# Nala VS : Autonomous Surface Vehicle

M. Galih Ghafara, Ramadhan Muhammad Hakim, Aryo Tri Septya Nugraha, Muh. Alif Farabi E., A. Reza Fahlovi

***Abstract*— This paper describes Nala VS as an autonomous surface vehicle made for entering the 2017 Roboboat Competition held by AUVSI Foundation in Daytona Beach, Florida. Nala VS is made by students of various majors of Institut Teknologi Sepuluh Nopember. The team has developed Nala VS by implementing innovative features such as using a catamaran flat-side inside type hull, making the hull fragments very portable because of block system construction method, building a computer system as data processing by using GPS and compass as a navigation system, and also using image processing as an obstacle avoidance system. Those combined innovative features aim to successfully run the missions.**

**Key words- Autonomous Surface Vehicle, Catamaran Flat-side Inside, Compass, GPS, Image Processing, Nala VS**

## I. Introduction

Barunastra Roboboat ITS Team is an autonomous surface vehicle team from Institut Teknologi Sepuluh Nopember (ITS), Indonesia. This team consists of undergraduate student from several majors. These majors are Marine Engineering, Naval Architecture and Shipbuilding Engineering, Electrical Engineering, Informatics Engineering, Information System, Industrial Engineering, and Mechanical Engineering. In 2016, the team succeeded to win the national autonomous competition named *Kontes Kapal Cepat Tak Berawak National* (KKCTBN) or Autonomous Boat Competition, held by the Education Ministry of Indonesia, with a boat named Nala V which means the fifth generation of boats made by Barunastra Roboboat ITS Team. In the same year before KKCTBN, Barunastra Roboboat ITS Team became third winner and achieved Savitsky Award with a boat named Nala Evo Mark II in AUVSI Foundation International RoboBoat Competition which was the first international competition the team participated in. This year, Barunastra Roboboat ITS Team plans to become a participant of AUVSI Foundation International RoboBoat Competition for the second time. The team will use a new boat named Nala VS which is the successor of the KKCTBN boat, Nala V.

The competition will be held at the Reed Canal Park's pond, Florida. Each team should accomplish various tasks that are separated into Land-Based Team Tasks and Water-Based Team Tasks. There are two sub-tasks in the Water-Based Team Task. The first is a mandatory Water-Based Task with the purpose to demonstrate the quality of engineering vehicle and should be completed before mission tasks. The second Water-Based Team Tasks are mission tasks with the purpose to demonstrate autonomy behaviour in some challenges. The challenges consist of Speed Challenge to demonstrate the quality of the path planning and naval engineering of the vehicle, Automated Docking to demonstrate the ability to launch an aerial drone and combine information from multiple sensor systems to make a decision in autonomous mode, Find the Path to demonstrate complex path planning in a crowded area, Follow the Leader to demonstrate dynamic target identification and precise navigation, and Return to Dock to demonstrate the ability to navigate back to the launch point without interacting with any obstacles.

## II. Design Strategy

The second section of this paper is design strategy that explains about the steps of how Nala VS made. The process of Nala VS started with research, design requirements, preliminary design, detailed design, and then production plan.

Since 2012, research on catamaran-hull type and trimaran-hull type has been carried out. Based on the research, the team discovered that catamaran-hull type is the most suitable for the design requirements. Catamaran mode might have drag or resistance smaller than those of monohulls at the same displacement[1]. And also this catamaran hull design is suitable for both stability and maneuverability.

The preliminary design is needed to answer the design requirements. The missions given by AUVSI Foundation International RoboBoat Competition require the ships have large volume, good stability, and maneuverability such as having a wide deck and good maneuverability at the same time to accomplish different mission.

After preliminary design, the team focuses on detailed design and production plan. The process provides mechanical systems that support the electrical system to work better. This is the role of the technical division of the team. The technical division is divided into Mechanical and Electrical-Programming. The mechanical division has a responsibility to build and control the boat physicly. The members of this division are from Marine Engineering and Naval Architecture and Shipbuilding Engineering. On the other hand, Electrical-Programming division members mostly consist of Electrical and Informatics Major. This division creates the brain of the boat so the ordinary boat is able to become an autonomous boat which can run automatically.

## III. Vehicle Design

This section represents vehicle design used in Nala VS that generally consists of mechanical and electrical-programming systems. The mechanical system manages hull design and propulsion whereas electrical-programming system manages the block diagram and drone system.

### A. Hull Design

The hull design applied by Barunastra Roboboat ITS Team is a Catamaran flat-side inside. This design avoids planning condition during its operational time. The wave interferences that cause turbulence wave flow avoided by flat-side inside hull design. By using a catamaran design, the load area and stability of boat is increased. A research on ship block construction method has been carried out for three months and the team discovered that this method in constructing the ship increases transverse strength, makes the connections act as watertight bulkheads, and makes the boat easily carried.


Fig. 1. Nala VS

Figure 1 above shows the catamaran-hull style Nala VS with the block system construction.

The catamaran type boat hull construction has many advantages over the conventional types of hull construction such as flat-bottomed or V-bottomed boat hulls. Some of the advantages of the catamaran type of boat hull construction include both increased safety and a smoother ride. Additionally, the catamaran of boat hull construction is quite well adapted for high speed running in choppy waters[2].

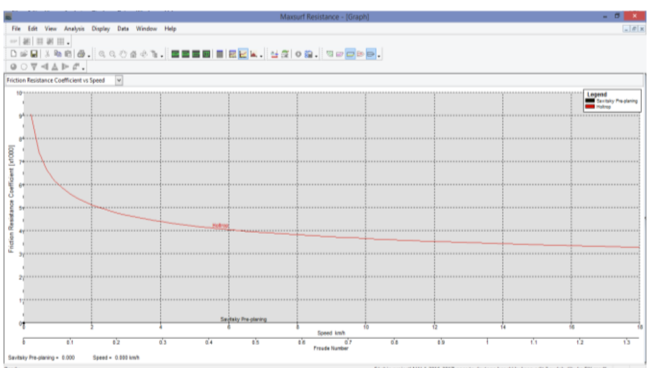

Fig. 2. Analysis of Friction Resistance VS Speed

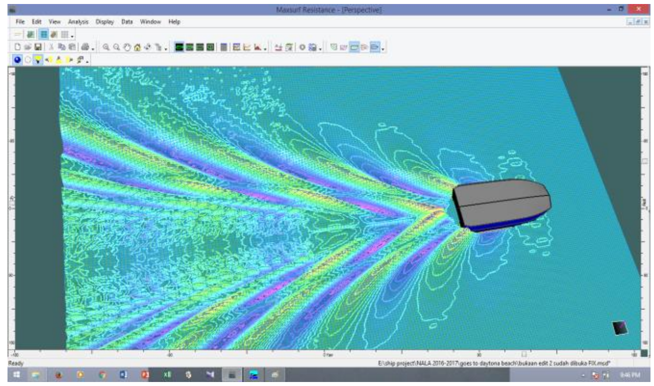

Fig. 3. The waves produced during simulation using Maxsurf Resistance Software.

Maxsurf resistance software is used for analyzing the simulation of Nala VS. The analysis method uses Savitsky pre-planning method and Holtrop method. Obtained wave flow and the graph of ship resistance versus speed is shown as result. During simulation, the speed is set at 3 knots with a froude number of 0.4.

In terms of seakeeping, multihull vessels also demonstrate better characteristics on heave, pitch, and roll motions. Both commercial softwares (i.e., Maxsurf and ANSYS AQWA) show similar results on the estimation of ship's seakeeping[3].

This is the final hull spesification of the ASV shown by Table 1 below:

Table 1.

FINAL HULL SPECIFICATION OF THE ASV SHOWED BY ITS HYDROSTATICS AT DWL

| NO. | MEASUREMENT | VALUE | UNITS |
|---|---|---|---|
| 1 | Displacement | 23.24 | kg |
| 2 | Volume (displacement) | 23235.2 3 | cm^3 |
| 3 | Draft Amidships | 9.08 | cm |
| 4 | Immersed depth | 9.08 | cm |
| 5 | WL Length | 144.42 | cm |
| 6 | Beam max extents o | 70.29 | cm |
| 7 | Wetted Area | 7189.17 | cm^2 |
| 8 | Max sect. area | 207.92 | cm^2 |
| 9 | Waterplane Area | 4094.05 | cm^2 |
| 10 | Prismatic coefficient (Cp) | 0.774 | |
| 11 | Block Coefficient (Cb) | 0.252 | |
| 12 | Max Section Area Coefficien | 0.326 | |
| 13 | Waterplane Area Coefficient | 0.403 | |
| 14 | LCB Length | -1.84 | from z |
| 15 | LCF Length | -4.51 | from z |
| 16 | LCB % | -1.275 | from z |
| 17 | LCF % | -3.126 | from z |
| 18 | KB | 5.72 | cm |
| 19 | KG Fluid | 0.00 | cm |
| 20 | BMt | 124.62 | cm |
| 21 | BML | 240.05 | cm |
| 22 | GMt corrected | 130.34 | cm |

| NO. | MEASUREMENT | VALUE | UNITS |
|---|---|---|---|
| 23 | GML | 245.77 | cm |
| 24 | KMt | 130.34 | cm |
| 25 | KML | 245.77 | cm |
| 26 | Immersion (TPc) | 0.004 | tonne/c |
| 27 | MTc | 0.001 | tonne. |
| 28 | RM at deg = GMt.Di | 52.85 | kg.cm |

Table 1 shows the final specification of Nala VS taken from maxsurf calculations.

### *B. Propulsion*

Nala VS uses a rudder and propeller propulsion system. This Autonomous Surface Vehicle (ASV) uses two propellers, each located at the stern of each hull. By using two propellers, speed increased significantly. The maneuverability of this boat, pattern of motion, and boat stability becomes controllable because the using of two propellers at the stern of each hull. This propulsion system improves Nala VS' ability to do a 180 degrees turn and helps this boat to be able to do a perfect U-turn.

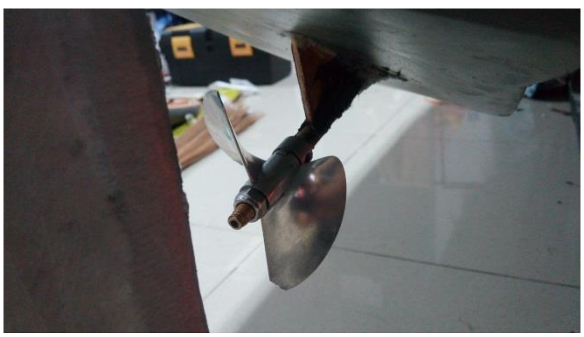

Fig. 4. Two blades propeller of Nala VS made of aluminum.

Fig. 5. Steering system of Nala VS using two rudders installed right behind each of the propeller.

The propeller specification is a two-blade propeller with 76 mm diameter and a stern tube with 7 mm diameter. The connection of rod between the propeller and the main motor is a fixed shaft with a diameter of 6.35 mm and length of 280 mm. The steering system of Nala VS uses a rudder right behind each propeller. The benefit of using two rudders is to increase wet surface area that maximizes boat maneuverability. Rudder specification is 280 mm long and 70 mm wide.

### *C. Block Diagram System*

The Block Diagram System used in Nala VS is represented by the figure below:

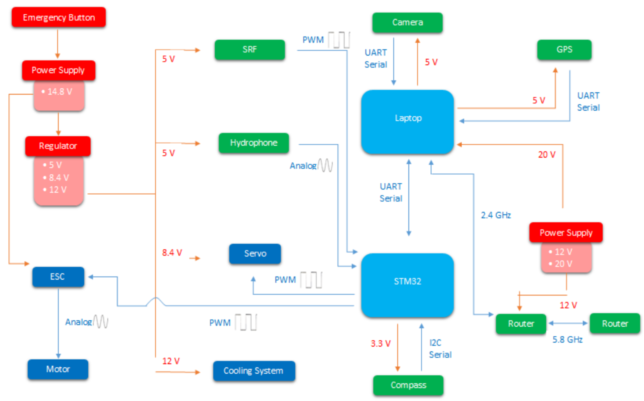


Fig. 6. Block System Diagram

Figure 1 shows the Block Diagram System used in Electrical System of Nala VS. This system explains communication flow of the boat. The electronic system is divided into four parts. There are input system as data source, processing system that's function is to process the input to be output, output system as the process result, and supply system that supports other system work.

The systems and their components are listed below:

### *1. Supply System*

Supply system is a system that give power to support other systems. The supply system used in Nala VS consists of:

a. Power Supply 20V

*This* power comes from laptop's battery to supply the laptop.

b. Power Supply 14.8V

The 14.8V power supply comes from a 4-cell Lithium Polymer battery to supply almost all the components in the boat.

c. Power Supply 12V

The 12V power supply is that to specifically supply the router.

d. Regulator

The regulator has a function to decrease the voltage of the battery from 14.8V to other 5V, 8.4V, 12V voltages making all the voltage needs fulfilled.

e. Emergency Button

The emergency button is a button available for emergency conditions (e.g., leakage or sinking), which needs all the electricity supply in the boat to be cut off as soon as possible. The greatest function of emergency button is avoiding any short circuit possibilities.

### *2. Sensor System*

The sensor system is a system that is used to read the input data and send it to the processing system. The system consists of:

a. SRF

The SRF is an ultrasonic distance sensor. Nala VS uses SRF type SRF-04 that can detect the distance of an object using an ultrasonic wave at 40KHz. The SRF generates an ultrasonic wave from the echo pin which is echoed back and captured by the trigger pin. From the echo, the data of the distance between the sensor and a specific object is created. This sensor will be used in the second and third mission.

b. Camera

The camera used for image processing is by its pixels. As a sensor, the camera collects data in the form of color and shape differences. The implementation in the boat is for the first and third mission task.

c. GPS (Global Positioning System)

The device shows boat position globally by its longitude, latitude, and height. Mainly, it used in the second mission and also to direct the boat to commute from one mission to another.

d. Compass

The compass colaborates with the GPS to show the boat's direction accurately in a range $0^{o}$-$360^{o}$. It is used in the first and second mission and also to commute the boat.

e. *Pinger Detector*

The fourth mission in AUVSI Foundation International RoboBoat Competition is to read the frequency created by the provided pinger. Nala VS uses a hydrophone to catch the frequency. A hydrophone is a device that functions as an underwater microphone to distingush signal frequencies then sends it to the microcontroller to be processed.

The overall specification of Nala VS Pinger Detector are Hydrophone type H2a-XLR, amplifier named ANEDEC that is handmade by Barunastra Roboboat ITS Team, microcontroller type STM32F429, and supply system from 4 9V battery plus a 5V Power Bank.

Hydrophone is used as a sound sensor. The sound changes the hydrophone capacitance and makes the bias circuit voltage also change. The bias circuit voltage changes variance is microvolt, so in order to process it to the microcontroller, Nala VS needs an audio signal amplifier. It uses a TL-082 op amp IC as the amplifier. In order to reduce unnecessary frequency, RC low pass filters and high pass filters are also needed. Here is the schematic and board design:

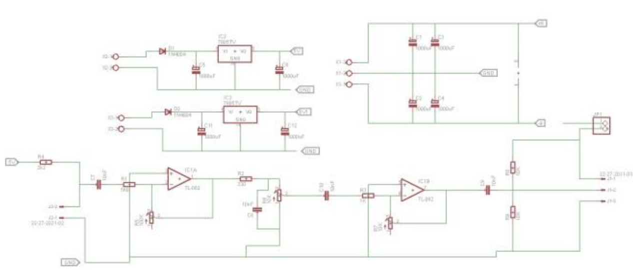

Fig. 7. Hydrophone Amplifier Circuit Schematic

Figure 2 shows the schematic of Hydrophone Amplifier Circuits of Nala VS. From this schematic, the team creates the design board that is shown in the figure below:

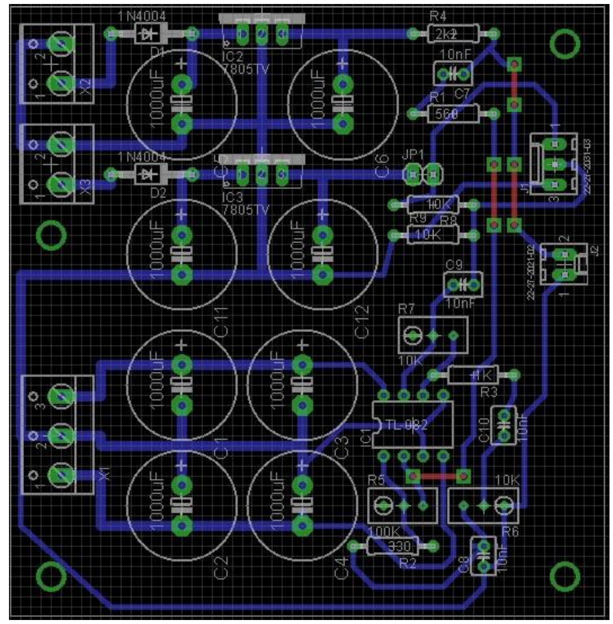


Fig. 8. Hydrophone Amplifier Board Design

Based on Figure 3, it can be concluded that Hydrophone Amplifier Circuit is the unity of small components and builds a board used in Nala VS. The Hydrophone Amplifier Circuit can be broken down into some parts listed below:

- First Stage Amplifier

Schematic of First Stage Amplifier can be seen in the figure below:

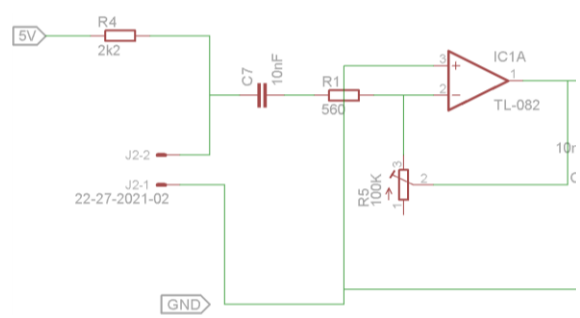


Fig. 9. First Stage Amplifier

In the first stage, the hydrophone sensor must be biased due to the equivalent component of H2-a hydrophone. The node between the hydrophone and bias resistor is called V_in. Then, the signal goes passed through the High Pass Filter Capacitor before entering Op-Amp. High Pass Filter blocks DC signal so DC signal information will not be amplified which will cause the output of the Op-Amp to be positively saturated. It ensures that only the high frequency signal will be amplified. The output of the First Stage Amplifier is called V_o1. Amplifier Gain from First Stage Amplifier is calculated by the formula below:

$$V_{o1} = -\frac{R_{f1}}{R_{i1}} Vin \quad (1)$$

Where:

$R_{i1} = 560\Omega$

$R_{f1} = 100k\Omega$

- Low Pass Filter (LPF)
  Low Pass Filter is figured by the schematics below:

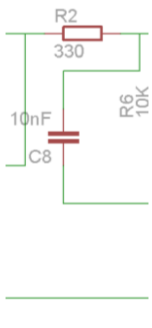


Fig. 10. Low Pass Filter

The Low Pass Filter used in the circuit is to block the undesired high frequency signals so high frequency noise signals will be reduced for the next stage amplifier. The LPF input is $V_{o1}$ and the output is $V'_{o1}$. The frequency response of RC Low Pass Filter and the cut-off frequency are calculated with formula below:

$$V'_{o1}(s) = \frac{1}{1 + R_{LPF} C_{LPF} s} V_{o1} \quad (2)$$

$$f_c = \frac{1}{2\pi R_{LPF} C_{LPF}} \quad (3)$$

Where:

$R_{LPF} = 330\Omega$

$C_{LPF} = 10nF$

- Voltage Divider
  The voltage divider is illustrated by the schematic below:

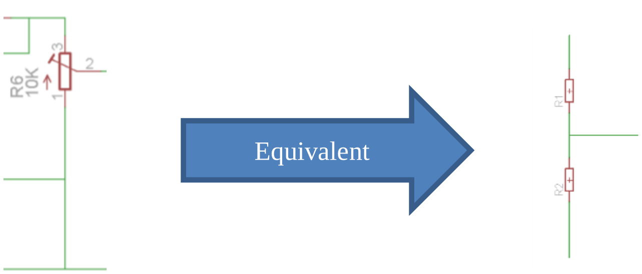


Fig. 11. Voltage Divider

The voltage divider is used to tune how high the amplitude of $V'_{o1}$ as the input to the Second Stage Amplifier. The output of the Voltage Divider is $V_{in2}$. The reduction equation for the Voltage Divider is:

$$V_{in2} = \frac{R_{vd2}}{R_{vd2} + R_{vd1}} V'_{o1} \quad (4)$$

- Second Stage Amplifier
  Second Stage Amplifier is shown in the figure below:

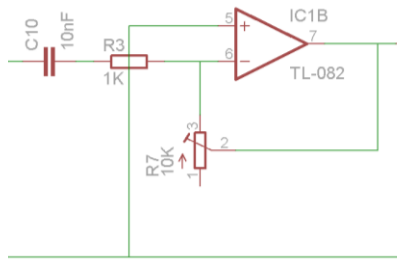


Fig. 12. Second Stage Amplifier

Just like the first stage amplifier, the configuration of this amplifier is the same as the first stage. This configuration is called Inverting Amplifier. The equation for this stage amplifier is:

$$V_{o2} = -\frac{R_{f2}}{R_{i2}} Vin2 \quad (5)$$

- Offset Bias
  Offset Bias has a schematic like the figure below:

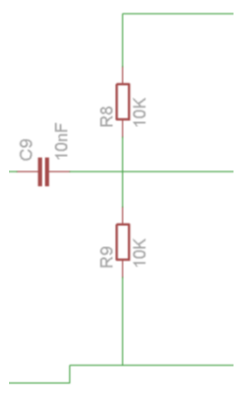


Fig. 13. Offset Bias

Offset bias is used to give 2,5 volt offset so the negative part and positive part of the sinusoidal signal from the hydrophone becomes a positif value, so this signal $V_{out}$ can be captured by the microcontroller Analog to Digital Converter (ADC). The equation for this bias circuit is:

$$V_{out} = \frac{R_{Bias}}{R_{Bias} + R_{Bias}} V_{Supply} + V_{o2} \qquad (6)$$

*E.g.* If the value of $V_{supply}$ becomes 5, the value of $V_{out}$ changes into something difference.

$$V_{out} = \frac{R_{Bias}}{R_{Bias} + R_{Bias}} (5) + V_{o2}$$

$$V_{out} = \frac{\frac{R_{Bias}}{1}}{2} (5) + V_{o2}$$

$$V_{out} = 2{,}5 + V_{o2}$$

After the signal has been amplified, the pinger signal can be processed to the microcontroller. The analog signal is sampled using ADC. The team put the ADC value to array variable and then process the data using Fast Fourier Transform (FFT) to have the frequency and power magnitude of the Pinger Sound Signal. Finally, the result of this process is sent to the PC with UART serial communication.

f. Router

The router is a communication device from boat to land and server. It provides the boat in the water to communicate with the server by request and response.

*3. Processing System*

Processing System is a center of data processing that consists of:

a. Laptop

The laptop is used to process big data which can not be processed by STM32 directly. The data are from the GPS and camera for image processing using library OpenCV. All data processed by the laptop will be sent to STM32.

b. STM32F407

The STM32F407 is a 32-bit microcontroller from STMicroelectronics. The function is to process input data from laptop, SRF, Hydropphone, and Compass then make decisions on what the boat should do.

*4. Output System*

The output system used in Nala VS consists of:

a. Servo

The servo is a rotary actuator that is used for turning the rudder and navigating the boat.

b. Electronic Speed Control (ESC)

Supplied from the battery and taking data from the STM32 in the form of Pulse Width Modulation (PWM), the Electronic Speed Control (ESC) has a function of setting the boat’s speed.

c. Motor

The motor provides the boat to move forward or backwards easily.

*D. Drone System*

The drone system used in Nala VS has specificiations such as DJI F450 frame type, APM 2.8 Flight Controller, uses GPS UBLOX M8N, and uses a 2212 920KV type brushless motor. The ESC used is Simonk 30A and the type of the microcontroller is STM32F407VG. The propeller used in this drone is made of carbon with the size of 10x4.5”.

## IV. Experimental Result

The team regularly simulates Nala VS both in land-based trials and water-based trials. Trials have a purpose of preparing the boat for the real competition. Nala VS does land-based trials in order to prepare and make sure that the boat is safe for water-based trials. The water-based trial has a function to simulate Nala VS in facing obstacles similar to those it the real competition. Before doing the water-based trial, Nala VS must pass the land-based trial to check whether or not the new program or algorithm is correct.

After conducting several trials, Nala VS has reached progression (i.e., way point GPS method, navigation system combining compass and GPS, position and area mapping using software QT Designer, image processing, and receive frequency that pinged by pinger underwater. There are some process left to be done such as integrating image processing with way point method.

## V. Acknowlegments

The participation of Barunastra Roboboat ITS Team in AUVSI Foundation International RoboBoat Competition 2017 is possible due to the support from many parties. The first is ITS who gave us support both in moral and facilities to do research, development, and trial of Nala VS. The team has some sponsors that support the financial need. The sponsors are Pertamina Gas, *Pelayaran Nasional Indonesia* (Pelni) or Indonesia National Shipping, *Biro Klasifikasi Indonesia* (BKI) or Indonesia Classification Society, and Spectrum. Pertamina Gas is a midstream and downstream gas industrial company in Indonesia. Pelni is Indonesian national shipping company. BKI is the only one national classification society in charge of making the class rules for Indonesian-flagged and foreign-flagged commercial vessels regularly operating in Indonesian waters. Then, Spectrum is local digital printing located in Surabaya, Indonesia.

## VI. References

[1] Setyawan, D. *et. al*. (2010, Nov). Development of catamaran fishing vessel. *The Journal fo Technology and Science*.[Online]. *21(4)*. pp. 167-174. Available: iptek2.its.ac.id/file/Development%20of%20Catamaran%20Fishing%20Vessel.pdf

[2] Catamaran boat hull construction, by N.R. Hesher Etal. (1962, Dec 11). *Patent 3,067,711* [Online]. Available: www.fiberglassics.com/library/images/5/51/Duopatent.pdf

[3] Luhulima, R. B. *et. al.,* "Selecting monohull, catamaran and trimaran as suitable passenger vessels based on stability and seakeeping criteria", presenterd at The 14th International Ship Stability Workshop (ISSW), Kuala Lumpur, Malaysia, Sept. 29-Oct. 1, 2014.