OAST SYSTEM TECHNOLOGY PLANNING

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INTRODUCTION AND SUMMARY

The space program is twenty years of age. Today we employ space projects effectively in some limited areas such as communications and weather forecasting. Opportunities appear to be opening for space systems to serve society in resource management, disaster warning, electronic mail, electronic business and banking, teleconferencing, broadcasting, distressed vehicle location, air-traffic control, zero-gravity and vacuum-produced equipment, and probably energy delivered from space. All of these programs and many others can be described as technologically feasible.

The future will see space platforms which are tens, hundreds, and eventually thousands of meters in size, using and producing kilowatts and megawatts of power, processing data at rates that could handle the contents of the Library of Congress each second--and all, of economic necessity, constructed at very low unit costs. Today's spacecraft are measured in sizes of a few meters, using at most a few hundred watts of power for transmitting and handling a tenth to a hundredth of a percent of forecast data rates, all painstakingly crafted at relatively high unit costs.

Preparing for the space program transition from the demonstration-oriented era to a cost-effective operational era presents extensive and challenging technology goals. Accordingly, the NASA Office of Aeronautics and Space Technology has developed a planning model for space technology consisting of a Space Systems Technology Model, technology surveys, and technology forecasts. The Technology Model describes candidate space missions through the year 2000 and identifies their technology requirements. The technology surveys and technology forecasts provide, respectively, data on the current and estimates of the projected status of relevant technologies. These tools are used to further the understanding of the activities and resources required to ensure the timely development of technological capabilities.

Basic electronics progress serves as the driver to future programs in that payloads are primarily comprised of sensors, data processors, and transceivers. The revolutionary growth that we have witnessed in electronics technology in recent years (Fig. 1) is evidenced not only in performance but also in reduction of cost and increase in reliability. All of these capabilities are progressing at the remarkable exponential rate of doubling every one to three years. This growth is reflected in virtually any measure of performance, cost, or reliability.

Expanded payload capability is stimulating the entire aerospace industry to conceive and advocate ambitious future program concepts. To support this expanding payload capability, comparable advances must be developed in the supporting technologies of power, structures, control, and transportation. Key technological forecasts for missions that "drive" technology requirements are summarized in Fig. 2. It is apparent from this figure that the future needs of technology growth are remarkably uniform and demanding. The coming twenty years must provide growth of three to four orders of magnitude whether we are concerned with the volume of transportation to Earth orbit, the handling and processing of data quantities, or the requirements of power and size of the spacecraft systems.

Technological capabilities for future space systems have been forecast to expand at an exponential rate. The realization of such technological advances will enable future space systems with enormous capability for providing benefits to serve vital national needs. At today's costs for generating these capabilities, the programs being considered would exceed reasonable budget levels. The costs illustrated in Fig. 3 for transportation to low Earth orbit, for handling data, for generating electrical energy, and for constructing spacecraft vehicles must be reduced substantially. With forecasts of capability increases of three to four orders of magnitude in the next twenty years, unit costs of accomplishment must be reduced by orders of magnitude. Although a corresponding 10^3 or 10^4 drop in unit cost is probably not realizable, a 10^1 or 10^2 reduction could help keep future programs, and their benefits, within reach.

THE TECHNOLOGY MODEL AND FORECASTS

The space missions or systems in the Technology Model, both near and far term, are divided by their area of application into four OAST Space Themes: Exploration, Global Services, Utilization of the Space Environment, and Transportation. The near-term missions are derived primarily from the current NASA five-year planning document. The far-term missions are derived from advanced studies conducted by OAST and other NASA offices. Figures 4 and 5 list the missions and systems of the Technology Model.

For each system in the Technology Model, the primary and secondary technologies that will enable or substantially enhance that system are identified, and where possible, the required level of achievement is noted.

As companion to the Space Systems Technology Model, a technology forecast handbook is being prepared. This will be a reference document containing historic trends and projections of each "capability measure," based on best available data from many sources.

OAST SPACE R&T PROGRAM PLAN

The OAST space technology plans are structured into major thrusts of

- Information Systems
- Spacecraft Systems

- Transportation Systems
- Power Systems

These interdisciplinary groupings provide a focus to technology activities, allowing long- and short-term goal orientation and intermediate milestone identification.

The Research and Technology (R&T) Base Program is the mainstream of technology program activity. While R&T base is the resource for bringing technology to a level of readiness for transfer to planned programs, technology readiness for program application often requires flight validation. This need may be satisfied by either aircraft or space demonstration, with the Spacelab available as a qualification test platform. Shuttle and Spacelab also provide a new and valuable "real space" environmental test facility in support of research and development. OAST technical planning avails itself of this capability.

Details of the FY 79-83 OAST Space R&T Program follow. For each planning thrust, a brief description of the elements is presented, long-range plans with expected benefits are given, and indications of the applicability of these space systems technologies to other NASA programs are presented.

Information Systems

Major elements of the information systems technology effort, summarized in Fig. 6 are instrument pointing, sensing and data acquisition, data processing, communications, data reduction, and data distribution. Long-range plans for this program include both augmentation of the base program in selected areas having potentially high payoffs in future mission applications or significant deficiencies in current activities, and intensified initiatives in certain specific technologies (Fig. 7) having direct benefit to planned and proposed NASA missions. Augmented programs in microwave radiometry and IR detectors will permit development of new and improved concepts for space sensors. Complementary to, and directly supporting, the sensor development activity is a program augmentation in instrument-pointing system technology to provide precise pointing and stabilization of sensor and experiment platforms. To build a strong technology base in advanced communications systems and services, program augmentations are planned in the areas of X-band power amplifiers, multibeam antennas, and data compression. The overall objectives of this effort are to reduce the time and cost required for the collection, processing, and dissemination of space-generated data by a factor of 100 to 1000 over a 10-year period.

Phased programs in NASA End-to-End Data Systems (NEEDS) and Efficient Sensing Systems (ESS) illustrated in Fig. 7 are planned to improve the efficiency and effectiveness of NASA information systems.

The Information Systems Technology Program has the potential to provide enabling and enhancing technologies to numerous possible NASA programs. The NEEDS Program could significantly reduce the cost of future SEASAT, LANDSAT, Shuttle, Global Earth Resources, and Environmental Monitoring Programs. The

ESS Program would optimize the data collecting capabilities of proposed TIROS, Environmental Monitoring, STORMSAT, and LANDSAT missions.

The NASA End-to-End Data Systems Program will build on ongoing critical technology developments by first providing a technology base for Real-Time Data Management and, in subsequent years, developing the technology for Low-Cost Data Distribution. The FY 79 system technology emphasis on Real-Time Management has two major thrusts: development of on-board data reduction technology followed by a Shuttle demonstration, and development of technology to expedite user access to space-generated data including a ground demonstration.

In the area of Efficient Sensing Systems, the overall objective is to expand usable data-gathering capability by a factor of 10. The first phase of this new initiative will focus on development of both high-resolution linear array infrared detectors for terrestrial observations and linear arrays of microwave radiometers to improve the spatial resolution of oceanic and ground monitoring. To implement these systems, a precision platform and tracking system will be developed to perform high-resolution imaging and spectroscopy experiments of planetary surfaces, atmospheres, and satellites. In subsequent years, the program will build on the augmented technology base to provide enhanced environmental monitoring systems, precision pointing capability, and multimission sensing technology.

Spacecraft Systems

Elements of this thrust include structures, assembly, guidance and control, materials, thermal control, on-board propulsion, and planetary entry. An immediate major objective is to provide the technology in structures, materials, assembly, and controls for economical large-area space structures. Objectives to be addressed later in the 5-year period include development of analytical methods for nonlinear large deflection; automated operations including techniques for the use of teleoperators, free-flying robotic manipulators; and development of technology relating to the use of extraterrestrial resources for the construction of future space systems.

Future needs in communications, Earth resources, and space industrialization will require spacecraft of several hundred meters to several kilometers in size compared to our current experience with spacecraft of several tens of meters. This represents a technology challenge beyond putting more of the same types of structure in orbit. Large structures are more flexible, thus requiring greater structural efficiency (stiffness and strength per unit mass). More sophisticated, distributed controls are required for both pointing and figure control. In addition, large structures must be assembled in space using manipulators and teleoperators not currently existing.

Figure 8 depicts the technology elements of this thrust leading to efficient large spacecraft. A current program has laid the groundwork for large space structure concepts. The proposed system technology augmentation--Large Space Systems Technology--beginning in FY 81, will define representative systems as focal points in order to establish structures, controls, and assembly technology requirements. Later phases would focus on technology test and verification activities of the two major structural categories--antennas and platforms. Additional new programs are planned for a new nonlinear deflection analysis capability, automated space operations (function, pointing, transmission, maintenance), and a technology program proposed to develop the ore processing procedures for extraterrestrial materials for use in space construction.

Figure 8 depicts the ongoing program and proposed augmentations. The augmentations include two new R&T base efforts: long-life composites and free-flying robotic manipulators. The first is needed to provide the design base for what is expected to be the principal structural material for spacecraft. The second will provide the technology needed for assembly, maintenance, and other future space operations.

The basic entry technology R&T program which is contained in the Spacecraft Systems thrust develops the gas dynamic, aerothermodynamic, and flight mechanics technology base required to improve entry spacecraft design, safety, reliability, and efficient aerodynamic operation for Earth orbital and planetary exploration missions. The near-term program establishes the technology base to assure survival and reliable performance of outer planet probes.

In the long term, the entry technology program establishes the aerothermodynamic technology and configurational design concepts required to achieve significant improvements in operational efficiency, safety, reliability, and economy for space transportation systems operational in the 1990s.

The primary thrust of the OAST spacecraft systems program is to provide technology readiness for the middle to late 1980s suitable for Earth communications, Earth observations, and space platforms; and deep space communications and astronomy in the 1990s (Fig. 9). However, the program will begin in the early 1980s to provide usable output suitable for supporting potential communications and Earth resources sensing mission, space construction base, and missions in radio astronomy and deep space communications.

Transportation Systems

Technology for launch vehicles and orbital transfer vehicles includes efforts in chemical propulsion, low-thrust propulsion, structures and materials, thermal protection systems, aerothermodynamics, and zero-gravity experiments (Fig. 10). Several objectives need to be addressed if desired technology advances are to be achieved. A continuing objective is to develop low-thrust propulsion for orbit-to-orbit cargo delivery and interplanetary transfer of scientific payloads. Other objectives are to advance chemical propulsion, materials and structures, and thermal protection systems technologies that will lead to fully reusable, much longer life vehicles that require minimum servicing and maintenance between flights.

The chemical propulsion objective is to provide a technology base for future large-scale, Earth-to-orbit propulsion systems including long-life, minimum maintenance reusable propulsion systems. Advanced structural concepts and materials for use in future transportation systems include fully reusable, low-maintenance structures capable of withstanding high temperature and composite structural elements to reduce vehicle weight. The continuing objective to develop low-thrust transportation for orbit-to-orbit and interplanetary service includes ion thrust systems, electromagnetic mass drivers, and magnetoplasmadynamic accelerations.

Another continuing objective is to demonstrate propulsion system concepts (such as long-life, highly flexible systems) suitable for a late-1980s reusable space-based orbital transfer vehicle.

A later specific objective is to provide a technology base for large-scale reusable propulsion systems for Earth-to-orbit vehicles, including minimum serviceability, low recurring costs, oxygen/hydrogen, oxygen/high-density-fuel engines, and high-performance, lightweight dual-fuel systems; and to conduct flight experiments to develop the technology for propellant management in zero-gravity environment.

A specific objective starting in FY 83 is to develop advanced, low-maintenance structural concepts; materials capable of withstanding high temperatures; and lightweight composite structural elements to reduce vehicle weight.

Although the transportation systems technology program is aimed at a future low-cost, high-capability space transportation system family of vehicles (Fig. 11), it will also provide potential enabling/enhancing technologies to such NASA programs as Shuttle/IUS improvement/growth, Shuttle derivatives, and high-energy planetary missions.

Power Systems

This technology program seeks to advance our capability to generate, store, process, and distribute electrical energy for use in space systems. Advances over current levels of technology are required to fully realize the advantages of the high performance needed for electric propulsion and to effectively use near-Earth space. As indicated in Fig. 12, the base program provides technology for both high-performance and multikilowatt low-cost future power requirements via the conduct of research in solar cells and arrays, batteries and fuel cells, thermo-electrics, Brayton cycle, thermionics, power management, and advanced concepts such as laser transmission. Augmentation of this program aimed at the increased performance and power level requirements anticipated in the 1980s and beyond appears to have high potential payoff and hence is planned.

Space energy costs have been very high, in the range of several thousand dollars per kilowatt-hour for past systems compared to terrestrial costs of a few cents per kilowatt-hour. As can be seen from Fig. 13, the cost of space energy has remained relatively constant for over a decade, so the cost reductions indicated for future potential missions represent a very important technology challenge and opportunity. Additional technologies which are significant for some of the largest power-using and -producing missions are large-structure construction and low-cost Earth-to-orbit transportation (described earlier).

Future missions are expected to have energy requirements 100 times or more greater than past missions; hence, investments should be made now in technology aimed at reducing costs if such future missions are to be kept within reasonable cost bounds. Space solar power installed in the past cumulates to less than 100 kW since the beginning of the Space Program, and we are faced with power demands on single missions under discussion for the 1980s which approximate that cumulative level and can anticipate growth to the megawatt range in the 1990s.

Figure 14 shows actual average power for some prior NASA missions and projected average power for some missions from the Technology Model. There is generally a smooth increase in power level when both actual and projected missions are considered, except for the SPS, which is orders of magnitude above the other missions. However, SPS is not a power user but a power producer and as such perhaps should not be expected to fit the trend of power-using systems. Similarly, the large power module also falls above the power levels for power user missions of the mid-1980s.

Such large increases in power levels also require technology advances in related space systems. Some which are prominent in the Technology Model are power storage and lifetime, heat pipes and heat rejection, automated power conditioning and power management, lightweight power system materials, and thermionics. Perhaps the most important technology need is to reduce significantly the cost of space energy.

The orbital power program is aimed both at reducing cost and at providing the technological basis for future high-power orbital systems. This program seeks to attack the critical problems of low-cost generation, maintainable bulk energy storage, large-scale thermal and power management, as well as to seek the economies of scale of central power through evolution of the enabling technology of power transmission.

As suggested in Fig. 15, significant program outputs that are projected are applicable to such near-term NASA programs as JOP, comet rendezvous, OTV, space processing, and public service COMSAT. Far-term goals, however, are to realize the combined advantages of high performance and low cost in enabling systems of the future, such as SPS and NEP.

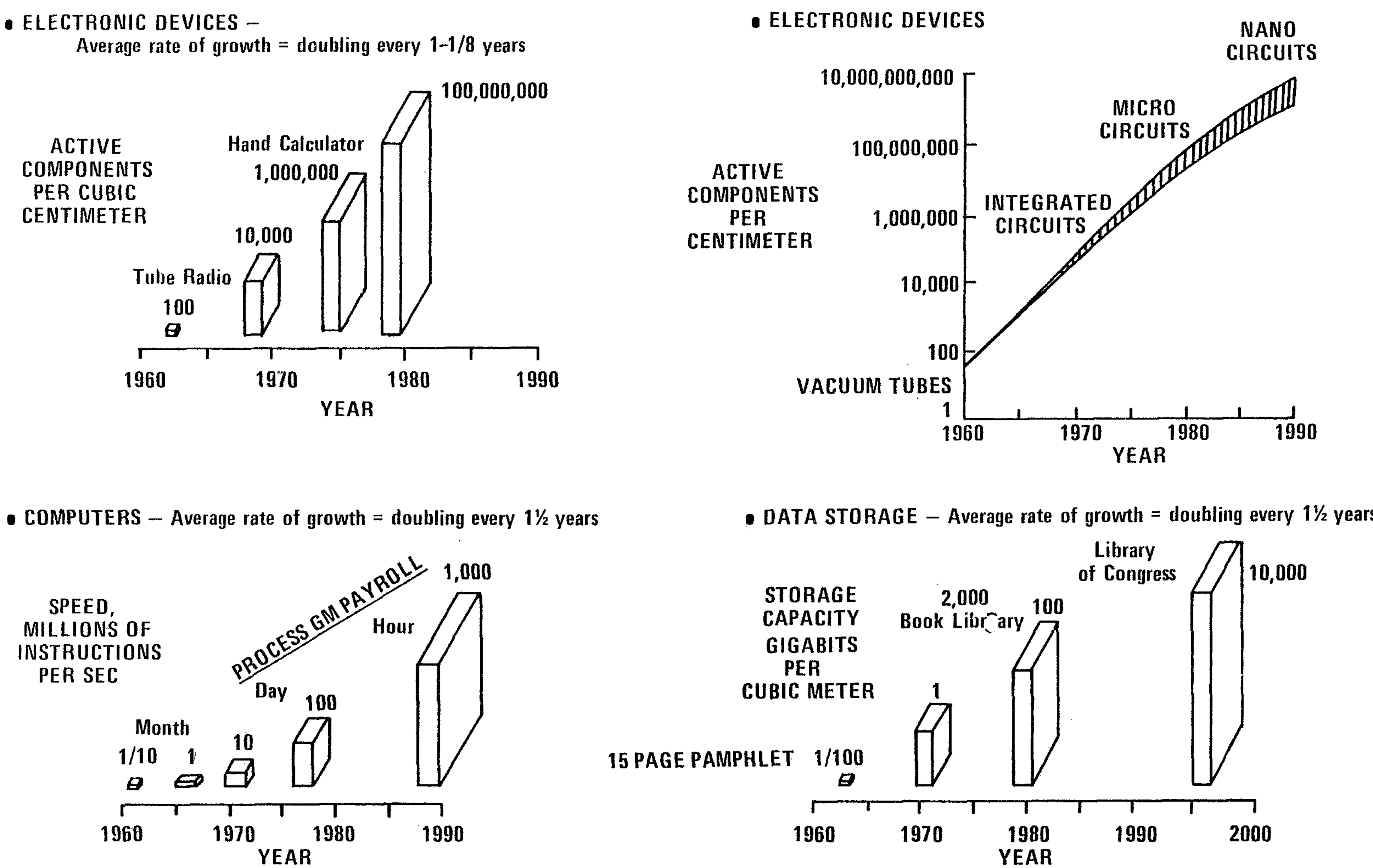


Figure 1. Basic Technology Growth

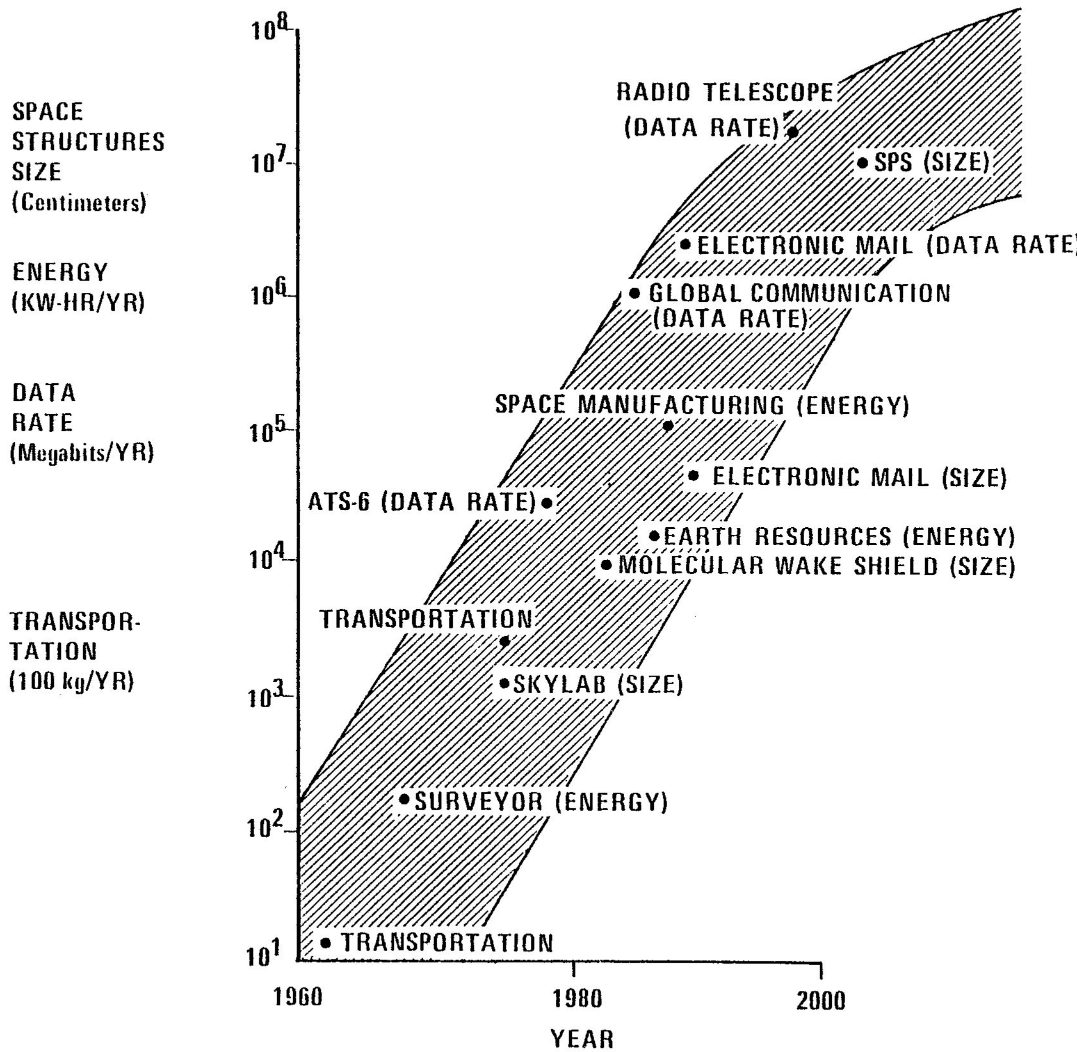


Figure 2. The R&T Challenge

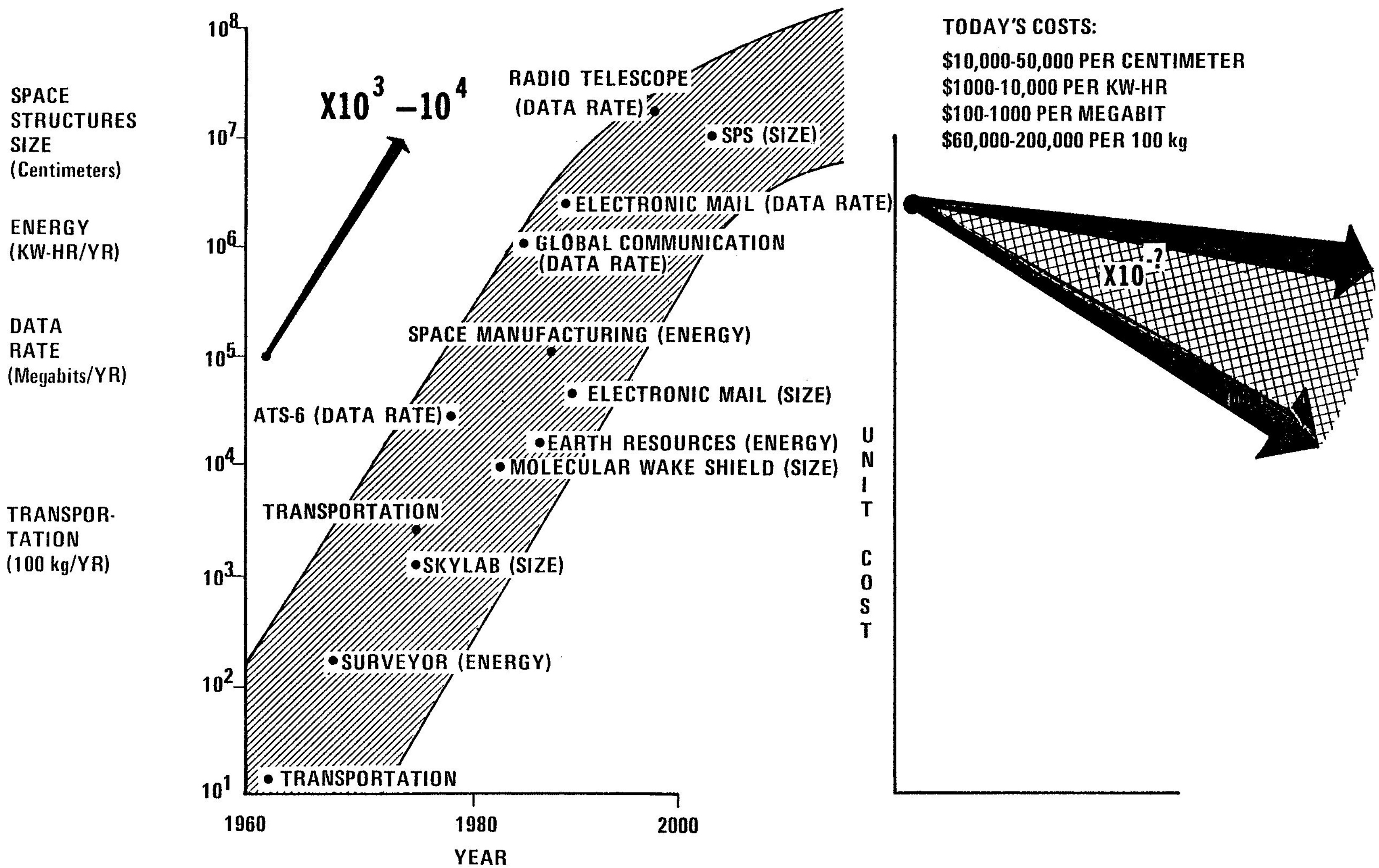


Figure 3. The R&T Challenge and Opportunity

VOLUME I: NEAR-TERM MISSIONS

EXPLORATION OF THE UNIVERSE

1. SOLAR MESOSPHERE EXPLORER (1981)
2. BIOMEDICAL SPACELAB EXPERIMENTS FACILITY (1981-83)
3. GALILEO–JUPITER ORBITER/PROBE (1982)
4. SOLAR POLAR MISSION (1983)
5. VENUS ORBITAL IMAGING RADAR (1983)
6. SPACELAB MULTIUSER INSTRUMENT PROGRAM (1983-84)
7. BIOMATERIALS PROCESSING LABORATORY (1983-84)
8. GAMMA RAY OBSERVATORY (1984)
9. SYNOPTIC TROPOSPHERE AND TERRASPACE ENVIRONMENT SATELLITE (1984-85)
10. COMET RENDEZVOUS (1985)
11. ORIGIN OF PLASMAS IN THE EARTH'S NEIGHBORHOOD (1986)
12. SOLAR PROBE (1986)
13. ADVANCED X-RAY ASTROPHYSICAL FACILITY (1986)
14. X-RAY OBSERVATORY (1986)
15. COSMIC BACKGROUND EXPLORER (1986)
16. SATURN ORBITER DUAL PROBE (1987)
17. COSMIC RAY OBSERVATORY (1987)
18. PINHOLE SATELLITE (1987)
19. MARS SAMPLE RETURN PROGRAM (1988)
20. LARGE AREA MODULAR ARRAY (1988)
21. AUTOMATED MOBILE LUNAR SURFACE SURVEY (1988-89)
22. EXTREME ULTRAVIOLET EXPLORER (1988-90)

Figure 4. OAST Space Systems Technology Model

VOLUME I: NEAR-TERM MISSIONS (CONT.)

GLOBAL SERVICES

23. SEASAT FOLLOW-ON (1982)
24. ENVIRONMENTAL MONITORING SATELLITE (1982-83)
25. GEODETIC SURVEY SATELLITE (1984)
26. TIROS-O (1984)
27. SOIL MOISTURE SATELLITE (1985)
28. STORMSAT-A (1985)
29. GLOBAL COMMUNICATIONS LAND MOBILE SERVICES (1986)
30. PUBLIC SERVICES COMMUNICATIONS SATELLITE (1986)
31. GEOSTATIONARY PLATFORM (1987-88)

UTILIZATION OF THE SPACE ENVIRONMENT

32. ADVANCED SPACELAB PROCESSING PAYLOADS (1982-83)
33. TELEOPERATOR ORBITER BAY EXPERIMENT (1983)
34. MOLECULAR WAKE SHIELD (1984)
35. SPACE MANUFACTURING MODULE (1984-85)
36. SPACE HEALTH CARE PROGRAM (1986)
37. LARGE POWER MODULE (1986-88)

SPACE TRANSPORTATION SYSTEMS

38. SPIN-STABILIZED UPPER STAGE (1984)
39. SOLAR ELECTRIC PROPULSION STAGE (1985)
40. ORBITAL TRANSFER VEHICLE (1988)

Figure 4 (Cont.). OAST Space Systems Technology Model

VOLUME II: FAR-TERM MISSIONS

EXPLORATION OF THE UNIVERSE

1. LARGE EARTH ORBITAL SOLAR OBSERVATORY (1992-95)
2. ASTROPHYSICS SPACE LABORATORY (1992-95)
3. ATMOSPHERIC PHYSICS LABORATORY (1993-95)
4. SPACE-BASED RADIO TELESCOPES (19[illegible]-2000)
5. AUTOMATED PLANETARY STATION (2000-2000+)

GLOBAL SERVICES

6. GLOBAL COMMUNICATIONS SYSTEM (1987-89)
7. GLOBAL CROP INVENTORY AND PRODUCTION FORECASTING SYSTEM (1987-89)
8. HIGH-RESOLUTION SEA SURVEY SYSTEM (1987-89)
9. DISASTER WARNING SYSTEM (1988-90)
10. EARTH ENERGY BUDGET MONITORING SYSTEM (1989-91)
11. LARGE-SCALE ALL WEATHER SURVEY SYSTEM (1993-96)
12. GEOLOGICAL MAPPING SYSTEM (1993-96)
13. GLOBAL NAVIGATION SYSTEM (1995-97)
14. SATELLITE POWER SYSTEM (2000–2000+)

UTILIZATION OF THE SPACE ENVIRONMENT

15. AUTOMATED PRECURSOR PROCESSOR (1990-92)
16. NUCLEAR WASTE DISPOSAL SYSTEM (1995-97)
17. TELEOPERATOR VEHICLE SYSTEM (1995-97)
18. LUNAR BASE AND AUTOMATED PRECURSOR SYSTEMS (1995–2000+)
19. SPACE STATION (2000–2000+)

SPACE TRANSPORTATION SYSTEMS

20. PRIORITY ORBITAL TRANSFER VEHICLE (1990-92)
21. CARGO ORBITAL TRANSFER VEHICLE (1990-92)
22. HIGH ENERGY ORBITAL TRANSFER VEHICLE (1991-93)
23. PRIORITY LAUNCH VEHICLE (1990-92)
24. HEAVY-LIFT LAUNCH VEHICLE (1995-2000)

Figure 5. OAST Space Systems Technology Model

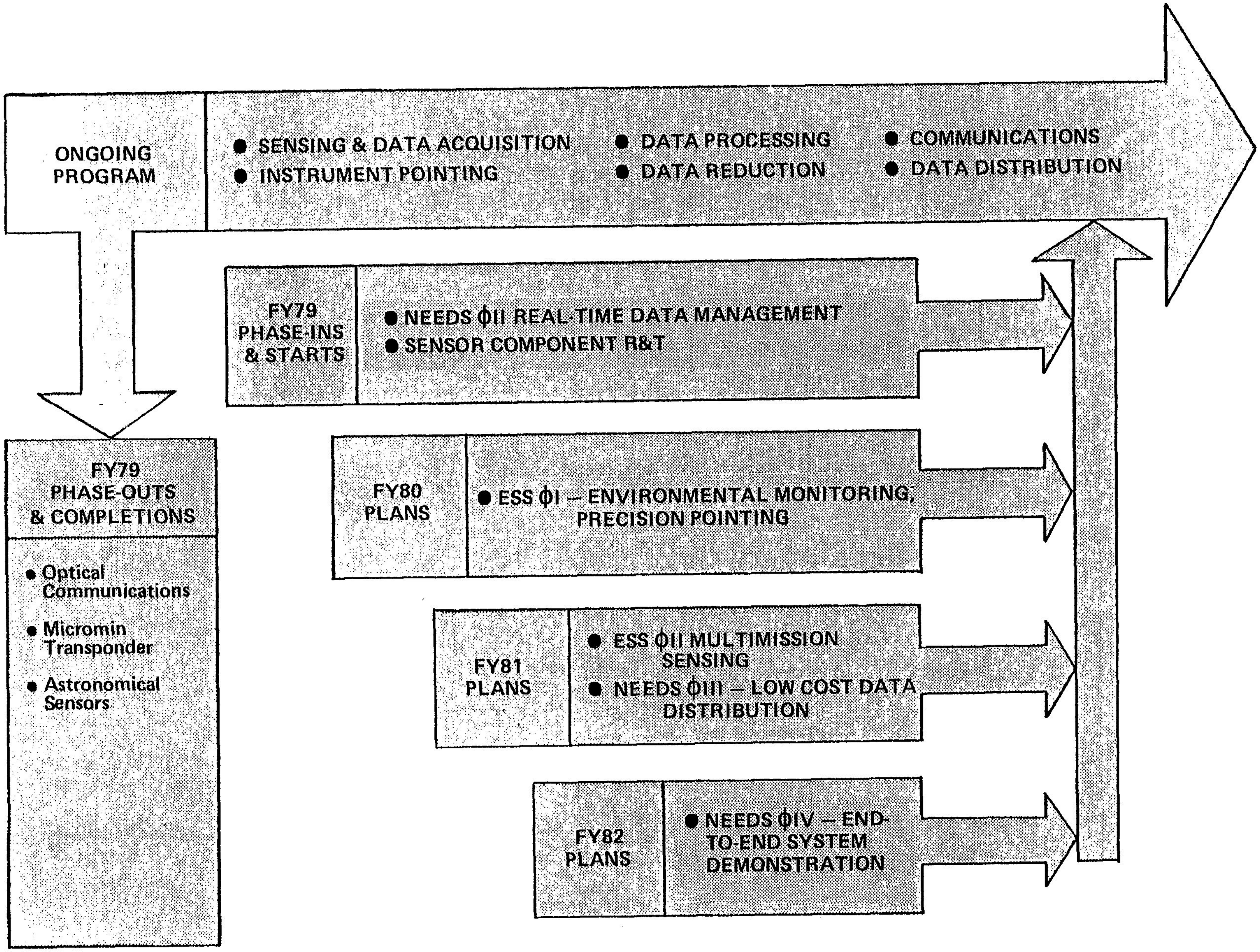


Figure 6. Information Systems Technology — 5 Year Plan

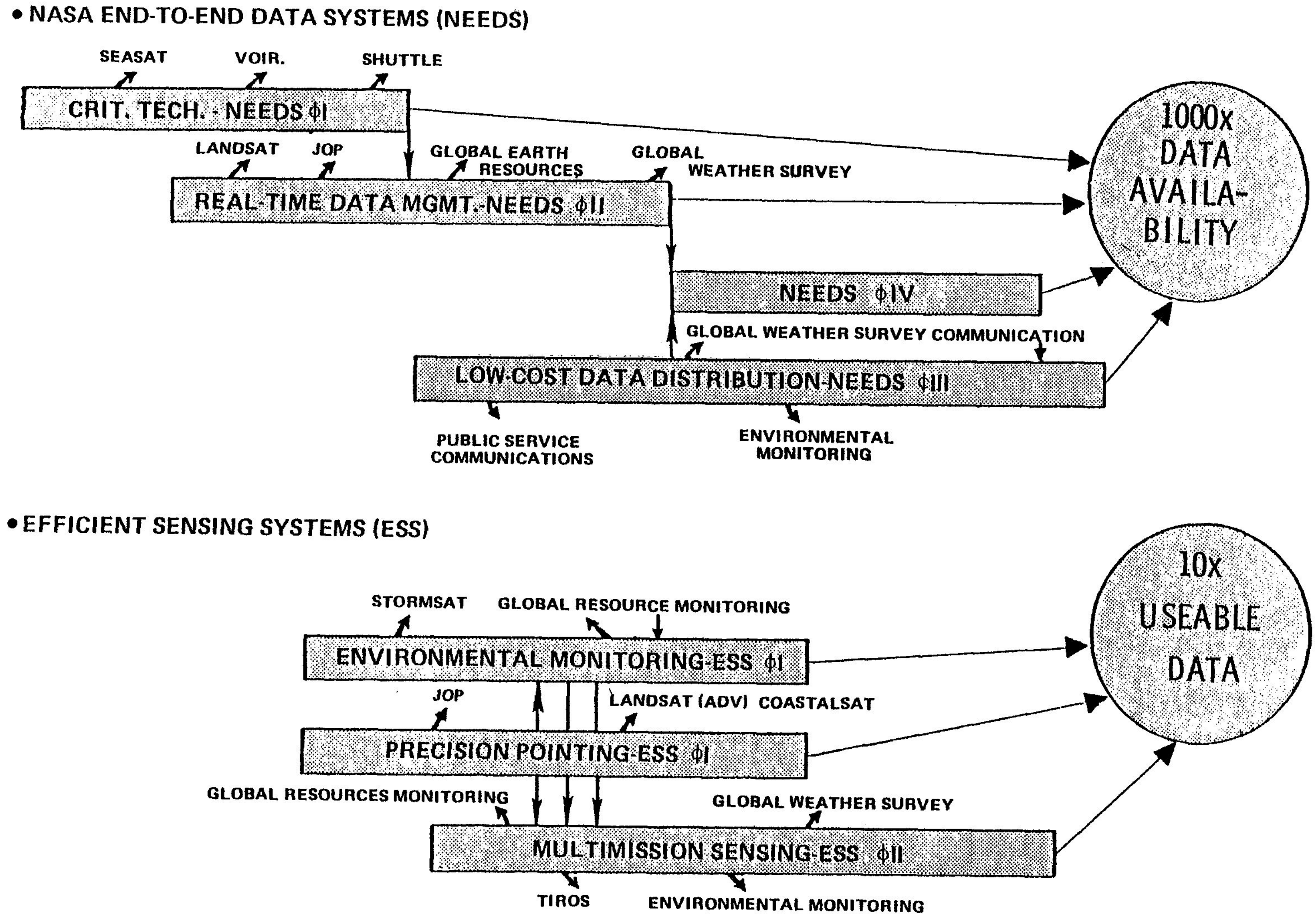


Figure 7. Information Systems Technology

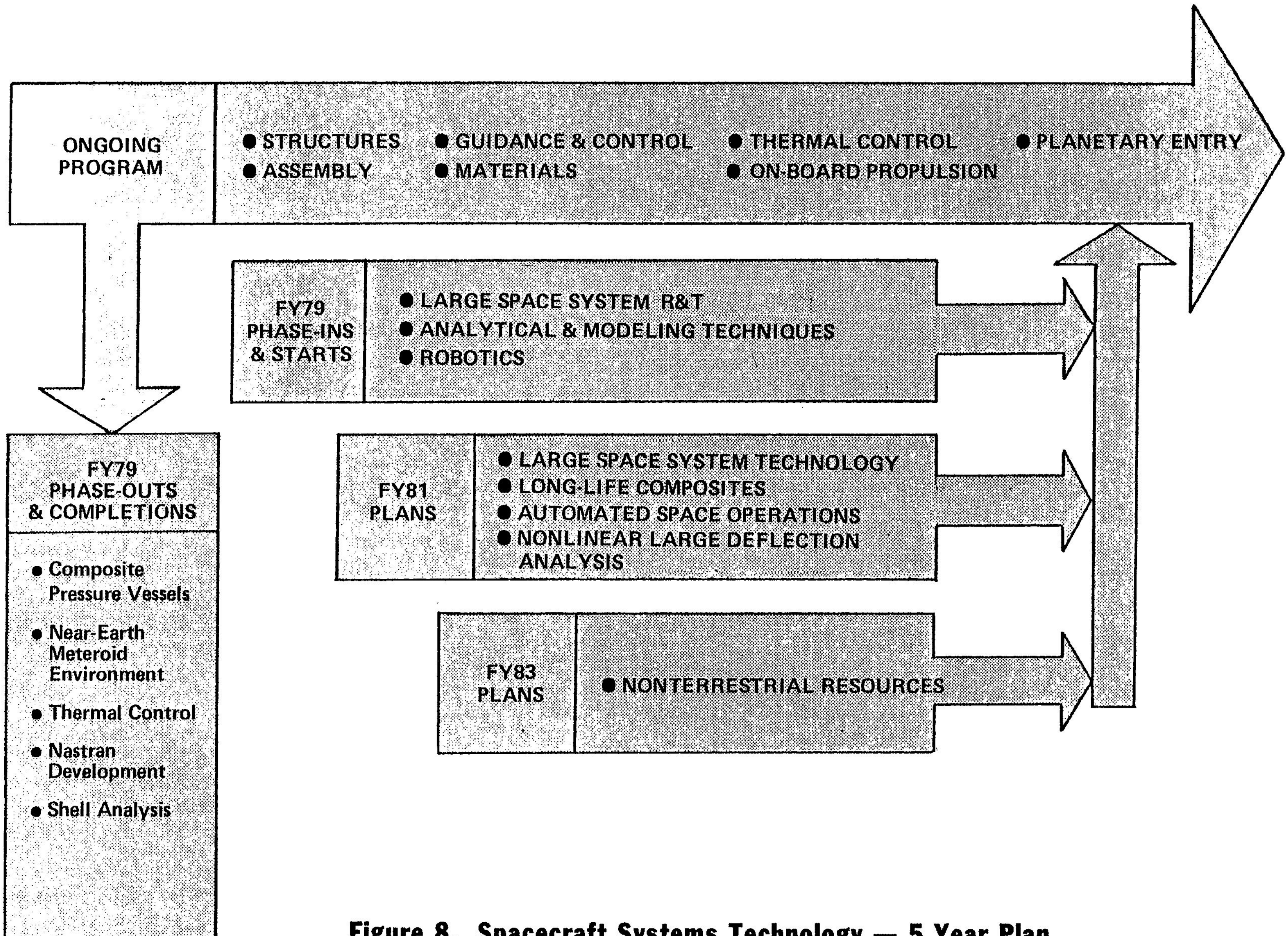


Figure 8. Spacecraft Systems Technology — 5 Year Plan

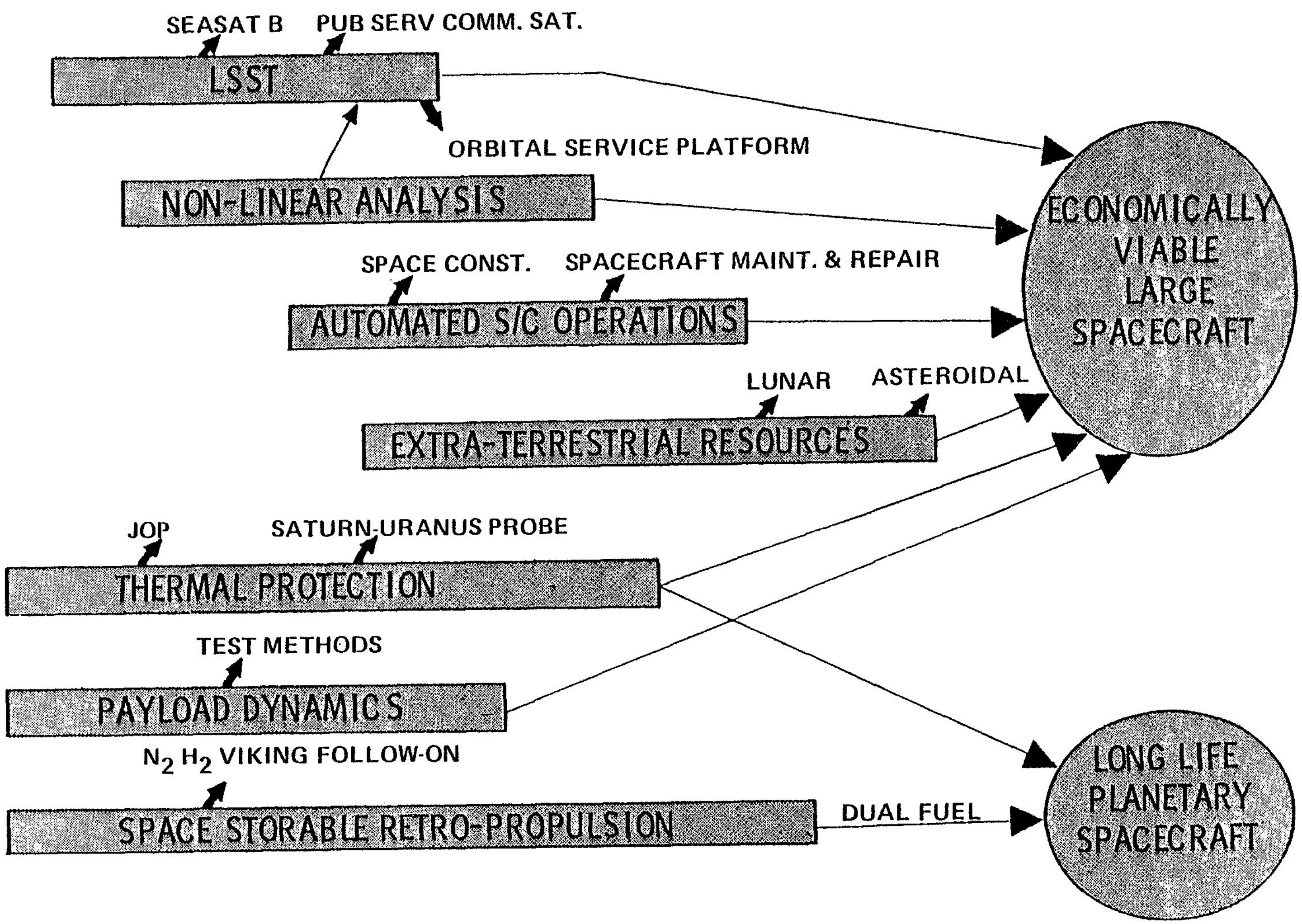


Figure 9. Technology for Spacecraft Systems

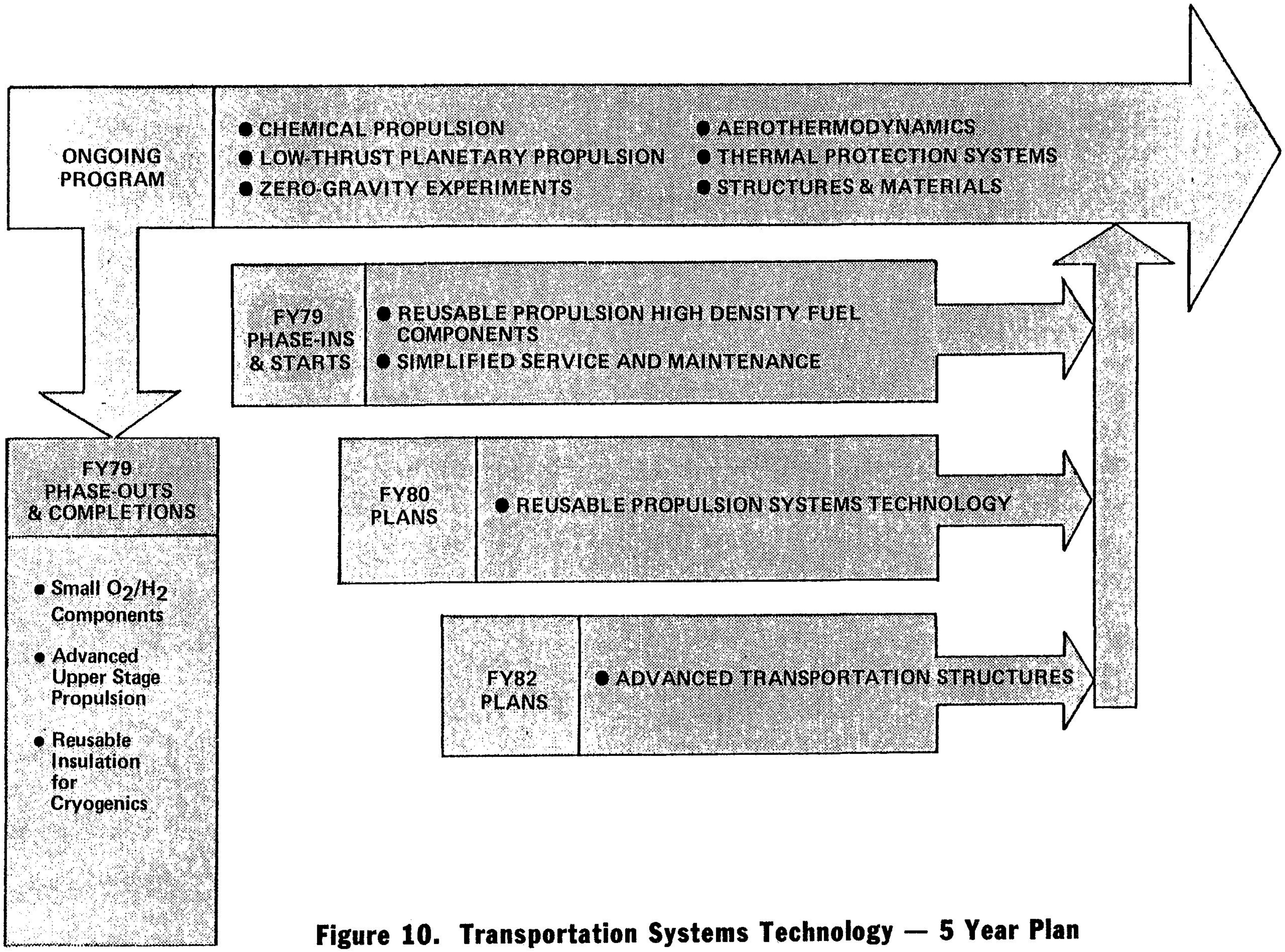


Figure 10. Transportation Systems Technology — 5 Year Plan

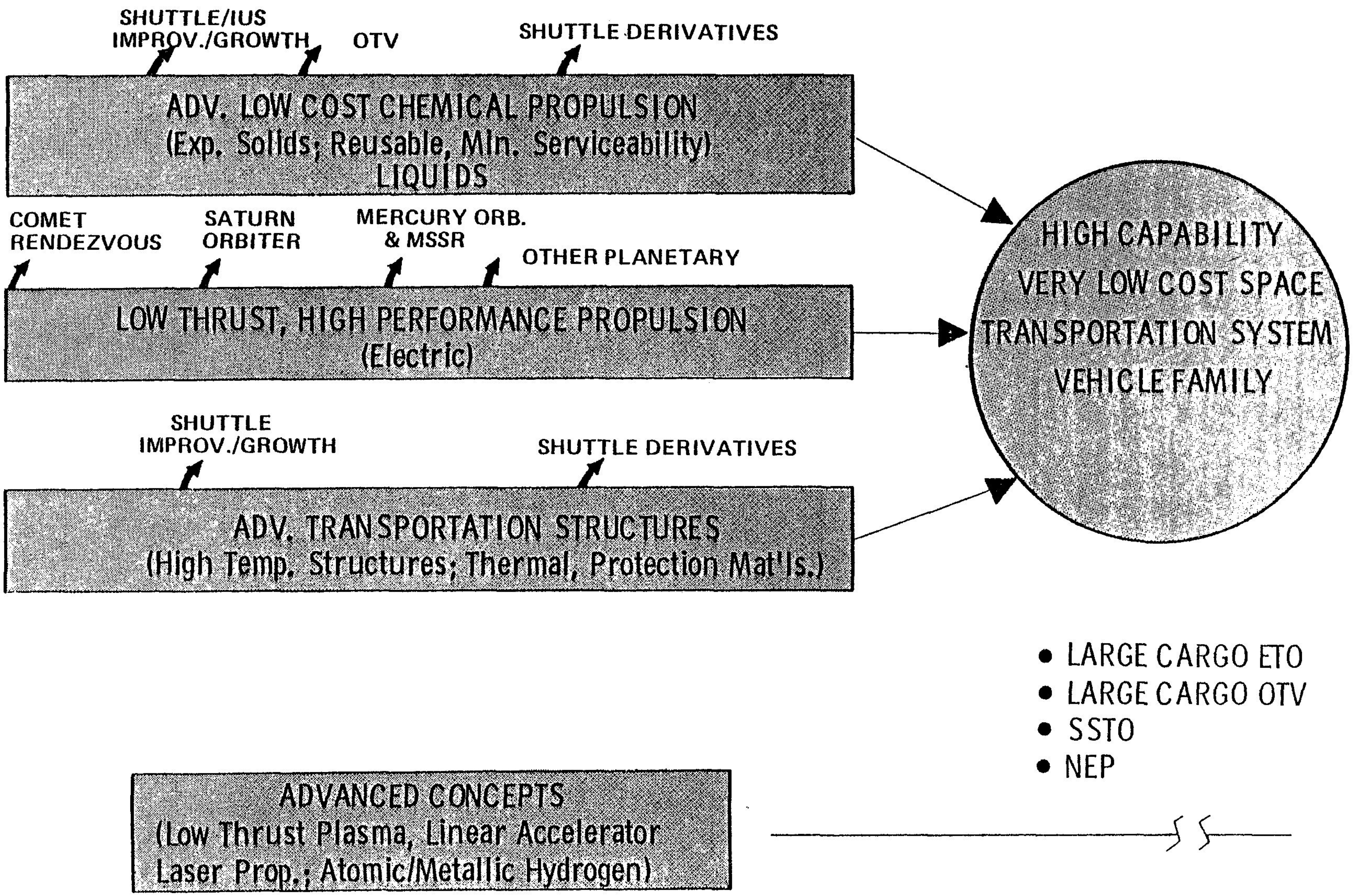


Figure 11. Transportation Systems Technology

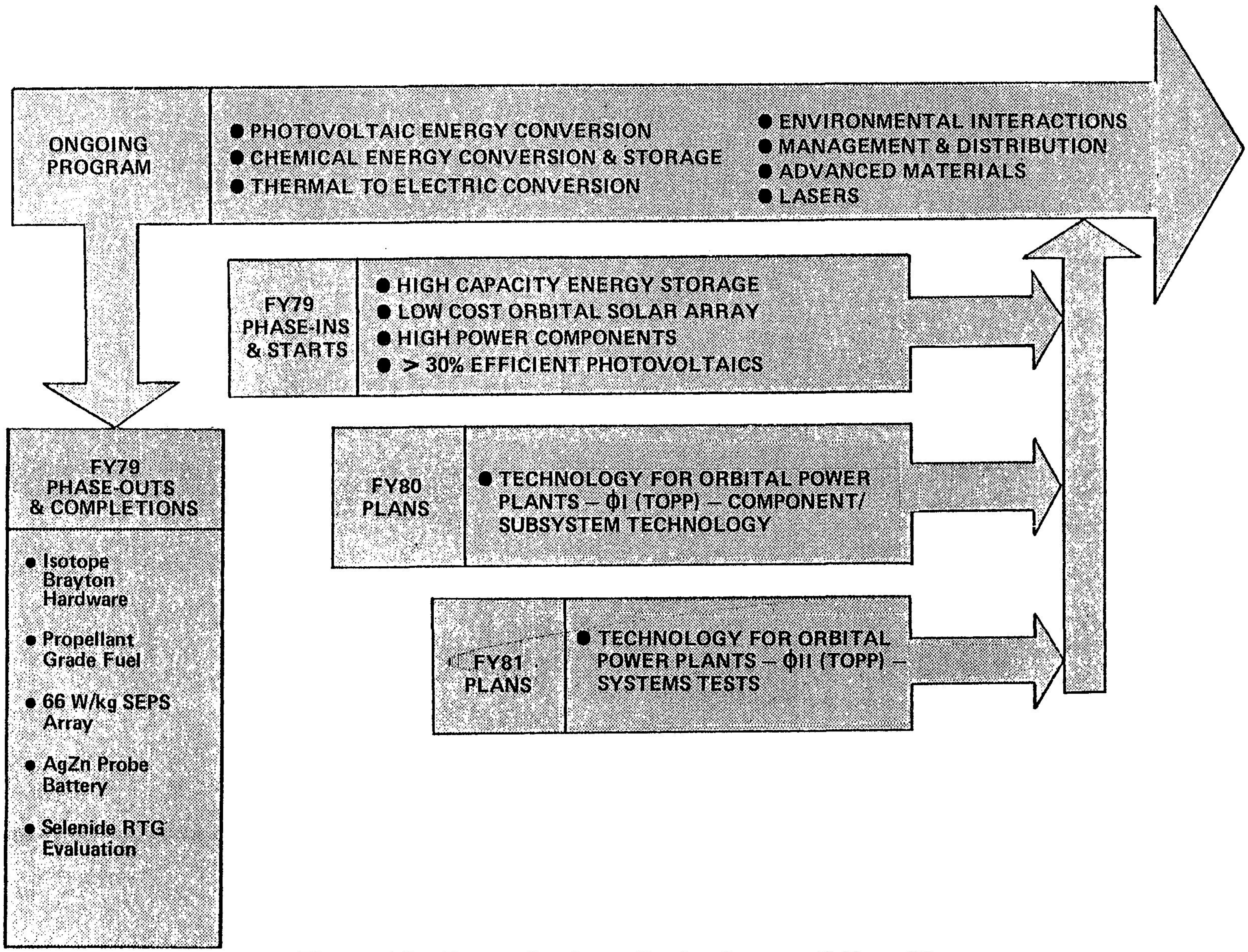
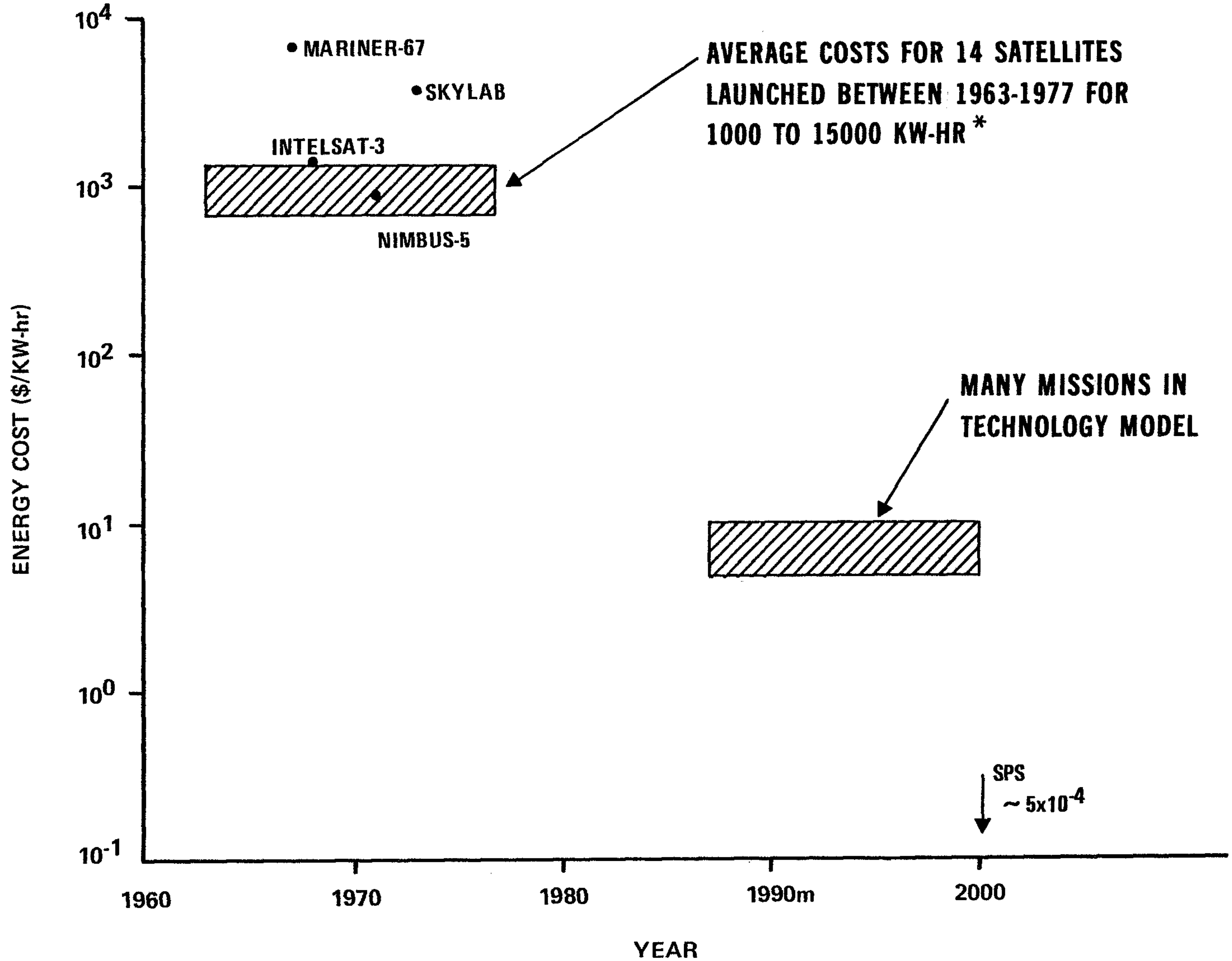


Figure 12. Power Systems Technology — 5 Year Plan



*AEROSPACE, ADVANCED SPACE POWER REQUIREMENTS REPORT

Figure 13. Space Power Costs

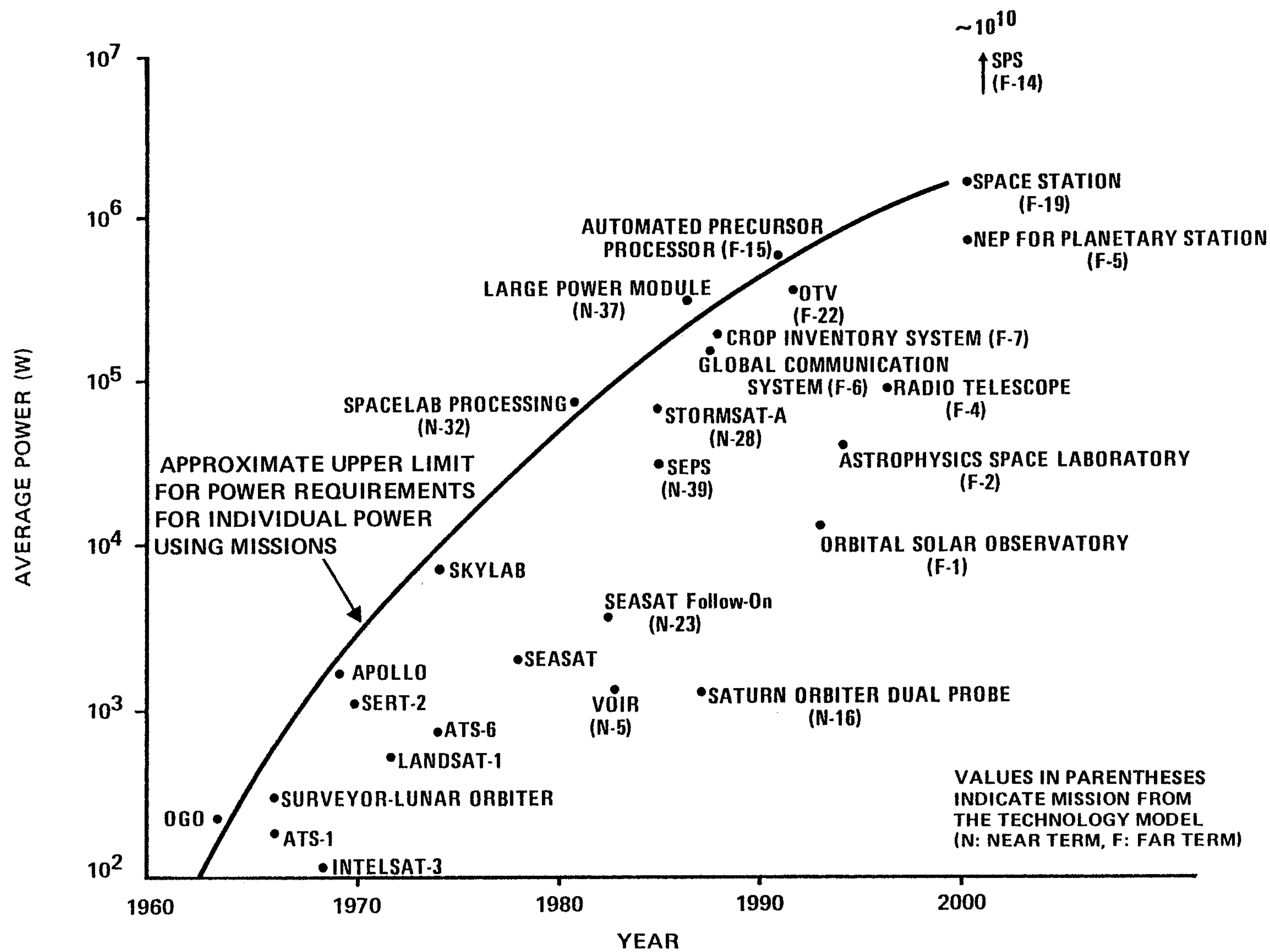


Figure 14. Mission Power Requirements

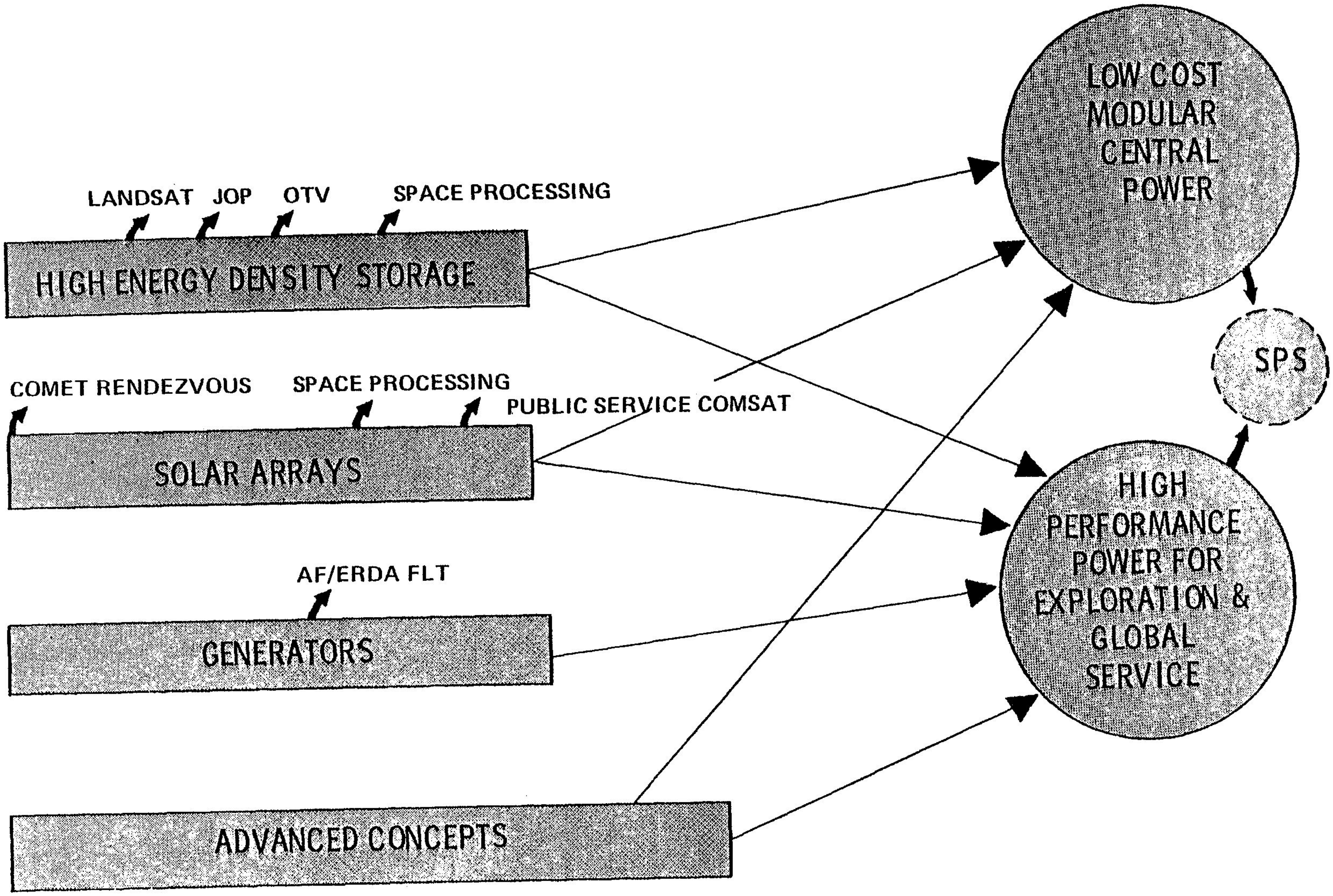


Figure 15. Power Systems Technology