Computerized Meteoroid Protection System Design for an Outer-Planet Spacecraft

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Theme

A SYSTEM of digital computer programs has been developed for use in selecting and evaluating meteoroid protection systems for outer-planets spacecraft. These programs use logic and equations commonly employed in radiation shielding analyses and extend their applicability to meteoroid vulnerability studies. The programs include the mission and its associated trajectories, the meteoroid environments near Earth and in interplanetary space, the configuration of the particular spacecraft, and the penetration of structural materials by hypervelocity particles.

Applying these programs to the design of a meteoroid protection system entails two phases. First, elementary models of the spacecraft structure are compared using tradeoff analyses in order to select a preferred structural arrangement from the various candidates. Then a detailed, computerized geometrical model of the entire spacecraft, incorporating the selected structure, is used to predict the survivability of the actual vehicle. The performance of the various structural candidates and the meteoroid protection system is expressed in terms of the number of penetrations and the probability of having no penetrations during the mission. By plan rather than coincidence, the computerized geometrical model is completely interchangeable and can be used to evaluate either meteoroid protection systems or radiation shielding systems.

Contents

The principal objective in designing the meteoroid protection system for the outer-planets spacecraft was to limit the possibility of damage to the electronic systems. If unprotected, the debris resulting from a penetration could conceivably damage or destroy individual electronic devices, or disrupt the operation of critical circuits. This latter possibility could occur due to severing of the wires (open circuits) or damage to the wiring insulation, causing short circuits. Though shielding is the most practical means of protection, it must efficiently prevent penetration by the numerous small meteoroids encountered during an interplanetary mission, but not unduly penalize the spacecraft in terms of added weight.

The preferred structural arrangement for the meteoroid protection system was selected from the six candidate concepts shown in Fig. 1. All these candidates had approximately the same weight per unit area, except for slight variations due to differences in materials. The candidates were compared in terms of the number of penetrations and the probability of no penetrations during a typical flight from Earth to Jupiter. For example, Figs. 2 and 3 show the expected penetration rates for the second candidate during Earth departure and interplanetary cruise.

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Index category: Meteoroid Protection Systems.

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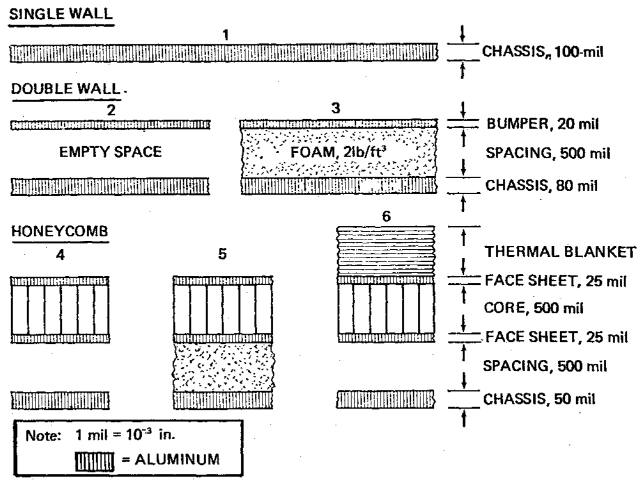

Fig. 1 Structural candidates.

Note that because of its brief duration, the Earth departure phase has practically no effect. In fact, Fig. 3 shows that the asteroidal particle environment is the dominant factor.

In the order of their decreasing ability to limit penetrations, the candidates were ranked as follows: 5, 6, 4, 3, 2, 1. Candidates 3, 4, 5, and 6 provided better protection than necessary according to a pre-established goal of providing a probability of no penetrations of at least 0.99 during the flight. Candidate 2 was just short of the goal; candidate 1 fell far short.

The final selection of the preferred structural arrangement resulted from considering not only the protection efficiency, but also other factors, such as complexity, cost, accessibility to the electronic subsystems after installation, and the operating life of the structure. In addition, the subjective factor of experience has shown us that an elementary structure that is used in a tradeoff study will perform better than anticipated when actual geometrical effects are included in the evaluation.

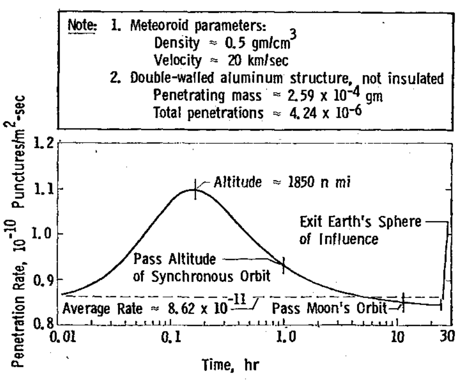

Fig. 2 History of sporadic meteoroid penetration rate during departure from Earth.

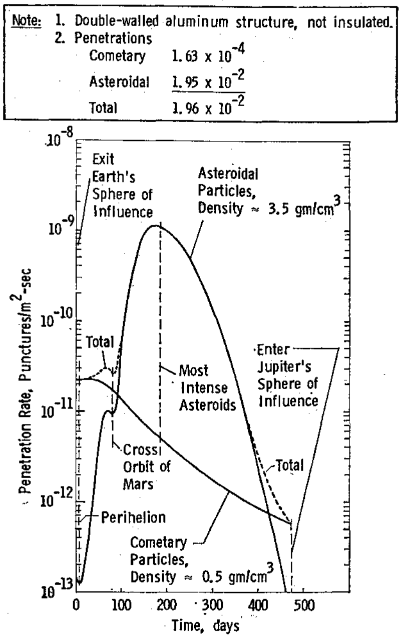

Fig. 3 Histories of cometary, asteroidal, and total penetration rates during interplanetary cruise.

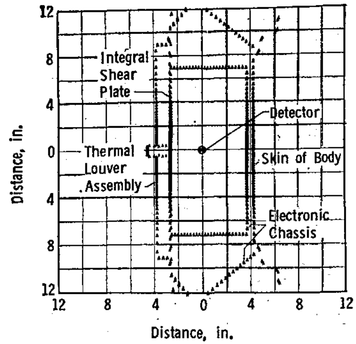

Fig. 4 Installation details of an electronic chassis.

Consequently, candidate 2 was selected as the preferred structure for the protection system. A computerized geometrical model of the entire spacecraft, incorporating this preferred structure, was prepared and evaluated for the same Earth-to-Jupiter mission. A section of the model depicting the structure in the vicinity of an electronics subsystem is shown in Fig. 4. The A's in the figure denote that the material is aluminum.

Table 1 compares the predicted number of penetrations and the probability of having no penetrations for the computerized geometrical model of the preferred (second candidate) structure. Note that our original choice of candidate 2, which was based partially on experience, has been justified by its improved performance in the computerized geometrical model.

Table 1 Comparison of results of the two modes of analysis

Mission phase & Sources of meteoroids	Mode 1 (concept 2)	Mode 2 (model spacecraft)
Number of penetrations		
Earth (sporadic)	4.23×10^{-6}	5.39×10^{-7}
Interplanetary		
Cometary	1.63×10^{-4}	2.09×10^{-5}
Asteroidal	1.95×10^{-2}	2.02×10^{-3}
Total	1.96×10^{-2}	2.05×10^{-3}
Probability of no penetrations		
Earth (sporadic)	0.99999567	0.999999461
Interplanetary		
Cometary	0.999837	0.9999791
Asteroidal	0.980726	0.997978
Total	0.980563	0.997957