A SOLAR POWERED UAV

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1 Introduction

Although aviation contributes only to about three percent of the anthropogenic greenhouse gas emissions, the general public considers it to be one of the great polluters. Therefore a high pressure is imposed on the aviation industry to develop new technologies for more sustainable aircraft. One very promising future sustainable technology is solar energy, which is the focus of this project.

It is very difficult to introduce such an innovative development into aircraft, since the aircraft industry is extremely conservative. Therefore, it is important to implement the new technology in small steps. An excellent way to start this is by designing an unmanned aerial vehicle (UAV) in which the development – in this case solar power - is incorporated. This leads to the following project objective statement:

"The project should deliver a design of a solar powered UAV which can be used as a test bed for future sustainable aircraft, while unveiling its market potential."

2 Requirements specification

The project objective statement gives rise to a number of requirements for the aircraft. In addition there are mission constraints, which lead to more requirements. Only the most important requirements for the aircraft are specified here:

- Cruise velocity of 20 m/s in clear sky conditions;
- Maximum take-off mass of 20 kg;
- Fly from one hour after sunrise to one hour before sunset between April 1st and September 30th in clear sky conditions;
- Fly for two hours when there is a cloud cover in the indicated period;
- Payload capacity of 4 kg;
- Ability to take-off and land in a crosswind of 15 kts.

3 Concept design

In a brainstorm session around 30 different designs for the concept design phase were generated. Among these concepts were both conventional and out of the box designs. After careful assessment of all the designs, the five most promising were selected:

- Blended wing body (BWB);
- Conventional;
- Canard;
- Flying wing;
- Hang glider.

All designs were developed in separate design teams which all used the same design assumptions for batteries, guidance & navigation, materials, payload, power regulator and solar cells.

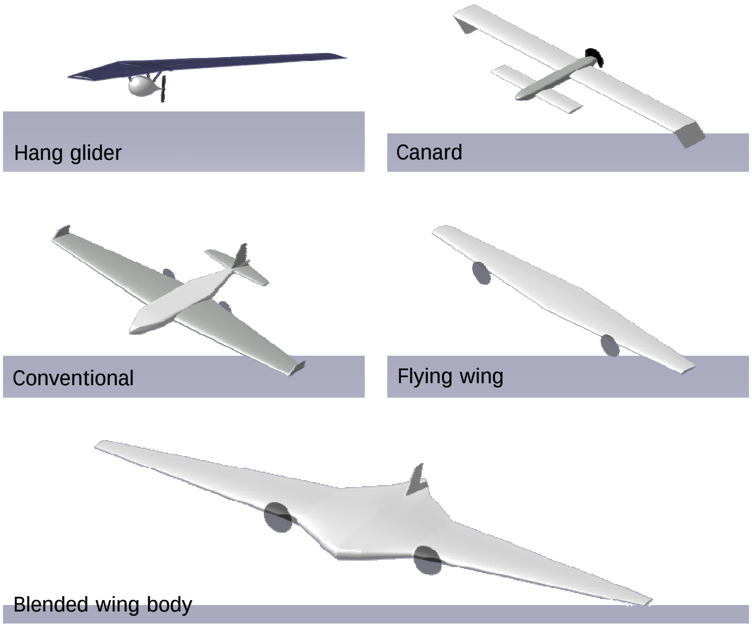

Figure 1: The various concepts

Blended wing body
A BWB combines the advantage of the high lift to drag ratio of a flying wing with the room for payload of a conventional aircraft. Also, the upper surface area can be used almost entirely for solar panels.

Conventional
The conventional configuration is an aircraft with a normal fuselage, wings and a standard tail. The design approach for this concept started with the inside-out approach. To maximise the solar area the top of the fuselage is flat. The conventional aircraft takes off using a launch vehicle and will be retrieved using a net.

Canard
The most important feature of the canard concept is the fact it has a horizontal stabiliser in front of the wing, instead of the conventional aft-mounted horizontal tail plane. The main advantage of this is that the stabiliser generates additional lift, reducing the induced drag. Furthermore the winglets are mounted downwards to make sure they will not cast shadows on the solar cells on the wing and wheels can be attached to them.

Flying wing
The flying wing is an aircraft consisting of only a wing, without a fuselage. The main characteristic is the low drag because there is only a wing. A drawback is the fact that the flying wing naturally possesses less longitudinal stability and elevator effectiveness due to the absence of a horizontal tail.

Hang glider
The SolarGlider concept design is based on the existing hang glider configuration. The wing is swept back in order to counteract the nose down moment. Under the wing's aerodynamic centre an aerodynamically shaped bubble is placed in which all subsystems and the engine are positioned.

4 Trade-off

An extensive trade-off process was conducted to select the best concept out of the presented five. In order to do so, criteria were established by which the various concepts were judged. To show the importance of a certain trade-off criterion with respect to another one, weight factors were coupled to the criteria. From the trade-off it followed that the blended wing body was the best concept. This is mainly because of the low drag inherent to the concept and the abundant area present for mounting solar cells, while providing sufficient space for storing payload. Apart from this, the BWB concept was selected because the technology is very promising for future sustainable aircraft.

5 Detailed design

The detailed design phase forms the final part of the Design Synthesis Exercise. In this phase, a more thorough analysis of the blended wing body design was performed. This analysis resulted in a detailed design of the various components of the aircraft. These components were designed by the various specialist groups. The final design was named the Vulcan.

The outer shape

The outer shape is mainly dependent on the area of the solar panels, the aerodynamic requirements and the size of the subsystems. The area of the solar panels gives the minimum upper area of the aircraft. The height of the aircraft is determined by the size of the subsystems and the payload. With these constraints the aerodynamics group divided the aircraft in three parts: the fuselage inner part, the fuselage outer part and the wings. For each of these parts, a different airfoil was selected. These airfoils determine the outer shape of the aircraft. This shape can be seen in the 2-dimensional views in figure 2.

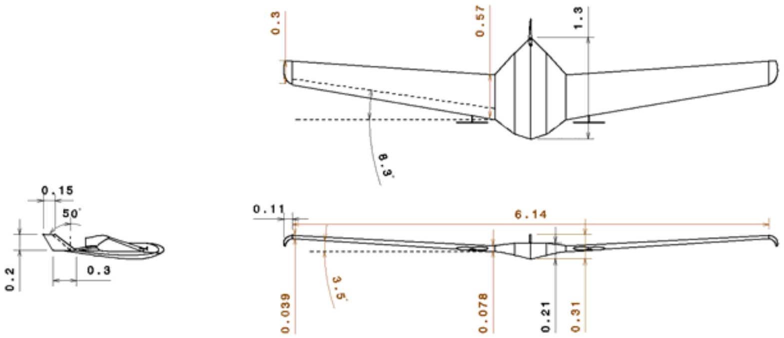

Figure 2: The outer shape of the Vulcan

The structure

Apart from giving the aircraft its desired shape, the structure also has to be able to withstand the loads imposed on it. For the Vulcan the conventional ribs and spars configuration was chosen. The ribs give the aircraft its form while the spars deliver bending stiffness to the wings. The combination of the ribs and the spars gives the wing torsional stiffness as well. These elements are made of Carbon Fibre Reinforced Polymer. This material provides the necessary stiffness but it is very light as well. For the same reasons, the skin is also made of these polymers. In figure 3, the structural lay-out of the Vulcan is shown. In the nose part of the fuselage the power and navigation systems are harboured. In the centre part of the fuselage the payload bay is placed.

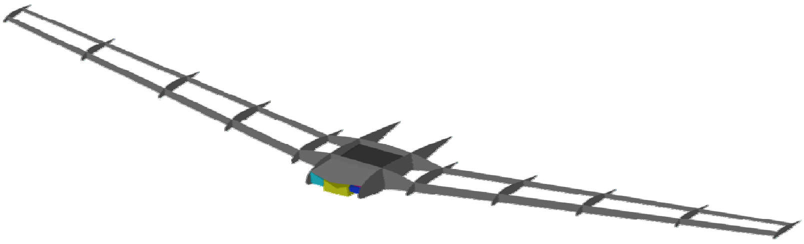

Figure 3: The structure of the Vulcan

The electrical system

Since the Vulcan receives its power from solar cells, all subsystems that need power are dependent on electricity. This also holds for the engines. For this reason electric engines are used. These engines are equipped with a propeller for the delivery of thrust. For the chosen engine type an electronic speed controller is required to regulate the speed of the engine. Also, in order to decrease the rotational speed of the propeller, a gearbox is used. These components form the propulsion system of the Vulcan. Another component of the Vulcan is the flight control computer. This computer functions both as attitude & control system and as guidance & navigation system. This computer also makes sure that the Vulcan is stable, because the aircraft is not naturally stable. It does so by steering the servos that regulate the deflection of the elevators, the rudder and the ailerons. In order to be controllable from the ground, the Vulcan is equipped with a radio. With this radio it is possible to transfer commands and data to and from the ground station.

All these systems work on a lower voltage than the solar panels deliver. The maximum power point tracker which regulates the voltage from the solar cells has a minimum voltage of 40 V. In order to reduce this value, a DC/DC converter is used. This lower voltage is also favourable for the battery. The battery is necessary as a back-up system in case the solar panels cannot provide enough power. This is for example the case in a cloud cover, but also in case of failure of multiple solar cells. In those cases it is possible for the Vulcan to fly for at least two hours, as required.

Operations

The take-off system of the Vulcan consists of a vehicle and a box to absorb shocks and mount the Vulcan on. The vehicle speeds up to about 40 km/h after which, with the push of a button, the aircraft is released and airborne. The retrieval of the Vulcan is done using a net. The net is designed such that the decelerations are less than 4.4 g, which can easily be withstood by the aeroplane. Furthermore, the Vulcan comes with a transportation box, which protects the aircraft during transportation. This box can also be used for storage and during the manufacturing process.

6 Characteristics of the Vulcan

The most notable specifications of the Vulcan are listed in table 1.

Wing geometry		
Aspect ratio	12	-
Span	6.33	m
Surface area	3.14	m^2
Mass		
Take-off mass	19.5	kg
Payload mass	4.0	kg
Performance		
Clear sky cruise speed	17.5	m/s
Cruise altitude	300	m
Zero-lift drag coefficient	0.0076	-
Power		
Battery capacity	24	Ah
Cruise propulsive power	135	W
Solar cell area	2.47	m^2

Table 1: Specifications of the Vulcan

A three-dimensional image of the Vulcan can be seen in figure 4.

Figure 4: A three-dimensional view of the Vulcan

7 Conclusions

The design has achieved the requirements stated before. The maximum take-off mass is below 20 kg (19.5 kg) including a payload of 4 kg. A level flight cruise speed of 20 m/s is achievable, but not the entire day. With a cruise speed of 17.5 m/s the Vulcan can fly from one hour after sunrise until one hour before sunset in the period from the 1st of April until the 30th of September. In case of a cloud cover in the same period it can fly for 2 hours using the back-up power subsystem.

The Vulcan has a very innovative design. An alternative shape is chosen where the wings are smoothly blended into the body. In this way the entire aircraft contributes to lift generation while drag is minimised. Also an alternative energy source, namely the sun, is used. The

energy from the sun is available everywhere, it is free and most important of all it is sustainable.
The market potential of a solar powered UAV turned out to be quite promising. The UAV market is increasing rapidly at an annual growth of about 15%. The total spendings in the UAV market for the coming decade are estimated to be $55 billion. The average cost of UAVs is about $5 million. The Vulcan can be sold at the very competitive price of about 300,000 euro, so that break-even is reached within 2.5 years.

8 Recommendations

To successfully continue the development of the Vulcan the following recommendations are given for the aerodynamics, power, structures and marketing. The Vulcan is marginally unstable and should be naturally stable to be more efficient as a flight computer is needed for artificial stability. The power subsystem can be optimised for efficiency. The structure should be analysed more thoroughly with a finite element model. Furthermore, to increase the market potential there are some challenges. One of those is to increase the availability of the Vulcan, for example by flying above the clouds. For the further development and marketing, cooperation with environmental institutes is desired as a larger sustainable tendency increases the market potential of the Vulcan. Also cooperation with the authorities is needed as the legislation for UAVs is continuously under development due to the technology push nature of the market.