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Publication Date
1960-04-01

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April 1960
Index Number NS 714-100

Bureau of Ships
Contract NObs-72092

SIO REFERENCE 60-17

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ABSTRACT

Skylighting which is symmetrical about the zenith generates a light vector diagram which is symmetrical about the vertical axis. When the sun departs from a position of symmetry the light vector diagrams become distorted. The extent of this distortion can to some extent be predicted from a knowledge of the scattering and reflecting properties of the water. The method of prediction is explained.

On the Effect of Sun Altitude on the Horizontal Distribution of Natural Light Underwater

In homogeneous water, at a fixed depth, the distribution of light with azimuth angle in the horizontal plane will of course depend on the sun's altitude in the sky. If the sun is exactly at the zenith in a clear sky the light vector diagram for the horizontal plane will be a circle, that is, the magnitude of the flux will be a constant for all azimuths. If the sun were just below the horizon and the sky were clear, one would also expect that the horizontal light vector diagram would approach a circle of somewhat smaller magnitude than in the previous case. A truly circular light vector diagram would result in the latter case if the sky dome exhibited a constant gradient from zenith to horizon at all azimuths, but this is not the case at sunset.

In between sunset and zenith-sun the horizontal light vector diagram is known[1,2,3] to be pesudo-elliptical in shape. Thus, as the sun moves from the zenith to the horizon, the horizontal light vector diagram must stretch into a pseudo ellipse, attaining a maximum major axis at some intermediate sun angle and then shrink back again to a near circular shape at sunset.

Experimental data has recently been obtained by Dr. T. Sasaki[3] at the Tokyo University of Fisheries, Scientific Research Institute and his co-workers, Watanabe, Oshiba, and Okami, which demonstrates this sequence of changes in the horizontal light vector diagram.

The phenomena can be explained and the sun angle for maximum distortion of the light vector diagram can be predicted from fundamental hydro-optical considerations. There are two major factors which govern the shape of the horizontal light vector diagram. The first of these is intimately associated with the scattering function of the water. From Figure 1 it can be seen that as the sun sets and the angle of incidence, i, increases to 90°, the angle of refraction, r, increases to 48.6°, and $\theta = 90^\circ - r$ decreases to 41.4°. Considering only the collimated light from the sun, the objective lens of the instrument, which is pointed horizontally, will face more and more into the forward lobe of the scattering from this collimated beam as the sun sets. The reading obtained will therefore increase more or less proportional to the scattering function of the water and if nothing intervened would reach a maximum at sunset.

However, as i increases, the reflection of the air-water surface increases in accordance with Fresnel's equations and the flux transmitted through the boundary decreases, finally reaching zero at $i = 90^\circ$. The two effects are illustrated in Figure 2.* The Fresnel transmission data are plotted from zero to one hundred percent on the ordinate. The scattering function curve is taken from measurements of a water sample having an attenuation coefficient of .302 per meter, and a total scattering coefficient of .148 per meter. The directional scattering from the sun's collimated beam is assumed to be proportional to the shape of this scattering curve but the magnitude of the flux measured would be influenced by the depth at which measurements were made and by the volume of water involved. In the present problem Sasaki has measured the magnitude of the scattering and the scattering curve in Figure 2 is placed to conform with his maximum readings.

* The Fresnel computations are here based on a flat interface. A roughened surface would no doubt alter the figures to some extent as would any change from the assumed scattering function of the water.

The horizontal flux measured in the direction of the sun as a function of i or θ will evidently be proportional to the product of these two curves, illustrated in Figure 2 by the dashed line.

From Figure 2 the maximum distension of the horizontal light vector diagram will occur when the sun is 70° from the zenith. The maximum distension reported by Sasaki occurred when the sun's angle from the zenith was 67.5°. Sasaki's normalized data are plotted in Figure 2 as circled points. In plotting these points the flux in the direction opposite to the sun has been subtracted since for normalized data this portion of the flux is not affected by the position of the sun.

This same phenomena should of course be observable at other angles than horizontal, and should be greatly exaggerated for observation angles less than 48° from the zenith.

1. Johnson, N. G. and G. Liljequist
"On the Angular Distribution of Submarine Daylight and on the Total Submarine Illumination," Svenska Hydrografisk - Biologiska Kommissionens Skrifter. Ny Serie 14 pp 3- 15 (1938).

2. Whitney, L. V.
"The Angular Distribution of Characteristic Diffuse Light in Natural Water J. Mar. Research 4, 122-131 (1941)

3. Sasaki, T.; S. Watanabe, G. Oshiba, and N. Okami
"Measurements of Angular Distribution of Submarine Daylight by Means of a New Instrument, Jour. of the Oceanographical Society of Japan, Vol. 14, #2 pp 1-6,1958.

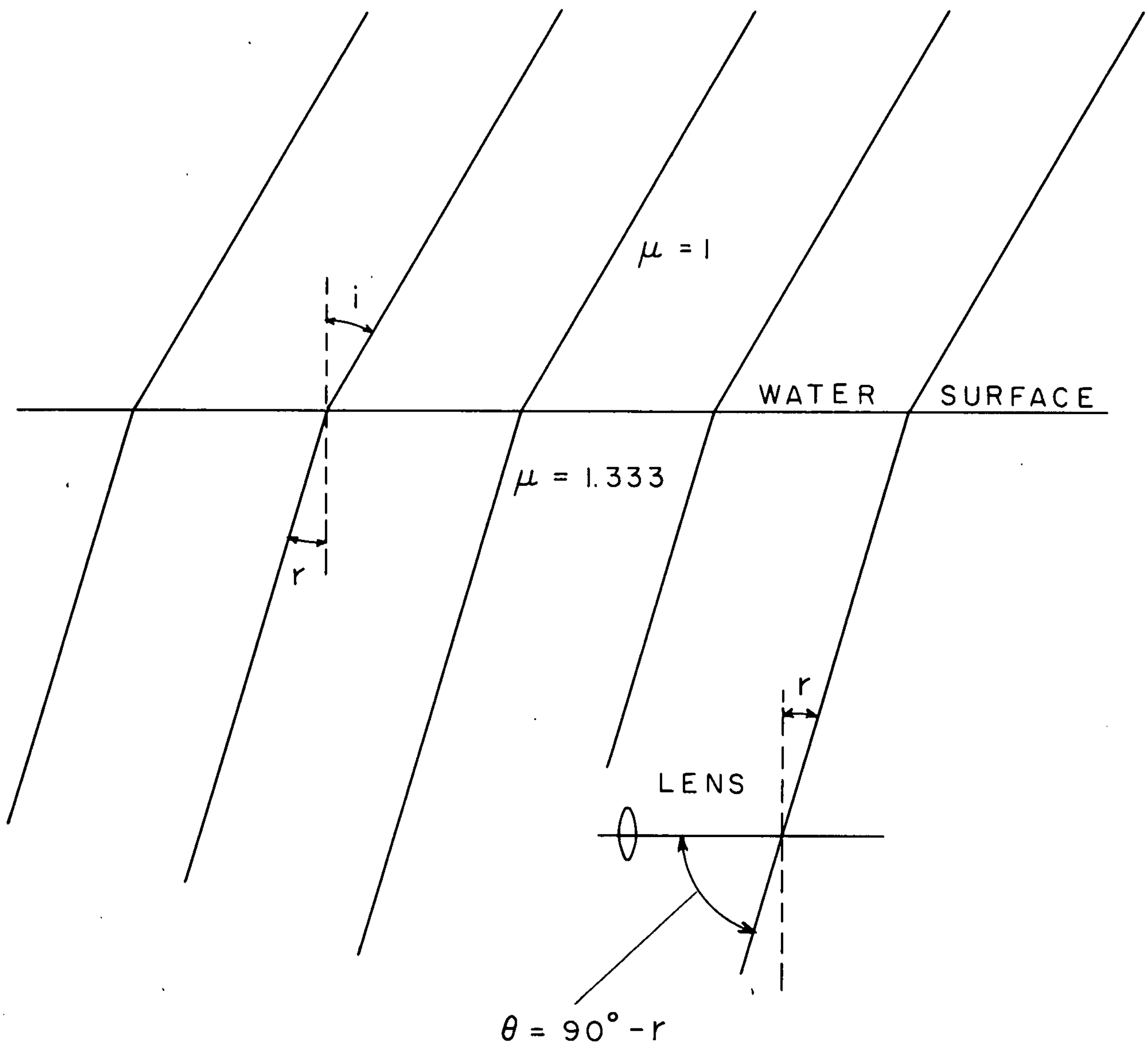

Figure 1

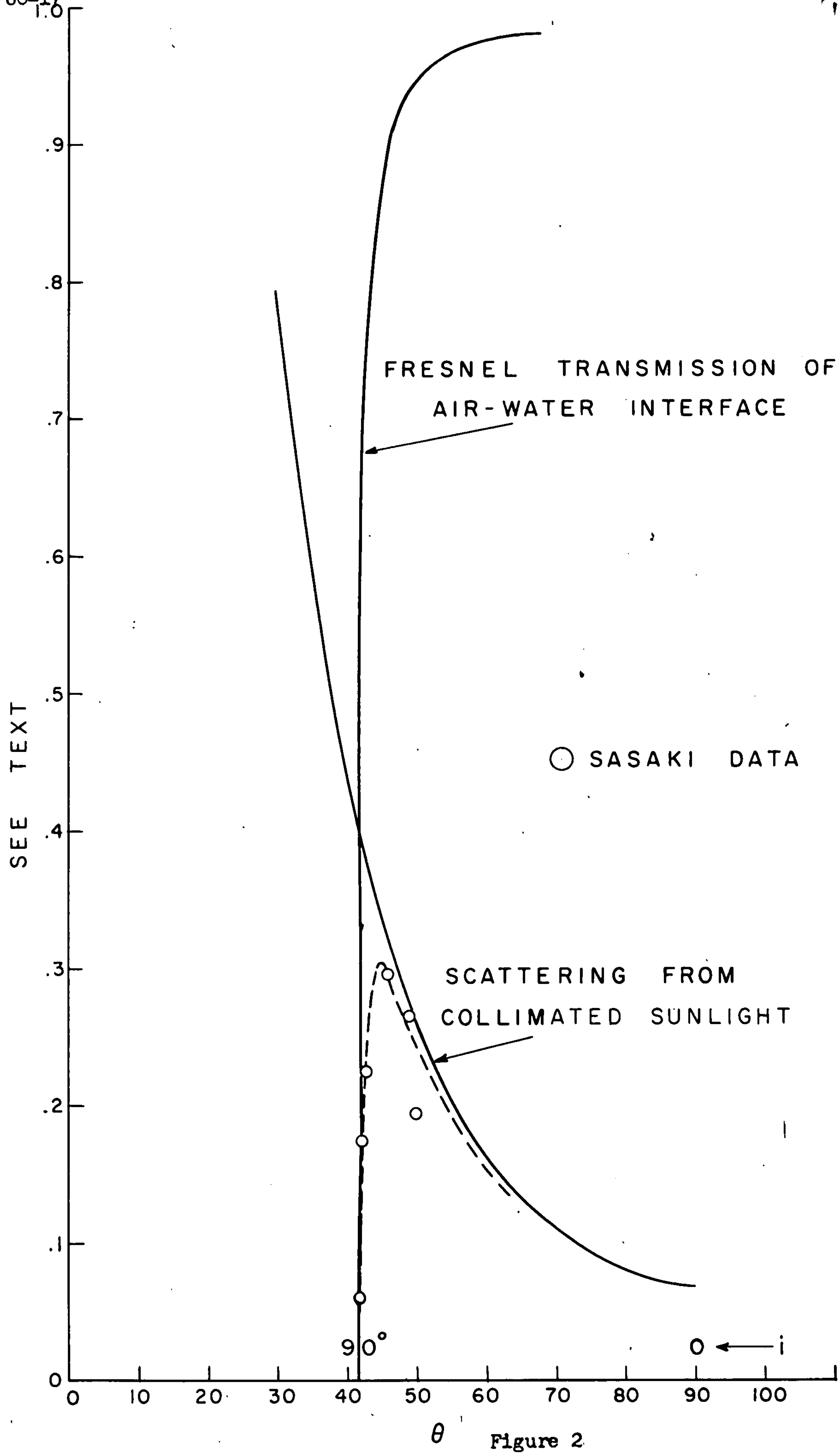
FRESNEL TRANSMISSION OF AIR-WATER INTERFACE
SASAKI DATA
SCATTERING FROM COLLIMATED SUNLIGHT
SEE TEXT
90°
0 ← i
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0 10 20 30 40 50 60 70 80 90 100
θ

Figure 2