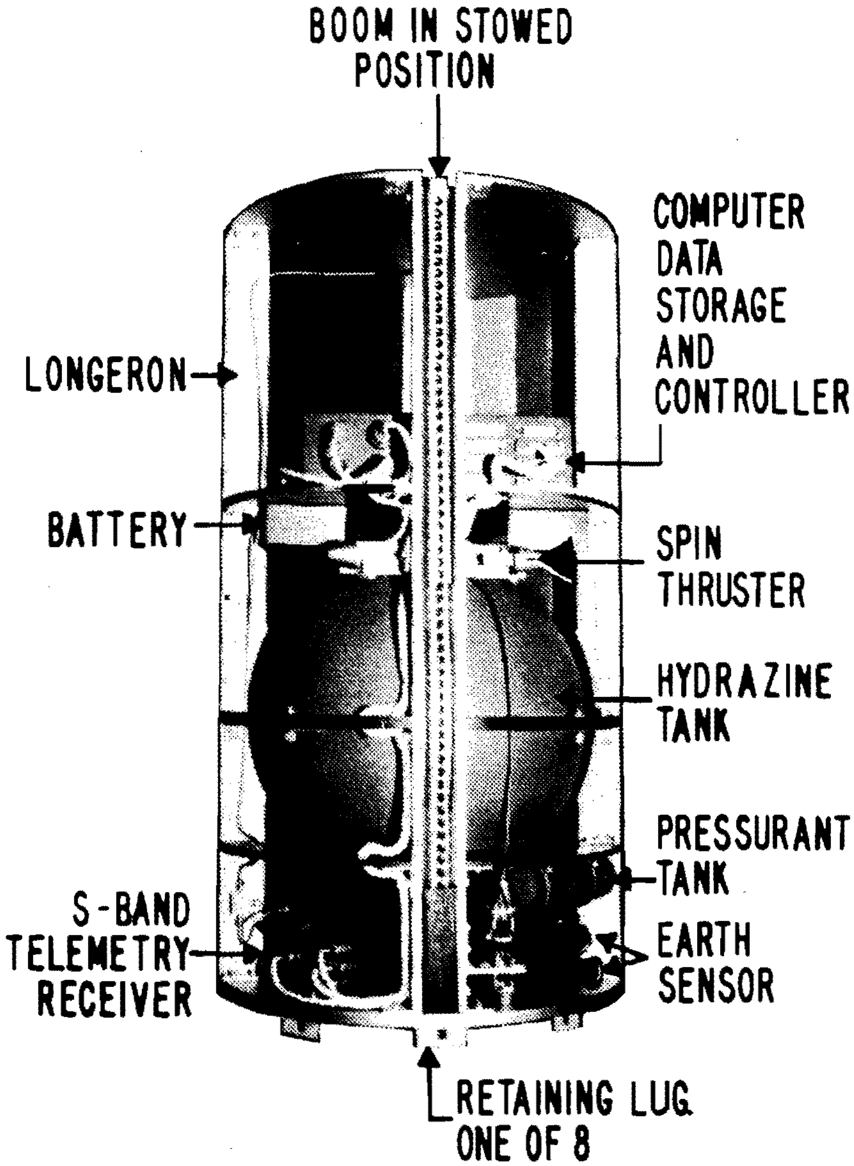

Figure 5
ORION Mock-up Internal Details

satellite and provide 15 watts of continuous power to the payload during eclipse while limiting depth of discharge sufficiently to support a three year mission life. To simplify system design a common multiple voltage regulated power bus will be provided.

CAPABILITY GAP

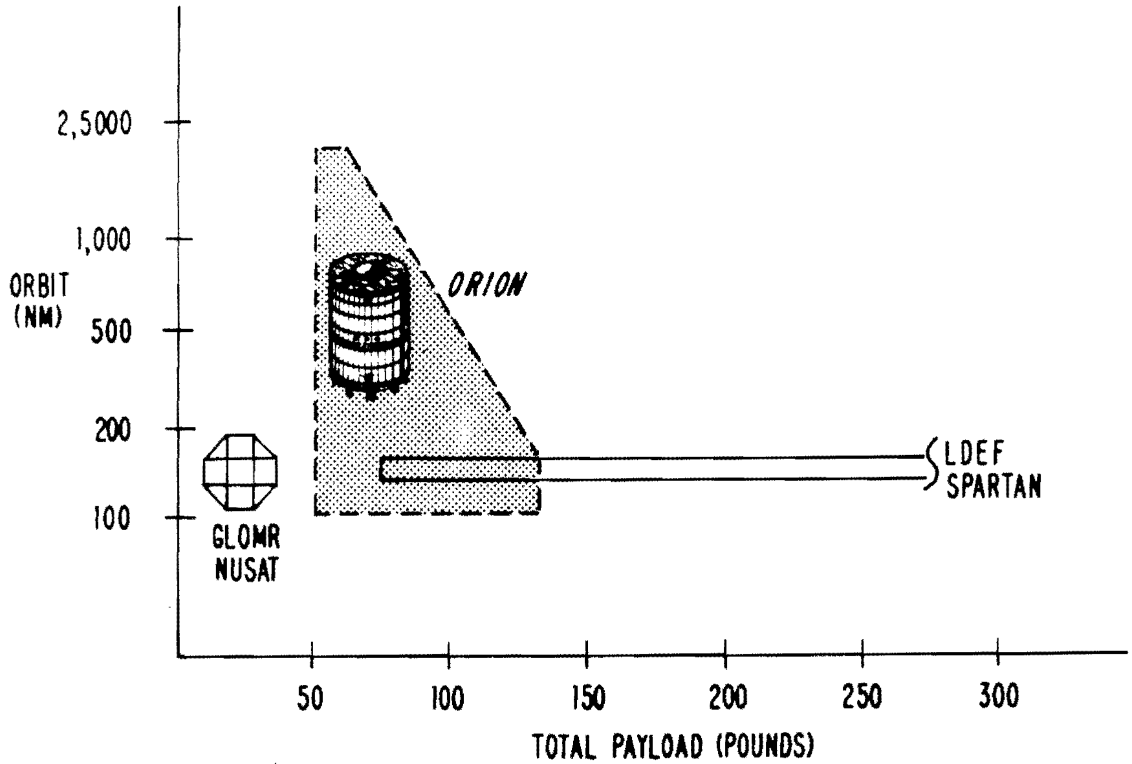

Figure 6
ORION Operating Envelope

Computer and Data Storage

Consistent with minimizing satellite operational costs ORION is being designed with a focus on autonomous operation, including experiment control, attitude determination and control and all housekeeping functions. To support the resultant increased processing demands a 16 bit system microprocessor is planned. The flexibility of operating the satellite from one or more autonomous ground stations also implies that on-board data storage must be provided. The Naval Postgraduate School has developed a non-volatile magnetic bubble memory data recorder for this purpose. The currently planned data recorder provides 12 mega-bytes of storage capability with peak data rates of over 2 mega-bits per second to support rapid data downloading to a single ground station.

Telemetry

Telemetry is one aspect of the satellite design that is most strongly influenced by mission specific considerations. VHF, UHF and S-band telemetry may be used and the most appropriate choice for a given mission depends of operational considerations. As a design baseline the USAF Space Ground Link Subsystem has been selected. This system operates at S-band and provides data rates on the order of 150 kilo-bits per second. Direct FM S-band telemetry, as would be appropriate for utilization of a single ground station can provide data rates in excess of 2 mega-bits per second.

ORION APPLICATIONS

Applications for the ORION mini-satellite include both space science and space missions. Due to the relatively low per unit costs, large constellations of ORION type satellites are feasible. Large constellations of communications satellites can provide global communications capability in a more robust manner that single geosynchronous communication platforms. One concept for a distributed communications system using ORION type vehicles is the Multiple Satellite System (MSSP) currently under development by DARPA. (Ref. 9) This concept involves a constellation of 240 small satellites forming a global packet switched data network. A smaller constellation of 40 satellites, designed to interface with existing Navy UHF communications equipment could provide a low cost back-up for fleet satellite communications. (Ref. 10) Low cost and propulsion capability make the ORION an excellent choice for use as an instrumented target for weapons testing. A constellation of independently controllable satellites provides a means of testing battle management systems. A suitably instrumented ORION could also "fly formation" other satellites. Variable drag elements such as inflatable and deflatable balloons would allow the ORION to maintain relative position with very little propellant usage. The Medium Altitude Daily Observation Satellite (MADOS), while larger than the ORION, indicates that small satellite have applications as low cost imaging platforms. (Ref. 11)

Many basis science missions have also been proposed. One mission involves using ORION's propulsion capability to place the satellite in a highly elliptical orbit into the lower Van Allen belt. The satellite has been proposed to support the Tethered Satellite Experiment (TSS-1) by providing a means of measuring near field interactions between a long tether and the surrounding fields. Two ORION type satellites, flying in formation, could be used to develop a worldwide geopotential model accurate to 10 cm. (Ref. 12) An ORION, could be instrumented as an all-sky heliospheric Imager (ASHI). By recording the brightness of scattered light from electrons in the interplanetary medium the imager could observe disturbances anywhere within one astronomical unit. These types of observations permit the anticipation of the arrival at earth of coronal mass ejections, co-rotating regions, and shocks. (Ref. 13)

CONCLUSIONS

The ORION concept has attained a level of design maturity that confirms that the vehicle can be built for component costs of less than $1.5 million. The project has achieved its primary purpose at the Naval Postgraduate School in stimulating creative thinking on the parts of the students and faculty relative to low cost satellite alternatives.

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