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ENGINEERING IN THE 21st CENTURY

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ENGINEERING IN THE 21st CENTURY

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Reasonable evolutionary trends in federal outlays for aerospace research and development predict a continuing decline in real resources (1970 dollars) until the mid eighties, and a growth thereafter to the 1970 level by 2000, still well below the 1966 peak. Employment levels will parallel this trend with no shortage of available personnel foreseen. These trends characterize a maturing industry. Shifts in outlook toward the economic use of resources, rather than "minimum risk at any cost," and toward missions aligned with societal needs and broad national goals will accompany these trends. These shifts in outlook will arise in part in academia, and will, in turn, influence engineering education. By 2000, space technology will have achieved major advances in the management of information, in space transportation, in space structures, and in energy. These advances will permit a variety of new or expanded services as well as enhanced capability for continued space operations. But the usefulness of these services and the extension of space exploration will absolutely require cost-effective systems. The economics of space systems must be the primary consideration if the space program foreseen for the 21st century is to become an actuality.

INTRODUCTION

To address the subject "Engineering in the 21st century" requires that we project iteratively both the availability of resources and the state-of-the-art that they will produce from now to then. For it seems clear that no matter how far-reaching our vision or how wide a horizon we see, what will be accomplished in the future United States space program will be paced by the resources committed to it. Also, the capabilities created by these resources will be different in kind and quality by the year 2000 than they are now.

This presentation will discuss the nature of the aerospace technology system that we might expect by the 21st century from a reasonable evolution of our resources and capabilities.

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RESOURCES

Resources can be projected as money or as manpower, although at root it is manpower and its productivity that one tries to measure. So we'll look at the likely future for aerospace employment. But we'll give particular attention to the changing job environment and to the future of aerospace education, because these qualitative factors may play a larger role in shaping the future than just numbers.

Aerospace Employment Outlook

The years 1977 and 1978 seem to be marking the beginning of a period of stability and moderate growth in the aerospace industry. For the first time in 5 years, the number of scientists and engineers engaged in aerospace related activities has increased. Aerospace research and development employment increased to 70,000 in 1977 and is now occupying a near-constant 18% share of the total R&D work force. It appears, however, that sustained inflation and economic pressures on the federal government will continue to limit the resources available to this industry.

In 1971 I observed that aerospace was becoming a mature industry and that future changes would be evolutionary, in that progress would be realized in in-

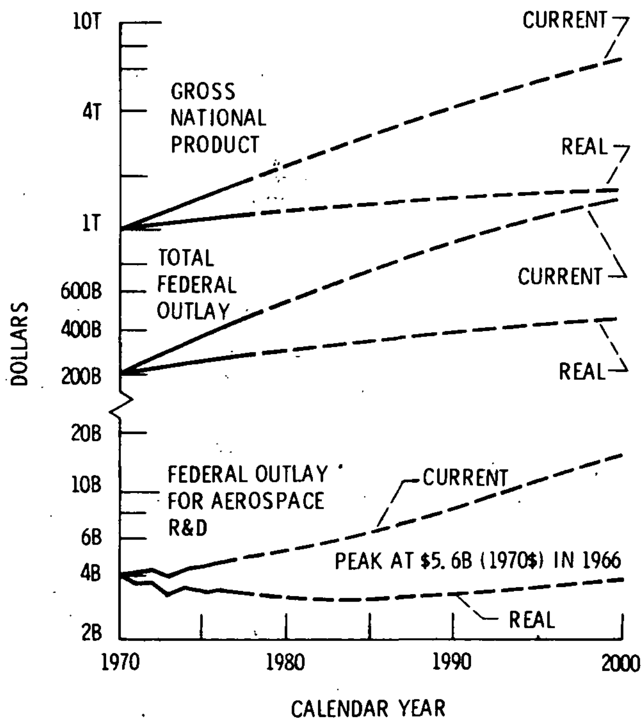

Fig. 1 Resources for Aerospace R&D (Refs. 2 and 3)(Real Values Are Given in 1970 dollars)

crements, not quantum jumps[1]. I still believe that, and, if anything, the conservative predictions I made in 1971 were not bearish enough. For example, the real decline of employment in the aerospace industry did not stop in the 1972-74 period as predicted, but instead seems to have now stopped in the 1976-78 period[2].

Figure 1 projects the gross national product, all federal outlays, and federal outlays for aerospace R&D. Except for periods of major conflict, the total federal outlay has been a relatively predictable fraction of the GNP (recently, around 22%). Assuming that wars or other federal acts of similar magnitude do not occur through 2000, the federal outlay may be predicted to grow moderately, in terms of 1970 dollars, from the $250 billion now to $360 billion by then. Federal outlays for aerospace R&D (NASA, DOD, and DOE) are also a predictable fraction of total federal outlays (2% in 1970 and 1.35% in 1975). It is estimated that this fraction will essentially approach a constant minimum value of 1.0% in the 1985-90 period. This estimate becomes the basis for the prediction of the real (1970 dollars) resources available for aerospace R&D shown in Fig. 1. Note that real (1970 dollars) resources will continue to decline until the mid eighties and will recover only to the 1970 level of $3.7 billion by 2000, still $2 billion below the 1966 peak. Aerospace resources are here tied to real GNP growth assumptions; however, real GNP growth can be greatly affected by the political outlook, international affairs, balance of trade, and other equally unpredictable factors.

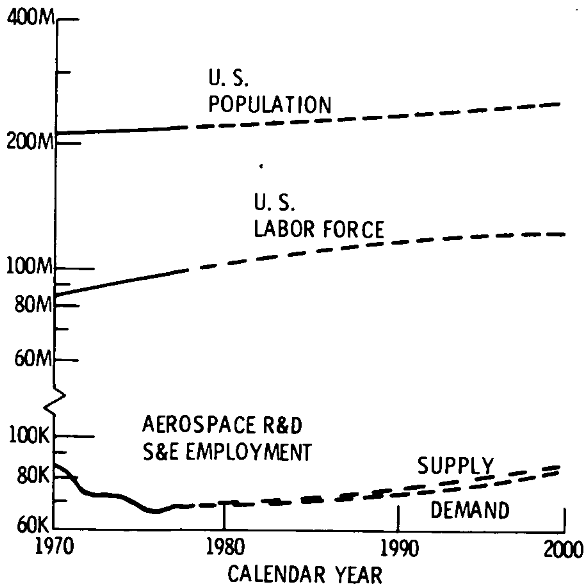

Fig. 2 Employment of Scientists and Engineers in Aerospace (Refs. 2 and 3). Peak S&E Employment of 101,000 occurred in 1968

Figure 2 is a projection of U. S. population and labor force through 2000. Science and engineering employment in aerospace R&D are shown at 0.067% of the projected labor force, a fraction that has been gradually approached since the high of the late sixties. Demand is shown as a function of the projected aerospace dollar resource from Fig. 1 and the actual aerospace R&D science and engineering employment level through 1977. The data that contribute to the employment demand projection show that there is a nearly constant $45,000 per employee fraction in the 1970-77 period (for 1970 dollars and aerospace R&D science and engineering employment figures).

This employment projection indicates a period of moderate growth starting in 1980, with a slight excess supply, and with a total employment by the year 2000 at the level of 1970. If this aerospace R&D science and engineering employment picture is a measure of total aerospace employment, then the indication is that employment levels by the year 2000 will still be below the 1966-67 level. Such a prediction underscores the evolutionary characteristic of a mature industry.

Figure 3 shows the average age of scientists and engineers within NASA since 1968. From 1968 to 1973, NASA reduced its staff by attrition, by reductions in force, and by new-employment freezes. The turnover thus achieved has not been sufficient to keep the mean length of experience from increasing, even though, currently, NASA is generally hiring recent college graduates to replace retirees. The data probably characterize the industry; in any case, NASA pro-

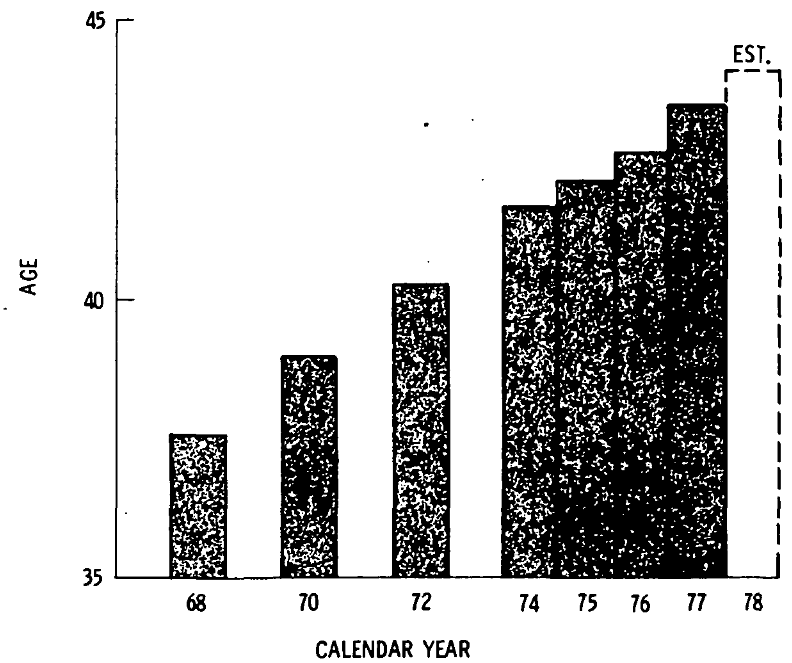

Fig. 3 Average Age of Scientists and Engineers within NASA (Ref. 4)

vides most of the leadership and direction to the space program. While levelling out will undoubtedly occur in the future, it is not apparent yet. One could whimsically conclude by these data that the average age of an aerospace scientist or engineer would be 65 by the year 2000!

The Changing Job Environment

The philosophical outlook on space projects has changed. A transition to "risk consonant with minimum cost" from the "minimum risk at any cost" approach of the sixties is apparent. Our industry, however, has not yet fully matured in this direction in that (1) it is still developing an awareness of "technology for economic gain" and (2) it is difficult to argue against the success produced by the Apollo approach; consequently, much of the space science and engineering workforce is not inclined to change.

There are other hazards in a diminished industry. For instance, the decline in the liquid chemical rocket market since the mid sixties indicates that the number of qualified industrial sources will drop from four to two by 1980. Of the remaining two, one will have 80% of the market by then. NASA is concerned that the number of competing sources is diminishing (and in some cases vanishing) and that this trend will have an unfavorable impact on the value of its future commitments with industry. A problem for NASA will be to maintain effectiveness from taxpayers' dollars under conditions that are conducive to inefficiency and loss.

Another hazard of diminished employment levels in any industry is the diminished inflow of original thought, ideas, and enthusiasm because of fewer bright people in the organization. The aerospace industry is particularly vulnerable to this hazard because it has traditionally attracted individuals who are schooled in conservatism, and through job experience tend to become more conservative.

The point of the foregoing is that many kinds of work environment changes that directly affect the aerospace scientist and engineer are appearing. This scientist or engineer will characteristically be more experienced in the eighties than he was in the sixties and he will continue to be somewhat reluctant to accept these changes because of the success of the sixties approach. Aerospace as a whole, and technologies in particular, will transcend these changes, develop effective methods of operating in an environment of change, and in some instances develop alternatives to the successful tradition of the sixties as NASA's mission continues to align with the national interest. Technologists will continue to devote an increasing work fraction, not to technology, but to the development of an awareness of their effectiveness to aerospace as a whole.

The Future of Aerospace Education

An initial observation is that less than 20% of current aerospace scientists and engineers were schooled in an aerospace department, so an assessment of aerospace education should really be an assessment of engineering education. Much has been and continues to be written and said about trends in engineering education[5-8]. From this continuing body of lore and from general observations both about the kinds of knowledge being acquired and about the changing nature of our society, some trends in engineering education can be predicted.

Traditionally, changes in style and content have come slowly in academia. But during the next decade large numbers of the older, tenured engineering faculty who were in place during the post-Sputnik boom will be replaced by a younger breed with a different outlook. So, to the extent that an institution expresses the sense of its faculty, change is coming.

One trend is toward a more interdisciplinary education. Most trend setters in engineering education recognize that the really challenging engineering problems are not just structural or electrical or chemical, but invariably require the judicious exercise of several disciplines for their solution. Moreover, the modern engineer increasingly finds that his technical accomplishment must fit into a social matrix if it is to succeed; and so he must deal with legal, medical, economic, social, and political issues and their specialists. Interdisciplinary degree programs, industrial internships, co-op programs, design-synthesis programs, even open universities and self-study programs reflect this trend.

The idea of life-long learning for a scientist or engineer simply to avoid technical obsolescence is well established. The increasing depth of technical subject matter will continue to motivate continuing education. But the desire for improved job mobility, career changes, and personal and professional development along the interdisciplinary lines just discussed will also motivate continuing education. These newer motivating factors are growing in importance and reflect cultural changes from a society mainly committed to producing goods to a society in which new aspirations, often vaguely put as "improved quality of life," are appearing. Continuing education will be provided by the traditional colleges and universities, but also increasingly by nontraditional opportunities such as company in-house courses, video-taped packages, professional society workshops and courses, and a host of self-study opportunities from publishers, libraries, television classes, etc.

Paralleling changes in institutional outlook, curricula, and opportunity will be changes in the student. Out of a decreasing number of persons of college age, a decreasing fraction has been electing engineering. Traditionally, the prospective engineering student has been a white, middle-class male who has completed a standard college preparatory program in high school wherein he excelled in mathematics and science. Many young people who might have fit that description have in recent years opted for programs and careers that they perceive as more people-oriented. As engineering education begins to be perceived as socially valuable in the contemporary context, many of these traditional students may return. Meanwhile, there are nontraditional sources for engineering students. Ethnic minorities comprise 14 or 15 percent of the U.S. population, but only 2.8 percent of all engineers[5]. Enrollments from these minorities are growing. The largest group under-represented in engineering is women, however. Women comprise about 10 percent of physical scientists, but less than one percent of the engineering profession[3]. Enrollments of women in engineering are up, but still small.

Concerning aerospace engineering education itself, a gradual upturn in its attractiveness to students is evident since the rapid decline of the early seventies[8]. The student notion of aerospace education as a tough curriculum, minimal reward, dismal employment outlook, method of indoctrination into the industrial-military establishment may be starting to fade. This upturn may in part be due to NASA's efforts to sell its fabulous story of accomplishment and to an increased awareness that aerospace technology can help solve great societal problems. Such awareness has been nurtured by the activities of people such as Gerry O'Neill of Princeton, who speaks of freeing earth's people from dependence on (and the consequence of utilization of) earth's resources by developing the nonterrestrial resources. While today's aerospace students may never realize this dream during their careers, it is nevertheless the kind of long-term goal that is attractive to young people. Meanwhile, NASA continues to push its efforts on communications, weather observation, survey and management of earth resources, power from sun or wind, and cleaner, quieter, and more fuel-efficient air transportation--all of which are socially oriented goals which require aerospace technology. As aerospace efforts continue to be conspicuously oriented towards societal need, aerospace education could, by the turn of the century, enjoy the social status it deserves.

SOME FUTURE TRENDS IN AEROSPACE TECHNOLOGY

By the year 2000 space technology will have achieved major advances in four areas: management of information, transportation, space structures, and energy. While these advances will have profound effects on what can be done in space, they can also be expected to have significant effect on many nonaerospace activities here on earth.

In the management of information, ultra-high-density mass-memory systems, developed principally by industry and largely without NASA support, will exist.

Such systems, capable of storing 10^{12} bits of information per cubic meter, will enable NASA to develop space-based end-to-end data management systems for automatic processing and control of information. Such sophistication in data management, coupled with more highly developed sensors and with microprocessors and teleoperators or robots, will create capabilities for future space missions that will be several orders of magnitude greater than present capabilities. Research at the frontiers of information and computer science will help create machines that not only store and use greater quantities of data, but will exercise logic that simulates the perceptive and cognitive functions of humans. Examples of such functions include extraction of information relevant to some purpose from a data stream, automated vision, decision-making on the basis of priorities, controlling parallel and interlinked operations, and even detecting and correcting malfunctions.

Figure 4 shows some of the possibilities from improved sensing and processing capability: advanced global communications, electronic mail, increased interstellar search range, personal communications, and performance of space tasks at remote distances, such as exploring planetary surfaces. These hardware capabilities will be matched by an increased need for them, particularly in the

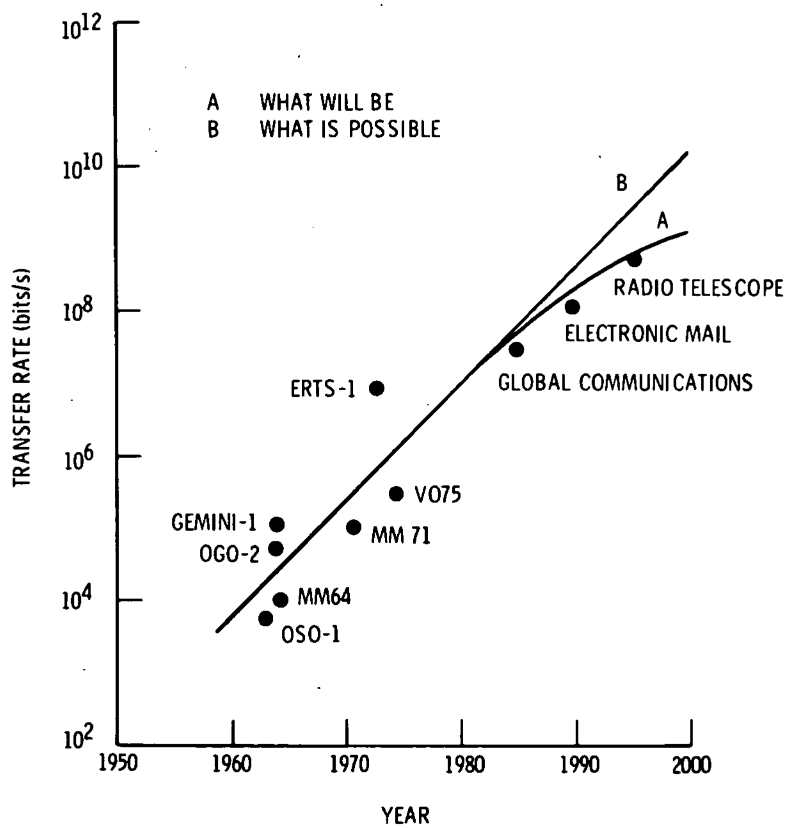

Fig. 4 Advances in Space Data Transfer Rate (Ref. 10)

areas of climate prediction and communications. Software advances, however, will have to accelerate commensurate with computer development. In particular, major advances in models and modelling techniques will be necessary if highly complex undertakings such as climate forecasting are to be successful.

These developments are in part for space purposes and in part for applications on earth. The proliferation of microprocessors, the growth of the teleoperator/robot industry and the dropping cost and increasing use of computers with more sophisticated logic and larger memory will have an enormous effect on terrestrial systems and services. Witness the availability of hand-held calculators with abilities beyond our computers of just a dozen years or so ago.

In transportation, considerable operating experience will have been accrued with the Space Shuttle. The synergistic effects of being able to launch large payloads that can be designed for minimum cost and high reliability will dramatically broaden the real uses of space. Earth-to-orbit transportation cost reductions will have been realized by a combination of increased earth-to-orbit traffic and new propulsion technology for reusable, minimum-maintenance systems. Orbit-to-orbit propulsion systems, capable of being refueled in space, will be operational, and the technology for producing and using propellants from nonterrestrial sources for these systems will be underway. Electric propulsion will have become an operational part of space transportation, first as propulsion for deep-space missions and auxiliary control of spacecraft and then, possibly, as primary orbit transfer propulsion. Electric propulsion technology will advance in the direction of low cost, light weight, and simplicity. The technology will provide a wide range of operating characteristics which will enable diverse applications.

Past the year 2000 our ability to conduct deep-space missions, such as manned exploration of planets, may be predicated on our ability to refuel transportation systems from terrestrially supplied depots or nonterrestrial propellant sources along the way. Figure 5 shows the performance of several propulsion systems, including a chemical propulsion system that is refueled at its destination for its return to earth. No projection is offered as to which alternative will materialize in the future, but it must be underscored that awareness of all options will become an increasingly vital part of technology planning and execution.

Figure 6 projects a growth in the size of space structures. In the next 20 years materials, processes, and deployment techniques will have been developed that will enable the placement and control of space platforms, antennas, and solar energy collectors, whose size may exceed an aggregate of 1 km. We have even ventured to put a space power system in Fig. 6 for reference. Advances will be marked more by the ability to assemble and control the shape and position of

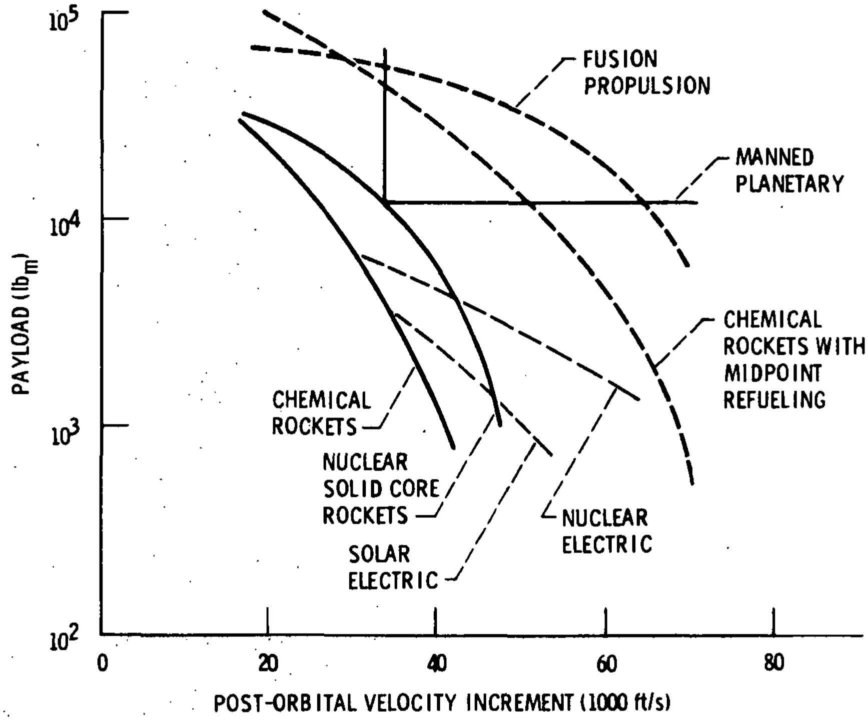

Fig. 5 Mission Performance Projections (with 4 Shuttle Launches; Ref. 10)

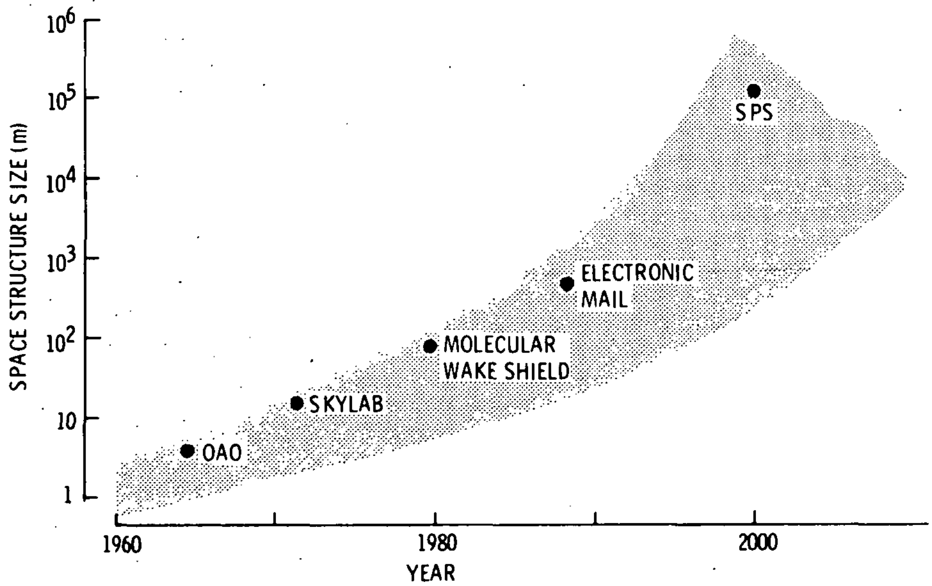

Fig. 6 Trends in Space Structure Sizes

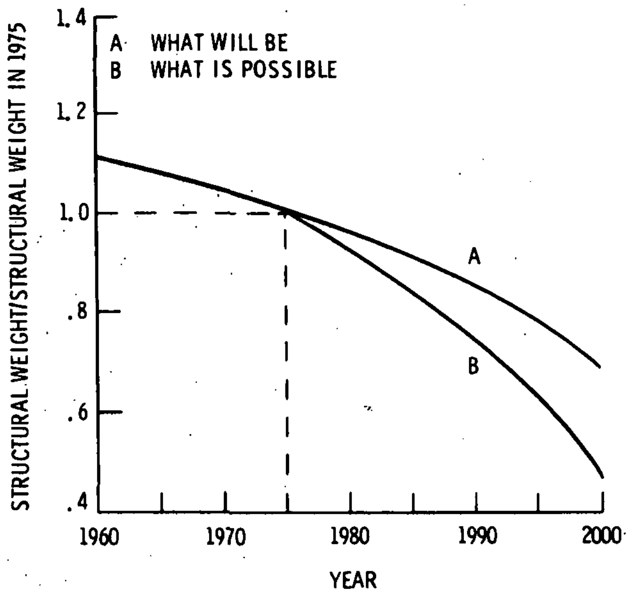

Fig. 7 Projected Improvement in Weight of Large Space Structures (Ref. 11)

these structures than by the stiffness or strength-to-weight ratio of the materials used in them. Figure 7 (curve A) shows a 30 percent improvement in weight by the year 2000, based on the use of compositiess and structural concepts that will evolve normally. A greater improvement (curve B) would require the development and use of additional new structural concepts and design techniques.

Energy production in space can also be forecast for growth (Fig. 8). Space power currently costs about \$1 million/kW_e. By 2000 a one-order-of-magnitude

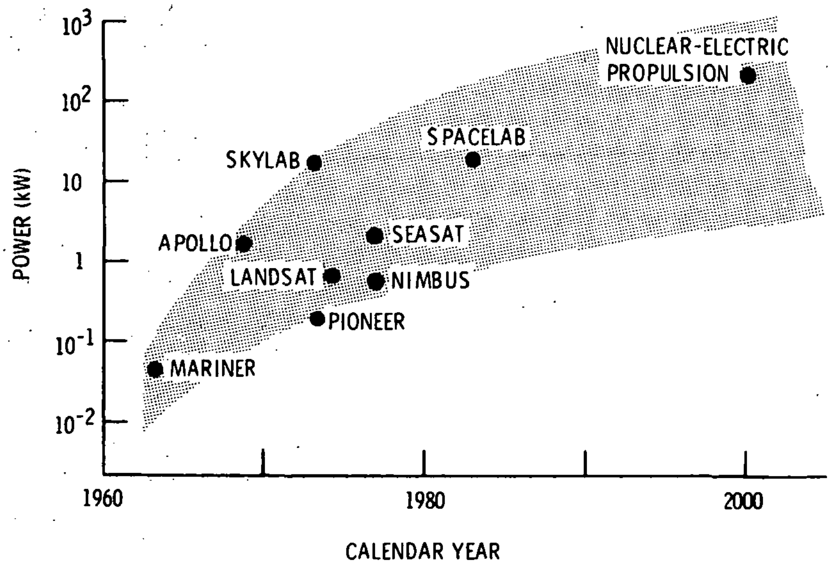

Fig. 8 Advances in Spacecraft On Board Power

cost reduction may have been realized. Technology will be oriented to the multihundred kilowatt level. A more modest reduction in space-power system weight will have been realized by then. A factor of four weight reduction will be realized for photovoltaic systems. It must be emphasized that the primary objectives will be to reduce installed cost of space power, and weight reduction may or may not be consonant with this objective, depending on the power system's application, the environment it must survive in, and the cost of transporting it.

In summary, individual technologies will be advanced only in consort with advances in neighboring technologies, with economics of the resulting system as the primary consideration. These technology interactions can be illustrated with Table 1. The table shows rather ambitious progression in earth-to-orbit transportation both in terms of unit launch cost and payload mass (columns A and B). Launch cost and mass are not independent, the more mass per year delivered, the lower cost per unit mass. The hardware mass (column C) is a fraction of the payload mass, the balance being propellant. The last two columns illustrate the total cost of placing hardware in space. The top three rows assume no improvement in hardware cost, and the bottom three rows assume a hardware cost improvement of the same order as the launch cost improvement. Clearly, the cost of hardware must improve commensurate with the transportation cost; otherwise, resources cannot be made available to support a total program of this magnitude by 2010.

Aerospace technologists must maintain and evolve a capability to find the cost-effective combinations of systems for the space program of the twenty-first century.

Table 1
LAUNCH COST AND HARDWARE COST INTERACTIONS

Year	A Launch Cost ($/kg) (Ref. 10)	B Payload Mass (kg/yr) (Ref. 10)	C Hardware Mass (kg/yr)	D Hardware Cost ($/kg)	Transportation Cost/year (A×B)	Hardware Cost/year (C×D)
1980	1000	1×10^6	0.8×10^6	3000	$1B	$2.4B
1995	200	20×10^6	8×10^6	3000	4B	24B
2010	50	100×10^6	30×10^6	3000	5B	90B
1980				3000	1B	2.4B
1995				500	4B	4B
2010				300	5B	9B

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16. Abstract

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