POWER REQUIREMENTS OF THE NASA SPACE PROGRAM

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ABSTRACT

Power requirements of the NASA space program through 1965 are discussed. Both auxiliary power and propulsive power missions are described. It is shown that auxiliary power requirements have been below 300 watts and that power levels of 30 kilowatts and above are under consideration for propulsion purposes.

The National Aeronautics and Space Administration is conducting a wide variety of space missions as part of the national effort in space exploration. Figure 1 indicates the average power requirements for missions planned during the next five years based on a recent revision of data previously discussed in reference 1. These data indicate the highest foreseeable auxiliary power requirements in any given year for non-military spacecraft. I should point out that NASA plans to launch a total of 260 space vehicles during the next decade and that there will be many vehicles flown in each year with power needs lower than the maximum values indicated in this figure. As is shown here, nearly all of the vehicles which are scheduled through 1963 will require average auxiliary power levels below about 250 electrical watts. The Scout and Delta vehicles will need

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less than 10 watts. An average power drain of about 20 watts is typical of the Pioneer V space probe and the Tiros satellites. You will recall that the Pioneer V satellite, which was launched on March 11, 1960, was able to transmit valuable information on particle energies and magnetic field phenomena in interplanetary space for distances up to 22 million miles. This was accomplished with a transmitter operating at only 5 watts. The Tiros weather satellite, which has provided much information on cloud cover to our Weather Bureau aimed at understanding the nature of weather problems, was operated at 19 watts and had a capacity for operating a total of three months.

The follow-on meteorological satellite, Nimbus, is estimated to require an average power of about 250 watts and will be equipped, in addition to TV camera systems, with infrared sensors to measure radiation from the earth in selected spectral regions. The one-man Mercury capsule, which will be tested in a ballistic trajectory later this year, will carry about 144 pounds of silver zinc batteries to provide an average power of 70 watts while in orbit, with a reserve for emergency power lasting 24 hours. The peak power demand will be about 1 kilowatt. Beginning in about 1965, the Saturn booster will be used to launch the Apollo spacecraft, which will be developed for the manned lunar circumnavigation mission. It is estimated that the average power level required will be 1.2 kilowatts for 14 days or a total of 400 kilowatt hours. A peak power demand of 4 kilowatts is estimated. Also, in the mid-1960's the Saturn may be used to establish an orbiting astronomical observatory in support of the manned flight program. The observatory is expected to require an average power of about 350 watts with a peak power of 400 to 500 watts. Evaluation of the various methods that are possible to achieve these requirements is now underway.

For the Venus probe planned in 1962, it is anticipated that an average power of about 400 watts will be required to be provided again by solar cells with a zinc silver-oxide battery as a backup. The size of the battery is undetermined at this time since this will depend upon the experiments to be performed and the spacecraft configuration. The power will be required for about 100 days.

I would now like to discuss in greater detail the requirements of a few of these missions that have been mentioned. The first of these is the lunar hard landing mission called Project Ranger. Ranger consists of a number of shots of Atlas Agena B's to the moon. The first two will be lunar fly-by's. The primary mission of these first two Ranger spacecrafts is twofold. They will establish the technical feasibility of the Ranger spacecraft and its components, including attitude control, gyros, etc. Their secondary objective is to carry out a set of scientific and engineering experiments. The third Ranger spacecraft, which is planned for launching in 1962, will direct a payload to the surface of the moon. The Jet Propulsion Laboratory and Aeronutronics Division of Ford Motor Company are responsible for development of the Ranger spacecraft. The first Ranger will contain two solar panels, each 10 square feet. They will provide a total of 140 unregulated watts. Eight and a half watts will be required for 7 scientific experiments. The balance will be required for use during propulsion, including communications power conversion, attitude control, engineering telemetry, command decoding, and controller and timing. It will contain 25 pounds of silver zinc batteries which can operate 45 hours as an emergency package. The Ranger lunar impact vehicle will also use the 140 watts solar supply and the same backup during a three-day period of transit from Earth to the moon. This Ranger spacecraft will contain an 11 pound package capable of furnishing .2 watts for experiments on the moon during a period of three months. These will be batteries. The solar cells which I have described are the common but improved silicon cells which have been discussed earlier in the conference.

Under ideal conditions, silicon cells will provide one kilowatt per 20 pounds of weight at 10% efficiency at an irradiance of 1.4 kilowatt per square meter. The availability of solar energy with distance from Earth has been given in reference 2, and is shown in Figure 2. It is shown that solar cells on a mission to Venus would be more efficient than to Mars. Under practical conditions, only a fraction of the theoretical power available is realized. We find that each solar cell unit of one to two square centimeters generally produces about 0.02 watt. This output will decrease with increasing temperature since the cell output is sensitive to temperature. It is also obvious that solar cells are large and require heavy supporting structure. As a result of these factors, practical solar cells weigh several hundred pounds per kilowatt. Another disadvantage to the silicon cells is their cost. Since silicon cells must be large there is a particular penalty in using them in low-Earth orbits due to aerodynamic drag. It has been determined that a satellite in a near-earth orbit must have an additional 100 miles altitude to compensate for aerodynamic drags to achieve satellite lifetimes that equal those having other power supplies.

Nickel-cadmium batteries are generally considered to have a storage capacity of between 12 to 20 watt hours per pound. When subjected to a repeated charge-discharge cycle, degenerative changes occur in the electrodes which eventually cause failure. Earth satellites, which are intended to circle the Earth for a year, will require as many as 6000 charge-discharge cycles. One answer to this recycling problem is the use of the nickel-cadmium batteries at less than their full capacity to prevent deterioration. Thus, we find that we must discharge the cells to only 10 per cent of capacity or about 1.2 - 2.0 watt hours per pound.

Because of these limitations, for long-lived systems there has been considerable interest in developing alternative power sources. Two of them, which are considered to be most promising, are fuel cells and nuclear isotope systems. The hydrogen-oxygen fuel cell has a theoretical output of about 1620 watt hours per pound of reactants. At a nominal 60 per cent conversion efficiency, the fuel consumption is only 1 pound per kilowatt hour. It is not feasible to provide estimated weights for fuel cells until research and development can provide an indication of electrode life at reasonable current drain and until methods have been worked out for the separation and removal of the reaction products, while, at the same time, avoiding mixing the gaseous fuels into the electrolyte under zero gravity conditions. This is being studied at present and it may be possible to provide some estimates soon.

Another promising auxiliary power source for moon missions in the Surveyor program, is the nuclear isotope thermoelectric system which has been brought to a high degree of development by the Atomic Energy Commission. The Surveyor is the name given to the spacecraft to be launched in the Centaur vehicle starting in 1963. It will land an instrumented payload softly on the moon. Design studies of the Surveyor spacecraft are underway in four laboratories - North American Aviation, Hughes, Space Technology Laboratories, and the team of McDonnel-Collins. It is hoped to select a design contractor early next year.

Figure 3 shows very preliminary power estimates for this soft lunar landing mission. As you can see, some of the experiments that have been suggested for this mission involve radiation measurements, lunar material sampling, TV scan, seismic data measurement, magnetic fields, etc. The NASA has asked the Atomic Energy Commission to determine the feasibility of developing and using a 15 watt radioisotope unit for this purpose.

During the 66 hour flight from Earth, approximately 100 watt average power would be needed with a peak of 150 watts allowed for a mid course maneuver requiring five minutes of peak power. Just prior to landing, a terminal maneuver lasting five minutes at 300 watts power is provided for auxiliaries to assist in achieving the desired soft landing. After landing an average power of about 15-25 watts may be required during the lunar day to conduct the various experiments and about 7-10 watts of average power will be required during the lunar night. The TV scan may use 100 watts for about an hour. There may be intermittent drilling of a hole on the lunar surface at 200 watts for one hour. Material analysis will consume approximately 100 watts of power for an hour. Scientific data transmission will require an hour's power at 75 watts. A continuous supply of 5 watts will be needed for the operation of the particle detector, magnetometer, seismometer and other scientific instruments.

We are also studying the requirements of the Prospector spacecraft which will be launched by the Saturn vehicle. Among other items, it may place a vehicle on the lunar surface to explore the moon over a 50 mile radius. One mission profile which has been considered assumes a system weight of 130 watt hours per pound for a hydrogen-oxygen fuel cell. For this case, a 200 pound source will be required and will be capable of moving a 1000-pound vehicle for 50 miles. Obviously radioisotope power supplies may be preferable. It is expected that the experiments for Prospector and their power requirements will be similar in nature to those described for Surveyor but will be performed over a much larger area of the lunar surface.

Although military communications systems may require power levels in the multi-kilowatt range, NASA requirements for powers above the kilowatt range involve primarily propulsive power or combinations of propulsive and communications power. In this connection, the solar-heated Sunflower I 3 ekw power supply is being developed by the NASA. The Sunflower I is expected to provide the electrical power for a 1 KW arc jet which is now being developed for use in satellite orbit control and stabilization. In this power range, it appears that solar energy systems will be lighter than reactor systems.

In addition, the NASA is also supporting the development of a 30 kilowatt arc jet engine at AVCO and General Electric Company and a 30 kilowatt ion engine at Hughes Aircraft which would be used with SNAP-8 electric power generating systems.

The SNAP-8 system is being developed jointly by the NASA and the AEC with the conversion equipment being developed under NASA contract at Aerojet-General Corporation and the reactor at Atomics International under AEC contract. In this system, a sodium-potassium (NaK) eutectic is heated in the reactor. This heat is then used to vaporize a mercury working fluid. The mercury drives the turbogenerator system and necessary pumps. The system is designed to deliver 30 kilowatts of electrical power and with two of these mercury vapor conversion systems operating from a single reactor, is intended to deliver 60 kilowatts of electrical power.

Figure 4 indicates the estimated payload capability of the SNAP-8 system in a space probe to Mars. It assumes that a 9000 pound spacecraft has been placed in a near Earth orbit. The 60 ekw SNAP-8 system can deliver about 6000 pounds to Mars for a trip time lasting about a year. The instrument package alone for this mission will exceed 3000 pounds. By comparison, it is seen that the all-chemical system is marginal or unacceptable for sophisticated missions requiring large payloads at interplanetary distances. On the basis of present schedules, flight testing of the nuclear electric SNAP-8 propulsion system may be possible in 1965.

With reference to systems of higher power than the SNAP-8, it is emphasized that the requirement for light weight requires the accumulation of fundamental information that is not now available. We must develop the state-of-the-art well beyond what is now available in order to achieve the light weight, high temperature, long life Rankine cycle nuclear reactor electric generating systems that are required for high energy space exploration missions. Such missions will require power supplies of 1 mwe or more.

In summary, a variety of missions, their power requirements, and how they have been or will be met have been described. It is shown that non-propulsive power demands have thus far been relatively modest, and that propulsive power requirements are likely to increase as sophisticated missions to interplanetary space requiring large payloads are planned.

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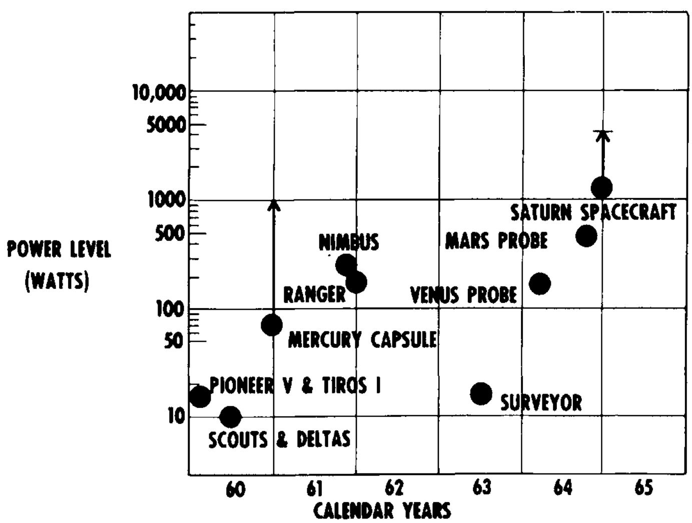

Figure 1. Estimated Electric Power Requirements

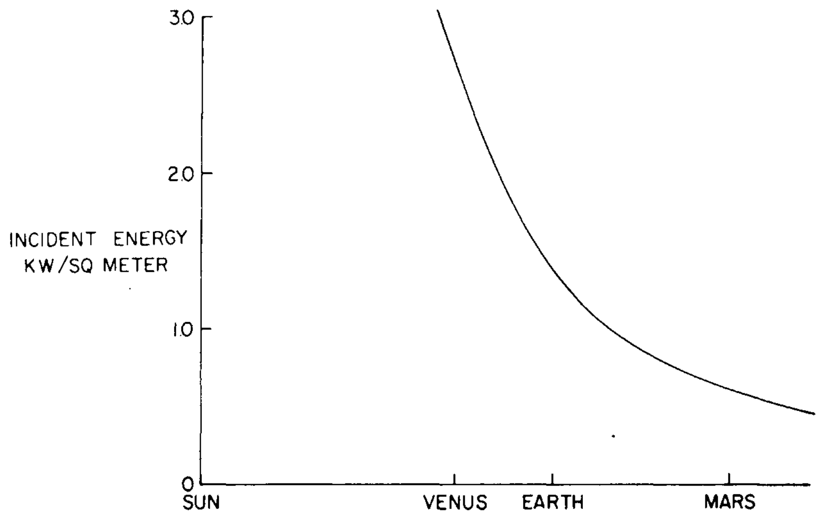

Figure 2. Solar Energy Available

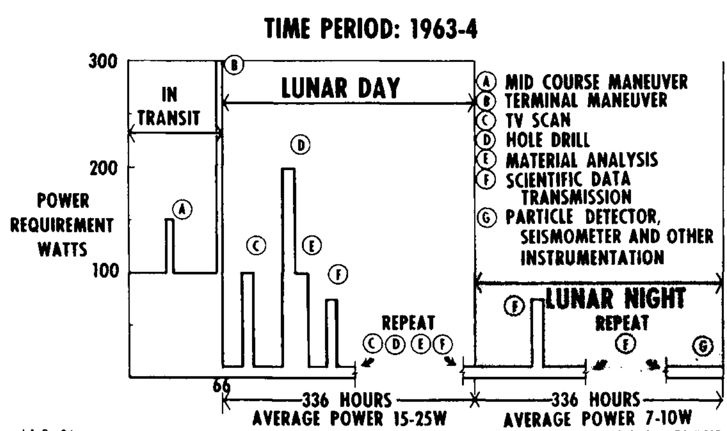

Figure 3. Power Estimates, Soft Lunar Landing Mission

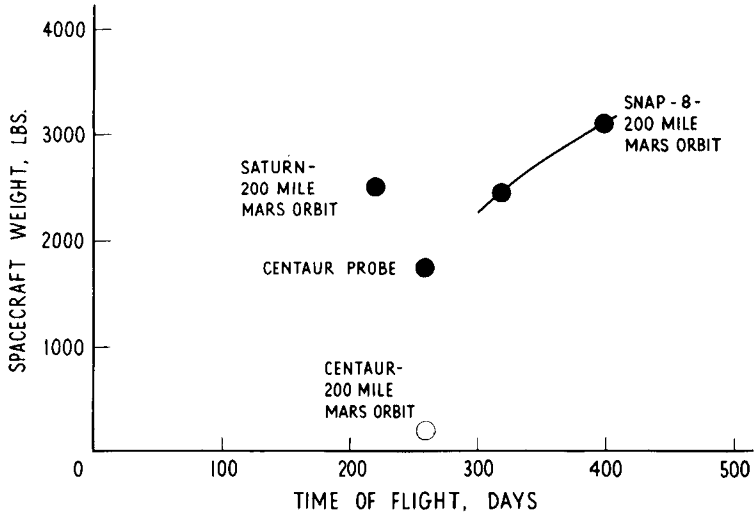

Figure 4. Mars Mission