

AD 685855

ECOM-5237
March 1969

AD

DEGRADATION OF LASER OPTICAL SURFACES

By
T. L. Barber

APR 23 1969
LIBRARY

ATMOSPHERIC SCIENCES LABORATORY
WHITE SANDS MISSILE RANGE, NEW MEXICO

Distribution of this
report is unlimited

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND

DEGRADATION OF LASER OPTICAL SURFACES

By

T. L. Barber

ECOM - 5237

March 1969

DA TASK - 1T061102B53A-18

**ATMOSPHERIC SCIENCES LABORATORY
WHITE SANDS MISSILE RANGE, NEW MEXICO**

**Distribution of this
report is unlimited.**

ABSTRACT

Problems of optical surface degradation became apparent while measurements were being made with a laser. After examination, it was concluded that the defects fell into two categories - those caused by atmospheric dust and those resulting from the effects of cleaning solvents. A procedure is described which minimizes both of these problems.

CONTENTS

	Page
ABSTRACT -----	iii
INTRODUCTION -----	1
DISCUSSION -----	1
CORRECTIVE TECHNIQUES -----	2
CONCLUSIONS -----	4
REFERENCES -----	5

INTRODUCTION

When using high-power lasers, the appearance of imperfections on optical surfaces often becomes a problem because these imperfections degrade the operation of the device by adding energy losses. The effects considered here are attributed to the action of very high intensity radiation on surface contaminants such as dust particles or cleaning residue. We have been concerned with the degradation of sapphire resonant reflectors and laser rods used in a 100 Mw Q-switched ruby laser and an erbium-doped glass pulsed laser. Under microscopic examination, it was observed that the imperfections of most concern in ruby, sapphire, and glass optical surfaces fall into two general classes: (1) spots and small circular indentations and (2) small conical craters.

DISCUSSION

The spots, under magnification, appear granular and protrude slightly as if material has been added to the surface. These spots were examined as to their chemical nature, using infrared absorption spectroscopy with a modified alkali halide pellet technique (1). This technique permits the removal of an individual spot and its identification. Calcite was specifically identified as a spot-forming material. Calcite is a relatively low-melting-point mineral (melting point 1339° C) and in the molten state is a relatively active, nonviscous liquid, capable of etching glass or sapphire.

The following example considered a 20-micron spherical sodium carbonate* particle illuminated by a ruby laser having an average beam energy of 0.01 Joule/mm². The calculations show that, with this ruby laser pulse, small carbonate particles can be easily melted by absorbing only 3.9% of the energy falling on them.

CALCULATIONS: A 20-micron spherical sodium carbonate particle having a specific gravity of 2.51 g/cm³ weighs 10.5x10⁻⁹g. Sodium carbonate has a specific heat of 0.256 cal/g C, a boiling point of 851 C, and a heat of fusion of 66 cal/g. Starting at 20 C room temperature, 2.91x10⁻⁶ cal. are required to melt this 20-micron particle.

This particle, being illuminated by a ruby laser having hot spots of 1 Joule/mm², will have 7.51x10⁻⁵ cal. falling on it. For this sodium

* Calcite was not used as the example because the necessary physical constants are not available. Sodium carbonate is considered a representative case.

carbonate particle to melt, only 3.9% of the energy falling on it must be absorbed.

Calcite starts subliming at 898° C. However, the rate of sublimation is very slow relative to the time frame of a laser pulse. The particle of calcite would thus be expected to become molten and flow out across the optical surface (Fig. 1). From heat conduction into the optical surface, the calcite particle would solidify before any appreciable sublimation could take place. If it were in contact with an optical surface, the molten calcite would dissolve into the surface forming an etched spot. This solid solution would then be firmly fastened to the surface.

A later pulse traversing the same path would be expected to warm but not melt the calcite because the calcite is in direct physical contact with the optical surface (Fig. 1) allowing rapid thermal transfer. Because of the difference in thermal coefficients of expansion

$$\frac{\text{Calcite}}{\text{Sapphire}} = \frac{25.14 (10^{-6})}{6.7 (10^{-6})}$$

the spot would pull loose from the optical surface, leaving a circular indentation approximately 1 micron deep.

Under magnification, certain of the imperfections on glass surfaces appeared to be small craters. These had a conical shape with irregular edges. More of these crater-like imperfections appeared after each cleaning. As more of these craters formed, appreciable chips would be dislodged from the glass surface. It was supposed that when the surfaces were cleaned, water and/or other solvents such as acetone were absorbed into them (2). Such an absorbed liquid would require weeks to evaporate under low-humidity conditions. With any slight imperfections on the surface, the water will weaken a glass surface as much as 20% (3).

CORRECTIVE TECHNIQUES

The working area around a laser should be kept as clean as possible, free from dust and contaminants such as cigarette smoke, approaching clean room conditions as closely as possible, thereby minimizing the number of necessary cleanings.

If any dust is present and the spots form, most of these spots can be removed by cleaning a surface with distilled water and a mild solution of HCl. This should be done only if the physical nature of the optical surface

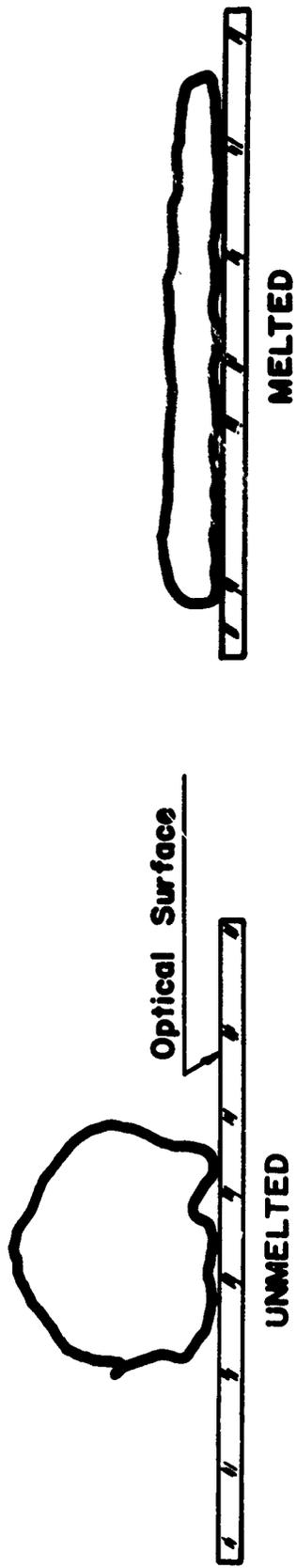


FIG. 1 SMALL CALCITE PARTICLE ON AN OPTICAL SURFACE AND MELTED ONTO AN OPTICAL SURFACE.

will not be damaged by acid. A second method was suggested * which consisted of starting a pulse laser system off with very low energy pulses and slowly increasing it until the required working level is attained. This will reduce optical surface problems. The dust is dislodged from the surface with the first weak pulses that are not capable of melting a dust particle.

In the second type of degradation, the craters are caused by liquids being absorbed a few microns into the glass surface during the cleaning operation, then producing miniature explosions when a strong laser pulse strikes the absorbed liquid. With the pulse laser starting off at low energy, the absorbed liquids slowly vaporize out of the surfaces, keeping the vapor pressure below that point necessary to cause the miniature explosions. Another solution to this type of degradation is a thorough vacuum drying at 100 C of the various optical components after each liquid cleaning. In the case of an erbium-doped glass rod, it was liquid cleaned, and without drying, was placed in its lasing cavity. After 100 shots, the lasing efficiency was down about 10%, and the rod ends were slightly pitted. After 400 shots, the lasing efficiency dropped approximately 50%, and the rod ends were badly pitted. Another glass rod was cleaned and vacuum dried. This rod, after several hundred shots, was still in excellent condition.

With the precautionary measures outlined here, the usefulness of optics in a laser system can be extended many times and more reproducible results obtained.

CONCLUSIONS

The types of degradation considered here fall into two general categories. The first category, which appears as spots and shallow indentations, is caused by low melting point mineral dust, such as calcite, dolomite, mirabilite, and gypsum, which are generally found in the atmosphere (4). The second category, appearing as small craters in the optical surfaces, is caused by liquids absorbed into the surface and exploding when the laser energy strikes the surface. With proper operational precautions as stated above, these problems can be minimized.

* Personal communication between James Mason of ASO, ASL, WSMR, and Dr. Martin Stickley of AFCRL, Bedford, Mass.

REFERENCES

1. Barber, T.L., "An Improved Method for Material Grinding in Solid Phase Infrared Analysis," Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico (To be published).
2. Dole, Malcolm, The Glass Electrode, John Wiley and Sons, 1941.
3. Wheeler, E.L., Scientific Glass Blowing, Inter. Sci. Pub., Inc., New York, 1958.
4. Hoidale, G.B., S.M. Smith, A.J. Blanco, and T.L. Barber, "A Study of Atmospheric Dust," Tech. Report ECOM-5067, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, March 1967.

ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Webb, W.L., "Development of Droplet Size Distributions in the Atmosphere," June 1954.
2. Hansen, F. V., and H. Rachele, "Wind Structure Analysis and Forecasting Methods for Rockets," June 1954.
3. Webb, W. L., "Net Electrification of Water Droplets at the Earth's Surface," *J. Meteorol.*, December 1954.
4. Mitchell, R., "The Determination of Non-Ballistic Projectile Trajectories," March 1955.
5. Webb, W. L., and A. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #1, March 1955.
6. Mitchell, R., and W. L. Webb, "Electromagnetic Radiation through the Atmosphere," #1, April 1955.
7. Webb, W. L., A. McPike, and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #2, July 1955.
8. Barichivich, A., "Meteorological Effects on the Refractive Index and Curvature of Microwaves in the Atmosphere," August 1955.
9. Webb, W. L., A. McPike and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #3, September 1955.
10. Mitchell, R., "Notes on the Theory of Longitudinal Wave Motion in the Atmosphere," February 1956.
11. Webb, W. L., "Particulate Counts in Natural Clouds," *J. Meteorol.*, April 1956.
12. Webb, W. L., "Wind Effect on the Aerobee," #1, May 1956.
13. Rachele, H., and L. Anderson, "Wind Effect on the Aerobee," #2, August 1956.
14. Beyers, N., "Electromagnetic Radiation through the Atmosphere," #2, January 1957.
15. Hansen, F. V., "Wind Effect on the Aerobee," #3, January 1957.
16. Kershner, J., and H. Bear, "Wind Effect on the Aerobee," #4, January 1957.
17. Hoidale, G., "Electromagnetic Radiation through the Atmosphere," #3, February 1957.
18. Querfeld, C. W., "The Index of Refraction of the Atmosphere for 2.2 Micron Radiation," March 1957.
19. White, Lloyd, "Wind Effect on the Aerobee," #5, March 1957.
20. Kershner, J. G., "Development of a Method for Forecasting Component Ballistic Wind," August 1957.
21. Layton, Ivan, "Atmospheric Particle Size Distribution," December 1957.
22. Rachele, Henry and W. H. Hatch, "Wind Effect on the Aerobee," #6, February 1958.
23. Beyers, N. J., "Electromagnetic Radiation through the Atmosphere," #4, March 1958.
24. Prosser, Shirley J., "Electromagnetic Radiation through the Atmosphere," #5, April 1958.
25. Arrandariz, M., and P. H. Taft, "Double Theodolite Ballistic Wind Computations," June 1958.
26. Jenkins, K. R. and W. L. Webb, "Rocket Wind Measurements," June 1958.
27. Jenkins, K. R., "Measurement of High Altitude Winds with Loki," July 1958.
28. Hoidale, G., "Electromagnetic Propagation through the Atmosphere," #6, February 1959.
29. McLardie, M., R. Helvey, and L. Traylor, "Low-Level Wind Profile Prediction Techniques," #1, June 1959.
30. Lamberth, Roy, "Gustiness at White Sands Missile Range," #1, May 1959.
31. Beyers, N. J., B. Hinds, and G. Hoidale, "Electromagnetic Propagation through the Atmosphere," #7, June 1959.
32. Beyers, N. J., "Radar Refraction at Low Elevation Angles (U)," Proceedings of the Army Science Conference, June 1959.
33. White, L., O. W. Thiele and P. H. Taft, "Summary of Ballistic and Meteorological Support During IGY Operations at Fort Churchill, Canada," August 1959.
34. Hainline, D. A., "Drag Cord-Aerovane Equation Analysis for Computer Application," August 1959.
35. Hoidale, G. B., "Slope-Valley Wind at WSMR," October 1959.
36. Webb, W. L., and K. R. Jenkins, "High Altitude Wind Measurements," *J. Meteorol.*, 16, 5, October 1959.

37. White, Lloyd, "Wind Effect on the Aerobee," #9, October 1959.
38. Webb, W. L., J. W. Coffman, and G. Q. Clark, "A High Altitude Acoustic Sensing System," December 1959.
39. Webb, W. L., and K. R. Jenkins, "Application of Meteorological Rocket Systems," *J. Geophys. Res.*, 64, 11, November 1959.
40. Duncan, Louis, "Wind Effect on the Aerobee," #10, February 1960.
41. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #2, February 1960.
42. Webb, W. L., and K. R. Jenkins, "Rocket Sounding of High-Altitude Parameters," *Proc. GM Rel. Symp.*, Dept. of Defense, February 1960.
43. Armendariz, M., and H. H. Monahan, "A Comparison Between the Double Theodolite and Single-Theodolite Wind Measuring Systems," April 1960.
44. Jenkins, K. R., and P. H. Taft, "Weather Elements in the Tularosa Basin," July 1960.
45. Beyers, N. J., "Preliminary Radar Performance Data on Passive Rocket-Borne Wind Sensors," *IRE TRANS, MIL ELECT, MIL-4*, 2-3, April-July 1960.
46. Webb, W. L., and K. R. Jenkins, "Speed of Sound in the Stratosphere," June 1960.
47. Webb, W. L., K. R. Jenkins, and G. Q. Clark, "Rocket Sounding of High Atmosphere Meteorological Parameters," *IRE Trans. Mil. Elect.*, MIL-4, 2-3, April-July 1960.
48. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #3, September 1960.
49. Beyers, N. J., and O. W. Thiele, "Meteorological Wind Sensors," August 1960.
50. Armijo, Larry, "Determination of Trajectories Using Range Data from Three Non-colinear Radar Stations," September 1960.
51. Carnes, Patsy Sue, "Temperature Variations in the First 200 Feet of the Atmosphere in an Arid Region," July 1961.
52. Springer, H. S., and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," July 1961.
53. Thiele, O. W., "Density and Pressure Profiles Derived from Meteorological Rocket Measurements," September 1961.
54. Diamond, M. and A. B. Gray, "Accuracy of Missile Sound Ranging," November 1961.
55. Lamberth, R. L. and D. R. Veith, "Variability of Surface Wind in Short Distances," #1, October 1961.
56. Swanson, R. N., "Low-Level Wind Measurements for Ballistic Missile Application," January 1962.
57. Lamberth, R. L. and J. H. Grace, "Gustiness at White Sands Missile Range," #2, January 1962.
58. Swanson, R. N. and M. M. Hoidale, "Low-Level Wind Profile Prediction Techniques," #4, January 1962.
59. Rachele, Henry, "Surface Wind Model for Unguided Rockets Using Spectrum and Cross Spectrum Techniques," January 1962.
60. Rachele, Henry, "Sound Propagation through a Windy Atmosphere," #2, February 1962.
61. Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," *J. Acous. Soc. Amer.*, 34, 2, February 1962.
62. Tourin, M. H. and M. M. Hoidale, "Low-Level Turbulence Characteristics at White Sands Missile Range," April 1962.
63. Miers, Bruce T., "Mesospheric Wind Reversal over White Sands Missile Range," March 1962.
64. Fisher, E., R. Lee and H. Rachele, "Meteorological Effects on an Acoustic Wave within a Sound Ranging Array," May 1962.
65. Walter, E. L., "Six Variable Ballistic Model for a Rocket," June 1962.
66. Webb, W. L., "Detailed Acoustic Structure Above the Tropopause," *J. Applied Meteorol.*, 1, 2, June 1962.
67. Jenkins, K. R., "Empirical Comparisons of Meteorological Rocket Wind Sensors," *J. Appl. Meteor.*, June 1962.
68. Lamberth, Roy, "Wind Variability Estimates as a Function of Sampling Interval," July 1962.
69. Rachele, Henry, "Surface Wind Sampling Periods for Unguided Rocket Impact Prediction," July 1962.
70. Traylor, Larry, "Coriolis Effects on the Aerobee-Hi Sounding Rocket," August 1962.
71. McCoy, J., and G. Q. Clark, "Meteorological Rocket Thermometry," August 1962.
72. Rachele, Henry, "Real-Time Prelaunch Impact Prediction System," August 1962.

73. Beyers, N. J., O. W. Thiele, and N. K. Wagner, "Performance Characteristics of Meteorological Rocket Wind and Temperature Sensors," October 1962.
74. Coffman, J., and R. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," October 1962.
75. Armendariz, M., E. Fisher, and J. Serna, "Wind Shear in the Jet Stream at WSMR," November 1962.
76. Armendariz, M., F. Hansen, and S. Carnes, "Wind Variability and its Effect on Rocket Impact Prediction," January 1963.
77. Querfeld, C., and Wayne Yunker, "Pure Rotational Spectrum of Water Vapor, I: Table of Line Parameters," February 1963.
78. Webb, W. L., "Acoustic Component of Turbulence," *J. Applied Meteorol.*, 2, 2, April 1963.
79. Beyers, N. and L. Engberg, "Seasonal Variability in the Upper Atmosphere," May 1963.
80. Williamson, L. E., "Atmospheric Acoustic Structure of the Sub-polar Fall," May 1963.
81. Lamberth, Roy and D. Veith, "Upper Wind Correlations in Southwestern United States," June 1963.
82. Sandlin, E., "An analysis of Wind Shear Differences as Measured by AN/FPS-16 Radar and AN/GMD-1B Rawinsonde," August 1963.
83. Diamond, M. and R. P. Lee, "Statistical Data on Atmospheric Design Properties Above 30 km," August 1963.
84. Thiele, O. W., "Mesospheric Density Variability Based on Recent Meteorological Rocket Measurements," *J. Applied Meteorol.*, 2, 5, October 1963.
85. Diamond, M., and O. Essenwanger, "Statistical Data on Atmospheric Design Properties to 30 km," *Astro. Aero. Engr.*, December 1963.
86. Hansen, F. V., "Turbulence Characteristics of the First 62 Meters of the Atmosphere," December 1963.
87. Morris, J. E., and B. T. Miers, "Circulation Disturbances Between 25 and 70 kilometers Associated with the Sudden Warming of 1963," *J. of Geophys. Res.*, January 1964.
88. Thiele, O. W., "Some Observed Short Term and Diurnal Variations of Stratospheric Density Above 30 km," January 1964.
89. Sandlin, R. E., Jr. and E. Arrijo, "An Analysis of AN/FPS-16 Radar and AN/GMD-1B Rawinsonde Data Differences," January 1964.
90. Miers, B. T., and N. J. Beyers, "Rocketsonde Wind and Temperature Measurements Between 30 and 70 km for Selected Stations," *J. Applied Meteorol.*, February 1964.
91. Webb, W. L., "The Dynamic Stratosphere," *Astronautics and Aerospace Engineering*, March 1964.
92. Low, R. D. H., "Acoustic Measurements of Wind through a Layer," March 1964.
93. Diamond, M., "Cross Wind Effect on Sound Propagation," *J. Applied Meteorol.*, April 1964.
94. Lee, R. P., "Acoustic Ray Tracing," April 1964.
95. Reynolds, R. D., "Investigation of the Effect of Lapse Rate on Balloon Ascent Rate," May 1964.
96. Webb, W. L., "Scale of Stratospheric Detail Structure," *Space Research V*, May 1964.
97. Barber, T. L., "Proposed X-Ray-Infrared Method for Identification of Atmospheric Mineral Dust," June 1964.
98. Thiele, O. W., "Ballistic Procedures for Unguided Rocket Studies of Nuclear Environments (U)," Proceedings of the Army Science Conference, June 1964.
99. Horn, J. D., and E. J. Trawle, "Orographic Effects on Wind Variability," July 1964.
100. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #1, September 1964.
101. Duncan, L. D., R. Ensey, and B. Engebos, "Athena Launch Angle Determination," September 1964.
102. Thiele, O. W., "Feasibility Experiment for Measuring Atmospheric Density Through the Altitude Range of 60 to 100 KM Over White Sands Missile Range," October 1964.
103. Duncan, L. D., and R. Ensey, "Six-Degree-of-Freedom Digital Simulation Model for Unguided, Fin-Stabilized Rockets," November 1964.

104. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #2, November 1964.
105. Webb, W. L., "Stratospheric Solar Response," *J. Atmos. Sci.*, November 1964.
106. McCoy, J. and G. Clark, "Rocketsonde Measurement of Stratospheric Temperature," December 1964.
107. Farone, W. A., "Electromagnetic Scattering from Radially Inhomogeneous Spheres as Applied to the Problem of Clear Atmosphere Radar Echoes," December 1964.
108. Farone, W. A., "The Effect of the Solid Angle of Illumination or Observation on the Color Spectra of 'White Light' Scattered by Cylinders," January 1965.
109. Williamson, L. E., "Seasonal and Regional Characteristics of Acoustic Atmospheres," *J. Geophys. Res.*, January 1965.
110. Armendariz, M., "Ballistic Wind Variability at Green River, Utah," January 1965.
111. Low, R. D. H., "Sound Speed Variability Due to Atmospheric Composition," January 1965.
112. Querfeld, C. W., "Mie Atmospheric Optics," *J. Opt. Soc. Amer.*, January 1965.
113. Coffman, J., "A Measurement of the Effect of Atmospheric Turbulence on the Coherent Properties of a Sound Wave," January 1965.
114. Rachele, H., and D. Veith, "Surface Wind Sampling for Unguided Rocket Impact Prediction," January 1965.
115. Ballard, H., and M. Izquierdo, "Reduction of Microphone Wind Noise by the Generation of a Proper Turbulent Flow," February 1965.
116. Mireles, R., "An Algorithm for Computing Half Widths of Overlapping Lines on Experimental Spectra," February 1965.
117. Richart, H., "Inaccuracies of the Single-Theodolite Wind Measuring System in Ballistic Application," February 1965.
118. D'Arcy, M., "Theoretical and Practical Study of Aerobee-150 Ballistics," March 1965.
119. McCoy, J., "Improved Method for the Reduction of Rocketsonde Temperature Data," March 1965.
120. Mireles, R., "Uniqueness Theorem in Inverse Electromagnetic Cylindrical Scattering," April 1965.
121. Coffman, J., "The Focusing of Sound Propagating Vertically in a Horizontally Stratified Medium," April 1965.
122. Farone, W. A., and C. Querfeld, "Electromagnetic Scattering from an Infinite Circular Cylinder at Oblique Incidence," April 1965.
123. Rachele, H., "Sound Propagation through a Windy Atmosphere," April 1965.
124. Miers, B., "Upper Stratospheric Circulation over Ascension Island," April 1965.
125. Rider, L., and M. Armendariz, "A Comparison of Pibal and Tower Wind Measurements," April 1965.
126. Hoidale, G. B., "Meteorological Conditions Allowing a Rare Observation of 24 Micron Solar Radiation Near Sea Level," *Meteorol. Magazine*, May 1965.
127. Beyers, N. J., and B. T. Miers, "Diurnal Temperature Change in the Atmosphere Between 30 and 60 km over White Sands Missile Range," *J. Atmos. Sci.*, May 1965.
128. Querfeld, C., and W. A. Farone, "Tables of the Mie Forward Lobe," May 1965.
129. Farone, W. A., "Generalization of Rayleigh-Gans Scattering from Radially Inhomogeneous Spheres," *J. Opt. Soc. Amer.*, June 1965.
130. Diamond, M., "Note on Mesospheric Winds Above White Sands Missile Range," *J. Applied Meteorol.*, June 1965.
131. Clark, G. Q., and J. G. McCoy, "Measurement of Stratospheric Temperature," *J. Applied Meteorol.*, June 1965.
132. Hall, T., G. Hoidale, R. Mireles, and C. Querfeld, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #3, July 1965.
133. McCoy, J., and C. Tate, "The Delta-T Meteorological Rocket Payload," June 1964.
134. Horn, J. D., "Obstacle Influence in a Wind Tunnel," July 1965.
135. McCoy, J., "An AC Probe for the Measurement of Electron Density and Collision Frequency in the Lower Ionosphere," July 1965.
136. Miers, B. T., M. D. Kays, O. W. Thiele and E. M. Newby, "Investigation of Short Term Variations of Several Atmospheric Parameters Above 30 KM," July 1965.

137. Serna, J., "An Acoustic Ray Tracing Method for Digital Computation," September 1965.
138. Webb, W. L., "Morphology of Noctilucent Clouds," *J. Geophys. Res.*, 70, 18, 4463-4475, September 1965.
139. Kays, M., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, 70, 18, 4453-4462, September 1965.
140. Rider, L., "Low-Level Jet at White Sands Missile Range," September 1965.
141. Lamberth, R. L., R. Reynolds, and Morton Wurtele, "The Mountain Lee Wave at White Sands Missile Range," *Bull. Amer. Meteorol. Soc.*, 46, 10, October 1965.
142. Reynolds, R. and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," October 1965.
143. McCluney, E., "Theoretical Trajectory Performance of the Five-Inch Gun Probe System," October 1965.
144. Pena, R. and M. Diamond, "Atmospheric Sound Propagation near the Earth's Surface," October 1965.
145. Mason, J. B., "A Study of the Feasibility of Using Radar Chaff For Stratospheric Temperature Measurements," November 1965.
146. Diamond, M., and R. P. Lee, "Long-Range Atmospheric Sound Propagation," *J. Geophys. Res.*, 70, 22, November 1965.
147. Lamberth, R. L., "On the Measurement of Dust Devil Parameters," November 1965.
148. Hansen, F. V., and P. S. Hansen, "Formation of an Internal Boundary over Heterogeneous Terrain," November 1965.
149. Webb, W. L., "Mechanics of Stratospheric Seasonal Reversals," November 1965.
150. U. S. Army Electronics R & D Activity, "U. S. Army Participation in the Meteorological Rocket Network," January 1966.
151. Rider, L. J., and M. Armendariz, "Low-Level Jet Winds at Green River, Utah," February 1966.
152. Webb, W. L., "Diurnal Variations in the Stratospheric Circulation," February 1966.
153. Beyers, N. J., B. T. Miers, and R. J. Reed, "Diurnal Tidal Motions near the Stratopause During 48 Hours at WSMR," February 1966.
154. Webb, W. L., "The Stratospheric Tidal Jet," February 1966.
155. Hall, J. T., "Focal Properties of a Plane Grating in a Convergent Beam," February 1966.
156. Duncan, L. D., and Henry Rachele, "Real-Time Meteorological System for Firing of Unguided Rockets," February 1966.
157. Kays, M. D., "A Note on the Comparison of Rocket and Estimated Geostrophic Winds at the 10-mb Level," *J. Appl. Meteor.*, February 1966.
158. Rider, L., and M. Armendariz, "A Comparison of Pibal and Tower Wind Measurements," *J. Appl. Meteor.*, 5, February 1966.
159. Duncan, L. D., "Coordinate Transformations in Trajectory Simulations," February 1966.
160. Williamson, L. E., "Gun-Launched Vertical Probes at White Sands Missile Range," February 1966.
161. Randhawa, J. S., "Ozone Measurements with Rocket-Borne Ozonesondes," March 1966.
162. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear for Small Thickness Layers," March 1966.
163. Low, R. D. H., "Continuous Determination of the Average Sound Velocity over an Arbitrary Path," March 1966.
164. Hansen, Frank V., "Richardson Number Tables for the Surface Boundary Layer," March 1966.
165. Cochran, V. C., E. M. D'Arcy, and Florencio Ramirez, "Digital Computer Program for Five-Degree-of-Freedom Trajectory," March 1966.
166. Thiele, O. W., and N. J. Beyers, "Comparison of Rocketsonde and Radiosonde Temperatures and a Verification of Computed Rocketsonde Pressure and Density," April 1966.
167. Thiele, O. W., "Observed Diurnal Oscillations of Pressure and Density in the Upper Stratosphere and Lower Mesosphere," April 1966.
168. Kays, M. D., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, April 1966.
169. Hansen, F. V., "The Richardson Number in the Planetary Boundary Layer," May 1966.

170. Ballard, H. N., "The Measurement of Temperature in the Stratosphere and Mesosphere," June 1966.
171. Hansen, Frank V., "The Ratio of the Exchange Coefficients for Heat and Momentum in a Homogeneous, Thermally Stratified Atmosphere," June 1966.
172. Hansen, Frank V., "Comparison of Nine Profile Models for the Diabatic Boundary Layer," June 1966.
173. Rachele, Henry, "A Sound-Ranging Technique for Locating Supersonic Missiles," May 1966.
174. Farnes, W. A., and C. W. Querfeld, "Electromagnetic Scattering from Inhomogeneous Infinite Cylinders at Oblique Incidence," *J. Opt. Soc. Amer.* 56, 4, 476-480, April 1966.
175. Mireles, Ramon, "Determination of Parameters in Absorption Spectra by Numerical Minimization Techniques," *J. Opt. Soc. Amer.* 56, 5, 644-647, May 1966.
176. Reynolds, R., and R. L. Lambirth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," *J. Appl. Meteorol.*, 5, 3, 304-307, June 1966.
177. Hall, James T., "Focal Properties of a Plane Grating in a Convergent Beam," *Appl. Opt.*, 5, 1051, June 1966.
178. Rider, Laurence J., "Low-Level Jet at White Sands Missile Range," *J. Appl. Meteorol.*, 5, 3, 283-287, June 1966.
179. McCluney, Eugene, "Projectile Dispersion as Caused by Barrel Displacement in the 5-Inch Gun Probe System," July 1966.
180. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear Calculations for Small Shear Layers," June 1966.
181. Lambirth, Roy L., and Manuel Armendariz, "Upper Wind Correlations in the Central Rocky Mountains," June 1966.
182. Hansen, Frank V., and Virgil D. Lang, "The Wind Regime in the First 62 Meters of the Atmosphere," June 1966.
183. Randhawa, Jagir S., "Rocket-Borne Ozonesonde," July 1966.
184. Rachele, Henry, and L. D. Duncan, "The Desirability of Using a Fast Sampling Rate for Computing Wind Velocity from Pilot-Balloon Data," July 1966.
185. Hinds, B. D., and R. G. Pappas, "A Comparison of Three Methods for the Correction of Radar Elevation Angle Refraction Errors," August 1966.
186. Riedmuller, G. F., and T. L. Barber, "A Mineral Transition in Atmospheric Dust Transport," August 1966.
187. Hall, J. T., C. W. Querfeld, and G. B. Hoidale, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," Part IV (Final), July 1966.
188. Duncan, L. D. and B. F. Engebos, "Techniques for Computing Launcher Settings for Unguided Rockets," September 1966.
189. Duncan, L. D., "Basic Considerations in the Development of an Unguided Rocket Trajectory Simulation Model," September 1966.
190. Miller, Walter B., "Consideration of Some Problems in Curve Fitting," September 1966.
191. Cermak, J. E., and J. D. Horn, "The Tower Shadow Effect," August 1966.
192. Webb, W. L., "Stratospheric Circulation Response to a Solar Eclipse," October 1966.
193. Kennedy, Bruce, "Muzzle Velocity Measurement," October 1966.
194. Traylor, Larry E., "A Refinement Technique for Unguided Rocket Drag Coefficients," October 1966.
195. Nusbaum, Henry, "A Reagent for the Simultaneous Microscope Determination of Quartz and Halides," October 1966.
196. Kays, Marvin and R. O. Olsen, "Improved Rocketsonde Parachute-derived Wind Profiles," October 1966.
197. Engebos, Bernard F. and Duncan, Louis D., "A Nomogram for Field Determination of Launcher Angles for Unguided Rockets," October 1966.
198. Webb, W. L., "Midlatitude Clouds in the Upper Atmosphere," November 1966.
199. Hansen, Frank V., "The Lateral Intensity of Turbulence as a Function of Stability," November 1966.
200. Rider, L. J. and M. Armendariz, "Differences of Tower and Pibal Wind Profiles," November 1966.
201. Lee, Robert P., "A Comparison of Eight Mathematical Models for Atmospheric Acoustical Ray Tracing," November 1966.
202. Low, R. D. H., et al., "Acoustical and Meteorological Data Report SOTRAN I and II," November 1966.

203. Hunt, J. A. and J. D. Horn, "Drag Plate Balance," December 1966.
204. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," December 1966.
205. Hansen, Frank V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range," January 1967.
206. Morris, James E., "Wind Measurements in the Subpolar Mesopause Region," January 1967.
207. Hall, James T., "Attenuation of Millimeter Wavelength Radiation by Gaseous Water," January 1967.
208. Thiele, O. W., and N. J. Beyers, "Upper Atmosphere Pressure Measurements With Thermal Conductivity Gauges," January 1967.
209. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," January 1967.
210. Hansen, F. V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range, New Mexico," January 1967.
211. D'Arcy, Edward M., "Some Applications of Wind to Unguided Rocket Impact Prediction," March 1967.
212. Kennedy, Bruce, "Operation Manual for Stratosphere Temperature Sonde," March 1967.
213. Hoidale, G. B., S. M. Smith, A. J. Blanco, and T. L. Barber, "A Study of Atmospheric Dust," March 1967.
214. Longyear, J. Q., "An Algorithm for Obtaining Solutions to Laplace's Tidal Equations," March 1967.
215. Rider, L. J., "A Comparison of Pibal with Raob and Rawin Wind Measurements," April 1967.
216. Breeland, A. H., and R. S. Bonner, "Results of Tests Involving Hemispherical Wind Screens in the Reduction of Wind Noise," April 1967.
217. Webb, Willis L., and Max C. Bolen, "The D-region Fair-Weather Electric Field," April 1967.
218. Kubinski, Stanley F., "A Comparative Evaluation of the Automatic Tracking Pilot-Balloon Wind Measuring System," April 1967.
219. Miller, Walter B., and Henry Rachele, "On Nonparametric Testing of the Nature of Certain Time Series," April 1967.
220. Hansen, Frank V., "Spatial and Temporal Distribution of the Gradient Richardson Number in the Surface and Planetary Layers," May 1967.
221. Randhawa, Jagir S., "Diurnal Variation of Ozone at High Altitudes," May 1967.
222. Ballard, Harold N., "A Review of Seven Papers Concerning the Measurement of Temperature in the Stratosphere and Mesosphere," May 1967.
223. Williams, Ben H., "Synoptic Analyses of the Upper Stratospheric Circulation During the Late Winter Storm Period of 1966," May 1967.
224. Horn, J. D., and J. A. Hunt, "System Design for the Atmospheric Sciences Office Wind Research Facility," May 1967.
225. Miller, Walter B., and Henry Rachele, "Dynamic Evaluation of Radar and Photo Tracking Systems," May 1967.
226. Bonner, Robert S., and Ralph H. Rohwer, "Acoustical and Meteorological Data Report - SOTRAN III and IV," May 1967.
227. Rider, L. J., "On Time Variability of Wind at White Sands Missile Range, New Mexico," June 1967.
228. Randhawa, Jagir S., "Mesospheric Ozone Measurements During a Solar Eclipse," June 1967.
229. Beyers, N. J., and B. T. Miers, "A Tidal Experiment in the Equatorial Stratosphere over Ascension Island (8S)," June 1967.
230. Miller, W. B., and H. Rachele, "On the Behavior of Derivative Processes," June 1967.
231. Walters, Randall K., "Numerical Integration Methods for Ballistic Rocket Trajectory Simulation Programs," June 1967.
232. Hansen, Frank V., "A Diabatic Surface Boundary Layer Model," July 1967.
233. Butler, Ralph L., and James K. Hail, "Comparison of Two Wind Measuring Systems with the Contraves Photo-Theodolite," July 1967.
234. Webb, Willis L., "The Source of Atmospheric Electrification," June 1967.

235. Hinds, B. D., "Radar Tracking Anomalies over an Arid Interior Basin," August 1967.
236. Christian, Larry O., "Radar Cross Sections for Totally Reflecting Spheres," August 1967.
237. D'Arcy, Edward M., "Theoretical Dispersion Analysis of the Aerobee 350," August 1967.
238. Anon., "Technical Data Package for Rocket-Borne Temperature Sensor," August 1967.
239. Glass, Roy I., Roy L. Lamberth, and Ralph D. Reynolds, "A High Resolution Continuous Pressure Sensor Modification for Radiosondes," August 1967.
240. Low, Richard D. H., "Acoustic Measurement of Supersaturation in a Warm Cloud," August 1967.
241. Rubio, Roberto, and Harold N. Ballard, "Time Response and Aerodynamic Heating of Atmospheric Temperature Sensing Elements," August 1967.
242. Seagraves, Mary Ann B., "Theoretical Performance Characteristics and Wind Effects for the Aerobee 150," August 1967.
243. Duncan, Louis Dean, "Channel Capacity and Coding," August 1967.
244. Dunaway, G. L., and Mary Ann B. Seagraves, "Launcher Settings Versus Jack Settings for Aerobee 150 Launchers - Launch Complex 35, White Sands Missile Range, New Mexico," August 1967.
245. Duncan, Louis D., and Bernard F. Engebos, "A Six-Degree-of-Freedom Digital Computer Program for Trajectory Simulation," October 1967.
246. Rider, Laurence J., and Manuel Armendariz, "A Comparison of Simultaneous Wind Profiles Derived from Smooth and Roughened Spheres," September 1967.
247. Reynolds, Ralph D., Roy L. Lamberth, and Morton G. Wurtele, "Mountain Wave Theory vs Field Test Measurements," September 1967.
248. Lee, Robert P., "Probabilistic Model for Acoustic Sound Ranging," October 1967.
249. Williamson, L. Edwin, and Bruce Kennedy, "Meteorological Shell for Standard Artillery Pieces - A Feasibility Study," October 1967.
250. Rohwer, Ralph H., "Acoustical, Meteorological and Seismic Data Report - SOTRAN V and VI," October 1967.
251. Nordquist, Walter S., Jr., "A Study in Acoustic Direction Finding," November 1967.
252. Nordquist, Walter S., Jr., "A Study of Acoustic Monitoring of the Gun Probe System," November 1967.
253. Avara, E. P., and B. T. Miers, "A Data Reduction Technique for Meteorological Wind Data above 30 Kilometers," December 1967.
254. Hansen, Frank V., "Predicting Diffusion of Atmospheric Contaminants by Consideration of Turbulent Characteristics of WSMR," January 1968.
255. Randhawa, Jagir S., "Rocket Measurements of Atmospheric Ozone," January 1968.
256. D'Arcy, Edward M., "Meteorological Requirements for the Aerobee-350," January 1968.
257. D'Arcy, Edward M., "A Computer Study of the Wind Frequency Response of Unguided Rockets," February 1968.
258. Williamson, L. Edwin, "Gun Launched Probes - Parachute Expulsion Tests Under Simulated Environment," February 1968.
259. Beyers, Norman J., Bruce T. Miers, and Elton P. Avara, "The Diurnal Tide Near the Stratopause over White Sands Missile Range, New Mexico," February 1968.
260. Traylor, Larry E., "Preliminary Study of the Wind Frequency Response of the Honest John M50 Tactical Rocket," March 1968.
261. Engebos, B. F., and L. D. Duncan, "Real-Time Computations of Pilot Balloon Winds," March 1968.
262. Butler, Ralph and L. D. Duncan, "Empirical Estimates of Errors in Double-Theodolite Wind Measurements," February 1968.
263. Kennedy, Bruce, et al., "Thin Film Temperature Sensor," March 1968.
264. Bruce, Dr. Rufus, James Masoa, Dr. Kenneth White and Richard B. Gomez, "An Estimate of the Atmospheric Propagation Characteristics of 1.54 Micron Laser Energy," March 1968.

265. Ballard, Harold N., Jagir S. Randhawa, and Willis L. Webb, "Stratospheric Circulation Response to a Solar Eclipse," March 1968.
266. Johnson, James L., and Orville C. Kuberski, "Timing Controlled Pulse Generator," April 1968.
267. Blanco, Abel J., and Glenn B. Hoidale, "Infrared Absorption Spectra of Atmospheric Dust," May 1968.
268. Jacobs, Willie N., "Automatic Pibal Tracking System," May 1968.
269. Morris, James E., and Marvin D. Kays, "Circulation in the Arctic Mesosphere in Summer," June 1968.
270. Mason, James B., "Detection of Atmospheric Oxygen Using a Tuned Ruby Laser," June 1968.
271. Armendariz, Manuel, and Virgil D. Lang, "Wind Correlation and Variability in Time and Space," July 1968.
272. Webb, Willis L., "Tropospheric Electrical Structure," July 1968.
273. Miers, Bruce T., and Elton P. Avara, "Analysis of High-Frequency Components of AN/FPS-16 Radar Data," August 1968.
274. Dunaway, Gordon L., "A Practical Field Wind Compensation Technique for Unguided Rockets," August 1968.
275. Seagraves, Mary Ann B., and Barry Butler, "Performance Characteristics and Wind Effects for the Aerobee 150 with VAM Booster," September 1968.
276. Low, Richard D. H., "A Generalized Equation for Droplet Growth Due to the Solution Effect," September 1968.
277. Jenkins, Kenneth R., "Meteorological Research, Development, Test, and Evaluation Rocket," September 1968.
278. Williams, Ben H., and Bruce T. Miers, "The Synoptic Events of the Stratospheric Warming of December 1967 - January 1968," September 1968.
279. Tate, C. L., and Bruce W. Kennedy, "Technical Data Package for Atmospheric Temperature Sensor Mini-Loki," September 1968.
280. Rider, Laurence J., Manuel Armendariz, and Frank V. Hansen, "A Study of Wind and Temperature Variability at White Sands Missile Range, New Mexico," September 1968.
281. Duncan, Louis D., and Walter B. Miller, "The Hull of a Channel," September 1968.
282. Hansen, Frank V., and Gary A. Ethridge, "Diffusion Nomograms and Tables for Rocket Propellants and Combustion By-Products," January 1968.
283. Walters, Randall K., and Bernard F. Engebos, "An Improved Method of Error Control for Runge-Kutta Numerical Integration," October 1968.
284. Miller, Walter B., "A Non-Entropy Approach to Some Topics in Channel Theory," November 1968.
285. Armendariz, Manuel, Laurence J. Rider, and Frank V. Hansen, "Turbulent Characteristics in the Surface Boundary Layer," November 1968.
286. Randhawa, Jagir S., "Rocket Measurements of the Diurnal Variation of Atmospheric Ozone," December 1968.
287. Randhawa, Jagir S., "A Guide to Rocketsonde Measurements of Atmospheric Ozone," January 1969.
288. Webb, Willis L., "Solar Control of the Stratospheric Circulation," February 1969.
289. Lee, Robert P., "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," March 1969.
290. Barber, T. L., "Degradation of Laser Optical Surfaces," March 1969.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author) U. S. ARMY ELECTRONICS COMMAND PORT MONMOUTH, NEW JERSEY		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP
3. REPORT TITLE DEGRADATION OF LASER OPTICAL SURFACES		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (First name, middle initial, last name) T. L. Barber		
6. REPORT DATE March 1969	7a. TOTAL NO. OF PAGES 5	7b. NO. OF REFS 4
8a. CONTRACT OR GRANT NO. A. PROJECT NO. -Task No. 1T061102B53A-18 d.	9a. ORIGINATOR'S REPORT NUMBER(S) ECOM - 5237	
9b. OTHER REPORT NUM(S) (Any other numbers that may be assigned this report)		
10. DISTRIBUTION STATEMENT Distribution of this report is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY ATMOSPHERIC SCIENCES LABORATORY U.S. ARMY ELECTRONICS COMMAND WHITE SANDS MISSILE RANGE, NEW MEXICO	
13. ABSTRACT Problems of optical surface degradation became apparent while measurements were being made with a laser. After examination, it was concluded that the defects fell into two categories - those caused by atmospheric dust and those resulting from the effect of cleaning solvents. A procedure is described which minimizes both of these problems.		

DD Form 1473

REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

UNCLASSIFIED
Security Classification

16. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Lasers						
2. Optics						
3. Laboratory Techniques						
4. Optical Surfaces						

UNCLASSIFIED

Security Classification

ATTC HAFB Cjden