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Apt Design Simulation of Unmanned Underwater Vehicle

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Abstract— Coastal areas are among the most vulnerable of all regions to global climate change which include global warming, rising sea levels, increasing sea-surface temperatures etc. Also rise in the foreign insurgency through the oceans is forcing the nations to enhance the maritime surveillance & security capabilities. To check coasts from climate change, foreign insurgency, reconnaissance and for surveillance, search & rescue operations continuous monitoring of the shore & the seabed is essential. Replacing the human divers with underwater vehicles with suite of sensors would ensure the continuous observation of the seashore & sea bed. Recent decades have witnessed increased interest in the design, development and testing of unmanned underwater vehicles for various civil and military missions. A great array of vehicle types and applications has been produced along with a wide range of innovative approaches for enhancing the performance of UUVs. Key technology advances in the Relevant area includes battery technology, fuel cells, underwater communication, propulsion systems and sensor fusion. These recent advances enable the extension of UUVs' flight envelope comparable to that of manned vehicles. For undertaking Longer missions, therefore more advanced control and navigation will be required to maintain an accurate position over larger operational envelope particularly when a close proximity to obstacles (such as manned vehicles, pipelines, underwater Structures) is involved. In this case, a sufficiently good model is prerequisite of control system design. The paper is focused on discussion on advances of UUVs from the modeling, control and guidance perspectives. Lessons learned from recent achievements as well as future directions are highlighted. In this paper flow analysis is performed on different casing models with different nose shapes in Cosmos Floxpress simulation software & the Apt design for casing is obtained from the results.

Keywords— Unmanned underwater vehicle, Auv, Mayaaug, Rov, Aosn, Cosmos Floxpress.

I. INTRODUCTION

Unmanned Underwater vehicles (UUVs) are all types of Underwater robots which are operated with minimum or without intervention of human operator. In the Literatures, the phrase is used to describe both a Remotely operated vehicle (ROV) and an Autonomous underwater vehicle (AUV). Remotely operated Vehicles (ROVs) are tele-operated robots that are deployed primarily for underwater installation, inspection and repair tasks. They have been used extensively in offshore industries due to their advantages over human divers in terms of higher safety, greater depths, longer endurance and less demand for support equipment. In its operation, the ROV receives instructions from an operator onboard a surface ship (or other mooring platform) through tethered cable or acoustic link. AUVs on the other hand operate without the need of constant monitoring and supervision from a human operator. As such the vehicles do not have the limiting factor in its operation range from the umbilical cable typically associated with the ROVs. This enables AUVs to be used for certain types of mission such as long-range oceanographic data collection where the use of ROVs deemed impractical. Ura in proposed the classification of AUVs area of applications into three different categories starting from the basic to more advanced missions:

a) Operations at a safe distance from the sea floor including observation of the sea floor using sonar, examination of water composition, sampling of floating creatures.

b) Inspections in close proximity to the sea floor and man-made structures such as inspection of hydrothermal activity, creatures on the seafloor and underwater structures.

c) Interactions with the sea floor and man-made structures i.e. sampling of substance on the seafloor and drilling.

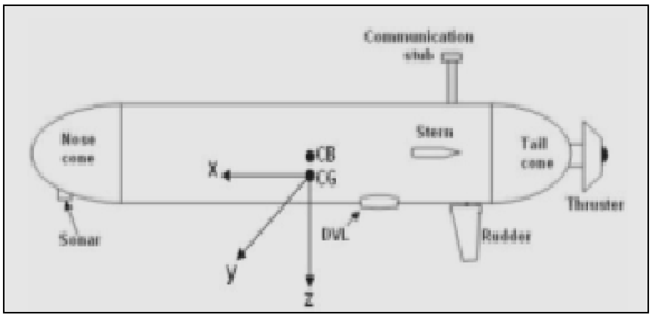

Figure 1 Longitudinal section of the Maya

The main objective of this project is to identify the right combination of the casing & control plane shapes to enhance aerodynamic performance of an UUV through fluid flow visualization over various casing & control surfaces of UUV.

Autonomous Underwater Vehicle (AUV), Remotely Operated Vehicle (ROV) and Autonomous Underwater glider (AUG) are the main autonomous underwater platforms currently available. The relationships between those three types of vehicles were shown in the below mentioned figure.

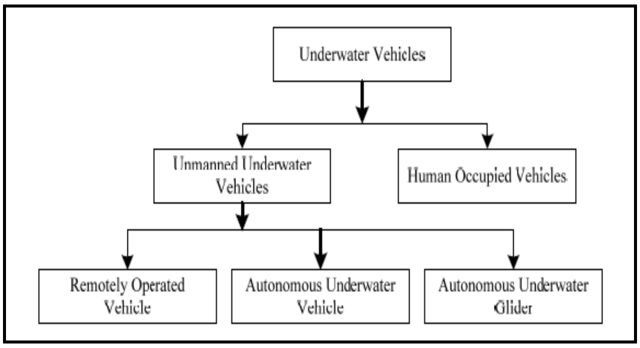

Figure 2 Classification of UUV

During this decade, AUVs grew from proof of concept test beds into first generation operational systems able to be tasked to accomplish defined objectives. A number of organizations around the world undertook development efforts focused on various operational tasks. Potential users surfaced and helped to define mission systems necessary to accomplish the objectives of their data gathering programs. This decade also identified new paradigms for AUV utilization such as the Autonomous Oceanographic Sampling System (AOSN) [Curtin] and provided the resources necessary to move the technology closer to commercialization.

Need for Unmanned Underwater Vehicle:

Coastal areas are among the most vulnerable of all regions to global climate change. Projected impacts from global warming include rising sea levels, intensification of tropical cyclones, larger storm surges, increasing sea-surface temperatures, growing acidification of surface waters needs constant monitoring. Also rise in the foreign insurgency & smuggling through the oceans is forcing the nations to enhance the maritime surveillance & security capabilities. Monitoring marine environment is difficult and costly for humans as divers have inherent problems which include:

i) high cost ii) unavailability of suitably trained personnel for the number of ships needing inspection iii) safety concerns iv) low output, and v) unsustainable working time & hostile underwater conditions to do a job.

To reduce the working load of divers and significantly accelerate inspection process, it would be highly desirable and efficient to deploy affordable UUV’s.

Applications of UUV: Applications of an UUV can be broadly classified into military applications & environmental monitoring:

- *Military Applications*
- *Environmental Monitoring*
- *Tsunami Surveillance System*
- *Deepwater seabed Mapping*

The Problem of deepwater seabed mapping: Detailed seabed mapping is a necessity for deep water oil and gas explorations. Due to range limitations, casing-mounted high resolution echo sounders cannot be utilized at deep waters. The conventional solution to this problem is to mount the echo sounders on towed or remotely operated vehicles (ROV) operating close to the seabed. This solution is inaccurate and time-consuming, and thus expensive.

II. LITERATURE REVIEW

The first AUV was developed at the Applied Physics Laboratory at the University of Washington as early as 1957 by Stan Murphy, Bob Francois and later on, Terry Ewart. The “Special Purpose Underwater Research Vehicle”, or SPURV, was used to study diffusion, acoustic transmission, and submarine wakes.

Other early AUVs were developed at the Massachusetts Institute of Technology in the 1970s. One of these is on display in the Hart Nautical Gallery in MIT. At the same time, AUVs were also developed in the Soviet Union (although this was not commonly known until much later). , AUVs are now becoming increasingly used to carry out underwater tasks, especially those that are too hazardous or impractical for manned or tethered underwater vehicles.

It is informative to understand what has happed over the past few decades relative to the development of AUVs. It is clear that the process has led to a technology whose time has arrived.AUV development began in the 1960s. A few AUVs vehicles are built mostly to focus on very specific applications / data gathering. There are not a great amount of published papers that describe these efforts.

- 1970 - 1980 - Explore the Potential of AUVs: Technology development; some test beds built.
- 1980 - 1990 - Experiment with Prototypes: Advances in technology reinforce development efforts, Proofs of Concept (POC) prototypes are developed/tested/used.
- 1990 - 2000 - Goal Driven Tech. Development: Broader based funding of technology development, Many AUVs developed internationally.

Autonomous underwater technology and underwater robotics are being vigorously pursued in many technologically advanced countries such as the U.S., Australia, Germany, Russia, Korea, and Japan. There are some companies like THALES, I ROBOTS and MARPORT which have been commercially making UUV of different specifications. Various research institutes across the world are making significant contribution to development of UUV'S in terms of energy source (battery), automaticity, endurance with different casing & control plane shapes. Here are some the commercially available UUV's

S.NO	Particular	Dimension(m)
1	Bare casing length	1.73m
2	Middle Body length	1.25
3	Casing maximum diameter	0.23
4	Nose length	0.22
5	Base diameter	0.06

TABLE I. SPECIFICATIONS OF AUV

Total casing length =Nose +mid-body + tail cone

III. DESIGN OF MAYA UUV

A small AUV called Maya, developed at the National Institute of Oceanography in Goa, India. Part of the development effort was done in the scope of an on-going India-Portugal collaboration program that aims to build and test the joint operation of two small AUVs for marine science applications.

Total length	1.73 m
Diameter	0.23 m
Nose shape	Slender Ellipsoid
Casing	Aluminum-6082
Nose and rear cones	FRPG
Total weight in air	54.7 Kgf
Drag coefficient	0.31
Depth range	200 m
Propulsion	DC brushless motor
Propulsion efficiency	0.26
Nominal speed	1.5 m/s
Endurance	7.2 hrs(Propulsion)
Power source	Li Polymer cells
Total average power	130W
RF communications	2.4GHz,115kbaud

TABLE II. SPECIFICATIONS OF MAYA

The total casing length L is the sum of nose, mid-body and tail cone lengths, and equals to 1.742m. The maximum casing diameter D = 0.234 m, results in a fineness ratio (L/D) equal to 7.44.

The mid-body section (or CPU) was machined from a single high quality solid round aluminum bar free of surface and deep defects as verified by ultrasonic tests of the raw material. The bar was first accurately bored along a horizontal X axis from either end, and then bored in a vertical Z direction to create a hollowed out receptacle that matched the external contours of the Doppler Velocity Log (or DVL). This is best seen in the Solid Works drawing of Fig.7 which provides an isometric 3D view of the complete AUV with the internal components. This approach to the construction of the main casing provides the freedom to adjust its wall thickness to the desired yield stress of the casing volume, besides accommodating the odd shape of the DVL sensor.

Both ends of the CPU are O-ring sealed by identical pressure end caps on which underwater connectors are mounted. Locking collars are threaded over the outer surface of the casing. Threaded holes on the collars are used to bolt the nose and rear cones to the main casing body.

A. Pressure Tests on the Bare Main Casing:

The main casing of length 1.24m and wall thickness of 6 mm was designed to withstand a maximum pressure of 40 bar (approx. 400m). As it was too long to fit in available pressure test chambers, it was decided to pressure test it at sea on a cruise of opportunity to the Arabian Sea. The unit was sealed at both ends by the end caps, and DVL port plugged with a dummy cap. The casing collars were secured to C-clamps and the entire unit lowered using the ships winch to a depth of 178 meters. It was submerged at this depth for a period of 1 hour. This straight forward method checks integrity against leakage of water through O-ring seals, the casing, and the pressure sensor mounted on the end cap all in one go. A drop of ~ 55 mbar (from atmospheric) in internal pressure caused by colder waters at 178m in contact with the bare casing was monitored with a miniature data logger.

B. Internal Components within the CPU:

The arrangement of internal parts is shown visually in figure below. Starting from the nose end of the casing, there is a module consisting of the batteries, electronics, and the attitude sensor mounted on a removable tray. The DVL and associated electronic cards fit neatly into the hollow made for it.

Moving past the DVL, the casing volume provides space for three integrated shaft seals and actuator motors. The upper rudder port was fitted out with a short white acetal stub which encloses the GPS and RF antenna. At the time of fabrication, it was decided to use the rudder port to house the antenna stub, as no provision had been made for it in the prototype design. There was an added curiosity to check how AUV performance would be affected with the use of a single rudder. Subsequent field tests have shown that 3 control foils (two stern and one rudder) can produce acceptable performance, but with increased roll during a heading change. (The 'roll' effect is examined in a companion paper by P. Maurya et. al. at this conference)

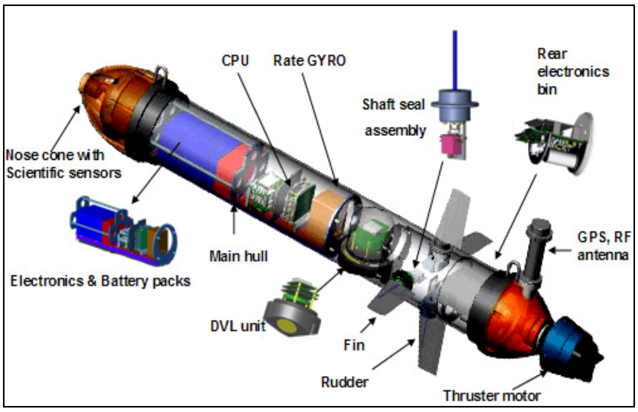

Figure 3 Nose and tail cones of Maya

The front nose cone and the tail fairing of the AUV were made from GFRP (glass fiber reinforced plastic) which is not designed to withstand high pressures, but as initial costs are low it allows speedy experimentation of the total body form in water. The front nose section can be detached from the main casing so as to access the end cap and the internal parts within the main casing. The volume within the cone can be used to accommodate wet sensors wired to power and signal connectors on the front end cap. A variety of nose cones can be fabricated and populated to accommodate mission-specific sensors. The shape of the nose cone is a low drag slender ellipsoid different from the torpedo shaped noses of other small AUVS namely REMUS (USA) or GAVIA (Iceland).

The photograph shows Dissolved Oxygen (DO) sensor mounted on tip of nose cone and the sensing part of chlorophyll-turbidity protruding from the base of the nose cone. A miniature CTD nose cone has also been used with the Maya casing. The tail cone section of Maya is split into two symmetrical halves that encase the stainless steel framework on which the DC thruster is mounted. It is attached to the collar over the rear end-cap of main casing. The shape of the combined tail cone section follows a Myring profile with an enclosed angle of 25 degrees and exponent 2 (Myring 1976). We adopted this shape as it has a gentle tapered profile that serves to direct the flow of water along the casing into the propeller blades of the motor. There is ample volume within the tail cone to also accommodate sensors, and a communications stub that now occupies the top rudder port.

C. Control Planes of Maya:

There are three control foils on Maya i.e. a pair of stern planes and a single rudder. The shape profiles of these foils follow a standard NACA 0015 section with an aspect ratio of 4.27 and a leading edge angle of 10.6 degrees. The NACA section is symmetric, is easy to machine, has a zero lift force at zero angle of attack, and possesses a good torsional rigidity with a high thickness to chord ratio. The shaft of the actuator motor otherwise known as the 'rudder stock' is embedded at a distance equal to a quarter of the root chord (Cr) from the leading edge of the foil.

Foil parameter	symbol	Value
Single Foil Span	b	0.16 m
Root chord	c_r	0.1 m
Tip chord	c_t	0.5 m
Mean chord	c	0.08 m
Thickness chord	(t/c)	0.15
Taper ratio	$A=(c_t/c_r)$	0.7
Exposed foil area	S_e	$0.024\ m^2$
Aspect ratio(foil)	AR_e	4.3
Leading edge angle	AL_e	10.6^0
Sweep angle at c/4	$A_{c/4}$	8.03

TABLE III. Major PARAMETERS of control planes.

IV. FLOW SIMULATION

Following hydrodynamic parameters that are required for the present project are observed in experimentation and in COSMOS FLOXPRESS, which are as follows:

- Drag force
- Lift force

DRAG FORCE: It refers to the force that acts on the solid body in the direction of the relative fluid flow velocity.

$$F_D = \frac{1}{2}\rho v^2 C_d A$$

LIFT FORCE: It refers to the vertical force that acts on the moving body by the fluid flowing around it.

$$F_L = \frac{1}{2}\rho v^2 C_l A$$

Casing Shape: To maintain the proportionality among the various dimensions of the casing shape, dimensions of the existing AUV MAYA were considered. Maya was developed at the National Institute of Oceanography in Goa, India.

Casing with different nose shapes:

With the aim of identifying the best nose shape for this configuration, casing is modeled with the above dimensions but with varying nose cone. Flow simulation was carried out on the following nose shapes.

- Conical
- Ellipsoid
- Tangent arc.

Input conditions / boundary conditions for flow simulation over the casing shapes with above mentioned nose shapes.

Medium: Water

- Velocity in x-direction: 6m/sec
- Velocity in y-direction: 0
- Velocity in z-direction: 0
- Temperature: 24 °C
- Pressure: 1.55MPa
- Surface roughness: 0.002
- Chord length =200mm
- Wing span= 250mm
- Angle of attack: 0 degrees.

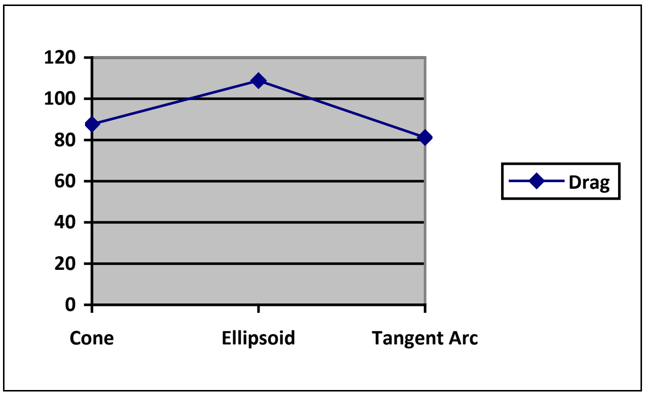

Figure 4 Drag

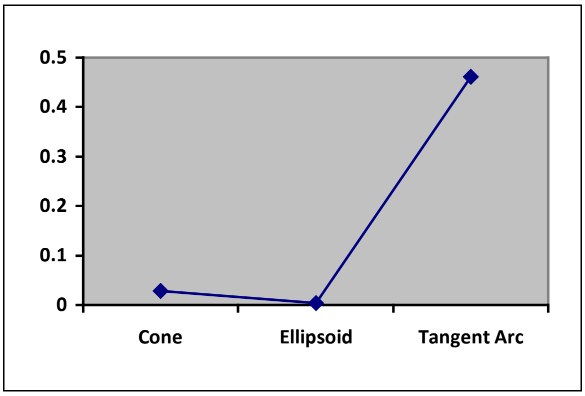

Figure 5 L/D Ratio

S.No	NOSE SHAPE	Drag (N)	Lift (N)	L/D
1	Cone	87.653	-0.243029	0.02865
2	Ellipsoid	108.801	-0.443817	0.0034
3	Tangent Arc	81.23	-2.157113	0.46125

Simulation results of casing with 3 different nose shapes.

From the above results, it clearly says that casing shape with tangent arc nose shape is the best suited for the UUV considering low drag and high negative lift.

V. RESULTS & CONCLUSION

Under similar boundary conditions & with water as medium, simulation was carried out on 3 different nose shapes (cone, ellipsoid & tangent arc) from the results of which it can be concluded that casing shape with tangent arc nose shape is the best suited for the UUV because of its low drag and high negative lift i.e. high L/D ratio.

From the simulation results which are shown in this article and are calculated according to the procedure, it can be seen that casing shape with tangent arc nose shape is the best suited for the UUV because of its low drag and high negative lift as said above.

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