

TERRESTRIAL QUARANTINE CONSIDERATIONS FOR
UNMANNED SAMPLE RETURN MISSIONS*

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(NASA-CR-132071) TERRESTRIAL QUARANTINE
CONSIDERATIONS FOR UNMANNED SAMPLE RETURN
MISSIONS (Jet Propulsion Lab.) 15 p HC
\$3.00

N73-24118

CSCL 6M

Unclas

G3/04 03934

Paper L. 7. 7
Joint Open Meeting of the Panel on
Planetary Quarantine and Working Group 5
16th Plenary Meeting of COSPAR
Konstanz, F. R. G.
May 23 - June 6, 1973

* This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

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Abstract

Numerous studies have shown that unmanned extraterrestrial sample return missions are technically feasible, with Mars the planet of primary interest. One consideration which has not received much attention in these studies is the possibility of contamination of the terrestrial environment by alien organisms returned with a vehicle containing an atmospheric or soil sample. For the purpose of understanding some of the possible implications of a terrestrial quarantine constraint on a mission and for developing a basic approach which can be used to demonstrate compliance beyond that developed for Apollo, a terrestrial quarantine study has been performed at the Jet Propulsion Laboratory. It is shown that some of the basic tools developed and used by the planetary quarantine community have applicability to terrestrial quarantine analysis. By using these tools, it is concluded that (1) the method of biasing the Earth aiming point when returning from the planet is necessary but, by itself, may not satisfy terrestrial quarantine constraints; and (2) spacecraft and container design significantly influence contamination transfer.

1.0 Introduction

The National Aeronautics and Space Administration (NASA) has established requirements for the biological quarantine of planets involved in unmanned exploration. All NASA unmanned planetary flight projects are governed by a uniform set of planetary quarantine (PQ) requirements as set forth in NHB 8020.12, "Planetary Quarantine Provisions for Unmanned Planetary Missions," April 1969. These planetary quarantine requirements do not apply to Earth itself.

This paper considers the quarantine aspects of returning samples to Earth in unmanned planetary spacecraft. Some of these quarantine considerations have been studied extensively in the United States in conjunction with the manned lunar missions by the Interagency Committee on Back Contamination [1] [2]. Terrestrial quarantine (or back contamination) is defined as contamination of the terrestrial biosphere with organisms or materials of extraterrestrial origin. Unmanned planetary sample return missions have quarantine aspects which differ considerably from both manned and "one-way" unmanned missions.

2.0 Mission and Spacecraft Description

2.1 Mission Description

The phases of an unmanned sample return mission are given in Figure 1. To provide familiarity with sample return concepts, a return mission from Mars was selected for this study. It is assumed that the outbound flight and the landing are analogous to that of a Mars lander such as described in Reference 3. The recovery and quarantine phase is assumed to be similar to the manned lunar missions as described in References 1 and 2. For the return phase it is assumed that an ascent vehicle containing

the Mars soil sample will rendezvous with a return vehicle in Mars orbit. The return vehicle is then injected from Mars orbit on a transfer trajectory to Earth.

The return flight of the mission can be appropriately described by considering the trajectory modes available as options and comparing the total mission durations, injection energies from Mars, and Earth arrival velocities. On the return portion of the flight, the interplanetary trajectory can be of a conjunction or an opposition class (Figure 2). The conjunction class is characterized by a minimum energy Mars-Earth trajectory (i. e. , minimum fuel requirements). In order to achieve this, the spacecraft must stay on Mars, or in Mars orbit, for a duration of over a year to await the desired planetary geometry. Conversely, the opposition class is characterized by a short stopover at Mars and shorter mission duration. However, the mission is penalized with a larger fuel requirement.

For this study the flight time to Mars is assumed to be approximately 200 days. The conjunction class return will result in a 509-day stay at Mars and an injection energy from Mars orbit of $5.4 \text{ km}^2/\text{s}^2$ with a resulting Earth arrival velocity of 5.6 km/s . The total mission duration is approximately 1020 days. The opposition class return was determined for a 40-day stay at Mars, which results in an injection energy from Mars orbit of $48 \text{ km}^2/\text{s}^2$, an Earth arrival velocity of 14.3 km/s , and a total mission duration of 465 days. In summary, the conjunction class has longer mission duration, but smaller injection energy from Mars and smaller Earth arrival velocity than the opposition class.

2.2 Spacecraft Description

A study by Langley Research Center depicted a set of typical spacecraft that could be used for a Mars sample return mission [4]. An example of a

Mars descent lander from this study is shown in Figure 3. In this design an indexable motor drive sample container is on the top part of the vehicle and is mounted on the Earth reentry heat shield. The container receives its samples from a rover vehicle by means of the sample transfer arm. At liftoff, the ascent vehicle separates from the rest of the lander and will later rendezvous with the orbiting return vehicle. In Figure 4 the ascent vehicle is shown mated with the return vehicle. The sample container and heat shield are then attached to the return, and the remainder of the ascent vehicle is subsequently detached and remains in Mars orbit. The return vehicle then injects into a Mars-Earth transfer trajectory.

As the return vehicle approaches Earth, two options are considered: (1) the injection of a capsule into Earth orbit with the capsule later being picked up by a space shuttle, or (2) the injection of a direct reentry capsule. A typical design for each sample return option is shown in Figure 5.

3.0 Analysis and Results

3.1 Trajectory and Navigation Considerations

The conjunction class and opposition class return trajectory modes were examined in detail in terms of navigation maneuver errors that would result in probabilities of accidental Earth impact and then compared to possible levels of terrestrial quarantine constraints.

The out-of-Mars orbit injection maneuver was analyzed to determine typical accidental Earth impact probabilities that would result from errors in that maneuver. The magnitude of the injection maneuver was found to be approximately 2.3 km/s for the conjunction class return and 7 km/s for the opposition return. Considering that an execution error in magnitude is

usually about 0.1 of 1% (based on the Mariner spacecraft series experience), an error estimate in that maneuver of 1 m/s was found to be reasonable.

The impact probability was calculated as a function of a distance from the center of Earth (B) in the Earth aim plane; the results are shown in Figure 6. An interesting observation is that impact probabilities can be substantially reduced by biasing (increasing B) in the opposition class return, whereas for conjunction returns the impact probability is relatively unchanged by biasing. This was due to the fact that the error ellipse for the opposition class is more elliptical than for the conjunction class.

In summary, the results show that accidental Earth impact probabilities due to likely execution errors in the out-of-Mars orbit injection maneuver will very likely be larger than 10^{-2} for reasonably desired aim points at Earth. If this value is modified by the probability of not being able to perform a corrective maneuver if on an impact trajectory, typically 10^{-2} , then such an error would satisfy a terrestrial quarantine constraint of 10^{-4} . This assumes that the probability of Earth contamination given accidental impact ($P_{C/I}$) is unity, and a value significantly less than unity would make the quarantine constraint easier to meet.

3.2 Spacecraft Considerations

A typical Mars lander/ascent vehicle was shown in Figure 3. As the vehicle resides on the surface, it is reasonable to assume that Martian material could transfer to the spacecraft surfaces by various natural or on-board mechanisms. Dust particles could become detached from the surface of the ascent vehicle and then be transferred to the orbiter surfaces during rendezvous by means of dynamic events such as vibration, contact of docking surfaces, and docking malfunctions.

The possibility of contamination transfer to the orbiting return vehicle is best discussed with the aid of Figure 4. The direct reentry capsule configuration (Figure 4 with details in Figure 5b) is used as an example for discussion of the contamination transfer mechanisms. When the ascent vehicle docks with the return vehicle, it is actually docking with the orbiter portion of the reentry capsule. When the ascent vehicle disengages and falls away from the return vehicle, the heat shield and sample container remain attached to the orbiter portion of the reentry capsule. The contamination on the sample container would be trapped in the interior of the reentry capsule. Special seals and bioshields would be necessary to control possible problems at the conjunction of the heat shield and the rear portion. To summarize, spacecraft leaving the Mars surface will be contaminated. The contamination transfer problems from the ascent vehicle to the return vehicle require detailed study. Spacecraft design will make a considerable difference in magnitude of these problems.

Design attention should be directed to the sample container and the on-board monitoring necessary to assure integrity of the container. Specifically, an adequate seal for the sample container is required not only to prevent terrestrial contamination during the return flight and recovery, but also to preserve the integrity of the sample. In addition, the possible disastrous consequences of the release of sample contents into the Earth's atmosphere due to meteorite impact or spacecraft breakup must be precluded. This could be accomplished by enclosing the sample container in a sphere with an outer ablative shield covering.

To determine the condition of the spacecraft as well as the integrity of the sample container during the landing phase of the mission, a TV system could be used to scan the surface of the ascent vehicle to (1) determine

surface contamination from planet soil by comparing reflective properties of an uncontaminated control surface against exposed surfaces, and (2) verify the proper operation of the sample gathering and encapsulation mechanisms. As the spacecraft returns to Earth, strain gauges or leak detection sensors could monitor the condition of the sample container to detect leaks or break-up. The complexity of these design considerations will be strongly dependent on the stringency of the terrestrial quarantine constraints.

4.0 Conclusions

From the results of the trajectory and navigation analysis for a Mars-Earth sample return trajectory, it is concluded that if a stringent terrestrial quarantine requirement is imposed, the constraint could not be satisfied by simply biasing the Earth aim point. Specifically, investigation of the out-of-Mars orbit maneuver shows that a standard magnitude error in that maneuver would result in an Earth impact probability of the order of 10^{-2} . Assuming a return midcourse maneuver "unreliability" of 10^{-2} , the overall probability of uncontrolled accidental impact would be 10^{-4} . Even if one assumes that accidental impact would result in the certainty of biological contamination, an overall terrestrial quarantine constraint on the order of 10^{-4} could still be satisfied. However, a constraint of the order of 10^{-8} would generally mean that terrestrial quarantine could not be satisfied by navigation strategy alone, i. e., biasing the Earth aim point. Other methods of controlling and monitoring contamination transfer, such as spacecraft design, would become increasingly important.

Finally, it is concluded that if planning of unmanned planetary return missions is to proceed, a terrestrial quarantine policy should be established.

References

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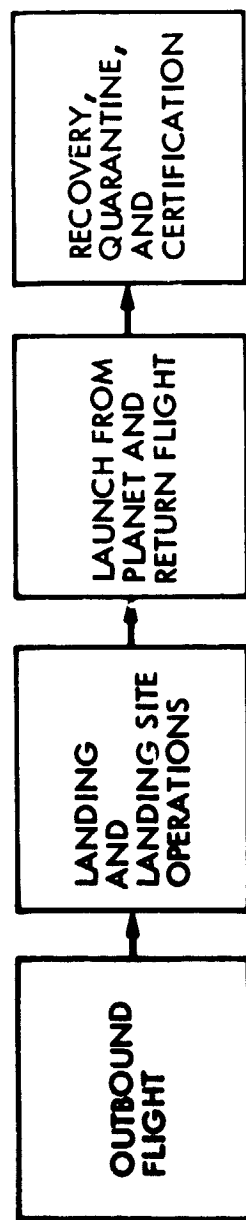


Figure 1. Phases of unmanned sample return missions

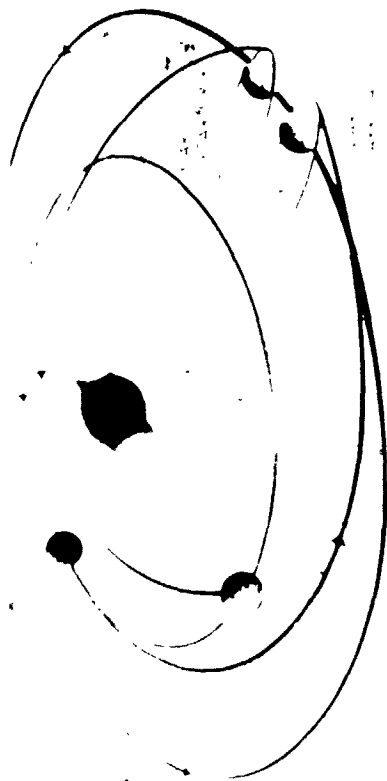


Figure 2. Mars sample return trajectory options

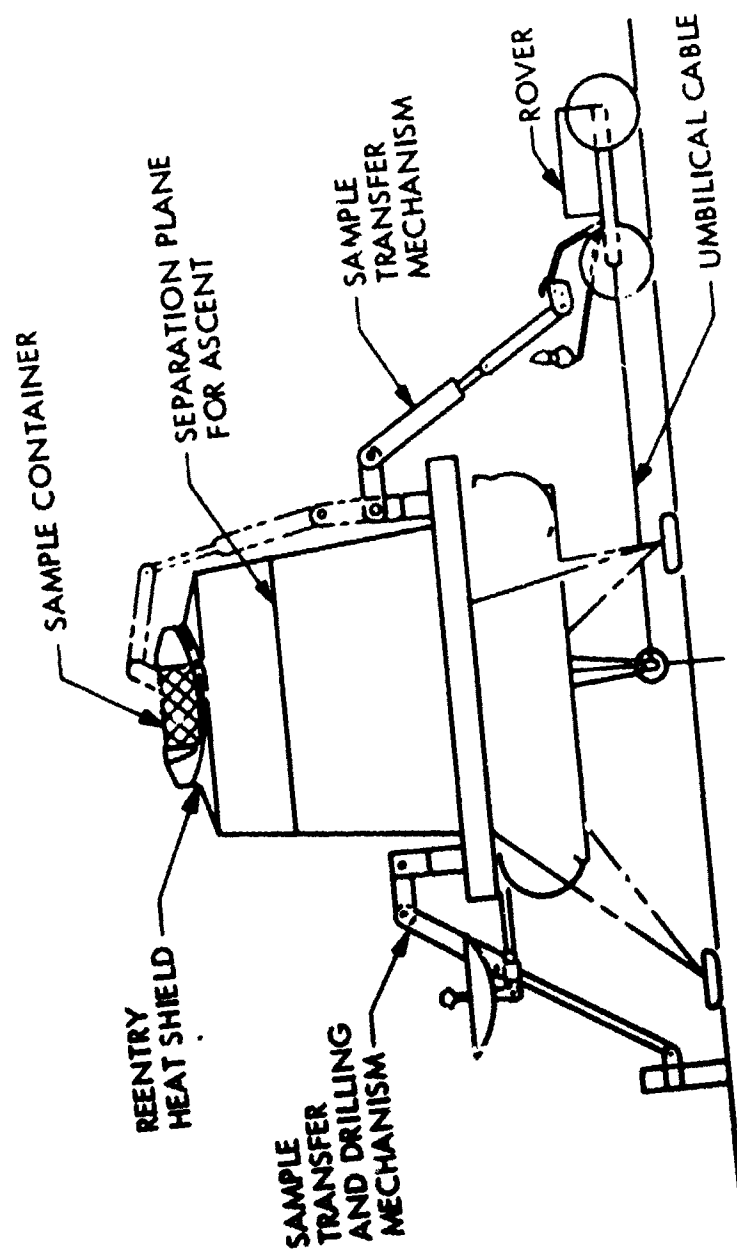


Fig. Typical Mars lander/ascent vehicle

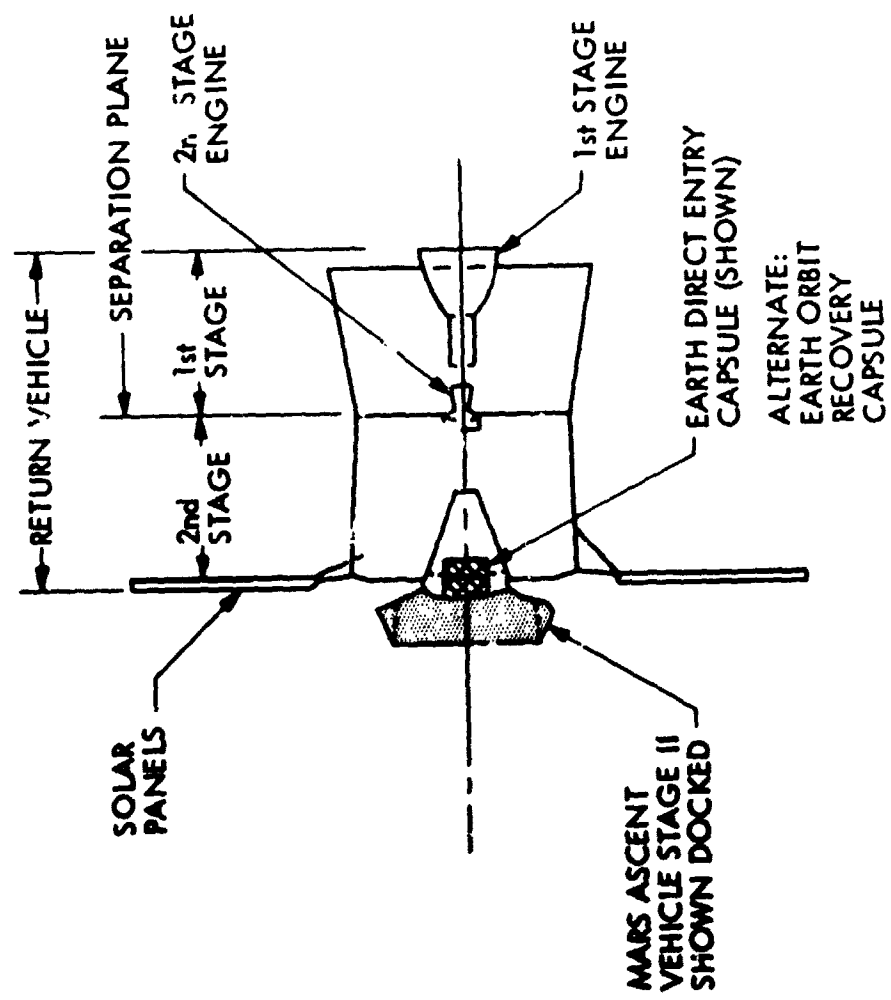


Figure 4. Mars ascent vehicle shown mated with return vehicle

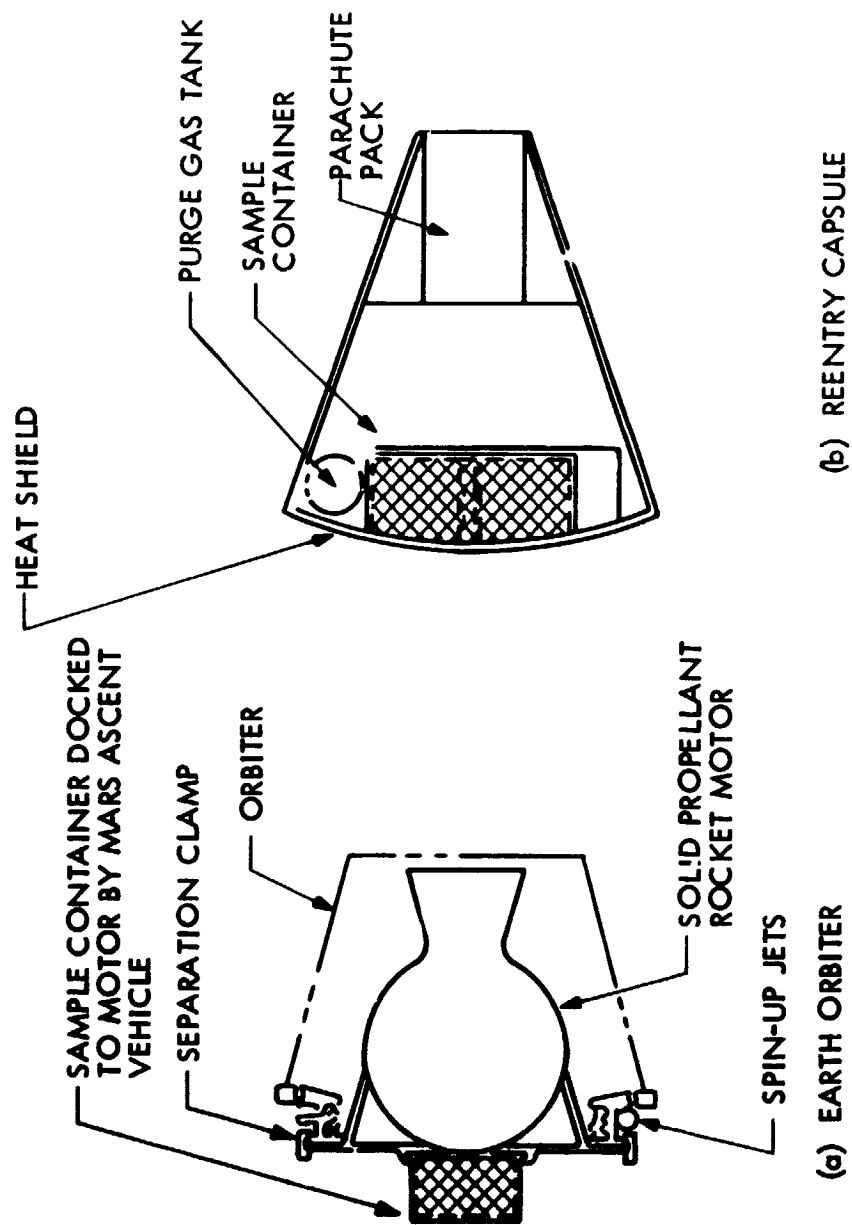


Figure 5. Typical design for an Earth orbiter and Earth reentry capsule

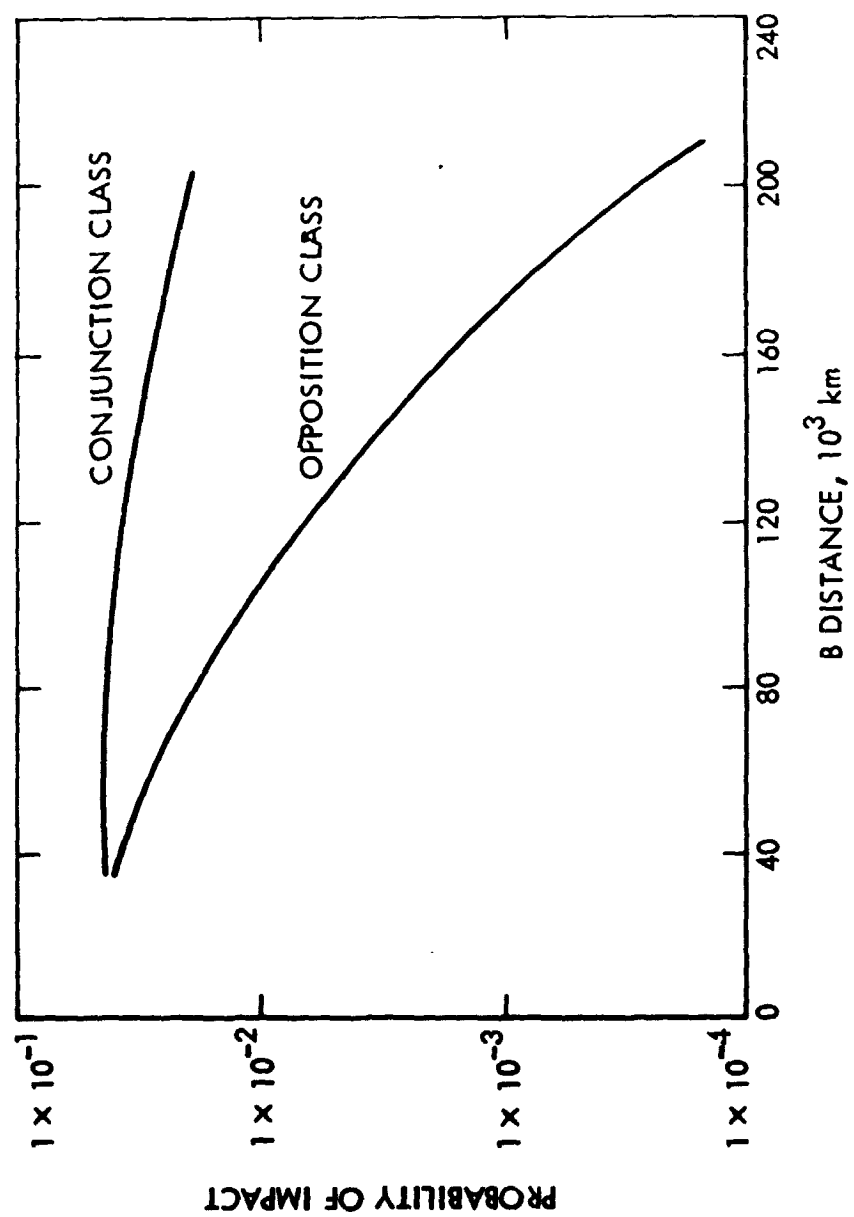


Figure 6. Probability of Earth impact by biasing Mars departure aim point