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LUNAR DUST DEGRADATION EFFECTS AND REMOVAL/PREVENTION CONCEPTS FINAL REPORT

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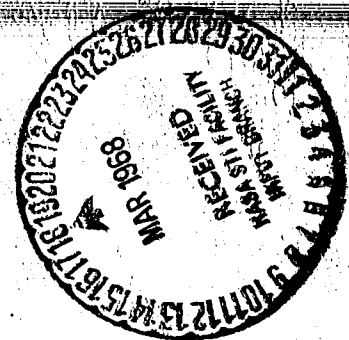
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LUNAR DUST DEGRADATION EFFECTS AND
REMOVAL/PREVENTION CONCEPTS

FINAL REPORT

Volume I - SUMMARY

Northrop/Huntsville Technical Report No. 321

7 June 1967

By

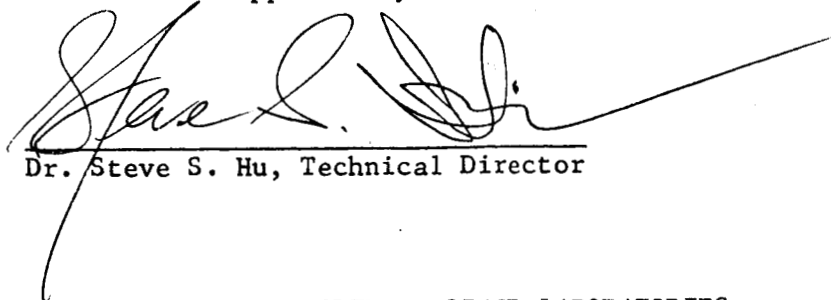
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GEORGE C. MARSHALL SPACE FLIGHT CENTER
PROPULSION AND VEHICLE ENGINEERING LABORATORY

Under Contract NAS8-20116

Reviewed and Approved by:



Dr. Steve S. Hu, Technical Director

NORTHROP SPACE LABORATORIES
HUNTSVILLE, ALABAMA

FOREWORD

The research effort described in this final report was performed by Northrop Space Laboratories for the Propulsion and Vehicle Engineering Laboratory of George C. Marshall Space Flight Center under Contract NAS8-20116. The report is composed of two volumes. The first volume represents a summary of the results of the investigation. Volume II presents a detailed description of the entire research effort. Mr. W. O. Randolph and Mr. W. B. McAnelly of the Fluid Mechanics and Thermodynamics Branch, Propulsion Division, served as the Contracting Officer's Representatives for the study.

In addition to those personnel appearing as co-authors of this report, several other individuals made significant contributions. Dr. E. Azmon served as an advisor on matters relating to the lunar surface and the characterization and preparation of simulated lunar dust. Mr. C. L. Densmore was responsible for all design work pertaining to the dust removal/prevention concepts and experimental models. Mr. E. W. Bentilla provided suggestions, based on heat transfer considerations, relative to the test apparatus and the design of the experiment.

TECHNICAL SUMMARY REPORT

Contract NAS8-20116

LUNAR DUST DEGRADATION EFFECTS
AND REMOVAL/PREVENTION CONCEPTS

By

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ABSTRACT

The report presents the results of a research effort to determine the degradation of radiator surfaces due to contamination by simulated lunar dust and to develop methods of removing or preventing the accumulation of dust on radiator surfaces. Spectral and total solar absorptance values of S-13 and aluminized Teflon thermal control coatings are presented for various degrees of basalt dust contamination and at two different angles of incidence. Both spectral and total infrared emittance values for S-13 and aluminized Teflon are provided for various loads of dust coverage.

The designs of several devices for removing or preventing dust accumulation are presented along with test results based on performance testing of these devices. The devices tested include a jet cleaning device, a vibrating surface device, and a mechanical brush device.

The report indicates that dust contamination, even at a relatively low level, can produce significant increases in the solar absorptance of a thermal control coating. There is indication, based on the experimental results reported that the use of an incompressible fluid jet is the most promising method of removing dust of those devices tested.

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SECTION I

INTRODUCTION

Northrop Space Laboratories, Huntsville, Alabama, and Northrop Systems Laboratories, Hawthorne, California, under Contract NAS8-20116 with the Propulsion and Vehicle Engineering Laboratory of Marshall Space Flight Center, have been engaged in a research effort concerned with determining the effect of dust on radiator surfaces and developing methods for preventing or removing accumulations of dust from such surfaces. The results of this investigation are summarized in this volume of the final report. Section II of this volume provides a brief discussion of the investigation relating to the degradation of a radiator surface due to dust. Section III provides a summary of that portion of the research effort devoted to the development of techniques for preventing or removing dust from a radiator surface in a simulated lunar environment. Conclusions and recommendation based on the results of the investigation are presented in Section IV. A more detailed description of the research effort is provided in Volume II of the final report.

SECTION II

DUST DEGRADATION OF SURFACE PROPERTIES

This phase of the investigation was directed toward establishing the effects of dust on the thermal radiation properties of radiator surfaces. The major goal of this work was to establish the manner in which the spectral and total solar absorptivity and infrared emissivity varied with the amount of dust contamination. Also the variation of solar absorptivity with angle of incidence was of interest.

A number of different types of dust materials and thermal control coatings were considered for testing. Candidates for the dust material, based on a literature survey, included granite, basalt, tektite, and chondrite. From these materials basalt was ultimately selected.

Thermal control coatings which were considered included two pigmented compositions, S-13 and Z-93, and two second-surface mirrors, aluminized Teflon and clear silicone. Ultimately S-13 was selected as the primary thermal control coating to be tested with a limited amount of work being carried out on aluminized Teflon and a very small amount on clear silicone. The Z-93 coating was not tested because of its high porosity (which would have rendered most dust-removal concepts impractical) and because of some difficulties associated with its application to the test panels. Notice should be taken that the selection of S-13 as the primary test coating was not based on its superiority to other thermal coatings. Instead, its selection was designed to provide a representative thermal control coating within the current state-of-the-art.

Basalt dust was obtained by means of a grinding operation involving grinding the basalt particles against themselves in a special rubber-lined mill to minimize any contamination from foreign media. The basalt powder was then sieved by means of a sieve-shaker apparatus through a series of screens to obtain fractions in specific particle size ranges. The fractions thus obtained were:

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larger than 500μ ,
 500μ to 250μ ,
 250μ to 125μ ,
 125μ to 105μ ,
 105μ to 74μ ,
 74μ to 62μ ,
 62μ to 53μ ,
 53μ to 44μ ,
 44μ to 37μ ,
and smaller than 37μ .

Early in the experimental work, the percentage of surface covered by dust proved to be the primary factor in the degradation of the surface properties. Neither particle size distribution nor the total weight of the dust proved to be significant parameters. For this reason, it became unnecessary to control particle size distribution as an experimental parameter in the measurement of solar absorptance and infrared emittance.

Application of the dust to the thermal control surface was accomplished by a dry dusting process which resulted in individual particles and groups of particles "sticking" to the surface. Measurement of dust coverage was accomplished by a counting technique under a microscope with a calibrated grid of 20 by 20 squares. The portion of each square covered by dust was determined and the average portion over the 400 was then obtained. This average value was then used as the fraction of dust coverage of the surface.

While no precise dust removal experiments were conducted as part of the dusting process, a number of general observations were made. It was observed that larger size particles (over 50μ) were easily removed by a slight tap of the sample in the vertical position or by a low-velocity gas jet. It was concluded, on the basis of experimental measurements, that the residual dust contamination, after tapping or blow-off with a gas jet, depended primarily on the initial amount of fines (particles with diameters below 2μ). For the basalt dust used, the amount of surface covered by fines was generally below 10 percent.

The principal experimental parameters which were varied during the measurement of solar absorptance and infrared emittance were the fraction of surface covered by dust and the angle of incidence (for solar absorptance only). All solar absorptance measurements were made with a Gier-Dunkle integrating sphere reflectometer in the spectral range from 0.34μ to 2.45μ . All infrared emittance measurements were carried out with a Perkin-Elmer spectrophotometer over a spectral range of 2μ to 14μ , with a black-body energy distribution of 395°K .

Both spectral and total solar absorptance were measured for undusted samples of S-13, aluminized Teflon, and clear silicone. In addition, these same two radiative characteristics were measured for S-13 and aluminized Teflon for various fractions of dust coverage up to 1.0 and at two angles of incidence (20° and 75°). For the clear silicone, only one data point was obtained, corresponding to dust coverage fraction of 0.35 and an angle of incidence of 20° . In all cases both spectral and total absorptance in the solar spectrum increased with increasing dust coverage. The effect was nonlinear in that a small fraction of dust coverage (~ 0.10) produced large percentage increases in total solar absorptance (~ 90 percent). After the initial rapid increase, the curve of total solar absorptance versus dust coverage flattened out and ended when dust coverage fraction reached 1.0 with a value of solar absorptance approximately equal to that of the dust. For S-13 total absorptance values ranged from ~ 0.19 (no dust) to ~ 0.85 (100-percent dust coverage). For aluminized Teflon the range was ~ 0.21 to ~ 0.86 .

As the angle of incidence increased, with dust present on the surface, total solar absorptance increased for both S-13 and aluminized Teflon. The amount of increase varied with the fraction of dust coverage, but larger increases tended to occur when larger fractions of dust were present. Notice should be taken, however, that no test with angle of incidence variation involved a dust coverage fraction greater than 0.5.

Spectral and total infrared emittance measurements were made for uncontaminated samples of S-13 and aluminized Teflon. Values were also obtained with dust fractions of ~ 1.0 . The dust produced moderate increases in infrared

emittance. The values of total infrared emittance were 0.83 for the clean S-13 and 0.88 with a dust coverage fraction of 1.0. For aluminized Teflon the clean sample had a value of 0.85, while with a dust coverage fraction of ~0.90 the infrared emittance was 0.92.

SECTION III

DUST REMOVAL/PREVENTION CONCEPTS

During the second portion of the research effort the primary goal was to investigate the most promising techniques for removing or preventing dust accumulation on a radiator surface under lunar environmental conditions.

Before proceeding with the conceptual design of dust removal/prevention devices, a representative radiator panel material and configuration had to be selected. Based on a literature survey of radiator designs for current space systems the decision was reached to use aluminum alloy 2024T4 for the panel material. A square, flat surface was established as the standard shape, with a simulated finned-tube (non-flat) radiator panel surface to be tested for any concept which appeared sensitive to radiator surface geometry. Because of experimental considerations the size of the test panel was established at 15.4 cm by 15.4 cm.

Basalt dust was selected for use as the simulated lunar dust, while S-13 was established as the thermal control coating to be used on the radiator panel.

A literature survey was conducted to determine previous dust removal/prevention concepts. The only significant item uncovered as a result of this survey concerned the use of an impact device to vibrate or shake dust loose from a surface under ultra-high vacuum conditions ($\sim 10^{-10}$ torr).

A total of eight different concepts were considered for application to the program. These concepts were as follows:

- Brush - The surface is wiped clean of dust by the sweeping action of a moving brush.
- Electrostatic Curtain - An electrostatically charged curtain sweeps over the surface lightly and removes the dust particles if they possess an electrostatic charge.

- Electrostatic Surface - Charged particles are driven off the surface by a continuously varying sinusoidal electrostatic force field which is generated by electrical conductors embedded in the thermal control coating.
- Jet and Shield - A transparent shield prevents dust from collecting on the radiator surface and a high-velocity gas jet blows the dust particles off the shield.
- Jet and Surface - A high-velocity gas jet blows the dust particles off the radiator surface.
- Spinning Shield - A spinning, transparent shield prevents dust from collecting on the radiator surface while its spinning action slings the dust off its own surface.
- Vibrating Shield - A vibrating, transparent shield prevents collection of dust on the radiator surface and is kept free of dust by the vibrating action which tends to bounce the dust particles off the shield.
- Vibrating Surface - The radiator surface itself is vibrated and this action tends to bounce the dust particles off the radiator surface.

As part of the basic conceptual design philosophy, the devices were to be compatible to one another with regard to interchange of parts or possible combination of devices. This philosophy permitted greater flexibility and efficiency during model fabrication and testing.

Performance parameters for grading or comparing the eight concepts were established. The performance parameters were divided into two categories: experimental and operational. The experimental parameters reflect the feasibility of carrying out a test program with experimental models of the concepts. The operational parameters are concerned with the practicality of a particular concept for an operational system on the Moon. These parameters were subdivided into two groups: operational factors and operational considerations. Essentially the operational factors were those parameters which were more quantitative in nature, while the operational considerations were those which were more qualitative.

Performance matrices were developed to present the grades assigned to each device for each parameter. In these performance matrices, mass and power requirements for each device were given special attention.

A presentation of the relative merits of the eight concepts was made to MSFC personnel on 29 June 1966. Attending this meeting were representatives from the Propulsion and Vehicle Engineering Laboratory, Aero/Astroynamics Laboratory, and Advanced Systems Office, along with Northrop personnel. Sketches of all eight concepts were delivered to the NASA Technical Representative at this meeting.

Based on a joint decision by NASA and Northrop, the vibrating surface was assigned priority No. 1. The jet and shield was assigned priority No. 2, while the brush operating on the transparent shield was given priority No. 3. These three devices were definitely to be tested. The electrostatic curtain, which was fourth in priority, was to be tested providing time and funds permitted.

Based on the priority established, working drawings were developed for the first three concepts. For the vibrating surface, provision was made for either a mechanical vibrator or a piezoelectric oscillator to be used as the source of vibration. For the jet and shield device, the design permitted the use of either compressible or incompressible fluids. A number of different materials were considered for the transparent shield. Evaluation of the relative performance of such materials resulted in the selection of arsenic trisulfide for the shield material.

For the mechanical brush device, the design permitted the testing of more than one brush material for wiping the test plate or shield. The electrostatic curtain design consisted only of a special slotted insert which was to be connected to a high-voltage generator and to be used with the mechanical brush device.

As previously noted, 15.4-cm square aluminum plates were selected for use as the radiator panel. These plates were of two types, flat and non-flat. On the non-flat plates, 2 half-cylindrical humps protruded from an otherwise flat

surface, to simulate the top of a fin-tube radiator surface. The design of test plates called for the upper face to be coated with S-13 paint while the lower face was to be coated with a spray-on resistance heating material.

Fabrication of the first three devices was performed by Metal Research, Inc. Because of lack of funds, the electrostatic device was never fabricated. The spray-on heater coatings for the test plates were applied by Electrofilm, Inc. The S-13 coatings for the same plates were applied by Northrop. Piezoelectric crystals were supplied by Gulton Industries, Inc. The arsenic-trisulfide glass was obtained from Servo Corporation of America and nozzles for both compressible and incompressible fluids were obtained from Spraying Systems Co.

In testing the dust removal/prevention devices, the basic philosophy was to carry out simple preliminary tests under atmospheric conditions, followed by tests at low pressure without a heat load in a bell jar or vacuum chamber. Based on the results from these two types of tests, the final tests of each devices were carried out in a vacuum chamber with a heat load.

Because of delays encountered in receiving certain parts of the apparatus, the actual order of testing was:

- 1) jet concept
- 2) vibrator concept
- 3) brush concept
- 4) electrostatic concept (preliminary only).

The final performance testing of each device was carried out in Northrop's 3.65- by 2.13-meter space chamber. Chamber wall temperature for such tests was maintained at 80°K by means of liquid nitrogen. Chamber pressure ranged from 10^{-6} to 10^{-5} torr. Solar simulation was supplied by a Strong Electric Corporation carbon-arc lamp.

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The test plates were thermally insulated from their surroundings except on their upper face which represented the test surface. Chromel-constantan thermocouples were used to measure equilibrium temperature of the plate. When used, the shield was mounted 4.5 cm above the plate. The shield temperature was measured by means of chromel-constantan thermocouples.

An initial calibration test run was carried out to establish the temperature distribution of the test plate and the consistency of the test data. This calibration run indicated that the test plate was essentially isothermal. The data appeared consistent and the experimental apparatus was considered ready for the performance tests.

An originally conceived, the jet concept was to be applied to cleaning the transparent shield. Because of the design of the experimental device, however, it was possible to conduct tests with the jet cleaning either the shield or the plate. As a result test runs for both combinations were carried out.

Early test results indicated that an incompressible fluid was more efficient than a compressible fluid for removing dust under vacuum conditions. Of the incompressible fluids tested, inhibisol (methyl chloroform) proved most effective and this fluid was used in all final tests involving the jet concept. Both ordinary glass and arsenic-trisulfide glass were used as shield materials.

The final tests with the inhibisol jet concept involved the use of the solar simulator and the resistance heater and was carried out in three parts. First the jet was used to clean a dusted S-13 plate without a shield. Second, the jet was applied to a dusted glass shield covering the S-13 plate. Finally the jet was used to clean a dusted arsenic-trisulfide shield covering the S-13 plate.

The initial dust coverage fraction, based on visual inspection, for all three runs was 0.25. After jet cleaning the dust coverage on the S-13 was 0.03 and for each shield the coverage was less than 0.05.

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Both the piezoelectric crystal and a mechanical vibrator (Goodman V-47) were tested during preliminary experiments with the vibrating surface. The mechanical vibrator, used as an impact device, proved to be the most effective way of producing vibrations in the test plate, and this means of vibration was used in the final performance test for the vibrating surface device. In the final test, initial dust coverage was 0.25 and after testing 0.23.

Initial performance tests with various materials resulted in the selection of styrofoam for the brush material to be used in the mechanical brush. Other materials initially tested included bristles and cheesecloth. Because of the disappointing performance of the arsenic-trisulfide shield during the jet and shield tests, the decision was made to test the mechanical brush on the S-13 plate surface rather than on the shield surface. The dust coverage for the final test of the mechanical brush was 0.25 before brushing. After brushing the coverage was 0.17.

Time and funding restrictions prevented a complete series of tests with the electrostatic concept. Preliminary tests of electrostatic removal were conducted. Basalt dust was sieved and allowed to fall in close proximity to a charged Van de Graaf sphere. The dust particles did not acquire sufficient charge to produce any effect. No movement was observed when these particles were subsequently placed in contact with a charged plate. Based on the preliminary experimental results, it appeared that a very high potential is required to charge the basalt particles to the point when they can be thrown off a charged plate.

Correlation of plate temperature data from the final test runs based on thermal network analysis were generally successful for the unshielded tests. For tests involving the arsenic-trisulfide shield, predicted temperatures for the plate were consistently greater (15-25 percent) than measured values. This difference appeared to result from either inaccurate values of the radiative properties of the arsenic trisulfide or some deficiency in the analytical model.

Thermal analysis of data indicated that in terms of minimizing plate temperature under a given heat load the jet and plate device was most effective. The mechanical brush was second, the jet and arsenic-trisulfide shield third, and the vibrator fourth. The presence of the clean arsenic-trisulfide shield produced an increase in plate temperature, but the resulting plate temperature was not radically increased by dust contamination on the shield.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The objectives of the research effort have been:

- to determine the effect of dust on radiator surfaces and
- to develop methods for preventing or removing accumulations of dust from such surfaces.

Based on the results of the study, certain conclusions and recommendations may be formulated.

The presence of basalt dust on either S-13 or aluminized Teflon thermal control coatings causes a general increase in spectral absorptance of the surface over all wavelengths in the solar spectrum. This in turn causes an increase in the total solar absorptance of the surface. The variation of total solar absorptance with dust contamination is nonlinear in nature. A relatively small degree of contamination (~10-percent dust coverage) can produce a large increase in solar absorptance (~90 percent). With dust present on the surface, the total solar absorptance of the surface tends to increase with angle of incidence.

The infrared emittance of the basalt dust is very nearly equal to the infrared emittance of the thermal control coatings. For this reason dust contamination produces very little change in the value of this property of the surface.

The removal or prevention of dust accumulation on the thermal control surface under simulated lunar conditions proved to be a difficult task. For the devices tested, the jet and plate device proved most effective. The jet and shield device was second with the mechanical brush and vibrating surface devices third and fourth, respectively. None of the devices proved completely effective. Because of experimental considerations, the surface area involved in testing the concepts was small ($\sim 256 \text{ cm}^2$).

With respect to specific working fluids or materials, for the jet the incompressible fluids proved more effective than the compressible fluids. Of

the incompressible fluids tested, methyl chloroform (inhibisol) gave the best performance. For the shield material the arsenic-trisulfide shield gave the best results. For the brush material, the styrofoam proved to be the most promising.

The fact that the presence of the shield caused the plate temperature to become less sensitive to the level of dust contamination appears significant. For situations where dust cannot be prevented or removed, the use of a shield would tend to reduce the increase in plate temperature.

Prediction of plate surface temperature with dust contamination and without the shield appears to pose no problem provided accurate property data are available for the surface as a function of dust coverage. For the case involving the plate covered by the shield with dust on the latter, accurate prediction of plate temperature is more difficult and deserves further study. In this respect, more accurate and complete values of the radiative properties of the shield material are desirable.

In the course of the research effort several new concepts were envisioned which appeared promising but were not adequately studied due to lack of time and funds. These included a transpiration cleaning action involving a porous thermal control coating, and a "peel-off" transparent sheet. These concepts, along with the electrostatic concept for which complete testing was not accomplished, appear worthy of further study.

The most general conclusion that can be reached based on the data collected is that considerable work remains to be done before the optimum dust removal/prevention system can be established. Furthermore, for each lunar craft or lunar mission, a specialized dust removal/prevention system may be required. If, however, dust contamination proves to be a problem in lunar exploration, this research effort represents an initial step toward the solution of the problem.