ADOPTION OF NEW SOUND SPEED EQUATIONS BY U.S. NAVAL OCEANOGRAPHIC OFFICE

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Introduction

It has become increasingly evident to the U.S. Naval Oceanographic Office that the accuracy of the KUWAHARA sound speed equations [1] presented as a function of temperature, salinity, pressure, and latitude is not sufficient for present day needs. *In situ* measurements of sound speed in sea water have indicated that at some depths the speed calculated by the KUWAHARA equation is 3 to 4 metres per second too slow. Because of this recognized need, a conference of interested parties was held at the Hydrographic Office (now U.S. Naval Oceanographic Office) in May 1961 for the purpose of resolving whether or not a new equation for the calculation of sound speed should be adopted. It was agreed by members of the conference that W. D. WILSON's equation [2] should be adopted for U.S. Navy applications. This decision was reached with the knowledge that currents research may yield equations which are somewhat more accurate.

According to WILSON, the mean standard deviation of the error between his equation and measured speeds over the range of variables (temperature — 4° C to 30° C, salinity 0 ‰ to 37 ‰, pressure 1 to 100 kg/cm²) is 0.03 m/sec. With temperature as the dependent variable, the maximum standard deviation is 0.74 m/sec at salinity 0 ‰ and atmospheric pressure (1.032 kg/cm²), and the minimum standard deviation is 0.08 m/sec at 36.55 ‰ salinity and 420 kg/cm² pressure.

The accuracy of the adopted equation at values greater than those shown above has had some limited evaluation by WILSON. The differences between the measured and computed velocities at some sample extreme values are :

Temperature	*Salinity*	*Pressure*	*Difference*
30.13°C	41.15 $^0/_{00}$	Surface	0.13 m/sec
39.85°C	34.99 $^0/_{00}$	Surface	0.06 m/sec
39.85°C	42.15 $^0/_{00}$	Surface	0.85 m/sec
39.85°C	42.15 $^0/_{00}$	381 kg/cm^2	0.65 m/sec
20.11°C	34.99 $^0/_{00}$	1 150 kg/cm^2	0.21 m/sec

Tables

To facilitate computation of sound velocity, *Tables of sound speed in Sea Water* (SP-58) where developed by the Oceanographic Office using the WILSON equation programmed for the IBM 7070 computer.

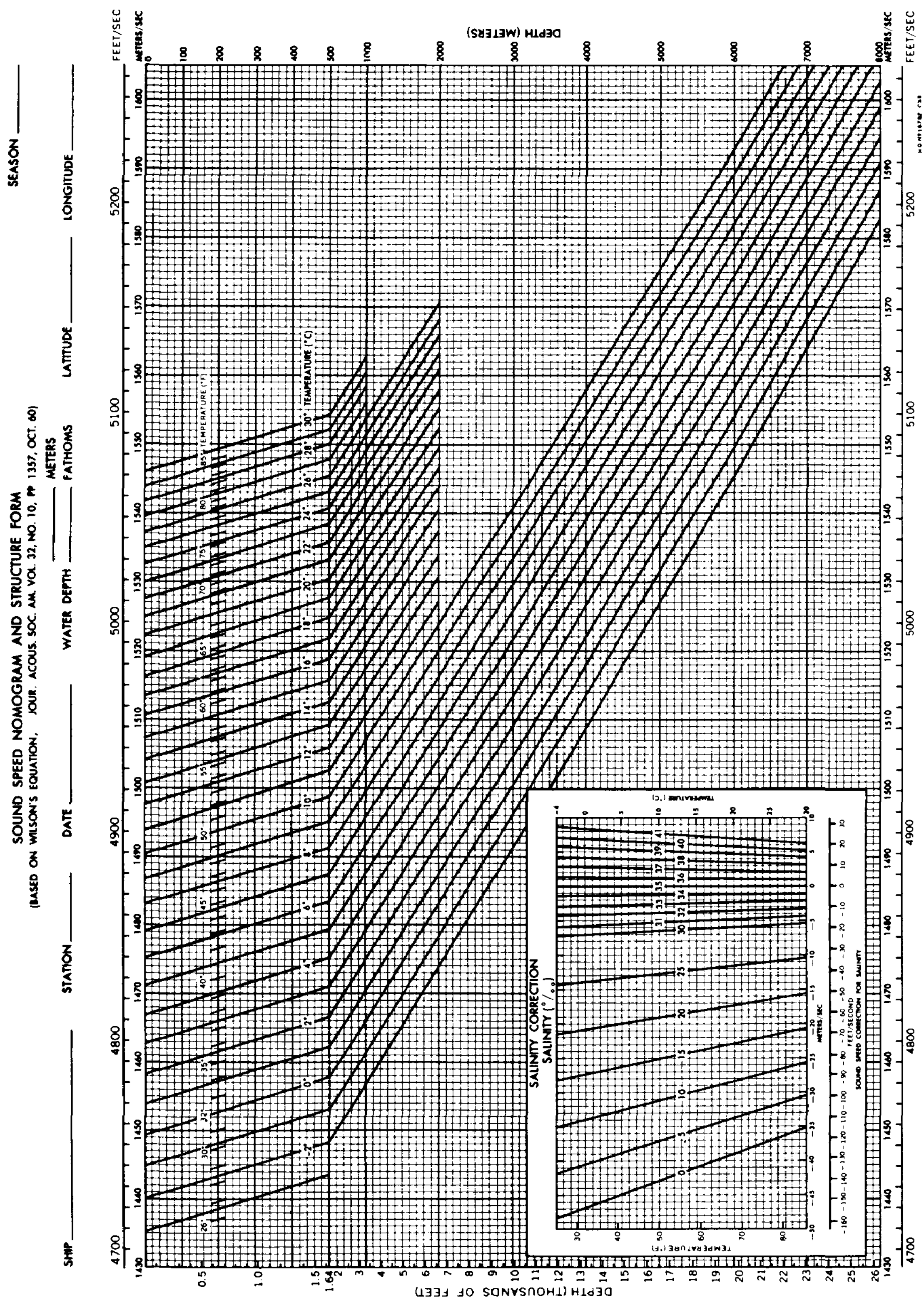
Although WILSON's equation is entered with pressure as a variable, by assuming a uniform water column of 0°C temperature and 35 $^0/_{00}$ salinity a depth-pressure relationship is established so that the tables can be entered with either depth or pressure as a variable. The tables are so designed that a minimum of interpolation is necessary for the pressure-depth correction. Salinity can be read to the nearest 0.01 $^0/_{00}$ and temperature to the nearest 0.01°C, thus eliminating interpolation of these variables.

The foregoing application of a uniform water column depends on the assumption that sound speed at a particular depth is a weak function of the temperature and salinity structure above that depth, an assumption supported by investigations of the U. S. Navy Electronics Laboratory [3]. In addition, direct comparisons were made at the Oceanographic Office between the speed presented in the tables using the pressure-depth relationship and those computed by using the actual pressures. Sound speeds were computed at standard depths, in one case using pressures computed from *in-situ* temperature and salinity values and in the other using pressures from an assumed water column at 0°C temperature and a salinity of 35 $^0/_{00}$. In the Gulf of Alaska and the Philippine Trench, this method indicated differences of 0.1 m/sec or less above 4 000 metres depth. In the Philippine Trench at 8 000 metres, the difference was less than 0.2 m/sec. These computations indicated that the changes in pressure attributed to differences in temperature and salinity from 0°C and 35 $^0/_{00}$ have only a minor effect on the sound speed at any depth.

Sound speed program

A sound speed nomogram and structure form was drawn from the values of sound speed given in the tables of SP-58 (figure 1). As in the tables, the pressure-depth relationship is based on a 0°C and 35 $^0/_{00}$ water column. The main body of the nomogram presents sound speed as a function of temperature and depth with salinity held at 35 $^0/_{00}$. Sound speed can be read to the nearest 0.5 m/sec. An inset is provided to correct the speeds for salinities other than 35 $^0/_{00}$.

The temperature structure at an oceanographic station can be plotted on the nomogram to determine an approximate sound speed. Large errors in absolute speed will occur in nearshore areas or enclosed seas where the


SOUND SPEED NOMOGRAM AND STRUCTURE FORM
(BASED ON WILSON'S EQUATION, JOUR. ACOUS. SOC. AM. VOL. 32, NO. 10, PP 1357, OCT. 60)
MARSDEN SQUARE NO
1° SQUARE NO
MONTH
SEASON
SHIP
STATION
DATE
WATER DEPTH
METERS
FATHOMS
LATITUDE
LONGITUDE
FEET/SEC
METERS/SEC
DEPTH (METERS)
DEPTH (THOUSANDS OF FEET)
TEMPERATURE (°F)
TEMPERATURE (°C)
SALINITY CORRECTION
SALINITY (°/oo)
SOUND SPEED CORRECTION FOR SALINITY

salinity may deviate radically from 35 ‰. The general shape of the speed structure can be easily determined for the normal oceanographic environment.

Station data on magnetic tape

Sound speed is computed from oceanographic station data stored on magnetic tape by using a program developed at the U. S. Navy Electronics Laboratory which has been modified and rewritten by the Oceanographic Office for the IBM 7070 computer. The program utilizes a basic formula developed by EKMAN to calculate density and includes a term which compensates for the variation of gravity with latitude. The program employs a pressure correction routine based on a procedure developed by N. P. FOFONOFF [4]. This routine provides pressure at any given depth as an integrated function of temperature and salinity in the water column from the surface to the point of interest. The atmospheric pressure is taken as the surface pressure and the surface water density is computed as a function of temperature, salinity, and pressure. The sound velocity at this level is then computed by means of the WILSON equation. Once this speed has been computed, the pressure and density terms at succeeding depths are determined by a method of successive approximation taking into account pressure and density terms of the preceding depths as well as *in-situ* temperature and salinity. Sound speed at each data point is calculated with the WILSON equation employing *in situ* temperature, salinity, and corrected pressure. The process continues until the deepest data point is reached.

References

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[4] FOFONOFF, N. P. and TABATA, S. : Program for oceanographic computations and data processing on the electronic digital computer ALWAC III-E. *Fisheries Research Board of Canada Manuscript Report Series* No. 25, pp. 18-26, 25 August 1958.