Spacecraft Standardization through Nuclear Power

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Theme

A CONCEPTUAL design study showed that two standardized shuttle-launched spacecraft using nuclear electrical power could serve many missions in a wide variety of orbits. Development costs could be amortized over very few missions, with significant savings thereafter.

Contents

A study[1,2] investigated whether the combination of the weight and volume capacity of the shuttle and the characteristics of nuclear electric power systems could make it possible to standardize spacecraft as well as subsystems. The standard spacecraft must provide space, mounting structure, environment and attitude control, power and telemetry for many missions with minimum changes and standard subsystems. Weight, volume, and thermal and solar array requirements (orbit-imposed) have usually led to custom design in the past. Nuclear systems provide power and heat independently of solar ocultation and aspect, and undegraded by Van Allen or solar radiation. The study examined feasibility of standard spacecraft design, applicability to specific missions, and costs.

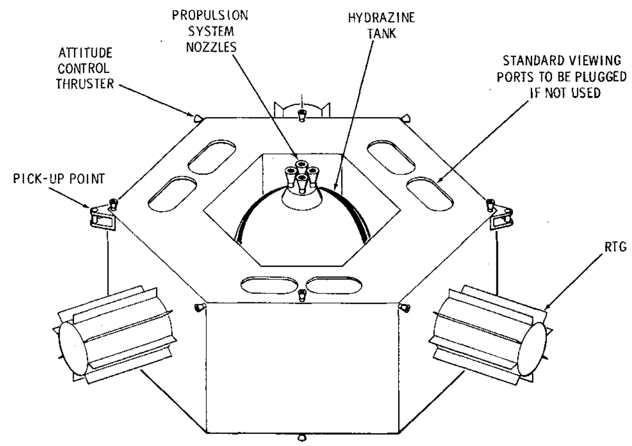

Fig. 1 Basic RTG spacecraft—external view.

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Table 1 Standard spacecraft design goals

Function	Requirement: RTG spacecraft	Requirement: Brayton spacecraft
Power	100–450 w (e)	500–2000 w (e)
Weight	1000–2000 lbs	up to 4000 lbs
Ferrying	interface with Shuttle, Agena or Centaur Tug, Chemical Tug	
Propulsion	small orbit change and/or stationkeeping capability	
Power	28 v d.c. ± 2% regulation, plus battery capacity	
Attitude control	3-axis stabilized, 0.1° accuracy	
TT & C	standardized, 1 MBS data rate	
Orbit	low to synchronous; any inclination, eccentricity	
Lifetime	minimum of 3 yr of expendables	
Thermal environment	equipment maintained −10 to +40C for all orbits	
Orientation	completely arbitrary in all orbits	

The classification of subsystem requirements (Table 1) as a basis of standardization resulted from analysis of the NASA unmanned mission model (interplanetary excluded). Correlation of size with power resulted in two groupings, with two satellite designs capable of serving most missions, except for a few special cases like the large observatories. Power levels from 150–450 w are handled by a satellite with one to three radioisotope thermoelectric generators (RTG). The 500–2000 w range is covered by a satellite with a Brayton cycle alternator fueled by from one to three of the same heat sources used in the RTG.

Figure 1 shows the standard RTG spacecraft configuration—a hexagonal prism with from one to three RTG units mounted externally on the side faces. Access to internal equipment is through the remaining sides. Top and bottom faces are used for mounting temperature sensitive items and for equipment needing an external field of view; large items can be mounted externally. Three sectors contain standard subsystems; three are available for payload. The center space can hold a hydrazine tank and fixed nozzle thrusters for orbit adjustments (1170 fps capacity); moments of inertia are suitable for spin stabilization during thrust. Total weight with payload can range from 1000–2000 lb.

Standard subsystems (about 300 lb, excluding the hydrazine and its tank) include a 28v±2% power supply, some battery capacity, VHF and S-band telemetry of 1 Mbit/sec capacity, redundant central digital computers, and a three-axis stabilization system.

Average temperatures are adjusted to the mission by varying areas covered by emissivity coatings and insulation and by movable vane louvers which regulate the flow of waste heat from the RTGs to the satellite body to control temperature variations. Most of the RTG waste heat radiates directly to space from the high temperature case and fins. With heat pipes to keep them uniform in temperature the end panels remain

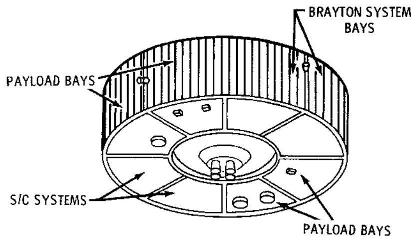

Fig. 2 Basic Brayton spacecraft—external view.

between −10°C and 40°C for all orbits, all sun aspects, and all equipment dissipation levels. Validity of the design was successfully tested against payload requirements of two missions—TDRS and advanced TIROS.

Figure 2 shows the standard Brayton satellite—a cylindrical annulus with a hydrazine tank and thrusters at the center. The outer cylinder is the Brayton cycle radiator—large enough for a system powered by three heat sources. The same system can be powered by only one or two sources by varying only the gas charge with little or no loss in efficiency. The radiator is made relatively uniform in temperature by dividing the working fluid into two streams which completely encircle the shell in opposite directions. Heat pipes carry the heat from the tubes across the shell. The low radiator temperature required for efficient Brayton cycle operations also provides a suitable environment for the enclosed volume, without other active temperature control. Parasitic loads keep the power level and Brayton turbine speed constant despite variations in payload demands. Insulation and coatings regulate the average temperature to keep the mounting surfaces within a 10–40°C range.

The annulus is divided into eight sector-shaped compartments, two occupied by the power system and two by other standard subsystems, leaving four for payload. The inner cylinder is the primary load bearing structure. The complete Brayton gas system is integrally mounted to the outer shell, permitting separate testing of the power system and its assembly to the spacecraft late in the integration sequence. Each flat surface consists of eight panels hinged to the inner ring; electronics are mounted on these panels. Except for power, the standard subsystems are functionally identical to those of the RTG spacecraft. Moments of inertia are suitable for spin stabilization if desired. A 4000 lb maximum weight allows for three fuel capsules, 560 lb of propellant, and 1900 lb of mission equipment. Adaptability to specific missions was confirmed by study of compatibility of ATS-F and Earth Observation Satellite payloads with the spacecraft.

Widespread use of radioisotope power systems would require increased radioisotope fuel production facilities, but supplies should be adequate for any foreseeable demands. Neptunium, found in reactor wastes in large quantities, can be converted to ^{238}Pu in many existing reactors, including commercial power units, or, if the demand warrants, in special radioisotope production reactors. Increased production should reduce the cost of plutonium below the current price used as a basis for the economic analyses done in the study. The wastes of high-temperature gas-cooled reactors, may have economically recoverable quantities of ^{238}Pu itself. Curium (^{244}Cm) occurs in significant quantities in current reactor wastes and could be extracted in large quantities at a cost below the current plutonium price.

Cost analyses compared standardized nuclear-powered spacecraft with mission-specialized (or "dedicated") solar-powered spacecraft for ten missions from the NASA 1972 mission model, five each in the RTG and Brayton system power ranges. Comparisons covered the actual spacecraft, the standard equipment provided for all missions, and integration. Launch, operational, and specialized mission equipment (payload) costs were not considered in this phase of the study. Cost increases for handling nuclear fuel were assumed to offset reductions in launch and operational costs due to standardization, and mission equipment costs should be relatively unaffected by the nature of the spacecraft. More accurate estimates require improved definition of both missions and shuttle utilization costs over what was available at the time of the study. The AEC is supporting further work in this direction.[3] The NASA investigation of a solar-powered standard spacecraft[4] will provide a basis for comparison with that approach.

In general, recurring costs for the standardized spacecraft are higher than those for the dedicated spacecraft, which was assumed to be more efficient in weight and power utilization with an associated reduction in recurring costs. The nonrecurring costs of the standardized spacecraft are lower because of reduction in spacecraft development, test and evaluation. Hence, the fewer the number of flights in a given mission, the greater the percentage of savings provided by use of standardized spacecraft.

The cost comparisons for the ten missions showed clear savings for the standardized spacecraft. Total costs for the items estimated were approximately $850 million using the specialized spacecraft approach; and approximately $725 million for the standardized spacecraft, including about $185 million for development of the two standard spacecraft. For additional missions, the savings will be considerably greater. An interesting result was that one mission (TDRS) requiring less than 500 w was more economically satisfied by the Brayton spacecraft.

The fundamental conclusions of the study areas follows.

1) The orbit-insensitivity of nuclear electric power systems makes it feasible to design standard spacecraft capable of serving a variety of missions with minimum modification. Power and thermal characteristics are the key elements.

2) Two spacecraft designs, based on use of the RTG and the Brayton power systems, can satisfy most of the unmanned Earth-orbiting missions in the NASA mission model. Both designs can operate at several power levels, the RTG from 150 to 450 w, and the Brayton from 500 to 2000 w, depending on the number of thermal sources (1 to 3) used. Both power units use the same thermal sources.

3) Significant savings are achieved in comparison with solar-powered spacecraft specifically designed for each mission.

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