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DIRECTIONAL LUMINOUS REFLECTANCES OF OBJECTS AND BACKGROUNDS FOR A MODERATELY HIGH SUN

by

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FOREWORD

The first report under Assignment 9 of Contract NObs-84075, entitled "Visibility" and identified as SIO Reference 64-3, contained terrain and background data suitable for use in visibility calculations under the atmospheric and lighting conditions which prevailed at the time of Visibility Laboratory research flight 74, as described and tabulated in that report (i.e., SIO Reference 64-3). This, the second report prepared under Assignment 9, presents additional data on terrains and backgrounds for the conditions prevailing at the time of flight 74; it is, therefore, a supplement to SIO Reference 64-3.

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1. INTRODUCTION

The photopic optical properties of natural terrains and man-made surfaces presented in this report are a supplement to the data reported by Gordon (1964). The data are presented in the form of directional luminous reflectances. A directional reflectance is the ratio of inherent luminance in the direction of the specified path of sight to the total illuminance on a fully exposed horizontal plane at ground level. These reflectances were measured under natural lighting conditions with a moderately high sun. The data are suitable for use with the atmospheric data described by Boileau (1964), i.e., a clear day with a sun at a zenith angle of 41.5° and a total illuminance of 5940 lumens/sq ft.

2. BACKGROUNDS

Gordon (1964) presented directional luminous reflectances for 14 terrains (numbered consecutively). This report presents 19 additional terrains in Table 1. Those numbered 15 through 31 are computed from the spectral reflectance data of Krinov (1947) for which more than one zenith angle and azimuth of the path of sight was measured. Terrains numbered 32 and 33, measured with the goniophotometer, are also appropriate for use with atmospheric data for a clear day with a moderately high sun.

Much of the spectral reflectance data reported by Krinov (1947) was for only one path of sight for a given terrain. These data have been included herein in Tables 2 and 3 in order to make available in the form of luminous reflectances the bulk of the data reported by Krinov. He reported 370 spectral reflectance measurements. This report and that of Gordon (1964) present data for 232 of these measurements. The remainder of the Krinov data are not suitable for use with the atmospheric properties reported by Boileau (1964) for one of the following reasons: 1) the zenith angle of the sun was too low, 2) the sky was completely cloudy, 3) the spectral data were not sufficiently complete in the visible range, or 4) the magnesium oxide reference plaque was not horizontal. The Krinov data reported in luminous reflectance form by Penndorf (1956) were for 13 average or characteristic spectral reflectances derived by Krinov.

The 69 terrains in Table 2 were measured for only the straight downward path of sight ($\theta = 180^{\circ}$). The measurements for the 51 terrains in Table 3 were made for an azimuth of path of sight of 90° and most of them for a zenith angle of 135°.

In Tables 1, 2, and 3 for every terrain measured by Krinov, a number in parenthesis follows the description. These are the numbers used by Krinov in his table of spectral reflectance measurements.

Table 1. Directional Luminous Reflectance of Terrain Backgrounds.

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight							
			180	165	150	135	120	105	100	95
15. Pasture meadow at end of summer (K No.75-77)[a]	45	0	0.0822							
	45	90				0.0882				
	45	180				0.0968				
16. Meadow (with clover and timothy) - dense growth, with flowers, midsummer (K No.82-84)[a]	45	90				0.135	0.154[b]			0.143
17. Meadow - with crow foot, dense grass with abundant flowers (K No.89-91)[a]	45	90				0.108	0.105[b]			0.133
18. Dry meadow - sparse low grass (K No.135-137)[a]	45	90	0.0845			0.0879		0.120		
19. Dry meadow - more dense low grass (K No.138-140)[a]	45	0	0.0796							
	45	90				0.109				
	45	180				0.144				

a. Directional luminous reflectances of terrains 15 through 31 were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

b. NOTE: The zenith angle of the path of sight is 115°.

Table 1. Directional Luminous Reflectance of Terrain Backgrounds.

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight 180	165	150	135	120	105	100	95
0. Oats - with spikes (K No.186-188)[a]	45	90				0.0866	0.130[b]			0.168
1. Millet - ripening (K No.198-200)[a]	45	0				0.0716				
	45	90				0.0593				
	45	180				0.114				
2. Wheat - before harvesting (K No.201-206)[a]	50	0				0.0895	0.274[b]			0.371
	50	180				0.111	0.292[b]			0.385
3. Wheat - in the flowering period (K No.207-211)[a]	50	0				0.0702	0.122[b]			0.268
	50	90					0.0863[b]			0.0980
4. Wheat - after mowing (K No.212-213)[a]	50	90					0.133[b]			0.152
5. Barley - Spiked (K No.224-226)[a]	45	90				0.113	0.155[b]			0.144

a. Directional luminous reflectances of terrains 15 through 31 were computed from spectrophotometric data taken by Krinov (1947) using C.I.E. Illuminant B.
b. NOTE: The zenith angle of the path of sight is 115°.

Table 1. Directional Luminous Reflectance of Terrain Backgrounds .

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight 180	165	150	135	120	105	100	95
6. Sand Dunes -- with sharply expressed micro-relief, dry, no shadows. (K No.248-254)[a]	40	90	0.250		0.370		0.375	0.345		
	40	270			0.222		0.243	0.233		
7. Soil - podsol - ploughed, dry (K No.287-289)[a]	45	0				0.105				
	45	90				0.189				
	45	180				0.179				
8. Soil - sandy loam, ploughed, moist (K No.295-298)[a]	45	0				0.203				
	45	90				0.112				
	45	180				0.212				
	45	270				0.180				
9. Soil - sandy loam, ploughed, dry (K No.299-301)[a]	45	0	0.153			0.159				
	45	90				0.159				
0. Soil, black earth, rich, ploughed, wet (K No.304-306)[a]	45	0	0.0204			0.0574				
	45	180				0.0614				

a. Directional luminous reflectances of terrains 15 through 31 were computed from spectrophotometric data taken by Krinov (1947) using C.I.E. Illuminant B.

Table 1. Directional Luminous Reflectance of Terrain Backgrounds.

	Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight 180	165	150	135	120	105	100	95
31.	Soil, black earth, rich, ploughed, dry (K No.307-310)[a]	45	0	0.0291			0.0339				
		45	90				0.0403				
		45	180				0.0466				
32.	Dirt - flat desert road freshly bulldozed to remove encroaching sage[c]	42	90	0.226	0.229	0.229	0.234	0.247	0.261	0.271	0.270
33.	Oiled dirt - flat desert road, oiled, with a light covering of dust[c]	42	90	0.100	0.102	0.102	0.104	0.109	0.118	0.121	0.124

a. Directional luminous reflectances of terrains 15 through 31 were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

c. Data taken with a goniophotometer at Naval Ordnance Test Station, China Lake, California, on 16 July 1962. The spectral reflectance of a sample of the dirt was measured with a Hardy spectrophotometer. Using C.I.E. Illuminant B, chromaticity coordinates were x = 0.370, y = 0.361, z = 0.269; dominant wavelength = 580 mμ; and excitation purity = 10 %.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds: The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Fir, late summer (mature forest), aircraft altitude 300 meters (K No. 25)	45	0	180	0.0319
Heather, dense growth, before flowering (K No. 53)	45	0	180	0.0398
Turf hillocks, covered with grass, summer (K No. 70)	45	0	180	0.0348
Edge of ravine, covered with sparse grass, almost dry, beginning of autumn (K No. 71)	45	0	180	0.0992
Edges of River Bank, covered with sparse grass, almost dry, beginning of autumn (K No. 72)	45	0	180	0.146
Alpine meadow, on mountain tops, covered with sparse grass, dried, beginning of autumn (K No. 73)	45	0	180	0.0806
Alpine meadow, on mountain tops, covered with sparse grass, mowed, dried, beginning of autumn (K No. 74)	45	0	180	0.110
Pasture meadow, beginning of autumn (K No. 81)	45	0	180	0.898
Lush meadow, lush dense grass, beginning of autumn (K No. 94)	45	0	180	0.0707

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds : The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Dry meadow, sparse dry grass on hills, beginning of autumn (K No.141)	45	0	180	0.0790
Meadow, dense, low grass, beginning of autumn, aircraft altitude 300 meters (K No.142)	45	0	180	0.0802
Shallows of river (in high water), covered with grass (K No.146)	45	0	180	0.112
Plantain, individual leaf (top surface) (K No.147)	45	0	180	0.105
Selin, individual clumps dried and yellowish, on sand dunes, end of summer (K No.153)	45	0	180	0.161
Mountain side, low sparse grass, beginning of autumn (K No.154)	45	0	180	0.133
Grass, near road, dusty (K No.161)	45	0	180	0.0733
Yantak (camel grass),roadside, heavily dusted (K No.165)	45	0	180	0.0487
Fallow, green, flowering (K No.166)	45	0	180	0.0618
Hillside, short grass (K No.167)	45	0	180	0.116
Lichens, greenish brown, on roadside and footpaths, over turf, dry (K No.169)	45	0	180	0.0544

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds : The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Moss, reddish brown, wet (K No.170)	45	0	180	0.0475
Sphagnum moss, in marshy, low land, wet (K No.171)	45	0	180	0.0992
Sphagnum moss, in marshy, low land, on bank of bog, dry (K No.172)	45	0	180	0.193
Moss on rocks, dark green on mountain outcrops, dry (K No.173)	45	0	180	0.0465
Moss on turf, reddish brown, dry (K No.174)	45	0	180	0.0363
Reindeer moss, on turf, dry (K No.175)	45	0	180	0.0877
Oats, spike forming period (K No.185)	45	0	180	0.0788
Oat field, stubble (K No.193)	45	0	180	0.0975
Lentil field, stubble (K No.194)	45	0	180	0.0647
Barley field, stubble (K No.195)	45	0	180	0.143
Millet, ripening (K No.197)	45	0	180	0.0567
Oat straw, in sheaves (K No.217)	45	0	180	0.209

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds : The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Soil, boggy, in boggy areas, very damp (K No.271)	45	0	180	(0.0588)[b]
Soil, grey podsol, ploughed, dry (K No.302)	45	0	180	0.0529
Soil, black earth, leached, ploughed, slightly moist (K No.303)	45	0	180	0.0874
Soil, black earth, rich, ploughed, wet (K No.304)	45	0	180	0.0204
Soil, black earth, rich, ploughed, dry (K No.307)	45	0	180	0.0291
Cliffs, bare, dry, on mountain tops (mountainous) (K No.313)	45	0	180	0.285
Cliffs, bare, dry, on mountain tops (tundra) (K No.314)	45	0	180	0.107
Hill slope, bare, dry (K No.315)	45	0	180	0.138
Turf, bare, dry (K No.318)	45	0	180	0.0381
Earth road, heavily trampled, black earth, dry (K No.319)	45	0	180	0.0832
Earth road, trampled, sand, loam (K No.320)	45	0	180	0.0876
Earth road, grey podsol (K No.322)	45	0	180	0.102

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

b. Parenthesis indicates estimate based on incomplete spectrophotometric data.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds: The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith angle of Path of Sight	Reflectance
Wheat straw, in sheaves (K No.218)	45	0	180	0.217
Rye straw, in sheaves (K No.219)	45	0	180	0.227
Lentil straw, in sheaves (K No.220)	45	0	180	0.0812
Boulders, in canyon of mountain stream, dry (K No.232)	45	0	180	0.222
Boulders, in canyon of mountain stream, wet (K No.233)	45	0	180	0.0866
Bottom of reservoir, sandy, moist (K No.235)	45	0	180	0.192
Turf hillock, bare, dry (K No.239)	45	0	180	0.0746
Edge of river bank, bare, dry (K No.240)	45	0	180	0.149
Wind-eroded place, dry (desert)(K No.241)	45	0	180	0.243
Shallows, sand with pebbles, moist (K No.246)	45	0	180	0.111
Iridescence in places of wind-erosion, whitish, with barely noticeable rosy shade, dry (desert) (K No.270)	45	0	180	0.356

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds: The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Earth road, black earth, leached (K No.323)	45	0	180	0.129
Earth road, little used, chestnut-brown earth (K No.324)	45	0	180	0.184
Earth road, trampled, podsol, dry (K No.325)	45	0	180	0.198
Earth road, covered with a layer of loess, dry (K No.327)	45	0	180	0.169
Road, end of winter, yellowish after rain, wet (K No.328)	45	0	180	0.756
Road, paved cobblestone, dry (tundra) (K No.329)	45	0	180	0.202
Road, paved cobblestone, dry (Northern Forest Belt)(K No.330)	45	0	180	0.318
Water in river, Kuban, muddy (K No.333)	45	0	180	0.201
Water in river, in the mountain over Dzhemagat, clear (K No.334)	45	0	180	0.165
Water in reservoir, very muddy, chocolate color (K No.335)	45	0	180	0.162
Snow, fresh (K No.337)	45	0	180	0.771
Roof, shingled, old, dry (K No.357)	45	0	180	0.146

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 2. Uni-directional Luminous Reflectance of Terrain Backgrounds: The Vertically Downward Path of Sight.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Bridge, wooden, old, grown dark (K No. 361)	45	0	180	0.275
Roof tile, new, red (K No. 370)	45	0	180	0.208

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 3. Uni-directional Luminous Reflectance of Terrain Backgrounds: Azimuth of Path of Sight Perpendicular to Sun.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Willow herb, dense growth, flowering period (K No.55)	45	90	135	0.120
Meadow (with clover and timothy) mowed (K No.85)	45	90	135	0.0976
Sedge meadow, dense grass in mid-summer (K No.92)	45	90	135	0.136
Meadow with daisies, period of abundant flowers (K No.93)	45	90	135	0.130
Lake, partially covered with vegetation, surface covered with vegetation (K No.144)	45	90	120	0.154
Sedge, dense near lake shore (K No.145)	45	90	135	0.125
Stream, surface covered with water weeds and sedge (K No.151)	45	90	135	0.0482
Duckweed, dense bunched growth, light green, beginning of summer (K No.152)	45	90	135	0.0650
Grass, young, green (K No.162)	45	90	135	0.149
Grass, last year's (dry), spring (K No.163)	45	90	135	0.115
Grass, summer green (K No.164)	45	90	135	0.0796

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 3. Uni-directional Luminous Reflectance of Terrain Backgrounds: Azimuth of Path of Sight Perpendicular to Sun.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Vetch, dense, bright green, before flowering (K No. 176)	45	90	135	0.111
Peas, to a considerable extent yellowed with bright green spots before ripening (K No. 177)	45	90	135	0.296
Buckwheat, before blooming (K No. 178)	45	90	135	0.127
Cabbage, well developed heads (K No. 179)	45	90	135	0.130
Potatoes, after flowering, dark green (K No. 180)	45	90	135	0.0863
White clover, flowering period (K No. 181)	45	90	135	0.135
Red clover, flowering period (K No. 182)	45	90	135	0.130
Red clover, young grass after first mowing (K No. 183)	45	90	135	0.116
Tomatoes, dense vegetation (K No. 196)	45	90	135	0.0496
Winter rye, spiked (K No. 214)	45	90	110	0.177
Winter rye, flowering (K No. 215)	45	90	135	0.0843

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 3. Uni-directional Luminous Reflectance of Terrain Backgrounds: Azimuth of Path of Sight Perpendicular to Sun.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Summer rye, spiked (K No.216)	45	90	135	0.123
Cotton, heavily coated with dust before flowering (K No.221)	45	90	135	0.112
Cotton, flowering (K No.222)	45	90	135	0.0826
Barley, before spikes (K No.223)	45	90	135	0.0794
Barley, golden yellow, ripe (K No.227)	45	90	135	0.264
Clay, dry, individual sample (K No.234)	45	90	135	0.666
Limestone, dry, single sample (K No.236)	45	90	135	0.530
Silt, from bottom of canal, dry (K No.237)	45	90	135	0.189
Conglomerate, dry, individual sample (K No.238)	45	90	135	0.243
Wind-eroded place, (desert), individual sample (K No.242)	45	90	135	0.267
Sand, individual sample (K No.247)	45	90	135	0.286
Sandstone, brick red, dry individual sample (K No.268)	45	90	135	0.246

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 3. Uni-directional Luminous Reflectance of Terrain Backgrounds: Azimuth of Path of Sight Perpendicular to Sun.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Sandstone, light grey, dry individual sample (K No.269)	45	90	135	0.611
Soil, podsol, ploughed, wet (K No.286)	50	90	135	0.0708
Shale, individual samples, dry (K No.316)	45	90	135	0.699
Salt marshes, individual samples, dry (K No.317)	45	90	135	0.246
Earth road, muddy and wet (K No.326)	45	90	135	0.0548
Road, paved cobblestone, dry (K No.331)	45	90	135	0.153
Road, paved cobblestone, wet (K No.332)	45	90	135	0.0596
Stones, gathered in a pile, dry (K No.355)	45	90	135	0.192
Brick, calcined, red (K No.356)	45	90	135	0.222
Roof, iron, painted red, old (K No.358)	45	90	135	0.139
Street, cobblestone, in city, wet (K No.362)	45	90	135	0.0980
Street, cobblestone, in city, dry (K No.363)	45	90	135	0.270

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

Table 9. Uni-directional Luminous Reflectance of Terrain Backgrounds: Azimuth of Path of Sight Perpendicular to Sun.[a]

Description	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Zenith Angle of Path of Sight	Reflectance
Street, wood block, in city, dry (K No. 364)	45	90	135	0.189
Quay, granite, in city, dry (K No. 365)	45	90	135	0.321
Square, asphalt, in city, dry (K No. 366)	45	90	135	0.804
Sidewalk, asphalt, in city, dry (K No. 368)	45	90	135	0.0252
Sidewalk, flagstone, in city, dry (K No. 369)	45	90	135	0.369

a. Directional luminous reflectances of terrains were computed from spectrophotometric data by Krinov (1947) using C.I.E. Illuminant B.

3. OBJECTS

The optical characteristics of man-made objects are herein described in terms of the directional luminous reflectances of a flat surface oriented in a series of directions in angle increments of 45°. The position of the surface is designated in terms of the zenith angle and azimuth relative to the sun of the normal from the surface. Diagrams depicting the orientation of the surfaces and the angle designations of the normal from each surface are presented in Fig. 1. These diagrams are to be used as aids in interpreting the directional luminous reflectance data on objects presented in Table 4.

Gordon (1964) presented directional reflectances for three man-made objects. This report presents in Table 4 additional data for two of these same objects, Nos. 2 and 3 respectively, and data for 9 additional objects. The additional data for objects 2 and 3 is for the 90° azimuth of the path of sight. The horizontal surface orientation, although previously reported, is herein repeated so that the complete set of data available for these objects for the 90° azimuth is in Table 4. The remaining objects, 4 through 12, are various Army materials and Navy ship paints.

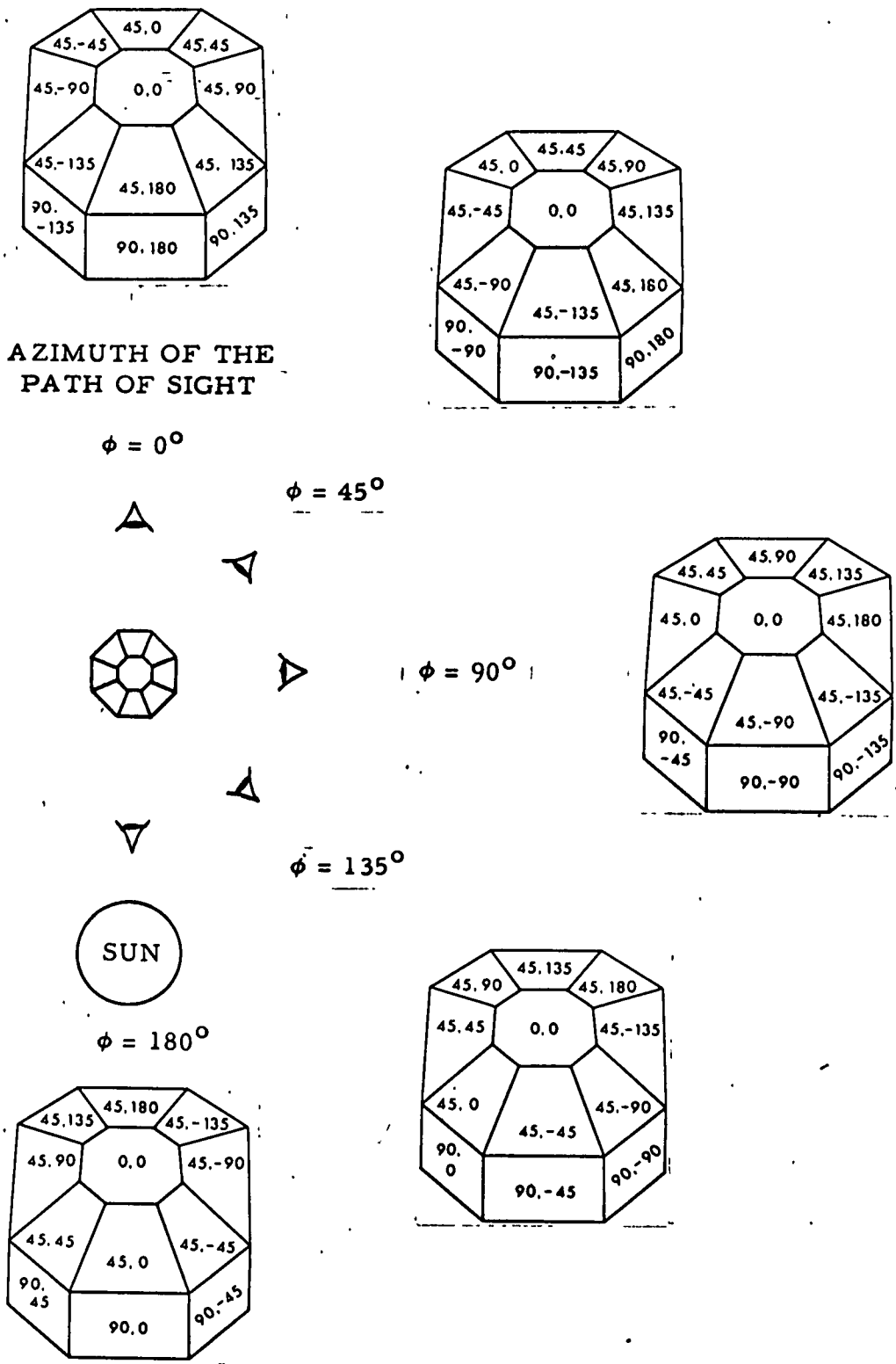

Fig. 1 Surfaces of three-dimensional objects; each number pair refers to the zenith angle and azimuth from the plane of the sun of the normal from the surface, respectively.

Table 4. Directional Luminous Reflectance of Objects.

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal From Surface: Zenith Angle	Normal From Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
2. Aluminum Paint[a]	55.8	90	0	0	0.362	0.362	0.370	0.380	0.385	0.420	0.440	0.440
	57.0	90	45	0	0.77	0.73	0.68	0.62	0.55			
	56.2	90	45	-90	0.292	0.303	0.342	0.400	0.455	0.495	0.51	0.51
	58.1	90	90	-45				0.415	0.485	0.61	0.66	0.73
	56.6	90	90	±90		0.210	0.225	0.255	0.285	0.340	0.350	0.370
3. Glossy White Paint[a]	55.5	90	0	0	0.92	0.91	0.90	0.89	0.86	0.78	0.70	0.64
	57.0	90	45	0	1.59	1.62	1.60	1.59	1.52			
	56.1	90	45	+90	0.72	0.74	0.79	0.82	0.82	0.88	0.88	0.86
	57.4	90	90	-45				1.05	1.16	1.26	1.27	1.28
	56.7	90	90	±90		0.320	0.340	0.375	0.430	0.470	0.475	0.480

a. Data taken with goniophotometer, January 1959

Table 4 Directional Luminous Reflectance of Objects

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
4. Olive Drab Paint[b]	40.4	0	0	0	0.170	0.200	0.240	0.286		0.425	0.490	
	40.4	0	45	180			0.0150	0.0135	0.0135	0.0136	0.0137	
	40.4	0	90	±135			0.0183	0.0153	0.0129	0.0113	0.0110	
	40.4	0	90	180			0.0135	0.0125	0.0107	0.0084	0.0077	
	39.6	90	0	0	0.170	0.161	0.158	0.160	0.165	0.170	0.174	
	39.6	90	45	-90			0.097	0.103	0.121	0.123	0.116	
	39.6	135	0	0	0.170	0.157	0.151	0.156	0.161	0.168	0.173	
	39.6	135	45	-45			0.180	0.184	0.186	0.190	0.197	
	39.6	135	90	0			0.138	0.130	0.129	0.132	0.138	
	39.6	135	90	-45			0.108	0.100	0.094	0.095	0.097	
	39.9	180	0	0	0.170	0.169	0.168	0.170	0.171	0.170	0.169	
	39.9	180	45	0			0.262[c]			0.235	0.225	
	39.9	180	90	0			0.159	0.148	0.141	0.139	0.141	
	39.9	180	90	±45			0.135	0.112	0.102	0.107	0.112	

b. Data taken with a goniophotometer, 10 October 1956.
c. NOTE: The zenith angle of the path of sight is 155°.

Table 4 Directional Luminous Reflectance of Objects

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
5. Olive Drab Duck Cloth[b,d]	40.4	0	0	0	0.130	0.132	0.138	0.153		0.270	0.332	
	40.4	0	45	180			0.0110	0.0099	0.0100	0.0100	0.0100	
	40.4	0	90	±135			0.0145	0.0116	0.0106	0.0100	0.0099	
	40.4	0	90	180			0.0116	0.0092	0.0080	0.0066	0.0060	
	39.6	90	0	0	0.130	0.120	0.122	0.138	0.152	0.171	0.184	
	39.6	90	45	-90			0.083	0.085	0.092	0.098	0.102	
	39.6	135	0	0	0.130	0.128	0.128	0.144	0.158	0.174	0.176	
	39.6	135	45	-45			0.136	0.130	0.131	0.135	0.138	
	39.6	135	90	0			0.147	0.145	0.122	0.114	0.113	
	39.6	135	90	-45			0.115	0.103	0.085	0.081	0.086	
	39.9	180	0	0	0.130	0.133	0.139	0.146	0.157	0.181	0.199	
	39.9	180	45	0			0.168[c]			0.156	0.164	
	39.9	180	90	0			0.159	0.129	0.117	0.115	0.116	
	39.9	180	90	±45			0.112	0.102	0.096	0.095	0.097	

b. Data taken with a goniophotometer, 10 October 1956.

c. NOTE: The zenith angle of the path of sight is 155°.

d. The spectral reflectance of the duck cloth was measured with a Hardy spectrophotometer. Using C.I.E. Illuminant B, chromaticity coordinates were x = 0.395, y = 0.403, z = 0.202; dominant wavelength = 577 mμ; and excitation purity = 32%.

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of the Path of Sight: 180	165	150	135	120	105	100	95
6. Olive Drab Fatigue Cloth[b,e]	40.4	0	0	0	0.168	0.186	0.220	0.274		0.460	0.50	
	40.4	0	45	180			0.0157	0.0137	0.0133	0.0131	0.0130	
	40.4	0	90	±135			0.0180	0.0151	0.0138	0.0115	0.0102	
	40.4	0	90	180			0.0151	0.0121	0.0101	0.0084	0.0077	
	39.6	90	0	0	0.168	0.170	0.182	0.199	0.220	0.288	0.333	
	39.6	90	45	- 90			0.097	0.116	0.147	0.170	0.175	
	39.6	135	0	0	0.168	0.152	0.149	0.158	0.171	0.200	0.225	
	39.6	135	45	- 45			0.170	0.170	0.186	0.220	0.233	
	39.6	135	90	0			0.132	0.124	0.131	0.140	0.147	
	39.6	135	90	- 45			0.097	0.084	0.084	0.102	0.116	
	39.9	180	0	0	0.168	0.155	0.155	0.158	0.162	0.178	0.196	
	39.9	180	45	0			0.209[c]			0.215	0.215	
	39.9	180	90	0			0.142	0.139	0.133	0.128	0.123	
	39.9	180	90	± 45			0.154	0.145	0.141	0.140	0.141	

b. Data taken with a goniophotometer, 10 October 1956.
c. NOTE: The zenith angle of the path of sight is 155°.
e. The spectral reflectance of the fatigue cloth was measured with a Hardy spectrophotometer. Using C.I.E. Illuminant B, chromaticity coordinates were x = 0.381, y = 0.396, z = 0.223; dominant wavelength = 574 mμ; and excitation purity = 26 %.

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of the Path of Sight: 180	165	150	135	120	105	100	95
7. Olive Drab Wool Cloth[b,f]	40.4	0	0	0	0.131	0.136	0.150	0.181		0.360	0.431	
	40.4	0	45	180			0.0120	0.0110	0.0108	0.0106	0.0107	
	40.4	0	90	±135			0.0160	0.0130	0.0120	0.0097	0.0084	
	40.4	0	90	180			0.0120	0.0095	0.0081	0.0068	0.0061	
	39.6	90	0	0	0.131	0.130	0.130	0.138	0.145	0.172	0.181	
	39.6	90	45	- 90			0.082	0.083	0.093	0.107	0.110	
	39.6	135	0	0	0.131	0.130	0.128	0.131	0.153	0.160	0.158	
	39.6	135	45	- 45			0.135	0.133	0.140	0.150	0.157	
	39.6	135	90	0			0.113	0.110	0.108	0.112	0.116	
	39.6	135	90	- 45			0.090	0.075	0.072	0.074	0.076	
	39.9	180	0	0	0.131	0.128	0.140	0.142	0.146	0.149	0.151	
	39.9	180	45	0			0.167[c]			0.168	0.166	
	39.9	180	90	0			0.135	0.116	0.109	0.106	0.107	
	39.9	180	90	± 45			0.125	0.101	0.093	0.091	0.094	

b. Data taken with a goniophotometer, 10 October 1956.
c. NOTE: The zenith angle of the path of sight is 155°.
f. The spectral reflectance of the wool cloth was measured with a Hardy spectrophotometer. Using C.I.E. Illuminant B, chromaticity coordinates were x = 0.423, y = 0.410, z = 0.167; dominant wavelength = 581 mμ; and excitation purity = 44 %

Table 4 Directional Luminous Reflectance of Objects

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
8. Ship Hull Paint, [g] No. 27	53.7	0	0	0	0.272	0.294	0.428	1.30	1.91	0.78	0.69	0.69
	53.6	0	45	180	0.0362	0.0304	0.0277	0.0275	0.0275	0.0278	0.0282	0.0281
Haze Gray (5-H) Spec. 52P45	53.5	0	90	±135			0.0224	0.0210	0.0206	0.0196	0.0199	0.0197
	53.6	0	90	180		0.0123	0.0149	0.0159	0.0167	0.0171	0.0175	
	53.5	90	0	0	0.272	0.276	0.276	0.276	0.276	0.248	0.240	0.236
	53.6	90	45	-90	0.158	0.154	0.151	0.150	0.148	0.148	0.148	0.148
	53.7	90	90	-45				0.071	0.096	0.167	0.233	0.309
	53.6	90	90	-90		0.0400	0.050	0.054	0.054	0.052	0.050	0.050
	53.7	90	90	-135			0.00425	0.0055	0.0079	0.0126	0.0158	
	53.7	180	0	0	0.272	0.263	0.272	0.283	0.304	0.283	0.287	0.290
	53.6	180	45	0		0.572	0.85	0.55	0.456	0.413	0.409	0.409
	53.6	180	90	0		0.312	0.365	0.420	0.406	0.362	0.364	
	53.5	180	90	±45		0.220	0.261	0.297	0.293	0.290	0.290	

g. Data taken with a goniophotometer on 21 November 1956.

Table 4 Directional Luminous Reflectance of Objects

Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of the Path of Sight: 180	165	150	135	120	105	100	95
9. Ship Paint,[g] No. 20, Gray Deck (Type A) Spec. 52P437	53.8	0	0	0	0.104	0.133	0.242	0.55	0.90	1.09	1.13	1.28
	53.5	90	0	0	0.104	0.102	0.097	0.097	0.100	0.111	0.115	0.121
	53.8	180	0	0	0.104	0.096	0.096	0.109	0.113	0.123	0.132	0.145
10. Carrier Deck Paint,[h] Gray (P-699)	40.6	0	0	0	0.116	0.140	0.176	0.228	0.272	0.332	0.368	
	39.5	45	0	0	0.116	0.126	0.126	0.126	0.132	0.145	0.164	0.194
	39.5	90	0	0	0.116	0.114	0.111	0.110	0.114	0.125	0.131	0.140
	39.5	135	0	0	0.116	0.111	0.107	0.109	0.111	0.122	0.132	0.150
	40.6	180	0	0	0.116	0.107	0.110	0.114	0.111	0.120	0.127	

g. Data taken with a goniophotometer on 21 Nov. 1956.
h. Data taken with a goniophotometer on 5 March 1958.

Table 4 Directional Luminous Reflectance of Objects

	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
11. Carrier Deck Paint, [h] Haze Gray, (Mil-P-15130)	40.8	0	0	0	0.198	0.235	0.410	0.61	0.325	0.334	0.382	
	40.7	0	90	180		0.0226	0.0228	0.0212	0.0190	0.0184	0.0184	
	40.0	45	0	0	0.198	0.224	0.190	0.184	0.187	0.193	0.210	
	39.7	45	90	-135		0.0370	0.0370	0.0344	0.0311	0.0288	0.0293	
	39.5	90	0	0	0.198	0.170	0.159	0.157	0.156	0.153	0.152	0.151
	39.1	90	90	-89		0.069	0.052	0.0442	0.0395	0.0380	0.0378	
	39.1	90		-91		0.056	0.0386	0.0322	0.0284	0.0255	0.0254	0.0254
	40.0	135	0	0	0.198	0.182	0.175	0.173	0.175	0.180	0.182	0.187
	39.7	135	90	-45		0.126	0.095	0.084	0.079	0.076	0.076	0.073
	40.8	180	0	0	0.198	0.195	0.206	0.228	0.207	0.211	0.215	0.222
	40.7	180	90	0		0.247	0.234	0.234	0.230	0.232	0.234	

h. Data taken with a goniophotometer on 5 March 1958.

Table 4 Directional Luminous Reflectance of Objects

	Object	Sun Zenith Angle	Azimuth of the Path of Sight Relative to the Sun	Normal from Surface: Zenith Angle	Normal from Surface: Azimuth	Zenith Angle of Path of Sight: 180	165	150	135	120	105	100	95
12	Submarine Deck Paint, Glossy Black, 122-2	45.5	0	0	0	0.0180	0.077	1.75	0.46	0.068	0.095	0.130	0.175
		45.5	180	0	0	0.0180	0.0145	0.0145	0.0155	0.0210	0.059	0.090	0.096

i. Data taken with a goniophotometer on 11 May 1960

4. CONTRAST AND CONTRAST TRANSMITTANCE

The most accurate means of determining the contrast of an object against a given background is to measure simultaneously the luminance of the object and the background. In order to utilize data taken on different days and over a small range of solar zenith angle, the data were put into the form of directional luminous reflectance. This form minimizes the effect of the change in total illuminance for small changes in sun zenith angle and air clarity. Thus the data from Sections 2 and 3 and from Gordon (1964) can be used in various combinations so as to obtain the contrast of 12 objects against 33 terrains. In addition, what has been termed an object may become a background for a given problem, or conversely what has been termed a background may be an object in yet another problem. Thus the number of contrasts derivable from the data are considerable.

The universal contrast transmittance is a function of the inherent background luminance, see Boileau (1964), as well as the beam transmittance and path luminance. All the data in this report and in Gordon (1964) are appropriate for use as background data for the computation of contrast transmittance with the data of Boileau (1964). The inherent background luminance is obtained by multiplying the appropriate directional luminous reflectance by the total illuminance, 5940 lumens/sq. ft.

5. REFERENCES

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