Unmanned Aerial Systems Solutions (UASS)

S900 and Stalker Improvement Program

Failure Modes and Effects Analysis

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This FMEA is presented to show the analysis done by UASS on the overall reliability and safety of the two Unmanned Aerial Systems as well as ways to mitigate possible failure modes for all subsystems, namely Propulsion, Payload, Power, Communications, and Ground Station including the autopilot.

This FMEA will include recommendations as to how to properly inspect and pre-flight the UASs to help mitigate the possibility of problems in flight and how to address these issues during flight.

Table of Contents

Purpose:

This Failure Modes and Effects Analysis (FMEA) is presented to show the analysis done by Unmanned Aerial Systems Solutions (UASS) on the overall reliability and safety of the UASs as well as ways to mitigate possible failure modes. The focus will mainly be on possible failure modes that have the possibility to be mitigated, such as keeping a log of battery usage to track fatigue in individual battery packs, and focus less on failure modes that are unpredictable and cannot be mitigated, such as an asteroid strike during a mission. Possible failure modes have been categorized in two ways; by the possibility of the failure occurring and the severity of the failure's effect on UAS operation. This FMEA will include recommendations as to how to properly inspect and pre-flight the UASs to help mitigate the possibility of problems in flight and how to address these issues during flight.

Severity levels are as follows:

- Minor: Flight operations can continue but with some loss of functionality and safety margin. Continuation of flight is determined on a situational basis.
- Moderate: Extreme loss of functionality and/or safety margin, but some flight control can be maintained. Return to base can be performed and is highly recommended.
- Severe: Flight operations cannot continue and RTB not possible. UAS must land in place.
- Critical: Flight operations will not continue safely, and UAS is not responding to manual or automated control inputs. Controlled landing not possible. ie. Lawn dart.

I. Propulsion

A. Summary:

The S900 and Stalker both utilize electric motors for propulsion. These are used to convert electrical energy into mechanical energy. Two major differences between the two UASs are the number and size of electric motors; the Stalker has 1 and the S900 has 6.

The S900's six DC motors are each rated at 500 watts and 400 rpm/V. Carbon fiber propellers are used with the S900 to achieve maximum flight capability in cold weather operations.

The Stalker DC motor is believed to have a maximum current draw of 60 Amperes. There are also carbon fiber propellers available for this platform. For both platforms the best practice to reduce catastrophic propulsion events will be to conduct efficient preflight and postflight inspections. Special attention should be paid to:

i. Propeller leading edges
ii. Motor mounts
iii. Motor connections

The specifics of the S900 and Stalker propulsion systems are discussed separately in the following sections.

S900

Figure 1. S900 frame with arms extended. The propellers are attached upside down in the photo due to indoor testing.

B. Failure Mode: Obstacle Strike

i. *Effects*: Damage to motor mounts, propellers, or arm. If only one propeller takes minimal damage, the system will likely be able to compensate and return safely to the ground station. If an arm,multiple propellers, or multiple motors are destroyed emergency landing should be attempted.
ii. *Safety and Performance Implications*: Damage could range from minor to extreme. Safety of public and UAS will vary with severity of damage.
iii. *Probability of Occurrence*: Low. Flight plan will be predetermined to avoid obstacles.
iv. *Severity of Failure*: Minor to Critical damage to system.
v. *Corrective Actions Required*: Operator awareness and pre/post flight checks can mitigate problems. Follow takeoff procedures and establish safe distance between personnel and UAS. Follow emergency landing procedures in the event of a catastrophic strike.
vi. REFERENCE: None

C. Failure Mode: Electronic Speed Control Failure

i. *Effects*: Loss of control potentially leading to flat spin or freefall.

ii. *Safety and Performance Implications*: Operator awareness and pre/post flight checks can mitigate problems. Follow emergency landing procedure. Check communication systems. Visually track UAS to minimize damage to system and personnel.

iii. *Probability of Occurrence*: Low, as long as the voltage regulator (VR) on the integration board remains functional and each of the Electronic Speed Controllers (ESCs) remains electrically isolated from other wires in the system. The VR functionality will be verified before powering the ESCs and the wire connections will be insulated and organized to minimize the probability of shorting out any of the ESCs.

iv. *Severity of Failure*: Severe consequences and damage will happen should this failure occur. The motor attached to whichever ESC fails will be under extreme risk. With the loss of a motor, the UAS will not fly as smoothly as it is designed for. This will put the mission and the system at risk. If only one ESC fails, the system could compensate enough to maintain flight for a safe landing.

v. *Corrective Actions Required*: Follow emergency landing procedures.

vi. REFERENCE: None

Figure 2. Carbon fiber propellers, motor, and ESC mounted to an arm of the S900. The propellers are attached upside down, at the time of this photo tests were being performed that required the propellers to be upside down.

Stalker

Figure 3. Motor and Propeller properly mounted to the Stalker Airframe.

D. Failure Mode: Obstacle Strike

i. *Effects*: Damage motor, propeller, wings, elevators, or ailerons.
ii. *Safety and Performance Implications*: Damage could range from minor to extreme. Safety of public and UAS will vary with severity of damage.
iii. *Probability of Occurrence*: Low. Flight path will be predetermined and planned to avoid potential hazards.
iv. *Severity of Failure*: If the propeller or motor take damage, this will greatly impede the ability of the system to sustain flight. The level of damage sustained to the wings, elevator, or ailerons would affect the severity of the outcomes. If the a small chip is obtained on the elevator, the system will likely be able to compensate and return safety to the landing area. If the ailerons are torn off, control of the system will be greatly compromised.
v. *Corrective Actions Required*: Operator awareness and pre/postflight checks can mitigate problems. Follow takeoff and landing procedures, maintain safe distance between UAS and personnel. Follow emergency landing procedures in the event of a catastrophic strike.
vi. REFERENCE: None

Figure 4. Stalker wing and aileron

Figure 5. Stalker elevator, rudder, and servos controlling them

E. Failure Mode: Electronic Speed Controller

i. *Effects*: Loss of control of the aircraft
ii. *Safety and Performance Implications*: Operator awareness and pre/post flight checks can mitigate problems. Follow emergency landing procedure. Check communication systems. Visually track UAS to minimize damage to system and personnel.
iii. *Probability of Occurrence*: Low. Verifying proper electrical isolation and insulation of leads within the system will minimize the chance of shorting out the speed controller. The functionality of the VR will be verified being powering the electronic speed controller.
iv. *Severity of Failure*: Severe consequences for the UAS and the mission will occur should the ESC fail. This will result in loss of control of the motor and in turn the propeller. This would cause the system to have no method of keeping itself in the air, which would result in critical failure.
v. *Corrective Actions Required*: Immediately execute emergency landing procedures.
vi. REFERENCE: None

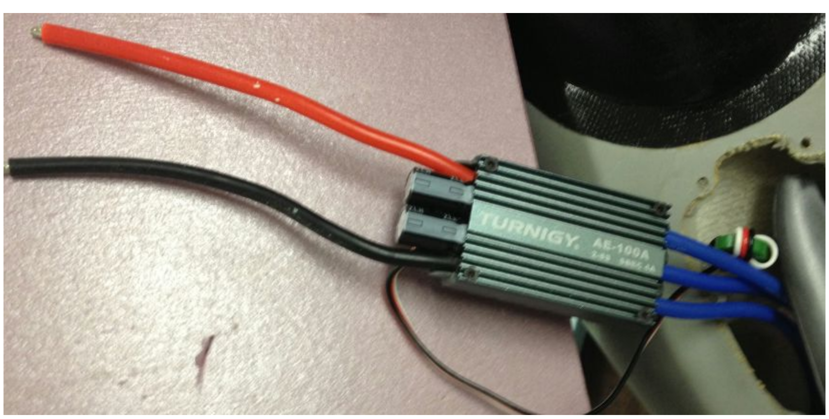


Figure 6. Electronic Speed Controller (ESC) for the Stalker UAS

II. Payload

Figure 7. S900 Payload Rails

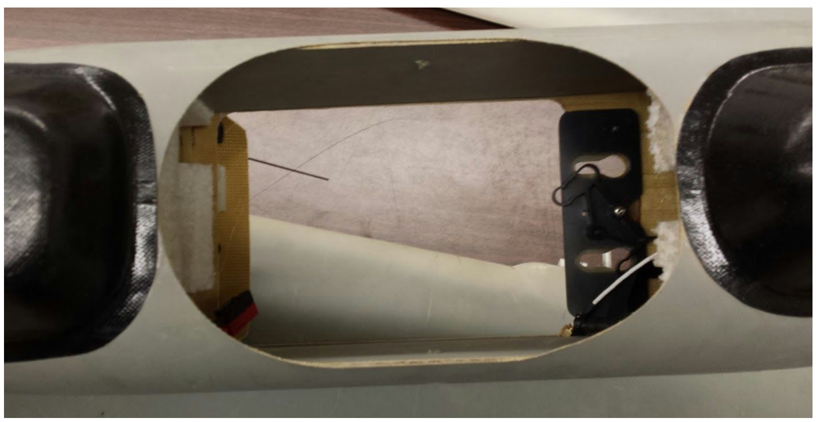


Figure 8. Stalker Payload Bay

A. Summary:

The payload attachment systems will work similarly for the S900 and the Stalker. There will be key differences between these systems. The basics of the payload systems will be points of attachment and integration to connect the payload to the UAS. There are three main concerns with the design of these attachment points: ensuring durability and strength to keep the payload airborne, providing appropriate connections to supply power to certain payloads from the UAS, and allowing for flexibility of attachment points to allow for positioning the payload to maintain an appropriate center of gravity.

B. Failure mode: Payload Detachment

i. *Effects*: If the payload becomes detached from the UAS, the mission would end prematurely. Depending on the height and distance from the ground station, the payload could be either lost or destroyed.

ii. *Safety and Performance Implications*: The loss of a payload could result in a complete mission failure. Not only would the mission be compromised, but a 2 kg object falling from the sky represents a hazard to humans, wildlife, and infrastructure below the flight path. The payload could detach in such a way that it remains attached to the Stalker but is oriented such that it is unable to record meaningful data. This would mean the data collected after the occurrence is unusable, resulting in only partial completion of the mission.
iii. *Probability of Occurrence*: Low, as long as the payload is within the 2 kg mass limit. The most likely location of failure would be the 3D printed material attaching the payload to the UAV. In the Engineering Analysis Paper, it is estimated that the tensile stress on a PLA part would not exceed the yield strength of the material when the payload is 2 kg.
iv. *Severity of Failure*: Critical
v. *Corrective Actions Required*: All actions required will be preventative and pre-emptive. Analysis of structural integrity will be performed with SolidWorks during the design and build process.
vi. REFERENCES

C. Failure mode: Wildlife Collision

i. *Effects*: Damage to or loss of payload, danger to the welfare of local wildlife.
ii. *Safety and Performance Implications:* Depending on how the payload is secured to the UAS, it could be damaged. No birds have been killed by UASs to date.
iii. *Probability of Occurrence*: Low
iv. *Severity of Failure*: Minor to Critical
v. *Corrective Actions Required*: Autopilot should keep the UAS away from areas or altitudes dense with wildlife. The size and noise of the UAS tends to aggravate most birds and the UAS can be viewed as a rival to the birds territory.
vi. REFERENCES
https://www.audubon.org/news/how-will-drones-affect-birds
https://www.youtube.com/watch?v=Hr-xBtVU4Ig

D. Failure mode: S900 Dome Becomes Detached or Broken

i. *Effects:* If the S900 dome becomes detached or broken, then the autopilot and other control hardware will become exposed to the elements.
ii. *Safety and Performance Implications:* In nice weather the S900 can fly perfectly fine without a dome, but in rain or snow it could damage the electronics and cause the S900 to crash.

iii. *Probability of Occurrence:* Low probability. The S900 dome will be very securely attached to the frame and be made of strong and flexible nylon, there is little chance of it detaching or breaking on its own. Nylon does not become brittle until temperatures around -100C, so the cold should not be able to damage the dome. If the dome does become detached or broken, then it is very likely that the S900 has crashed or had a very nasty collision.
iv. *Severity of Failure:* On its own, it is only a problem in bad weather, but it implies that the situation is more severe.
v. *Corrective Actions Required:* If the S900 is being flown in bad weather, then it should be landed and retrieved as soon as possible.
vi. REFERENCES
http://www.sciencedirect.com/science/article/pii/0014305788900729

E. Failure mode: S900 Landing Gear Servos Malfunction

i. *Effects:* If the landing gear servos malfunction while the landing legs are retracted, then the S900 will be unable to land properly.
ii. *Safety and performance implications:* S900 will be able to fly as usual, but landing it safely will be substantially harder. The S900 will land on its payload which will probably cause it to tip over. If the propellers are still spinning then they will be damaged.
iii. *Probability of occurrence:* Low. If all the electronics are hooked up properly then there should be almost no chance that the servos are sent a signal with enough power to fry them. The design of the S900 should prevent the servo wires from shorting out. The only way that the servos should fail is from normal wear and tear, and since they are metal geared servos that are only used a couple of times during flight, they should last well beyond the lifetime of the S900.
iv. *Severity of failure:* Moderate. Payload and propellers may be damaged while landing.
v. *Corrective actions required*: Land the S900 very carefully and away from people. If possible, land in a soft area. Do not try and catch the S900.
vi. REFERENCES

III. Power

A. Summary:

The main safety concern with the LiPo battery is thermal runaway where the battery rapidly and uncontrollably increases in temperature until it combusts. It is sometimes referred to as “rapid disassembly” in the battery industry. When this happens, the UAV will require an immediate landing before all battery cells catch fire and the UAV commences an uncontrolled and immolated crash. This is a worst case symptom to which there are several causes. Other concerns are loss of performance which could lead to mission abort or premature landing.

B. Failure mode: Physical Damage

i. *Effects*: Breach of battery pack, rupture of inside components.
ii. *Safety and Performance Implications*: Possible thermal runaway.Chemical reaction may be delayed and could happen 30 minutes or an hour later.
iii. *Probability of Occurrence:* By themselves, the battery packs can easily be punctured.
iv. *Severity of Failure*: Possibly critical
v. *Corrective Actions Required*: Place the battery in a fireproof location and observe it for safety reasons. If flaming, use a class D fire extinguisher. Cells may be hot. Carefully inspect LiPo batteries which have been involved in a crash for even the smallest of cracks, splits, punctures or damage to the wiring and connectors.
vi. REFERENCES: http://manuals.hobbico.com/sup/supz1030-lipo-handling.pdf

C. Failure mode: Frozen battery

i. *Effects*: The battery voltage will likely drop resulting in lower power output and shorter flight duration
ii. *Safety and Performance Implications*: Less charge means the UAV won't be able to fly as long and may not be able to complete mission or even return to launch site.
iii. *Probability of Occurrence*: Minimal. As long as batteries are kept at room temperature before flight active use should keep the batteries warm. Batteries will also be wrapped in insulation for thermal protection of other UAV elements
iv. *Severity of Failure*: Minimal. Loss of charge would be detected with time to safely return UAS.
v. *Corrective Actions Required*: If battery is 'frozen' before launch time, use a different set of batteries. If Batteries seem to be losing charge due to cold in flight return UAS to base and reassess flight requirements and if possible replace batteries.
vi. REFERENCES:
Isaac Thompson, UAF Graduate Student studying Li-Po battery systems; http://blog.flitelab.com/2014/11/26/lipo-battery-cold-weather-usage-tips/;

D. Failure mode: Overcurrent

i. *Effects*: Overcurrent is a state where the current output of the batteries exceeds the capacity of the wiring. This leads to excessive heat and melting of insulation around wiring, causing short circuiting and fire hazards.

ii. *Safety and Performance Implications*: The melting of insulation around the wiring leads to short circuiting of battery and wiring. The high battery capacity will cause sparking and likely lead to a battery/wiring fire.
iii. *Probability of Occurrence*: Low if proper wire sizing calculations are performed and current requirements are adhered to strictly.
iv. *Severity of Failure*: Critical
v. *Corrective Actions Required*: During this situation power to all systems will fail causing UAS to become entirely inoperable. The UAS will crash, and a fire is highly likely.
vi. REFERENCES: http://batteryuniversity.com/learn/article/safety_concerns_with_li_ion; https://www.maxamps.com/lipo-care.php

E. Failure mode: Moisture in battery leads/compartment

i. Effects: Corrosion of electrical leads, and reduced power output from batteries will likely occur.
ii. Safety and Performance Implications: Corrosion can cause electrical connection issues leading to isolated system failures. Low power output can reduce lift and thrust of electrical motors causing flight difficulties.
iii. Probability of Occurrence: If batteries and leads are properly installed and protected from moisture the probability will be low.
iv. Severity of Failure: Minor to Moderate
v. Any Corrective Actions Required: Proper system checks should be performed during preflight checks to ensure electrical connections are secure. During this time any questionable connections and battery systems should be replaced. During flight a low voltage or current condition should be detectable and UAS should be returned to base as soon as possible for performance of corrective action.
vi. REFERENCES: http://www.icharger.co.nz/articles/ArticleId/3/Lipo-Lithium-Battery-Safety-Guide.aspx;

F. Failure mode: Wiring malfunctions

i. Effects: Wiring malfunctions will cause loss of power to isolated systems during flight.
ii. Safety and Performance Implications: Depending on the system that loses power the UAS could become inoperable or could have intermittent telemetry and connection issues.
iii. Probability of Occurrence:

iv. Severity of Failure: The severity is entirely dependent on the system that loses power. This could range from Minor (telemetry issues) to Critical (loss of motor power)

v. Any Corrective Actions Required: During any loss of power to any system the UAS should return to base if control can be maintained. If power to motors is lost the UAS will become inoperable and a crash is imminent. Thus, it is necessary that all wiring be checked and properly secured prior to each flight. Checks should include verifying that each electrical connection is secured properly and free of corrosion, no breaks in wiring insulation is apparent, and all wires are secured in proper wiring holders and harnesses.

vi. REFERENCES:
http://batteryuniversity.com/learn/;
http://www.w8ji.com/battery_wiring.htm;

IV. Communications

A. Summary:

The communications systems operate similarly between the S900 and the Stalker UAS. It is divided into three distinct subsystems: telemetry, video feed, and RC manual controller.

The telemetry system links the autopilot and the ground station together, providing for the aircraft's vital statistics to be transmitted to the ground station and allowing the ground station to make flight plan changes while the UAS is in flight. A depiction of what the XBee XSC pro looks like is shown in the figure below.

The video feed provides for high definition video to be sent from the onboard video camera back to the ground station for real time monitoring. It is depicted in the figure below with the ground system on the left and the air system on the right.

The RC manual controller provides for the operator to take manual control of the aircraft, a necessity for takeoff and landing of the Stalker UAS.A directional antenna will also be considered with one or more of these communication links. This would provide increased range of both the Stalker and the S900 in terms of communication distance but will consequently require more precise pointing of the antenna due to the more narrow beamwidth as the gain of the antenna is increased. The base manual controller is shown in the figure below without the additional yagi antenna.

B. Failure mode: Loss of Telemetry Signal

i. *Effects*: The Ground Station will no longer be able to communicate with the Autopilot on board the aircraft.

ii. *Safety and Performance Implications*: Information regarding battery charge state and the orientation and position of the aircraft will be lost. This loss of pertinent flight information will make assessing the state of the aircraft impossible. The ability to make in-flight edits to the current flight plan will also be lost.
iii. *Probability of Occurrence*: High. It is likely that missions will take the UAS at distances close to the max range of the system. If there are other RF signals in the area (which is likely in today's communications driven world) it could suddenly reduce the maximum range of the Telemetry signal. Depending on the terrain the signal could be lost suddenly as well since trees, mountains, buildings and other obstructions will block a portion of the RF signal.
iv. *Severity of Failure*: Minor. The UAS will not suddenly fall out of the sky when the telemetry signal is lost. Once the signal is lost the UAS will try to reestablish connection automatically.
v. *Corrective Actions Required*: Immediate autopilot action would be to continue on the established flight plan for a short time and attempt to acquire signal again. If loss of signal persists then the autopilot would revert to a failsafe mode in which it would return to the launch/home location. Manual control is not recommended if telemetry is lost. Only manually control if absolutely necessary and if UAS is in line of sight and near to the controlling site.
vi. REFERENCES
http://plane.ardupilot.com/wiki/apms-failsafe-function/

C. Failure mode: Loss of Video Feed Signal

i. *Effects*: The Ground Station will no longer receive the video being recorded on the aircraft.
ii. *Safety and Performance Implications*: Seeing the physical location of the aircraft will be impossible if it flies out of sight of the pilot. This will increase the risk with manually piloting the aircraft should they be out of sight. Additionally, the on board data storage device will be the only means of recovering any video obtained on the mission.
iii. *Probability of Occurrence*: High. This communication link has the shortest range of the three links and missions will likely take the UAS out of the range of the video link.
iv. *Severity of Failure*: Minor. No major systems need the video link to be functioning. If the video feed goes out the only impact is that all video needs to be stored on board the UAS.
v. *Corrective Actions Required*: The main correction will be to bring the aircraft into the sight of the pilot to ensure that if an emergency landing is required, they will be able to bring it down smoothly. If the video feed

comes back online when flying closer, the maximum range of the video transmission has been reached. The mission can carry on as normal without the video link, as it is not necessary for flight. The only impact is the ability to investigate the surrounding of the aircraft in real time, either for the mission or piloting purposes.

vi. REFERENCES: None

D. Failure mode: Loss of Remote Controller Signal

i. *Effects*: The pilot will no longer be able to manually control the aircraft and it will rely solely on the telemetry/autopilot for instructions on where to fly.

ii. *Safety and Performance Implications*: Manual override of the aircraft will be impossible if the RC signal is lost. The dramatically increases the risk with any mission due to the fact that if something goes wrong with the autopilot or ground station there will be no way to pilot or emergency land the aircraft. The mission could carry on as normal using the autopilot with an increased risk should any other system fail.

iii. *Probability of Occurrence*: Medium. This link has a similar range to the Telemetry and will likely go out under similar conditions as the other communication links that have been discussed.

iv. *Severity of Failure*: Moderate. The controller signal is what controls the UAS. Anytime control is lost it is a bad thing and care should be taken. The autopilot will be in control of the UAS majority of the time so no immediate damage will occur.

v. *Corrective Action Required*: Corrective action is not immediately necessary should the RC signal go down. The mission can continue as normal and function off the autopilot along. The risk associated with this is great, as was mentioned before, so it is recommended that the aircraft lands as soon as it is convenient for diagnosing why the link failed.

vi. REFERENCES: None

E. Failure mode: Inadequate Pointing of Directional Antenna

i. *Effects*: The directional antenna is used to increase the range of the communication systems for the aircraft. If the antennas are not pointing in the direction of the aircraft, there will be no communication with it.

ii. *Safety and Performance Implications*: If the antenna is misaligned slightly, the maximum communication distance with the aircraft will be diminished. The antenna will not have excessive gain, so the beamwidth is not too narrow to manually point if necessary. This problem could potentially cause one of the problems listed in sections b through d but would have an easier fix.

iii. *Probability of Occurrence*: High. People will not be able to keep the antenna pointed at the UAS at all times because people will always make mistakes.
iv. *Severity of Failure*: Minor. This will happen regularly and has a simple fix. The manual controller is the only connection with a directional antenna at the moment and connection will reestablish once the pointing is corrected.
v. *Corrective Actions Required*: Corrective actions will include pointing the antenna in the right direction. Find a new guy to hold the antenna because the last guy failed.
vi. REFERENCES: None.

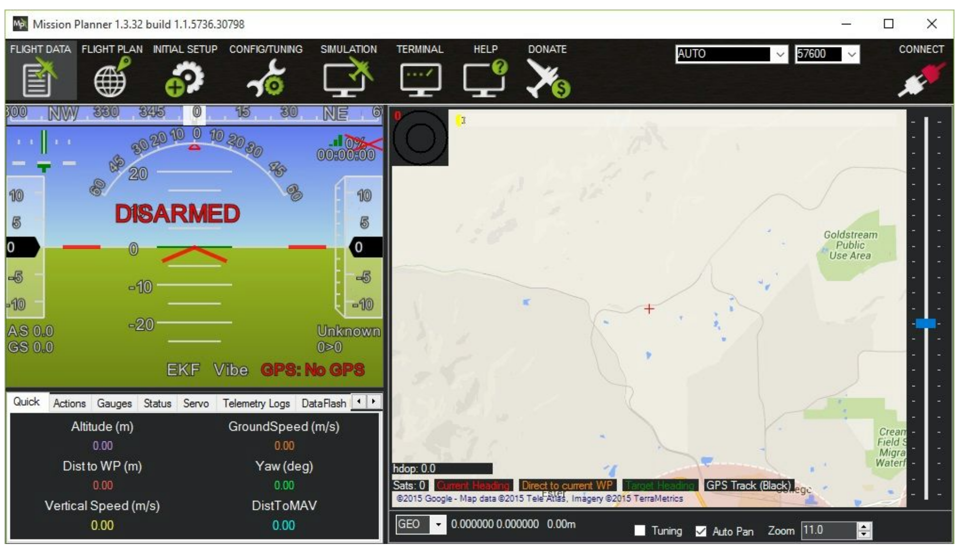
V. Ground Station & Autopilot

A. Summary and Theory of Operation:

The Ground Control Station (GCS) / Autopilot will work to a similar capacity for both the S900 and the Stalker UASs.

For the Autopilot and Ground Station to work together to avoid possible problems, all components that can be used to support the PixHawk will be plugged into it. There are still problems that can occur, but monitoring these issues with Mission Planner software will help. Mission Planner has many failsafes that can be set up to provide preventive measures and they will be set up prior to flight for both the S900 and Stalker. To provide these preventive measures however, the PixHawk will need to be set up correctly and have operational control presets available.

The main concerns for the GCS / Autopilot will include, but not be limited to Vibrations, Mechanical Failures, Compass Interface and GPS glitches.



B. Failure mode: Vibrations

i. *Effects*: Vibrations cause the accelerometer based altitude and horizontal position estimates to drift from the actual position

ii. Safety and Performance Implications: The actual location of the UAS will not be reflected in the accelerometers values, this can cause the UAS to go into unplanned/unsafe areas.

iii. Probability of Occurrence: The probability of vibrations disrupting the UAS's accelerometer are rare, but not unlikely.

iv. Severity of Failure: The range of severity is minor to moderate, depending on the extent of vibrations and how dramatically they affect the accelerometer.

v. Any Corrective Actions Required:Corrective actions may include attempting to take manual control of the UAS and landing it, using a RC controller, if it is within line of sight. If it is outside of the line of site and the vibrations are suspected to be minor then the UAS should attempt to return to base. The UAS should be immediately landed if the vibrations are moderate. After the flight Mission Planner can be used to graph the dataflash's IMU messages AccX, AccY and AccZ values, this will indicate in what direction the vibrational disruptions were occurring. Figure A2 in appendix A illustrates the Mission Planners IMU software for vibration analysis.

vi. References: http://planner.ardupilot.com/wiki/common-diagnosing-problems-using-logs/

C. Failure mode: Compass Interference

i. *Effects*: Interference from other electrical devices near the autopilot system may cause the compass heading to be thrown off course.

ii. Safety and Performance Implications: The UAS may begin circling or even become so thrown off course that it begins flying in the opposite direction.

iii. Probability of Occurrence: The probability of interference is low, since we can arrange the electrical devices in a way in which they do not interfere with the autopilots system.

iv. Severity of Failure: The severity compass interference ranges from minor to moderate as the UAS could be thrown completely off course and potentially crash because of interference. Yet, since the interference would generally be known fairly quickly upon launching the UAS the UAS would probably still be within line of sight and therefore could be landed manually.

v. Any Corrective Actions Required: Do a compass reading check before flying. Using Mission Planner after a flight to graph the tlog's Mag_field and throttle values allow the user to see when there are spikes in magnetic interference. There is a significant interference if the value of magnetic interference spikes above 60% when the throttle is raised. See figure A4 in appendix A for more details.

vi. References: http://planner.ardupilot.com/wiki/common-diagnosing-problems-using-logs/

D. Failure mode: GPS Glitches

i. *Effects*: Positional errors from GPS glitches can cause the UAS to sporadically think that its position is incorrect and make drastic flight patterns to correct its position
ii. Safety and Performance Implications: GPS glitches may cause the UAS to behave unpredictably when connected to Mission Planners autopilot system
iii. Probability of Occurrence: The probability of GPS glitches are minimal, yet the location of Fairbanks at 45 % inclination and the lack of other GPS systems makes it.
iv. Severity of Failure: The severity for GPS glitches range from minor to severe because if the GPS does have a glitch, the UAS may go in the wrong direction that the GPS previously predicted that it would go. This could cause no damage or it may cause the loss of the UAS system.
v. Any Corrective Actions Required: Place GPS where there would be no interrupted signals. Choose a dome cover that would not interrupt the signal from the satellites to the GPS.
vi. References: http://copter.ardupilot.com/wiki/gps-failsafe-glitch-protection/

APPENDIX

Ground Station Figures

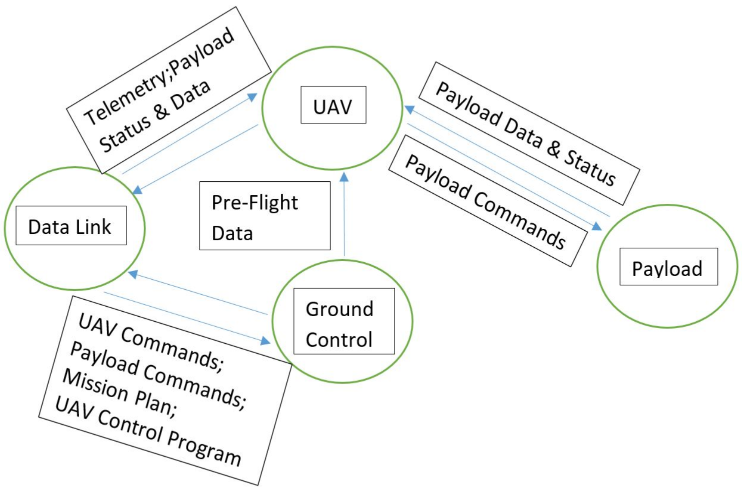


Figure A1: Block diagram summary of the ground stations

Figure A2: Mission Planners dataflash IMU messages AccX, AccY and AccZ values, these values indicate in what direction the vibrational disruptions were occurring.

Figure A3: Dataflash logs and graphing the ATT message's Roll-In vs Roll and Pitch-In vs Pitch in Mission Planner

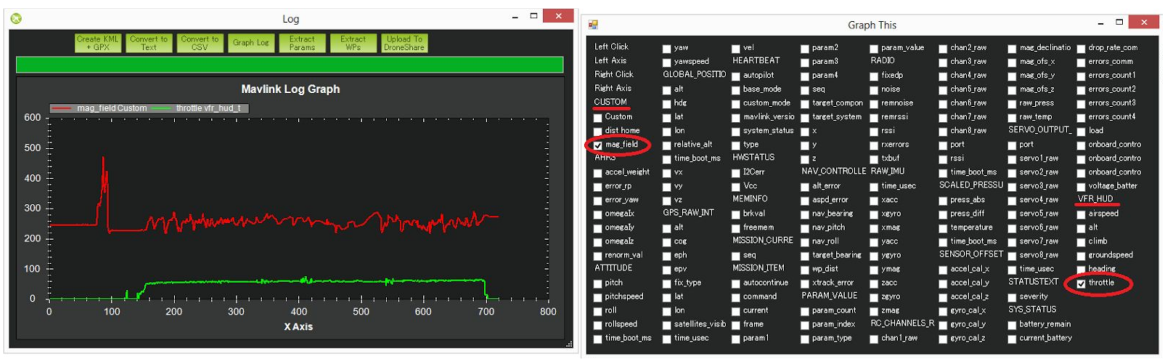


Figure A4: Mission Planners tlog's Mag_field and throttle values allow the user to see when there are spikes in magnetic interference

Power references: References: http://www.gibbsguides.com/Glossary_L_to_P.htm; http://batteryuniversity.com/learn/; http://www.dronethusiast.com/ultimate-drone-battery-care/; this PDF; this PDF; this PDF; and this PDF.