

Appendix A: Surface Optical Property Data

Most surface property values contained in this Appendix are courtesy of NASA/ GSFC.^[*] Properties for materials marked with an asterisk^[*], however, are design values used by a particular program and are not from the NASA reference.

Unless otherwise noted, values are for beginning-of-life. For some surfaces, degraded values are shown for various periods of time on orbit. Because degradation rates are highly dependent on orbit altitude and the amount of contamination a surface experiences on a particular satellite, reported degraded values should be considered as rough estimates only. [Chapter 4](#) contains extensive data on the degradation of optical solar reflectors and other materials.

Although all values shown are believed to be representative of those used for thermal design analyses in the industry, no guarantee of their validity is implied. In cases where a thermal design is sensitive to any of these parameters, surface optical property measurements and/or a solar-thermal balance test of the thermal design must be conducted to verify flight performance.

| Material | α Solar | ϵ IR |
|--|----------------|---------------|
| Optical Solar Reflectors (OSR) | | |
| Optical solar reflector (OSR), silvered fused silica (quartz)* | 0.07 | 0.80 |
| Optical solar reflector (OSR), diffuse* | 0.10 | 0.80 |
| Optical solar reflector, indium-tin-oxide (ITO) coated* | 0.07 | 0.76 |
| Optical solar reflector, silvered quartz, Helios program | 0.07 | 0.79 |
| Teflon, aluminized, 0.5 mil* | 0.14 | 0.40 |
| Teflon, aluminized, 1 mil* | 0.14 | 0.48 |
| Teflon, aluminized, 2 mil, sample 1* | 0.14 | 0.60 |
| Teflon, aluminized, 2 mil, sample 2* | 0.08 | 0.66 |
| Teflon, aluminized, tape, 2 mil* | 0.17 | 0.76 |
| Teflon, aluminized, sheet, 2 mil* | 0.16 | 0.65 |
| Teflon, aluminized, 5mil, sample 1* | 0.22 | 0.81 |
| Teflon, aluminized, 5 mil, sample 2* | 0.13 | 0.81 |
| Teflon, aluminized, 5 mil, sample 3* | 0.17 | 0.77 |
| Teflon, aluminized, 5 mil, sample 4* | 0.14 | 0.75 |
| Teflon, aluminized, 7.5 mil* | 0.15 | 0.80 |
| Teflon, aluminized, 10 mil, sample 1* | 0.13 | 0.87 |
| Teflon, aluminized, 10 mil, sample 2* | 0.17 | 0.83 |
| Teflon, aluminized, 10 mil, sample 3* | 0.15 | 0.85 |
| Teflon, silvered, 2 mil* | 0.08 | 0.68 |
| Teflon, silvered, 5 mil | 0.08 | 0.81 |

| Material | α Solar | ϵ IR |
|--|----------------------------------|---------------------------------|
| Teflon, silvered, 10 mil* | 0.09 | 0.88 |
| Black Coating | | |
| Black Z306 polyurethane paint, 3 mils thick, BOL* | 0.95 | 0.87 |
| Black Z306 polyurethane paint, 3 mils thick, 3 years GEO* | 0.93 | 0.87 |
| Black Z306 polyurethane paint, 3 mils thick, 5 years GEO* | 0.92 | 0.87 |
| Carbon black paint NS-7 | 0.96 | 0.88 |
| Catalac black paint | 0.96 | 0.88 |
| Chemglaze Z306 black paint, BOL | 0.96 | 0.91 |
| Chemglaze Z306 black paint, EOL (time, orbit not specified)* | 0.96 | 0.84 |
| Delrin black plastic | 0.96 | 0.87 |
| Ebanol C black. | 0.97 | 0.73 |
| Ebanol C black, 384 hours UV | 0.97 | 0.75 |
| GSFC black paint 313-1 | 0.96 | 0.86 |
| GSFC black silicate MS-94 | 0.96 | 0.89 |
| Hughson black paint H322 | 0.96 | 0.86 |
| Hughson black paint L-300 | 0.95 | 0.84 |
| Martin black paint N-150-1 | 0.94 | 0.94 |
| Martin Black Velvet paint | 0.91 | 0.94 |
| Paladin black lacquer | 0.95 | 0.75 |
| Parsons black paint | 0.98 | 0.91 |
| Pyramil black on beryllium-copper | 0.92 | 0.72 |
| Rough black matte, black paint* | 0.90 | 0.90 |
| 3M Black Velvet Paint, BOL | 0.97 | 0.91 |
| 3M Black Velvet Paint, 2.5 years* | 0.97 | 0.84 |
| 3M Black Velvet Paint, EOL* | 0.97 | 0.84 |
| Velvestat black plastic | 0.96 | 0.85 |
| Black anodize (see Anodize section) | | |
| Films and Tapes | | |
| Aclar film, aluminized, 1 mil | 0.12 | 0.45 |
| Aclar film, aluminized, 2 mil | 0.11 | 0.62 |
| Aclar film, aluminized, 5 mil | 0.11 | 0.73 |
| Kapton, aluminized, aluminum side* | 0.12 | 0.03 |
| Kapton, aluminized, 0.08 mil | 0.23 | 0.24 |
| Kapton, aluminized, 0.15 mil | 0.25 | 0.34 |
| Kapton, aluminized, 0.25 mil | 0.31 | 0.45 |
| Kapton, aluminized, 0.50 mil | 0.34 | 0.55 |

| Material | α Solar | ϵ IR |
|--|----------------------------------|---------------------------------|
| Kapton, aluminized, 0.50 mil, Dacron cloth reinforced* | 0.35 | 0.53 |
| Kapton, aluminized, 1 mil, sample 1 | 0.38 | 0.67 |
| Kapton, aluminized, 1 mil, sample 2, BOL* | 0.36 | 0.61 |
| Kapton, aluminized, 1 mil, sample 2, 3 years GEO* | 0.54 | 0.61 |
| Kapton, aluminized, 1 mil, sample 2, 5 years GEO* | 0.66 | 0.61 |
| Kapton, aluminized, 1.5 mil | 0.40 | 0.71 |
| Kapton, aluminized, 2 mil, sample 1, BOL* | 0.39 | 0.73 |
| Kapton, aluminized, 2 mil, sample 1, 3 years (orbit not specified)* | 0.55 | 0.73 |
| Kapton, aluminized, 2 mil, sample 1, 5 years (orbit not specified)* | 0.67 | 0.73 |
| Kapton, aluminized, 2 mil, sample 2* | 0.41 | 0.75 |
| Kapton, aluminized, 2 mil, with indium-tin-oxide coating, BOL* | 0.34 | 0.75 |
| Kapton, aluminized, 2 mil, with indium-tin-oxide, 3 years (orbit not specified)* | 0.47 | 0.75 |
| Kapton, aluminized, 3 mil | 0.45 | 0.82 |
| Kapton, aluminized, 5 mil, sample 1, BOL* | 0.49 | 0.83 |
| Kapton, aluminized, 5 mil, sample 1, 2.5 years (orbit not specified)* | 0.61 | 0.83 |
| Kapton, aluminized, 5 mil, sample 1, EOL (time, orbit not specified)* | 0.70 | 0.83 |
| Kapton, aluminized, 5 mil, sample 2 | 0.46 | 0.86 |
| Kapton, aluminized, silicon oxide coated, 0.5 mil, BOL | 0.12 | 0.18 |
| Kapton, aluminized, silicon oxide coated, 0.5 mil, 4000 hours UV | 0.28 | 0.24 |
| Kapton, aluminized, chromium/silicon oxide coated (green), 1 mil | 0.79 | 0.78 |
| Kapton, aluminized, aluminum-oxide coated, 1 mil | 0.12 | 0.20 |
| Kapton, aluminized, aluminum oxide coated, 1 mil, 1800 hours UV | 0.12 | 0.20 |
| Kapton, aluminized, silicon oxide coated, 1 mil | 0.11 | 0.33 |
| Kapton, aluminized, silicon oxide coated, 1 mil, 2400 hours UV | 0.22 | 0.33 |
| Kapton, silvered, aluminum oxide coated, 1 mil | 0.08 | 0.19 |
| Kapton, silvered, aluminum oxide coated, 1 mil, 2400 hours UV | 0.08 | 0.21 |
| Kapton, black (carbon loaded), 1 mil, BOL | 0.92 | 0.88 |
| Kapton, black (carbon loaded), 1 mil, 5 years GEO* | 0.92 | 0.88 |
| Kapton, black (carbon loaded), 1 mil, 10 years GEO* | 0.89 | 0.88 |
| Kimfoil polycarbonate film, aluminized, 0.8 mil | 0.19 | 0.23 |
| Kimfoil polycarbonate film, aluminized, 0.20 mil | 0.20 | 0.30 |
| Kimfoil polycarbonate film, aluminized, 0.24 mil | 0.17 | 0.28 |
| Mylar, aluminized, 0.15 mil (internal use only, disintegrates in sunlight) | – | 0.28 |
| Mylar, aluminized, 0.25 mil (internal use only, disintegrates in sunlight) | – | 0.34 |
| Mylar, aluminized, 3 mil (internal use only, disintegrates in sunlight) | – | 0.76 |
| Mylar, aluminized, 5 mil (internal use only, disintegrates in sunlight) | – | 0.77 |

| Material | α Solar | ϵ IR |
|--|----------------------------------|---------------------------------|
| Silica cloth* | 0.18 | 0.86 |
| Skylab sail, initial | 0.15 | 0.35 |
| Skylab sail, 1900 hours UV | 0.19 | 0.36 |
| Skylab parasol fabric (orange), initial | 0.51 | 0.86 |
| Skylab parasol fabric (orange), 2400 hours UV | 0.65 | 0.86 |
| Tedlar, goldized, 0.5 mil | 0.30 | 0.49 |
| Tedlar, goldized, 1 mil | 0.26 | 0.58 |
| Tefzel, goldized, 0.5 mil | 0.29 | 0.47 |
| Tefzel, goldized, 1 mil | 0.26 | 0.61 |
| Teflon, goldized, 0.5 mil | 0.24 | 0.43 |
| Teflon, goldized, 1 mil | 0.22 | 0.52 |
| Teflon, goldized, 5 mil | 0.22 | 0.81 |
| Teflon, goldized, 10 mil | 0.23 | 0.82 |
| Tape, 235-3M, black | 0.95 | 0.90 |
| Tape, aluminum* | 0.10 | 0.04 |
| Tape, 425-3M aluminum foil | 0.20 | 0.03 |
| Tape, aluminum, 2 mil, BOL* | 0.15 | 0.04 |
| Tape, 850-3M, aluminized Mylar | 0.15 | 0.59 |
| Tape, 7361 Mystic aluminized Kapton* | 0.09 | 0.03 |
| Tape, 7452 Mystic aluminum foil | 0.14 | 0.03 |
| Tape, 7800 Mystic aluminum foil | 0.21 | 0.03 |
| Tape, Y9360-3M, aluminized Mylar | 0.19 | 0.03 |
| White Coatings | | |
| Skyspar, Andrew Brown Co.* | 0.22 | 0.91 |
| Barium sulphate with polyvinyl alcohol | 0.06 | 0.88 |
| Biphenyl (white solid) | 0.23 | 0.86 |
| Cat-a-lac white paint | 0.24 | 0.90 |
| Chemglaze A276 white paint* | 0.23 | 0.88 |
| Chemglaze A276, 15000 hrs UV in LEO, no atomic oxygen* | 0.60 | 0.88 |
| Chemglaze A276, 15000 hrs UV in LEO, atomic oxygen exposure* | 0.35 | 0.88 |
| DuPont Lucite acrylic lacquer | 0.35 | 0.90 |
| Dow Corning DC-007 white paint | 0.19 | 0.88 |
| Flamemaster Corp. STM K797 white paint, BOL* | 0.22 | 0.85 |
| Flamemaster Corp. STM K797 white paint, 4 years GEO* | 0.60 | 0.85 |
| NASA/GSFC NS43-C white paint | 0.20 | 0.92 |
| NASA/GSFC NS44-B white paint | 0.34 | 0.91 |
| NASA/GSFC NS74 white paint | 0.17 | 0.92 |

| Material | α Solar | ϵ IR |
|---|----------------------------------|---------------------------------|
| NASA/GSFC NS-37 white paint | 36 | 0.91 |
| Hughson A-276 white paint | 0.26 | 0.88 |
| Hughson A-276 white paint, 1036 hours UV | 0.44 | 0.88 |
| Hughson V-200 white paint | 0.26 | 0.89 |
| Hughson Z-202 white paint | 0.25 | 0.87 |
| Hughson Z-202 white paint, 1000 hours UV | 0.40 | 0.87 |
| Hughson Z-255 white paint | 0.25 | 0.89 |
| Magnesium oxide white paint | 0.09 | 0.90 |
| Magnesium oxide aluminum oxide paint | 0.09 | 0.92 |
| Opal glass | 0.28 | 0.87 |
| OSO-H 63W white paint | 0.27 | 0.83 |
| P764-1A white paint | 0.23 | 0.92 |
| Potassium fluorotitanate white paint | 0.15 | 0.88 |
| Sperex white paint | 0.34 | 0.85 |
| Dow Corning Thermatrol DC-92-007, BOL* | 0.19 | 0.82 |
| Dow Corning Thermatrol DC-92-007, 4 years GEO* | 0.57 | 0.82 |
| 3M-401 white paint | 0.25 | 0.91 |
| Titanium oxide white paint with methyl silicone | 0.20 | 0.90 |
| Titanium oxide white paint with potassium silicate | 0.17 | 0.92 |
| Vita-var PV-100 white paint* | 0.22 | 0.82 |
| Z93 white paint* | 0.19 | 0.89 |
| S13 GLO white paint* | 0.19 | 0.89 |
| S13G white paint, BOL* | 0.21 | 0.88 |
| S13G white paint, 4 years GEO* | 0.56 | 0.88 |
| S-13G-LO white silicone paint, 10 mils thick, BOL* | 0.22 | 0.88 |
| S-13G-LO white silicone paint, 3 years GEO* | 0.39 | 0.88 |
| S-13G-LO white silicone paint, 10 mils thick, 5 years GEO* | 0.47 | 0.88 |
| Polyurethane white paint* | 0.27 | 0.84 |
| 3M White Velvet 400 series white paint* | 0.30 | 0.87 |
| ZOT (IITRI YB-71) white paint, BOL* | 0.20 | 0.91 |
| ZOT (IITRI YB-71) white paint, 2.5 years (orbit not specified)* | 0.45 | 0.91 |
| ZOT (IITRI YB-71) white paint, EOL (time, orbit not specified)* | 0.70 | 0.91 |
| Zerlauts S-13G white paint, BOL | 0.20 | 0.90 |
| Zerlauts S-13G white paint, 2.5 years (orbit not specified) | 0.52 | 0.85 |
| Zerlauts S-13G white paint, EOL (time, orbit not specified) | 0.70 | 0.85 |
| Zerlauts Z-93 white paint | 0.17 | 0.92 |
| Z93 white paint, 10 years GEO* | 0.55 | 0.92 |

| Material | α Solar | ϵ IR |
|---|----------------------------------|---------------------------------|
| ZOT (zinc orthotitanate) with potassium silicate | 0.13 | 0.92 |
| Zinc oxide with sodium silicate | 0.15 | 0.92 |
| Zirconium oxide with 650 glass resin | 0.23 | 0.88 |
| Other Paints | | |
| Brilliant aluminum paint | 0.30 | 0.31 |
| Chromacoat aluminum paint, BOL* | 0.28 | 0.05 |
| Chromacoat aluminum paint, 3 years (orbit not specified)* | 0.33 | 0.05 |
| Chromeric 586 silver paint | 0.30 | 0.30 |
| DuPont 4817 silver paint | 0.43 | 0.49 |
| Epoxy aluminum paint | 0.77 | 0.81 |
| Finch 643-1-1 aluminum paint | 0.22 | 0.23 |
| NASA/GSFC NS-43-G yellow paint | 0.38 | 0.90 |
| NASA/GSFC NS-53-B green paint | 0.52 | 0.87 |
| NASA/GSFC NS-43-E green paint | 0.57 | 0.89 |
| NASA/GSFC NS-43-C white paint | 0.20 | 0.92 |
| NASA/GSFC NS-55-F green paint | 0.57 | 0.91 |
| NASA/GSFC NS-79 green paint | 0.57 | 0.91 |
| Epon 828 leafing aluminum paint | 0.37 | 0.36 |
| 80-U leafing aluminum paint | 0.29 | 0.32 |
| Naval Research Lab leafing aluminum paint | 0.24 | 0.24 |
| Naval Research Lab leafing aluminum paint | 0.28 | 0.29 |
| Silicone aluminum paint | 0.29 | 0.30 |
| Metals | | |
| Aluminum, buffed* | 0.16 | 0.03 |
| Aluminum, heavily oxidized* | 0.13 | 0.30 |
| Aluminum, polished, BOL* | 0.15 | 0.05 |
| Aluminum, polished, EOL (time, orbit not specified)* | 0.15 | 0.05 |
| Aluminum, vapor deposited | 0.08 | 0.02 |
| Aluminum, vapor deposited, on fiberglass | 0.15 | 0.07 |
| Aluminum, vapor deposited, on stainless steel | 0.08 | 0.02 |
| Beryllium copper | 0.31 | 0.03 |
| Chromium, vapor deposited, on glass | 0.56 | 0.17 |
| Chromium, vapor deposited, on 5 mil Kapton | 0.57 | 0.24 |
| Constantan-metal strip | 0.37 | 0.09 |
| Copper, buffed | 0.30 | 0.03 |
| Copper foil tape, plain | 0.32 | 0.02 |
| Copper foil tape, sanded | 0.26 | 0.04 |

| Material | α Solar | ϵ IR |
|--|----------------------------------|---------------------------------|
| Copper foil tape, tarnished | 0.55 | 0.04 |
| Germanium, vapor deposited, on glass | 0.52 | 0.09 |
| Gold, vapor deposited, on glass | 0.19 | 0.02 |
| Gold, electroplated | 0.23 | 0.03 |
| Gold, polished, BOL* | 0.30 | 0.05 |
| Gold, polished, EOL (time, orbit not specified)* | 0.30 | 0.05 |
| Gold, sandblasted* | 0.48 | 0.14 |
| Inconel X foil, 1 mil | 0.52 | 0.10 |
| Iron oxide, vapor deposited, on glass | 0.85 | 0.56 |
| Molybdenum, vapor deposited, on glass | 0.56 | 0.21 |
| Nickel, vapor deposited, on glass | 0.38 | 0.04 |
| Nickel, electroless | 0.39 | 0.07 |
| Nickel, Kannigen alloy | 0.45 | 0.08 |
| Platinum foil | 0.33 | 0.04 |
| Rhodium, vapor deposited, on glass | 0.18 | 0.03 |
| Silver, vapor deposited, on glass, un-oxidized | 0.04 | 0.02 |
| Silver, polished, un-oxidized* | 0.04 | 0.02 |
| Silver, oxidized* | – | 0.03 |
| Silver, Denton vapor deposited, with protective overcoat* | 0.06 | 0.03 |
| Silver beryllium copper | 0.19 | 0.03 |
| Stainless steel, polished | 0.42 | 0.11 |
| Stainless steel, sandblasted | 0.58 | 0.38 |
| Stainless steel | 0.47 | 0.14 |
| Stainless steel, machine rolled | 0.39 | 0.11 |
| Stainless steel boom, polished | 0.44 | 0.10 |
| Stainless steel 304, 1 mil foil | 0.40 | 0.05 |
| Tantalum foil | 0.40 | 0.05 |
| Titanium, vapor deposited on glass | 0.52 | 0.12 |
| Titanium* | 0.40 | 0.55 |
| Tungsten, polished | 0.44 | 0.03 |
| Tungsten, vapor deposited, on glass | 0.60 | 0.27 |
| Anodized Aluminum | | |
| <p>The optical properties of anodized surfaces are highly dependent upon the anodizing process used. While the anodize properties shown below are representative, actual values may differ substantially from those shown here. Absorptance and emittance measurements of samples of the flight finish should therefore be made. A process for achieving controlled aluminum anodize properties is discussed in Chapter 4.</p> | | |
| Black anodize, sample 1 | 0.65 | 0.82 |

| Material | α Solar | ϵ IR |
|--|----------------------------------|---------------------------------|
| Black anodize, sample 2* | 0.86 | 0.86 |
| Black anodize, sample 3 | 0.76 | 0.88 |
| Black anodize, sample 4 | 0.88 | 0.88 |
| Blue anodize sample 1 | 0.67 | 0.87 |
| Blue anodize sample 2 | 0.53 | 0.82 |
| Brown anodize | 0.73 | 0.86 |
| Chromic anodize | 0.44 | 0.56 |
| Clear anodize sample 1 | 0.27 | 0.76 |
| Clear anodize sample 2 | 0.35 | 0.84 |
| Gold anodize | 0.48 | 0.82 |
| Green anodize | 0.66 | 0.88 |
| Plain anodize | 0.26 | 0.04 |
| Red anodize | 0.57 | 0.88 |
| Sulphuric anodize | 0.42 | 0.87 |
| Yellow anodize | 0.47 | 0.87 |
| Metal Conversion Coatings | | |
| <p>The optical properties of conversion coatings are highly dependent upon the process used. While the properties shown below are representative, actual values may differ substantially from those shown here. Absorptance and emittance measurements of samples of the flight finish should therefore be made.</p> | | |
| Clad 7075 aluminum, BOL* | 0.25 | 0.04 |
| Clad 7075 aluminum, 3 years GEO* | 0.26 | 0.04 |
| Clad 7075 aluminum, 5 years GEO* | 0.27 | 0.04 |
| Irridite aluminum | – | 0.11 |
| Alzac A-2 | 0.16 | 0.73 |
| Alzac A-5 | 0.18 | – |
| Black chrome | 0.96 | 0.62 |
| Black copper | 0.98 | 0.63 |
| Black irridite | 0.62 | 0.17 |
| Black nickel | 0.91 | 0.66 |
| Dow 7 on polished magnesium | – | 0.49 |
| Dow 7 on sanded magnesium | – | 0.65 |
| Dow 9 on magnesium | – | 0.87 |
| Dow 23 on magnesium | 0.62 | 0.67 |
| Ebanol C, black | 0.97 | 0.77 |
| TiNOX on copper* | 0.95 | 0.05 |
| Maxorb, nickel oxide or black chrome on nickel foil* | 0.90 | 0.10 |

| Material | α Solar | ϵ IR |
|---|----------------------------------|---------------------------------|
| Blue anodize titanium foil* | 0.70 | 0.13 |
| Anodized titanium foil, 1 mil, BOL* | 0.70 | 0.10 |
| Anodized titanium foil c.p., 1 mil, 5 years GEO* | 0.70 | 0.10 |
| Composite Coatings | | |
| Aluminum oxide, Al ₂ O ₃ , 12 λ /4, on buffed aluminum | 0.13 | 0.23 |
| Aluminum oxide, Al ₂ O ₃ , 12 λ /4, on buffed aluminum, 2560 hours UV | 0.13 | 0.23 |
| Aluminum oxide, Al ₂ O ₃ , 12 λ /4, on fused silica glass | 0.12 | 0.24 |
| NASA/GSFC dark mirror coating, SiO-Cr-Al | 0.86 | 0.04 |
| NASA/GSFC composite, SiO _x -Al ₂ -Ag | 0.07 | 0.68 |
| Inconel with Teflon overcoat, 1 mil | 0.55 | 0.46 |
| Silver beryllium copper with Kapton overcoat | 0.31 | 0.57 |
| Silver beryllium copper with Parylene C overcoat | 0.22 | 0.34 |
| Silver beryllium copper with Teflon overcoat | 0.12 | 0.38 |
| Miscellaneous | | |
| Vespel polyimide SP1* | 0.89 | 0.90 |
| Polyethylene, black * | 0.93 | 0.92 |
| Tedlar, black* | 0.94 | 0.90 |
| Tedlar, white* | 0.39 | 0.87 |
| Fiberglass epoxy (BOL and EOL are the same)* | 0.72 | 0.89 |
| Fiberglass polyimide, BOL* | 0.75 | 0.89 |
| Fiberglass polyimide, 2.5 years (orbit not specified)* | 0.78 | 0.89 |
| Fiberglass polyimide, EOL (time, orbit not specified)* | 0.80 | 0.89 |
| Graphite epoxy (BOL and EOL are the same)* | 0.93 | 0.85 |
| Astroquartz fabric* | 0.22 | 0.80 |
| Beta cloth* | 0.40 | 0.86 |
| Grafoil BOL* | 0.65 | 0.34 |
| Grafoil EOL* | 0.61 | 0.34 |

[*]J. H. Henninger, *Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal Control Coatings*, NASA Reference Publication 1121 (1984).