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METEROIDS AS A POSSIBLE HAZARD TO SPACE VEHICLE OPERATIONS: AN ANNOTATED BIBLIOGRAPHY

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MAY 1963

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Compiled by

CHARLES G. GROS

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Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

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ABSTRACT

This work treats of meteoroids as a possible hazard to space vehicle operations. Citations to meteors and other interplanetary debris have been included when the material was of relevance to meteoroids as well. Citations to combined environmental parameters affecting the reliability of space vehicles in flight have also been included when meteoroids constituted one of the parameters. The period covered is from 1956 through 1962, with a few earlier citations. The resources of the Technical Information Center, Lockheed Missiles & Space Company, were utilized.

Search completed December 1962

1. Alexander, W. M., et al.
INTERPLANETARY DUST PARTICLES OF MICRON SIZE PROBABLY ASSOCIATED WITH THE LEONID METEOR STREAM, National Aeronautics and Space Administration, Washington, D. C. NASA Technical note D-1154, Dec 61, 6p. ASTIA AD-268 741

An interplanetary dust particle event, coincident with the Leonid meteor shower and lasting approximately 70 hours, was recorded by a sensor on the Vanguard III satellite. During this interval the satellite's microphone system registered impacts of approximately 2800 dust particles with momenta exceeding 1/100 dyne-second. The impact rate varied by as much as two orders of magnitude within a few hours. The microphone system was almost omnidirectional, so the radiants of the dust particles cannot be defined. Association of these dust particles with the Leonid meteor stream is suggested by the coincidence in time and by the location of the satellite. Vanguard III traversed five major meteor streams, but the impact rates significantly exceeded the background rate only during this one interval. This is the first case in which a significant increase in the directly measured impact rate of dust particles possibly can be associated with a major meteor stream.

2. Alexander, W. M., H. E. LaGow, and L. Secretan
A summary of direct measurements of the meteoric and the thermal environments on space vehicles. In INSTITUTE OF ENVIRONMENTAL SCIENCES. NATIONAL MEETING, 6–8 APRIL 1960, LOS ANGELES, CALIF. PROCEEDINGS, 1960. p. 103

Direct measurements of vehicle environmental conditions in space near the vicinity of the earth have been made from the Magnaray-Environmental Satellite, 1959 Eta. The environmental parameters measured on 1959 Eta were: (1) skin and package temperatures, (2) erosive sputtering, and (3) micrometeoroid impacts and damage. The information reported in this paper is interim in nature.

3. Assistant Secretary of Defense (Research and Engineering), Washington, D. C. SHOCK, VIBRATION AND ASSOCIATED ENVIRONMENTS. PART V. Bulletin no. 30, pt. 5, May 62, 171p. ASTIA AD-276 199

Includes:

Measurement and simulation of space environments
Scientific satellites and the space environment
Micrometeoroid impact damage.

4. Atkins, J. H., et al.
EFFECTS OF SPACE ENVIRONMENT ON MATERIALS, National Research Corp., Cambridge, Mass. Rept. for May–Aug 60. Dec 60, 66p. (WADD TR 60-721) (Contract AF 33(616)6288, Proj. 7381) ASTIA AD-254 075

In an attempt to provide information regarding the effects that space environment will have on the performance of materials to assist in the selection of materials for space applications, a study of meteoroids and their influence on materials was made.

5. Atkins, J. H., et al.
Meteoroids and their influence on materials. In EFFECTS OF SPACE ENVIRONMENT ON MATERIALS. National Research Corp., Cambridge, Mass. Rept. for May–Aug 1960. WADD tech. rept. no. 60-721. (Contract AF 33(616)-6288, Proj. 7381) p. 48–52. ASTIA AD-254 075

The nature of the meteoroid environment and the effects of this environment on materials are briefly discussed. Suggestions are made for future research projects.

6. Barber, E. and D. I. Sweitzer
ASTRONAUTICS INFORMATION. MICROMETEORITES, HIGH VELOCITY IMPACT STUDIES, AND PROBLEMS OF SPACE TRAVEL RELATING TO PARTICLE IMPACT. Jet Propulsion Lab., California Inst. of Tech., Pasadena. Literature search no. 143. 15 Oct 1959. 45p. (Contract NASw-6) ASTIA AD-231 586

Review of information on the existence of micrometeorites, interplanetary dust and other small particles in space and their possible influence on interplanetary flight. Included is general material of interest for background research; composition of meteorites, as well as of smaller particles, as a possible indication of the type of matter in space; properties, such as mass, size, thermal constants; kinematics, such as velocities, orbits, and distributions of meteoric particles; meteorological effects including astronomical lighting and effects on weather; impact studies; particle acceleration; and space travel problems.

7. Bauer, Carl A.
METEOROIDS IN THE UPPER ATMOSPHERE.
Missile Systems Division, Lockheed Aircraft Corporation, Van Nuys, Calif. Rept. no. LMSD-3134. 25 Nov 1956. 43p.

Following a discussion of the physical characteristics and estimated number of meteoroids, a discussion of meteorite impacts includes information on the pitting process, penetration, and pitting and erosion effects of meteoroids. In a separate discussion of meteoroids in the upper atmosphere, numeral calculations, counts of meteoroids in the atmosphere, and an equation for the velocity of fall of micrometeorites are included.

8. Beard, D. B.
Interplanetary dust distribution and erosion effects.
In ADVANCES IN ASTRONAUTICAL SCIENCES, v. 3 (Proceedings; Western Regional Meeting of the A. A. S., Aug 1958), ed. by N. V. Peterson and H. Jacobs. N. Y., Plenum Press, 1958. p. 23-1 to 23-6. Also available in: SURFACE EFFECTS ON SPACECRAFT MATERIALS (Proceedings, First Symposium, Palo Alto, Calif., 12–13 May 1959), ed. by J. F. Clauss. N. Y., Wiley, 1960. p. 379–386.

The presence and extent of minute material in the solar system are inferred from observations of the outer solar corona and the brightness of the night sky. Calculations based on the observations show that the dust concentration decreases with increasing solar distance as about r^{-145}, where r is the solar distance. The density of particles depends inversely on the particle radius to roughly the 3.5 power. Considerations of the orbits of particles in the combined gravitational fields of the sun and the planets (and the observations themselves) show concentrations of the dust in the plane of the ecliptic and in the region of the planets. Roughly 10^{-5} to 10^{-6} particles larger than 4μ should impact per square centimeter per second on a satellite skin – 30 to 300 impacts/sq. cm.-yr. This figure is in agreement with direct observations made with Explorer I.

9. Beard, D. B.
Meteoritic impact. ARS JOURNAL 31: 87–88, 1961.

A study of the impact of meteoroids on a space vehicle skin is examined from a consideration of the different physical processes by which energy transfer can occur shows that only evaporation is significant, that erosion is negligible, and that puncture is less likely than previously thought by many authorities, the threshold thickness in centimeters being only 0.6 cm for one puncture per year per 100 m^2 of surface.

10. Beard, David
SOLID INTERPLANETARY MATTER. Technical Information Division, Sandia Corporation, Albuquerque, New Mexico. Sandia Corporation Research Colloquium. Report no. SCR-252. Jan 1961. 22p.

In a discussion of the possible damage of interplanetary dust to space vehicles, it is concluded that micrometeorites might erode satellite surfaces, and that damage to coatings especially designed for the maintenance of proper working temperatures is always possible, as is surface puncture from the larger and more rarely incident particles.

11. Bedrosian, Edward
EFFECT OF MICROMETEORITE COLLISIONS ON SPHERICAL WIRE-MESH PASSIVE REFLECTORS. Rand Corp., Santa Monica, Calif. Rept. no. RM-3274-NASA. Aug 1962. 17p. (NASA Contract NASr-21(02)) NASA N62-15090

The possible effects of micrometeorites are investigated for reducing the useful lifetime of a spherical wire-mesh passive-reflector communications satellite. Theoretical conditions are postulated under which a wire composing part of the mesh might be severed by a hypervelocity collision with a micrometeorite. This criterion, taken with the known flux of micrometeorites, is used to compute the probability that such collisions will degrade the electrical performance of such a reflector. It is concluded that they will not significantly affect its useful lifetime.

12. Bjork, R. L.
Effects of a meteoroid impact on steel and aluminum in space. In PROCEEDINGS OF THE Xth INTERNATIONAL ASTRONAUTICAL CONGRESS (LONDON, ENGLAND, 1959). Vienna, Springer-Verlag, 1960. p. 505–514.

The formation of craters by hypervelocity particles is calculated in detail using a hydrodynamic model. The range of velocity considered is from 5.5 to 72 km/sec, which encompasses the meteoric velocity regime.

These calculations lead to craters considerably smaller than previously predicted by extrapolations from experimental data. Using a reasonable estimate of the meteoroid flux as a function of mass leads to the conclusion that space structures will survive about two orders of magnitude longer in time than had previously been supposed.

13. Bjork, R. L. and C. Gazley, Jr.
ESTIMATED DAMAGE TO SPACE VEHICLES BY METEOROIDS. Rand Corp., Santa Monica, Calif. Rept. no. RM-2332. 20 Feb 1959. 23p. (Contract AF 33(038)-6413) ASTIA AD-230 073

The probability of meteoroid damage to space vehicles depends on the frequency, velocity, and mass of meteoroids in space, and on the depth to which they will penetrate a vehicle skin. Available estimates of the mass and frequency of meteoroids in space are combined with a new penetration theory to yield a range of estimates of skin-penetration probability, which has, however, appreciable uncertainty because of the difficulty of estimating meteoroid mass and frequency. The results indicate, for example, that a surface 1 meter square and 1 millimeter thick will be punctured sometime between 7 weeks and 620 years.

14. Bjork, R. L.
Meteoroids vs. space vehicles. ARS JOURNAL 31: 803–807, Jun 1961.

To assess the effects of meteoroids on space vehicles in flight, the paper includes a resume of current knowledge of mass, flux rate, velocity and density of meteoroids, and of that relative to the effects of an individual meteoroid impact. Penetration rate as a function of armor thickness is derived for aluminum and steel. Al is found to give better protection, weight-wise, than steel. Results of a discussion of the probability of meteoroid puncture – as a function of vehicle area, exposure time and armor thickness – are given in graphical and analytical form: the armor weight required to protect the vehicle to any confidence level may be derived from these results. Two examples exhibit typical armor weights and the masses of the important meteoroids. In uncertain instances, the conservative estimate is always chosen so the armor weights given may be regarded as upper limits. Areas of research in which more knowledge might lead to future weight reduction are indicated.

15. Bjork, Robert L.
Meteoroid hazard to nuclear spacecraft.
NUCLEONICS 19: 91–92, Apr 1961.

The problem of how meteoroid impacts in space affect nuclear-powered space systems is complicated by a lack of accurate, direct observations of meteoroid masses, densities and velocities. It is accordingly difficult to tell how often and how deeply meteoroids penetrate spacecraft. Meteoroid flux and penetration, and radiator shielding, are discussed in this paper.

16. Black, S. D.
SETTING THE STRUCTURAL DESIGN CRITERIA FOR SPACE DEBRIS EFFECTS IN CISLUNAR AND OUTER SPACE TRAVEL. S. A. E. Paper no. 520E, 14p. (Paper presented at S. A. E. Nat. Aeronautic Meet., New York, 3–6 Apr 62)

This paper is directed toward evaluating the limits to be set in material selection and structural design so that the existing space debris environment can be tolerated by a space vehicle. Equations depicting the present state of knowledge are presented, and interpretations of these and other data by various scientists are offered. Particle impact, pitting and erosion, and sputtering and vaporization are discussed, with equations and present-day theories presented for each section. The relevance of these data to space vehicle design is discussed.

17. Broyles, A. A.
DAMAGE TO X-RAY DETECTORS BY METEORITES.
Rand Corp., Santa Monica, Calif. Rept. no. RM-2314.
21 Jan 1959. 23p. (Contract AF 33(038)-6413)
ASTIA AD-219 799

The effect of meteorites on a beryllium window covering an x-ray detector on a satellite has been estimated with the aid of the latest meteor density information from astronomical and satellite measurements. Bjork's formula for the depth of penetration of high velocity particles striking a surface was employed to obtain a fraction of the order of 10^{-6} of the area of the window punched out by meteorites per year. Methods for reducing the amount of sunlight leaking through the holes to the photomultiplier tube are considered. Splitting the beryllium sheet into two parts appears to be quite promising.

18. Davison, E. H. and P. C. Winslow, Jr.
DIRECT EVALUATION OF METEOROID HAZARD.
I.A.S. paper no. 62-7. 30p. (Paper presented at 30th annual I.A.S. meeting, N.Y., 22–24 Jan 1962.) Also available in: AEROSPACE ENGINEERING, 21: 24–33, Feb 1962.

The hazard to space vehicles from natural space debris is explored and a survey of available information pertinent to this problem presented. The need for direct measurement of this hazard is obvious and some of the problems involved in making these direct measurements are explored. It is concluded that a definite hazard exists but that it can only be poorly assessed on the basis of present information.

19. Davison, Elmer H. and Paul C. Winslow, Jr.
SPACE DEBRIS HAZARD EVALUATION.
National Aeronautics and Space Administration.
NASA Technical note no. D-1105. Dec 1961.
95p. ASTIA AD-268 737

The hazard to space vehicles from natural space debris is explored and a survey of available information pertinent to this problem presented. The need for direct measurement of this hazard is obvious and some of the problems involved in making these direct measurements are explored. It is concluded that a definite hazard exists but that it can only be poorly assessed on the basis of present information.

20. Downing, M. and R. M. Rhodes
AN INVESTIGATION OF THE NATURAL ENVIRONMENT OF AN ARTIFICIAL SATELLITE. Convair, A Division of General Dynamics Corporation, San Diego, Calif. Report no. ZPh-039. 17 Aug 1959. 29p.

Report of an investigation of the natural environment of an infrared observing satellite. Naturally occurring phenomena, and naturally occurring infrared background radiation, are considered. Neither Van Allen radiation nor meteorites were felt to be a real hazard to the satellite.

21. Duberg, J. E.
THE METEORITIC HAZARD OF THE ENVIRONMENT OF A SATELLITE. National Aeronautics and Space Administration, Washington, D. C. TN D-1248

In a brief description of our knowledge of meteorites, their composition, and frequency of occurrence, a meteoroid flux as a function of mass that has been proposed by F. L. Whipple is compared with the direct measurments obtained to date by rockets, satellites, and space probes. On the assumption of a Poisson distribution for the probability of impacts and a penetration law which represents a mean of those proposed for high-velocity impact, the probability of penetration of Earth satellite surfaces is obtained.

22. Dubin, M.
Cosmic debris of interplanetary space. In VISTAS IN ASTRONAUTICS, v. II (Proceedings, 2nd Annual Astronautics Symposium), ed. by M. Alperin and H. F. Gregory. N. Y., Pergamon Press, 1959. p. 39–45.

Interplanetary and satellite orbit space contains debris of asteroidal and cometary origin. Such particulate material moving at heliocentric velocities interacts at very high-energy densities upon collision with planetary atmospheres and space vehicles. Direct measurements of the dust component of this cosmic debris have been undertaken with rocket and satellite vehicles. These measurements involve the determination of the spatial density and size distribution of cosmic dust, as well as the impact damage to space vehicles. Various experimental techniques used on high-altitude vehicles are described; in particular, the experimental equipment used on Aerobee rockets and on the IGY satellite, Alpha 1958. Specifically, the method using the ultra-sensitive, acoustical accelerometer has been developed and its operation over a large range of impact strengths and its area sensitivity are described. Some results from measurements made with such equipment are presented. The associated problem of abrasion damage from cratering is also discussed in relation to experiments using rocket-launched vehicles. Although additional measurements are warranted to obtain accurate environmental criteria concerning cosmic debris, preliminary estimates of the distribution of cosmic dust may be made on the basis of the measurements to date.

23. Edmiston, R. M.
THE PRODUCTION OF METEOROID HOLE AREA IN A SPACE VEHICLE NEAR THE EARTH. I. A. S. Paper no. 62-29. 28p. (Paper presented at 30th annual I. A. S. meeting, N. Y., 22–24 Jan 1962.)

A method is presented for determining the time dependence of the production of meteoroid hole area in the skin of a space vehicle in the vicinity of the earth. It is assumed that the vehicle is constructed of a single wall and that the penetrating particle makes only one hole in the skin, i.e., that it does not pass through the vehicle and out the opposite wall. The present work indicates that for relatively long missions of a sizeable vehicle, a reasonable probability that the hole area will be limited to a small value cannot be assured without tremendous weight penalties if a single wall is employed. Extension of the present analysis is required in order to make it applicable to multiple wall concepts.

24. Eichelberger, R. J. and J. W. Gehring
EFFECTS OF METEOROID IMPACTS ON SPACE VEHICLES. Ballistic Research Labs., Aberdeen Proving Ground, Md. BRL rept. no. 1155. Dec 1961. 48p. (Presented at the American Rocket Society, Space Flight Report to the Nation, N. Y. Coliseum, 9–15 Oct 1961.) (Proj. 503-04-011) ASTIA AD-272 340

The mechanism of crater formation due to hypervelocity impact is described, using a variety of experimental observations and theory as a basis. The currently accepted empirical correlations are also presented. The evidence is considered in the light of the problem of meteoroid impacts upon space vehicles, and such generalized predictions as are possible at the present state of the art are derived.

25. Eldred, K., William Roberts, and R. White
STRUCTURAL VIBRATIONS IN SPACE VEHICLES.
Northrop Corp., Hawthorne, Calif. Rept. on dynamic problems in flight vehicles for Jan 1961. Dec 1961. 457p. (WADD TR 61-62) (Contract AF 33(616)6486, Proj. 1370; in cooperation with Western Electro-Acoustic Lab., Inc., Los Angeles, Calif.) ASTIA AD-273 334

Report of a study on forcing functions and their characteristics, methods of estimating a combined response, and proof tests required to qualify structure and equipment. Part One discusses the various sources of vibratory energy which can result in vehicle vibration including rocket noise, aerodynamic pressure fluctuations, wind shear and gust, meteorites and direct mechanical coupling. Part Two discusses the prediction oı vibratory response through both empirical and analytical approaches, and includes a thorough discussion of the single degree of freedom system, resonance-on-resonance, panels, shells, mobility, generalized force, joint acceptance, correlations and other statistical tools. Part Three discusses fatigue and malfunction, the properties of an ideal test, implications of and methods for obtaining a simplified composite response and an examination of various test equivalences.

26. English, R. E. and D. C. Guentert
Segmenting of radiators for meteoroid protection.
ARS JOURNAL 31: 1162–1164, 1961.

Only the punctured segments of a vulnerable radiator surface need be sacrificed if the surface is segmented. However, since a system using segmentation and mechanisms for leak detection is heavier and more complex than a system not using them, reliability is still affected. For missions requiring high survival probability, segmentation offers the greatest potential gain, even though this gain depends largely on success in solving problems inherent in the more complex system.

27. Finkelman, E. M.
Optimized protection against environmental hazards in space. AEROSPACE ENGINEERING 21: 41–48, Dec 1962.

In an analysis of the interacting and combined effects of the radiation and micrometeoroid environments on spacecraft design, it is concluded that the weights involved in assuring adequate protection against these hazards emphasizes the importance of optimizing shield weights.

28. Froelich, J. E. and A. R. Hibbs
CONTRIBUTIONS OF THE EXPLORER TO SPACE TECHNOLOGY. California Inst. of Tech., Jet Propulsion Lab., Pasadena. Progress rept. no. 20-359, 3 Sep 58, 10p. (Contr. DA-04-495-ORD-18) ASTIA AD-216 729.

The Explorer program philosophy is presented and demonstrated in the description of missile design and flight operation of the Explorers. Scientific measurements of the Explorer, cosmic-ray intensity, temperature environment, and micrometeorite densities, are described, and the significance of the measurments discussed.

29. Funkhouser, J. O.
A PRELIMINARY INVESTIGATION OF THE EFFECT OF BUMPERS AS A MEANS OF REDUCING PROJECTILE PENETRATION. National Aeronautics and Space Administration, Washington, D. C. TN D-802. Apr 1961, 17p.

Aluminum bumpers and main targets were impacted with 0.062-inch-diameter copper projectiles. The reduction in total penetration was caused primarily by the breakup of the projectile after impacting a 0.031-inch-thick bumper spaced 1 inch in front of the main target at a velocity between 8000 and 9000 feet per second. With an average projectile velocity of 11,500 feet per second, a bumper thickness between 0.01 inch and 0.02 inch gave the best protection against penetration, and an increase in the spacing of a 0.031-inch-thick bumper in front of the main surface beyond a distance of 2 inches had very little effect on the total penetration.

30. Gazley, C., Jr.
Meteoritic interaction with the atmosphere; theory of drag and heating and comparison with observations. In AERODYNAMICS OF THE UPPER ATMOSPHERE. Rand Corp., Santa Monica, Calif. Rept. no. R-339. Jun 1959. p. 6-1 to 6-58. (Papers presented at the Symposium on Aerodynamics of the Upper Atmosphere, Santa Monica, 8–10 Jun 1959.)

The meteoroid deceleration, mass loss, and luminosity are formulated in such a form as to allow direct comparison with observation. The purpose of this comparison was to deduce the applicability of conventional aerodynamic drag and heating relations to the meteor case. An attempt was made to use only the more reliable measurements – such as velocity and heights of appearance, maximum luminosity, and disappearance. Observations of deceleration, absolute luminosity, and variation of luminosity were not used.

31. Gettings, H.
S-55 to explore threat of punctures from "space dust." MISSILES AND ROCKETS 8: 14–15, Jun 1961.

NASA is preparing an extensive investigation into the micrometeoroid puncture hazard to manned spacecraft beginning with the launch of an S-55 satellite aboard a Scout. Proposals are being considered concerning the problems of stabilizing and orienting micrometeoroid data-gathering satellites, optimum orbits and building vehicles with larger surface-area collectors. Some of the later satellites in the program will be launched into polar orbits.

32. Goettelman, R. D., et al.
THE METEOROID AND COSMIC-RAY INVIRONMENTS OF SPACE VEHICLES AND TECHNIQUES FOR MEASURING PARAMETERS AFFECTING THEM. Stanford Research Inst. Rept. for period 15 Feb–15 Nov 1960. Feb 1961. 115p. (WADD TR-60-846) (Contract AF 33(616)-7015) ASTIA AD-262 013

This study of the meteoroid and cosmic-ray environments of vehicles in space incorporates terrestrial observations of the secondary effects of mechanisms that operate above the earth's atmosphere and the data obtained from in situ measurements by rocket- and satellite-borne detectors. Several meteoroid environment models are suggested, including: a continuous particle field with no time variation of flux; representing the long-period loading conditions for a space vehicle, a model to represent meteoroid clouds (as contrasted to the continuous particle field) which might damage such vehicles during flight, and an altitude-dependent modification of the continuous particle field model which postulates a meteoroid halo (or belt) surrounding the earth to an altitude of about 4000 km. Techniques for measuring the meteoroid and cosmic-ray environments are discussed, and some new approaches for detector developments are presented.

33. Goldmann, J. B. and W. L. Hollister
EFFECTS OF MICROMETEORITES ON SPACE: AN ANNOTATED BIBLIOGRAPHY. Lockheed Missiles and Space Division, Lockheed Aircraft Corporation, Sunnyvale, Calif. Special Bibliography SB-61-37. Jul 1961. 46p.

References on the effects of cosmic dust, micrometeorites, and meteorites on space vehicles. The erosive effects of micrometeorites and cosmic dust, and the penetration effects of meteorites are included. The effects of erosion and penetration on thermal contact surfaces, the effects on structures and optical devices, and both the theoretical and experimental research results on erosion and penetration were included as well.

34. Gray, P. D., et al.
ROCKETS IN SPACE ENVIRONMENT. PHASE I. PARAMETER STUDY. Aerojet-General Corp., Azusa, Calif. Phase rept., 30 Jun–30 Sep 1961. Rept. no. 2112. 27 Oct 1961. 195p. (Contract AF 04(611)7441, Proj. 3058-03) ASTIA AD-275 189

Design criteria for space propulsion systems are studied by defining the space environment, determining the behavior of rocket engine materials and components in this environment, developing design criteria based on the results of these material behavior tests, and designing a piggyback space experiment to verify the conclusions and design criteria established previously. Environmental factors to be considered include: radiation (nuclear, infrared, and ultraviolet), micrometeoroids, temperature, vacuum, and zero gravity. Environmental factors constituting the space environment between 300 and 22,000 n. mi. altitude are defined. The propulsion-system materials and components most likely to be exposed to this environment are established, and available data regarding the behavior of these materials in the space environment surveyed. Deficiencies in these data are determined, and appropriate tests planned for obtaining data now lacking.

35. Gray, P. D., et al.
ROCKETS IN SPACE ENVIRONMENT. PHASE II. INDIVIDUAL COMPONENT INVESTIGATION. Aerojet-General Corp., Azusa, Calif. Phase rept., 1 Oct 61—30 Mar 62. Rept. no. 2263. 11 Apr 62. 173p. (Contract AF 04(611)7441, Proj. 3058-03) ASTIA AD-278 055

Test data indicated that, in many cases, materials and components now used in liquid-propellant propulsion systems would be suitable for space applications. Meteorites constituted one of the environmental parameters considered.

36. Grimminger, G.
PROBABILITY THAT A METEORITE WILL HIT OR PENETRATE A BODY SITUATED IN THE VICINITY OF THE EARTH. Rand Corp., Santa Monica, Calif. Rept. no. P-18. 22 Apr 1948. 26p. ASTIA AD-267 751

A body situated at sufficiently great altitudes (about 200 km or above) is exposed to impact by the meteorites entering the earth's atmosphere. A preliminary attempt is made to estimate the probability that a body situated in the vicinity of the earth will be hit by a meteorite and to estimate the metal plate thickness necessary to prevent perforation by the impact of meteorites of different sizes. For stainless steel skin thicknesses ranging from 0.05 to 0.02 inch it is necessary to consider meteorites as small as those corresponding to magnitude 8 to 11, respectively. In general, it is found that for meteorites which are large enough to present a perforation hazard the probability of a hit is negligibly small, particularly if the body is not exposed to meteoritic impact for excessively long periods of time.

37. Gustavson, J.
Meteoritic dust. JET PROPULSION 27: 207–8, 1957.

Meteoroids, which may be of cometary origin, are porous, fragile materials with bulk densities of less than one. They are composed of compacted dust and ices (H_2O, NH_4, CO_2). Upon heating, the meteoroid gives off its frozen gasses and is left as a fragile structure which easily disintegrates into micrometeoroids. About 90% of the meteor trails are formed either by the meteoroids or by the shattered product, the micrometeoroids.

The total accretion of meteoroids and meteorites is estimated to be 1,000 tons a day.

38. Hansen, C. F.
THE EROSION OF METEORS AND HIGH-SPEED VEHICLES IN THE UPPER ATMOSPHERE. National Advisory Committee for Aeronautics, Washington, D. C. TN-3962. Mar 1957. 38p. ASTIA AD-125 284

Using a simple inelastic collision model of meteor-atmosphere interaction, analytic relations for velocity, deceleration, size, and relative luminous magnitude of meteors are derived and expressed in dimensionless parametric form. The analysis is compared with available quantitative observations of meteor behavior and it is indicated that a large fraction of the atmospheric bombardment energy is used in eroding meteor material. The erosion from large, high-speed vehicles as they traverse the high-altitude, free-molecule portion of the atmosphere is calculated, on the assumption that the vaporization process is similar to that which occurs for meteors. The maximum possible erosion does not create significant mass loss. The minimum and maximum velocity of meteors and the heating of meteors and radiation losses are discussed in two appendices.

39. Hart, Eugene M.
EFFECTS OF OUTER-SPACE ENVIRONMENT IMPORTANT TO SIMULATION OF SPACE VEHICLES. Cornell Aeronautical Lab., Inc., Buffalo, N. Y. Rept. for 1 Nov 1959–30 Sep 1960. Aug 1961. 106p. (ASD TR 61-201) (Contract AF 33(616)6858, Proj. 6114) ASTIA AD-269 014

Results of a literature survey defining the effects of the outer-space environment important to the simulation of space vehicles are presented. Only the natural environment of space is considered and the survey is limited to the solar system with particular emphasis on the region in the near vicinity of the earth-moon system and at heights greater than 80 kilometers above the earth's surface. To specify those effects that need to be incorporated into a space training simulator, the exterior environment, its effects on the vehicle and crew, and the malfunctions that may result must be determined. Meteorite hazard is considered. These subjects are treated, along with a consideration of the adequacy of the existing data in the study. Recommendations for further study are presented.

40. Henderson, R. E. and Paul Stanley
The effect of micrometeorites on reflecting surfaces. In INSTITUTE OF ENVIRONMENTAL SCIENCES. NATIONAL MEETING, 6–8 APRIL 1960, LOS ANGELES, CALIF. PROCEEDINGS, 1960. p. 109–118

Optical system criteria for long lifetime capability in the micrometeoritic flux in space are shown to be quite different than those for other systems, i.e., particles as light as 10^{16} g will cause craters materially reducing the specular reflectivity of optical surfaces. A requirement for determining the frequency of very light micrometeorites is therefore important in order to determine whether optical power systems are operable in space.

41. Hibbs, A. R.
The distribution of micrometeorites near the earth. JOURNAL OF GEOPHYS. RESEARCH 66:371–377, 1961.

Micrometeorite impacts recorded by the artificial satellite Explorer I in February 1958 have been examined statistically to determine their distribution with latitude, altitude, and longitude relative to the satellite-earth-sun angle (satellite local time). The latitude distribution shows an interesting peak near the equator, which is, however, not statistically significant. The distribution in longitude relative to the satellite-earth-sun angle corresponds to an altitude distribution and apparently contains no information that is not better shown in this latter distribution. With suitable analysis, the altitude distribution yields information on the velocity of the particles relative to the center of the earth. It is concluded that the average particle measured by Explorer I was in a closed orbit around the earth rather than on an impact trajectory from a great distance to the surface of the earth.

42. Hodge, P. W., F. W. Wright, and D. Hoffleit
An annotated bibliography on interplanetary dust. SMITHSONIAN CONTRIBS. TO ASTROPHYS. 5(8): 85–111, 1961.

References to significant papers on the study of interplanetary dust are presented. Some references have been included from BIBLIOGRAPHY ON METEORITIC DUST WITH BREIF ABSTRACTS compiled by Hoffleit (Harvard College Observatory Reprint Series II-43, 45pp., 1952), and now out of print. Some papers relating to interplanetary dust outside the earth's atmosphere are also included.

43. Hoenig, S. A.
Meteoric dust erosion problem and its effect on the earth satellite. AERONAUTICAL ENGINEERING REVIEW 16: 37–40, Jul 1957.

The hazards of meteoric dust for space flight are reviewed; for short-lived vehicles the hazard appears negligible.

44. Hoffleit, D.
BIBLIOGRAPHY ON METEORITIC DUST WITH BRIEF ABSTRACTS. Harvard College Observatory, Cambridge, Mass. Tech. rept. no. 9. 45p. (Reprint ser. II-43, 1952.) (Contracts NOrd 10449, T.O.1 and N5ori-07647) ASTIA AD-5639

A bibliography on meteoritic dust and closely allied topics; for most of the 505 references an abstract of a sentence or two has been added to enhance their usefulness. The arrangement is by senior author.

45. House, Philip A.
SELF-SEALING OF AEROSPACE SHIPS BY THE DOUBLE HOLLOW WALL CONCEPT. Nonmetallic Materials' Lab., Aeronautical Systems Div., Wright-Patterson Air Force Base, Ohio. Rept. for Mar–Oct 61 on Nonmetallic and Composite Materials, 19 Feb 62, 14p. (ASD TDR 62-248) (Proj. 7340) ASTIA AD-273 284

The system devised is capable of automatically sealing aerospace vehicles in case of puncture by such foreign objects as micrometeoroids. The evaluation was aided by the use of an outer elastomeric rubber sheet which elongated before being punctured, resulting in a hole approximately 0.075 in. in diameter. This may not be the case in a space ship punctured by a micrometeroid traveling at such speed that the rubber sheet would not elongate; the puncture would probably be at least the size of the particle. The system consists of two fluids separated by a membrane and when it is punctured the two fluids mix, immediately solidify, and seal the puncture. The fluids which were most successful were a polypropylene oxide-toluene diisocyanate adduct thickened with a colloidal silica and triethylene tetramine.

46. Jaffe, L. D. and J. B. Rittenhouse
BEHAVIOR OF MATERIALS IN SPACE ENVIRONMENTS. Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena. Technical rept. no. 32-150. 1 Nov 1961. 116p. (Contract NASw-6) ASTIA AD-266 548

Included in a discussion of the quantitative effects of space environments upon engineering materials is the effect of meteors.

47. Jaffee, L. D. and J. B. Rittenhouse
Effects of meteoroids. In BEHAVIOR OF MATERIALS IN SPACE ENVIRONMENTS. Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena. Tech. rept. no. 32-150, 1 Nov 1961. p. 49–64. (Contract NASw-6) Also available as: A.R.S. Paper no. 2033-61 (Presented at A.R.S. Space Flight Report to the Nation, N.Y., 9–15 Oct 1961), and in: ARS JOURNAL, 32: 320–346, 1962.

Erosion by meteoroids is significant only close to the earth. The probability of penetration by meteoroids falls sharply with increasing distance from the earth. Much more frequent than penetration is spalling of fragments from the inside of walls struck by meteoroids. The efficiency of walls in preventing penetration and spalling can be increased by splitting the walls into a thin front plate and a thicker main plate; quantitative bases for the design of such spaced armor are presented.

48. Jazwinski, Andrew H.
A TECHNIQUE OF EVALUATING FUEL LOSSES DUE TO METEOROID PUNCTURE AND SOME TIMELY EXAMPLES. General Dynamics/ Astronautics, San Diego, Calif. N. Y., American Rocket Society, 1962. ARS Paper 2471-62. 12p. (Presented at the ARS Lunar Missions Meeting, Cleveland, Ohio, 17–19 Jul 1962.) NASA N62-14456

From a reasonably conservative estimate of meteoroid environment effects, a method is presented for the evaluation of fuel losses due to puncture of storage tanks. The analysis was applied to a fuel tank transported to the Moon to be used for Earth-return, and to a fuel storage tank in an Earth-circular orbit. Fuel losses were studied as a function of tank-skin thickness for aluminum and steel skins. It was found that weight for weight a steel skin is superior to an aluminum skin for thicknesses that allow punctures at a given probability. If such thicknesses are used so as to exclude all punctures at a given probability, the inverse is true. Steel skins are always superior in terms of mean losses. In general, fuel losses due to meteoroid puncture were found to be significant for single-skin tanks. Meteoroid shields should be considered as a means of reducing possible fuel losses.

49. Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena. RESEARCH SUMMARY NO. 36-11, 1 AUGUST–1 OCTOBER 1961. 1 Nov 1961. 95p. (Contract NASw-6) ASTIA AD-268 117

Includes information on meteorites.

50. Johnson, A. L.
Spacecraft radiators. SPACE AERONAUTICS 37: 76–82, 1962.

A review of the data and methods available to the designer of active low-temperature radiators coping with problems of meteoroid protection, fluid and coating selection, and minimum weight. Materials parameters are covered in detail, and several basic design procedures outlined.

51. Johnson, Francis S., ed.
SATELLITE ENVIRONMENT HANDBOOK.
Lockheed Missiles & Space Division, Lockheed Aircraft Corp., Sunnyvale, Calif. Rept. no. LMSD-895006. Dec 1960. Various paging.
Also available as SATELLITE ENVIRONMENT HANDBOOK, ed. by Francis S. Johnson. Stanford Univ. Press, Stanford, Calif., 1961. 155p.

Includes reviews and summaries of information on the structure of the upper atmosphere and of the ionosphere, solar and penetrating radiation, micrometeorites, radio noise, geomagnetism, and thermal radiation from the earth.

52. Jones, C. D., ed.
PRELIMINARY INVESTIGATION OF INTERPLANETARY LUNAR AND NEAR PLANET ENVIRONMENTS AND METHODS OF SIMULATION. Research Foundation, Ohio State Univ., Columbus. Jul 1961. 216p. (ASD TR 61-267) (Contract AF 33(616)5914, Proj. 1309) ASTIA AD-268 719

Summaries of the natural environments of Mars, Venus, the Moon and interplanetary space are presented. The primary induced environmental stresses associated with thermal radiation, cosmic atomic and subatomic radiation, meteoroid particles, vibration, shock, acceleration, and low pressure are described for operation near the above bodies. An environmental test philosophy is included.

53. Kaechele, L. E., and A. E. Olshaker
Meteoroids – Implications for the design of space structures. AEROSPACE ENG. 19:44–45, 98, May 1960.

The meteoroid environment and the effects of meteoroid impact are briefly described with respect to their relationships and their bearing on the design of space structures.

54. Kornhauser, M.
Prediction of cratering caused by meteoroid impacts. JOURNAL OF THE ASTRONAUTICAL SCIENCES, 5: 58–63, Autumn-Winter 1958.
Also available in: ADVANCES IN ASTRONAUTICAL SCIENCES, v.2 (Proceedings, 4th Annual A.A.S. Meeting, Dec 1957), ed. by N. V. Peterson and H. Jacobs. N.Y., Plenum Press, 1958. p.33-1 to 33-13.

Data from high-speed laboratory experiments, explosive craters, and meteorite impacts are correlated to obtain an approximate expression for depth of penetration in terms of target material properties and kinetic energy of the impacting particle.

The practical problem of prediction of meteoroid cratering may logically be separated into two distincet problem areas: (a) the probabilities of collisions with meteoroids of all sizes and velocities; (b) the estimation of the crater size resulting from each collision.

55. LaGow, H. E. and L. Secretan
The micrometeorite penetration experiment. National Aeronautics and Space Administration, Washington, D. C. In JUNO II SUMMARY PROJECT REPORT, VOLUME II. EXPLORER VII SATELLITE. TN D-608. Jul 1961, p. 263–272.

Experiments to measure micrometeorite penetration and molecular sputtering (i.e., the removal of material as though by evaporation, leaving the surface in an abraded and roughened condition), utilizing photoconducting CdS cells were part of the instrumentation of Explorer VII (1959 IOTA). A description of the experiments and the results obtained from their measurements are presented.

56. Langton, N. H.
The mechanical penetration of bumper screens, BRIT. INTERPLANET. SOC. JOURNAL 13: 283–294, Sep 1954.

The mechanical penetration of bumper screens by an iron or stone meteorite is investigated theoretically. Tables and graphs showing the penetrations for different sized meteorites at varying impact velocities are given. These values are compared with those for the thermal penetrations, and conclusions about the design of bumper screens and spaceship hulls presented.

57. Langton, N. H.
Meteors and spaceflight, SPACEFLIGHT 1:
92–100, 1957.

Approximately 75×10^{16} meteors are consumed in our atmosphere daily. Although the great majority are of negligible size and mass, they are capable of erosive effects when their velocities are considered. The chance of a collision with a meteorite larger than a grain of sand during space journeys of a few weeks duration is very small. However, the number of collisions with smaller particles would be large, and after several hours the accumulation of damage might become serious. In order to protect the space vehicle it will be necessary to use meteor bumper screens, preferably fabricated from chrome steel. Protection against larger meteorites (with which the chance of collision is very small) is not presently feasible due to the extreme weight penalties imposed by thickened hulls or bumper screens.

58. Lehr, S. N., V. J. Tronolone, and P. V. Horton
EQUIPMENT DESIGN CONSIDERATIONS FOR
SPACE ENVIRONMENT. Space Technology
Labs., Inc., Los Angeles. Rept. no.
STL/TR-60-0000-09224. Sep 1960. 68p.
ASTIA AD-269 301

Information from a literature survey and from STL experience is presented as an aid to the design and fabrication of electronic equipment for space vehicles. Data on the behavior of materials in space covers information not available in the usual engineering handbooks.

Space environments are considered in terms of temperature, high vacuum, micrometeorites, radiation, and other phenomena, with particular attention to the effects of such environments, insofar as they are known or conjectured, upon plastics, metals, organic and inorganic materials, and electronic parts.

59. Library Services Section, Air Information Div., Washington, D. C. THERMODYNAMICS AND SURFACE EFFECTS OF SPACECRAFT AND SATELLITES. SELECTED BIBLIOGRAPHY. 19 May 1961, 10p. (AID rept. 61-67) ASTIA AD-257 911

A bibliography on thermodynamics and surface effects of spacecraft and satellites, from 1957 to 1961, includes material on meteors.

60. Little (Arthur D.), Inc., Cambridge, Mass. Interactions with the meteoroid environment. In LIQUID PROPELLANT LOSSES DURING SPACE FLIGHT. Second quarterly progress rept., rept. no. 63270-00-02. May 1961. Sect. III, p.35-61. (Contract NAS5-664)

A theoretical and experimental evaulation of "meteor bumpers" as protective devices against the meteoroid hazard indicates that theory may be over-optimistic with respect to the protection that bumpers will afford.

Consideration is given to the development of a protection system in which meteoroids are detected while they are distant from the vehicle. However, the large power required to achieve even minimum acceleration for any reasonable size shield or vehicle, would appear to preclude this as a practical solution of the meteoroid problem. It is concluded that optical sighting may be a useful method for obtaining meteoroid data in satellite experiments.

61. Little (Arthur D.), Inc., Cambridge, Mass. Interactions with the meteoroid environment. In LIQUID PROPELLANT LOSSES DURING SPACE FLIGHT. First quarterly progress rept. Jan 1961. Sect. IV, p.39-48. (Contract NAS5-664)

Section II discusses the meteoroid environment. Section IV describes interaction of meteors with the vehicle structure and includes a design study of systems for protection against meteors.

62. Mickle, E. A.
Flight Propulsion Lab. Dept., General Electric Co., Evendale, Ohio. A DISCUSSION OF PROBABILITIES OF METEORIC PENETRATION OF SPACE VEHICLES, TUM 58132-19. 18 Jul 1958. 14p.

Expressions are obtained for the probabilities of avoiding a puncture, and of ascertaining that the total area of puncture will not exceed a specified amount. In arriving at these expressions, the necessary assumptions are carefully noted and their plausibility discussed. An attempt to obtain a quantitative result for an arbitrary condition is unsuccessful because of lack of data.

63. Nazarova, T. N.
Investigation of meteoric particles by third Soviet satellite. ARS. JOURNAL 31: 1341–44, 1961. (English trans., ARTIFICIAL EARTH SATELLITES, No. 4: 165–70, 1960.)

The third satellite carried apparatus for recording the number of particle impacts. Where detector material was ejected on collision with its surface and a particle, the momentum of ejection was also recorded. Ballistic piezoelectric transducer was utilized in measuring "ejection impulses." Apparatus details, results obtained from its use, and features of the phenomena observed are included in this article.

64. Nazarova, T. N.
Results of a study of impacting of meteoric matter by means of instruments mounted on space rockets. In ARTIFICIAL EARTH SATELLITES, ed. by L. V. Kurnosova. N. Y., Plenum Press, 1961. v.3/5, p.524–527.

Instruments similar to those used in the third Soviet artificial earth satellite were installed on the space rockets launched on 2 January, 12 September and 4 October, 1959. On the first space rocket the equipment was designed to record particles having masses in the ranges 2.5×10^{-9} - 1.5×10^{-8}g; 1.5×10^{-8} - 2×10^{-7}g and greater than 2×10^{-7}g. The signal was telemetered after 16 impacts in the most sensitive range, after 4 impacts in the next, and after each impact in the coarsest range. Each impact was recorded by the instruments installed on the second and third space rockets. Tabulated results for the three space rockets and for the third artificial earth satellite show that the density of meteoric matter is not constant in the earth's vicinity, varying both in time and space. During the flight of the second and third space rockets the greatest number of recorded discharge impulses referred not to the minimal impulses which could be recorded by the instrument, but to high-value impulses.

65. Nysmith, C. R. and J. L. Summers
PRELIMINARY INVESTIGATION OF IMPACT ON MULTIPLE-SHEET STRUCTURES AND AN EVALUATION OF THE METEOROID HAZARD TO SPACE VEHICLES. National Aeronautics and Space Administration, Washington, D. C. TN D-1039. Sep 1961. 27p.

Small Pyrex glass spheres, simulating stony meteoroids, were fired into 2024-T3 aluminum alclad multiple-sheet structures to evaluate the effectiveness of multisheet hull construction as spacecraft meteoroid penetr tion. The meteoroid hazard to vehicles in the space near the earth was also evaluated on the basis of the meteoroid distribution as determined from astronomical and satellite measurements, high-speed impact data, and hypothesized meteoroid structures and compositions for two representative space vehicle structures, one with a single-sheet monocoque hull, and one with a glass-wool-filled, double-sheet hull.

66. Ossefort, Z. T. and J. D. Ruby
THE EFFECTS OF A SIMULATED SPACE ENVIRONMENT ON THE PROPERTIES OF ELASTOMERS. Rock Island Arsenal Laboratory, Ill. 15 May 1961. 61-1999

In addition to particle bombardment by tiny meteorites, the following simulated space parameters were studied for their effect on elastomers: high and low temperatures; actinic solar radiation; very high vacuum; and cosmic radiation undiminished by atmospheric penetration.

67. Ovenden, M. W.
Meteor hazards to space-stations. BRITISH INTERPLANETARY SOCIETY. JOURNAL, 10: 275–286, Nov 1951.

A summary of the analysis of Grimminger and examination of the possible astronomical factors affecting its validity. The existence of iron meteors is shown to require a reduction in Grimminger's collision times by a factor of about 2. Radar observations provide direct evidence for the assumed number of meteors/magnitude relationship down to magnitude 7; extrapolation beyond this limit is uncertain because of the removal of smaller meteors by the Poynting-Robertson effect. The Poynting-Robertson effect may increase Grimminger's times by a factor of about 3, although a much more drastic increase due to this effect cannot be ruled out. The danger from meteor showers, including the daylight streams detected by radar, is shown to be comparable with that from sporadic meteors. Contrary to published statements, the discovery of micrometeorites does not demand any alteration to the statistics. The greatest uncertainty in the estimates of collision times occurs in the imperfect knowledge of the mass of a meteor of given magnitude; errors in theory here may require, at the worst, a decrease in collision times by a factor of 50. It is concluded that, for space station lifetimes of more than one year, either a heavily-armoured hull or a "meteor bumper" will be required.

68. Prevention of Deterioration Center, National Research Council, Washington, D. C. ENVIRONMENTAL EFFECTS ON MATERIALS AND EQUIPMENT. ABSTRACTS. VOLUME I, NUMBER I. Jan 1961, 36p. ASTIA AD-249 580

Contents:

Shock and vibration
Thermal factors and effects
Space and near space
  Atmospheric composition
  Dissociated gases
  Gravitational fields
  Ionized gases
  Meteorites and micrometeorites
  Radiation
Celestial bodies
Combined factors and effects

69. Prevention of Deterioration Center, National Research Council, Washington, D. C. ENVIRONMENTAL EFFECTS ON MATERIALS AND EQUIPMENT. ABSTRACTS. VOLUME I. NUMBER 2. Feb 1961, 72p. ASTIA AD-252 069

Includes material on micrometeorology and meteorites.

70. Radio Corp. of America, Camden, N. J.
STUDY OF INSTRUMENTATION AND TECHNIQUES FOR MONITORING VEHICLE AND EQUIPMENT ENVIRONMENTS AT HIGH ALTITUDE. INSTRUMENTATION AND MONITORING TECHNIQUES. Final rept.
Jun 1960. 79p. (WADC TN 59-307, Vol. 3)
(Contract AF 33(616)6407, Proj. 8223)
ASTIA AD-268 090

Instrumentation techniques are presented which are available within the state-of-the-art; an instrumentation system is proposed for the monitoring of high-altitude environments encountered by typical vehicles. The high altitude environmental effects on typical vehicles and equipment are summarized. The present airborne-instrumentation state-of-the-art is presented for measuring temperature, pressure, strain, vibration, acceleration, radiation, meteorite detection, and acoustic noise. A feasible instrumentation system is discussed for monitoring these deleterious environments.

71. Rae, William J. and Henry P. Kirchner
A STUDY OF METEOROID IMPACT PHENOMENA.
Cornell Aeronautical Lab., Inc. Quarterly progress rept., 14 Dec 1961 – 14 Mar 1962.
21p. (RM-1655-M-1) (NAS 3-2121)

Modern blast wave theory is applied in an examination of the phenomena that occur when meteoroids collide with satellites and other space vehicles.

72. Riddell, F. R. and H. B. Winkler
FROM ICBM RE-ENTRY TO METEORITE ENTRY.
A.R.S. Paper no. 61-113-1807. 38p. (Paper presented at Joint National I.A.S.-A.R.S. Meeting, Los Angeles, 13 – 16 Jun 1961.)

If instrumented space probes are not decelerated in some fashion in space, they will approach the earth at velocities as high as 140,000 ft/sec. The possibility of decelerating such recovery vehicles by atmospheric braking is examined. Since this velocity is well into the meteor range of velocities, data on meteorites (i.e., bodies that survive entry into the atmosphere and reach the earth's surface) are used to orient the analysis. Meteorites are known to cover a wide range of sizes from a few microns to hundreds of feet in diameter. There is evidence, however, that in the intermediate-size range from a few inches to a foot or two in diameter, only objects in the lower meteor velocity range survive. Conceivable, recoverable, deep-space probes fall into this size range. Analysis shows that while very small and very large objects may survive throughout the meteor velocity range, there may well be an upper limit of from about 50,000 to 60,000 ft/sec for objects of intermediate size.

73. Rodriguez, D.
Meteoroid shielding for space vehicles.
AEROSPACE ENGINEERING, v. 19(12): 20–3, 55, 58, 60, 62, 64–6, Dec 1960.

Evaluation of currently available information on meteoroid environment of space, and on hypervelocity impact. Development of design charts (via guide line approach) established in terms of which attempt is made to assess effects on meteoroid shielding requirements of uncertainties in state-of-art information.

74. Simpson, M. H.
Analysis of hyper environments and their relation to military hardware in the interior of a space vehicle.
In INSTITUTE OF ENVIRONMENTAL SCIENCES. NATIONAL MEETING, 6–8 APRIL 1960, LOS ANGELES, CALIF. PROCEEDINGS, 1960. p. 11–18.

Discusses the natural environments of space as they affect the design and testing of military components, subassemblies, and subsystems within the interior of a space vehicle; analytical determinations of the factors of mass heat transfer of conduction, convection, and radiation; the factors of low absolute pressures, ozone, radiation, ionization, and meteoritic dust; and the relation in effects for the designer.

75. Singer, S. F.
The effect of meteoric particles on a satellite.
JET PROPULSION, 26: 1071–75, 1087, 1090, Dec 1956.

While erosion effects of high velocity meteoric dust on space vehicles are of great importance, they are not easily predictable. This paper discusses some physical models to allow calculations of the erosion rate; they lead to widely differing values. Laboratory experiments with artificially accelerated dust particles should furnish more reliable guides for a theory. Even so, important indications are derived for the choice of material and construction of a satellite skin to minimize meteor effects. Atmospheric sputtering is shown to be unimportant, e.g., in the case of an aluminum skin. An erosion experiment for the Vanguard satellite is described. It is based on a radioactive method which has many advantages in terms of sensitivity and simplicity. The results can be used to study the effect of the sun on dust particles in interplanetary space.

76. Singer, S. F.
Effects of interplanetary dust and radiation environment on space vehicles. In PHYSICS AND MEDICINE OF THE ATMOSPHERE AND SPACE (2nd International Symposium on the Physics and Medicine of the Atmosphere and Space, San Antonio, Texas, 10–12 Nov 1959.), ed. by O. O. Benson, Jr. and H. Strughold. N.Y., Wiley, 1960. p. 60–90.

A discussion of (1) meteoric erosion and sputtering, and (2) the effects of high-energy, including cosmic rays and the radiation belt, and the design of appropriate radiation shielding.

77. Soberman, R. K. and L. Della Lucca
MICROMETEORITE MEASUREMENTS FROM THE MIDAS II SATELLITE (1960–61). Air Force Cambridge Research Labs., Geophysics Research Directorate, Bedford, Mass. GRD Res. Notes 72; ARCRL 1053. Nov 1961. 14p. NASA N62-14364.

Discusses micrometeorite data accumulated by the Midas II satellite, which was launched 24 May 1960 into an approximately 500-km circular equatorial orbit. Data were obtained by three acoustic detectors and two wire-grid detectors, and the discrepancy between acoustic and wire-grid data is discussed. Results are compared with those obtained from other satellite measurements.

78. Space structure hardens in orbit. MACHINE DESIGN, 34: 14, 1 Mar 1962

An outline is given of processes under consideration for building special "rigidizing" characteristics into fabrics to make them impervious to meteoroid attack, temperature extremes, and cosmic radiation.

79. Stanley, P. E. and R. B. McClure
An experiment to determine the effect of meteorites on reflecting surfaces. Preprint no. 47SL-61 In I.S.A. PROCEEDINGS (Instrument Society of America Winter Instrument-Automation Conference and Exhibit, St. Louis, Mo., 17–19 Jan 1961. Pittsburgh, Pa., ISA, 1961. p. 47SL-61-1 to 47SL-61-6.

The mounting of reflecting surfaces on artificial earth satellites for a number of purposes has aroused interest. Since the cost of such installations is very high, some estimate of the expected damage to the optical surfaces by meteoritic impact is desirable. A review of the existing knowledge of the nature of meteorites and the probability of impact shows that the damage is quite dependent upon the mass of minimum meteoric particles. An experiment which may provide information on the number of smaller dust particles in the vicinity of the earth is proposed. The required instrumentation is described and procedures suggested.

80. Stanyukovich, K. P.
Elements of the theory of impact of solid bodies at high (cosmic) velocities. In ARTIFICIAL EARTH SATELLITES, ed. by L. V. Kurnosova. N.Y., Plenum Press, 1961. v. 3/5, p. 292–333.

Meteorite impact at cosmic velocities on the surface of planets is related to micrometeorite collision at the surface of artificial earth satellites and space rockets. In the latter case the force of gravity can be disregarded in studying the scattering of the products of explosion from the crater. This study is confined to the explosion of charges of different powers and calorific values. The problem of meteorite explosion is thus reduced to the explosion of an equivalent quantity of explosive. A study of the ultimate effects of the ordinary explosion and the explosion of meteorites on solid surfaces yields the conclusion that small bodies, both of the solar system and in general, occurring in space, are continuously destroyed and disintegrate as the result of intercollisions.

81. Stewart, R. J.
CONSIDERATION OF METEROID PENETRATION OF AN APOLLO TYPE SPACE VEHICLE STRUCTURE. Grumman Aircraft Engineering Corporation, Bethpage, N. Y. Grumman Note no. ADN 06-02c-61.1. Feb 1962.

82. Swetnick, M. J.
Meteoric abrasion studies proposed for Vanguard. In ADVANCES IN ASTRONAUTICAL SCIENCES (Proceedings, 3d Annual A.A.S. Meeting, Dec 1956), ed. by N. V. Peterson. N. Y., Plenum Press, 1957. v. 1, p. 59–64. Also available in JOURNAL OF ASTRONAUTICS, IV: 69–71, Winter 1957.

Vanguard satellites will study the effect of meteoric impact on the skin of the satellite. Meteoric impacts will have an abrasive effect resulting in the erosion of the satellite skin. Two methods of studying meteoric abrasion of satellite skins have been approved for inclusion in the satellite program. One method is designed to correlate erosion with variations of the resistance of a thin metallic ribbon that is subjected to meteoric impact. The other method correlates erosion with variations of the intensity of beta-particle radiation. Both methods are briefly described and discussed.

83. Szego, G. C.
METEORITE HAZARDS TO AN EARTH SATELLITE. Flight Propulsion Lab. Dept., General Electric Co., Evendale, Ohio. TUM 58132-17. 10 Jul 1958. 8p.

Discusses sporadic and shower meteors, meteorites, and micro-meteorites including methods of tracking; composition; velocity, size and time distribution, and accretion by the earth.

84. Thomas, R. N. and W. C. White
The physical theory of meteors. IV. Inquiry into the radiation problem – a laboratory model. ASTROPHYSICAL JOURNAL, 118: 555–567, Nov 1953.

Discussion of the similarity in atomic spectrum between meteor and artificial meteor (ultra-speed pellet). The meteor is equivalent to a mono-energetic atomic beam; the pellet, to a high-temperature furnace in a highly transient and probably nonequilibrium state. The excitation mechanism is probably atom-atom inelastic collision in both cases. A consideration of the pellet molecular spectrum strengthens these conclusions. The pellet molecular spectrum appears to provide information on diffusion processes in the wake. Current spectrophotometric data on both meteor and pellet are very incomplete.

85. Thompson, A. B. and C. F. Gell
METEOROIDS AS A HAZARD IN SPACE FLIGHT: A SURVEY OF PRESENT INFORMATION. A.R.S. Paper no. 2138-61. 23p. (Paper presented at A.R.S. Space Flight Report to the Nation, N. Y., 9–15 Oct 1961.)

A review of current knowledge of meteoritic material in space – flux, mass, density, velocity, etc. – based on satellite, rocket, radio, and visual sources. Results of hypervelocity impact tests are analyzed to better define penetration relationships for development of a meteoroid risk probability. The effects of meteoroid penetration into manned space cabins are deduced based on animal tests, and a brief review of the effectiveness of various wall structures for reducing possible penetration is included.

86. Timpone, F.
Meteorites (I Meteoriti). RIV. AERONAUT., 36: 1423–1431, Sep 1960. (In Italian)

Describes macro- and micrometeorites in terms of size, composition, distribution in space, and impact effects.

87. Tuckerman, A. J., V. I. Mizuno, and P. J. D'Anna
A POSSIBLE SOLUTION TO METEOROID DAMAGE CONTROL. Norair Div., Northrop Aircraft, Inc., Hawthorne, Calif. NOR-60-312. 3 Oct 1960. 9p. (Advance copy of a paper to be presented at American Ordnance Association Meeting, Cleveland, Ohio, 20 Oct 1960.)

Describes the incorporation of repair or damage control equipment into the structure of pressurized space vehicles. Some type of self-sealing mechanism appears to be the most suitable approach to repair of damage in space and to reduction of hazards from meteoric penetration. Under the self-sealing concept, the arrangement of the structure of the cabin wall would play an important role in the self-sealing configuration. In the preliminary phase of this work a study of several self-sealing configurations was made under static test conditions, and these tests proved the self-sealing concept quite feasible. In order to test the structures under dynamic conditions, a particle accelerator was constructed. It is concluded that a satisfactory self-sealing membrane can be developed for meteoroid damage control of space vehicles.

88. Tuckerman, A. J., V. I. Mizuno, and P. J. D'Anna
Self-sealing sandwich for meteoroid protection. SPACE/AERONAUTICS, 35: 56–57, Mar 1961.

Investigation indicates that a satisfactory self-sealing sandwich structure for meteoroid damage control is feasible, with elastomeric adhesives best for bonding the sealing to the vehicle structure.

89. Utah Univ., Salt Lake City.
HIGH-VELOCITY IMPACT STUDIES. Final rept., 15 Jul 1958–30 Sep 1961. Tech. rept. no. 24. 31 Oct 1961. 14p. (AFOSR-1937) (Contract AF 49(638)462) ASTIA AD-271 470

Contents:

Impact-flash and spray-particle investigation
Spectral analysis impact of copper spheres into copper targets
A laboratory investigation of meteor physics
Light-gas-gun development
Electrostatic acceleration of small particles
Impact and cratering investigations on steel and aluminum in space

90. Wacholder, B. V. and E. Fayer
STUDY OF INSTRUMENTATION AND TECHNIQUES FOR MONITORING VEHICLE AND EQUIPMENT ENVIRONMENTS AT HIGH ALTITUDES. VOL. II. EFFECTS OF HIGH-ALTITUDE ENVIRONMENTS ON VEHICLES AND EQUIPMENT. Radio Corp. of America, Camden, N. J. Final rept. on crew and environmental data sensing and instrumentation. Jun 1960. 98p. (WADC TN 59-307, v. 2) (Contract AF 33(616)6407, Proj. 8223)
ASTIA AD-274 641

Environments deleterious to the vehicle, and a chart indicating which of the environments affects the various materials and subsystems, are presented. An analysis of the effects of the environments on such materials as metals, plastics, ceramics, elastomers, surface coating materials, lubricants, and hydraulic fluids is made. An analysis is also made of the environmental effects on vehicle subsystems taken from the X-15, Dyna-Soar, and Mercury Systems. The subsystems are typical of those to be used in future high altitude vehicles. The subsystems analyzed are structure, flight control, communications, environmental control, escape, and auxiliary power units.

91. Wallace, R. R., Jr., J. R. Vinson, and M. Kornhauser
EFFECTS OF HYPERVELOCITY PARTICLES ON SHIELDED STRUCTURES. A.R.S. Paper 1683-61. 11p. (Paper presented at A.R.S. Lifting Re-entry Vehicles: Structures, Materials and Design Conference, Palm Springs, Calif., 4–6 Apr 1961.)

The vulnerability of future re-entry systems is a major design problem. From an offensive point of view optimum hardening is desirable, and from a defensive viewpoint maximum destruction of incoming vehicles is imperative. One defensive measure to which a vehicle may be hardened is the use of hypervelocity projectiles. Moreover, all vehicles with orbital or space mission capability will be continuously subjected to hypervelocity particles in space (meteoroids). It is therefore desirable to develop advanced design criteria for efficient, light-weight shielding by investigating each of the parameters involved.

To accomplish this a test program was conducted in which over 300 hypervelocity projectiles were fired at structural walls protected by single shields. Projectile material, size, and velocity; shield material, thickness, and shield to wall spacing were the variables investigated. An extensive statistical analysis of variance for the five phases of the test program and a three step breakdown involving each of the above parameters were made.

Pertinent results of the test program and statistical analysis are presented, and, based upon these, design criteria, data, and trends set forth. It was found, for instance, that in these structures over 50% of the external structural weight for single walled particle protection can be saved by proper design and use of meteor bumpers without sacrifice of safety. It is concluded that a definite advance in hypervelocity impact knowledge was attained.

92. Wheeler, W. M.
THE DETECTION OF MICROMETEOROIDS IN THE VICINITY OF THE EARTH. Missile and Ordnance Dept., General Electric Co., Philadelphia. TIS 56SD188. 19 Oct 1956. 19p.

A comparison of leading theories on the amount of meteoritic material entering the earth's atmosphere. Rocket research attempts to resolve the existing uncertainties are reviewed, and proposals made for obtaining more satisfactory information. Meteoritic effects on long range missiles are discussed as well.

93. Whipple, F. L.
The meteoritic risk to space vehicles. In VISTAS IN ASTRONAUTICS. N.Y., Pergamon Press, 1958. p. 115–124. Also available in PROCEEDINGS OF THE VIIIth ASTRONAUTICAL CONGRESS (BARCELONA, SPAIN, Oct 1957). Vienna, Springer-Verlag, 1958. p. 418–428.

Discussion of the distribution of meteoritic material and its rate of fall on the earth as functions of mass and velocity. With a simple theory, the probabilities are calculated that surfaces in space in the neighborhood of the earth may be punctured by meteoric action. A table of data and probabilities is given. It is calculated that a near-earth satellite of radius 20 inches and skin thickness 0.5 mm Al will be punctured on the average of once in five days.

Upper limits to the effects of skin erosion on a space-exposed surface are calculated on the basis of erosion by meteoritic dust, by corpuscular radiation from the sun and by gases of the extended solar corona. The erosive effect from meteoritic dust is comparable to the combined effects from the other two causes and gives a rate of skin (Al) erosion of the order of 2×10^{-10} gm/cm^2/sec or less. Optical surfaces exposed to space should not be effected functionally by erosion over periods less than about a year. The expected degree of accuracy of the observed data is discussed, and it is concluded that the uncertainties arise from combined theoretical and observational limitations.

94. White, J. B.
Meteoric effects on altitude control of space vehicles. ARS JOURNAL, 32: 75–78, Jan 1962.

With general methods developed for determining meteoric disturbances for any known vehicle configuration, these methods are applied to the 24-hour communication satellite for illustrative purposes. Probable disturbance is in the order of 10^{-3} deg/sec. Calculated impact density agrees favorably with that measured by Explorer I and a Vanguard.

95. Wiederhorn, Norman M.
THE SPACE ENVIRONMENT AND ITS INTERACTIONS WITH LIQUID PROPELLANTS AND THEIR STORAGE SYSTEMS. Little, Arthur D., Inc., Cambridge, Mass. Rept. no. C-63270-02-1. Sep 1961. 109p. (Contract NAS 5-664) ASTIA AD-266 034

Contents:

Magnetic fields in space

The vacuum of space (Particles in space; Simulation of the space vacuum; Effects of the space vacuum upon the storage of liquid propellants

The effects of zero G upon storage of liquid propellants

Electromagnetic radiation in space (Electromagnetic radiation: Interactions of electromagnetic radiation with the propellant storage system

Particulate radiation in space (Particulate radiation environment-solar winds – solar flares – Van Allen radiation; Interactions of particulate radiation with a propellant and its storage system

Meteoroids in space (Meteoroid environment; Interactions of meteoroids with space vehicles)

Bibliography

96. Younger, D. G. and S. Lampert
AN EXPERIMENTAL STUDY ON MULTI-WALL STRUCTURES FOR SPACE VEHICLES. Aeronutronic, Newport Beach, Calif. Rept. on construction techniques and application of new materials, 1 Jun–30 Nov 1960. Rept. no. U-1042. Jan 1961. 60p. (WADD TR 60-800) (Contract AF 33(616)6641, Proj. 1368) ASTIA AD-253 530

Contains the results of an experimental study performed to evaluate the design techniques developed in an earlier report on this program, WADD TR 60-503 (AD-250 269). The structural index and design-constraint parameters reflecting the structural requirements for manned space structure are evaluated, and a representative, cylindrical, double-wall shell is developed using the principles of minimum-weight design. Using specimens of half-scale cross-sectional dimensions, tests are performed on both wide columns and cylindrical shells. The meteorite hazard is one of the environmental parameters involved.

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