Paper SS-21,
1st Annual USU Conference on Small Satellites,
7-9 October 1987, Logan, UT.

SYSTEM DESIGN AND CAPABILITIES OF A CURRENT TECHNOLOGY, LOW-COST, SMALL SATELLITE

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Ball Aerospace, with its successful background and strong interest in low-cost lightweight satellites, is studying the designs of current technology satellites for a variety of launchers (e.g., STS/GAS, Pershing, Scout, Poseidon, Conestoga, Titan II, ILV, and Delta II). Ball Aerospace has completed the design of a current technology, multi-mission, low-cost Scout-compatible satellite. This paper summarizes the system design features and capabilities of this Ball Scout Satellite (BSS). The BSS is designed to accomodate a wide range of Earth and celestially oriented missions, both spinning and 3-axis stabilized. The BSS design provides a marked improvement in payload support capabilities (mass, power, data rate, pointing, interfaces, flexibility, reliability, etc.) than was previously available with earlier Scout satellites, and at a lower cost in current-year dollars.

INTRODUCTION AND SUMMARY

Since the first launch of the Scout in December 1962, the capabilities of a small (few hundred pound) satellite in low Earth orbit have been of keen interest. Since the phasing down of the Scout and the few satellites developed in the seventies (e.g., Transit, HCMM, SAGE, Magsat), little has been done to establish the capabilities of a more modern satellite design using 1980's design architecture with current technology and available hardware.

Ball Aerospace, with its successful background and strong interest in low-cost lightweight satellites, is studying the designs of current technology satellites for a variety of launchers (e.g., STS/GAS, Pershing, Scout, Poseidon, Conestoga, Titan II, ILV, and Delta II). Ball Aerospace has completed the first phase of a low-cost, current technology, multi-mission, Scout-compatible satellite design[1]. This paper summarizes the system design features and capabilities of this Ball Scout Satellite (BSS).

The BSS is designed to accomodate a wide range of Earth and celestially oriented missions, both spinning and 3-axis stabilized. The BSS design, using off-the-shelf current technology hardware, provides a marked improvement in payload support capabilities (mass, power, data rate, pointing, interfaces, flexibility, reliability, etc.) than was previously available with the 1970's satellites, with a lower effective bus cost in current-year dollars and significantly lower life-cycle costs.

MISSION DESIGN SET

The design process for the BSS began with the identification of the variety and range of low Earth orbit mission applications to be captured. While many other mission types can be accommodated with the BSS, the following twelve mission/orbit types were selected as the design references:

Earth Oriented Missions

The majority of Earth science, reconnaisance and communications missions can be accommodated with either polar nadir pointers or orbit-normal spinners:

Nadir Pointers (3 Cases). Earth mapping polar nadir pointer missions were examined for two sun-synchronous orbits (12 AM-12 PM, and 6 AM-6 PM) and a polar non-synchronous orbit.

Orbit Normal Spinners (2 Cases). Earth mapping polar orbit normal spinner missions were examined for two sun-synchronous orbits (3 AM-3 PM, and 6 AM-6 PM).

Astro Oriented Missions

The majority of astro-science missions can be accommodated with either zenith pointers, celestial pointers, or sun-line spinners:

Zenith Pointers (3 Cases). All-sky survey polar zenith pointer missions were examined for two sun-synchronous orbits (12 AM-12 PM, and 6 AM-6 PM) and a polar non-synchronous orbit.

Celestial Pointers (2 Cases). All-sky 3-axis inertial celestial pointers were examined for equatorial (maximum launch weight) orbit with either slow or fast retargetting capabilities.

Sun-line Spinners (2 Cases). Solar observing sun-line spinners were examined in both a polar sun-synchronous (6 AM-6 PM) orbit and an equatorial non-synchronous orbit.

SCOUT LAUNCH VEHICLE

With the 108th Scout recently launched from VAFB September 1987, the Scout launch vehicle capabilities and design restraints are well understood.[2] The standard Scout series 25 "E" section adapter/separation system and the 42 inch diameter heat shield have been selected as baseline.

Figure 1 shows the typical Scout launch profile. About 2 minutes after lift-off, the two piece Scout heat shield is ejected. Some 10 minutes later, the BSS is separated from the spent spinning Scout 4th stage. The BSS despin yo-yo's are deployed reducing the spin rate from ≈160 rpm to near zero. The subsequent solar array deployment and ACS control enablement stabilize the BSS for reorientation to its on-orbit attitude.

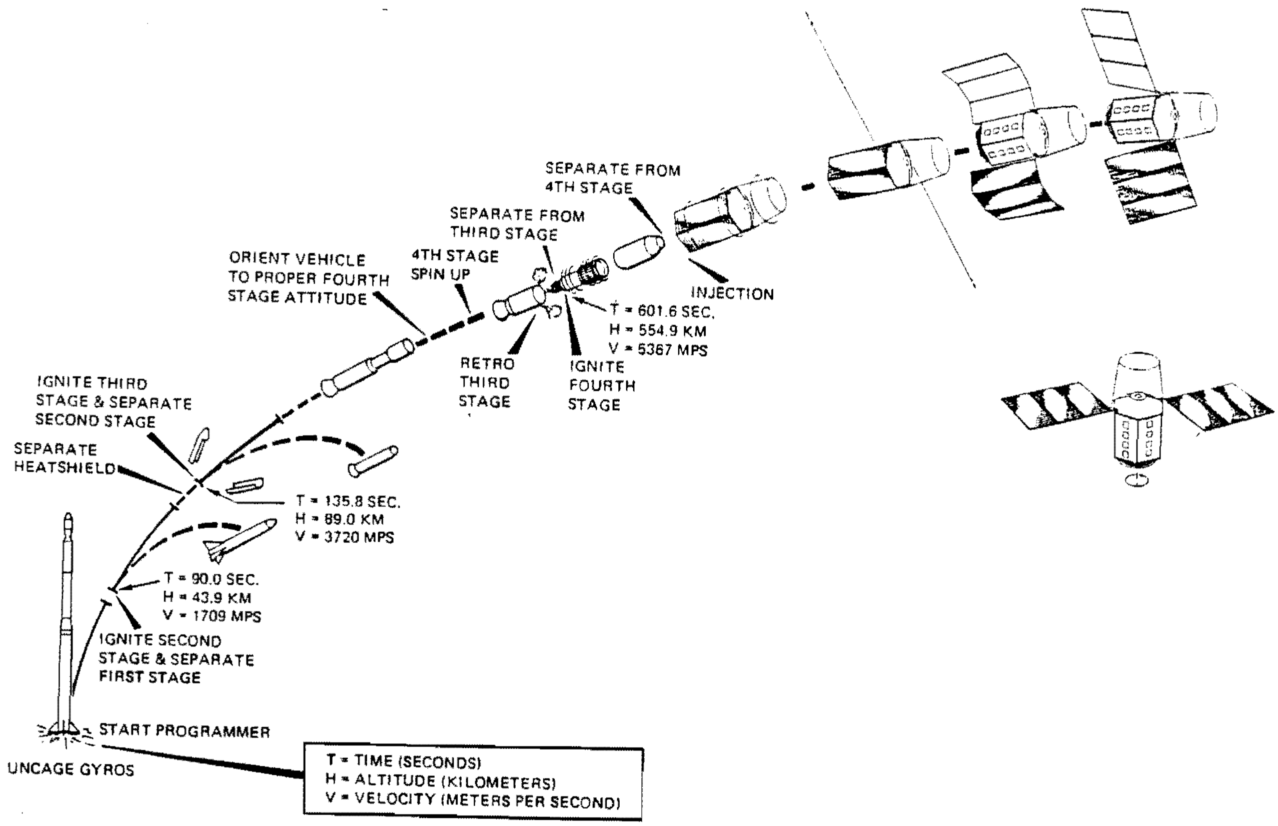

Fig. 1 Scout Launch

The selected twelve mission design set are all supported by just three Scout launch types/capabilities. The following launch masses have already been adjusted for fairing size, adapter and separation systems, etc. All selected mission orbits are 400 km circular:

Polar from VAFB	at 90° (polar) inclination:	178 kg
	at 97° (sun-sync) inclination:	173 kg
Equatorial from San Marcos	at 4° (equatorial) inclination:	233 kg

The Scout injection errors are large. For a 400 km circular target orbit, perigee altitude can be expected (95%) to deviate anywhere from +10 km to -100 km, and apogee altitude from +200 km to -110 km, with inclination uncertainties ~1°. These large probable deviations require a BSS satellite propulsion subsystem to be able to correct the orbit errors for precise (e.g., sun-synchronous) target orbits.

BALL SCOUT SATELLITE DESIGN

The simple BSS design uses existing, current technology hardware in a flexible design that allows for ready, low-cost tailoring of the hardware set for a selected mission. The compact hexagonal BSS configuration, with two 3-sided wrap-around solar panels extending below the adapter, provides ample payload volume inside the Scout 42 inch diameter heat shield (see figs. 2,3). The satellite height has not yet been reduced to its minimum in the design process.

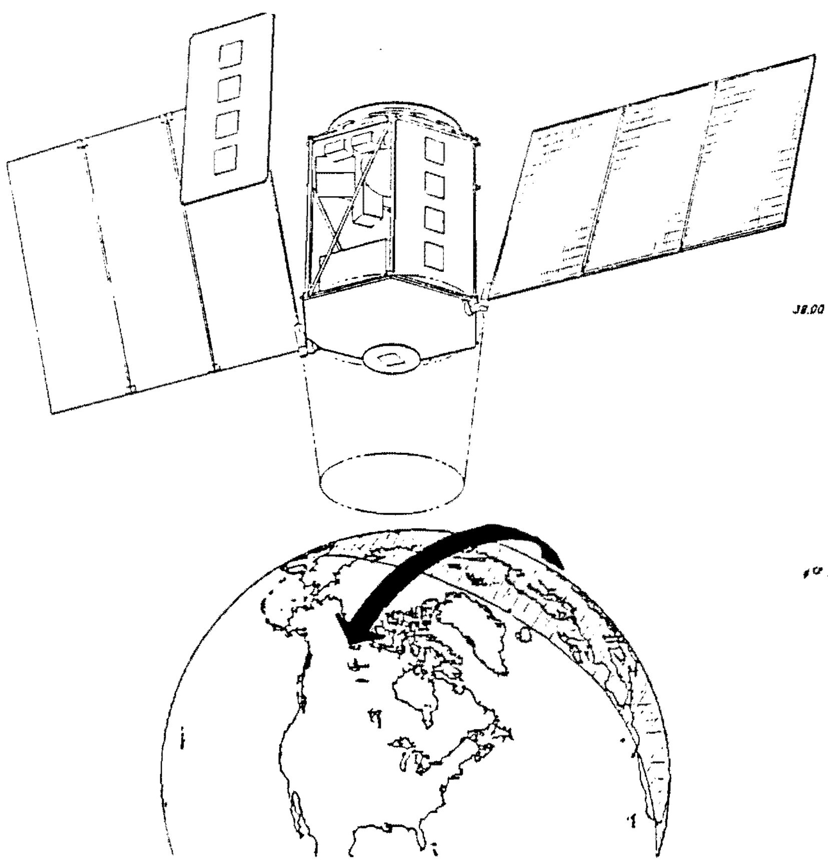

Fig. 3 **BSS Deployed Configuration**

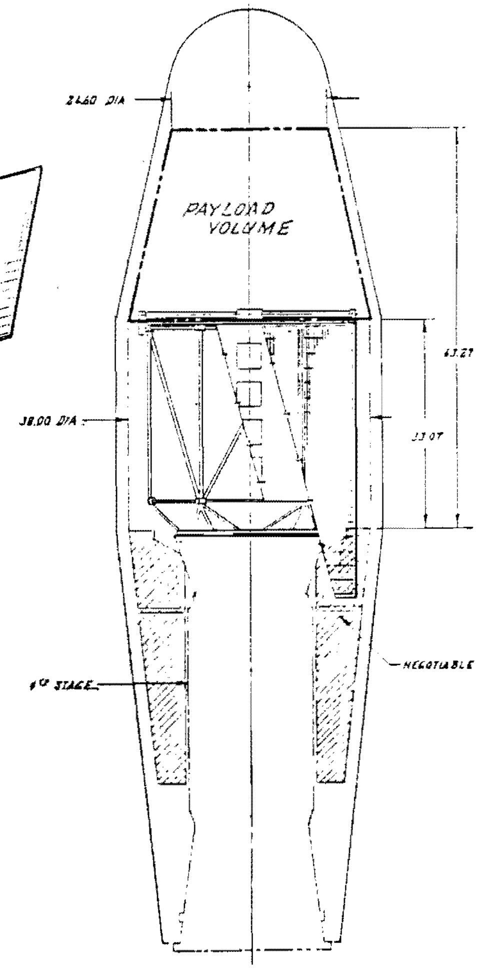

Fig. 2 **BSS Stowed for Scout Launch**

The BSS design features an architecture that:

1) is based on current technologies, such as composite materials, distributed micro-processors, solid state data storage, command/telemetry busses, etc.
2) allows the ready incorporation of new/alternative cost effective technology/ components as they become available,
3) maximizes the sharing of typically redundant payload/bus capabilities (e.g., data handling, target tracking, etc.), and
4) allows ready cost effective tailoring of component set to meet unique mission requirements.

The following sections summarize the key features of the BSS subsystems.

<u>Mechanical Systems</u>

The low-cost structure design takes advantage of and incorporates the Scout-provided series 25 "E" satellite side of the support ring with its 18 hard points. The basic hexagonal structure is a modular truss work of composite tubes and titanium end-fittings with two aluminum honeycomb decks top and bottom to provide flat mounting surfaces for the satellite equipment and payload interface. The only deployments are the yo-yo despin and two 3-panel solar arrays. Where array articulation is required, a single internally redundant 1 degree of freedom ±90° actuator is used to control both arrays.

Telecommunications

The BSS is designed to communicate through any of three networks (TDRSS MA/SA, SGLS, GSTDN/DSN) using Ball Aerospace's microstrip switched antennas and the appropriate transponder. The antennas selected for the BSS are the SME 16.5 dbi medium gain antenna, and -5 dbi hemispherical low gain antenna, and the 13.4 dbi strip. All or some combination of these antennas satisfy all twelve design reference missions to any of the three networks. A relatively arbitrary assignment of a specific network for each of the twelve missions was made for this mission capabilities assessment. In general, BSS data rate capabilities are a function of the network, not of the mission application. Separate highly-tuned transmit and receive antennas are used with no diplexer. Ball Aerospace electronic despinning/switching is used. While RF amplifiers can be readily accommodated, none were assumed for these BSS mission telecom capabilities assessments.

Table 1
BSS COMPONENETS AND SUPPLIERS

COMPONENTS	SUPPLIER
MECHANICAL SYSTEMS	
Composite Tubes	Hercules
End Fittings/Brkts	Ball Aerospace
Decks, Upper, Lower	Ball Aerospace
Devices, S/A Deployment	Ball Aerospace
Actuator, Solar Array Drive	Schaeffer
Support Ring/Adapter, Scout 25 "E"	LTV
Antenna Mast	Ball Aerospace
Balance	Ball Aerospace
TELECOMMUNICATIONS	
Transponder,TDRSS, 2.5w	Motorola
Transponder, GSTDN, 2w	Loral
Transponder, SGLS, 3w	Loral
Antenna Strips (6 each,13.4 dbi)	Ball Aerospace
Antenna#1 (LGA, hemi, -5 dbi)	Ball Aerospace
Antenna#2 (LGA, hemi, -5 dbi)	Ball Aerospace
Antenna#1 (SME Set, -5/+16.5 dbi)	Ball Aerospace
Antenna#2 (SME Set, -5/+16.5 dbi)	Ball Aerospace
Antenna Switcher	Ball Aerospace
Power Divider	Ball Aerospace
Power Combiner	Ball Aerospace
RF Cables	Ball Aerospace
RF Amplifier, 10 watt	Loral
POWER/PYRO	
Solar Array	Spectrolab
Battery #1 (6 AH)	GE
Battery #2 (6 AH)	GE
Shunt Regulator	Gulton
Shunt Load Bank	Ball Aerospace
S/A String Switcher	Ball Aerospace
CABLING	
Signal	Ball Aerospace
Power	Ball Aerospace
CMD & DATA HANDLING	
DSP Processor, w/Freq Std	Ball Aerospace
Payload Bus Interface, BIF	Ball Aerospace
DSU (SRAM, 1000 MB)	Ball Aerospace
TEMPERATURE CONTROL	
MLI	Ball Aerospace
Heaters, Film (4 Zones)	Ball Aerospace
Paint	Ball Aerospace
ATTITUDE CONTROL	
Scan Wheel, H=5.5 NMS	Ithaco
Horizon Scanner	Barnes
Horizon Scanner Electronics	Barnes
Horizon Sensor#1	Ithaco
Horizon Sensor#1 Electronics	Ithaco
Horizon Sensor#2	Ithaco
Horizon Sensor#2 Electronics	Ithaco
Sun Sensor, 2-Axis	Adcole
Sun Sensor Electronics	Adcole
Magnetometer, 3-Axis	Schonstedt
Mag Torque Rods (3, 50 A-M2)	Ball Aerospace
Pitch Reaction Wheel (H=2 NMS)	Bendix
Yaw Reaction Wheel (H=2 NMS)	Bendix
Yo-Yo Despin, 2 Unwrap	Ball Aerospace
Nutation Damper, Ring	Ball Aerospace
PROPULSION	
N2H4 Tank, 12.9" GPS	PSI
Fill/Drain Valves (2)	Pyronetics
Filter	Puroflow
Transducers	Kulite
Thruster/Valve Assy (2, 1 lb)	Rocket Research
Propellant/Pressurant	Rocket Research
Lines/Fittings	Rocket Research

Power/Pyro

Electrical power is provided by a simple, low-cost direct energy transfer power system. The two single-sided solar arrays (3 m^2) can be configured and deployed into any of several possible fixed orientations, or articulated ±90° as required by orbit geometry. One (or two) 6 AH batteries provide power to supplement the arrays. The shunt regulator dumps excess power to the shunt radiator. If required by the mission/payload thermal design, the BSS can provide array string switching to dispose excess heat on the arrays instead of the bus.

Command and Data Handling/Storage

The Ball Aerospace distributed subsystem processor (DSP) network provides efficient and flexible data/telemetry bus network architecture with powerful distributed μ-processors (CMOS 8086's), rad-hardened and SEU tolerant . The Ball DSP system approach allows powerful data processing and life-cycle cost reduction capabilities to be incorporated into the entire project (e.g., packet telemetry, flex formats, data reduction/compression, autonomous subsystem operations, software portability, simple interface/integration control, built-in test capabilities, low-cost lap-top test/integration/operations simulators, teleoperations[3], etc.)

For the BSS, the DSP integrates the processing functions required by the data handling, power and attitude control subsystems into a single unit. Autonomous safing responses, built-in test and payload macros are supported by the DSP modular software. The DSP includes a single 10^9 solid state memory (CMOS/SRAM) board, internally redundant with graceful failure modes. The BSS also provides the payload with a Ball DSP bus interface unit (BIF) μ-processor, greatly simplifying interface verification and operations validation.

Temperature Control

The basic simple, passive temperature control subsystem is comprised of MLI blankets, paint and 4 zone film heaters. Louvers and other thermal control devices can be accommodated, but are not required by the satellite bus for the twelve reference design missions.

Attitude/Articulation Control

Attitude sensing, control and determination are handled through a flexible, tailorable set of components. The basic satellite control range is to ≤0.2° with knowledge to ≤0.1°. For precision pointing missions (e.g., star staring, planet/comet tracking), while expensive precision trackers can be accommodated, it is most cost-effective for the precision payload to pass the sensed pointing errors to the BSS. If the payload provides error signals to arcsecs the BSS can control the attitude to arcsecs.

All BSS mission applications use magnetic torquing and reaction wheel(s) except the spinners. Spinner applications use only mag torquing (and horizon sensors). A single horizon scanning pitch wheel is used for the nadir and zenith pointers. Polar non-sync nadir/zenith orbiters require adding a yaw wheel. Elliptical orbits require the addition of another horizon scanner. Optional sun sensors provide improved ground determination. The celestial 3-axis controlled pointers use sun sensors and a single pitch wheel for slow retargetting and two wheels for fast retargetting.

Propulsion

For orbit correction and maintenance, the BSS has an optional low-cost, lightweight, integral blowdown N_2H_4 propulsion system with two 1 pound thrusters. The girth-

Table 2
EARTH MISSIONS, BSS MASS BREAKDOWNS

COMPONENTS	MASS (kg)	NADIR POINTER POLAR Sun-Sync 12AM-12PM	NADIR POINTER POLAR Sun-Sync 6AM-6PM	NADIR POINTER POLAR Non-Sync	ORBIT-NORMAL SPINNER POLAR Sun-Sync 3AM-3PM	ORBIT-NORMAL SPINNER POLAR Sun-Sync 6AM-6PM
MECHANICAL SYSTEMS, Kg		23.7	23.7	25.2	26.7	26.7
Composite Tubes	3.0	x	x	x	x	x
End Fittings/Brkts	5.0	x	x	x	x	x
Decks, Upper, Lower	10.0	x	x	x	x	x
Devices, S/A Deployment	2.0	x	x	x	x	x
Actuator, Solar Array Drive	1.5			x		
Support Ring/Adapter, Scout 25"E"	2.0	x	x	x	x	x
Antenna Mast	1.7	x	x	x	x	x
Balance	3.0				x	x
TELECOMMUNICATIONS, Kg		9.4	9.4	7.2	6.9	6.8
Transponder,TDRSS, 2.5w	3.5	x	x		x	
Transponder, GSTON, 2w	3.5					x
Transponder, SGLS, 3w	3.9			x		
Antenna Strips (6 each,13.4 dbi)	2.7	x	x			
Antenna#1 (LGA, hemi, -5 dbi)	0.2	x	x	x		
Antenna#2 (LGA, hemi, -5 dbi)	0.2	x	x			
Antenna#1 (SME Set, -5/+16.5 dbi)	0.3			x	x	x
Antenna#2 (SME Set, -5/+16.5 dbi)	0.3				x	x
Antenna Switcher	1.8	x	x	x	x	x
Power Divider	0.3	x	x	x	x	x
Power Combiner	0.2	x	x	x	x	x
RF Cables	0.5	x	x	x	x	x
RF Amplifier, 10 watt	0.7					
POWER/PYRO, Kg		22.7	19.1	22.7	22.7	19.1
Solar Array/Substrate (3 m2)	11.2	x	x	x	x	x
Battery #1 (6 AH)	3.6	x	x	x	x	x
Battery #2 (6 AH)	3.6	x		x	x	
Shunt Regulator	2.3	x	x	x	x	x
Shunt Load Bank	2.0	x	x	x	x	x
S/A String Switcher	0.2					
CABLING, Kg		7.0	7.0	7.0	7.0	7.0
Signal	2.5	x	x	x	x	x
Power	4.5	x	x	x	x	x
CMD & DATA HANDLING, Kg		22.9	22.9	22.9	22.9	22.9
MCDU Processor, w/Freq Std	15.9	x	x	x	x	x
Payload Bus Interface, BIF	1.8	x	x	x	x	x
DSU (SRAM, 1000 MB)	5.3	x	x	x	x	x
TEMPERATURE CONTROL, Kg		4.2	4.2	4.2	4.2	4.2
MLI	3.4	x	x	x	x	x
Heaters, Film (4 Zones)	0.6	x	x	x	x	x
Paint	0.2	x	x	x	x	x
ATTITUDE CONTROL, Kg		10.4	10.4	12.8	7.1	7.1
Scan Wheel, H=5.5 NMS	6.8	x	x	x		
Horizon Scanner	0.4					
Horizon Scanner Electronics	1.5					
Horizon Sensor#1	0.2				x	x
Horizon Sensor#1 Electronics	1.0				x	x
Horizon Sensor#2	0.2				x	x
Horizon Sensor#2 Electronics	1.0				x	x
Sun Sensor, 2-Axis	0.1					
Sun Sensor Electronics	0.3					
Magnetometer, 3-Axis	0.3	x	x	x	x	x
Mag Torque Rods (3, 50 A-M2)	1.4	x	x	x	x	x
Pitch Reaction Wheel (H=2 NMS)	2.4					
Yaw Reaction Wheel (H=2 NMS)	2.4			x		
Yo-Yo Despin, 2 Unwrap	2.0	x	x	x	x	x
Nutation Damper, Ring	1.0				x	x
PROPULSION, Kg		18.4	18.4	0.0	18.4	18.4
N2H4 Tank, 12.9" GPS	2.7	x	x		x	x
Fill/Drain Valves (2)	0.1	x	x		x	x
Filter	0.1	x	x		x	x
Transducers	0.2	x	x		x	x
Thruster/Valve Assy (2, 1 lb)	0.7	x	x		x	x
Propellant/Pressurant	14.0	x	x		x	x
Lines/Fittings	0.5	x	x		x	x
CONTINGENCY (15%)		17.81	17.27	15.30	17.37	16.82

Table 3
ASTRO MISSIONS, BSS MASS BREAKDOWNS

	ZENITH POINTER			CELESTIAL POINTER		SUN-LINE SPINNER	
COMPONENTS	POLAR	POLAR	POLAR	EQUATORIAL	EQUATORIAL	POLAR	EQUATORIAL
	Sun-Sync	Sun-Sync	Non-Sync	Non-Sync	Non-Sync	Sun-Sync	Non-Sync
	12AM-12PM	6AM-6PM		Slow Retarget	Fast Retarget	6AM-6PM	
MECHANICAL SYSTEMS, Kg	22.0	23.7	25.2	25.2	25.2	26.7	26.7
Composite Tubes	x	x	x	x	x	x	x
End Fittings/Brkts	x	x	x	x	x	x	x
Decks, Upper, Lower	x	x	x	x	x	x	x
Devices, S/A Deployment	x	x	x	x	x	x	x
Actuator, Solar Array Drive			x	x	x		
Support Ring/Adapter, Scout 25"E"	x	x	x	x	x	x	x
Antenna Mast		x	x	x	x	x	x
Balance						x	x
TELECOMMUNICATIONS, Kg	9.8	9.4	9.4	9.4	9.4	6.8	9.4
Transponder,TDRSS, 2.5w		x	x	x	x		x
Transponder, GSTDN, 2w						x	
Transponder, SGLS, 3w	x						
Antenna Strips (6 each,13.4 dbi)	x	x	x	x	x		x
Antenna#1 (LGA, hemi, -5 dbi)	x	x	x	x	x		x
Antenna#2 (LGA, hemi, -5 dbi)	x	x	x	x	x		x
Antenna#1 (SME Set, -5/+16.5 dbi)						x	
Antenna#2 (SME Set, -5/+16.5 dbi)						x	
Antenna Switcher	x	x	x	x	x	x	x
Power Divider	x	x	x	x	x	x	x
Power Combiner	x	x	x	x	x	x	x
RF Cables	x	x	x	x	x	x	x
RF Amplifier, 10 watt							
POWER/PYRO, Kg	22.7	19.1	22.7	22.7	22.7	19.1	22.7
Solar Array/Substrate (3 m2)	x	x	x	x	x	x	x
Battery #1 (6 AH)	x	x	x	x	x	x	x
Battery #2 (6 AH)	x		x	x	x		x
Shunt Regulator	x	x	x	x	x	x	x
Shunt Load Bank	x	x	x	x	x	x	x
S/A String Switcher							
CABLING, Kg	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Signal	x	x	x	x	x	x	x
Power	x	x	x	x	x	x	x
CMD & DATA HANDLING, Kg	22.9	22.9	22.9	22.9	22.9	22.9	22.9
MCDU Processor, w/Freq Std	x	x	x	x	x	x	x
Payload Bus Interface, BIF	x	x	x	x	x	x	x
DSU (SRAM, 1000 MB)	x	x	x	x	x	x	x
TEMPERATURE CONTROL, Kg	4.2	4.2	4.2	4.2	4.2	4.2	4.2
MLI	x	x	x	x	x	x	x
Heaters, Film (4 Zones)	x	x	x	x	x	x	x
Paint	x	x	x	x	x	x	x
ATTITUDE CONTROL, Kg	10.4	10.4	11.7	6.4	8.8	7.1	7.4
Scan Wheel, H=5.5 NMS	x	x	x				
Horizon Scanner							
Horizon Scanner Electronics							
Horizon Sensor#1						x	x
Horizon Sensor#1 Electronics						x	x
Horizon Sensor#2						x	x
Horizon Sensor#2 Electronics						x	x
Sun Sensor, 2-Axis				x	x		x
Sun Sensor Electronics				x	x		x
Magnetometer, 3-Axis	x	x	x	x	x	x	x
Mag Torque Rods (3, 50 A-M2)	x	x	x	x	x	x	x
Pitch Reaction Wheel (H=2 NMS)				x	x		
Yaw Reaction Wheel (H=2 NMS)			x		x		
Yo-Yo Despin, 2 Unwrap	x	x	x	x	x	x	x
Nutation Damper, Ring						x	x
PROPULSION, Kg	18.4	18.4	0.0	0.0	0.0	18.4	0.0
N2H4 Tank, 12.9" GPS	x	x				x	
Fill/Drain Valves (2)	x	x				x	
Filter	x	x				x	
Transducers	x	x				x	
Thruster/Valve Assy (2, 1 lb)	x	x				x	
Propellant/Pressurant	x	x				x	
Lines/Fittings	x	x				x	
CONTINGENCY (15%)	17.61	17.27	15.47	14.67	15.03	16.82	15.05

mounted 12.9 inch diameter GPS tank holds up to 14.0 kg of propellant. The fully loaded system can provide the BSS with a minimum of 186 m/s ΔV for Scout injection error correction and orbit maintenance.

MISSION-TAILORED COMPONENT SET

While the simple, flexible system architecture of the BSS allows ready accommodation of a wide range of suppliers' components, this mission capabilities assessment utilizes only subsets of the basic off-the-shelf components/suppliers shown in Table 1.

Mass Summary

Tables 2 and 3 show mass breakdown of the selected subsystem hardware for each of the twelve design reference missions. Tables 4 and 5 show a subsystem mass summary for each mission application of the BSS.

Table 4
BSS MASS SUMMARIES, EARTH MISSIONS

	NADIR POINTER			ORBIT-NORMAL SPINNER	
	POLAR	POLAR	POLAR	POLAR	POLAR
BALL SCOUT SATELLITE	Sun-Sync	Sun-Sync	Non-Sync	Sun-Sync	Sun-Sync
SUBSYSTEM MASS, Kg	12AM-12PM	6AM-6PM		3AM-3PM	6AM-6PM
MECHANICAL SYSTEMS	23.7	23.7	25.2	26.7	26.7
TELECOMMUNICATIONS	9.4	9.4	7.2	6.9	6.8
POWER/PYRO	22.7	19.1	22.7	22.7	19.1
CABLING	7.0	7.0	7.0	7.0	7.0
COMMAND & DATA HANDLING	22.9	22.9	22.9	22.9	22.9
TEMPERATURE CONTROL	4.2	4.2	4.2	4.2	4.2
ATTITUDE/ARTICULATION CONTROL	10.4	10.4	12.8	7.1	7.1
PROPULSION	18.4	18.4	0.0	18.4	18.4
CONTINGENCY (15%)	17.8	17.3	15.3	17.4	16.8
SATELLITE BUS MASS, Kg:	**136.5**	**132.4**	**117.3**	**133.2**	**129.0**

Table 5
BSS MASS SUMMARIES, ASTRO MISSIONS

	ZENITH POINTER			CELESTIAL POINTER		SUN-LINE SPINNER	
	POLAR	POLAR	POLAR	EQUATORIAL	EQUATORIAL	POLAR	EQUATORIAL
BALL SCOUT SATELLITE	Sun-Sync	Sun-Sync	Non-Sync	Non-Sync	Non-Sync	Sun-Sync	Non-Sync
SUBSYSTEM MASS, Kg	12AM-12PM	6AM-6PM		Slow Retarget	Fast Retarget	6AM-6PM	
MECHANICAL SYSTEMS	22.0	23.7	25.2	25.2	25.2	26.7	26.7
TELECOMMUNICATIONS	9.8	9.4	9.4	9.4	9.4	6.8	9.4
POWER/PYRO	22.7	19.1	22.7	22.7	22.7	19.1	22.7
CABLING	7.0	7.0	7.0	7.0	7.0	7.0	7.0
COMMAND & DATA HANDLING	22.9	22.9	22.9	22.9	22.9	22.9	22.9
TEMPERATURE CONTROL	4.2	4.2	4.2	4.2	4.2	4.2	4.2
ATTITUDE/ARTICULATION CONTROL	10.4	10.4	11.7	6.4	8.8	7.1	7.4
PROPULSION	18.4	18.4	0.0	0.0	0.0	18.4	0.0
CONTINGENCY (15%)	17.6	17.3	15.5	14.7	15.0	16.8	15.1
SATELLITE BUS MASS, Kg:	**135.0**	**132.4**	**118.6**	**112.5**	**115.2**	**129.0**	**115.4**

Table 6
EARTH MISSIONS, BSS ORBIT-AVERAGE POWER BREAKDOWNS

COMPONENTS	Orbit-Avg. POWER (Watts)	NADIR POINTER POLAR Sun-Sync 12AM-12PM	NADIR POINTER POLAR Sun-Sync 6AM-6PM	NADIR POINTER POLAR Non-Sync	ORBIT-NORMAL SPINNER POLAR Sun-Sync 3AM-3PM	ORBIT-NORMAL SPINNER POLAR Sun-Sync 6AM-6PM
MECHANICAL SYSTEMS, Watts		0.0	0.0	0.0	0.0	0.0
Composite Tubes	0.0	x	x	x	x	x
End Fittings/Brkts	0.0	x	x	x	x	x
Decks, Upper, Lower	0.0	x	x	x	x	x
Devices, S/A Deployment	0.0	x	x	x	x	x
Actuator, Solar Array Drive	0.0			x		
Support Ring/Adapter, Scout 25"E"	0.0	x	x	x	x	x
Antenna Mast	0.0	x	x	x	x	x
Balance	0.0				x	x
TELECOMMUNICATIONS, Watts		5.7	5.7	3.8	5.7	3.1
Transponder,TDRSS, 2.5w	5.6	x	x		x	
Transponder, GSTDN, 2w	3.0					x
Transponder, SGLS, 3w	3.7			x		
Antenna Strips (6 each,13.4 dbi)	0.0	x	x			
Antenna#1 (LGA, hemi, -5 dbi)	0.0	x	x	x		
Antenna#2 (LGA, hemi, -5 dbi)	0.0	x	x			
Antenna#1 (SME Set, -5/+16.5 dbi)	0.0			x	x	x
Antenna#2 (SME Set, -5/+16.5 dbi)	0.0				x	x
Antenna Switcher	0.1	x	x	x	x	x
Power Divider	0.0	x	x	x	x	x
Power Combiner	0.0	x	x	x	x	x
RF Cables	0.0	x	x	x	x	x
RF Amplifier, 10 watt	8.3					
POWER/PYRO, Watts		4.0	4.0	4.0	4.0	4.0
Solar Array/Substrate (3 m2)	0.0	x	x	x	x	x
Battery #1 (6 AH)	0.0	x	x	x	x	x
Battery #2 (6 AH)	0.0	x		x	x	
Shunt Regulator	4.0	x	x	x	x	x
Shunt Load Bank	0.0	x	x	x	x	x
S/A String Switcher	0.1					
CABLING, Watts		0.0	0.0	0.0	0.0	0.0
Signal	0.0	x	x	x	x	x
Power	0.0	x	x	x	x	x
CMD & DATA HANDLING, Watts		15.3	15.3	15.3	15.3	15.3
MCDU Processor, w/Freq Std	10.3	x	x	x	x	x
Payload Bus Interface, BIF	1.0	x	x	x	x	x
DSU (SRAM, 1000 MB)	4.0	x	x	x	x	x
TEMPERATURE CONTROL, Watts		6.0	6.0	6.0	6.0	6.0
MLI	0.0	x	x	x	x	x
Heaters, Film (4 Zones)	6.0	x	x	x	x	x
Paint	0.0	x	x	x	x	x
ATTITUDE CONTROL, Watts		5.6	5.6	7.6	6.3	6.3
Scan Wheel, H=5.5 NMS	4.3	x	x	x		
Horizon Scanner	0.0					
Horizon Scanner Electronics	2.5					
Horizon Sensor#1	0.0				x	x
Horizon Sensor#1 Electronics	2.5				x	x
Horizon Sensor#2	0.0				x	x
Horizon Sensor#2 Electronics	2.5				x	x
Sun Sensor, 2-Axis	1.8					
Sun Sensor Electronics	0.5					
Magnetometer, 3-Axis	0.7	x	x	x	x	x
Mag Torque Rods (3, 50 A-M2)	0.6	x	x	x	x	x
Pitch Reaction Wheel (H=2 NMS)	2.0					
Yaw Reaction Wheel (H=2 NMS)	2.0			x		
Yo-Yo Despin, 2 Unwrap	0.0	x	x	x	x	x
Nutation Damper, Ring	0.0				x	x
PROPULSION, Watts		0.1	0.1	0.0	0.1	0.1
N2H4 Tank, 12.9" GPS	0.0	x	x		x	x
Fill/Drain Valves (2)	0.0	x	x		x	x
Filter	0.0	x	x		x	x
Transducers	0.0	x	x		x	x
Thruster/Valve Assy (2, 1 lb)	0.1	x	x		x	x
Propellant/Pressurant	0.0	x	x		x	x
Lines/Fittings	0.0	x	x		x	x
CONTINGENCY (25%)		9.2	9.2	9.2	9.3	8.7

Table 7
ASTRO MISSIONS, BSS ORBIT-AVERAGE POWER BREAKDOWNS

	ZENITH POINTER			CELESTIAL POINTER		SUN-LINE SPINNER	
COMPONENTS	POLAR	POLAR	POLAR	EQUATORIAL	EQUATORIAL	POLAR	EQUATORIAL
	Sun-Sync	Sun-Sync	Non-Sync	Non-Sync	Non-Sync	Sun-Sync	Non-Sync
	12AM-12PM	6AM-6PM		Slow Retarget	Fast Retarget	6AM-6PM	
MECHANICAL SYSTEMS, Watts	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Composite Tubes	x	x	x	x	x	x	x
End Fittings/Brkts	x	x	x	x	x	x	x
Decks, Upper, Lower	x	x	x	x	x	x	x
Devices, S/A Deployment	x	x	x	x	x	x	x
Actuator, Solar Array Drive			x	x	x		
Support Ring/Adapter, Scout 25"E"	x	x	x	x	x	x	x
Antenna Mast		x	x	x	x	x	x
Balance						x	x
TELECOMMUNICATIONS, Watts	3.8	5.7	5.7	5.7	5.7	3.1	5.7
Transponder,TDRSS, 2.5w		x	x	x	x		x
Transponder, GSTDN, 2w						x	
Transponder, SGLS, 3w	x						
Antenna Strips (6 each,13.4 dbi)	x	x	x	x	x		x
Antenna#1 (LGA, hemi, -5 dbi)	x	x	x	x	x		x
Antenna#2 (LGA, hemi, -5 dbi)	x	x	x	x	x		x
Antenna#1 (SME Set, -5/+16.5 dbi)						x	
Antenna#2 (SME Set, -5/+16.5 dbi)						x	
Antenna Switcher	x	x	x	x	x	x	x
Power Divider	x	x	x	x	x	x	x
Power Combiner	x	x	x	x	x	x	x
RF Cables	x	x	x	x	x	x	x
RF Amplifier, 10 watt							
POWER/PYRO, Watts	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Solar Array/Substrate (3 m2)	x	x	x	x	x	x	x
Battery #1 (6 AH)	x	x	x	x	x	x	x
Battery #2 (6 AH)	x		x	x	x		x
Shunt Regulator	x	x	x	x	x	x	x
Shunt Load Bank	x	x	x	x	x	x	x
S/A String Switcher							
CABLING, Watts	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Signal	x	x	x	x	x	x	x
Power	x	x	x	x	x	x	x
CMD & DATA HANDLING, Watts	15.3	15.3	15.3	15.3	15.3	15.3	15.3
MCDU Processor, w/Freq Std	x	x	x	x	x	x	x
Payload Bus Interface, BIF	x	x	x	x	x	x	x
DSU (SRAM, 1000 MB)	x	x	x	x	x	x	x
TEMPERATURE CONTROL, Watts	6.0	6.0	6.0	6.0	6.0	6.0	6.0
MLI	x	x	x	x	x	x	x
Heaters, Film (4 Zones)	x	x	x	x	x	x	x
Paint	x	x	x	x	x	x	x
ATTITUDE CONTROL, Watts	5.6	5.6	7.7	5.6	7.6	6.3	3.6
Scan Wheel, H=5.5 NMS	x	x	x				
Horizon Scanner							
Horizon Scanner Electronics							
Horizon Sensor#1						x	x
Horizon Sensor#1 Electronics						x	x
Horizon Sensor#2						x	x
Horizon Sensor#2 Electronics						x	x
Sun Sensor, 2-Axis				x	x		x
Sun Sensor Electronics				x	x		x
Magnetometer, 3-Axis	x	x	x	x	x	x	x
Mag Torque Rods (3, 50 A-M2)	x	x	x	x	x	x	x
Pitch Reaction Wheel (H=2 NMS)				x	x		
Yaw Reaction Wheel (H=2 NMS)			x		x		
Yo-Yo Despin, 2 Unwrap	x	x	x	x	x	x	x
Nutation Damper, Ring						x	x
PROPULSION, Watts	0.1	0.1	0.0	0.0	0.0	0.1	0.0
N2H4 Tank, 12.9" GPS	x	x				x	
Fill/Drain Valves (2)	x	x				x	
Filter	x	x				x	
Transducers	x	x				x	
Thruster/Valve Assy (2, 1 lb)	x	x				x	
Propellant/Pressurant	x	x				x	
Lines/Fittings	x	x				x	
CONTINGENCY (25%)	8.7	9.2	9.7	9.2	9.7	8.7	9.9

Power Summary

Table 6 and 7 show the orbit-average power consumption breakdown of the selected BSS subsystem hardware for each of the twelve design reference missions. While the orbit averages can be further refined in detail, this breakdown provides an overall basis for assessment of power availability to the payload. Table 8 and 9 shows a BSS orbit-average power consumption summary for each mission.

BSS Mission Application Configurations

Figures 4 through 8 show the versatile low-cost BSS in some of its various mission applications. Figure 4 shows nadir pointing mission applications. Figure 5 shows orbit normal spinner mission applications. Figure 6 shows zenith pointing mission applications. Figure 7 shows celestial pointing mission applications.

Table 9
BSS POWER SUMMARIES, ASTRO MISSIONS

	NADIR POINTER			ORBIT-NORMAL SPINNER	
	POLAR	POLAR	POLAR	POLAR	POLAR
BALL SCOUT SATELLITE	Sun-Sync	Sun-Sync	Non-Sync	Sun-Sync	Sun-Sync
SUBSYSTEM POWER, Watts	12AM-12PM	6AM-6PM		3AM-3PM	6AM-6PM
MECHANICAL SYSTEMS	0.0	0.0	0.0	0.0	0.0
TELECOMMUNICATIONS	5.7	5.7	3.8	5.7	3.1
POWER/PYRO	4.0	4.0	4.0	4.0	4.0
CABLING	0.0	0.0	0.0	0.0	0.0
COMMAND & DATA HANDLING	15.3	15.3	15.3	15.3	15.3
TEMPERATURE CONTROL	6.0	6.0	6.0	6.0	6.0
ATTITUDE/ARTICULATION CONTROL	5.6	5.6	7.6	6.3	6.3
PROPULSION	0.1	0.1	0.0	0.1	0.1
CONTINGENCY (25%)	9.2	9.2	9.2	9.3	8.7
SATELLITE BUS POWER, Watts:	**45.9**	**45.9**	**45.9**	**46.7**	**43.5**

Table 8
BSS POWER SUMMARIES, EARTH MISSIONS

	ZENITH POINTER			CELESTIAL POINTER		SUN-LINE SPINNER	
	POLAR	POLAR	POLAR	EQUATORIAL	EQUATORIAL	POLAR	EQUATORIAL
BALL SCOUT SATELLITE	Sun-Sync	Sun-Sync	Non-Sync	Non-Sync	Non-Sync	Sun-Sync	Non-Sync
SUBSYSTEM POWER, Watts	12AM-12PM	6AM-6PM		Slow Retarget	Fast Retarget	6AM-6PM	
MECHANICAL SYSTEMS	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TELECOMMUNICATIONS	3.8	5.7	5.7	5.7	5.7	3.1	5.7
POWER/PYRO	4.0	4.0	4.0	4.0	4.0	4.0	4.0
CABLING	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMMAND & DATA HANDLING	15.3	15.3	15.3	15.3	15.3	15.3	15.3
TEMPERATURE CONTROL	6.0	6.0	6.0	6.0	6.0	6.0	6.0
ATTITUDE/ARTICULATION CONTROL	5.6	5.6	7.7	5.6	7.6	6.3	8.6
PROPULSION	0.1	0.1	0.0	0.0	0.0	0.1	0.0
CONTINGENCY (25%)	8.7	9.2	9.7	9.2	9.7	8.7	9.9
SATELLITE BUS POWER, Watts:	**43.5**	**45.9**	**48.4**	**45.8**	**48.3**	**43.5**	**49.5**

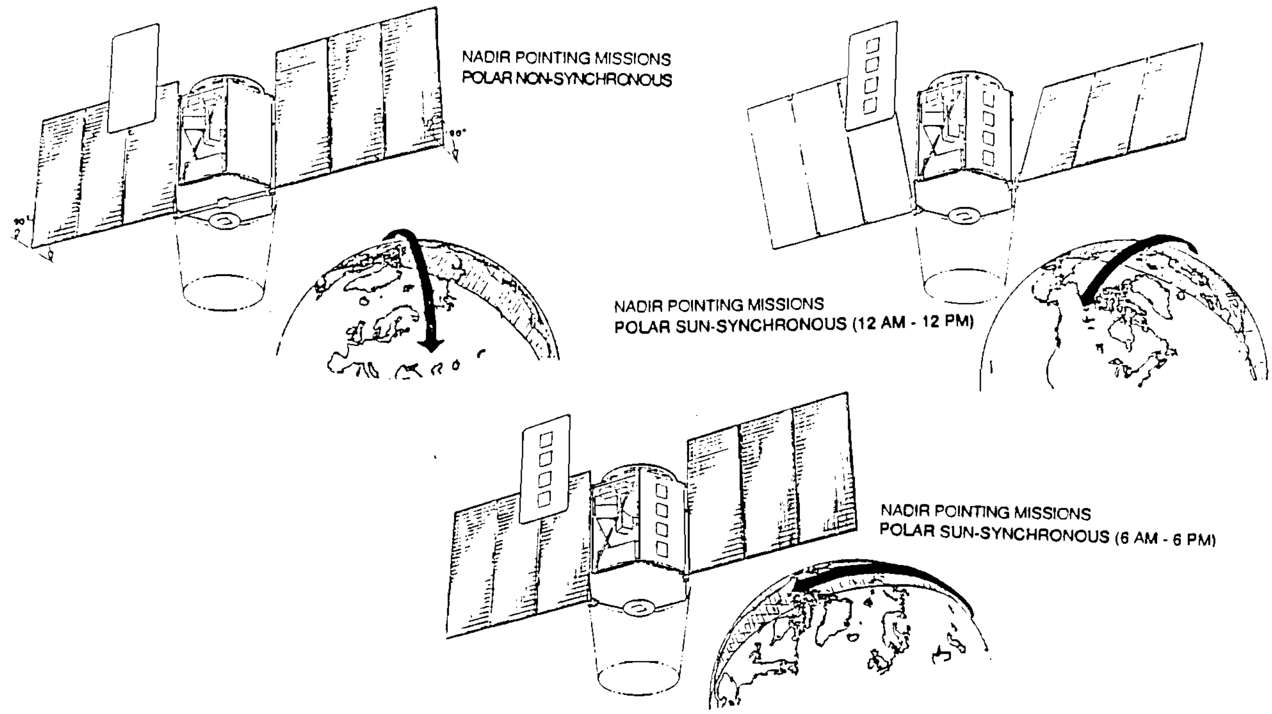

Fig. 4 Nadir Pointing Mission Configurations

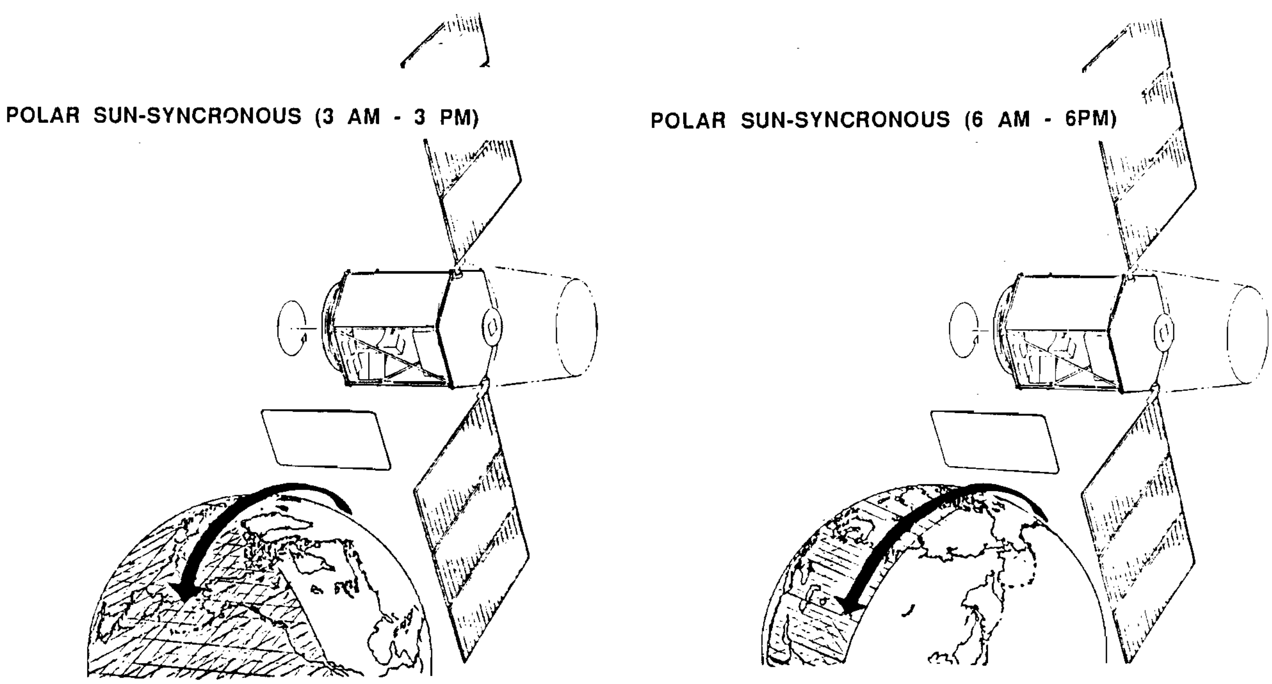

Fig. 5 Orbit Normal Spinner Configurations

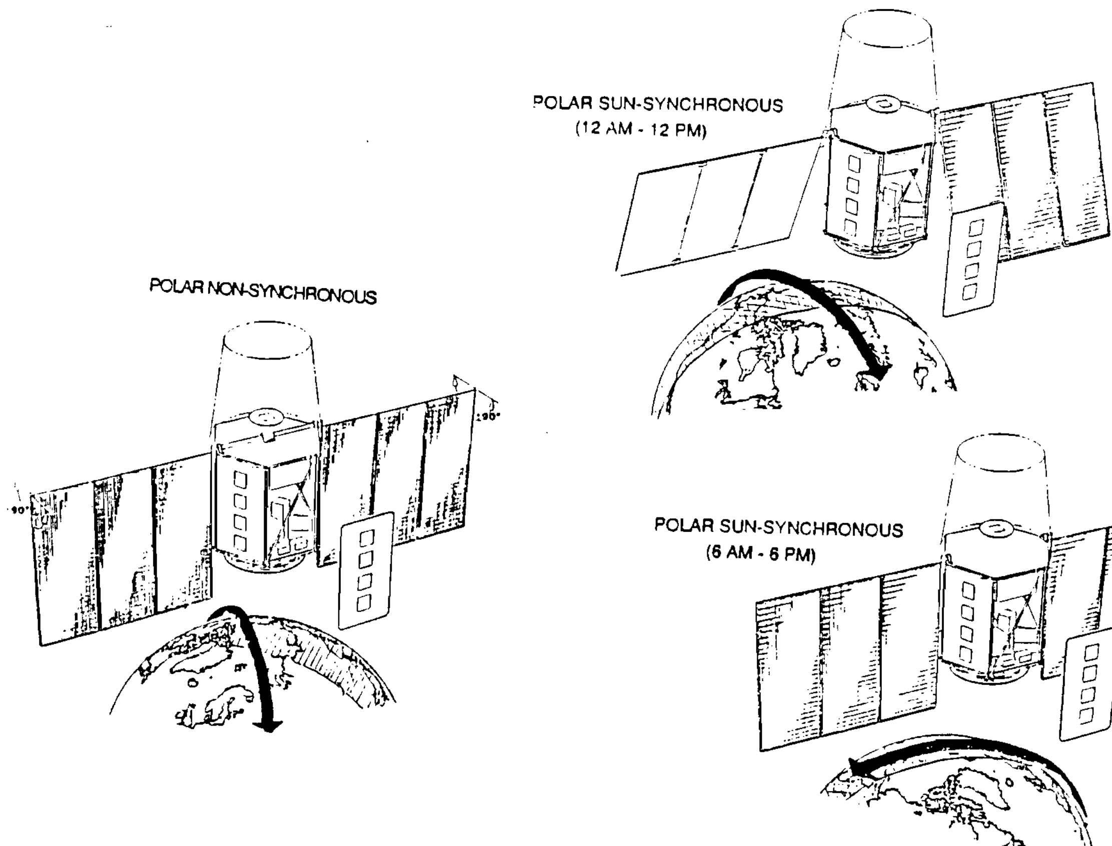

Fig. 6 Zenith Pointing Mission Configurations

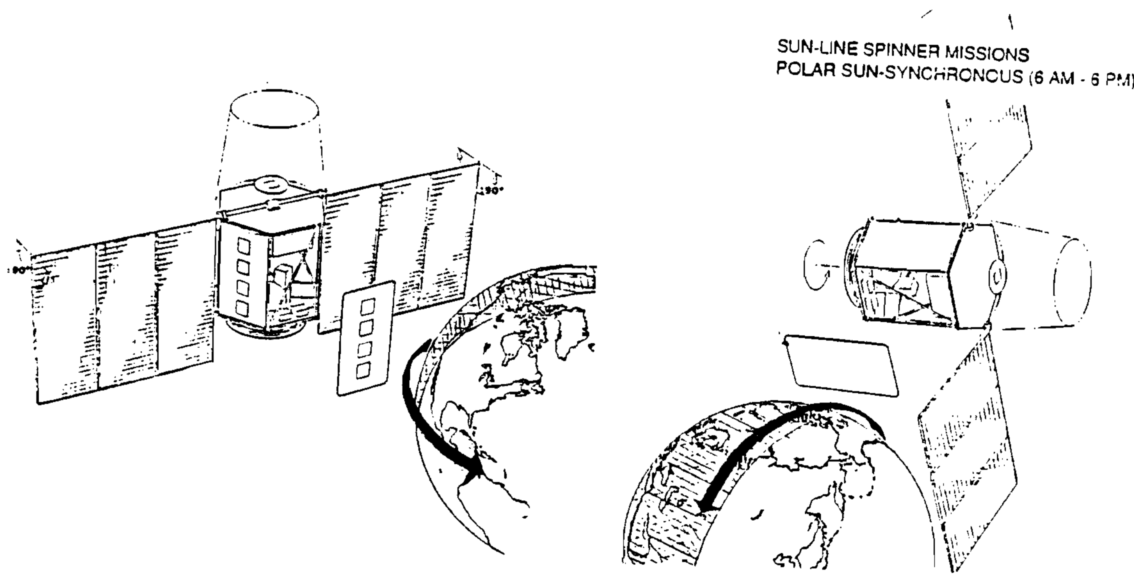

Fig. 7 Celestial Pointing Mission Configurations

PAYLOAD CAPABILITIES SUMMARY

The BSS is capable of being readily tailored to a wide range of mission applications.

Table 10
PAYLOAD CAPABILITIES, EARTH-ORIENTED MISSIONS

	NADIR POINTER			ORBIT-NORMAL SPINNER	
	POLAR	POLAR	POLAR	POLAR	POLAR
	Sun-Sync	Sun-Sync	Non-Sync	Sun-Sync	Sun-Sync
	12AM-12PM	6AM-6PM		3AM-3PM	6AM-6PM
ALTITUDE, INCLINATION	400 Km, 97°	400 Km, 97°	400 Km, 90°	400 Km, 97°	400 Km, 97°
SCOUT LAUNCH MASS	173 Kg	173 Kg	178 Kg	173 Kg	173 Kg
COMM/TRACKING NETWORK	TDRSS MA	TDRSS SA	SGLS	TDRSS MA	GSTDN/TDRSS
SOLAR ARRAY ARTICULATION	Fixed	Fixed	Articulated	Fixed	Fixed
SUNLIT AVERAGE S/A POWER	155 Watts	330 Watts	330 Watts	233 Watts	330 Watts
NUMBER OF REACTION WHEELS	Pitch	Pitch	Pitch+Yaw	None	None
BALL SCOUT SATELLITE BUS POWER	45.9 Watts	45.9 Watts	45.9 Watts	46.7 Watts	43.5 Watts
BALL SCOUT SATELLITE BUS MASS	136.5 Kg	132.4 Kg	117.3 Kg	133.2 Kg	129.0 Kg
DATA STORAGE	1000 Mb	1000 Mb	1000 Mb	1000 Mb	1000 Mb
POINTING CONTROL/KNOWLEDGE	0.2°/0.1°	0.2°/0.1°	0.2°/0.1°	0.2°/0.1°	0.2°/0.1°
ΔV CAPABILITY	186 m/s	186 m/s	0	186 m/s	186 m/s
REAL-TIME/PLAYBACK DATA RATE	2 Kbps	20 Kbps	1 Mbps	4 Kbps	8 Kbps
PAYLOAD MASS	**37 Kg**	**41 Kg**	**61 Kg**	**40 Kg**	**44 Kg**
PAYLOAD POWER	**42 W**	**196 W**	**137 W**	**84 W**	**199 W**

Table 11
PAYLOAD CAPABILITIES, ASTRO-ORIENTED MISSIONS

	ZENITH POINTER			CELESTIAL POINTER		SUN-LINE SPINNER	
	POLAR	POLAR	POLAR	EQUATORIAL	EQUATORIAL	POLAR	EQUATORIAL
	Sun-Sync	Sun-Sync	Non-Sync	Non-Sync	Non-Sync	Sun-Sync	Non-Sync
	12AM-12PM	6AM-6PM		Slow Retarget	Fast Retarget	6AM-6PM	
ALTITUDE, INCLINATION	400 Km, 97°	400 Km, 97°	400 Km, 90°	400 Km, 4°	400 Km, 4°	400 Km, 97°	400 Km, 4°
SCOUT LAUNCH MASS	173 Kg	173 Kg	178 Kg	233 Kg	233 Kg	173 Kg	233 Kg
COMM/TRACKING NETWORK	SGLS	TDRSS MA	TDRSS SA	TDRSS MA	TDRSS SA	GSTDN	TDRSS SA
SOLAR ARRAY ARTICULATION	Fixed	Fixed	Articulated	Articulated	Articulated	Fixed	Fixed
AVERAGE S/A POWER	155 Watts	330 Watts	330 Watts	330 Watts	330 Watts	330 Watts	330 Watts
NUMBER OF REACTION WHEELS	Pitch	Pitch	Pitch+Yaw	Pitch	Pitch+Yaw	None	None
BALL SCOUT SATELLITE BUS POWER	43.5 Watts	45.9Watts	48.4 Watts	45.8 Watts	48.3 Watts	43.5 Watts	49.5 Watts
BALL SCOUT SATELLITE BUS MASS	135.0 Kg	132.4 Kg	118.6 Kg	112.5 Kg	115.2 Kg	129.0 Kg	115.4 Kg
DATA STORAGE	1000 Mb	1000 Mb	1000 Mb	1000 Mb	1000 Mb	1000 Mb	1000 Mb
POINTING CONTROL/KNOWLEDGE	0.2°/0.1°	0.2°/0.1°	0.2°/0.1°	<0.2°/0.1°	<0.2°/0.1°	0.2°/0.1°	0.2°/0.1°
ΔV CAPABILITY	186 m/s	186 m/s	0	0	0	186 m/s	0
REAL-TIME/PLAYBACK DATA RATE	1 Mbps	2 Kbps	20 Kbps	2 Kbps	20 Kbps	50 Kbps	20 Kbps
PAYLOAD MASS	**38 Kg**	**41 Kg**	**59 Kg**	**121 Kg**	**118 Kg**	**44 Kg**	**118 Kg**
PAYLOAD POWER	**45 W**	**196 W**	**135 W**	**137 W**	**135 W**	**140 W**	**134 W**

While the payload support capabilities can vary widely depending on specific tailoring, the following assessments of the twelve design reference missions serve to indicate typical BSS payload support capability ranges. These are typical capabilities that can be met simultaneously. Higher capabilities can be provided through suitable trade-offs.

Table 10 and 11 show the summary payload capabilities for the Earth-oriented and astro-oriented missions, respectively. In general, BSS playback data rate capabilities are a function of the communications network, not of the mission application. The payload mass and power capabilities range over the twelve reference missions as follows:

Earth-Oriented Payload Capabilities

Nadir Pointers:	Mass: 37- 61 Kg	Power: 42-196 Watts
Spinners:	Mass: 40- 44 Kg	Power: 84-199 Watts

Astr-Oriented Payload Capabilities

Zenith Pointers:	Mass: 38- 59 Kg	Power: 45-196 Watts
Celestial Pointers:	Mass: 118-121 Kg	Power: 135-137 Watts
Spinners:	Mass: 44-118 Kg	Power: 134-140 Watts

CONCLUSION

The Ball Scout Satellite provides substantial payload support capabilities for a wide range of mission applications, both spinning and 3-axis stabilized. The use of current design architecture and off-the-shelf current technology hardware, provides a low-cost, reliable, tailorable, versatile Scout satellite bus.

ACKNOWLEDGEMENTS

The authors wish to thank the entire BSS design team at BASD, and especially Jack James for his support in the preparation of this paper.

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