Q

\

QUARANTINE CONSTRAINTS AS APPLIED TO SATELLITES*

A. R. Hoffman, W. Stavro, and C. Gonzalez

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103, USA

(NASA-CR-132073) QUARANTINE CONSTRAINTS AS APPLIED TO SATELLITES (Jet Propulsion Lab.) 15 p HC $3.00 CSCL 06M

N73-24116

Unclas
G3/04 03932

Paper L. 7. 9
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.

QUARANTINE CONSTRAINTS AS APPLIED TO SATELLITES

A. R. Hoffman, W. Stavro, and C. Gonzalez

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103, USA

Abstract

Plans for unmanned missions to planets beyond Mars in the 1970s include satellite encounters. Recently published observations of data for Titan, a satellite of Saturn, indicate that conditions may be hospitable for the growth of microorganisms. Therefore, the problem of satisfying possible quarantine constraints for outer planet satellites was investigated. This involved determining the probability of impacting a satellite of Jupiter or Saturn by a spacecraft for a planned satellite encounter during an outer planet mission. Mathematical procedures were formulated which (1) determine the areas in the aim-plane that would result in trajectories that impact the satellite and (2) provide a technique for numerically integrating the navigation error function over the impact area to obtain impact probabilities. The results indicate which of the planned spacecraft trajectory correction maneuvers are most critical in terms of satellite quarantine violation.

1.0 Introduction

The United States is currently planning unmanned exploratory flyby missions to planets beyond Mars in the 1970s. One of the scientific goals of these missions is the investigation of the satellites of the outer planets. The trajectories of such missions therefore necessitate relatively close flyby encounter distances to the satellites.

Concern for the biological preservation of these satellites has been voiced by the planetary quarantine community, in particular for such satellites as Titan of Saturn, where the probability of life is believed to be equivalent to, if not greater than, on the planet itself. As a result of this concern, a study was initiated to determine the implications of a satellite quarantine constraint on outer planet missions with close satellite encounters.

This paper presents the results of this investigation. The assumptions and method of analysis are presented first, and a parametric analysis is then performed for a typical Jupiter-Saturn mission with planned satellite encounters of Io at Jupiter and Titan at Saturn.

2.0 Method of Analysis

It will be assumed for the purposes of this paper that a quarantine constraint imposed on satellites of the outer planets will be violated if a spacecraft impacts a satellite. The likelihood of violation of the quarantine constraint from sources other than spacecraft impact (e.g., spacecraft debris) is assumed to be significantly smaller. Consequently, these other sources have been deleted from this investigation.

The possibility of inadvertent impact of a satellite will always be present due to the inherent errors and uncertainties in the spacecraft navigation system. The theoretical *a priori* calculation of such accidental impact probabilities therefore becomes of primary importance in the analysis of the satellite quarantine problem for outer planet missions.

The _a priori_ probability of accidentally impacting a satellite can be determined if the following information is given:

(1) A baseline spacecraft trajectory for a mission.

(2) The trajectory correction maneuver plan for such a mission.

(3) The quantitative errors that exist in these midcourse maneuvers as well as the injection maneuver.

(4) The orbit determination errors (e.g., planet and satellite ephemerides).

Given the information above, mathematical procedures now exist that can determine the probability of impacting the encounter planet. These tools, however, could not be utilized to determine the impact probabilities of satellites. The first step in this study, therefore, was to devise a procedure and develop the necessary tools to perform such a calculation. The procedure used in this analysis is the following:

(1) Determine the areas in the aim-plane of the encounter planet that would result in trajectories which impact the satellites of the planet.

(2) Integrate the probability distribution resulting from the navigation errors over these areas to determine the probability of satellite impact.

A theoretical formulation was devised and a computer program developed to perform the first step in the procedure outlined above. The results showed that these areas were approximately elliptical in most practicable cases. Because of this result, the available conventional tools for performing step 2 in the procedure above could not be used, since they integrated the probability distribution over a circular area (which represents the impact area for a planet). Another new formulation was therefore developed and programmed to perform the integration over an elliptical area.

With these software tools developed, it becomes possible to determine the satellite impact probability and thus the satellite quarantine implications for satellite encounter missions.

3.0 Application to a Sample Mission

3.1 Mission Characteristics

The mission selected for analysis is a typical Jupiter-Saturn mission. The particular trajectory analyzed is one which encounters the satellite Io at Jupiter and the satellite Titan at Saturn. The trajectory correction maneuver plan for such a mission is depicted in Figure 1. Injection plus six trajectory correction maneuvers are planned, three during the Earth-Jupiter phase and three during the Jupiter-Saturn phase. The times and purposes for these maneuvers are given in Figure 1.

For such missions, an important required parameter is the 1σ total delivery error in the navigation system. Representative values are given in Table 1 and will be used here as sample numbers in order to investigate their implications on satellite quarantine. These errors are given in the Jupiter aim-plane for the injection plus the first three trajectory correction maneuvers, and in the Saturn aim-plane for the Jupiter-Saturn leg maneuvers as well as the last pre-Jupiter maneuver (see Figure 1). As shown in the results, both the size and the ellipticity of these values are important.

3.2 Application Procedure

Using the developed tools and the trajectory and navigation characteristics, the probability of satellite impact was calculated. The probability of satellite impact was found to be a function of two variables: the closest approach distance r and orientation angle α. These variables are depicted in the planet aim-plane geometry shown in Figure 2. The orientation angle represents the location of the trajectory aim-point with respect to the center of the satellite in ecliptic space. Although the closest approach distance r of the spacecraft to the satellite for Io is fixed relative to the planet by the geometry of the nominal trajectory, it can be allowed to change considerably with respect to the satellite without severely handicapping the mission. For Titan, the distance is determined by science and engineering requirements, since no specified flyby geometry is necessary for gravitational assist, as there is for Jupiter.

In the analysis, various values of r were used and, for each value, α was varied from 0 to 360°. In doing so, the probability of impact changes as α is changed, even though r is fixed. An important observation is that the magnitude of the changes is larger when either the satellite impact area or the navigation errors become more elliptic. For the special case where the satellite impact area and the 1σ navigation errors are circular, the impact probability becomes a function of r only and not of α.

Since impact probability changes as α varies (for a fixed r), one is interested from a quarantine point of view in knowing the maximum value. These values are listed in Table 2 for both Io at Jupiter and for Titan at Saturn.

3.3 Interpretation of Results

The resulting impact probabilities have some very interesting and important implications for satellite quarantine. To determine whether satellite quarantine was violated, it was necessary to assume a satellite quarantine constraint (1×10^{-5}) and determine whether the contamination probability was equal to or greater than the constraint. In interpreting the impact probabilities in terms of the contamination probabilities (i. e., of violating a quarantine constraint), it must be noted that the stated values do not take into account the probability of being able to perform a corrective maneuver. Typically, this would decrease by approximately two orders of magnitude [1] the values listed in Table 2 for the injection maneuver and trajectory correction maneuvers 1 through 5. Maneuver 6, since it is the last maneuver in the mission, cannot be adjusted by the probability of performing a corrective maneuver because none are planned.

The determination of the contamination probabilities gives the following important results:

(1) The injection maneuver, which can be a critical maneuver relative to violating the Jupiter quarantine [1], does not violate a typical satellite quarantine on a Jupiter satellite.

(2) Maneuver 3, which was critical in terms of violating a Saturn quarantine [1], does not violate a Saturn satellite quarantine.

(3) Maneuvers 2 and 3 for Jupiter and maneuver 5 for Saturn (see Figure 1) would violate a sample satellite quarantine constraint of 10^{-5} only for very close satellite encounter distances (less than 5,000 km) and for specific flyby geometries.

(4) Maneuver 1 would violate an Io quarantine of 10^{-5} for flyby distances of up to 40,000 km; however, the impact probability can be reduced to negligible values by changing the satellite flyby geometry.

(5) Maneuver 4 seems to be the most critical since it would violate a Titan quarantine constraint of 10^{-5} for flyby distance of up to 11,000 km regardless of flyby geometry. The reason for this is the circularity of both the satellite impact area and the navigation error ellipses.

(6) Maneuver 6 would violate a Titan constraint of 10^{-5} for Titan flyby distances of less than 12,000 km for specific flyby geometries. The reason for this is that no subsequent maneuvers can be relied upon to correct an impact trajectory.

As mentioned before, the probability of impact values listed in Table 2 is strongly dependent on the eccentricity of the navigation error ellipse. To illustrate this dependence, Figure 3 shows the variation of Titan impact probability versus orientation angle for maneuver 4 (fairly circular error ellipse), and Figure 4 shows the variation for maneuver 6 (highly elliptic error ellipse).

4.0 Summary and Conclusions

The implications of a satellite quarantine constraint on a typical outer planet satellite encounter mission were studied from the point of view of satellite impact probabilities. Two important conclusions should be drawn from this effort:

(1) Significant differences exist between planetary and satellite quarantine implications on outer planet missions. For example,

trajectory correction maneuvers that result in a possible satellite quarantine violation are different from those violating <u>planetary</u> quarantine.

(2) Analytical tools for determining the probability of a spacecraft impacting a satellite are now available for application to any set of trajectory and navigation characteristics for satellites.

References

[1] W. Stavro and C. Gonzalez, "Planetary Quarantine Considerations for Outer Planet Missions," Advances in the Astronautical Sciences, The Outer Solar System, Vol. 29, Part 1, pp. 465-486, American Astronautical Society, Tarzana, Calif., 1971.

Table 1. Total navigation delivery errors (1σ)

Maneuver	Jupiter aim-plane			Saturn aim-plane		
	$\sigma_{\vec{B}\cdot\vec{R}}$, km	$\sigma_{\vec{B}\cdot\vec{R}}$, km	Correlation coefficient	$\sigma_{\vec{B}\cdot\vec{R}}$, km	$\sigma_{\vec{B}\cdot\vec{R}}$, km	Correlation coefficient
Injection	120,000	521,000	0.176			
Maneuver 1	2,302	11,213	0			
Maneuver 2	1,200	823	0.08			
Maneuver 3	1,100	436	0.08	402,000	201,000	-0.985
Maneuver 4				4,037	4,233	-0.137
Maneuver 5				651	2,123	-0.043
Maneuver 6				414	2,000	-0.083

Table 2. Maximum probabilities of satellite impact

Maneuver	Closest approach, km	Probability of satellite impact (maximum)	
		Io at Jupiter	Titan at Saturn
Injection	Any	$<10^{-6}$	
Maneuver 1	5,000	5×10^{-2}	
	10,000	3.7×10^{-2}	
	15,000	2.3×10^{-2}	
	20,000	1.1×10^{-2}	
	30,000	1.6×10^{-3}	
	40,000	1×10^{-4}	
Maneuver 2	5,000	2.4×10^{-3}	
	$\geq$8,000	$<10^{-6}$	
Maneuver 3	5,000	1.3×10^{-3}	$<10^{-6}$
	$\geq$7,000	$<10^{-6}$	$\ll 10^{-6}$
Maneuver 4	8,000		4×10^{-2}
	10,000		1.8×10^{-2}
	12,000		6.1×10^{-3}
	14,000		1.9×10^{-3}
Maneuver 5	8,000		5×10^{-3}
	10,000		2×10^{-4}
	$\geq$12,000		$<10^{-6}$
Maneuver 6	8,000		2.8×10^{-3}
	10,000		1×10^{-4}
	$\geq$12,000		$<10^{-6}$

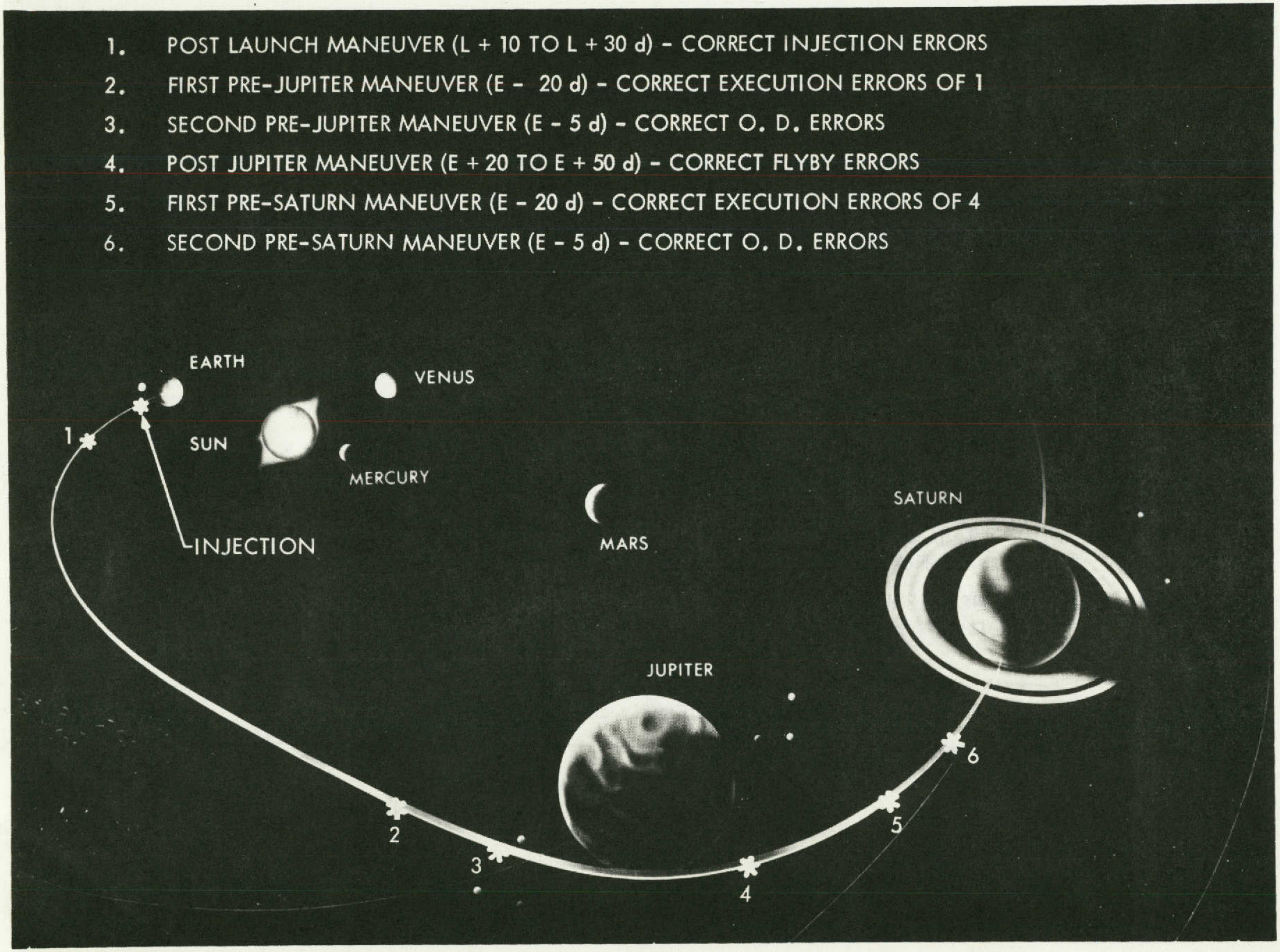

Figure 1. Trajectory correction maneuver plan for Jupiter-Saturn mission

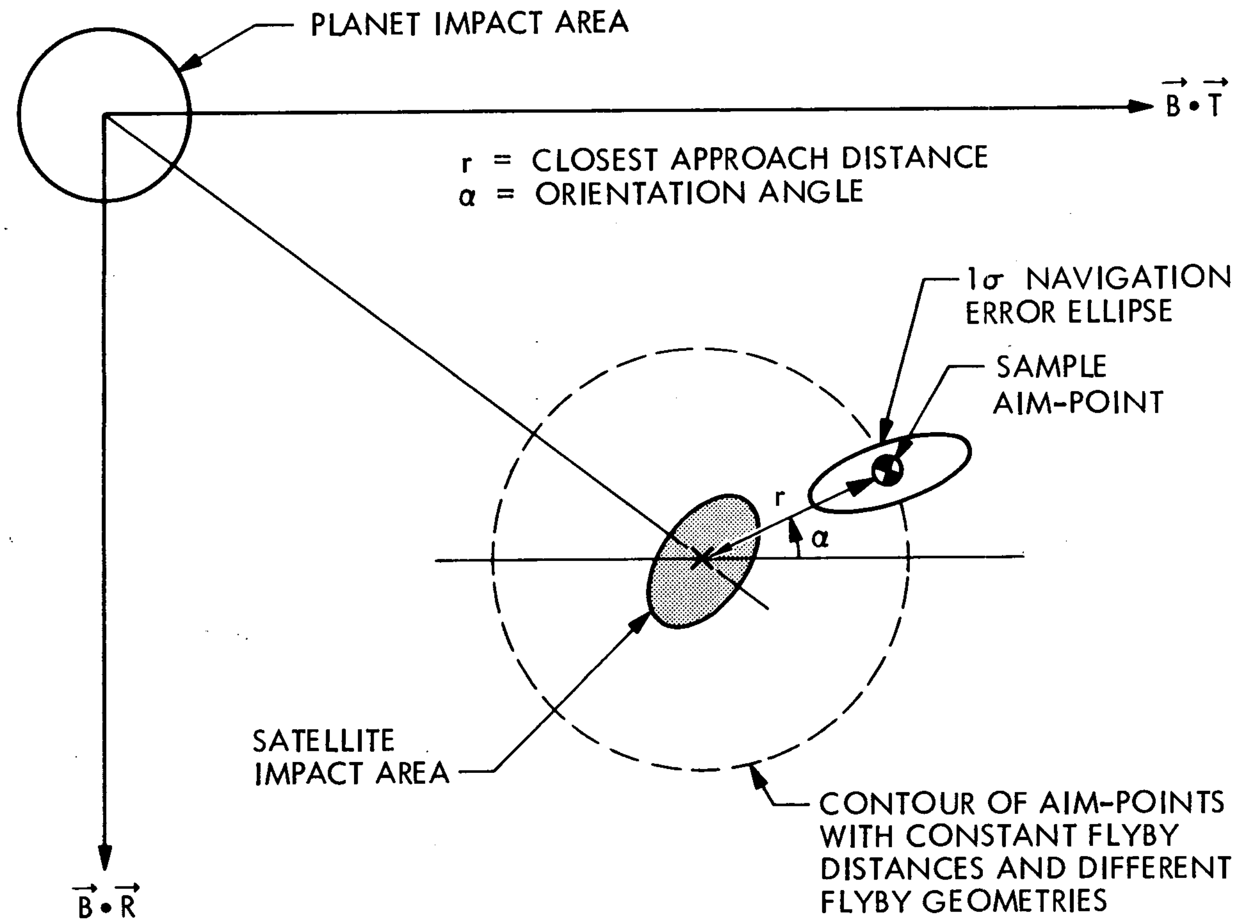

Figure 2. Planet aim-plane (not to scale)

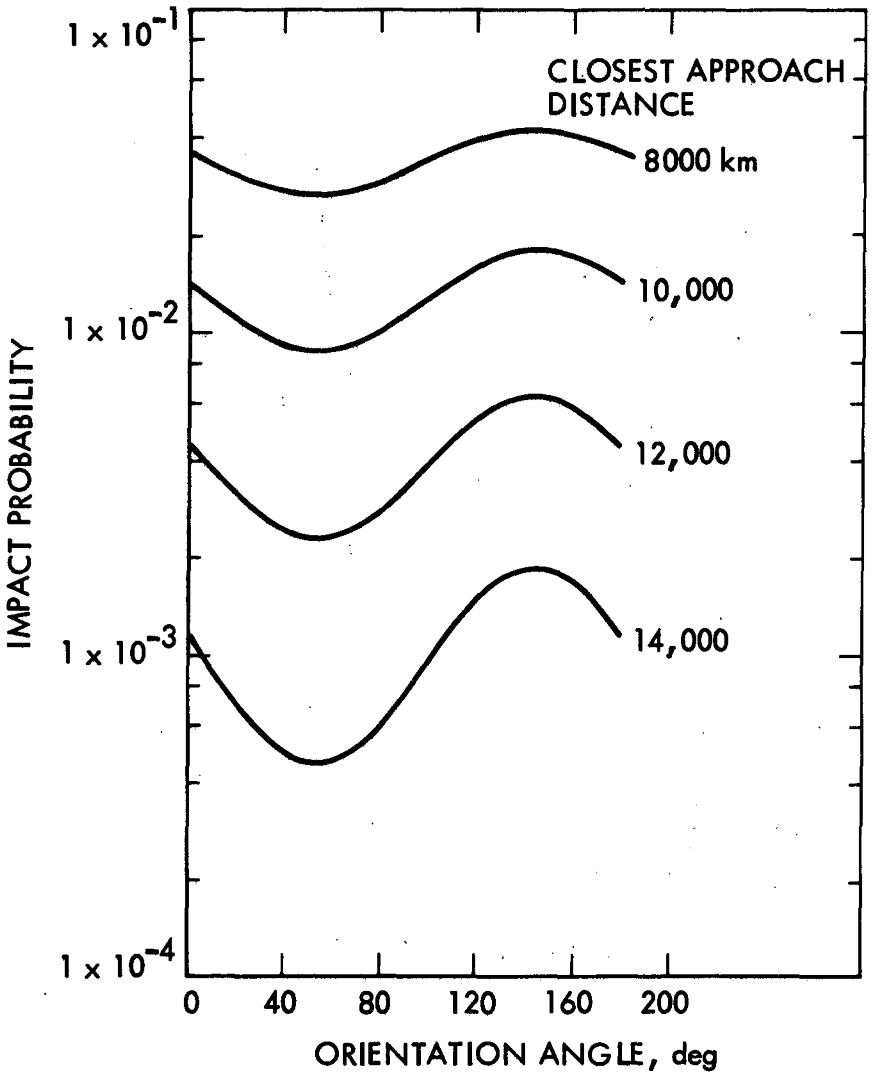

Figure 3. Titan impact probabilities for various flyby designs (maneuver 4)

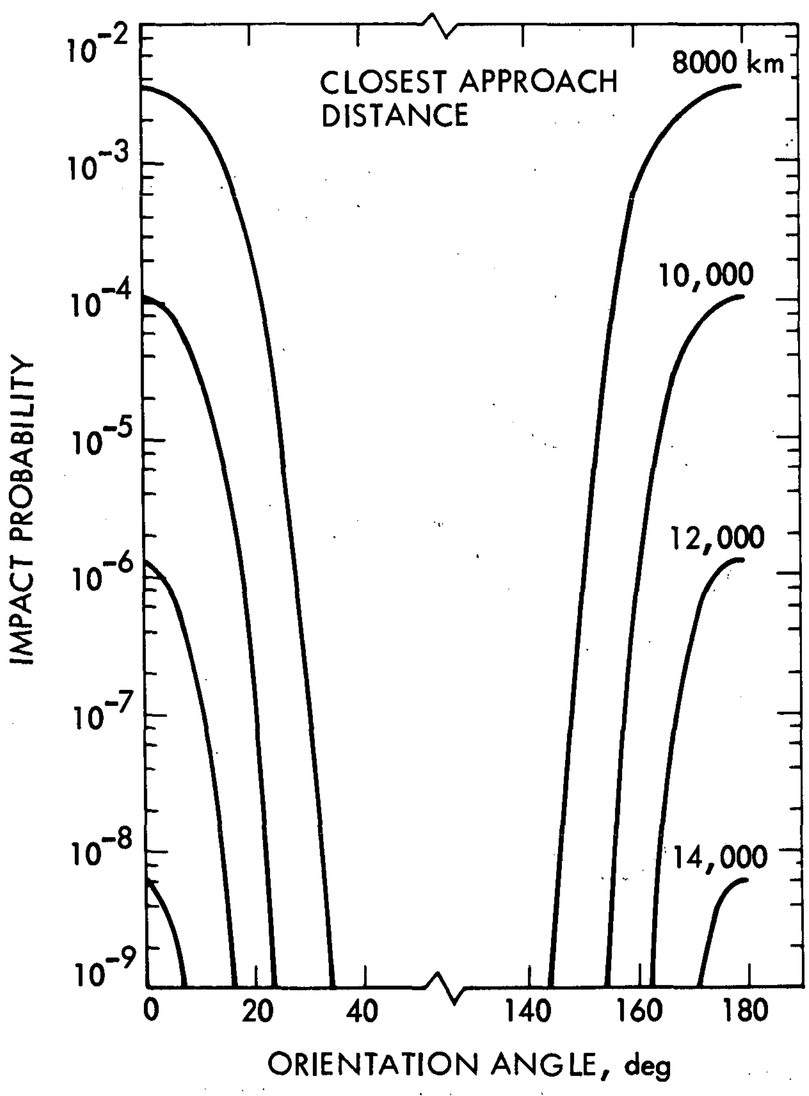

Figure 4. Titan impact probabilities for various flyby designs (maneuver 6)