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MANNED MARS MISSION COST ESTIMATE

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ABSTRACT

The potential costs of several options of a manned Mars mission are examined. A cost estimating methodology based primarily on existing Marshall Space Flight Center (MSFC) parametric cost models is summarized. These models include the MSFC Space Station Cost Model and the MSFC Launch Vehicle Cost Model as well as other models and techniques. The groundrules and assumptions of the cost estimating methodology are discussed and cost estimates presented for six potential mission options which have been studied. The estimated manned Mars mission costs are compared to the cost of the somewhat analogous Apollo Program cost after normalizing the Apollo cost to the environment and groundrules of the manned Mars missions. It is concluded that a manned Mars mission, as currently defined, could be accomplished for under $30 billion in 1985 dollars excluding launch vehicle development and mission operations.

COST ESTIMATING METHODOLOGY

The costs for the manned Mars missions were primarily estimated using adaptations of existing parametric cost models which relate the cost of historical NASA programs to certain technical characteristics of those programs (e.g. weight, power, etc.). Figure 1 is a typical example of such a relationship. The majority of the hardware items required for the mission were estimated at the subsystem level using such cost estimating relationships (CER's). Specifically, the models utilized and their application were:

(1) COST MODEL: MSFC Launch Vehicle Cost Model

WHERE APPLIED:
- LEO Departure Stage and Engines
- Mars Arrival and Departure Stage and Engines
- Descent Stage and Engines
- Ascent Stage and Engines
- Earth Braking Stage
- KSC Launch Facilities

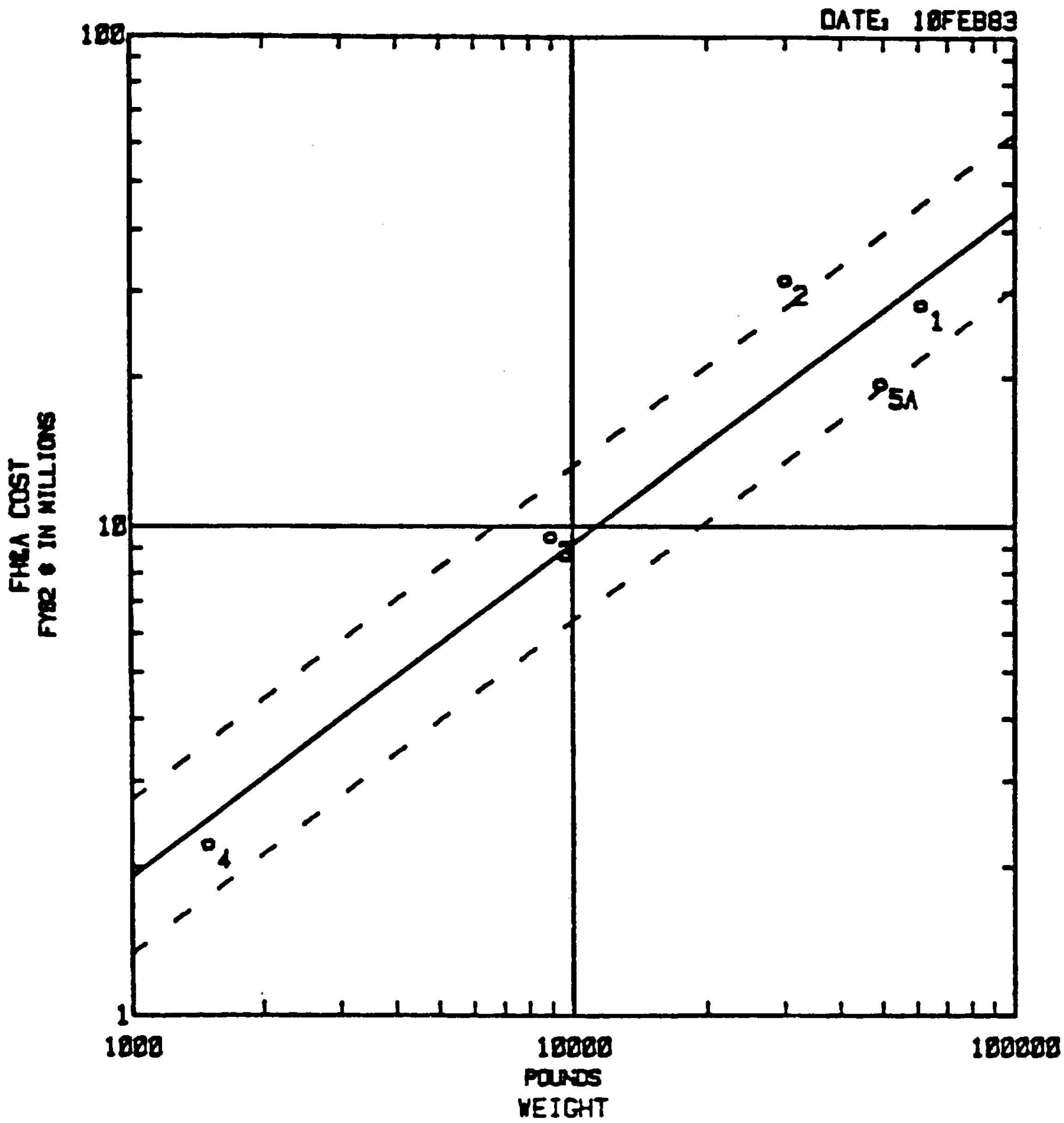
STRUCTURES/TPS-TANKS

FH&A COST

FY82 $ IN MILLIONS=(.0172) POUNDS$^{(.6815)}$

CC=.9578

SEA=.3027



EACH DATA POINT REPRESENTS COMBINED LOX AND FUEL TANKS

FIGURE 1

(2) COST MODEL: MSFC Space Station Cost Model

WHERE APPLIED: Mission Modules
Mars Excursion Module

(3) COST MODEL: GSFC Spacecraft Instruments Cost Model

WHERE APPLIED: Venus and Mars Moon Probes
Mission Module Experiments
Mars Surface Experiments

Certain elements of costs which were not estimated parametrically included STS and SDV-3R Launch Vehicle operations costs (i.e. costs per flight) which were taken from other currently ongoing MSFC studies. Also, insufficient definition existed to parametrically estimate Mission Control and Training Facilities and these were estimated strictly by engineering judgement. Some costs were not estimated, because of the lack of definition; these included low Earth orbit (LEO) assembly/logistics facilities, Orbital Transfer Vehicle (OTV) operations costs, Orbital Maneuvering Vehicle (OMV) operations costs, Space Station operating costs, Space Station facility cost impacts and Mission Operations costs.

OTHER GROUNDRULES AND ASSUMPTIONS

All costs presented are in constant 1985 dollars and include the prime contractor cost with fee.

A 14% allowance has been included for Program Support costs (which is generally consistent with other large NASA programs including Apollo and Shuttle and is also consistent with the allowance being carried in the current estimates of the Space Station Program). Program Support includes such activities as crew training and simulation, mission planning, computer support, software and data reduction, ground transportation, parallel development programs, propellants and consumables, tests using existing facilities (e.g. wind tunnel tests, KC 135 Zero G tests, etc.) and other costs which cannot be explicitly identified in a conceptual definition.

A 5% allowance has been included at the program level (i.e. 5% of total program cost) as an allowance for a major prime contractor integration contract. This is, again, generally representative of the experience of other major space programs.

The Mars spacecraft Mission Module assumes some inheritance from Space Station habitation modules and associated subsystems. This was reflected in the cost estimates of the appropriate Mission Module subsystems (e.g. pressurized structure, solar arrays, fuel cells, environmental control and life support, crew accommodations, and other selected subsystems) through the use of complexity factors in the range of 0.7 to 0.9. (Meaning that the items costed would be expected to cost from 70% to 90% of historical trends).

Some discussion has been given to utilizing inherited hardware for two stages of the Mars mission spacecraft. The Low Earth Orbit Departure Stage might be a derivative of External Tank (ET) hardware or possibly SDV-3R hardware (which itself might utilize ET hardware). The Mars Departure Stage in some configurations studied could be an Orbital Transfer Vehicle which will likely be in the NASA inventory of vehicles by the late 1990's. Because these hardware inheritance concepts are preliminary ideas and because they are dependent upon the configuration of the Mars mission stages, no cost savings have been assumed at the present time. The potential exists, however, for some reductions in stage cost as these options are further explored.

The Mars mission Earth-to-LEO transportation costs assumes use of the Shuttle at $100 million per flight and the SDV-3R at $80 million per flight. Because OTV and OMV traffic requirements have not been identified, no costs are included for these systems. It is expected that any such costs, when identified, will be relatively minor.

A 15% weight contingency has been included in all weights which were used as CER independent variables. In addition, a 35% cost contingency has been included at the module/stage level in the cost estimate. These contingencies are meant to reflect uncertainties in the weight estimating, cost estimating, and program definition processes and are considered adequate for the level of definition of the project.

In general, the cost estimates reflect the prototype approach, with one system test hardware article and one flight article. An exception to this is the Mars Excursion Module ascent and descent engine development program which assumed 15 test articles (consistent with historical engine development programs).

The manned Mars mission cost estimate assumes the existence, availability and use of the SDV-3R launch vehicle, Space Station, Orbital Transfer Vehicle, Orbital Manuervering Vehicle, STME Engine, RL100 Engine, TDRS and a deep space communications capability. This groundrule is based upon the assumption that each of the above systems will be developed prior to the time-frame of the manned Mars mission for use in other programs. This premise is perhaps most debatable in the case of the SDV-3R launch vehicle. However, if the Mars mission is the first user of the SDV-3R, there are undoubtedly other space programs which would greatly benefit from the existence of a heavy lift capability. Due to these uncertainties, the development cost of the SDV-3R is carried in the manned Mars mission as a "below the line" cost and is not charged to the Mars mission in this analysis.

COST ESTIMATES

Major cost estimating emphasis was placed upon estimating the costs of six potential manned Mars mission options. These cases were: (A) 1999 Opposition, LOX/LH_2 Propulsive-Braked; (B) 1999 Conjunction, LOX/LH_2 Propulsive-Braked; (C) 1999 Opposition, Aerobraked; (D) 1999 Conjunction, Aerobraked; (E) 2001 Opposition LOX/LH_2 Propulsive Braked; and (F) 2001 Opposition, Aerobraked.

While numerous other missions are possible, it is felt that these six represent a viable sampling of cases which should be representative of the costs to be expected for a manned Mars mission. Table 1 and Figure 2 present summary cost data for these configurations. These costs, which exclude the development cost of the SDV-3R launch vehicle, range from a total of about $23 to $24 billion for the aerobraked cases, to about $26 to $27 billion for the propulsive-braked options. Due to the flight mechanics of the 1999 mission opportunities, the propulsive energy required for the conjunction class missions is less than the energy required for the opposition class missions (see "Mission Concepts and Opportunities" by Young). This is reflected in the cost shown in Table 1 in the Stages and Transportation cost line items which are the costs of the stage hardware and the Shuttle/SDV-3R transportation operations, respectively. The Spacecraft and Science costs however, are higher for the conjunction class missions, reflecting the impact of the longer stay times of these missions.

TABLE 1

MANNED MARS MISSION COST SUMMARY

(ALL COSTS FY85 $ IN MILLIONS)

	Case A 1999 Opposition Propulsive Braked	Case B 1999 Opposition Propulsive Braked	Case C 1999 Opposition Aerobraked
Spacecraft	$11,201	$12,009	$11,201
Stages	$8,095	$7,028	$6,389
Science	$1,439	$1,818	$1,439
Transport	$2,500	$1,460	$1,300
Facilities	$2,330	$2,330	$2,330
Integration	$1,278	$1,232	$1,133
TOTAL	$26,843	$25,877	$23,792

	Case D 1999 Conjunction Aerobraked	Case E 2001 Opposition Propulsive Braked	Case F 2001 Opposition Aerobraked
Spacecraft	$12,009	$11,201	$11,201
Stages	$5,387	$7,327	$5,629
Science	$1,818	$1,439	$1,439
Transport	$1,220	$1,860	$1,460
Facilities	$2,330	$2,330	$2,330
Integration	$1,138	$1,208	$1,103
TOTAL	$23,902	$26,365	$23,162

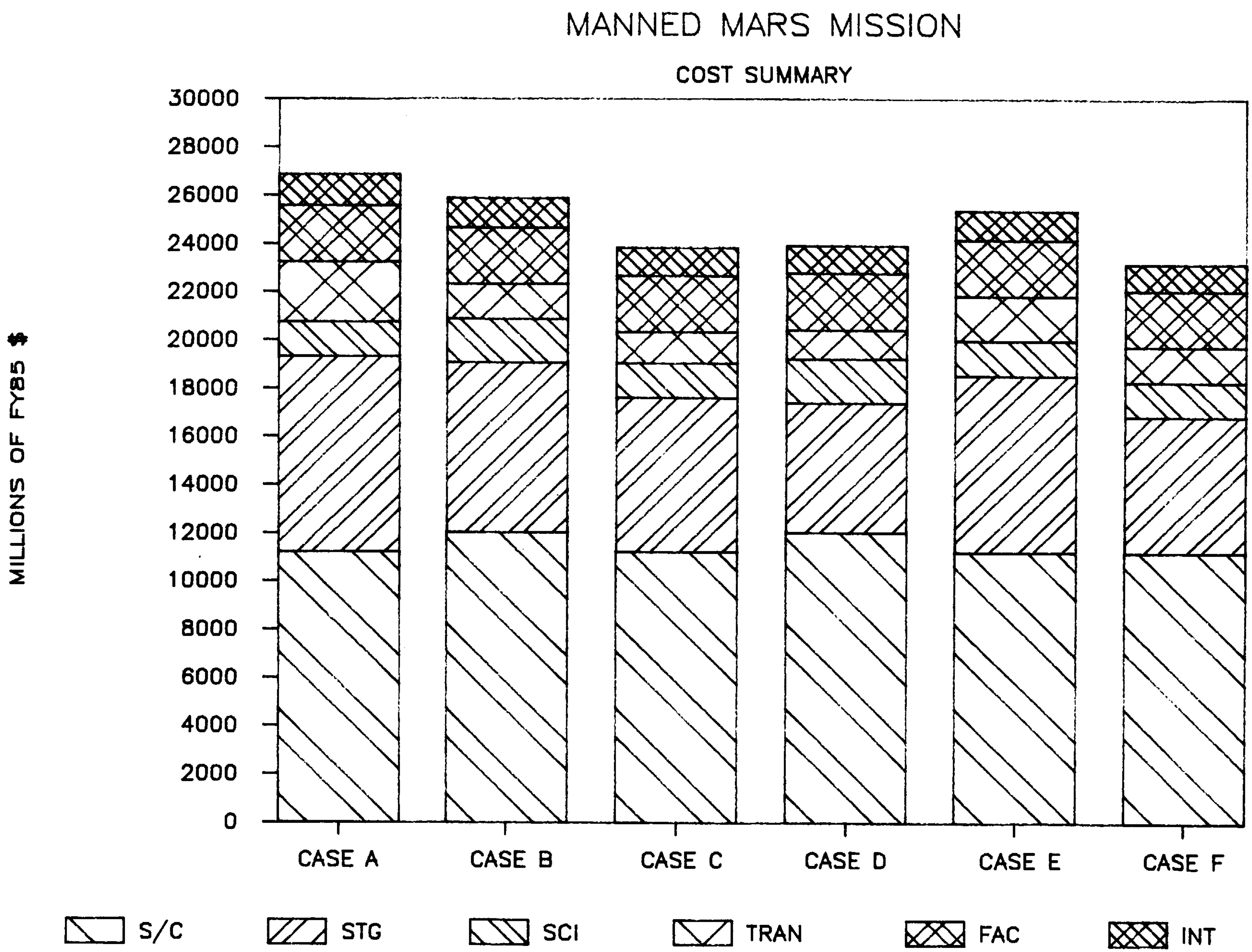

MANNED MARS MISSION
COST SUMMARY
MILLIONS OF FY85 $
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
CASE A
CASE B
CASE C
CASE D
CASE E
CASE F
S/C
STG
SCI
TRAN
FAC
INT

FIGURE 2

From the cost and technical standpoint, Case F appears to be the most attractive option of the six cases investigated. For simplicity, the remainder of this paper will refer to Case F, the 2001 Opposition Mission with aerobraking.

Table 2 and the corresponding pie chart of Figure 3 detail the $23.1 billion dollar cost estimate for this mission. Nearly 50% of the total cost is attributable to the Spacecraft. As can be seen from Table 2, this cost further subdivides into the Habitation Module, the Laboratory/Logistics Modules and the Mars Excursion Module (MEM). Nearly one fourth of the total cost is for interplanetary stages which include the LEO Departure Stage, the Mars Arrival and Departure Stage, the MEM Ascent and Descent Stages and the Earth Braking Stage. The remaining fourth of total program costs is accounted for by the Experiments and Probes (6%), Transportation Operations (6%), ground based facilities (10%), and an allowance of about 5% for project level integration. The SDV-3R development cost is cited on Table 2 as a "below the line" cost.

As can be seen from Table 2, a little over three fourths of total cost would be expended in the development phase of the project and the remaining cost in the production phase. Development includes all system hardware DDT&E, and system test articles and facilities; production includes flight article procurement and transportation operations.

Figure 4 displays the anticipated annual funding requirements of the manned Mars mission. The distribution of funding assumes a nine-year development and production span and a distribution of funds corresponding to a Beta distribution with 60% of costs incurred in 50% of the time for development costs and uniform funding for production costs (a typical distribution for NASA projects). Peak year funding would occur in year three, with a requirement of about $5.6 billion. The inflection point in year seven is due to the buildup of flight hardware production activities.[1]

[1] It should be noted that this prediction process estimates actual costs as they would appear looking back in time from the end of the program. If the values are to be used for budgeting, reserves for program growth should be identified at the peak years and beyond, to reflect actual historical program trends.

TABLE 2

MANNED MARS MISSION PRELIMINARY COST ESTIMATE

(FY85 DOLLARS IN MILLIONS)

2001 OPPOSITION

ALL AEROBRAKE

CASE F

	DDT&E	PRODUC-TION	TOTAL
Mission Module-Habitation Module	$3,774	$1,135	$ 4,909
Mission Module-Lab/Log Module	$1,704	$ 283	$ 1,987
Mars Excusion Module	$3,778	$ 527	$ 4,305
Spacecraft Subtotal	$9,256	$1,945	$11,201
LEO Departure Stage	$2,533	$ 426	$ 2,959
Mars Arrival & Departure Stage	$1,131	$ 225	$ 1,356
MEM Ascent & Descent Stages	$1,212	$ 102	$ 1,314
Earth Braking Stages	$ 0	$ 0	$ 0
Stages Subtotal	$4,876	$ 753	$ 5,629
Experiments & Probes	$ 763	$ 676	$ 1,439
SDV Transportation	-----	$ 960	$ 960
STS Transportation	-----	$ 500	$ 500
Transportation Subtotal	-----	$1,460	$ 1,460
Launch Facilities	$2,130	-----	$ 2,130
Mission Control	$ 100	-----	$ 100
Training Facilities	$ 100	-----	$ 100
Facilities Subtotal	$2,330	-----	$ 2,330
Space Station Impacts	TBD	TBD	TBD
Program Level Integration	$ 861	$ 242	$ 1,103
Total	$18,086	$5,076	$23,162
Launch Vehicle Development	$ 3,000	$1,000	$ 4,000

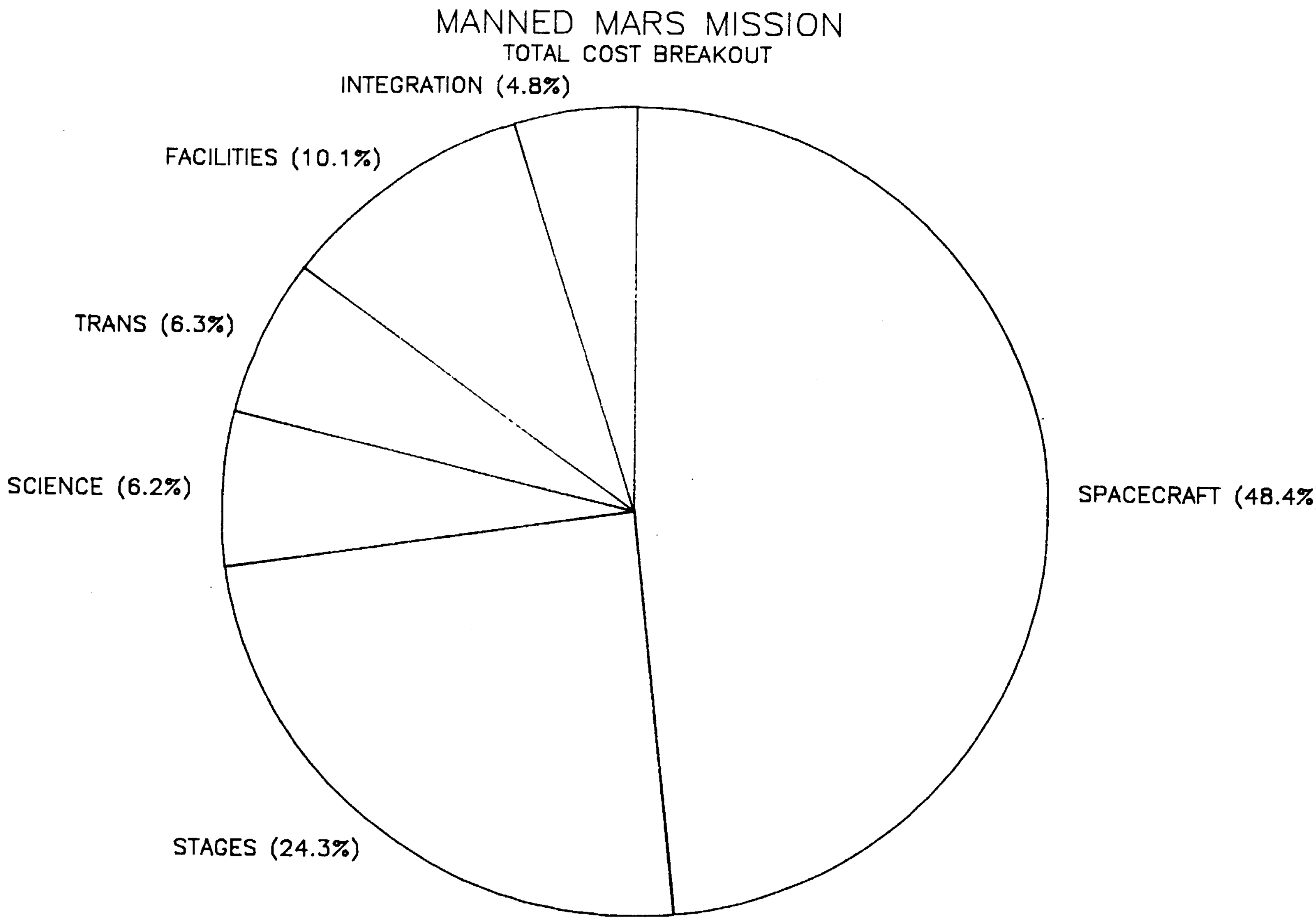

MANNED MARS MISSION
TOTAL COST BREAKOUT
INTEGRATION (4.8%)
FACILITIES (10.1%)
TRANS (6.3%)
SCIENCE (6.2%)
STAGES (24.3%)
SPACECRAFT (48.4%)

FIGURE 3

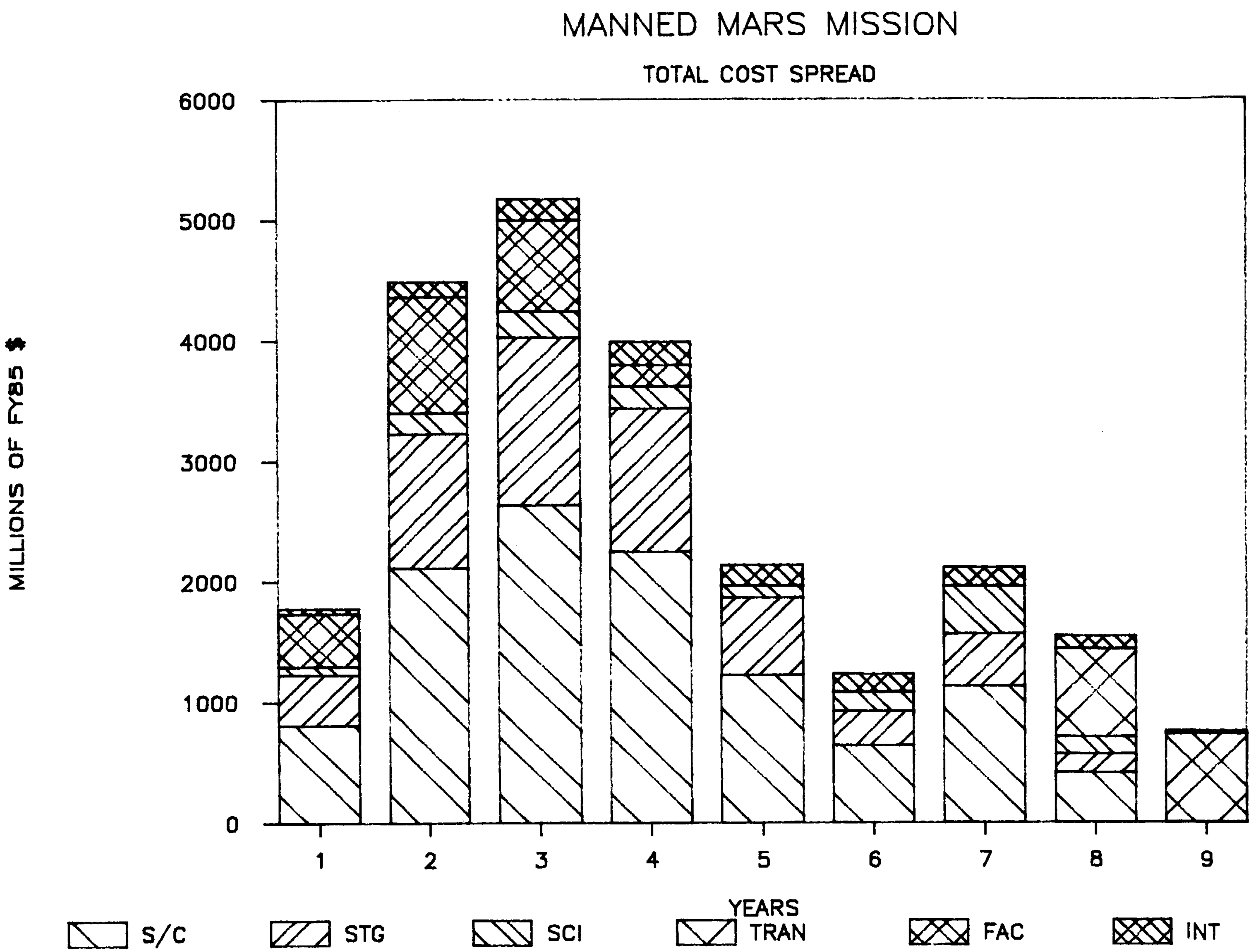

MANNED MARS MISSION
TOTAL COST SPREAD
MILLIONS OF FY85 $
6000
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
YEARS
S/C
STG
SCI
TRAN
FAC
INT

FIGURE 4

COMPARISON OF MANNED MARS MISSION AND APOLLO COST

The historical space project most comparable to the manned Mars mission is the Apollo Program. In fact, there is a tendency to assume that the cost of a mission to Mars will cost as much as the Apollo Program (in the same year dollars). There are a number of reasons why this need not be true. The comparison of the cost of Apollo to the cost of a manned Mars mission requires cognizance of several fundamental differences in the cost drivers of these two programs.

First, the Apollo Program was mission and schedule constrained. The goal was to put man on the Moon by the end of the (1960's) decade. Thus cost, the third variable in any program, became the unconstrained variable. Cost was allowed to grow in order to meet the mission and schedule goals which were deemed to be unchangeable. Presumably, the Mars mission will be accomplished in an environment that allows flexibility in all three program variables such that something near the optimum mission, schedule, and cost can be achieved.

Secondly, at the beginning of the Apollo Program, the space infrastructure was still in its infancy. The Mars mission, on the other hand, will benefit from a space program with a forty year experience base.

Thirdly, because space was such a new and largely unknown environment in which to operate (and also probably because the funding was available), the Apollo Program had extremely intensive redundancy and test philosophies. The typical flight system was preceeded by dozens of test articles. From this beginning, the space program has matured to the point where the typical manned system today (e.g. Shuttle or Space Station) has, at most, one test article.

Finally, the cost of the Apollo Program which is widely quoted (about $20 billion in "then-year" dollars or about $80 billion in 1985 dollars) purchased the entire series of Saturn Vehicles and Apollo Moon landing missions. The manned Mars mission cost presented in this paper is for the initial mission only.

Therefore, before comparisons are valid, the $80 billion price tag for Apollo must be analytically normalized to a basis consistent with the environment of the Mars mission as estimated in this paper.

Figure 5 shows such a normalization. The $20 billion ($80 billion in 1985 dollars) cost of Apollo is shown broken into its major components.

The first normalization excludes the Saturn I and Saturn IB launch vehicles which were precursors to the Saturn V development program and have no analogous requirements in the manned Mars mission. This reduces the $80 billion Apollo cost to around $73 billion.

The second adjustment reduces the large number of test articles in each of the Apollo Program line items to the equivalent of one prototype test article and one flight article for the non-engine program line items and to the equivalent of 15 test articles for the engine development line item. This adjustment to today's test philosophy reduces the cost down to around $61 billion.

In order to be consistent with manned Mars mission cost, the final adjustment deletes the cost of all Apollo missions beyond the first mission. This reduces the Apollo cost to about $37 billion.

This cost still includes some artifacts of the Apollo era way of doing business which were difficult to quantify. These include parallel development programs and heavy Supporting Research and Technology activities. Also note that about $16 billion ($14 billion plus a pro rata share of mission support) is relatable to the launch vehicle. Therefore, the basic Apollo cost which is comparable to the manned Mars mission cost estimate is around $21 billion, which is actually slightly lower than the range of costs estimated in this paper. Considering the increased challenges due to the greater interplanetary distances involved in the Mars mission, cost in the mid-to-upper twenty billion dollar range for the Mars mission seems appropriate.

1539-85

COST COMPARISON OF APOLLO AND MANNED MARS MISSIONS

APOLLO PROGRAM "THEN–YEAR" COSTS ($ M)	
SPACECRAFT	$ 8482
SATURN I	767
SATURN IB	1128
SATURN V	7172
ENGINE DEV.	901
MISSION SUPT.	2003
TOTAL	$20453

$80 BILLION 1985 $

ADJUSTING APOLLO COST TO EXCLUDE PRECURSOR LAUNCH VEHICLE DEVELOPMENT AND TO 1985 $

APOLLO EXCLUDING SATURN I & IB 1985 $ M	
SPACECRAFT	$33512
SATURN V	28337
ENGINE DEV.	3560
MISSION SUPT.	7101
TOTAL	$72510

ADJUSTING APOLLO COST TO TODAY'S TEST PHILOSOPHY

APOLLO WITH REDUCED TEST ARTICLES 1985 $ M	
SPACECRAFT	$25792
SATURN V	26962
ENGINE DEV.	2017
MISSION SUPT.	5946
TOTAL	$60717

ADJUSTING APOLLO COST TO 1 MISSION FOR COMPARISON TO MANNED MARS

APOLLO WITH REDUCED FLIGHT ARTICLES 1985 $ M	
SPACECRAFT	$17248
SATURN V	14072
ENGINE DEV.	2017
MISSION SUPT.	3619
TOTAL	$36956

- TO COMPARE COST OF APOLLO TO COST OF A MANNED MARS MISSION REQUIRES COGNIZANCE OF SEVERAL FUNDAMENTAL DIFFERENCES IN THE COST DRIVERS OF THESE TWO PROGRAMS
  - APOLLO WAS MISSION AND SCHEDULE CONSTRAINED (COST WAS THE UNCONSTRAINED VARIABLE)
  - MODEST INFRASTRUCTURE AT START OF APOLLO
  - APOLLO HAD EXTREMELY INTENSIVE TEST PHILOSOPHY
  - THE $80 BILLION PURCHASED MULTI–MISSIONS

- ANALYTICALLY NORMALIZING HISTORICAL APOLLO COST TO A BASIS MORE CONSISTENT WITH MANNED MARS DECREASES THE $80 BILLION APOLLO PROGRAM TO ABOUT $37 BILLION
  - THIS COST STILL INCLUDES PARALLEL DEVELOPMENTS, HEAVY SR&T AND OTHER ARTIFACTS OF APOLLO WAY OF DOING BUSINESS
  - ABOUT $16 OF THE $37 BILLION IS RELATABLE TO LAUNCH VEHICLE
- CONCLUSION: THE APOLLO ANALOGY SUGGESTS THAT THE COST FOR AN INITIAL MANNED MARS MISSION SHOULD BE IN THE $20 BILLION RANGE (1985 $) EXCLUDING LAUNCH VEHICLE/ENGINE DEVELOPMENT

FIGURE 5

CONCLUSIONS

The preliminary engineering cost analysis of the manned Mars mission indicates that the cost, excluding launch vehicle development and mission operations, should be less than $30 billion in 1985 dollars for the initial mission. This cost estimate independently compares well with the cost of the somewhat analogous Apollo Program when the cost of that program is normalized to the environment and groundrules of the estimate for the manned Mars mission.[2]

[2] A separate paper (by K. Cyr) describes the budgetary requirements and timing which might reasonably be anticipated for the program, illustrating that missions in this time period are feasible within reasonable budget levels.