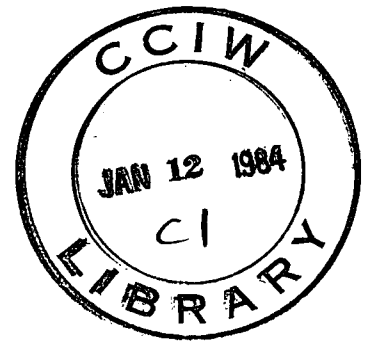# HYDRAULICS DIVISION

## TECHNICAL NOTE

**DATE:**        April, 1983        **REPORT NO.:**   ES. 83-02

**TITLE:**        The Effect of Replacing the Multiband

Transmittance Sensor Glass Window with a Plastic

Lucite SAR Window

**AUTHOR:**        R. Desrosiers

**REASON FOR REPORT:**        Request by J. Diaz, Technical Operations Divison,

NWRI

**CORRESPONDENCE FILE NO.:**   Study 372

## 1.0    INTRODUCTION

It was found that after many hundred profiles cracks began to appear and spalling occurred near the edges of the glass windows used in the NWRI multiband transmittance sensor. The glass (Schott BK 7 UVB NVS) window was replaced with a Dupont Lucite SAR (trademark) acrylic window. The structural calculations were discussed in detail in Reference 1. Reference 2 found that temperature cycling was not the likely cause of the problem.

This note discusses the potential optical effects caused by the transition from glass to plastic, and circuit changes required.

## 2.0    EFFECT OF THE CHANGE IN REFRACTIVE INDEX OF THE PLASTIC COMPARED TO THE GLASS

The refractive index of the Lucite SAR is 1.42. The refractive index at the helium d line of BK 7 glass is 1.517. Because the instrument is calibrated in air and used in water the reflectivity difference between plastic in water/air compared to glass in water/air will cause a difference in the signal. Also remember that because of the folded path, there are two possible reflections at the window and two at the retromirror, which are different in water compared to air.

For near normal incidence, the reflected power between a surface of refractive index $n_1$ and a surface of refractive index $n_2$ is

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

Thus consider the following interfaces.

Air/Plastic Window

$$R = \frac{(1.42-1)^2}{(1.42+1)^2} = 0.03012 \times (\text{number of surfaces} = 2) = 0.06028 \tag{1}$$

### Air/Glass Retromirror

$$R = \frac{(1.517-1)^2}{(1.517+1)^2} = 0.04219 \times (\text{number of surfaces} = 2) = 0.08438 \tag{2}$$

The sum of (1) + (2) is 0.14462

### Water/Plastic Window

$$R = \frac{(1.42-1.33)^2}{(1.42+1.33)} = 0.00107 \times 2 = 0.00214 \tag{3}$$

### Water/Glass Window

$$R = \frac{(1.517-1.33)^2}{(1.517+1.33)^2} = 0.00431 \times 2 = 0.00863 \tag{4}$$

The sum of (3) + (4) is 0.01077.

Thus with a plastic window and a glass retromirror the difference in reflectivity between being immersed in water and air is 0.14462 - 0.01077 = 0.13385 or 0.134 approximately

Compare this to the previous embodiment of the sensor in which both the window and retromirror were BK7. There are a total of four BK 7 surfaces. Thus in air the reflectivity would be.

Air/Glass:

$$R = \frac{(1.517-1)^2}{(1.517+1)^2} = 0.04219 \times (\text{number of surfaces} = 4) = 0.1688$$

Water/Glass:

$$R = \frac{(1.517-1.33)^2}{(1.517+1.33)^2} = 0.00431 \times 4 = 0.01724$$

Thus the difference is 0.1688 - 0.0172 = 0.152, in comparison to the value of 0.134 for the plastic.

Thus for a full scale value of one in water, the full scale value would be set to (1-0.152) or 0.848 or 0.85 using glass and 1-0.134 or 0.866 or 0.87 using plastic.

## 3.0    THE EFFECT OF WINDOW BENDING

Unlike glass which is very stiff, and does not deform under pressure, the plastic window would follow any deformation of the aluminum bulkhead.  H. Savile (Reference 1) has calculated that this sag is 0.06 mm.  The plastic window deformation will cause a lensing effect.  The bending of the window would have an effect as follows.

Using a formula from W. Smith Optical Engineering McGraw hill, 1966, p. 446, the radius of curvature R is, given a sagittal depth or height S, and a semidiameter of the plastic window Y,

$$R = \frac{Y^2+S^2}{2S}$$

The sag of the plastic would be the same as that of the aluminum.  Using the value of 0.06 mm, for S and 88/2 = 44 for Y,

$$R = 16,133 \text{ mm} = 16.1 \text{ m}.$$

To the first order a glass or plastic dome with water interface on one side and air on the other may be approximated as a water lens with curvature R. This is easily verified. The power of the water/plastic surface is

$$\phi_a = \frac{1}{R}(N_{plastic} - N_{water})$$

where $N_{plastic}$ = refractive index of plastic
$N_{water}$ = refractive index of water

The power of the plastic/air surface is

$$\phi_b = \frac{1}{R}(N_{air} - N_{plastic})$$

$N_{air}$ = refractive index of air = 1.

Neglecting the thickness of the plastic, to the first order, the power of the "lens" will be simply the surface contributions namely

$$\phi = \phi_a + \phi_b = \frac{1}{R}(N_{plastic} - N_{water} + N_{air} - N_{plastic})$$

$$= \frac{1}{R}(N_{air} - N_{water}) = \frac{1}{R}(1-N)$$

Because R is negative, it acts as a positive lens of power

$$\phi = \frac{1}{16,133}(1 - 1.33) = 2 \times 10^{-5} \text{ or focal length}$$

$$f = \frac{1}{\phi} = 48.9 \text{ metres.}$$

The focal length of the existing lens is approximately 100 mm. The addition of the plastic lens would result in a lens of power 1/100 +

1/48,900 or of focal length 99.8 mm. The approximate field of view is the radius of the field stop divided by the focal length.

This aperture is approximately 3.2 mm diameter. Thus the nominal field of view is 1.6/100 radians or 0.9167 degrees. If the focal length is 99.8 mm the field of view is 0.9816°.

Using San Diego Harbour data from T. Petzold, The Volume Scattering Function of Selected Ocean Waters, Scripps Institution of Oceanography, 1972, p. 59, the normalized scattering integral between 0 and 0.79433 degrees is 0.20056. Between 0 and 2.00 degrees it is 0.23109. Using linear interpolation we can calculate the effect from 0 to 0.9167° and then the effect from 0 to 0.9186° and compare the two. Simple calculations show that the effect on the integral is 0.2190 - 0.2187 or (0.003/0.2187) x 100 = 0.2%. This is the change in the error function which itself is about 20% of the true attenuation value, resulting in a change in the attenuation coefficient of 20 x 0.2 or 0.04%, which is negligible.

## 4.0    CHANGE IN THE PATH LENGTH

The thickness of the plastic is 9.525 mm compared to a thickness of 22.25 mm for the glass. Because the glass was thicker than the original window used for 100 m depth, a spacer was inserted. The plastic window is of the same thickness as the old glass window and so this spacer can be removed, thus maintaining exactly the same path length.

## 5.0    ABRASION RESISTANCE

The Lucite SAR was chosen specifically for its abrasion resistance. It is a new material unlike regular acrylic. Rubbing the surface with steel wool with light pressure has no visible effect, whereas compete scratching is observed with regular acrylic. It was for this reason that regular acrylic was not used as the window material in the first instance. While Lucite SAR is very abrasion resistant compared to

regular acrylic it is not quite as resistant as ordinary glass. For this reason a number of spare windows have been provided.

## 6.0 CIRCUIT CHANGES REQUIRED

As of June 1982, the full scale output voltage of the multiband transmittance sensor in air was changed from 4.25 V to 3.7 V to provide a transmittance in water which corresponded to that of previous sensors. This was doe at the request of Technical Operations Division. Thus correction factors which were previously used were no longer required.

The old value of 4.25 V was taken as 0.85 x the full scale voltage 5 V. If plastic would be used the value would be 0.866 x 5 = 4.33 V. If a correction factor of 1.15 is used to obtain similarity between the old and new instruments, then the value in air with the glass would be 4.25/1.15 or 3.7 V as was mentioned above. For plastic this would be 4.33/1.15 = 3.77 V. The change as a percentage of full scale from 3.7 to 3.77 would be only (3.77 - 3.7)/5 x 100 = 1.3% which is relatively small. This minor voltage change may be allowed for by adjustment of the potentiometers R17, R19, R21, R23, R25 on the sensor amplifer (see drawing SKE 80-024C, p. 116 of Operating Manual NWRI Multiband Transmittance and Temperature Profiler, ES-1116). Because of the small amount of adjustment required, these adjustments are not strictly necessary.

## 7.0 CONCLUSIONS

The effects of changing the glass window to plastic were calculated and found to be negligible. Two minor modifications were required, although one of these was optional. These were:

(1) Removal of a spacer ring (required).
(2) Adjustment of gain potentiometers to correct for a 1% variation in signal (optional).

## 8.0   REFERENCES

1.  H. Savile.  ESS Technical Note E82-06.

2.  R. Desrosiers, letter to H. Savile dated 16 November 1982.