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LONG RANGE PLANNING FOR SPACE

TRANSPORTATION SYSTEMS

By H. H. Koelle

George C. Marshall Space Flight Center
Huntsville, Alabama

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SUMMARY

The long range objective of the NASA space flight program is the manned exploration of the moon and the planets. This report presents current thinking in the area of long range planning of the Future Projects Office at GCMSFC. It also presents the major system parameters that are important to future launch operations.

The report shows that the Atlantic and Pacific Missile Ranges will be able to handle all launch operations in the foreseeable space flight program. Also, that it is possible to estimate launch operations costs of present and future launch vehicles as a function of firing rate to a degree of accuracy satisfactory for planning purposes.

INTRODUCTION

The long range objective of the NASA space flight program is the manned exploration of the moon and the planets.

This ambitious goal will determine to a large extent the design approach development program and operational launch rates of future launch vehicles beyond the presently approved SATURN program.

Therefore, a concentrated effort is presently being made to develop an integrated and balanced approach in order to determine future launch vehicle and launch operations requirements.

At present, it is generally agreed that the Atlantic Missile Range (AMR) should be developed to the limit of its capabilities before considering the development of another launch site which, if required, might be located closer to the equator than the AMR.

The purpose of this report, therefore, is to present the current thinking of the Future Projects Office at MSFC in the area of long range planning, and to discuss the major system parameters of importance to future launch operations.

The report is broken down in the following major areas:

1. Program Requirements
2. Resources
3. Cost Relationships
4. Typical Integrated Program Requirements
5. Resources and Program Balance
6. Trends of Space Transportation Cost
7. Conclusions

DISCUSSION

1. Program Requirements

We are facing, in the near future, several major decisions involving, potentially, a noticeable share of our national resources. It is anticipated that some 50 to 100 billion dollars will be spent for national civilian and military space flight activities over the next 20 years. This expenditure will be heavily influenced by decisions, made within the next two or three years, which will set the pace for the launch vehicle program. The areas of major decisions are as follows:

SATURN C-2 Program
Orbital Operations Program
SATURN Long Range Improvement (C-3)
Use of F-1 Engine (NOVA?) (C-3?)
Launch Vehicle Final Objective Within the State of the Art
Manned Lunar Landing
Manned Planetary Exploration
Nuclear Propulsion

Obviously, there is a choice with respect to the timing of the major mission accomplishments within the national space flight program as shown in Figure 1. This choice of an early or a rather late mission accomplsihment is also a function of lead time as indicated. Past experience has shown that such major decisions will not be made unless all factual data concerning the relationship of performance, cost, schedule, and probability of successful mission accomplishment have been established, and a proper choice has been offered to the persons with authority to make such an important decision. The type of work necessary to compile the data needed for decision making will be discussed below.

If the broad program shown in Figure 1 is translated into launch vehicle programs, the picture shown in Figure 2 emerges. Again a relationship between decision making, development cycle, operational availability, and financial resources can be noted. It is easy to see that the successful accomplishment of the vehicle development program is a mandatory requirement for later mission accomplishments.

From here on, the emphasis will be on launch vehicles and launch operations.

2. Resources

It will be very helpful, for the later assessment of the possible range and size of the extrapolated launch vehicle program, to take a quick look at our national resources. A very broad picture is obtained by looking at Figure 3 which is an indication of the total work force and productivity of the U. S. Approximately 1/7 of the total national resources is available to the U. S. Government for direct expenditures, of which more than fifty percent goes into major national security (Fig. 4). The portion of national security expenditures which is of major interest to us is used for missile and launch vehicle development and production (Fig. 5). A closer look at these and related figures reveals the total funds available exclusively for space flight development and operations during the past three years as shown in Table 1. This table indicates that some 1.5 billion dollars will be spent during this fiscal year, and it is safe to assume that this figure will increase with time. However, it is difficult to estimate how much this will increase, because national policy and international politics are involved.

Therefore, it is obvious that a single projection of funds available for space flight will not serve the purpose for system studies, but, rather, a spread of several typical funding rates versus time should be considered. This has been attempted and the resulting figures for a typical "modest" (A*), "ambitious" (B*) and "rather high" (C*) funding program have been plotted as Figure 6. It is interesting to note that, even in the case resulting in almost 8 billion dollars in 1970, the percentage of the GNP expended for major national security was kept constant at 9.2% (which we experience today). The major assumption here is that (except for a 2.5% increase per year due to inflation) the expenditure for conventional weapons is kept constant, and the increase from the natural growth of the GNP goes into space flight activities. This assumption does not require new taxes nor major changes in the economical and industrial structure of the U. S.

Table 1

ESTIMATED TOTAL FUNDS AVAILABLE FOR SPACE FLIGHT DEVELOPMENT AND OPERATION IN THE PERIOD 1959 TO 1961

(Millions of Dollars)

	FY 1959	FY 1960	FY 1961
NASA			
Salaries and Expenses	86.5	94	169.5
Research and Development	225.3	333	656.0
Construction and Equipment	72.2	96	89.5
TOTAL	384.0	523	915.0
DEPARTMENT OF DEFENSE			
Military Astronautics	324	408	351
Military Personnel	≈56	≈62	≈70
Emergency Funds	-	≈25	≈50
TOTAL	380	495	471
ATOMIC ENERGY COMMISSION	26.5	19.8	≈40
NATIONAL SCIENCE FOUNDATION	≈2	≈4.5	≈6
INDUSTRY	≈26	≈36	≈66
UNIVERSITIES	≈1.5	≈1.7	≈2
APPROX. TOTAL:	820	1080	1500

Thus, it is felt that, while this highest rate of funding is considered a practical upper limit, it will not be the upper limit for available resources in case of a national emergency or in case of an international space flight program which might materialize by 1970. In this case, a quick look at the composition of the UNESCO Budget of 1959 might be of interest. Table 2 indicates the share of the U. S. contribution in relation to the total resources of a typical technical/scientific international program. The material presented in this section is required to judge the national capabilities after the basic cost relationships for space transportation have been established. This will be done in the following section.

3. Cost Relationships

It is very important to have a full appreciation of the cost distribution in the field of space transportation where a systems optimization is required. Without knowing the interrelationships of performance, cost, and schedule, it is very difficult to attack the problems at the proper point. A typical dimensionless cost distribution of a launch vehicle program is shown in Table 3. The majority of the R&D expenditures is for engineering of the individual stages, and shifts to the hardware procurement in the operational phase.

While this typical breakdown indicates where the money goes in such a project, to obtain the full picture a detailed cost and operational analysis is required for each project under consideration.

The following cost breakdown and cost definitions might be useful to identify cost areas:

DIRECT OPERATING COST

$$C_O = C_V + C_P + C_T + C_L + C_M + C_C + C_S + C_Q$$

where:

C_V = Vehicle production cost

C_P = Propellant cost

C_T = Vehicle transportation cost

C_L = Vehicle launch cost

C_M = Vehicle maintenance and repair cost

C_C = Crew cost

Table 2

MEMBERSHIP CONTRIBUTIONS TO UNESCO BUDGET (1959)

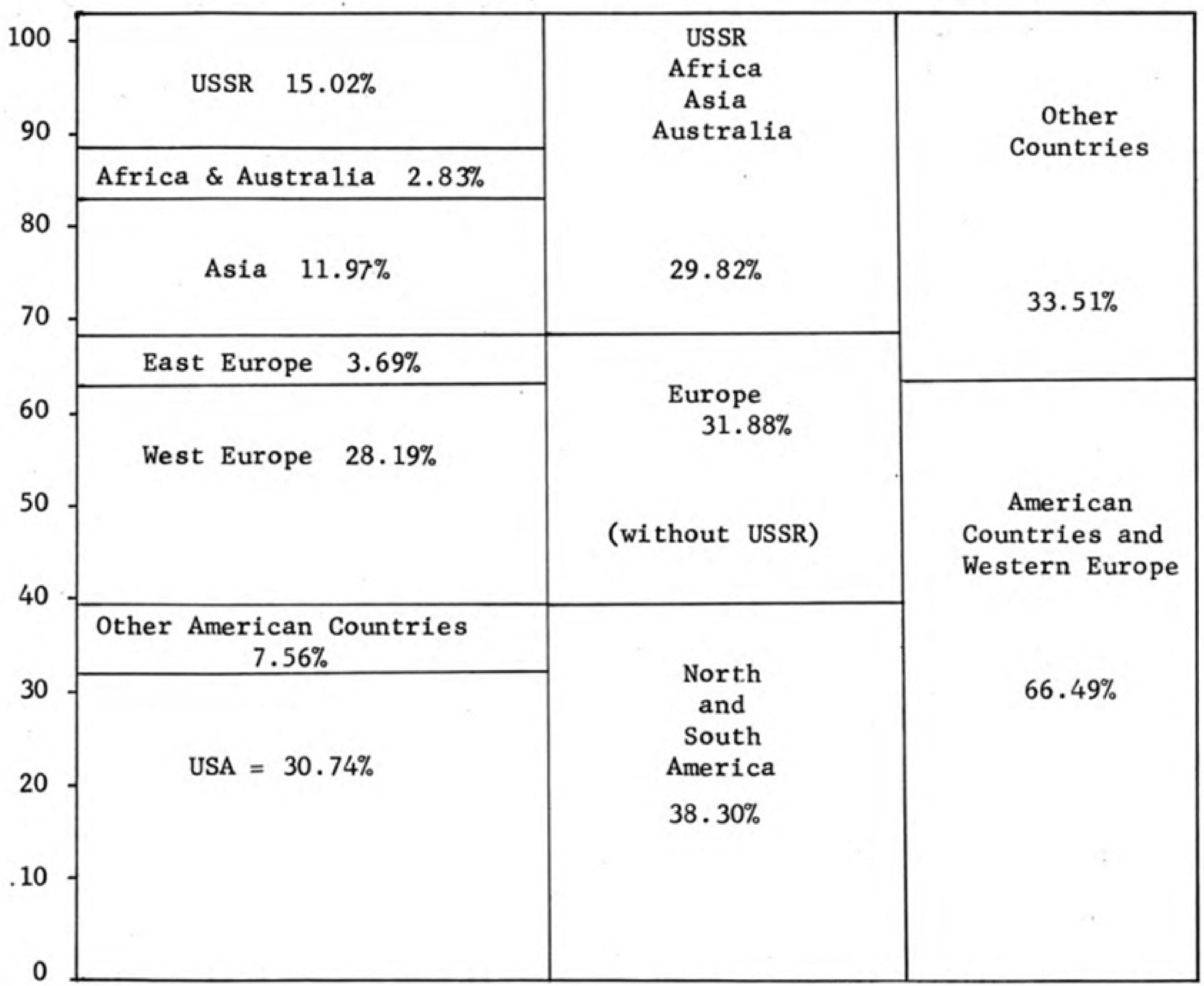


Table 3

TYPICAL FUNDING DISTRIBUTION

ITEM	PROGRAM	
	R&D (%)	Operational (%)
Engineering	43	18
Booster	15	6
Upper Stages	10	4
Engines	11	6
GSE	3	1
G&C	4	1
Supporting Research	3	2
System Studies	2	2
Flight Hardware	33	55
Booster	13	16
Upper Stages	9	19
Engines	8	14
G&C	3	6
Ground Support Equipment	4	3
Facilities	9	8
Mission and Payload Integration	3	5
Launch Operations	3	7
	100	100

C_S = Capital cost

C_Q = Other recurring cost

INDIRECT OPERATING COST

$$C_I = C_R + C_G + C_F + C_D + C_Z$$

where

C_R = Range cost and general overhead

C_G = Ground support equipment cost

C_F = Launch facility cost

C_D = Vehicle development cost

C_Z = Other non-recurring cost

The total operating cost is

$$C = C_O + C_I$$

While most of these cost items are quite well covered by previous investigations, or quite well understood, there are some areas which will have to be investigated in much greater detail before satisfactory relationships can be established. A few of these cost items, not yet adequately covered, will be discussed here.

Vehicle launch cost covers all expenses in connection with the checkout, prefiring, and launch operations at the launch site. This cost can be expressed in manpower required and the necessary general support for that manpower. This item does not include facility, GSE, and range use cost. In first approximation, this cost item might be expressed by the following:

$$C_L = P_n \times K_{Pd}$$

$$= \frac{t \,.\, N}{365} \left[a_1 + b_1 \sqrt{W_O}\right]$$

where t is the pad time required per launch and assumed to be

$$t = \frac{100}{N^*} + \frac{\sqrt[3]{W_O}}{y}$$

P_n = Number of pads

K_{Pd} = Cost of operating one pad

N^* = Accumulated firings

N = Annual firing rate

W_o = Liftoff weight of vehicle

y = Consecutive year of operational use of vehicle

For a SATURN size vehicle with a 1.2 million-lb liftoff weight, the pad time estimated is shown in Figure 7. In actual operations, the required pad time will cut across the lines as indicated in the examples given. A, B, and C represent typical programs with gradually increasing firing rates as will be discussed later.

The vehicle maintenance and repair cost for recoverable vehicles might be approximated as follows:

$$C'_M = K_{V,n} \cdot W_{s,n} \left(i_1 + i_2\right) \quad \left[\$/\text{unit}\right]$$

Ship or Air Recovery

$$C_{sh} = n_{sh} \cdot K_{sh} \quad \left[\$/\text{year}\right]$$

where

K_V = Vehicle production cost index

W_s = Dry weight of stage

i_1 = Refurbishment factor (labor)

i_2 = Refurbishment factor (hardware)

n_{sh} = Number of ships or aircraft

K_{sh} = Operating cost per ship or aircraft

The total effect of booster recovery on the project cost is shown in Figure 8. It is obvious that a considerable potential saving of funds is connected with the recovery and reuse of stages, but it is quite difficult to estimate the refurbishment factor.

Another item which requires considerable study is the "crew cost" which includes the training and the crew housing facilities at the launch site.

Of particular interest is the cost resulting from the services obtained from the range. This item is normally taken care of in government operations by making these expenses a line item in the budget of the responsible agency. However, in a true systems analysis, these range use costs have to be investigated in detail and charged against the individual flights. It might be possible to express these costs as a simple function of firing rate; e.g.,

$$C''_R = (a_2 + \frac{b_2}{N}) \times 10^6$$

where a_2 and b_2 are constants to be determined in each particular case. This relationship, using $a_2 = 0.2$, and $b_2 = 2.4$, is shown in Figure 9.

Other items of great interest are the cost for facilities, such as a launch position and the ground support equipment. While these items have to be investigated in each case with a particular condition in mind, it might be possible to approximate these expenditures for the purpose of system study by simple equations such as:

$$C_{G,F} = a + b \sqrt{W_o}$$

where the vehicle size is the only parameter. A few typical curves are shown in Figure 10. Another variable which might be introduced here is the number of complexes or sets required.

The specific payload cost, C**, which gives the total cost for the delivery of a payload to a particular point or position in space, has proved to be one of the most valuable comparison factors. This is defined as follows:

$$C^{**} = \frac{C}{Y \cdot N \cdot R_m \cdot W_{11}} \quad [\$/\text{lb}]$$

where

$$R_m = a_6 + b_6 \cdot \ln N^*$$

with

C = Total operating cost

Y = Number of years of operation

N = Annual firing rate

W_{11} = Weight of actual payload delivered

R_m = Mission reliability

N^* = Accumulated firing rate

a_6, b_6 = Constants

A typical mission reliability function (with $a_6 = 0.22$; $b_6 = 0.105$), assumed to be characteristic for multistage launch vehicles with a low altitude orbit rendezvous mission, is plotted in Figure 11. Mission reliabilities experienced for several ballistic missiles and space vehicles are also shown in this graph for comparison purposes. These data were taken from information which has been made public.

All required information and some cost factors and respective interrelationships have been discussed. This is required to consider integrated program requirements covered in the following section.

4. <u>Typical Integrated Program Requirements</u>

The major problem in long range planning for space transportation lies in the fact that the payload requirements are known only, with some accuracy, for the time period of 1960 to 1965. The payload requirements for the period 1966 to 1975, which are the determining factor for the design and development of the next generation launch vehicle, are unfortunately, not known at the present time.

However, to estimate what might be required in the future, a few typical payload requirements, in equivalent weights for a 300-nautical mile orbit, are listed below. It should be kept in mind, however, that these typical figures will change with time as the state of the art of space transportation changes.

1.	Construction of a 6-man space laboratory	0.1×10^6 lb
2.	Logistic support of a 6-man space laboratory	0.2×10^6 lb/year
3.	Construction of a 50-man space station	1.0×10^6 lb
4.	Manned lunar circumnavigation	1.0×10^6 lb
5.	Manned lunar landing of single 3-man crew and return	1.0×10^6 lb
6.	Construction of 10-man lunar observatory	6.0×10^6 lb
7.	Establishment of a 24-hour communication satellite system	0.2×10^6 lb

8. Logistic support of a 10-man lunar observatory — 3.5×10^6 lb/year

9. 15-man fast planetary expedition — 6.0×10^6 lb

A simple example to illustrate some of the major system parameters will be discussed before going to integrated space flight operations and their problems.

The solution of a simple systems problem might answer the following question: What is the most desirable size launch vehicle to transport a given volume over a five-year period, from the earth's surface to a low altitude orbit? The transport volume (total payload delivered) is the main variable. The vehicle is considered to be fully expendable.

All cost elements have been considered in this study and the results are shown in Figures 12 and 13. From Figure 12 it is easy to recognize that there is an optimum vehicle size for each given transport volume and operational time period. This optimum size, however, points toward small vehicle sizes which would require a very large number of launch pads and, therefore, might require more real estate than available. Thus, it seems that a compromise will have to be made between the optimum economical and optimum operational condition. This compromise is shown in Figure 13. From this graph it seems that no larger vehicle than the SATURN is required for transport volumes up to 3 million lb/year, provided there are no single payload requirements exceeding the capability of a single SATURN vehicle. For greater transport volume requirements, a larger vehicle might prove attractive.

This simple example, however, does not present a very accurate picture. First, there will be more than one type of vehicle involved to accomplish the desired transportation task and, second, the build-up of payload capabilities will be more gradual; it is not expected to be constant over a given number of years. These two limitations have been removed in another study of which some of the more interesting results are now discussed (Table 4). If these firing rates are multiplied by the payload weight and the mission reliability anticipated, the total payload capability is obtained as shown in Figure 14. If the actual payload delivered is divided by the theoretical maximum capability (100 percent mission reliability), the transport efficiency as shown in Figure 15 is obtained. Using the pad times given in Figure 7 for programs A, B, and C, the number of pads required to sustain this launch rate is given in Figure 16. The total direct cost for the launch operation of such typical programs is shown in Figure 17, and assumes a two-year lead time for funding prior to the launch date. This results in a peak requirement in FY 1968 because the firing rate is assumed constant after 1970.

Table 4

TYPICAL FIRING RATES AND DISTRIBUTION OF LAUNCH ATTEMPTS IN VARIOUS VEHICLE CLASSES

			FY 1960	61	62	63	64	65	66	67	68	69	70	ff
CLASS I	SCOUT	A		8	12	12	12	12	12	12	12	12	12	=
		B.		8	12	18	24	24	24	24	24	24	24	=
		C		8	16	24	30	36	36	36	36	36	36	=
CLASS II	THOR-AGENA	A	15	15	12	12	12	12	12	12	12	12	12	=
		B	15	18	18	18	18	18	18	18	18	18	18	=
		C	15	18	24	24	24	24	24	24	24	24	24	=
CLASS III	AGENA/CENTAUR	A	6	12	18	24	24	24	24	24	24	24	24	=
		B	6	12	24	30	36	36	36	36	36	36	36	=
		C	6	12	24	36	48	48	48	48	48	48	48	=
CLASS IV	SATURN	A			2	4	6	8	12	16	20	24	30	=
		B			3	4	8	15	24	36	48	54	60	=
		C			3	4	8	15	24	48	72	96	120	=
CLASS V	"NOVA"	A						1	2	4	6	9	12	=
		B						3	7	12	18	24	30	=
		C						3	7	12	24	36	48	=

5. Resources and Program Balance

When attempting to balance the financial resources and the space flight program, one has to have the cost for development, manufacturing, and operation of the payloads and/or spacecraft, as well as the cost for ground equipment and general overhead, in addition to the launch operation cost. Since these are not known at the present time, this balancing procedure cannot be accomplished.

An arbitrary example was chosen which might illustrate the relative portion required by the launch vehicle program, considering only the direct operating cost. By arbitrarily combining the launch rate A with funding plan A*, B with B*, and C with C*, one obtains the curves shown in Figure 18. While a very large portion of the total amount of money is available for research and development in the early years, more production and operational money will be required in the later years. If the firing rates and funding plans, and the combination thereof, should be correct by coincidence, one would expect that 60 to 70 percent of the total funds will be needed for the basic transportation. It would not be surprising if the other cost elements would demand a larger share of the total funding. It should be kept in mind, however, that the major portion of the payload capacities available will be used by ordinary cargo, such as food, water, construction materials, and propellants bought into orbit for orbital launch vehicles going to the moon or planets. Therefore, only a limited number of payloads and spacecraft would have to be developed.

6. Trends of Transportation Cost

The trends of transportation cost are best summed up by plotting the direct operating cost (vehicle manufacturing, propellants, ground transportation and launch operations) versus time for some typical missions. The first mission of interest is the transportation of payloads from the earth's surface to a low altitude orbit (96-min = 300 NMi). This has been done in Figure 19 for three typical firing rates, A, B, and C, for an integrated launch operation with five different vehicle types participating. Expected actual mission reliabilities have been included. The dotted lines indicate the same program but with the largest class (NOVA size) vehicle eliminated. The graph is valid only for all-chemical propellant launch vehicles - nuclear propulsion has not been considered as this will not influence the trend before 1970. As can be seen from the plot, an order of magnitude reduction of the basic transportation cost can be expected about every seven years. Based on a fairly aggressive space flight program, it seems feasibly to reach a $100/lb figure early in the 1970's; particularly if booster and stage recovery is introduced. Introducing nuclear propulsion and full recovery should bring the transportation cost down by another order of magnitude in the later 1970's.

The trends for lunar transportation cost (soft lunar landing) are somewhat more difficult to determine. An estimate of the trends in this mission area is shown in Figure 20. The specific cost can fall anywhere within the band because it will depend on the composition of the launch vehicle program. Similar trends can be established for planetary soft landing missions, as shown in Figure 21 for Martian soft landings. Further studies are required to establish more accurate data. From both curves it can be concluded that the specific transportation cost for both of these missions will drop by two orders of magnitude within the next ten years. Whether this trend continues and offers lunar soft landing cost of \$10/lb early in the 1980's remains to be seen. As far as can be judged today, there is a good possibility of accomplishing this.

7. Conclusions

Considering the broad picture of launch operations in the future, the following statements seem to be justified:

(1) It is very likely that AMR and PMR will be able to handle all launch operations within the foreseeable national space flight program provided nuclear safety requirements can be satisfied.

(2) It is possible to estimate launch operations cost of present and future launch vehicles as a function of firing rate to a degree of accuracy satisfactory for planning purposes. Further studies are required to determine the influence of the individual cost parameters.

(3) The launch pad utilization for space vehicles has developed into one of the most important system parameters and a great effort to reduce the launch time for each launch vehicle seems to be justified.

(4) A close cooperation between all parties concerned is required to determine the relationships between performance, cost, and facility requirements with a greater degree of accuracy.

Fig. 1 MAJOR MISSION ACCOMPLISMENT

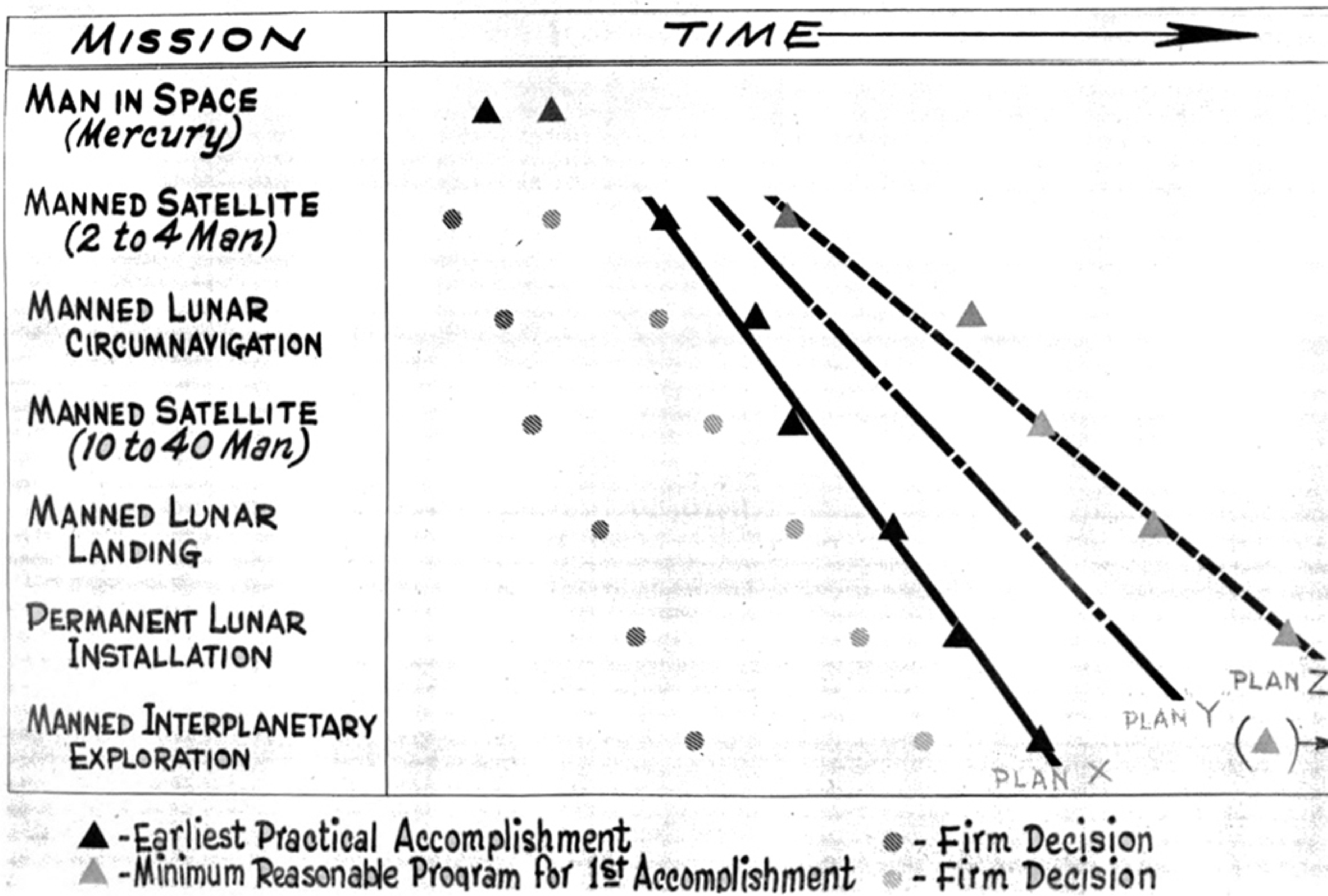


Fig. 2 LAUNCH VEHICLE DEVELOPMENT
(GROSS ESTIMATES)

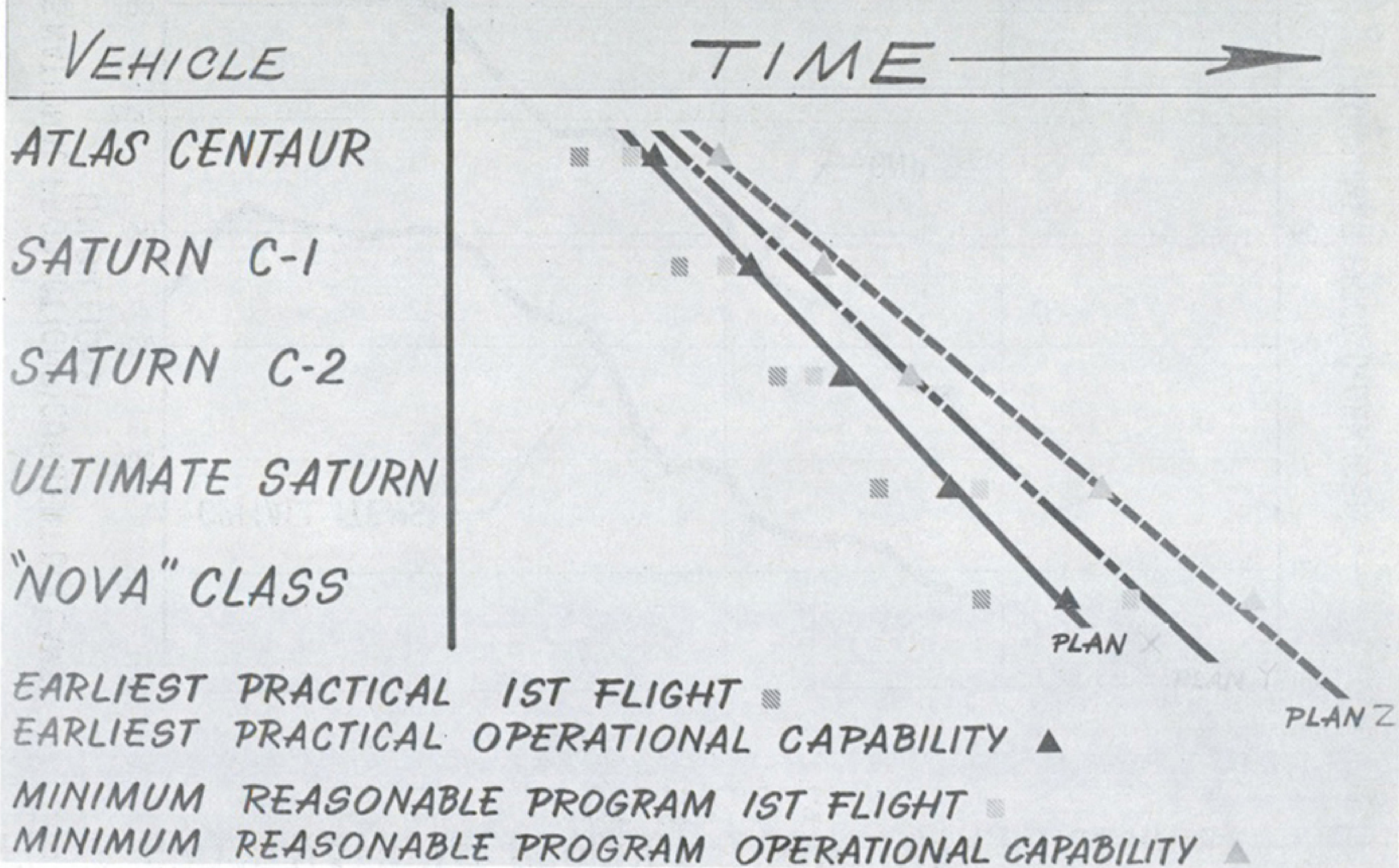


Fig. 3 **GROSS NATIONAL PRODUCT & CONSUMER PRICE INDEX OF THE U.S.**

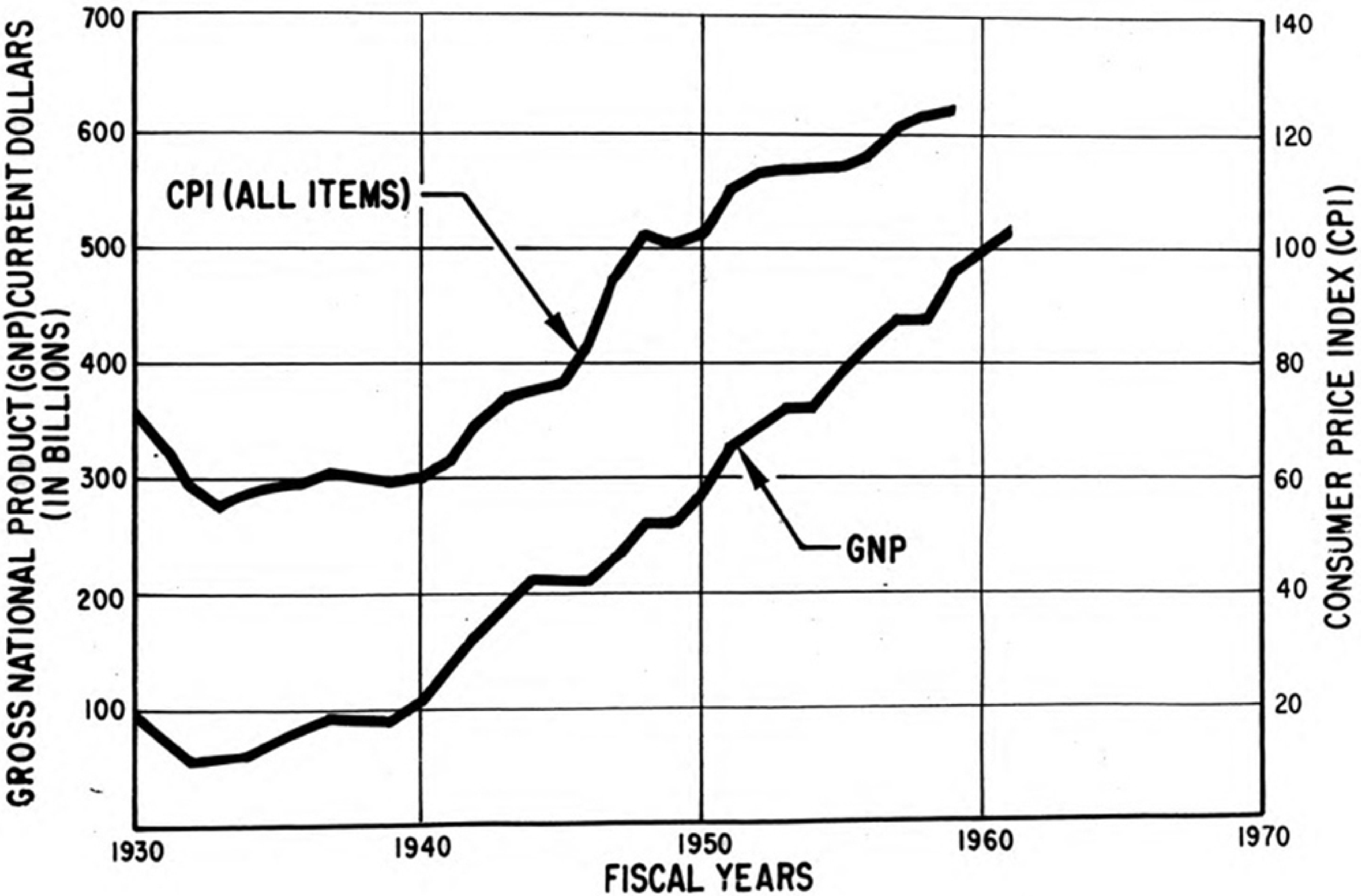


Fig. 4 **TOTAL GOVERNMENT BUDGET & MAJOR NATIONAL SECURITY EXPENDITURES**

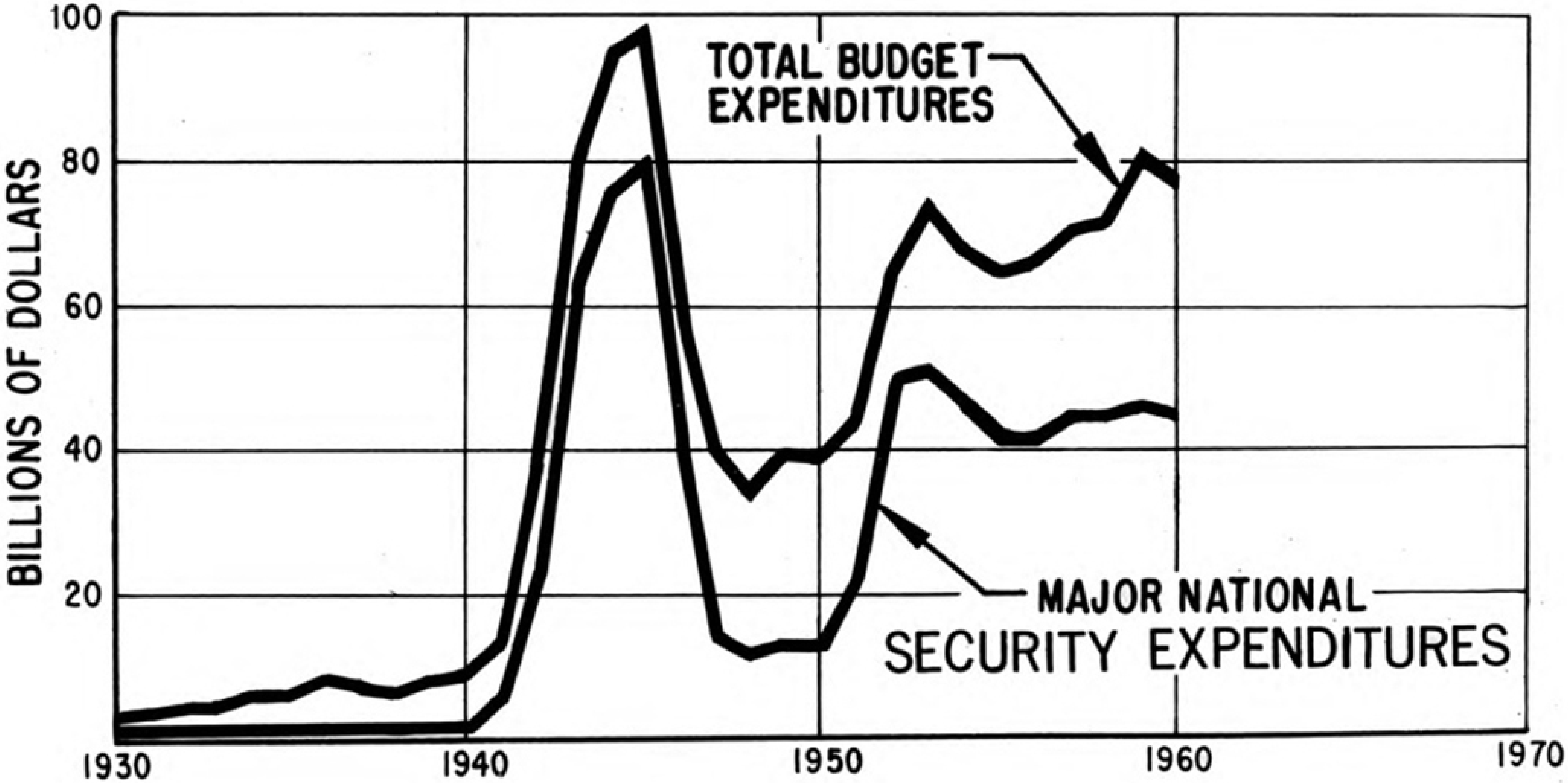


Fig. 5
FUNDS AVAILABLE FOR MISSILE DEVELOPMENT AND PRODUCTION

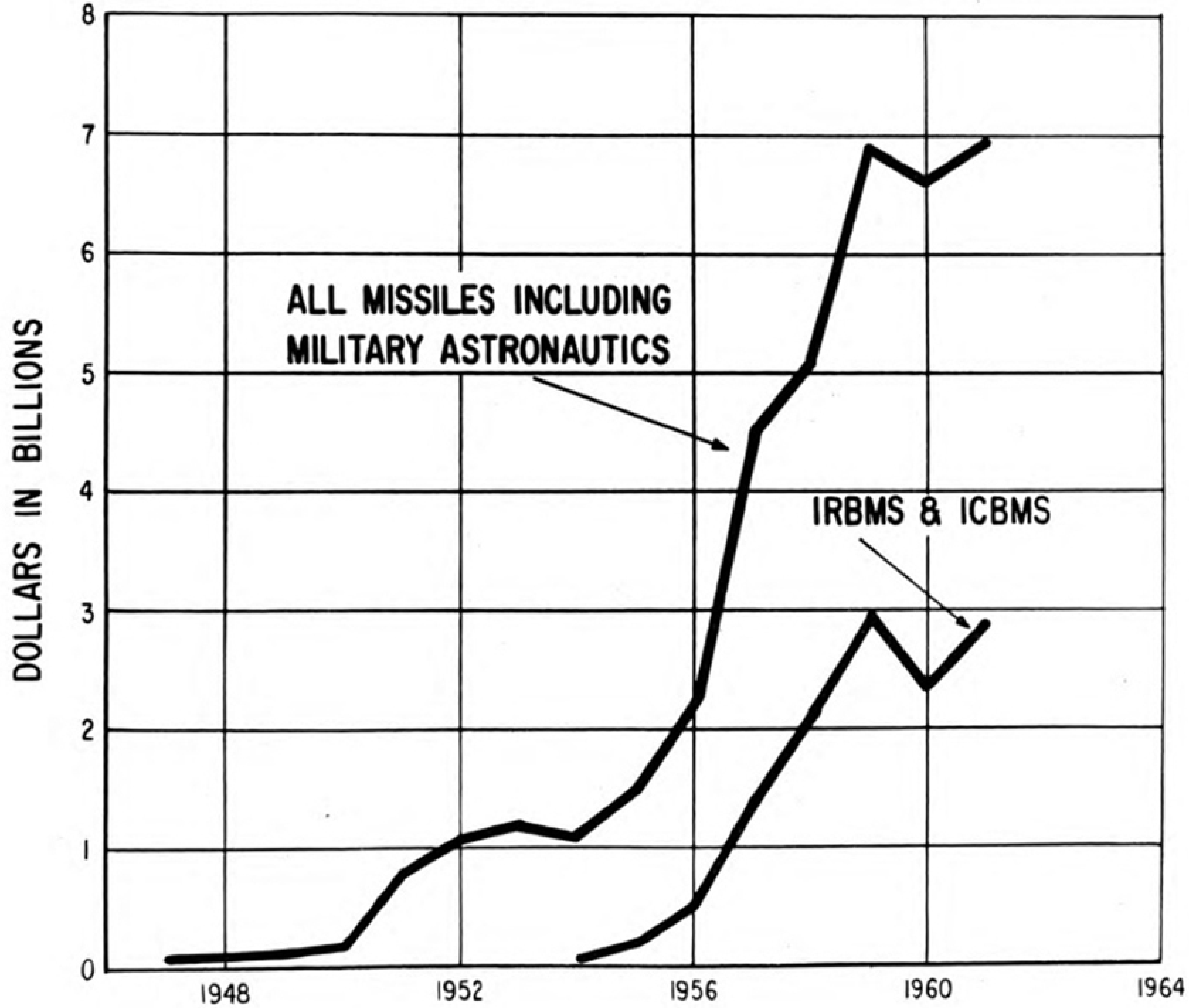


Fig. 6 TYPICAL FUNDS FOR ASTRONAUTICAL ACTIVITIES

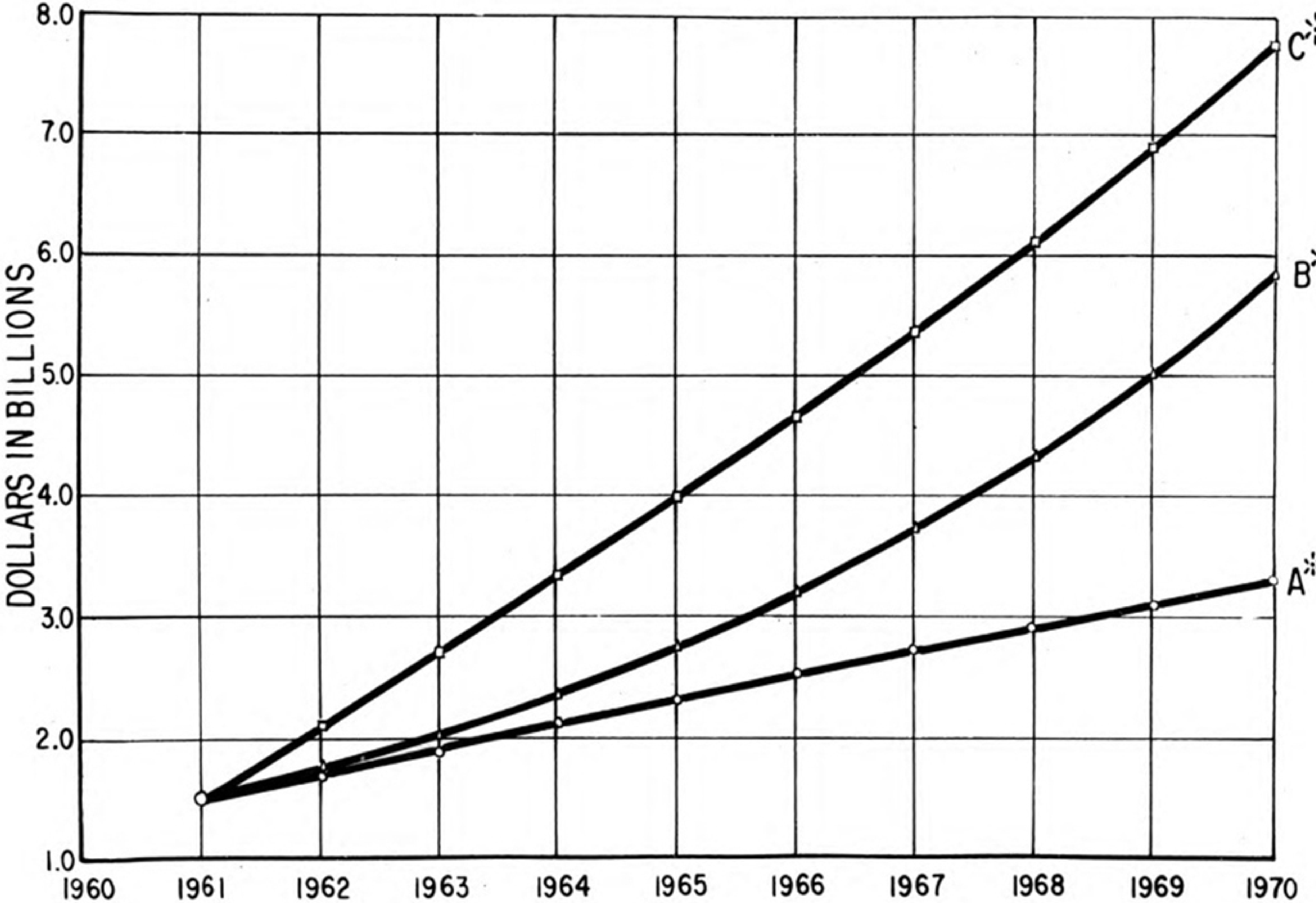


Fig. 7 ESTIMATED PAD TIME FOR SATURN SIZE VEHICLE

USING AUTOMATIC CHECKOUT PROCEDURES

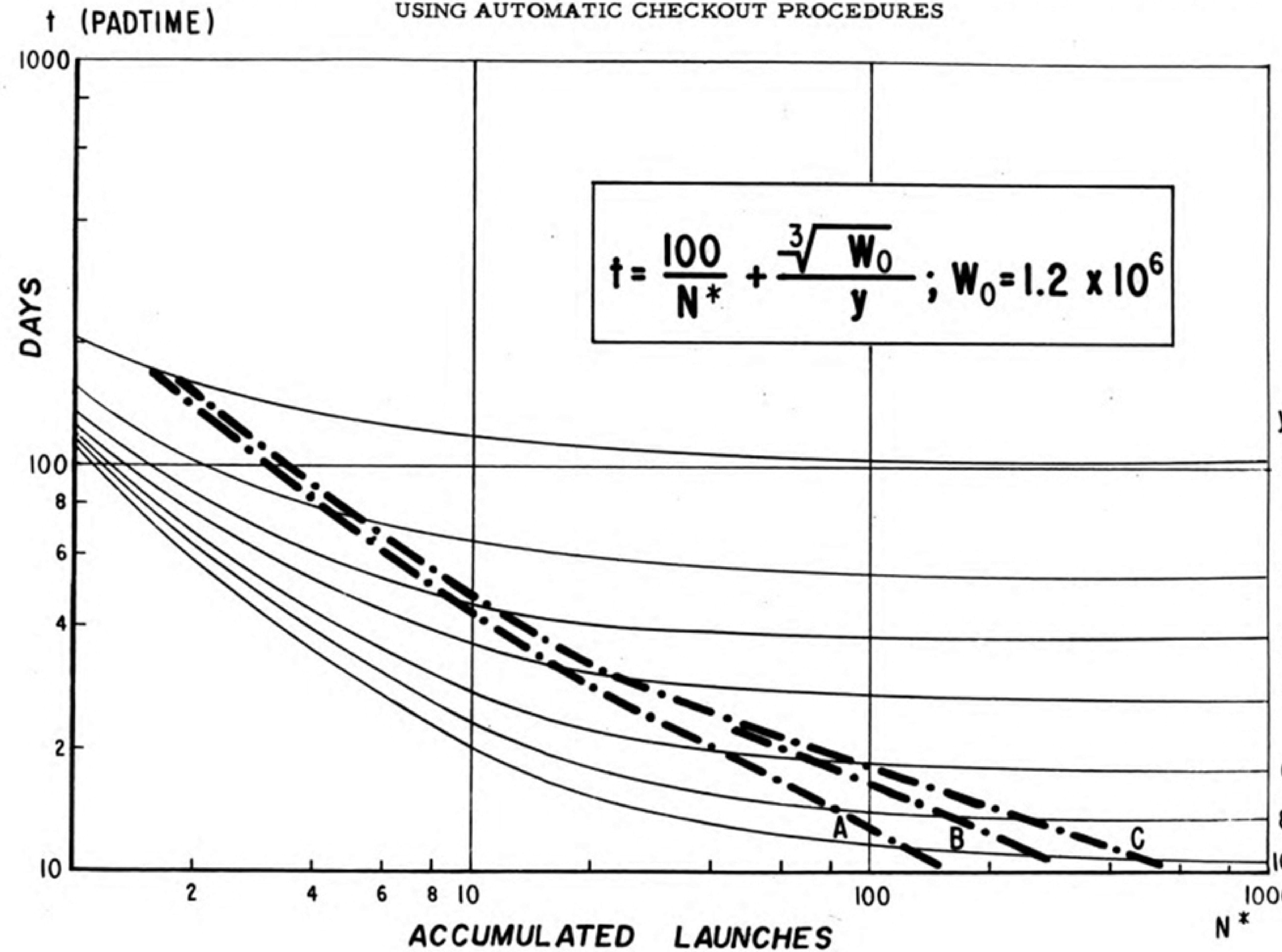
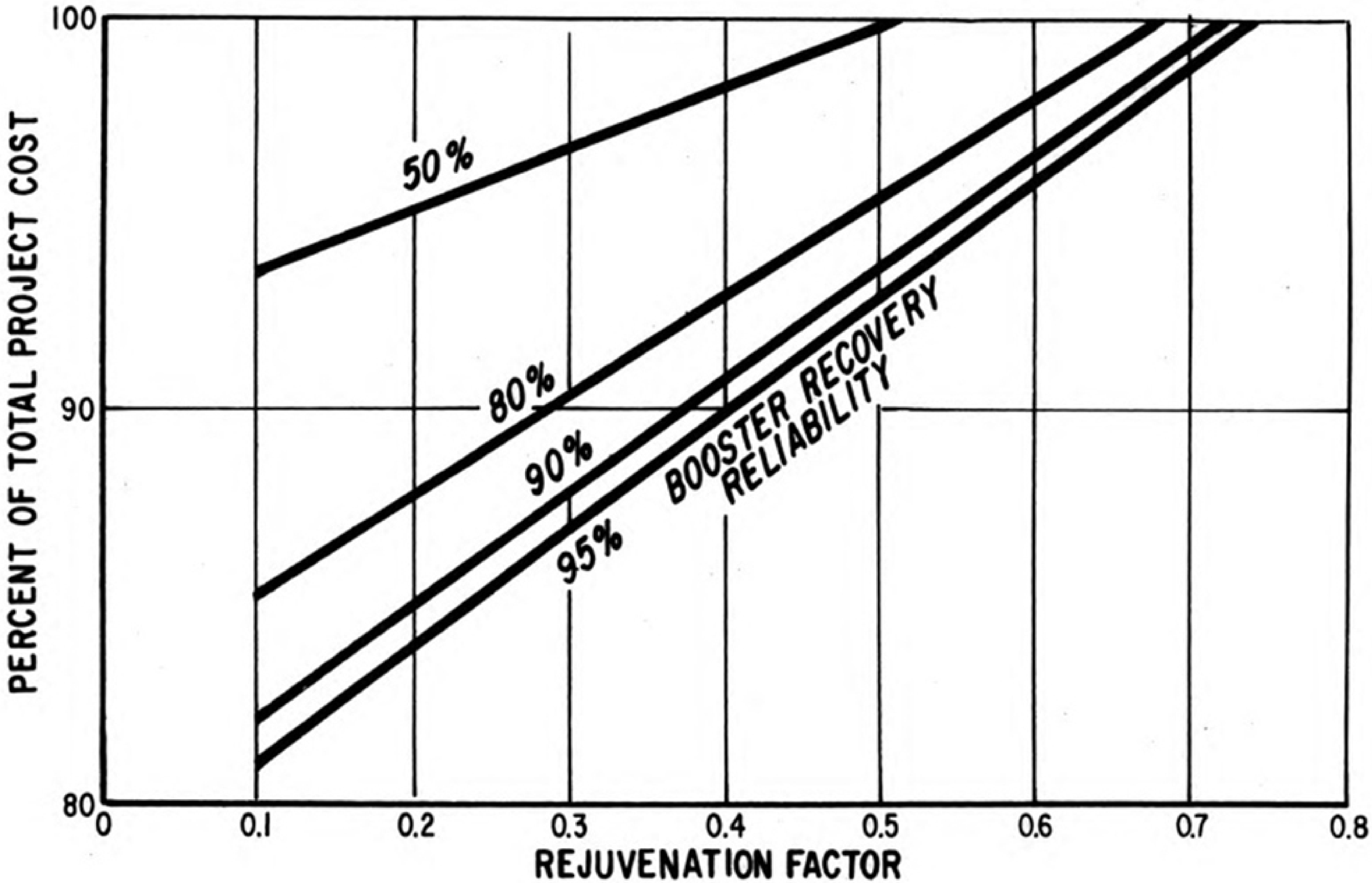


Fig. 8 THE EFFECT OF BOOSTER RECOVERY ON TOTAL PROJECT COSTS



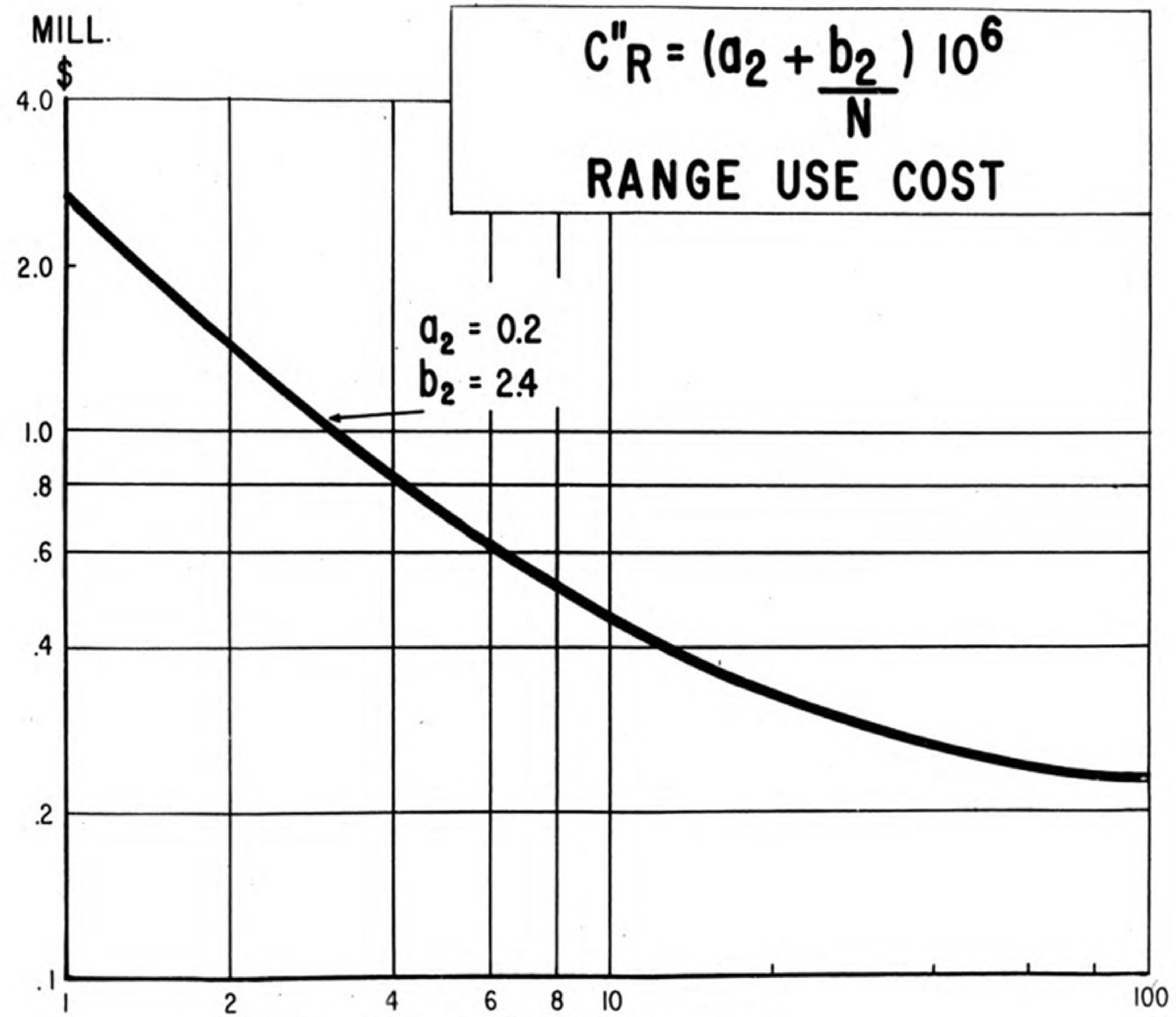


Fig. 9 ANNUAL FIRING RATE N

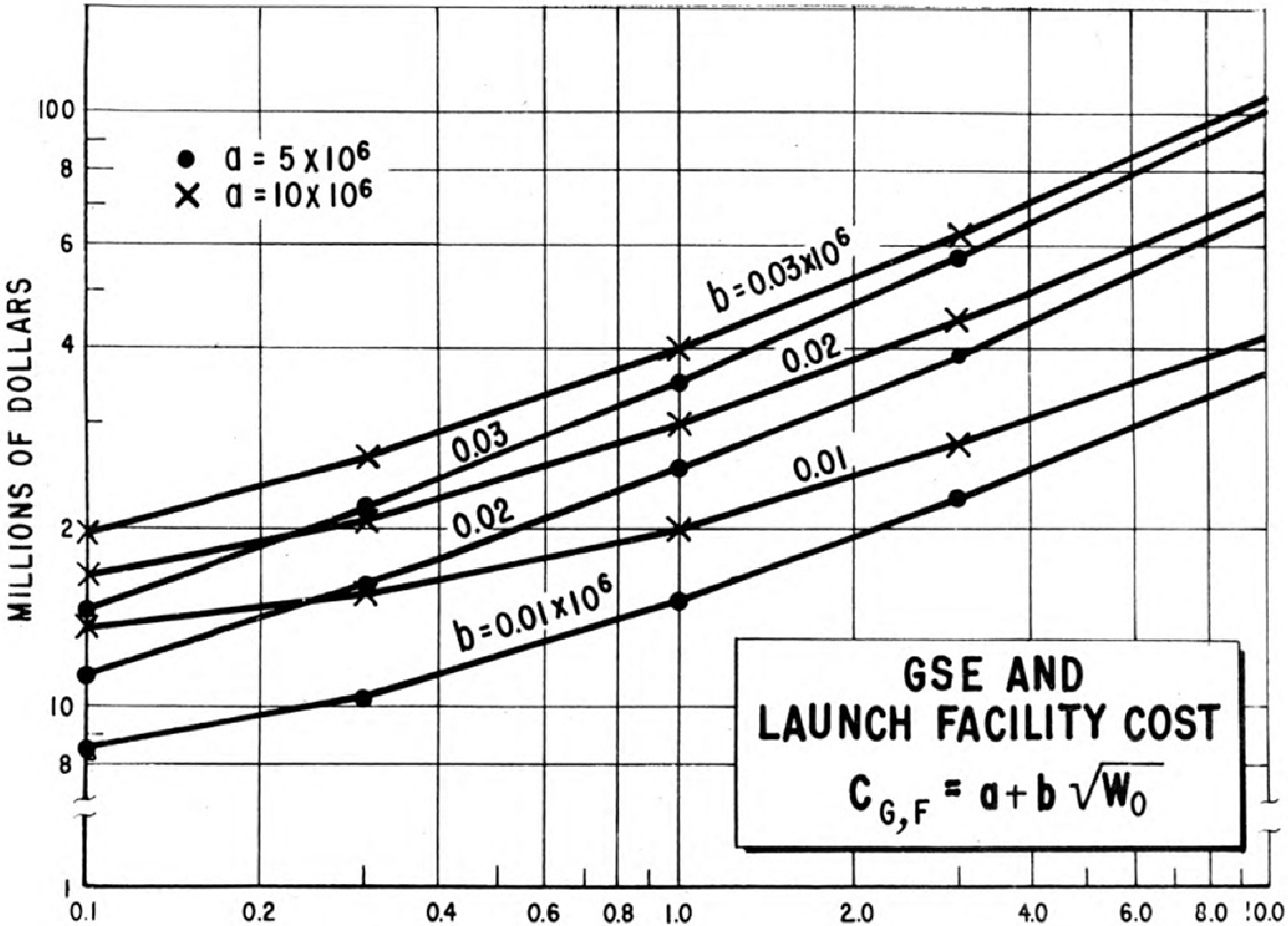


Fig. 10 VEHICLE TAKE-OFF WEIGHT (10^6 lb)

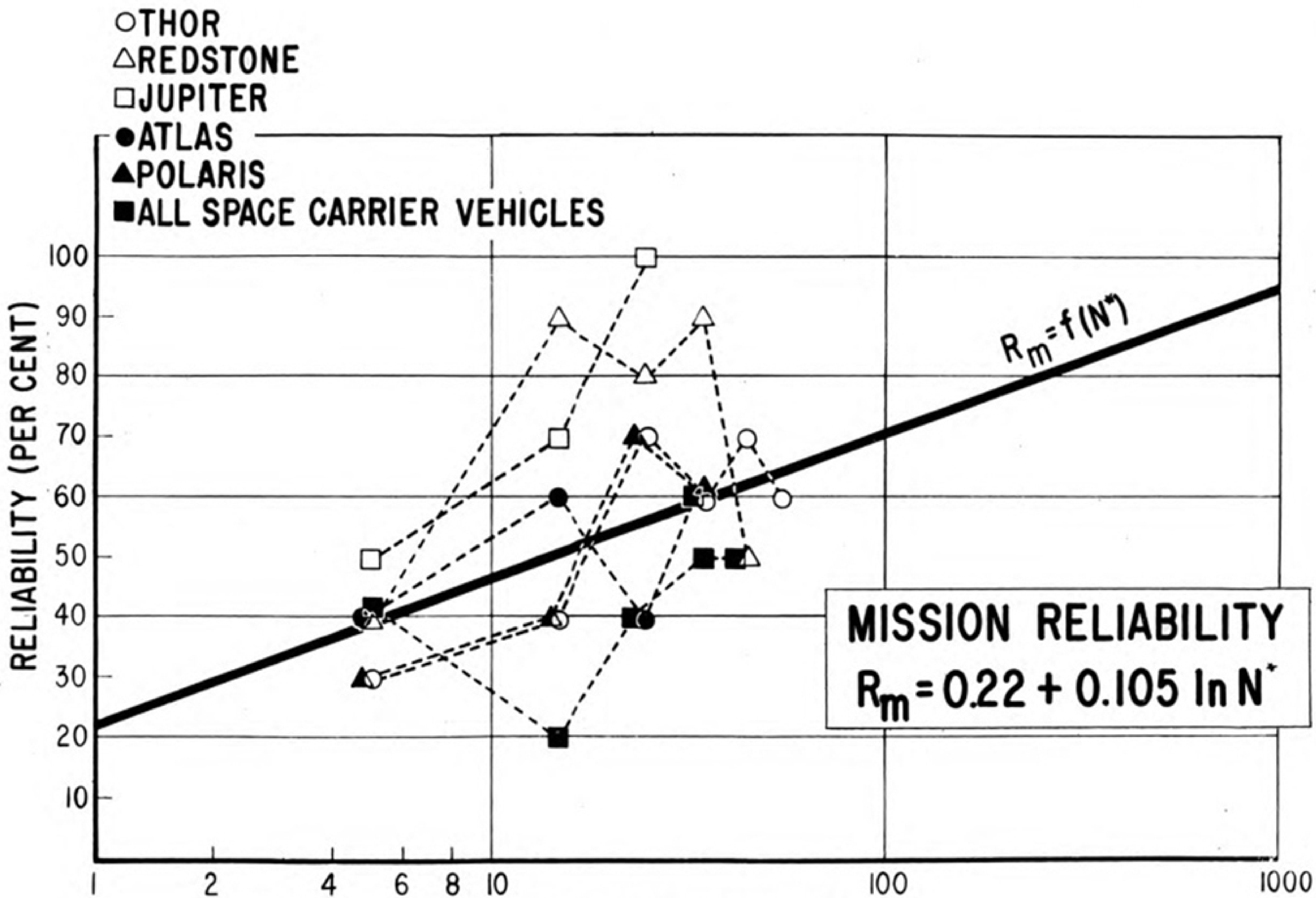


Fig. 11 ACCUMULATED LAUNCHES

Fig. 12
AVERAGE TOTAL OPERATING COST FOR THE 1966 TO 1970 PERIOD VS TAKE-OFF WEIGHT OF ORBITAL CARRIER VEHICLE WITH TRANSPORT VOLUME AND AVERAGE NUMBER OF PADS AS PARAMETERS

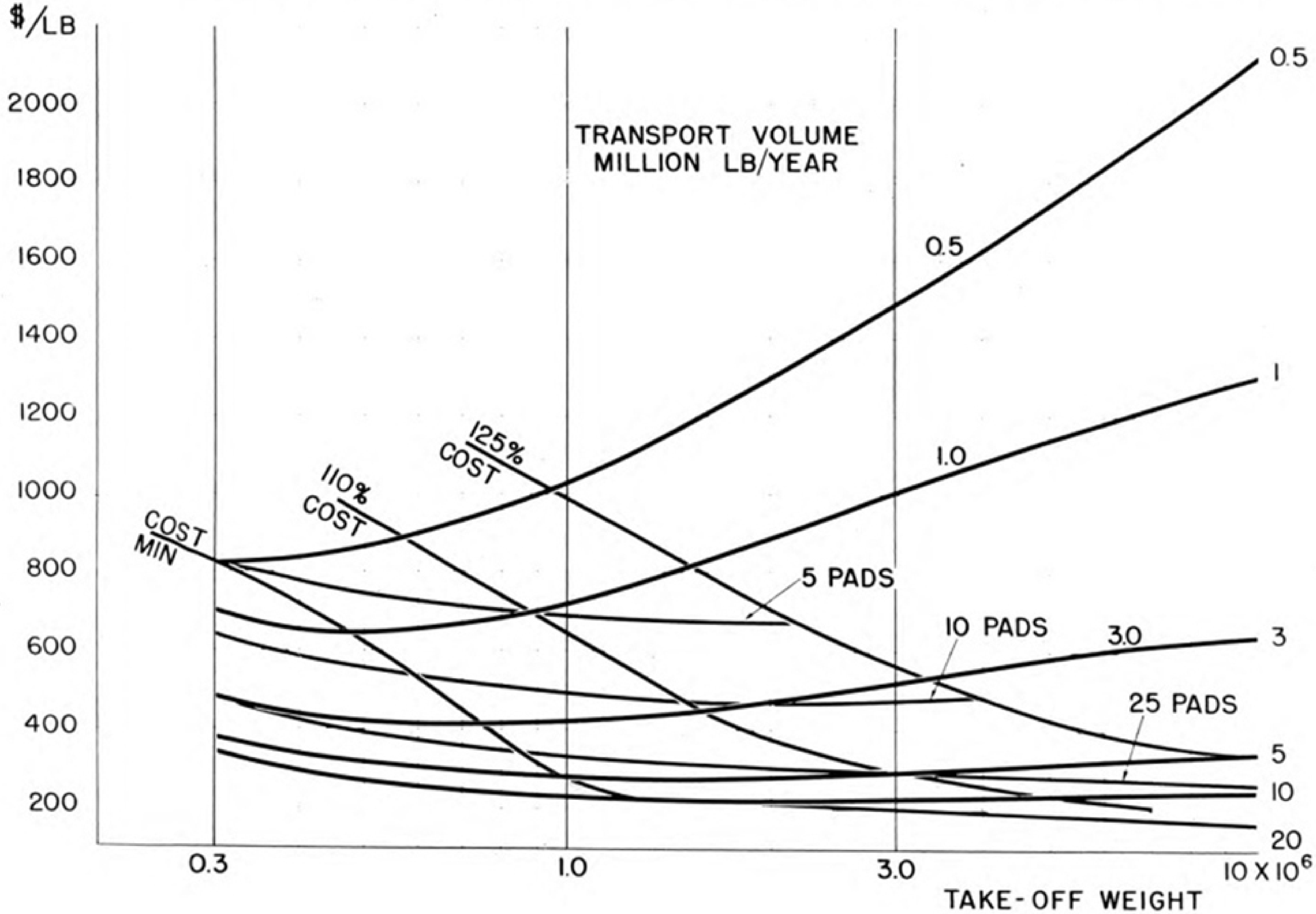


Fig. 13

LAUNCH VEHICLE WEIGHT VS. TRANSPORT VOLUME WITH NUMBER PADS AND COST PARAMETERS VALID FOR FIVE YEAR OPERATIONAL LIFETIME

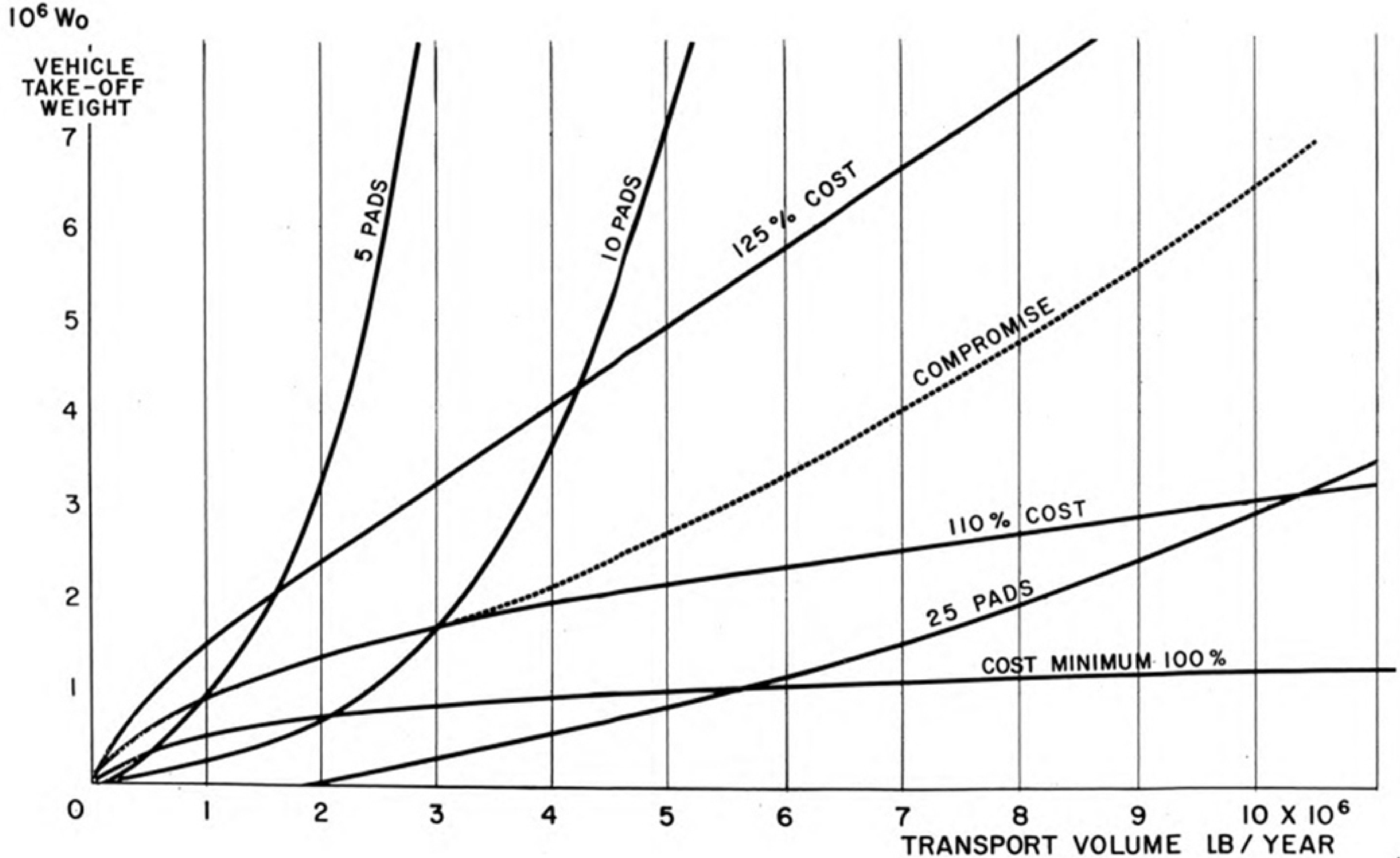


Fig. 14 ANNUAL TRANSPORT VOLUME CAPABILITY FOR TYPICAL FIRING RATES SELECTED

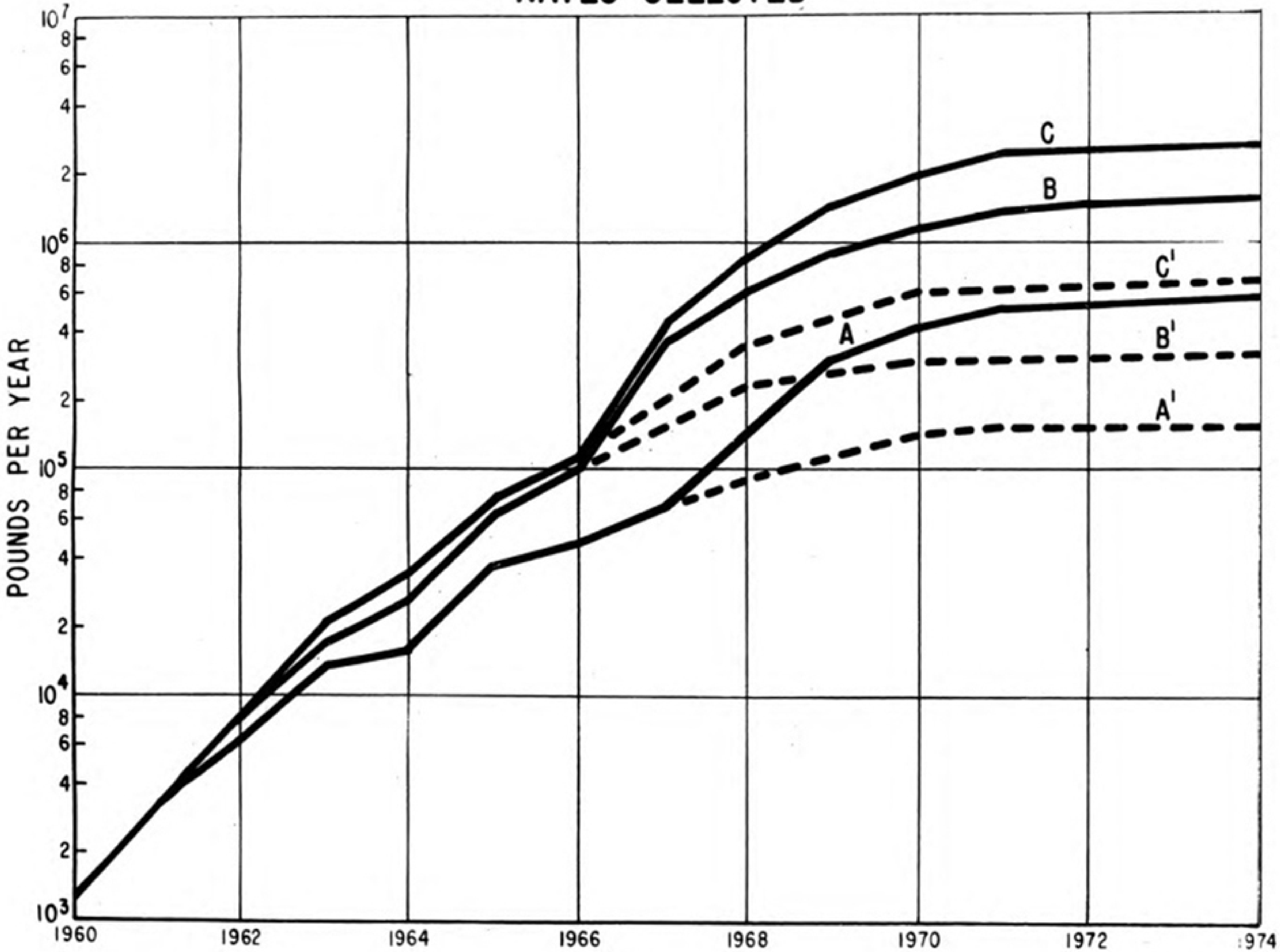
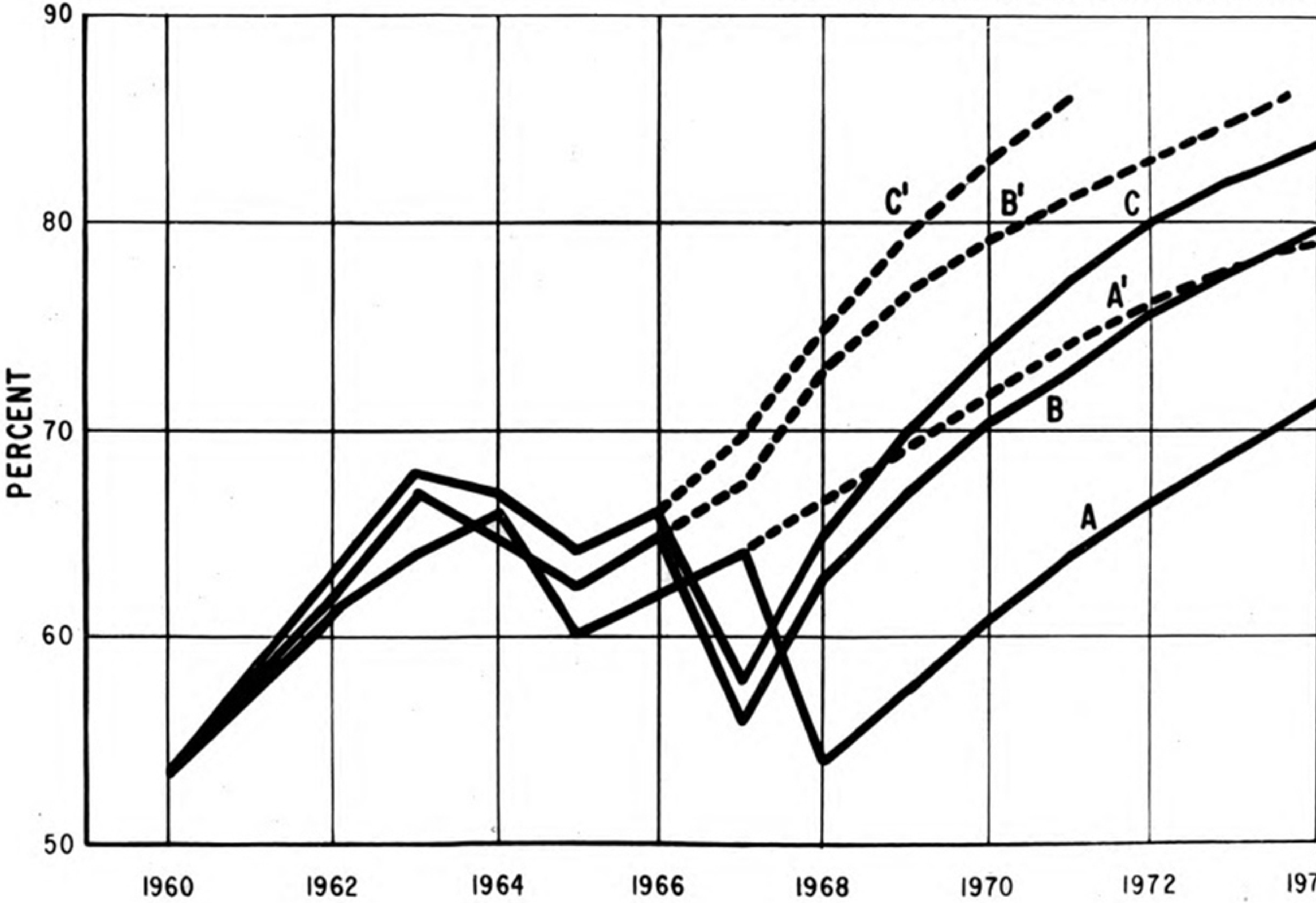


Fig. 15

TRANSPORTATION EFFICIENCY = $\frac{\text{ACT. PAYLOAD CAPABILITY}}{\text{MAX. PAYLOAD CAPABILITY}}$



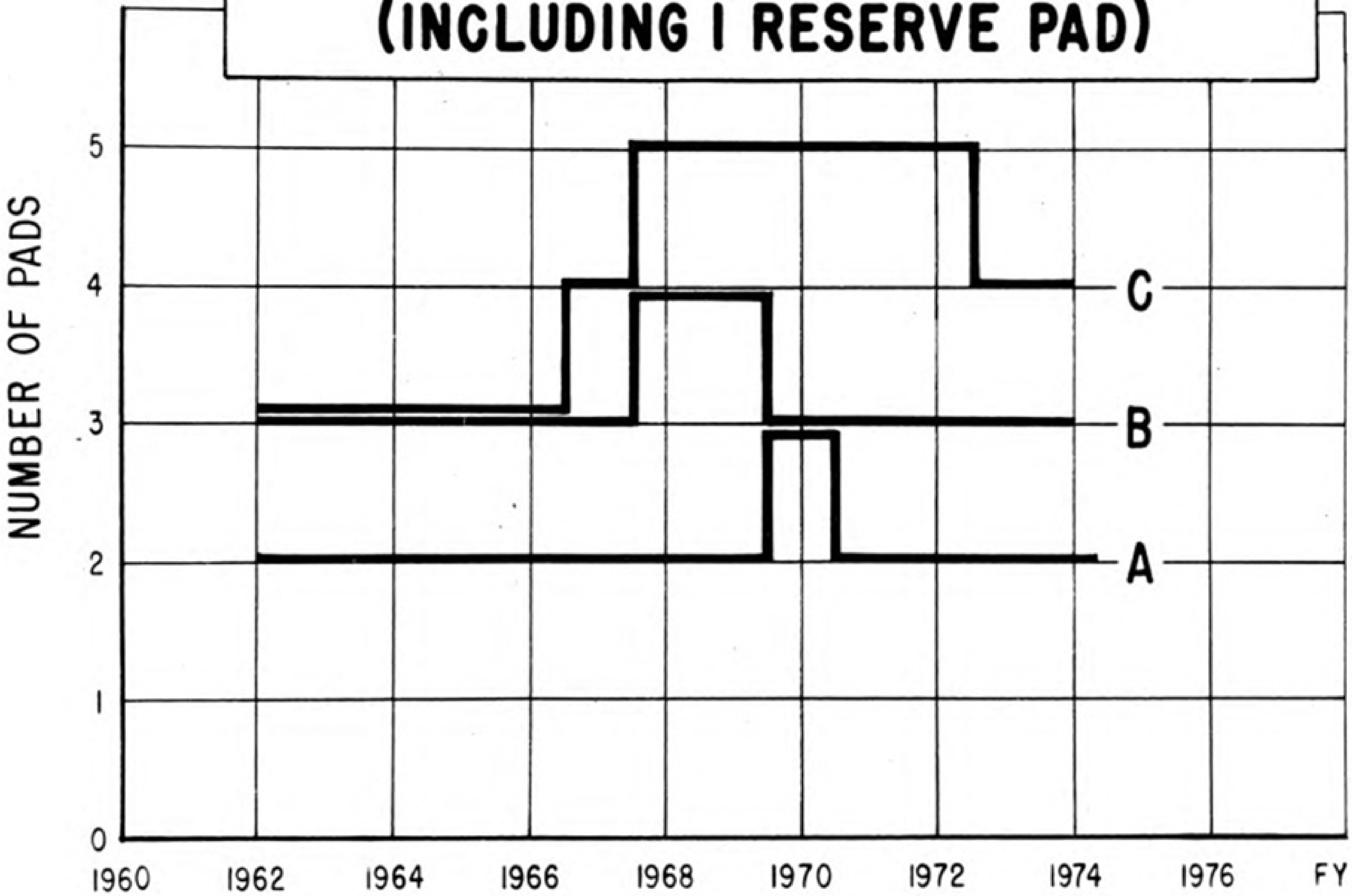


Fig. 16 **NUMBER OF PADS REQUIRED FOR SATURN SIZE LAUNCH VEHICLES FOR THREE TYPICAL PROGRAMS (INCLUDING 1 RESERVE PAD)**

Fig. 17

FUNDING REQUIREMENTS FOR DIRECT OPERATING COST (LAUNCH VEHICLES) FOR SELECTED TYPICAL PROGRAMS

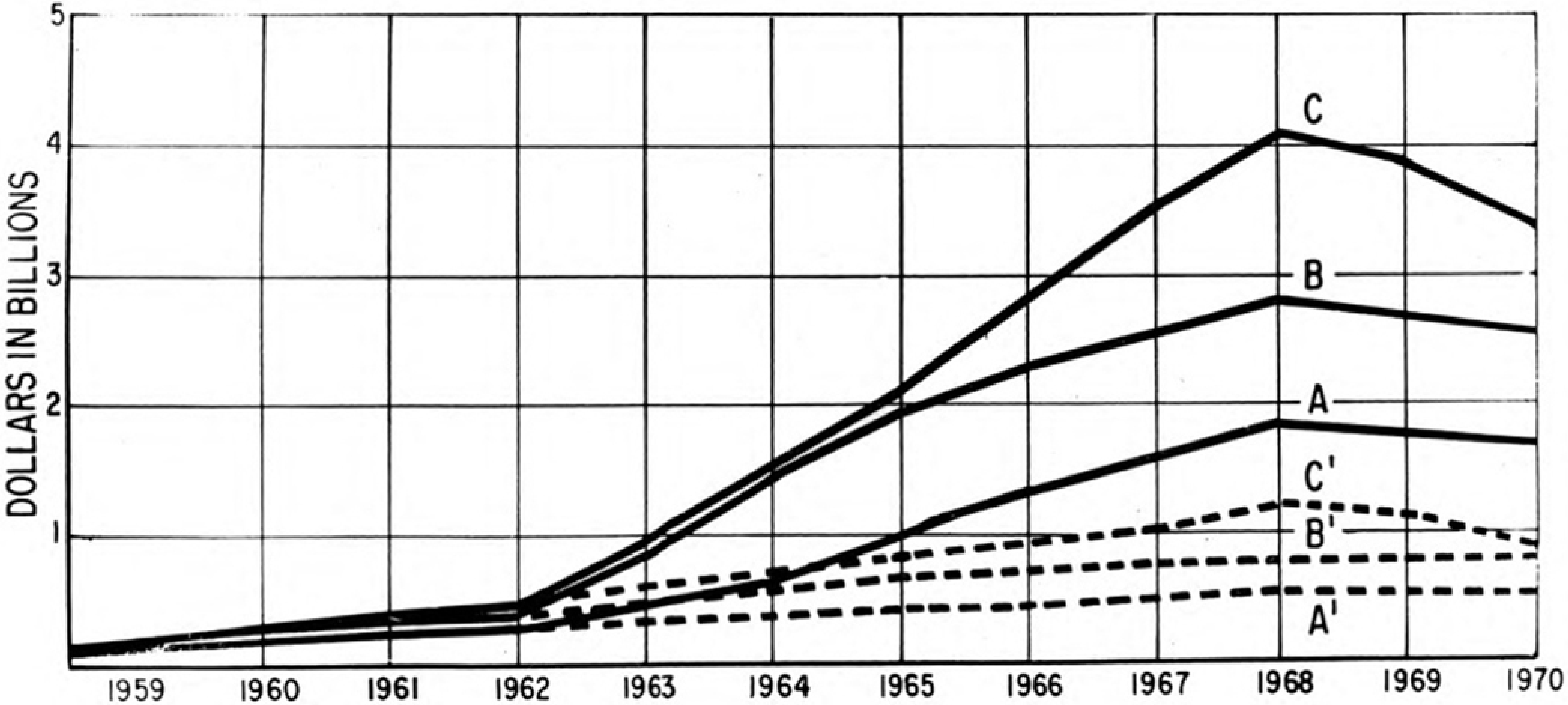
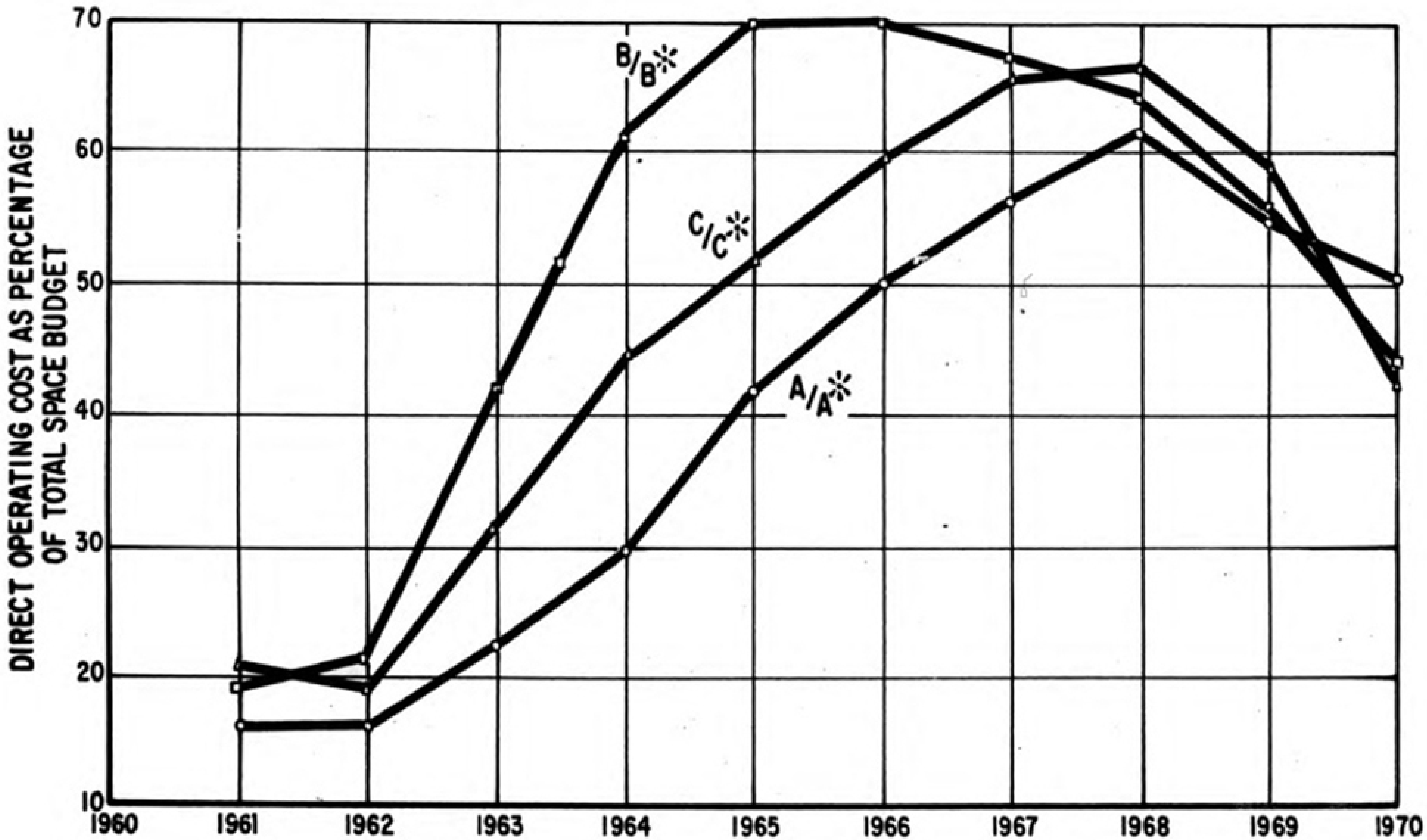


Fig. 18

PERCENT OF TOTAL SPACE FLIGHT BUDGET REQUIRED TO COVER THE DIRECT OPERATING COST FOR SPACE TRANSPORTATION FOR THREE TYPICAL FIRING RATES AND THREE ARBITRARILY COMBINED FUNDING RATES



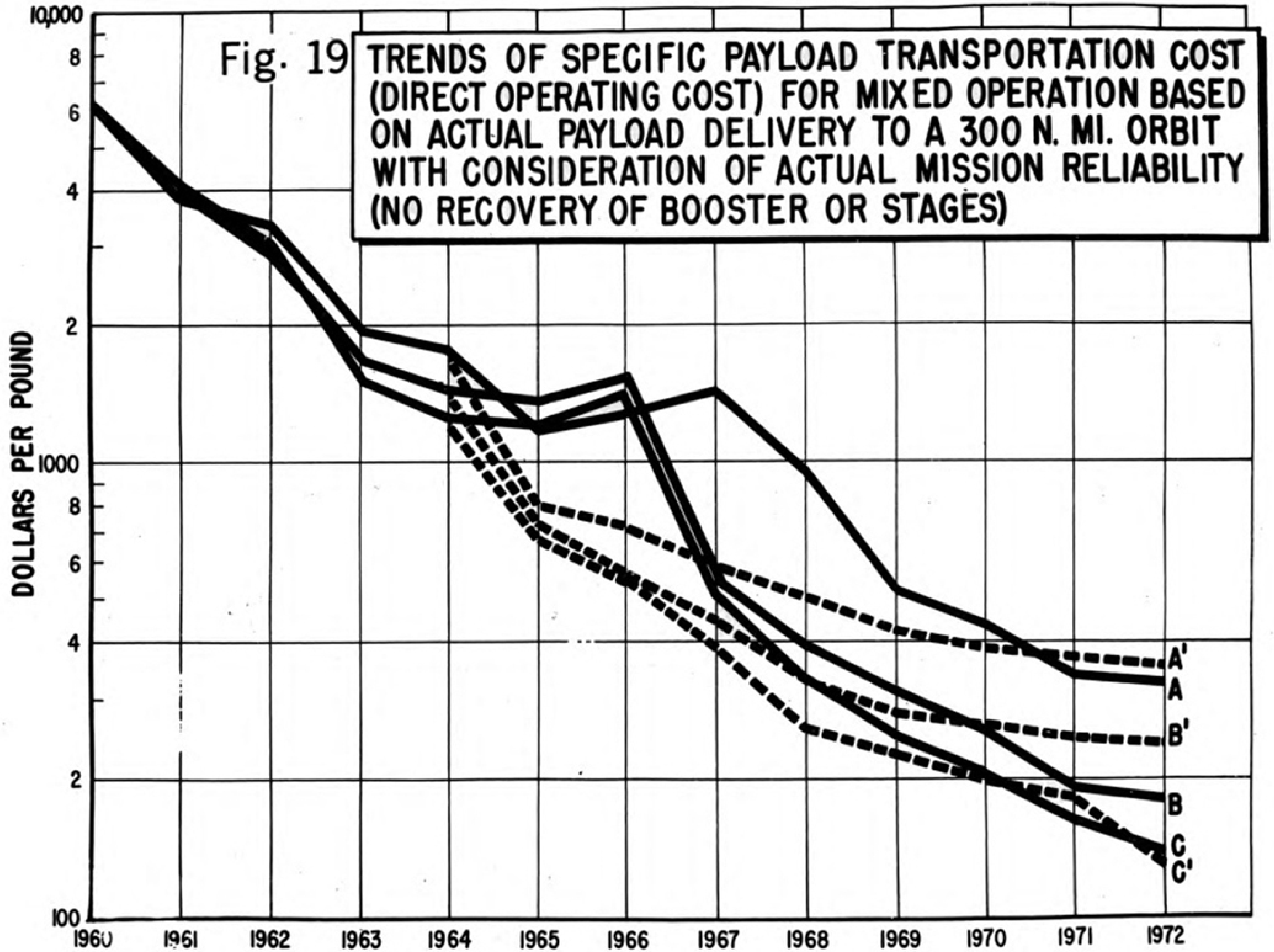


Fig. 19 TRENDS OF SPECIFIC PAYLOAD TRANSPORTATION COST (DIRECT OPERATING COST) FOR MIXED OPERATION BASED ON ACTUAL PAYLOAD DELIVERY TO A 300 N. MI. ORBIT WITH CONSIDERATION OF ACTUAL MISSION RELIABILITY (NO RECOVERY OF BOOSTER OR STAGES)
DOLLARS PER POUND
10,000
8
6
4
2
1000
8
6
4
2
100
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
A'
A
B'
B
C
C'

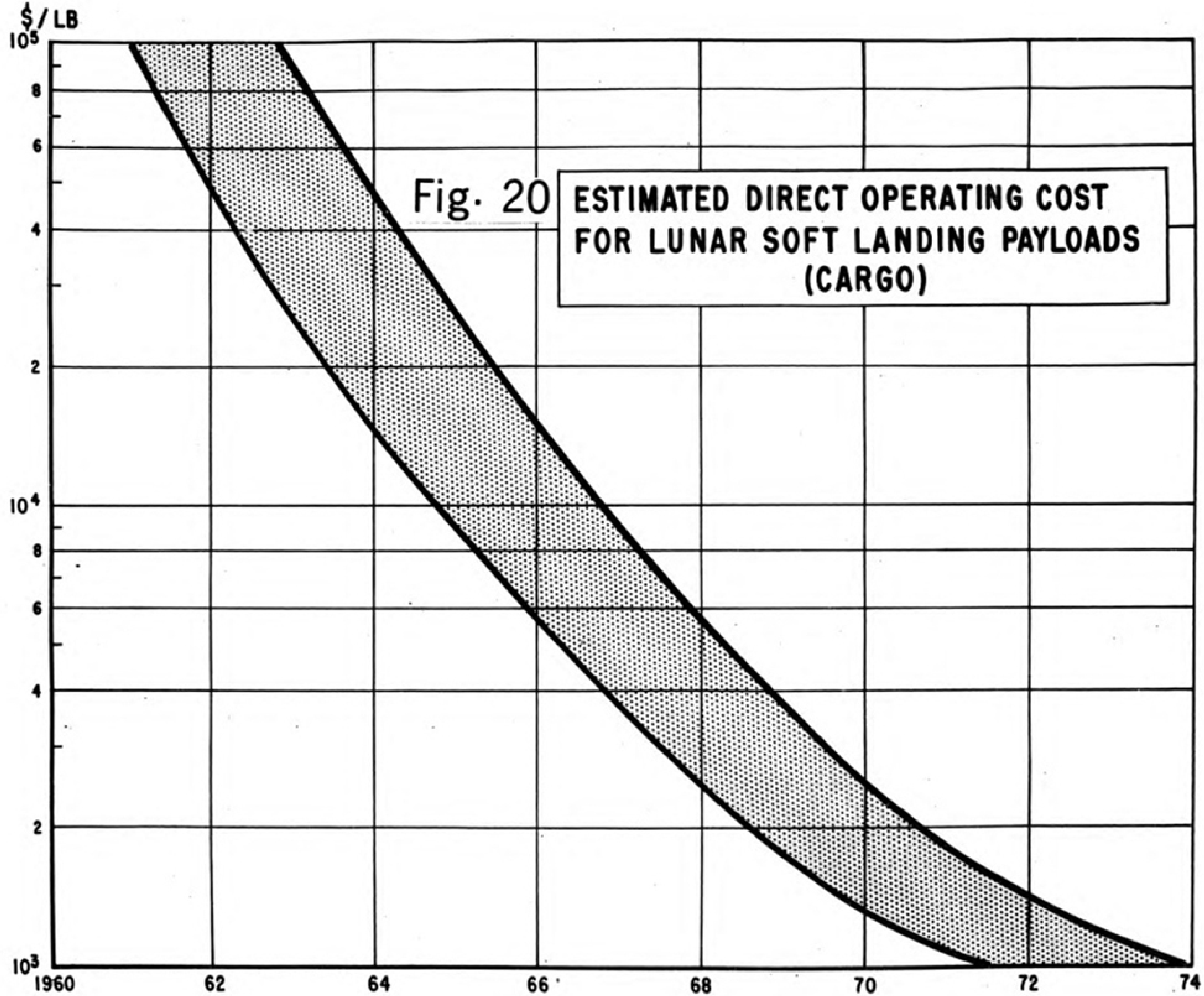


Fig. 20 ESTIMATED DIRECT OPERATING COST FOR LUNAR SOFT LANDING PAYLOADS (CARGO)

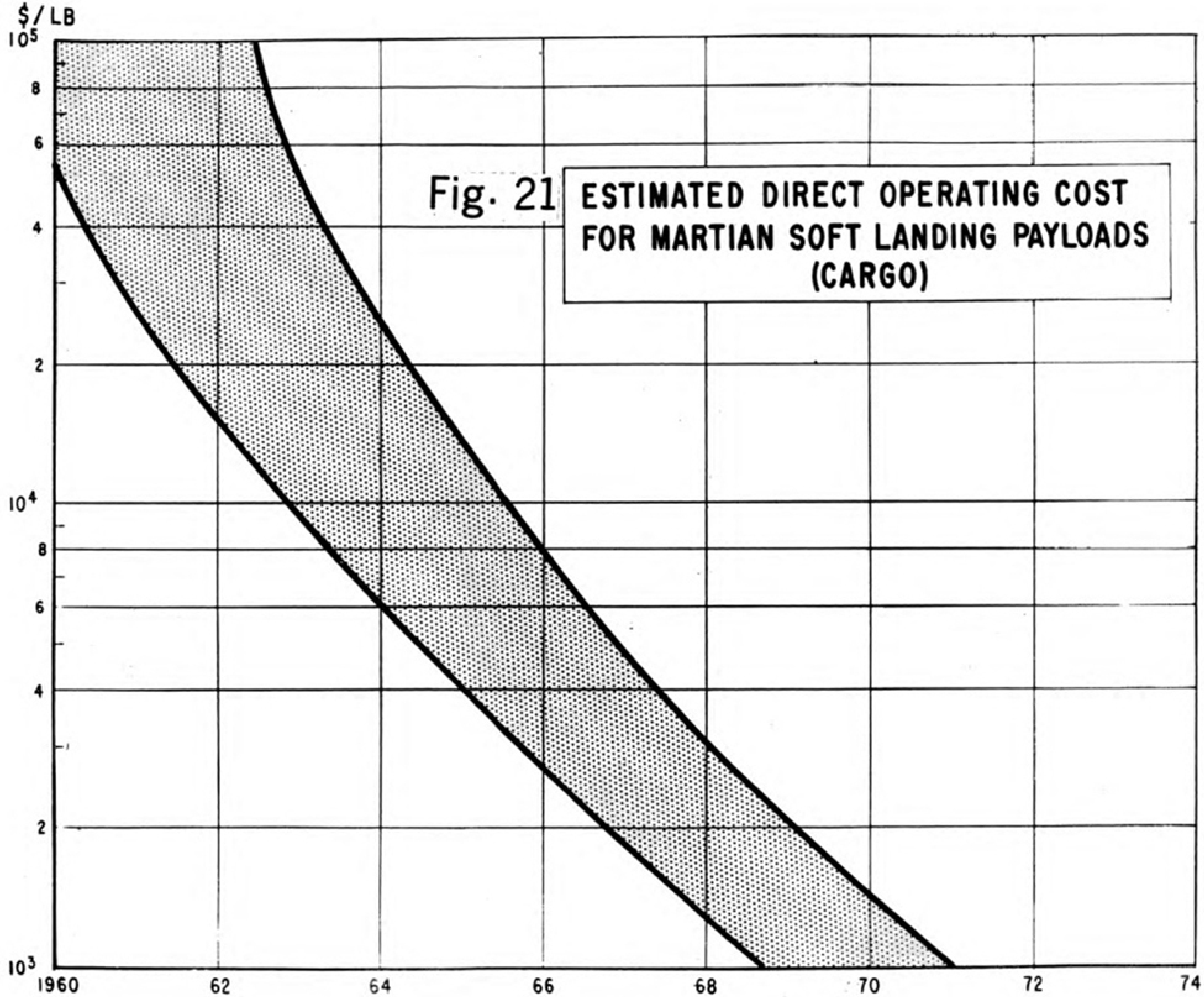


Fig. 21 ESTIMATED DIRECT OPERATING COST FOR MARTIAN SOFT LANDING PAYLOADS (CARGO)