Revisions to an Empirical Surface Loss Model Using a Correction for pH-Dependent Attenuation

Presented at the 127th Meeting of the
Acoustical Society of America, June 1994,
Cambridge, Massachusetts

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PREFACE

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            "Revisions to an Empirical Surface Loss Model Using a
            Correction for PH-Dependent Attenuation"

1. Please make the following corrections to the recently published
reference (a):

   a) Page 5: Correct the equation for SL_{m-s} to read:

$$SL_{m-s} = -20 \ LOG \left[0.3 + \frac{0.7}{1 + \left(\frac{FH}{10}\right)^2} \right]$$

   b) Page 10: Correct the equation for SL CORRECTION to read:

   $$SL \ CORRECTION = -.000281(FH)^3 + .0113(FH)^2 - .199(FH) + .0467$$

2. Any questions in this regard can be directed to R. J. Christian,
NUWC/NLONDET (Code 3112) commercial: (203)440-6149.

R. J. CHRISTIAN
By direction

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13. ABSTRACT (Maximum 200 words)

This document contains the presentation entitled "Revisions to an Empirical Surface Loss Model Using a Correction for pH-Dependent Attenuation," presented at the 127th meeting of the Acoustical Society of America, 7 June 1994, Cambridge, Massachusetts.

14. SUBJECT TERMS

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REVISIONS TO AN EMPIRICAL SURFACE LOSS MODEL USING A CORRECTION FOR pH-DEPENDENT ATTENUATION

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VIEWGRAPH 1

Empirically derived surface loss values are not obtained directly but are derived from propagation loss measurements that include at least two other components. Surface loss is determined by making assumptions with regard to spreading loss, volume attenuation, and bottom loss (if appropriate). Marsh and Schulkin [1] analyzed an extensive set of transmission loss data from surface duct propagation to obtain surface loss values. They assumed that attenuation was entirely due to magnesium sulfate and used the early Marsh-Schulkin [2] attenuation formula. (Thorp [3], Mellen et al. [4], and Francois Garrison [5] attenuation formulae were not known at the time.) Corrections to the Marsh-Schulkin surface loss data have been computed which account for the differences between the Marsh-Schulkin and Mellen et al. attenuation formulae. The revised values show less loss for all frequency-waveheight (FH) products. The Kuo [6] perturbation theory estimates of surface loss are shown to be in good agreement with the revised data at low FH products.

SURFACE LOSS MEASUREMENTS

BUBBLE ATTENUATION

SURFACE DUCT

SOURCE

DUCT LEAKAGE

RECEIVER

SINGLE SURFACE
INTERACTION

SURFACE LOSS = SOURCE LEVEL - TRANSMISSION LOSS - RECEIVE LEVEL

QUESTION: CAN THE SAME MODEL BE USED FOR DUCT AND NON-DUCT
CASES ?
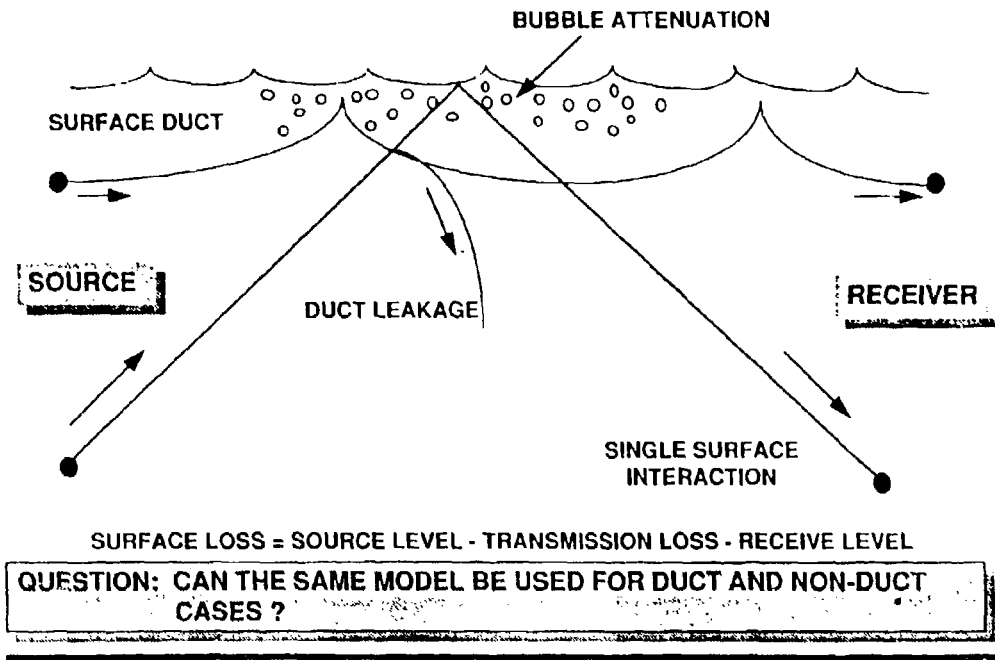
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VIEWGRAPH 2

Experimental measurements of surface boundary reflection loss has historically involved two different geometries: (1) multiple boundary interaction (surface duct) and shallow water propagation measurements where the surface loss is found by range averaging the results based on the number of surface reflections, and (2) single interaction measurements where loss at the surface boundary is found from a single source-surface receiver acoustic path. Both of these techniques derive surface loss values from propagation loss measurements that include at least two other components. Assumptions are made with regard to spreading loss, volume attenuation, surface duct leakage, and, possibly, bottom loss (if appropriate). Questions are raised about the appropriateness of a surface loss model based on ducted propagation conditions for use with non-duct situations. There is also concern about the accuracy of some of the older measurements when more simplistic attenuation models were the "state of the art."

A PROBLEM IN UNDERWATER SOUND MODELING

ATTENUATION

- THE MELLEN pH-DEPENDENT MODEL IS USED BY NUWC FOR ACOUSTIC MODELING (PRINCIPALLY BELOW 40 KHZ),

BUT

- THE MARSH-SCHULKIN SURFACE LOSS MODEL, NOW WIDELY USED, WAS VALIDATED USING THE MARSH-SCHULKIN ATTENUATION MODEL; THE COMBINATION OF THE TWO AGREES WITH THE EXPERIMENTAL DATA,

SO

- IS IT CONSISTENT TO USE MARSH-SCHULKIN SURFACE LOSS WITH MELLEN ATTENUATION?

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VIEWGRAPH 3

The Mellen pH-dependent attenuation model [4] is used by the Naval Undersea Warfare Center (NUWC), Detachment New London, for Acoustic modeling of Navy sonar applications (principally below 40 kHz). Implementation of the Mellen model required an examination of those empirically derived boundary loss models based on attenuation models different from the Mellen model. The Marsh-Schulkin (M-S) surface loss model [1], which is widely used, was derived using the Schulkin-Marsh (S-M). Prediction models using the combination of (M-S) surface loss and (S-M) attenuation were found in agreement with experimental data. A critical look at the appropriateness of using the M-S surface loss with Mellen attenuation is required.

MARSH - SCHULKIN SURFACE LOSS MODEL

- EMPIRICALLY DERIVED FROM THE AMOS, WHOI, AND NRL SURFACE LOSS MEASUREMENTS

- NORTH ATLANTIC OCEAN AND MEDITERRANEAN SEA LOCATIONS

- EXPLOSIVE SOURCES, FREQUENCIES 0.3 TO 16 KHZ.

- SURFACE DUCT PROPAGATION, LOW GRAZING ANGLES

- MOSTLY LOW SEA STATES

- ABSORPTION: $MgSO_4$ RELAXATION (SCHULKIN - MARSH)

- G. LEIBIGER FIT TO DATA USED IN GSM PROPAGATION MODELING.

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VIEWGRAPH 4

A review of the M-S model finds that it is based on empirically derived results from separate surface loss measurements by the Acoustic, Meteorological, and Oceanographic Survey (AMOS), Woods Hole Oceanographic Institute (WHOI), and the Naval Research Laboratory (NRL). The measurements were done mainly in the North Atlantic Ocean and some in the Mediterranean Sea. Explosive sources were used to measure acoustic surface duct receptions in the 0.3 to 16 kHz frequency band. The data consists of thousands of measurement samples that were collected in low sea state conditions (average SS2). Surface loss values were derived after accounting for propagation loss including absorption based on M-S magnesium sulfate ($MgSO_4$) relaxation formula. A fit to the M-S composite data was done by Gus Leibiger [7] formerly at NUWC Detachment New London and is used in both the Generic Sonar Model and the Ray mode acoustic propagation models.

LEIBIGER FIT TO MARSH-SCHULKIN SURFACE LOSS DATA

$$SL_{m-s} = -20 \, LOG \left[0.3 + \frac{0.7}{\left(1 + \frac{FH}{10}\right)^2} \right]$$

Y-axis: SURFACE LOSS (dB), values -2, 0, 2, 4, 6, 8, 10, 12

X-axis: FREQUENCY - WAVEHEIGHT (kHz-ft), values 10^0, 10^1, 10^2
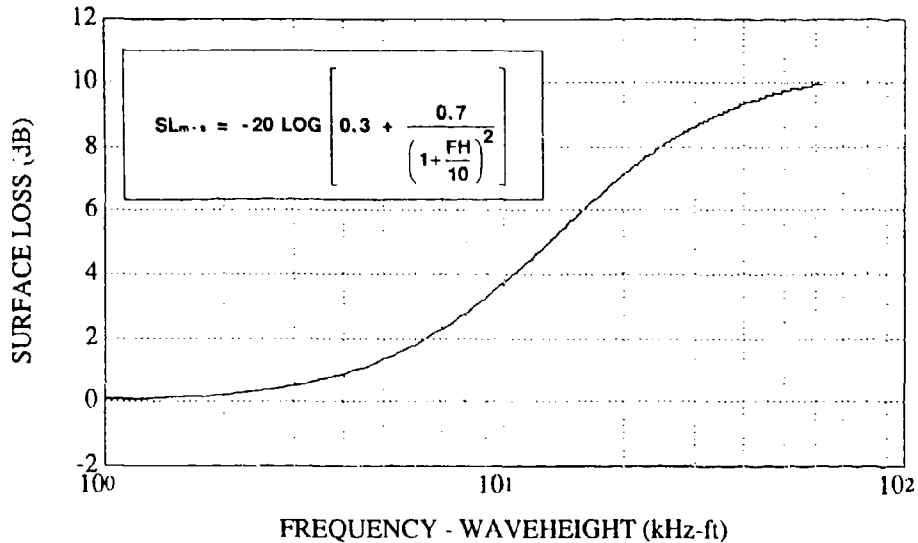
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VIEWGRAPH 5

The M-S data incorporates the frequency-waveheight (average waveheight) product as the independent variable for the Leibiger fit. There is no grazing angle dependence since the data are from surface duct measurements and the grazing angle is very small, 2-3 degrees. Thus, the M-S empirical surface loss model is used for low grazing acoustic propagation modeling. The surface loss results presented in this slide need to be corrected for the difference between the older AMOS, WHOI, NRL attenuation models [1] and the newer and more accurate Mellen attenuation model.

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ATTENUATION LOSS MODELS

	H$_2$O	MgSO$_4$	B(OH)$_3$	MgCO$_3$	pH-dep	Comments
	--------------- MECHANISM ---------------					
SCHULKIN-MARSH (AMOS)	X	X				FIRST RELAXA-TION FORMULA
THORP	(X)	X	X			IDENTIFIEDLOW F RELAXATION
FISHER-SIMMONS[9]	X	X	X			IMPROVED MgSO$_4$ & B(OH)$_3$ VALUES
THORP-LOVETT	(X)	X	X		X	LIMITED pH-DEP
FRANCOIS-GARRISON	X	X	X		X	NEGLECTS MgCO$_3$
MELLEN	(X)	X	X	X	X	MELLEN & F-G "STATE OF THE ART"

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VIEWGRAPH 6

Since these measurements were taken and the Marsh-Schulkin result derived, it was discovered that the attenuation of sound in seawater was significantly higher than had been assumed for the Marsh-Schulkin Analysis [3].

The new chemical Relaxation Absorption mechanisms, both pH-dependent, have been discovered [4]. The boric acid (B(OH)$_3$) relaxation is the dominant mechanism (fr≈1 kHz) At frequencies below several kilohertz. The magnesium carbonate (MgCO$_3$) relaxation is never dominant but can be significant in the 10-20 kHz regions.

Since surface loss is determined from transmission loss by assuming the value of attenuation, the revision of attenuation values higher would result in the revision of surface loss values lower.

COMPARISON OF "OLD" AND "NEW"
ATTENUATION FORMULAE
(PACIFIC OCEAN)
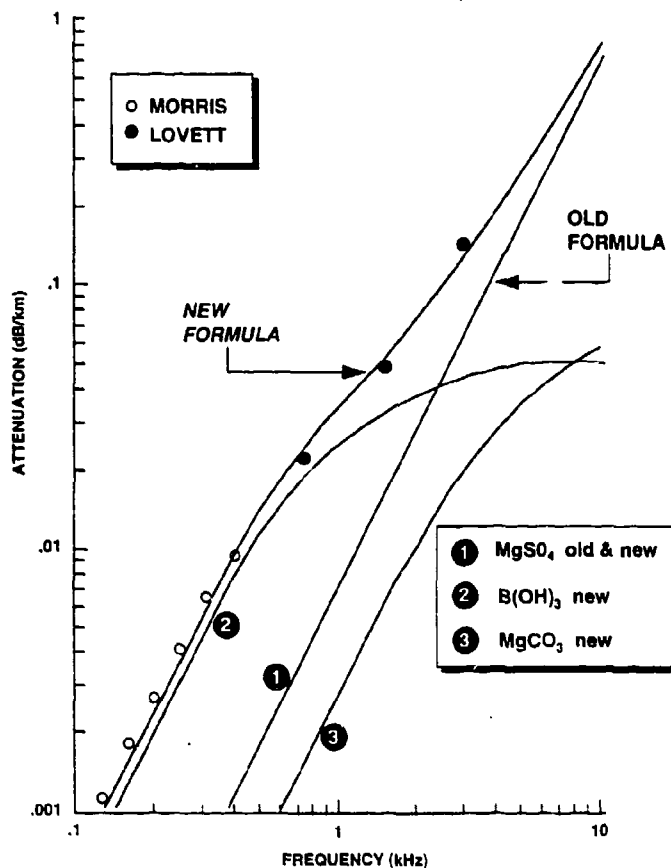
VIEWGRAPH 7

The three-component attenuation in seawater has been expressed as the Global Attenuation Model by Mellen [4] illustrated here for the North Pacific Ocean. A similar pH-dependent attenuation formula, which neglects the $MgCO_3$ component, has been developed by Francois and Garrison [5].

The $MgSO_4$ term is not pH-dependent, the $B(OH)_3$ and $MgCO_3$ components are pH-dependent. All components depend on temperature.

The value of pH can vary with the depth and also vary significantly from ocean to ocean at deeper depths [8-11]. At the surface, however, pH-values tend to be uniform due to the contact with the well-mixed atmosphere, and are usually the highest in the water column (typically pH > 8.3) [12].

3 - COMPONENT ABSORPTION MODEL (MELLEN)

$$A = A_1 (MgSO_4) + A_2 (B(OH)_3) + A_3 (MgCO_3)$$

$$A_n \simeq \frac{a_n f^2 f_n}{(f^2 + f_n^2)}$$

$a_1 = 0.5 \times 10^{d(km)/20}$ $f_1 = 60 \times 10^{(T-4)/50}$

$a_2 = 0.1 \times 10^{(pH-8)}$ $f_2 = 1 \times 10^{(T-4)/70}$

$a_3 = 0.03 \times 10^{(pH-8)}$ $f_3 = 6 \times 10^{(T-4)/30}$

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T = TEMPERATURE IN DEG C

VIEWGRAPH 8

As expected, the predicted attenuation using the Global Attenuation Model is greater for a surface duct than the older formulas (AMOS, WHOI, NRL), which were based only on the $MgSO_4$ relaxation. As mentioned previously, the high pH (the higher the pH, the higher the attenuation) in a surface duct makes the difference greater than it might be for deeper depths. This difference would also hold for shallow water [12].

ABSORPTION LOSS
MELLEN (pH-DEPENDENT) COMPARED WITH AMOS-NRL-WHOI IMPLEMENTATIONS
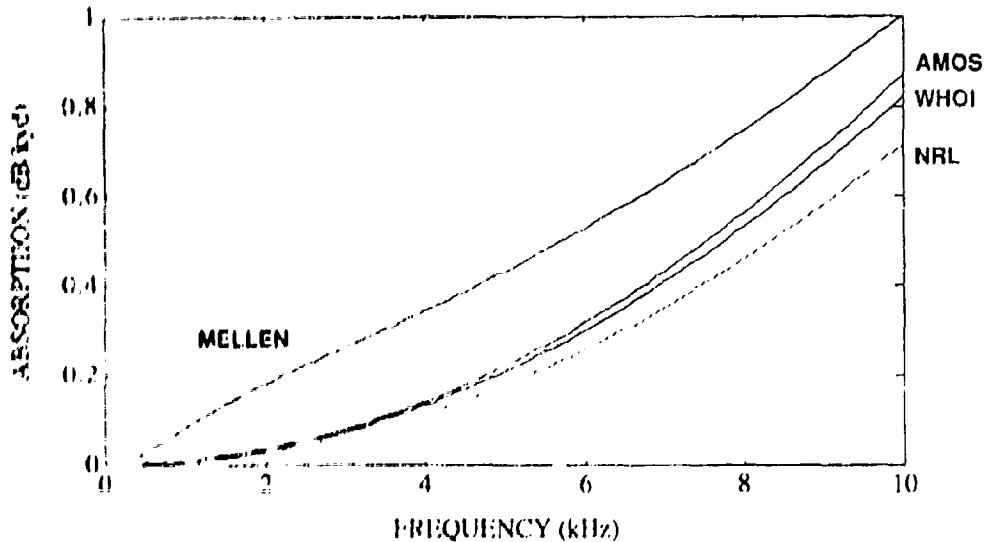
VIEWGRAPH 9

The frequency dependence of the Mellen vs. the AMOS-WHOI-NRL absorption loss is shown for the North Atlantic Ocean where the measurements were made. The Mellen result is for the mean absorption computed over the expected range of inputs associated with the sites of the surface loss measurements; specifically, pH = 8.25-8.18, temperature = 4-20°C, and salinity = 36.5-35.0 ppt. It is evident that the greater absorption loss of the Mellen model will result in a smaller derived surface loss relative to the original M-S analysis.

MARSH-SCHULKIN SURFACE LOSS WITH MELLEN pH ABSORPTION CORRECTION

$$SL_{rev}(FH) \cong SL_{m-s}(FH) + R_s \bullet \left[\alpha_{mellen}(F) - \alpha_{m-s}(F)\right] \quad (DB / BOUNCE)$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{\text{SL CORRECTION}}$$

WHERE,

$SL\ CORRECTION = -.0063(FH)^3 + .0022*(FH)^2 - .351(FH) + .085$

SL_{M-S} = LEIBIGER FIT TO MARSH-SCHULKIN (dB/ BOUNCE)

α_{MELLEN} = MELLEN ATTENUATION (dB PER KYD)

α_{M-S} = MARSH-SCHULKIN ATTENUATION (dB PER KYD)

R_s = MEAN SKIP DISTANCE (KYD PER BOUNCE)

H = AVERAGE WAVEHEIGHT = 2.5 FT (AMOS-WHOI-NRL DATA)

F = FREQUENCY IN KHZ

AND

$$R_s = \frac{\sqrt{L}}{2} = 5\ KYD$$

WHERE L = M-S (AMOS) MEDIAN
SURFACE LAYER DEPTH (100 FT)

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VIEWGRAPH 10

The absorption correction to the M-S surface loss can be found by applying the difference between the Mellen and M-S absorption to the mean ship distance (R_S) of the surface duct data. Following the results of the M-S analysis, the R_S is estimated to be 5 kyd. It was found that most of the M-S data are associated with an average wave height of H = 2.5 ft (SS2) and that therefore the FH-dependence of the surface loss data is principally a frequency-dependent phenomenon. However, there was a small amount of data at higher (SS4) and lower (SS0) wind speeds that did follow the FH-dependence seen at the SS2 conditions. The resultant SL correction is described with a cubic polynomial in FH, but it is noted that the coefficients were computed at a constant H = 2.5 ft, however, the expression is believed valid at other waveheights (SS0-SS4) and other attenuation environments.

MARSH-SCHULKIN SURFACE LOSS CORRECTED
FOR MELLEN ABSORPTION
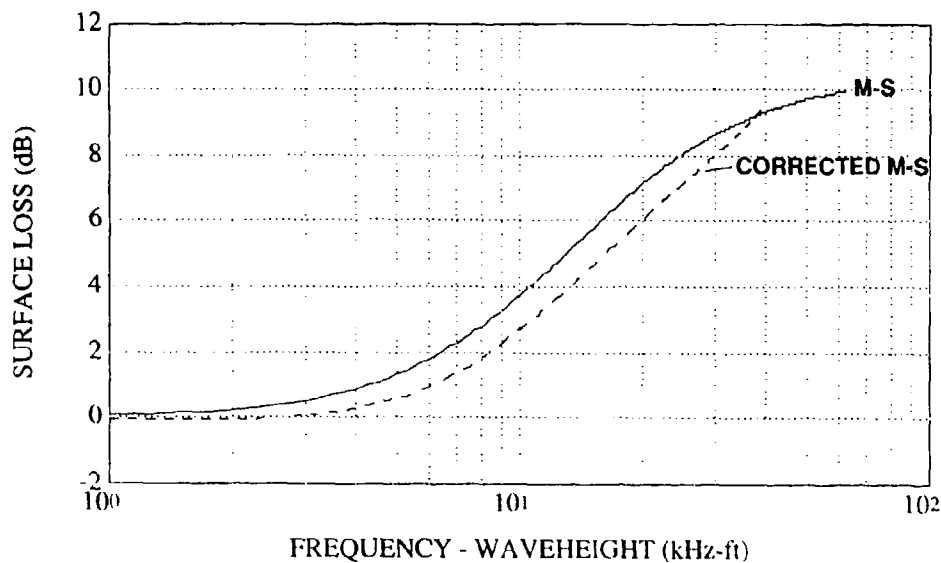
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VIEWGRAPH 11

The corrected M-S surface loss (as presented by the Leibiger fit) is shown in the viewgraph by the dashed line. The M-S surface loss has been reduced to a point where effectively zero surface loss is predicted for FH products less than 4. The magnitude of the correction is approximately 1 dB and is significant considering the small amount of surface boundary loss seen in the measurements. It is the corrected M-S surface loss relation that should be used for low grazing angle acoustic propagation modeling that uses the Mellen absorption model.

CORRECTED MARSH-SCHULKIN RESULTS COMPARED WITH ROUGH SURFACE SCATTERING THEORY OF KUO
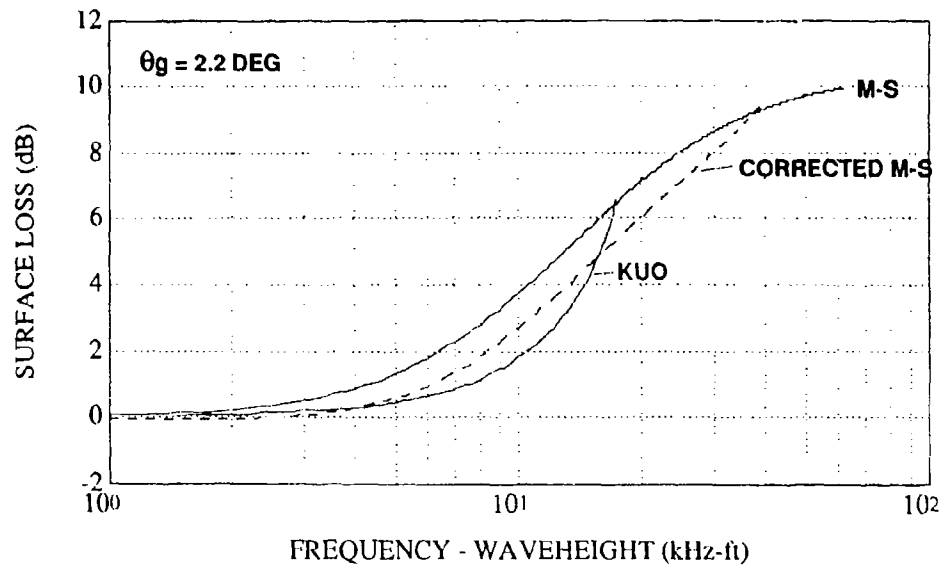
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VIEWGRAPH 12

A comparison of the corrected M-S with a rough surface scattering theory such as Kuo [6] shows that there is fair agreement below FH = 10 -- a far better agreement than with the uncorrected model. This comparison suggests that for FH < 10, the rough surface scattering mechanism is useful in explaining the empirical results. At higher FH values, it is evident that the Rayleigh parameter assumption R < 0.5 of the small perturbation theory is becoming invalid and precludes a meaningful comparison with the M-S results.

DAHL HIGH FREQUENCY (20-50 KHZ)
MEASUREMENT RESULTS
(APL-UW TR 9307 MAY 1993)

SINGLE REFLECTION NEAR-SURFACE BOUNDARY LOSS ATTRIBUTED TO BUBBLE ATTENUATION.

$$SBL(dB) = \frac{.00126}{\sin \theta} U^{1.57} F^{0.85} \qquad U \geq 4 \text{ m/s}$$

$$= SBL\big|_{U=4 \text{ m/s}} \; e^{10(4-U)} \qquad U < 4 \text{ m/s}$$

where   U = wind speed (m/s)

F = frequency (kHz)

θ = grazing angle (deg)

ASSUME PIERSON-MOSKOVITZ WINDSPEED-WAVEHEIGHT RELATION

$$SBL = \frac{.006}{\sin \theta} F^{0.85} H^{0.78}$$

where   H = average waveheight (ft)

$$SBL\big|_{2.2°} \cong 0.15 (F H)^{0.8}$$

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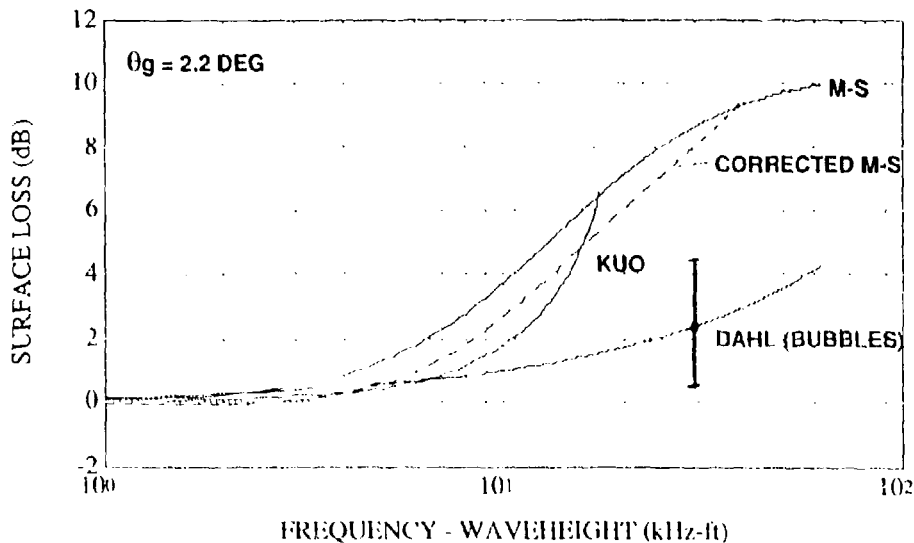## VIEWGRAPH 13

The M-S data at higher FH values are associated with higher frequencies up to 16 kHz where a bubble absorption mechanism for losses near the surface is expected to play an important role. Recent measurements by Dahl [13] at 20 to 50 kHz are used to empirically model the near-surface boundary loss due to bubbles. The surface boundary loss (SBL) equations for the Dahl model are shown with functional dependence on wind speed, frequency, and grazing angle. The model was used in comparison with the M-S data by invoking the Pierson-Moskovitz [14] windspeed-waveheight relation in order to obtain SBL as a function of frequency waveheight. The expression for SBL can be approximated by a power law relation in FH. The expression for SBL has been calculated for a grazing angle of 2.2° associated with the M-S data.

CORRECTED MARSH-SCHULKIN SURFACE LOSS COMPARED WITH DAHL HIGH FREQUENCY MEASUREMENT RESULTS

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VIEWGRAPH 14

The Dahl SBL is compared with the corrected M-S results. The error bar at FH = 30 shows approximate limits of the experimental uncertainty. The lower limit of applicability of the model is for U = 4 m/s (H = 0.7 ft) and F = 20 kHz with an FH = 14 kHz-ft.

It is evident that there is a difference between the two empirical models with M-S showing 6 dB greater surface loss at higher FH values. This result suggests that there is another loss mechanism (perhaps surface duct leakage) that is not included in the more complex propagation path of the M-S analysis.

CORRECTED MARSH-SCHULKIN SURFACE LOSS COMPARED WITH SINGLE INTERACTION BUBBLE MEASUREMENT AND MODELING RESULTS
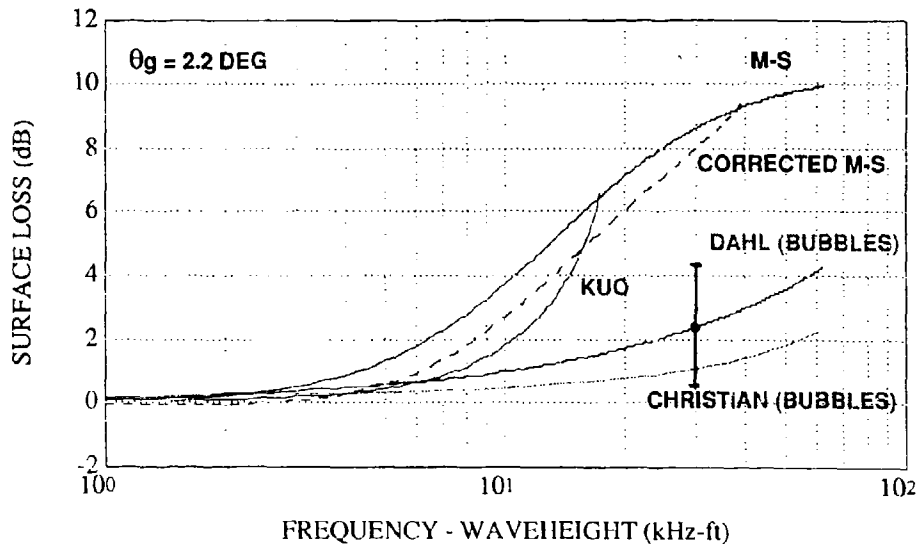
8/29/94   15

VIEWGRAPH 15

The loss due to near-surface bubbles for a single interaction geometry is modeled by Christian [15] and plotted for applicable FH products between 1 to 60 kHz-ft, corresponding to windspeeds of 7.5 to 12 m/s and frequencies of 1 to 10 kHz. Promising agreement between the Dahl measurements and the model are seen for windspeeds up to ~12 m/s. The similarity between the models at both high and low FH values suggests that the Dahl relation may be able to be extended to lower frequencies (< 20 kHz) than the measurements. The comparison of the Christian model with the M-S data also points to the differences between the surface duct data analysis and the single interaction treatments of the surface boundary loss.

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SUMMARY/CONCLUSIONS

- CORRECTING THE MARSH-SCHULKIN DUCTED SURFACE LOSS MEASUREMENTS FOR THE DIFFERENCE BETWEEN THE $MgSO_4$ ABSORPTION AND THE CURRENT 3-COMPONENT ABSORPTION MODEL (MELLEN) YIELDS SMALLER SURFACE LOSS VALUES.

- CORRECTED SURFACE LOSS VALUES AT LOW F-H PRODUCTS (< 10 KHZ-FT) SHOW AGREEMENT WITH ROUGH SURFACE SCATTERING THEORY (EG. KUO). LOSSES ARE NEAR ZERO FOR F-H PRODUCTS < 5 KHZ-FT.

- SINGLE INTERACTION BUBBLE MEASUREMENTS AT HIGH FREQUENCY (DAHL, 20-50 KHZ) AND MODERATE FREQUENCY MODELING (CHRISTIAN, 1-10 KHZ) SHOW CONSIDERABLY LESS SURFACE LOSS THAN THE HIGH F-H PRODUCT M-S DATA. RESULTS SUGGEST ADDITIONAL LOSSES ASSOCIATED WITH SURFACE DUCT PROPAGATION ARE PRESENT IN THE M-S RESULTS.

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VIEWGRAPH 16

It has been shown that correcting the M-S surface loss empirical model for the difference between a $MgSO_4$ absorption and the Mellen three-component model yields smaller surface loss values by up to 1 dB. The corrected M-S relation shows agreement with rough surface scattering theory with near-zero losses seen at low FH products (< 5 kHz-ft). Comparison of the corrected M-S surface loss relation with that derived from ducted measurements, with single interaction bubble measurements (Dahl) and modeling (Christian) show considerably less loss associated with the single interaction results at high FH products. The additional loss associated with surface duct propagation may be due to duct leakage.

SUMMARY/CONCLUSIONS (cont)

- IN-DUCT SURFACE LOSS (ATTENUATION PLUS DUCT LEAKAGE) CANNOT BE REPRESENTED BY THE SAME EXPRESSION AS NON-DUCT LOSS (ATTENUATION ONLY)
- FOR IN-DUCT SURFACE LOSS, THE CORRECTED MARSH-SHULKIN EXPRESSION PLUS MELLEN ATTENUATION GIVES RESULTS CONSISTENT WITH THE MARSH-SCHULKIN DATA.

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VIEWGRAPH 17

It appears that the in-duct surface loss cannot be represented by the same expressions as those non-duct cases. However, the corrected M-S expression used with the Mellen attenuation provides consistent results with the Marsh-Schulkin data. Non-duct acoustic propagation modeling should incorporate the single interaction surface loss models, where possible, and the surface duct modeling should implement the corrected M-S results together with the Mellen absorption model.

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