Module 7: Imaging Artifacts

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I. SOUND SPEED

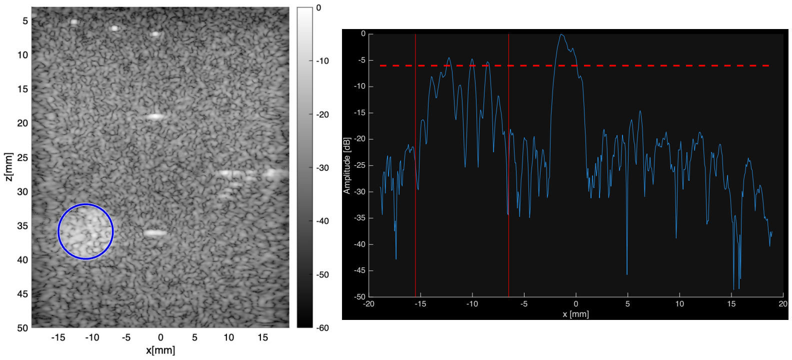

FIG. 1. 1460 m/s (fat)

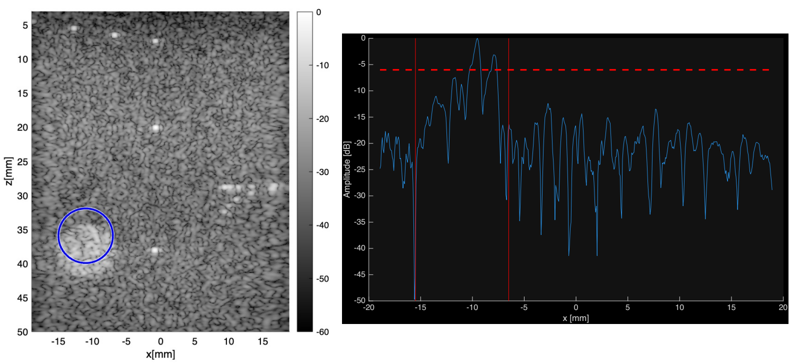

FIG. 2. 1540 m/s (typical mean)

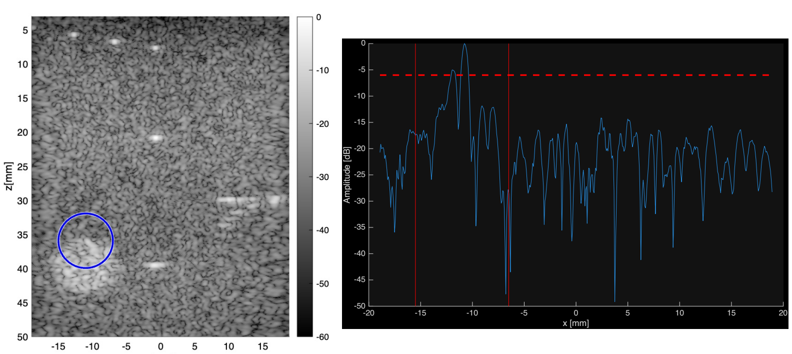

FIG. 3. 1600 m/s (muscle)

Three different sound speeds were used to beamform the plane wave image: 1460 m/s (fat), 1540 m/s (typical mean), and 1600 m/s (muscle). The choice of sound speed significantly affects the reconstructed image in several ways, for example:

- **Object positioning:** When the sound speed changes, objects appear at different depths in the reconstruction. Lower sound speed (1460 m/s) makes objects appear shallower, while higher sound speed (1600 m/s) makes them appear deeper. This occurs because beamforming calculates depth as $z = ct/2$, where c is the assumed sound speed and t is the time-of-flight.

- **Point scatter resolution:** The lateral resolution of the point scatter is most affected by sound speed selection. With incorrect sound speed (either 1460 m/s or 1600 m/s), the point scatter appears broader with reduced lateral resolution. The correct sound speed (1540 m/s) produces the sharpest, most focused point scatter with the best lateral resolution.

The point scatter resolution serves as a key indicator for sound speed accuracy: the sound speed that produces the sharpest point scatter is closest to the actual sound speed of the medium.

II. ADJUSTING Z-AXIS

To enable pixel-by-pixel comparison of images reconstructed with different sound speeds, the z-axis must be scaled appropriately with sound speed. The solution is to express depth in units of wavelength (λ) rather than meters.

The problem: When sound speed changes, the time-of-flight calculations in beamforming change, causing objects to appear at different depths. This occurs because depth is calculated as $z = ct/2$, where c is the sound speed. When c increases, the same time delay is interpreted as a greater depth, shifting objects in the reconstructed image.

The wavelength solution: The wavelength is defined as $\lambda = c/f$, where f is the frequency. By expressing depth in wavelengths instead of meters, we create a coordinate system that automatically adjusts with sound speed changes. This can be implemented by scaling the z-axis proportionally:

$$z_{\text{scaled}} = z_{\text{meters}} \times \frac{c}{c_{\text{ref}}} \tag{1}$$

where c_{ref} is a reference sound speed (e.g., 1540 m/s).

Why it works: When sound speed increases, two effects occur simultaneously:

1. Objects appear deeper in the reconstruction (larger z)

2. The wavelength increases proportionally ($\lambda \propto c$)

These effects cancel out when depth is expressed in wavelengths. Mathematically:

$$z_{\text{wavelengths}} = \frac{z_{\text{meters}}}{\lambda} = \frac{z_{\text{meters}}}{c/f} = \frac{z_{\text{meters}} \times f}{c} \tag{2}$$

Since the time-of-flight t remains constant for a given scatterer, and $z_{\text{meters}} = ct/2$, we have:

$$z_{\text{wavelengths}} = \frac{ct/2 \times f}{c} = \frac{ft}{2} \tag{3}$$

This expression is independent of sound speed c, ensuring that objects remain at the same position in wavelength coordinates regardless of the sound speed used for reconstruction. This enables direct pixel-by-pixel comparison across images reconstructed with different sound speeds.

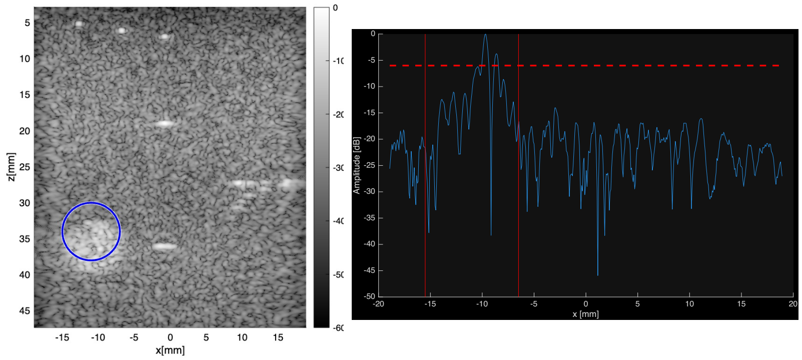

FIG. 4. 1460 m/s (fat) with adjusted z-axis

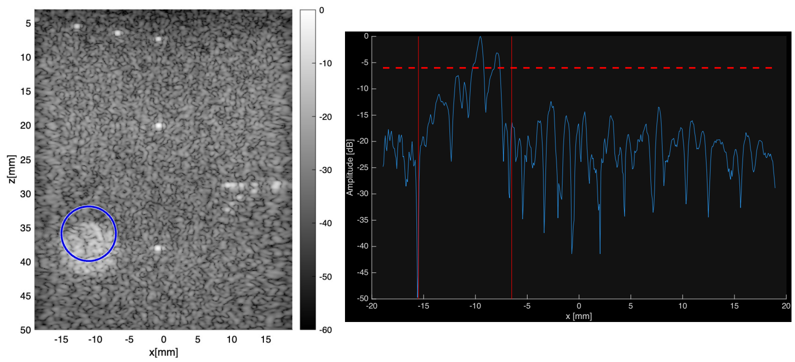

FIG. 5. 1540 m/s (typical mean) with adjusted z-axis

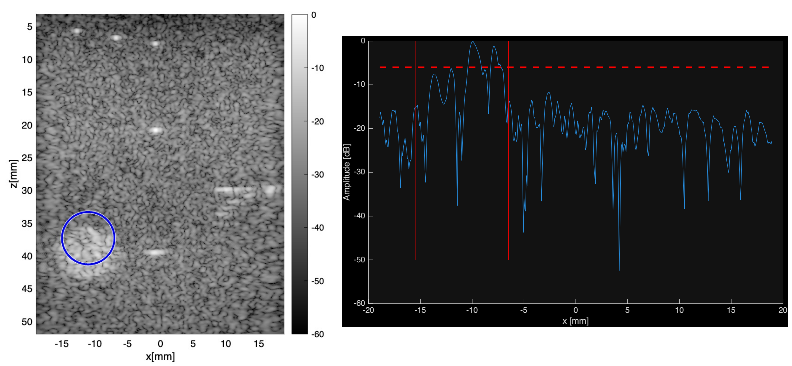

FIG. 6. 1600 m/s (muscle) with adjusted z-axis

With the z-axis adjusted according to sound speed, all three images now align perfectly in terms of object positioning and size.

III. SOUND SPEED EVALUATION CRITERIA

Based on the observations from the previous experiments, the correct sound speed for reconstruction can be determined using the following criterion: **the sound speed that produces the sharpest point scatter with maximum lateral resolution is the correct one**.