1. Technical Summary – Outline key technical and scientific principles your concept utilizes in its design and functionality. **(1,000 words maximum)**

Smart Autonomous Visual Emergency Drone (SAVED) is an autonomous and cost-efficient data collector drone that may traverse difficult conditions, collect visual and numerical data of the site in need of an emergency response, and process data through Machine Learning (ML) to create suggestions to emergency responders or its users. SAVED's technical and scientific principles can be divided into four sections: flight and ground controllers, mechanical design, machine learning and the Ubuntu server.

SAVED uses semi-autonomous flight. While the drone does not decide on the regions of the disaster-stricken area targeted, it autonomously decides *the manner in which* it will follow a route or target location set by the user. The ground and flight control systems are shown in Figure 19 in Disastair_SUPPLEMENTARY_MATERIAL.pdf. Ground control (the user's Windows computer) runs QGroundControl, the GUI interface used to run both (a) jMAVSimulator and (b) the actual drone. In order to run QGroundControl and jMAVSimulator, the user can follow DisastAir's guide provided here: https://github.com/DisastAir/Drone-Control. This involves downloading jMAVSim, QGroundControl, GStreamer and PX4-Autopilot on the client's computer. The batch file "setup.bat" is used to download all packages needed, and "run.bat" will open the Cygwin-based PX4 shell in which the user can startup the drone and command it.

In order to run the simulation, the user must run commands provided in the Github repository provided above. This starts a Software-In-The-Loop (SITL) simulation, which recreates the behaviour of a real-time controller. PX4_Simulation.png in the Github repository "Disastair_Additional_Files" (https://github.com/DisastAir/Disastair_Additional_Files) shows QGroundControl's flight page, QGC_Flight_Route.png shows QGroundControl's flight route creator and jMAVSimulator.png shows jMAVSimulator. In order to use the simulator, the user can either enter commands into the PX4 shell or the QGroundControl GUI. PX4_Console.png shows the PX4 shell. The simulation is used to learn how to operate the drone, practice and draw mission flight routes

In order for PX4 to run on the actual drone, there are additional packages DisastAir must download and set up before delivering to the customer. The flight controller, an Arduino Nano 33 BLE Sense, runs PX4 firmware. GStreamer, meant for video streaming, and PX4-Avoidance, run on the flight controller alongside the PX4 firmware. Before the drone flies, the client must connect their drone and laptop running QGroundControl together to configure video and home settings. Lastly, MAVLink Protocol, using the drone's transceiver, is used to communicate with the receiver connected via micro-USB to the client's laptop. At this point, drone control is ready for usage.

PX4 contains a library of commands which allow the user to operate the drone through the shell or QGroundControl. These include "takeoff", "land", creating flight routes, initiating the flight route, creating a geofence (delimiting where the drone can fly), creating rally points (alternate locations for the drone to land), and more. The possible flight routes are “survey,” “corridor scan” and “structure scan.”

Overall, flight and ground control involves (a) installing open source software (primarily PX4), (b) configuring the drone, (c) sending flight commands via the PX4 shell and/or QGroundControl (e.g. mission planning, takeoff, landing, etc.).

Second, the mechanical design of the drone involves both structural design, electronic integration, basic dynamics, and fluid dynamics calculation of the aerodynamic forces acting upon it. For structural design, the most important aspect is the compromization between lightweightness and structural integrity, whilst maintaining a perfect weight distribution ratio. For electronic integration, it includes the mountings of all electrical parts. For basic dynamics, it utilizes all the fundamental force principles and other dedicated design principles for autonomous drones, especially the ones specific to quadcopters. For fluid dynamics, it is a constant battle between generating enough forces to lift and control the altitude, yaw, and pitch of the drone, whilst minimizing the power consumption and judders during flight. These main design directions prompted us to research into a variety of topics, ranging in complicity. Some important topics include Euler’s angle, Quadcopter’s Equations of Motions, design principles of high lift propellers, quadcopter stability increasing techniques, and blade element method to estimate the maximum thrust of which it may generate. These ideas influenced design decisions of SAVED by providing numerical support to the functionality of SAVED, hence enhancing its overall quality.

Third is machine learning. Although SAVED may not be fully autonomous, it poses a certain level of intelligence. Contrary to most ML models, SAVED takes advantage of pre-existing packages and models from Sci-Kit Learn and PyTorch, maximizing the package efficiency and may be easily run remotely via the cloud. This eliminates the need to incorporate image classification neural networks, dramatically decreasing computational-cost. It also is pre-trained, with hyperparameters tuned to maximize classification accuracy while minimizing runtime. Once the data have undergone dimensionality reduction and are prepared to be processed, it will be inputted into a Decision Tree Classifier that utilizes reinforcement learning to improve its overall quality. Since its data are all transmitted remotely via radio, the user may run the ML algorithm in real time, which is efficient and will save time, especially beneficial in this time-sensitive industry. Its ability to process data while the drone is returning to base also eliminates the risk of losing the data if the drone is damaged or they become corrupted.

Fourth, file transfer and setup for the Ubuntu server. We will be using schtasks to automatically send all video files sent from GStreamer to Ground Control (user’s computer) via SFTP (Secure File Transfer Protocol) to the Ubuntu server. This server will contain the machine learning algorithms, and, using a Cron job, will send the results back to the user’s computer.

2. Need Statement – Describe the challenge your concept will address. Provide information and resources on why the concept is important and how it will be used in the selected industry. **(1,000 words maximum)**

Disaster response has become increasingly critical in the recent decade as climate change has begun to induce more frequent and impactful natural disasters. Streamlining the approach to these events can mitigate the long-term effects these can have on smaller communities less equipped to face these challenges. For example, the recent Haiti earthquake has drawn many nearby countries to either send resources, military and rescue teams as humanitarian support. However, the Haitian government was incapable of responding effectively to the situation, with the death toll rising to 1900 after 2 days, due to low budgets and mismanagement.

Low-Income Countries (LICs) often have little infrastructure set in place to respond to these disasters, and cannot afford the level of response communities and civilians need when dealing with a crisis. Providing LICs, supporting charities, and Non-Governmental Organizations with an affordable option in crisis-response is essential in combating global inequality and mortality rates in Low Income Countries

Examples of slow and insufficient government responses to natural disasters will only continue to increase in High-Income Countries as well. Recent floods, forest fires, and heat domes in British Columbia, Canada, reveal how little the government is prepared for the forthcoming wave of climate disasters, and the disastrous delay in the delivery of aid to civilians when arterial highways and roads are obliterated. Air lift routes and alternate paths were essential in saving lives due to the flooding, but it took about 3 days for planned air lifts and responses to occur due to the uncertainty around road damage. Streamlining the data-collection process could have provided British Columbians with the information necessary to plan ahead, preventing the use of dangerous highways and lessening casualties. Countries across the world will face similar levels of threats as climate change's impacts increase.

During the disaster, the user (i.e. a member of a disaster response team) deploys the drone, which flies autonomously in a user-set location and time period. Visual data collected during this time is processed in an advanced machine learning system on one of DisastAir's remote servers for rapid analysis, which is then sent back to the user's computer. SAVED's machine learning algorithms use heat signatures and movement to scan for possible survivors. SAVED also identifies possible evacuation routes for survivors and rank routes based on efficiency for emergency services to reach certain high priority locations. The camera would provide key damage mapping, possibly with orthomosaic imaging for the highest quality analysis of the situation on the ground. Indicators for damage (destruction of buildings, usability of remaining infrastructure, visibility, etc.) would both be updated at a time interval set by the customer, but could also be viewed live via drone footage and real-time layering. This map would also display progression of the disaster and provide customized metrics measuring the rate of change in the disaster.

Accessibility and fluidity is crucial to disaster response. SAVED is key to responding to disasters in an efficient manner as it makes crisis response accessible and fluid, with the drone connecting to software that can be used on the user's device. This removes the need for expensive government funded equipment, often used by national and municipal disaster response agencies, and puts response power in the hands of civilians who may be in impoverished, remote, and politically unstable areas. These communities get the short end of the stick when governmental aid is deployed as they are usually most difficult to reach and expensive to support. Unfortunately, current drones in the market are expensive and therefore inaccessible to low-income countries

DisastAir provides accessibility through its low cost. Ease of use is prioritized with its smart user interface, autonomous launch, and operation program; this is essential in mitigating the effects of natural disasters in low income countries who host impoverished communities and remote communities in high income countries. Communities lacking access to clean water, food, and education cannot prioritize planning for natural disasters, thus DisastAir prioritizes the simplicity of the user interface and makes it easy to use for anyone, anywhere.

Drones on the market aren't equipped to provide constant feedback through an autonomous program, and usually have a short-range camera meant to assist or guide a first responder through a terrain with low visibility. Our drones can be launched the instant a disaster is reported, and provide great range of vision through a long-distance camera, providing a head-start for the first responder instead of hovering by them as they deal with threats and obstructions.

3. Background Technology – State existing technology upon which the concept is built. Note any competing technologies or relevant patents and explain how your proposed concept is innovative and better than existing technologies that produce similar results. **(1,000 words maximum)**

SAVED builds on top of numerous open source technologies in order to produce a highly cost effective and reliable drone. Some of these technologies and techniques include pitching moment reduction, advanced flight control, and cost-effective machine learning (ML) techniques for image classification.

SAVED is especially innovative because it utilizes recent discoveries in quadcopter stabilization techniques. Tilting the motors decreases its sensitivity to lateral movements, reducing the pitching moment and hence increasing its stability, especially when hovering in windward condition. This maximizes the quality of data collected under difficult weather conditions. In addition, paired with a simple mono-axis gimbal controlled by a single gyroscope, it allows the drone to conduct micro adjustments when filming, increasing the video resolution and eliminating any chance of blurred, unprocessable data.

Further, electronics used onboard the drone are unorthodox. In order to reduce costs, an Arduino BLE Sense 33 board, with onboard 9 axis inertial, humidity, temperature, barometric, gesture, proximity, light color and light intensity sensors, combine a large portion of the drone's necessary inputs in a small, an cost-effective (~$30 USD) form. Most DIY drones use flight controllers that are created or promoted by the flight controller software creator, such as Pixhawk for PX4. However, since PX4's firmware is also compatible with the Arduino BLE Sense 33, there is no need for that.

Although SAVED is controlled mostly through PX4, it is equipped with a variety of other sensors, capable of navigating using gyro stabilization, IMU control for pre planned routes, and obstacle avoidance using multiple cameras. For example, in the case of a GPS failure, another method of calculating the location of the drone is to utilize the accelerometer installed on the drone, and approximate its location using the direction of which it tried to fly towards, and its velocity at the given timestep. It may also use gyro stabilization to reduce juddering of the drone or the camera mounted on the gimbal, utilizing feedback generated from the gyroscope to control the finer movements of the drone.

In addition to flight control, a special feature of SAVED is its cost-effective machine learning algorithm. It utilizes the already well-developed infrastructure of Sci-Kit Learn and PyTorch, processing image data by normalizing, grayscaling, and resizing the image, undergo histogram equalization, pixel importance through random forest classifiers, and finally processed through the decision tree classifier to filter out all data with little to no relevance to the users.

Although SAVED will not use the state of the art convolutional neural networks (CNN), its strength lies in the shorter runtime, without making too much compromisation to its accuracy. As an aid to improve the quality of the outcomes, SAVED will also utilize reinforcement learning (RL) and grid search techniques during hyperparameter tuning and will continue to become better trained as the user feeds it additional data. Furthermore, SAVED uses radio transmission to transfer data in realtime, which is very useful to all prospective customers and time-efficient. It also has an omni-directional range of 6km and directional range of 80km, which exceeds the abilities of other competitors.

Even though emergency response drones are quite common, SAVED does not have any direct competitors simply because it targets a different user group. For example, a major competitor of SAVED are the drones manufactured by DJI. DJI's drones range from consumer to industrial grades, some of which have similar footprints as SAVED. However, even their most entry level drone, which only has a fraction of the total functionalities that SAVED processes, is near 1000 USD, rendering a largely inaccessible brand of products.

SAVED, even while being a budget option, offers all the features included in other products of similar price and much more. This makes it accessible to everyone, including charity organizations and departments that are less wealthy than those in a first world country.

In addition, autonomous flight renders all existing competitors inferior, as they all still require constant human input through an RC controller, taking vital time from first responders and aid workers who could be contributing to more time-intensive aid efforts/coordination. Autonomous flight also removes a significant portion of human error while piloting a drone.

In summary, SAVED builds itself upon the current existing infrastructures and technologies, including autonomous flight control techniques, cost-effective machine learning, pitching moment reduction, and radio transmission of data. It is especially innovative considering its low price point and its numerous features.

4. Concept Details – Describe in detail the concept's conceived function, operations, proposed development and any other information about the technical or scientific merits that will make this product successful. Show that the component technologies or combination is realistic and plausible within a reasonable development timeframe. You can refer to similar uses, research expert testimony, prototype or demonstration and other research. **(2,000 words maximum)**

SAVED is rendered as a conceptual emergency response drone that may collect data through semi-autonomously navigating to a desired location and process them using machine learning (ML). As a micro aerial vehicle, there are three critical general development directions for SAVED to ensure its functionality - its mechanical design, its flight control mechanisms, and its machine learning algorithms.

The main frame of SAVED is constructed with 3D printed Fire Resistant ABS, printed with 20% cubic infill, meaning the drone is structurally sound in all directions, and somewhat heat resistant, useful when scouting out the surroundings of an uncontrolled fire. ABS is also a very durable material, with a medium level of elasticity, meaning it will not flex during normal flight but offer a buffer in the event of being struck by small objects. It is also lightweight, compared to materials of similar price point and structural integrity. This is especially helpful since it will reduce the power required to generate sufficient thrust force. Although it may seem large, SAVED only have a footprint of 423mm*423mm*190mm, which is quite small for a quadcopter equipped with six cameras (one mounted on a gimbal), gps, video transmitter, 9-axis gyroscope, and numerous other sensors. It also has two LiPO 4s 14.8V 5200mAh batteries, providing a very long range for the drone, while maintaining its small form factor. This makes SAVED especially nimble, able to navigate through tight spaces autonomously.

While the frame is the housing of all components and maintaining its lightweightness and durability is critical, its most prominent feature is the tilted motor mounts. Each of these motor mounts are omni-directionally tilted at negative 5 degrees relative to the origin. This reduces the pitching moment of as Japanese researchers Otsuka, Daisuke, and Keiji have discovered. The reduction of pitching moments consequently increases the stability of SAVED in windward conditions, albeit fractionally decreasing the maximum thrust.

Another feature of the frame is its serviceability. It is broken down into multiple components, all may be disassembled via machine screws and nuts. This elongates the lifespan of SAVED, in comparison to most other products on the market. It makes SAVED more sustainable as well, as a simple malfunction may be easily repaired, without having to discard it due to lack of access to components or permanent mounting points. In the case of other components that have a lack of mounting holes, they are mounted in through a clip mechanism, where it will snuggly fit into the space dedicated for the component, while leaving a narrow gap for the users to leverage and remove them in the event of an emergency reparation. Aside from having the ability to disassemble the product itself, these components are both standardized components, either through American National Standardization Institute (ANSI) or International Organization for Standardizations (ISO). It makes acquiring replacement parts especially easy and cost effective.

While the frame houses a vast amount of features, the most important aspect of a quadcopter is its rotaries and thrust generation. If the propeller cannot generate sufficient thrust, the quadrocopter will have a difficult time lifting itself off the ground; inversely, if the propeller generates too much thrust, it may be extremely difficult to maintain it in a stable, hovering position to collect data. Therefore, it is a delicate craft to balance. Using both existing data provided by the motor manufacturer and the simulation performance data generated in ANSYS Fluent Student, the final dimensions of the propellers powering SAVED is 5.6 inches in diameter, and 4.2 inches in pitch. This follows the design principles of high revolutions per minute (RPM), low pitch, minimizing judderings while still generating sufficient amounts of thrust. This is especially important for data collection as well, as any micro movements may impact the stability of SAVED, decreasing the quality of the videos recorded. This is also mitigated through having a gimbal setup on the camera, controlled via a 9-axis gyroscope maximizing the image resolution of the main camera for data collection.

Even though the mechanical design of SAVED is already in shape, there are many other potential design aspects available for further development, mostly in terms of further strengthening the structure by introducing ribs and other triangular support into the frame, reduce the overall drag by eliminated unnecessarily large surfaces, and optimizing the performance of the propeller. As there is a vast reserve of existing literature on quadcopters and the mechanical prototype is already functional, future development will focus predominantly on component optimization.

A hybrid concept between the mechanical design and flight control is the electrical hardware of SAVED. As aforementioned, most of these components are mounted as a press-fit or via machine screws. Even though they are already integrated into the mechanical design, there are still many other aspects of electrical hardware that must be developed. A topic that bridges with mechanical design is to minimize the space saved for wirings. For example, the USB dongles can be redesigned to reduce its footprint, same with the six cameras. A simple method would be to remove its plastic shells and replace them with mounting brackets. In addition, another potential development is to reroute these wires through dedicated locations, fastened via flexible clips. This is very common in 3D printed plastic and moldings.

Adding onto flight control from the “Technical Summary” question, communication works via radio control. While the user will pre-upload flight routes, they can also control the drone manually, if need be, via QGroundControl. MAVLink will also send flight logs from the drone to Ground Control.

Furthermore, drone control involves the usage of failsafes in case something malfunctions. Failsafes are configured onto the drone through QGroundControl. Dangerous/critical battery levels return the drone to home position if critical or lands at current position if dangerously low. All other failsafe triggers (loss of mission track, geofence and data link loss) trigger the drone to land back at the home position.

Drone obstacle avoidance functions completely in-house on the drone controller. The external package used for this is PX4-Avoidance, an ROS node (Robot Operating System). Four cameras around the sides of SAVED and one on top work in tandem with PX4-Avoidance to move around obstacles and return to the flight path.

Aside from the mechanical design and flight control, ML also plays a crucial role in ensuring the full functionality of SAVED. This ML algorithm is very rudimentary, it utilizes the basis of existing open source packages and combines a variety of well designed techniques into one collective model. For every nth frame in a video or camera roll, this specific image is selected and transformed into a five dimensional dataset, consisting of the coordinate of the pixel and its RGB color code. To improve the quality of the collected dataset, they are preprocessed using PyTorch, by undergoing histogram equalization and image normalization, grayscaling it entirely, and processed through pixel importance with a parallel random forest classifier, its key features become more pronounced while unimportant features and neglected, resulting in a higher accuracy and lower computational-cost.

As the classifier goes through a series of criteria to judge if the image may be of use to the emergency responders. If so, similar data will be outputted while the rest are neglected. If these classifications are deemed useful, all similar data are kept and processed; alternatively, if they are null, then similar data will be discarded. The decision tree “grows” overtime, improving its accuracy and self-tuning along the way.

For complex image processing, the most common choice is a Convolutional Neural Network (CNN). It allows maximum customizability, tunability, and detail recognition. It is the state of the art technique for ML image classification. However, its main faults lie in the runtime and hardware required to process given data. Therefore, the lack of CNN on SAVED is not the sign for its lack of technical complicity, but solely because it follows a completely different development goal - accuracy is not of paramount importance if it is computationally costly to process.

For maximum user friendliness, SAVED is equipped with a pretrained ML network, with a high level of customizability in terms of its baseline dataset. This is designed to train the network to become more accurate at classifying a specific aspect of emergency response, such as damage assessment, spotting early signs of wildfire, and locating the site of an accident. Like dimensionality reduction, this is designed to increase the efficiency of getting useful information to first responders. This pretrained ML network is also very useful for users who do not have access to mass datasets, allowing them to fully utilize the service simply by purchasing the product.

To tune the hyperparameters, the best method to maximize accuracy while minimizing runtime is to set up a grid search for the best possible iteration. For every training and validation dataset, a hyperparameter is changed, and its error value is calculated. The set with the lowest error per timestep is then utilized, given that the accuracy is 80%+.

This ML system has yet to be developed fully, and there does not exist a model that follows the exact schematics of this system on the current market. However, it should not be a major obstacle to turning this concept into reality. Dimensionality reduction and Decision Tree Classifiers are both very well developed ML techniques image classifications. There are many pre-existing models and journals that have utilized similar schematics to achieve high quality results for damage assessment, such as the research done by Merz, Kreibich, and Lall on tree-based flood assessment algorithms. Therefore, this ML design conceptually is plausible, even though a prototype of it does not exist at this exact moment.

In summary, SAVED will be able to utilize sophisticated flight control concepts and ML techniques to collect and process data, while its mechanical infrastructure will support it in all aspects. Although it must undergo further developments before it may be classified as a functioning prototype, the current state of existing technologies more than shows the plausibility of a such product to come forth to reality.