FLIGHT VEHICLE POWER FORECASTS

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ABSTRACT

Requirements for flight vehicle power dominantly for space applications have been forecasted for time references of 1962 and 1966. These forecasts have been synthesized and categorized for portrayal on charts. The charts are described and their differences, as a function of time, are pointed out. Similarly, forecasts of optimum application of energy conversion methods are presented and described. Comment is offered on the more significant problems and intriguing aspects of certain specific energy conversion methods. A comparison of the two charts for 1966 is made.

Flight vehicle power is all power necessary to operate any vehicle in flight excluding the primary propulsion but including the power required for electric propulsion and for extraterrestrial stations and sites. The flight vehicle power technical area encompasses energy source technology, dynamic and static energy conversion, electrical, hydraulic, and pneumatic power transmission, component integration, and compatibility with utilization equipment. The flight vehicle power technical area is relatively broad and virtually all phases of aerospace missions will depend upon an adequate and reliable supply of power. In particular, many space missions will be critically dependent upon an adequate and reliable supply of power. The magnitude of conceptual space activity is immense and the perimeter of knowledge that exists relative to this activity and to the solution of problems is infinitesimal though ever increasing. Within the total complex presented above, it is extremely difficult to present future requirements for flight vehicle power in all its aspects and in a clear, concise manner. The following, therefore, has been chosen as a fundamental, though somewhat over simplified approach.

Flight vehicle concepts for application to future aerospace missions have evolved in many forms. One of the better foundations for future requirements for flight vehicle power can be formulated from these concepts; forecasts of power requirements can be derived from them and for distinct time periods these can be synthesized into general vehicle categories.

Figure 1 is a synthesis of forecasts of 1962 requirements for flight vehicle power. The ordinate of the figure is kilowatts of power required to the load; the abscissa is the duration of that power. The reference time, 1962, is that time when technology must be available to permit commitment to a specific vehicle. The actual acquisition of an operational vehicle through the phases of design, subsystem integration, development, fabrication and test would thus be at a time many years beyond the reference time.

The power requirements are forecasted for six bounded areas representing general vehicle categories:

Short duration power measured in seconds and minutes with levels up to close to the highest for this time period will be required by boosters.

Power within a narrow, high level range for durations between an hour and a day will be required by boost glide and glide re-entry vehicles and also by unmanned air vehicles.

A rather wide range of power requirements for modest power levels at durations near one day to a wide range of power requirements up to moderate power levels for durations exceeding two years will be required by earth satellites.

Lunar vehicle power requirements extend from moderate power levels for durations in the neighborhood of one week to low power levels for durations of months.

For interplanetary vehicles for this time reference the power requirements are modest in level but of long duration.

Figure 2 presents a synthesis of forecasts of 1966 requirements for flight vehicle power. This figure, in comparison with the previous one, illustrates the growth in power requirements for the four year period between 1962 and 1966.

The power requirements for boosters increase in level of power but not in duration.

A new category of vehicles, recoverable boosters, enters with a narrow range of power requirements at a relatively high level for durations of minutes.

Boost glide and glide re-entry requirements have expanded around their 1962 area.

Under the influence of increased vehicle speed, unmanned air vehicle requirements tend to extend to lower durations and at the same time have increased significantly in power level.

The power requirements for earth satellites have an increase of slightly less than an order of magnitude in power level.

Lunar vehicles have an expansion in their power requirements to higher levels, particularly for the durations of the order of months.

A second new area of power requirements appearing in 1966 is that for lunar and space stations. These have high power level requirements and durations extending from the neighborhood of one week to close to one year.

Interplanetary vehicle requirements remain at durations measured in years, while increasing by several orders of magnitude.

The boundaries presented on these figures should be viewed as being capable of appropriate stretching as specific circumstances demand, rather than being inflexible. The power levels and durations within the areas of these figures can be subject to considerable adjustment as new technology is acquired and breakthroughs occur as a result of applied research effort. Further, factors and inter-actions are accounted for in the sophistication of vehicle and power subsystem detailed design that cannot be accounted for in these forecasts.

Extrapolation of technological trends into the future and predictions of future technical capabilities form the basis for the flight vehicle concepts categorized in Figures 1 and 2. Figure 3 illustrates an example of the results of such extrapolations and predictions. This figure presents a synthesis of forecasts of 1962 areas of optimum application of energy conversion methods. As was the case for the previous figures, the ordinate is kilowatts of power required to the load and the abscissa is the duration of that power. The referenced time, 1962, is that time when the status of energy conversion technology will permit its commitment to a power subsystem for a specific vehicle. The actual acquisition of an operational subsystem through the phases of detail design, system integration, development, fabrication and test would thus be at a time several years later than the reference time. Factors such as current technical status, potential for improvement, weight, availability, installation problems, reliability, and costs were considered in the synthesis which defines the areas for the energy conversion methods covered. This figure has been based upon the flight vehicle power technical area applied research program. Significant portions of this program will be reviewed in consonance with this figure.

Primary batteries are and will continue to provide optimal power at low levels and short durations. For this reason and also because improvements have a direct and most advantageous payoff for both primary power and secondary batteries for electrical storage, applied research in the battery area deserves emphasis. Improvements in watt hours output per pound of battery and in depth of discharge and cyclical life of secondary batteries must be sought. As the electrical storage means for photovoltaic power subsystems, the battery has significant influence on these subsystems; this point will be re-emphasized later in connection with the photovoltaic conversion area.

Chemical dynamic subsystems have an extensive range of application and potential. Applied research in the chemical dynamic area must have the goals of reduced subsystem specific weight (including fuel) and increased duration. These goals may be restated as increased component efficiency and durability, reduced specific fuel consumption, and increased life from minutes and hours to days and weeks. A most intriguing aspect of the chemical dynamic area is the potential of the cryogenic (liquid hydrogen and oxygen fueled) dynamic power subsystem. This subsystem has great promise for moderate to high power requirements for durations up to several days and in its ability to be integrated with an environmental control subsystem has a great advantage over other power subsystems in certain important applications.

Fuel cells have a high theoretical efficiency and, therefore, have the potential to furnish the longest duration of any conversion method using chemical energy sources. They have the further advantage of converting chemical fuel directly to electrical power. Fuel cells are judged to be optimal for flight vehicle durations from one day up to a few weeks for powers up to moderate levels. If this judgment is to be correct, however, there are significant problems to be solved in the fuel cell area. As applied research has been accomplished the initial optimism concerning fuel cells has been reduced due to lack of ready success and the arising of new problems. Electrode problems, operation in the environment of space, the sophistication of a fuel cell subsystem, and regenerative processes require aggressive technical effort and large step increases in technology.

The importance and influence of photovoltaic power subsystems today is well known. Batteries and photo cells have been the outstanding energy conversion methods used for satellites to date. Photovoltaic power subsystems give promise of dominance of the long duration power picture up to modest power levels by virtue of the record they are establishing. Progress being made through applied research to increase photo cell efficiency, reduce cell costs, provide protective coatings, provide solar concentrators, and in orienting arrays of cells will add to the utility of photovoltaic power subsystems. As has been mentioned, the battery as electrical storage, has a significant influence on photovoltaic power subsystems. Battery improvements to reduce required battery storage weight must be made and must parallel photo cell efficiency improvement if the investment in the latter is to prove to be worthwhile.

Thermoelectric and thermionic conversion devices have the presumed natural reliability advantage of static conversion devices in combination with fair efficiency levels (with thermionic devices having the theoretically higher but yet unproven level) and a lighter weight than photovoltaic power subsystems. Thus it is forecasted that these devices will find optimum application in the intermediate power range above photovoltaic power levels for long durations. However, vigorous applied research efforts must be devoted to the area if it is not to be overrun by the improvements and background of experience in photovoltaic subsystems on one side and to such intriguing developments in the solar dynamic area as the NASA Sunflower program and the Air Force Stirling Engine program on the other side. In particular, the problems that today confront thermionic converters must be solved in a reasonable time period or the optimism held forth for thermionic conversion will have been misleading.

Initial development in solar dynamic power subsystems will find optimum application for the area shown on the figure. Approximately this same area will be sustained in time against the competition of nuclear dynamic subsystems by the acquisition of technology associated with improved solar collectors, advanced working fluids (such as rubidium), thermal storage and improved radiators. The problems of immediate importance in the solar dynamic area are those related to heat transfer in a zero gravity environment. The continuing zero gravity experimentation being carried out by the Air Force in C-131 and KC-135 aircraft must be extended through space flight experimentation with the first solar dynamic demonstration unit.

This brief review of the predominant aspects of the flight vehicle power applied research program has, of necessity, excluded such intriguing new topics as photoemission and plasma generators and such important technological areas as power transmission and fluid power, all of which are influential in the total flight vehicle power picture. It has also neglected a very important nuclear energy conversion area which will now be brought into focus.

Figure 4 is a synthesis of forecasts for 1966 areas of optimum application of energy conversion methods. In comparison with the previous figure for 1962 it illustrates the changes anticipated to result from applied research effort. The appearance of the nuclear dynamic area in the high power, long duration region is the most noteworthy change. The changes in the chemical dynamic and fuel cell areas are also significant; that of the fuel cell at the present time being the most optimistic. For the area of high power nuclear dynamic energy conversion, a long lead time is necessary to acquire the technology for power subsystems using it. Problems associated with the use of advanced working fluids at high operating temperatures and refractory metal components need a long lead time in order to reach a timely solution. Experimentation, including space flights and actual use in a flight vehicle of the SNAP 2 power subsystem, is judged to be required to fill in very important gaps in the nuclear dynamic power subsystem technical area. Although the SNAP 2 power subsystem was not mentioned in connection with the Figures 3 and 4 because it is a special case, it must be pointed out that this power subsystem has been and will be in the future of great value in the nuclear dynamic power subsystem area.

In conclusion, a comparison of 1966 forecasts of requirements for flight vehicle power, Figure 2, with 1966 forecasts of optimum energy conversion methods, Figure 4, is interesting. The most significant feature is that for the exclusively space oriented halves of the figures (for the left hand portions of the figures) no single energy conversion method will exclusively fit any single vehicle category. This has intriguing implications in connection with power subsystem competition. It must be concluded that a comprehensive and aggressive applied research program that gives adequate emphasis to critical problems in all the energy conversion methods cited must be pursued to achieve the best aerospace vehicles in the future.

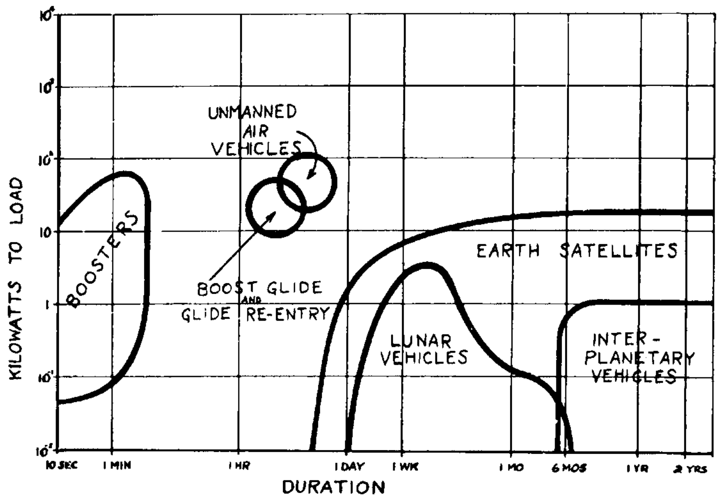

Fig. 1. Synthesis of Forecasts of 1962 Requirements for Flight Vehicle Power.

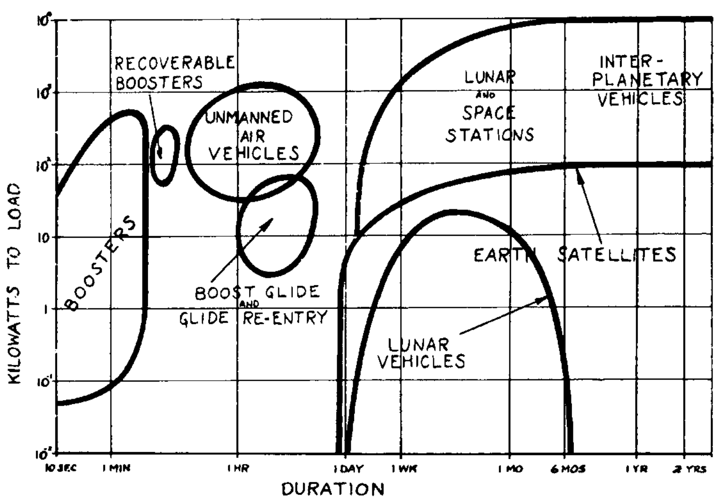

Fig. 2. Synthesis of Forecasts of 1966 Requirements for Flight Vehicle Power.

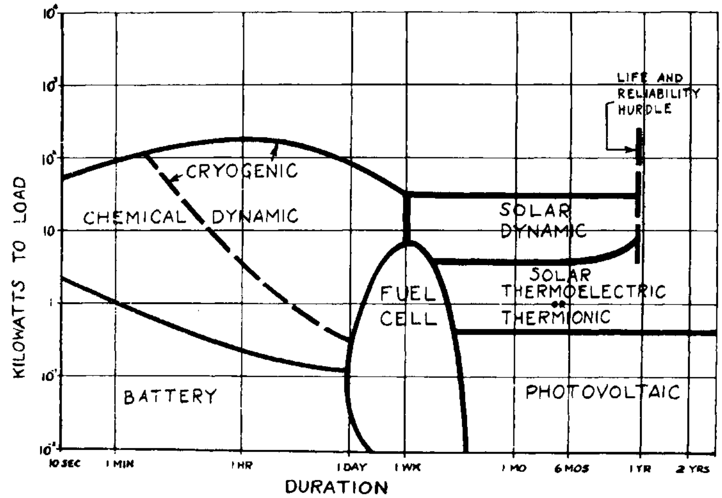

Fig. 3. Synthesis of Forecasts of 1962 Areas of Optimum Application of Energy Conversion Methods.

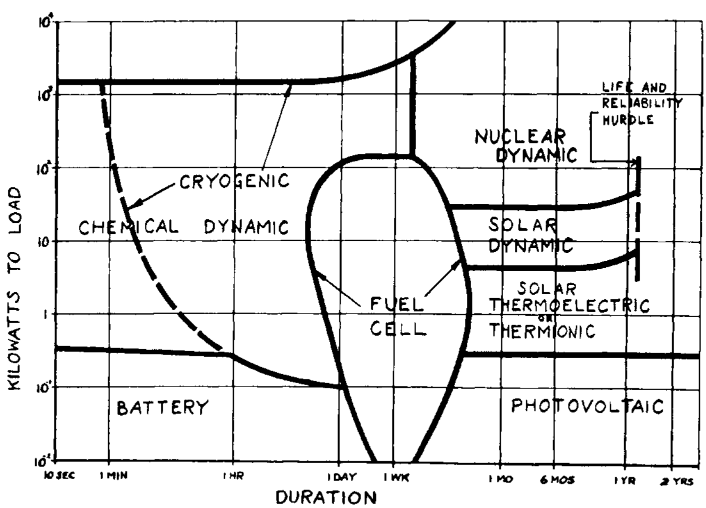

Fig. 4. Synthesis of Forecasts of 1966 Areas of Optimum Application of Energy Conversion Methods.