The Great Midwestern Regional Rocket Competition Flight Readiness Report

Team Star One

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I. EXECUTIVE SUMMARY

The Great Midwestern Regional Rocket Competition calls for a high-powered rocket to be designed to reach an apogee of 3,000 ft and use at least two methods to measure and report on its flight performance. This report details the stages in the design, construction, test, and expectations of the rocket for Team Star One for the University of Illinois at Urbana-Champaign.

Our team determined the LOC PK-84 Precision Magnum Kit to be the best model to use. The rocket body is 5.54 in in diameter to allow for more space to maneuver in the construction process as well as a larger payload to ensure all methods of measurement can fit. The length is 80 in. to accommodate the two parachutes that will be used during the launch (one small drogue at apogee and one main at 700 ft). In order to ensure the rocket can be recovered in flyable condition, the primary material in the rocket body is dense cardboard with plywood fins.

The construction process took about 3 days to complete. Most of the rocket components were pre-fabricated so we only had to apply appropriate amounts of 5-minute epoxy to ensure the stability of the body. The fins have a high likelihood of being damaged on impact, so we ensured all three were securely embedded in the body of the rocket as well as heavily epoxied to both the body tube and the inner centering tube.

Onboard, the rocket features a payload bay with an electronics sled to hold the two measurement devices that will be employed. The first device is a StratoLogger altimeter that will be used to collect height reached as a function of time as well as control the dual-deployment recovery system. Second, we incorporated a BMP180 Barometer into an Arduino Uno microcontroller.

To reach the goal apogee of 3,000 ft, we ran simulations of the body with test weights and motors in RockSim 9. From these simulations, we concluded that the ideal weight of the loaded body before launch is 299 oz. using a Cesaroni K400 single-use rocket motor, in which case the rocket would reach an apogee of 3,534.09 ft in 16.2 seconds. In order to achieve this weight (the fully loaded body was too light after construction) we added weights to the payload bay in the form of two 2lb weight plates.

We wanted to more accurately locate the drag force and center of pressure (CP), so we organized a trial launch of the rocket. The trial launch only included the StratoLogger to test the dual-deploy recovery system and the appropriate parachutes (no weights were added to the payload for the trial launch). Using data from the trial, the CP was adjusted and appropriate weight could be added, as well as adjustments to the dual-deploy recovery system.

II. Design Features of Rocket

Based on rough simulations using RockSim 9, our team first decided that the best kit to use to achieve the goals laid out by the The Great Midwestern Regional Rocket Competition was the LOC Precision Magnum Kit with a Cesaroni K400 single-use rocket motor. The kit measures 80 in. long with a diameter of 5.54 in. This leaves enough room to easily apply epoxy to inner components during construction as well as allowing for a large payload bay that can comfortably fit all necessary electronic components. Also, the length will accommodate the drogue and main parachutes as well as the necessary electric matches, ejection charges, wadding, and shock cords. The majority of the rocket body is dense cardboard while the fins are solid plywood to withstand both forces during launch as well as during impact during the recovery.

At apogee, we will initiate a dual-deployment recovery system triggered by the StratoLogger altimeter. The 24 in. diameter drogue parachute on a 25 ft nylon shock cord will deploy at apogee to slow and control the descent of the rocket. Once the StratoLogger altimeter measures a height of 700 ft, the 80 in. parachute on a 30 ft nylon shock cord will be deployed to greatly decrease the impact speed of the body once it reaches the ground. This deployment system is designed to minimize drift of the rocket during descent, making the recovery of the body and electronics easier for the team.

III. Design Features Of Payload Bay

A. Construction of Payload Bay

The first and most basic component that had we had to decide on when building the payload system was the kind of material and size of a payload bay platform we wanted to use. We decided not to use the stock payload platform due to its inability to hold all of the equipment that we need to fit inside the payload bay. On top of the other objectives of wanting the payload bay to be stable and secure, we also wanted to construct the payload bay in a cost efficient manner with materials that we had with us in the lab. Originally, we opted to use a payload platform out of 2 rectangular pieces of balsa wood with a piece of Styrofoam sandwiched in between. However, after consultation with more experienced rocket hobbyist, we found out that balsa will not be an ideal selection as we had to drill holes into the payload platform to secure the electronics. The hobbyists then recommended that we used plywood for the platform and let us use some of the leftover plywood they had been using to construct their very own rocket. We then needed to source for materials that would allow us to attach the platform bay to the metal rails. We needed to find an object that would fit the diameter of the rails and had a surface area that would be large enough to allow us to epoxy the material and the payload platform. Materials such as straws and hoses were considered. We concluded on using plastic tubing as it was light, cheap and did the job perfectly. Lastly, we used hexagonal nuts to secure the plastic tubing in place.

When assembling the payload bay, we had to take into account the significant amount of wiring that would be required to connect all the devices. Our objective with regards to the wiring was to make the wiring as neat and organized as possible and to allow us to take apart specific components of the payload bay with ease. In order to do so, we had to take into consideration the extra length of wire that was required to sufficiently pull the base and top of the payload bay apart to examine the devices on the inside. As such, the wires that had to run through the entire length of the payload bay were measured such that they were about 1.5-2x the length of the payload bay.

B. Payload Electronics: StratoLogger

The StratoLogger was chosen due to its ability to assist us in our objective to have a rocket with a dual deployment mechanism. There are 2 outputs on the StratoLogger that allows us to deploy the drogue chute at apogee to minimize the drift while the main chute will be deployed at a specific set altitude to slow the rocket down for a gentle touchdown. This device was chosen compared to other similar devices due to its small size, precision and ability to collect flight data such as temperature and altitude.

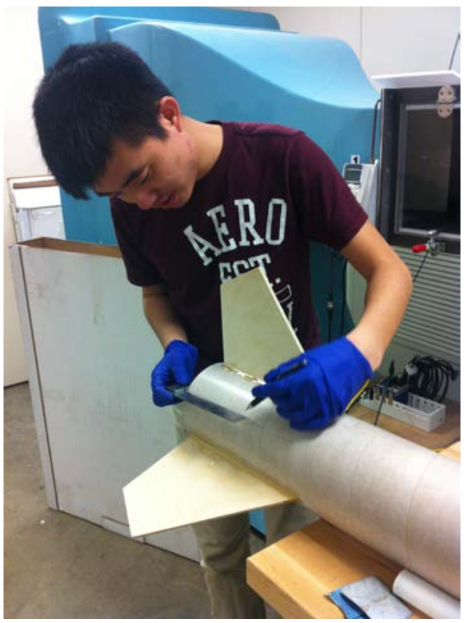
After we had constructed the payload platform, we next had to consider the components that had to fit on it and where they should be placed. Our mentors advised that the StratoLogger should not be placed directly on the payload sled as there was a sensor at the bottom, and as such may produce inaccurate results if placed in such a manner. Taking their advice into consideration, we had to brainstorm of methods to ensure that the StratoLogger was on some sort of raised platform and ensure that it is kept stable and secure throughout the launch. After consultation with more experienced members of the model rocket community, we decided the best method to secure the StratoLogger would be to secure it with 2 screws and a long bolt at 2 corners which are diagonal from each other. By using this method, we were able to ensure that the long bolt is sufficiently secured to the platform bay with a screw and the StratoLogger is secured to the long bolt with another screw. The use of the long bolt would be to ensure that there would be sufficient gap between the platform and the StratoLogger to allow accurate readings to be taken.

C. Payload Electronics: Arduino/Bosch BMP 180 Barometer

The Bosch BMP180 was chosen for its wide barometric pressure range with high accuracy. It also has low power consumption and includes a temperature sensor. To allow for accurate barometric measurements from the StratoLogger and BMP 180 barometer, we drilled static pressure sampling holes into the payload bay. Four holes, each of 0.286 inches in diameter and spaced them equally apart at 90 degrees around the rocket's circumference, were carefully drilled. The purpose of these holes would be to minimize the pressure variations due to wind currents perpendicular to the rocket's direction of travel.

D. Payload Electronics: Key Switch

There were 2 options that were presented to us when it came to arming rocket's payload. One was the commonly used method of activating the rocket electronics using a key ignition switch just before launch. In this method, the key would be in the ignition and at its off position at all times until the rocket is ready for launch. Once the key ignition has been turned on, only then can the key be removed and we would have to listen for the beeps sounded off continuously by the StratoLogger to verify that the settings are correct. At the end, there will be series of continuous beeps that would indicate that the ejection charges were in place and ready to be ignited by the StratoLogger to deploy the parachute at apogee and 700 ft. However, we were also given feedback that it was possible that the key ignition switch has malfunctioned before which would pose us with a huge setback.



The other alternative that we were presented with was the option of using the twist and turn method to close the circuit. In this method, two exposed wires would be left taped to the exterior of the rocket. Just before launch, the tapes would be removed, the wires would then be connected and given a twist to ensure that the circuit stays closed before it is then taped to the exterior of the rocket and launched. Despite the simplicity of the twist and turn method, we were not convinced that this method would be fail-proof and thus choose to stick with the more conventional method of using a key ignition switch. So far we have been very pleased with how the key ignition switch has been functioning and the concerns that were posed to us have not yet arose.

E. Construction of Rocket Body

The first component attached were the fins of the rocket. We carefully coated the joints between the fin and the outside of the rocket with epoxy, ensuring that a thick and strongly joint layer was formed. Since no one had the experience of building a rocket, we consulted our coaches regarding this issue and they advised us to apply another layer of epoxy on the inside of the rocket due to the fact that if an external force is applied to the fins, there is a possibility that the fin may end up breaking from the rocket. Keeping their advice in mind, we applied a layer of epoxy on the joints inside the rocket on 2 out of 3 fins that were present. This is because only 2 of the fins were accessible from the cavities at the bottom of the rocket. On the 3rd fin, we added an additional layer of epoxy to ensure that the strength at the joint would be strong enough to withstand the external loads that will be exerted on them.

F. Ejection Charges

The ejection charges were place at opposite ends of the payload that would ignite to create a force that would detach the nose cone from the payload and base of the rocket from the payload to deploy the drogue and main parachute respectively. In order for the charges to be ignited by the StratoLogger, we had to drill a hole at the top and the base of the payload bay to run a wire through. We then connected the wire to a connector before connecting it to the ejection charge to ensure that both the positive and negative terminals of the wire would not come into contact and result in a short circuit. The holes that were made at the top and base of the payload bay were then sealed with epoxy to ensure that the residue and force from the ejection charge does not enter the payload bay and interfere with the sensors when the charge goes off. The ejection charges were also taped down at the top and base of the payload bay to ensure that the maximum force would be applied in the direction that we want to minimize the possibility of the parachutes not being deployed.

IV. Rocket Center of Mass/Pressure & Performance Simulation

We primarily relied on RockSim 9 to perform simulations to locate the center of pressure of the Magnum rocket, gauge the accuracy of the simulated results with actual recorded data during the test flight, and estimate the mass required to bring the maximum altitude of the rocket near 3,000 feet given the large K400 motor that we chose to use.

Conveniently, the basic simulation model for the kit that we chose to use, the LOC PK-84 Magnum, was already included in the RockSim 9 database. This meant that the dimensions of the rocket as it came out of the box as issued by LOC was already in place with the correct fin sizes, body tube diameter, motor mount tube, and so on. While we used a payload bay instead of a standard tube coupler and added minor protrusions such as screws and a key switch on the circumference of the body tube, we did not tamper with the basic shapes and dimensions of the fundamental components that came with the Magnum kit. Therefore, the estimated center of pressure should be accurate to within less than an inch. Regardless, we measured the weight of each component of the rocket and made sure to override the mass per our exact measured data and took the time to double check that the dimensions that were given matched with the dimensions of the actual shipped parts.

With these parameters set in place, the simulator estimated that the rocket should fly up to a little over 2100 feet for our test flight with the I540, which turned out to be an overestimation. The actual maximum altitude measured by the StratoLogger was a little over 1750 feet. This was quite a large difference, but it turns out that according to the experiences of high-powered rocket hobbyists in Central Illinois Aerospace (CIA), RockSim's algorithm consistently tends to overestimate the maximum altitude by more or less 10%. While our error turned out to be a more liberal 20%, we decided to proceed with RockSim's accuracy with its tendency to overestimate in our minds.

Using the K400 with the original weight of the LOC Magnum rocket would imply a maximum altitude of over 5,000 feet – which is way beyond the allotted altitude for this competition – we had to devise a method to bring the altitude of the rocket down. The two most sensible options were to either increase the drag of the rocket, or add extra mass. We

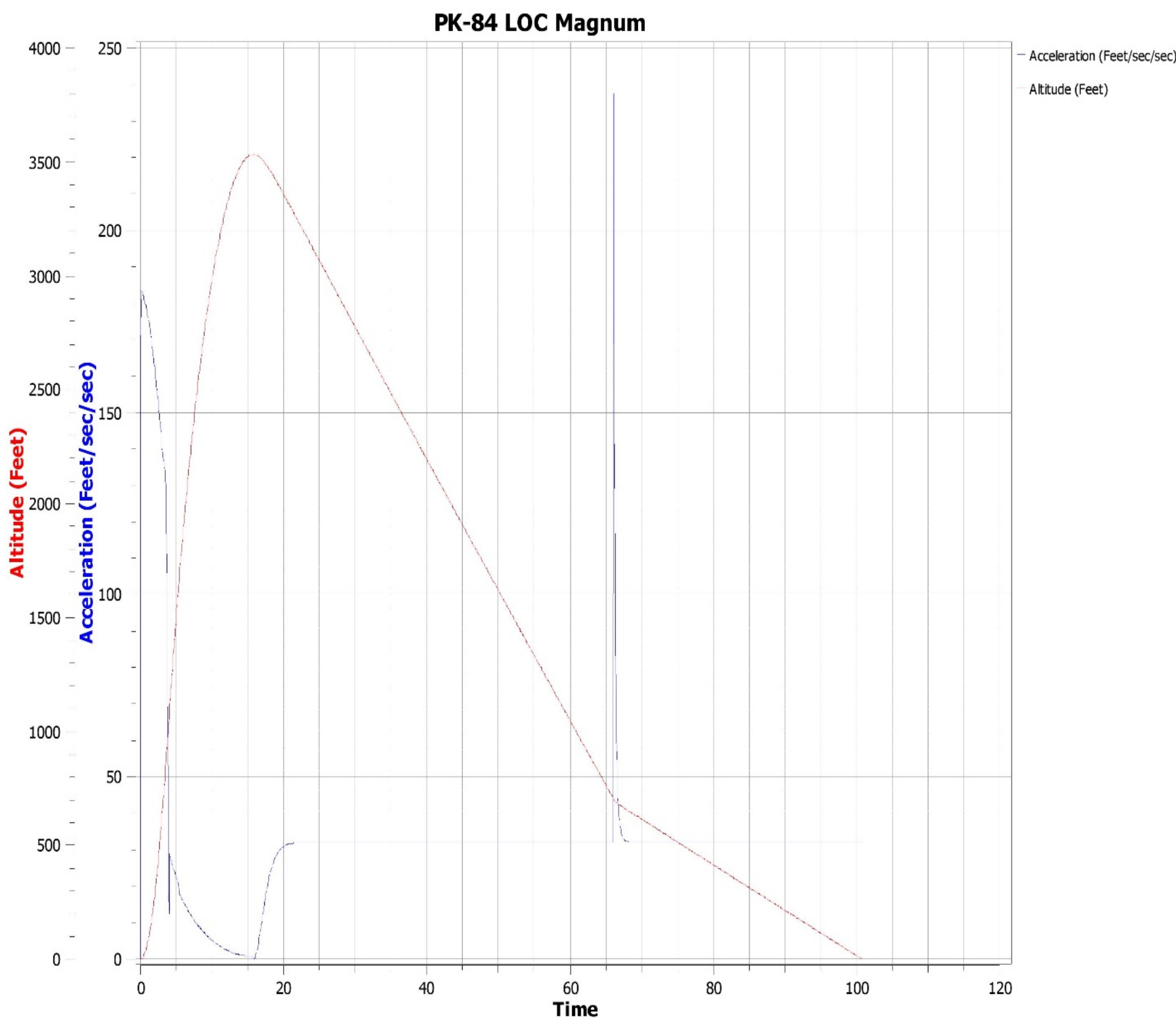


***Figure 1*: Diagram showing the simulated altitude and acceleration of the rocket in flight.**

chose to go with the latter, since altering the drag of the rocket could lead to dangerous aerodynamic problems, wherein an unbalanced distribution of drag could steer the rocket way off course. However, it turns out that adding extra weight to the rocket is not an easy task either, mainly because of the magnitude of the weight that we would have to add. To bring RockSim's estimated maximum altitude down from 5,000 to 3,000 feet, the program suggested that the rocket should be another 7.5 lbs heavier. This was quite a tricky problem, and we ended up nutting only 4 extra lbs on the payload bay. The reason for this goes back to RockSim's tendency to overestimate. While adding only 4 extra lbs increases the estimated altitude to 3,500 feet as shown in Fig. 1, given the discrepancy that we noticed from our test flight data and the simulation (20% overestimation), the actual flight could go as low as 2,800 feet – and while this is quite a large range that could significantly narrowed by more test flights, the lack of the availability of a K400 motor on our end made this the most reliable option for estimating the maximum altitude of the rocket.

The next course of action with the simulation was to determine the appropriate parachutes that would provide a reasonable descent rate for the rocket given the extra weight that we added to lower the maximum altitude of the rocket. In reality, these two procedures were performed side by side, back and forth fashion, since the parachutes themselves contributed to the total mass of the rocket in their own ways, and finding the parachutes with the right drag properties depended on the mass of the rocket. This interdependence was solved mostly through trial and error, looking for the best possible combination of the drogue and main parachutes that would yield both a desirable maximum altitude and the descent rates with the drogue and main parachutes deployed. Ultimately, we settled with two parachutes made the Apogee – a 24" Fruity as the drogue, and an 80" Angel as the main. They provide a safe descent rate of around 60 ft/s and 20 ft/s, respectively.

Finally, with all the components of the rocket decided and set in stone, we ran the simulation that yielded the altitude and acceleration records as shown in Figure 1, and the center of gravities and pressure as measured before and after burnout, which are shown in Figure 2 and 3, respectively. The maximum altitude was 3534.09 ft and the maximum acceleration was 222.41 ft/s^2.

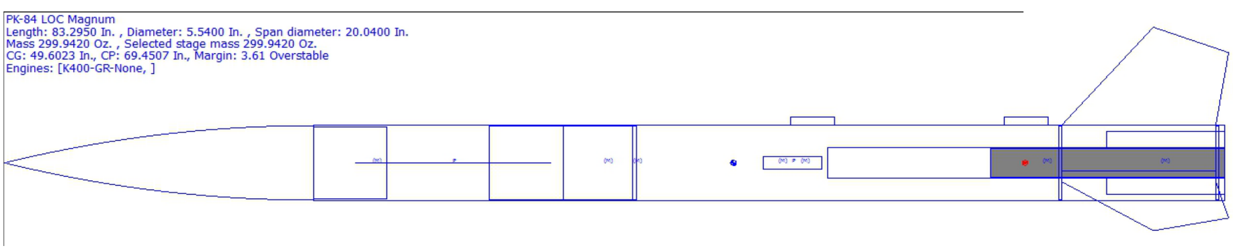


Figure 2: **The locations of the center of gravity and pressure on the rocket with the loaded K400 engine.**

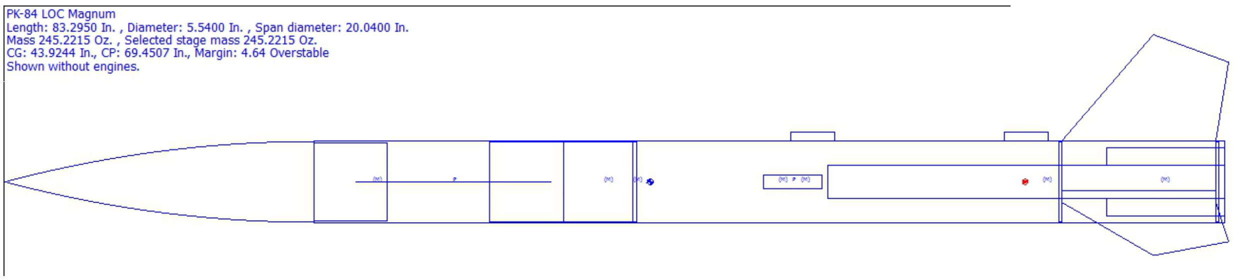


Figure 3: **The locations of the center of gravity and pressure after motor burnout.**

V. Test Flight & Validation

Our objective for this test flight was to check the safety if the fins and the working condition of ejection charges as well as verify the size of parachutes allowed for an appropriate descent rate. We also wanted to test the dual-deployment system and check the condition of the rocket upon landing.

We managed to conduct a test flight at an open field in Rantoul, Illinois on 19 April, 2014. Our main objectives for conducting the test flight was to ensure that the rocket was structurally sound and all the electronics on the rocket would work accordingly. At the test launch, there were a few very experienced hobbyists who guided us throughout the whole test launch process. Due to limitations that were posed on site, we were advised to use the friction fit method to secure the individual sections of the rocket together. We were informed that in the worst case, both parachutes will deploy at apogee and nothing catastrophic will happen to the rocket. The hobbyists then looked at our parachutes and also informed us that our drogue chute was too large in size and informed us that it would cause our rocket to drift very far from the point of launch a as it descends. On that note, he kindly allowed us to use a smaller chute that he had instead. He then guided us along and assisted us with the tying of the shock chords to the chutes. Next, we filled the ejection charges with gunpowder and placed it upright to ensure that there would be a maximum force at to our desired location. With the ejection charges in place and the rocket assembled, the rocket was now ready for launch.

At the launch pad, we had to verify that the StratoLogger was programmed such that it would deploy the drogue chute at apogee and main chute at 700 feet by listening to the beeps that the StratoLogger produced. We also had to listen out for a continuous beeping sound at the end of the sequence that would notify us that the ejection charges are connected and detected by the StratoLogger. With all those sounds being heard, we were confident that the rocket would launch without any hiccups.

The test launch went very smoothly with the rocket ascending to a height of 1700 feet. However, at apogee, both chutes were deployed at the same time as the friction fit did not hold the bottom of the rocket and the payload bay together. With this observation, we concluded that we had use shear pins for future flight launches to ensure that both chutes do not get deployed at the same time. The descent rate of the rocket was reasonable and the rocket landed softly on a field 50 feet from the launch pad. When we picked the rocket up, we inspected the rocket and were glad to find that there was no damage done to the rocket throughout the flight.

VI. Conclusion

Team Star One is eager to demonstrate the performance of the rocket and its onboard data-collection devices in The Great Midwestern Regional Rocket Competition. Using rocket simulation programs and trial launches, we were able to design a rocket with optimal size, weight, and thrust to carry a payload bay that combines a conventional data-logging system with one less intuitive. As a whole, our group is young and inexperienced in high-powered rocketry, but we have been able to quickly learn and utilize resources available to engineer a rocket that can effectively reach 3,000 ft and safely be recovered.

VII. Budget

The Illinois Space Grant Consortium allotted a total budget of $1,000 for the Star One team to spend on a rocket kit and assorted construction materials. The majority of the costs were used to procure the PK-84 Magnum Rocket Kit from LOC Rocketry as well as the motors used for competition and test launching. The total project cost is about $470.27, which is significantly under the allotted budget. The team would like to extend thanks to NASA and the Space Grant Consortium for a wonderful opportunity to participate in this year's competition. The cost breakdown is illustrated in Table 1 below.

Table 1: Project Star One Budget

Item	Vendor	Quantity	Price per Unit	Unit Subtotal
PK-84 Magnum Rocket Kit	LOC Rocketry	1	$196.85	$196.85
PK-84 Magnum Payload Bay	LOC Rocketry	1	$40.00	$40.00
30' 1 in. Tubular Nylon Shock Cord (Drogue)	Champaign Surplus	1	$13.00	$13.00
I540 Rocket Motor	Cesaroni Technology	1	$50.66	$50.66
K400 Rocket Motor	Cesaroni Technology	1	$112.95	$112.95
Building Supplies (epoxy, paint, etc.)	Various	1	$56.81	$56.81
Grand Total				**$470.27**

Figure 4: **Final Star One Rocket configuration with paint design.**

Thank You To NASA & The Illinois Space Grant Consortium For The Support

Sincerely,
Team Star One