RSI Technical Note 031

Blow-down of the Nemo Float due to Current
Revision 2

Rolf Lueck

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Rockland Scientific International Inc.
520 Dupplin Rd
Victoria, BC, CANADA, V8Z 1C1
www.rocklandscientific.com

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1 Introduction

In this document I predict the change of elevation (blow-down) of the Nemo due to current. The Nemo is a syntactic foam float used to support a MicroRider turbulence measurement system in a tidal channel (Figure 1). This platform also supports a 3-axis Nortek Vector current meter and a downward directed AD2CP (acoustic doppler current profiler).

The Nemo is attached to a mooring line. The other end of the line is attached to an acoustic release and this, in turn, is connected to a short line and an anchor. Currently, the anchor consists of two railway wheels that have a mass of approximately 700 kg. The system was used for 2 days in Grand Passage, Nova Scotia between 2013-08-06 to 2013-08-08, with current speeds as high as $2.2\,\mathrm{m\,s^{-1}}$.

In section 2, I use data collected in Grand Passage to estimate the blow-down of the Nemo. In section 3, I develop a simple model of the blow-down and push-back of the Nemo and use the Grand Passage data to predict the blow-down as a function of current speed.

Figure 1: The Nemo shortly before its deployment in Grand Passage. The black pressure case protruding from the nose is the MicroRider turbulence measurement system. The Vector CM is just aft of the two straps used to tie lead weight to the underside of the float. Extra floatation was added aft of the tail fin. The yoke for the anchor line is the blue structure near mid body.

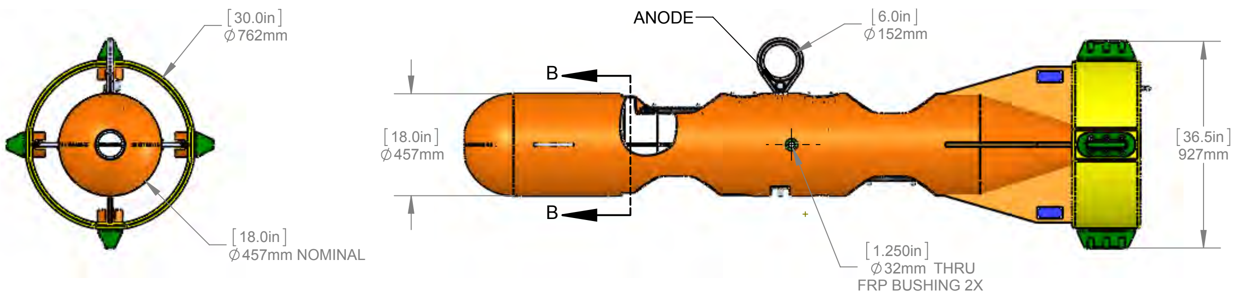

Figure 2: A dimensional drawing of the Nemo without instrumentation.

Figure 3: A close up view of the bridle. During slack water the Nemo pitches up until it is arrested by the horizontal member of the bridle.

2 Blow-Down in Grand Passage

There was no altimeter on the Nemo when it was deployed in Grand Passage. So, the elevation of the Nemo (its distance above the bottom) has to be estimated indirectly. Even if it had carried an altimeter, the large positive pitch of the mooring (35°) during slack tide would have provided challenges (Figure 4, upper panel).

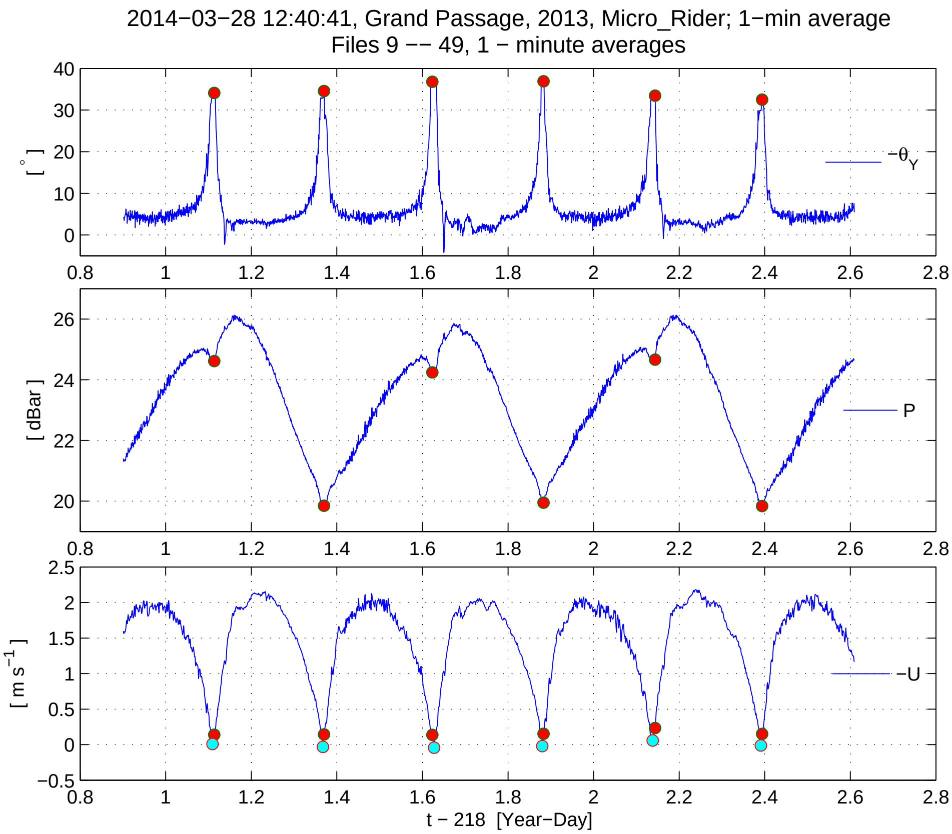

Figure 4: Upper panel – Pitch of the Nemo with nose up being positive. Middle panel – Pressure sensed by the MicroRider without adjustment for pitch, which is numerically equal to height of water above the pressure transducer. Lower panel – current speed. The times of maximum pitch are indicated by the red filled circles. The times of minimum speed are indicated by the filled cyan circles and are only shown in the lower panel.

2.1 Estimation using pressure

We can use the pressure record of the MicroRider to estimate the blow-down but first, I will explain the peculiar asymmetry of the pressure record. During high-water slack (the first, third and fifth red circles in the middle panel of Figure 4), the nose is pitched up at 35° and the measured pressure is less than the pressure at the bridle. As the speed starts to increase, the pitch is rapidly reduced and the pressure increases. Within about one-half hour, the pitch is less than 10° and it decreases slowly. The increase of pressure due to decreasing pitch becomes small and the measured pressure begins to decrease because the water surface is dropping (ebbing tide). The measured pressure decreases until it reaches a minimum (the even numbered red circles in Figure 4). Just before reaching the minimum pressure, the nose will pitch up and add an additional decrease of pressure. As soon as the current speed increases again, the nose will pitch down and increase the pressure, and the increasing pressure will eventually be dominated by the rising level of the surface.

If the tidal elevation were determined exclusively by a single sinusoidal component, then we could use the temporal mid-point between slack waters to estimate the pressure at the vertical location, L above the bottom, where L is the length of the mooring line. The main tidal constituent is M_2, but the solar tide, O_1 makes a significant contribution. Thus, the surface elevation half-way in time between low- and high-water is not the same as it is half-way between high- and low-water. There is a tidal elevation asymmetry. The pitch-adjusted pressure, the measured pressure, and the time of slack water (Table 1) indicate that the tidal amplitude is about 2.2 m.

P_θ dBar	P_M dBar	t YD - 218
25.5697	24.6166	1.1136
20.8166	19.8519	1.3700
25.2590	24.2407	1.6230
20.9709	19.9503	1.8829
25.5978	24.6607	2.1436
20.7530	19.8400	2.3938

Table 1: The pitch-adjusted pressure, P_θ, measured pressure, P_M, and the time, t, of slack water in Grand Passage.

The estimates of the pressure at an elevation of L above the bottom, at times midway between slack waters, fluctuates by more than 0.1 dBar (Table 2, first column). Some of this variation is caused by the O_1 tide. The difference between the predicted and the measured pressure at the temporal mid-points (Table 2, column 3) alternates between a large (-1.3 dBar) and a small (-0.3 dBar) difference, on the flood and ebb tides, respectively – which is another feature caused by the O_1 tide.

P_{mid} dBar	P_M dBar	$P_{mid} - P_M$ dBar	U_{mid} $\mathrm{m\,s^{-1}}$	t_{mid} YD - 218	Δt_{mid} YD
23.19	24.53	-1.34	2.05	1.2422	0
23.04	23.27	-0.23	2.02	1.4965	0.2544
23.12	24.33	-1.22	1.89	1.7530	0.2564
23.28	23.64	-0.35	1.90	2.0136	0.2606
23.18	24.47	-1.30	2.00	2.2686	0.2551

Table 2: The conditions temporally mid-way between slack waters deduced from the pitch record. P_{mid} is the predicted pressure, P_M is the measured pressure, U_{mid} is the current speed, t is the time, and Δt_{mid} is the time difference between successive mid-points.

The speed at the mid-points is consistently near 2.0 m s^{-1} and fluctuates by only 4 % (Table 2, column 4). The time between successive mid-points is approximately 6 h and 9.5 min (last column). If the only significant tidal constituents are the M_2 and the O_1 tides, then averaging over an even number of slack-water cycles should give a good estimate of the average blow-down, namely −0.78 dbar (Table 3).

$\overline{P_{mid} - P_M}$ dBar	$\overline{P_{mid} - P_M}$ dBar
-0.784	-0.775

Table 3: The difference between predicted and measured pressure, averaged over the first- and last-four slack-water cycles shown in Table 2.

The above analysis can also be based on the time of minimum speed (Figure 4, cyan circles) rather than maximum pitch (Figure 4, red circles). These times differ by typically 6 min. However, the average blow-down based on speed (−0.76 m) is not changed significantly from the values based on pitch (Table 3).

2.2 Estimation using AD2CP bottom echoes

Alex Hay (Dalhousie University) has provided the bottom echoes from the downward directed AD2CP (Figure 5). The AD2CP is located aft of the bridle and pitching motions will contribute in the opposite manner to the measured pressure record (upper panel) than it does for the MicroRider pressure signal.

The instrument estimates the along-beam distance to the bottom for each beam. The half-angle between opposing beams is 20°. The signals are only sensible during strong flows and, even then, there are a lot of wild data (Figure 5, lower panel). During slack-water, the data are highly erroneous with many values as small as −100 m, i.e. negative distances. If one tries to fit “by eye and mind” a parabolic curve to the non-erroneous values when there is some significant current, then the blow-down appears to be between 0.5 to 1 m.

The main contribution of the acoustic data is that it does not contradict my estimate from the pressure record.

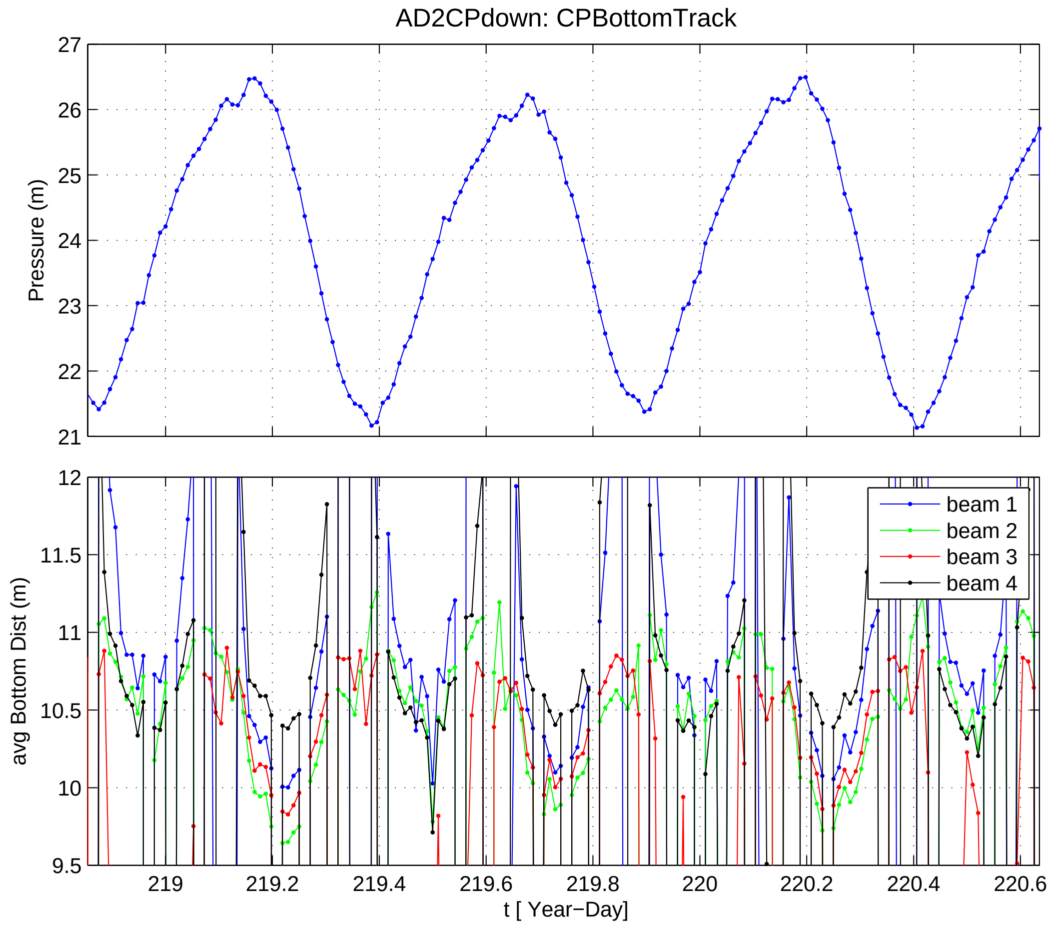

Figure 5: Upper panel – The pressure from the AD2CP located 0.5 m aft of the bridle point. Lower panel – The along-beam range to the bottom. All data with values shorter than 9.5 m are highly erroneous and many reach to −100 m.

3 Blow-down Model

For the Islay Sound deployment, the net buoyancy of the Nemo will be significantly increased compared to the deployment in Grand Passage (Table 4). The reason for the increase of buoyancy is that, for the Grand Passage deployment, we attached about 22 kg of lead to the underside of the Nemo, near its nose, and added about 120 N of buoyancy to its tail, in the form of three spheres (Figure 1). This was done to reduce the torque that lifted the nose upward during slack water. For the Islay Sound deployment we will not add weight and will, instead, add buoyancy to the tail of the float, to make the pitch as small as practical.

Grand Passage	Islay Sound
1350 N	1730 N

Table 4: The net buoyancy of the Nemo as deployed in Grand Passage and its future deployment in Islay Sound.

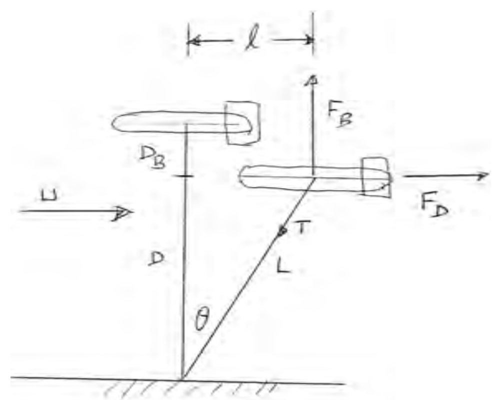

Figure 6: A cartoon of the forces of drag, buoyancy and tension for the Nemo.

The balance of forces on the Nemo consists of the tension, T, of the mooring line, the upward lift due to its net buoyancy, F_B, and the force of drag, F_D (Figure 6). The length of the mooring line is L, its vertical component is D, and the angle between them is θ. This angle is zero during slack water. The angle during flow can be estimated from the blow-down value ($D_B = 0.78\,\mathrm{m}$) in Grand-Passage, namely,

$$\theta = \cos^{-1}\left(\frac{D}{L}\right) = 23^\circ \tag{1}$$

using $D = L - D_B = 9.22\,\mathrm{m}$ for a mooring line length of $L = 10\,\mathrm{m}$. The force of drag, at a speed of $2.0\,\mathrm{m\,s^{-1}}$, is then

$$F_D = F_B \tan\theta = 567\,\mathrm{N}\ . \tag{2}$$

The coefficient of drag is

$$\hat{C}_D = \frac{F_D}{U^2} = 142\,\mathrm{N\,s^2\,m^{-2}}\ . \tag{3}$$

Although we do not need to know the drag coefficient for the float, it does provide a check on the estimated drag force. The drag coefficient is

$$C_D = \frac{F_D}{\frac{1}{2}\rho A U^2} = \frac{2}{\rho A}\hat{C}_D = 1.69 \ , \tag{4}$$

where $A = 0.164\,\mathrm{m}^2$ is the cross-sectional area based on a diameter of $0.457\,\mathrm{m}$ and $\rho = 1025\,\mathrm{kg\,m}^{-3}$ is the density of seawater. This is too high by at least a factor of 2 and I may have over estimated the blow-down in Grand Passage. If we base the cross-sectional area on the diameter ($0.76\,\mathrm{m}$) of the rear stabilizer (Figure 2), then $C_D = 0.61$ which is certainly an over estimate because the rear stabilizer does not provide full blockage of the flow.

Assuming that the coefficient of drag will remain unchanged when the Nemo is deployed in Islay Sound, we can predict that the angle of the mooring line will be

$$\theta = \tan^{-1}\left(\frac{\hat{C}_D U^2}{F_B}\right) \ , \tag{5}$$

the blow-down will be

$$D_B = L - D = L\left(1 - \cos\theta\right) = L\left(1 - \cos\left(\tan^{-1}\left(\frac{\hat{C}_D U^2}{F_B}\right)\right)\right) \ , \tag{6}$$

and the push-back will be

$$l = L\sin\theta = L\sin\left(\tan^{-1}\left(\frac{\hat{C}_D U^2}{F_B}\right)\right) \ . \tag{7}$$

All of these length values can be non-dimensionalized by the mooring line length, L. The non-dimensional blow-down as a function of speed is shown in Figure 7.

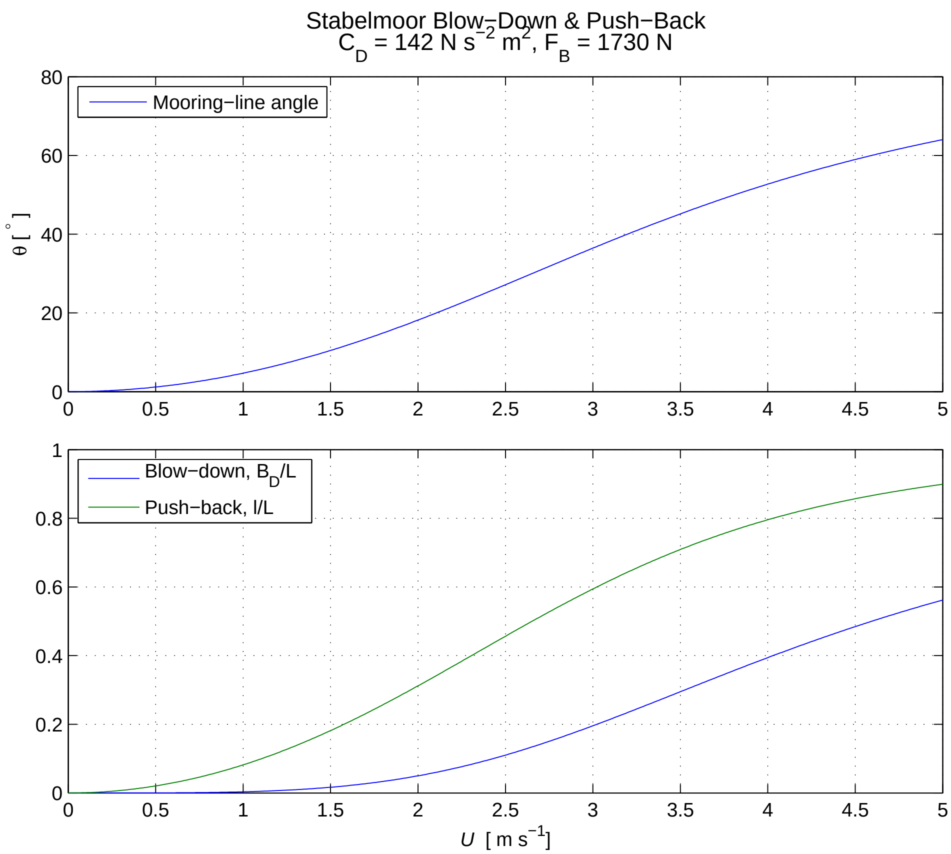

Figure 7: Upper panel – The angle of the mooring line with respect to vertical. Lower panel – The non-dimensional blow-down (B_D/L) of the Nemo and its Push-back (l/L) for the net buoyancy expected in Islay Sound, based on a coefficient of drag of $\hat{C}_D = 142\,\mathrm{N\,s^2\,m^{-2}}$.

4 Islay Sound Implementation

We have been informed that the hub-height for Islay Sound is 25 m and that the rotor has a diameter of 26 m (Kevin Ransom, Patrac). This gives us an aperture that extends from 12 to 38 m above the bottom. We definitely should remain within this aperture for all flow conditions. In addition, I would prefer to be within the inner two-thirds of the aperture, as much as possible. I have used the blow-down model to predict the height above the bottom of the Nemo for the anticipated range of tidal speeds in Islay Sound (Figure 8). Verbal communication (Peter Wilson, Partrac) indicates that the maximum spring-tide speed is 4.5 to 4.8 $\mathrm{m\,s^{-1}}$. I expect that the neap-tide speeds will be less than half of these values. In addition, only speeds greater than 1 $\mathrm{m\,s^{-1}}$ are likely to produce turbulence of interest to this project.

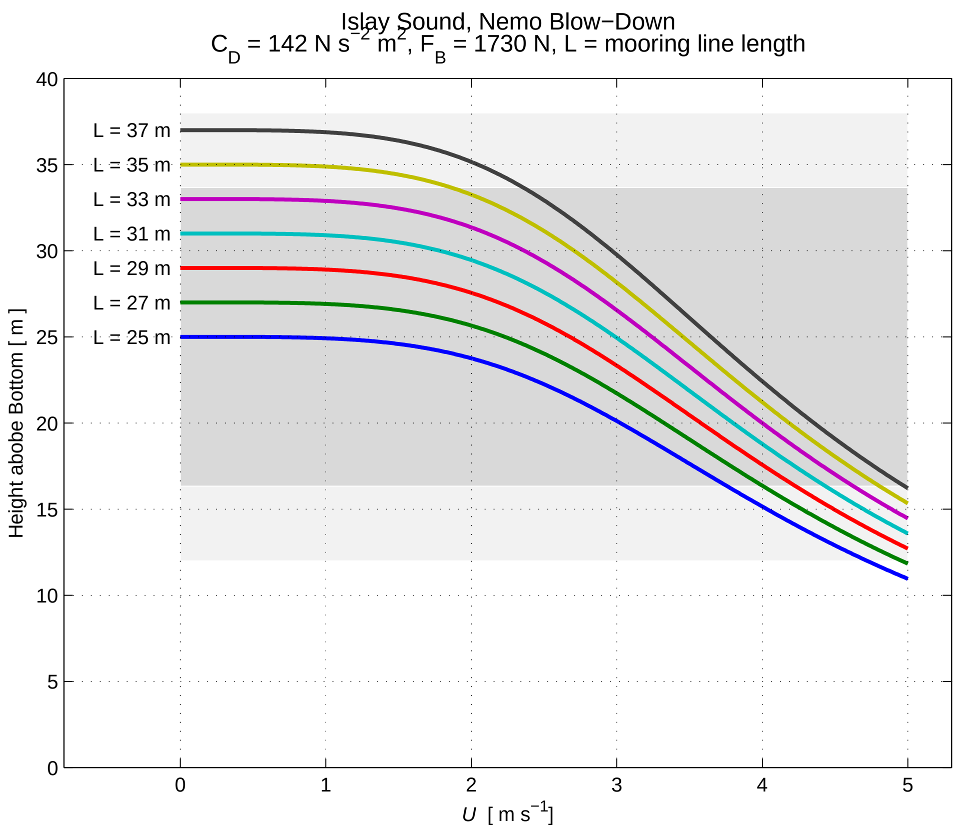

Figure 8: The height above the bottom of the Nemo for various mooring-line lengths, L, as a function of flow speed, U. The light grey region is the 26 m diameter aperture of the rotor when it is centred 25 m above the bottom – the hub-height. The dark grey region is the inner two-thirds of the aperture.

My recommendation is to use a mooring line length that places the Nemo at 32 m above the bottom, during slack water (between the cyan and magenta lines in Figure 8). This will keep the Nemo within the inner two-thirds of the aperture for speeds up to 4.5 $\mathrm{m\,s^{-1}}$, and within the entire aperture up to 5 $\mathrm{m\,s^{-1}}$. The push-back of the mooring is shown in Figure 9.

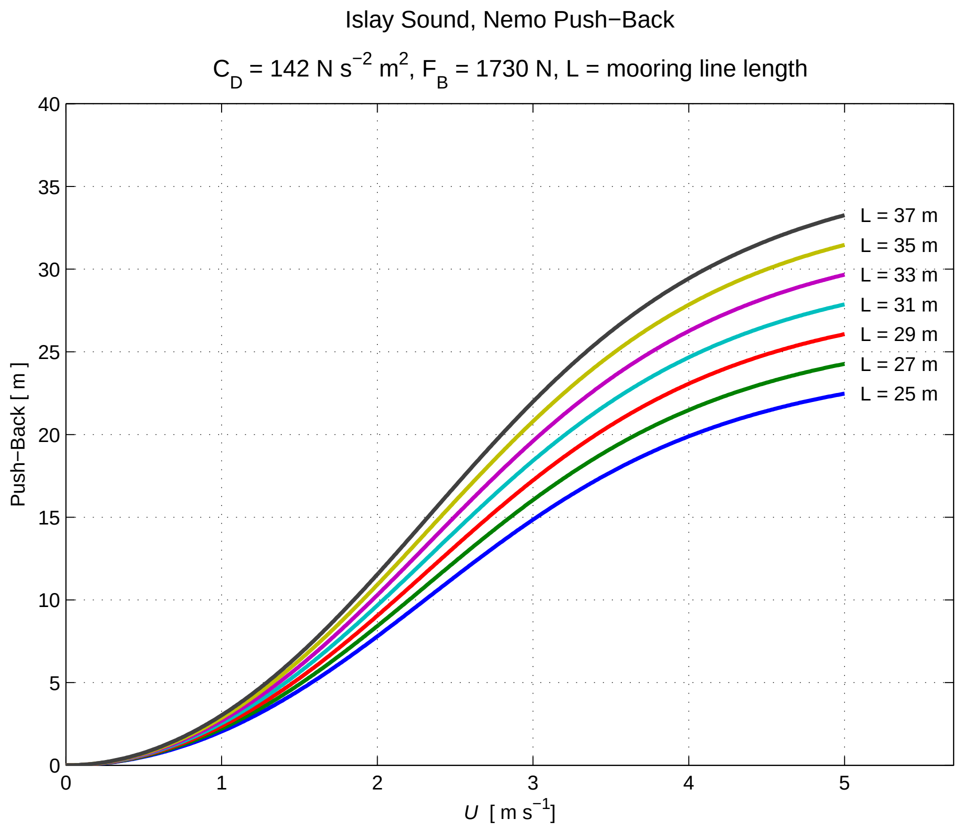

Figure 9: The horizontal distance that the Nemo is pushed back by the current, for various mooring line lengths, L, as a function of current speed, U.

5 Inner Sound Implementation

We have been informed that the hub-height for Inner Sound is 14.5 m, that the rotor has a diameter of 18 m, and that the depth is approximately 35 m (Kevin Ransom, Patrac). This gives us an aperture that extends from 5.5 to 23.5 m above the bottom.

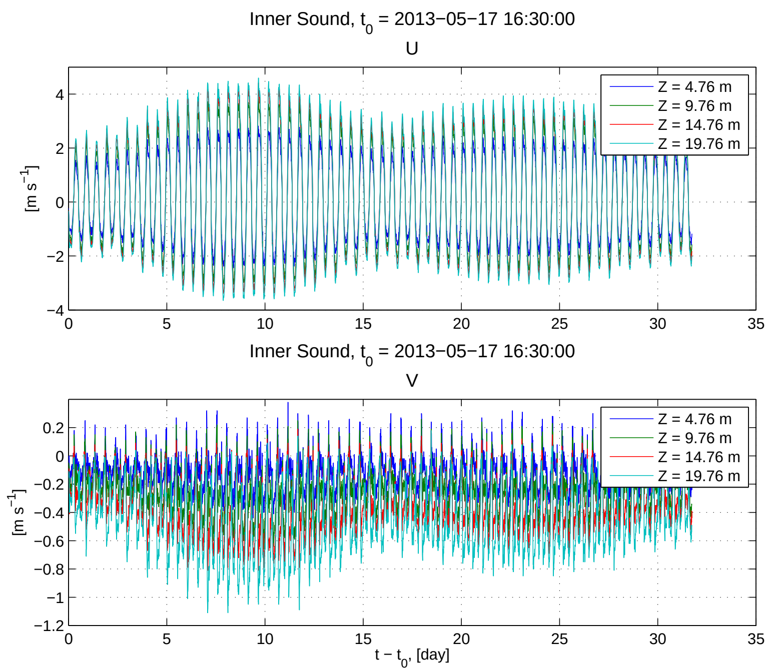

Figure 10: Ten-minute averages of zonal- (upper panel) and meridional-current (lower panel) for four different heights above the bottom in the Inner Sound.

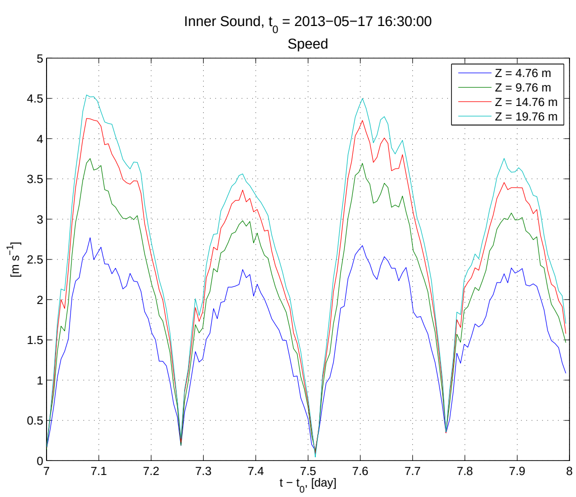

Figure 11: The speed in the Inner Sound during the height of the spring tide.

An estimate of the tidal current in the Inner Sound is provided by data collected in May of 2013 (Figure 10). The current is mainly zonal and is stronger to the east than to the west.

The maximum speed in the depth range of a possible Nemo deployment is $4.5\,\mathrm{m\,s^{-1}}$ (Figure 11)

I have used the blow-down model to predict the height above the bottom of the Nemo for the anticipated range of tidal speeds in the Inner Sound (Figure 12).

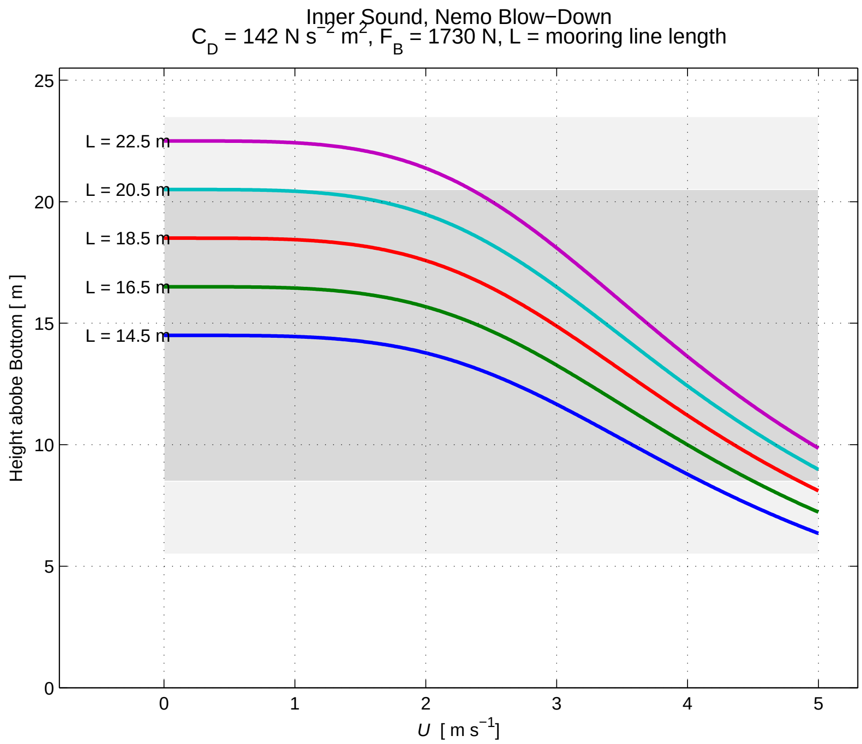

Figure 12: The height above the bottom of the Nemo for various mooring-line lengths, L, as a function of flow speed, U, in the Inner Sound. The light grey region is the 18 m diameter aperture of the rotor when it is centred 14.5 m above the bottom – the hub-height. The dark grey region is the inner two-thirds of the aperture.

My recommendation is to use a mooring line length that places the Nemo at 19 m above the bottom, during slack water (between the cyan and red lines in Figure 12). This will keep the Nemo within the inner two-thirds of the aperture for speeds up to $5\,\mathrm{m\,s^{-1}}$. The push-back of the mooring is shown in Figure 13 and could be as much as 17 m.

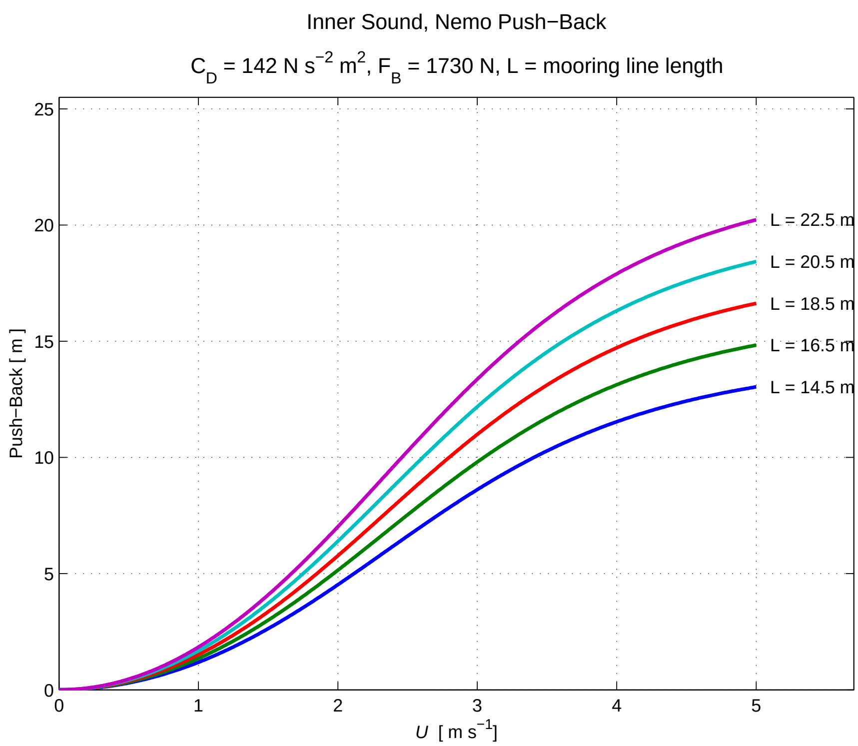

Figure 13: The horizontal distance that the Nemo is pushed back by the current in the Inner Sound, for various mooring line lengths, L, as a function of current speed, U.

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