CAN THE UNITED STATES AFFORD A LUNAR BASE?[1]

Paul W. Keaton
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Introduction

Establishing a lunar base will require steady funding for a decade or two. The question addressed here is whether such a large space project is affordable at this time. The relevant facts and methodology are presented so that the reader may formulate independent answers. We show that a permanent lunar base can be financed without increasing NASA's historical budgetary trends.

Costs of placing a permanent base housing 24 people on the Moon were estimated in a 1968 Stanford University and NASA Ames Research Center study (ref. 3). The group concluded that over a 15-year period, the total development, acquisition, delivery, and building costs would be $17.4 billion, which translates to $58 billion in 1985. A 1984 investigation by Scientific Applications, Inc., estimated a $16-billion cost for a temporary manned reconnaissance outpost on the Moon (ref. 4). And a NASA Lyndon B. Johnson Space Center team (ref. 5) has estimated that it would cost between $80 billion and $90 billion to place a permanent base on the Moon. The NASA team emphasized base self-sufficiency and assumed that the lunar base project would require 25 years to complete.

As a comparison, the Apollo Program was completed in 11 years and cost about $85 billion (in 1985 dollars), during a period in which the U.S. gross national product (GNP) was less than one-half the current level. Thus, a $90-billion lunar base project requiring 22 years to complete would have less than one-fourth the annual impact on the U.S. economy as did the Apollo Program during the 1960's. Assuming that a permanent lunar base will cost less than $100 billion, we turn now to the question of whether the United States can afford such a cost. First, we consider the historical trends of the U.S. GNP.

U.S. Economic Trends

During the past 22 years, the United States has accumulated more national income than it did in all its previous history. After correcting for inflation, we find that the gross national product has increased at an average rate of 3.2% per year despite all the globally and nationally significant events affecting the growth rate in one way or another during the last 100 years.

Taking GNP data from the Department of Commerce (refs. 6 and 7) and implicit price deflation numbers from the Office of Management and Budget (OMB) (ref. 8), we show in figure 1 a plot of U.S. GNP in 1985 dollars for the years 1889 through 1984. In addition, 1985 projections of the Congressional Budget Office (CBO) (ref. 9) indicate that the growth trend is expected to continue through 1990 and beyond.

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[1]This paper was adapted from references 1 and 2.

The most striking feature of the GNP data curve is its close fit to a single exponentially rising function ae^{bt}, where t is the time in years and a and b are adjustable parameters. Making a least-squares fit to the actual constant dollar data, we determine that $b = 0.032$, which is the average annual growth rate of the GNP since the year 1889.

The exponential function of figure 1 exhibits a doubling time of 21.7 years. Hence, in recent decades, the total real income of the Nation has roughly doubled every generation, whereas the population has increased by less than 30%. One doubling time is adopted here as a natural unit of time to use for a long-range view of the U.S. economy.

U.S. Federal Budget Trends

To devise a rationale for projecting long-range U.S. expenditures for a national space program, we note that all Federal space funds, like other Government funds, are under constant and conflicting pressures from various segments of the public: military agencies, the private sector, scientific and engineering communities, and political coalitions. We assume that space program supporters will continue to fight for, and to receive, the same fraction of their category of funding source that they have fought for, and received, in the past. For our purposes, those funding sources must be identified in categories that are narrow enough to enable us to distinguish among past budget trends and broad enough to allow room for the statistical "give and take" of the budget process averaged over many years and several political administrations. To accomplish this objective, we observe that for the past 30 years, space activities have been funded mainly by NASA and the Department of Defense (DOD), and we identify the pools of Federal money that supply their funds.

The U.S. Federal budget constitutes less than 25% of the Nation's GNP. Figure 2 shows a 27-year distribution of Federal Government spending as separated into categories of national security, social welfare, and "other." These are categories that can be traced through the documents of the U.S. Department of Commerce (refs. 6 and 7). Civilian space programs are funded mostly through NASA from the "other" category, which has remained more or less a constant fraction of the GNP as shown in figure 2. To compare, we observe that military space programs come from the national security category, which remained at a roughly constant dollar budget from about 1960 to 1982.

Thus, if we were projecting both military and civilian space programs, we would use a combination of these two trends — constant dollar and constant fraction of GNP — as guidelines for extrapolating Government expenditures on space activities into the future (ref. 1). Here, however, we will restrict ourselves mainly to the NASA budget and make a constant-fraction-of-GNP extrapolation. First, however, we need to determine the length of time in the future that past and present trends can reasonably be expected to last.

How Long Will Economic Trends Continue?

We can think of the GNP as the sum of a large, exponentially rising component ae^{bt}, with a characteristic time of $1/b$, and a small modifying term that averages to zero and accounts for major events such as a worldwide depression or a world war. The average growth rate is then the sum of a statistically significant number of random and uncorrelated events $b_i(t)$, such as the invention of the transistor (positive) and the influx of Japanese cars to the U.S. market (negative). The growth rate may be written as a sum of the individual events, $b = \Sigma\, b_i(t)$, for which the least-squares search shows that, on the average, b has been a constant over the past 97 years even though the components $b_i(t)$ have not been constant. By analogy with physical systems, we hypothesize that b cannot change

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rapidly over a period of time $1/b = 31$ years. This hypothesis is consistent with the observation that the value of b depends on many random events.

It is easy to show that if the average GNP growth rate changes slowly over 31 years, then the cumulative GNP is relatively insensitive to the growth rate changes. For example, if we represent b by a function starting at 0.032, which decreases linearly with time to 0.0 in 31 years, we find that the projected cumulative GNP over the next 22 years will decrease from the constant b projection by only 10%. As for the value of b, it is interesting that Merrill Lynch projects a 3.1% annual growth rate in real GNP for the period of 1983-93 (ref. 10). The 1984 World Bank projection indicates that the industrial nations' economies (of which the U.S. economy is by far the largest) will have a growth rate for 1985-95 of 2.5%/yr to 4.3%/yr (ref. 11). And an extensive study by the International Institute for Applied Systems Analysis (ref. 12) shows a combined economic growth rate for the United States and Canada of 2.0%/yr to 3.3%/yr for 1985-2000 and 1.1%/yr to 2.4%/yr for 2000-2015. It seems, then, that diverse approaches are consistent with a U.S. GNP growth rate in the neighborhood of 3.0%/yr. Once that rate is accepted as reasonable, the current analysis is relatively insensitive to slow variations from 3.0% growth rates in the future.

We turn now to the question of projecting future U.S. expenditures on civilian space programs.

Future Civilian Space Funding

The actual U.S. GNP in fiscal year 1985 was $3937 billion (ref. 13). Starting with 1985 as year zero, we can integrate the exponential curve to show that, at a 3.2%/yr growth rate, the cumulative GNP will be $123 000 billion (in 1985 dollars) during the 22 years from the end of 1985 through 2007. We agree, as discussed earlier, to put a 10% uncertainty on this number to account for the large uncertainty in the future growth rate b.

Figure 3 shows that, historically, about 0.5% of the U.S. GNP has been spent for all space activities, with about 0.34% going to NASA. Alternatively, NASA's budget outlays in fiscal year 1985 (FY85) were $7.3 billion (ref. 14) or 0.18% of the 1985 GNP. Assuming that the NASA budget continues to grow — along with the "other" budget category in figure 2 — at a constant percentage of the GNP, we can anticipate that NASA's cumulative budget for 1986 through 2008 will be $220 billion to $420 billion, depending on whether we take 0.18% or 0.34% of the cumulative GNP.

Of the 0.34% of GNP historically spent on civilian space activities, about one-half can be attributed to large "discretionary" acquisitions (the Apollo and Space Shuttle Programs) and the other one-half can be attributed to space science and technology, aeronautics, overhead, etc. We therefore deduce that during the next 22 years, the United States will spend between $110 billion (1/2 × 0.0018 × $123 000 billion) and $210 billion (1/2 × 0.0034 × $123 000 billion) on large, discretionary space projects such as a space station, a lunar base, or manned Mars missions.

Although $110 billion is more than enough to build both a space station and a lunar base in the next 22 years, we should not adopt this figure as a lower limit without further thought. A corollary to our earlier hypothesis (that economic trends cannot change quickly in a time $1/b$) is that a trend is not validated until it has persisted for a time $1/b$. To give excessive weight to the NASA budget history in the 1970's would be inconsistent. If we adopt the procedure of giving twice as much weight to NASA's budget for the last 15 years as we give to that for the first 15 years, then we find that 0.24% (instead of 0.18% or 0.34%) is the predicted trend for the future NASA budget as a fraction of GNP. One-half of this figure comes to 0.12%, or $150 billion, to be spent on large space projects over one GNP-doubling time. In light of these observations, it seems safe to assume that a lower limit of 0.1% of the U.S. GNP will be spent on large space projects over the next 22 years. This percentage comes to $120 billion in 1985 dollars.

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Concluding Remarks

When we are projecting costs, past experience often proves a better guide to future actions than predictions based on "first principles." We have observed that the average growth rate of the U.S. GNP has varied very little from 3.2%/yr during nearly a century and that the growth rate consists of a statistical average of many uncorrelated phenomena. These observations suggest the hypothesis that the average growth rate will change slowly during a period of approximately 31 years. We deduce from this hypothesis that economic trends that have lasted for three decades will change only slowly over the next three decades. Our results are obtained from a consistent application of these concepts. Our results agree with other current forecasts.

An affordable space program may be defined as one not so large as to keep the GNP per capita from increasing. In that sense, an amount 5 times any of the alternatives discussed here would be affordable. In other words, the United States can afford a much larger space program than any mentioned herein.

Over the long term, the U.S. economy is robust. Barring unforeseen and unprecedented difficulties, it will generate a GNP of about $123 000 billion during the next 22 years, 0.24% of which is likely to be spent by the Government on civilian space programs. Past patterns of spending suggest that one-half of this $300 billion will be available for major national commitments to large, focused space programs.

Even though the future space budget was deduced using a conservative analysis, $150 billion over 22 years would fund a much larger project than most planners seem willing to suggest publicly. The dangers of not making major long-term commitments now are twofold: an unnecessarily miserly approach to our nation's space program can be a self-fulfilling prophecy, and without a long-range perspective, we run the risk of spending the money unwisely by fits and starts.

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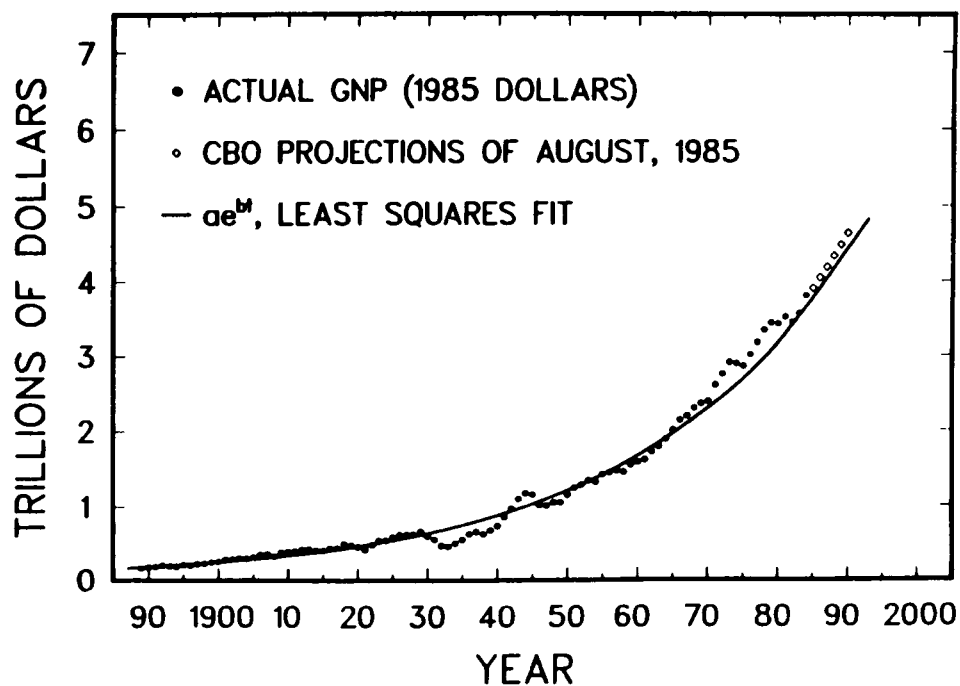
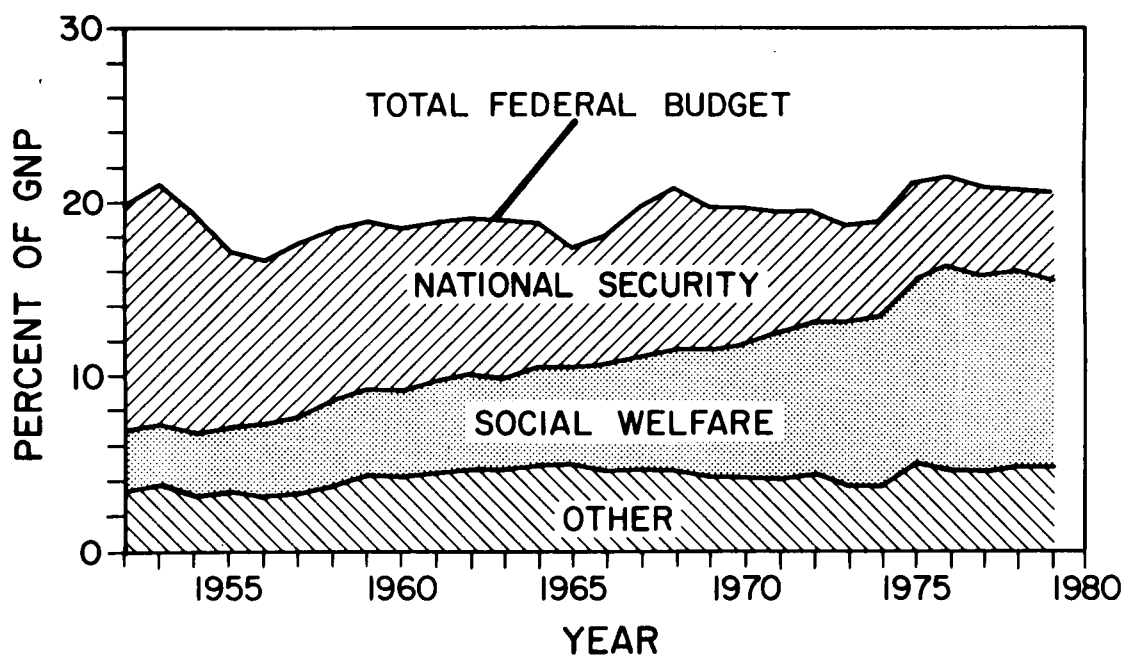Figure 1.- U.S. gross national product as a function of years.

Figure 2.- U.S. Federal expenditures as a fraction of the gross national product.
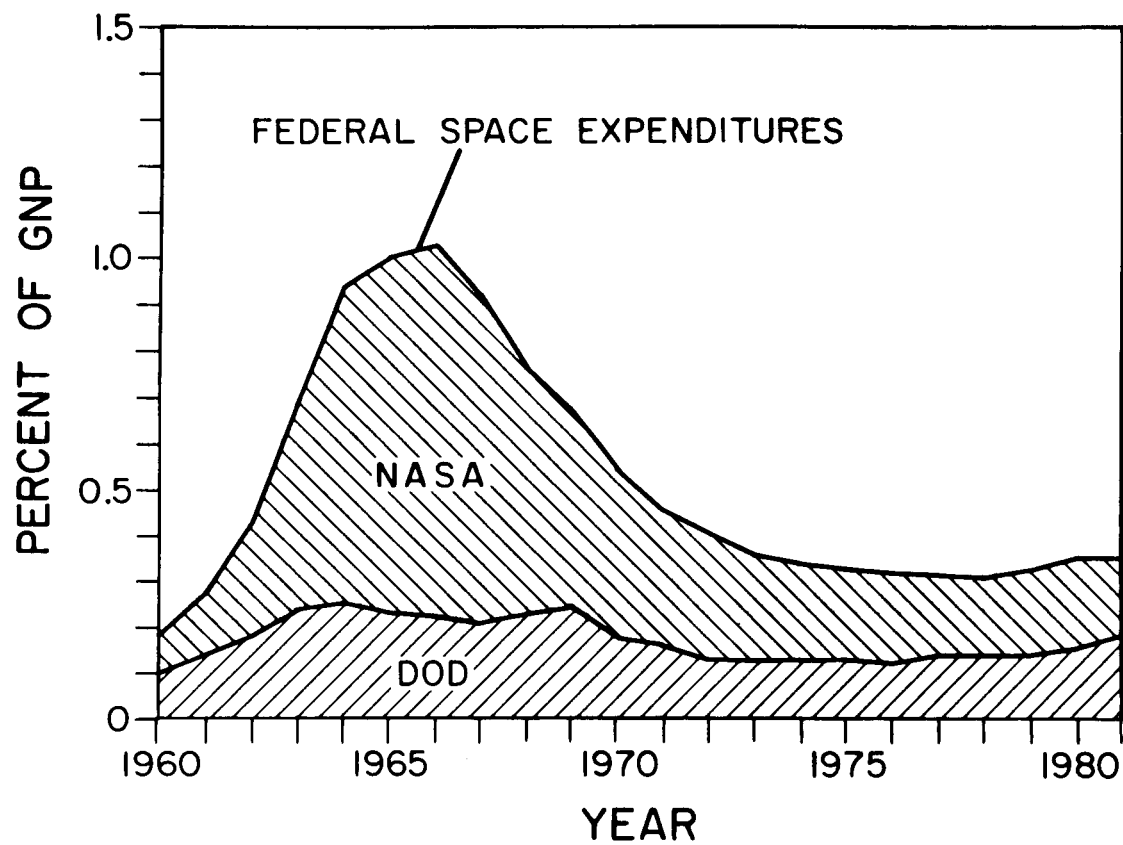
Figure 3.- Federal expenditures on space activities as a fraction of the gross national product.