Seaglider Pilot's Guide

SCHOOL OF OCEANOGRAPHY
and
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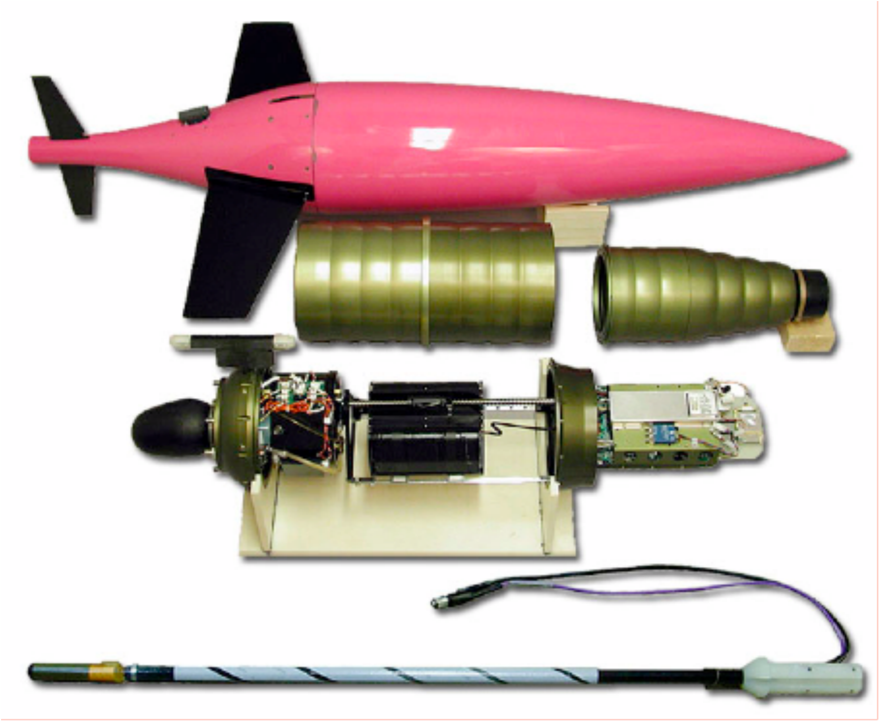

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Chapter 1
Introduction

1.1 Purpose

This document is an introduction to the use and operation of the University of Washington Seaglider. It provides necessary background and operating information for new pilots who will be responsible for the operation of Seagliders. This guide is meant to be used closely with the reference manuals. It is not a hardware maintenance or troubleshooting manual, nor does it deal with details of the software that controls the Seaglider's operation.

1.2 Conventions

Parameters that are used to control the operations of Seaglider are given in uppercase bold font, and have leading $ signs (**$T_DIVE**). File names that are used in Seaglider command, control, or operations are given in lowercase bold font (**cmdfile**). Computer commands given at a prompt, especially when directly connected to the Seaglider are given in italic font (*go 2bcf8*).

Chapter 2
History

The history of buoyancy-driven oceanographic instruments begins with Archimedes (287 BCE - 212 BCE). Archimedes's life began and ended in Syracuse, Sicily, but he was educated and spent part of his life in Alexandria, Egypt. He is generally regarded as one of the three greatest mathematicians of all time (Newton and Gauss complete the triumvirate) and is considered the father of hydrostatics, static mechanics, and integral calculus. Archimedes's Principle, the most well known of his hydrostatic results, is the basis for all buoyancy-driven vehicles. It states that the buoyant (upward) force on a submerged object is equal to the weight of the fluid that is displaced by the object. This fact is used in the variable mass, fixed volume (ballast) control systems of modern submarines and submersibles, and in the fixed mass, variable volume control systems of small profiling oceanographic instruments.

The use of buoyancy control in oceanographic instruments dates from the mid-1950's. By 1955, Henry Stommel of the Woods Hole Oceanographic Institution and John Swallow in the United Kingdom had ideas for neutrally buoyant floats whose positions could be tracked acoustically. Swallow was the first to build such a device, which contained a free-running 10kHz acoustic source and was tracked from a surface ship. By the 1970's, transponding versions running at 3-4kHz had extended shipboard detection ranges to 50 km, and a 200Hz version used the Sound Fixing and Ranging (SOFAR) sound channel (Stommel's original idea) to remove the requirement for ship-based tracking. By the 1980's, Tom Rossby at URI had developed the inverse of the SOFAR float (called RAFOS, SOFAR spelled backwards) that relied on moored sound sources and an acoustic receiver on the float. By adding a compressee (an object whose compressibility is approximately the same as that of seawater), these floats could also be ballasted to follow a particular density surface, rather than a pressure surface. About the same time, John Dahlen's group at Charles Stark Draper Laboratory developed a moored profiler that used a variable buoyancy device to propel itself up and down along the mooring wire, measuring temperature, conductivity and currents.

In the 1990's, Russ Davis and his group at Scripps Institution of Oceanography added a variable-buoyancy device to a neutrally buoyant float to create profiling floats. These floats (called Autonomous Lagrangian Current Explorers, or ALACE) had the ability to inflate an external bladder, thereby changing their displaced volume, but not their mass. The resulting buoyancy force allowed the float to make profile measurements from its neutrally-buoyant depth to the surface. At the surface, position and profile data were transmitted via the Service ARGOS satellite system. By the year 2000, hundreds of this type of float were deployed worldwide, both of the Scripps design and a design from Webb Research Corporation of Falmouth, Massachusetts.

Gliders share a common heritage: Henry Stommel's vision, published in 1989 in *Oceanography* [Stommel, 1989]. Stommel imagined a fleet of vehicles that "...migrate vertically through the ocean by changing ballast, and they can be steered horizontally by gliding on wings. During brief moments at the surface, they transmit their accumulated data and receive instructions. Their speed is about 0.5 knot." A prototype gliding vehicle was fielded as early as 1991 by Webb Research Corporation (WRC). This vehicle demonstrated the basic configuration subsequently used by all three gliders. A few years later, the ONR-sponsored Autonomous Ocean Sensing Network (AOSN) program, led by Tom Curtin, sponsored three groups to develop autonomous underwater gliders: Webb Research Corporation, whose glider is called Slocum, a team of Scripps Institution of Oceanography (Russ Davis) and Woods Hole Oceanographic Institution (Breck Owens) who developed Spray, and the University of Washington (Charlie Eriksen) who developed Seaglider. All groups worked with similar design goals: small enough to be handled by two people, relatively low acquisition and operation costs, horizontal speeds of around 30 cm/s, endurance of up to a year, GPS positioning and two-way data telemetry at the surface, and basic sensor payloads, including a CTD. By the year 2000, all groups had operational models that addressed these design goals. This document addresses the details of operation of the University of Washington Seaglider, developed jointly between the UW School of Oceanography and the Applied Physics Laboratory.

Chapter 3
Principles of Operation

3.1 Density

Density is defined as mass per unit volume:

$$\rho = M/V, \text{ or dimensionally, } \rho = M/L^3.$$

Oceanographers routinely switch between SI (mks) and cgs units when referring to seawater densities. Densities are referred to in g/cm^3 (with typical 1000m ocean values of 1.0275) or kg/m^3(with typical 1000m ocean values of 1027.5kg/m^3). To further complicate matters, oceanographers have a shorthand notation for density, called σ. σ is defined as follows.

$$\sigma = (\rho - 1000)kg/m^3 .$$

So the typical 1000m density is 27.5 in σ units. In particular, we will use the unit σ_T, which means that the density of the seawater parcel in question is computed using the in situ (observed) temperature of the parcel. Densities discussed in glider operations will typically be given in cgs units (g/cm^3), and we will use the shorthand cc (cubic centimeters) for cm^3.

3.2 Forces

3.2.1 Static Forces

Seaglider's flight is controlled by systems that change pitch, roll, and buoyancy. It is designed to operate within a few hundred cc's of neutral buoyancy over a seawater density range of about 10 σ_T units. Pitch is controlled to allow upward pitches for climbing, and downward pitches for diving and exposing the antenna at the surface. Roll is controlled to effect bank angles, which in turn, cause turns. Pitch and roll are controlled by altering the center-of -mass of the vehicle. Buoyancy is controlled by changing the displaced volume of the Seaglider.

3.2.1.1 Gravity

Seaglider moves a mass inside its pressure hull to change its pitch and roll attitude. The high-voltage (24V) battery pack is axially asymmetric. In addition, an 1100g brass weight is mounted on the bottom face of the roughly 6500g pack. This battery and weight is mounted in an assembly called the mass shifter. The battery pack is translated forward and aft to effect changes in vehicle pitch. It is rotated within the pressure hull, and the axial asymmetry effects vehicle roll when the 24V battery pack is rolled from side to side.

Seaglider achieves static trim by addition of ballast (lead weight) inside the fairings. The position and amount of lead is determined by mission and trim requirements. Payload, either additional batteries or sensors, can also change the amount of ballast.

3.2.1.2 Buoyancy

Buoyancy is the unbalanced (positive) upward force on a submerged object arising from the vertical pressure gradient. It was Archimedes who, as mentioned above, stated that the buoyant (upward) force on a submerged object is equal to the weight of the fluid that is displaced by the object.

Submerged objects can alter their buoyancy by changing their density, either by changing their mass or volume. Submarines typically alter their buoyancy by changing their mass while maintaining their volume. This is done by flooding or blowing seawater from fixed volume ballast tanks.

Gliders, along with ALACE/APEX floats, SOLO floats, the Charles Stark Draper Laboratory Profiling Current Meter (PCM) and others, are fixed-mass, variable-volume devices. They change their buoyancy by changing their displaced volume while keeping their total mass fixed. Typically, this is done by moving hydraulic oil from a reservoir inside a pressure hull to inflate or deflate a rubber bladder external to the pressure hull. The mass of a Seaglider is determined by accurately weighing the full-up instrument in a completely dry condition.

Example 3.1: Suppose a Seaglider has a mass of M = 52,223g. In seawater of density 1.0275g/cm^3, what must the Seaglider's volume be in order for it to be neutrally buoyant at that density?

Answer: From section 3.1.1, $V = M/\rho$, hence V = 52,223g/1.027g/cm^3 = 50,825.3cm^3.

Example 3.2: How much must Seaglider's volume change to compensate for a density change of 1 σ_T unit?

Answer: Recall that 1 σ_T unit = 1kg/m^3, or 0.001g/cm^3. Let $\Delta V = V_2 - V_1$, and let M and V_1 be as given in Example 1. We are given that $\Delta\rho$ = 0.001g/cm^3. Some algebra leads us to the following,

$$\Delta V = \frac{\Delta\rho V_1^2}{(M - \Delta\rho V_1)}$$

Using the values of M and V_1 from Example 1, we compute ΔV = 49.5cm^3. This result leads to the following.

Rule of Thumb: In Seaglider it takes about 50cm^3 of volume change to compensate for 1 σ_T (1kg/m^3) of density change.

Seaglider uses a system called the Variable Buoyancy Device (VBD), to change its buoyancy. This system acts as described above to change the Seaglider's displacement without changing its mass. The Seaglider has about 800cm^3 of volume change available from its VBD. Here is an example of how that available VBD range is partitioned on a typical mission.

	cc
Total VBD available	800
Positive buoyancy required to expose the antenna	(150)
VBD remaining	650
Negative thrust in densest water	(250)
VBD remaining	400
Equivalent σ_T units of stratification	8

In this example, the Seaglider could fly normally with -250cc of negative displacement in the densest water, fully expose the GPS/Iridium (GPSI) antenna, and accommodate 8 σ_T units of density difference between the densest water and lightest water.

An important and unique feature of Seaglider is the compressibility of its pressure hull. The pressure hull is designed to have the same compressibility as seawater, and is called an isopycnal hull. Most other oceanographic equipment is contained in pressure hulls that are essentially right circular cylinders, designed for strength and to maintain a fixed volume at all rated pressures. These pressure hulls acquire positive buoyancy as they are pressurized, which requires compensation (subtraction of displaced volume) to maintain a prescribed buoyancy. That same compensation has to be recovered by pumping to achieve positive buoyancy. Seaglider's isopycnal hull avoids that need, as the pressure hull does not acquire positive buoyancy from the compression of the surrounding seawater. For dives to 1000m, this results in about a 10% energy savings in the overall 24V energy budget.

3.2.2 Dynamic Forces

3.2.2.1 Lift

Seaglider gets lift from its body and its wings, which convert the vertical force provided by the buoyancy engine (VBD) into forward motion. Some additional lift comes from the vertical stabilizer while banked (executing turns).

3.2.2.2 Drag

The Seaglider hull form is a shape that was designed to maintain laminar flow over about 70% of its hull length [Humphreys, Smith, et al., 2003]. Drag is partitioned into two types in the Seaglider flight model: induced drag and everything else (skin friction, form drag, etc.).

3.2.2.3 Hydrodynamic Model

A hydrodynamic model for Seaglider was created and verified during the development program. It is used by pilots to help with buoyancy trim, and is the mechanism by which depth-averaged currents are inferred for a Seaglider dive. The model has three parameters: lift, drag, and induced drag, traditionally called a, b, and c. For our purposes, it is convenient to think of the hydrodynamic model as a black-box that produces estimates of the Seaglider's velocity as a function of computed buoyancy and observed pitch,

$$v_{model} = F(buoyancy_{computed}, pitch_{observed}) \,.$$

The v_{model} can be resolved into horizontal and vertical components. In particular, the horizontal component, u_{model}, can be used with the observed compass headings throughout a dive to determine a dead-reckoned glider track through the water. This results in a predicted surfacing position, based on the GPS-determined dive starting point. The difference between this predicted surfacing position and the actual GPS-determined surfacing position is what provides the estimate for depth-averaged current. Similarly, the vertical component, wmodel, can be compared with wobserved= dpdt, to adjust the VBD trim, and then to estimate vertical velocities in the water column. For details on the Seaglider hydrodynamic model, consult [Eriksen, Osse, et al., 2001].

3.2.3 Environmental

3.2.3.1 Stratification

Stratification is the term used to described the static stability of the ocean, with denser water below lighter water. Strong stratification means a large change in density between two depths; weak stratification is a small change in density between two depths.

Example 3.3: Off the Washington coast in winter, the surface water has density $\rho = 1.0245$, while the water at 1000m depth has density $\rho = 1.0275 g/cm^3$. This is a difference of $3\sigma_T$ units, which by our rule of thumb of section 3.2.1.2, implies that $150 cm^3$ of volume change will be required to maintain constant buoyancy forcing through the stratification from 1000m to the surface.

Example 3.4: Port Susan testing. Port Susan is an arm of Puget Sound, between Camano Island and the mainland. The south fork of the Stillaguamish River empties into the head (northern end) of Port Susan, providing large seasonally varying freshwater inputs. Port Susan is tidally mixed, and is also exposed to the southeast and northwest, so feels the prevailing winter and summer breezes. It is the primary site for Seaglider sea trials, because it has relatively low boat traffic, is 100m deep, and has a convenient launch ramp. However, it is a challenging site in which to fly Seagliders, because of the strong tidal currents and the large stratification due to the freshwater river input. Sometimes the stratification in Port Susan is right at, or slightly beyond, the Seaglider's ability to compensate, as this example shows. Here is another example of the partition of available VBD (displacement), assuming a Seaglider with 800cc of buoyancy available.

	cc
Total VBD available	800
Positive buoyancy required to expose the antenna	(150)
VBD remaining	650
Negative thrust in densest water ($\sigma_T = 23.0$)	(125)
VBD remaining	525
Equivalent σ_T units of stratification	10.5
Minimum surface σ_T for normal operations	12.5 = 23.0 - 10.5

Note that the choice of maximum negative thrust in the densest water is the only pilot-changeable value in this table. And it has a practical lower limit, which is the ability to fly at the bottom of the dive. In this scenario, if the surface density is $\sigma_T = 11.0$, it is likely that only about half the antenna mast will be exposed at the surface, depending on the depth of the freshwater lens.

3.2.3.2 Currents

Depth-averaged current over the course of a Seaglider dive influences the distance covered over the ground by Seaglider. The depth-averaged aspect of the current is important - the Seaglider can make progress towards a waypoint even in the presence of strong adverse surface currents by diving through deeper waters with more favorable currents. The maximum deep-water depth-averaged current that Seaglider can stem is 40cm/s, or 0.8kts. That is the practical limit and requires driving the Seaglider as hard as it can be driven (in the buoyancy sense). These dives tend to be done with large negative thrust on the dive (-350cc), and vertical velocities of about 18cm/s. The dives take about three hours between surfacings, or about eight dives per day. The VBD pumps from stop-to-stop on each dive. This regime uses energy at about ten times the rate of a typical dive off the Washington coast, where the dives are eight hours long (three dives per day), and the VBD stays within about half its full range. But it has been shown in two deployments in the Kuroshio that Seaglider can make crossings of a strong western-boundary current. This is done in a triangular track, with an inshore and then an offshore transect of the strong current, and a return upstream in the calmer water offshore of the strong current. One might imagine interesting tracks in the equatorial Pacific that would exploit the equatorial undercurrent.

Vertical shear in the currents induces turning moments on the Seaglider body. Large vertical velocities (upwelling or downwelling) can introduce large control changes in buoyancy, and in some cases, cause dives to truncate or abort prematurely.

3.3 Control of Static Forces

Seaglider's flight is controlled by specification of the location or state of three systems, which effect changes to the vehicle's pitch, roll and buoyancy. All positions are encoded by linear potentiometers, digitized by 4096-count analog-to-digital (A/D) converters. The A/D counts run from 0 to 4095. Physically attainable limits (also called hardware limits) for each system are determined empirically at the time of assembly. A safety margin is added to these physical limits to arrive at a software limit, which is that position (in A/D counts) beyond which the Seaglider operating software will not command that particular system. Associated with each system are the following.

1. A center position, which is intended to be the vehicle neutral for that system, in a particular environment.
2. A factor that converts A/D counts to physical displacement, which is based on the mechanical design.
3. A gain that relates movement of each system to the effect it has on the Seaglider.

See the Appendix at the end of this document for detailed information.

3.3.1 Pitch

Pitch is controlled by moving the 24V battery pack forward and aft along the longitudinal axis of the Seaglider. The motion is accomplished by an electric motor, geared to drive a worm-gear in such a way that 217.39 A/D counts equals 1cm of battery mass travel (**$PITCH_CNV**). Seagliders typically respond to movement of the battery pack in the longitudinal axis by pitching about 15-20° per centimeter of mass travel. This **$PITCH_GAIN** is a parameter, as it is dependent on the particular sensor suite and trim ballast installed on each Seaglider.

Here are some typical pitch ranges and values for Seaglider.

	hardware limit (A/D counts)	software limit (A/D counts)
full forward (down, -)	20	45 (**$PITCH_MIN**)
full aft (up, +)	3402	3377 (**$PITCH_MAX**)
$C_PITCH (example)		2346

Note that A/D counts are always positive, but displacement may be positive or negative, relative to a given **$C_PITCH**. Pitch is usually trimmed so as to have about 70% of the pitch travel available for pitching down (forward of **$C_PITCH**), and 30% available for pitching up (aft of **$C_PITCH**).This is to ensure a good surface position, sufficiently pitched down to fully expose the antenna.

Example 3.5: How many centimeters is the battery pack forwardof its center position, when the Seaglider is in its surface (fully pitched-down) position?

Answer: By the values in the table above, the pitch position will be 45 A/D counts when fully forward. Given a **$C_PITCH** of 2346 and a **$PITCH_CNV** of 217.39 A/D counts/cm, we have that the pitch position = (45 counts - 2346 counts)*(1 cm/217.39 counts) = -10.585cm, or 10.585cm forward of the pitch center.

Example 3.6: How many A/D counts will cause 5° of vehicle pitch? Assume a **$PITCH_GAIN** of 16 /cm of mass travel.

Answer: The number of A/D counts that corresponds to 5° of vehicle pitch is 5° * (1 cm/16°) * 217.39 A/D counts/cm = 67.9 A/D counts ≈ 68 A/D counts.

Example 3.7: Suppose the pilot made a trim bias correction of **$C_PITCH** to 2375. What was the presumed pitch bias (in degrees)?

Answer: The previous **$C_PITCH** was 2346 as given in the table above. Then the pitch bias is computed as follows, (2346 A/D counts - 2375 A/D counts) * (1 cm/217.39 A/D counts) * 16°/cm = -2.13° . The Seaglider was pitched 2.13° down.

3.3.2 Roll

Roll is controlled by rotating the 24V battery pack inside the hull. The pack is axially asymmetric, and weighted on its ventral face (as normally installed). An electric motor and gear train rotate the mass such that 35.37 A/D counts is equivalent to 1 degree of battery mass rotation (**$ROLL_CNV**). Seagliders typically respond to the rotation of the battery pack by rolling about 1/2° for every 1° of battery pack rotation, which is also dependent on the amount and distribution of trim lead.

The control strategy is to roll the 24V battery pack a specified amount (40°) in the appropriate direction when a turn is indicated, then roll back to neutral (center) when the desired heading is reached. Note that the Seaglider turns in the opposite sense from its bank angle on the dive (opposite from upright airplane control), and in the same sense as its bank angle on the climb (same as upright airplane control). Here are some typical roll ranges and values for Seaglider. Two roll centers are used because various asymmetries in form result in different roll trim on dives and climbs.

	hardware limit (A/D counts)	software limit (A/D counts)

full roll to port (-)	0	150 (**$ROLL_MIN**)
full roll to starboard (+)	3983	150 (**$ROLL_MAX**)
$C_ROLL_DIVE (example)		2000
$C_ROLL_CLIMB (example)		2050

3.3.3 Buoyancy

Buoyancy is controlled by a mechanism called the Variable Buoyancy Device (VBD). It is a hydraulic system whose purpose is to maintain a specified total vehicle displacement by varying the size of an oil-filled bladder external to the Seaglider pressure hull. The system pumps oil from an internal reservoir into the external bladder to increase displacement, and allows oil to bleed from the external bladder into the internal reservoir to decrease displacement. Linear potientiometers on either side of the internal reservoir measure the position of the reservoirs rolling diaphragm. The mean of the two values is reported as the position of the diaphragm, which can be interpreted as the amount of oil in the internal (or external) reservoir. The geometry of the system results in 4.0767 A/D counts per cm^3 of oil (**$VBD_CNV**). The point of neutral buoyancy is designated **$C_VBD**, and is set relative to the densest water to be encountered on a mission. VBD control is calculated to achieve specific results, which depend on pilot specified quantities: Seaglider vertical velocity, distance to next waypoint, and maximum glide slope. VBD control is the gas pedal or throttle. Specific VBD control issues will be discussed in more detail later. Here are some typical VBD ranges and values for Seaglider.

	hardware limit (A/D counts)	software limit (A/D counts)	volume (cm^3)
V_{max}	105	205 (**$VBD_MIN**)	557 (wrt**$C_VBD**)
V_{min}	3610	3560 (**$VBD_MAX**)	-266 (wrt**$C_VBD**)
Range			823
$C_VBD		2476	

Note that V_{max} is the maximum displaced volume of the Seaglider, and V_{min} is the minimum displaced volume of the Seaglider. When given in cm^3, they are with respect to (wrt) a given **$C_VBD**.

Example 3.8: A typical ballasting case, which demonstrates how the available range in VBD is utilized. Values are from a recent deployment of SG012 off the Washington coast. Assume that the **$C_VBD** and limit values in the table above are appropriate for a 1000m density of $\rho = 1.0275 g/cm^3$. How much negative buoyancy is available at 1000m?

Answer: From the table above, $-266 cm^3$ of displacement (relative to neutral) are available at 1000m. Multiplying by the water density, the buoyancy force available is 273g. Note that there are also $557 cm^3$ of positive displacement available, relative to the 1000m water density. We know that the Seaglider antenna requires $150 cm^3$ of positive displacement for optimal exposure. That leaves $407 cm^3$ of displacement available to overcome stratification. From our rule-of-thumb, $50 cm^3$ is equivalent to one σ_T unit, so $400 cm^3$ is equivalent to $8\sigma_T$ units. That means that Seaglider can get its antenna fully exposed in surface water with a density as low as $(1.0275 - 0.008) g/cm^3 = 1.0195 g/cm^3$.

3.4 Features of Control

3.4.1 Canonical Dive

The Seaglider performs its mission by repeating a canonical dive until either commanded to stop or until an abort condition is reached. Numerous aspects of the canonical dive are under the control of the pilot, through an extensive set of parameters. A few are indicated in the sketch below. Many more are not shown; consult the *Parameter Reference Manual* for more information. The canonical dive is shown schematically in Figure 1.

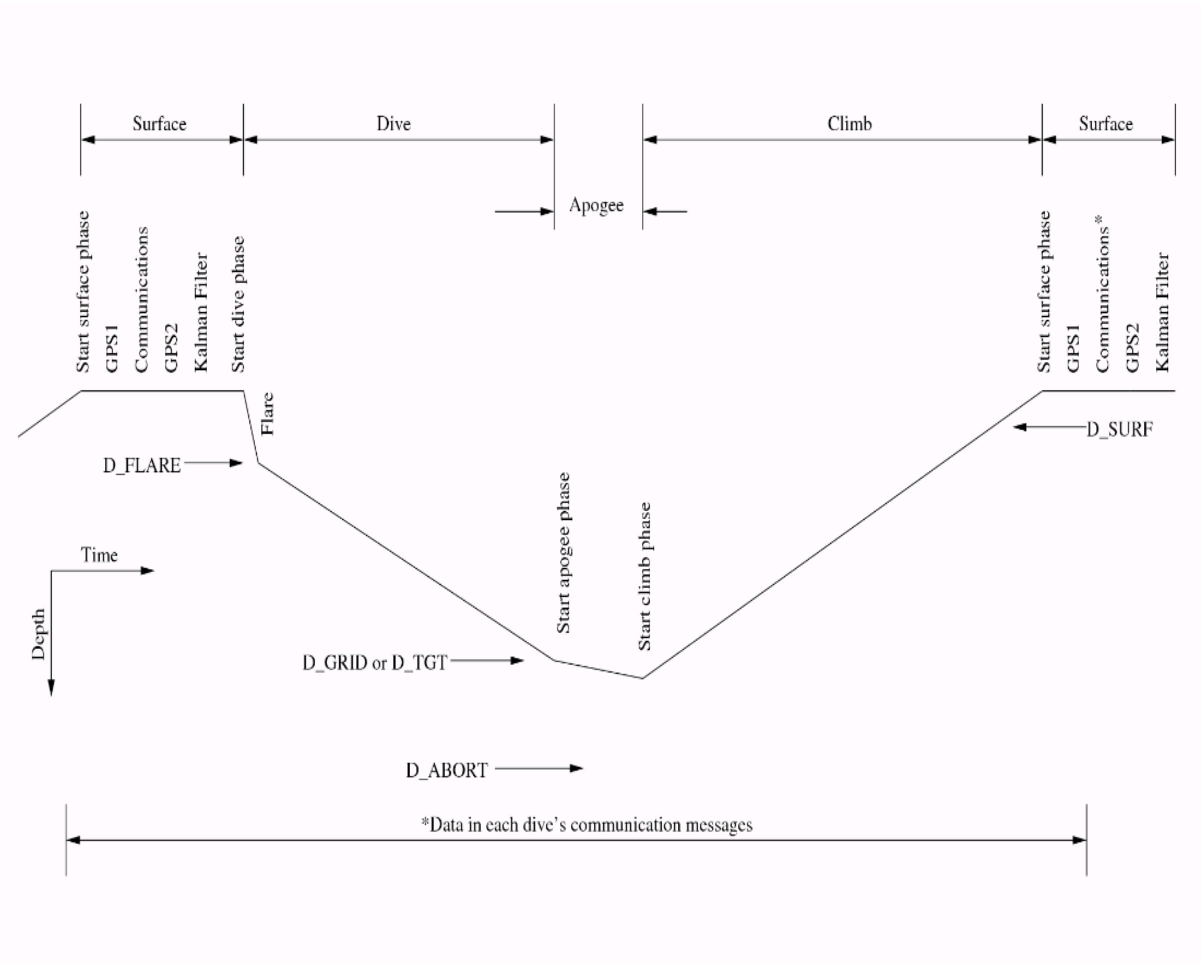

Figure 1. A schematic of a Seaglider autonomous run profile, with run phases indicated by the intervals at the top of the figure and the profile data boundaries indicated by the interval at the bottom of the figure. The figure is not to scale in either dimension.

3.4.2 Control Design

The Seaglider flight control scheme has two guiding principles: maintain constant vertical velocity and minimize the total energy expenditure during a dive.

Constant vertical velocity is desired because the Seaglider samples its sensors evenly in time. Constant vertical velocity then implies the samples are equally spaced in depth. Sample intervals are specified by the pilot through the **science file**. They may vary by pilot-specified depth bands, but are uniform within each specified depth band.

The desired vertical velocity is not specified directly by a parameter, but is calculated from parameters that describe the target depth of a dive (**$D_TGT**) and the time to complete a dive (**$T_DIVE**). **$D_TGT** is in meters, and **$T_DIVE** is in minutes, and is the time from surface-to-surface., discounting pumping time at the bottom of the dive. So, the desired vertical velocity, w_d = (2 * **$D_TGT** * 100cm/m)/(**$T_DIVE** * 60s/min) cm/s.

Example 3.9: A typical normal value for w_d is 10 cm/s. What ratio of **$D_TGT** : **$T_DIVE** yields w_d = 10cm/s?

Answer: A bit of simple algebra gives (**$D_TGT/$T_DIVE**) = (10 cm/s * 60 s/min)/(2 * 100 cm/m) = 3 m/min. So, to achieve a wd of 10 cm/s, choose **$D_TGT** and **$T_DIVE** in a ratio of 3. Our typical first shallow test dive uses **$D_TGT** = 45 m and **$T_DIVE** = 15 min.

The buoyancy and pitch used on any individual dive is chosen by the Seaglider operating software to achieve the best results on that dive. The choices are bounded by parameters **$MAX_BUOY**, the maximum negative buoyancy allowed on a dive, and **$GLIDE_SLOPE**, the maximum glide slope allowed on the dive. The choices are also bounded by physical limits, neutral buoyancy (need some negative buoyancy to glide) and the stall angle. The software has to choose a buoyancy value between 0 (neutral) and **$MAX_BUOY**, and a desired pitch angle between the stall angle and **$GLIDE_SLOPE**. The choice is determined by the distance to the next waypoint. The pitch angle is chosen to achieve the desired horizontal distance: maximum if the waypoint is distant, minimum if the waypoint is close, or the exact distance, if possible. Once the pitch angle is chosen, the buoyancy is chosen to achieve the desired vertical velocity in the densest water (deepest depth).

The main energy draw on Seaglider is pumping hydraulic oil from the internal reservoir to the external bladder at depth, where the pump has to overcome the seawater pressure acting on the bladder. The pump consumes about 70% of the energy budget of Seaglider. Control during flight is generally designed to minimize the total amount of pumping required on a dive. In particular, no bleeding is allowed on descent (dive) to maintain the desired vertical velocity. Pumping as necessary is allowed on the climb to maintain the desired vertical velocity. Pitch is essentially fixed at all phases of the operation, with the exception of slight pitch maneuvers on the climb to compensate for the changes in mass distribution and buoyancy due to pumping oil from the internal reservoir into the bladder. Details of the control scheme are given in the description of the run phases below.

3.4.3 Run Phases

The phases of a Seaglider autonomous run are described below. Two of the phases, launch and recovery, are generally performed at the beginning and end of the mission. The other phases, surface, dive, apogee and climb, are meant to be repeated sequentially, once each profile, until the end of the mission. The surface phase is where the GPS positions are acquired, where communication is attempted and where the navigation calculations for the next dive are made. Various depth, time and functional triggers exist to cause the Seaglider to move from one phase to the next.

Data acquisition is done in the dive, apogee and climb phases of an autonomous run. During each of these phases, the glider continuously collects data from the scientific instrumentation at a rate set specified in the **science file**. Although other actions are performed during these phases, the data collection process is never interrupted. Another periodic action performed during the profile phases (dive, apogee and climb) is guidance and control (G&C). G&C operations occur at intervals defined in the **science file**. Three operations occur during G&C, if necessary: pitch adjustment, VBD adjustment, and roll adjustment.

When G&C operations occur, the Seaglider is said to be in active G&C mode. When G&C corrections are not being made, the Seaglider is said to be in passive G&C mode. These definitions of active and passive modes refer to G&C operations only. They do not apply to data acquisition intervals or activities. The Seaglider is acquiring data during all profile phases, whether in active or passive G&C mode. In passive G&C mode, the Seaglider processor enters a low-power sleep state between data acquisition points. The Seaglider flies in the state specified in the previous active G&C mode.

3.4.3.1 Launch

The launch phase begins when the field operator has initiated the Sea Launch procedure, performed a self-test if indicated, and all launch dialogue has completed. (Details of the launch procedure will be given in Chapter 5, Mission Execution.) The Seaglider is in its surface position (rolled to neutral, pitched fully forward, and pumped to **$SM_CC**, typically maximum VBD for launch), and enters a normal surface phase: acquires GPS1, and initiates a communication session via Iridium satellite telephone.

3.4.3.2 Surface

The surface phase begins at the end of climb-phase data acquisition. The following steps are performed.

1. Surface Maneuver: The surface position of the Seaglider is as follows: pitched fully forward (to the software limit), rolled to neutral (**$C_ROLL_CLIMB**), and pumped to VBD = **$SM_CC**. Note that if the Seaglider surfaces with VBD > **$SM_CC**, no bleeding is done to force VBD = **$SM_CC**. There are several ways to enter the surface maneuver. The Seaglider is in the surface position at launch, after normal completion of a dive (reached **$D_SURF**), in recovery phase, or after **$T_MISSION** minutes have elapsed from the start of the dive without achieving **$D_SURF** in climb phase. The first test in surface phase is to see if the Seaglider depth is less than **$D_SURF**. If so, the Seaglider pitches fully forward and pumps to **$SM_CC**. If not, the Seaglider first pumps VBD to its maximum value, and checks the depth again. If the depth is less than **$D_SURF**, the Seaglider moves the pitch mass to its full forward position. This behavior is designed to try to get the Seaglider to the surface in the event of a **$T_MISSION** timeout.

2. GPS1: Once the desired surface position is attained, GPS position 1 (**$GPS1**) is acquired. The GPS receiver is turned on and left on until a satisfactory position is acquired or until **$T_GPS** minutes have elapsed. Once an initial position is acquired, the Seaglider waits an additional **$N_GPS** samples for a GPS position with an HDOP < 2.0. If one occurs, acquisition stops and that position is accepted. If one has not occured in **$N_GPS** samples, the last position is accepted.

3. Communications: Wireless communication via Iridium begins following acquisition (or timeout) of **$GPS1**. The Seaglider powers up the Iridium phone, waits a specified time for registration with the Iridium system, then attempts a data call to the basestation. If the call is successful, the Seaglider logs into the basestation as a dial-up user, and uses a modified XMODEM protocol to transfer files: **data**, **log** and engineering files from the Seaglider to the basestation, and command, control, diagnostic and special purpose files from the basestation to the Seaglider. Details of these files and their effects are given in Chapter 4, Command and Control. If all file transfers were not accomplished, the Seaglider waits **$CALL_WAIT** seconds and tries again. It tries up to **$CALL_TRIES** times, and if not successful, continues with the surface phase, marking files as appropriate for later transfer, and incrementing the **$N_NOCOMM** parameter.

4. Measure surface depth and angle: After the communications session, the Seaglider computes the average of 10 pressure readings and then the average of 10 pitch angles to obtain a measurement of the Seaglider's surface position. These values are written into the **log file** for the next dive.

5. GPS2: After the surface pressure and pitch angle average is completed, a second GPS fix, **$GPS2**, is acquired. This fix is the most recent position of the glider prior to diving.

6. Navigation and flight calculations: Finally are the calculations of the parameters which determine the glider flight path of the next profile: buoyancy, pitch angle, and heading. These computations include the Kalman filter, if enabled, and the digital bathymetry table lookup, if enabled. Upon completion of the calculations, the surface phase is completed and a new dive phase (and new profile) is started.

3.4.3.3 Dive

The dive phase begins upon completion of the navigation and flight calculations that conclude the surface phase. Initially, pitch is in the full forward position and the VBD volume is equal to the endpoint of the surface maneuver. At the start of the dive phase, a VBD adjustment (bleed) only is executed during the first G&C operation to get the Seaglider as fast and deep as possible (recall that pitch is still in the maximum forward position). When the Seaglider reaches a prescribed depth, **$D_FLARE**, it goes into a regular G&C operation (pitch, VBD, roll) to move to the desired pitch, VBD position and course computed for the profile.

If the glider speed is too fast on the dive section of the profile (too heavy), VBD pumping is not allowed to correct the speed error. This is an energy conservation consideration. As the Seaglider descends into denser water, it will become less negatively buoyant and will slow down. If corrective pumping were allowed on the dive, it is possible that additional bleeding would be required to compensate as the Seaglider reached denser water. That would then mean more pumping to eventually reach the buoyancy endpoint of the surface maneuver. Excess speed is tolerated on the dive to help minimize total energy expenditure on the profile.

In the dive phase, the Seaglider turns to starboard by banking to port (opposite to upright aircraft flight).

3.4.3.4 Apogee

When the target depth is reached, the Seaglider enters the apogee phase. The apogee phase is a two-G&C-cycle procedure to smoothly fly from the dive phase to the climb phase without stalling. During the first G&C cycle of this phase, the glider is pitched to an intermediate angle, **$APOGEE_PITCH**, rolled to neutral, and the VBD is pumped to 0 cc. The course adjustment and passive G&C mode are skipped. A second G&C cycle is then executed and the glider is first pitched, then VBD is pumped, to the inverse positions of the dive (pitch = -pitch, VBD = -VBD).

Data sampling continues throughout the apogee phase.

3.4.3.5 Climb

The climb phase begins at the completion of the second G&C cycle of the apogee phase. The Seaglider is positively buoyant and pitched up, headed for the surface at the same target vertical rate as achieved on the dive phase of the profile.

As in the dive phase, data acquisition and G&C continue at the intervals specified in the **science file**.

If the glider speed is too fast on the climb section of the profile (too light), VBD bleeding is NOT allowed to correct the speed error. This is an energy conservation consideration. There are two reasons. One is that any oil that is bled will need to be pumped again during the surface maneuver. Second, as the glider climbs it will enter less dense water, hence becoming less positively buoyant and slowing down. VBD pumping operations are allowed in the case of the glider being too heavy and slowing down. The **$MAX_BUOY** restriction does not apply to the climb phase. This will not affect the amount of energy used during the profile since the oil will be pumped anyway during the surface maneuver.

In the climb phase, the Seaglider turns to starboard by banking to starboard (as in aircraft flight).

When the Seaglider reaches the depth **$D_SURF**, it enters the passive G&C mode and continues to acquire scientific data at the specified interval for a time equal to **$D_SURF**/(wobserved m/s), or for a maximum of 50 data points, whichever is shorter. After this period of data acquisition, the Seaglider enters the surface phase.

3.4.3.6 Recovery

The recovery phase is entered either by command of the pilot (when it is necessary or desireable to keep the Seaglider at the surface) or by an error condition detected by the Seaglider operating software. In the recovery phase, the Seaglider stays on the surface and acquires a series of GPS fixes which are sent to the basestation so that the Seaglider can be recovered.

In recovery, the Seaglider enters a loop of obtaining a GPS fix and communicating every **$T_RSLEEP** minutes. In practice, there are about two minutes of overhead in this process, so that the actual time between phone calls is closer to **$T_RSLEEP** + 2 minutes. This recovery loop may be exited by sending a **$RESUME** directive in the **cmdfile**. The Seaglider will then continue diving.

Chapter 4
Command and Control

4.1 Seaglider

4.1.1 Serial Communications

Direct communications with Seaglider is done by connecting one end of the supplied serial communications cable to the serial port on the Seaglider, and the other to a serial port on a computer. Any reasonable terminal emulation program should be able to talk to the glider. Port settings are 9600 baud, 8N1, and no hardware handshaking.

4.1.2 Power on/off

The Seaglider is powered on and off by use of an external magnet, usually mounted at the end of a wand. The magnet is held in the appropriate location (marked on the forward fairing) for at least 1/2 second. The starboard side turns the Seaglider on, the port side turns the Seaglider off. (The mnemonic is "Right ON! "). Once the Seaglider is turned on, and the serial communication is established properly, a short start-up banner should appear on the terminal, along with a request to enter a carriage return within one minute.

4.1.3 TOM8, PicoDOS®, Seaglider Operating Program main.run

There are three "levels" of software operating on the computing hardware stack on Seaglider. The lowest level is the TOM8 monitor that runs on the TT8 processor. Running above that is the PicoDOS® operating system that controls the CF8 interface between the TT8 and the Compact Flash (CF). Finally, the Seaglider operating code, nominally called main.run, runs on top of PicoDOS®, and resides on the CF.

Starting at the TOM8 monitor, one can start PicoDOS® by typing *go 2bcf8* at the TOM8 prompt. That starts PicoDOS®. From PicoDOS®, the command main starts the Seaglider operating code, and enters the start-up dialog.

In a fully commissioned Seaglider, a short program is loaded into the TT8 flash that automatically executes main.run at power on, so the operator should only see the Seaglider operating code startup dialog.

4.1.4 Menus

Interaction with the Seaglider while directly connected is by a text-based multi-level menu system. Menu items are specified either by number or by keyword match. Item numbers and keywords are shown for each entry in the menu system. For example,

1 [param] Parameters and configuration

is the first line of the main menu, which means that the Parameter and configuration menu can be accessed by entering 1 or param. The menu system is simple to navigate, and multi-level jumps are permitted.

4.1.5 Extended PicoDOS®

Commands available are described in the *Seaglider Extended PicoDOS® Reference Manual*.

4.1.6 Files on Seaglider Compact Flash (CF)

See the Seaglider File Formats Manual for names and formats of files on the Seaglider Compact Flash.

4.2 Basestation

4.2.1 Function

The Seaglider basestation is the shoreside computer end of the Seaglider system. It has three main responsibilities. It supports a modem (or modems) and dial-up users (Seagliders). It handles one side of the modem-to-modem file transfer protocol that moves files to and from the Seaglider. And it does the data processing necessary to produce scientific and engineering data profiles, and perform simple error-detection and notification.

4.2.2 Configuration

The Seaglider basestation runs on a Linux platform. Various distributions have been used successfully. The basestation software package consists of a collection of scripts, a patched version of the XMODEM send and receive programs, and configuration instructions. The basestation is configured to auto-answer dial-up calls, possibly screened by callerID. Seagliders log in as normal dial-up users, and send and receive files from their home directory. Seaglider pilots need access and write permission in those home directories in order to modify command and control files. Scripts are executed at login and logout that control and log various aspects of the basestation transactions.

4.2.3 Files

The Seaglider pilot interacts with four files on the basestation to command and control Seaglider: **cmdfile**, **targets**, **science**, and **pdoscmds.bat**. The basestation utilities cmdedit, targedit, and sciedit are used to modify **cmdfile**, **targets**, and **science**. The **pdoscmds.bat file** is created and modified by any text editor. See the Seaglider File Formats manual for names and formats of files on the basestation.

Chapter 5
Mission Execution

5.1 Planning

Mission planning is an important part of Seaglider piloting. A basic understanding of Seaglider's operating envelope, and its strengths and weaknesses is critical to planning effective science missions. The general idea is to go far by going slow - it's the square-law dependence of drag on velocity that gets you. "Half a knot on half a watt" is the Seaglider motto. The sections below give the operating limits of the Seaglider.

5.1.1 Environment

5.1.1.1 Stratification

As discussed in 3.2.3.1, the range of stratification in which a Seaglider can operate normally is constrained by the total amount of VBD change available, and the amount of (negative) buoyancy required for the flight plan. The pilot (or scientist) should determine the likely range of densities to be encountered on a proposed mission, and see if there is sufficient VBD change available to accommodate that range. Compromises can be made by reducing maximum operating depth, at the expense of duration, or by reducing thrust at apogee, at the expense of horizontal speed.

5.1.1.2 Currents

The maximum depth-averaged current that Seaglider can stem is 40 cm/s, or 0.8 knots. That performance requires ballasting for 350cc of negative displacement, specifying vertical velocities of almost 20 cm/s, and diving to 1000m. Dives last about three hours in that case, and total mission length is of order six weeks. Remember that it's the depth-averaged current that counts. Surface currents can be a problem, especially when doing shallow dives (see below). Plans for crossing strong currents, such as the Kuroshio or Gulf Stream, should be carefully considered, and contain both return (upstream) plans and bail-out plans.

5.1.1.3 Bathymetry

The Seaglider is least efficient operating in shallow water and most efficient in deep (up to 1000m) water. The practical shallow water limit is about 75m. It is hard to make progress toward a waypoint in water shallower than that, for three main reasons: turn radius, pump time, and surface time. Seaglider's turning radius (a few tens of meters at typical 25 cm/s horizontal speeds) is such that a significant portion of a shallow-water dive can be spent turning onto the desired course. Seaglider's pump is optimized for efficiency at pressures equivalent to 1000 m ocean depth, its rate at shallow-water pressures (about 2cc/s) means that a significant portion of a shallow-water dive can be spent pumping. And finally, the time on the surface can be a significant percentage of the dive time, and if surface currents are adverse, the Seaglider can easily lose as much distance toward a waypoint while on the surface as it gains on the dive. The UW's operating guidelines are to operate deeper than 200m on offshore (deepwater) missions, and to try to stay deeper than 75m on coastal or estuarine missions.

The current model of Seaglider is rated to 1000m depth. Deep-water target depth (**$D_TGT**) is typically 990m to allow for the apogee maneuver and the discreteness of the sampling times.

Knowledge of the bathymetry of the operating area is important, too. Seaglider can read a digitized bathymetry map to determine how deep to dive, or can rely on the on-board altimeter to find the bottom and initiate the apogee maneuver appropriately.

5.1.2 Science requirements

5.1.2.1 Track

Seaglider can cover about 20 km/day (12 nm) through the water in normal flight. It can station-keep within about a factor of two of the dive depth (2 km on 1 km dives, 200 m on 100 m dives). The navigation system on Seaglider is waypoint-based, not track-based. The system decides on the most efficient way to reach the next waypoint, but does not attempt to stay on a given track. Track-based navigation can be approximated by using more waypoints along a desired track.

5.1.2.2 Sampling

Sensor sampling intervals are specified in the **science file**. The practical lower limit on sampling is 4 seconds. If only the conductivity and temperature sensors are sampled, it may be possible to sample every 2 seconds, but with the oxygen and BB2F optical sensors, 4 seconds is the lower limit. The **science file** also gives the ability to turn off sensors, or only energize them every nth sample, in a given depth range (or ranges).

5.1.3 Endurance

Total endurance, by any metric, is dependent on many factors, including depth of dive, specified vertical velocity, type of track, stratification, pump efficiency, and communications performance. (The 24V battery pack is the limiting factor: it serves the pump and the modem.) Seaglider has completed open-ocean missions of seven months duration, in conditions of minimal stratification (Labrador Sea in winter) where power conservation was the guiding factor. Missions north of Oahu around the HOT site typically lasted four months, due to stratification, and the science requirement to resolve tides. Seaglider missions in Puget Sound are typically planned for six weeks, or less.

5.2 Preparation

5.2.1 Refurbishment

This evolution is done in the laboratory between deployments. It requires a complete opening and disassembly of the Seaglider to the major sub-assembly level, in order to replace batteries, inspect hydraulics, motors, gear assemblies, change compact flash or SIM cards as necessary, and other operations as necessary. Preparations for deployment following refurbishment are basically the same as those for a new Seaglider.

5.2.2 Calibrations

Compass calibrations are required each time battery packs are replaced. Sensor calibrations should be performed before and after each deployment, as schedule and budget permit.

5.2.3 Bathymetry maps

The Seaglider has the ability to read digital bathymetry maps of an operating area. These maps should be prepared and loaded on the Seaglider's compact flash prior to deployment. It is possible to upload new map files to the glider while underway, but it is easier to do it beforehand.

5.2.4 Ballasting

This is the procedure for adding or subtracting lead weights to trim the Seaglider for the desired flight characteristics in a given density environment. The initial diplaced volume determination is done in the saltwater test tank at the UW School of Oceanography. Further ballasting for particular environments can be done using the Seaglider trim spreadsheet and a simple algebraic calculation.

5.2.5 Hardware checkout and self-test

The hardware checkout procedure is done in the lab, perhaps prior to final close-up, to ensure the Seaglider is functional. The self-test is done from within the Seaglider operating program, and tests all Seaglider systems, including the GPS and modem. The interactive self-test is the best way to ensure the Seaglider is working properly before proceeding.

5.2.6 Deck dives

These are simulated dives, so named because they have traditionally been done outside on a deck, so that the antenna has a clear view of the sky. Simulated pressure and pitch observations are generated to allow test dives (**$SIM_W** and **$SIM_PITCH**). This is a valuable way to test the end-to-end data path, since the basestation is involved and has to deal with "real" **data files**. The "Test Launch! " menu item (in the Launch menu) should be used for deck dives.

5.2.7 Transport

Before packing the Seaglider for transport, use the menu option hw/misc/travel to prepare the Seaglider for transport. For short trips, the Seaglider can be transported in its wooden handling cradle. Longer trips or commercial shipment require disassembly (to the pupa level), and use of the plastic shipping cases.

5.3 Launch

The actual Seaglider launch procedure is initiated by an operator directly connected to the Seaglider via the serial communications cable. The operator selects the "Sea Launch! " menu option from the Launch menu. A self-test should be executed at this time.

The pilot's responsibilities are to review the results of the self-test file, and to ensure that the proper parameters and **cmdfile** directives are in place when the Seaglider is launched. The Seaglider will transfer the results of the self-test and a complete dump of all the parameters prior to launch. The pilot should carefully review these files prior to giving a positive answer when the field operator asks for clearance to launch.

Once the pilot has given clearance to launch, the Seaglider goes into a normal surface procedure: acquires GPS1 and initiates a communications session. At that time, the usual file uploads are done, including **cmdfile**, and **science**, **targets**, and **pdoscmds.bat**, if they exist. The normal launch procedure is to place a **$QUIT** directive in the **cmdfile**, which will hold the Seaglider on the surface while surface position and acoustic ranging performance are verified. If the physical launch goes well, and the field team reports satisfactory surface position and acoustic ranging, the pilot can ensure that the proper shallow (test) dive parameters are in place, then put the **$RESUME** directive in the **cmdfile**. That will start the first dive. Once the **cmdfile** has been successfully transferred, and the communications session is successfully completed, the **$QUIT** directive should be placed back in the **cmdfile**, so the Seaglider will hold at the surface following its first dive.

5.4 Test and Trim Dives

5.4.1 Diveplot

Data from the initial test dive should be examined in detail prior to making any parameter changes or letting the Seaglider continue on its second dive. The pilot is responsible for ensuring that the Seaglider is operating properly in all respects, that trim issues (if any) are within the adjustment range of the Seaglider, and that the Seaglider is cleared to continue on its mission. Affirmative answers to these questions will allow the pilot to release the field team for other duties.

It is most efficient to plot the data from the initial dive and inspect the plots. One example of such a series of plots are those produced by a Matlab script diveplot.m.

5.4.2 Initial Revision of Trim

Initial adjustments of trim are done in order pitch, VBD, and roll. These adjustments are made by changing the system neutrals (**$C_PITCH**, etc.), based on regressions of controlled (or expected) quantites versus observed outcomes.

For pitch, a linear regression is made between observed vehicle pitch, as measured by the inclinometer, and pitch control, the position of the pitch mass in cm relative to **$C_PITCH**. This linear regression will give a pitch bias and a pitch gain. We choose to adjust the **$C_PITCH** so that the pitch bias is zero. This can be done using the approach given in example 3.7. We generally only adjust half-way to the calculated

$C_PITCH after one dive, however, since the regressions are not always robust enough to be fully trusted after only one dive. It may take another short dive to get **$C_PITCH** reasonably close to neutral pitch.

Once pitch is close, deeper dives can be undertaken, which then will provide more steady-state flight observations. These can be used to adjust **$C_VBD**, if necessary. These adjustments are initially made by comparing the observed Seaglider vertical velocity, , with the Seaglider hydrodynamic model predictions of vertical velocity as a function of calculated buoyancy and observed pitch angle. The **$C_VBD** is adjusted to make the predicted and observed vertical velocities more closely agree. Once again, based on experience, adjustments based on regressions of small numbers of dives are done in steps of about half the predicted adjustment.

Roll trim is an ongoing process, and continues throughout the deployment. Turn rate is regressed against roll control; the idea is to trim the Seaglider to fly straight, not to trim it to be flat. Separate roll centers are used for the dive and the climb phases. But environmental conditions can cause the Seaglider to require a lot of turning to stay on course, so the corrrect value of the roll neutral points can be elusive.

5.4.3 Progression of Dives

Typical launches progress as follows: two dives to 45m, then one or two dives to 200m-250m, then one or two dives to 500m, then full depth dives. The exact sequence depends on Seaglider performance, water depth, and other operational considerations, but the idea is to get a progression of longer and longer dives, for better tuning of the Seaglider pitch, VBD, and roll.

5.5 Monitoring

Once the initial Seaglider trim is established on a deployment, the pilot mainly monitors the Seaglider performance. This includes how the Seaglider itself is working, and how well the Seaglider is accomplishing its scientific mission. On routine deployments, checking the Seaglider status once per day may be sufficient. There may be times when more frequent checking is appropriate.

5.5.1 Seaglider Performance

The basics are simple. Here are some of the things to monitor.

- Is the Seaglider communicating as expected? Check the Seaglider's **comm.log** file on the basestation for the latest communication. Do the throughput rates and communication session information seem normal (>200Bps)? Are at least two-thirds of the communications sessions completed successfully with one phone call? Are there many missing or incomplete pieces of **data** or **log files**?

- Are the GPS positions current? Are the GPS positions current in time and reasonable in position? Are the positions acquired in reasonable amounts of time (~45s for GPS1, ~15s for GPS2)? Are the HDOP values generally less than 2.0?

- Are the sensors functional and providing believable profiles?

- Are the Seaglider control systems (pitch, roll and VBD) working normally? Check the motor currents and rates of movement of the device. Is there a trend? Are there retries or errors? Regress VBD in groups of ten dives or so sequentially in time and look for trends. Small rate hydraulic leaks have been found in this way. They manifest themselves as the Seaglider apparently getting heavier. In fact, the Seaglider is actually losing buoyancy for a given amount of oil in the internal reservoir - oil is going somewhere other than into the external bladder.

- Is the specified surface buoyancy sufficient to fully expose the antenna? Check **$_SM_DEPTHo** in the **p*.log** file. Values of 0.7m are about normal. Anything over 1.0m should be cause to adjust **$SM_CC**.

5.5.2 Data Completeness and Quality

Be sure that all the data for each profile has been transferred successfully to the basestation. There are many ways to do this. One simple way is to compare the size of the processed p*.dat file to the file size specified as the first argument in the **$DATA_FILE_SIZE** line in the **p*.log** file. If there are missing pieces, the **comm.log** file can be an easy way to determine which chunk of data was incompletely transferred. The resend_dive command in the extended PicoDOS® command set allows for individual chunks of **data** or **log files** to be resent at the next Seaglider surfacing.

5.5.3 Troubleshooting

The contents of the **p*.log** files, the **capture file** mechanism, and the extended PicoDOS® command set (used via the **pdoscmds.bat file**) provide useful tools for troubleshooting.

5.5.4 Resources

Call the UW Seaglider Fabrication Center for further help and information.

5.6 Recovery

A normal Seaglider recovery is initiated by directing the Seaglider to a specified recovery point. The Seaglider pilot will often have had the Seaglider performing relatively shallow (short) dives at the recovery point while awaiting word on the arrival of the recovery team. That way, the Seaglider is relatively close to the surface at all times, and there are regular opportunities to place the Seaglider at the surface. The actual recovery is initiated by putting the **$QUIT** directive in the **cmdfile**. An adjustment to **$T_RSLEEP**, the time (min) to sleep between calls while in recovery, is often made at this time. The **.pagers** file mechanism is generally used to transmit the most recent Seaglider surface position to the recovery team via SMS to an Iridium handset or cell phone.

It is important for the pilot to check the **$INTERNAL_PRESSURE log file** parameter prior to authorizing recovery, to check for possible battery outgassing.

Recoveries have also been accomplished with general locations from Iridium and specific location via acoustic ranging., when GPS was not available.

Physical recovery depends on the vessel in use. From low-freeboard vessels, recovery can be directly into the wooden handling cradle. From larger vessels, a lasso is generally placed around the vertical stabilizer and the Seaglider is lifted aboard.

Once on deck, the Seaglider is powered off, rinsed with fresh water if available, the antenna is removed, and covers are placed on the sensors. If a computer and communications cable are available, the Seaglider can be powered on and put in the 'travel' mode as described above.

Chapter 6
Special Topics

6.1 Scenario Run

A scenario run is a finite sequence of prescribed values for pitch, roll, and VBD. It is used primarily in tank tests to determine the displaced volume of a Seaglider, do systems checks, or validate vehicle trim configurations. The following sections will describe the setup, phases of operation, and the data download for a Seaglider scenario run.

6.1.1 Setup

1. Select the "Pre-launch" menu item.
2. Select "Set scenario mode".
3. Specify the scenes by entering the desired values for pitch, roll, VBD, and duration.
4. Adjust the parameter values shown on the menu page if needed. These are the key values that have an effect in scenario runs.
5. Store the scenes if desired.
6. Return to previous menu
7. Go to the "Pre-Launch" menu again.
8. Select "Test Launch! "

6.1.2 Run Phases

A scenario run is divided into four phases: launch, scene, transition and recovery.

6.1.2.1 Launch

The test launch dialog will get the Seaglider to the initial state, and start data collection. Once the first state (scene) is established, Once the values are achieved, the Seaglider starts the first scene. The mission timer starts at the completion of this countdown. It is reasonable to stay connected to the Seaglider until the first few data acquisition cycles have been completed. Then disconnect the communcations cable, install the connector plug and physically launch the Seaglider.

The launch phase is a special case of the transition phase between scenes, as it is a transition from the (possibly random) deck setup initial conditions to the static values specified for pitch, roll and VBD in the initial scene.

6.1.2.2 Scene

A scene is a set of static values for pitch shifter position, roll shifter position, VBD volume, and duration specified during the setup of the scenario run. The Seaglider holds those values for the duration specified for the scene, then goes to the transition phase to change those values to those specified for the next scene.

The time entered for each scene applies to the static (passive) portion of the scene only. The time in the transition phase (needed for performing the active G&C to achieve desired pitch, roll and buoyancy) is additional.

For example, suppose we have specified a scenario with two scenes of the following pitch, roll, VBD, and duration.

Scene	Pitch(cm)	Roll(deg)	VBD(cc)	Time(sec)
1	-1.0	0	-100	60
2	1.0	0	100	60

Then the total run time will be as follows.

Phase	Time
Launch	Varies, depending on initial conditions of pitch, roll, and VBD
Scene 1	60 seconds
Transition (1-2)	About 4 seconds for pitch and about 90 seconds to pump 200 cc
Scene 2	60 seconds
Recovery	Varies, depending on time for surface maneuver
Total	4-10 minutes

6.1.2.3 Transition

During the transition (active) phase, the Seaglider changes the pitch position, roll position and VBD volume to the values specified for the next scene. Once the values are attained, the next scene begins and the values are held constant for the time specified in the duration parameter. The Seaglider takes some time to stabilize following the transition phase. This is particularly true for transitions involving large pitch changes, which impart significant momentum to the Seaglider. Scene durations of at least 60 seconds are appropriate for tank testing.

6.1.2.4 Recovery

During a scenario run, the Seaglider goes into recovery phase if any of the following conditions are met.

1. The target depth, **$D_TGT**, is exceeded. Target depth in a scenario run is used like the abort depth parameter in an autonomous run.
2. The abort depth, **$D_ABORT**, is exceeded. This should never happen because the target depth should be reached first (**$D_TGT** < **$D_ABORT**).
3. The maximum mission time, **$T_MISSION**, is exceeded.
4. All defined scenes are completed.

6.1.3 Data Access

After the run, the data can be viewed using the sumasc command from the picoDOS>> prompt, or uploaded to the lab computer using the xmodem commands at the picoDOS>> prompt.

Files could be moved to a Seaglider basestation and then converted to the normal **p*.[log, asc, eng]** format. If a scenario run is aborted for some reason, the data up to the point of power-off are in the files **thisdive.dat** and **thisdive.log**.

6.2 Ballasting

A separate procedure for ballasting is in preparation.

Chapter 7
Nomenclature

7.1 Terminology

Run	Phase	Mode	Action
Scenario	Launch	Active (G&C)	Pitch (Fwd/Aft)

Autonomous	Surface	Passive (G&C)	VBD (Pump/Bleed)
	Dive	Sleep (TT8)	Roll (Port/Stbd)
	Apogee		
	Climb		
	Recovery		

7.2 Conventions

Variable Buoyancy Device		
Internal Bladder Condition	Empty	Full
Operation	Pump (make more buoyant)	Bleed (make less buoyant)
Overall Buoyancy	Positive	Negative
A/D Count	< center	> center
Value (cc) from Neutral	Positive	Negative
Pitch Mass Sensor		
Mass Shifter Position	Forward	Aft
Operation	Dive	Climb
A/D Count	< center	> center
Value (cm) from Neutral	Negative	Positive
Roll Mass Sensor		
Mass Shifter Position	Port	Starboard
Turn Type	Starboard in dive, port in climb	Port in dive, starboard in climb
A/D Count	< center	> center
Value (deg from neutral)	Negative	Positive
Inclinometer		
Roll	Port wing down	Starboard wing down
Degree Reading	Negative	Positive
Pitch	Nose down	Nose up
Degree Reading	Negative	Positive

Appendix: Table of Conversion Factors

	Pitch	Roll	VBD
Hardware Limits	Determined and set by assembler	Determined and set by assembler	Determined and set by assembler
Software Limits	**$PITCH_MIN, $PITCH_MAX**	**$ROLL_MIN, $ROLL_MAX**	**$VBD_MIN, $VBD_MAX**
Center	**$C_PITCH**	**$C_ROLL_DIVE, C_ROLL_CLIMB**	**$C_VBD**
Conversion Factors	**$PITCH_CNV** (217.39 cts/cm)$^{-1}$	**$ROLL_CNV** (35.37 cts/deg)$^{-1}$	**$VBD_CNV** (4.0767 cts/cc)$^{-1}$

Gain	**$PITCH_GAIN**	~0.5 vehicle deg/deg	~1.0 vehicle displacement/cc
Timeout	**$PITCH_TIMEOUT**	**$ROLL_TIMEOUT**	**$VBD_TIMEOUT**
Maximum Errors	**$PITCH_MAXERRORS**	**$ROLL_MAXERRORS**	**$VBD_MAXERRORS**
Dead Band	**$PITCH_DBAND**	**$HEAD_ERRORBAND**	**$VBD_DBAND**
Rate of Motion	**$ROLL_AD_RATE**	**$PITCH_AD_RATE**	**$VBD_PUMP_AD_RATE_SURFACE,** **$VBD_PUMP_AD_RATE_APOGEE,** **$VBD_BLEED_AD_RATE**