# SOLution

*Students:* Y.H.A. Brouwers, J.A.L Daneels, T.M.T. Doornbos,
H. Huang, H.J.A. Lemmens, B.J. Nijenhuis,
J.A. Pascoe, C.A.A.M. Peters, A.W.H. Ravenstijn,
E. van Ruitenbeek

*Project tutor:* ir. J.A. Melkert

*Coaches:* dr.ir. S. Koussios, ir. H.J.K. Lemmen

## 1 *Introduction*

The world's concern for a more sustainable future is becoming more evident each year. Fossil fuels are becoming outdated and the future lies in ecologically sound energy sources such as solar energy. In aviation this trend is still in its early stage. However, more and more technological research is being performed to investigate the possibilities of solar powered aircraft. Furthermore, a growing demand exists in unmanned aerial vehicles (UAVs). The market is expected to more than double over the next decade to an estimated value of $55 billion worldwide.

The combination of these two factors has led to the development of the SOLution. The SOLution is a large solar powered model aircraft, which can be used for commercial ends or research activities. Nowadays most aerial observation is done by polluting aircraft or helicopters, which could easily be replaced by an ecologically sound aircraft. Furthermore using an unmanned vehicle would reduce the total costs involved, since no high pilot costs are incurred.
What makes the SOLution unique is the combination of its core competencies. It is sustainable, affordable and will be commercially available. Furthermore it has high performance qualities compared to other solar powered aircraft.

In the following sections the design process leading to the final concept is elaborated, after which the properties and possibilities of the SOLution will be discussed, followed by a conclusion and recommendations. First the requirements will be presented.

## 2 Project objective statement and top level requirements

The project objective statement is defined as follows:

*Design a large solar powered model aircraft, discovering its possible (commercially attractive) applications and potential as a test bed for more sustainable aircraft, by 10 students within 10 weeks.*

The top level requirements are:

- Maximum take-off mass 20 kg
- Maximum payload of 4 kg
- Manageable size
- Level flight cruise speed of 20 m/s
- Comply with current model aircraft regulations
- Being able to take-off in wind force 5 conditions
- Being able to land in wind force 4 conditions
- Being able to land and take-off on a grass runway
- Being able to take-off and land in a 15 kts crosswind
- Fly non-stop one hour after sunrise until one hour before sunset in the period from April 1st and September 30th in clear sky conditions
- Being able to fly two hours in heavy overcast

Further requirements relate to the design of the aircraft. These include criteria on propulsion, aerodynamic design, the control system and electrical systems.

## 3 Conceptual design and trade-off

During the conceptual design phase many straw man concepts were created of which five concepts were chosen for further development. These concepts will be discussed shortly.

**Twin Boom**

The configuration of the Twin Boom concept is shown in Figure 6.1. The configuration consists of two booms attached to the wing on which an inverted V-tail is mounted. Under the wing a small fuselage is mounted, in which the payload bay is located. The main advantages of this concept are its good stability characteristics and manageable size. The main disadvantage is that it has many structural components which make the manufacturing costly and complex. Furthermore the booms may be susceptible to flutter. The performance characteristics are good, aside from the fact that 20 m/s cannot be reached during an entire day.

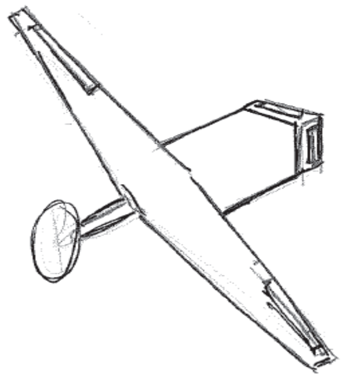

Figure 6.1: Twin Boom

**V-Tail**

The V-Tail concept is shown in Figure 6.2. This concept has many advantages and is applied on several other solar powered aircraft. Since it is a proven concept the feasibility risk is reduced. Furthermore the performance characteristics are good, however it also lacks the capabilities of reaching 20 m/s all day. The main disadvantage is the size of the aircraft.

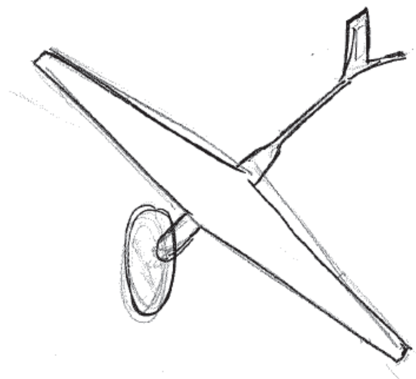

Figure 6.2: V-Tail

**Conventional**

In Figure 6.3 the Conventional design is shown. This concept has good stability properties as well as low risks incorporated in the design. However the dimensions of the aircraft are impractical and the performance characteristics are marginal.

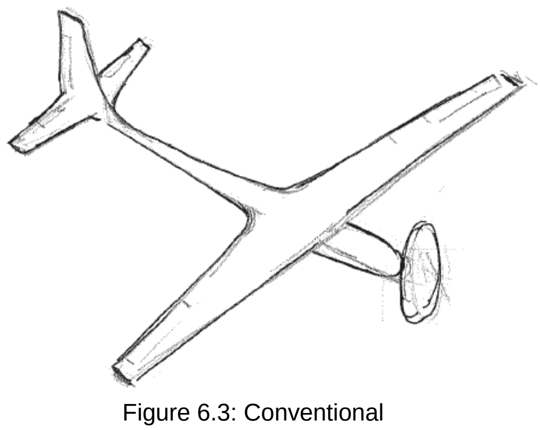

Figure 6.3: Conventional

**Canard**

Canard configurations (Figure 6.4) are known to have less drag, since the canard creates positive lift. However due to the low aspect ratio chosen for the design, the induced drag is still high, which has a negative effect on the performance. The advantage of this design is that it is easy to manufacture because of the simple wing shape.

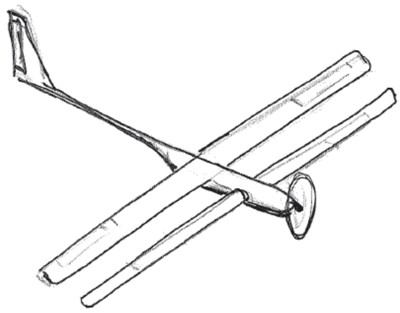

Figure 6.4: Canard

**Flying Wing**

The concept that has the most potential is the Flying Wing (Figure 6.5). This is the only concept that met the required flight speed. Furthermore it is the least complex to manufacture, since it has the fewest components of all the designs. The main disadvantage is that flying wings have problems with stability, and therefore have a high risk factor with respect to feasibility.

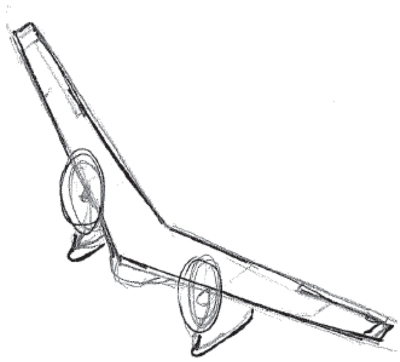

Figure 6.5: Flying Wing

The choice for the final design was based on several criteria which were integrated in the trade off. The most important factors were the performance, risk and operability of the aircraft. Other criteria included the cost and complexity of the aircraft. Based on these factors the choice was made to further continue with the flying wing concept. Its main advantage over the other concepts was its performance capabilities and the operability of the aircraft. The flying wing however, did not score high in the risk assessment. More specific, the flying wing was expected to have problems with stability, since it has no tail. Nevertheless, this concept was chosen since the stability problems were expected to be surmountable, and it brought a challenge along with it. The V-tail concept scored high as well, but the performance was slightly less and there was less of a challenge.

## 6.4 Aerodynamic design

The first step in the aerodynamic design was the selection of the wing surface area. To achieve an acceptable stall speed, a wing area of 3.4 $m^2$ was chosen, giving a stall speed of 8.9 m/s and a $C_{Lmax}$ of 1.1. Next an aspect ratio (AR) was selected. The drivers for choosing the AR were induced drag, which is lower when the AR is higher, and space inside the wing. Space inside the wing is lower when AR is higher, as a higher AR means a shorter chord (for equal surface area) and the thickness of the wing is a function of the chord. Taking all this into consideration an AR of 15 has been selected. Together with the surface area, this results in a span of 7.1 m.

To achieve a favourable lift distribution a taper ratio of 0.5 has been selected. To provide a large enough arm for the elevons to control the pitching moment a sweep angle of 20° is applied. A dihedral of 1° has been selected to provide spiral stability.

As deflecting the elevons to trim the aircraft creates extra drag, it is desired that the required elevon deflection in cruise be as small as possible. This is achieved by applying a twist of 3° to the wing, minimising the pitching moment.

The airfoil selected for the SOLution is the NACA 0015-63. The considerations for the choice of airfoil were that it should have a low pitching moment, that its top surface shape should not present problems for attaching solar cells and that it should have a sufficiently high $C_{Lmax}$. Low pitching moment is specifically important for flying wings due to the small tail arm and thus low elevator effectiveness when compared to conventional aircraft.

Directional stability is provided by the pods located under the wing, which act as vertical stabilisers.

Control of the aircraft is provided by elevons, located at the outboard trailing edge of the wing, and rudders, located at the trailing edge of the pods. The elevons can be deflected symmetrically to provide pitch control and asymmetrically to provide roll control. The rudders when deflected asymmetrically provide yaw control. When the rudders are deflected symmetrically they act as speed brakes.

While the SOLution is on the ground the control surfaces are supplemented by brakes mounted on the rear wheels. These can be used differentially, providing additional yaw control.

## 6.5 Performance

The energy that is used for flight is solar energy, which is converted into electrical energy through solar cells. The solar cells employed on the SOLution are GaAs cells with an efficiency of 28.5%. These cells are capable of providing 800 W when the solar flux is at its maximum. This power is then converted to thrust by the electromotor and the propeller.

The engine and propeller were sized to have an optimal efficiency during cruise, since this is the most energy consuming flight phase. There is a single engine mounted in the front of the aircraft to which a gearbox and a propeller are attached. For an optimal efficiency of the propeller, the propeller is sized with a radius of 40 cm and for the electromotor an off the shelf type is chosen, which delivers the required power at a high efficiency.

The SOLution is a high performance large solar powered model aircraft. The aircraft has a cruise speed of 19 m/s in April and September and from May until August the aircraft even has a cruise speed of 20 m/s or more. The cruise speed is calculated under the assumption of clear sky conditions and a take-off with fully charged batteries. Taking-off with fully charged batteries is necessary because the first few hours of the day the sunlight is not sufficient to give enough power to obtain high cruise speeds. Then, during the day, the batteries will charge when there is more power available than is necessary for flight. Charging the batteries continues until the sun starts to set, from that point on energy is taken from the charged batteries, since the direct solar energy is not sufficient for flight.

The take-off and landing distance of the aircraft are relatively large. The aircraft has a take-off distance of 223 m and a landing distance of 380 m in windless conditions and on a grass or asphalted runway. This means that the aircraft needs a long landing strip. However, since most landing strips have a length of 400 m or more, this is not a problem.

The big advantage of the SOLution is that the aircraft is capable of flying an entire day in clear sky conditions without refuelling. However, since the sky is not always clear, the aircraft must also be able to fly with overcast.

During overcast conditions the incoming energy from the sun will not be sufficient to continue flight. Therefore the batteries need to supply the extra power needed. The power required during overcast is 400 Watts, and with the current batteries it is thus possible to continue flight for two hours. If more endurance is required, the aircraft can diminish its flight speed, which will significantly increase the amount of flight time, since the power required scales with the third power of airspeed.

## 6.6 Structure

The biggest challenge in designing the inner structure of the SOLution was to make it as light as possible while still strong enough to cope with loads and moments and stiff enough to prevent too large deflections/deformations in the wing. To achieve this, use is made of materials that combine lightweight with high strength such as carbon composite and wood (i.e. balsa wood and fir wood).

The construction that has been developed for the wing, fuselage and vertical pods can be seen in figure 6.6.

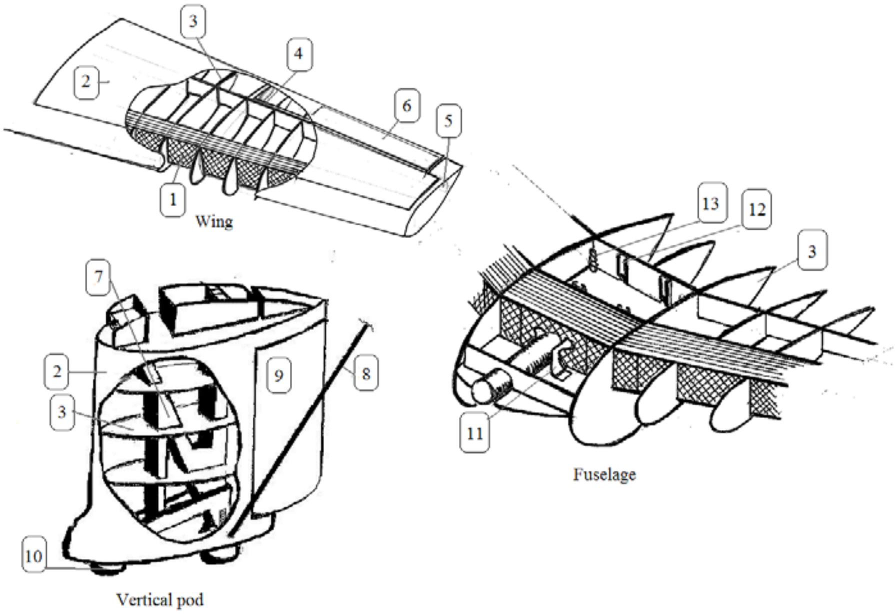


Figure 6.6: The aircraft's structure

The primary part of the wing structure consists of a rectangular, carbon composite torsion beam which takes up all the forces and moments. Balsa ribs give shape to the wing. The top side of the wing is covered with laminated solar cells and foil is used to cover the bottom and nose of the wing.

The vertical pods are constructed in a similar way to the wing, but their main construction is a truss structure built from fir wood, which absorbs the impact of landing. The vertical pods store the rudders and landing gear. To take up the side-ways forces on the landing gear, when landing on only one pod, a cable is added between the pod and the torsion beam. The payload cabin in the fuselage is attached to the fuselage structure with a rail system and is detachable from the aircraft, providing easy access to it.

The structure as a whole guarantees a safe flight under all flight conditions, up to a load factor of 7.0 (strong gusts).
An overview of the different structural parts, their function, the material they are made of and their masses can be found in Table 6.1.

| Nr. | Part | Function | Material | Mass |
|---|---|---|---|---|

| | | | | [kg] |
|---|---|---|---|---|
| *Wing* | | | | |
| (1) | Beam | Absorb loads and moments | Carbon composite | 1.87 |
| (4) | Spar | Hold the ribs together | Fir wood | 0.25 |
| (5) | Wing tips | Close the wing at the outer | Plastic | 0.05 |
| (6) | Elevons | Provide control | Standard balsa wood / Fir wood / Aluminium | 0.28 |
| *Vertical pods* | | | | |
| (7) | Truss | Absorb landing impact | Fir wood | 0.29 |
| (8) | Tension cables | Prevent pods from collapsing | Steel | 0.10 |
| (9) | Rudders | Provide control | Standard balsa wood / Fir wood / Aluminium | 0.13 |
| (10) | Wheels | Provide on ground mobility | Aluminium / Rubber | 0.10 |
| *Fuselage* | | | | |
| (11) | Engine mount | House the engine | Aluminium / Rubber | 0.12 |
| (12) | Payload Rails | Connect the payload bay | Aluminium | 0.10 |
| (13) | Threads | Provide adjustable height | Plastic | 0.06 |
| *Entire aircraft* | | | | |
| (2) | Skin | Provide aerodynamic shape | Foil / plywood / Laminated solar cells | 5.45 |
| (3) | Ribs | Provide aerodynamic shape / Prevent buckling | Standard balsa wood / Fir wood | 0.71 |

Table 6.1 – The structural parts

## 6.7 Marketing

The UAV market is a rapidly growing and evolving market. Over the next decade, the total market is estimated to be worth about $55 billion, of which $31.2 billion will be invested in production and $23.8 billion in R&D. This makes it interesting to look at the market potential of the SOLution.

The use of UAVs is especially interesting for tasks that fall in the category in one of the three D's, namely Dull, Dirty and Dangerous. Typical applications include surveillance, aerial imaging, or military missions. Furthermore the SOLution can be used as a test bed for further research, or for hobby purposes. Also advertising and demonstration belong to the possibilities for the SOLution.

Based on the potential applications of the SOLution and the growing UAV market, an estimation is made that this aircraft will take up 0.06% of the total market. We reckon that the target market is not limited to the Dutch market, but also lies abroad. This is due to several factors, firstly the Dutch market is rather small, and secondly, the possibilities in the Netherlands are limited due to the regulations regarding model aircraft. The regulations for example state that the aircraft has to stay in the line of sight, which is a very restricting factor.

Lastly, the climate is not optimal. Regions near the equator also have a higher solar flux, which increases the aircraft's performance significantly.

The target markets include the United States, Asia, the Middle East, Europe and South America, of which the US is the biggest player in the industry.

A cost estimation and a profit and loss statement together with the market analysis reveal that the estimated sales volume over five years will be sixty aircraft and the break even sales price is $142,000. This has led to a sales price of $150,000 per aircraft, which is based on a marketing strategy that has as goal being low priced, and staying just above the total production costs. This should make the aircraft compatible in the UAV market.

## 6.8 Conclusion and recommendations

The result of the design process has led to a solar powered model aircraft that is shown in Figure 6.7. First of all it has very good endurance capabilities. The aircraft can fly two hours longer than required per day. Secondly the performance characteristics are such that the aircraft reaches a flight speed in cruise of 19 m/s during the entire period from April 1st to September 30th. Moreover during the period from May until August it can even fly 20 m/s throughout the day. These results are based on a Dutch climate, which implies that if the client wishes to use the aircraft closer to the equator, the performance will be even better.

The total mass of the aircraft is 19.6 kg, which meets the mass requirement of maximum 20 kg. However, experience shows that aircraft tend to become heavier than anticipated when built. This will form a problem and thus deserves extra attention.

The market potential of the SOLution is very promising. Estimations reveal that the entire UAV market will more than double over the next decade, and that the SOLution is capable of taking up 0.06% of the total market.

Since the SOLution is solar powered it does not produce polluting emissions, which contributes to a sustainable environment. Moreover, it has low operational costs since no fuel costs are incurred. Lastly the sales price of the SOLution is also low cost in comparison to other (solar powered) UAVs.

A recommendation for further development would be to install an autopilot in the aircraft, so no pilot is required, which would further reduce the operational costs. This can of course also be done by the client himself. Since the SOLution has a 4 kg payload capacity, the client can exchange part of the payload capacity for an autopilot.

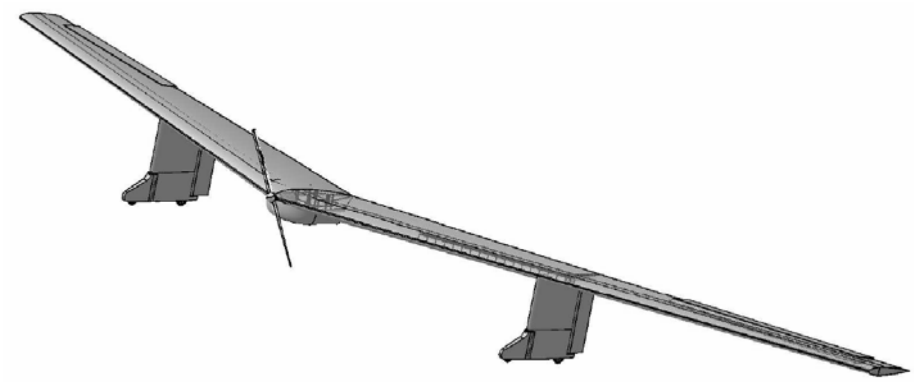

Figure 6.7: The SOLution