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NASA TM X-2408

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THE MANNED SPACECRAFT CENTER GEMINI MICROMETEORITE-COLLECTION EXPERIMENT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1971

1. Report No. NASA TM X-2408	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE MANNED SPACECRAFT CENTER GEMINI MICROMETEORITE-COLLECTION EXPERIMENT		5. Report Date October 1971
		6. Performing Organization Code
7. Author(s) Robert E. Flaherty, MSC		8. Performing Organization Report No. MSC S-239
		10. Work Unit No. 914-50-18-22-72
9. Performing Organization Name and Address Manned Spacecraft Center Houston, Texas 77058		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Two aluminized Plexiglas samples were flown on the Gemini IX spacecraft June 3 to 6, 1966. The samples had a combined sampling area of 1.41×10^{-3} square meter and were exposed to the space environment for 16 hours 47 minutes. One stainless steel sample, vapor coated with multilayers of aluminum to a thickness of 10 microns, was flown on the Gemini XII spacecraft November 11 to 14, 1966. This sample had an area of 7.06×10^{-4} square meter and was exposed for 6 hours 24 minutes. There was no evidence of extraterrestrial-particle impact on any of the surfaces. However, a wide variety of surface effects was encountered and recorded; these effects exemplify the problems encountered in micrometeorite particle-collection experiments.

17. Key Words (Suggested by Author(s)) · Gemini · Sample Contamination · Micrometeorites · Micrometeorite Collection · Gemini Experiment S-12 · Hypervelocity Impact	18. Distribution Statement

19. Security Classif. (of this report) None	20. Security Classif. (of this page) None	21. No. of Pages 20	22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

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SUMMARY

Three controlled micrometeorite-collection samples were exposed to the environment of space in Gemini experiment S-12. Two aluminized Plexiglas samples were flown on Gemini IX, and one stainless steel sample, vapor coated with multilayers of aluminum to a thickness of 10 microns, was flown on Gemini XII. On the Gemini IX mission, the samples had a combined sampling area of 1.41×10^{-3} square meter and were exposed to the space environment for 16 hours 47 minutes. The Gemini XII sample had an area of 7.06×10^{-4} square meter and was exposed for 6 hours 24 minutes. Although there was no evidence of extraterrestrial-particle impact on any of the surfaces, a wide variety of surface effects was encountered and recorded. It is concluded that the samples were contaminated with a heavy background of terrestrial particles and, from the anticipated flux rate, that the overall experiment area-time product was 1600 times too small to record a single impact of a 5×10^{-11} gram particle (the limiting mass detectable on this surface).

INTRODUCTION

Three controlled collection samples were successfully exposed to the space environment in Gemini experiment S-12, "Micrometeorite Collection Experiment." The experiment hardware is shown in figures 1 and 2. The Meteoroid Sciences Branch, Space Physics Division, at the Manned Spacecraft Center (MSC), was the guest experimenter for the S-12 experiment, which was originated by Dr. Curtis Hemenway of the Dudley Observatory. In this experiment, a wide variety of samples was exposed to the environment about the spacecraft on the Gemini IX and XII missions. In the Gemini S-12 collection program, two types of samples were prepared: (1) Plexiglas, aluminized to 3 percent light transmission, and (2) stainless steel, vapor coated with 10 microns of aluminum. These materials were chosen to provide a smooth substrate that could be highly polished. The thin coating of aluminum on the Plexiglas sample provided a uniform background so that micrometeorite impacts, with bottom lighting, would appear as points of light. By this technique, meteoroid-interaction areas could be detected down to a lower limit of 5 microns in diameter. This sample was expected to provide accumulative flux of meteoroid impacts; and, through a calibration program, information on

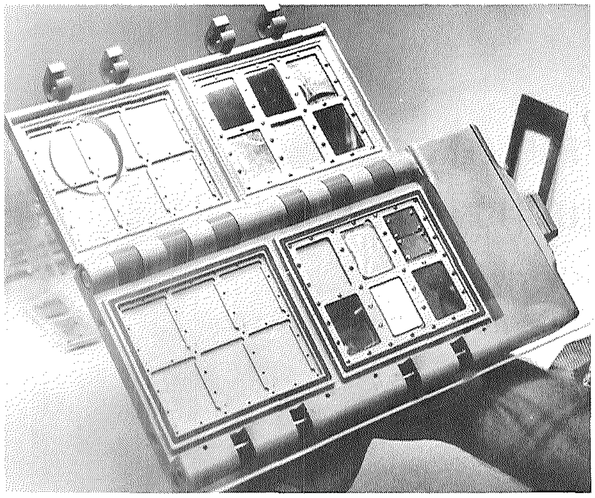

Figure 1. - The S-12 collection hardware with several typical examples.

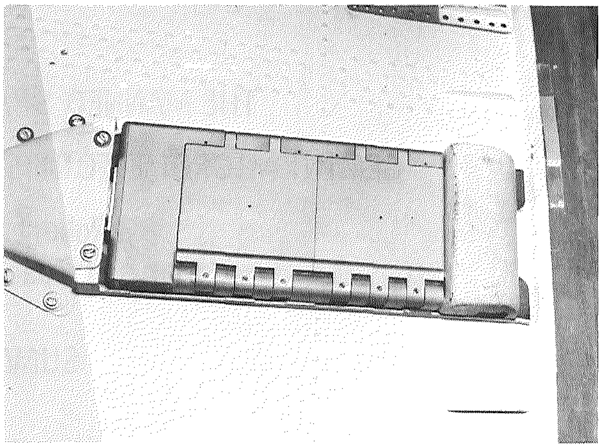

Figure 2. - The S-12 hardware mounted on the spacecraft.

the impacting mass was to be obtained. The stainless steel sample was used to provide a smooth substrate for the 10-micron layer of aluminum. This sample was designed to provide information on the impacting meteoroid mass through existing penetration equations for aluminum. These exposed samples have been investigated for high-velocity meteoroid interaction and to determine the degree and variety of contamination in the immediate area of an orbital spacecraft.

The MSC best-fit flux curve, based on penetration data from Explorers XXIII and XVI and Pegasus I, II, and III (as presented in ref. 1), gives an accumulative flux of 0.54 impact/m^2day for masses of 10^{-12} gram and larger. With the total area time of 1.16×10^{-3} m^2day on both Gemini IX and XII, no impacts were expected from meteoroids with masses of 5×10^{-11} gram and larger.

GEMINI IX

Participation and Results

After the Plexiglas samples were aluminized to approximately 3 percent light transmission, the surfaces were microscopically scanned with a Leitz microscope at ×250 under a laminar-flow clean table. This microscopic survey, with bottom lighting, did not reveal a single hole in the aluminum film on any of the samples. A top-lighting examination revealed many polishing scratches that were visible through the aluminum coatings. These samples were sealed in a clean container and shipped to the principal investigator for installation in the flight hardware. One control sample was kept in a clean container at the MSC.

Two of these samples were successfully exposed for 16 hours 47 minutes on the Gemini IX mission and were recovered. The exposed samples and the two backup samples that had gone through the same preflight environment were returned to the MSC in a sealed plastic container. This container was opened under a laminar-flow clean table, and each sample was placed in a separate, clean, transparent container that, when sealed, permitted microscopic examination. Immediate preliminary scanning of both flight and backup samples indicated a heavy particle background (average of 1 to 2 particles/mm^2), with a size distribution peaking between particle average diameters of 4 and 5 microns. Because particles were found on the exposed and unexposed (i.e., flight and backup) samples, it was concluded that the collection surfaces had been contaminated in the handling procedure.

A detailed microscopic survey of the flight samples revealed many unusual surface effects in the aluminum film, many of which were also observed on the backup samples. For the purpose of this paper, surface effect is defined as any surface irregularity, blemish damage, and so on.

These unusual effects, found on the flight and backup samples, were categorized into the following groups. (Typical effects of each group are shown in the following paragraphs.)

Group 1 is defined as a circular array of holes in the aluminum film with average diameters of 5 to 200 microns. The individual holes in the clusters are 1 to 30 microns in diameter. These clusters of holes in the film are often found in larger groups. Some individual clusters consist of a large hole with numerous small holes surrounding it. At magnifications up to ×765, there is no visible damage to the Plexiglas substrate. These characteristic effects from the flight sample are shown in figures 3 and 4. Group 1 effects that were found on the backup samples are shown in figures 5 and 6.

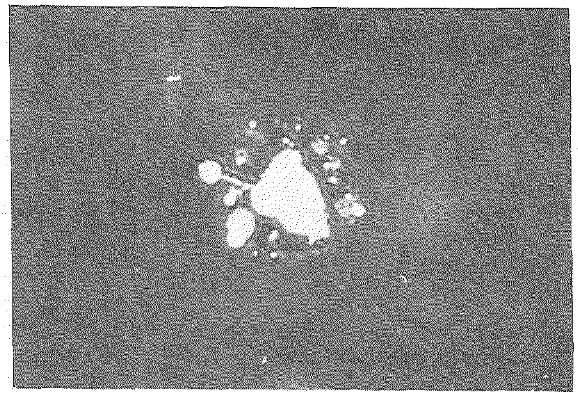

Figure 3. - A ×200 view of 90-micron effect.

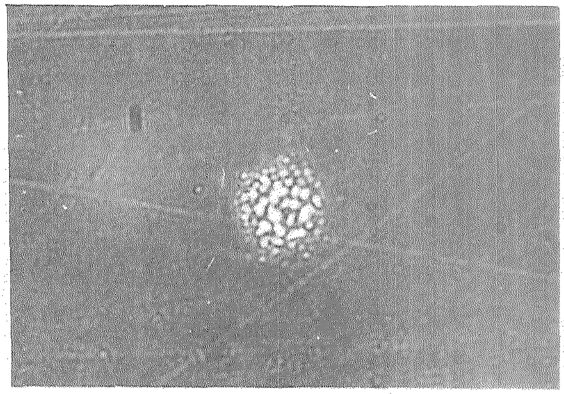

Figure 4. - A ×765 view of 15-micron effect.

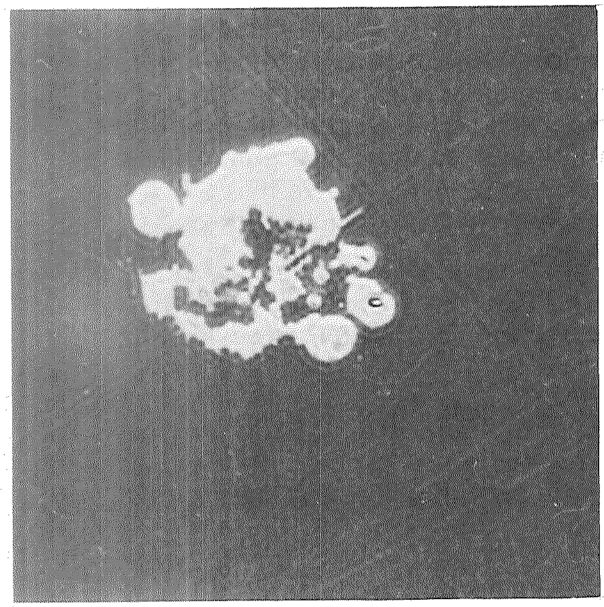

Figure 5. - A ×200 view of 180-micron effect.

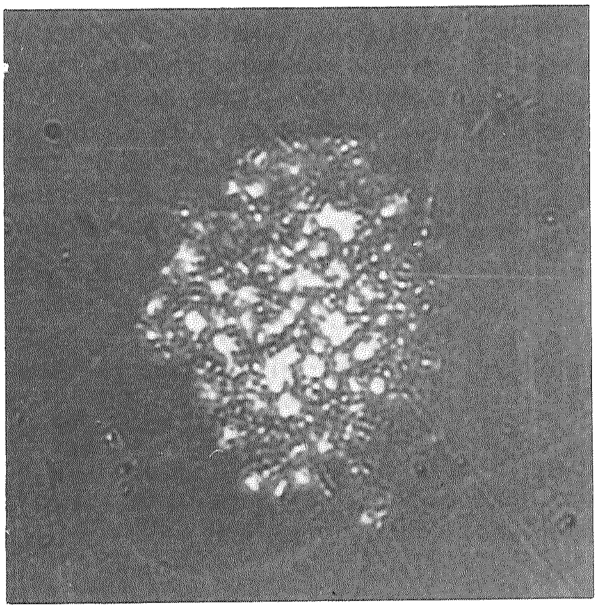

Figure 6. - A ×765 view of 50-micron effect.

Group 2 is defined as a cluster or group of irregular holes that appear to be associated with polishing scratches in the Plexiglas surface. This effect appears to have been caused by a liquid coming in contact with the aluminum film that ran along the scratch depression, damaging the aluminum film. Typical examples from the flight samples are shown in figures 7 to 10. Group 2 effects found on the backup samples are shown in figures 11 to 14.

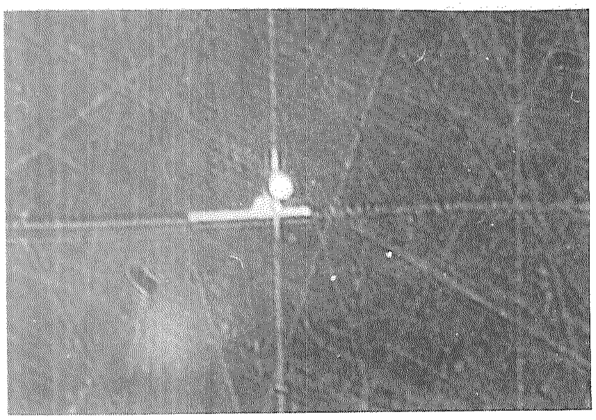

Figure 7. - A ×765 view of 3-micron hole and of 18-micron scratch effect.

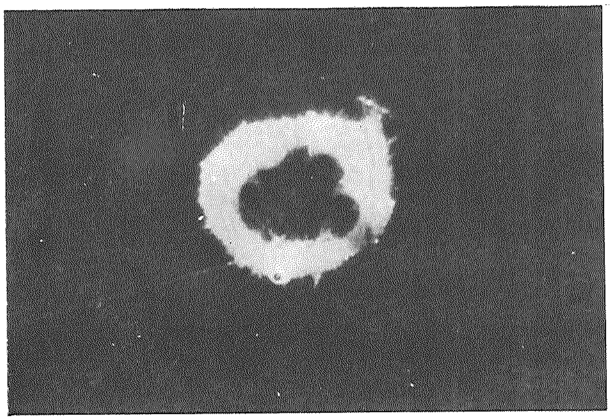

Figure 8. - A ×765 view of 35-micron-diameter effect.

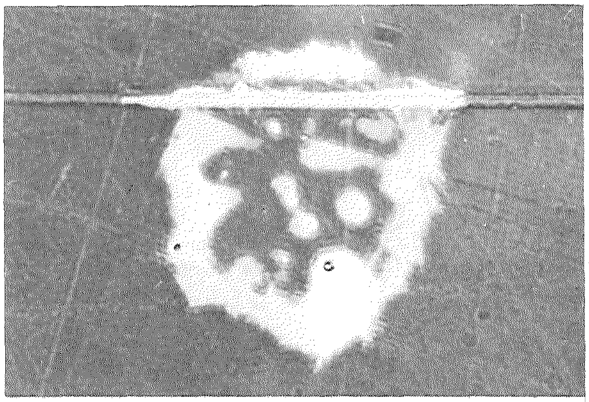

Figure 9. - A ×765 view of 45-micron irregular hole and scratch effect.

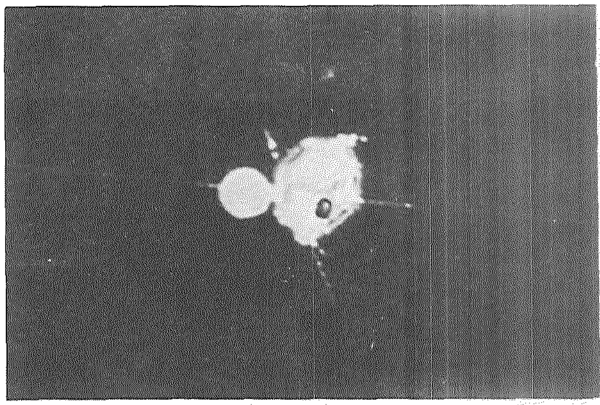

Figure 10. - A ×765 view of 15- by 20-micron irregular hole with multiple-scratch effect.

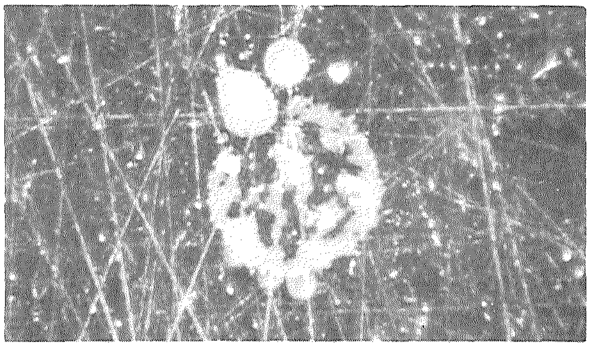

Figure 11. - A ×765 view of 35-micron effect.

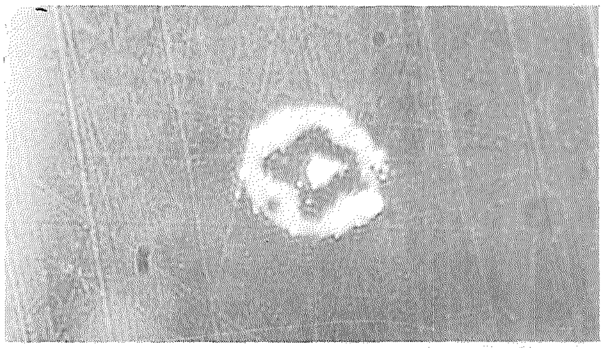

Figure 12. - A ×765 view of 20-micron effect.

Group 3 is defined as a circular array of contaminant that has no visible effect on the aluminum film or Plexiglas substrate. This effect appears to have been caused by a droplet that was filled with small particles (1 to 5 microns in diameter). The liquid evaporated, leaving concentric circles of small dark particles adhering to the surface. The perimeter of the array has a stain that was evidently caused by the liquid. This effect, as found on the flight sample, is shown in figure 15. The corresponding group was not well represented on the backup sample.

Group 4 is defined as a group of "whiskerlike" and apparently crystalline structures found only in one area on the flight sample (figs. 16 and 17). The identical crystalline structure was not found on the backup samples.

Group 5 is defined as a circular array similar to that of group 3, but with no effect on the aluminum film or the Plexiglas. However, this effect has a dark, circular center portion in addition to the stain around the perimeter. This effect was found only on the flight sample and is shown in figure 18.

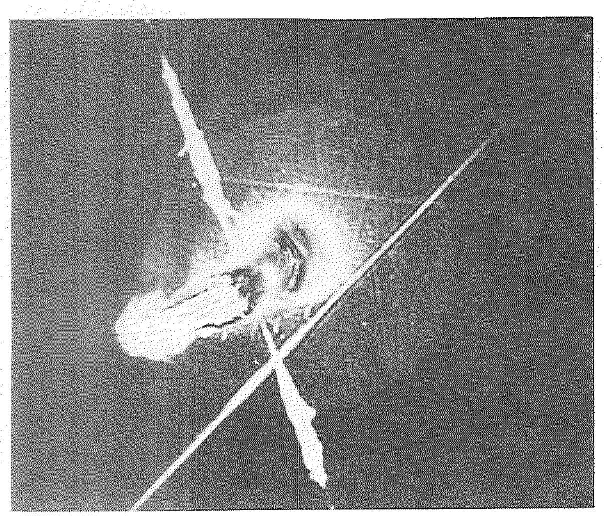

Figure 13. - A ×200 view of particle on surface that caused a 65-micron-diameter translucent area and a 150-micron scratch effect.

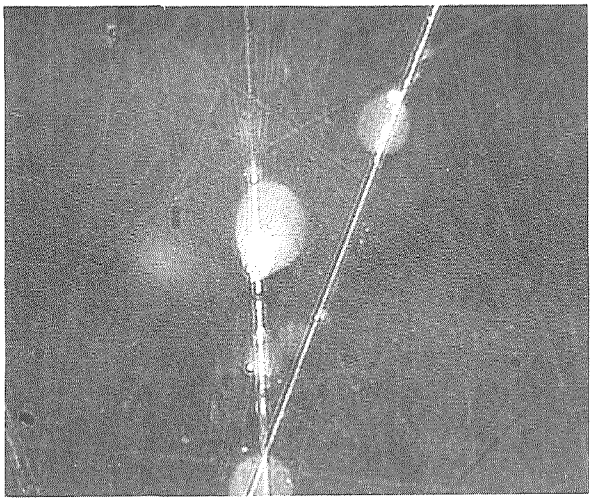

Figure 14. - A ×765 view of scratch effect.

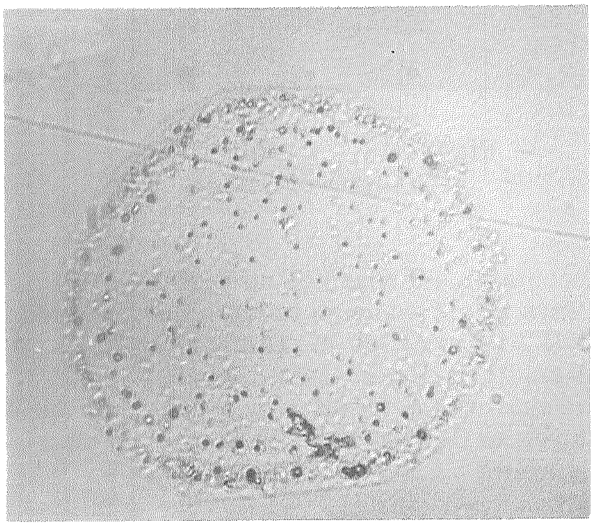

Figure 15. - A ×340 view of 175-micron-diameter circular area.

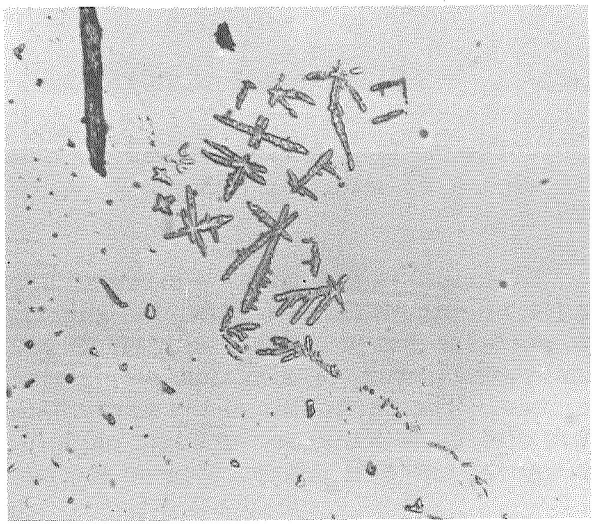

Figure 16. - A ×45 view of crystalline structure. (Note large number of particles.)

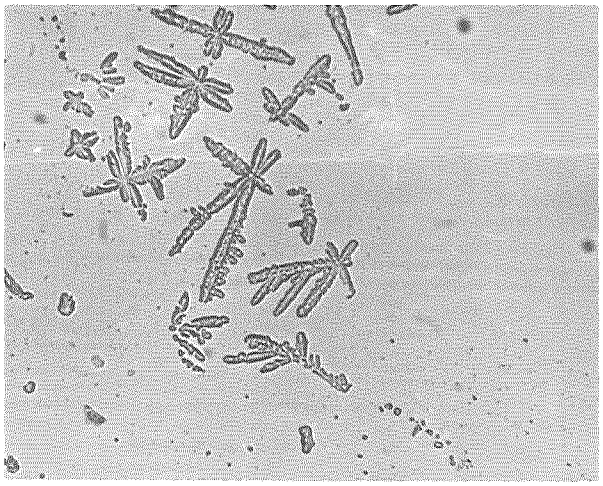

Figure 17. - A ×180 view of the crystalline structure of figure 16.

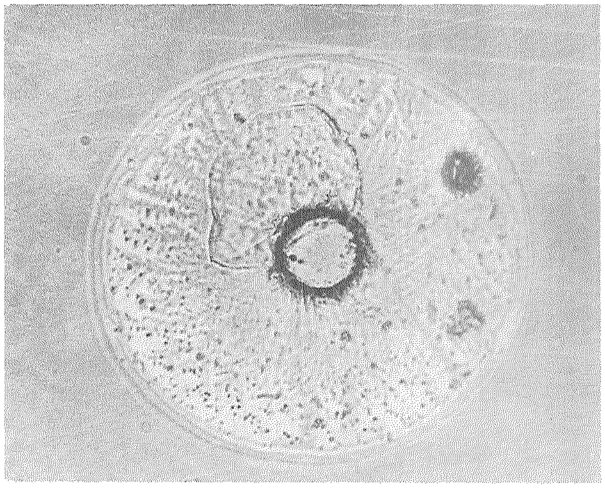

Figure 18. - A ×340 view of 20-micron array. (Note stain around perimeter and in central area).

Group 6 is defined as an irregular film adhering to the aluminum surface. Some of these films have a color spectrum visible near the edge. This effect (fig. 19) was not found on the backup sample.

Group 7 is defined as areas of high concentration of holes in the aluminum film; these holes range from submicron size to 50 microns in diameter. This effect is shown in figure 20. No deformations of the Plexiglas substrate were observed at ×760 magnification. Corresponding effects found on the backup samples are shown in figure 21.

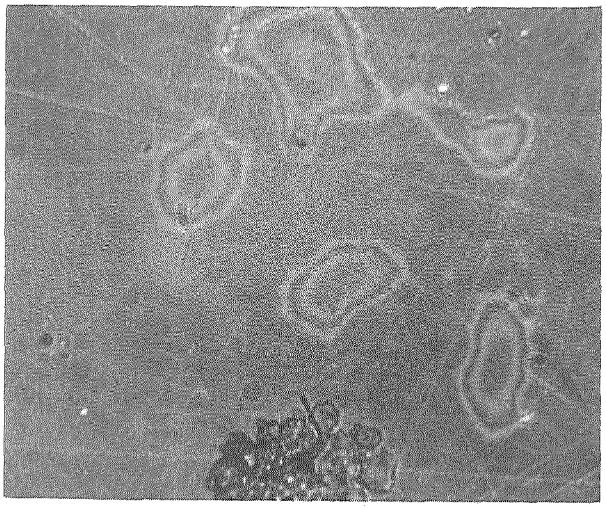

Figure 19. - A ×765 view of aluminum film.

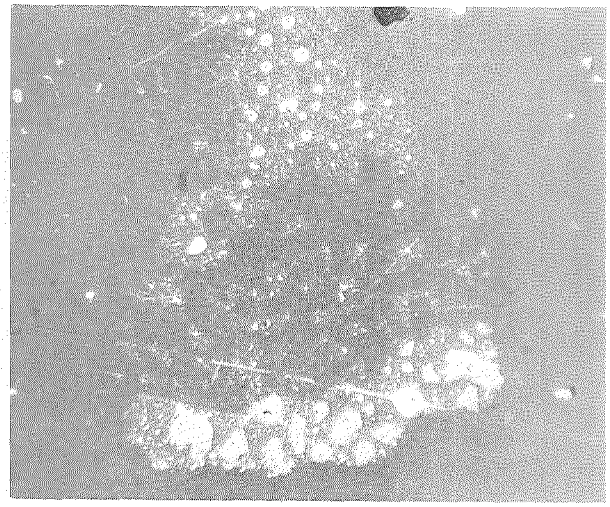

Figure 20. - A ×200 view of large area with multiple holes in the aluminum film.

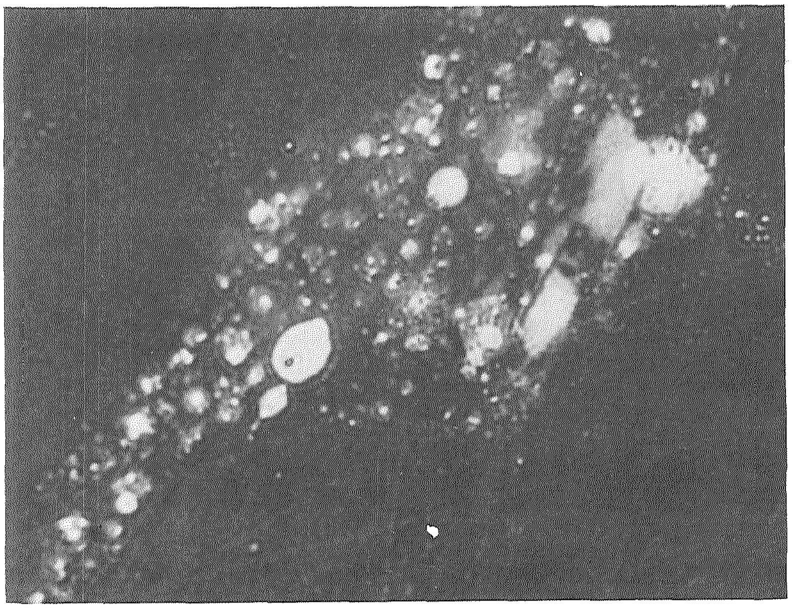

Figure 21. - A ×160 view of multiple holes.

Other Effects Found Only on the Backup Samples

Group 8 is defined as areas of oblong defects in the aluminum film, ranging in size from 4 by 15 microns to 15 by 30 microns. These defects are only in the aluminum film, and there is no apparent damage to the Plexiglas surface. Each of these oblong defects has an associated ring of contaminants. Multiple and complex ring structures of contamination are visible in areas of multiple defects. This effect is shown in figure 22.

Figure 22. - A ×765 view of multiple defects. (Note how aluminum is pushed toward the edges.)

Group 9 is defined as areas of high contamination showing evidence of an evaporated liquid that has left a translucent deposit on the aluminum surface. Often, the aluminum film in the central region of the deposit has been etched away. This effect is also found on the edge of some other translucent regions. These effects are shown in figures 23 to 25. Other translucent regions were found that had no effect on the aluminum film, as shown in figure 26.

Group 10 is defined as particle contamination associated with residue from an evaporated liquid (figs. 27 and 28). Group 11 is defined as a large crystalline structure, as shown in figures 29 and 30.

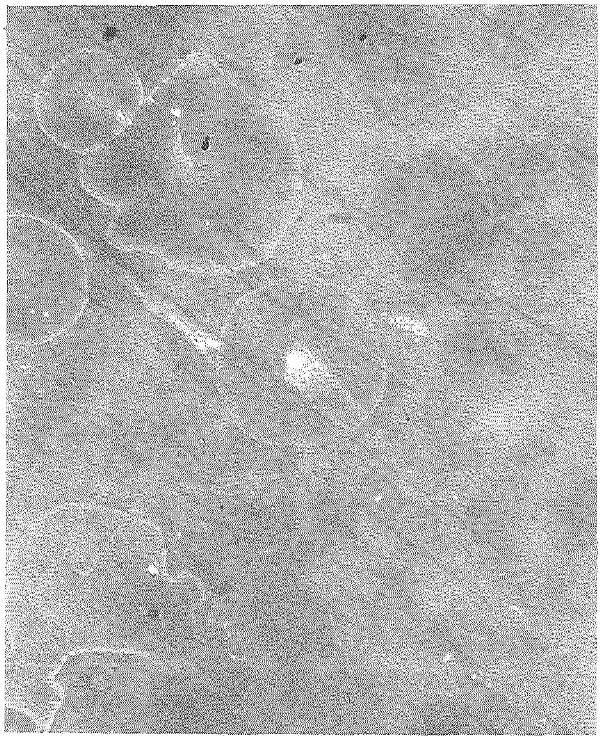

Figure 23. - A ×200 view of area with center etched away.

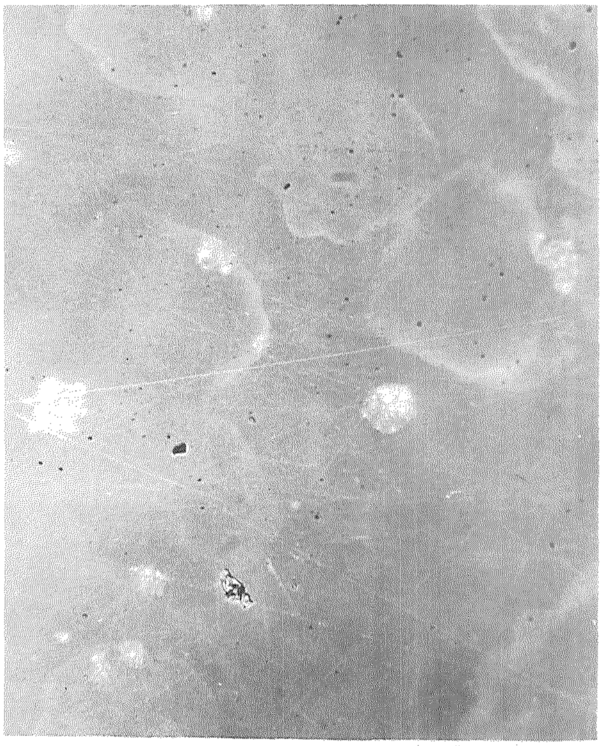

Figure 24. - A ×200 view of area with edges etched away.

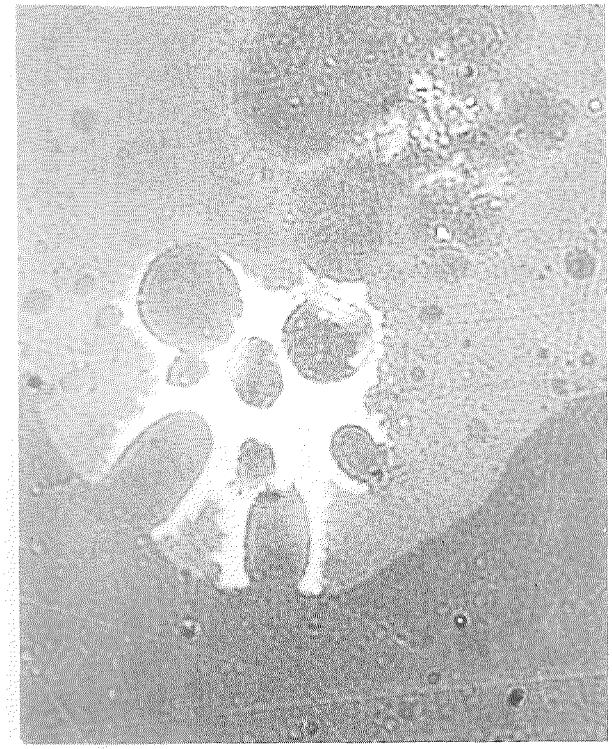

Figure 25. - A ×765 view of irregular etched effect.

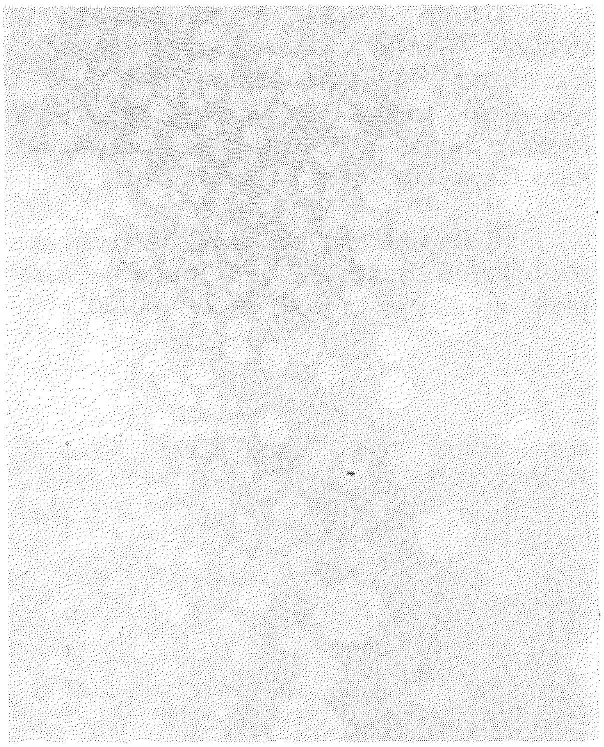

Figure 26. - A ×65 view of multiple white translucent spots.

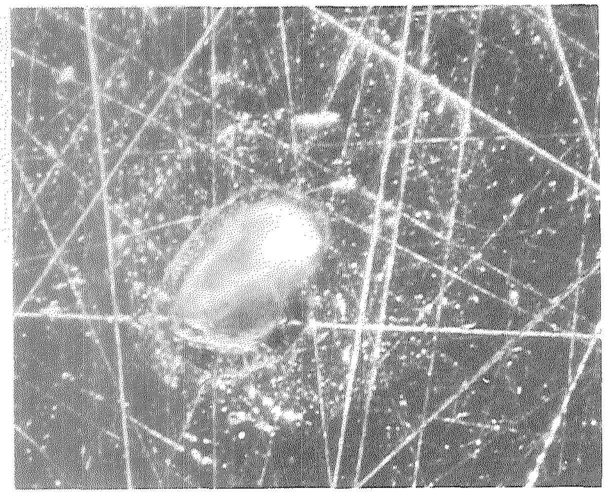

Figure 27. - A ×765 bottom-lighted view of milky translucent area around 15- by 30-micron particle.

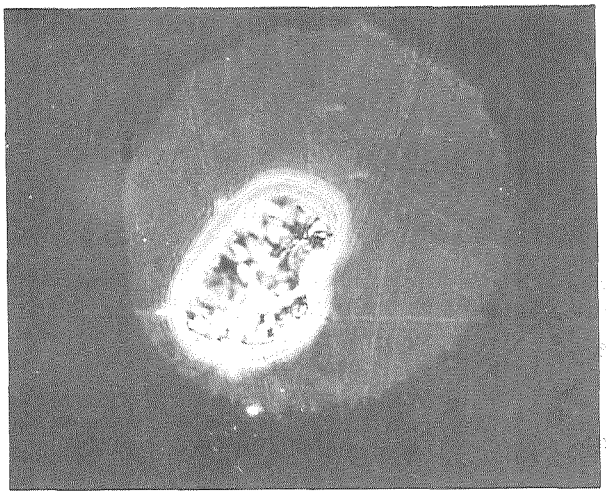

Figure 28. - A ×765 top-lighted view of translucent area around 15- by 30-micron particle.

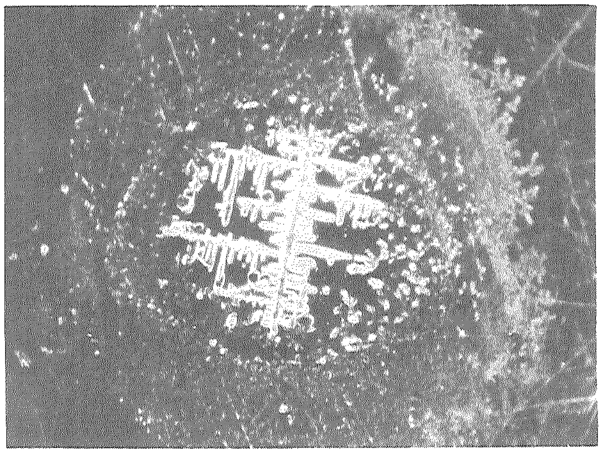

Figure 29. - A ×340 view of 100-micron-diameter effect.

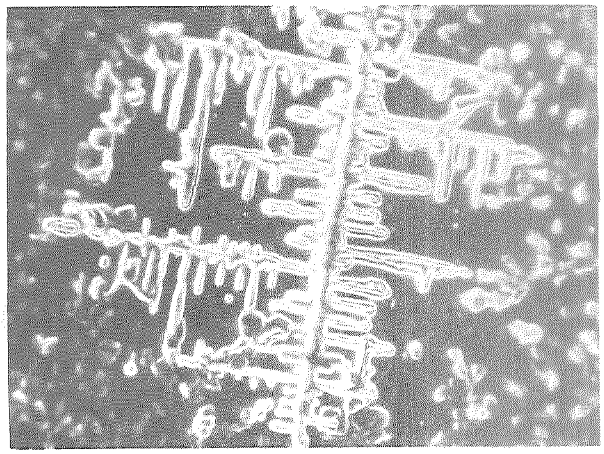

Figure 30. - A ×765 view of 100-micron-diameter effect.

GEMINI XII

Participation and Results

For the Gemini XII mission, stainless steel samples were highly polished and vapor coated with multiple layers of aluminum to an overall thickness of approximately 10 microns. Immediately after this coating was completed, the samples were sealed in a transparent clean container. The preflight microscopic examination at ×250 revealed several spherical objects on the surface, presumably created during the aluminization. No other microscopic surface imperfections or irregularities were found on either the flight or the backup samples.

After the mission exposure of 6 hours 24 minutes, the samples were recovered and stowed in the spacecraft. The flight and backup samples were shipped to the MSC in a clean container. Immediate preliminary scanning of both samples on a laminar-flow clean table revealed a mean contamination level of approximately 0.1 particle/mm^2 in the size range of 2 to 10 microns in diameter. However, at the submicron sizes, the contamination level was 1.7 particles/mm^2. (Note: These smaller particles could not be resolved at ×765; i.e., they appear only as a point of light with either side or top lighting.)

The surface effects found on the flight and backup samples are categorized into the following groups.

Group 1a includes spheres, on the surface of the aluminum, that were observed before and after flight. The spheres range in size from 20 to 250 microns in diameter. Their surface texture is identical to that of the surrounding aluminum, thus tending to indicate that they are either coated or solid spheres of aluminum. This effect is shown in figures 31 and 32.

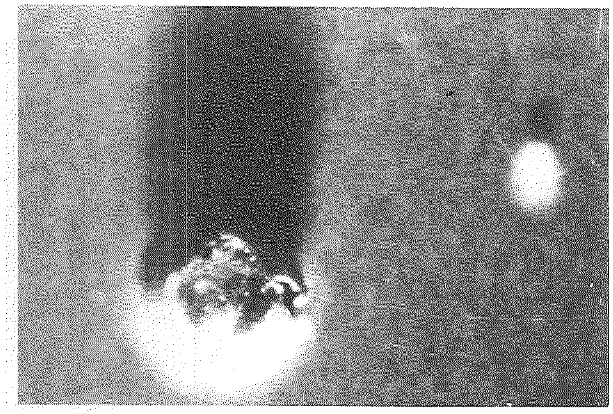

Figure 31. - A ×200 view of 125-micron-diameter sphere, top and side lighting. (Note that sphere has been partially crushed.)

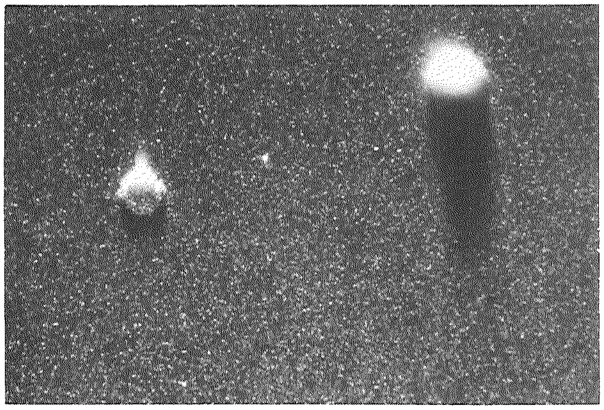

Figure 32. - A ×340 view of group 5a and group 1a.

Group 2a includes large areas of multiple holes in the aluminum film. Most of these effects are irregular; however, some have a very circular profile (figs. 33 and 34). All of these holes have very steep sides through the 10 microns of aluminum, and some have residue in the bottom. At magnifications up to ×765, there was no visible damage to the stainless steel surface. Several effects, with numerous particles adhering to the aluminum surface, are shown in figure 35; the photomicrograph in figure 36 was taken 2 months later. (Note that the particles have disappeared, leaving holes in the aluminum film. The holes conform to the shape of the corresponding particles.) This group-2a effect was also observed on the backup sample, but to a lesser extent, and is shown in figures 37 and 38.

Figure 33. - A ×765 view of 40-micron-diameter hole in aluminum, focused on residue in bottom.

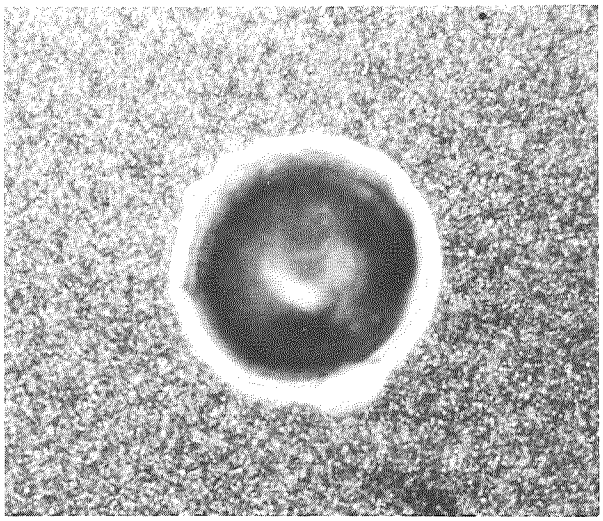

Figure 34. - A ×765 view of 40-micron-diameter hole in aluminum, focused on top surface of aluminum.

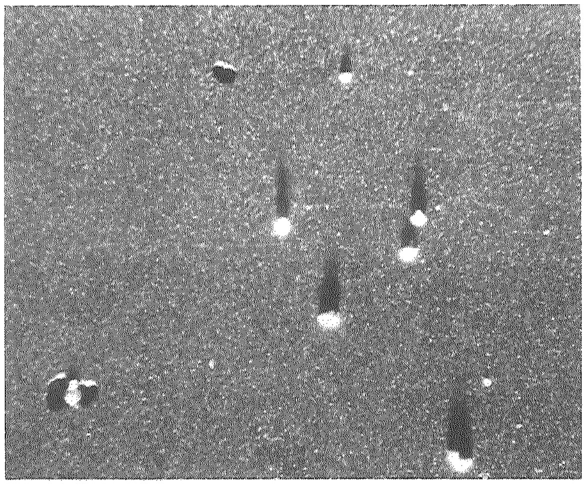

Figure 35. - A ×105 view of hole and multiple particles.

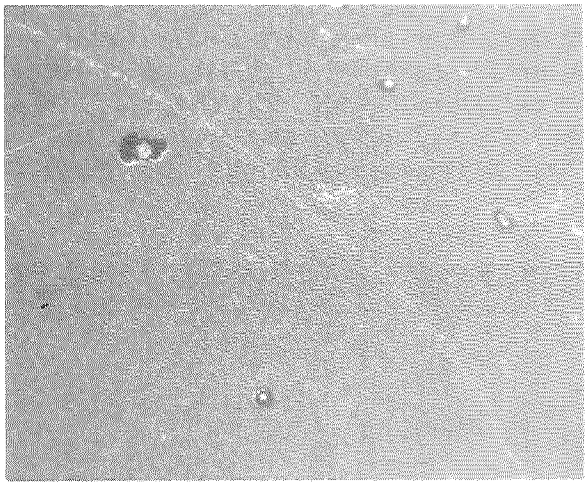

Figure 36. - A ×105 view of hole and multiple particles taken 2 months after view in figure 35.

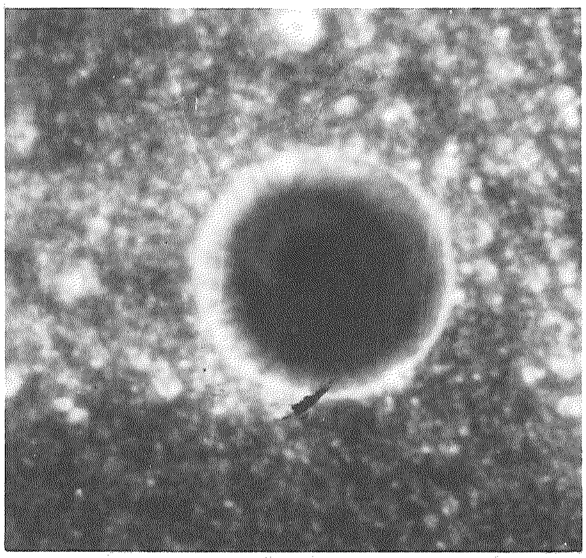

Figure 37. - A ×765 view of 20-micron-diameter hole, focused on top surface of aluminum.

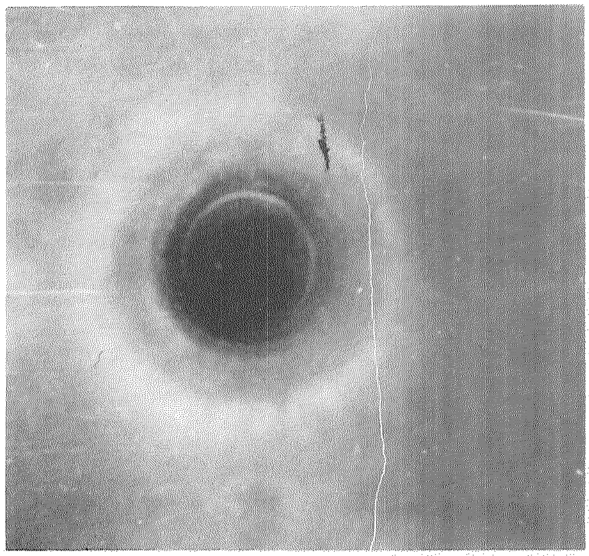

Figure 38. - A ×765 view of 20-micron-diameter hole, focused on bottom of hole.

Group 3a includes bumps on the surface of the aluminum film. The texture of these bumps is identical to that of the surrounding aluminum. This effect was not present on the flight or backup samples before shipment and, therefore, indicates a transparent contaminant. The effect is always circular and approximates a flattened hemisphere. These effects are shown in figures 39 to 41. The corresponding effects found on the backup samples are shown in figures 42 and 43.

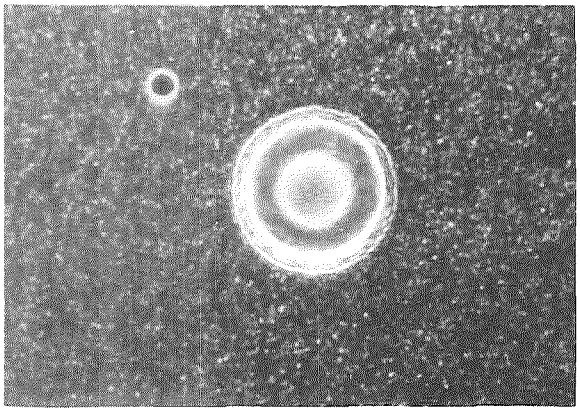

Figure 39. - A ×765 view of group 1 effect, focused on lower surface.

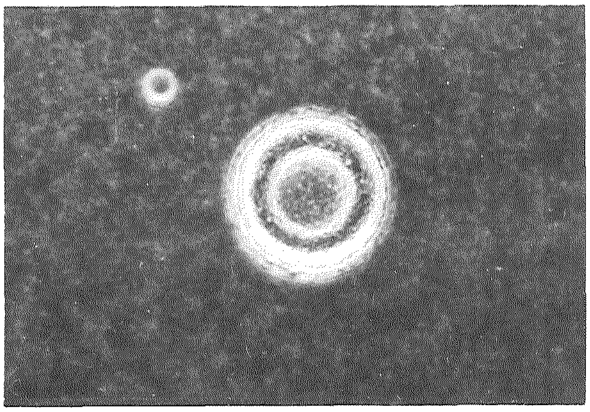

Figure 40. - A ×765 view of group 1 effect, focused on top of effect.

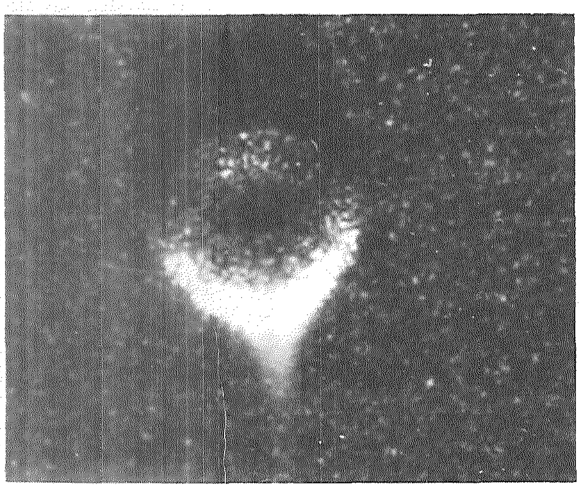

Figure 41. - A ×765 view of 20-micron effect with side lighting. (Note shadow.)

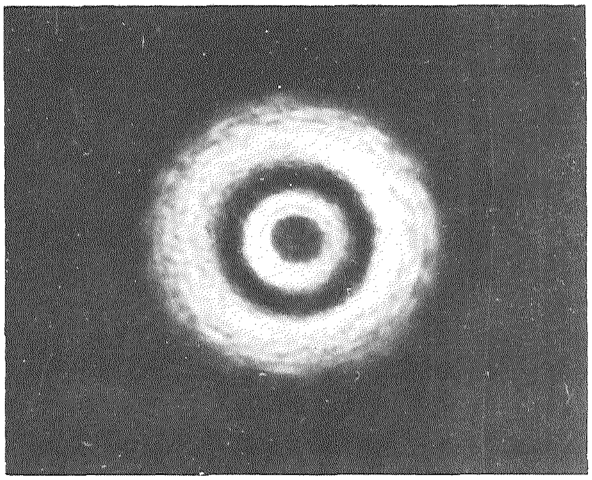

Figure 42. - A ×765 view of 25-micron effect, focused on lower surface.

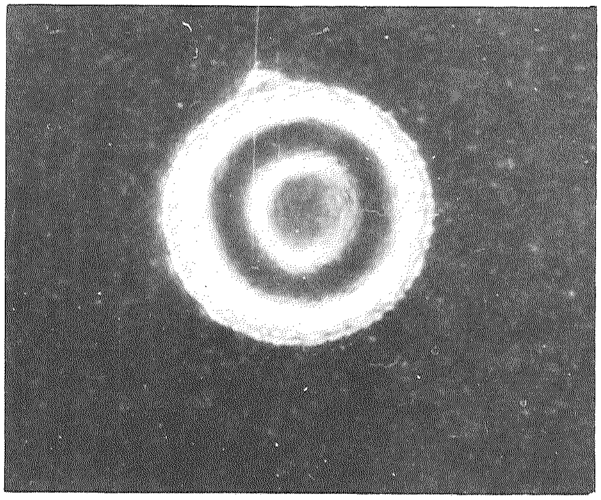

Figure 43. - A ×765 view of same effect, focused on top surface.

Group 4a includes an irregular group of nodules on the surface, approximately 200 microns across. Only one instance of this phenomenon was found on the flight sample and none on the backup. This effect is shown in figure 44.

Group 5a includes a circular array of contamination, as if caused by an evaporated liquid (fig. 45). The corresponding group found on the backup sample is shown in figures 46 and 47.

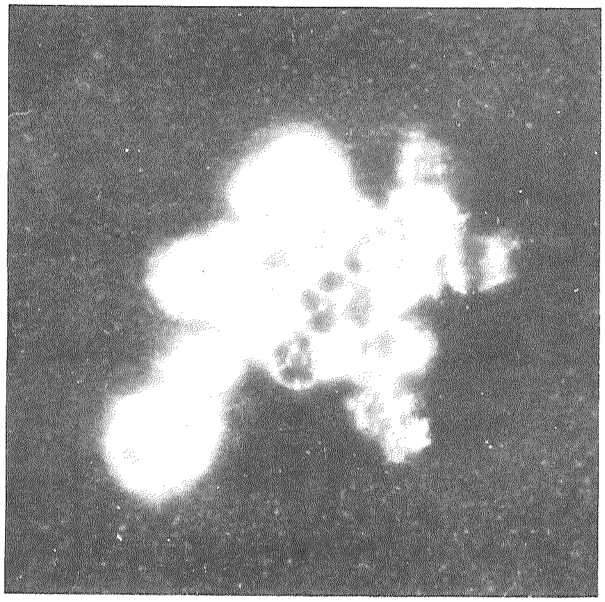

Figure 44. - A ×765 view of 45-micron group of nodules.

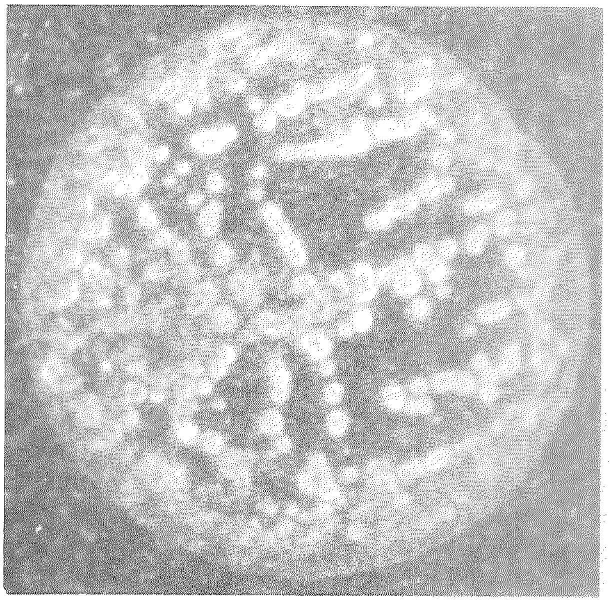

Figure 45. - A ×765 view of 70-micron effect.

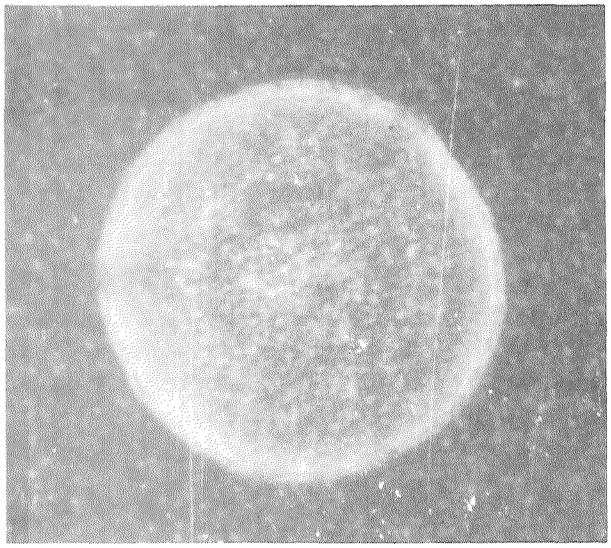

Figure 46. - A ×765 view of 30-micron effect.

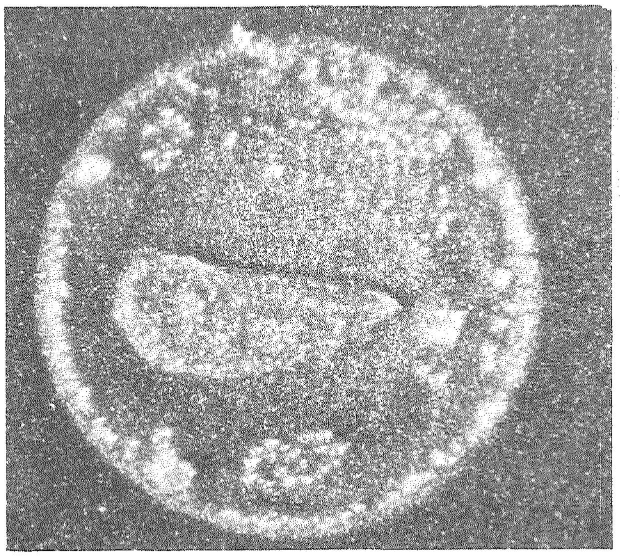

Figure 47. - A ×765 view of 40-micron effect.

DISCUSSION OF RESULTS

Gemini IX

The frequency of the various kinds of individual surface effects, other than the general particle background (i.e., surface particles, dust, etc.) of 1 to 2 per square millimeter for the Gemini IX flight and backup samples, is approximately 0.2 per square millimeter. The frequency of large multiple effects — such as those of groups 1, 7, 8, 9 — is approximately 0.5 per square centimeter.

The effects of groups 1 and 2 are well represented on both flight and backup samples, and it is concluded that these effects did not occur as a result of space exposure. The circular effects of groups 3 and 5 were not represented on the backup samples and could have been collected during the space exposure. However, there was no apparent interaction with the sample surface; that is, no deformation on the Plexiglas or removal of the aluminum film. Similar effects were found on the surface exposed on the same mission for the Ames Research Center (ref. 2). As the characteristics of these types of effects are not consistent with impacts at even the lowest expected relative velocity, it is concluded that they were not caused by meteoroids. A similar conclusion can be reached for the "whiskerlike" crystalline structures of group 4, the thin films of group 6, and the multiple holes in the aluminum film of group 7 (which caused no detectable damage to the Plexiglas). The effects of groups 8, 9, 10, and 11, found only on the backup samples, are good examples of the types of contamination to be expected even under well-controlled conditions.

From this discussion, it is concluded that there are no hypervelocity meteoroid interactions larger than 5 microns in diameter on the samples exposed on the Gemini IX mission.

Gemini XII

For the Gemini XII experiment, the effects of group 1a were observed before flight and are clearly not of meteoritic origin.

An examination of figures 35 and 36 (showing the group 2a effects) reveals particles near several large holes in the aluminum coating. These particles were removed during the sample handling, leaving holes in the aluminum coating that conform approximately to the particle shape. These particles could have adhered to the surface during space exposure. If the particle collection in group 2a is caused by space exposure, then the relative intercept velocity was less than expected (i.e., greater than 4 km/sec). Therefore, the particles are considered contamination and not of extraterrestrial origin, indicating the great care that must be used in interpreting all collection data. The circular holes in figures 33 and 34 of group 2a were represented on the backup sample. Again, conclusions are difficult to make. Perhaps aluminum spheres were sputtered onto the samples during the first aluminum vapor coating and were subsequently shadowed by multiple layers of aluminum. At a later time, the particles were dislodged, leaving the observed hole with the deposit in the bottom. This effect was also found on the backup sample, as shown in figures 37 and 38.

The effects of group 3a are well represented on the backup sample, and it is concluded that this effect is not the result of space exposure. The globular cluster shown in group 4a (fig. 44) was not represented on the backup sample and could be the result of the space exposure. However, the cluster is not considered to be of meteoritic origin because of the low intercept velocity. Group 5a represents circular contamination areas, which were also found on the backup sample, indicating only the possibility of space origin.

CONCLUDING REMARKS

From the 16 hour 47 minute exposure of two aluminum-coated Plexiglas samples on the Gemini IX mission and the 6 hour 24 minute exposure of an aluminum-coated stainless steel sample on the Gemini XII mission, it is concluded that the samples were contaminated with a heavy background of terrestrial particles and that there were no high-velocity meteoroid interactions with the exposed samples larger than 5 microns in diameter. (This size corresponds to a meteoroid mass of approximately 5×10^{-11} gram.) From this mass and the total area time for both experiments of 1.16×10^{-3} m^2day, only a weak upper limit can be placed on the accumulative meteoroid flux; that is, the accumulative flux for all meteoroids of mass 5×10^{-11} gram and larger does not exceed 845 impacts/m^2day. Judging from the anticipated flux rate of 0.54 impact/m^2day, the overall experiment area-time product was 1600 times too small.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, April 1, 1971
914-50-18-22-72

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