# USP Assignment 01

Calculation of sound speed as a function of temperature T, Salinity S, and depth Z,30-04-2024

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***Abstract*—This paper mainly explains the influence of the sound speed in seawater when temperature, salinity, and depth vary, utilizing a MATLAB-based approach. Selecting suitable empirical formulae is to represent the sound speed variations and develop them within the MATLAB interface. To understand the impact on the speed of the sound underwater, the Essential parameters such as temperature and salinity are orderly varied with the depth considered as a variable. The results obtained from the MATLAB code describe how sound speed changes with parameters such as temperature, salinity, and depth. This paper contributes to a better understanding of sound propagation in seawater.**

***Index Terms*—Empirical Equations, Salinity, MATLAB, Acoustics, Oceanography, Thermocline.**

## I. Introduction

Behavioral understanding of sound in the ocean is the main concern for various applications ranging from underwater communication to marine applications. Depending on environmental parameters such as temperature, salinity, and pressure influence the speed of sound at certain depths. We determine the sound speed as a function of temperature, pressure, and salinity with the help of the provided interface by MATLAB.

Developing a code in MATLAB using empirical equations for measuring the sound speed at different depth values based on the variations of essential parameters like temperature, and salinity. The graph between the speed of sound versus depth for various temperatures and salinities will be plotted. By observing these relationships, we gain insights into how temperature, salinity, and depth affect sound propagation in the ocean, which is important for understanding and modeling underwater acoustics.

## II. Methodology

Essential steps are taken into account to measure the speed of sound in oceans. Firstly, the suitable steps required to determine an accurate sound speed profile are empirical equations, numerical models, and available solutions. Factors such as accuracy, computational complexity, and practical feasibility helped to evaluate each approach smoothly.

However, the empirical equation approach was selected due to its simplicity and accuracy in representing sound speed variations in seawater, while other approaches are a little more complex than this method.This approach necessitated parameterized, where the parameters temperature, salinity and depth are represented along with their respective ranges and units. This method provides insights into the conditions of real-world oceanography and facilitates the accurate representation of sound speed variations. Implementation details involved the utilization of the MATLAB programming environment, chosen for its suitability for numerical computations. An algorithm was developed to implement the selected empirical equation, incorporating mathematical expressions and logic to account for the effects of temperature, salinity, and depth on sound speed.

## III. Implementation

The empirical formulae are used for the practical implementation process consisting of two major steps, choosing the needed approach for the given problem and coding this approach with the help of the MATLAB environment. The creation of MATLAB environment setting was carried out by defining the MATLAB software version and any toolboxes or libraries required.

The core of the implementation was composed of designing the MATLAB code in which an algorithm was created to determine the sound speed taking into account the forms of empirical data. The algorithm consisted of mathematical expressions and logical operations to ensure that the sound speed was correctly determined with the influence of temperature, salinity, and depth considered. Input data processing was of utmost significance, which comprised of the acquisition and processing of input data such as temperature, salinity, and depth values. This step thereby made the input data to be well-formed and ready for use by algorithm.

More importantly, the construction of the MATLAB code was based on functions, individual variables, as well as control flow structures so that the program could run seamlessly. Quality Assurance methods, comprising of testing and validation, were executed as a control measure of compliance with the process of implementation. This training also included performance of the instruments and a comparison of the calculated speed of sound against the reference values known or theory-based. The development part, in turn, transformed the approach into a indispensable MATLAB code. The accuracy was set during the calculation of sound speed by making use of

MATLAB's capabilities for the inputs of temperature, salinity, and depth.

## IV. Results and Discussions

By adjusting certain parameters like temperature and salinity, MATLAB produced a visual plot that helped users understand how the speed of sound behaves at various depths. Two subplots with a step size of five are present: one at various temperatures, and the other at various salinities. The y-axis in each subplot shows the depth in meters, and the x-axis the sound speed. Plots using various colored lines to indicate the speed of sound at various parameters are easy to understand. These lines provide insight into how these factors alter sound speed at various salinities and temperatures.Plots produced by MATLAB were used to show how salinity and temperature affected the speed of sound at various depths.

### *A. Figures*

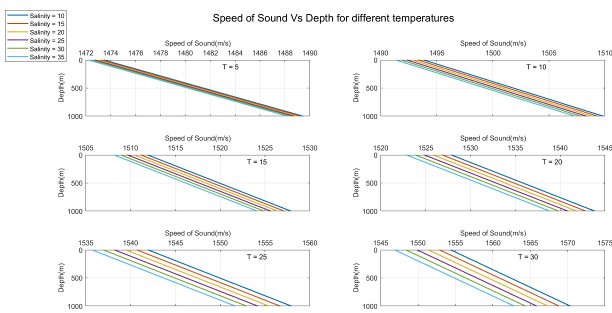


Fig. 1. Depth vs Sound speed with Different Salinity's for Each temperature

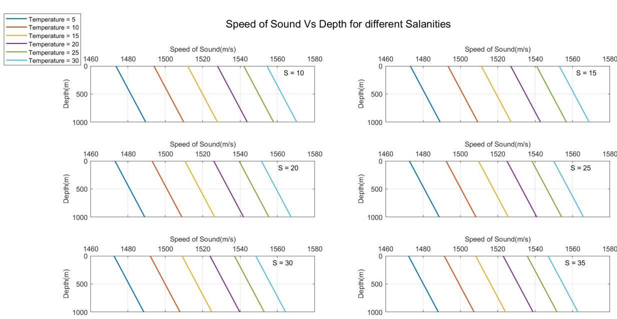


Fig. 2. Depth vs Sound speed with Different temperatures for Each Salinity

### *B. Discussions*

We used an empirical equation eq1, valid only for a depth of 0 to 1000 meters, to determine the speed of sound.

$$\begin{aligned} c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 \\ +(1.34 - 0.01T)(S - 35) + 0.016z \end{aligned} \tag{1}$$

Variations in sound velocity c in the ocean are relatively small. As a rule, c lies between about 1450 m/s and 1540 m/s. Even though the changes of c are small, the propagation of sound can be significantly effected. The sound velocity can be measured directly by velocimeters or calculated by empirical formulae if the temperature (T) salinity (S) hydrostatic pressure (P) or depth (z) are known.

The speed sound profile may be influenced by the region's surface. In regions with polar temperatures, the sound's surface velocity is the same as its depth velocity. The sea surface temperature rises in non-polar areas, which causes the sound to travel faster. The sea surface in the polar regions forms a mixed layer with a nearly constant temperature. This area is referred as the surface duct region. The temperature drops rapidly and the sound speed decreases with depth below this line. We refer to this area as the thermocline. The deep sound channel has a constant temperature in the region following the thermocline. As a result, the pressure causes the sound to travel faster. Deep sound channel axis represents the lowest speed sound. In the event of a polar region, the deep channel axis indicates the sound's speed at zero meters of depth. We observed that the speed of sound varies when one of the parameters is changing such as temperature and pressure. The speed of sound increases when temperature increases and salinity decreases, which means that salinity and temperature play a key role in determining the speed of sound underwater at a certain depth.

## References


[1] William A. Kuperman and Philippe Roux, "UNDERWATER ACOUSTICS," Marine Physical laboratory, Scripps Institution of Oceanography University of California, San Diego, January 2007.

[2] K. H. Talib, M. Y. Othman, Saiful Aman Hj Sulaiman, M. A. M. Wazir and A. Azizan,"Determination of speed of sound using empirical equations and SVP,"IEEE 7th International Colloquium on Signal Processing and its Applications, Penang, Malaysia, 2011 , pp. 252-256.

## Appendix A
## MATLAB Code

```
T = 5:5:30;
S = 10:5:35;
Z = linspace(0,1000,10);
C = zeros(length(T), length(S), length(Z)
    );
% Calculate sound speed for each
    combination of T, S, and Z
for i = 1:length(T)
    for j = 1:length(S)
        for k = 1:length(Z)
            C(i, j, k) = 1449.2 + (4.6 *
                T(i)) - ((0.055) * T(i)^2)
                 + ((0.00029) *
            T(i)^3) + (1.34 - (0.01 * T(i
                )) *
            (S(j) - 35)) + (0.016 * Z(k))
                ;

        end
    end
end
figure;
for i = 1:length(T)
      subplot(3,2,i)
    for j = 1:length(S)
        plot(squeeze(C(i, j, :)),Z, '
            linewidth', 1.5);
        hold on;
    end
    text(max(xlim-7), min(ylim+120),
       sprintf('T = %d', T(i)))
    set(gca, 'XAxisLocation', 'top', '
       YAxisLocation', 'left', 'YDir',
    'reverse', 'FontSize', 10);
    xlabel('Speed of Sound(m/s)',Fontsize
       =10);
    ylabel('Depth(m)',Fontsize=10);
    hold off;
    grid on;
end
sgtitle('Speed of Sound Vs Depth for
    different temperatures')
legend(arrayfun(@(x) sprintf('Salinity =
    %d', x), S, 'UniformOutput', false),
'Location', 'northwestoutside');
figure;
for j = 1:length(S)
     subplot(3,2,j)
     for i = 1:length(T)
        plot(squeeze(C(i, j, :)),Z, '
            linewidth', 1.5);
        hold on;
    end
    text(max(xlim-7), min(ylim+120),
       sprintf('S = %d', S(j)))
    set(gca, 'XAxisLocation', 'top', '
       YAxisLocation', 'left', 'YDir',
    'reverse', 'FontSize', 10);
    xlabel('Speed of Sound(m/s)',Fontsize
       =10);
    ylabel('Depth(m)',Fontsize=10);
    hold off;
    grid on;
end

sgtitle('Speed of Sound Vs Depth for
    different Salanities')
legend(arrayfun(@(x) sprintf('Temperature
     = %d', x), T, 'UniformOutput',
false), 'Location', 'northwestoutside');
```