TEAM ODYSSEY

DRUSE-TH06-942

SRM Institute of Science and Technology, Kattankulathur

COMPREHENSIVE DESIGN REPORT

DRDO Robotics and Unmanned Systems Exposition (DRUSE 2018)

ABSTRACT

The aim of the project is to design an unmanned system that is capable of defence applications. The theme selected by our team was **“Surveillance of a Ship”** for the **DRDO Robotics and Unmanned Systems Exposition.** The task of the surveillance was accomplished by designing an **Amphibious Reconnaissance Vehicle** that has the ability to operate in both **aerial** and **underwater** mode.

In order to commence the task, the vehicle will be released from the base ship. It will traverse to the destination ship by underwater navigation and then operate in the aerial mode to initiate the surveillance task autonomously. The surveillance task involves providing the live video feed of the ship to the base ship along with the tracking of a specific object for the operator.

TABLE OF CONTENTS

TASK APPROACH

The vehicle has been designed to reach the target ship and conduct surveillance operations while avoiding detection at all times. This task is accomplished in six stages. Each stage has been explained in detail below.

AERIAL OPERATION

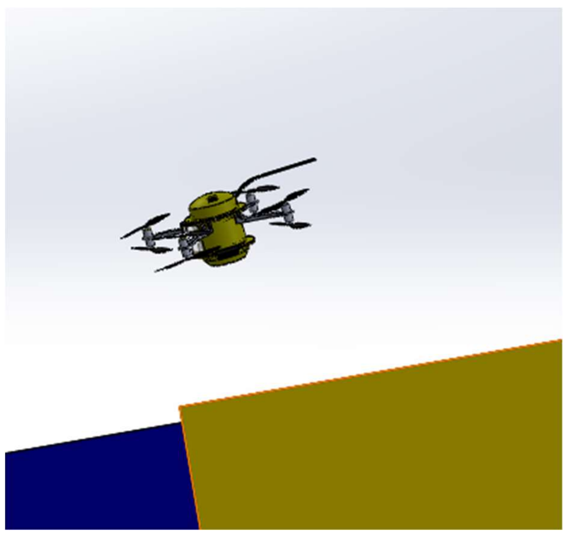

Figure 1: Take-off from Ground Station

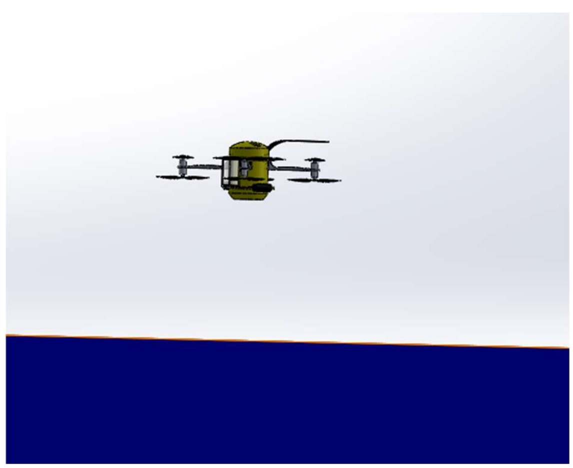

Figure 2: Aerial Operation

Once the location of the ship has been determined, Kalam I will autonomously take off from the ground station which can either be the coast or a friendly ship which is nearby. At this stage of the operation, the hydraulic cylinders on board the vehicle will be kept empty. The vehicle will take off with its propellers aligned with the vertical axis and it will then fly to the surface of the water and land on it. Kalam-I will now have the capability to move on the surface without sinking. The direction of the vehicle's movement and the height to which it can fly will be determined by the thrust produced by its individual motors which in turn, is controlled by the speed of rotation of the propellers. During the testing phase it was determined that the maximum thrust that a single motor can produce at full throttle is 1168 grams.

AERIAL TO UNDERWATER TRANSITION

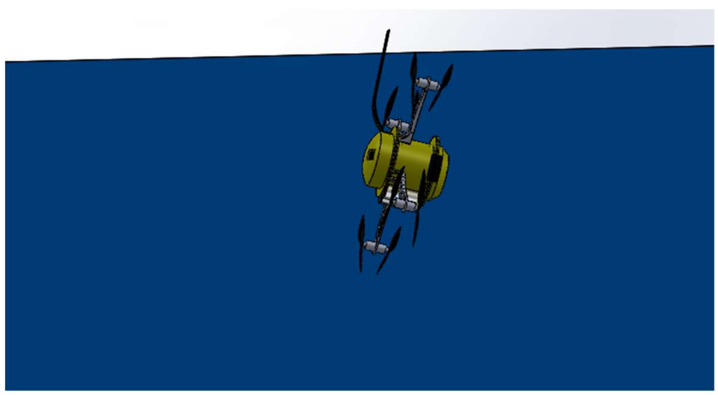

Figure 3: Aerial to Underwater Transition

The aerial to underwater transition occurs in the form of a predetermined sequence of operations and commands designed to configure the vehicle for underwater operations. This sequence of operations is as follows.

i. After landing on the surface of the water, all of the vehicle's eight propellers will be stopped. The vehicle has been designed to ensure that the total mass of water displaced by the vehicle will be equal to the weight of the vehicle. In other words, the vehicle will sink till it is completely submerged underwater, at which point the force due buoyancy and the force due to weight in the opposite direction will become equal and the vehicle will not sink any further.
ii. The first pump will be activated, causing the water outside to enter Kalam-I's on board hydraulic cylinders till it completely fills up with water. This operation will have two consequences.

First, the additional weight added due to the water will cause the vehicle to begin to sink.

Second, is that it will cause a change in the centre of mass position resulting in its subsequent misalignment with the vehicle's buoyancy center. The misalignment of these two points will produce a righting torque which in turn will cause the vehicle to pitch down by ninety degrees. In the event of harsh weather conditions, the turning operation will be aided by the rotation of the eight propellers.

Hence as a result of the aerial to underwater transition operation, the propellers will now be aligned with the horizontal axis thereby vehicle will now be configured for underwater operations.

UNDERWATER OPERATION

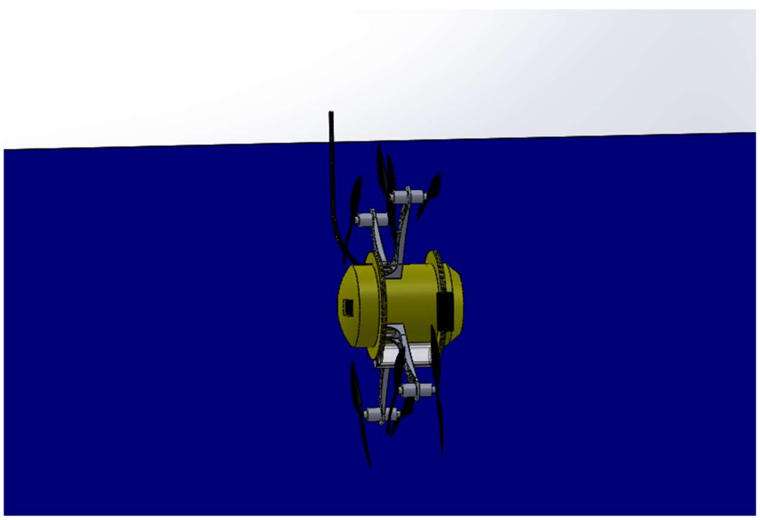

Figure 4: Underwater operation

Kalam-I will now travel to the ship using the eight propellers working underwater. The telemetry data on the ground station gives the pilot the capability to be able to navigate the vehicle to the ship manually. The outer surface of Kalam-I has been designed in such a manner that it does not have any concave curvature which can reflect back any sonar waves thereby enhancing the stealth capabilities of the vehicle.

A mast is designed to ensure that the GPS module and the Radio Receiver does not come in contact with water at any point of time during the mission, hence preventing any RC link loss or loss of GPS lock.

UNDERWATER TO AERIAL TRANSITION

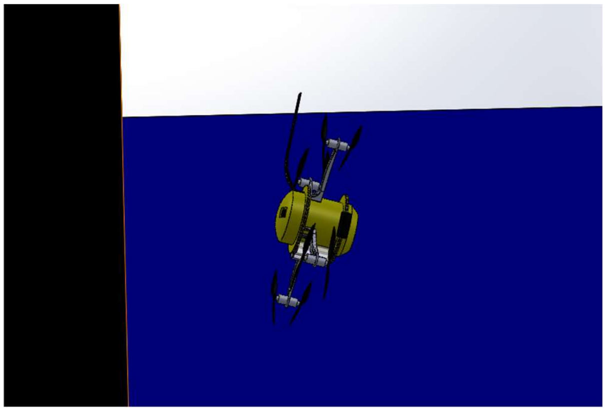

Figure 5: Underwater to Aerial Transition

Twenty seconds before reaching the target ship's GPS coordinates, Kalam-I will start draining its cylinders and initiate the underwater to aerial operational transition. This stage is similar in nature to the aerial to underwater operational transition stage. The empty cylinders cause the centre of mass of the vehicle to go back to its original position. The change in the centre of mass position will result in a righting torque, thereby causing the whole vehicle to start pitching up by ninety degrees. This will result in the propellers being aligned with the vertical axis and hence initiate configuration for aerial operations.

The time period of this stage of the transition can be further reduced by assisting the turning operation with the rotation of the propellers. Once the cylinders are emptied, the weight will reduce and the now downward force created due to the new weight will once again match the force due to buoyancy. This results in the vehicle starting to move to the water surface. Therefore, at the end of this stage Kalam-I will be configured for aerial operations and hence will start working like an aerial vehicle again having reached the ship on which it needs to conduct surveillance.

AERIAL OPERATION AND SURVEILLANCE

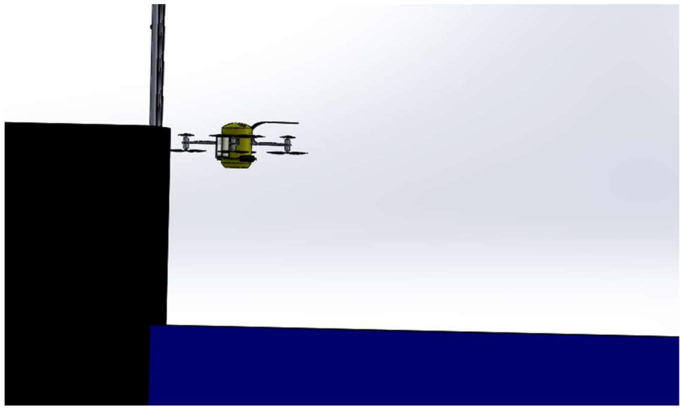

Figure 6: Aerial Operation; surveillance of the ship

Kalam-I will now start flying in the air and start to proceed closer towards the ship in order to do surveillance. During this time, the pilot along with the team will have a live view of the entire ship and another feed of the image processing camera's data will go to the ground station computer to perform image processing for pre-fed image template to perform object search and detection. The results of both these feeds coming from the cameras will be displayed on the computer.

This task will be performed autonomously with the help of a pre-uploaded mission on the flight controller which can be modified as per real-time requirements. If a further need of inspection is there or any other unforeseen requirement comes up, the pilot can take manual control of the vehicle.

RETURN TO GROUND STATION

After completing the surveillance of the target ship, Kalam I will now land on water and follow the above steps in the reverse order for it to go back to the ground station.

PROTOTYPE I

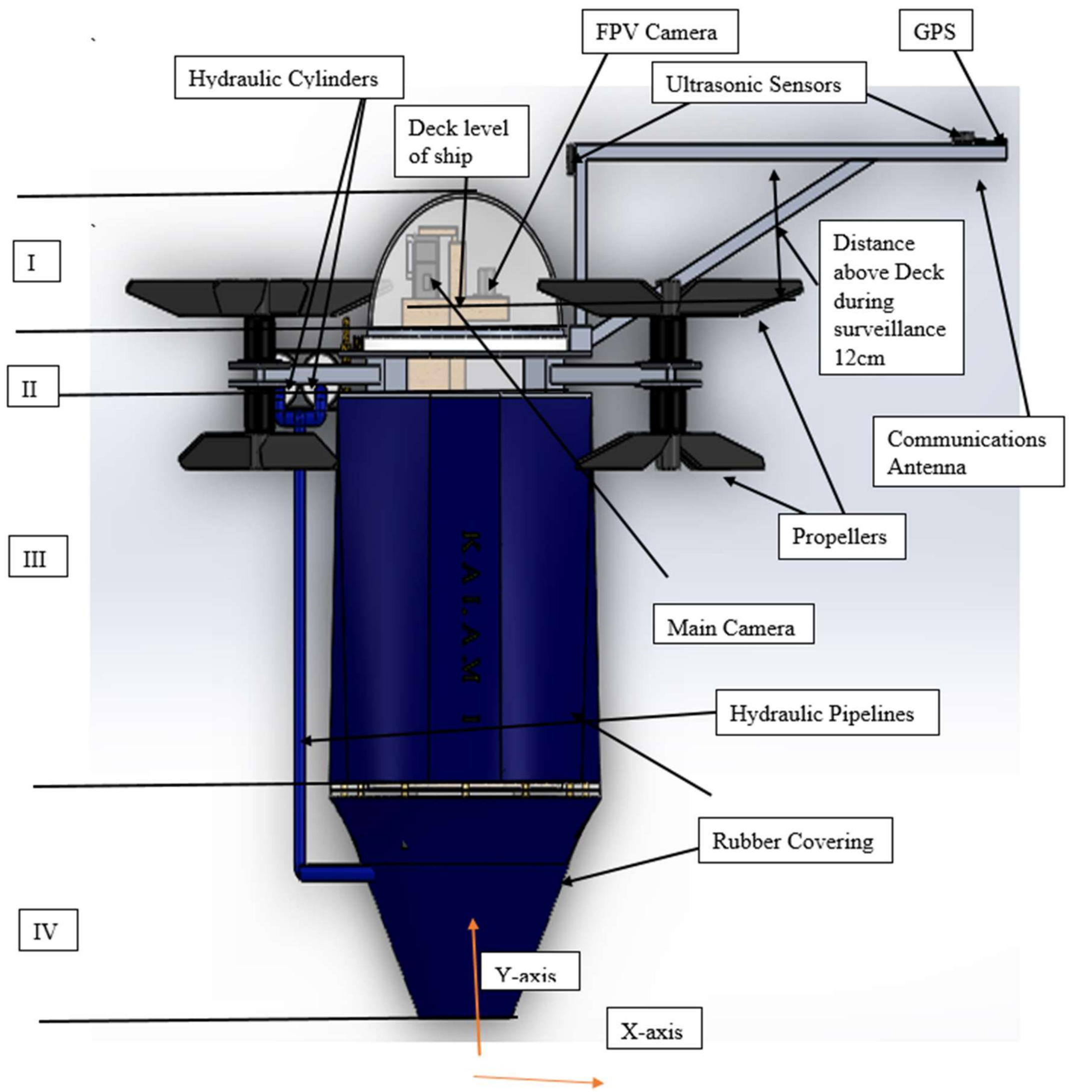

Figure 7: Kalam I

I. Reconnaissance and Camera Compartment
II. Propulsion Compartment
    - Propulsion
    - Hydraulic cylinders
III. Electronics Compartment
IV. Hydraulic Compartment

FRAME

It is an octocopter with four arms and powered by eight coaxially mounted BLDC motors. This X-8 configuration provides additional stability and manoeuvrability. For additional strength, the mainframe uses two sets of octagonal aluminium plates which are used to hold the electronics cabinet and the propeller arms together. The arms are being kept ninety degrees apart with Aluminium being chosen as it is lightweight, cheap and has a high strength to weight ratio.

PROPELLERS

The propellers' diameter 9.5 inch and the pitch is forty-five degrees. The base propeller T9545 is being modified to operate quietly to enhance the stealth capabilities.

ELECTRONICS CABINET

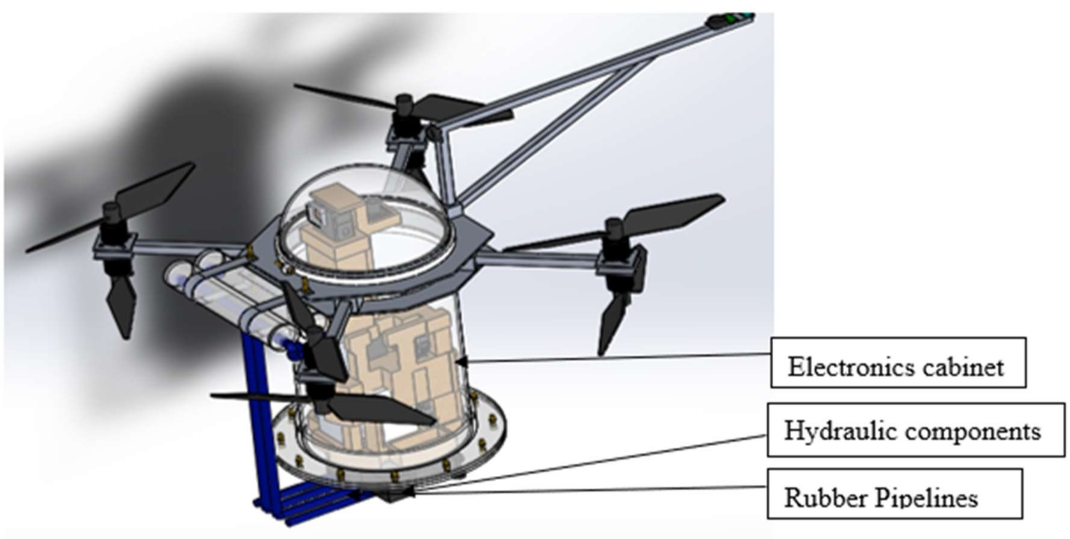

Figure 8: Kalam I without rubber covering

The electronics cabinet is an airtight compartment used to prevent the onboard electronics from coming in contact with water. The cabinet weighs 4.188kg and is installed in the middle of the frame. Its structure is made out of transparent acrylic with a thin layer of rubber installed as a cover to enhance fluid dynamics. The inner support structure is built from balsa wood to fix the positions of the components. The electronic components inside is modelled as per their standard dimensions and weight.

The main camera is positioned above the propellers allowing only a very small portion of the vehicle (12cm height) to remain above the deck level of the ship during the live video feed thereby avoiding detection. To ensure that the buoyancy centre lies above the centre of mass and their perfect alignment, the components in the cabinet have been moved to the lower section of the cabinet with the upper section relatively empty and both the centre of mass and buoyancy have been balanced to align them together.

HYDRAULIC CIRCUIT

While operating as an aerial vehicle, the axis of the propellers needs to be aligned with the vertical axis whereas while operating as an underwater vehicle, the axis of the propellers needs to be aligned with the horizontal axis. The hydraulic circuit in the project has been implemented in order to allow the vehicle to smoothly transition from aerial operation configuration to underwater operation configuration and visa-versa.

During the underwater operation, the vehicle will attempt to align its centre of mass and buoyancy centre with the vertical axis. Hence a change in the centre of mass position will cause a change in the orientation of the vehicle. The centre of mass position of Kalam I is controlled by the charging and discharging of the on-board cylinders.

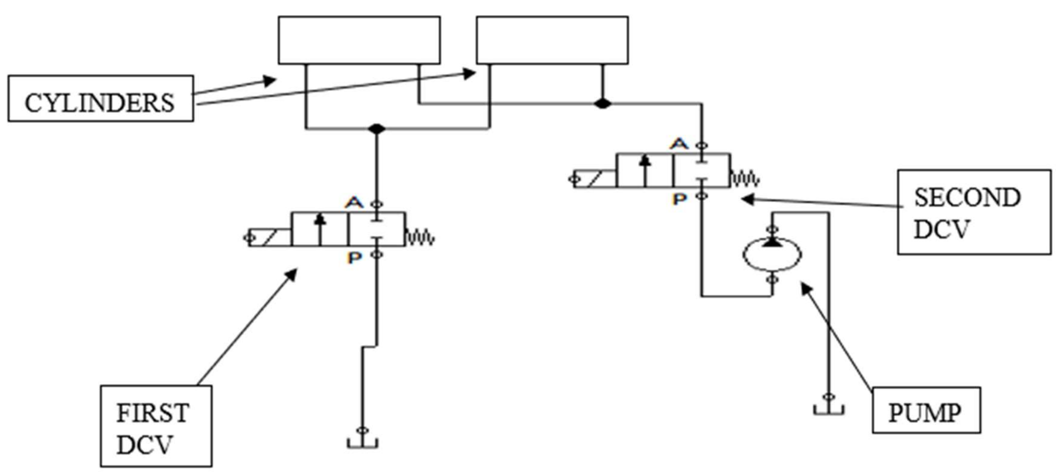

Figure 9: Hydraulic Circuit

The movement of water in the cylinder is controlled with the help of a (Generic DC 12V 5.5m 1000L/H Brushless Motor Submersible Water Pump) hydraulic pump and two 2/2 solenoid controlled spring return Direction Control Valves (DCVs).

While operating in the air, the cylinders are kept empty. Once the vehicle is completely submerged in water, the first DCV (on the left side) is energised allowing water to enter its cylinders, causing it to pitch downwards and configuring it for underwater operation.

During the underwater operation, the cylinders are filled and the DCVs are de-energised. After reaching the ship, Kalam I will need to empty its cylinders to configure for aerial operations. Hence, the second DCV is energised, the pump is switched on and water sucked out of the cylinders. This causes it to pitch upward and configure for aerial operation.

TECHNICAL SPECIFICATIONS

The technical specifications for the first prototype are shown in the table below.

Sr. no	SPECIFICATIONS	
1	Weight of vehicle (cylinder discharged)	5.347 kg
2	Force of buoyancy	4.937 kg
3	Volume of cylinders	500 ml
4	Weight of vehicle (cylinder charged)	5.711 kg
5	Centre of mass deviation	9.39mm
6	Initiating turning torque	6.0336 kg cm
7	Telemetry underwater range	20kms
8	Telemetry underwater depth range	20m
9	Telemetry range in air	40kms
10	Telemetry Module frequency	900 MHz
11	RC Transmitter frequency	2.4 GHz
12	FPV Transmitter frequency	1.2 GHz

PROTOTYPE II

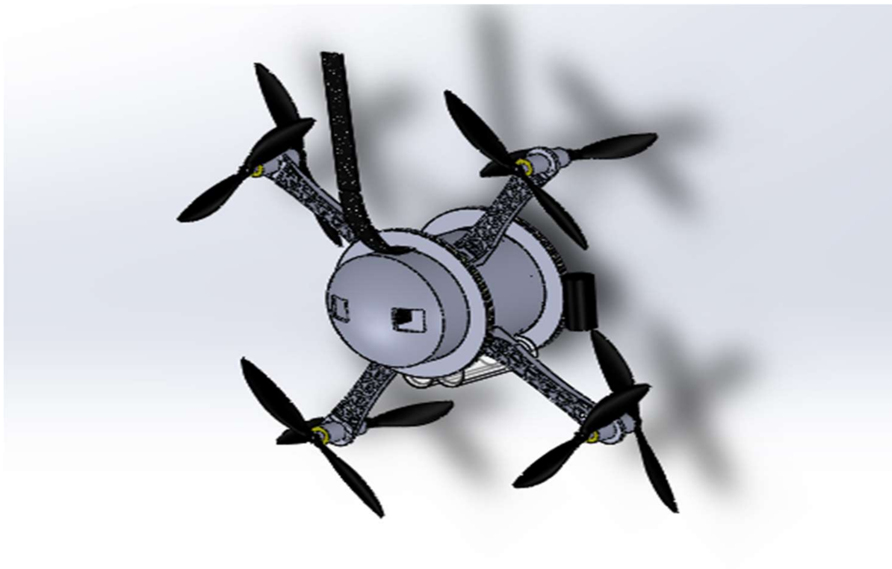

Figure 10: Prototype II Design

A lightweight and durable glass fibre reinforced plastic body gives structural integrity and shape to the whole vehicle. This structure is designed and manufactured in such a way that enables it to support the cantilever loads of the propeller arms, mountings for internal systems and also the aerodynamic outer structure for its smooth propulsion through fluidic mediums (i.e. aerial and underwater).

DESIGN

The vehicle is made of 3 sub-bodies viz; Upper (Surveillance system) Cabinet, Central (Electronic Control system) Cabinet and lower (Power system) Cabinet. The upper and lower cabinets are single side open and curved hollow surfaces on either side. Whereas, the central cabinet is a hollow cylinder which has both its ends open. With similar cross sections at the intersections, which provides the uniform internal and external surface for our desired design aspects for further integration of our vehicle.

Upper body has 2 transparent sheets of clear Acrylic (Poly-methyl methacrylate, PMMA) embedded into the glass fibre layers of the composite body. This provides a window for the surveillance system to detect the outer surroundings, while the system is isolated inside the cabinet. Also, being the front most body in the direction of motion in aerial as well as underwater propulsion, this body part has curved surface area favouring the structure aerodynamically, reducing the fluidic resistance due to a smaller normal surface area to the motion.

The bottom body acts a power cabin with batteries installed at lowermost cabinet internally. With enough space for batteries, this separable cabin can be disengaged easily for charging purposes. With the flat bottom, providing the flat base for installation of landing gear and also enhanced fluid particles flow by the end of the body, favouring the motion and stabilization of vehicle in motion.

The central body is the most crucial in structure, as it has the propeller arms attached to structure and caring most of the vehicle's load, also supporting the other body part together.

Being an X-8 motor configuration, the four arms need to project radially outwards in four perpendicular directions from the circumference of the body. In order to mount the arms on to the body, Stainless Steel L- shaped channels are being implanted into the composite structure in a cross configuration, providing rigid cantilever support at the circular periphery. With one side embedded into the Polymer matrix, the other side provides structural strength which is enough to support the arms by bolting them to the support channels. It also comprises various electrical subsystems internally, it has a multi-level space separated by a thin sheet of polycarbonate providing base for mounting and isolation of the various elements.

The bodies are attached to each other by placing a leak-proof flange structure at each of the two intersections i.e., at Upper body-Central body intersection and other at the Bottom body-Central body intersection. This flange is made up of lightweight polypropylene, consisting of two O-rings grooves on either side. O-rings pair along with silicone sealant on each side flange promises leak-proof sealing, keeping the inside totally free of water in immersed conditions.

All these 5 parts (3 body parts and 2 flanges) along with arms are also secured with Stainless Steel struts running through the extended collar at each intersection and propeller arms which keep the total structure in the same secured position.

This total setup assures best of the structural stability and rigidity, providing waterproof interior and also being lightweight at the same time.

MATERIAL

The main structure is made up of glass fibre reinforced polymer composite, which is an advanced material made upon thermoset matrix material which is reinforced by fine strands of glass fibre mat. The structure is made of single layer of glass mat and double layered structure at some points which requires high rigidity. This has a thickness of 2-3 mm and has low density (0.9-1.0 g/cm^3). Thus, the whole structure weighs lighter than the Acrylic (1.2g/cm^3) structure used in Prototype-I. Composites can be easily moulded to required shapes as long as the fibre run straight along the structure giving the strength. Patterns and mould were developed initially before building the original structure.

The propeller arms are the one commercially available copter arms, which are used to build DIY copter kits. These commercially bought arms are made up of polyamide nylon and are designed especially for flying copter. They were modified according to our need of mounting two BLDC motors onto the single arm coaxially in the opposite direction. This setup was experimentally tested before being implemented in the final design, which proved to be a better alternative to the previously used Aluminium channel in Prototype-I, which was comparatively heavier.

The flange is made up of Polypropylene (Density: 0.95g/cm^3) which is lightweight and is turned on the lathe machine according to planned design requirements for waterproof sealing. This too weighs lower than previously used Aluminium (Density: 2.7g/cm^3) flanges in Prototype-I.

ELECTRONICS CABINET

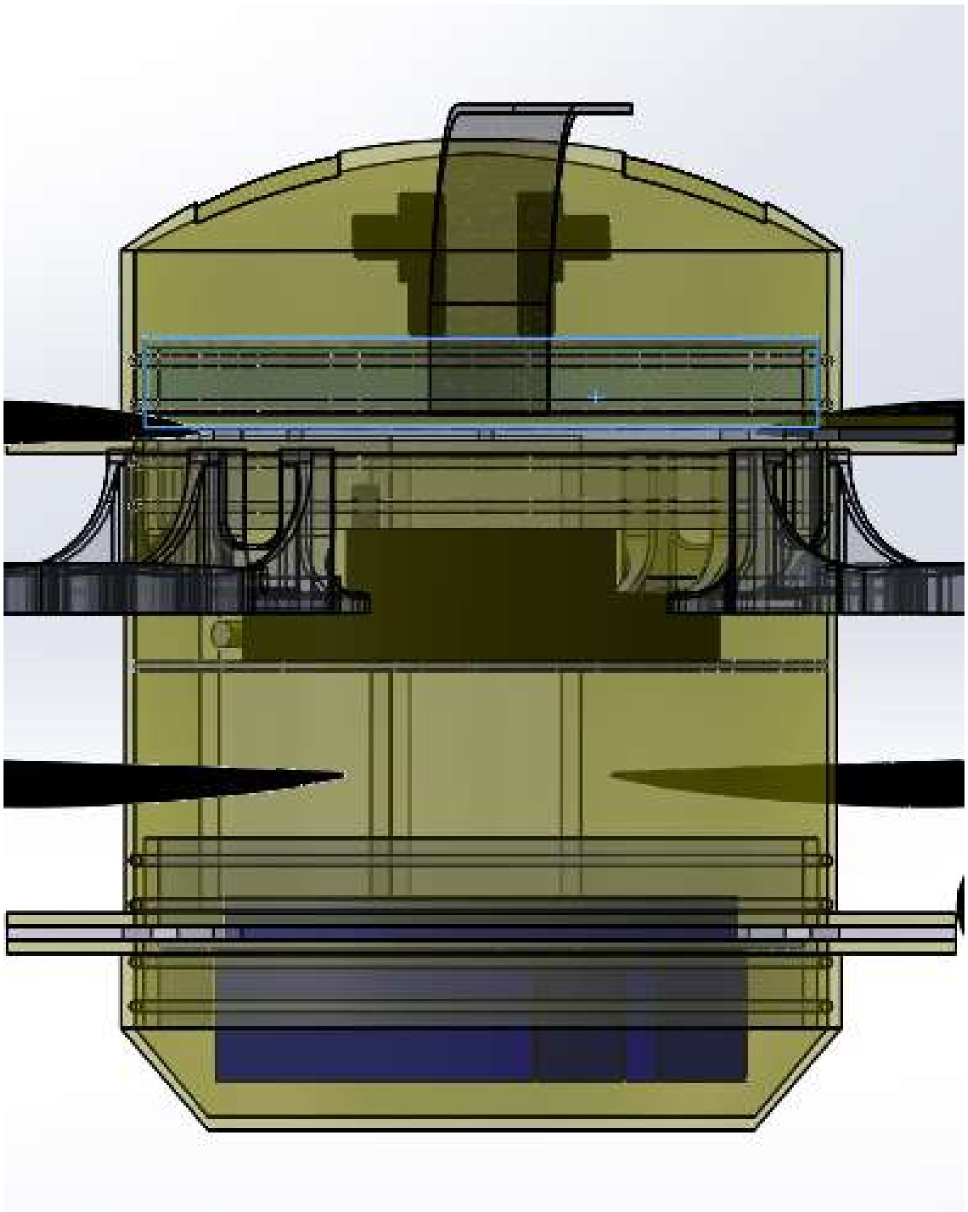

Figure 11: Inner cabinet layout

An electronic cabinet is a waterproof compartment designed to protect its content from the water outside. It is frequently used in building underwater vehicle in order to protect the on-board electronic system. Since Kalam-I’s mission will also require it to go underwater for a brief period of time, the same concept of a waterproof compartment has been implemented.

Electronics cabinet is made out of glass fibre having nylon flange coupling with o rings and is designed to meet multiple requirements of the vehicle. First, the electronic components inside need to be protected from the water from the water outside. This has been accomplished with the uses of two nylon flanges and four o rings on each flange. The two rings, primary and secondary, form a waterproof between the flange and the outer surface of the cabinet. This has been done on either sides of the flange.

The second requirement is that the buoyancy force created by the vehicle should equal its weight. In this aspect of the design, the electronic cabinet plays a critical role being the largest part in the vehicle and has been designed taking this factor into consideration.

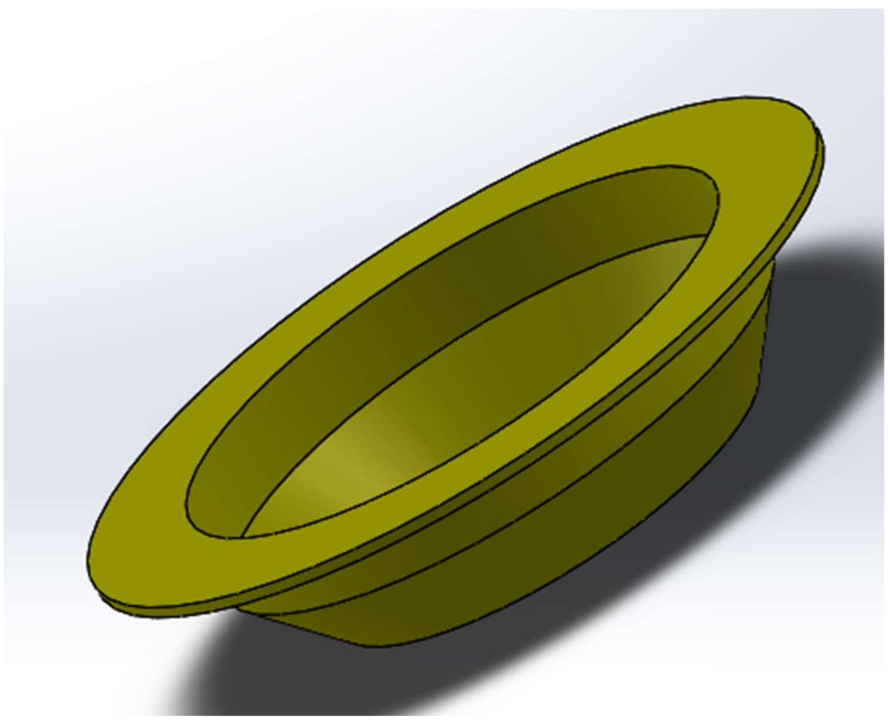

Figure 12: Lower end cap

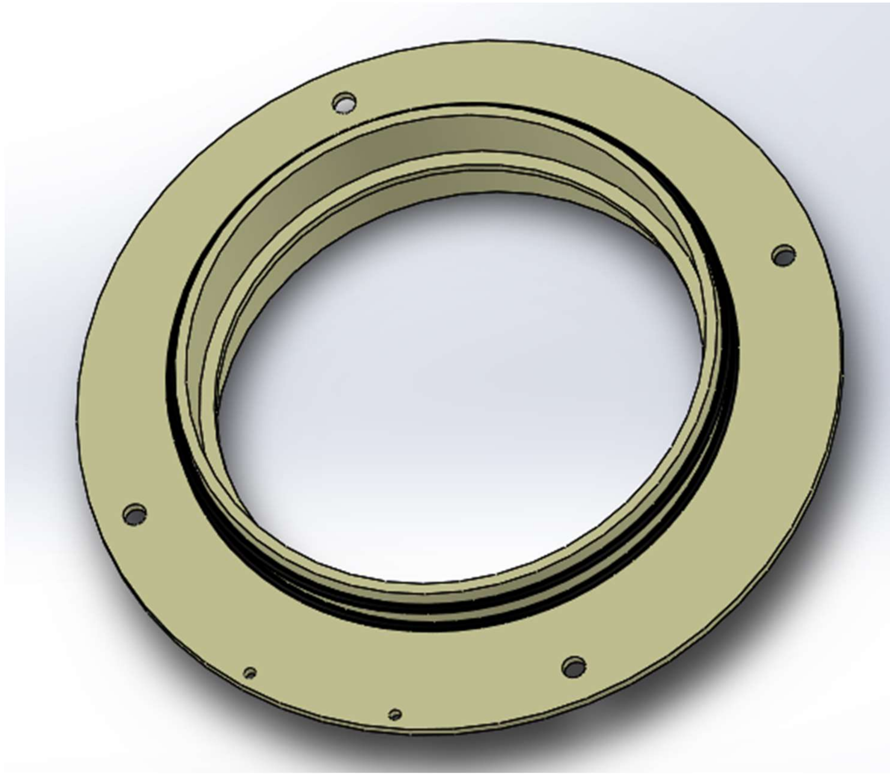

Figure 13: Nylon Flange

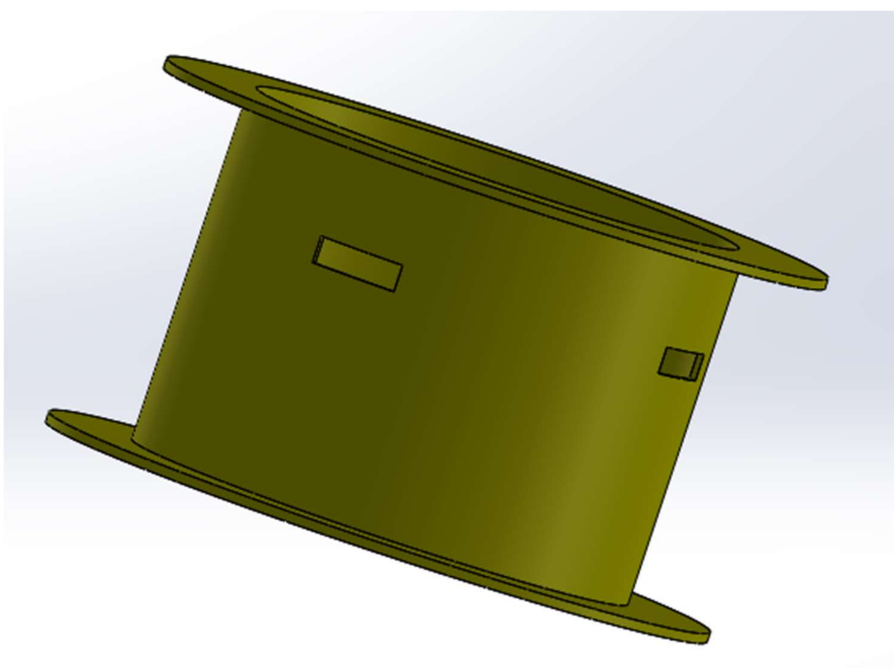

Figure 14: Central Cylinder

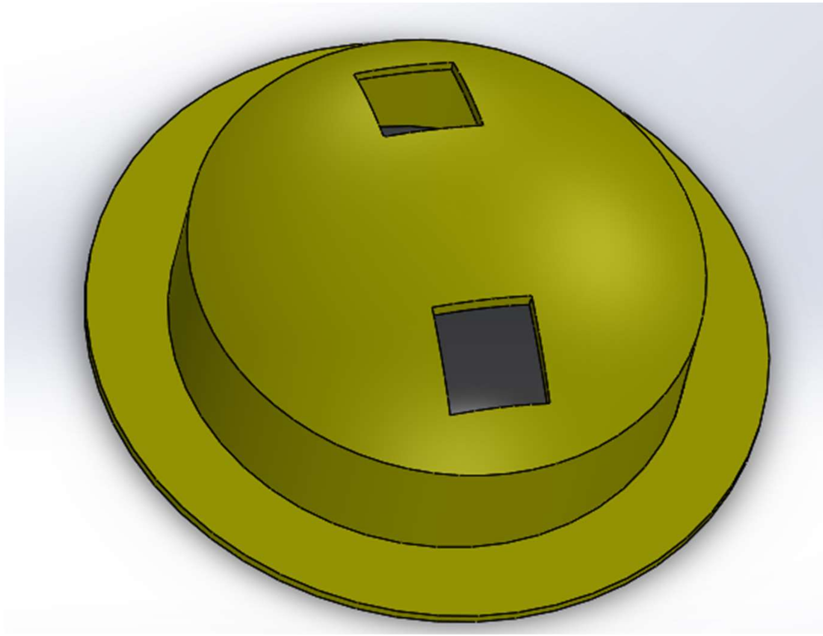

Figure 15: Upper end cap

The third requirement is that the cabinet needs to be able to provide easy access to all the components. This has been done by subdividing the cabinet into several sub-compartments. The first and lowest compartment as shown in the figure is the battery compartment which contains both the batteries. The compartment directly above it is Arduino compartment which contains both the main and the micro Arduino. The next compartment is the autopilot compartment which contains the Pixhawk and the telemetry module. The final and topmost compartment is the surveillance compartment which contains the cameras, its battery along with its receiver and transmitter.

HYDRAULIC SYSTEMS AND UNDERWATER OPERATIONS

During the underwater operations, the vehicle is designed to exploit one of the fundamentals principles in the working of underwater vehicle. The principle is that an underwater vehicle always has a tendency to align its buoyancy centre and its centre of mass with the vertical axis and that the buoyancy centre is always above the centre of mass. All underwater vehicle are inherently designed to ensure that its buoyancy centre and centre of mass are aligned and that the former is positioned above the latter as such a configuration would naturally enhance the stability of the vehicle during operations being in line with its nature physical tendencies.

The vehicle designed by the team needs to be able to travel both underwater and in the air. In the air, the vehicle's propellers must be aligned with the vertical axis and underwater it must be aligned with the horizontal axis. Such a scenario requires the vehicle to have the capability to pitch up and down at the pilot's command. This requirement has been met by the team by exploiting the abovementioned principle.

The vehicle has two on-board hydraulic cylinders and is equipped with two pumps. One of the pumps is used to make water enter the cylinders while the other pump is used to remove water from the cylinders. The total volume of the cylinders is 250mL. The vehicle is designed to ensure that when the cylinders are kept empty, the buoyancy centre and centre of mass are both aligned with the vertical axis and that the buoyancy centre lies above the centre of mass and that weight of the vehicle matches the buoyancy force created by the water it displaces. The centre of mass of the vehicle was found from the design software Solidworks 2017 while the centre of buoyancy of the vehicle was found by finding the centre of mass of the water displaced by the vehicle in the exact curvature using the same shape.

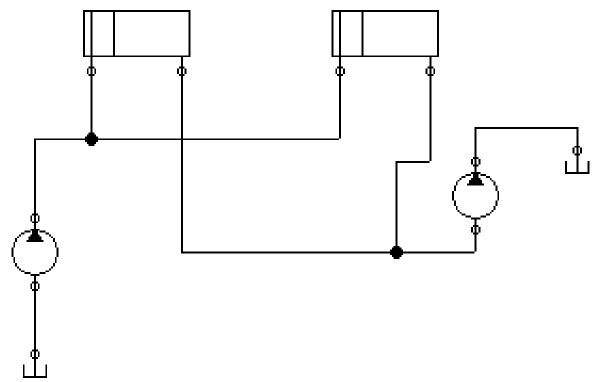

Figure 16: Hydraulic Circuit

During the aerial operations, both cylinders are kept empty. In order to transition to the underwater operational configuration, the on-board cylinders need to be filled. When the cylinders are filled completely, two phenomena occur. First, the additional mass causes the vehicle to begin to sink. Second, when the cylinders are filled, they cause the centre of mass of the vehicle to shift by 5.261mm towards themselves. This results in a turning couple of 2.237kgf due to the buoyancy force and weight of the vehicle which causes the vehicle to pitch down. Now the propellers are aligned with the horizontal axis and hence configured for underwater operations. In order to transition to aerial operational configuration again, both the cylinders are emptied. The resultant reduction in weight causes the vehicle to come to the surface. The centre of mass subsequently returns to its original position and this causes the vehicle to pitch up and hence configure for aerial operations again. This procedure needs to be carried out when the vehicle has reached the ship and needs to conduct surveillance operations again.

WEIGHT DISTRIBUTION

For the second prototype, each component that was to be installed in the vehicle was individually weighed and subsequently a detailed weight distribution table for the entire vehicle was formed.

The table is shown below:

S.NO	COMPONENT NAME	WEIGHT (gm)	Nos	TOTAL WEIGHT (gm)
1	Frame	760	1	760
2	Cabinet	1160	1	1160
3	Hydraulic pump	70	2	140
4	Batteries	190	2	380
5	Pixhawk	72	1	72
6	Telemetry module	40	1	40
7	Cameras	30	2	60
8	Arduino	60	2	120
9	Camera receiver	24	2	48
10	ESCs	40	8	320
11	Camera battery	160	1	160
12	Struts	40	4	160
13	Cylinders	75	2	150
14	Nuts & bolts	4	8	32
TOTAL CALCULATED WEIGHT				**3602**

ELECTRONICS (COMMON FOR BOTH PROTOTYPE-I AND PROTOTYPE-II)

The electronics for the vehicle have been chosen so that they are highly redundant. Another constraint present was that they had to occupy minimum space and weigh less in order to increase range and flight time. A combination of:

i. Microprocessor: For the flight controller
ii. Microcontroller for underwater controller
iii. Low level microcontroller for general purpose operations like obstacle avoidance, and operation of valves.

The flight controller uses a telemetry link of 900Mhz.The microcontroller is plugged into the USB of the on-board computer and this serial link is used to communicate with the Arduino microcontroller.

COMMUNICATION LINKS

The vehicle is using four communication links in total for:

1. Telemetry: 900MHz
2. Pilot RC control: 2.4GHz
3. First Person View (FPV)
    i. First Person View (FPV) 1: 1.2GHz
    ii. First Person View (FPV) 2: 5.8GHz

The above mentioned frequencies were chosen after seeing any possible interference and provide maximum range.

1. **Telemetry: 900MHz**: The modules chosen for telemetry are the RFD 900 which operate at 900MHz. With a half wave monopole 2.1dBi antenna, it provides a range of more than 30-40kms LOS.
2. **Pilot RC control: 2.4GHz:** The pilot RC control works on 2.4GHz and provides a range of 5kms. If need arises, with a help of a 433MHz Arkbird repeater, the range can be increased to 20-25kms.
3. **FPV (First Person View):** 1.2GHz and 5.8GHz. Considering both Aerial and Underwater operations, we have chosen FPV cameras which operates at different frequencies because 1.2GHz provides higher penetration and the 5.8GHz with the right antenna provides high range at lower power input.

AUTONOMOUS CAPABILITIES

The vehicle is capable of having manual pilot control as well as complete autonomous capabilities.

The vehicle has 2 controllers:

1. Flight controller: For Aerial Operations
2. Underwater controller: For Underwater Operations

The Control between both the controllers can be shifted with the help of a switch on the pilot RC and an 8 channel relay on the vehicle.

AUTOPILOT AND FLIGHT CONTROL SYSTEM

The Autopilot is the heart of the UAS, and will be responsible for all flight controls in autonomous mode. As most our operations happen on-board, the flight controller is considered as a low level computer that works in coordination (depending on flight situations) with the higher level on-board computer. The Pixhawk 2 autopilot is a highly tested and reliable open-source system, a feature which is very important for its integration with our systems. The team has considerable experience with the APM: Pixhawk 2, APM: Pixhawk and Ardupilot Mega autopilot systems on the basis of which we have come to a conclusion of using Pixhawk 2 for the competition. It is a very powerful flight control unit which uses isolated Inertial Measurement Unit (IMU) and Flight Management Unit (FMU), effectively reducing interference to sensors. It also contains a Triple redundant IMU system which consists of 3 x Accelerometer, 3 x Gyroscope, 3 x Magnetometer, 2 x Barometer which enhances the safety and reliability of the system. The selection of Pixhawk was based largely on the following hard points:

• Open Source, Highly flexible and trusted autopilot

• Abundant connectivity options for peripherals

• Integrated backup system for in flight recovery and manual over ride via hardware (not involving any electronics)

• Redundant power supply and automatic failover

• Powerful Cortex M4F processor for running complex algorithms for stable flight dynamics and navigation.

• Affordability

• Open-source Ground Control Station called Mission Planner for programming all parameters, waypoints, Geofence etc.

COMPARISON BETWEEN PROTOTYPE-I & PROTOTYPE-II

PROTOTYPE – I

Advantages

1. Lower cost of structure
2. Inner components are visible since structure is made from acrylic
3. Easier to fabricate
4. Camera can be positioned anywhere
5. Simple Design

Disadvantages

1. More weight
2. Prone to error during fabrication
3. Offers more fluid flow resistance
4. Electronics cabinet not compact
5. Larger size
6. Less strength

PROTOTYPE – II

Advantages

1. Less weight
2. Less fluid flow resistance
3. Modular and compact electronics cabinet
4. Less prone to sonar wave detection due convex outer structure
5. Relatively higher strength

Disadvantages

1. Cost is higher
2. Relatively more complex design
3. More difficult to fabricate
4. Camera is restricted to only two positions

COST ESTIMATION

PROTOTYPE – I

The first prototype was fabricated for the zonal level of the competition. The total cost of the first prototype was Rs 60,041. The part by part cost distribution is shown below.

Sr. no	COMPONENT	COST
1	Aluminium billets	2216
2	Lathe	1300
3	O rings	500
4	Acrylic sheets	500
5	Laser cutting	413
6	Acrylic cylinder	1500
7	Nut bolts	800
8	Struts	120
9	Aluminium channels	1121
10	Pipes and connectors	725
11	Polycarbonate sheets	590
12	Pumps	640
13	Aluminium plates	769
14	Welding	700
15	Motors	3450
16	Propellers	3200
17	ESCs	7000
18	Relay	430
19	Arduino	470
20	Pixhawk	6590
21	Batteries	8750
22	Power distribution board	500
23	Silicon wires & heat shrink	672
24	RFD 900	5000
25	Ultrasonic sensor	2547

26	FPV Camera	3197
27	Transmitter & receiver	6341
	TOTAL COST	**60041**

PROTOTYPE- II

The second prototype was made for the final level of the competition. The total cost for building the vehicle was Rs 63765. The part by part cost distribution is shown below.

Sr. no	COMPONENT	COST
1	Nylon billet	1130
2	Lathe	1000
3	O rings	500
4	Acrylic sheets	500
5	Laser cutting	413
6	Acrylic cylinder	400
7	Nut bolts	800
8	Struts	120
9	Glass fibre casting	8000
10	Pipes and connectors	725
11	Polycarbonate sheets	590
12	Pumps	640
13	Frame	800
14	Motors	3450
15	Propellers	3200
16	ESCs	7000
17	Relay	430
18	Arduino	470
19	Pixhawk	6590
20	Batteries	8750
21	Power distribution board	500
22	Silicon wires & heat shrink	672
23	RFD 900	5000
24	Ultrasonic sensor	2547
25	FPV Camera	3197
26	Transmitter & receiver	6341
TOTAL COST		63765

RESEARCH AND TEST DATA

EXPERIMENT 1: THRUST MEASUREMENT OF A SINGLE MOTOR WITH PROPELLERS OF DIFFERENT DIAMETER

This test was done to determine the thrust of a single motor for different propellers. The given BLDC motors are sold along with a maximum thrust rating from the manufacturer. However, before implementing these motors in Kalam II, the maximum thrust needs to be separately determined by the team. This task has been accomplished with the help of a weight scale. The given motor is attached to the top of a weight. As the propeller rotates, it produces a thrust in the upward direction causing the motor to be pushed in the downward direction towards the weight scale. Thus, the reading obtained in the scale is the thrust produced by the motor.

Apparatus Required:

- Weight scale
- Lithium Polymer Battery
- Microcontroller to control the speed of the motor
- Brushless DC Motors
- Electronic Speed Controller

Technical Specifications:

- Motors: A2212, 1800KV, 8T, BLDC
- Propellers:
  - 10 inches diameter, 45 degree pitch
  - 8 inches diameter, 45 degree pitch
- Battery: 3 cell Lithium Polymer (LiPo) at 12.6 volts
- Weighing scale: Range 0-10kg, least count 1 gram

Procedure:

- The motor is mounted on a weight scale with the help of the motor mount and tape.
- The motor is then connected to the electronic speed controller.
- The positive and negative terminals of the battery are connected to the corresponding wires on the speed controller.
- The speed controller is connected to the CR3 terminal of the receiver.
- The Arduino is connected and the code is feed for 20%, 40%, 60%, 80-% and 100% thrust with a delay of 2 seconds.
- The code is run, initiating the motors and the readings are noted.
- The same procedure is repeated for a different propeller.

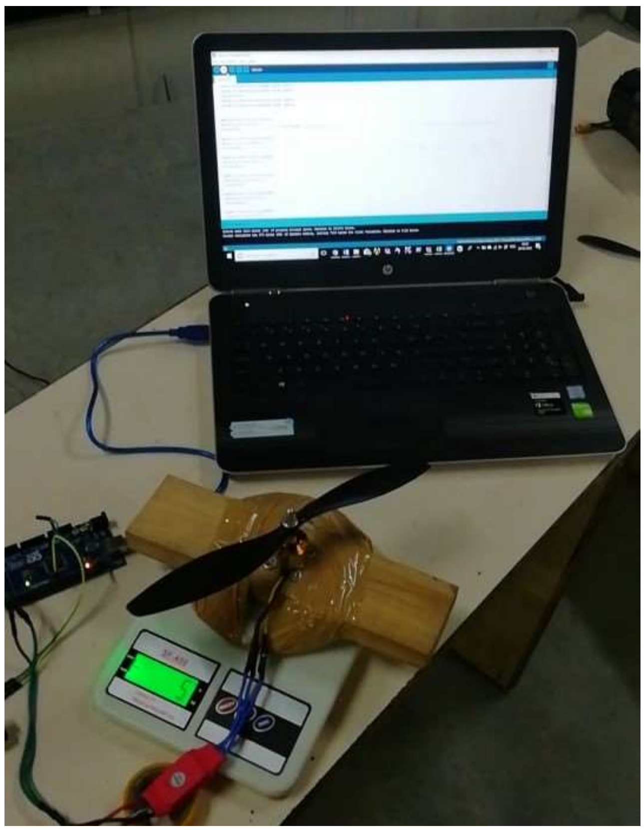

Figure 17: Setup of Thrust measurement of a single motor

Observation:

S.NO	PROPELLER DIAMETER (inches)	THROTTLE (%)	THRUST (gm)
1	8	20	143
		40	338
		60	583
		80	813
		100	929
2		20	114
		40	270
		60	488
		80	715
		100	916
3		20	122
		40	293
		60	528
		80	750
		100	910
4	10	20	167
		40	457
		60	769
		80	1018
		100	1168
5		20	123
		40	331
		60	612
		80	876
		100	1168
6		20	126
		40	365
		60	660
		80	924
		100	1132

Inference:

The experiment shows that a single motor can provide a maximum thrust of 1.168 kg. Hence the use of 8 such motors would provide a maximum thrust of 1.168 x 8 = 9.344 kg.

Result:

The given motor was test and its maximum thrust was determined to be 1.168 kg.

EXPERIMENT 2: THRUST MEASUREMENT OF 2 MOTORS MOUNTED COAXIALLY

Aim: To determine the thrust generated by two coaxial mounted motors fitted with 10 inch propellers, efficiency of a co-axial mount configuration and optimum weight of the vehicle. In the previous experiment, it was determined that a single motor can generate a maximum thrust of 1.168kg. Hence, theoretically, the use of two motors should provide a maximum thrust of 2.336kg. However, in a coaxial mount, there is always is some loss in the total thrust generated and it is critical to determine the actual thrust generated in a co-axial configuration to calculate the optimum weight of the vehicle.

The arm is connected to a rectangular plywood piece the setup has a pivot. The other end of the plywood piece rests on the top of a weight scale. When the motors rotate, they produce a thrust in the forward direction, this causes the setup to rotate in the counter clockwise direction about the pivot putting pressure on the weight scale.

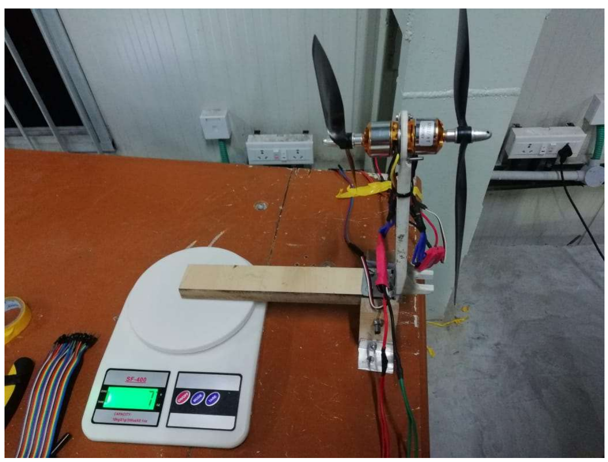

Figure 18: Coaxial Thrust measurement setup (1)

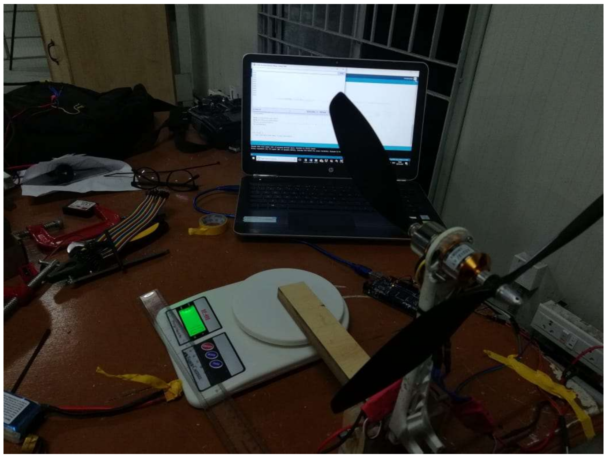

Figure 19: Coaxial Thrust measurement setup (2)

Apparatus Required:

- Weight scale
- Lithium Polymer Battery
- Microcontroller to control the speed of the motor
- Brushless DC Motors
- Electronic Speed Controller
- Motor Arm
- Plywood

Technical Specifications:

- Motors: A2212, 1800KV, 8T, BLDC
- Propellers:
    - 10 inches diameter, 45 degree pitch
- Battery: 3 cell Lithium Polymer (LiPo) at 12.6 volts
- Weighing scale: Range 0-10kg, least count 1 gram

Procedure:

- The motors are mounted on a single arm with the help of the motor mount
- The arm is attached to a rectangular plywood piece and a pivot is formed at their intersection.
- The motor is then connected to the electronic speed controller.
- The positive and negative terminals of the battery are connected to the corresponding wires on the speed controller.
- The speed controller is connected to the CR3 terminal of the receiver.
- The Arduino microcontroller is connected and code is feed for 20%, 40%, 60%, 80-% and 100% thrust with a delay of 2 seconds.
- The code is run, initiating the motors and the readings are noted.

Observation:

S.NO	THROTTLE (%)	THRUST (gm)
1	20	250
	40	670
	60	1128
	80	1530
	100	1730
2	20	228
	40	642
	60	1036
	80	1435
	100	1730
3	20	211
	40	600
	60	1109
	80	1500
	100	1650

Calculations:

Maximum thrust of a single motor (from previous experiment) = 1.168 kg.

Therefore, Maximum thrust with two motors = 1.168 x 2 = 2.336 kg.

Actual maximum thrust with co-axial configuration = 1.730 kg.

Hence, efficiency = 1.750 / 2.336 = 0.7405 = **74.05 %.**

As there are four such arms,

Maximum thrust generated by the vehicle = 1.730 x 4 = **6.92 kg.**

For maximum efficiency, the weight of a multirotor should be half its maximum thrust. Therefore, recommended weight = 6.92kg / 2 = **3.46kg**.

Inference:

The experiment shows that two co-axially mounted motors can provide a maximum thrust of 1.730kg and the recommended weight of the vehicle for an octa-quadcopter is 3.4 kg. Hence the vehicle will have designed to not exceed this weight limit during aerial operation.

Result:

- The co-axially mounted motors were tested and their maximum thrust was determined to be 1.730 kg.
- Efficiency of Co-axial mount: 74.05%
- Recommended weight: 3.4 kg

CAPABILITIES

The vehicle has the capability for amphibious operations. Aerial operation along with underwater operation provides an advantage over other vehicles that are used for surveillance. Apart from this, the vehicle has the following capabilities:

- Autonomous capabilities
- Stealth Capabilities
- Obstacle Avoidance
- Live Video Feed
- Object Detection

AUTONOMOUS CAPABILITIES

The control of the vehicle is divided into two phases depending on the operation mode of the vehicle. The two modes of operation include

- Manual Control
- Autonomous Traversal

The Manual Control of the vehicle is operated using the Arduino Mega. The vehicle operates in the Manual Control mode when it traverses underwater from the base ship to the destination ship. During this operation, the operator at the base ship will have the control over the vehicle. The underwater traversal ensures that the vehicle goes to the destination ship unidentified by the crew members presents onboard.

The vehicle when reaches the destination ship, performs the surveillance task autonomously. The autonomous control of the vehicle is operated using Ardupilot along with GPS module. The GPS provides the coordinates for the autonomous navigation when the vehicle is operated in the aerial mode.

STEALTH CAPABILITIES

In order to ensure that the vehicle is not detected by any individuals present on the ship, the following steps have been taken to give the vehicle stealth capabilities.

- The vehicle is operated at one-meter depth ensuring no wake formation and no RC/Telemetry link loss.
- The main camera used for surveillance is located at the very top of the electronics cabinet. Hence only a small portion of the vehicle will be above the deck (12cm) and the rest will be hidden by the hull.
- The propellers are being designed to function quietly
- The obstacle avoidance also helps in maintaining the stealth of the drone by preventing any collisions.
- The flight controller uses multiple PID controllers to stabilize itself and make the error least as possible in order to achieve maximum accuracy during autonomous waypoint navigation and with the help of inertial navigation and a GPS, it will be able to hover and hold a position about a particular location in order to provide maximum stealth during surveillance.

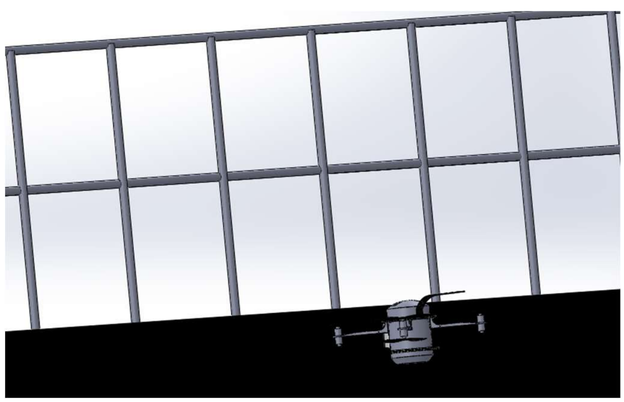

Figure 20: Vehicle during surveillance of the ship

OBSTACLE AVOIDANCE

The purpose of obstacle avoidance is to protect the vehicle from any physical damages due to a collision of the vehicle with the ship's wall while in Underwater or Aerial operations. The obstacle avoidance algorithm is designed so that whenever the drone goes very close to the wall of the ship, the drone will prevent itself from colliding with it.

The latitude and longitude of waypoints as well the obstacles are converted into Universal Transverse Mercator in order use them as 2D coordinates. To check whether the obstacles are obstructing the path of the aircraft, intersection points between the obstacle (circle) and the current trajectory (first waypoint to second waypoint – straight line) are computed. If the obstacle is indeed obstructing the aircraft's path, a small detour is planned using the intersection points and the midpoint of the shorter arc (in order to minimize change in original trajectory) formed by the intersection points and the obstacle. The coordinates are then converted back into latitude and longitude and then fed into the aircraft's flight in order to avoid obstacles.

$$D = radius\ of\ obstacle + safety\ circle\ radius + aircraft's\ turning\ radius$$

In the figure given below, during the autonomous navigation of the vehicle, there is a possibility that it may collide with the ship if it comes in the path of the vehicle.

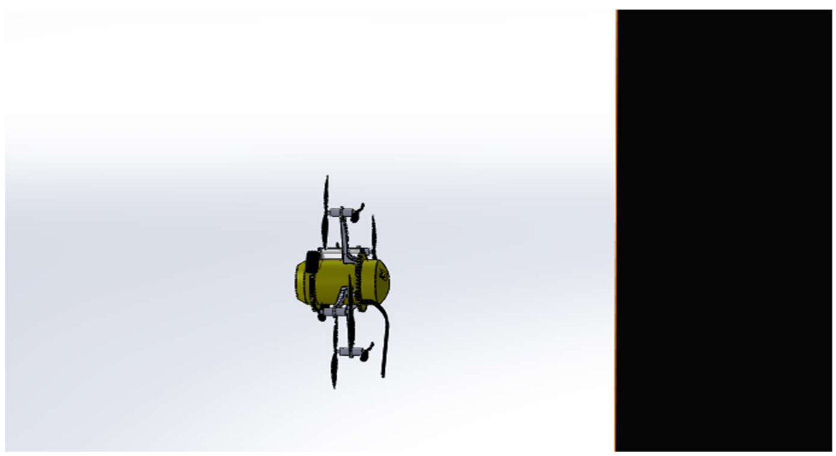

Figure 21: Vehicle approaching obstacle

If there is a chance of collision, then the ultrasonic sensor will send the signal to the controller which turns the vehicle in another direction, thus avoiding collision with unwanted objects.

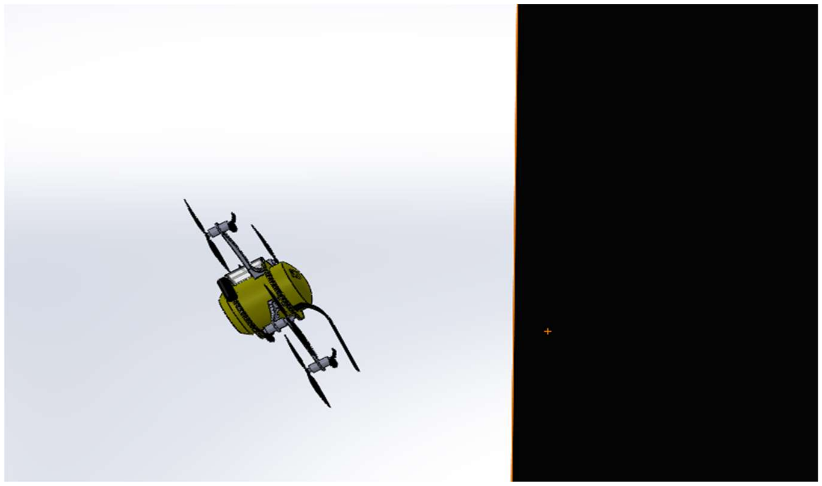

Figure 22: Vehicle after avoiding obstacle

LIVE VIDEO FEED

There are cameras installed in the electronics cabinet whose main purpose is to provide a video feed to the operator. The controls of the vehicle is maintained with the help of these cameras. They provide the opportunity to the operator to review any given object on the deck of the ship.

Figure 23: Video Feed from the camera

OBJECT DETECTION

The camera is also used to carry out image and video processing for object detection. The imaging feed will be processed on the ground station in order to find a pre-fed object which matches the visual appearances, like the given colour and shape from a distance. The object detection is carried out so as to filter the object of given colour and enhance the image. A range of colours is being given in HSV (hue, saturation, value) format. The enhancement of the image is done by using erode and dilate functions. Along with this, the mask image is generated that converts the given image in gradient where the object is clearly visible in the video feed. The Hough circles are formed on the generated image to track the object.

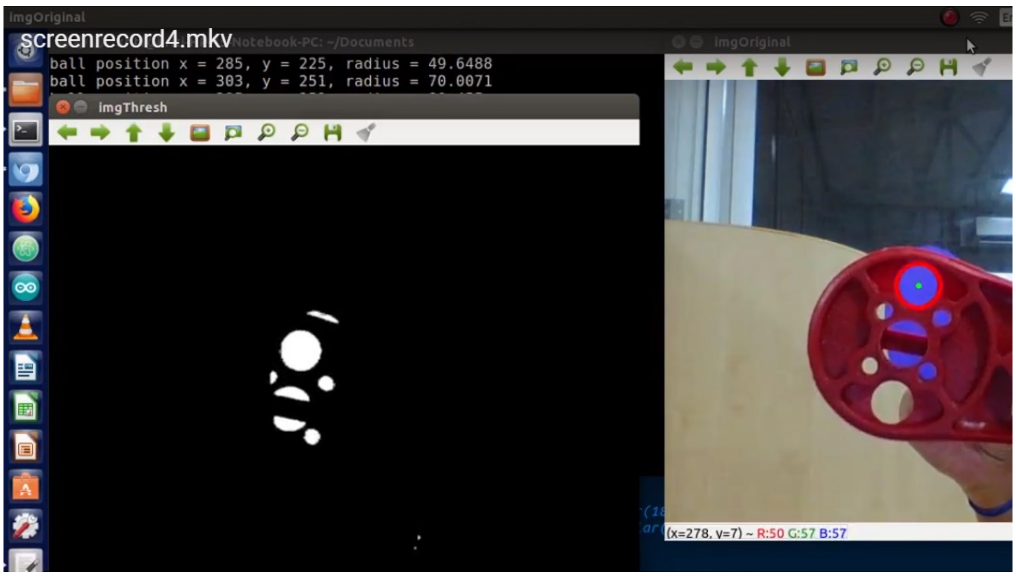

Figure 24: Detection of Blue Object

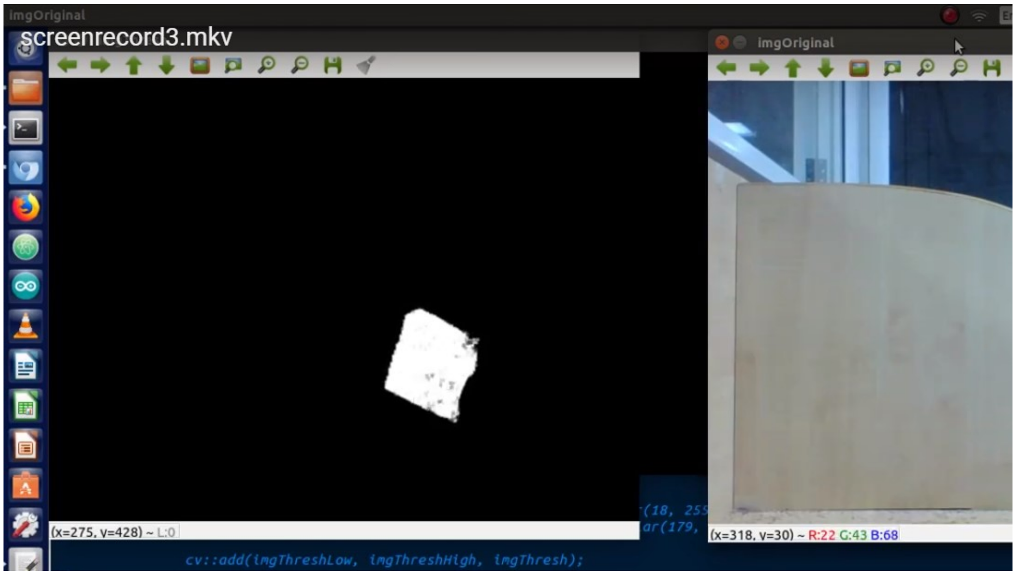

Figure 25: Detection of Orange Object

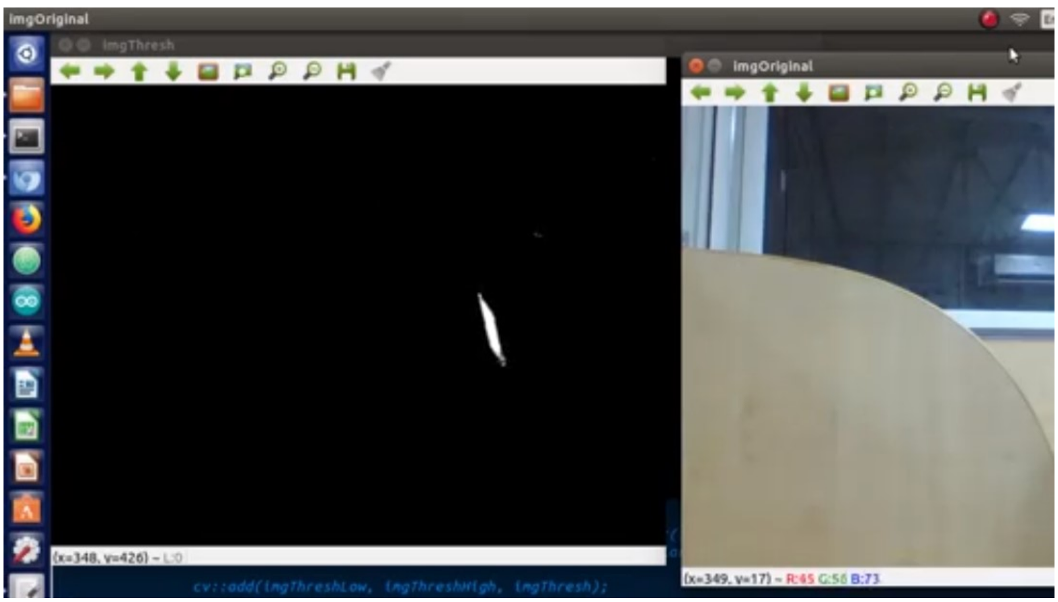

Figure 26: Detection of Green Object