C-3.2. VELOCITY PROCESSING ALGORITHM. The following algorithm calculates the east (X), north (Y), vertical (Z), and error (E) velocity components from the raw ADCP Doppler frequency data. We describe the algorithm using FORTRAN-like variables and arithmetic.

The algorithm input has NBINS of range-gated Doppler frequency in four arrays (D1, D2, D3, D4) containing frequency estimates from the four transducer beams. Heading is from the flux-gate compass. Pitch and roll data are from the tilt sensors mounted inside the transducer head. The algorithm produces three, resolved-velocity arrays each with NBINS of velocity data at depths corresponding to those measured with zero pitch and roll.

In this algorithm, steps 1 and 2 are done once for each ping. Step 3 begins a loop that ends in step 6. The loop executes NBINS times for each ping.

Step 1 — Determine Rotation Angles from Sensor Readings. For each new set of pitch, roll, heading, and Doppler frequency data, find the rotation angles for the conversion matrix RR, PP, and HH. There are three cases that vary depending on how the tilt sensors are fixed to the ADCP.

Case 1 - Pitch and Roll Axes Fixed to ADCP. The sensor axes are fixed to the ADCP axes and rotate with the ADCP. Use this set of equations with pendulum attitude sensors. The rotation angles are:

```
RR = ROLL
PP = ARCSIN(SIN(PITCH) * COS(ROLL) / KA)
HH = HEADING
```

where $KA = SQRT(1 - (SIN(PITCH) * SIN(ROLL))^2)$

Case 2 - Roll Axis Fixed to ADCP. The roll axis is fixed to the ADCP, and the pitch axis in gimballed inside the roll axis.

```
PP = PITCH
RR = ROLL
HH = HEADING
```

Case 3 - Pitch Axis Fixed to System. The pitch axis is fixed to the ADCP, and the roll axis is gimballed inside the pitch axis.

```
PP = PITCH
RR = ROLL
HH = HEADING + DD
```

where DD = ARCSIN(SIN(PITCH) * SIN(ROLL) / KB)
$KB = SQRT(COS(PITCH)^2 + (SIN(PITCH) * SIN(ROLL))^2)$

Notice in case 1, an adjusted reading of the pitch sensor was used for the pitch rotation angle, while case 3 requires an adjustment to heading.

Step 2 — Calculate Trigonometric Functions and Scaling Factors. Find the Z component of the conversion matrix M(I,J) that expresses in earth coordinates a vector initially acquired in instrument coordinates. For the three different cases, the components are:

```
CP = cos(PP)    CR = cos(RR)    CH = cos(HH)    C30 = cos(30)
SP = sin(PP)    SR = sin(RR)    SH = sin(HH)    S30 = sin(30)
```

Case 1 - Tilt Sensors Fixed to ADCP.

```
M(3,1) = -SR*CP
M(3,2) =  SP
M(3,3) =  CP*CR
```

Case 2 - Roll Axis Fixed, Pitch Axis Gimballed Inside Roll.

```
M(3,1) = -SR*CP
M(3,2) =  SP
M(3,3) =  CP*CR
```

Case 3 - Pitch Axis Fixed, Roll Axis Gimballed Inside Pitch.

```
M(3,1) = -SR
M(3,2) =  CR*SP
M(3,3) =  CP*CR
```

Form the scale factors for the depth index:

```
SC(1) = C30 / (M(3,3)*C30 + ZSG(1)*M(3,1)*S30)
SC(2) = C30 / (M(3,3)*C30 + ZSG(2)*M(3,1)*S30)
SC(3) = C30 / (M(3,3)*C30 + ZSG(3)*M(3,2)*S30)
SC(4) = C30 / (M(3,3)*C30 + ZSG(4)*M(3,2)*S30)
```

where ZSG is a sign that varies depending on the orientation and beam pattern of the transducers. The transducers can face up or down and have concave or convex beam patterns. ZSG is given in the following table.

	Up Convex	Up Concave	Down Convex	Down Concave
ZSG(1)	+	-	+	-
ZSG(2)	-	+	-	+
ZSG(3)	+	-	-	+
ZSG(4)	-	+	+	-

Form the transducer to instrument-coordinate system scaling constants and the error velocity constant:

$$VXS = C / (F_t * 4 * \sin(30))$$
$$VYS = C / (F_t * 4 * \sin(30))$$
$$VZS = C / (F_t * 8 * \cos(30))$$
$$VES = C / (F_t * 8)$$

where C = speed of sound in the profiled water (in cm/s); see ¶C-1
F_t = is the transmitted sonar frequency (Hz).

Step 3 – Depth Cell Correction for Pitch and Roll. The pitch and roll information maps the tilted, range-gated, Doppler frequency estimates into depth cells (bins) at the same depth. The following loop executes from 1 to the number of bins (NBINS).

```
REPEAT  for IB = 1 to NBINS
    J1 = IB*SC(1) + 0.5
    J2 = IB*SC(2) + 0.5
    J3 = IB*SC(3) + 0.5
    J4 = IB*SC(4) + 0.5
```

where J1, J2, J3, and J4 are integers of the constant depth indices for Doppler frequency data in the IB^{th} bin of the input arrays D1, D2, D3, D4.

Now check that all indices are >0 and ≤NBINS, and that the data in D1(J1), D2(J2), D3(J3), and D4(J4) are valid. The latter test normally uses the STATUS nibble from the ADCP with the Doppler frequency data. If any of the four estimates are bad, skip to the end of the loop.

Step 4 – ADCP Coordinate Velocity Components. Find the VX, VY, VZ, and VE instrument-coordinate velocities for the IB^{th} bin. This conversion depends on transducer orientation (up/down) and beam pattern (concave/convex). The four cases are (Note: D1-D4 are in Hz; Table 4-3 shows scaling factors):

```
UPWARD CONVEX
    VX = VXS * (-D1(J1) + D2(J2))
    VY = VYS * (-D3(J3) + D4(J4))
    VZ = VZS * (-D1(J1) - D2(J2) - D3(J3) - D4(J4))
    VE = VES * (+D1(J1) + D2(J2) - D3(J3) - D4(J4))

DOWNWARD CONVEX
    VX = VXS * (+D1(J1) - D2(J2))
    VY = VYS * (-D3(J3) + D4(J4))
    VZ = VZS * (+D1(J1) + D2(J2) + D3(J3) + D4(J4))
    VE = VES * (+D1(J1) + D2(J2) - D3(J3) - D4(J4))

UPWARD CONCAVE
    VX = VXS * (+D1(J1) - D2(J2))
    VY = VYS * (+D3(J3) - D4(J4))
    VZ = VZS * (-D1(J1) - D2(J2) - D3(J3) - D4(J4))
    VE = VES * (+D1(J1) + D2(J2) - D3(J3) - D4(J4))

DOWNWARD CONCAVE
    VX = VXS * (-D1(J1) + D2(J2))
    VY = VYS * (+D3(J3) - D4(J4))
    VZ = VZS * (+D1(J1) + D2(J2) + D3(J3) + D4(J4))
    VE = VES * (+D1(J1) + D2(J2) - D3(J3) - D4(J4))
```

Check whether the absolute value of VE (error velocity) exceeds a preselected value (e.g., three times the expected velocity standard deviation). VE checks the validity of the calculation of the three orthogonal velocity components VX, VY, and VZ. This is possible because the ADCP needs only three beams to calculate the three velocity components. The fourth beam provides redundant data and allows computation of a "data reasonableness" velocity component.

Step 5 — Convert to Earth Coordinates. The conversion to earth coordinates (shown by the letter E added to the variable name) is done by multiplying the velocity vector by the conversion matrix. For the three cases described above, the results are:

Case 1 - Tilt Sensors Fixed to ADCP.

```
VXE =  VX * (CH*CR + SH*SR*SP) + VY*SH*CP + VZ * (CH*SR - SH*CR*SP)
VYE = -VX * (SH*CR - CH*SR*SP) + VY*CH*CP - VZ * (SH*SR + CH*SP*CR)
VZE = -VX*SR*CP                + VY*SP    + VZ*CP*CR
```

Case 2 - Roll Axis Fixed, Pitch Axis Gimballed Inside Roll. Same as the case 1 transformation.

Case 3 - Pitch Axis Fixed, Roll Axis Gimballed Inside Pitch.

```
VXE =  VX*CH*CR + VY*(CH*SR*SP + SH*CP) + VZ*(CH*SR*CP - SH*SP)
VYE = -VX*SH*CR - VY*(SH*SR*SP - CH*CP) - VZ*(SH*SR*CP + CH*SP)
VZE = -VX*SR    + VY*CR*SP              + VZ*CP*CR
```

Step 6 — Place Results in Output Array. The output arrays U, V, and W are indexed by the bin index IB. U is the east(+)/west(-) component, V is the north(+)/south(-) component, and W is the down(-)/up(+) component. From the directions of the earth-coordinate axes it can be seen that

```
U(IB) = VXE
V(IB) = VYE
W(IB) = VZE
```

This completes the processing for the IBth bin. From here, loop back to process the remaining bins. When all the bins are processed, the velocity processing algorithm is complete.

C-4. ECHO SPECTRAL WIDTH

The ADCP determines the echo spectral width by measuring the second moment of the backscattered water-mass echo for each depth cell (bin). It is a measurement of the expected statistical uncertainty in a single-ping, mean water-mass velocity measurement. See RDI's *Principles of Operation: A Practical Primer* for information on calculating spectral width.

C-5. ECHO INTENSITY

The ADCP echo-intensity data are a measurement of the intensity of the backscattered echo for each depth cell. See RDI's *Principles of Operation: A Practical Primer* for information on calculating echo intensity.