t: ECONOMIC ASPECTS OF COMMUNICATION SATELLITE SYSTEMS

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PREFACE

This study was conducted under NASA Contract No. NASr-21(02), monitored by the Office of Space Flight Programs. It was prepared for presentation at the International Symposium on Space Communication, sponsored by URSI in Paris, September 1961.

ECONOMIC ASPECTS OF COMMUNICATION SATELLITE SYSTEMS

Introduction

There can be no doubt that communication satellites are technically feasible even at the present time. In purely physical terms, the advantage of communication satellites is the opportunity they offer for line-of-sight transmission over long distances. Satellites promise a jump in capacity primarily for transoceanic communications. From an economical point of view, two questions arise: First, what is the cost of communication satellite systems? Secondly, provided the cost of such systems is reasonable, what are the prospects for utilizing a vast increase in transoceanic capacity? This paper is an attempt to examine these two questions within the limitations of present knowledge.

I. Cost of Communication Satellite Systems

The total cost of any communication system is the aggregate of three categories of expenditures:

a. Research and development cost.

b. Initial installation costs.

c. Operating costs.

It is clear that this breakdown also applies to satellite systems.

A. Research and Development

One of the critical factors determining the economical attractiveness of a communication satellite system is the operating lifetime of the satellites. In the research and development phase the major emphasis will be on extensive reliability testing. This includes orbital testing and, as a consequence, the research and development costs are likely to be high.

Representative estimates for research and development costs range from approximately 40 million dollars in case of very simple satellites to as much as 150 million dollars for large satellites in 24-hour orbits.

It appears that the ground terminals require not much development effort because they are likely to be similar to installations presently in use at radar sites or as terminals in some of the more powerful tropospheric beyond-the-horizon links. Ground stations used during the development phase can be used as operational stations provided they are favorably located.

B. Initial Installation Costs

This item includes the price of installing the operational ground stations and placing enough satellites in orbit to provide the desired capacity and continuity of service of the operational system.

C. Operating Cost

The operating costs include not only the cost of operating the ground terminals but also the cost of replacing satellites after occurences of failures. It is important to note that communication satellite systems will show a cost pattern that is markedly different from that of other communication systems. The yearly operating cost of conventional systems (for example, microwave relay) is typically 15 to 20 per cent of the initial installation cost. On the other hand, the yearly operating cost of a communication satellite system would be 15 to 20 per cent of the ground terminal installation cost plus the cost of replacing all satellites, if, for example, the mean time to failure of the satellites were one year. Thus, the ratio between operating cost and initial installation cost may be markedly different from that in conventional communication systems. This is an important factor, when costs are compared with those of other systems.

D. Total Systems Cost

To compute the total systems cost one has to aggregate research and development cost, initial installation cost plus the operating costs which include the cost of satellite replacement. Adding operating costs directly to investment, however, is not appropriate. Operating costs take the form of a future stream of expenditures. To make them commensurate with initial investment, such streams must be discounted. They are like an annuity, and it is the present value of the annuity that must be added to the initial investment to arrive at the total costs. This is neither a financial trick nor trivial. This procedure is simply a recognition of the fact that a certain amount of money invested today will produce more than the same amount of money's worth of resources five years hence.

The discount factor for the operating cost is easily determined from the relation

$$K = \frac{1}{p}\left[1 - \frac{1}{(1+p)^Y}\right] \tag{1}$$

where p is the annual interest rate and Y is the operating life of the system in years. Some typical discount factors are listed below.

			Systems Life		
			10 years	15 years	20 years
Interest rate	4%	K =	8.13	11.12	13.58
	6%		7.35	9.72	11.47
	8%		6.71	8.56	9.81
	10%		6.14	7.61	8.51

The total cost of the ground terminal part of a system in terms of present-day money is determined by

$$T + K\,O_T \qquad (2)$$

where T - installation cost of the ground terminals

O_T - yearly operating cost of the ground terminals

K - discount factor defined in Eq. (1).

The total cost of the orbiting part of a satellite system is a somewhat more involved quantity. The following basic numbers are needed:

N - the number of satellites in orbit

S - the cost of a satellite

n - the number of satellites launched by one launch vehicle

L - the cost of the launch vehicle, including all the costs of launching it

P - the probability that the launch vehicle performs satisfactorily, i.e., that the satellites reach the desired orbits.

The cost of establishing the first orbiting subsystem is then given by

$$\frac{N}{P}\left(S + \frac{L}{n}\right) \qquad (3)$$

Next, it is necessary to determine the cost of replacing satellites during the lifetime of the system in terms of present-day money. This cost can be written as a simple relation only, if, during the lifetime of the system, the launch cost L, the probability P and the time interval between satellite replacements remain constant. In this particular case, the total present-day cost of maintaining N satellites in orbit would simply be

$$\frac{K}{m} \; \frac{N}{P} \quad (S + \frac{L}{n}) \tag{4}$$

where m is the mean time to failure of the satellites and K the discount factor introduced in Eq. (1).

However, relation (4) oversimplifies the real situation. First, it is almost certain that the satellite lifetime will increase over the period of the systems life. It is clear that reliability improvements will be made as operating experience accumulates. Secondly, it is possible that launch costs and launch vehicle costs decrease as the launching becomes a routine operation, and finally, one may also expect an increase in the probability of achieving orbit successfully. These factors can be taken into account as follows: Let the subscript λ on P_λ and L_λ designate the event that a replacement launch takes place λ years from now. Then, in terms of present-day money the cost of replacing <u>all</u> N satellites λ years hence is

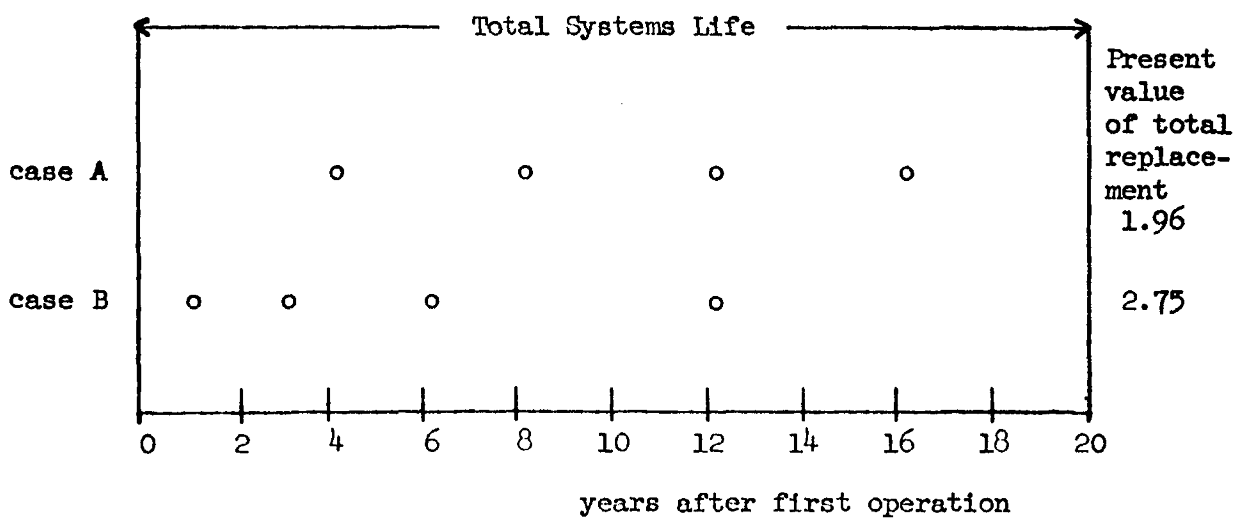
$$\frac{1}{(1 + p)^{\lambda}} \; \frac{N}{P_\lambda} \quad (S + \frac{L_\lambda}{n}) \tag{5}$$

where p is again the discount rate. Thus, the total replacement cost of the satellites is given by

$$\sum_{\lambda} \quad \frac{1}{(1 + p)^{\lambda}} \; \frac{N}{P_\lambda} \quad (S + \frac{L_\lambda}{n}) \tag{6}$$

where the summation is to be taken to include all satellite replacements during the entire life of the system. Equation (6) reduces to Eq. (4) if L_λ and P_λ are constant and if the time between replacements is constant. Unfortunately, it is most difficult to make predictions at this time concerning future satellite lifetimes, launch costs and launch success probability. But these factors influence the total cost not only in an absolute sense very significantly, but it is also very difficult to make relative comparisons between systems with different satellite designs and different launch vehicles.

The following example illustrates the variation of the replacement cost, when only one of the important parameters is changed. Consider a system with a total operating life of 20 years. Let the lifetime of the satellites be 4 years, so that the satellites have to be replaced 4 years after the initial operational date, and again 8 years, 12 years and 16 years after initial operation (case A). Now consider the case where the satellites become more reliable during the life of the system. Let us assume that the first set of satellites will operate one year, the second set two years, and the subsequent sets three years, six years and eight years respectively. In this situation, replacements will be necessary one year, three years, six years and twelve years after initial operation (case B). The replacement schedule in the two hypothetical cases is shown below



It is important to note that the total number of satellites launched is the same in both cases. Yet in case B the total satellite replacement cost in terms of present-day money is 2.75 times the launch cost of a set of satellites, while in case A the total satellite replacement cost is only 1.96 times the launch cost of one set of satellites (a discount rate of 8% is assumed). This example shows that the satellite replacement cost is not only dependent on the total number of satellites launched during the life of the system, but is also quite strongly dependent on when they have to be launched.

The total cost of a communication satellite system is given by:

$$\text{Total cost} = \left\{D + T + \frac{N}{P}\left(S + \frac{L}{n}\right)\right\} + \left\{K\, O_T + \sum_{\lambda} \frac{1}{(1+p)^{\lambda}} \frac{N}{P_{\lambda}} \left(S + \frac{L_{\lambda}}{n}\right)\right\} \tag{7}$$

Here, *D* is the development cost and the meaning of the other symbols is as before. The terms in the first bracket are the cost of establishing first operation of the system and the terms in the second bracket represent the present-day value of the future operating costs. If all the values appearing in Eq. (7) are known for a given system, the exact calculation of the systems cost is possible. However, even without using specific values we can extract some general trends of the systems costs.

It was already mentioned that the lifetime of the satellites is the most uncertain quantity at the present time. How the lifetime of the satellites influences the total systems cost is illustrated in Fig. 1. Because so many parameters appear in the cost equation, a few plausible assumptions had to be made in the calculation of these curves. First, development costs were not included and would have to be added. The total systems life was assumed to be 15 years and the discount rate of 8% per year (discount factor K = 8.56) was assigned. Furthermore, the yearly operating cost of the ground terminals was taken as 20% of their initial installation cost. Finally, the assumption was made that the operating life of the satellites, the launch cost and the probability of reaching the desired orbits successfully remain constant during the entire 15-year period. The figure reveals the strong dependence of the total cost on satellite life, in particular in the case of systems where the orbiting part of the system represents a large part of the investment.

In order to compare the cost of communication satellite systems with the cost of other communication systems (e.g., submarine cables or overland microwave relay), one is induced to express the cost of the system in cost per channel. This involves several hazards. In the first instance, the cost of submarine cables or overland microwave relay is proportional to circuit length, so that the basic unit is the cost per channel-mile. Clearly, the cost per channel-mile is a meaningless quantity in the case of communication satellites because the cost is independent of the circuit length; the only condition is that the satellite be simultaneously visible from the two terminals. Secondly, the number of channels is a quantity which is not known very exactly, even if both the satellite and the ground equipment are specified in fair detail. Variations in the required channel quality, in the amount of systems margin which is allowed, and several other factors permit the prediction of the number of channels only within a certain range. This is not very serious when one attempts to consider the <u>relative</u> cost of various communication satellite systems in terms of cost per channel, because it is then possible to make identical assumptions. However, the comparison with other means of communication becomes quite hazardous in terms of absolute costs per channel.

Figure 2 is an illustration of the relative behavior of the cost per channel of satellite systems. The assumption was made that a certain fixed amount of money is invested to establish the orbiting part of the system. The cost of the ground terminals is varied and the simplifying assumption was made that the number of channels is directly proportional to the cost of the ground terminals. The cost per channel of a system in which the initial launch cost is equal to the installation cost of the ground terminals and in which the satellite lifetime is one year, was arbitrarily assigned as unity. Figure 2 shows the sharp decrease of the cost per channel as the number of channels is increased in this example by enlarging the size of the ground station. Figure 2 also brings into focus again the strong dependence on satellite lifetime, in particular when the lifetime is less than two years. The important conclusion which one draws, is that the economical attractiveness of communication satellites is primarily in the area of large capacity long distance trunk circuits.

It might be interesting to note that the cost per channel of communication facilities which are in domestic use in the United States (this includes various types of cables as well as microwave relay) is roughly proportional to $x^{-2/3}$, when x is the number of channels. Such a curve is also shown in Fig. 2 and it appears that the cost per channel of satellite systems shows a similar behavior.

The actual cost figures for the cost per channel depend, of course, on the basic numbers used in the cost Eq. (7) and are subject to a wide range of uncertainties. But even with fairly pessimistic assumptions concerning satellite reliability and launch costs, satellite links are cheaper per channel than submarine cables for any but short links if the number of channels is large. On the other hand, only with very optimistic assumptions could one conclude that satellites will be competitive with microwave relays in conventional overland applications.

II. Demand

Communication satellites promise very large increases in the number of channels for transoceanic traffic. As such, they appear to promise economies of large-scale operation; they promise lower unit costs than submarine cables if high output rates (or, what is the same thing, high utilization rates) can be achieved--high relative to current international telecommunication traffic. How large an increase in output the market will support depends on two factors: (1) how demand increases over time, and (2) how sensitive utilization rates are to price reductions. Prices are particularly important. To judge by the current rate of $240,000 for a transatlantic voice channel, substantial price reductions should be possible with either the new cables or communication satellites. If consumers respond to lower prices by greatly increasing their use of international telecommunication facilities, communication satellites are very likely to be the more economical of the two alternatives.

Unfortunately, both the course of future demand and the responsiveness of the market to lower prices are very difficult factors to estimate. Economic projections 10 or 20 years into the future are always highly uncertain.

Despite the uncertainties, however, an examination of the growth of international communications is useful in judging whether there is any hope for enough traffic to support a satellite system. Since overseas telephone and telegraph presently dominate the market, let us look at those first. Later we shall discuss very briefly some of the new uses that have been proposed.

Overseas Telephone and Telegraph Services. Overseas telephone communications have grown steadily and rapidly. Figure 3 shows the annual totals for inbound and outbound overseas messages for the United States for the period 1930-59. During those 30 years the number of messages increased by a factor of 100. In the last 10 years the volume of messages roughly tripled. As is evident from the regular slope of the line, the rate of growth has been remarkably constant since 1946. If that same growth rate persists, the volume of overseas messages will reach 10 to 12 million by 1970 and around 40 million by 1980. The dotted line B in Fig. 5 is based on a growth rate like that of the postwar period. The dashed line A is based on a substantially higher growth rate, which predicts 20 million or so messages in 1970 and 100 million by 1980. A corresponds roughly to the assumption of a 15-per cent annual increase.

The history of toll rates is an important consideration in interpreting Fig. 3. The period of stable growth from 1946 to the present coincides with a period of stability in international telephone rates. The last change, for example, in rates between the United States and London occurred in 1945. When increases in price level are taken into account, it is clear that there has been a modest decline in real rates. Thus the real price of calls between London and the United States fell about 20 per cent during the 15 years from 1946 to the present. Prior to 1946, rates were reduced in 1929, in 1934, in 1936, and in 1945. In addition, special night rates were introduced in 1936.

The growth of telephone traffic during the 1929-45 period follows rather closely the pattern of real rate changes. From 1929 to 1934 real rates rose, because nominal rates were fixed while the price level was falling. During those years international telephone traffic actually declined. From 1934 on, however, real rates fell dramatically, so that by 1946 they were about 20 per cent of what they had been in 1929. These were also the years during which telephone traffic experienced its fastest growth. In 1946 message volume was about 20 times what it had been in 1935. Thus, for the 30 years covered by our data there is a high correlation between real rate changes and the volume of telephone calls. When real rates were fairly stable (1946-59), there was a stable growth in number of calls; when real rates rose (1929-34), the number of calls declined; when real rates fell substantially (1935-45), there was a rapid growth in number of calls.

In brief, historical data on the growth of international telephone traffic indicate that (1) the demand for international telephone service has grown rather impressively over the last 30 years, and (2) utilization rates are quite sensitive to price reductions. If both statements are true, and if they continue to hold in the future, a growth in number of telephone messages such as that represented by <u>A</u> in Fig. 5 is certainly a possibility--that is, of course, if potential reductions in toll rate are in fact realized. Furthermore, it should be noted that the increase in utilization will exceed the increase in message volume. Estimates of message volume by itself ignore one dimension of utilization--namely, the duration of calls. Not only will the number of calls increase if toll rates are reduced, but the average length of calls will increase.

In terms of both revenue generated and message volume, international telegraph traffic exceeds telephone traffic, at least in the case of the United States. For a number of reasons, however, the telegraph business is likely to play a minor role in the communication-satellite picture.

First and most important, much less communications capacity is required for telegraph transmission than for telephone. One telephone voice channel is roughly equivalent in capacity to 20 telegraph channels. Thus, telegraph is a modest consumer of the one thing a satellite system provides--large quantities of long-line capacity.

Second, with telegraph there is less opportunity for increasing utilization by reducing toll rates, because long-line transmission costs are a relatively small proportion of the total cost of a message; reductions in transmission costs will not appreciably affect the cost per message.

Third, telegraph also looks less promising from the point of view of traffic growth. The volume of telegraph messages to and from the United States, for example, is only about 25 per cent greater today than it was 30 years ago, though all of that growth has occurred since the end of World War II. Certain special forms of telegraph service--private leased lines and Telex (a means of conducting conversations by telegraph)--have been growing rapidly, but these constitute a relatively small part of the total.

Proposed Supplemental Uses. No consideration of the demand for communication satellites would be complete without a discussion of the varied assortment of supplemental uses that have been suggested: international commercial television, data transmission, facsimile transmission, closed-circuit television, and so on. In the fields of international telephone and telegraph, we at least have a history to rely on, but there is virtually no experience to help in evaluating these other uses. What can be said is, therefore, even more tentative and less quantitative than predictions in the other two fields.

Commercial television is the use that has received most attention. The operational difficulties in international television are well known by now. Time and language differences limit the market. For much of the world, simultaneous broadcast of the daily fare would be out of the question, and even briefly delayed broadcasts, such as those used for different time zones in the United States, would not be feasible. Special events like the Olympics could be broadcast simultaneously to some areas. But even here, delayed broadcast by tape would probably be more satisfactory. For delayed broadcast the question is: What advantage would satellites offer over delivery by fast aircraft--that is, how much more would television sponsors be willing to pay for satellite transmission? Such transmission is going to be costly. Even with favorable assumptions, it appears that the annual cost of 600-voice channels in a communication satellite will be substantially larger than the cost of ordinary microwave relays.

One important possibility for encouraging new uses, such as delayed television facsimile transmission, and data transmission, is to inaugurate a policy of varying prices with the time of day. During "off-peak" periods, communication-satellite systems will have large "excess capacity." Once the system is in operation, the cost of using the excess capacity will be slight. Thus, it may be possible--say, during the night--to use the satellites for transmitting facsimile mail and taped television or data at very low prices. Unless some such arrangement is made, the potential demand for such uses is likely to be small.

If a low-cost method is found for bringing closed-circuit television into homes and offices, this could generate an important demand for international communication capacity, probably a much more important demand than that of commercial television. Though much more expensive than telephone, it would provide a close substitute for travel for many business and official purposes.

Thus new forms of international communications--probably some kinds that are not recognized today--will add something to the demand for capacity. Whether they will dramatically increase total demand or will have only a modest effect is hard to say.

Communication satellites promise substantial reductions in cost, as compared to submarine cables, if high rates of utilization can be achieved. The real economical question, therefore, is demand: Just how soon will demand be sufficient to support such systems? If we judge on the basis of past growth of international telephone traffic, plus possible channeling of telegraph traffic and potential new uses, that day may not be too far in the future.

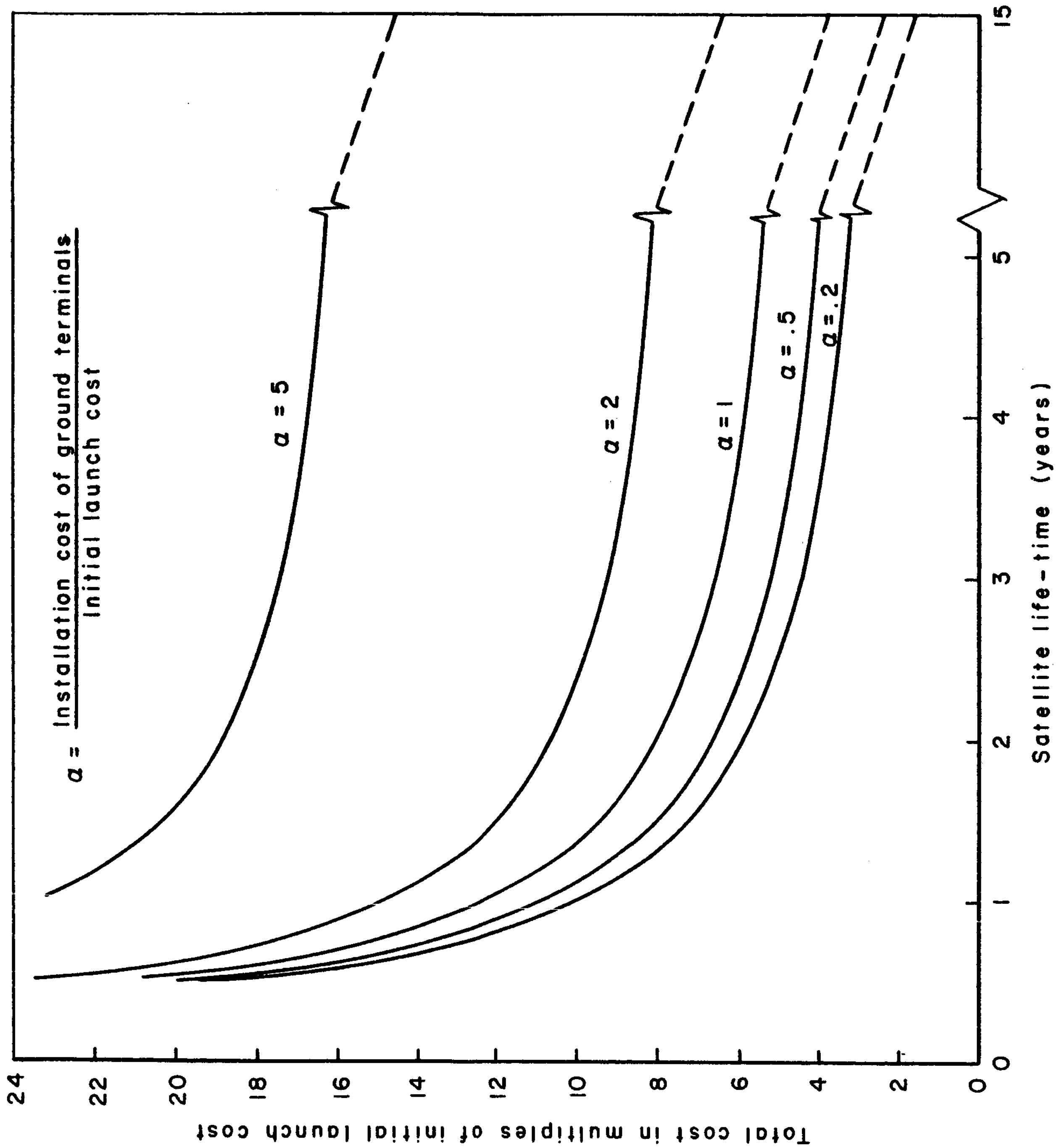


Fig. 1 — Total systems cost

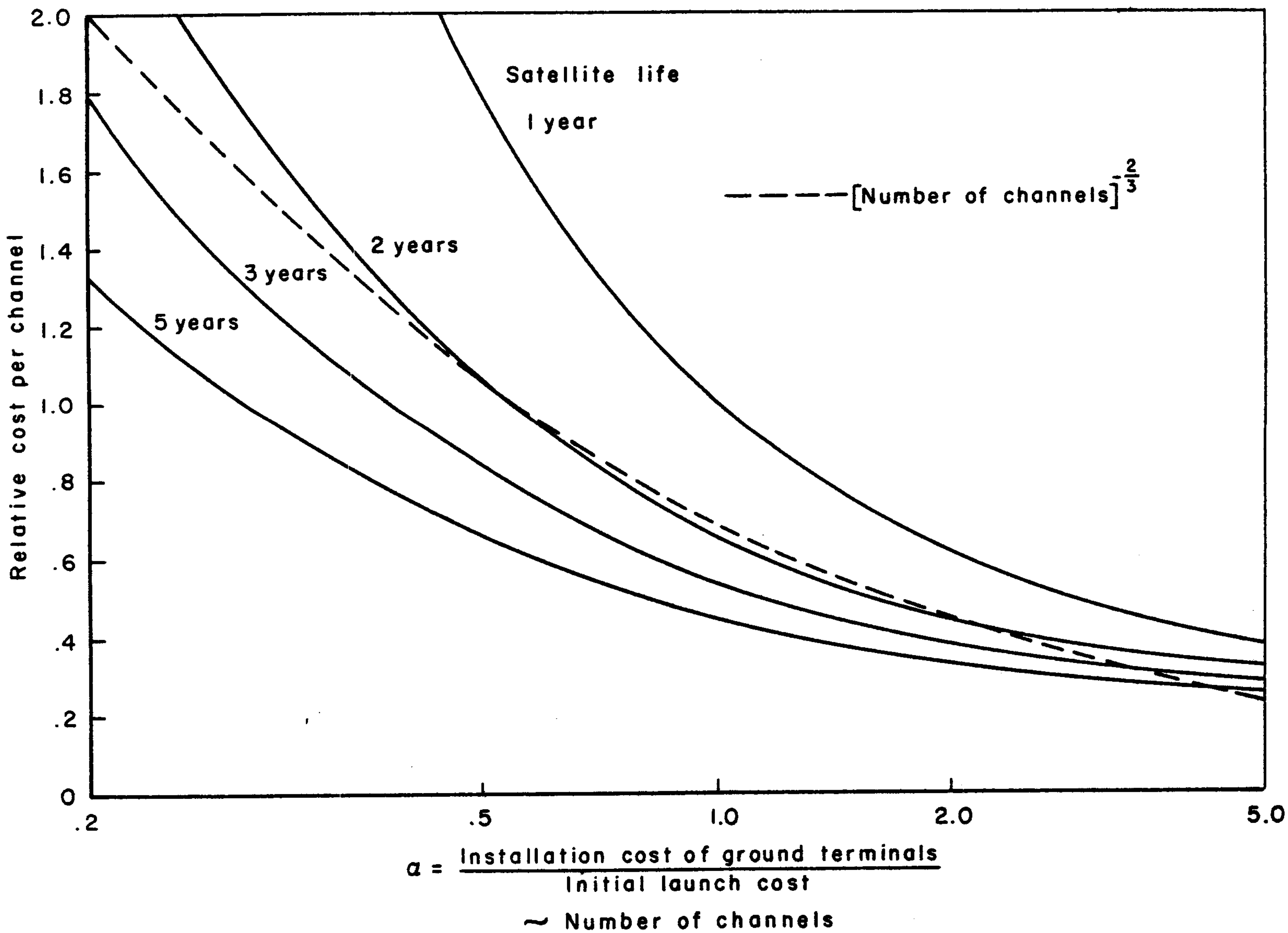


Fig. 2 — Relative cost per channel

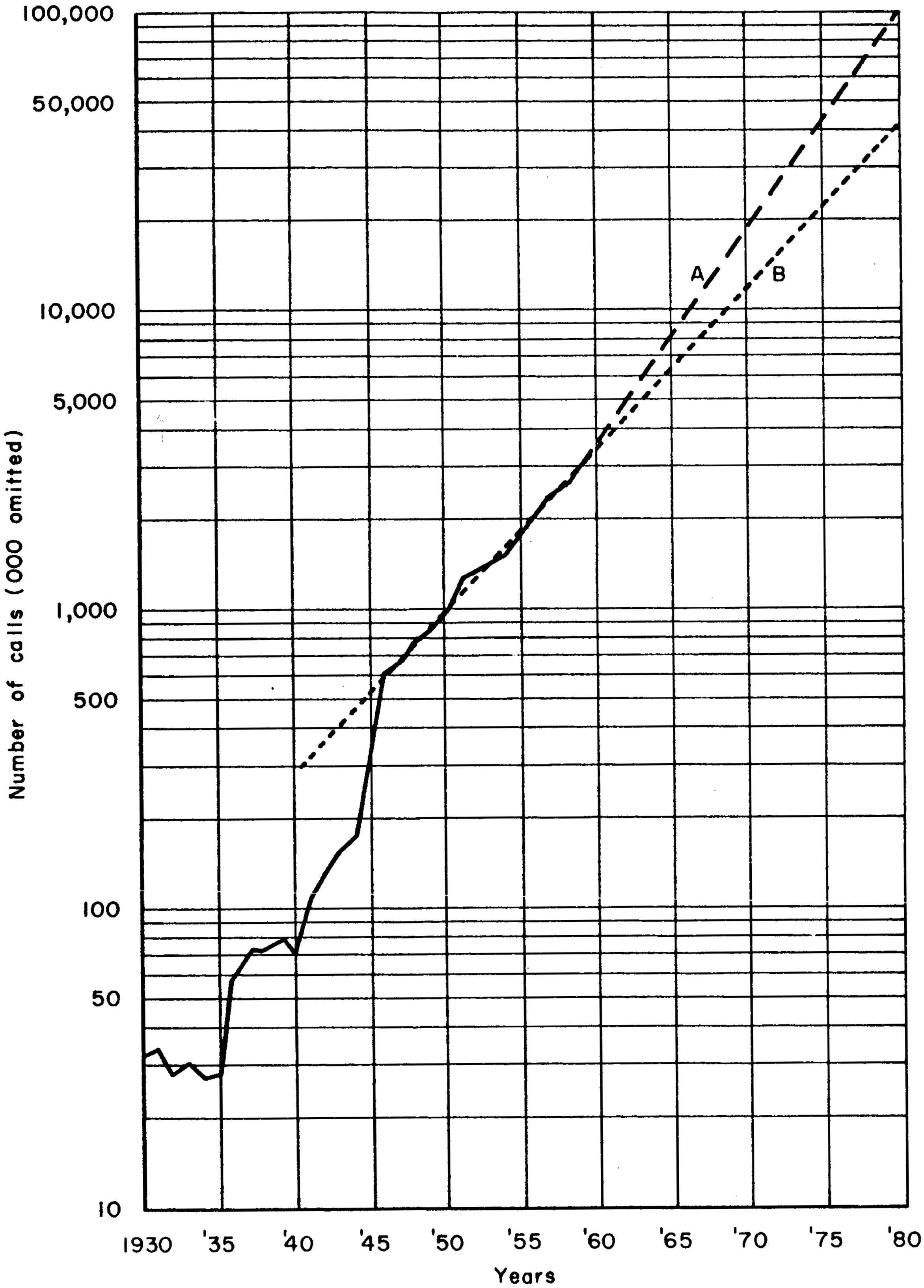


Fig.3 — U.S. overseas telephone calls inbound and outbound per year (1930 - 1959)