PLANETARY QUARANTINE ANALYSIS FOR AN UNMANNED MARS ORBITER

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Abstract

The United States Mariner Mars 1971 Program was planned to place two planetary vehicles in Martian orbit to obtain scientific measurements of the physical characteristics of the planets. To assure that Mars will be maintained as a biological preserve, the probability of contaminating the planet with viable terrestrial microorganisms from the launch vehicle or the spacecraft has been analyzed.

This paper describes the analysis approach and the planetary quarantine model being applied to the program for allocating and estimating the probability of contamination associated with potential biological contamination sources. It is shown that three sources – accidental impact of the spacecraft, loose particles, and gases used for attitude control and pressurization – form the major hazards. Furthermore, the results of the analysis indicate that with the planned mission

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strategy, including aiming point and delivery biases, and the imposition of facility and procedural control during the systems test operations to minimize particulate and microbial contamination of the spacecraft, the planetary quarantine constraints for the Mariner Mars 1971 mission are being satisfied.

1. Introduction

The United States' concern for the biological preservation of the planets,in consonance with the Committee on Space Research (COSPAR) agreements and the Outer Space Treaty [1], necessitated the development of planetary quarantine requirements, policies, and approaches for planetary flight programs [2]. This digest will identify the considerations and approaches that are used for the Mariner Mars 1971 orbital mission to assure concerned organizations that the United States is pursuing an active planetary quarantine program.

The United States policy is established by the National Aeronautics and Space Administration (NASA), following the recommendations of the Space Science Board of the National Academy of Sciences. The objective of the NASA policies is to prevent the transfer of terrestrial life to the planets of biological interest so that life detection experiments will not be invalidated and the planet's environment will not be irreversibly altered. The Planetary Quarantine Office of NASA implements national policy for unmanned planetary missions by means of a planetary quarantine document [3] that requires all flight projects to demonstrate compliance with specified quarantine constraints before launch approval is granted.

Each planetary project performs an analysis to show that the probability of contamination associated with a flight will be less than a specified value. The value specified by the Planetary Quarantine Office for each mission is established from the planet contamination constraint accepted from COSPAR, which is based on the estimated number of missions to that planet to be conducted during the period of biological interest, the proportion of United States launches, and the apportionment of the total constraint against the various types of missions (i.e., lander, orbiter, fly-by). The mission allocation for Mariner Mars 1971 is 7.1×10^{-5}.

In performing the planetary quarantine analysis, the project utilizes NASA directives, provisions, and standards. Among the latter is a value for probability of growth and proliferation for any microorganisms reaching Mars, $P_G = 10^{-4}$.

2. Mission Profile

The primary objective of the Mariner Mars 1971 Project is to insert spacecraft into orbit about Mars to obtain scientific information about the planet and its environment, and to make exploratory investigations that will form the basis for future experiments, specifically those relevant to the search for extraterrestrial life. The Mariner Mars 1971 spacecraft was launched by an Atlas Centaur launch vehicle from Cape Kennedy. Flight time to Mars is 168 days.

The mission profile for the Mariner Mars 1971 Program is given in Fig. 1. The mission profile can be defined in two segments, the heliocentric and the areocentric. The heliocentric portion of the mission is from injection to, but not including, orbit insertion. The areocentric portion takes place after and including orbit insertion.

3. Planetary Quarantine Model and Analysis

From the mission profile and from a flight sequence of events, all potential contaminating sources are identified. A planetary quarantine model (Fig. 2) is then determined. This probability "tree" permits estimation of constraint levels as it relates to each identified source. Confirmation that these estimates will not be exceeded is obtained by performing an analysis utilizing information from prior flight experience, literature surveys, experimentation, and engineering judgment. The results of this analysis are used for selecting appropriate mission strategies, i. e., aiming point biasing and orbit periapsis altitude selection.

Two categories of contamination sources are identified, namely large impactable sources and ejecta efflux sources. Examples of the first category are the launch vehicle, spacecraft, medium-gain antenna plug or large pieces that could impact the planet as a result of trajectory aiming errors, orbital decay, and catastrophic events during the quarantine period. The second category includes fluids or particles that consist of a relatively small amount of material expelled at any time.

The spacecraft portion of the model is considered in more detail in Fig. 3. The numbers under each source are the prelaunch allocations.

The "trajectory aiming and delivery errors" source considers the accidental impact of the spacecraft as a result of injection, orbit determination, and maneuver execution errors and subsequent delivery dispersions during the heliocentric and areocentric phases of the mission. These probability allocations are met by mission and navigation strategy, including aiming point and delivery biases. Catastrophic events that could occur while the spacecraft is in orbit include spacecraft disintegration by explosion and uncontrolled spin. The probability of contamination by spacecraft disintegration was analytically determined by calculating the probability that an explosion or uncontrolled spin would occur and that the event would result in placing a large equipment item into a decaying orbit or impact trajectory.

There are three major ejecta efflux sources: propellant, debris, and continuous. Debris ejecta, including loose particles, is the principal contamination source; thus the largest suballocation is given to it. All of these sources were analyzed in detail. The probability values that were used in the calculations are summarized in Table 1. The estimate for the number of organisms in or on a given ejecta efflux source is dependent on the source that is being analyzed. For example, the item of interest for the debris ejecta is the number of organisms on the exposed surface of the spacecraft, whereas for the gas efflux an estimate of the number of organisms in the on-board nitrogen gas bottles is appropriate. The probability of ejection P_E of a single microorganism and the probability P_T that the organism is placed on an impact trajectory are also source dependent. An example of the manner in which these source dependent parameters were estimated is shown in Fig. 4 for meteoroid spall. The estimate corresponds to the largest value of $P_E \times P_T$ over the expected range of ejecta size and density.

The probability that an organism will survive ejection is assumed to be 1.0 for those ejection processes involving cold release. Organisms released through meteoroid impact are subjected to some heat. Consequently, using engineering judgment, the estimate for meteoroids is 0.5.

The probability of survival of a microorganism in the space environment was a difficult parameter to estimate because none of the studies in the literature could be directly related to the Mariner Mars 1971 mission conditions. The probability of survival value is assumed to be a function of the amount of time the particle is exposed to the environment after release from the spacecraft. The environmental exposure, whether during the heliocentric or areocentric portions of the mission, will be for a minimum of several days and may extend for months. Based on the results of ultraviolet (UV) experiments in published literature, the time of expected exposure, conferences with experts in the field, and engineering judgment relative to the protection afforded by material surrounding an organism, the probability of survival was estimated to be 1×10^{-3}.

The probability that a microorganism will survive atmospheric entry depends upon the size and emissivity of the particle on which it resides. Particles that encounter the atmosphere will do so at relatively high velocities. Dependent upon particle parameters, temperatures sufficient to produce sterilization could be achieved. An estimate of 1×10^{-2}, based on engineering judgment, was selected.

The probability of release was assumed to be 1.0. The probability of growth was given a value of 1×10^{-4} by directive from the NASA Planetary Quarantine Office in accordance with the recommendations of the Space Science Board.

The principal hazards from a planetary contamination standpoint are spacecraft impact, debris ejecta, and attitude control and pressurant gas efflux. During the heliocentric portion of the mission, maneuvers are performed in such a fashion that the probability estimates are within the probability allocations for spacecraft accidental impact events. For the areocentric portion of the mission, the orbit is chosen with a periapsis altitude such that the spacecraft will remain in orbit (Fig. 5), even after mission completion, for much more than the duration of the period of biological exploration, which for Mars is defined as being through January 1, 1989, 17 years after insertion. Debris ejecta, including loose particles released by spacecraft dynamic events or meteoroid impact, are a hazard near encounter and during the areocentric portion of the mission. To meet the planetary quarantine constraint for this source, the spacecraft was carefully cleaned prior to launch. The attitude control and pressurant gases are a potential principal hazard.

However, during the filling process for Mariner Mars 1971, the gases are filtered through 0.5 μ filters into precleaned tanks.

4. Microbial Burden Control and Estimation

Based on the planetary quarantine analysis, an upper permissible microbial burden level was established for the spacecraft at the time it was placed within the nose fairing, i.e., encapsulation. For a nominal mission, this level was 1×10^5.

To assure that the permissible level would not be exceeded, the spacecraft were assembled, tested, and encapsulated in Class 100 laminar down-flow tents (Fig. 6); clothing and access restrictions for personnel were established; and an extensive cleaning program using isopropyl alcohol on critical spacecraft surfaces was implemented. Microbiological assays (Fig. 7) were taken using the swab rinse method [4]. The United States Public Health Service verified the assays. The estimated microbial burden on the exposed surfaces of the Mariner IX spacecraft was 3.1×10^4. This estimate is the lowest that has been measured on any Mariner spacecraft, indicating the effectiveness of the cleaning and handling program.

5. Summary

Satisfaction of the planetary quarantine requirements by all United States planetary flight programs enables NASA to assure concerned organizations that this nation has established biological safeguards in its planetary programs and that a course is being followed that will result in the planets being maintained as biological preserves for scientific investigations.

The United States unmanned Mars orbiter project has analyzed the probability of contaminating Mars with viable terrestrial microorganisms carried on or ejected from the launch vehicle or spacecraft. A mathematical model has been constructed to allocate and to estimate probability of contamination associated with identified contaminating sources or events. Mission strategy, including aiming point biasing and orbit periapsis altitude selection, was developed to satisfy the probability allocations for accidental spacecraft impact. To assure that permissible microbial burden levels would not be exceeded, extensive cleaning and facility personnel control programs were implemented. The analysis and microbiological assay results indicate that the planetary quarantine constraints for the orbiter mission are being satisfied.

6. Acknowledgments

The support of M. Christensen and R. Koukol of the Jet Propulsion Laboratory, P. LaLime and G. Simko of AVCO, and N. Fields of the United States Public Health Service during the Mariner 1971 Planetary Quarantine Program, specifically for their cleaning, contamination control, or microbiological monitoring efforts, is deeply appreciated. Also, the cooperation and support of the spacecraft test and operations team is gratefully acknowledged, especially V. Ohanesian, T. Laney, T. Shaw, R. Forney, and J. McGee.

Table 1. Probability values

Parameter	Estimate	Information source
Number of organisms	Source dependent	Encapsulation bioassay, expected dieoff
Probability of ejection	Source dependent	---
Probability of surviving ejection*	1.0	Engineering judgment
Probability of impact	Source dependent	---
Probability of surviving space environment	1×10^{-3}	UV experiments in literature
Probability of surviving atmospheric entry	1×10^{-2}	Engineering judgment
Probability of release	1.0	---
Probability of growth	1×10^{-4}	NASA directive

*With meteoroid bombardment, 5×10^{-1}.

References

[1] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, TIAS 6374, January 27, 1967.

[2] Fox, D. G., Hall, L. B., and Bacon, E. J., Development of Planetary Quarantine in the United States, contributed paper L. 1. 1, presented to the Joint Open Meeting Panel on Planetary Quarantine and Working Group 5, 14th Plenary Meeting of COSPAR, Seattle, Washington, U. S. A., June 1971.

[3] Planetary Quarantine Provisions for Unmanned Planetary Missions, National Aeronautics and Space Administration, NHB 8020. 12, April 1969.

[4] Standard Procedures for the Microbiological Examination of Space Hardware, National Aeronautics and Space Administration, NHB 5340. 1A, October 1968.

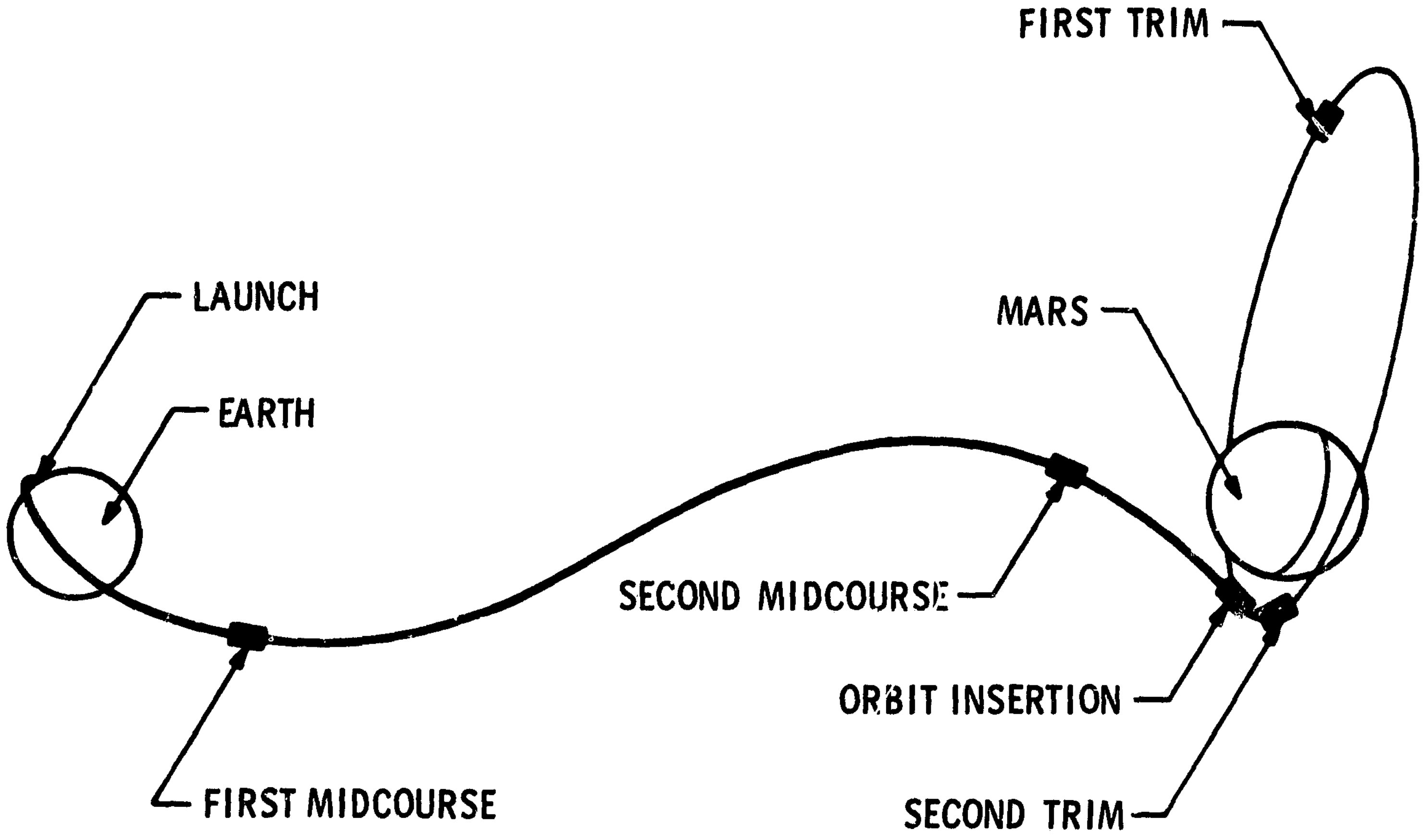

Fig. 1. Mission profile

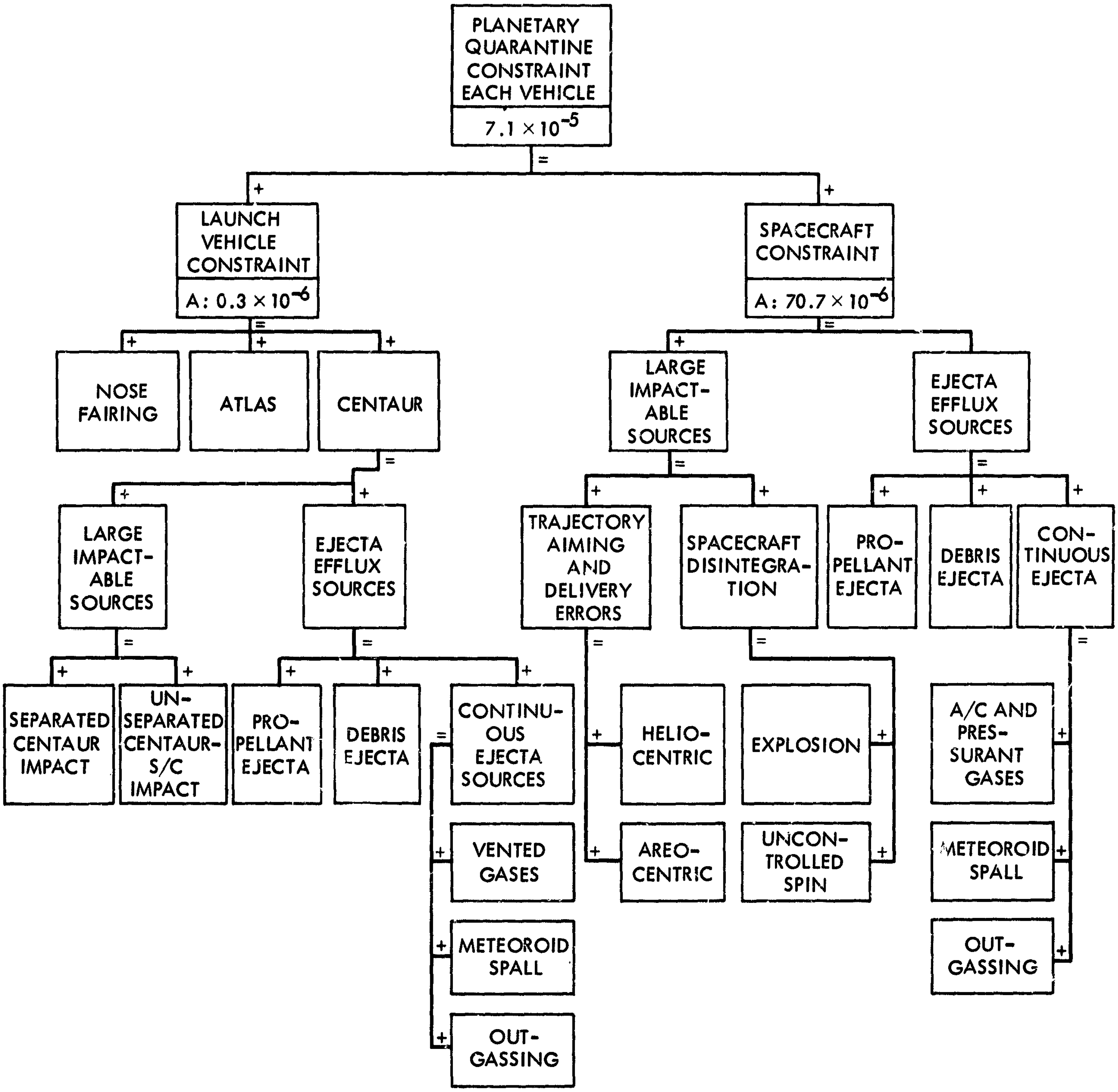

Fig. 2. Planetary quarantine model

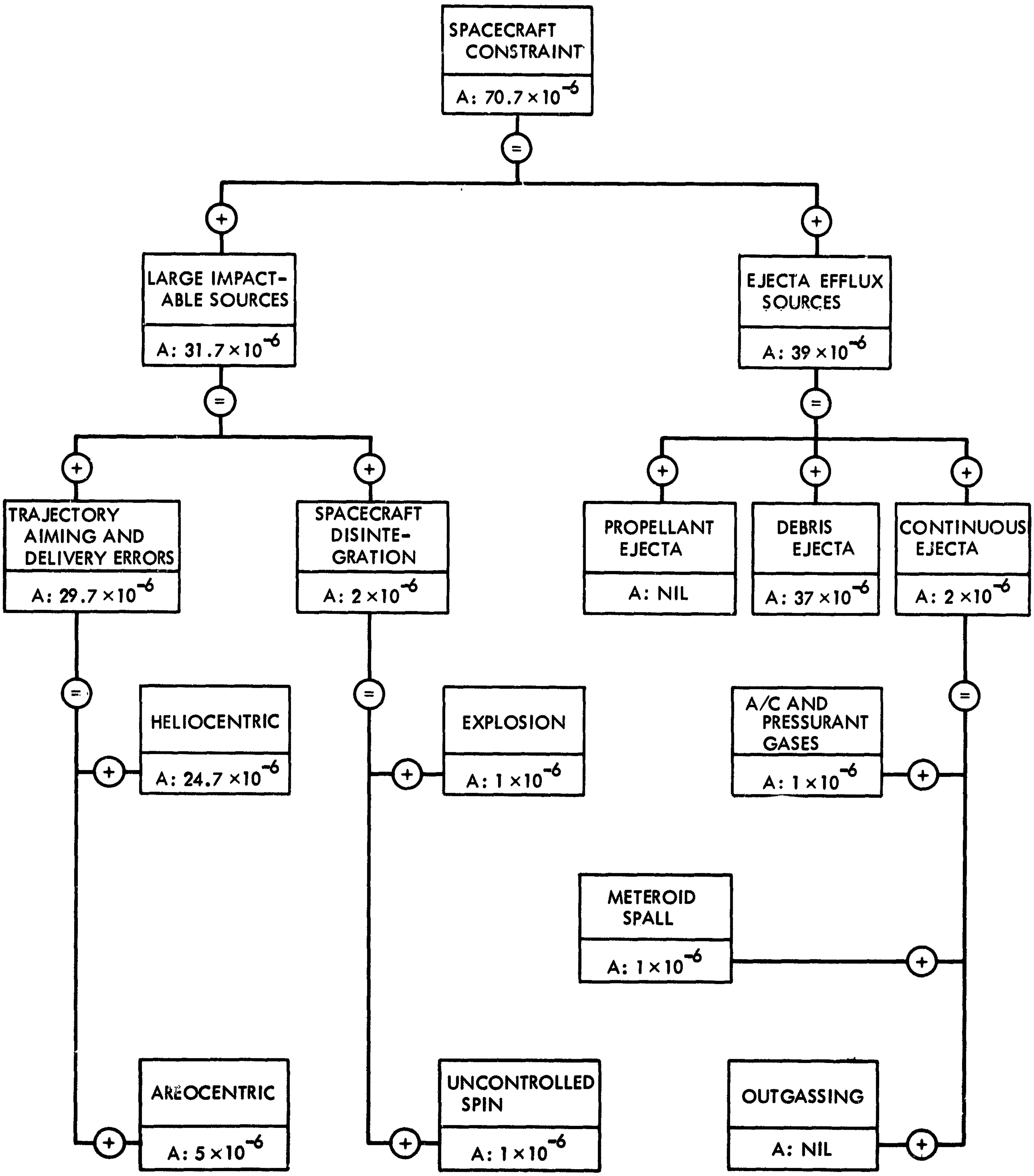

Fig. 3. Planetary quarantine model – spacecraft

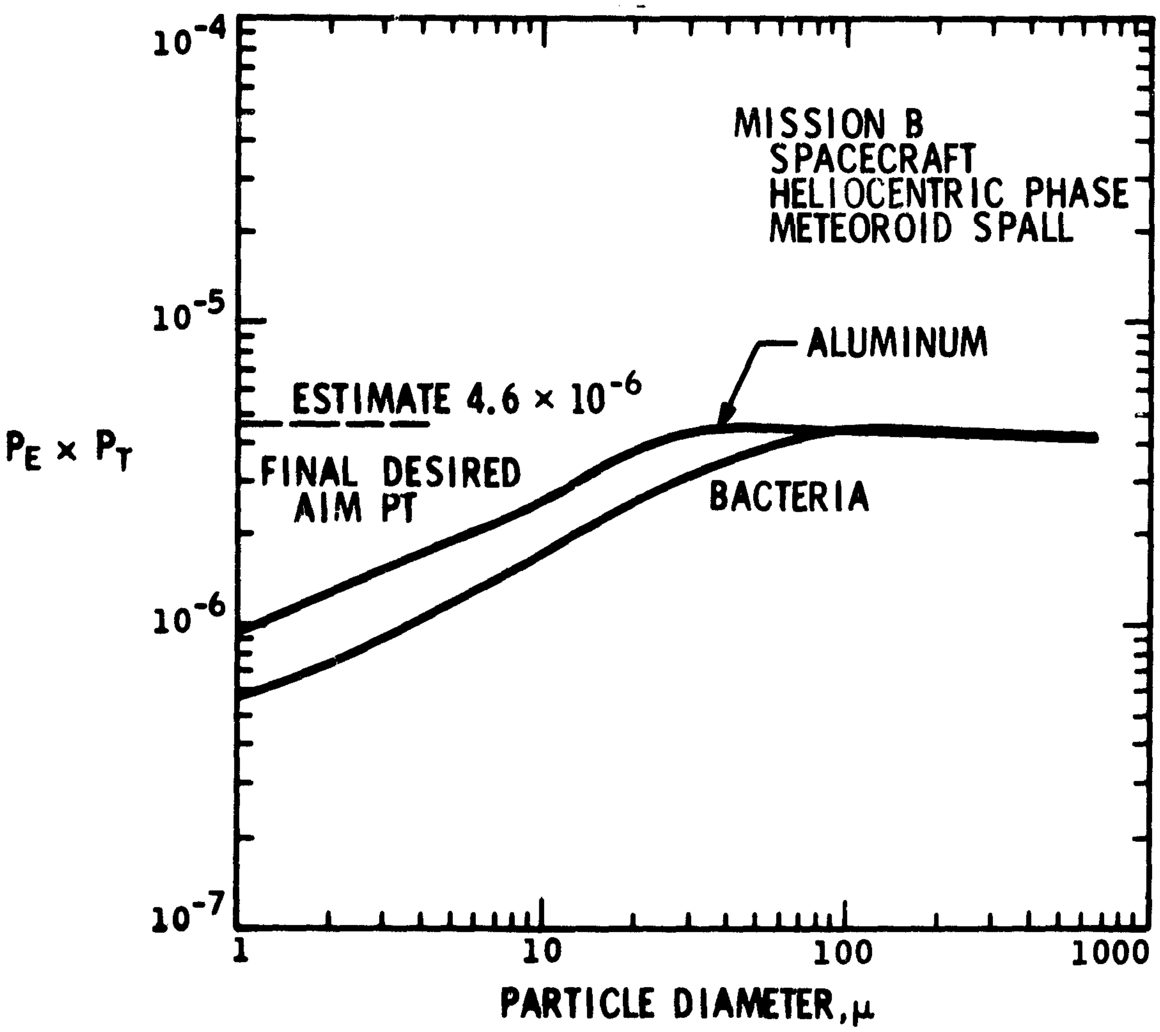

Fig. 4. Example of source dependent parameter, $P_E \times P_T$

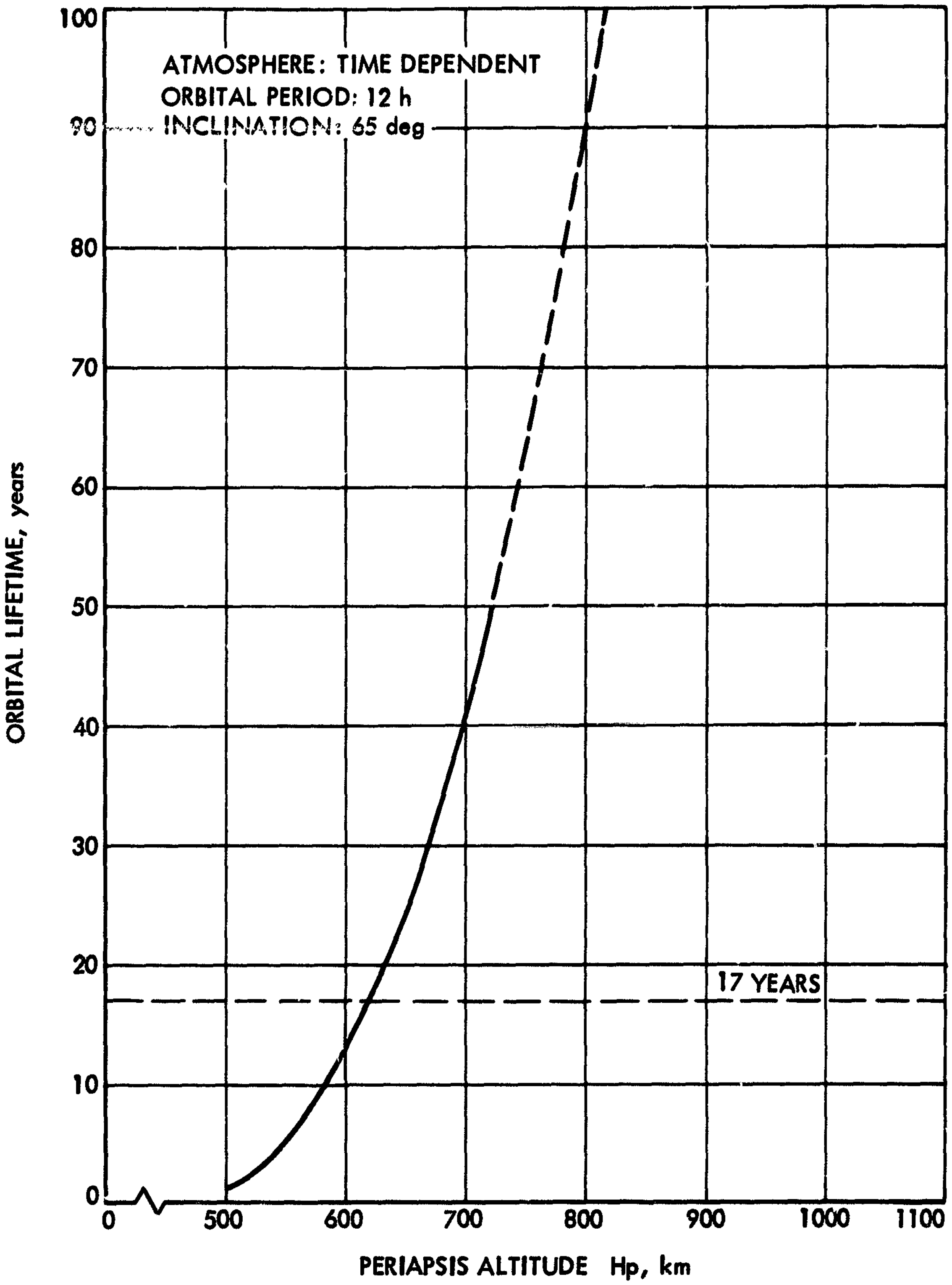

Fig. 5. Spacecraft orbital lifetime

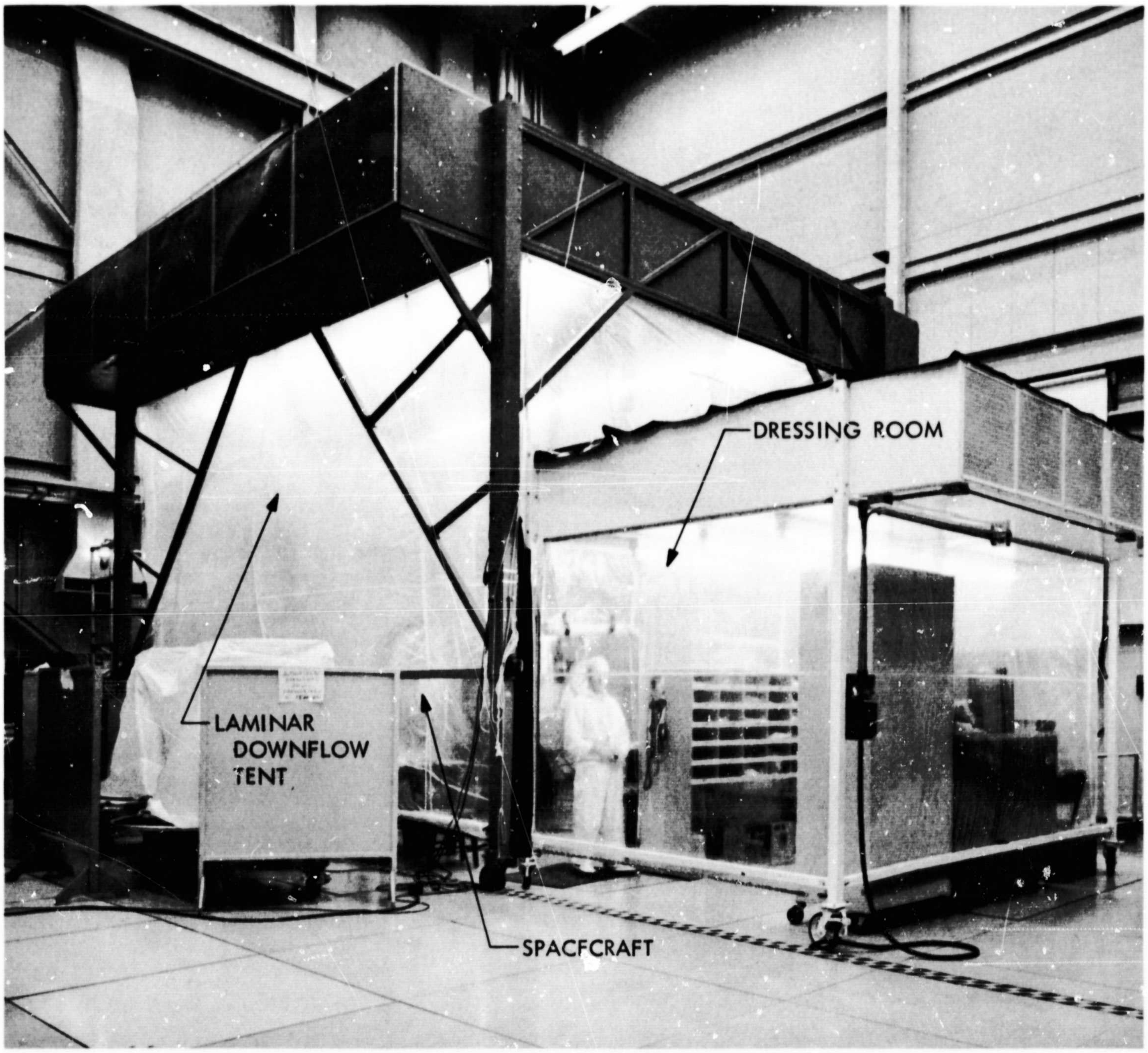

Fig. 6. Spacecraft laminar downflow tent

Fig. 7. Microbiological sampling of the Mariner 1971 spacecraft