# 21. CHEAPER, CLEANER, BETTER, GREENER

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## 21.1 Introduction

Carbon dioxide emissions are thought to be a major contributor to the greenhouse effect. Most western governments have made strict agreements on emission reductions in, for example, the Kyoto protocol or in EU treaties. Demand for air travel is predicted to increase over the coming decades; in order to meet carbon emission targets drastic steps must be taken by aircraft designers to produce a new generation of low emission craft. It is probable that sources of carbon dioxide emissions, especially non-essential sources such as recreational flight, will be heavily targeted by taxes. It is inevitable that the market for carbon neutral aircraft will open up as time passes by.

The brief is to design a new 4-seater aircraft which will provide general aviation users with an acceptable and affordable environmentally friendly alternative. This alternative aircraft must be suitable for flight training, Personal Pilot Licensing (PPL) and instrument rating, normal private use and it must have neutral carbon emissions and a restricted noise level. The design is primarily driven by environmental considerations. The mission need statement therefore becomes:

*Define a preliminary design, driven by environmental considerations, for a four-seater general aviation aircraft with a carbon neutral life cycle.*

## 21.2 Design requirements and constraints

The design requirements and constraints were evaluated for feasibility and adapted where necessary. The final requirements are given in table 21.1.

| Design requirement | Value |
|---|---|
| Unit production costs | $ 200,000 (including non-recurring costs) |
| Number of units | 5,000 |
| Number of passengers including pilot | 4 |
| First flight | 2010 |
| Minimum life span | 30 years |
| Flight hours | 20,000 hours |
| Number of flights | 12,000 |
| Mission requirement | Value |
| Range | 926 km |
| Cruising speed | 200 km/h at 3050 m |
| Maximum take-off length | 500 m screen height (tarmac) |
| System requirement | |
| Near neutral carbon emissions on a systems level | |
| Noise level not exceeding 62 dB | |
| In flight emergency solution must be provided | |
| Disposal plan after end of life must be provided | |
| Generation of an energy footprint of the production and disposal of the aircraft | |
| Training requirement is for PPL and instrument rating | |

Table 21.1: List of design requirements and constraints

## 21.3 Market needs analysis

To evaluate the needs of pilots, both students and instructors, market needs research, including a questionnaire, was performed. As a direct result of the research, features that will be incorporated into the aircraft include a low wing for excellent visibility, a retractable undercarriage, a 2 by 2 seat layout and a glass cockpit.

Given three years to establish itself in the market, it is expected that sales will be 225 aircraft in 2013 with a subsequent increase in demand of approximately 20 per year each year, resulting in the requirement of 5000 aircraft sales to be reached in 2029. This growth may be much larger due to the rapid increase of low cost airlines in Asia and their need to train many new pilots. The use of bleeding edge technology combined with the negative carbon footprint makes it excellent value for money compared to its competitors.

The market for this aircraft does not yet exist and depends on global politics to make it financially viable. It depends on government environmental policies to increase costs related to the more conventionally fuelled aircraft, for instance by introducing environmental taxes or increasing the price of aviation fuel. If these changes occur it will make this aircraft more desirable as pilots who own it are likely to pay reduced taxes and thus reduce their flying costs.

## 21.4 Concept generation and exploration

The trade-off enabled a qualitative distinction to be made between the different options available. From initial research, four complete concept aircraft were conceived as depicted in figure 21.1

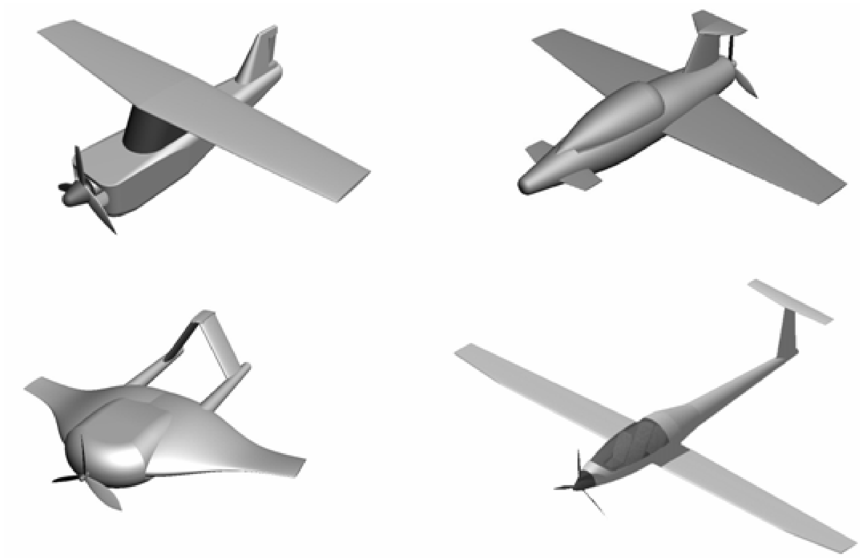

Figure 21.1: Concepts generated

Concept one combines the most conventional and reliable ideas to produce a high wing bio-fuelled combustion engine which drives a pull prop. The airframe is largely wooden trusses, and the high wing is intrinsically stable.

Concept two sports canards and a hydrogen gas turbine with a mid wing, driven by a push propeller. The airframe is largely composite based.

Concept three uses an electric motor powered by fuel cells. The fuselage is a lifting body with an inverted v tail mounted on twin booms with a large internal volume to accommodate the bulky fuel system. Metal is the primary structural material.

Concept four uses batteries to power an electric motor. The batteries are recharged on the ground. The layout is based around glider designs with the aim of reducing drag. The slender high aspect ratio wing provides a high L/D. The results of preliminary investigations into the concepts are provided in table 21.2.

| | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|---|---|---|---|---|
| Take-off Mass [kg] | 1989 | 1418 | 2080 | 1200 |
| Empty Mass [kg] | 1338 | 981 | 1112 | 860 |
| Fuel Mass [kg] | 296 | 71 | 38 | 480 (batteries) |
| Power [kW] | 243 | 217 | 109 | 61 |
| Wing Area [m2] | 29.76 | 16 | | 16 |
| Aspect ratio | 11 | 12 | | 12 |
| Span [m] | 18.1 | 13.9 | 10.5 | 13.9 |
| Cd | 0.093 | 0.086 | | |
| Cd0 | 0.017 | 0.016 | | 0.015 |
| CLmax | 1.6 | 1.7 | | 1.6 |
| L/D | 15 | 15 | | 20 |

Table 21.2: Comparison of concept specifications

## 21.5 Trade-off

Since the concepts yielded no clear winner a qualitative trade-off process was employed to differentiate between them. Table 21.3 lists the criteria each concept was judged against; the weighing factors are used to illustrate how important that particular element is with regards to the overall mission statement.

| | | | |
|---|---|---|---|
| Carbon Emissions | 20% | Operating costs | 5% |
| Handling qualities | 25% | Feasibility | 10% |
| Performance | 10% | Disposal | 10% |
| Production costs | 10% | Noise | 10% |

Table 21.3: Trade-off criteria and weightings

Achieving carbon neutrality is vital to the fulfilment of the mission statement and is ranked correspondingly high. However as the aircraft is to be sold into the trainer market it must have superior handling qualities to distinguish it from its competitors; nobody will buy an aircraft if it flies poorly, no matter how green it may be.

Table 21.4 gives the completed trade-off study. Concept four's advantages over the others are clearly visible: the use of batteries has the potential to drastically reduce CO2 emissions when combined with a low drag airframe. Wood is an ideal construction material in this scenario; it is the only place in the aircraft's life cycle that offers the potential to remove carbon from the system in large amounts.

| | CO2 emissions | Handling qualities | Production costs | Operational costs | Performance | Feasibility | Disposal | Noise | Total |
|---|---|---|---|---|---|---|---|---|---|
| weighting factors | 0,2 | 0,25 | 0,1 | 0,05 | 0,1 | 0,1 | 0,1 | 0,1 | 1 |
| **Materials** | | | | | | | | | |
| wood | 5 | | 3 | 2,5 | 3 | 3,5 | 4,5 | | 2,53 |
| alloys | 2 | | 2,5 | 4 | 4 | 5 | 4 | | 2,15 |
| composites | 2,5 | | 3 | 3 | 4,5 | 4 | 3,5 | | 2,15 |
| **Powerplant** | | | | | | | | | |
| Turbo prop | 2 | 3,5 | 2 | 4 | 4 | 4 | 2 | 2 | 2,88 |
| piston | 2,5 | 3 | 4 | 3 | 3 | 4,5 | 3 | 3 | 3,15 |
| electric motor | 4,5 | 4 | 4,5 | 4,5 | 2,5 | 3 | 4 | 5 | 4,03 |
| **Power supply** | | | | | | | | | |
| Bio fuels | 3,5 | | 2,5 | 3 | | 4 | | | 1,5 |
| Batteries | 4 | | 2,5 | 4,5 | | 3,5 | | | 1,63 |
| Hydrogen (cryo) | 2 | | 2 | 3 | | 3 | | | 1,05 |
| Hydrogen (Comp) | 3 | | 3 | 4 | | 2 | | | 1,3 |
| **Concepts** | | | | | | | | | |
| Conventional (I) | 3 | 3 | 3 | 3 | 3,5 | 4 | 3,5 | 3,5 | 3,25 |
| Reduced drag (II) | 4 | 2,5 | 2 | 3 | 3 | 2 | 3,5 | 3 | 2,93 |
| Lifting body (III) | 2,5 | 1 | 1,5 | 2 | 3,5 | 1 | 2,5 | 2 | 1,9 |
| Glider-like (IV) | 5 | 4 | 4 | 3,5 | 2 | 3 | 4 | 5 | 3,98 |

Table 21.4: Complete trade-off

## 21.6 Selected concept

The Batt-wing is a tail-dragging, low-wing, T-tailed and largely wooden aircraft. The propeller is driven by an electric motor powered by battery packs. As can be seen in figure 21.2, the batteries are located around the front spar of the wings, and in the tail boom. The seating is a conventional, 2 by 2 layout. The aircraft has a span of 15.5 m and a total wing area of 20 m2. The fuselage is 8 meters long, has a maximum width of 1.3 meters and is 1.1 meters high. The main landing gear is retractable and folds forward into the fuselage, under the seats of the pilots.

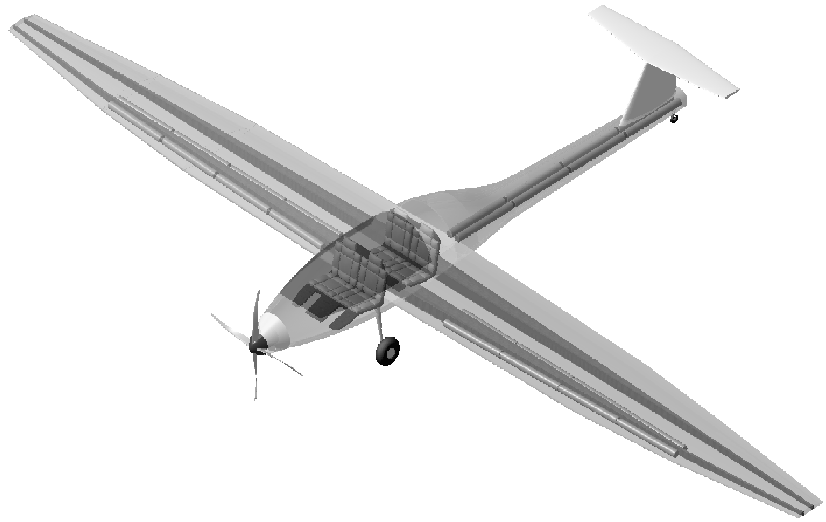

Figure 21.2: Batt-wing

The aerofoil section and wing planform used were designed specifically to induce a very small amount of drag in cruise; the high performance sailplane section guarantees 70% laminar flow on the leeward side. The planform exhibits near elliptical lift distribution while remaining relatively simple to manufacture. Fuselage drag was estimated using simple turbulent flat plate calculations with a correction factor to account for pressure drag.

From the basic aerodynamic and structural data calculated, performance parameters were derived as given in table 21.5.

| | |
|---|---|
| Range with 4 people | 900 km |
| Cruise Velocity | 56 m/s |
| Cruise Altitude | 3050 m |
| L/D CRUISE | 32.7 |
| Maximum Takeoff Mass | 1100 kg |
| Takeoff Distance | 498 m |

Table 21.5: Performance characteristics

The required energy is stored in Lithium-Sulphur batteries. Although still in a development phase, an operational prototype exists providing the necessary high energy density. The major drawback of Li-S batteries is the relatively short cycle life; however, even with needing replacement every 3 years and taking into account all involved costs, the system works out 40% cheaper per flying hour when compared to conventional trainer aircraft.

Wood moved out of general aerospace use when cheap metal alloys became widely available in the 1960s; aluminium is a superior construction material for airframes. However given the requirement for carbon neutrality, wood becomes a much more attractive solution. Modern technologies, such as the use of laminated sections, mitigate many of wood's disadvantages. The majority of the airframe is comprised of Douglas Fir from Scandinavia farmed from forests. It is vital that sustainability is ensured; without it the carbon offset will not be produced.

The factory location has been chosen in Eastern Europe mainly due to close proximity to raw materials and labour costs. A need has been realised for the manufacturing process of the aircraft to be as green as possible. The best way to obtain this is to offset the carbon dioxide being produced by using a renewable energy source for a proportion of the factories power. The main choices are to use either wind or solar power due to the plants location. Due to the use of renewable power for the plant it can be estimated that compared to similar sized aircraft factories a reduction of carbon dioxide emissions by 80% will be made. This is associated with the large amount of manual labour being used as apposed to large machinery.

The aircraft can be produced for approximately $180,000, therefore meeting the requirement for a unit selling price of $200,000. After selling approximately 700 units the investment will breakeven in 2013, giving a reasonable 4% return on investment thereafter. Production will cease in 2027, after which the final aircraft will be sold in 2029 when the final of the required 5000 units will be sold. Despite the propulsion system contributing approximately 42% of the total production cost, considerably more than similar aircraft, the total operating costs are lower than similar aircraft ensuring that it is more competitive.

The sustainable aspect of the design was considered at all phases of design and for all stages of the product life-cycle. Focusing on using a sustainable supply chain during production helps reduce the carbon and energy footprints. During the aircraft's operational life it produces zero carbon emissions if green energy sources are used to recharge the batteries. When being disposed off, most materials can be recycled, including the batteries. All these considerations have led to achieving the project's aim of carbon-neutrality.

## 21.7 Conclusions

After completing a detailed evaluation of the chosen concept, the mission goal, namely to "define a preliminary design driven by environmental considerations for a four-seat general aviation aircraft with a carbon neutral lifecycle", has been met with success. Even though a complete and highly accurate carbon lifecycle analysis proved far too time consuming and costly for the preliminary design, the design team is confident that the carbon footprint is in the worst case scenario neutral, with more realistic projections showing a net absorption of carbon throughout the process due to the use of wood as a structural material.

Electric aircraft are very new to the aerospace industry, but show dazzling promise. Electricity can be generated in clean, renewable ways and electric motors are proven to be far more reliable than combustion engines, while producing zero emissions. The aircraft equals or exceeds the performance of the majority of other existing aircraft in its class, demonstrating that battery driven electric motors can match the specifications of their heavily polluting conventional combustion engine counterparts. If the selected batteries are available with the expected performance and at the predicted price, the Batt-wing will represent outstanding value for money when compared to current light aircraft. Batteries have seen rapid improvement over the past decade; the technology is expected to advance even further over the coming years. The final fate of the electric aircraft will lie with the actual increase in performance of the batteries. However, with all the investments in research towards better batteries, the future for electric aviation looks bright.

## 21.8 Recommendations

As the market for this aircraft partially depends on politics to create its sales potential, further research is required to fully assess the possible impact of government policy regarding greenhouse gas emissions upon the general aviation sector. Should governments decide that there is no substance to the claims that human production of greenhouse gases have an impact upon global warming, the market for the aircraft will be limited.

The feasibility of the propulsion systems depends on the availability of Li-S technology in 2010. Further investigation of this area should be completed to ensure that batteries will be available which are capable of meeting the specification. It is worthwhile to investigate Li-polymer batteries for training flights specifically, as the costs are already very competitive at $ 17 per hour. In addition to the research into higher specific energy chemistries, increased cycle-life is worth investigation as well. As an emerging technology, the Li-S batteries have yet to be fully life-cycle and safety tested. Preliminary tests must be carried out to ensure certification is approved.

Loads on the fuselage need to be analysed in greater detail to assess airframe mass more precisely; refining these calculations could change structural mass drastically. Battery placement needs to be considered in greater depth to find an optimal storage location. Wing-fuselage attachment requires a more detailed design.
The profit margin assumed in the cost estimate section is open to change at the behest of market fluctuations; the market must be constantly monitored to determine if a reassessment of the profit margin is required.

The entire supply chain must be accountably sustainable; it is recommended that to reduce cost, suppliers who are already certified as sustainable will be retained.