Headquarters U.S. Air Force

Integrity - Service - Excellence

Spacecraft Estimating Considerations Class A vs Class C

2007 SCEA/ISPA Joint Conference

June 2007

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Purpose

- **To analyze the differences (cost/technical) between Class C and Class A space systems**
  - **Characterized CLASS A vs. CLASS C satellites**
    - Data set included Air Force, NASA and Commercial data
    - Determined average size, life, power and cost of Class A / Class C

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Class A vs Class C

Typical Space Vehicle Characteristics

	CLASS C	CLASS A
Mission priority	Medium to High	Highest
Allowed risk	Medium	Lowest feasible
Flight-type vehicle or experiment	Single unit for flight	Two: one for flight, one for qualification tests
Acquisition cost	Medium	Highest
Vehicle complexity	Low to medium complexity; usually only a single experiment	High, usually with full up mission(s) or two or more different experiments
Typical launch time	Not critical	Narrow launch windows
Typical orbit	Attached to host vehicle	Free-flyer
Typical on-orbit time	Months	Years
Experiments carried on vehicle	Usually one or more Class C, but could include other classes	Usually several Class A, but may include Class B, Class C, and/or Class D
Use of redundancy in vehicle	Usually a single string: redundancy used if safety critical	Used to assure critical functions, & independent failure of experiments
Probable failure mode of vehicle	Partial or total loss of data	Soft or only partial loss of data
Retrievability or in-orbit maintenance	Usually retrievable or maintainable in orbit	Not usually possible
Experiment complexity	Usually low or medium complexity	Usually complex, or with complex interfaces, or both
Use of redundancy in experiment	Usually a single string: redundancy used if safety critical	Redundancy used in all critical functions, where practical
Probable failure mode of experiment	Partial or total loss of data	Soft or only partial loss of data

SOURCE: MIL-HDBK-343, Table IV

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Class A vs Class C

Typical Space Vehicle Test Requirements

	CLASS C	CLASS A
Maximum Operating Environments	MIL-STD-1540 definitions for each assembly level	MIL-STD-1540 definitions for each assembly level
Testing Tolerances	MIL-STD-1540	MIL-STD-1540
Development tests	As required	As required
Component acceptance	MIL-STD-1540 (component acceptance)	MIL-STD-1540 (component acceptance)
Component qualification	Not required (acceptance test only)	MIL-STD-1540 to design levels
Qual thermal margin	0 deg C	10 deg C
Qual vibration margin	0 dB	6 dB
Qual acoustic margin	0 dB	6 dB
Qual shock margin	0 dB	6 dB
Experiment acceptance	MIL-STD-1540 (vehicle acceptance)	MIL-STD-1540 (vehicle acceptance)
Experiment qualification	Not required (acceptance test only)	MIL-STD-1540 (vehicle qualification)
Qual margins (environ)	0 deg C; 0 dB	10 deg C; 6 dB
Vehicle acceptance	MIL-STD-1540 (vehicle acceptance)	MIL-STD-1540 (vehicle acceptance)
Vehicle qualification	Not required (acceptance test only)	MIL-STD-1540 (vehicle qualification)
Qual. Margins (environ)	0 deg C; 0 dB	10 deg C; 6 dB

SOURCE: MIL-HDBK-343, Table VIII

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Class A vs Class C
Characteristics

	CLASS C to CLASS A
Avg. Design Life	**6.2X**
Avg. BOL Power	**8.5X**
Avg. Weight	**10.9X**
Avg. Months Award to Initial Launch	**1.8X**
Avg. NR+T1 Space Vehicle Cost per Pound ($/lb)	**1.6X**

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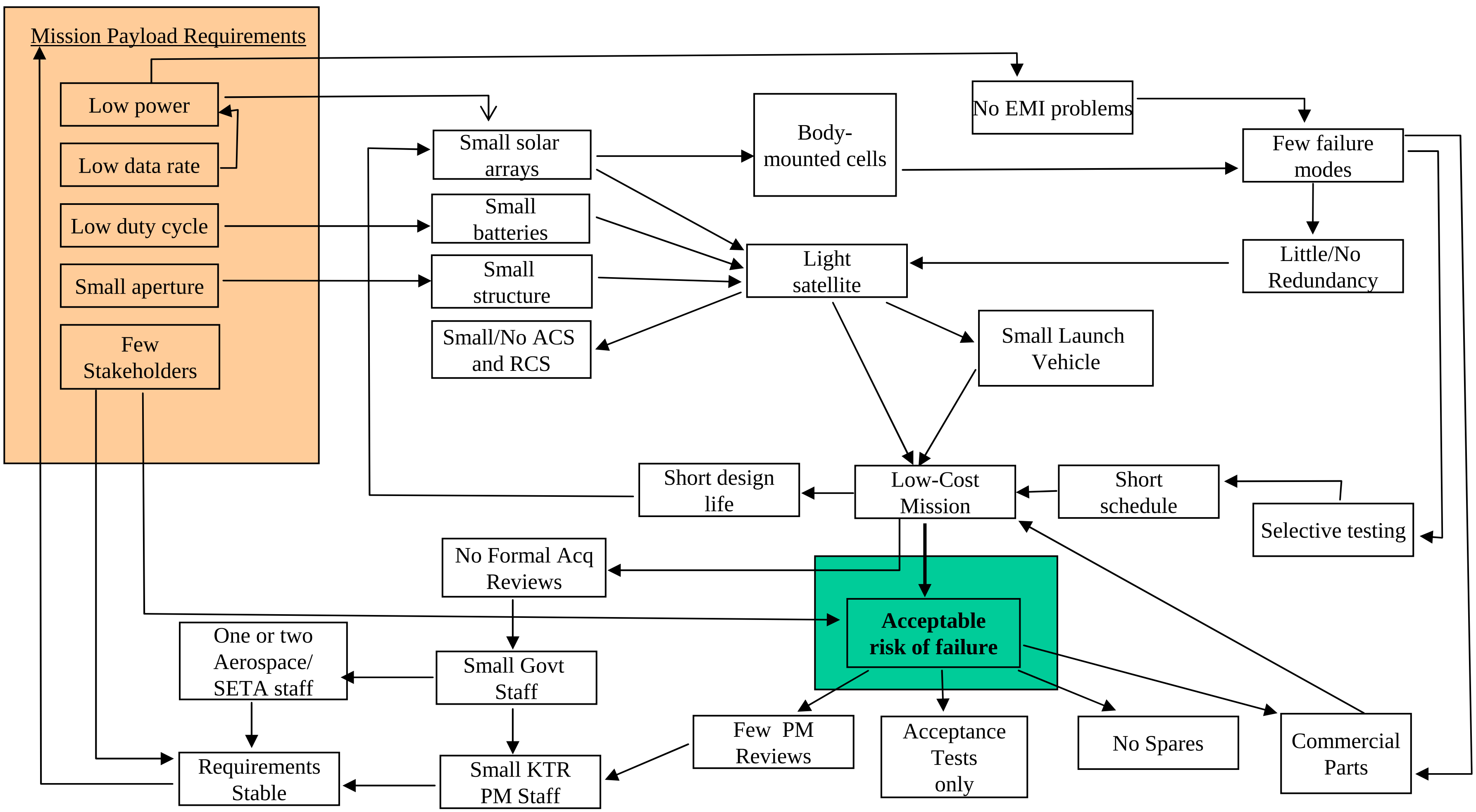
"Class C" Starts with Less Mission



Financing the Fight

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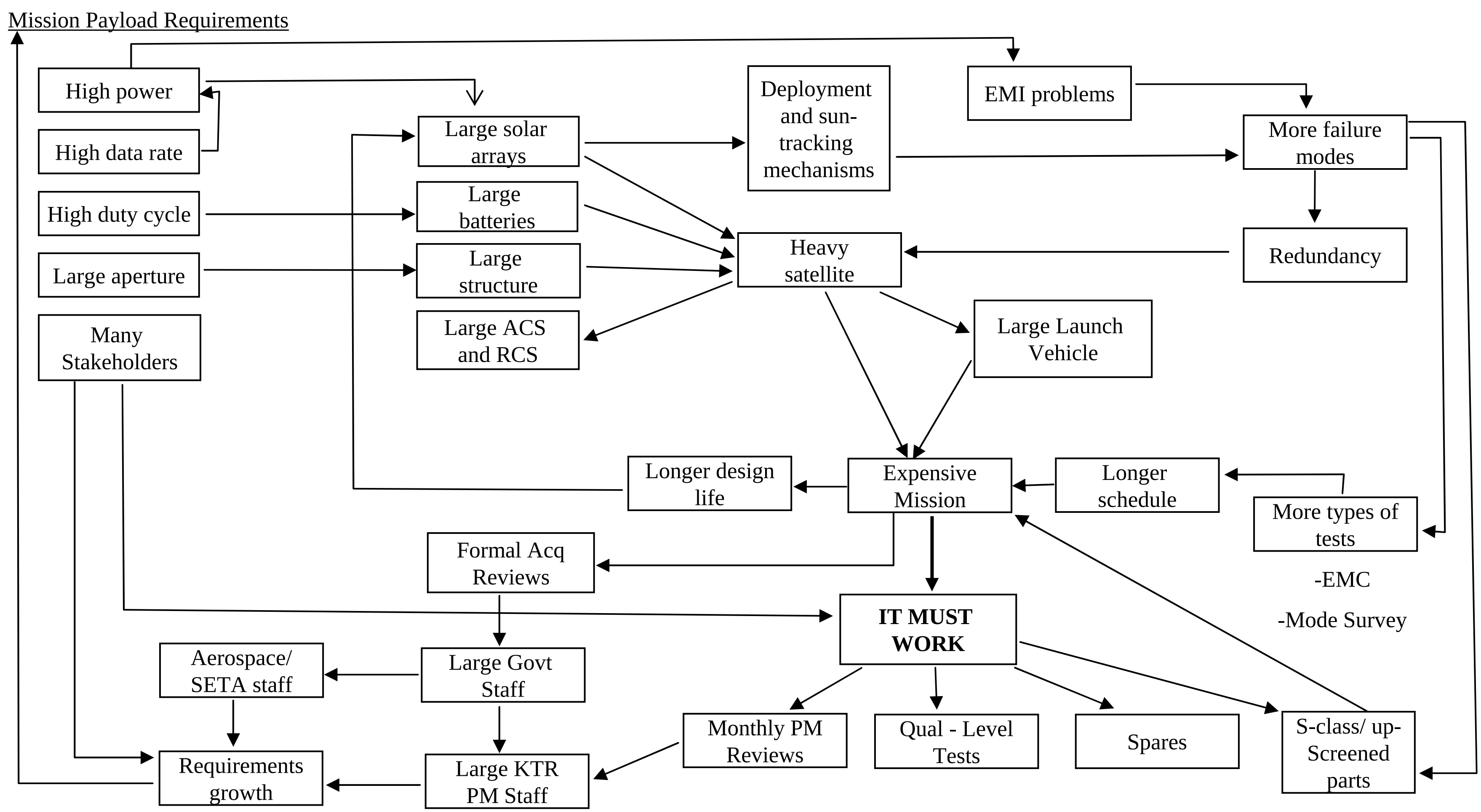
What makes a Satellite Become "Class A"



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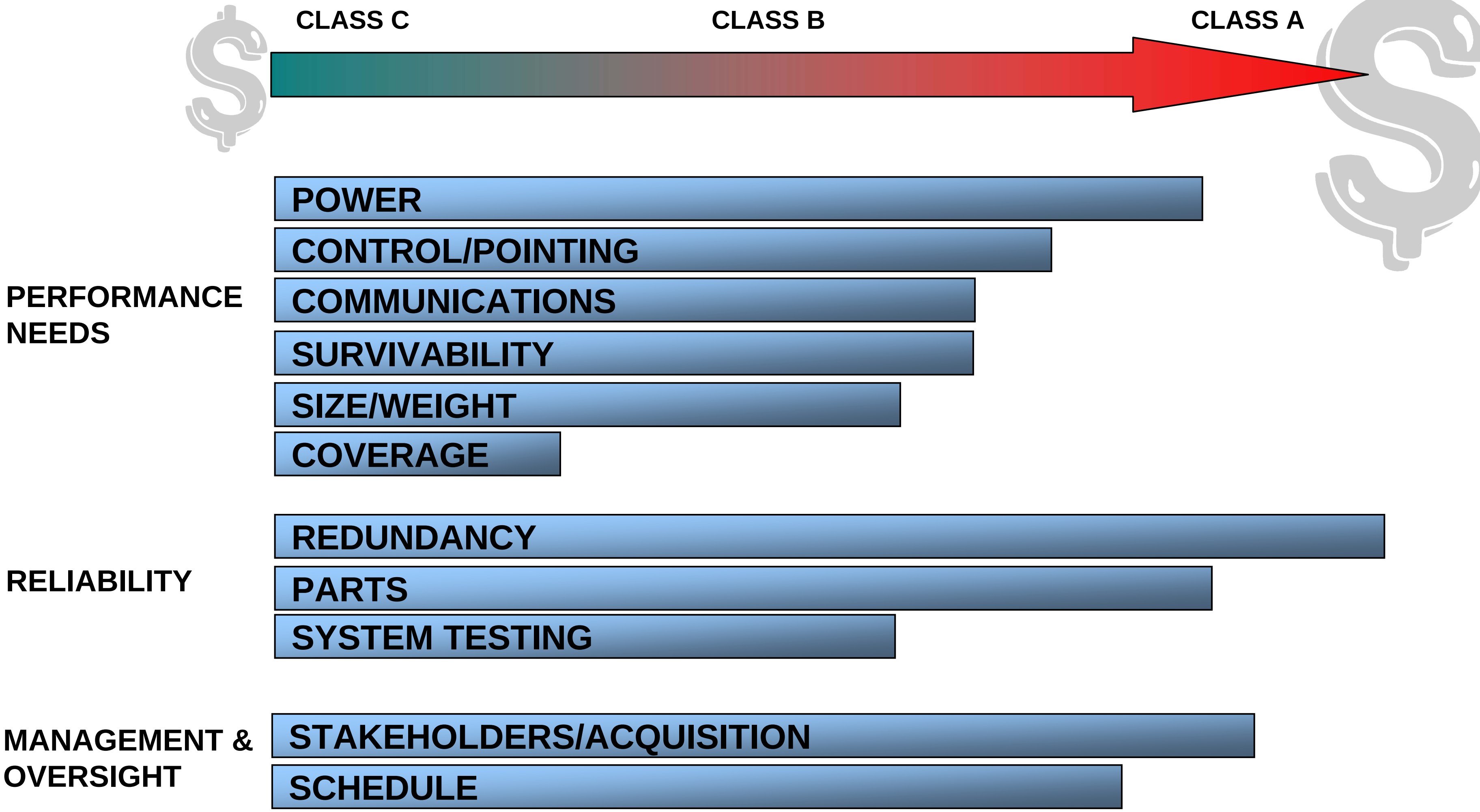
Class A vs Class C

Mission Requirements Drive Cost



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Power

BOL POWER	**Large payloads require more power**
EPS	**More power requires larger EPS systems, with more redundancy, to accommodate larger and more critical payloads**
EMI CONFLICTS	**Larger EPS systems lead to more EMI conflicts**
THERMAL ISSUES	**More power leads to more thermal issues**

RETURN TO DRIVERS

SEPM | STRUCTURE | EPS | PROPULSION | AGE

IA&T | THERMAL | ADCS | TT&C

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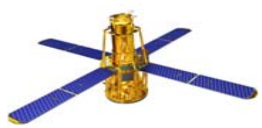
Size/Weight

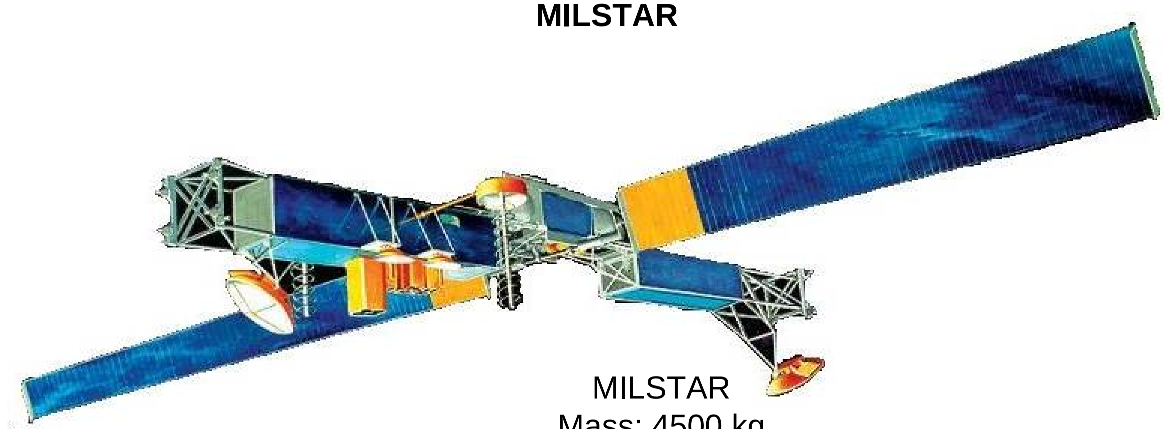
PAYLOAD SIZE vs FIELD OF VIEW	**The structure must support the payload, but cannot block view of sensors**
SOLAR ARRAY SIZE vs LAUNCH VEHICLE FAIRING	**Class A spacecraft structure may be constrained by the size of the launch vehicle fairing; requiring tighter structure design and increased thermal costs**
MASS REQUIREMENTS vs LAUNCH VEHICLE CAPABILITY	

RHESSI



Class C Spacecraft
Mass: 291 kg

MILSTAR



MILSTAR
Mass: 4500 kg

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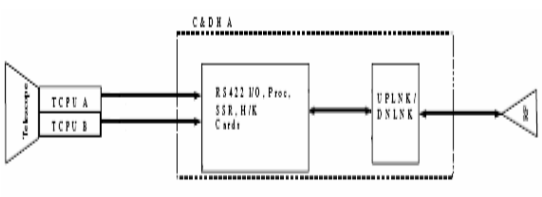
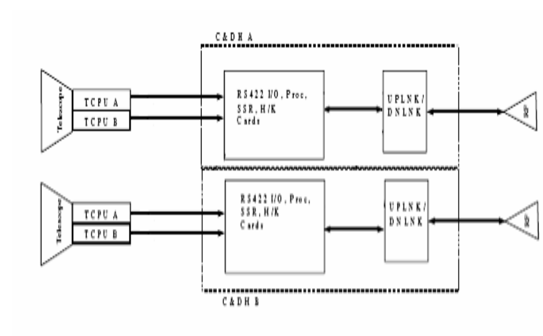
Redundancy

TYPE	CLASS C	CLASS A
SINGLE-STRING (NONE)	VERY LIKELY	NOT LIKELY
BLOCK REDUNDANCY	LIKELY	NOT LIKELY
CROSS-STRAPPING	NOT LIKELY	VERY LIKELY

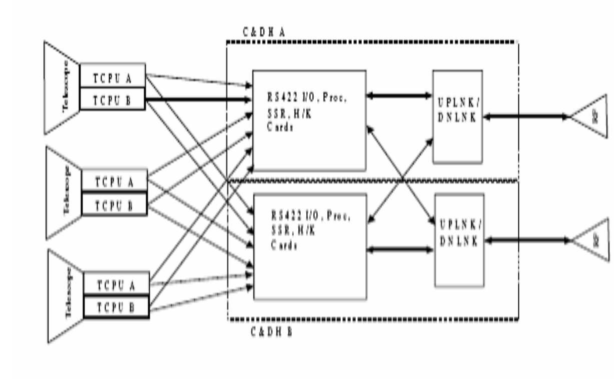
SINGLE STRING



BLOCK REDUNDANCY



CROSS-STRAPPING



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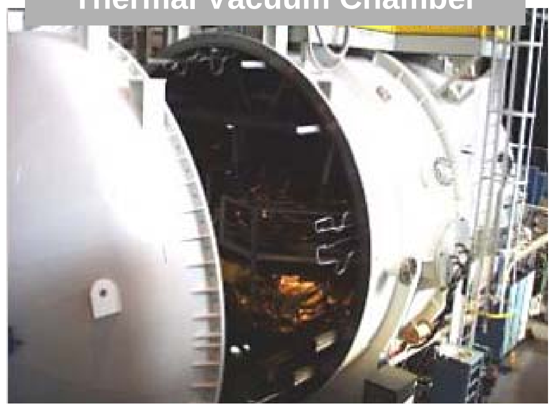
Parts

TYPE	CLASS C	CLASS A
PART SELECTION (BUY vs BUILD)	Generally use off-the-shelf parts	Stricter requirements often demand S-level or custom parts
QUALIFICATION TESTING	Not required at component level	Required at component level

Payload Level Shock Test

Thermal Vacuum Chamber



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Stakeholders/Acquisition

Number of Stakeholders	**Large amount of stakeholders, participating actively, will lead to additional meeting requests, additional program management costs, and higher documentation costs**
Participation of Stakeholders	
Documentation	

Class C

Managed by O-3 or O-4

Less Oversight

Class A

Managed by O-6 to O-8

ACAT-1

Requirements vetted by JROC

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Schedule

PROGRAM LENGTH	Class A programs have a considerably longer duration from award to launch; Program management will be required through the duration of the program
COMPLEX PAYLOADS	Complex payloads often incur delays; those delays may lead to a standing-army IA&T and SEPM

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Next Steps

- Analysis consistent with and provides 1st order quantification of MIL-STD guidelines

- Provides starting point for future analysis and cost modeling

BACKUP

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Control/Pointing

POSITIONING	Class A spacecraft, generally with longer mission durations, require more accurate and reliable attitude determination
STABILITY	Class A spacecraft performing high-resolution imaging require increased stability
POINTING ACCURACY	Pointing accuracy may drive the need for deployable antennas

Cost

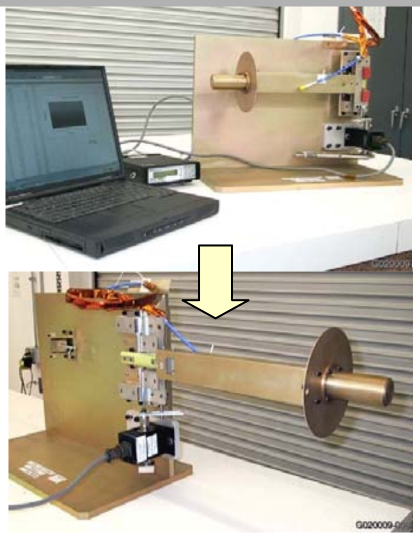
Determination Sensors

- Inertial Reference/ Measurement Units
- Star Trackers
- GPS Receivers
- Earth Sensors
- Sun Sensors
- Magnetometers

Control Actuators

- Gimbaled Flywheels (Integrated Power & ACS)
- Control Moment Gyros (CMG)
- Reaction Wheels
- Thrusters (REA)
- Gimbal Drives
- Electromagnetic Torque Rods

Antenna Deployment Test



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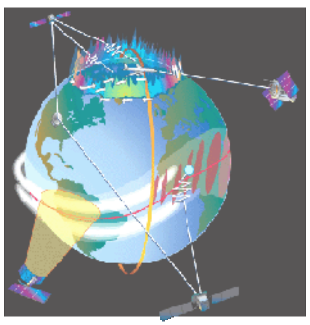
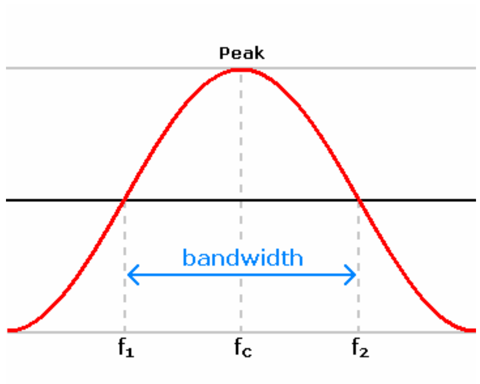
Communications

TIMING OF COMMUNICATIONS	**Class A missions requiring real-time information may require crosslinks; complex simulation models must be developed**
DATA RATE / FREQUENCY	**Class A payloads communicating at high data rates may require more power, more testing, and possibly custom components**
BIT ERROR RATE	**Class A systems will require a lower Bit Error Rate**
ENCRYPTION	**COMSEC equipment requires additional persons for testing or other handling**

CROSSLINK COMMUNICATION





Encryptor/Decryptor

"<u>Two man rule</u>": Requirement for two or more officials to authenticate and authorize sensitive operations

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Survivability

HARDENING	Class A vehicles are more "hardened" to sustain a longer mission life
AUTONOMOUS OPERATIONS	Class A defense satellites may need to operate autonomously in the event of temporary disconnect with ground stations
DEFENSE	Class A satellites will use additional defense mechanisms to defend itself from intentional damage

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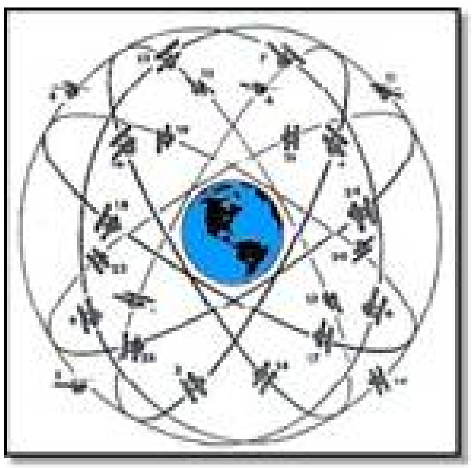
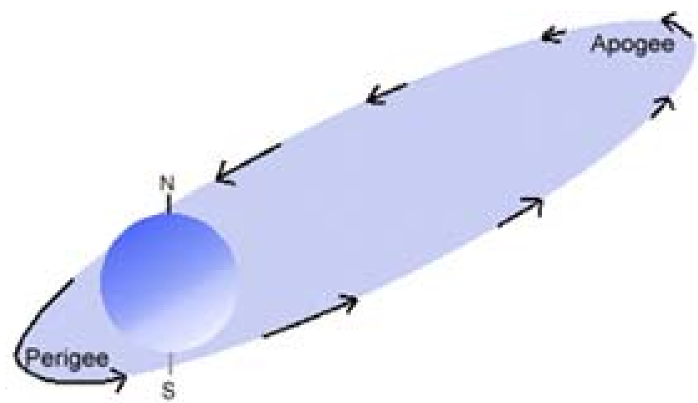
Coverage

NUMBER OF SPACECRAFT	**National Security-critical missions may require additional spacecraft to reduce risk; and may require more costly orbits**
ORBIT	
ALTITUDE	





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System Testing

TYPE	CLASS C	CLASS A
QUALIFICATION TESTING	Required to meet standards; can over-design structure and eliminate need for DTV	Mil-Std-343 requires spacecraft to be built to exceed specifications
EMI CONFLICTS	Fewer EMI conflicts	Larger payloads use more power and increase likelihood of EMI/EMC conflicts


Acoustics Chamber


Thermal Vacuum Chamber


EMI/EMC Chamber

MIL-HDBK-343 TESTING RQMTS

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Class A vs Class C
Approach

- **REVIEWED MIL-HDBK-343 & OTHER GUIDANCE**
  - Reviewed MIL-HDBK-343, Design, Construction, and testing Requirements for One of a Kind Space Equipment
  - Reviewed NASA Procedural Requirements 8705.4, Risk Classification for NASA Payloads; also reviewed General Environment Verification Specification for STS & ELV Payloads, Subsystems, and Components
- **COMPARED USCM CLASS A & USCM CLASS C**
  - Reviewed means of size, life, power and cost of Class A and Class C spacecraft;
  - Built estimates & actuals of USCM Class A & C spacecraft at component level; compared Class A & C at component level

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Class A vs Class C
MIL-HANDBOOK 343

- **DIFFERENCES IDENTIFIED IN MIL-HDBK-343 GUIDANCE:**
  - Class A vehicles have a higher documentation requirement, with monthly reviews of the contractor, where Class C vehicles many only require quarterly reviews
  - Class A vehicles are tested at the part level, where Class C vehicles are tested at the component level
  - Class A vehicles are required to be tested for acceptance AND qualification, where Class C vehicles are only required to be tested for acceptance
  - Class A vehicles must withstand 10 deg C beyond requirements
  - Class A vehicles must have a 6 db margin for: acoustics, vibration and shock