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ANALOGIES BETWEEN EM AND ACOUSTIC WAVES*

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Introduction

The purpose of this report is to summarize the results of a considerable amount of work in the field of acoustic simulation of radar return so that the reader may be readily confident about the validity of this inexpensive laboratory tool.

Acoustic simulation readily permits experimental verification of scatter theories which would otherwise be costly and time consuming.

Wave Equations

Electromagnetic

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}$$

$$\nabla \times H = \epsilon \frac{\partial E}{\partial t}$$

Acoustic

$$\nabla P = -\rho_l \frac{\partial u}{\partial t}$$

$$\nabla \cdot u = -K_l \frac{\partial P}{\partial t}$$

for plane sinusoidal waves in the x-direction:

$$\frac{dE_y}{dx} = -i\omega\mu H_z$$

$$\frac{dH_z}{dx} = -i\omega\epsilon E_y$$

$$\frac{dP}{dx} = -i\omega\rho_l u_x$$

$$\frac{du_x}{dx} = -i\omega K_l P$$

taking the divergence of (1) and the substitution of (2)

$$\nabla^2 E = \mu\epsilon \frac{\partial^2 E}{\partial t^2}$$

$$\nabla^2 H = \mu\epsilon \frac{\partial^2 H}{\partial t^2}$$

$$\nabla^2 P = \rho_l K_l \frac{\partial^2 P}{\partial t^2}$$

$$\nabla^2 u = \rho_l K_l \frac{\partial^2 u}{\partial t^2}$$

where

E = electric field vector

H = magnetic field vector

ϵ = dielectric constant

μ = permeability

P = pressure field scalar

u = particle velocity vector

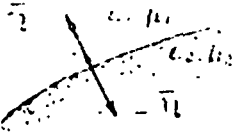
ρ_l = density of the medium

K_l = compressibility of medium

Simulation of electromagnetic waves using acoustic waves is always feasible when their respective boundary conditions are nearly the same.

BOUNDARY CONDITIONS

Electromagnetic



Most General Form

$$\bar{n} \times (\bar{E}_1 - \bar{E}_2) = Q \quad (1)$$

$$\bar{n} \times (\bar{H}_1 - \bar{H}_2) = J_s \quad (2)$$

When:

$$M_1/M_2 = \text{Dielectric/Dielectric} \quad Q = 0 \\ J_s = 0$$

$$M_1/M_2 = \text{Dielectric/Perf. Cond.} \quad Q \neq 0 \\ \sigma = \infty \quad \bar{E}_2 = \bar{H}_2 = 0 \quad J_s = 0$$

$$M_1/M_2 = \text{Dielectric/Imp. Cond.} \quad Q \neq 0 \\ \sigma = \text{finite} \quad J_s = 0$$

$$\text{Perfect} \\ M_1/M_2 = \text{Conductor/Imp. Cond.} \quad Q \neq 0 \\ \bar{E}_1 = \bar{H}_1 = 0 \quad J_s \neq 0$$

Acoustic



Most General Form

$$P_1 = P_2 \quad (1)$$

$$\bar{n} \cdot (\bar{U}_1 - \bar{U}_2) = 0 \quad (2)$$

When:

$$M_1/M_2 = \text{Liquid/Liquid} \quad P_1 = P_2 \\ \bar{n} \cdot (\bar{U}_1 - \bar{U}_2) = 0$$

$$M_1/M_2 = \text{Liquid/Solid Rigid} \quad P_1 = P_2 = 0 \\ \bar{n} \cdot (\bar{U}_1 - \bar{U}_2) = 0$$

$$M_1/M_2 = \text{Liquid/Semielastic Solid} \quad P_1 = P_2 = 0 \\ U_{\text{total}} = U_t = 2U_{\text{incident}}$$

$$M_1/M_2 = \text{Solid/Elastic Rigid Solid} \quad P_1 = P_2 = 0 \\ \bar{n} \cdot (\bar{U}_1 - \bar{U}_2) = 0$$

Conductors

Perfect Conductor: $\sigma \rightarrow \infty$
 Imperfect Conductor: $\sigma = \text{finite}$
 Insulator: $\sigma = 0$

Solid Surfaces

Rigid Surface: $\mu \Rightarrow \infty$
 Elastic Surface: $\mu = \text{finite}$
 Liquid Surface: $\mu = 0$

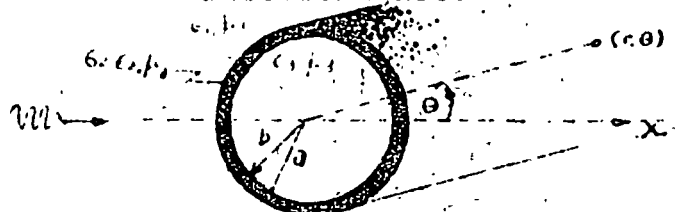
For the EM and Acoustic field $\bar{n}$ is a unit vector normal to the surface. The equations state that the tangential components of $\bar{E}$ and $\bar{H}$ are continuous across the boundary as are the pressure P and the normal component of the particle velocity $\bar{v}$.

Boundary conditions at a perfect conductor require the tangential electric field to be zero and the tangential magnetic field to be two times the incident field. On the other hand at a perfectly elastic wall (pressure release surface) the dynamic pressure is zero and the normal component of the total particle velocity is twice the normal component of the incident particle velocity. In each of these situations there is no wave propagation beyond the interface.

When a plane electromagnetic wave is normally incident on a perfectly conducting plane surface, the field components are both parallel to the surface and the electric field component can be made equivalent to either the pressure of the particle velocity in the acoustic wave using a perfectly elastic boundary in the first case and a perfectly rigid boundary in the second.

SCATTERING FROM A CYLINDER

Electromagnetic



$b = 0$ Dielectric Cylinder

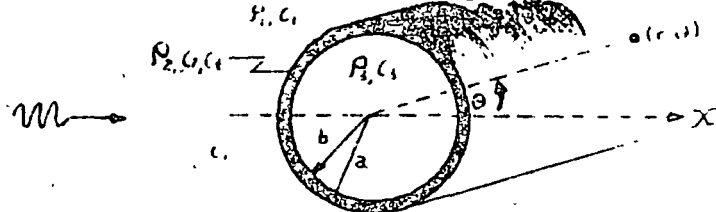
(W. L. Weeks, 1964)

$\sigma \rightarrow \infty$ Conducting Cylinder

(W. L. Weeks, 1964)

$b \approx a$ Thin Cylindrical Shell

Acoustic



$b = 0$ Solid Elastic Cylinder

(R. D. Doolittle, 1966)

$\mu \rightarrow \infty$ Rigid Cylinder

$b = 0, \mu = 0, \lambda = 0$ Liquid Cylinder

(P. Tamarkin, 1949)

$$\Phi_{\text{total}} = \Phi_{\text{incident}} + \Phi_{\text{scattered}}$$

$$\Phi_{\text{incident}} = \Phi_0 e^{iKx} = \Phi_0 \sum_{n=0}^{\infty} i^n \epsilon_n J_n(Kr) \cos(n\theta)$$

$$\Phi_{\text{scattered}} = \Phi_0 \sum_{n=0}^{\infty} i^n \epsilon_n a_n H_n^{(1)}(Kr) \cos(n\theta)$$

$$\text{where: } \epsilon_n = 2 - \delta_{n0} = \begin{cases} 1 & \text{for } n = 0 \\ 2 & \text{for } n \neq 0 \end{cases}$$

a_n = constant depending on the boundary conditions

J_n, H_n = Bessel and Hankel functions

$e^{-i\omega t}$ = time dependence has been suppressed

$\Phi = E$ = Electric Potential

σ = Conductivity

ϵ = Permittivity

μ = Permeability

$\Phi = P$ = Pressure Potential

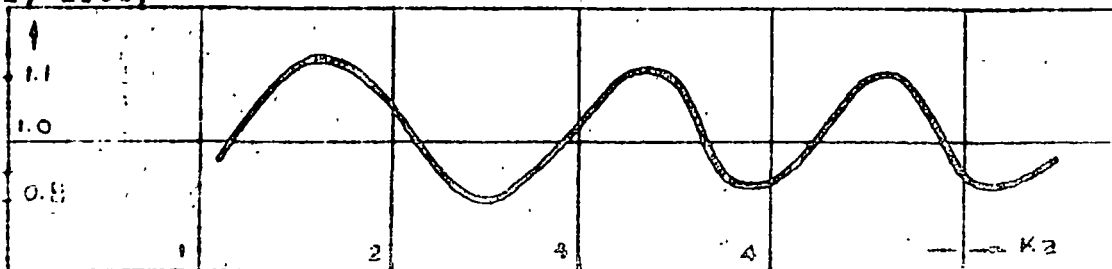
μ = Lamé Constant

ρ = density

$c_{1,t}$ = Velocities (Longitudinal, transverse)

(H. Ufberg, 1966)

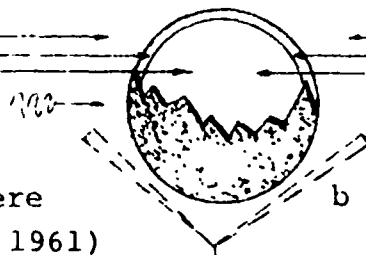
Scattering from Rigid or Conducting Cylinder



SCATTERING FROM A SPHERE

Electromagnetic

$\epsilon, \mu, k_1, k_2, k_3$



Acoustic

ρ_1, c_1, c_t
 ρ_2, c_2, c_t
 ρ_3, c_3

$b = 0$ Dielectric Sphere
(D. T. Thomas, 1961)

$\sigma \rightarrow \infty$ Conducting Sphere
(R. F. Goodrich, 1961)

$b \equiv a$ Spherical Shell
(A. L. Laden, 1952)

$b = 0$ Solid Elastic Sphere
(R. Hickling, 1962)

$\mu \rightarrow \infty$ Rigid Sphere
(R. B. Lindsay, 1960)

$b = 0, \mu = 0, \lambda \neq 0$ Liquid Sphere
(A. L. Laden, 1952)

$$\Phi_{\text{total}} = \Phi_{\text{incident}} + \Phi_{\text{scattered}}$$

$$\Phi_{\text{incident}} = \Phi_0 \exp(iKr \cos \theta) = \Phi_0 \sum_{n=0}^{\infty} (2n+1) i^n P_n(\cos \theta) j_n(Kr)$$

$$\Phi_{\text{scattered}} = \Phi_0 \sum_{n=0}^{\infty} a_n h_n(kr) P_n(\cos \theta)$$

where a_n = constant depending on the boundary conditions

P_n = Legendre polynomial

h_n = spherical Bessel function

J_n = Bessel function

$e^{-i\omega t}$ = time dependence has been suppressed

$\Phi = E$ = Electric Potential

σ = Conductivity

ϵ = Permittivity

μ = Permeability

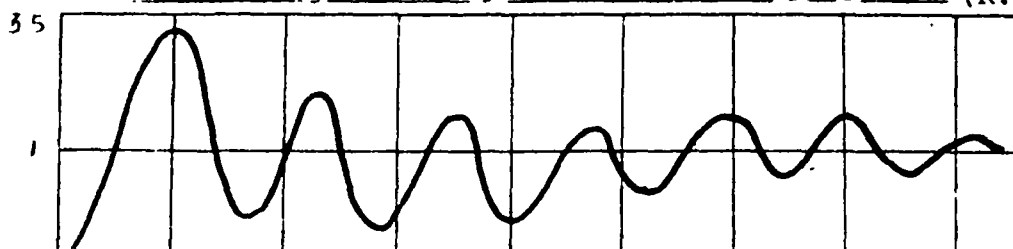
$\Phi = P$ = Pressure

μ = Lamé Const.

ρ = Density

$c_{1,t}$ = Velocities of Sound

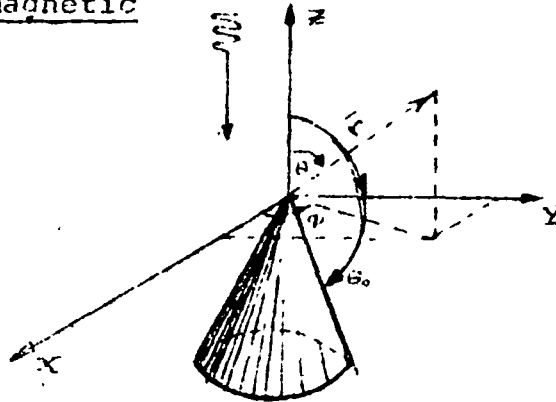
Scattering from Rigid or Conducting Sphere (R. F. Goodrich, 1961)



SCATTERING FROM A CONE

Electromagnetic

Acoustic

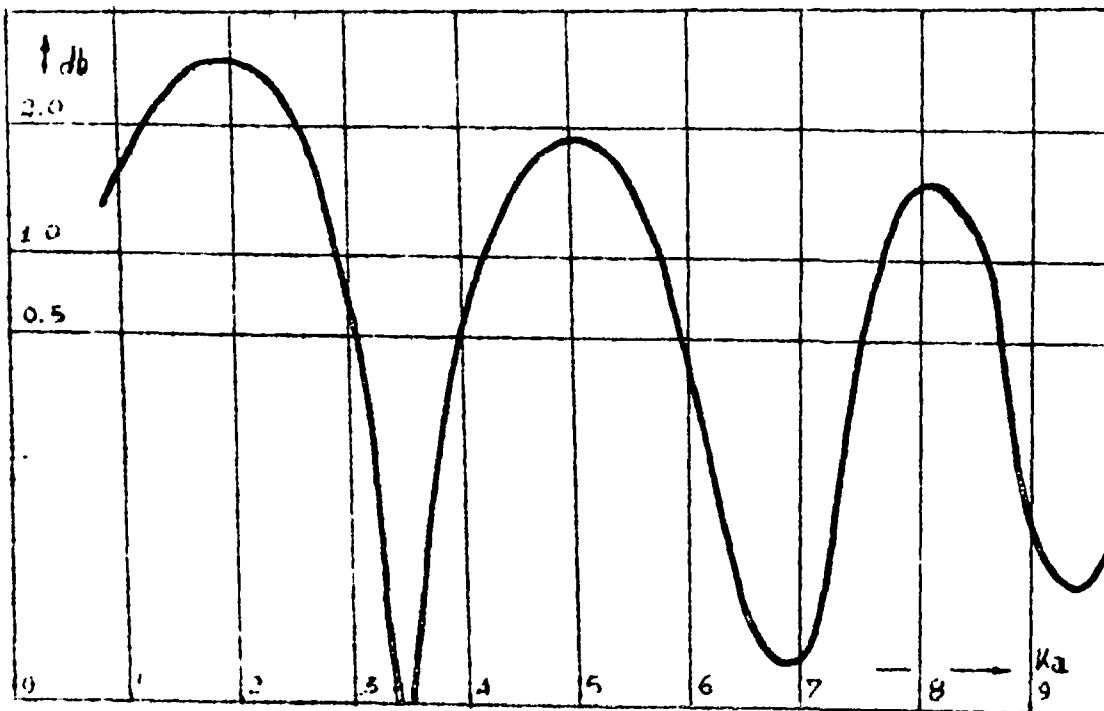


$$\begin{aligned} x &= r \cos \phi \sin \theta \\ y &= r \sin \phi \sin \theta \\ z &= r \cos \theta \end{aligned}$$

For the special case of a finite cone, flat-backed (base is circular or radius a), and a given height h with a semivertex angle $\pi - \theta_0$, the scattered far field amplitude is given by the following approximation formula (good for high frequencies). (R. F. Kleinman, 1966)

$$S = \frac{4i\pi}{\lambda^2} \tan^2 \theta_0 \int_0^h e^{2iKu} du$$

Flat-backed cone $\pi - \theta_0 = 4^\circ$ (R. F. Kleinman, 1966)



Experimental Verification

For nearly smooth surfaces, the surface characteristic constant $1/B = 0$, and (3.15) gives the scattering coefficient. This result compares very closely with published results [Nielson, 1960] for new ice as shown in table 2.

For rough (not nearly smooth) surfaces, (3.14) describes the relationship of the scattering coefficient σ_0 and other variables such as the angle of incidence θ , wavelength λ , standard deviation σ and surface covariance constant B , etc. Two curves of the scattering coefficient σ_0 versus θ for each of the three values of λ/B , 0.1, 0.5, and 1.0 for σ/λ equal to 0.05, and 0.1 are shown in figure 4. It may be noticed that as the surface becomes rougher, or as λ/B increases for a specified λ , the scattering coefficient curve becomes flatter, showing the relative importance of the contribution of the power return from the surface at angles other than those near zero. As expected, when the surface becomes smoother or $1/B$ decreases, the received power seems to come primarily from near-zero angles. These curves are quite similar to those recently published [Campbell, 1959; Dye, 1959; Edison, 1960]. The experimental data [Nielson, 1960] on desert and new ice also seems to follow the pattern of these theoretical curves described above.

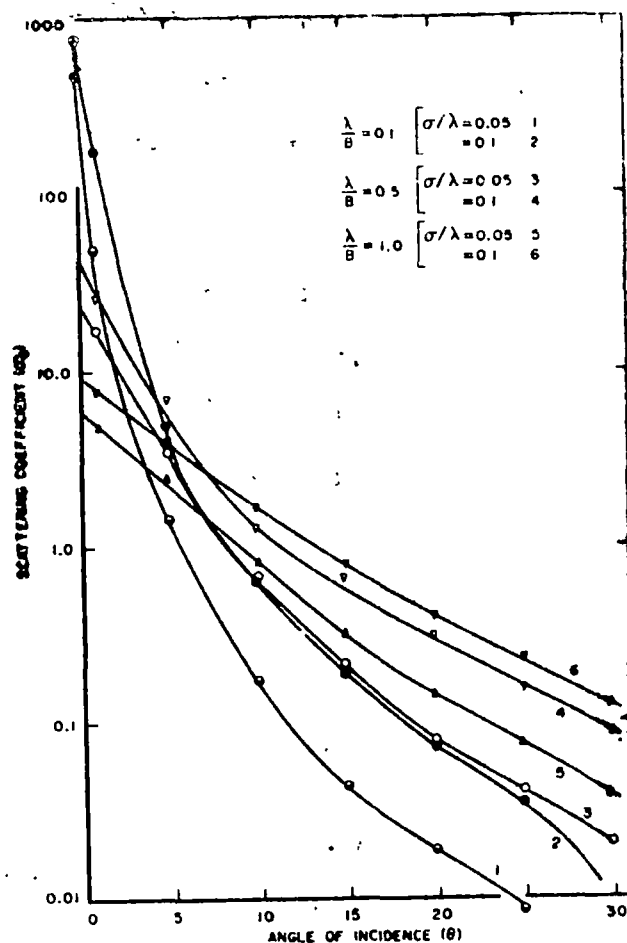


FIGURE 4. Scattering coefficient versus the angle of incidence.

The scattering coefficient (σ_0) for nearly smooth surfaces is inversely proportional to the wavelength, but varies directly with (σ^2) , $(\theta \cot^2 \theta)$ and $1/B$, where σ , θ , B are standard deviation, angle of incidence, and the terrain characteristic constant respectively. For rough surfaces it has a negative exponential

factor, where the exponent is made up of $\frac{\sigma^2 \cos^2 \theta}{\lambda^2}$

times a constant. The surface characteristic constants B and σ can be calculated from the radar return data. Although approximate, the theoretical results agree well with the experimental data; and therefore, suggest the usefulness of the approach. The application of these results may be extended to the moon-echo data, with proper corrections for Faraday and liberation effects, etc. This investigation has established that for near-vertical incidence, the normalized autocovariance for the terrain elevation is more often of the exponential form $\exp(-|r|/B)$ rather than the Gaussian form, $\exp(-r^2/B)$. The former may well be more appropriate for finer terrain irregularities than those considered in this

Comparison of theoretical versus experimental scattering coefficient
(Normalized)

θ°	σ_0 Theoretical	σ_0 Experimental
30	1.000	1.000
40	0.291	0.308
50	0.084	0.089
60	0.022	0.024
70	0.004	0.004

* H. S. HAYRE & R. K. MOORE. Theoretical Scattering Coef for near Vertical Incidence from Contour Maps, Journal of Research Vol. B5D, Sept-1961 pp 431.

The distinction between beam-width and pulse-length limiting of the illuminated area is a function of altitude¹ and is given by

$$1 + \frac{v\tau}{2h} = \sec \theta_0 \quad (6-1)$$

where

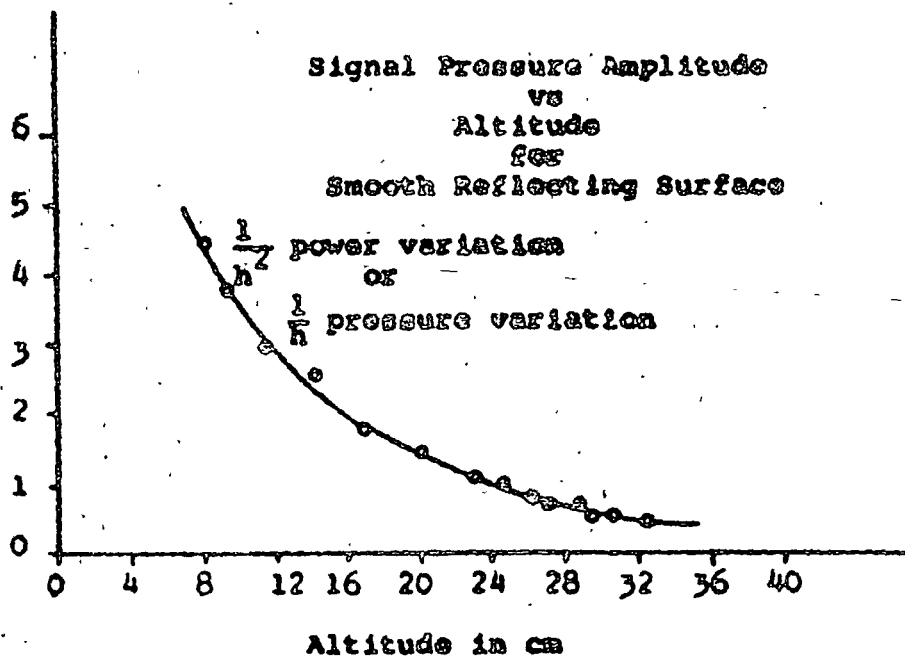
v is the velocity of propagation,

τ is the pulse width,

h is the altitude, and

θ_0 is the effective half-angle of the antenna pattern.

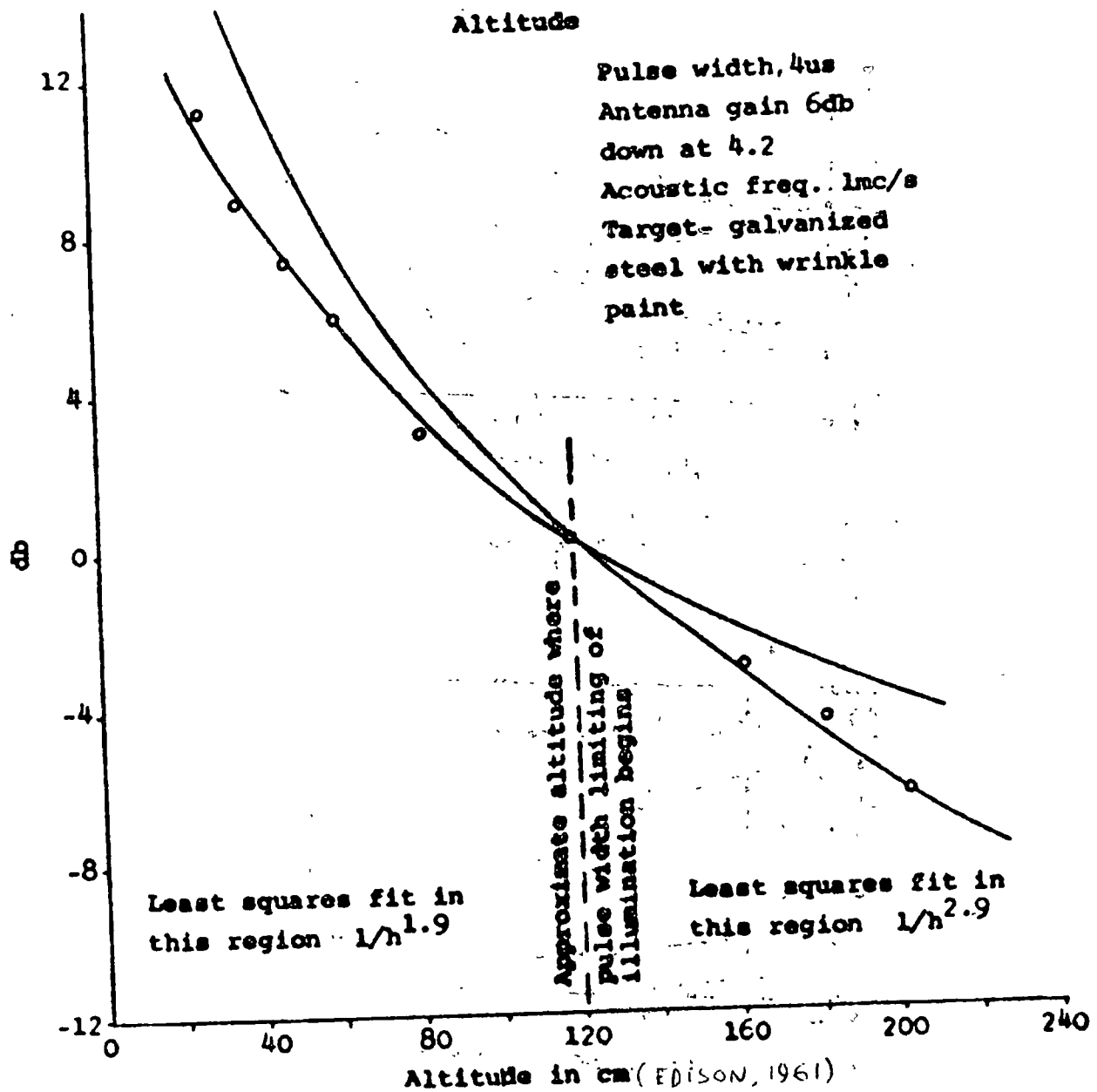
Relative Mean Pressure Amplitude

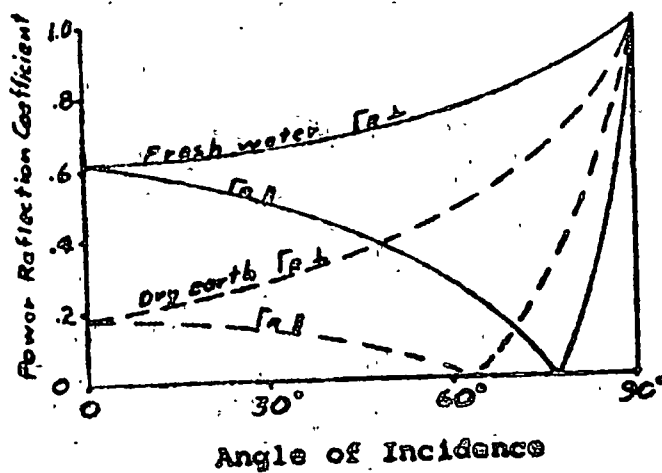


Signal vs Altitude over Smooth Surface (EDISON, 1961)

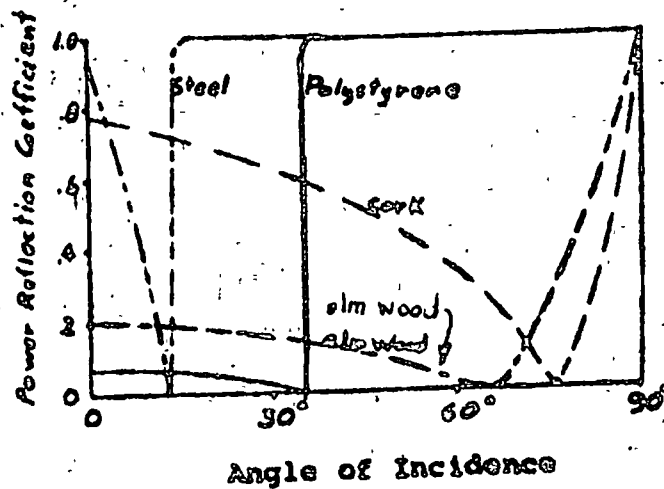
Mean Scatter-Power Signal

vs
Altitude

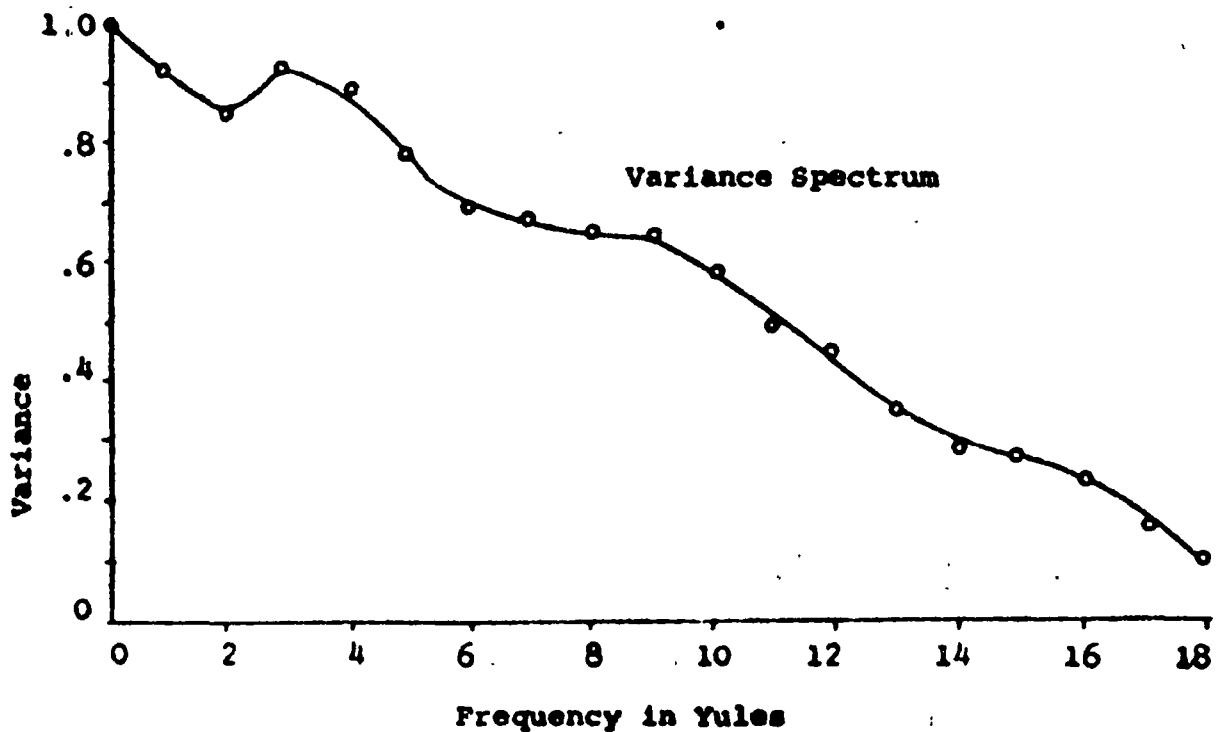
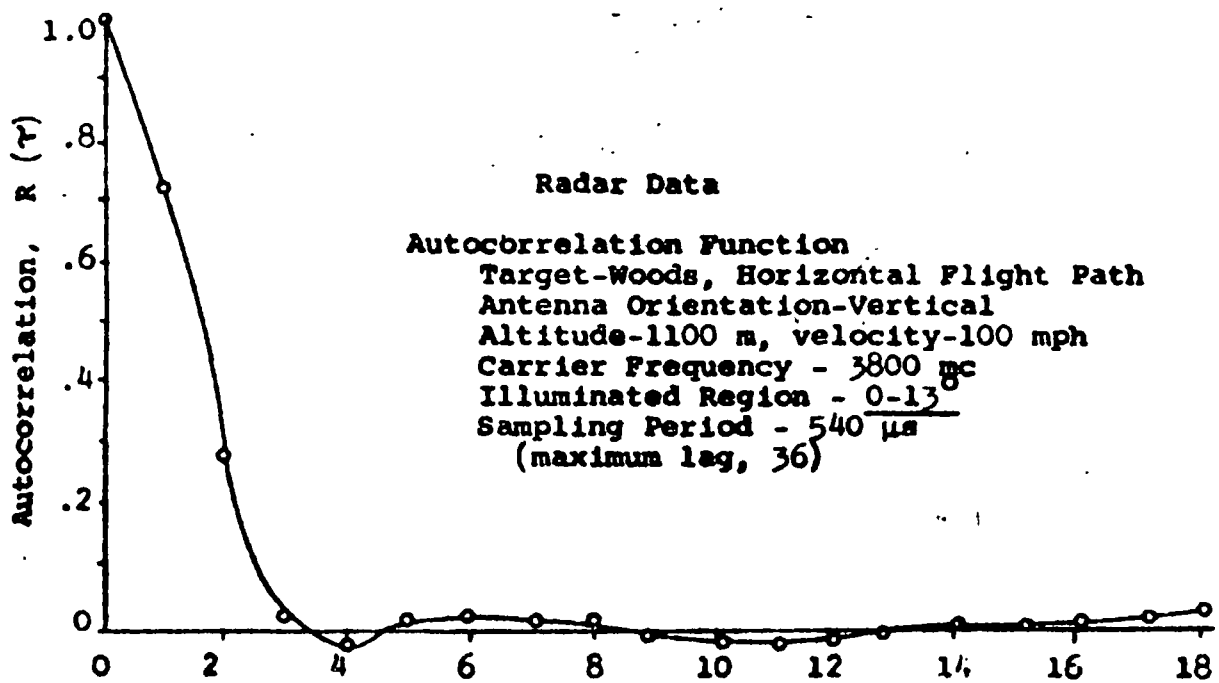




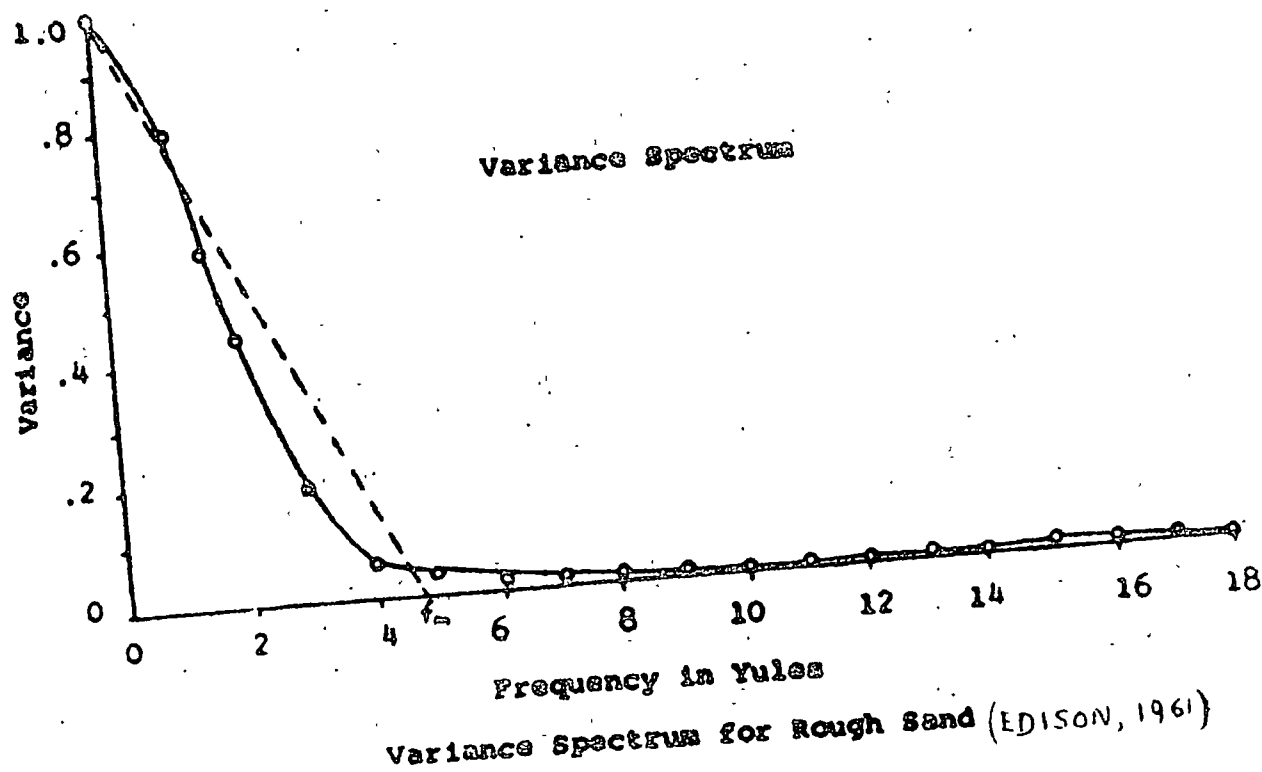
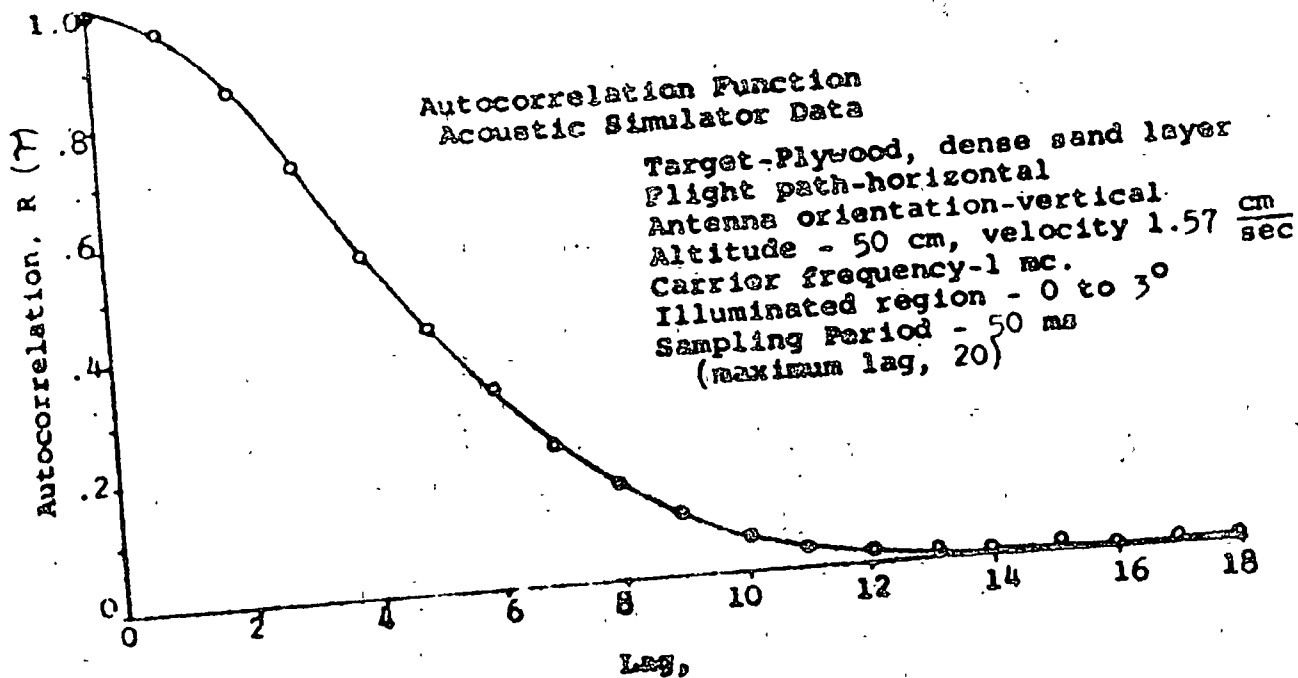
Reflection Coefficients for TM and TE Waves
Figure 3-8

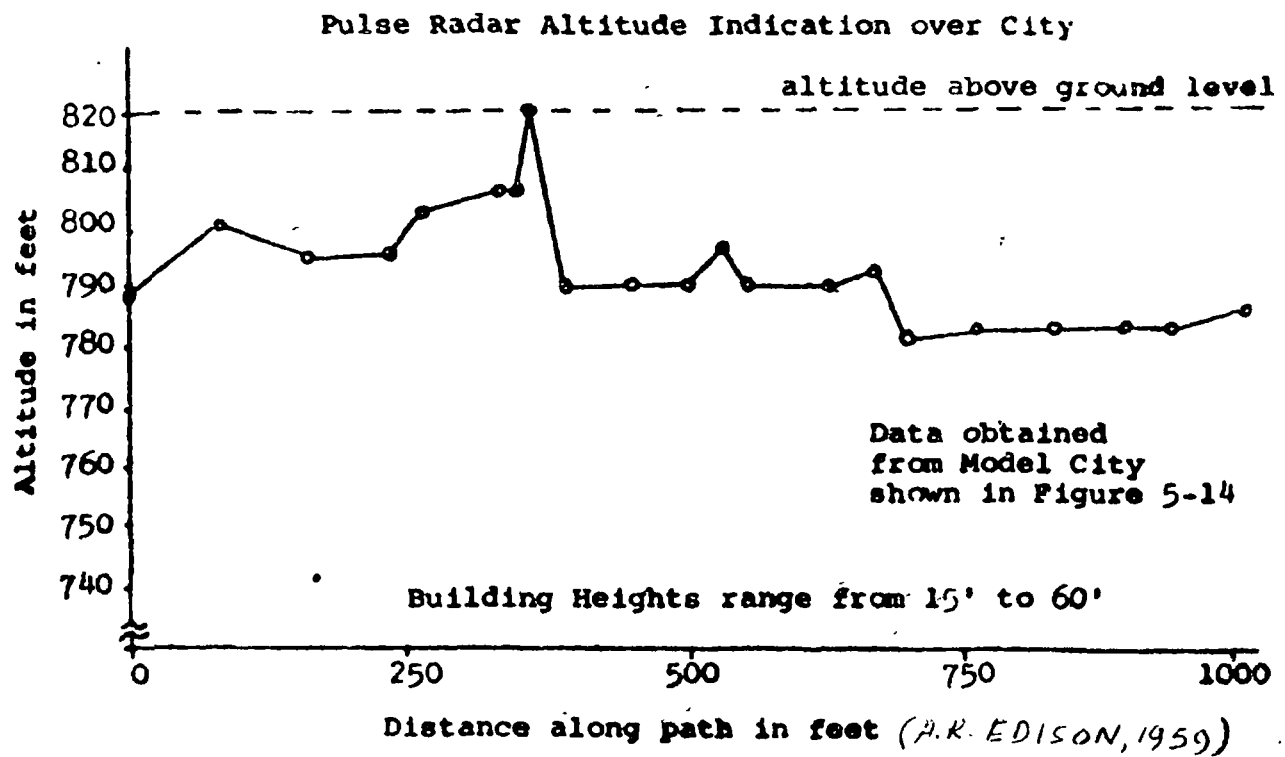


Reflection Coefficient for Acoustic Waves (EDISON, 1961)

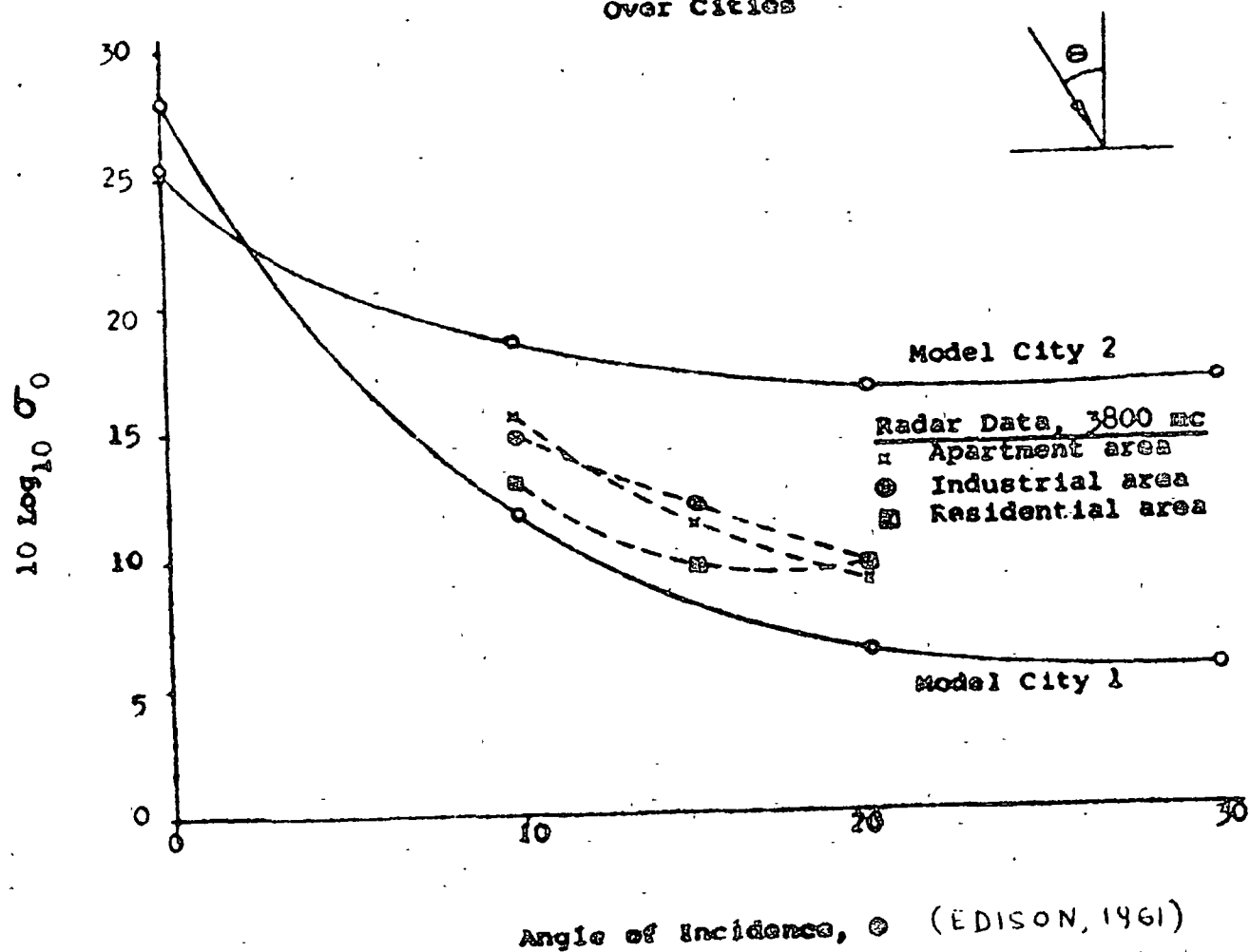


Variance Spectrum for Wooded Terrain (EDISON, 1961)





Radar Backscattering Cross Sections Over Cities



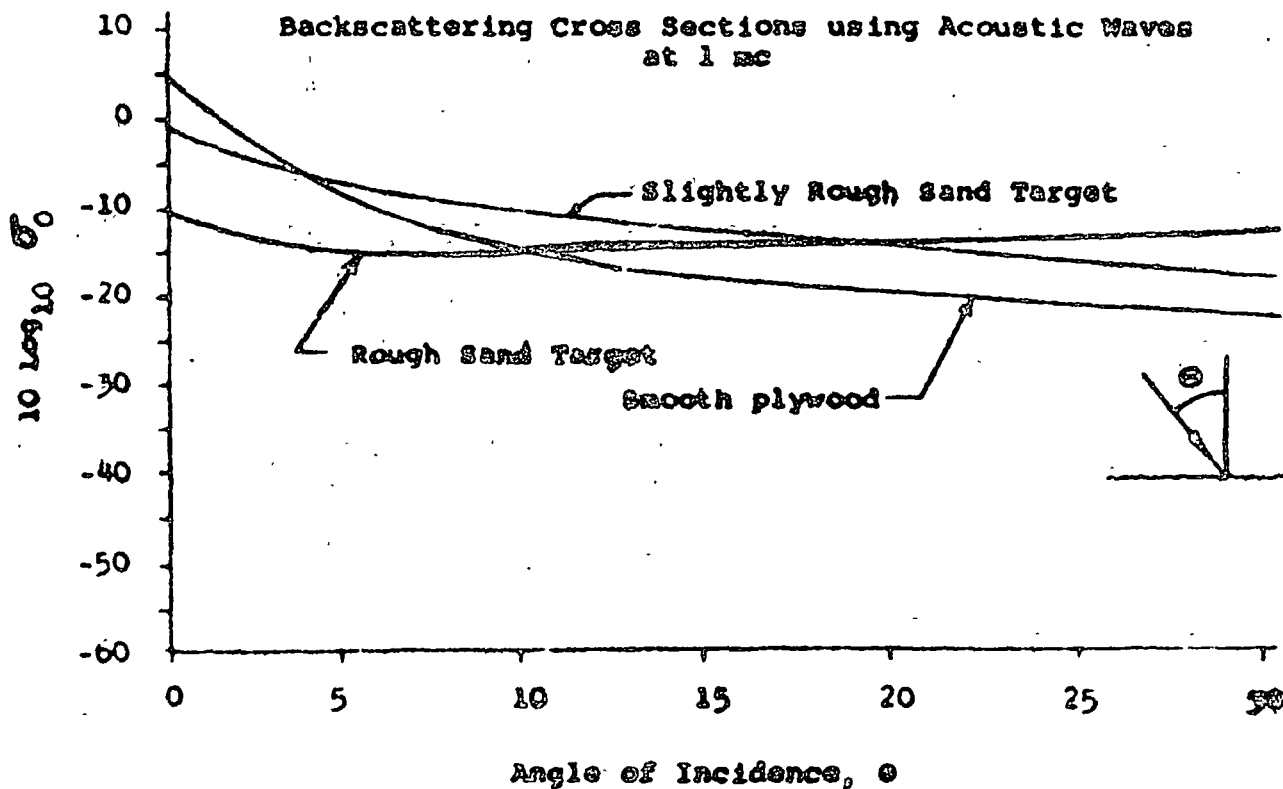
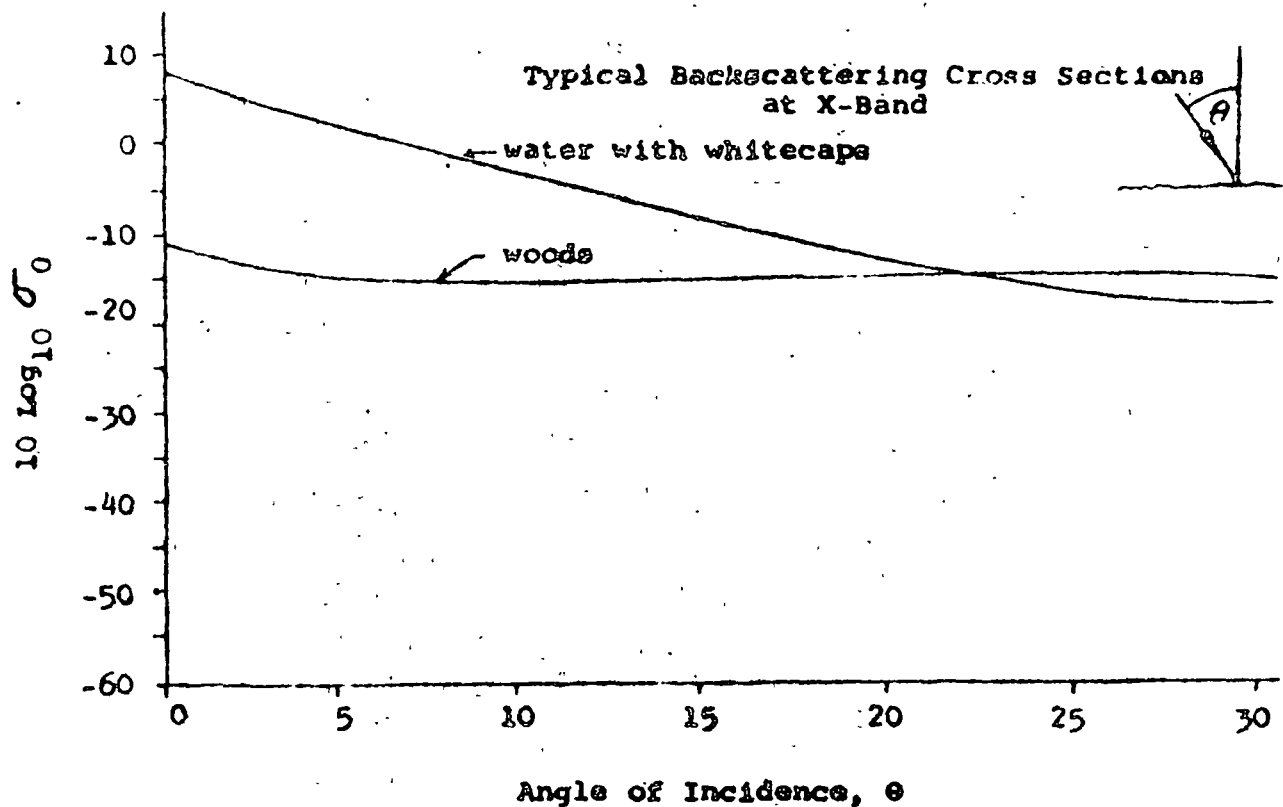
TARGET RECOMMENDATIONS (EDISON, 1961)

Terrain	Target Base	Sand Particle size, wavelengths	Distance Between Particles, Wavelengths
Woods	Plywood	1-2	0 - 1/2
Farmland	"	1-2	1 - 5
Desert	"	---	-----
Cities	" (buildings) ^a	$\frac{1}{2}$ -1	1 - 5
Water (smooth)	galv. steel	$< \frac{1}{2}$	3 - 5
Water (rough)	" "	$\frac{1}{2}$ -1	1 - 2
Mountains	" " (shaped) ^b	$\frac{1}{2}$ -1	1 - 2

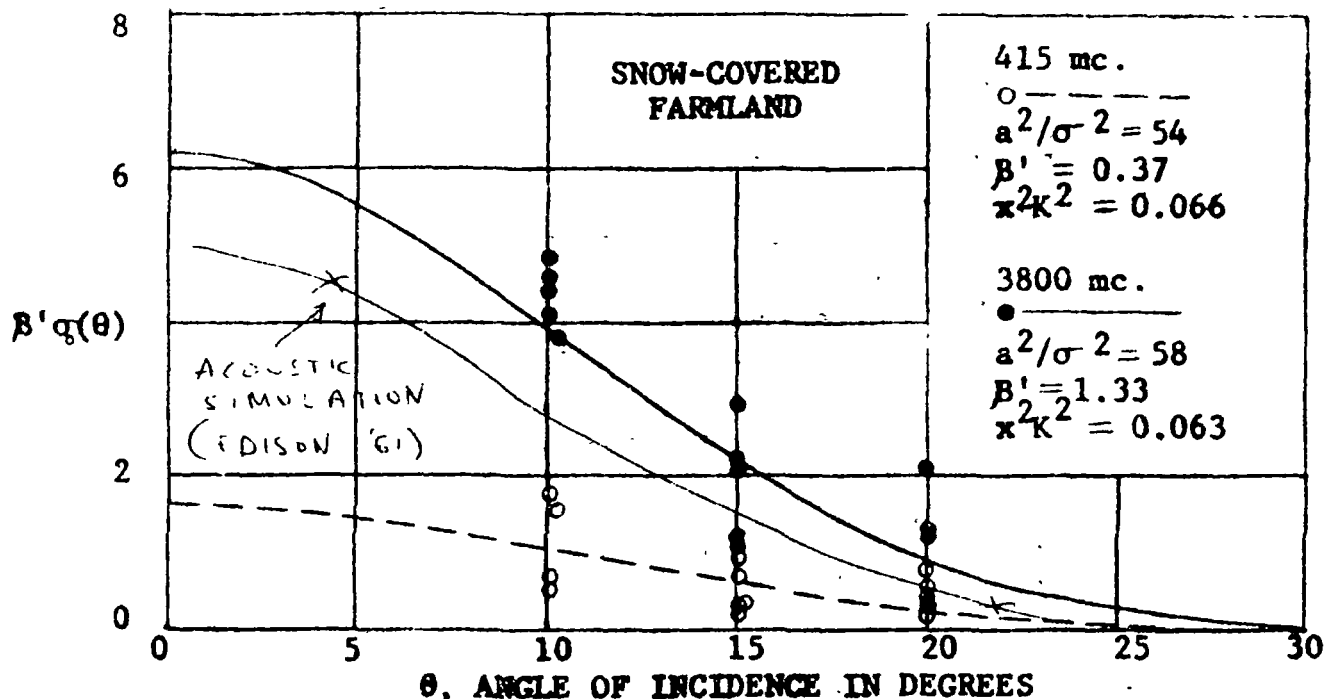
^aBuildings are pine blocks cut to size.

^bSteel can be formed into appropriate contours.

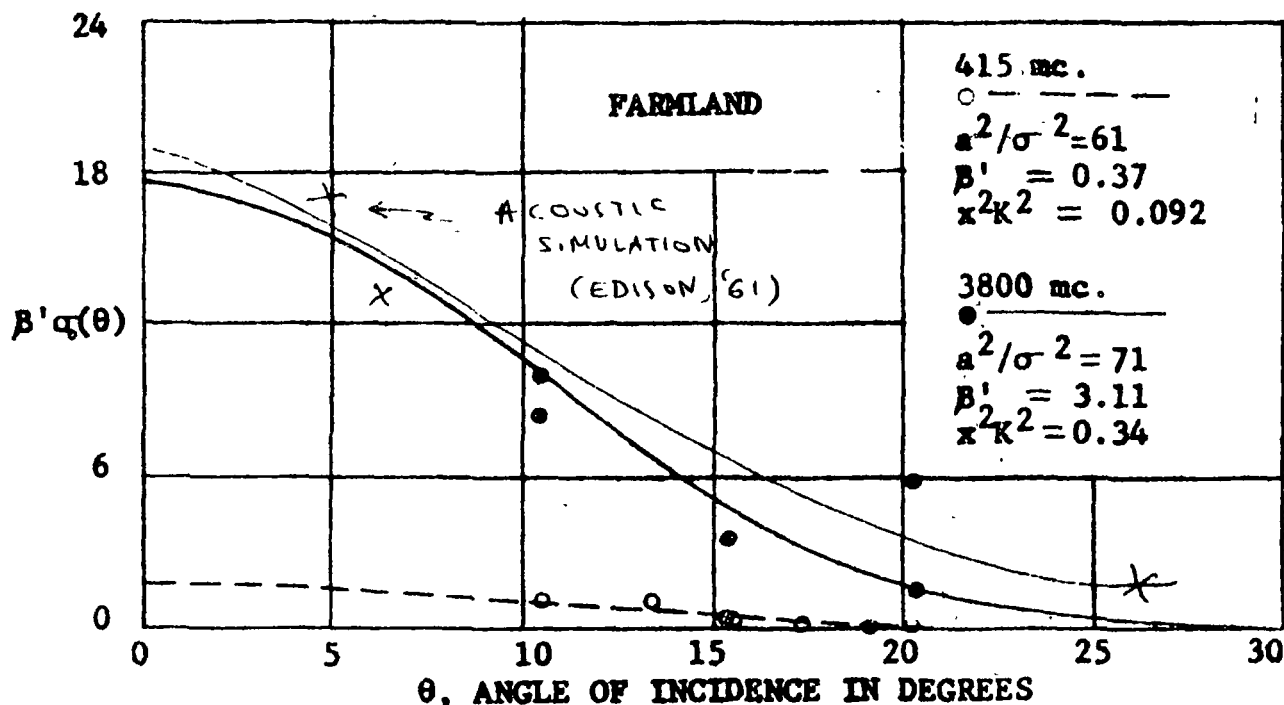
It should be observed that the slope of the radar backscattering cross section curves is important in modeling practice. The absolute level of the curves can be increased or decreased by proper scaling.



Typical Radar Back-Scattering Cross Sections (EDISON, 1961)

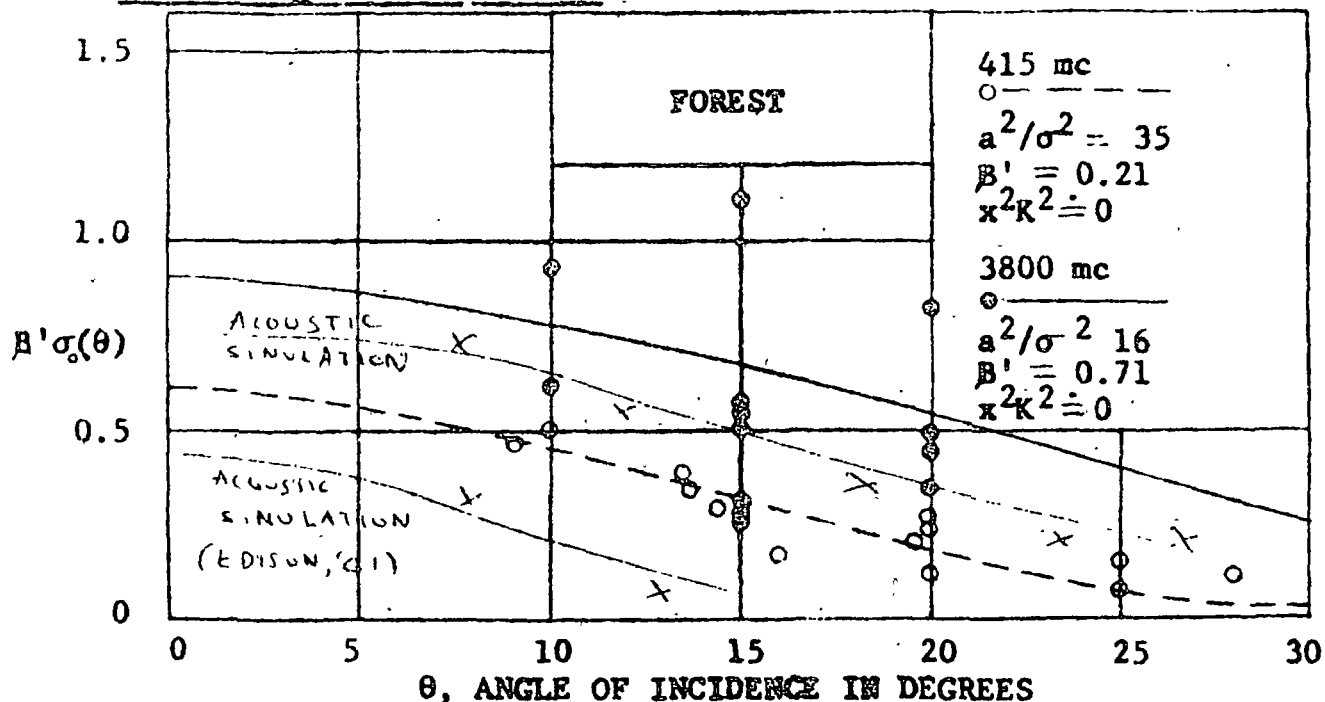


Median scattering curves for snow-covered farmland near Wahpeton, North Dakota. The target area was flat crop land containing two dry stream beds and was covered by eight inches of dry snow. (EDISON, '59).



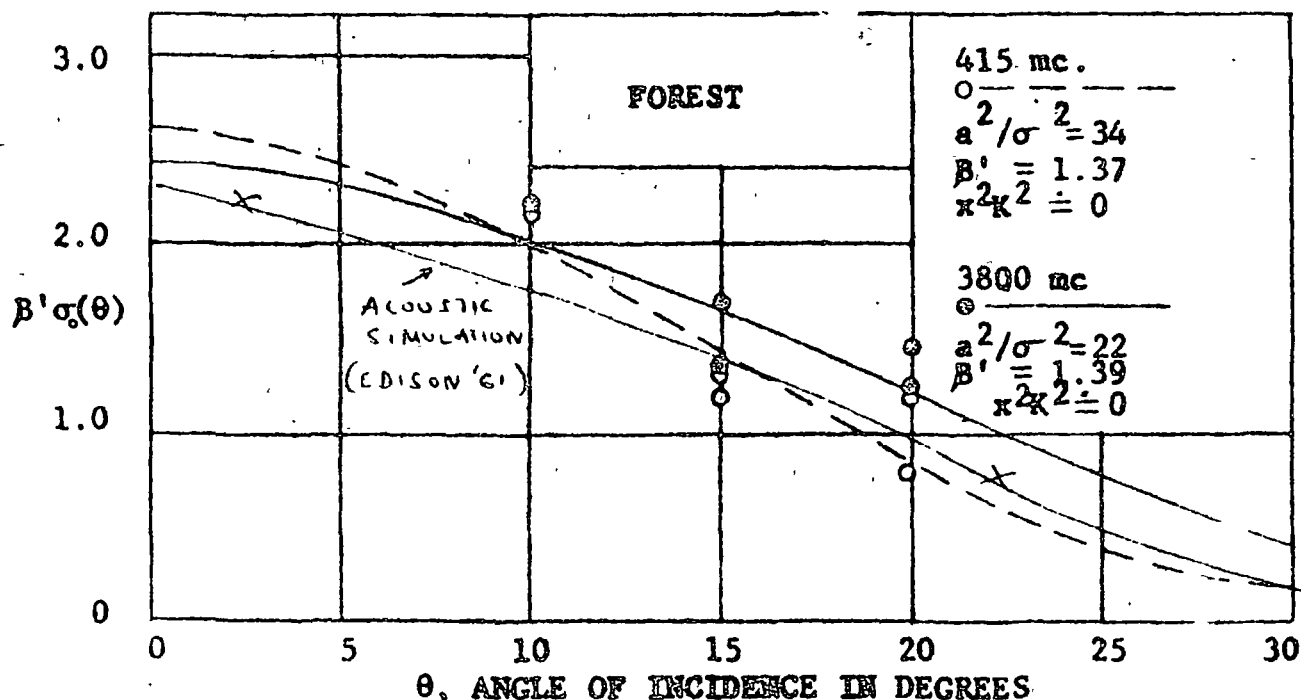
Median scattering curves for farmland near Cameron, Missouri. The target area was flat pasture and crop land containing a single line railroad. (EDISON, '59)

7.0a Scattering Cross Sections



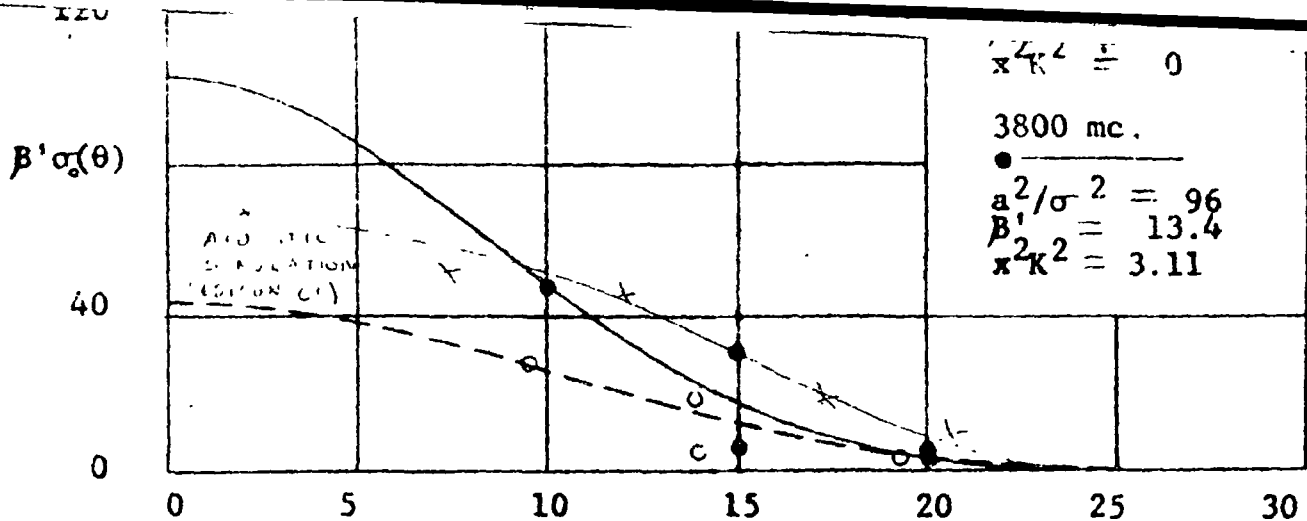
Median scattering curves for the forest at Pine Island, Minnesota. The target area was very flat and densely covered with pine, hemlock, birch, white ash, and elm trees from 20 to 40 feet in height.

(EDISON '59)

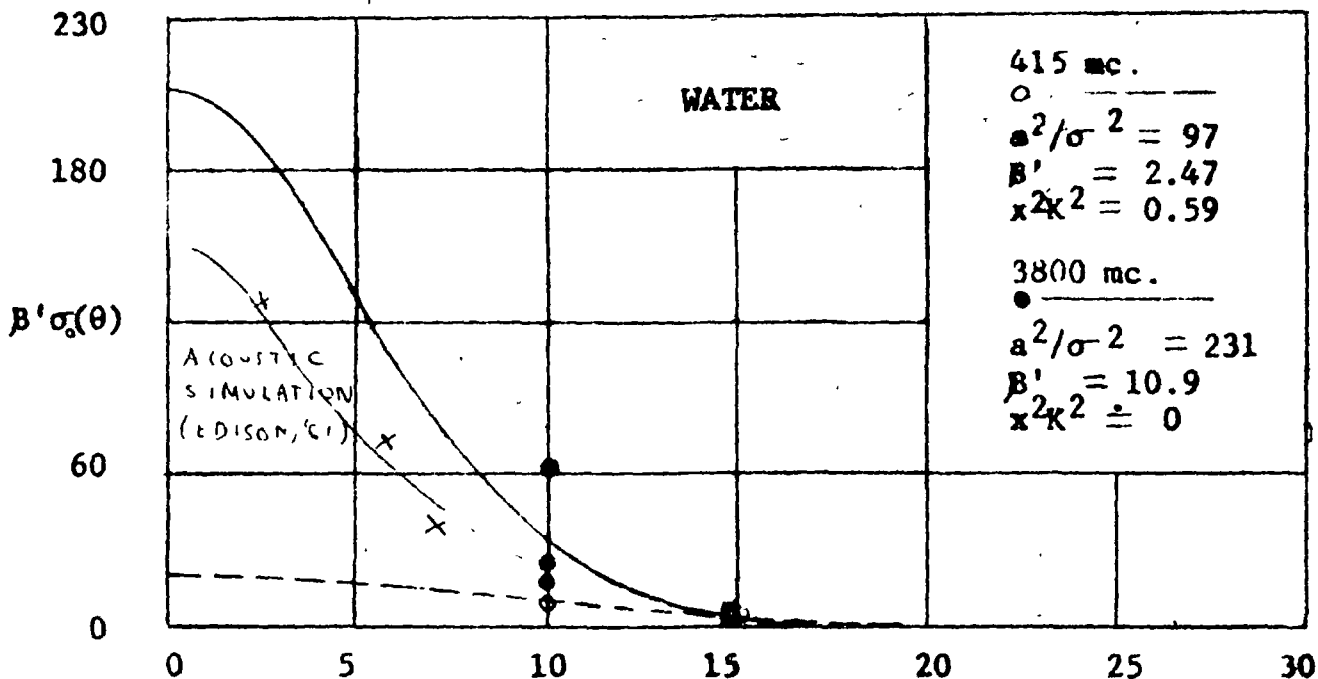


Median scattering curves for the forest at Presque Isle, Maine. The target had a snow-and-ice-covered rolling surface with a homogeneous covering of snow-bare ever-green fir and pine trees from 20 to 50 feet in height.

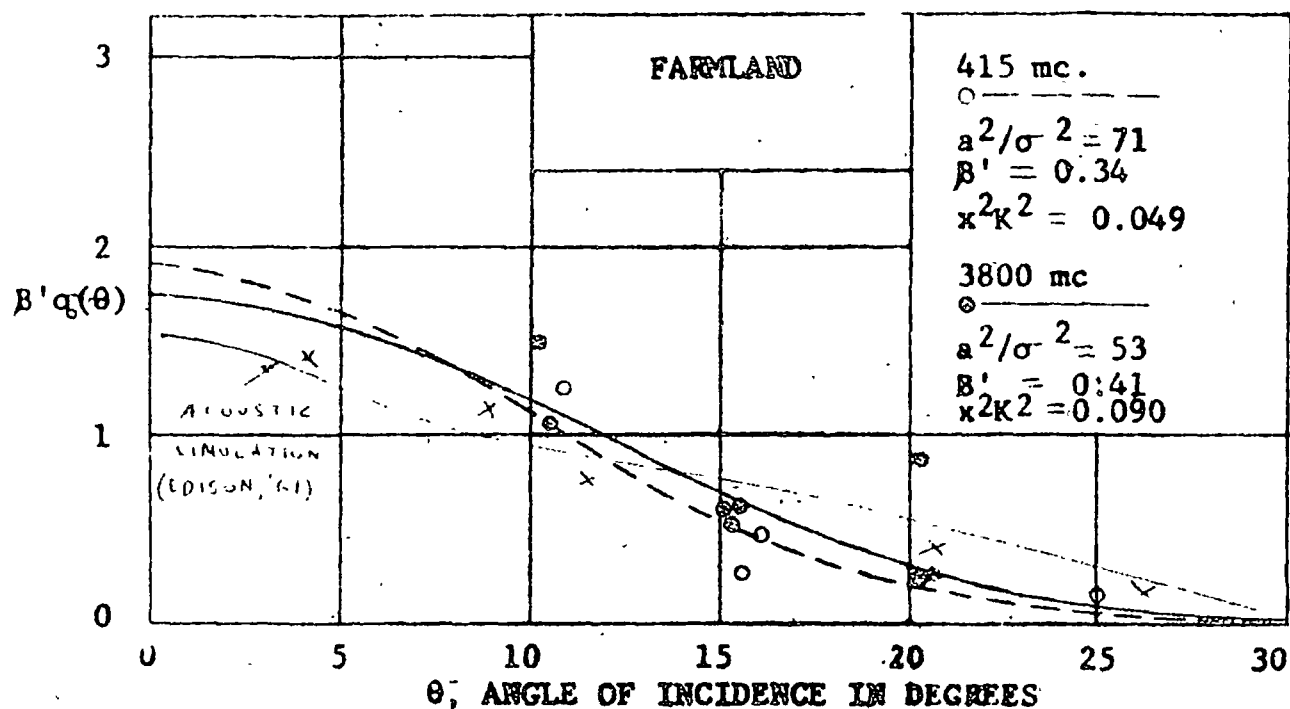
(EDISON '59)



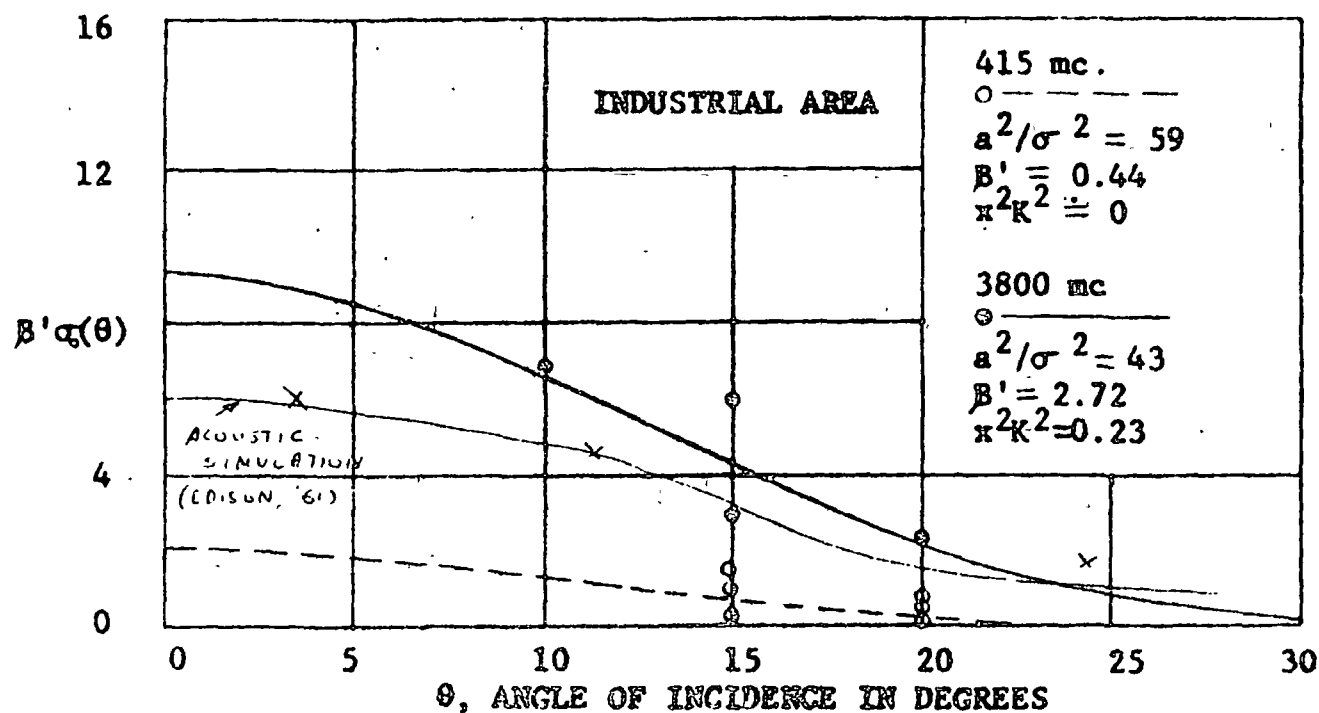
Median scattering curves for a moderately rough surface on Lake Bemidji, Minnesota. The ripples and swells were about 15 to 20 inches vertically from peak to trough and three to four feet horizontally from peak to peak. (EDISON, '59)



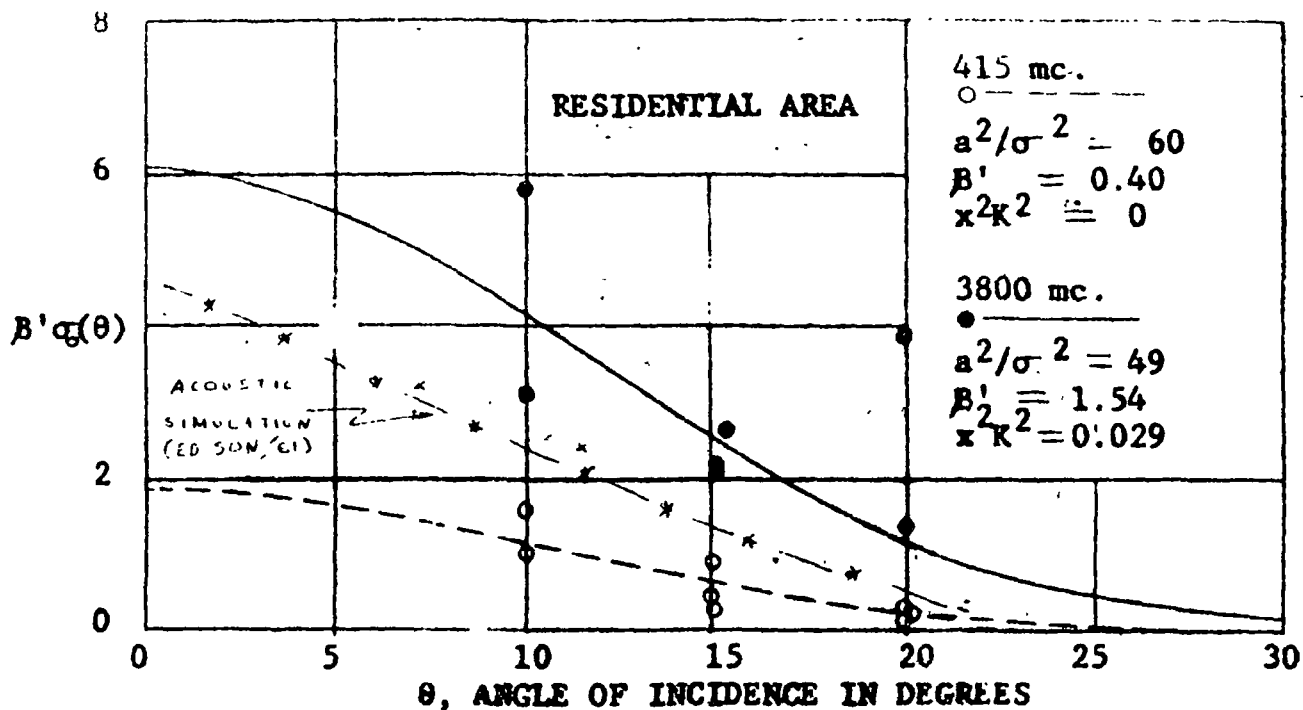
Median scattering curves for a relatively smooth surface on the Salton Sea in California. The air over the target was quite calm at the time of the flights. (EDISON, '59)



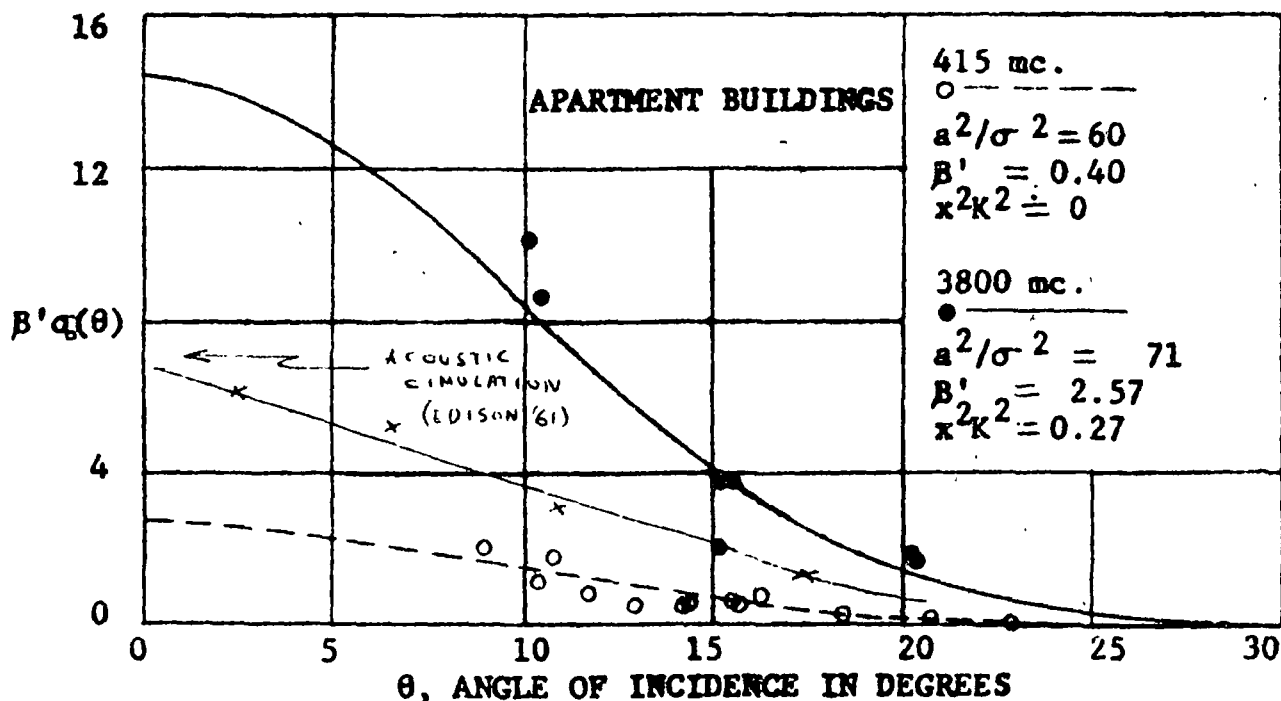
Median scattering curves for farmland near Sioux City, Iowa. The target area was flat crop land which had recently been plowed. (EDISON, '59)



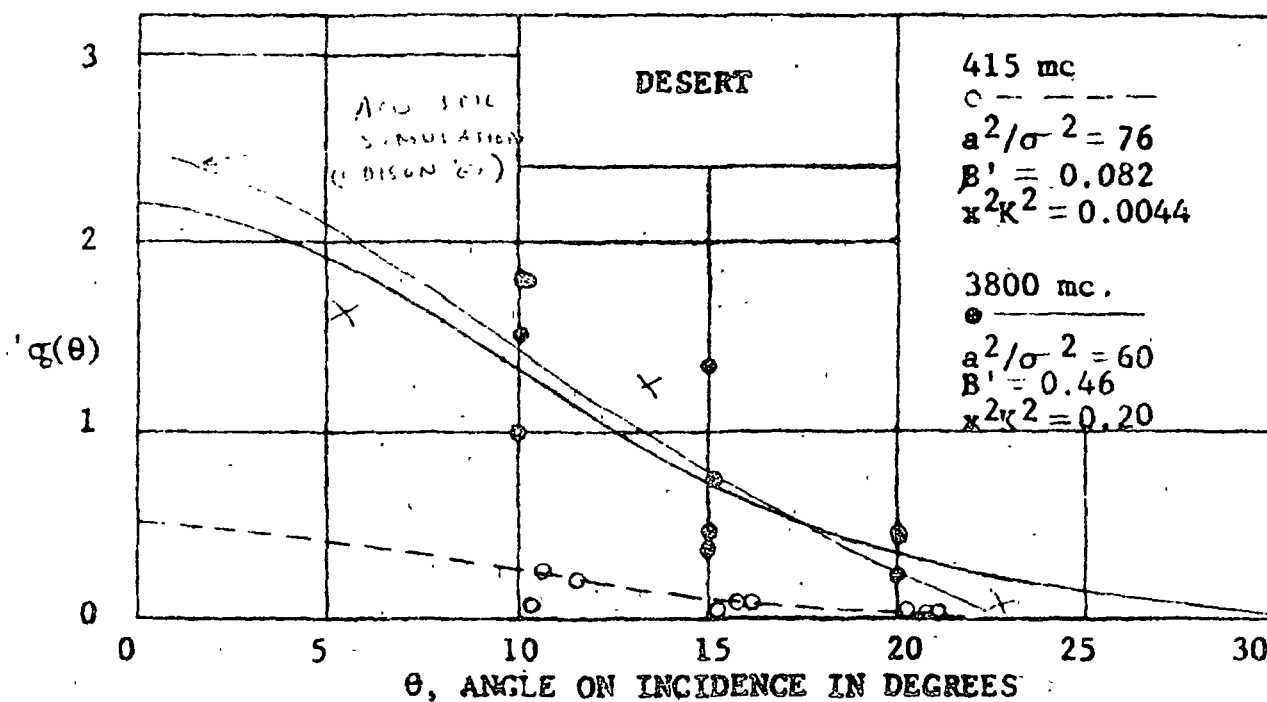
Median scattering curves for industrial area in Minneapolis, Minnesota. The target contained a pre-dominant number of metal roofed factory buildings with a railroad yard at one edge. (EDISON, '59)



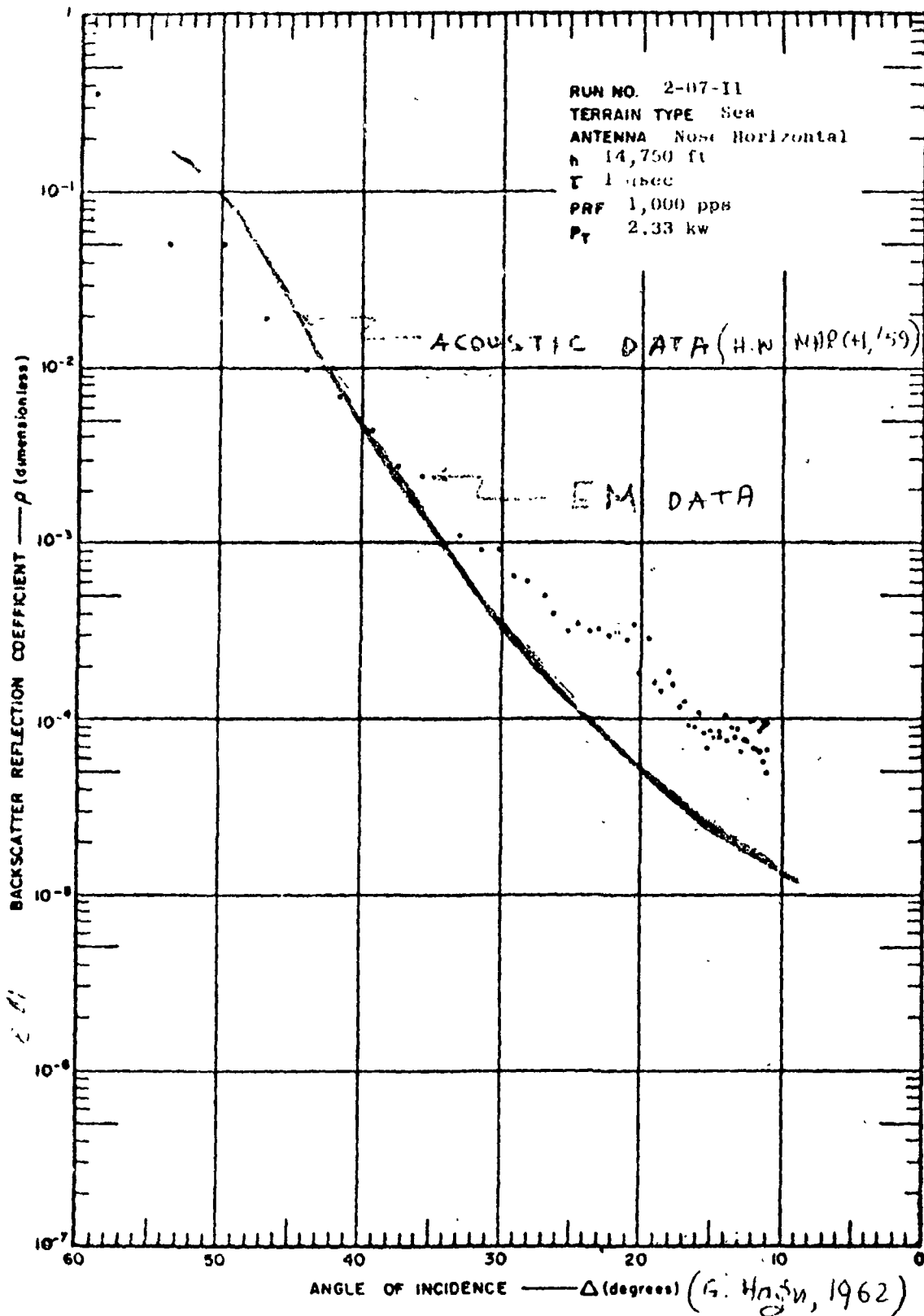
Median scattering curves for a residential area in Minneapolis, Minnesota. The target area was built up of one and two story brick and frame houses with pitched roofs, and had many old, well established trees.
 (EDISON, 1959)

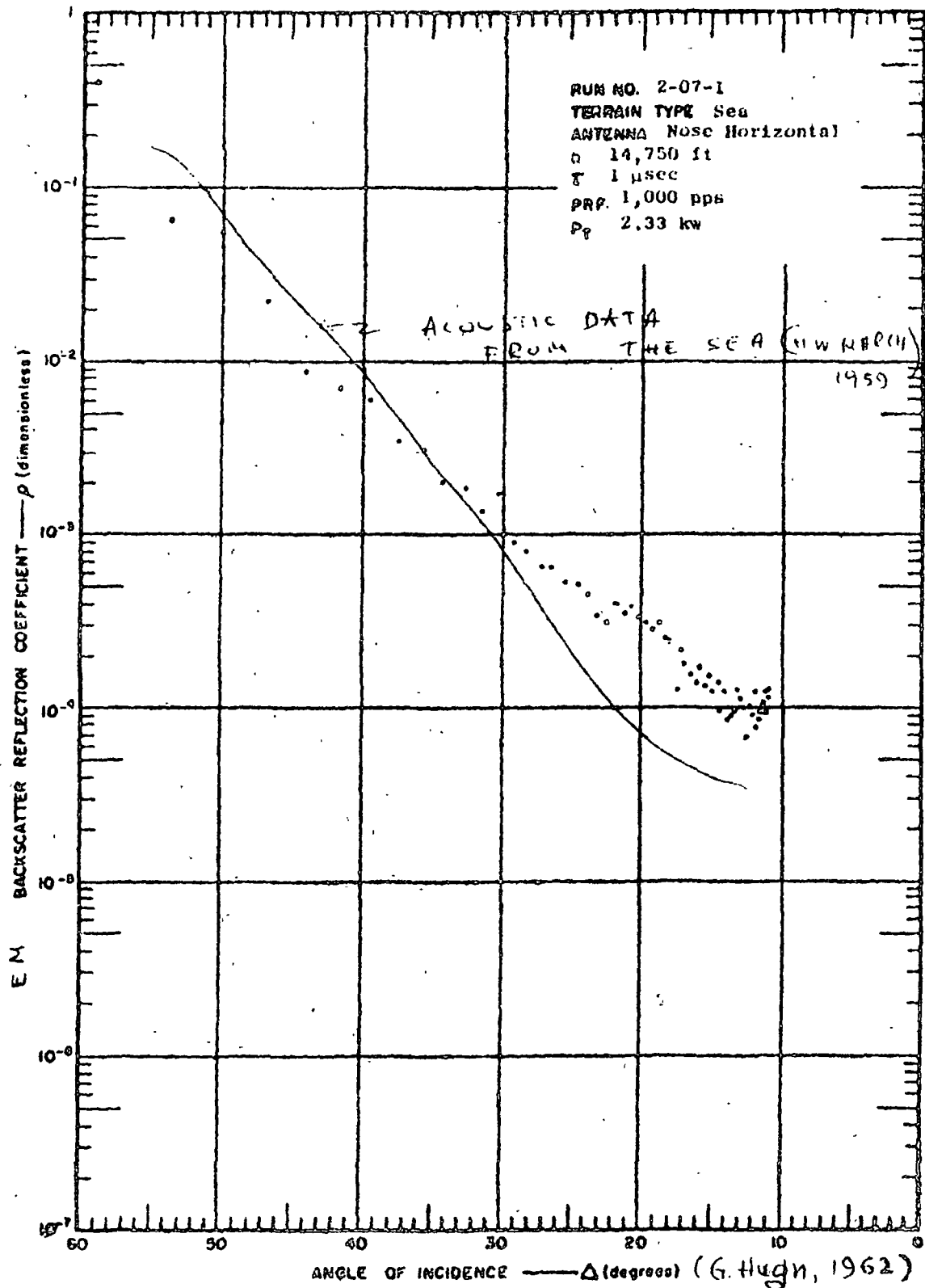


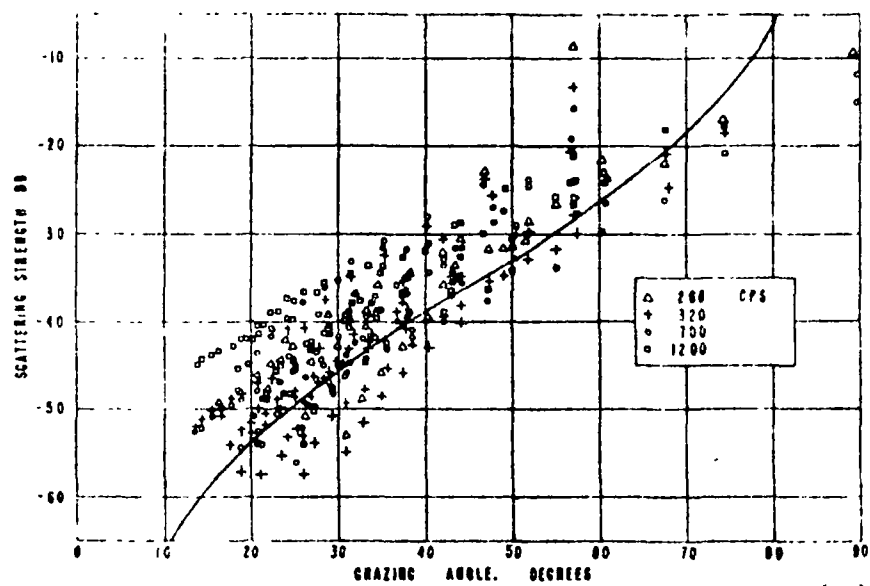
Median scattering curves for an area of apartment buildings in Kansas City, Missouri. The majority of the buildings were built of brick, flat roofed, and several stories tall.
 (EDISON, 1959)



Median scattering curves for a desert area near Salton Sea, California. The target area was flat, arid, sandy, and barren. (EDISON '59)

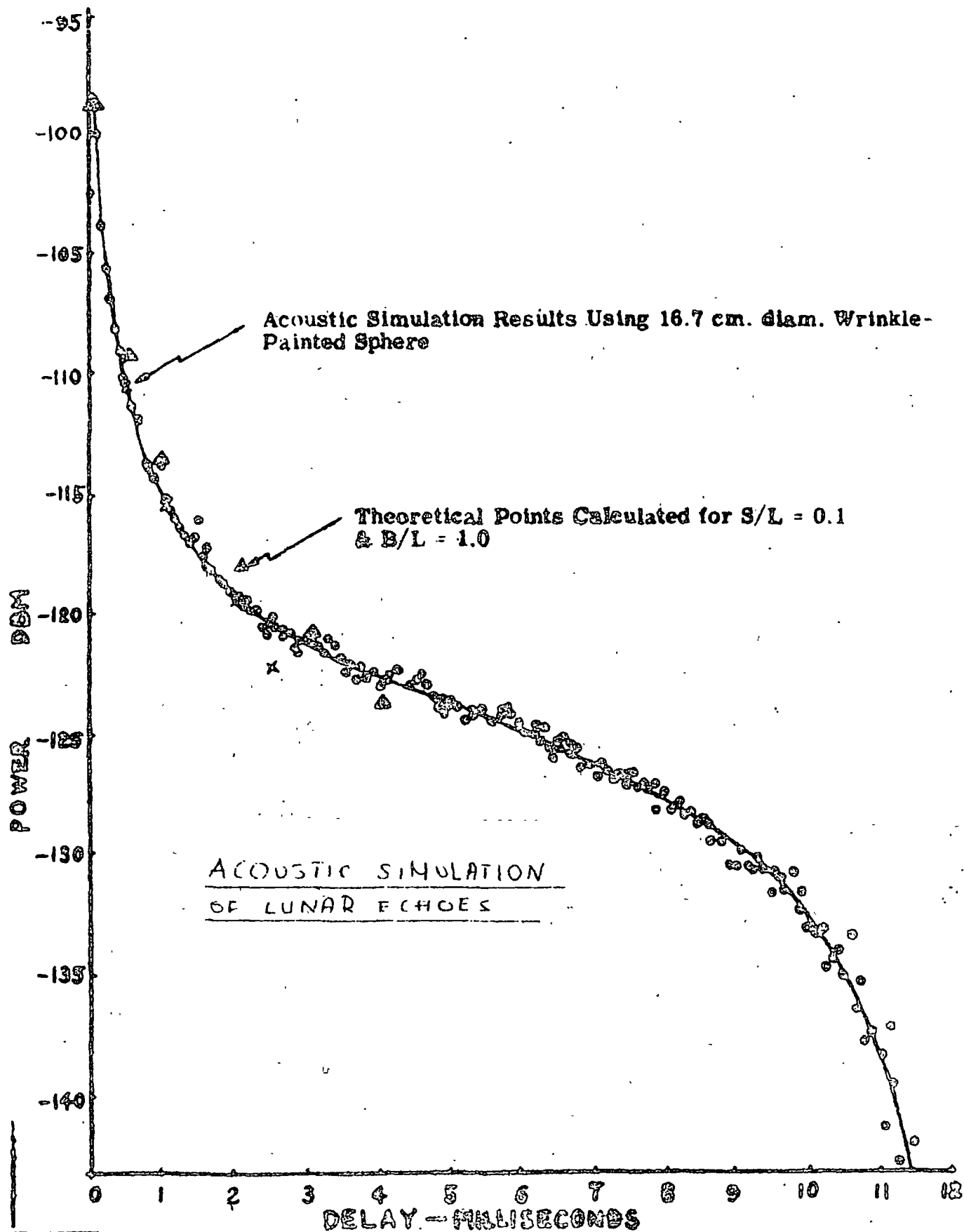






Scattering strength vs grazing angle. (H W March, '63)

ACOUSTIC SCATTERING FROM THE SEA



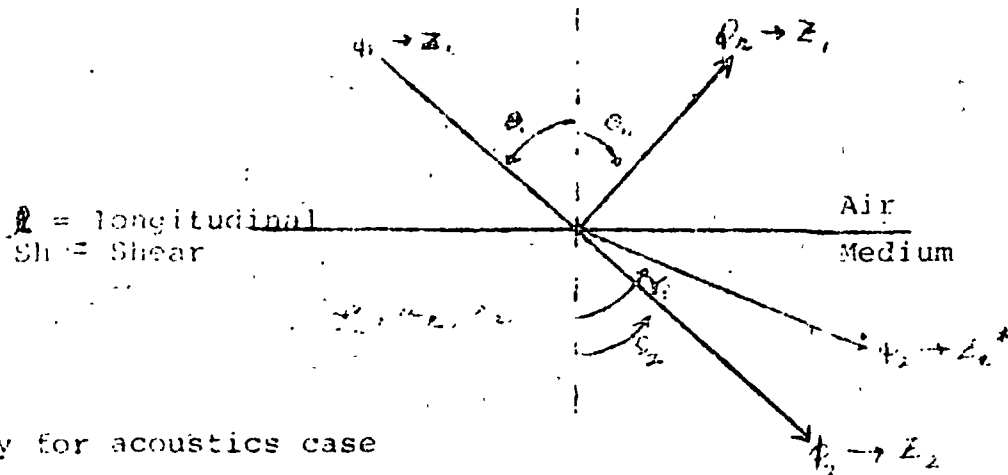
REFERENCES

- Abramowitz, W., A. Crews, and R. Erath. Ocean Surface Reverberation: Surface Interface Scattering. Grumman Research Department, May, 1966, Report No. RE-252.
- Bechtel, M. E. Scattering Coefficients for the Backscattering of E. M. Waves from Perfectly Conducting Spheres. Cornell Aeronautical Laboratory, Inc., Buffalo 21, New York, December, 1962, pp. 7-11.
- Doolittle, R. D. and H. Uberall. Journal of Acoustical Society of America, Vol. 39, 1966, pp. 272-275.
- Edison, A. R. An Acoustic Simulation for Modeling Backscatter of Electromagnetic Waves. September, 1961, Technical Report EE-62.
- Edison, A. R., R. K. Moore, and B. D. Warner. Radar Return at Near-Vertical Incidence. September, 1959, Technical Report EE-24.
- Goodrich, R. F., B. A. Harrison, R. E. Kleimman, and T.B.A. Senior. Diffraction and Scattering from a Sphere. Air Force Cambridge Research Laboratory, Bedford, Massachusetts, December, 1961, Report 3648-1-T.
- Hagn, George. An Investigation of the Direct Backscatter of High Frequency Radio Waves from Land, Sea Water, and Ice Surfaces. (1962) STANFORD RESEARCH INSTITUTE, CALIFORNIA
- Harrison, C. W., Jr., and R. O. Heinz. On Radar Cross Section of Rods, Tubes, and Strips of Finite Conductivity. Scandia Corporation...Monograph, July, 1963.
- Hickling, Robert. An Analysis of Echoes from a Solid Elastic Sphere in Water. California Institute of Technology, Technical Report No. 85-20, March, 1962.
- Kleinman, R. E. and T. B. A. Senior. Diffraction and Scattering from a Cone. Air Force Cambridge Research Laboratory, Bedford, Massachusetts, January, 1963, Report 3648-2-T.
- Lindsay, R. B. Mechanical Radiation. McGraw-Hill Book Company, New York, 1960, pp. 101-105.
- Lorden, A. L. Backscattering of E. M. Waves from Spheres and Spherical Shells. Air Force Cambridge Research Center, Cambridge, Massachusetts, 1962, Technical Report No. 15, pg. 36.

- Marsh, H. W. "Sound Reflection and Scattering from the Sea Surface". Journal of the Acoustical Society of America, Vol. 35, No. 2. (1963)
- Tauconkin, P. Journal of Acoustic Society of America, Vol. 21, 1949, pp. 612-616.
- Thomas, D. T. Approximation for Backscatter from Dielectric Sphere. Antenna Laboratory, Ohio State University, Report 1116-14, October, 1961.
- Uberal, H., R. D. Doolittle, and J. V. McNicholas. "Use of Sound Pulses for a Study of Circumferential Waves", Journal of Acoustical Society of America, Vol. 39, No. 3, 1966, pg. 576.
- Ugincius, Peter. Creeping Wave Analysis of Acoustic Scattering by Elastic Cylindrical Shells. U. S. Naval Weapons Laboratory, Dahlgren, Virginia, February 26, 1968, Technical Report.
- Weeks, W. L. Electromagnetic Theory for Engineering Applications. John Wiley and Sons, Inc., New York, 1964, pp. 516-523.
- Clarke, Kenneth K. "Fading Channel Simulators," Proceedings of the IEEE, 1966, pg. 83.
- Chapin, E. W. and W. K. Roberts. "A Radio Propagation and Fading Simulator Using Radio-Frequency Acoustic Waves in a Liquid," Proceedings of the IEEE, 1966, pg. 1072.

COMPARISON OF REFLECTION TRANSMISSION COEFFICIENTS

Acoustics (Liq/Solid)	EMW (General)
$c^2 = \frac{\lambda + 2\mu}{\rho}$	$\frac{1}{\epsilon \mu}$
C = Velocity of Propagation (longitudinal)	
$b^2 = (\text{shear}) \quad \mu/\rho$	
$\nabla^2 \phi_s + k_s^2 \phi_s = 0$	$\nabla^2 E + k^2 E = 0$
$\vec{V} = \nabla \phi + \nabla \times \Psi$	$\vec{E} = -\nabla \phi + \frac{\partial \vec{A}}{\partial t}$
<u>SNELL'S LAW</u>	
$k_1 \sin \phi_1 = k_1 \sin \phi_{11} = k_2 \sin \gamma_2$	$k_1 \sin \phi = k_{11} \sin \phi_{11} = k_2 \sin \phi_2$
$Z_l \quad Z_i = \rho c \sec \phi_i \quad i = 1$	$\sqrt{\frac{\mu}{\epsilon}} \sec \phi$ Vertical Polarization
$Z_{sh} = Z_t \quad \rho b \sec \gamma$	$\sqrt{\frac{\mu}{\epsilon}} \cos \phi$ Horizontal Polarization
Reflection Coefficient (longitudinal) $V = \frac{Z_{tot} - Z_i}{Z_{tot} + Z_i}$ $i = 2$	$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$
Transmission Coefficient W (longitudinal) $= \frac{2(Z_1 \cos 2\gamma_2)}{Z_{tot} + Z_1}$ $i = 2$	$T = \frac{2Z_2}{Z_1 + Z_2}$
Transmission Coefficient (shear) $= \frac{2(Z_t \cos \gamma_2)}{Z_{tot} + Z_i} \quad i = 2$	
$Z_{tot} = Z_l \cos^2 2\gamma_2 + Z_t \sin^2 2\gamma_2$	
$Z_i = \rho_i C_i / \cos \theta_i, \quad Z_t = \rho_t b_2 / \cos \gamma_2$	



*Only for acoustics case

Hook's Law

x_{ij} = stress in i to plane of application

$$[x_{ij}] = [c_{ij}] [x_{ij}] \quad \text{strain}$$

j direction of applied force

$$i = x_1 y_1 z$$

$$c_{ik} = c_{ki}$$

$$i = x_1 y_1 z$$

$$\Rightarrow 6 \text{ diag} + 15 \text{ off diag} = 21 \text{ constants}$$

For isotropic case

$$[x_i] = [2a + \lambda, \lambda, \lambda] [x_i]$$

$$x_1 = (2\mu + \lambda)x_1 + \lambda x_2 + \lambda x_3 = 2a x_1 + \lambda(x_1 + x_2 + x_3)$$

μ, λ are Lamé constants

APPROXIMATE COUNT OF RCS MCS PEAKS
(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) (23) (24) (25) (26) (27) (28) (29) (30) (31) (32) (33) (34) (35) (36) (37) (38) (39) (40) (41) (42) (43) (44) (45) (46) (47) (48) (49) (50) (51) (52) (53) (54) (55) (56) (57) (58) (59) (60) (61) (62) (63) (64) (65) (66) (67) (68) (69) (70) (71) (72) (73) (74) (75) (76) (77) (78) (79) (80) (81) (82) (83) (84) (85) (86) (87) (88) (89) (90) (91) (92) (93) (94) (95) (96) (97) (98) (99) (100)

DB	S. NO.	ANGLE	DB	S. NO.	ANGLE	DB	S. NO.	ANGLE	DB	S. NO.	ANGLE	
1	2	28.1	2	15	88	13.0	45	177	33.0	47	268	18.9
2	4	28.1	16	88	12.5	46	180	41.1	48	270	34.0	
3	6	28.1	17	89	17.0							
4	7	28.6	18	90	36.0	0	180	41.1	0	270	34.0	
5	8	28.1				1	182	33.5	1	271	24.6	
6	10	24.6	0	90	36.0	2	184	28.2	2	272	22.6	
7	12	14.8	1	94	17.6	3	186	31.3	3	274	18.6	
8	17.3	16.6	2	95	13.5	4	187	32.2	4	275	13.0	
9	18	17.2	3	96	15.6	5	189	31.5	5	277	13.0	
10	18.5	17.8	4	99	17.5	6	190	27.9	6	280	15.0	
11	19	16.9	5	101	20.6	7	192	27.5	7	282	19.0	
12	20	16.3	6	102	21.4	8	193	31.5	8	285	17.0	
13	22	16.6	7	107	17.0	9	194	30.5	9	286	18.0	
14	24.5	13.0	8	108	18.7	10	195	27.0	10	288	14.6	
15	26.2	13.8	9	110	19.5	11	197	28.1	11	290	15.6	
16	28	12.3	10	112	16.5	12	199	30.5	12	293	15.0	
17	31	12.0	11	114	16.5	13	201	23.5	13	294	16.4	
18	33	11.6	12	116	13.6	14	203	26.8	14	296	14.5	
19	33.8	10.6	13	118	14.4	15	207	21.0	15	298	12.0	
20	35	9.8	14	120	17.6	16	209	26.5	16	300	13.5	
21	36	9.5	15	121	16.0	17	210	23.0	17	304	31.4	
22	37	8.7	16	124	21.8	18	212	21.0				
23	38	11.5	17	126	20.3	19	213	23.3	0	304	31.4	
24	41	11	18	127	18.5	20	216	24.0	1	305	19.6	
25	43	9.3	19	128	20.5	21	218	20.7	2	307	9.5	
26	44	13	20	132	22.0	22	222	23.3	3	308	9.5	
27	45.6	13	21	134	19.7	23	223	23.2	4	310	9.0	
28	46	10.4	22	135	18.5	24	225	20.0	5	311	9.4	
29	48	9.5	23	136	15.6	25	228	22.0	6	313	13.5	
30	49	12.4	24	138	16.3	26	230	24.7	7	314	10.6	
31	51	10.5	25	140	21.0	27	232	23.5	8	315	11	
32	52	11.5	26	142	19.5	28	233	20.3	9	317	11	
33	54	14.7	27	144	19.4	29	235	17.3	10	319	8.8	
34	56	28.3	28	145	21.5	30	237	21.9	11	320	6.5	
0	56	28.3	29	146	22.5	31	238	21.5	12	322	13.5	
1	58	17.3	30	148	19.6	32	240	17.5	13	324	9.5	
2	62	12.4	31	150	23.2	33	242	16.7	14	326	7.5	
3	63	14.0	32	152	23.6	34	244	19.6	15	327	6.5	
			33	154	16.5	35	245	22.8	16	329	9.5	
4	65	15.3	34	158	25.3	36	248	22.5	17	331	9.0	
5	66	16.0	35	160	25.3	37	250	24.0	18	332	5.5	
6	68	15.4	36	161	23.7	38	251	23.0	19	334	6.5	
7	70	15.3	37	163	27.0	39	252	23.0	20	335	8.8	
8	72	16.2	38	166	27.0	40	254	21.2	21	337	13.3	
9	73	18.3	39	167	28.3	41	257	19.8	22	340	14.4	
			40	168	27.5	42	258	18.5	23	342	17.3	
10	74	18.3	41	170	28.3	43	261	16.5	24	344	17.8	
11	76.8	20.3	42	172	31.5	44	263	13.3	25	348	13.4	
12	80	20.2	43	174	25.7	45	265	12.5	26	349	12.5	
13	81	15.4										

APPROXIMATE COUNT OF RCS PEAKS
(AF-MDC-HDRP-RAT SCAT FACILITY PROJECT 6503)

S.NO.	ANGLE ⁰	DB	S.NO.	ANGLE ⁰	DB	S.NO.	ANGLE ⁰	DB	S.NO.	ANGLE ⁰	DB
0		27.2	50	54	13.2	0	90	34	50	125.9	21.3
1	2	23.6	51	55	20.7	1	90.5	23.6	51	126	21.5
2	3.7	18	52	56	28.1	2	91	20.3	52	126.5	19.7
3	5	25.5				3	92	21	53	127.9	19.7
4	6	18.7	0	56	28.1	4	92.5	20.5	54	128	21
5	7.8	10.2	1	56.7	21.2	5	93	18.5	55	128.5	20.3
6	10	12.4	2	58	16.1	6	94	17.7	56	129.9	18.6
7	11	10.6	3	58.3	14.5	7	94.5	17	57	131	16.3
8	11.9	12.3	4	59	12.7	8	95	14.6	58	131.5	17.2
9	13	16.1	5	59.9	11.8	9	96.5	15	59	132.5	18.7
10	14.2	15.7	6	61.5	9.1	10	97	12.8	60	132.8	18.4
11	16	17.5	7	63	15.2	11	98.3	11.9	61	134	19.7
12	16.2	18	8	64.2	18.1	12	99	12.5	62	136.7	18.6
13	17	17.7	9	65	13.8	13	100	14.5	63	137.9	10.5
14	17.6	17.4	10	65.5	13.7	14	100.9	18.8	64	138.3	14.2
15	19	15.6	11	65.9	14.7	15	101	18.6	65	139	10.3
16	20.1	16.8	12	66	16	16	102	17.5	66	140.9	19.0
17	22	13.6	13	67	11	17	102.3	17	67	141	21.4
18	22.2	10.3	14	68	14.2	18	103.8	17.7	68	142.5	21.2
19	24.1	9.8	15	68.8	14	19	104.1	18	69	143	22.1
20	25.6	10.7	16	69	13	20	105	21.6	70	144	18.2
21	26	11.7	17	70.5	15.1	21	106	21.5	71	144.5	17.5
22	27	8.2	18	71	16.4	22	106.5	22.9	72	145	20.6
23	28	11.8	19	72	15.8	23	107	21.5	73	145.5	15.8
24	29	7.8	20	72.8	17.2	24	107.5	20.3	74	146.5	18.1
25	31	11.3	21	73	17.2	25	108	20.0	75	147	19.2
26	32.2	7.7	22	73.5	17.2	26	109	20.3	76	148.5	21.3
27	33	11.8	23	73.9	17.2	27	109.5	18.8	77	149	21.9
28	33.5	11.8	24	74.1	18.2	28	111	14.1	78	149.5	21
29	34.1	10.2	25	75	15.7	29	112.2	10.6	79	150.5	16.8
30	36	8.8	26	76	18.4	30	113	13.7	80	151	16
31	36.5	7.7	27	77	19.5	31	113.9	14.9	81	151.9	13.6
32	37	8.5	28	77.5	21.6	32	114.2	15.7	82	152.5	21.2
33	38.2	7.7	29	78.9	19.3	33	115	11	83	153.8	22.8
34	39.8	7	30	79	18.7	34	116	15.5	84	155.5	21.1
35	40.2	7.5	31	80	18	35	116.3	14.5	85	155.9	20.5
36	40.4	11.4	32	81	15.8	36	117	9.5	86	156.2	18
37	41	9.7	33	81.5	17.8	37	117.5	13.7	87	158.2	23.1
38	42	9.4	34	82.2	15	38	118	11.2	88	159	21.3
39	43	8.8	35	83.9	9.8	39	119	11.6	89	159.9	22.5
40	44	8.6	36	84.8	13.5	40	119.9	15.7	90	161	16
41	44.1	10.5	37	85.6	14	41	120.5	16.2	91	162	21.1
42	45.8	8.2	38	85.9	15.9	42	120.8	15.4	92	163	20.1
43	46	10	39	87	12.7	43	122	14.5	93	164	24.1
44	47	9	40	87.3	14	44	123	13.5	94	165	30.8
45	48	8.4	41	87.6	15	45	123.9	14.5	95	168	27.4
46	49.3	8.3	42	88	16.9	46	124	18	96	169	28.5
47	50	8.8	43	88.5	18.7	47	124.5	17.5	97	169.9	30.5
48	51	6.9	44	90	34	48	125	17	98	172.5	30.7
49	53	11.3				49	125.5	18.7	99	173	28.4

		S. NO. ANGLE ^o		DB		S. NO. ANGLE ^o		DB	
101	175	30.3	42	225.5	22.5	5	314	9	
102	178	32.7	43	226	25	6	316	13.5	
103	180	33	44	228	24.7	7	318	10.5	
104	180.5	32.3	45	229	20.5	8	322	8	
105	181	34.6	46	231	23	9	324	10.8	
106	182	39.5	47	232	25	10	325	10.5	
107	183	40	48	233	25.5	11	326	9.5	
			49	236	21.5	12	329	9.7	
0	180	41	50	238	20.5	13	330	13.5	
1	181	37.1	51	240	22	14	332	8.5	
2	182	32.3	52	242	23.5	15	333	11.5	
3	183.9	33.1	53	243	22.5	16	335	11	
4	184.5	31.1	54	246	21.8	17	337	11.5	
5	186	27.8	55	248	22.8	18	338	12.5	
6	187	28.1	56	250	25.5	19	340	16.8	
7	189	35.2	57	252	22.8	20	341	16.7	
8	190	33.6	58	254	22	21	342	15.5	
9	191	29.5	59	256	22.6	22	345	14.9	
10	193	28.6	60	259	18.9	23	347	14	
11	194	28	61	262	18.5	24	349	14.5	
12	195	32.5	62	265	18	25	352	11.5	
13	196	28.8	63	267	15.6	26	354	13	
14	199	22.4	64	268	17.5	27	357	25	
15	200	29.6	65	270	34.5	28	359	28.3	
16	200.5	25							
17	201.5	25.2	0	270	34.5				
18	202	21.5	1	272	20.5				
19	203	25.2	2	274	17.5				
20	204	25.2	3	276	14.5				
21	205	25.6	4	277	15.5				
22	206	22.3	5	279	16.5				
23	207	20.5	6	281	19.5				
24	208	21.2	7	284	15.5				
25	210	26.3	8	285	17.5				
26	212	24	9	290	15.0				
27	213.9	19.5	10	292	15.5				
28	214	17.1	11	293	16.5				
29	215	18	12	294	17				
30	216.1	20.7	13	295	13.5				
31	217	21	14	296	12.5				
32	219	20.1	15	297	13				
33	220	21.9	16	300	10.8				
34	220.2	21.7	17	302	16				
35	221	21.6	18	304	31				
36	221.9	22							
37	222	22	0	304	31				
38	223	16.1	1	306	9.5				
39	223.5	17	2	307	5.5				
40	224	18.7	3	309	10.5				
41	225	20.6	4	312	13.5				