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Final Report

Analysis of Vertical Towed Body

Contract Number: N00014-05-M-0136

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14. ABSTRACT
Bluefin Robotics Corporation performed a concept design study for a new ONR program to develop a Vertical Towed Body (VTB) for acoustic arrays. The work described here involved gathering preliminary requirements for the VTB from the government and various vendors. This information was used to create a concept structural design for the VTB suitable for hydrodynamic analysis. The concept underwent three major revisions. The long term goal is to design, build and test the VTB. The body will then be demonstrated to ONR.

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1 Deliverables

This document serves as the following contract deliverable CLINs:

1. Item 0001AD – Progress Report for period 9/3/05 – 12/9/05
2. Item 0001AE – Final Report

2 Long-Term Goals

Bluefin Robotics Corporation was subcontracted to Titan (now L3) on 9/13/05 under a new Office of Naval Research (ONR) program to develop a Vertical Towed Body (VTB) for acoustic arrays. The work described here was a direct Bluefin effort from ONR to jump-start that program by gathering preliminary requirements for the VTB. The long term goal is to design, build and test the VTB. The VTB will then participate in demonstrations related to the WSQ-11 Torpedo Defense program being run by PMS-415 in theQ4 '07 timeframe. The body will be demonstrated to ONR in the March '07 timeframe.

A concept for the VTB is depicted in Figure 1. It is a towed vertical acoustic source. The purpose of the concept is to provide a 360-degree horizontal beam pattern, which will allow ensonification of the entire torpedo threat volume using a single ping.

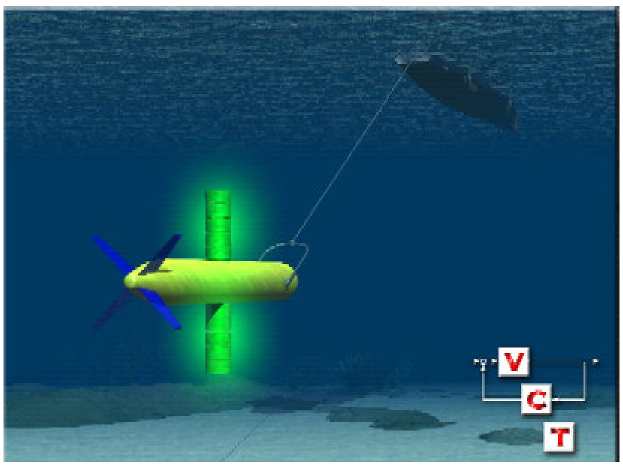


Figure 1 – Concept of Vertical Towed Body, courtesy of VCT

3 Objectives

The following items are envisioned as part of the design for the Vertical Towed Body:

- **Vertical source array:** This will be a cylindrical vertical acoustic source array designed by Image Acoustics and built by FSI and provided as a unit by ONR. The array will be capable of producing a cardioid beampattern in the horizontal plane. Penn State University/Applied Research Lab (PSU/ARL) will provide tuning inductors and impedance matching to the tow cable. This source will provide a Source Level in excess of 200dB without cavitating at ~100ft depth.
- **Passive pitch and roll control:** The body will be hydrodynamically designed by Vehicle Control Technologies (VCT) to maintain the source array in the vertical orientation to ±3 degrees in both pitch and roll over a tow speed range of 5-35 kts.

- **Pass through for Towed Array:** The VTV is intended to be towed behind a ship on a custom cable. It is expected that the tow cable will have a connection for several high power acoustic channels, DC power and a fiber optic serial link. The unit will pass through power and fiber connections to an aft NIXIE connector suitable to tow a short towed array. The VTB will be designed to withstand the tension caused by the additional drag of this array.
- **Communication with topside**. The unit will communicate via a serial connection over one of the Fiber Optic links in the tow cable. The unit can be commanded to turn on-board sensors on and off and a self test. The towed body will report its status as well as the depth and attitude as reported by its onboard HG-1700 IMU.
- **Critical angle tow**. The VTB will not provide onboard depth control. The depth of the VTB will be set by appropriate choice of cable scope and ship speed.
- **Folds for handling**. The source array will fold into the VTB to allow it pass through a standard tow transom on an AOE-6 with a goal to minimize the impact of the existing AN/SLQ-25A handling system. The unit should handle "like a NIXIE."
- **Testing and Demonstration**: The target platform for test and demonstration is an AOE-6. The competed system should be in the water by March '07. It will be in a major government demonstration in Q4 of '07. Before delivery, the unit will be tow tested at the David Taylor Model Basin tow tank and at-sea.

4 Work Completed

4.1 Work for Period 6/2/05 – 7/2/05

- None.

4.2 Work for Period 7/2/05 – 8/2/05

- Bluefin attended a meeting with Titan (L3) and ONR on 7/19 to develop a list of requirements for the VTB. Preliminary requirements were set at this meeting with APS/ARL and Image Acoustics in attendance.

4.3 Work for Period 8/2/05 – 9/2/05

- Bluefin toured the USNS Arctic at Naval Station Norfolk on 8/22 to determine the layout and limitations set by the NIXIE winch room. A mock-up test-body was brought to the tour to test the ability of handlers to deploy and retrieve the body through the transom.

4.4 Work for Period 9/2/05 – 10/19/05

- A preliminary mechanical concept (REV A) was developed 9/12 which meets the preliminary requirements. The design was made in collaboration with Vehicle Control Technologies, which has responsibility for the hydrodynamic stability of the design.
- Bluefin attended a meeting with Titan (L3) and ONR on 09/29 to kick off the VTB concept development. A deadline of Nov 1 was established for GFI design input required by Bluefin and VCT.

4.5 Work for Period 10/19/05 – 11/18/05

- On the direction of L3, a number of assumptions were made about the configuration of the source array and its support electronics. These assumptions were used along with other information about the source, drag and cable that had become available to develop a revised VTB mechanical concept (REV B).
- On11/14, Bluefin hosted a GFI review meeting with ONR. GFI design input was received at this meeting allowing Bluefin and VCT to continue preliminary concept design. The REV B concept design was presented at this meeting.

4.6 Work for Period 11/18/05 – 12/9/05

- The VTB concept design was updated (REV C) to reflect the information received at the 11/14 meeting. This included a heavier source array and the inclusion of the array tuning components inside the pressure vessel.
- A parametric analysis was done to explore how moving components affect the weight and trim of the body. This analysis was forwarded to VCT.
- A Phone con was held with L3 on 12/14 to report the results of the weight and trim analysis.
- As of 12/9, work is completed on this contract. The design work is in abeyance awaiting input from ONR.

5 Costs

The total contract award value is $24,927.00. The contract was negotiated as Fixed Price. Costs incurred by period are given below.

	7/2/2005	8/2/2005	9/2/2005	10/19/05	11/18/05	12/9/05
Total Cost	$0	$4,537	$9,336	$14,290	$22,349	$24,927

6 Technical Progress

6.1 Visit to USNS Arctic

In order to define the outer envelope of the VTB concept design, an on-site visit to an AOE-6, the USNS Arctic, was made on 8/22/05 by personnel from Bluefin, L3 and VCT. The VTB must go through the transom hole into the AN/SLQ-25A NIXIE handling room. A mock-up test body was brought to the ship to assess handling issues. Pictures of the hole exterior and interior are shown in Figure 2. This hole measures 11.5” x 11.5”. The following are observations from that visit:

- While retrieving the test body through the hatch, it seemed apparent that the retrieval of the towed array (attached to the tail) may be difficult. The best case scenario seems to allow approximately 30” of clearance between the tail of the tow body and the internal edge of the hatch. This dimension may end up being less depending on how long the strain relief section of the nose cable is. A longer wider cable section may not fit properly through the sheave above the winch. Minimizing VTB length is recommended.
- The use of straight control fins may not be possible. The cable is supposed to be twist resistant, so it may be difficult for the operator to adjust the orientation of the tow body to align the fins with the corners of the square hatch. A very long towed array may also make any kind of handling difficult. This could result in severe fin damage. A ring foil configuration, which eliminates the need for proper orientation is recommended.

Figure 2 - USNS Arctic, transom hole, exterior and interior with test body.

6.2 Preliminary Concept Design – Rev A

A preliminary mechanical concept was created in SolidWorks™ on 9/12/05 to meet the initial requirements put together by ONR, L3 and Bluefin and stability analysis done by VCT. This concept (Rev A) is shown in a folded and deployed configuration in Figure 3. Rev A shows a nose tow point using a connector that is currently undefined. Moving aft from the tow point is a small pressure vessel. This holds the HG-1700 Inertial Measurement Unit (IMU) and interface electronics. Aft of the pressure vessel is the source array which is mounted on a pivoting central hinge to allow it to fold into the body. The mid-body structure is open on the forward top and aft bottom of the array to allow the array to fold. Aft of the mid-body is the after-body which tapers down and has an "X" fin configuration.

Rev A was presented at the VTB kick-off meeting held on 9/29/05. This is a very simple model. The array configuration is not known precisely. There is no allowance for any tuning electronics in the forward pressure vessel. There is no wet cabling and there are no provisions for assembly. However, the envelope and fin configuration are accurate.

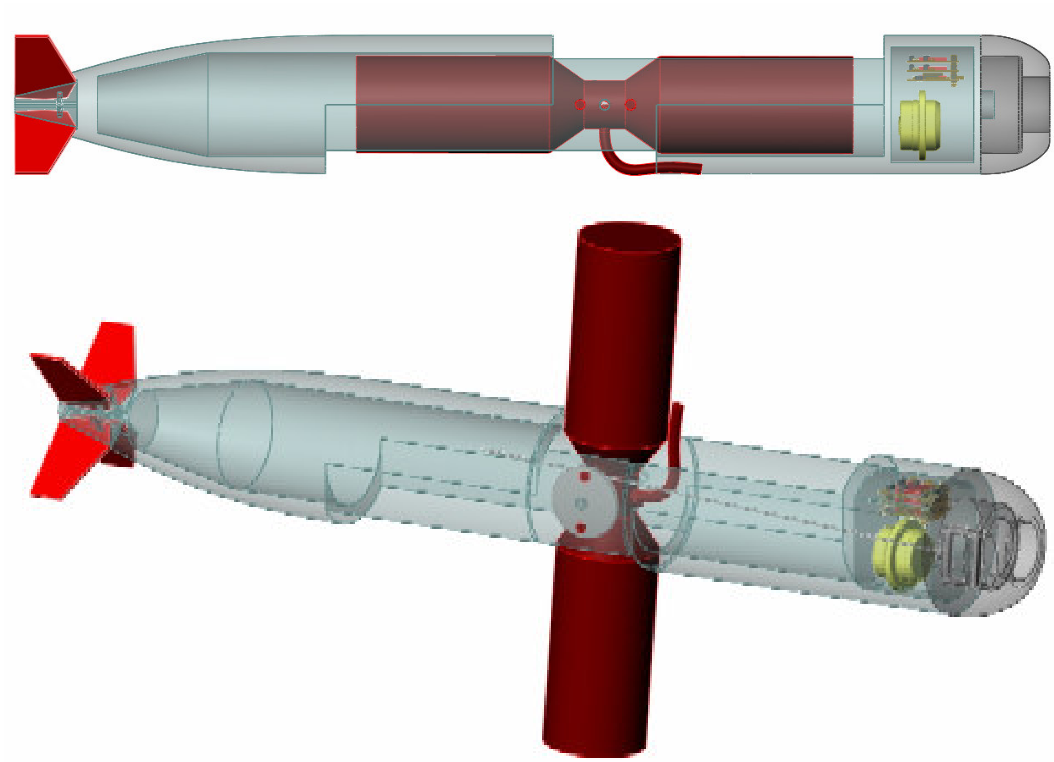


Figure 3 – VTB Rev A Mechanical Concept, folded and deployed.

6.3 Revised Concept Design – Rev B

The Concept Design was revised in preparation for the 11/14/05 GFI Review meeting. The revision was based on new information from a number of sources. This information is listed below, grouped by source.

VCT Information:

VCT provided the following requirements and information:

- The VTB center of gravity in the athwart ship direction (Cg-y) must be zero. The VTB must be symmetric Port/Starboard. The Bluefin design must incorporate internal ballast that can be adjusted in the y-axis to accommodate this requirement.
- Hydrodynamic effects are unknown for the cavities that exist in front of and behind the towed source when array is vertical. These cavities that are created when the source unfolds may need to be faired during towing, depending on flow-through the structure. It is recognized that a mechanism to deploy the fairings automatically (spring/pop up) could

be complicated. Bluefin will therefore provide bolt-on cavity covers for the purposes of testing at David Taylor and at-sea.

- The modeled drag for the vertical acoustic source, i.e. a right circular cylinder size 6" diameter and 31" long, at the VTB is 4,425 lbs at 25 kts. The modeled drag seen at the tow ship is 13,100 lbs at 25 kts. This helps define the strength of the VTB in tension.
- Passive pitch and roll control were modeled for an in-water weight of 50 lbs. At 25 kts, there is no issue. At 5 Kts, with the Cg_x at 3.125 ft from the nose (center of hull volume), the pitch angle is 10 deg nose up. To get the pitch to near zero (to keep it from coupling into roll), the Cg_x needs to be located ~2.4 ft from the nose. This Cg_x number was used as a design goal for REV B.
- Transverse forces on VTB are due to sideslip of the VTB during tow ship maneuvers. The steady side loads during turns will depend on ships speed, turn rate and the sideslip angle at the source. Preliminary estimates show that the sideslip is expected to be between 5 and 10 degrees. The table below shows the loads (in Lbs) as a function of speed for these two sideslip angles. This helps define the strength of the VTB in twist.

Steady Side Force	Sb =	0.4922
	Sideslip Angle	
Speed (Kts)	**5.0**	**10.0**
5	4.3	8.5
10	17.1	34.1
15	38.5	76.7
20	68.4	136.3
25	106.9	213.0
30	154.0	306.8
35	209.6	417.5

- A very important piece of information with respect to the acoustic performance is shown in Figure 4. As a cylinder is towed through the water perpendicular to the flow, a pressure field is created around its circumference. This is due to water having to flow around the cylinder; increased velocity (due to increased water volume) causes lower pressure. Velocity is highest and pressure lowest at 90^o where 0^o is in the direction of travel. Eventually the flow separates from the cylinder towards the aft angles. This effect is more pronounced for higher velocities. Lowering the pressure can be described as reducing the static hydrodynamic pressure (or head) on the cylinder. The plot in Figure 4 shows the pressure reduction in the units of feet of head as a function of the angle around the cylinder. The various curves are parameterized by velocity. So for example, for a 25 kt tow, the pressure on the cylinder at 90^o is at a level that it would have if it had zero velocity but were located 60 feet shallower. This pressure field reduction has an important impact for acoustics. The acoustic field is a pressure wave. As acoustic source level increases, the pressure amplitude increases. If the maximum amplitude of the pressure wave exceeds the hydrostatic pressure, the acoustic source cavitates (boils water). Acoustic performance drops off drastically once cavitation initiates. Damage to the source (pitting) can also be caused by continued cavitation. What Figure 4 shows is that the source must be towed deeper (an additional 60ft for 25 kts) in order to avoid acoustic cavitation, since towing has effectively lowered the hydrostatic pressure. This is a difficult problem to solve. Faring the source could reduce the pressure field, however the fairing would create a wing. Sch a lifting surface would have hydrodynamic implications. This wing would also have to have to be fairly long causing problems for folding the unit. There is some hope that fairing the front of the cylinder only could alleviate some of this problem. This modeling remains to be done.

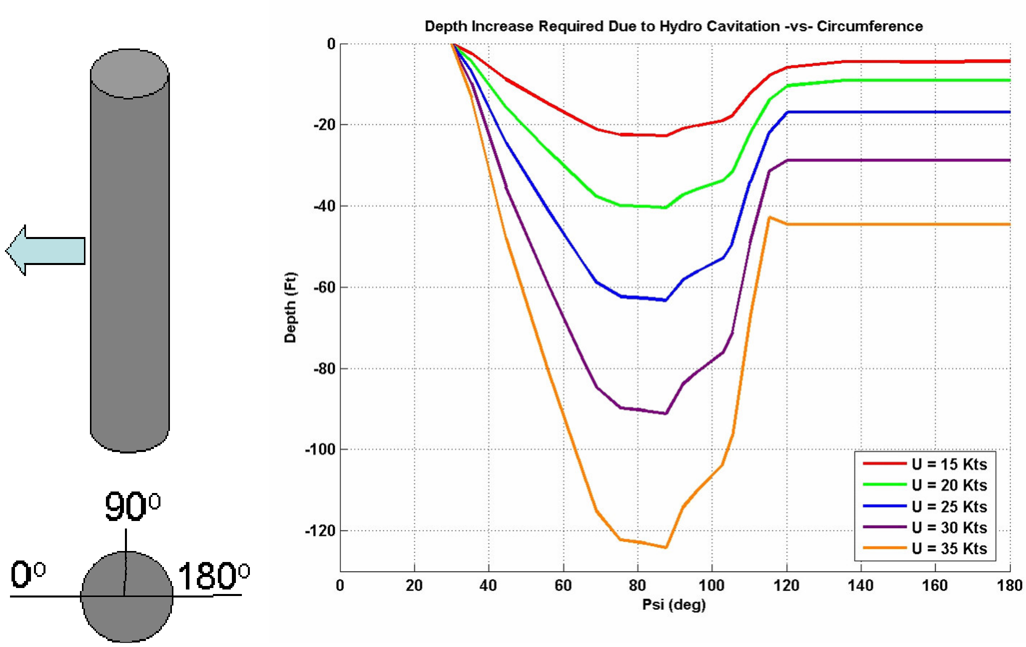
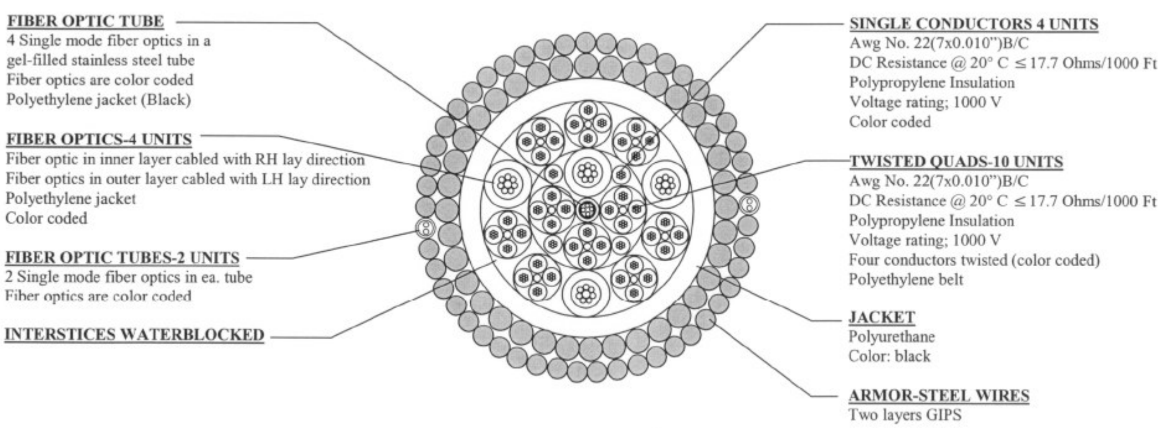


Figure 4 – Hydrodynamic cavitation around source

South Bay Information:

South Bay provided the following information on the custom cable that will be used to tow the VTB.



ESTIMATED VALUES

Nominal O.D.----------------------	1.040"
Weight in Air----------------------	1,220 Lb/1000 Ft
Weight in Seawater---------------	880 Lb/1000 Ft
Breaking Strength----------------	48,000 Pounds
Maximum Load-------------------	12,000 Pounds
Min. Bend Diameter--------------	24 Inches

Figure 5 – Tow Cable Design

- The maximum operating tension of the AN/SLQ-25A NIXIE tow winch is 20,000 lbs.

Image Acoustics

Image Acoustics provided the exterior design envelope of the source array shown in Figure 6. Image will provide the active source elements. Bluefin will design and provide the center pivoting section that attaches the two source halves to the VTB. Image has made an end cap for the purposes of testing each array section as shown in Figure 7. This is a basis for the VTB design, but will probably have to be modified to accommodate connectors.

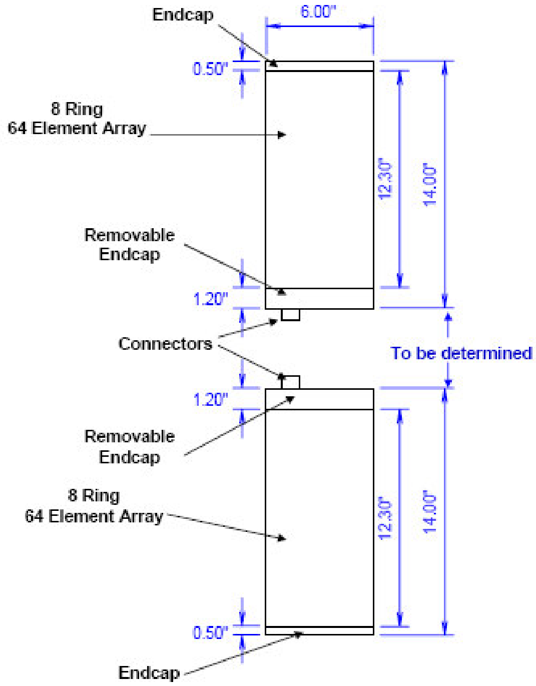


Figure 6 – Source Array envelope

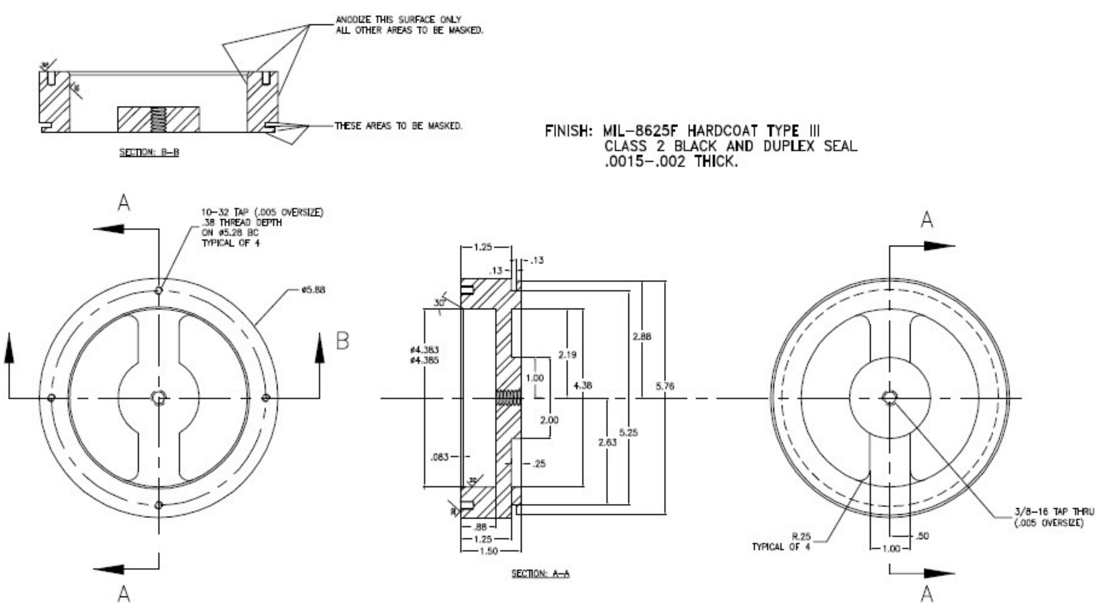


Figure 7 – Source Array End Cap, Mechanical Design

L3 Information

The structural and hydrodynamic aspects of the concept design were basically on hold waiting for input regarding the size and shape of the support electronics for the array and the final weight of the array. In order to move the process forward, on 11/1/05 L3 requested that Bluefin make the following assumptions and proceed with a revised design:

- Array length: Assume the array center grows to 5", making the total Array length ~33.4" (14.2" arrays + 5" center gap).
- Array weight: Assume weight either 120 or 145 lbs dry, assume each array filled with a quart of oil.
- Support electronics length: Assume the array support electronics occupies an additional volume inside the PV of 8.65" diameter and 10" long with an additional 1" length on one end for cabling.
- Support electronics weight: Assume array support electronics package weighs 10 lbs.

The goal for this revision was to maintain the overall body diameter of 9.5" and length of 75" and meet the VCT design goal for Cg_x = 2.4' from the nose.

Rev B Concept Design

The VTB Rev B Mechanical concept is shown in Figure 8. The REV B concept design was presented at the 11/14/05 GFI review meeting. This is a more complete design. This includes the assumed array size and weight and room for the support electronics. There are provisions for assembly, the beginnings of a wet cable layout as well as a mechanism for folding the array. The ring tail structure is a notional design only. VCT had no design input into this element.

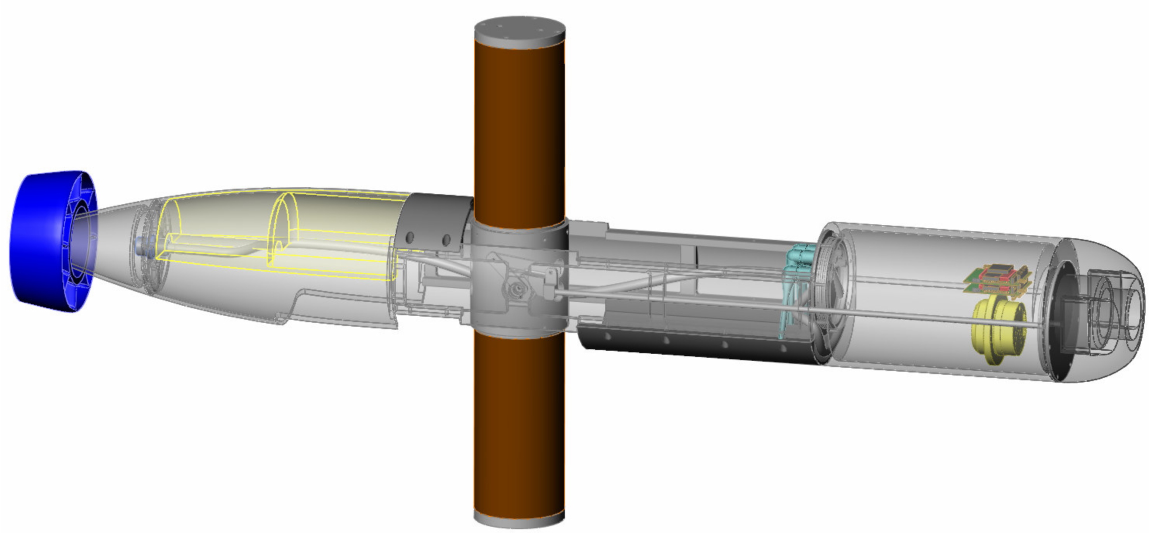


Figure 8 – VTB Rev B Mechanical Concept

An exploded view of the VTB Rev B assembly is shown in Figure 9. Structural parts will be machined from Aluminum. Some non-structural pieces may be machined from engineering plastics (ABS, Delrin, etc.) for weight and cost reduction. The body will be built from multiple pieces for ease of manufacture and assembled with fasteners.

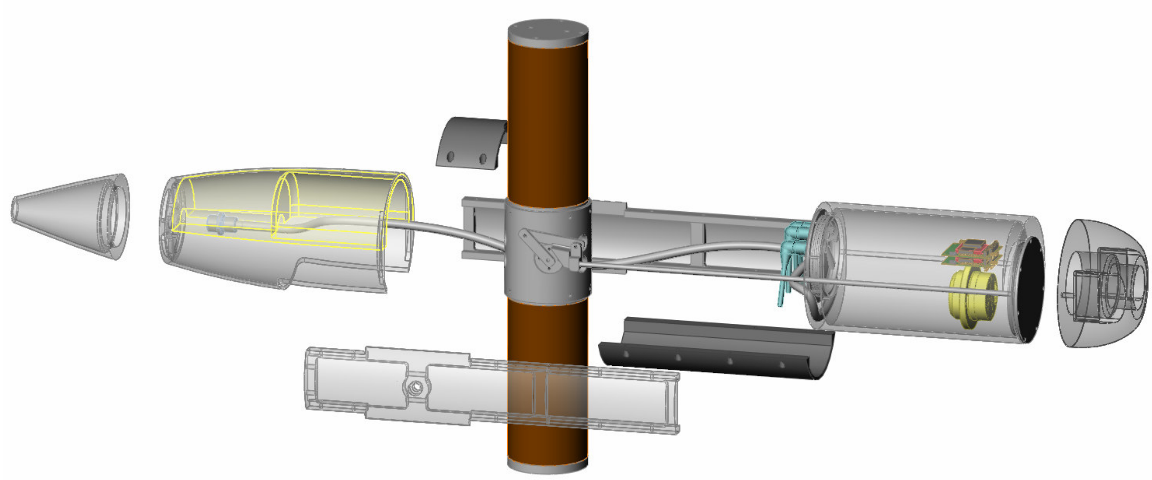


Figure 9 – VTB Rev B Mechanical Concept, exploded view

The pressure housing will be a tension bearing element, as shown in Figure 10. In Rev B, Bluefin explored an internally overlapping cylindrical construction to maximize internal volume and allow mechanical pass-by for folding mechanism. The holes down the side wall allow insertion of rods to actuate the folding mechanism from the nose of the vehicle. It is anticipated that an operator could actuate the fold via a handle on the vehicle nose prior to the VTB entering the ship transom.

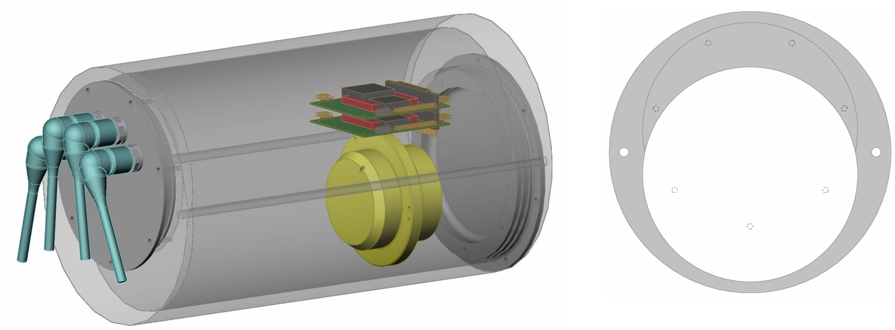


Figure 10 – Pressure Housing Concept

The Rev B design verifies that it is possible to route wet cables within the VTB to serve the array and the aft connector for the towed array pass-through function. This is shown in Figure 11. At the writing of this report, neither the aft "Nixie" connector nor the forward custom connector designs have been made available to Bluefin. This remains an outstanding issue.

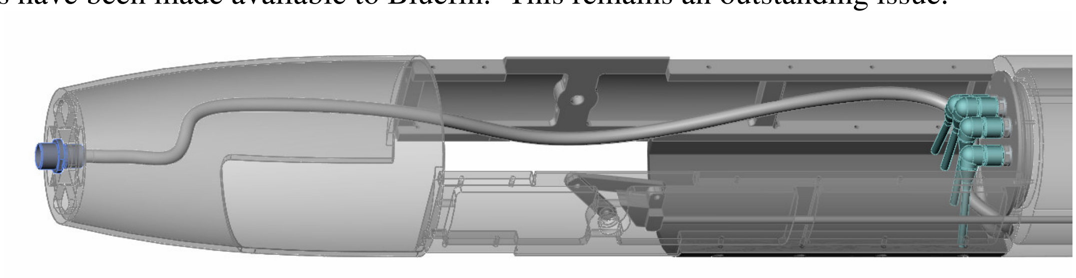


Figure 11 – Wet Cable Concept

The center of the acoustic array is a support structure, pivot point and cable routing area, as shown in Figure 12. This is envisioned as a machined aluminum piece sleeve which slips over the end caps on the array elements themselves and bolts through the exterior. The cable connections in this revision are undefined. There is room for connectors to molded wet cables or swage locks to oil-filled cables. The wet cable decision is pending.

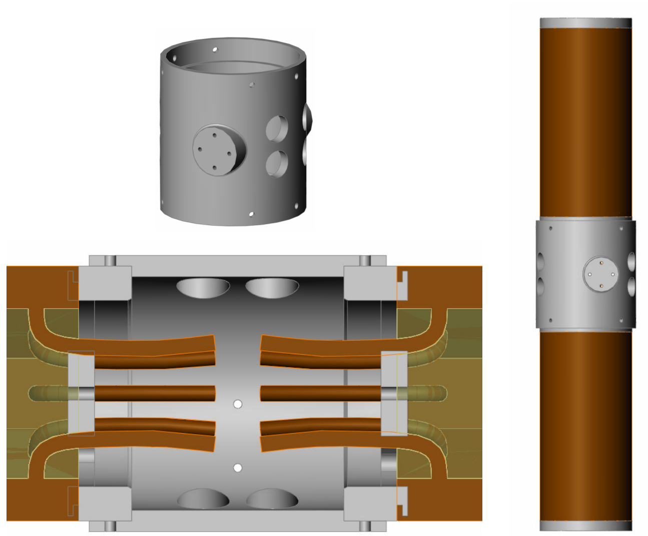


Figure 12 – Source Array Center Mounting

The center of the array section will be a connection point for a pivoting mechanism. The pivot point is offset forward in the body, so that the array is stowed high when folded. This allows room for wet cables, ballast, etc. to be stowed low in the VTB. The array is folded into the body via a linkage mechanism, as shown in Figure 13. The concept needs to be developed further to allow locking with single hand operation.

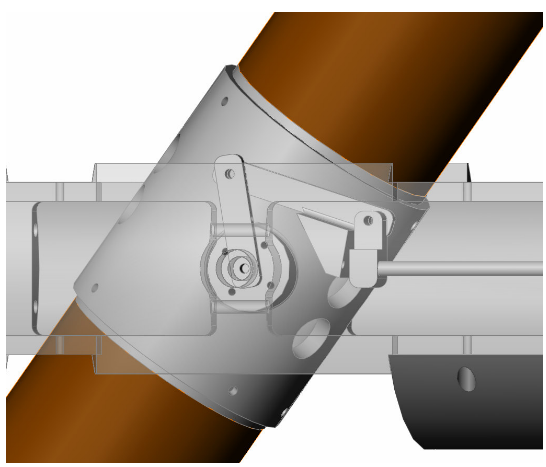


Figure 13 – Array Folding Mechanism Concept

Figure 14 shows a side view of VTB Rev B. This revision was unable to meet the VCT goal for the axial center of gravity Cg_x = 2.4 ft (28.8 in). Currently the Cg_x = 2.9 ft (35.3 in). The issue here is that the array itself accounts for ~ 60% of the total weight of the VTB. The array weight is fairly far back. The Cg could only be moved where it is by the inclusion of a buoyant foam pack in the tail which is probably not allowed for acoustic reasons.. Another issue is the overall weight of the body. The dry weight = 243 lbs and the wet weight = 139 lbs. Generally such bodies are designed to be neutrally buoyant in seawater to minimize hydrodynamic issues. The non-zero wet weight is problematic. Unfortunately, due to constraints of the VTB length and diameter imposed by handling requirements from ONR, there is no place on the body to add buoyant material. The VTB as specified seems to be volume limited.

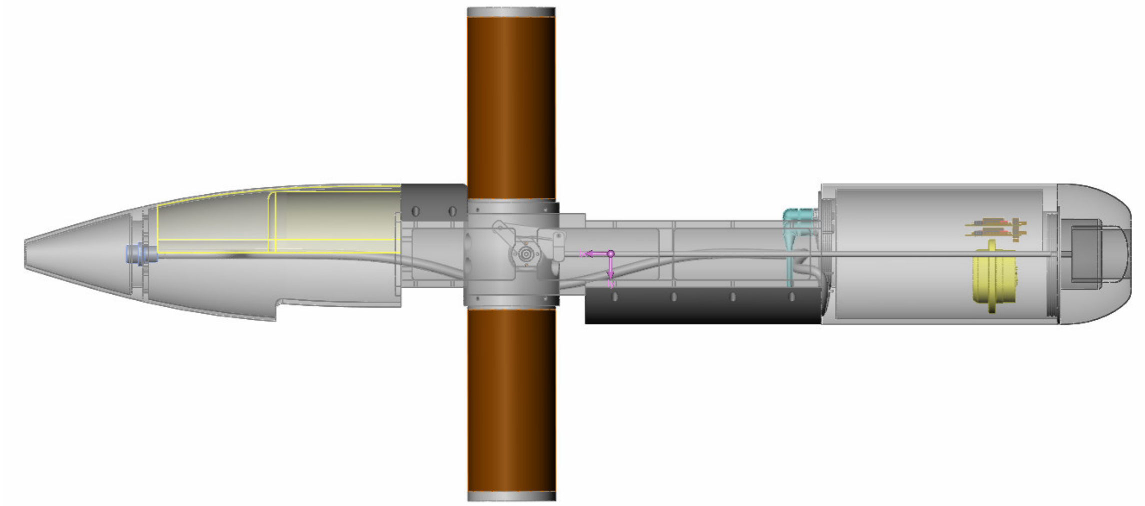


Figure 14 – VT Rev B, side view

6.4 Revised Concept Design – Rev C

At the GFI Review Meeting on 11/14/05, new information was received to further specify the VTB. This included:

- Definition of the acoustic source support electronics by PSU/APL. The tuning inductors and cable impedance matching is accomplished with 32 inductors, as shown in Figure 15. This increases the weight of the forward electronics section by ~50 lbs. There is concern about the heat and EMI that will be generated by these components. PSU/ARL requests that they be shielded and surrounded with oil.
- Final decision on the source array weight. A few days after the meeting, a decision was mad to use a tungsten center mass in the array. The implication of this decision is that the array would be heavier, with a weight of ~145 lbs.

Figure 15 – Inductor Core for Acoustic Source

As a result of the new information, the concept design was again updated to Rev C, as shown in Figure 16. This again is a detailed design. The full weight of the array is modeled. All 32 inductor cores are now placed inside the forward pressure vessel.

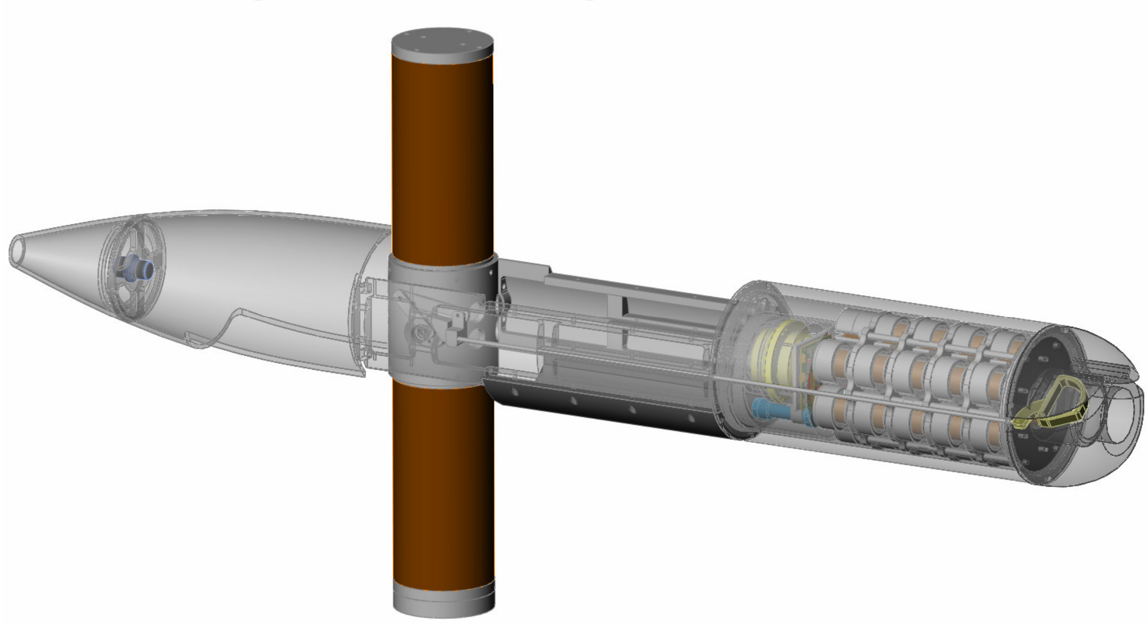


Figure 16 - VTB Rev C Mechanical Concept

The overlapping cylinder construction of the Rev B pressure vessel had to be abandoned in order to fit the inductors into the available volume. A new Pressure Vessel concept was created, as shown in Figure 17. The design has a separate air-filled (1 atm) steel housing inside larger oil-filled housing. The air filled housing holds the HG-1700 IMU, computer interface, depth sensor and fiber optic interface boards, essentially all the heat/EMI sensitive components. The inductors populate the oil-filled section. This configuration effectively isolates the heat and EMI created by the inductors from the other electronic components. It also allows simple oil-filled cables to be fed directly from the PV to the array via simple swage-lock penetrators. This will eliminate the need for bulky wet connectors on the PV.

Mechanically, the rod to fold transducer is fed through a long hold in the wall of outer housing. A handle will be attached in the nose of the body to allow the user to fold the array. Delrin plates and non-magnetic rods will be used to mount ferrite cores to the PV forward end cap. A machined plastic chassis will be used to mount the various electronics inside the air filled housing.

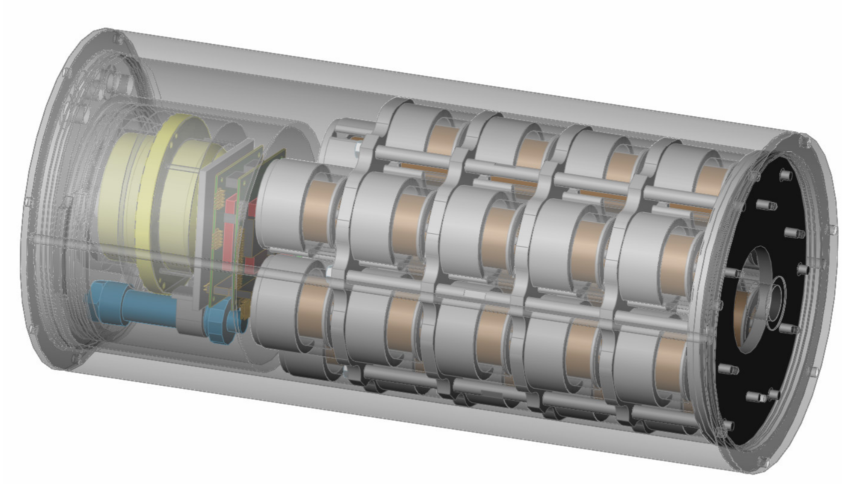


Figure 17 – Pressure Vessel Concept for Rev C

Below is a table which details the weight breakdown of VTB Rev C. Note that ehe wet weight is fairly high. Again this will induce a hydrodynamic problem. These are all still preliminary numbers as the detailed design has not been completed. Some weights will increase and some will decrease as the details are done. Connectors, cables, and hardware are not included in these numbers. Actuation linkages are likely to be 2-3lbs. These numbers assume no flotation foam. The electronics housing is 9.5" diameter x 20.4" long. 10-15lbs can probably be saved with a more expensive (Titanium) housing.

Verticle Tow Body	**Weight in air (lbs)**	**Displaced volume (cu.in)**	**Displaced sea water (lbs)**	**Weight in sea water (lbs)**
			(64lbs per cu.ft)	
Electronics Housing				
Cores and associated chassis	52	internal volume		
Housing assembly*	50	1448		
Nav & Main electronics	4	internal volume		
Oil	13	internal volume		
Total	119	1448	53.6	65.4
Array Assembly				
Top & Bottom array	141	788		
Center mounting collar	5	54		
Total	146	842	31.2	114.8
Fairings				
Mid and tail fairings	24	285		
Nose	9	205		
Total	33	490	18.1	14.9
Total	**298**	**2780**	**103.0**	**195.0**

6.5 Trim Analysis on VTB Rev C Concept Design

The requirements from VCT for pitch and roll stability essentially boil down to moving the center of gravity (Cg) in front of the center of buoyancy (Cb). Several different layouts of the VTB Rev C were made to try to accomplish this goal. These configurations are shown in the figures below. All indicated dimensions are in inches.

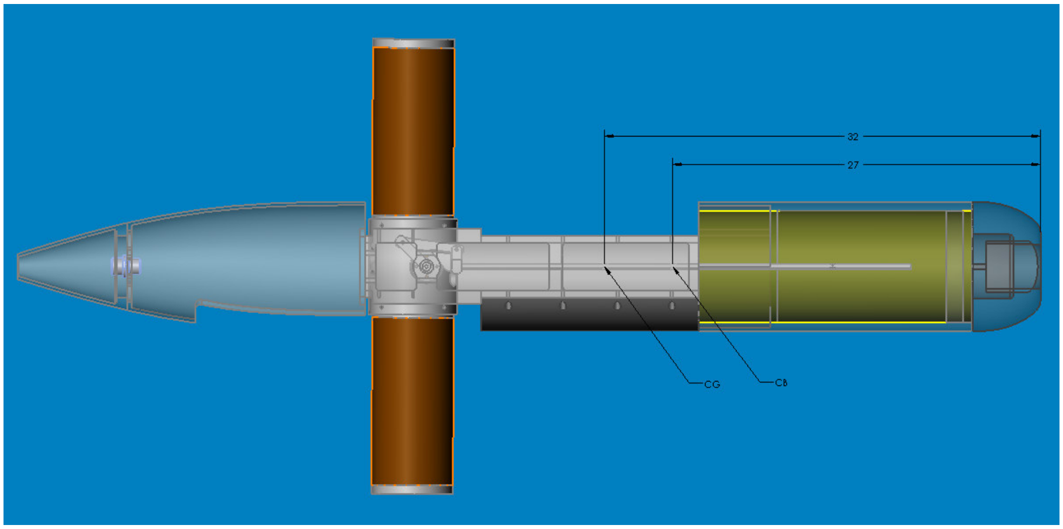


Figure 18 – VTB Rev C, baseline

Figure 18 shows the baseline configuration (Dry weight = 310 lbs, Wet weight = 206 lbs). The Cg is located 5” behind the Cb.

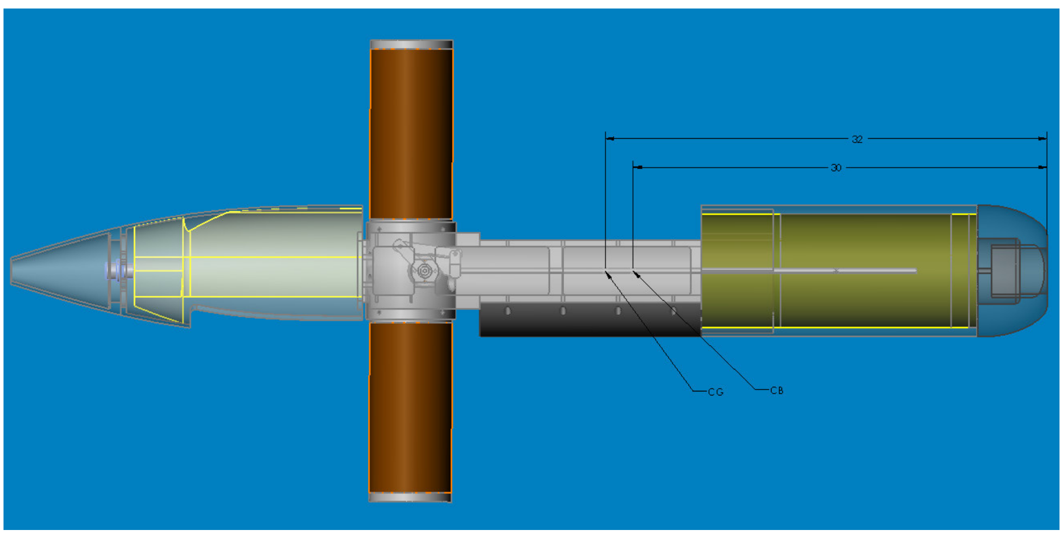


Figure 19 – VTB Rev C, baseline with foam

Figure 19 shows the baseline configuration supplemented by as much buoyant foam material that will fit in the tail section (Dry weight = 314 lbs, Wet weight = 201 lbs). Note that not all of the tail volume is available due to the space required for the array in the stowed position. The Cg is now located 2” behind the Cb and the wet weight of the body is reduced 5 lbs. Unfortunately, this places a pressure release surface behind the array. This will probably have a detrimental effect on the acoustic beampattern in the aft direction, making the solution unacceptable.

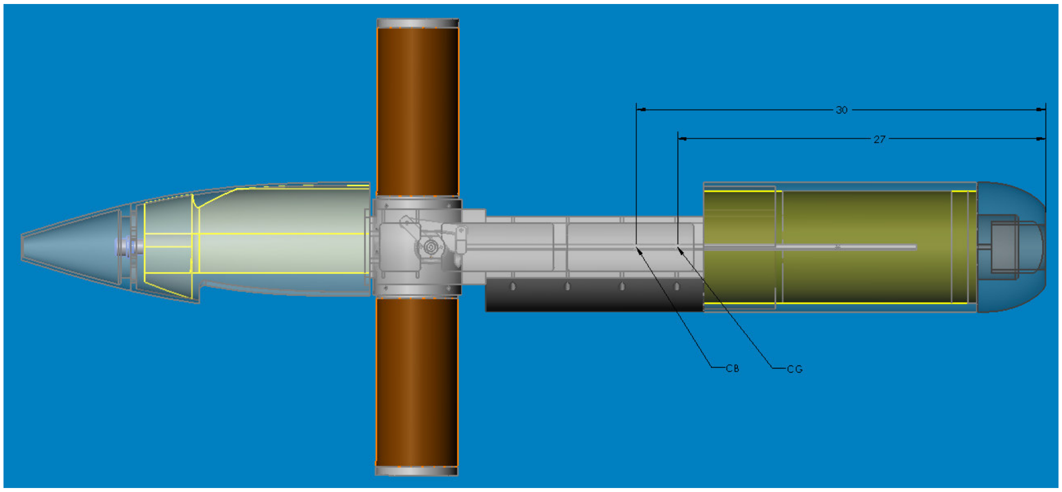


Figure 20 – VTB Rev C, baseline with foam and lead

Figure 20 shows the baseline configuration supplemented by as much buoyant foam material that will fit in the tail section and an additional 80lb of lead in the vehicle nose (Dry Weight = 387 lbs, Wet weight = 274 lbs). The Cg is now located 3" in front of the Cb, which was the desired effect. However, the overall body weight and the wet weight have been increased substantially. This will be unacceptable for the hydrodynamics. Again the foam in the tail is problematic acoustically.

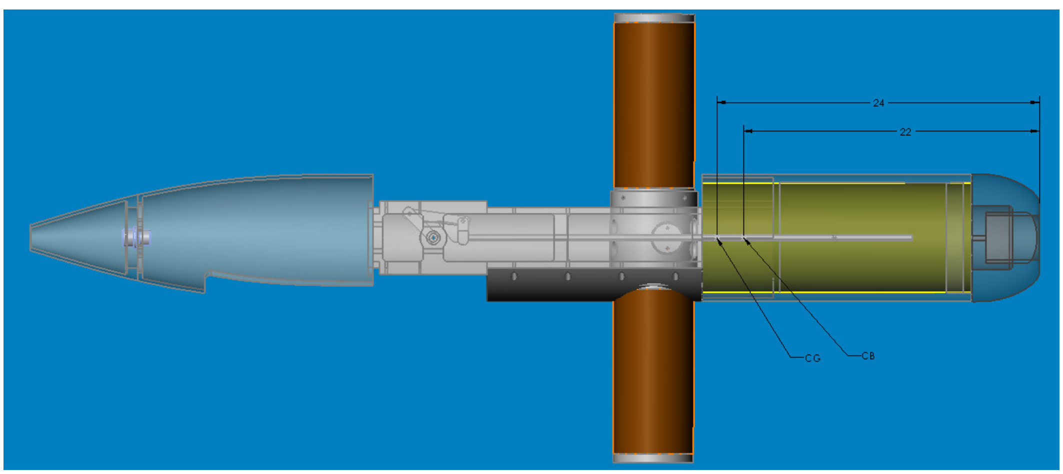


Figure 21 – VTB Rev C, baseline, array moved forward

Figure 21 shows the effect of moving the array as far forward as possible in the body in the baseline configuration, since the array is the source of much of the overall weight (Dry weight = 310 lbs, Wet weight = 206 lbs). The Cg is still 2" behind the Cb, so this does not solve the problem. The solution of sliding the pressure vessel behind the array was briefly considered. However, the PV is essentially a bubble, which like the foam would be unacceptable acoustically behind the array.

This analysis shows that it is going to be difficult if not impossible to move the center of gravity in front of the center of buoyancy (with the current constraints). Even if the array was moved as far forward as possible, there is no way to push the CG ahead of the CB unless a very large nose mass or lots of aft flotation is allowed. The weight of the pressure vessel electronics helped out, but the sizable electronics have also forced the pressure vessel to get longer, so the array has moved backward again in going from Rev B to Rev C.

The relative Cb-Cg positioning and the high Wet Weight of the VTB creates a hydrodynamic problem that was analyzed by VCT. The baseline configuration of Figure 18 was used for the following results. The table below shows the depth, drag and, pitch angle of the VTB Rev C at various tow speeds, assuming the tow cable specified in Figure 5. The acoustic source array must be held in a vertical orientation over a wide speed range (5-35 kts) for proper tactical performance. Unfortunately, the VCT analysis shows that the body will pitch almost 40 degrees at 5kts.

Config	SPEED Knots	TB Pitch Deg	TRAIL Feet	Tension at TB Lbs	TXI at TB Lbs	TZI at TB Lbs	Cable Angle at TB Deg	DEPTH at TB Feet	Tension at Ship Lbs	Cable Angle at Ship Degrees
259_23_B	5	38.8	1,901	190	140	-129.2	42.7	717.7	1,061	17.6
259_23_B	10	18.3	1,977	452	432	-131.6	16.9	404.1	2,080	8.6
259_23_B	15	11.3	1,991	974	961	-158.6	9.4	297.5	4,230	5.6
259_23_B	20	7.7	1,996	1,722	1,713	-182.2	6.1	243.9	7,343	4.0
259_23_B	25	5.5	1,999	2,689	2,681	-196.0	4.2	211.4	11,384	3.1
259_23_B	30	3.9	2,002	3,869	3,864	-200.7	3.0	189.6	16,341	2.5
259_23_B	35	2.9	2,003	5,261	5,258	-201.7	2.2	173.9	22,211	2.1

To correct the VTB pitch problem at low speed, VCT looked at adding a static deflection to the aft fins. This creates lift as the body is towed and levels out the body. Figure 22 shows that a 30 degree angle is needed to correct the pitch at 7 kts. The assumptions in this plot are a speed of 7 kts, Cg_x = -0.20 ft, a net buoyancy of 206 lbs, nose tow and Cg_z = 0.02 ft.

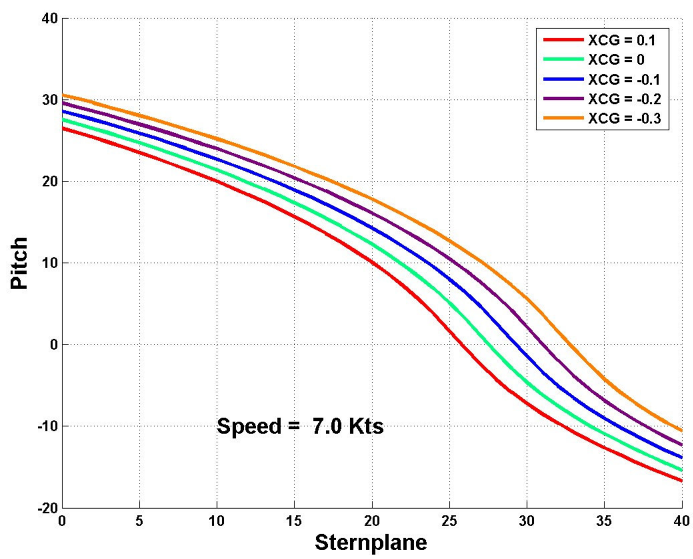


Figure 22 - VTB pitch as a function of sternplane angle

6.6 Aft Fin Actuation

On 1/6/06 L3 requested that Bluefin estimate the cost and complexity of adding pitch fin actuation to the body. This would allow (static) adjustment of the fin pitch angle as a function of speed. While active (dynamic) control of the body pitch is not envisioned at this time, all the hardware would be in place to accomplish both tasks. Dynamic control could be achieved by adding a PID control algorithm (firmware upgrade) to the local VTB computer. A rough concept for the actuated tail is shown in Figure 23.

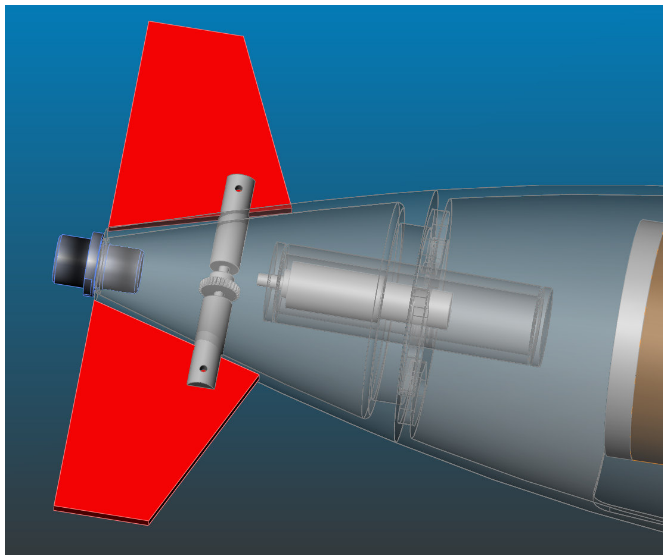


Figure 23 – Concept for Pitch fin actuation

The motorized actuator does significantly increase the complexity of the VTB. Some of the elements that would be considered in a full actuated fin design are listed below:

- Fins
  - Fin design and manufacturing of (machined, cast, composite layup)
  - Shaft attachment
- Torque transmission
  - Shaft design
  - Bearings or bushings in sea water
  - Position feedback (Hall effect, resolver in sea water?)
  - Right angle gearing (worm, bevel, in sea water?)
- External cone
  - Bearing / shaft support
  - Towed array connector mounting
  - Towed array cable pass-by
  - Actuator mounting
- Actuator(s)
  - Degrees of freedom (fins in “+” or “X” configuration?)
  - Type of motor

  - Motor commutation
  - Gear selection (planetary gearbox)
  - Housing
    - Seals
    - Bearings
    - Connector
  - Safety systems
    - Mechanical stops
    - Over current protection
  - Oil compensation
- Electronics
  - Purchase, design new, reuse existing?
  - Packaging
  - Interface to host?

Some design concerns are as follows:

- The towed array connector and cable may be difficult to locate in the tail. The connector shown is not the Nixie connector as the design of this connector has still not been made available to Bluefin.
- It may not be possible to place the actuator shafts at the center of lift of the fins.
- If “X” configuration is required, the pitch and roll are coupled requiring two actuators and a smart control algorithm. Actuator integration will be much more difficult.
- Torque requirements need to be modeled by VCT.
- The mere presence of fins on the VTB raises concerns about the fins being broken during recovery. With actuation, impact on the fins may impart damage to the shafts, bearings, housing, gears, etc.

It is estimated that the actuated tail will increase the cost of the VTB design and build by an additional 1/3 of the present cost.

7 Conclusions

The VTB design is currently over-constrained by performance requirements:

- The required acoustic Source Level has dramatically increased the weight of the array and the associated electronics as well as the required tow depth.
- The requirement that the VTB fold and fit through the AOE-6 transom hole (“like a NIXIE”) severely limits the volume available for VTB components, resulting in a non-neutrally buoyant body.

These constraints result in several high risks for the program going forward:

- Poor hydrodynamic performance: excessive pitch requiring the addition of a complex actuation system to the VTB.
- Poor acoustic performance: earlier onset of acoustic cavitation requiring deeper tow.
- Poor handling performance: dry weight in excess of 300 lbs (i.e. not a NIXIE).
- Increased design/manufacture complexity: possibly lower reliability.

- Schedule Risk: hydrodynamic testing may reveal further problems that may require another design iteration to correct.

8 Recommendations

- **Bluefin recommends that the handling constraints be relaxed to allow deck-based launch and recovery.**

This would result in a neutrally buoyant (~400 lb) body, handled by crane that would meet all hydrodynamic and acoustic functional performance requirements with low risk. This would be accomplished by adding fairings to the acoustic source to prevent early cavitation and increasing the overall volume of the vehicle to allow inclusion of buoyancy and ballast elements to accomplish overall static trim and neutral buoyancy for hydrodynamic stability.

Appendix 1 - VTB Specification

The Bluefin VTB build specification with information to date is listed below. Items in BLACK will not change. Items in BLUE are were in flux at the time of this writing.

System:

- Body will have an HG-1700 IMU.
- Body will have a depth sensor.
- Pressure vessel will have leak detection and several temperature sensors to monitor internal PV temperature.
- Temperature of the acoustic array will be monitored with several temperature sensors in each section.
- Body will have a cable tension and angle measurement in the tail cone (attached to towed array)
- Body will have a cable tension and angle measurement in the nose section.
- Body will allow for testing of the following Tow Tank configurations:
    - No vertical array
    - Smooth Vertical array
    - Smooth Vertical array with ribbon fairing attached
    - Smooth Vertical array with rotatable airfoil sections (i.e. large hard fairings for cable)
    - Uniform grit over the entire surface of vertical array

Mechanical:

- Body will be robust to towing speeds up to 35 kts.
- Typical operating depth 100-200ft. However the body will survive to 2000 ft in case ship stops with full cable scope out.
- Body will be symmetric Port/Starboard.
- CG-y must be zero. Internal ballast must be adjustable to accommodate this.
- Body will contain a pressure vessel. Pressure vessel must be forward of vertical array.
- Pressure vessel will contain IMU, CPU to run IMU, power regulation, Fiber Optic telemetry board, depth sensor and support electronics for acoustic array. All units mounted on a chassis. PV length to be minimized.
- The tow cable under specification, D=1.04” Sg=0.88 lb/foot in seawater. The forward electro-mechanical connector is currently unspecified (probably custom for this cable), but will have to support the drag of the body and array behind the body.
- Body will be towed by a nose tow, centered on body nose.
- Body will have a strain relief boot at the nose.
- Nose shape to be provided by VCT (2.5” length).
- Body will support an acoustic source broken into two sections, each 6” in diameter and 14” long. The array will be supported perpendicular to the towed body. The array will be cylindrical in cross section. Array weight is approximately 145 lbs w/o oil with a Tungsten center mass material. Mechanical and electrical interfaces are currently unspecified.
- The array will be supported by a non-acoustic center section and fold into the body. The folding will be manual but provision should be made for future upgrade to motorized folding

if possible. It may be desirable to allow unit to fold via cable/rods fed to the nose of the vehicle to allow personnel inside ship to fold unit just prior to going through transom hole.

- Length allocated to the center folding is TBD (~5")
- Body will have bolt-on covers to close holes left in fairing when array is unfolded for hydro testing.
- All wiring leading from aft of pressure vessel into the vertical array must be accommodated and allow the unit to fold. This is probably 2 bundles of 16 wires, (plus temp sensor wires) one going to top and one to bottom array section. (could be one bundle split out inside vertical array)
- Body must withstand 4,400 lbs of drag, 3,200 lbs generated by vertical source and 1,100 lbs by towed array at 25 kts.
- Body when folded will fit through a square hole 11.5" x 11.5" on an AOE-6. Body will have a generally cylindrical cross section (except probably in area of array) with a diameter <10".
- Body can be no longer than 75"
- Weight to be minimized.
- Body will have a passive X wing or ring stabilizer. These fins will not be actuated. The stabilizer section will be 25.5" long. In this length the body will taper from full diameter to zero and the fins will taper from zero to full diameter (fore to aft) (VCT to provide shapes)
- The array is allowed to encroach into the stabilizer section as much as possible to meet the body length requirement.
- The Cb-Cg separation in the Z direction is >0.25".
- CG_X located 2.4' from nose.
- A long (200ft) towed array will stream off of the body. There will be a standard Navy "NIXIE" electro-mechanical connector on the aft centerline of the body for pass-through of wires from the body to the towed array. Aft connector will have 1,100 lbs of tension at 25 kts.
- A cable containing a pair of power wires and a 2-4 fiber optic fibers will pass from the aft of the pressure vessel to the aft connector.
- A Fiber-Optic slip ring may be required to counter-act twist in the cable.

Electrical:

- There will be a forward connector to take signal and power from the cable.
- The CPU will configure and service the IMU, depth sensor, leak and temp sensors, and interface with the fiber optic telemetry to report data.
- Cable will contain 16 wires per array at 1KV each and 2-4 fibers (22 KVA total), 2 twisted pairs will carry power (one for towed body, one for towed array). The cable design is in flux.
- There will be a fiber optic interface that passes signals originating in the towed array from the aft connector to the towing cable. The towed body will break into this fiber and multiplex status/attitude information onto this data stream. This fiber interface will be provided by CSC. Body will report status/attitude at 10Hz.
- The instruments inside the pressure vessel will be powered by a pair of wires on the tow cable.
- Most of the lines in the tow cable will be dedicated to high power (22 kW) acoustic signals and will be broken out in the pressure vessel into two bundles and sent to ½ the array each.

These will carry very high power (22 KVA) on transmit (20% duty cycle) and must be well shielded within PV to keep noise out of instrumentation.

- The 32 matching transformers for the array will be housed inside the pressure vessel.
- The power and data fiber(s) for the towed array will be broken out of the tow cable in the PV and sent through a separate aft PV penetrator for pass-through to the aft body connector.
- The CPU will monitor the temperature in the vertical source array and provide status up the tow cable. This will be done with several embedded temp sensors in each array half. Wiring from the array to the PV should be accommodated.