Study on The Development of Guidance System Technology for 122-140 mm Artillery Rocket

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Abstract

The increase in artillery rocket accuracy means there will be fewer rockets to be used to destroy a target. This could reduce the needed budget and risk of weapon mobilization. Therefore, this research investigates the advancement in the guidance system technology for Artillery rockets, especially for 122-140 mm caliber. The objective of the research is to find a direction for the development guidance system for the Indonesian artillery rocket (RHAN). The research uses descriptive-analytic method, in which data was collected from literature studies and inductive analysis was performed. The data shows two kinds of actuators were used, a canard and thrusters. In canard mode, 2 strategies were used, i.e. with bearing to isolate the roll from the rocket, in which 5 control algorithms were used, and without bearing, which 2 control algorithms were used. In thruster mode, there was 5 control algorithms used. Further analysis shows that the best performance is obtained from 2 modes of the canard strategy with bearing, and 2 modes of the thruster strategy. Therefore, it is concluded that the 4 modes can be used to be implemented in RHAN which needs to be added to the control system.

Keywords: *MRLS, Rocket, Control system, Canard, Thruster, Circular Error Probable.*

1. Introduction

The R-Han 122B rocket is a 122 mm caliber rocket with a maximum firing range of 29 km developed by the National Rocket Consortium to replace the MLRS (Multiple Launch Rocket System) Grad and Vampire munitions currently used in the Indonesian Navy Marines. This consortium consists of the Ministry of Defense, PT Pindad, PT Dahana, PT DI, and LAPAN. In 2019 the R-Han 122B rocket obtained an airworthiness certificate for the Artillery Ground to Ground Rocket military air weapon category, which was issued by the Feasibility Center, Defense Facilities Agency, Ministry of Defense of the Republic of Indonesia (Sutrisno, 2019). By obtaining the airworthiness certification, the R-Han 122B rocket has met the standard to be used by the TNI.

In addition to marine units, MLRS is also used by Armed TNI-AD units. The MLRS used by Armed units is Astros II purchased from Brazil. MLRS Astros II has several types of rockets, including the SS-30 (127 mm caliber), SS-40 (180 mm caliber), SS-60 (300 mm caliber), and SS-80 (300 mm caliber), each with shooting ranges of 30 km, 40 km, 60 km, and 80 km. With the ability to manufacture the R-Han 122B, the Astros II rocket with various calibers will also be made domestically.

The MLRS rocket is basically a ballistic rocket, which flies without a control system. So that it can be affected by several disturbances that ultimately affect the rocket's drop point, including: rocket propellant manufacturing quality, inaccurate positioning of the center of mass of the rocket, deflection of the launch 'rail', nozzle quality, wind conditions, and inaccuracy of fin installation. Figure 1-1 shows the results of one of the studies on the contribution of imperfections and disturbances to the rocket to the point of fall (disperie) (O. S. Dullum et al., 2017)

The MRLS rocket control system has undergone significant developments. One of them, in 2000 the US Army Aviation and Missile Command demonstrated the application of technology to increase the accuracy and range of the MLRS. The addition of a guidance and control package results in a weapon system that can destroy targets at a range of up to 70 km with significantly fewer munitions. This not only increases the system's destructive capabilities but also reduces the ammunition costs incurred in manufacturing and transporting ammunition to the battle zone. The control module is located at the nose of the MLRS rocket and consists of an Inertial Measurement Unit (IMU), four electro-mechanically actuated canards, GPS, thermal battery, guidance computer, and power supply system. (Jenkins, 2000)

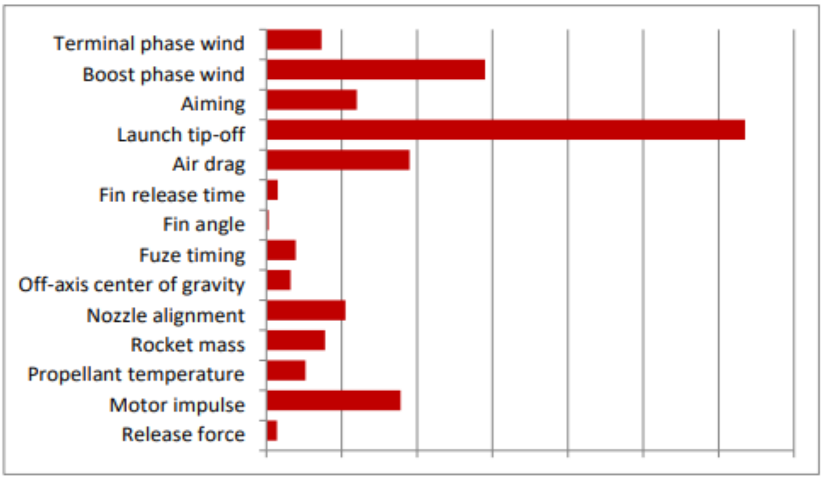

Figure 1-1: The relative contribution of imperfections and disturbances in the rocket to the dispersion of (O. S. Dullum et al . 2017)

The R-Han 122B rocket that has been developed at this time is an uncontrolled ballistic rocket. To improve the accuracy of the R-Han 122B, it is necessary to study the use of the control system on the rocket. This study uses a descriptive qualitative research method, which is a research method used to describe an object's natural condition, where the position of the researcher as the key instrument. The objective of the research is to find a direction for the development guidance system for the Indonesian Artillery rocket (RHAN). The increase in rocket Artillery accuracy means there will be fewer rockets to be used to destroy a target. The data collection technique is done by triangulating data (combined), data analysis is inductive, and the results of qualitative research emphasize meaning rather than generalization.

2. Methodology

The literature review method was used to obtain data. by using the keywords thrusters and canard rocket control systems, and the criteria for control rockets around the 122-140 mm class, the data obtained in the form of the results of the development of rocket control system technology around the 122-140 mm class.

During the last ten years, there have been many publications related to control systems for artillery rockets of 122 mm to 140 mm caliber. From these publications in general there are two types of control systems that can be used for artillery rockets. The first control system is to use a movable canard (Gligorijević et al., 2016)(Guo et al., 2016)(Kumar et al., 2017)(Pavkovic et al., 2012)(Shi et al., 2018)(Yang, 2020)(Zhang et al., 2016)(Zhou et al., 2016), and the second is to use a thruster (Gao et al., 2016)(Głębocki & Jacewicz, 2020)(Ozog et al., 2020)

2.1. Control System Using Canard

The canard control system is a control system that uses movable fins that are placed on the front of the rocket. (see Figure 2-1).

From the literature study, several categories of canard control system applications were obtained. The first category is applied to a rolling airframe without a roll bearing between the warhead and the rocket motor. In this category, the canard rotates with the entire body of the rocket. The second category is applied to rolling airframes with roll bearings between the warhead and the rocket motor. In this category the canard and warhead do not rotate, while the rear of the rocket rotates. The third category is for application to non-rolling airframes. In this category the canard and the entire body of the rocket do not rotate. The fourth category is for application to rolling and non-rolling airframes.

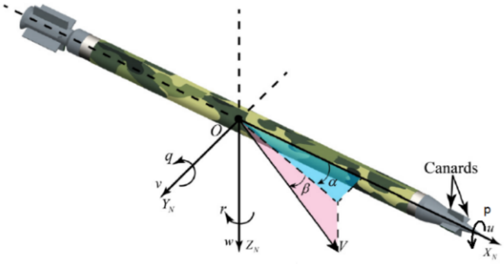

Figure 2-1: u, v and w are the translational velocities and p, q and r are the rotational velocities of roll, pitch and yaw. (Shi, 2018)(Zhao, 2018)

2.1.1 Applications on Rolling Airframes Without Roll Bearings

The use of canards in warheads for rolling airframes without roll bearings between warheads and rocket motors has been researched by (Shi, 2018). This study discusses the potential use of robust adaptive control to improve stability and autopilot performance for 122 mm caliber rockets whose control system rotates with the rocket. In a rotating rocket, there will be uncertainties in aerodynamics and thrust (Z. Shi et al., 2018). To overcome this problem, a robust autopilot adaptive output feedback control design was made. In this study, the flight phase was divided into three, namely the boost phase, the free flight phase and the guided phase. The autopilot system here works only in the guided phase. From the simulation results, it can be seen that the algorithm created can guide the rocket to follow the given acceleration command and give a zero value for tracking error. This adaptive controller also works well in conditions of interference due to yaw and pitch coupling and in conditions of loss of control effectiveness. This adaptive controller also works well even though the gyroscope yaw and pitch is given noise.

Then (Zhao, 2018) published the implementation of feedback adaptive control output to improve the stability and autopilot performance of 122 mm caliber rockets in a spin state. This method is used to overcome uncertainty in control effectiveness and moment coefficient. A new method was developed for synthesizing the autopilot acceleration of a spinning rocket. Using square-up theory and linear matrix inequality (LMI) in autopilot adaptive output feedback design. Uncertainty in control effectiveness and moment coefficient is a challenge in rocket control. Adaptive control is an appropriate method for the problem of uncertainty in control. In this study, a non-linear dynamic model and coupled 6 DoF were created to simulate the autopilot that was made. From the simulation results, it can be seen that the autopilot system is stable in tracking even though there is a variable uncertainty factor. (Zhao, 2018)

The two studies above are only limited to partial simulations so that the performance of the control system on rocket dispersion has not been tested

2.1.2 Applications on Rolling Airframes with Roll Bearings

The use of canards in warheads for rolling airframes with roll bearings between warheads and rocket motors was carried out by Mingereanu (Mingereanu et al., 2014). In this study, the concept of terminal guidance for a 122 mm artillery rocket uses the predicted impact point (PIP) algorithm. This study also observed the effect of ignition delay in the center of the thrust curve of the rocket motor (with the same total impulse) on the firing range of a 122 mm artillery rocket equipped with terminal guidance. The autopilot system used is based on accelerometer, gyroscope and GPS sensor data. The autopilot system starts to activate after the rocket fuel burns out, this is to avoid damage to electronic components from high acceleration when the rocket motor burns.

First, the autopilot will instruct the canard to de-roll the warhead (with the rest still rolling). Next the autopilot will keep the attitude of the rocket stable until the rocket reaches apogee. When the rocket has reached apogee, the autopilot will work to control the rocket towards the target based on the PIP algorithm. From the research of giving the ignition delay in the middle of the thrust curve of the rocket motor, it can be seen that the distance of the rocket can be increased by 20%. However, this paper does not discuss in detail how to provide ignition delay in the middle of the thrust curve of the rocket motor. The research is only limited to partial simulations so that the performance of the control system on rocket dispersion has not been tested.

In the following year (Guo et al., 2016) published a trajectory correction control system on a 122 mm artillery rocket, with a control system in the form of a pair of canards on the warhead (see Figure 2-2). Trajectory correction is carried out using two algorithms according to the flight phase, namely in the rocket phase to apogee (ascending) and at the time after the rocket passes apogee (descending). When going to the apogee, the transverse guidance law is used, while after passing the apogee, the proportional guidance law is used. In this research, hardware test was conducted with loop simulation system. Hardware tested is a control system which includes onboard computer, actuator from canard and guide system algorithm. From the results of one simulation, with this control system, the lateral deviation of the rocket drop is 4 m and the longitudinal deviation is 1 m, while without the control system, the lateral deviation of the rocket drop is 533 m and the longitudinal deviation is 673 m. After the monte-carlo analysis, statistically the CEP (Circle Error Probable) of the rocket is 4.1 m for the rocket with the control system and 446.3 m for the rocket without the control system. (Guo et al., 2016)

Later in the same year, (Mandic, 2016) also published about the flight path steering (FPS) and instantaneous impact point (IPP) control systems on artillery rockets equipped with canard control systems (see Figure 2-2). In this publication there is no mention of the caliber of the rocket used, but the firing range is 40-50 km. The control system used consists of IMU, 4 canards, GPS and computer. This control system is located on the warhead where the warhead with the rocket motor is connected to the roll bearing. The flight path steering guiding algorithm is used when the rocket goes to apogee. At this time the rate of change of the angle of the flight path is kept constant. In apogee the guidance algorithm is changed to an instantaneous impact point where the rocket is guided to a predicted drop point. What is new from this research is that the control system algorithm that is designed can also overcome the occurrence of total impulse deviation, thrust, eccentricity of thrust and wind. The focus in this research is on these factors. From the simulation results for artillery rockets at a distance of 50 km where if there is a total impulse deviation of 4%, dispersion can occur as far as 3 km, then using the control system algorithm in this study the dispersion distance is only 12 m. (Mandic, 2016)

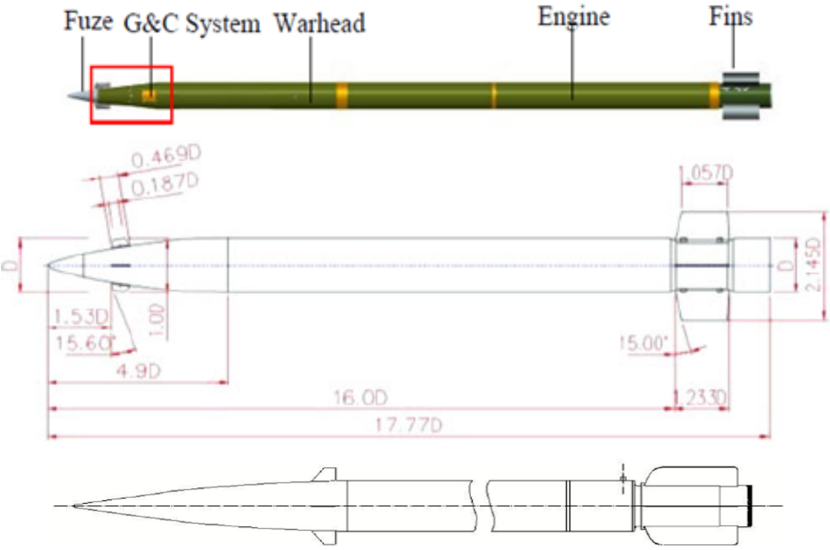

Figure 2-2: From top to bottom are the rocket models in the research of

(Guo et al., 2016)(Mandic, 2016)(Zhiyuan Guo, 2016)

Furthermore, (Zhiyuan Guo, 2016) published research on the effect of aerodynamic uncertainty and thrust on the robust stability of the algorithm in controlling 122 mm caliber rockets during cruising. In this paper, it is assumed that the flight phase of the rocket is divided into three, namely the boost phase, the cruise phase and the controlled phase. In the research, the rocket motor used has a booster and a sustainer in one chamber, where in the cruising phase the rocket's flight height is maintained constant by the global autopilot system using a gain scheduling technique based on time as a parameter. (Zhiyuan Guo, 2016) From the simulation results, it can be seen that the designed autopilot is robust and not affected by noise from measurements and the condition of the rocket during flight. With the addition of simple controls, the rocket can be maintained to fly at a constant altitude. The research is only limited to partial simulations so that the performance of the control system on rocket dispersion has not been tested.

(De Celis, 2017) conducted research on dynamic modeling, control design and algorithms for control systems of 140 mm caliber artillery rockets with spin (Figure 2-3). This study discusses discrete-time guidance and control algorithms based on proportional navigation. A complete non-linear simulation model is created that represents the real state when the rocket flies. Stability is achieved through very high spin (hundreds of turns per second, 150 Hz). There is a roll bearing so that the warhead does not rotate. From the simulation results the control and navigation system works well with the created method. The CEP value is reduced by 90% compared to unguided rockets.

One year later, de Celis (2018a) published research on the use of hybrid algorithms to combine measurements from sensors such as the Global Navigation Satellite System (GNSS), IMU and semi active laser quadrant photodetector (SALK) in a modified proportional control system. The rocket used is the same as in (Raul de Celis, 2017). In this study, the CEP values were compared for unguided rockets, rockets with GNSS/IMU, and rockets with GNSS/IMU/SALK. Guided rockets with GNSS/IMU/SALK had the smallest CEP where the CEP reduction was 95%. (de Celis, 2018b) also discusses the combination of the hybrid attitude determination method with gravity vector estimation. The accelerometer, GNSS, and semi-active laser quadrant photodetector (SALK) measurements were combined. The use of the novel attitude determination method, without the use of the rotation determination method through a gyroscope. The rocket used is the same as that of Raul de Celis in 2017. From the simulation, it can be seen that the algorithm made works well. Simulations were carried out for the aerodynamic coefficient error of 0%, 5% and 7.5%. Guided rockets with GNSS/accelerometer/SALK had the smallest CEP where the CEP reduction reached 99% for the 0% aerodynamic error case, 97% for the 5% case and 87% for the 7.5% case. (De Celis, 2018b)

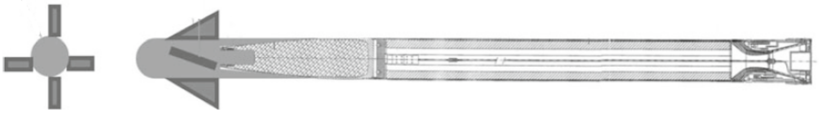

Figure 2-3: The 140 mm caliber rocket model in the research of (de Celis. 2017, 2018a) and (Lopez. 2019).

The latest research related to this type of canard modification was carried out by Lopez (2019). In his research, an inertial, GNSS sensor has been combined with a low-cost quadrant photo-detector [SALK] sensor for use in terminal guidance. The rocket used is the same as in (de Celis, 2017). In this study, the CEP values were compared for unguided rockets, rockets with GNSS/IMU and rockets with GNSS/IMU/SALK. Guided rockets with GNSS/IMU/SALK had the smallest CEP where the CEP reduction was 95%.

2.1.3 Applications On Non-Rolling Airframes Without Roll Bearings.

The application of using canards in warheads for non-rolling airframes without roll bearings between warheads and rocket motors (Siddiq et al., 2012). Research on the autopilot roll design of the 122 mm artillery rocket uses the State-Dependent Riccati Equation (SDRE) technique. In this study the rocket was controlled after the flight phase, where the rocket fly ballistic, and the spin of the rocket was reduced due to the damping of the fins. In this phase, the roll of the rocket is made to zero with the autopilot roll. The autopilot roll made in this paper does not match the yaw and pitch motion. The advantage of this autopilot design is that the elements of the SDRE matrix are chosen to produce a robust autopilot roll, so that the autopilot roll can operate in various conditions. Simulations were carried out at a shooting elevation angle of 50°, initial roll orientation of 90°, 122°, 150°, and 180° and at a flight height of 4000 m, 6000 m, and 7000 m, which shows that the autopilot roll that has been designed works well. In this study, the partial simulation has not shown the effect of this autopilot on the accuracy of the fall of the rocket.

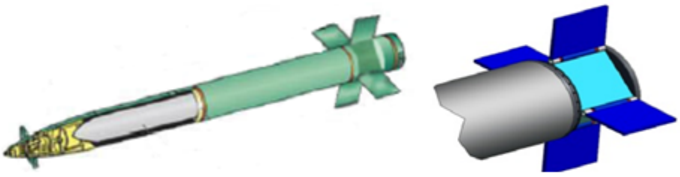

Figure 2-4: The 122 mm caliber rocket model (Siddiq et al., 2012, 2013).

In the following year (Siddiq et al., 2013) published a roll, yaw and pitch integrated autopilot design of a 122 mm artillery rocket using the SDRE technique. The method used is the same as in previous studies, where in the ballistic flight phase the rocket roll is made to zero through canard deflection with an SDRE-based autopilot roll. Once the rocket rolls to zero, it activates the integrated autopilot roll, pitch and yaw. This study also simulates the falling point of the rocket which shows that the dispersion of the rocket with the autopilot system is significantly reduced compared to that without using the autopilot (unguided). From the simulation the distance dispersion is reduced from 1132 m for unguided rockets to 164 m for guided rockets.

2.1.4 Applications On Rolling and Non-Rolling Airframes

The use of canards in the warhead, for rolling and non-rolling airframes is carried out by (Yang, 2020), who uses a control system with a cyclic control concept and uses an impact point prediction control system based on target tracking for 122 mm caliber rockets. The number of canards used for rocket control is 3 units (see figure 2-5), in addition to reducing mass, it also provides controllability in vertical and horizontal directions. The dynamic model used is a non-linear 6 DoF model. From the simulation results, the cyclic control system works well and gives a CEP of 4.25 m compared to the unguided rocket which has a CEP of 219.5 m. This paper also compares the performance of the control system studied with proportional navigation. From the results of the case study, the miss distance

Figure 2-5: Model 122 mm caliber rocket. (Yang, 2020)

2.2. Thruster Control System

Thruster is a set of thrusters that are placed around the rocket and produce thrust in a short time in the direction normal to the axis of symmetry of the rocket. This thruster is used to control the behavior of the rocket to follow commands from the control system.

(Pavkovic et al., 2012) published about the application of a pulse-jet control system for correction of artillery rocket flight paths. The control method used is trajectory tracking with pulse-frequency modulation (TT with PFM). This control scheme consists of two phases, the moment after the combustion of the rocket motor and when the rocket passes through the apogee. As a comparison for the performance of this guidance method, it is compared with the window-based trajectory tracking guidance method. Both of these methods use the same hardware but differ in algorithms. The simulation model used includes disturbances in roll, pitch, yaw, total impulse, thrust misalignment and wind. The model used for the simulation is a 262 mm caliber rocket with a length of 4.7 m. However, this method can also be applied to 128 mm caliber rockets. From the simulation results of 100 samples using the TT guidance method with PFM, the CEP is 5.1 m, whereas if it is unguided, the CEP is 482 m. (Pavkovic, 2012)

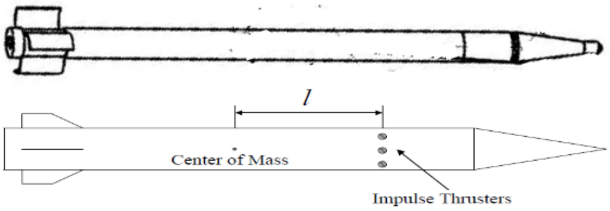

Figure 2-6: (Above) The Hydra-70 rocket in the Burchett publication (2014) and (below) the 122 mm caliber rocket model in the publication Gao (Gao et al., 2015, 2016)

(Burchett, 2014) uses a Taylor Series controller, on a non-linear 6 DOF simulation, and uses a Jacobian matrix inversion to calculate the desired pulse magnitude and direction. In this study, the Hydra 70 rocket (see Figure 2-6) was used for simulation. From the simulation results, it can be seen that there is a reduction in the CEP of unguided rockets by 20 m to 0.4 m for guided rockets.

Gao et al, used a lateral thruster on a 122 mm caliber rocket (see figure 2-6) with an optimal control scheme. The deviation of the falling point of the objective function is optimal, with variations in the timing and angle of thruster ignition. The results of the Monte Carlo simulation show that the uncontrolled rocket has a CEP of 359 m. The CEP is increased to 38 m with the general fire control scheme, and to 20 m with the optimal control scheme. The reduction in CEP and the reduction in thruster fuel consumption proves the optimal effectiveness of the controls used. (Gao et al. 2015)

(Gao, et al., 2016) applied the control of 10 thrusters with a power of 60Ns on a rolling airframe without a roll bearing of a 122 mm caliber rocket. Simulations were carried out to see the trajectory correction capability under conditions of various impulse shapes (square, triangle, trapezoid), maximum thrust, impulse duration and total impulse of the thruster. From the simulation results, it can be seen that the trajectory correction ability has a linear relationship to the total impulse and gets better with increasing the impulse. From the simulation results, it can be seen that the trajectory correction ability has no relationship with the shape of the impulse, the maximum thrust and the duration of the impulse.

(Ozog et al., 2020) published a guide scheme for a 128 mm caliber artillery rocket with a set of thrusters. The method used is trajectory tracking with Pulse Frequency Modulation (PFM) to obtain effective control. The controller starts to activate when the rocket reaches the top of the trajectory. The simulation results show that a significant reduction in dispersion was achieved, i.e. from 141 m for uncontrolled rockets to 24 m for controlled rockets.

(Glebocki and Jacewicz, 2020) conducted a parametric Monte-Carlo study for a 160 mm artillery rocket equipped with a set of solid propellant lateral thrusters, located before the center of mass, with the aim of reducing dispersion and collateral damage. Modification of the path shape in the terminal phase, which demonstrated that the proposed guiding method, can reduce the dispersion by more than 250 times. From the simulation results, the CEP reduction that can be obtained is 96% for the 20o elevation angle and 80% for the 50o elevation angle.

3. Result and Analysis

From the data obtained, the development of control system technology on rockets around the 122-140 mm class can be summarized as follows:

Table 1: Summary of research on artillery rocket control systems

No	Author/ Year	Application	Type of guidance	Rocket/Result/ Dispersion
1	Shi [2018]	Canard, rolling airframe, without bearing.	4 canard units, adaptive output feedback control.	122 mm, partial simulation (not to dispersion).
2	Zhao [2018]		Improved adaptive output feedback control.	
3	Mingereanu [2014]	Canard, rolling airframe, with bearing.	The number of canards is not stated, predicted impact point.	122 mm, partial simulation.
4	Qing-wei Guo [2016]		2 canard units, trajectory corrected, proportional guidance law.	122 mm, distance 33 km, CEP to be 4.1 m from 446 (99%).
5	Mandic [2016]		4 unit canard, flight path steering, instantaneous impact point.	Caliber isn't stated, distance 50 km, Dispersion from 3 km (with noise assumption) to be 12 m (99%).
6	Zhiyuan Guo [2016]		4 canard units, dual thrust, gain sche-duling	122 mm, partial simulation .
7	De Celis [2017]	Canard, rolling airframe, with bearing, high rate spin (150 Hz).	4 canard units, double loop feedback system & modified proportional navigation.	140 mm, CEP reduced 90% to any distance.
8	De Celis [2018a]		4 canard units, double loop feedback system & modified proportional navigation, com-bined sensor.	140 mm, CEP reduced 95% to any distance.
9	De Celis [2018b]		4 canard units, double loop feedback system & modified proportional navigation, hybrid attitude determination with gra-	140 mm, CEP to reduced 99%, 97%, 87% for the case of coefficient error aerodynamics 0%, 5% and 7.5%.

			vity vector estimation.	
10	Lopez [2019]		4 canard units, double loop feedback system & Modified proportional navigation, sensors variation GNSS, IMU, SALK.	140 mm, with combining a GNSS/IMU/SALK to reduced CEP 95%.
11	Siddiq, et al [2012]	Canard, non-rolling airframe, without bearing.	4 unit canard, SDRE; robust roll, pitch, yaw control.	122 mm, partial simulation .
12	Siddiq, et al [2013]		4 unit canard, SDRE; robust roll, pitch, yaw control.	122 mm, CEP reduced from 1132 m to be 164 m (85%).
13	Yang [2020]	Canard, rolling and non rolling airframe.	2,3, or 4 canard with cyclic concepts, stochastic maneuvering model based impact point prediction method, tracking targets.	122 mm, CEP reduce from 219 m to be 4.25 m (98%).
14	Pavkovic, B. [2012]	Thruster, rolling airframe.	Trajectory tracking with PFM, optimization of control logic and pulse.	262 mm & 128 mm, to reduced CEP from 482 m to be 5,1 m (98%).
15	Burchett, B. T. (2014)		Control strategy of symmetrical projectile linear model, predicted impact point.	70 mm, to reduced CEP from 20 m to be 0.4 m (98%).
16	Gao, M., et al [2015]		Trajectory correction with Impact point deviation, optimization of firing phase dan firing time.	122 mm, to reduced CEP from 359 m to be 38 m, and with optimization 20 m (89% & 94%).
17	Gao, M., et al [2016]		Trajectory correction with variations in impulse shape, maximum force, impulse duration and total impulse.	122 mm, partial simulation.
18	Ozog, et al [2020]		Modified trajectory tracking with PFM.	128 mm, to reduced CEP from 141 m to be 24 m (83%).
19	Glebocki, et al (2020)		Trajectory shaping, Augmented impact point prediction.	A 160 mm, CEP reduced 95, 91, 87, 78% for elevation angle 20°, 30°, 40°, 50°.

Source : (Author. 2021)

The most widely used control method is canard, with configurations 2, 3, and 4. In this configuration there are 2 main variants, namely by using bearings to isolate roll from the control system that is in the nose or not (roll from the entire rocket body is stopped). In the thruster control mode, the variations are time, ignition angle, number, and ignition profile. In all implementations, the new control system is activated when the thrust of the rocket runs out, with 2 variants, when the trajectory is still ascending or when it is descending, with the aim of compensating for disturbances (aerodynamics, tip-off, alignment etc.) ideal ballistic trajectory. The reduction impact of each method is shown in Figure 3-1.

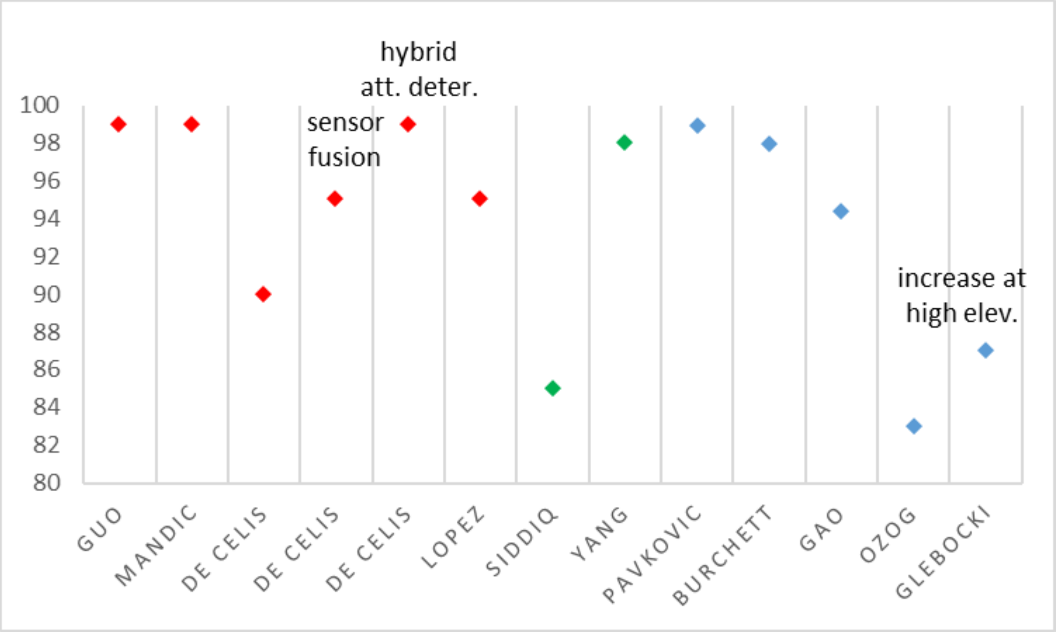

Figure 3-1: CEP reduction due to control implementation (red = canard, rolling AF with bearing, green = non rolling AF, blue = thruster) Source : (Author. 2021)

Based on Figure 3-1 above, it can be seen that on average, the use of the Canard control system on rocket munitions is relatively better than the use of the Thrusters control system. The Canard control system has an average CEP reduction of 96.16%. The use of the Thrusters control system on rocket munitions has an average CEP reduction of 92%.

The difference in CEP reduction in the Canard and Thruster control systems is influenced by the control algorithm and sensors used. Because the publications obtained have not yet reached the implementation (flight test), the selection of the right algorithm from the two modes will be more influenced by the ease of implementation. For the context of RHAN, the use of GNSS as a sensor, for example, must use a multi-satellite system (GPS/GLONASS/Beidu) because there is no single satellite system under Indonesian control. In terms of robustness, from the various simulation conditions in the literature, it can be seen that the canard has a weakness in the variation of the aerodynamic error coefficient. Where with a variation of 0%, 5% and 7.5% error obtained a decrease in CEP reduction from 99%, 97%, and 87%. While the thruster has a sensitivity to variations in firing angle, where with elevation angles of 20^o, 30^o, 40^o, and 50^o, the CEP reduction decreases from ,95, 91, 87, and 78%.

4. Conclusions

The research conducted is a control system study in the last ten years for rockets of 122 to 140 mm caliber. The data shows that there are two types of actuator control systems developed, namely canard and lateral thruster. In canard mode there are 2 application strategies, namely with bearing, where 5 control algorithms have been applied, and without bearing, where 2 control algorithms have been applied. For thruster mode, 5 control algorithms have been applied. From the results of the implementation of the CEP, there are 2 control modes with canards and 2 control modes with thrusters, which have the potential to be implemented in RHAN.

The next study that is recommended to be carried out is determining the appropriate design for the implementation of the RHAN rocket control system that has been considered in this paper.

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Contributorship Statement

All authors have the same proportional contributions. AR, WN, ANM, are contributed for control system using canard and editing the article. ZA and RS are contributed for introduction and thruster control system. RHT and YHY are contributed for results, analysis and reviewing the article.

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