Seaglider refurbishment training: Ballasting theory & tools

IOP Seaglider Group
APL-UW
April 2024

Definitions

Volmax: maximum volume of the glider (i.e., volume when all moveable oil is in the external bladder), in cc's. Getting an accurate estimate of volmax is key to ballasting. We get an initial estimate of volmax in a tank, and a more refined estimate during the test deployment. Volmax is a constant for a given glider configuration (external payload and VBD settings).

Neutral volume: This is the volume of the glider including external bladder position at which the glider is neutrally buoyant at the desired apogee density. By definitions below, the bladder position at this point is 0cc and C_VBD AD counts.

Thrust: buoyancy in cc relative to the neutral position defined by C_VBD. Negative thrust means the glider is "heavy".

Target thrust ($MAX_BUOY): This is the desired amount of negative thrust that we want to have at apogee so that we can maintain speed throughout the entire dive.

$C_VBD: The position of the oil reservoir in AD counts that defines where the glider thinks it has zero thrust at apogee density.

Apogee density ($RHO): Reference density in sigma-theta units. Typically set to the most dense water expected to be seen.

$VBD_MIN, $VBD_MAX: AD limits of the VBD system (VBD_MIN is pumped to max, VBD_MAX is bled to minimum)

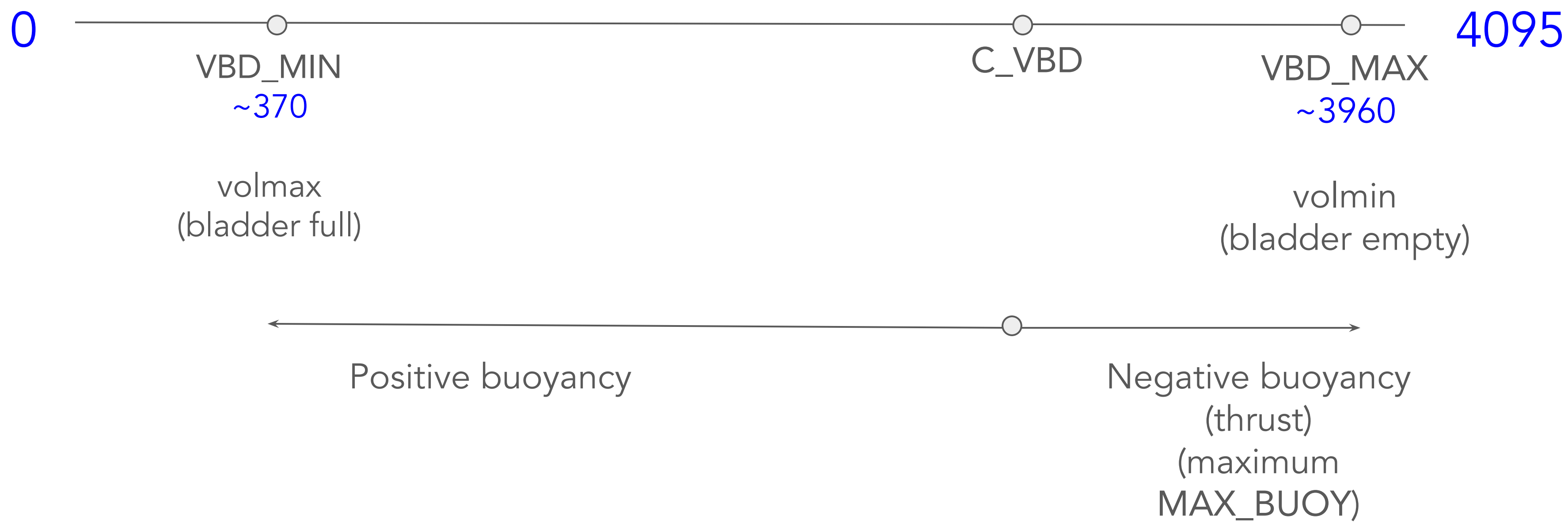
Goal of ballasting

Determine the total mass of the glider (i.e., how much lead to add/remove) needed to achieve the desired thrust at a given density while preserving enough reserve positive buoyancy for the glider to surface in the widest possible range of surface densities.

The glider is ballasted according to:

- Target density (at max depth, typically 1000 m) in the area of operation.
- Thrust – typically 150 to 250 cc. Larger thrusts are needed to overcome strong currents.
- Reserve buoyancy – e.g., in areas with a very fresh surface layer, it can be crucial to have enough reserve buoyancy so the glider can surface

Ballasting strategy



Ballasting strategy

1. Weigh glider to get scale mass
2. Obtain an estimate of volmax (e.g., in tank or from test dives)
3. Compute the target mass needed for a given target density & thrust:
    a. Target thrust fixes C_VBD because we never need to get heavier than that thrust, so we can set C_VBD such that when bled to VBD_MAX (minimum buoyancy) we will be at target thrust:
    C_VBD = VBD_MAX – thrust/VBD_CNV
    b. With C_VBD fixed we know how positive we can get: it's the difference between neutrally buoyant at C_VBD (when the glider has minimum volume, volmin) and having maximum buoyancy when pumped to VBD_MIN:
    volmax = volmin + (VBD_MIN – C_VBD)*VBD_CNV
    c. Because volmin = mass / RHO, we can rearrange (b) to solve for mass:
    mass = RHO*(volmax – (VBD_MIN – C_VBD)*VBD_CNV)
4. Difference between scale mass and target mass = amount of lead to add or remove
5. Double check that at Volmax, glider will be able to raise antenna (~150cc) in lowest density surface water expected:
    a. RHO_min = Mass / (Volmax - 150)

*VBD_CNV = cc's of oil per AD count = -0.2453 (constant, same for SG and SGX)

Ballast worksheet

Access from the Tools menu on the basestation3 visualization:

Ballast worksheet: generic tool to compute the target mass based on scale mass, volmax, etc.
– we use this when we already have an estimate of volmax from the ballast tank

VBD regression: uses dive data to estimate the glider's volmax by regressing observed vertical velocity (w) against w from the glider flight model.
– we use this after Puget Sound test dives to get a more accurate estimate of volmax
– that volmax can then be input in the ballast worksheet to get final ballast numbers prior to deployment

Ballast worksheet

VBD min counts	648	Automatically populated from the most recent log file
VBD max counts	3962	
scale mass as flown in field (g)	51657	← actual mass of glider
target thrust for final ballast (g)	-150	Typical values we use for testing in Puget Sound For open ocean, typical target values are -250 g thrust, 1.0275 g/cc density
target density for final ballast (g/cc)	1.023	
antenna volume loss (cc)	150	Volume that is out of the water when the glider is at the surface. Antenna is always 150cc.
volmax from regression of field test data (cc)	51097.06696	volmax - from tank or from regression to field data
calculate		This button calculates the final ballast results from the above parameters

Deepglider parameters (leave blank for SG/SGX):

abs compress (model or fixed) (m^3/dbar)		Ignore for SG/SGX
therm expan (model or fixed) (m^3/°C)		
ref temperature (°C)		
apogee temperature (°C)		
apogee pressure (dbar)		
calculate Deepglider		

comments

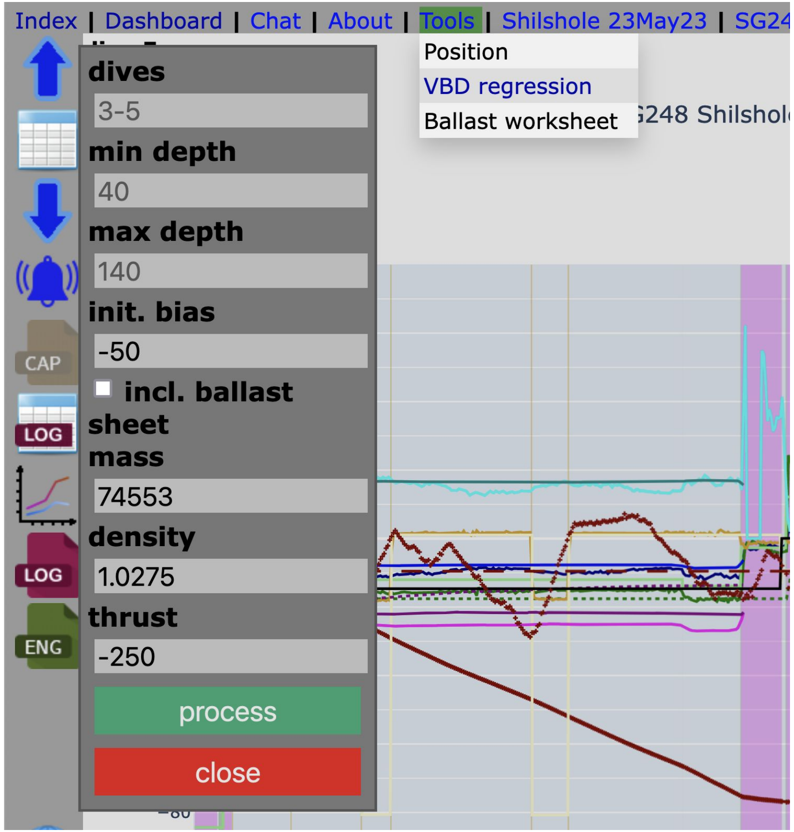
Optional box for adding comments
(for record keeping purposes)

Final ballast results

lead to add for final ballast (g)	-72.9263859	Calculated final ballast and lead to add/remove
target mass for final ballast (g)	51584.07361	
final scale mass after adjustments (g)		Optional - enter the actual final mass (for record keeping)
predicted volmax at final ballast (cc)	51090.61101	
predicted C_VBD at final ballast	3364.252075	Good starting place for trimming the glider (typically ~200 counts higher than the actual C_VBD if ballasted on ~150m flights for open ocean operating at 1000m)
minimum surface density (g/cc)	1.012631623	The glider will struggle to surface if the surface is less dense than this
maximum buoyancy (cc)	666.296634	
neutral stroke (%)	81.96294734	

VBD regression tool (basestation3)

Iterative regression of observed vs. modeled vertical velocity, varying flight coefficients and VBD bias. The resulting best fit gives us our best estimate of volmax.



Dives over which to compute the regression- only use dives for which the glider flew well. We use at least 3 dives to 150 m to get best regression results.

Depth range over which to compute the regression (avoid the upper ~40 m and lowest ~10 m, when the glider model isn't accurate)

First guess of bias for the iterative regression process

Include the ballast sheet tool in the regression output

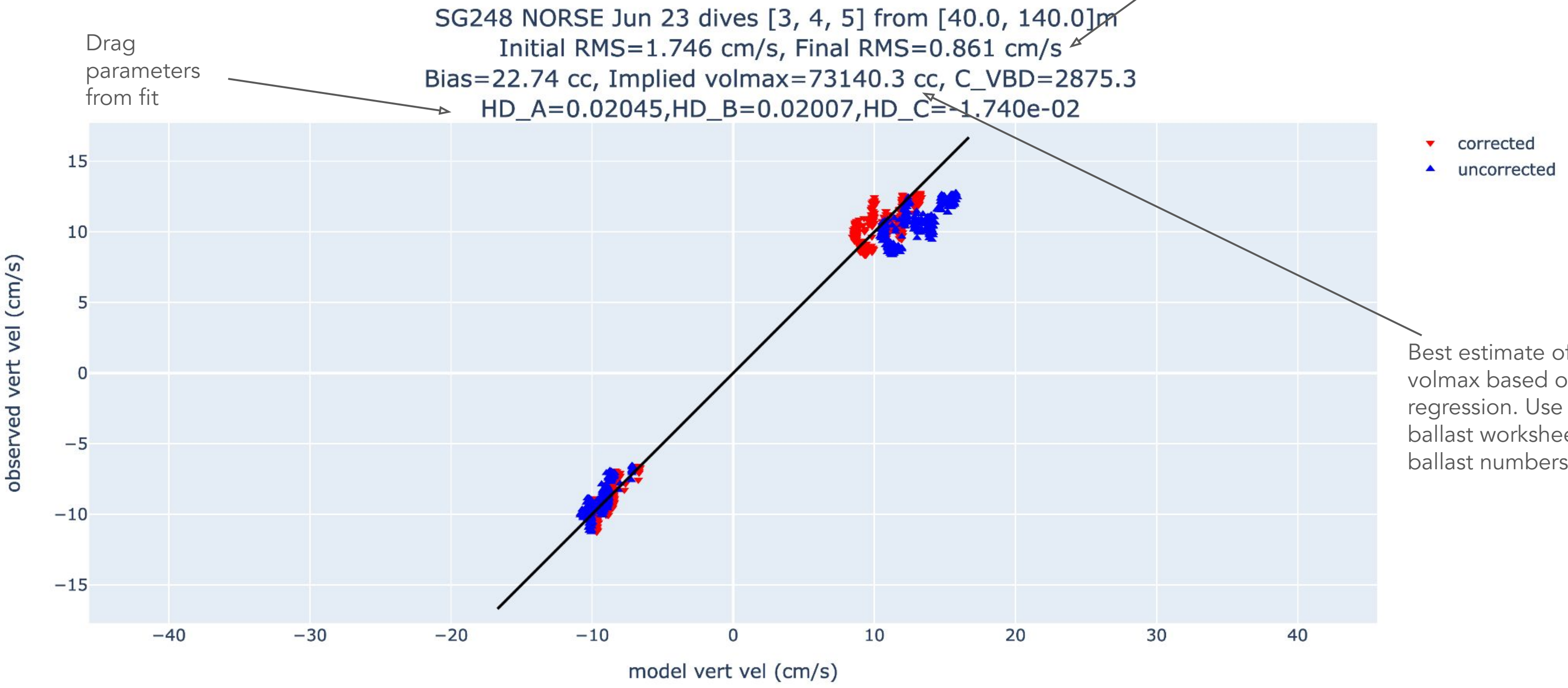
Scale mass - populated from the log file

Target density and thrust - only used for the ballast estimate

Output of VBD regression tool

RMS difference between modeled & observed data. Values <1 imply the regression is doing a good job.

Drag parameters from fit

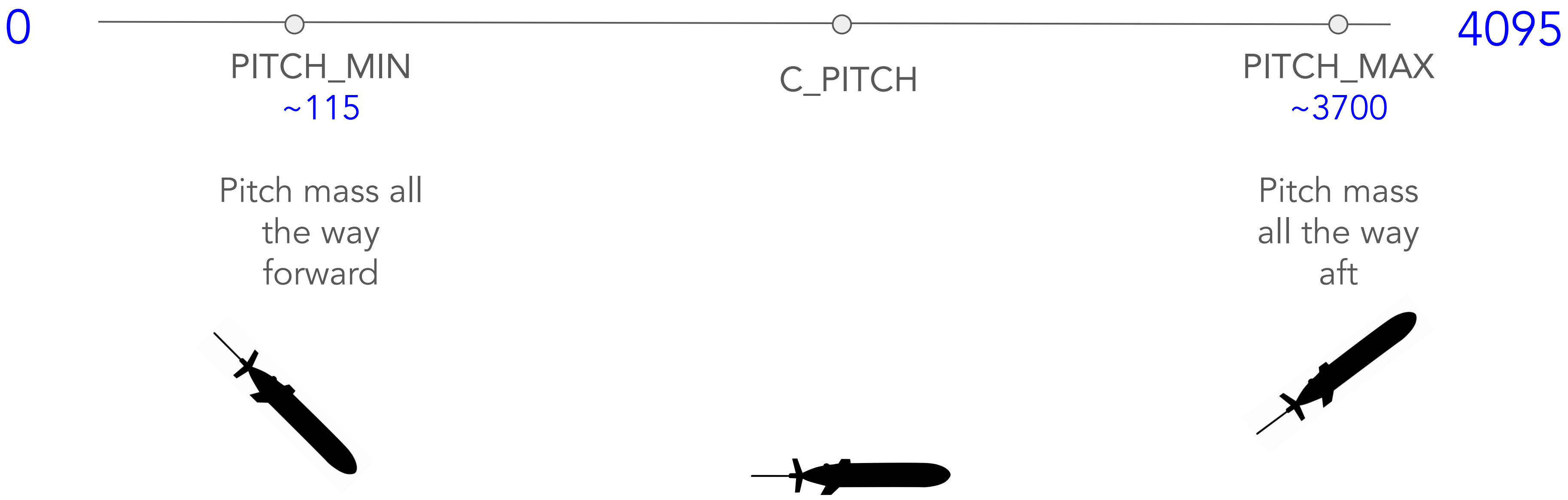


Best estimate of the glider's volmax based on the regression. Use this in the ballast worksheet to obtain final ballast numbers.

Lead placement

Following a trip to the tank (if available) or a field test, adjust the lead position as needed to achieve the desired trim.

Ballasting: pitch



Ballasting: lead placement to affect pitch

We aim *approximately* for –60° pitch when the glider is at the surface and ±18° when the glider is diving/climbing

- If pitch is too flat/steep, lead can be placed forward/aft

We aim *very roughly* for C_PITCH=2400 (± a few hundred AD counts)

- If C_PITCH is much lower than this (i.e., pitch center is too far forward, so the glider can't pitch down enough and surface angle is low), place lead forward

Ballasting: roll

We look for vehicle rolls that are symmetric to port/starboard and *roughly* ±18°

If the vehicle is not rolling enough to one or both sides, lead can be placed on the port/starboard

The SGX mass shifter can roll up to ±80° (compared to ±40° for the original SG), but needs this extra throw to achieve sufficient vehicle roll to turn. To achieve symmetric rolls with SGX, lead placement is typically asymmetrical