DATA FOR VEHICLE DESIGN FOR EARTH ORBIT TO MARS ORBIT AND RETURN*

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Based on the mission of manned exploration of the planet Mars, a preliminary survey is given of typical mass data for orbit launched vehicles. Using nuclear heat exchanger propulsion systems and relatively short mission durations (one year), these vehicles are large --of the order of 10^3 tons. In the case of Mars, there are definitely "good" and "bad" launch time periods because of the eccentricity of its orbit. Limiting cases are discussed and remarks as to costs, schedules, and further study requirements are presented.

INTRODUCTION

Manned exploration of the planet Mars is one of the major goals of astronautics. It can be expected that during the next decade men will travel to Mars and return safely to Earth.

It is impossible today to describe this first expedition in any great detail because too many elements are unknown. However, we can attempt a description that will convey an impression of the size of the task ahead based upon our present knowledge.

Let us agree on a mission profile:

Step 1 - Earth surface to a low, circular satellite orbit. Rendezvous, assembly, refueling, launch operation, etc., take place in this orbit as required. We will assume that a sufficiently large Earth

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*This paper does not represent official thinking of the George C. Marshall Space Flight Center or of the National Aeronautics and Space Administration.

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launch vehicle is available, and that the Earth orbital technique is adequately developed.

Step 2 - Launch from that orbit with a propulsion system of sufficiently high thrust so that near-impulsive maneuvers can be assumed.

Step 3 - Free-flight periods to Mars interrupted only by vernier propulsion, course correction propulsion, and attitude control maneuvers.

Step 4 - Rocket braking to enter an orbit around Mars at an altitude of 1000 km.

Step 5 - Stay in that orbit for the Mars exploration period. A Mars excursion module (MEM) with a small crew is separated from the orbiting vehicle and descends to the surface using aerodynamic braking. The MEM ascends to the orbiting vehicle to transfer the crew for return to Earth.

Step 6 - Rocket maneuver to initiate return flight from Mars orbit.

Step 7 - Free-flight similar to Step 3.

Step 8 - Direct entry into the Earth's atmosphere and aerodynamic braking using a special Earth landing vehicle.

Other profiles are possible. The question of profile organization will not be discussed in this paper. Only an estimate of the payload and speed requirements for the interplanetary transport ship will be given, from which sizes will be derived. Different papers in this volume discuss Steps 1, 5, and 8. The combination of all this will give a broad survey of the overall mission, viz., to get man safely to Mars and back.

It goes without saying that other missions can be of interest, e.g., fly-by only, or orbit only.

We will make the assumption here that nuclear heat exchanger type propulsion systems are available. It is not anticipated that more advanced propulsion systems will be operational in the early 1970's.

DESIGN PARAMETERS

The major design parameters that we have to establish are the payload and speed requirements for the interplanetary transporters. We will find that "good" and "bad" launch time periods exist, in one case because of the varying solar activity, and in the other because of the eccentricity of the Mars orbit.

Many will feel that the following data are unduly pessimistic, and the author might agree if you take the data at their face value. But a look at past history shows that "fairly exact" conceptual designs invariably turned out to be highly optimistic when compared to the actual article. A simple explanation is that an "exact" conceptual design is "exact" only as to the items considered. The many elements that are either unknown or not considered because they are too insignificant on the level of conceptual design, or, are plainly and simply forgotten, make the situation worse. In an attempt to compensate for these contingencies, it behooves us to be quite pessimistic on the main elements, hoping that the margins thus created will lead to near-correct final data.

There is another reason why overly optimistic considerations will hurt our case. We want to show that manned exploration of the planets during the next decade is feasible within our technical and economic capabilities. Generally, we have broad opposition; we will just deliver more ammunition to the arguments of opponents if we are caught in unduly optimistic assumptions.

In all cases, it is assumed that two interplanetary vehicles of the same size leave from Earth orbit and enter Mars orbit. One of the two is manned (crew ship), the other one unmanned (cargo ship). Only the crew ship has the capability of returning to Earth. The cargo ship remains in Mars orbit; therefore, it can carry a relatively large amount of cargo, usually sufficient for one or two MEM vehicles. Operationally, it appears to be mandatory to have two MEM vehicles with the expedition, because, different from the lunar case, all help for astronauts stranded upon Mars has to come from the Mars orbiter and cannot be sent from Earth. As to how best use is made of the two MEM vehicles, is an object of further study. Such a split of the task appears to have some additional advantages; as, for example, the redundancy of a number of vital elements which can be introduced.

Payload of the Interplanetary Ships

The payload consists of:

1. Crew and life support systems (living and command module),
2. Environmental shelter,
3. Earth entry vehicle,
4. Mars excursion module (MEM).

Because of the split in crew and cargo ship, we shall disregard the MEM. Let it suffice to say, that with aerodynamic braking and a one-stage chemically propelled ascent vehicle, the mass of a two-man MEM will be between 20 and 90 metric tons.* The large difference reflects not only different propellants, but also a different degree of optimism.

As the environmental shelter weight increases, the life support system becomes lighter because we may assume that some of the radiative protection material can contribute to the life support system, e.g., water. The shelter assumptions are probably very conservative. The assumptions are as follows:

1. No more than 50 rems/man per trip,

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*Bare minimum mass studies performed under NASA Contract No. NAS8-5026 indicate 10 tons as a lower limit.

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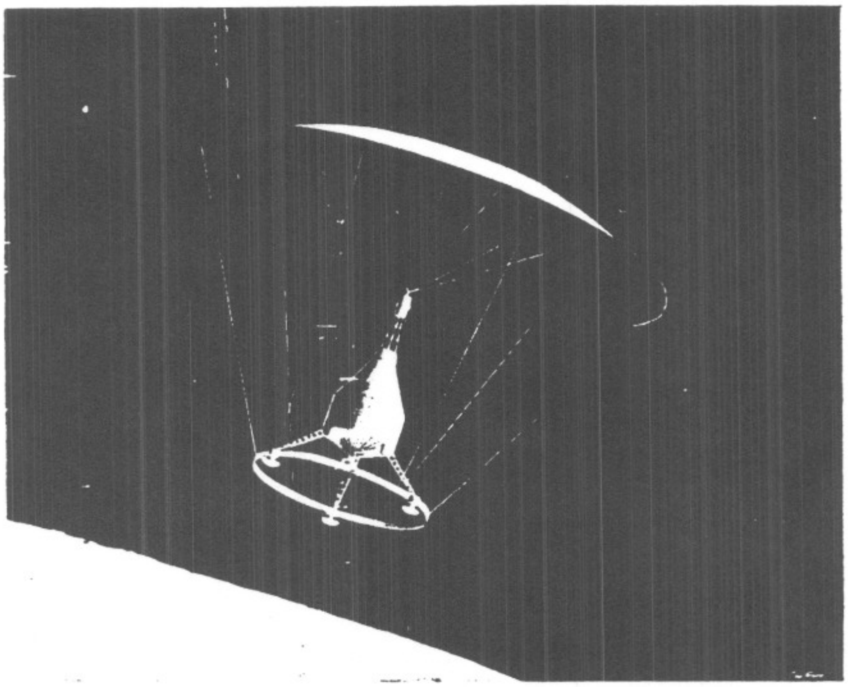

Fig. 1 Mars Excursion Module (MEM) Landing
(Artist's impression. Courtesy Astronautics Div. of General Dynamics Corp.)

2. 200 kg local shielding per man, e.g., eyes,
3. For the one year mission, 30 gr/cm^2 of shielding is available from structures and equipment,
4. For the three year mission, 40 gr/cm^2 of shielding is available from structures and equipment,
5. Under the most favorable conditions, total shielding requirements are 50 gr/cm^2, and 220 gr/cm^2 under the least favorable conditions.

The payload weights are summarized in Table 1. These masses have to be carried by the crew ship throughout the mission; therefore, a one-way cargo ship of the same initial size will deliver considerably more into the satellite orbit around Mars. It is apparent without further investigation that a MEM can be transported.

Table 1
PAYLOAD MASS IN TONS

Item	1 - Year Mission 5 - Man Crew		3 - Year Mission 8 - Man Crew
	Quiet Sun	Active Sun	Average Sun
Crew and Comfort	1	1	5
Living Mod./Life Support	7	5*	10
Control Equipment	2	2	2
Storage Room	2	2	2
Internal Power	2	2	2
Scientific Equipment	2	2	2
Environmental Shelter	10	20	150
Earth Entry Vehicle	6	6	7
TOTAL	32	40	180

*The increase in mass of the environmental shelter permits a decrease of life support system mass.

B. Speed Requirements

A careful trajectory optimization is required for actual planning. For this survey, it will suffice to make a good choice that could undoubtedly be further improved. Table 2 shows the data used.

One of the ground rules used to select the trajectories is to maintain the Earth atmospheric entry speed at or below 12.5 km/sec.

Since 1971 represents very favorable conditions and 1979 unfavorable conditions, these trajectory choices represent limiting cases of the effects of Mars' orbital eccentricity. To exaggerate this, we shall assume that for 1971 the payloads for a "quiet sun" apply, and for 1979 those of an "active sun" apply. For this reason, from now on we shall refer to simply "good" or "bad" years.*

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*This is almost true since "quiet sun" is expected to occur approximately in 1974 and "active sun" approximately in 1978.

Table 2

SPEED REQUIREMENTS IN KM/SEC
(INCLUDES ESTIMATED GRAVITY LOSS)

Item	1-Year Mission 10-Day Stay Time		2.7-Year Mission (Hohmann) 450-Day Stay Time
	1971	1979	No Strong Variation (Year)
Launch from 97 min. Earth Orbit	6.6	11.9	3.9
Mid-course Correction	0.1	0.1	0.3
Braking, 1000 km Mars Orbit	4.0	7.2	2.2
Launch, 1000 km Mars Orbit	6.4	7.6	2.2
Mid-course Correction	0.1	0.1	0.4
Earth Entry, Aerodynamic	12.2	12.5	11.2

DESIGN SAMPLES

It is assumed that all major propulsive maneuvers occur in a nearly impulsive fashion. It is well known that the same effect can be obtained with moderately low acceleration systems by the method of multi-burn pericenter impulses. The use of this technique has not been explicitly assumed, but the mass data would not change noticeably if the multi-burn engine characteristics are assumed to be similar to those of a more standard engine.

This paper does not permit going into the astrionics aspect in any detail. Suffice it to say that MARINER II showed that the communication problems are well in hand, and that relatively simple guidance systems are adequate (inertial, either full or body mounted, together with Earth based radio guidance for injection and star reference for attitude). It goes without saying that more developments are required to obtain higher accuracy and longer lifetimes, to combine inertial and optical systems, to derive full benefit from the presence of the crew, etc. But, to repeat, astrionic systems do not seem to be the bottleneck for manned Mars missions.

The "design samples" (Tables 3-6) are very simple breakdowns of mass distribution. They do not represent results of actual design studies; however, the numbers are typical, based upon many conceptual studies.

For the Hohmann mission, data are given for both chemical and nuclear propulsion. Because of these results, the one-year trips are evaluated for nuclear propulsion only.

In no case were detailed investigations performed in areas such as hydrogen storage or reliquefaction, meteoroid protection, etc. It is hoped that the quite liberal assumptions for inert weights will compensate for this omission.

Table 3

EIGHT-MAN HOHMANN MARS MISSION (CHEMICAL)

Payload Weight (tons)	180
Third Stage	
Performance -	
Specific Impulse	425 sec
Thrust	100 tons
Weights (tons) -	
Propulsion System	3
Structure	20
Propellants	184
TOTAL	207
Interstage Weight (tons)	4
Second Stage	
Performance -	
Specific Impulse	425 sec
Thrust	250 tons
Weights (tons)	
Propulsion System	5
Structure	35
Propellants	313
TOTAL	353
Interstage Weight (tons)	7

First Stage	
Performance -	
Specific Impulse	425 sec
Thrust	1000 tons
Weights (tons) -	
Propulsion System	15
Structure	75
Propellants	1369
TOTAL	1459
Orbital Launch Mass	2210 tons

A. Table 3 Comments.

Earth orbital launch mass for a favorable year is estimated at 1,500 tons, and for an unfavorable year the mass will be 3,000 tons. Since two such vehicles will have to be launched for a landing mission, it is apparent that a tremendous effort is involved. This is the reason no further investigation will be made as to the use of chemical propulsion systems only.

Table 4

EIGHT-MAN HOHMANN MARS MISSION (NUCLEAR)

Payload Weight (tons)	180
Third Stage	
Performance -	
Specific Impulse	800 sec
Thrust	75 tons
Weights (tons) -	
Propulsion System	7
Structure	8
Propellant (H_2)	80
TOTAL	95
Interstage Weight (tons)	3
Second Stage	
Performance -	
Specific Impulse	800 sec

Thrust	75 tons
Weights (tons) -	
Propulsion System	7
Structure	10
Propellant (H_2)	103
TOTAL	120
Interstage Weight (tons)	4
First Stage	
Performance -	
Specific Impulse	800 sec
Thrust	400 tons
Weights (tons)	
Propulsion System	25
Structure	25
Propellant (H_2)	303
TOTAL	353
Orbital Launch Mass	755 tons

B. Table 4 Comments.

Earth orbital launch mass for a favorable year is estimated at 530 tons, and for an unfavorable year the mass will be 1,100 tons.

Table 5

FIVE-MAN ONE-YEAR MARS MISSION (1971)

Payload Weight (tons)	32
Third Stage	
Performance -	
Specific Impulse	800 sec
Thrust	40 tons
Weights (tons) -	
Propulsion System	4
Structure	6
Propellant (H_2)	59
TOTAL	69
Interstage Weight (tons)	1

Second Stage	
Performance -	
Specific Impulse	800 sec
Thrust	100 tons
Weights (tons) -	
Propulsion System	8
Structure	9
Propellant (H_2)	86
TOTAL	103
Interstage Weight (tons)	2
First Stage	
Performance -	
Specific Impulse	800 sec
Thrust	400 tons
Weights (tons) -	
Propulsion System	25
Structure	30
Propellant (H_2)	359
TOTAL	414
Orbital Launch Mass	621 tons

Table 6

FIVE-MAN ONE-YEAR MARS MISSION (1979)

Payload Weight (tons)	40
Third Stage	
Performance -	
Specific Impulse	800 sec
Thrust	50 tons
Weights (tons) -	
Propulsion System	4
Structure (tankage)	8
Propellant (H_2)	85
TOTAL	97
Interstage Weight (tons)	1
Second Stage	
Performance -	
Specific Impulse	800 sec
Thrust	150 tons
Weights (tons) -	

Propulsion System	10
Structure (tankage)	20
Propellant (H_2)	247
TOTAL	277
Interstage Weight (tons)	3
First Stage	
Performance -	
Specific Impulse	800 sec
Thrust	1000 tons
Weights (tons) -	
Propulsion System	50
Structure (tankage)	80
Propellant (H_2)	1852
TOTAL	1982
Orbital Launch Mass	2400 tons

C. Table 6 Comments.

Even though quite favorable propulsion parameters are assumed, the initial mass is very high. This points out that investigations to alleviate this situation are urgently needed. Improvements may be realized from the following:

1. Reduction of payload,
2. Increase of accepted risk, leading to structural weight reductions,
3. Reduction of mission objectives, e.g., no landing,
4. Rigorous trajectory optimization,
5. Aerodynamic braking to establish Mars satellite orbit,
6. Permit very high Earth arrival speeds by, e.g., partial rocket braking,
7. Propulsion improvements,
8. Increase in mission duration,
9. Elliptic capture orbits,
10. More effective staging, e.g., tank staging only.*

It is expected that a drastic reduction of the 2,400 tons is possible; it

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*Dropping of empty tanks, retaining the propulsion system for further usage.

will not come easily and may very well require the development of unorthodox techniques, e.g., points 5, 7 (ORION), or 9 above.

EMPIRE RESULTS*

One of the EMPIRE study contracts, namely Contract No. NAS8-5026 with General Dynamics/Astronautics, outlined a minimum Mars landing mission. The main parameters established are:

A. Nuclear propulsion is used for Earth departure, Mars capture, and Mars departure.
B. Chemical propulsion is used to establish a highly elliptic orbit around Earth upon return.
C. Vehicle and life support system (shielding) are highly integrated.
D. Optimum benefit is derived by designing the vehicle for the space environment.
E. A minimum Mars excursion module is carried aboard the crew ship, i.e., crew and cargo ships are not separated.
F. The crew consists of eight men.
G. Mission duration is 450 days and Mars capture period is 20 days.
H. Earth orbit launch mass for 1973 is 880 tons and for 1975 is 1,250 tons.

These data are not inconsistent with our simple results derived earlier.

ADDITIONAL REMARKS

After looking at some typical mass distributions, it is apparent that we are still a long way from a true conceptual design. However, it should be noted that the results described in the EMPIRE study are based on considerable detail. Then, what is missing is work leading to a preliminary design, which certainly goes far beyond the scope of this paper.

No paper such as this would be complete without mentioning two more

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*The abbreviation "EMPIRE" refers to contracts listed under LITERATURE, numbers 10.10, 10.11, and 10.12.

subjects: cost and schedule.

Figure 2 shows the results of an attempt to construct a schedule. Even such a simplified and naive try leads to the conclusion that a first mission attempt will at best be made in 1973 and more probably in 1975.

It is quite dangerous to outline costs of a program such as this because costs are to a large degree dependent upon bookkeeping. Let us look at two extreme examples and a "balanced" or more reasonable example:

A. One might say that the cost of the interplanetary program is equal to the cost of the space flight program until 1980, assuming an interplanetary program is conducted; minus cost of the space flight program until 1980, assuming no interplanetary program is conducted. From this point of view, the cost will be low, perhaps hardly more than $\$10 \times 10^9$ and possibly even zero dollars.

B. The other extreme is to say that the cost of the interplanetary program is equal to the sum of all programs that assisted, in any way, the interplanetary program. From this point of view, almost the total National space flight program cost is charged to manned exploration of the planets; thus, we may obtain a cost figure like $\$100 \times 10^9$.

C. A more balanced point of view is represented by the following information which represents expenditures from 1966 to 1979:

   1. Development of the interplanetary ships equals $\$9 \times 10^9$. This includes crew cabin, Mars excursion module, and Earth entry vehicle. Excluded are all propulsion systems, Earth surface-to-orbit vehicles, and orbital operations.
   2. Production and procurement of all systems equals $\$2 \times 10^9$.
   3. All operational costs equal $\$5 \times 10^9$. This includes Earth surface-to-orbit transport and orbital operations.
   4. The sum of 1, 2, and 3 is $\$16 \times 10^9$.

Electrically propelled manned interplanetary vehicles may be developed and utilized by 1979. Based on this, approximately \$5.5 x 10^9 should be added to the above total.

As explained above, an interplanetary program might cost about \$20 x 10^9 spread over a 13-year period. This equals approximately 20 percent of the expected NASA budget for this time period, which looks quite reasonable. These data offer the hope that the Nation may set out on planetary exploration in the next one to two decades.

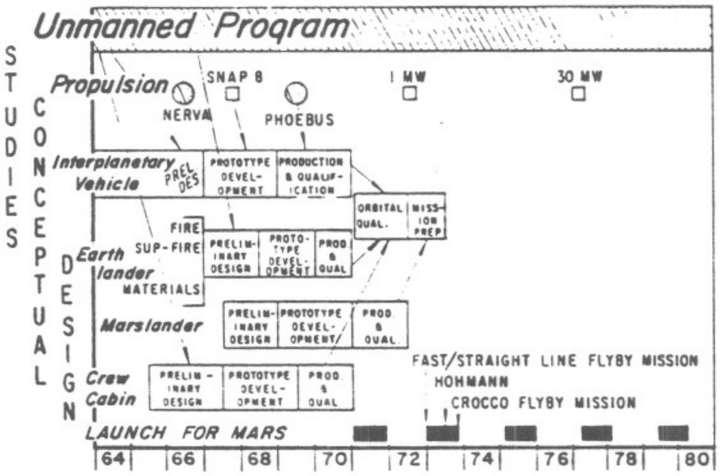

Fig. 2 Schedule

How good are electric propelled vehicles for the interplanetary transportation task? Without going into detail because their period of operation is in the distant future, some general information is given in Table 7 below.

Table 7

ORBITAL LAUNCH WEIGHTS IN TONS

	Hohmann Trip	Fast Trip
Nuclear Heat Exchanger	755	621
Ionic Propulsion	330	250

In each case, this is a reduction by a factor of more than two. Furthermore, the electrically propelled vehicles appear to be less sensitive to the "good" and "bad" astronomical constellations for Mars flights. On the other hand, the tremendous task of developing a man-rated electric system must not be underestimated. More study is needed to assess the relative economy, instead of the relative performance, of the competing systems.

I think another remark is in order to focus attention on the difficulties introduced by the change in performance requirements with year of launch for Mars missions. It is apparent that we cannot develop an interplanetary ship for 1973, another for 1975, etc. Therefore, the selected design must have inherent flexibility to cope with requirements that fluctuate widely, and this may for example, require rigorous use of tank-staging methods as proposed by Mr. K. Ehricke. As a fringe benefit, multiple use of the same propulsion system would evolve naturally with such a design.

Another significant thought comes to mind; the experts do not agree on whether artificial gravity is required. However, they do agree that our design task becomes considerably more difficult if the answer is "yes." Personally, this writer thinks and hopes, that the answer is "no." It is felt that the available information points in this direction, and even if the astronauts would require special medical treatment after the mission, this appears to be the simplest solution by far. In case the answer is "yes," the next question is, how much artificial gravity is needed? It is the author's opinion that 1/10 g or so will suffice. This will at least simplify the problem.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions. The main conclusions of this study are:

1. Orbital launch masses using nuclear heat exchanger propulsion systems are large--of the order of 1,000 to 5,000 tons for various years.
2. Electric propulsion systems may reduce these weights by a factor of considerably more than two.

3. Orbital operations appear to be required at both Earth and Mars.
4. No problems have been encountered which appear to be impossible to solve.
5. No problems have been detected that would require state of the art advancements far beyond APOLLO technology.

B. Recommendations. Some typical recommendations for further study are:

1. Detail conceptual design studies of the interplanetary vehicle are needed with special emphasis upon close overall mission integration.
2. We should determine which missions can be performed with chemical propulsion systems only.
3. Careful overall optimization of the tracjetory profile should be accomplished.
4. Careful study of the mission profile, i.e., the where, how, and why of mission staging; mission duration; etc., is needed.
5. Special study of how to alleviate the problem of the "difficult" time period, 1975 - 1983, should be untertaken.
6. Further systems analysis regarding the tasks involved, resources, and schedules is needed.
7. What is the proper role of electric propulsion in the area of manned interplanetary flight?
8. We should define the more advanced propulsion systems that may play a role. What role will mixed high-low acceleration propulsion have from orbit?
9. We should detail the definition of mission staging operations that are required. This should be an input for studies such as orbital operations, and must be closely integrated with NOVA studies.
10. Sub-systems such as the life support systems, MEM, Earth

entry vehicle, and other support vehicles require detailed conceptual design effort.

C. Concluding Remarks.

In summary, the situation for Mars exploration seems to be as follows: We are beginning to understand the problem. We can ask sensible questions, but are quite far away from establishing a firm plan on how to explore the planets with manned flights. We should be in a much better position in perhaps a year from now if we work hard at it. Let's get going!

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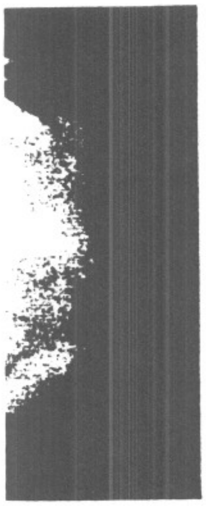

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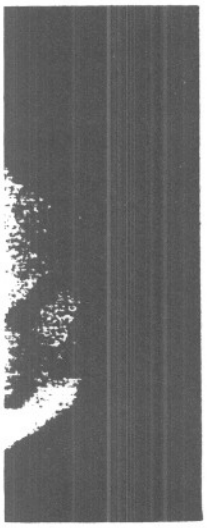

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