

# Bouyancy Engine Design and Testing for ITB Hybrid AUV

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**Abstract**— Hybrid Autonomous Underwater Vehicle is the collaboration concepts between Sea Glider and Autonomous underwater Vehicle. The specific characteristic of Sea glider is long endurance, wide range, and limited payload or sensor to support the mission. Different with the AUV as the real surveillance underwater vehicle, they have almost the same payload and emergency system but with limited endurance and range if compared with the sea glider system. Dual concepts of this characteristics will be combined. The main mission for this vehicle is adopted on AUV but for submerged and surfacing mode has adopted from Sea glider Concepts with their buoyancy Engine. This Paper will describe the step-by-step method to design the buoyancy engine for this hybrid AUV. And also, the laboratory testing to validate the design and analysis will be described.

**Keywords**— hybrid AUV, sea glider, buoyancy engine

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## I. INTRODUCTION

THE concept of sea glider is to change their volume and buoyancy to have cycle vertically to gain movement along the sea water depth column. With additional control surface, this vertical movement is converted into forward and turning movement, depend on the control surface configuration. Wing-lift drives forward motion both as the vehicles ascend and descend, so they follow sawtooth paths. The shallowest points on the sawtooth are at the surface where satellite navigation and communication are carried out [1]. How this mechanism works on this vehicle is illustrated in Figure 1.

Buoyancy propulsion is well suited to the performance objectives of this class of vehicle. It provides the vertical sampling needed in the stratified ocean where variability along a horizontal path is often resulted mainly from vertical migration of patterns.

Unlike the conventional sea glider, the hybrid AUV has capability to maintain its depth level with neutral buoyancy condition. On this level and state, the hybrid AUV can execute the common AUV task. That is why this hybrid AUV have more complex sensor if compared to the conventional sea glider. How this vehicle work is illustrated in Figure 2.

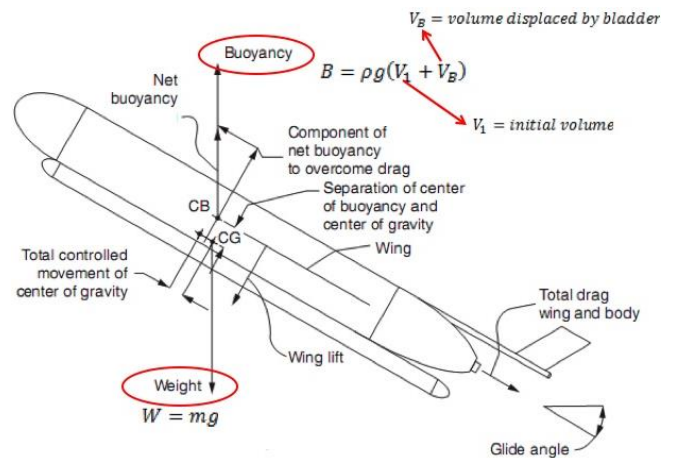


Figure 1 Buoyancy propulsion mechanism on underwater Slocum Sea glider [1]

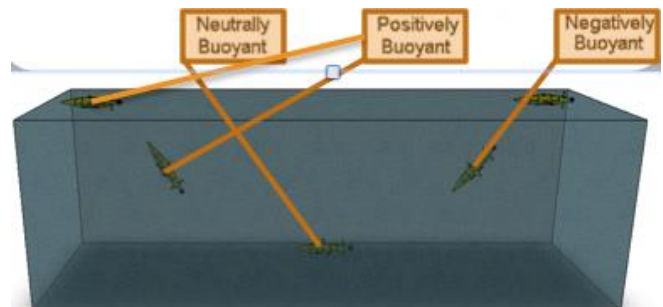


Figure 2 The state of hybrid AUV work

The overall specification of this Hybrid AUV will be described in **Error! Not a valid bookmark self-reference.** [2].

Table 1  
Comparison of vanishing point detection at the campus library

Dimension (L × W × H)	2700 mm × 1200 mm × 203 mm
Speed	Max. 4 knot
Weight on Air	50 kgf
Power	1.5 HP
Endurance	10 hrs
Max Operating Depth	2500 m
Propulsion & Control	1 HP Electric Thruter & Bouyancy Engine
Payload	Obstacle Avoidance sonar, Acoustic moderm, CTD, Iridium Satellite Communication (on surface)

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II. APPROACH AND METHODS

There are so many buoyancy engine types that are already applied on underwater applications. All of them were compared, and a compromising choice has been made between component's availability in the market and the required specifications. Some of the buoyancy engine on the world is shown in Figure 3.

The best buoyancy engine that is very suitable for this hybrid AUV had been compared carefully. Finally the buoyancy engine mechanism of this hybrid AUV generally adopt from oil bidirectional pump. The detail of schematic buoyancy engine is described in Figure 4.

After the schematic was found, the next stage is to find the available component and to design for additional part to integrate all of this system.

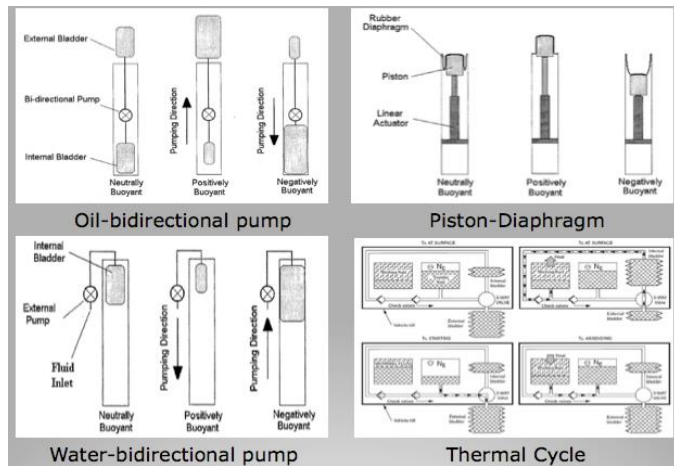


Figure 3 Existing Buoyancy Engine Type[3]

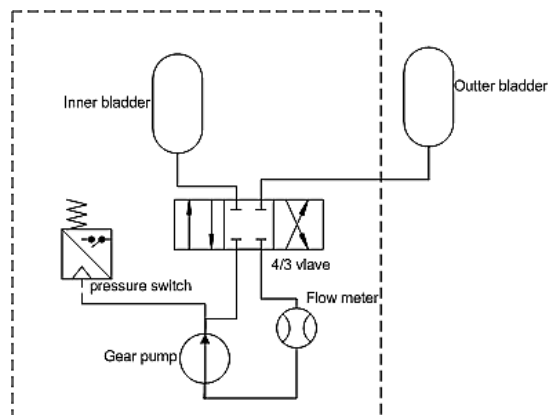


Figure 4 Buoyancy engine schematic for ITB Hybrid AUV

A. Hydraulic Pump Selection

- HP05 - 0.2 - 2011 - A
- Displacement: 0.2 cc/rev
- $N_{min}$ : 1800 rpm
- $N_{max}$ : 7000 rpm
- $N_{nom}$ : 3000 rpm
- $\eta_v$ : 73
- $\eta_m$ : 62
- $\Delta p$ : 280 bar

$$P = \frac{Q \cdot \Delta p}{0.6 \cdot \eta_v} = \frac{\left(0.2 \frac{cc}{min}\right) \cdot (3000 \text{ rpm}) \cdot \left(\frac{1}{1000} \frac{l}{cc}\right) \cdot (280 \text{ bar})}{0.6 \cdot (0.73)} = 383.6 \text{ W}$$

Power : 383.6 W

B. Electric Motor selection

The selection steps to define the motor efficiency is illustrated on the diagram in Figure 5.

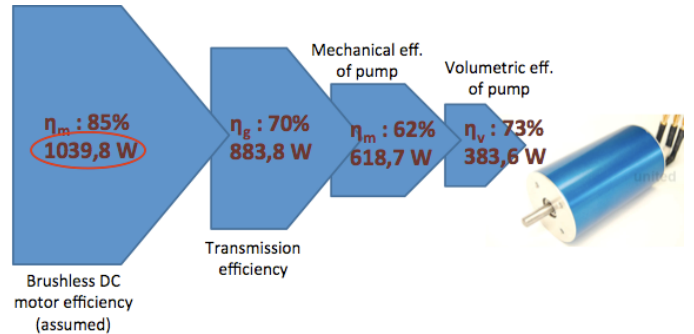
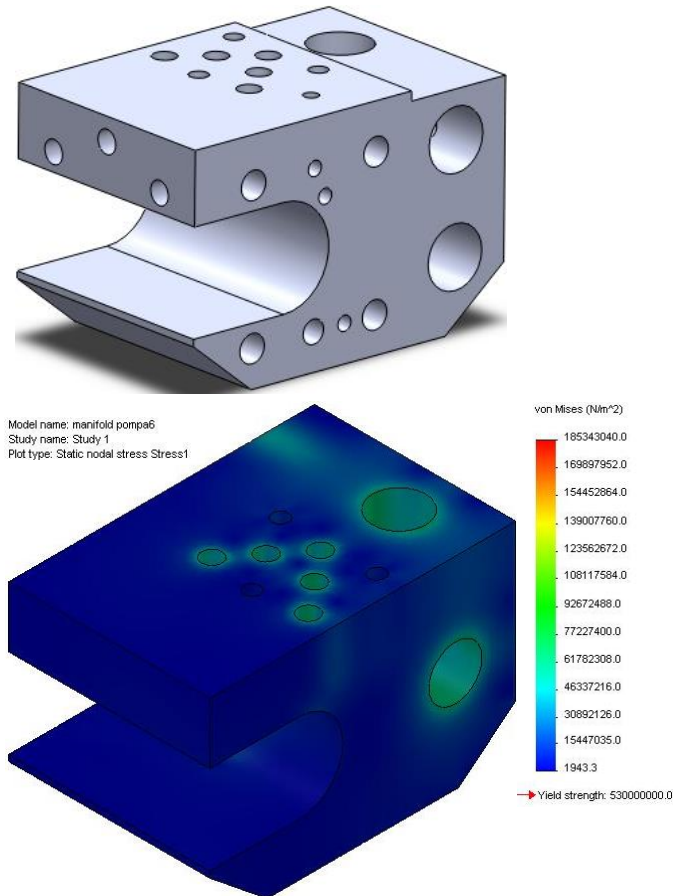


Figure 5 Motor Selection steps (Efficiency).

C. Additional Part Design

All of those component will be integrated on the main frame and also the manifold. Some of additional part on this buoyancy engine is described in Figure 6.



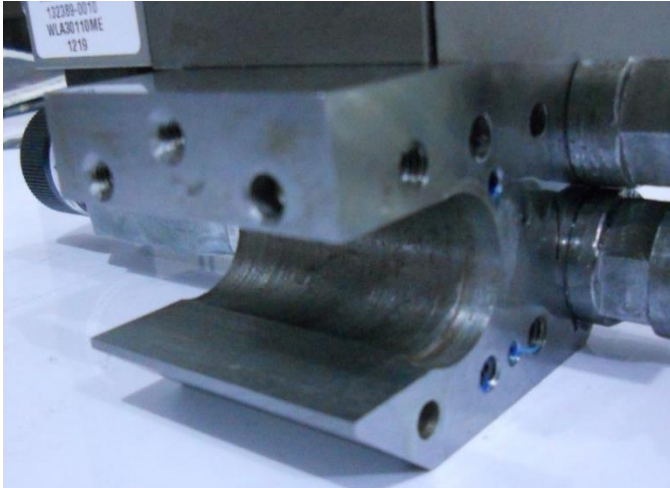


Figure 6 Manifold design, analysis, and manufacture

All of those components are finally integrated as illustrated in Figure 7.

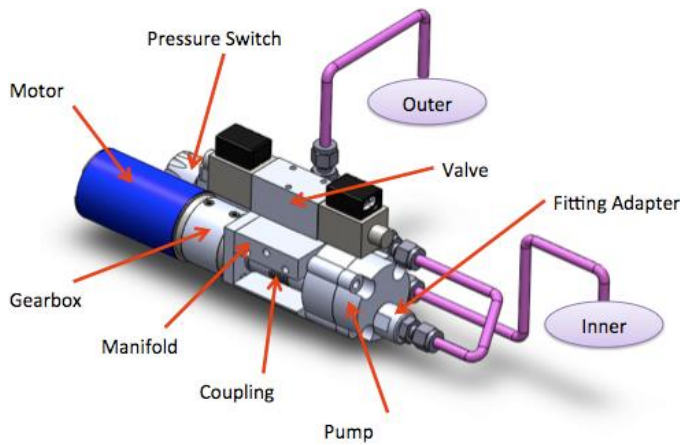


Figure 7 Final schematic integration design of buoyancy engine

And if combined with the modular composite dry box, the overall buoyancy engine on this hybrid AUV will be as shown in Figure 8.

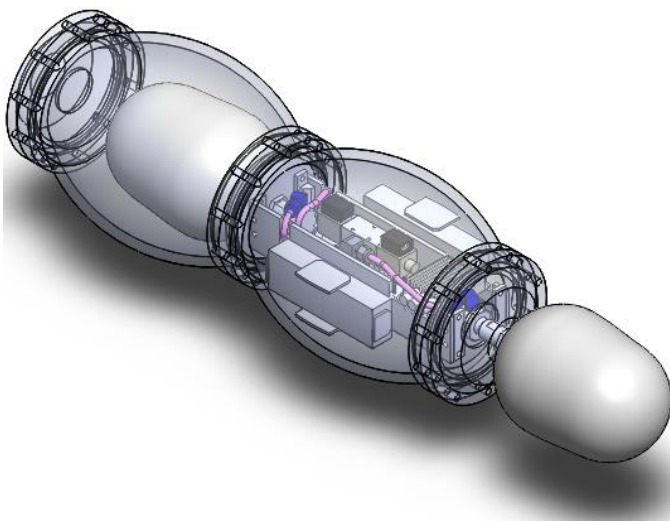


Figure 8 Buoyancy Engine module assembling

On the Hybrid AUV's full configuration, the buoyancy engine is arranged as illustrated in Figure 9.

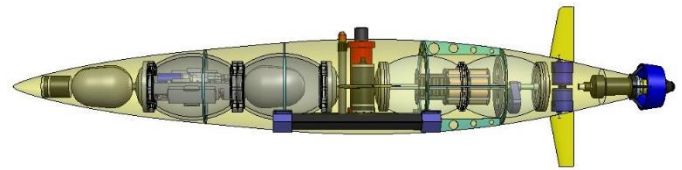


Figure 9 The Buoyancy Engine arrangement on fully Hybrid AUV Design

### III. TESTING AND RESULTS

The buoyancy engine mechanism has tested in the laboratory with external pressure simulation. The series of testing is divided into 2 main stages.

#### A. Testing the pressure control flow

The purpose of this testing is to test the endurance and performance of the hydraulic system of buoyancy engine. The testing setup is described in Figure 10 and Figure 11.

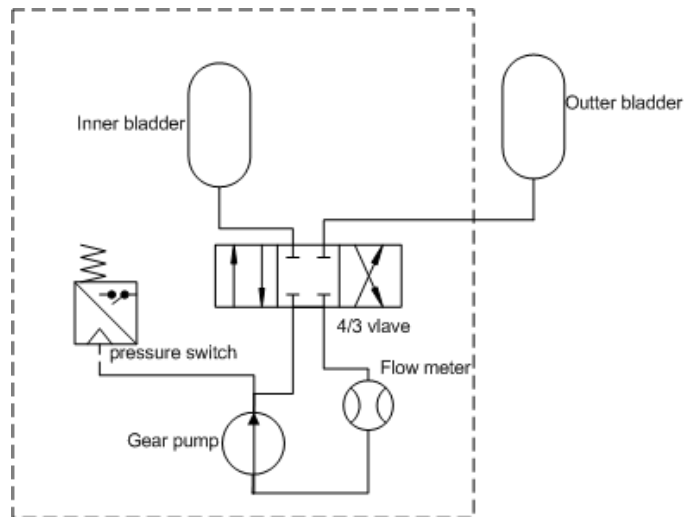


Figure 10 Schematic pressure control flow testing setup

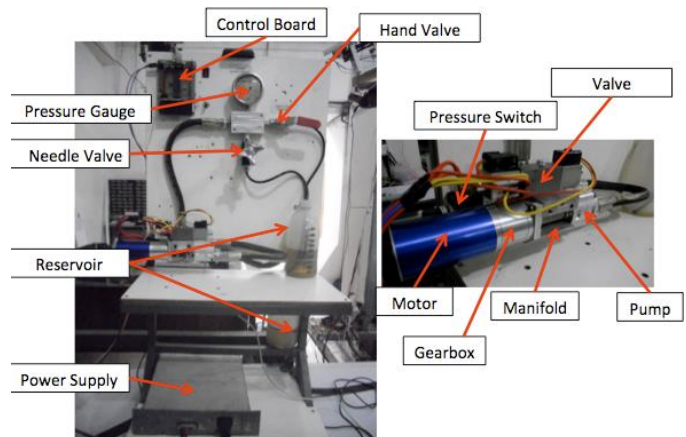


Figure 11 Laboratory testing setup of pressure control flow of buoyancy Engine

The testing result of this buoyancy engine is presented in Figure 12 and Figure 13.

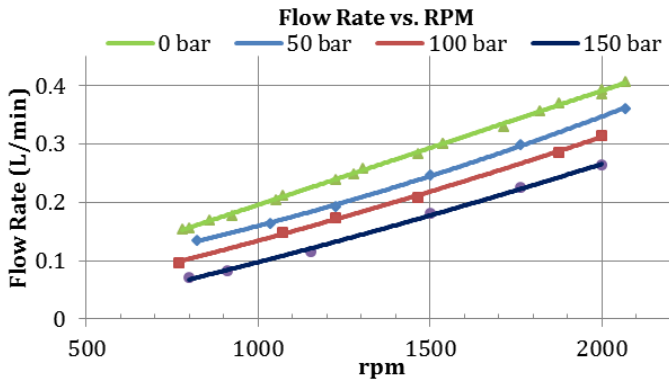


Figure 12 Chart of Flow rate versus RPM

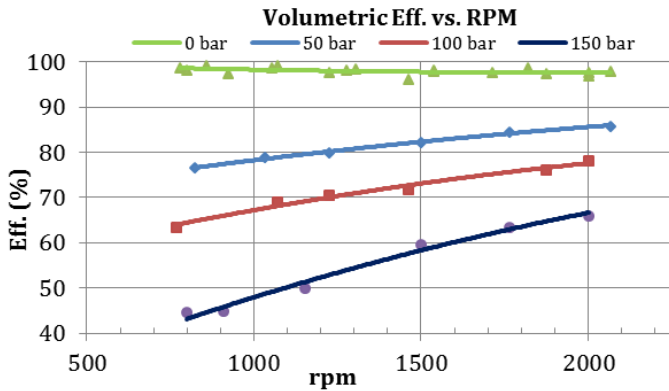


Figure 13 Chart of volumetric efficiency versus RPM

By this result, the behavior estimation can be extracted with this series of calculation as the following.

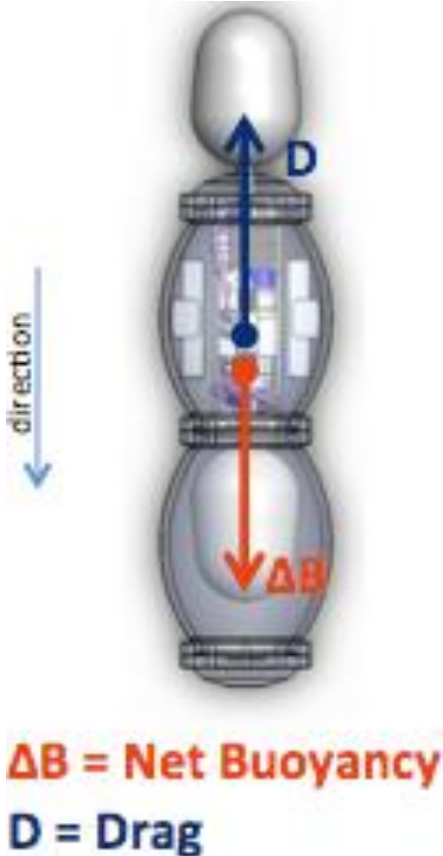


Figure 14 Independent buoyancy engine Free Body Diagram

With the following assumptions:

- Pump speed 1800 rpm
- Cylinder geometry ( $\varnothing = 0.233$  m;  $L = 1$  m)
- Low Re number
- Water density:  $1000$  kg/m<sup>3</sup>
- Depth: 1000 m

$$C_d = \frac{2\pi}{\ln\left(\frac{2L}{D}\right) - 0.72} = 4.39^* \quad (2)$$

$$\Delta B = D \quad (3)$$

$$\rho \cdot V \cdot g = \frac{1}{2} C_D \cdot \rho \cdot V_\infty^2 \cdot A \quad (4)$$

$$V_\infty = \sqrt{\frac{V \cdot g}{C_D \cdot A}} \quad (5)$$

where

$\rho$  = water density

$V$  = displaced volume

$C_D$  = drag coefficient

$V_\infty$  = vehicle velocity

$A$  = cylinder cross-section

With these equations [4], finally we can estimate the velocity of dive and surfacing characteristics, with assumption of bare buoyancy engine and neglected overall body of Hybrid AUV.

The calculation results of velocity is presented in Figure 15 and Figure 16.

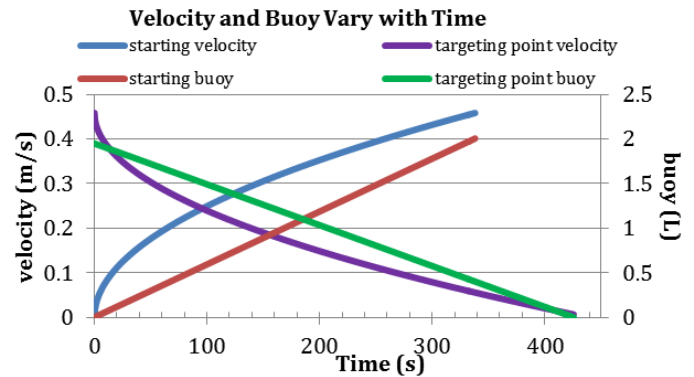


Figure 15 Chart of Velocity and Buoyancy vary with time

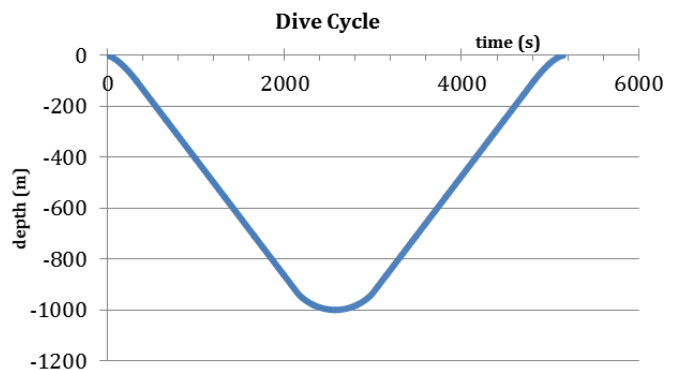
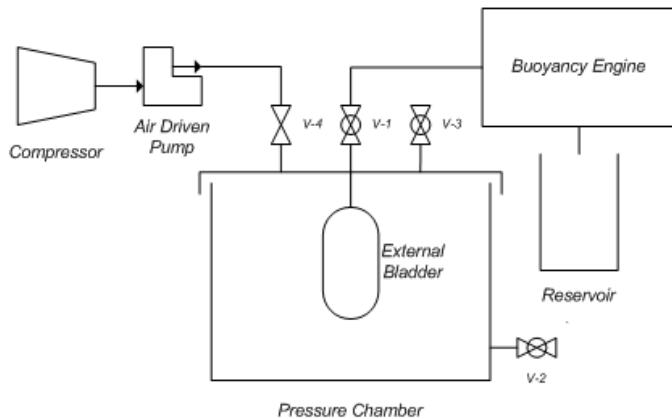


Figure 16 Chart of Dive Cycle



**Figure 17 Testing Setup Schematic with Pressure Chamber**



**Figure 18 Testing Setup with Pressure Chamber**

#### B. Testing with external pressure from Pressure Chamber

This purpose of this testing is to make sure the buoyancy engine still can operate with external operating pressure, and the hydraulic pump still have enough power to push the fluid from internal bladder to external bladder. The schematic of this testing is described in Figure 17.

#### IV. CONCLUSIONS

From this design and testing of Buoyancy engine for ITB Hybrid AUV, we can conclude with some information as follow:

- Buoyancy engine was designed with the most efficient and was tested correctly on laboratory.
- The buoyancy Engine as the main and critical system on this hybrid AUV has worked properly, with the maximum working volume of 4.5 liter, or almost equal to 4.5 kg displacement.
- The flow rate of the buoyancy engine depends on the operating depth. The maximum flow rate at surface is 0.4 L/min.

The maximum operating pressure of this buoyancy engine is 150 bar, even though the maximum operating pressure of hydraulic pump until 280 bar. Need improvement specification

for another supporting component such as Solenoid valve and bladder.

#### ACKNOWLEDGMENTS

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