**The Need**

While volunteering with a small charity in Malawi, the need for a better means to transport supplies became visible to me. Malawi is an extremely poor country, and has a very limited road network. It can be extremely difficult or impossible to reach even close places due to the lack of infrastructure in a hilly environment. During the rainy season roads are destroyed in minutes, and where this happens it becomes impossible to deliver medicine and other supplies short of walking, and even this can become impossible due to swollen rivers. Right now, this adds up to a situation where food, animal feed and medicine become simply unavailable to many people for often long periods of time.

I spent my time in Malawi setting up a DJI drone to be used for aerial surveying, and two things became quickly apparent. Firstly, that this drone could fly in minutes it would take hours to reach by any other means, and secondly that it was extremely ill equipped to be operating in such an environment. Though the drone was limited by its range and lack of payload capacity, the speed with which it could move from place to place meant that for moving even tiny things like keys it was useful outside of its intended photographic purpose. However, its usefulness was cut short by the exposed gimbal becoming damaged, meaning a replacement needed to be ordered. In the UK or any other developed country this would have meant a wait of a couple of days or less, but here it meant waiting for the next group to come out, which was ultimately a fortnight but could have been much longer. If the drone had been used for anything critical this would have been an enormous issue.

Using the drone further it became obvious, even though it was very useful, that it was not designed for the rough, harsh and disconnected environment found in undeveloped countries. Everything was incredibly delicate, bespoke and constantly craved internet connectivity. All of the design margins were a little too tight: what might have worked perfectly on a football pitch in the UK couldn’t quite handle sloped gravel in Malawi. For this reason, I decided to pursue creating an alternative to this end, built with the developing world in mind from the beginning and through every design stage.

**Objective Statement**

To produce an aerial system to autonomously transport a useful payload in developing countries.

**Phases of project:**

1. Analysis of requirements
2. Conceptual design
3. Preliminary design
4. Production and testing of scale prototype
5. Detailed design
6. Production of working prototype
7. Testing and iteration of prototype in UK
8. Trial of prototype in Malawi
9. Production of additional units to be deployed in developing world

**1 - Requirements**

The objective above can be broken into several design requirements to be met in order to successfully complete this project:

1. To minimise cost to a level acceptable to small charities
2. To have a useful range in an undeveloped setting
   1. Battery range
   2. Flight control range
3. To be able to take off and land from a small, rough area
   1. VTOL capability
4. To have the ability to carry a useful payload
   1. Medical supplies
   2. Food/ Animal feed
   3. Spare parts
5. To be easily maintainable in an isolated and undeveloped setting
   1. Maximal redundancy
   2. Large margins
   3. Simply replaceable parts
   4. Delicate components well protected
6. To be able to fly from areas without power
   1. Deployable solar cells
7. Resilience to hot and dusty environment
8. Ability to autonomously survey large ground areas

**Analysis**

1. *Cost*

Minimising cost is absolutely critical to the success of this project. The drone is only useful if its cost means it can be deployed to places where it will be at some degree of risk, and given that it will have to take off and land remotely to the operator this risk is increased further. The drone will also be most useful to small charities operating in difficult areas, who often do not have large budgets to spend. Therefore, to be viable as an alternative to driving, walking or some other means of transportation, the value given by the drone will have to significantly outweigh its capital outlay.

1. *Useful range in an undeveloped setting*

This means the ability to fly a great enough distance from the base to be a considerably better option than the alternatives of driving or walking. E.g. if the drone requires half an hour of set up, it needs to be able to go far enough to outweigh driving for the same time. In the case of Fisherman’s Rest in Malawi, the schools were within a 20-mile radius of base. The two main constraints that will limit the vehicle range are the battery and the range of the transmitter. This means for the fisherman’s rest prototype, the battery must have sufficient capacity for 40 miles plus take off, landing and a safety margin. The transmitter must be able to reliably operate at this 20-mile radius.

1. *Take-off/Landing from a small, rough area*

The majority of locations where the drone will be needed will not have access to a large enough flat area for a conventional take-off landing. For this reason, some sort of vertical take-off/landing (VTOL) system will have to be used. Malawi is very hilly, and the ground is extremely uneven in most places. For this reason, the drone will need to be very stable on landing, able to land on potentially rocky surfaces and on ground that will have some degree of slope.

1. *Payload Capacity*

In order to be useful, the drone will need to be able to carry a meaningful payload. Many of the deliveries done by Fisherman’s Rest are either chicken feed or porridge, both of which are packaged in 10kg bags. This means that 10kg is a useful minimum mass that will need to be transported. Neither of these are especially dense, which means that a volume capacity of at least 0.12m3 will be required. Spare parts for things like vehicles, generators etc will also need to be transported, and so for this reason a way of securing a smaller, heavier item in the larger volume will be required. As the payload will be removed halfway through the flight, flight characteristics, especially stability, cannot vary depending on payload.

1. *Maintenance in undeveloped countries*

The drone is intended for use in undeveloped countries, where access to expert knowledge and availability of spare parts are extremely limited. As well as this the harsh normal use conditions such as bumpy landings, rough transportation etc mean that the vehicle will need to be rugged enough to stay together under these conditions. As well as this, as much of the aircraft as possible must be reparable using the simple materials available in undeveloped countries, such as tape, plywood, glue etc. The parts that will be unable to be fixed without a replacement shipped from the west will need to be well protected, limited in number, and as redundant as possible. It will also be necessary to make these parts as modular as possible to aid repair by unskilled persons.

1. *Flying in areas with limited electricity*

While much of the undeveloped world now has access to electricity, there are still large areas without, and crucially what supply there is, is often inconsistent or is very likely to be unavailable during times of crisis when the drone would be most useful. For this reason, the ability to be charged from an irregular supply, car battery, small generator or its own solar panels will be crucial.

1. *Resilience to environment*

The areas in which the drone will be operating will experience very high temperatures, heavy rain and will be extremely dusty. The ability to operate consistently in these environments is crucial. The ability to operate in dust especially will be critical to the longevity of the aircraft.

1. *Ground surveying*

There are many reasons for wanting to be able to scan an area of ground, and this was the main reason for the drone being deployed in Malawi initially.

**2 - Conceptual Design**

The requirements in section 1 can be boiled down to:

* Cheap
* Resilient
* Long range payload capacity
* VTOL

From this, several rough designs could be sketched out:

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| Conceptual Designs – Top and Front Views | |
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| 3. | 4. |

**Design 1**.

This design takes off and lands always with the nose facing the horizon. This gives it a wide base to land on as legs can be situated at the extremities of the wings and tail. It will take off using the 3 vertical motors, then transition into forward flight using the nose engine once it is airborne. Cargo would be stored in the fuselage with batteries in the wings and avionics in the nose.

**Design 2.**

This flying wing design would take off and land on legs extending from its wingtips. The four motors provide both vertical and horizontal thrust, with pitch authority coming from elevons on the back of the tail. Cargo would be stored in the centre of the wing with batteries further out. Avionics would be contained in a pod under the nose.

**Design 3.**

This design would take off and land on its tail as in design 2, however has its motors protruding from the nose on pylons. They could then be vectored independently, with the large advantages of a) removing the need for delicate control surfaces close to the ground and b) maintaining considerable control authority even at very low speeds. Combinations of rotations from the 4 pylons would allow the removal of all other control surfaces from the aircraft, reducing cost and complexity. Situating landing legs on the wingtips creates a very wide base, and the thrust acting from so high above the ground minimising ground effect would lead to a very stable platform on take-off/landing.

**Design 4.**

This is a similar configuration to design 1, however the 4 vertical propellers and pusher design mean it would be slightly more stable during take-off/landing, and somewhat more efficient in forward flight.

**3 - Preliminary Design**

Due to its increased durability, control and potentially lower cost, design 3 was chosen to be moved forward into the preliminary design phase. This is split into 5 major areas:

* Systems and controls
* Aerodynamics and stability
* Propulsion
* Weights and sizing
* Structures

**Systems and Controls**

There are many off the shelf and open source solutions to the problem of flight control. These provide the autopilot for the aircraft, along with all avionics and sensors, in one package. Due to the unique take-off/landing profile, some modification will ned to be made to whatever flight controller is used.

**Aerodynamics and Stability**

Aerodynamic efficiency is critical to the success of this project. Care will need to be taken over the aerofoil selection, and a scale model will need to be produced for wind tunnel testing. Positioning of the wings will need to be done so as to maintain a neutral pitching moment as the lack of tail plane means active pitching via thrust vectoring is inefficient.

**Propulsion**

There are many types of motor available that will need to be evaluated and a trade-off between cost and performance will have to be made. The geometry of the propellers will be a critical design factor, as their thrust and efficiency specifications will directly influence the size of the battery, the heaviest element of the aircraft.

**Weights and Sizing**

To maintain stability, a properly placed centre of mass is of critical importance. The aircraft will need to be built around the cargo bay which must be placed on the COM to remain stable before and after loading. Mass must be saved at every opportunity to minimise weight and thus increase performance.

**Structures**

Due to the fact that the drone will take off and land on its wingtips vertically, reinforcement will need to be made to the wing structure to allow it to hold the mass of the aircraft in the vertical as well as the horizontal plane. The structure will need to be resilient enough to survive comparatively rough handling (eg transported on bad roads in the back of a pickup). Delicate components must be protected from kinetic shocks and the environment, and physically inaccessible to curious people who might touch and damage them if exposed.