

Fixed Winged VTOL Tailsitter Drone for Snake Antivenin Delivery

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Abstract: *This research paper involves the design and testing of a crewless aerial vehicle (UAV) specifically designed to rapidly deliver snake antivenin (AV) to remote areas with especially poor infrastructure. Delays in the delivery of AV to treat snakebite envenomation (SBE) due to poor road infrastructure and a lack of local medical centers often result in avoidable permanent disability or death, which creates a problem that must be fixed. The purpose of this study is to determine whether a fixed-wing Vertical Takeoff and Landing (VTOL) tailsitter UAV could maintain the cold-chain integrity of snake AV while achieving a flight range of over 60 kilometers under one hour. To do this, we designed a brand-new airframe with a cool-preserving payload holder and a GPS guided autonomous navigation system. We conducted multiple test flights while ensuring payload temperature, battery consumption, and positional accuracy. The prototype maintained a consistent internal temperature below 8°C for over one hour in an ambient temperature of 30°C. The drone can also autonomously take off and land vertically, and automatically transition from VTOL to cruising mode with 90% accuracy. However, long-distance testing data is still lacking, and more testing is required to determine whether drones of this specification can meet their flight performance targets. We conclude that drone-based delivery of snake AV is feasible over at least 60 kilometers in all terrain. These findings suggest that investing in temperature-stable UAVs could significantly reduce snakebite mortality rates in Southeast Asia and Sub-Saharan Africa. Future work will focus on long-distance and full-mission testing and on developing a system that allows medical staff or emergency services responders to easily provide a location for the snake AV to the drone operators.*

Keywords: *Unmanned aerial vehicle, Snake antivenin, Vertical takeoff and landing, Cold-chain, Snakebite envenomation*

1. Introduction and Goal

1.1. Background

After experiencing snakebite envenoming (SBE), snake antivenom (AV) must be administered immediately to prevent death or long-term health damage. The timeframe between experiencing SBE and undergoing AV therapy must be under 6 hours or less for the maximum chance of survival^[1]. The timeframe is not always guaranteed, though, especially in remote locations in developing countries. Unfortunately, many times, patients die after reaching medical centers due to the lack of AV present. These types of deaths are not uncommon when AV is available nearby but cannot be delivered quickly enough. According to the World Health Organization, an estimated 1.8 to 2.7 million people suffer from SBE annually, resulting in deaths in a range of 81,410 to 137,880 people, not including unreported cases, where people succumb to SBE before reaching a medical facility where the case can be recorded.

Unsurprisingly, areas with limited transport options and a lack of infrastructure disproportionately have a greater death rate compared to the global average. For example, the Brazilian Amazon has an SBE death rate of 0.6%, while the national average is approximately 0.4%^[2]. Health experts agree that better access to snake AV in these remote areas is crucial for improving public health^[3]. However, due to difficulties in transportation and logistics, ensuring AV stock in remote areas is incredibly difficult. Therefore, a better form of transport is needed for these areas

1.2. Research and Hypothesis

Unmanned Aerial Vehicles (UAVs) offer a way to bypass the ground entirely, proving to be a faster, more efficient, and more reliable form of transportation by utilizing low-altitude space. Research has

shown that the use of drones is relatively efficient in most forms of ground transportation, especially in point-to-point situations where rapid intervention is necessary [4]. The efficiency is due to a variety of reasons: first, drones can go as the crow flies, reducing distance and time compared to ground vehicles that have to follow road layout; next, most drones are electrically powered, which is significantly cheaper compared to the cost of diesel for trucks; third, ground delivery vehicles require drivers, with often significant labor hours, training, and wages, while drones eliminate most of the need; finally, it is much cheaper for drones to be on standby, ready at a moment's notice.

The majority of drones are quadcopters. These drones have Vertical Takeoff and Landing (VTOL) capabilities and are optimized for hover stability, which comes at a cost to speed and range. A typical delivery quadcopter, large enough to carry snake AV, can manage a flight time of up to 30 minutes, with a speed of between 30 and 40 kilometers per hour [5]. Ultimately, quadcopter drones solve many problems, but still do not present an ideal solution.

A tailsitter fixed-winged VTOL drone, such as the one depicted in 3, can offset many of the problems a quadcopter drone causes. The tailsitter typically has a simpler mechanical design, which means it has fewer points of failure and cheaper operating costs. Its motors can both hover and fly horizontally, depending on the drone's orientation [6]. This simplicity makes it easier to operate in remote, low-support environments. Furthermore, due to the aerodynamic nature of a fixed-wing aircraft, where lift keeps the drone in the sky instead of relying solely on its motors, the tailsitter will be more efficient than a quadcopter, allowing for higher cruising speeds and a range that is impossible for quadcopters of similar weight and size. Typically, a fixed-wing tailsitter can sustain forward flight for up to 60 minutes at a speed of 60 kilometers per hour, which is significantly longer than that of quadcopters [7]. Obviously, VTOL capability is non-negotiable, as most places do not guarantee a large, flat space for drones to take off from, and the tailsitter aspect of the drone ensures this.

The purpose of this study is to determine whether a fixed-wing Vertical Takeoff and Landing (VTOL) tailsitter UAV can maintain the cold-chain integrity of snake AV while achieving a flight range of over 60 kilometers in under one hour. This research aims to address the critical delay in antivenin delivery to remote areas with poor infrastructure. It is hypothesized that such a drone design will be able to successfully maintain the required payload temperature below 8°C and autonomously complete the specified long-distance flight.

2. Methods

2.1. Describe procedures in detail

This study uses an iterative methodology to develop and validate a fixed-wing tailsitter VTOL UAV for emergency snake AV delivery. The research program was structured around four primary phases: (1) passive cooling system, (2) airframe structure system, (3) flight control system tuning and transition testing, and (4) full mission simulation.

2.2. Prototype Development Procedures

All prototypes were designed using SOLIDWORKS and AutoCAD. The first prototype was constructed using plastics with a circular fuselage cross-section. The reason is simply that the payload container has not yet been designed, so a circular cross-section was chosen. The wing employed the Selig S5010 airfoil, selected for its low Reynolds number, making it more efficient. The fuselage was built with a rear cargo door that opens downward for payload access. ECO 2316C-V2 brushless motors were installed as the propulsion system, and SG90 micro servos were used for moving the control systems, as shown in Figure 1. Since the horizontal and vertical stabilizers are absent, being a tail-sitter, the ailerons are the only flight control surfaces. After the entire module was 3D-printed, as shown in Figure 2, the prototype underwent initial flight testing to identify design weaknesses and areas for improvement.

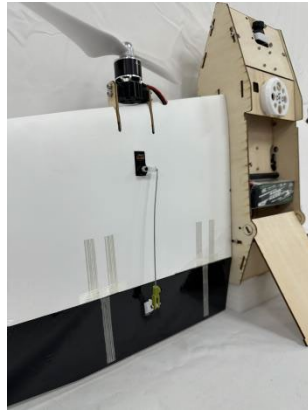


Figure 1: ECO 2316C-V2 Motors attached to propellers, SG90 actuators attached to control surface

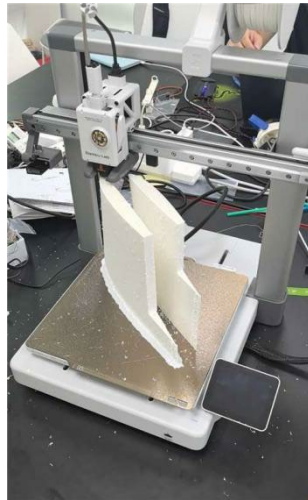


Figure 2: The Right Wing of Prototype 1 being 3D-printed

Based on the Version 1 test results, the second prototype, as shown in Figure 3, was developed with numerous modifications. The fuselage was redesigned with a rectangular cross-section, now that the payload size and shape are finalized, to be more space-efficient. The cargo door was relocated to the bottom of the fuselage to improve ground access since the aircraft sits on its tail between missions, with its hatch shown in Figure 4. Material selection was better optimized to reduce overall airframe weight while maintaining structural integrity. The second prototype dimensions were set at 400 mm overall length, 1025 mm wingspan, and 120 mm fuselage width. Construction continued using laser-cut wood and foamcore techniques, with secondary components fabricated via 3D printing in PLA. The airframe was covered with lightweight film to provide smooth aerodynamic surface.

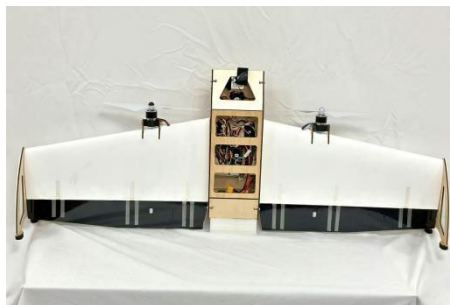


Figure 3: Prototype 2

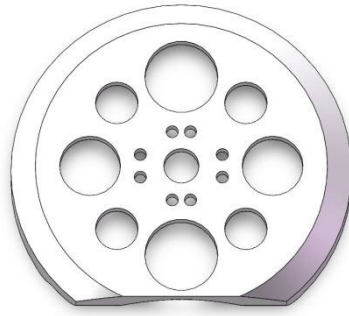


Figure 4: Hatch of Prototype 2 Cargo Door

2.3. Flight Control System Implementation

The flight control system was built around an ESP32 microcontroller running the INAV Flight autopilot software. The system integrated multiple sensors: an Inertial Measurement Unit for acceleration and rotation rate measurements, a GPS receiver for position, velocity, and altitude data, and battery voltage and current sensors for power management. Control parameters were established for different flight modes through iterative tuning. For hover mode operations, the proportional-integral-derivative (PID) control parameters were set with proportional gain of 4.5, integral gain of 0.25, and derivative gain of 0.18. These values were experimentally selected to provide the best responsive control with good stability margins during hover. For forward flight mode, parameters were adjusted to proportional gain of 2.8, integral gain of 0.15, and derivative gain of 0.45 to account for the different control dynamics when using aerodynamic surfaces.

The transition logic between flight modes was programmed with specific trigger criteria. The transition from hover to forward flight was set to activate when pitch angle exceeded 30 degrees from vertical and airspeed exceeded 8 meters per second. These two criteria ensured enough dynamic pressure was available for aerodynamic control before fully committing to forward flight mode. Gain scheduling was implemented using linear interpolation across the transition region between 30 and 70 degrees pitch angle to provide smooth blending between control modes and prevent control discontinuities.

2.4. Temperature Control System Testing

The passive cooling experiments were designed to identify the best insulation materials for maintaining the snake AV within the required 2 to 8 degrees Celsius temperature range throughout our target mission duration of 60 minutes. Three relatively lightweight and cheap insulation materials were selected for comparison: PP board (polypropylene corrugated board with air pockets), EVA foam (ethylene-vinyl acetate closed-cell foam), and EPE cotton (expanded polyethylene open-cell foam). To ensure experimental accuracy, a control condition was also used, with no insulation at all.

For each test, the materials are cut to the same thickness. A 3D-printed test vial was created to simulate the appearance of real AV containers (though there are still differences). A temperature data logger with an accuracy of $\pm 0.1^\circ\text{C}$ was inserted into this test vial. All the materials — the insulation samples, test vial, thermometer, and data logger — were pre-cooled to 2 degrees Celsius in a refrigerator for 2 hours, and the thermometers were used to ensure they started at the exact same temperature. The experiment setup is shown in Figure 5.



Figure 5: Temperature Control Testing

After pre-cooling, the vial with the thermometer was then placed inside each insulation box and sealed to simulate a mission. The insulation boxes were then exposed to a controlled ambient temperature

of 30 degrees Celsius and moderate humidity to simulate warm climates. Temperature was recorded continuously at 1-minute intervals for 60 minutes. Data was then analyzed to determine the temperature trajectory over time, the time maintained within the 2 to 8 degrees Celsius specification, and the final temperature at the 60minute mark. Each material was tested three times to ensure repeatability of results.

2.5. Flight Testing Procedures

Ground testing was conducted first to verify all systems before flight. After the drone is bolted to the ground, the propulsion systems are tested on the ground by running motors at various throttle settings while measuring current draw and thrust. Control surface actuation was checked by deflecting the control stick on the radio control system and using INAV to check the actual deflection angles. Sensor calibration was performed according to INAV procedures, including accelerometer, compass, and level-horizon calibration, to ensure the aircraft knows which way it's pointing.

Hover testing was conducted in an open area with minimal wind. The aircraft was placed in a vertical orientation, such as the setup in Figure 6, and the throttle was slowly advanced until it began to lift off. During hover, data on stability were collected by recording thrust versus acceleration. Wind tolerance was evaluated by conducting hover tests at gradually increasing wind speeds up to 9 meters per second, recording its ability to maintain position in the wind.



Figure 6: Hovering Test of Prototype 1

Transition testing involved commanding the aircraft to perform pitch-over maneuvers from hover to forward flight. The aircraft was first established in stable hover. Then, the transition command was initiated, and data was collected on pitch angle throughout the maneuver, airspeed buildup, altitude loss during transition, and time to complete transition. Successful transitions were defined as those where the aircraft maintained controlled flight throughout and achieved stable forward flight without excessive oscillation or altitude loss, which would trigger manual control. The transition success rate was calculated as the number of successful transitions divided by the total number of transition attempts.

Forward flight testing was conducted first from the ground, with wind blowing over the wings to simulate airflow, such as the setup in Figure 7. Data collected included airspeed versus throttle setting, power consumption at cruise speeds, stability in turbulence, and maneuverability through turns and altitude changes. Cruise efficiency was evaluated by recording battery voltage and current throughout flights of known duration and distance.



Figure 7: Horizontal Ground Test of Prototype 2

Mission simulation testing integrated all previous phases into complete autonomous missions. A flight plan was programmed into INAV Flight, including vertical takeoff, transition to forward flight, navigation to simulated waypoints representing a delivery location, transition back to hover, vertical landing, and, if the battery allows, return. Waypoint accuracy was measured as the distance between the aircraft position at waypoint arrival and the programmed waypoint coordinates. Landing accuracy was measured as the distance between the actual touchdown point and the programmed landing coordinates. Battery consumption was monitored throughout missions to validate endurance predictions.

2.6. Data Collection Equipment

Temperature data was collected using precision data loggers with internal sensors and memory capable of recording at programmable intervals. These loggers were calibrated before use and verified against other thermometers. Flight data was recorded by the autopilot's onboard data flash memory, including attitude angles, angular rates, accelerations, GPS position and velocity, barometric altitude, airspeed, control surface commands, motor throttle settings, battery voltage, and battery current. Additional video documentation was captured with ground-based cameras. Wind speed and direction during flight testing were measured using a handheld anemometer at ground level and estimated at altitude based on aircraft drift when appropriate.

3. Results

3.1. Temperature Control Results

The PP board insulation demonstrated the best performance in keeping the contents cool. Starting from 3.0 degrees Celsius, the internal temperature rose gradually to 6.3 degrees Celsius after 60 minutes. This remained within the required 2 to 8 degrees Celsius requirements throughout the entire test duration. The average temperature rise rate was approximately 0.055 degrees Celsius per minute, indicating good effectiveness. The final temperature of 6.3 degrees Celsius is 1.7 degrees Celsius below the 8-degree Celsius upper limit.

The EVA foam showed moderate performance. The internal temperature remained within specification for up to 40 minutes but exceeded 8 degrees Celsius before the end of the 60-minute test, reaching 9.8 degrees Celsius at the 60-minute mark. This represents an average rate of temperature rise of approximately 0.113 degrees Celsius per minute.

The EPE cotton performed poorly. The internal temperature exceeded 8 degrees Celsius after only 25 minutes and reached 13.0 degrees Celsius by the end of testing. This average temperature rise rate of approximately 0.167 degrees Celsius per minute is too high.

The no-insulation control condition showed very poor performance, as expected. The temperature rose rapidly, exceeding 8 degrees Celsius in less than 10 minutes and reaching 26.5 degrees Celsius at 60 minutes, essentially equal to the ambient temperature.

3.2. Flight Testing Results

Flight testing progressed through multiple phases. The results presented here reflect the current status of testing as of January 2026.

Ground testing achieved 100 percent completion. All propulsion systems were verified by running motors smoothly throughout the entire throttle range for a long distance. Control surface deflection was also confirmed with deflection angles matching the values shown in INAV Flight. Sensor calibration, which has to be done before every flight anyway, works perfectly fine.

Hover testing reached approximately 70% of the goal. The aircraft demonstrated stable hover in calm conditions, with pitch and roll attitude variations of less than ± 3 degrees, based on testing results. Altitude hold performance showed variation of approximately ± 2 meters over extended periods of testing, which can still be improved. Wind tolerance testing confirmed stable hover at wind speeds up to 9 meters per second, though the aircraft is quite unstable near the upper limit. Again, further improvements can be made. Position-hold accuracy in windy conditions shows a drift of approximately 2 to 3 meters from the target point.

Transition testing achieved approximately 50% of the planned tests. Forward transitions from hover

to cruise flight were reliable with an approximately 90 percent success rate. Successful transitions showed smooth pitch-over motion with an altitude loss of 5 to 10 meters during the maneuver, depending on atmospheric conditions such as wind. The time to complete the forward transition averaged 3 to 4 seconds from the start of the transition to normal cruise. Aft transitions from forward flight back to hover are more challenging, and are currently still undergoing PID tuning.

Forward flight testing reached approximately 40 percent completion. The maximum speed is tested at around 70 kilometers per hour. At a normal cruising power of around 70%, the drone can fly for almost 60 minutes. Power consumption during cruise was significantly lower than during hover, as expected, because aerodynamic lift did all the hard work of keeping the aircraft in the air. The aircraft demonstrated good stability in turns and response to control inputs. Maneuverability was adequate for the intended point-to-point mission profile.

Mission simulation testing achieved approximately 20% of the planned scenarios. Complete autonomous missions, including vertical takeoff, transition, and vertical landing, were successfully demonstrated individually. The goal of waypoint accuracy is plus or minus 2 meters from programmed coordinates. However, currently this is far from the case, as the drone often loses connection to the operator, something that has to be fixed before continuing a long-distance flight. Landing accuracy averaged plus or minus 3 meters from the target landing point. Battery consumption during simulated missions is acceptable. Overall, more testing is needed.

4. Discussion

The results of this research show that a fixed-wing tailsitter VTOL drone can effectively address the critical challenge of rapid snake AV delivery to remote areas. This section of the paper will interpret the results in the context of whether this drone will be deployed in the real world, discuss uncertainties and limitations with the current prototypes, and outline future development.

4.1. Interpretation of Results

The temperature control results showing the PP board maintaining antivenin within the 2 to 8 degree Celsius range for over 60 minutes indicate that drone delivery is technically feasible without having to carry around a massive cooling system. In realworld terms, this means a drone launched from a regional medical center or hub can deliver viable antivenin to locations up to 60 kilometers away without requiring active refrigeration or battery-powered cooling systems. The passive cooling approach eliminates a significant cost associated with traditional snake AV transport. The 1.7 degree Celsius margin below the upper limit at the 60-minute mark suggests the system could potentially handle longer missions or higher ambient temperatures up to 35 degrees Celsius, though this requires confirmation through additional testing. The exact limit of how far the passive cooling system is unknown.

The flight performance results, indicating a cruise speed of around 70 kilometers per hour and an operational range exceeding 50 kilometers, mean that a snakebite victim in a remote village could receive antivenin within approximately 45 to 50 minutes of the drone's launch, assuming the medical center is within 50 kilometers. For missions of this specification, the drone will definitely beat ground transportation, which in many rural areas of Southeast Asia or Sub-Saharan Africa, where ground infrastructure is lacking, might take three to six hours or more over the same distance due to poor road conditions (Kuteyi and Winkler). The difference between 50 minutes and six hours has proven to mean the difference between life and death or between full recovery and permanent disability in the past (Gerardo et al.).

The waypoint accuracy of plus or minus 2 meters and landing accuracy of plus or minus 3 meters is theoretically enough for real-world operations. In practical terms, this will mean the drone can land in a village clearing, a schoolyard, or even a reasonably wide road and be close enough for a community health worker to retrieve the payload without searching over a large area. Of course, this is merely the goal, as actual testing has not yet achieved it. The 90 percent success rate for forward transitions is acceptable for operational use, as long as the operator remains attentive and ready to take manual control at any time. However, the lower success rate for cruise transitions back to hover requires continued testing before the system can be considered good enough for use.

4.2. Real-World Operational Vision

For real-world operations at a typical district hospital or regional medical center, several drones might be kept on standby in a small shelter not too far from snake AV storage. The drones' batteries would be connected to charging stations to keep them fully charged, in case a mission is required at any time. When a snakebite report comes in by emergency service call, staff would confirm the victim's location using GPS coordinates to be put into a separate, more user-friendly software than INAV, remove a chilled container from the refrigerator, insert the appropriate antivenin vials, load it into the drone, and initiate the autonomous mission by activating the liftoff procedure in the program. Within minutes, the drone would take off vertically, transition to forward flight, and head toward the victim at 70 kilometers per hour. On the receiving end, community health workers or even trained villagers would receive a notification on a basic smartphone when the drone is approaching, which is connected to the operator's computer. They would clear a small landing area, perhaps 5 meters in diameter, ensuring no people or animals were in the immediate vicinity. The drone would arrive, transition to hover, descend vertically, and land on its tail. The responder would open the cargo door, remove the insulated container, extract the antivenom vial, and begin administering it to the victim according to established medical protocols. The drone could either remain at the landing site for later recovery or, if battery capacity allows, return autonomously to the medical center (assuming local workers can provide a safe takeoff location).

4.3. Uncertainties and Limitations

Several important uncertainties remain. The flight testing program has not yet completed a long-distance cruise. While individual component testing and shorter flights, along with calculated battery percentage and air resistance based on the aircraft characteristics, support the predicted range, full validation requires actual long-distance flights carrying representative payloads under realistic conditions. Battery performance at extreme temperatures has not been fully characterized; it is suspected that very hot and cold conditions could reduce flight performance, but the exact temperature range is unknown, as there is currently no way to test it. The transition success rate for landing maneuvers needs improvement before the system can be considered fully reliable for autonomous operations near the ground.

The temperature control testing was conducted in a controlled environment rather than during actual flight. In real missions, the payload will experience vibration, airflow around the fuselage, and possibly sun exposure, which could affect thermal performance. The PP board insulation performed well in the ground tests but requires inflight testing, such as flying for 60 minutes and then measuring the temperature.

4.4. Future Direction

Continued development should focus on completing the long-distance flight-testing program to confirm the drone's maximum range. The transition control parameters for aft transitions require further tuning to improve the accuracy and stability of the landing sequence. To improve usability for ground staff unfamiliar with the technology, an application with an easy-to-use interface should be created so that medical staff operating the drone can easily deploy it. Finally, for this drone to be actually deployed, there has to be communication with health or governmental organizations, so that things such as deployment across medical systems or airspace usage can be determined.

5. Conclusions

This research successfully demonstrated that a fixedwing tailsitter VTOL drone can maintain snake antivenin within the required 2 to 8 degrees Celsius temperature range for at least 1 hour, and a flight range of at least 50 kilometers is certain. The hypothesis that such a drone design would meet both thermal and flight performance targets was supported by the experimental results.

The PP board insulation maintained the internal payload temperature at 6.3 degrees Celsius after 60 minutes in 30 degrees Celsius ambient conditions, which remains below the 8 degrees Celsius upper limit, meaning the snake AV will not degrade. The prototype achieved a cruise speed of approximately 70 kilometers per hour, an operational range exceeding 50 kilometers, and a forward transition success rate exceeding 90 percent. However, lateral navigation accuracy did not achieve the desired waypoint accuracy within plus or minus 2 meters, and the aft transition to landing has not been fully validated yet. While some specifications meet the requirements for emergency antivenin delivery to remote populations,

others do not, so more progress is needed before a definitive conclusion on full operational viability can be formed.

The practical implication, should all testing be completed, is that snakebite victims in rural areas lacking road infrastructure could receive life-saving antivenin well within the critical six-hour window, most of the time within one hour, depending on the delivery distance. The airframe unit cost below 2000 RMB and per-mission cost below 50 RMB make the technology economically viable for deployment in developing countries where SBE incidence is highest. From an environmental perspective, the all-electric drone delivery system delivers approximately 85% lower carbon emissions per kilometer compared to conventional fuel-powered motorcycle and ambulance delivery in remote regions, while the fully recyclable PP board used for passive cooling further enhances the system's energy-saving benefits and reduces its full lifecycle environmental footprint.

Future work must complete long-distance flight validation, improve aft-transition reliability, and conduct full end-to-end mission testing. With continued development, this technology can support the World Health Organization's 2030 goals for reducing snakebite mortality and transform rural healthcare access through aerial medical logistics.

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