Development of Ground Test System For RKX-200EB

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Abstract. After being postponed for seven years, the development of RKX-200EB now restarts by initiating a ground test, preceding the real flight test. The series of the development starts from simulation test using the real vehicle and its components, focusing on a flight sequence test using hardware in the loop simulation. The result of the simulation shows that the autonomous control system in development is able to control the X tail fin vehicle, since take off using booster, separating booster-sustainer, making flight maneuver using sustainer with average cruise speed of 1000 km/h, and doing bank to maneuver up to ±40 deg heading to the target. The simulation result also shows that the presence of sustainer in vehicle control can expand the distance range by 162% (12.6 km) from its ballistic range using only a booster.

1. Introduction
Referring to 2010 Program Manual Control System related to the development of RKX-200EB (Figure 1), a two-stage guided rocket, the development in 2016 aims at mastering the technology of control system with medium sub sonic vehicle using a solid rocket booster-sustainer, which is applied in the ground test included in several tests in laboratory using the hardware in the loop simulation method [1][2] and booster-sustainer static test to ensure the characteristic of rocket motor and to measure delay time when booster and sustainer are separated.

Not only focusing on the system development of RKX-200EB ground test, the test also directly involves the autonomous control system [3] to make it simpler and enable it to implement in the hardware control system of RKX-200EB.

In brief, the development is expected to revive RKX-200EB program, which has been stalled since 2012. The target of the year is making an optimum simulation and a ground test, as a preparation of the real flight test. The simulation is done using flight sequence step by step, including necessary maneuvers.

Similar TNI rockets, such as the C-802 and C-705 that imported from China are also rocket 2 stages, rely on solid rocket booster and turbo jet engines sustainer to fly and maneuver toward the target [4][5]. This RKX-200EB was developed in an effort to reduce the dependence of rocket technology from abroad.

Figure 1. RKX-200EB in 2010
2. Target of RKX-200EB Development
There were at least three big agenda related to the development of RKX-200EB, ensuring that the entire system in the test works well before the expected flight test.

- **Flight Sequence Test and Hardware in the Loop Simulation System (HILS)**
  The flight simulation test of RKX-200EB used HILS method. In the simulation, the Micro Controller that would interact in the real flight test later was directly used.

- **Roll Stability Test using Mini Wind Tunnel System**
  A mini wind tunnel was used to test RKX-200EB concerning its roll stability in the real time. The target smart roll became the purpose of the system development using control techniques to stop roll and later to maneuver to the determined target. It was forced to connect with HILS system point 1 if possible.

- **Characteristic and Real Delay Measurement on Static Test System**
  It was the static test of booster-sustainer motor rocket of RKX-200EB that included characteristic test and measurement of delay time when the booster and the sustainer were separated.

3. Methodology
As there were three big targets to achieve in the system development of RKX-200EB ground test, each target had particular methodology in formulating the system to develop. Exclusively for the first target, namely Flight Sequence Test, it was completed using methods:

- Hardware in the Loop Simulation (HILS) [6] test in a computer to make sure that RKX-200EB could be controlled since ignition of booster, ignition of sustainer, and maneuver control to the target.
- Removing the controller entirely by real controller (NI MyRIO), replacing the programming in the computer. This used Integrated Simulation System (ISS) [7] that had been developed earlier.
- Combining ISS, making the separation test using the real RKX-200EB.

4. Component Test of RKX-200EB
The paper solely explains the first point of the three targets mentioned above, namely Flight Sequence Test and Hardware in the Loop Simulation System (HILS). In the meantime, the other two points would be explored in a separated paper. The test involved almost all components that would be attached in the real flight test. Figure 2 shows RKX-200EB that has been integrated and ready in a laboratory test.

![Figure 2. RKX-200EB in the test laboratory](image-url)
The activities in the simulation system development mainly involved modules and tools, so that the result of the simulation might be as close as possible to the reality. Block diagram of the development is seen in the following Figure 3.

![Block diagram of the development system](image)

**Figure 3.** Block diagram of the development system

4.1. **Real Payload System**

Payload RKX-200EB in the simulation was designed and produced in its real form. It means that all structures and components, such as micro controller, inertial measurement unit (IMU) and navigation sensor (GPS) were real components, which would be used in the real flight test.

Meanwhile, the technical specifications of micro controller and peripherals used in the payload were:

- Single Board NI MyRIO (Xilinx FPGA and Dual-core ARM® Cortex™-A9 processor), Figure 4 left.
- IMU Micro Strain 3DM-GX3-25 (is a high-performance, miniature Attitude Heading Reference System (AHRS), utilizing MEMS sensor technology), Figure 4 right.

![NI MyRIO](image) ![Microstrain 3DM-GX3-25](image)

**Figure 4.** Onboard controller components

- Peripherals needed in the onboard controller were:
  - 1 chn TTL serial for IMU
  - 1 chn serial TTL for telemetry
  - 1 chn serial for GPS, including converter RS-232 to TTL
  - 1 chn for detecting separation
  - 1 chn DIO for igniting rocket sustainer
  - 4 chn output PWM for servo motor actuator
  - 4 chn DIO (digital input output) for other needs
  - 4 chn AI (analog input) for reading encoder actuator
  - 2 chn AI (analog input) for other needs
4.2. Power Module
RKX-200EB needed two units of power modules. The first one was LiPo 3S 11.1V 5000mAH, which was used for micro controller, IMU, GPS and other modules located outside the payload block. The second one was LiPo 2S 7.4V 5000mAH (Figure 6) for actuator and encoder.

Exclusively for the laboratory test, external power modules with capacity 12V and 5V were also prepared to replace the earlier modules, as seen in Figure 7. There was a switch to enable choosing either internal or external power.

4.3. Real Telemetry System
The telemetry radio in use in the laboratory test of RKX-200EB was identical with the real module telemetry commonly used in flight tests. It was MaxStream xTend 900 MHz, hopping in frequency 902 – 928 MHz.

Telemetry radio and GPS structure block was located at the nose cone, the front part of the rocket. All communication data was sent wirelessly in real time from the rocket to the ground station, as in the real flight test.
4.4. Real Actuator System
RXX-200EB had four units of actuators that were controlled independently. They applied the control system X-Fin Tail Control, as seen in Figure 8. Each actuator was composed of two units of servo motors, as the torque enhancer, and one unit of encoder, as the sensor for the actuator’s fin position. High voltage torque, steel gear servo motor product of Hitec, HS-7954SH had the maximum torque capacity 29 kg.cm and speed 0.12 sec / 60 deg. It was completed with analog encoder product from US Digital.

![Figure 8. Actuator RXX-200EB](image)

4.5. Real Body RXX-200EB
The system development of RXX-200EB ground test intentionally used a metal body frame, as commonly used in the real flight test. This aimed at making accurate placement of all components and modules attached in RXX-200EB, as in the real flight. In the development of RXX-200EB before flying, several things could become reference and warning points, including wiring complexity in the payload module, actuator placement in a narrow room in the nozzle area, types and uses of cables and connectors for external connection and internal connection between the two stages, and many other things (Figure 9).

![Figure 9. Structure of RXX-200EB](image)
4.6. Flight Simulator
In conducting the simulation, the system was assisted by XPlane flight simulator [8][9]. Vehicle model of RKX-200EB developed in XPlane (Figure 10) was considered realistic to be the model of this simulation.

![RKX-200EB in simulation](image)

**Figure 10.** RKX-200EB in simulation

Connection between XPlane and Controller Computer was done using UDP protocol. In this case, XPlane would produce data on aerodynamic, attitude and vehicle position in flight. On the other hand, XPlane received data of motion field (moving X fin) to control the movement of the vehicle. The close loop process could be used by PID control or other control strategies to simulate the vehicle flight using the method of hardware in the loop simulation (HILS).

XPlane software was completed with XPlane Maker, for designing the vehicle and its equipment, including engine rocket, wing, fin, booster (using JATO / Jet Assisted Take Off facility) [10], Cg setting and others so that RKX-200EB vehicle (Figure 11) could fly in the simulation.

![Model design using XPlane Maker](image)

**Figure 11.** Model design using XPlane Maker

5. Simulation Test
The simulation involved tools having been built earlier, namely Integrated Simulation System (ISS), in order to simplify and to shorten the test in laboratory. In the test, all components mentioned above were involved entirely, along with XPlane as the flight simulator. Several tests done in the simulation were:

5.1. Measuring thrust in simulation for each stage (booster and sustainer)
This was necessary to ensure that RKX-200EB model had a thrust corresponding to the real design. Booster ignition was done using JATO facility, which was followed by sustainer that might later become a very significant feedback in setting the ignition time delay between both of them.
In RKX-200EB design, the booster had thrust of 500 kgf, and burning time 3.8 sec while the sustainer had 80 kgf, and burning time 24 sec. Based on flight test in 2010, there had been separation time delay around 7 sec. Compared with its design, the flight simulation of RKX-200EB was expected to have not only the same frame dimension but also the same thrust. The following figure shows the result of thrust simulation and speed compared to time.

![Figure 12. Simulation result of thrust booster, delay time separation and thrust sustainer](image1)

Based on the chart seen in Figure 12 above, the flight simulation of RKX-200EB was done with thrust booster force 499 kgf within 3.9 sec, followed by delay in sustainer ignition (which was assumed as delay of booster-sustainer separation) for 6.5 sec, and continued by sustainer ignition with constant thrust of 79.45 kgf for 30 sec. The combination of the three variables resulted in maximum speed of 1,247 km/h, equivalent to 1.16 Mach. Sustainer ignition was able to boost the vehicle up to 1,047.6 km/h, until it finally went gliding to the target.

5.2. Vehicle control

The development of autonomous control system for RKX-200EB was significantly different from that of RKX-200TJ in terms of programming, although both used X tail fin control strategy. Control program for RKX-200TJ could not be applied directly to RKX-200EB, because of big difference in speed. RKX-200EB had cruise speed 800 - 1000 km/h, when sustainer was turned on, and its control fin functioned well within the speed. However, when the sustainer was off, the control fin barely functioned except only for stability and was unable to maneuver though the speed was still above 400 km/h.

![Figure 13. Simulation of thrust and altitude](image2)  
![Figure 14. Simulation of roll and pitch](image3)
As seen in Figure 13, the simulation result showed that when sustainer was on and making maneuver to the target, the fall of RKX-200EB was successfully delayed although its altitude had declined. As a comparison, if it relied only on booster, the vehicle would reach not more than 4.8 km distance with launching angle of 50 deg. However, with sustainer and its control system, the distance range of the vehicle could expand to 12.6 km, with initial heading of 154 deg and final heading of 67 deg. The condition of X tail fin control with sustainer, as seen in Figure 14, showed that the vehicle’s pitch in the program was maintained at 0 deg, and at the same time, the vehicle made maximum roll of -40 deg (according to the program), to maneuver to the left, heading to the target. The complete simulation result can be seen in Figure 15, in the format of KML file in Google Earth software.

5.3. Separation system test
The current separation system was the first design since its debut flight in 2010, and there had been no change. This research aimed at testing the real design in the real component series that showed separation between booster and sustainer. The simulation of the separation was done by adding a piston in the sustainer part, which forced the booster backward (Figure 16). Moreover, the separation time was a moment before the sustainer ignition.
6. Conclusion and Recommendation

The first point of targets in development of RKX-200EB ground test was related to laboratory test of sequence test program using HILS facility. It led to several conclusions that the autonomous control system was able to make series of programs since booster ignition, separation between booster and sustainer, ignition of sustainer and maneuvering to the target based on the planned program. RKX-200EB was able to make banking maneuver up to ±40 deg to the target while the sustainer was still on. The control system worked well using thrust sustainer, followed by X tail fin directing the vehicle to the target as far as 12.6 km with change in heading maneuver up to 87 deg. The success in the simulation system would encourage further tests in the sequence of RKX-200EB development, as a long term development of RPS.

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