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Conceptual design of a light sport aircraft

Michael Frederick Boer

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering by course work and research project.

Johannesburg, May 2016

Declaration

I declare that this research project is my own, unaided work, except where otherwise acknowledged. It is being submitted in partial fulfilment of the requirements for the degree of Masters of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

Signed this 24 day of May 2016



_____

Michael Frederick Boer.

Abstract

The design of a conceptual aircraft was required to fulfil the recreational and commercial flight training roles as part of a rural development initiative. The regulations regarding the airworthiness of aircraft and the South African microlight and ultralight aircraft market were investigated to determine the niche performance requirements. The large sales enjoyed by the new Light Sport Aircraft (LSA) category created an opportunity to design an aircraft conforming to both the non-prescriptive ultralight and prescriptive LSA consensus standards. This would allow the aircraft be used in several countries. The best practices regarding design for manufacture used in industry were investigated to create a framework of consideration for the detailed design of the aircraft. The performance of the market leading ultralight and LSA was analysed. The Cessna C-162 Skycatcher and Tecnam P-92 were investigated as the main competitors. Flight speed, payload, structural efficiency and aerodynamic efficiency were analysed to set target performance requirements. The aircraft was required to have a minimum power utilisation of 1.05kt/hp, minimum useful load of 250kg and a minimum cruise speed of 110kts. The aircraft was constrained to a 100hp engine. These performance user requirements were used with cost, environmental and operational requirements to design a high-level concept. The concept was developed so that each major system on the aircraft had been designed to create a complete concept. The method used to develop several concepts for several systems and assess them against the user requirements was developed from the dialectic engine principle of destruction and creation. This process was performed simultaneously. The systems were broken into basic principles and components before being creatively integrated into improved systems. Three design features were generated and patented. The designs included a propeller spinner that assisted with air induction for better cooling, a winglet to assist with breakdown of wake vortices and an excrescence free flap system for a light aircraft. The only design used on this aircraft was the flap system. The aircraft concept was further refined using the same destruction and creation synthesis technique. The concept aircraft was the subject of a detailed business plan and launch strategy that would use the aircraft to leverage funding to start a new industry in the Eastern Cape province. The performance of the aircraft concept was calculated using standard performance techniques that were modified for use, based on experience with other light aircraft. The major emphasis was on the energy available to accelerate, climb and turn. The method developed to analyse a descending turn without power was used to demonstrate that the aircraft could manoeuvre better than the competitors at low power settings. The energy levels needed to surpass the competition were used to design an aircraft with a significant energy margin at speeds of 65-85KCAS, making the aircraft ideal for flight training. The aircraft was designed with a higher aspect ratio and lower wing loading than the competitors to achieve better energy levels and better performance in hot and high conditions. The reduction in maximum speed was not significant when compared to the turn and manoeuvre performance. The structure of the aircraft was then designed to withstand the loads prescribed by the consensus standards. The aircraft was shown to comply with the standards. The completion of the structural design of the major components allowed for the design to be costed. The business plan was revised to include the cost of the manufacturing facility and total investment cost required to realise the project. The proposer of the project funded a full-size mock-up of the aircraft that was launched at a major airshow. The regulatory framework of regulations and technical standards was extensively revised, making the process of obtaining production-built type approval for a design less onerous. Recommendations for structural testing and transient energy analysis were made.

Published work

Aspects of this research report have been published in the following references:

M.F. Boer and L. Thiel. Business plan 1 – Airspire (Pty) Ltd, launch of SkyWake™. *Wits Commercial Enterprise (Pty) Ltd project WRCA006*, Johannesburg, October 2007.

M.F. Boer, A. Hoffe, A. Cachucho, L Biebuyck, T. Herron and J, Nash. An improved spinner for propeller engines. *Provisional South African patent SA 2007/04439.*

M.F. Boer and L. Thiel. Business plan 2– Airspire (Pty) Ltd, launch of SkyWake™. *Wits Commercial Enterprise (Pty) Ltd project WRCA006*, Johannesburg, August 2009.

M.F.Boer and R. Beach. Design registration for SkyWake™ Light Sport Aircraft, *F2010/00928.*

M.F. Boer, C. Bodill, A. Schwarck, J. Reeves, A. Bholla, S. Mowatt and J. Nash. *Aircraft control surfaces and mechanisms for moving same*, Complete South African patent 2010/00868.

M.F. Boer and A. Hoffe. *Method for reducing in flight wake vortices and an aircraft wingtip arrangement used in such method* US 8894018 B2

M.F. Boer, G Mumford, N de Lange. *Civil Aviation Regulations Part 44: Maintenance of Non-Type Certificated Aircraft.* Recreation Aviation Administration of South Africa submission to the South African Civil Aviation Authority, January 2011.

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List of symbols

Symbol	Unit
$	United States Dollar
a	angle of attack
C_D	coefficient of drag
C_{Do}	zero-lift coefficient of drag
C_F	coefficient of skin friction
C_L	coefficient of lift
C_M	coefficient of pitching moment
C_P	coefficient of power
d	diameter
D/q	equivalent parasite drag area
EW	empty mass
g	gravitational constant
J	advance ratio
k	skin roughness
KCAS	knots, calibrated air speed
KEAS	knots, equivalent air speed
KIAS	knots, indicated air speed
KTAS	knots, true air speed
LED	light emitting diode
MTOW	maximum take-off mass
n	revolutions per second or number of g
NACA	National Advisory Committee on Aeronautics
NASA	National Aeronautics and Space Administration
OEW	operating empty mass
Q	form factor
R	South African Rand
r	turn radius
Re	Reynolds number
$Re_{cut\text{-}off}$	cut-off Reynolds number
SEP	specific excess power
S_G	take-off or landing distance
S_{REF}	reference wing area
S_{WET}	wetted area
T	thrust
t	time
V	speed or velocity
V_A	manoeuvre speed
V_C	cruise speed
V_D	dive speed
V_H	level flight speed
V_L	take-off; landing speed

Symbol	Unit
V_S	stall speed
w	turn rate
W	weight

List of Abbreviations

AME	Aircraft Maintenance Engineer
AMO	Aircraft Maintenance Organisation
AP	Approved Person
ATO	Aviation Training Organisations
BCDA	Blue Crane Development Agency
BCRM	Blue Crane Route Municipality
SACAA	Civil Aviation Authority
CAR	Civil Aviation Regulations
CAS	Calibrated (Computed) Air Speed
CEO	Chief Executive Officer
CGE	Computable General Equilibrium
DEAET	Department of Economic Affairs, Environment and Tourism
DO	Design Organisation
dti	Department of Trade and Industry
EAA	Experimental Aircraft Association
E-LSA	Experimental Light-Sport Aircraft
GP	Gross Profit
JAR	Joint Airworthiness Requirement
FAA	Federal Aviation Authority
FAJ	Floor Assembly Jig
IDC	Industrial Development Corporation
IDZ	Industrial Development Zone
LSA	Light Sport Aircraft
MAUW	Maximum All-Up Weight
MO	Manufacturing Organisation
MOA	Memorandum of Association
MPTO	Manufacturing, Processing and Testing Organizations
MPL	Microlight Pilot's License
MTOW	Maximum Take-Off Weight
NAC	National Aerospace Centre
NTCA	Non-Type Certified Aircraft
NPV	Net Present Value
PDI	Previously Disadvantaged Individual
PPL	Private Pilot's License
SA	Single engine certified aircraft
SABS	South African Bureau of Standards
SPV	Special Purpose Vehicle
STF	Structural test facility
STOL	Short Take Off and Landing
ULM	Ultralight Motorised
US	United States of America
Wits	University of Witwatersrand

1. Introduction

1.1. Blue Crane Development Agency agreement with the University of the Witwatersrand

To create employment and upgrade skills in the Blue Crane Regional Municipality, the Blue Crane Development Agency (BCDA) developed a strategy to design an ultralight aircraft, which can be manufactured by a manufacturing organisation housed within the industrial park. Wits Commercial Enterprise (Pty) Ltd (Wits Enterprise), the intellectual property commercialisation company of the University of Witwatersrand, and the University of the Witwatersrand's School of Mechanical, Industrial and Aeronautical Engineering (Wits University) was contracted to design the aircraft and a Memorandum of Agreement (MoA) was accordingly signed.

The design brief was for an ultralight aircraft with the following characteristics:

1. Composite or Aluminium structure.
2. Good flying qualities with low stall speed and high speed cruise (100 – 120kts).
3. Fuel efficient piston engine using unleaded/low-lead fuel or diesel.
4. Range ±1000 km, endurance ±4 hours.
5. Retractable or fixed undercarriage.
6. Tractor or pusher propeller configuration.
7. Two/four seat configuration.
8. Comply with microlight/ultralight regulation.
9. Performance to satisfy international export market.

In addition, the detailed design must allow for:

10. Cost efficient construction, low prototype and tooling cost.
11. Maximum local material content.
12. Black Economic Empowerment beneficiation / job creation.

The design project started on 1 August 2006 and ended on 31 January 2008 with the delivery to BCDA of the production drawings of the aircraft. The design forms the core of this report.

1.2. Ultralight aircraft types

Ultralight aircraft occupy a niche between microlight aircraft and type certified light aircraft within the general aviation industry. This class of aviation has rapidly grown internationally to become a safe and affordable recreational aviation activity and is considered to be the fastest growing segment of the general aviation industry. In most affluent countries, ultralights now account for about 20% of the civil aircraft fleet [1]. In developing countries, ultralights are used for flight training and for commercial operation such as crop-spraying, border-patrol and Rhino protection [2].

As a result of the transformation of these lightweight aircraft into high performance aircraft, capable of very respectable speed and range, many international aviation authorities established a category of aircraft that could be subject to minimum regulation. It should be noted that the weight and speed limits for this class of aircraft are rarely the same between any two countries.

Most countries now require an ultralight pilot's license/certificate however internationally there is no common set of ultralight rules. The safety regulations used to approve ultralights vary between countries, the strictest being the United Kingdom, Italy, Sweden and Germany, while they are almost non-existent in France and the United States. This disparity between regulations is a major barrier to international trade and overflight, as is the fact that these regulations are invariably sub-ICAO (International Civil Aviation Organisation), which means that they are not internationally recognised [3].

Ultralight aircraft in the United Kingdom and New Zealand are generally called microlight aircraft and in France and Italy they are called ultralight motorised (ULM). Some countries further differentiate between weight shift and 3-axis aircraft, calling the former microlight and the latter ultralight. It should be noted however that the United States definition of an ultralight is significantly different from that in most other countries and can lead to some confusion. The United States ultralight is a single seat vehicle with an empty weight of less than 115 kg and a top speed of 102 km/h. The Australian definition is a one or two seat aircraft with maximum take-off mass of less than 540kg. The ULM is defined as a two seat aircraft with maximum take-off mass of less than 450kg and a maximum stall speed of 65 km/h. The United Kingdom defined an ultralight in the microlight category with an operating empty mass of no more than 150kg with a maximum fuel capacity of 50 litres and a maximum take-off mass of 390kg. This definition has been revised with a distinction between single seat and two seat aircraft. Single seat aircraft have a maximum take-off mass of 300kg and two seat aircraft a maximum take-off mass of 450kg, both having a maximum stall speed of 65 km/h [4].

The introduction of the FAA Light-Sport Aircraft (LSA) category in 2004 introduced a type of aircraft in the United States which more closely resembles the ultralight categories in other countries. For Light Sport Aircraft a sport pilot certificate is required, which is similar in requirements to ultralight licenses in other countries.

At the time of the preliminary design of the aircraft the European aviation community was working on regulations that were intended to resolve the non-standard definition of the LSA within a reasonable time frame.

There are several types of aircraft which qualify as ultralights. The different categories comprise of land/sea aircraft, land/sea powered parachutes, weight-shift-control aircraft (land/sea trike), gyroplanes, balloons, and airships. These aircraft can be used for private sport and recreation and commercial flight training, rental, and towing. Rotary-wing aircraft, with the exception of helicopters, have not been included due to the complexity of operating these aircraft.

1. **Weight shift (trike):** The first generation ultralights were controlled by weight shift. Most of the current weight shift ultralights use a hang glider-style wing, below which is suspended a three wheeled crash-structure containing the engine and pilot/passenger. These aircraft are controlled by pilot moving his/her centre of mass laterally or longitudinally [3]. Trikes are the least expensive in terms of both start-up and up-keep cost.
2. **Glider/sailplane:** Gliders and sailplanes only carry functionality on a recreational level because they rely on rising air mass rather than an engine to keep them aloft. Whilst some gliders have engines, the primary job of the engine is simply to raise the glider to an altitude

suitable for gliding, at which point the engine is turned off. Gliders with no engine rely on tow-aircraft, winches and occasionally land vehicles for launching purposes.

3. **Powered parachutes:** The powered parachute is a parachute that has an attached frame with an engine, propeller and wheels. The powered parachute is one of the more popular forms of recreational sport flying, due to its relatively low cost of start-up and licensing. Powered parachutes are an extremely versatile sport aircraft
4. **Powered paragliding:** Also known as paramotoring, is a form of ultralight aviation where the pilot wears a small engine with a propeller on his back. The low and slow flying capability, feeling of freedom, portability, low equipment and maintenance costs for this type of flying are considered its greatest merits.
5. **Lighter than air sport aircraft:** These aircraft include the likes of airships and hot air balloons and can vary significantly in design. All lighter than air sport aircraft function using buoyancy with the filler gas being less dense than air, allowing the balloon to climb and allow for a particular altitude to be maintained.
6. **Helicopter:** there are a number of single and two-seat helicopters that fall under the microlight categories in countries such as New Zealand. However, few helicopter designs fall within the more restrictive United States ultralight category.

1.3. Light Sport Aircraft

In the United States the general aviation industry began declining in the late 1970's, lasting throughout the 1980's and into the mid-1990's. Part of this decline was attributed to an increase in liability claims on aircraft manufacturers over ageing aircraft resulting in dramatic increases in aircraft manufacturing costs. Manufacturers of standard general aviation aircraft thus reduced their production of single-engine personal and sport aircraft. Manufacturers estimated that these liability claims contributed upwards of 30% to the cost of a new aircraft [1]. In 1994, Congress passed legislation restricting aircraft product liability lawsuits, and manufacturers again began looking at the personal and sport market [5]. Subsequent to the terrorist attacks of 11 September 2001, the market again began to decline as significant restrictions were placed on general aviation. Most of these restrictions have since been lifted but the production costs of single-engine piston aircraft have continued to increase. The United States General Accounting Office Report "Status of the Industry, Related Infrastructure, and Safety Issues" noted that the cost of a single-engine piston aircraft increased from $25,000 in 1975 to $112,000 in 1990, representing more than a doubling of cost in constant dollar terms. In January 2003, the list price of a Cessna Skyhawk, a representative single-engine piston aircraft with standard equipment was $155,000 [1].

These constraints, coupled with competing cheaper leisure-time activities had the effect of reducing the general aviation market segment. As the growth in pilot population slowed, hang gliders started to evolve into ultralight aircraft. Since 1992, the growth of kit aircraft and home built experimental aircraft has increased dramatically, the worldwide sale of kit aircraft in 1992 was 1,943 and the number of sales in 2002 was approximately 9,000 [5]. The ultralight community then petitioned the Federal Aviation Administration (FAA) to liberalise regulations and permit heavier, faster, more powerful aircraft and the carriage of one passenger. The Experimental Aircraft Association (EAA), the designated body for recreational flying which, represents both recreational flyers and home-builders, had simultaneously been working with the FAA to expand the home-built activity and petitioned for the Light Sport Aircraft consensus standards. To encourage growth in pilot numbers, the Young Eagles Program was instituted

to give children a flight in a recreational aircraft to emphasize the low operating costs and enjoyment associated with ultralight aircraft. The EAA flew their 1,000,000th Young Eagle on 17 December 2003, the centenary of powered flight. The pilot for the historic flight was General Charles "Chuck" Yeager, he piloted a Douglas C-47.

With the recognition of a declining pilot population and the implications to all air travel, in September 2004 the FAA generated an entirely new category specifically designed to address the desire of people wishing to fly aircraft primarily for recreational (non-business/compensation) purposes. The Light Sport Aircraft (LSA) regulation is a comprehensive package specifically addressing recreational aviation by addressing all aspects of the operation of light sport aircraft including a new pilot certificate, a new flight instructor certificate, maintenance rules, and medical and aircraft certification. This new category of the sport aviation market effectively reduced the barriers to becoming a pilot in the United States as it substantially lowered capital investment and operating costs. Aircraft in this category are cheaper to purchase, are more fuel efficient and have a lower maintenance cost than larger aircraft. Pilots are not required to hold a medical certificate, but only need to carry a valid United States driver's license to meet the medical eligibility requirements. The basic sport pilot certificate requires a minimum of 20 hours training and a driver's license (as opposed to a medical examination).

It is feasible that this sport pilot and aircraft classification will enlarge the aviation market among those who are already pilots, attract a significant number of new pilots to general aviation as well as convert existing pilots downgrading to cheaper aircraft or for other reasons.

Sport pilots can fly six categories of aircraft as shown in Figure 1. Included in this image is the minimum number of training hours required to earn a sport pilot certificate in that category.



Figure 1. Light Sport Aircraft categories [6]

The Light Sport Aircraft is not a new concept. Aircraft within this category have existed since the 1930's, the most famous example of a vintage aircraft complying with the 2004 S-LSA regulation is the Piper J-3 Cub. The J-3 was developed for flight training, with the occupants seated in tandem configuration. Between 1937 and 1947 twenty thousand J-3 aircraft were produced and in 2014 the aircraft was made Pennsylvania's official state aircraft [7]. The 2004 regulation served only to provide a standard for performance and safety, whilst limiting unconventional designs. The LSA regulations saw a resurgence in interest in aircraft such as the compliant J-3. Cub Crafters has re-designed the J-3 using modern materials and the Carbon Cub sold 38 units (Q1-Q3) in 2014 [8].

Light Sport Aircraft (LSA) can be manufactured and sold ready-to-fly under new LSA certification. Aircraft certified as LSA may be used for sport and recreation, flight training, and aircraft rental. They can also be licensed as Experimental Light Sport Aircraft (E-LSA) if kit-built. Both United States and foreign manufacture of LSA is permissible under the Federal Aviation Regulations.

Light sport aircraft are defined as simple, low performance aircraft that, since its original certification, has continued to meet the following criteria [6]:

- A maximum take-off weight of not more than:
    - 300kg for light-than-air aircraft
    - 600kg for aircraft not intended for operation on water.
    - 650kg for an aircraft intended for operation on water or a glider.
- A maximum airspeed in level flight with maximum continuous power of not more than 120 knots under standard atmospheric conditions at sea level.
- A maximum never-exceed speed of not more than 120 knots for a glider.
- A maximum stalling speed or minimum steady flight speed without the use of lift-enhancing devices of not more than 45 knots at the aircraft maximum certificated take-off weight and most critical centre of gravity.
- A maximum seating capacity of no more than two persons, including the pilot.
- A single, reciprocating engine, if powered.
- A fixed or ground-adjustable propeller if a powered aircraft other than a powered glider.
- A fixed or auto-feathering propeller system if a powered glider.
- A fixed-pitch, semi-rigid, teetering, two-blade rotor system, if a gyroplane.
- A non-pressurised cabin, if equipped with a cabin.
- Fixed landing gear, except for an aircraft intended for operation on water or a glider.
- Fixed or repositionable landing gear, or a hull, for an aircraft intended for operation on water.
- Fixed or retractable landing gear for a glider.
- Powered parachute.
- Weight-shift-control aircraft.

1.4. South African ultralight manufacturers

There is a large diversity and range of ultralight and Light Sport Aircraft on the market in South Africa, available either in kit or fully built form. Fully built aircraft are assembled locally from imported components; there are hence no fully South African manufactured aircraft. The design features of the aircraft models are broad. Some are modern versions of designs that have been proven in classic aircraft, while others are imports from Europe and Australia where lighter aircraft have been in the marketplace for more than a decade. Some of the more popular aircraft and their manufacturers are profiled in Table 1.

Table 1. South African ultralight manufacturers [9].

Manufacturer	**Aircraft model**	**Technical Description**	**Photo**
Rainbow Aircraft	Cheetah XLS (Ultralight-production built))	High wing braced monoplane with aluminium tubular structure, clad with Dacron.	
Davies Aircraft Corporation	Thunderbird (Microlight-production built)	Enclosed cabin high-wing braced two-seat aircraft. Dacron clad.	
Whisper Aircraft	Whisper (Motorglider-production built)	High aspect ratio exposed-motor glider.	
The Airplane Factory	D-6 Sling (Light Sport Aircraft-kit built)	Low-wing two-seat Aluminium semi-monocoque structure.	
Micro Aviation SA	Bantam BJ-22 (Microlight-production built)	Semi-enclosed cabin high-wing braced two-seat aircraft. Dacron clad.	

1.5. Certification of an aircraft design

The build quality and airworthiness of ultralight aircraft (LSA category in the United States) now rivals that of certified light aircraft. It is possible that some aircraft can satisfy both sets of requirements and can hence be available for registration as either an ultralight or type-certified aircraft. In recent years there has been a dramatic rise in the number of general aviation pilots flying high performance ultralights due to the lower costs. Ultralight pilots are permitted to self-perform some of the simple maintenance tasks, resulting in a lower cost of operation, although the pilot must then follow the ultralight regulations such as avoiding densely populated urban areas and not flying at night. Many older pilots have been willing to trade these operational restrictions for the lower operational costs, and as a result many ultralights are now flown by experienced general aviation pilots or ex-commercial pilots. In addition, further growth in this market has been driven by the fact that ultralight pilots are not required to pass periodic physical examinations, as is the case for general aviation pilots.

Although ultralight aircraft (classified as microlights in some countries) started out in the early 1980's as slow, lightweight and uncomplicated aircraft, many have evolved into fast, sophisticated machines. The ultralight aircraft have thus rapidly transformed into high performance aircraft, capable of very respectable speed and range. These aircraft are now often referred to as recreational aircraft. In South Africa these aircraft are included in the Non-Type Certificated Aircraft (NTCA) category.

The design, manufacture, approval, and maintenance of non-type certificated aircraft (NTCA) are controlled and enforced by the South African Civil Aviation Authority (SACAA) through rules and regulations contained in the Civil Aviation Regulations (CAR) of 1997. With the growth of the NTCA sector, along with international trends, the SACAA has developed regulatory provisions in order to properly control and regulate this class of aircraft. The CAR control certification and airworthiness, operation and the commercial use of NTCA. In addition, separate parts of the CAR (applicable to both NTCAs and type certified aircraft) control the design of all products, parts and appliances as well as the licensing of design, manufacturing, and maintenance organisations.

The plan for the industrialisation of the business was thus largely dictated by the need to comply with the regulatory environment. Of importance are those NTCA regulations that pertain specifically to production-built aircraft i.e. aircraft of which the prototype has been constructed and approved in terms of SACAA regulations for the issue of a certificate of airworthiness and which are made available either fully-assembled or in kit form.

The relevant parts are:

Part 24: ***Airworthiness Standards: NTCA Aircraft***

This Part was signed by the Minister for promulgation in July 2007. The airworthiness, aircraft documentation, maintenance, inspection and type approval processes are described.

Part 43: ***Maintenance standards: All aircraft types***

This Part describes the procedures for continued airworthiness of an aircraft. Part 43 applies to all aircraft types and describes the personnel, documentation, maintenance (scheduled and un-scheduled), repair, overhaul and substitution of aircraft components.

Part 147: *Design Organisations* (DO) for Products, Parts and Appliances.

This part applies to approvals of organisations wanting to produce designs for commercial gain such as production-built non-type certificated aircraft.

Part 148: *Manufacturing Organisations* (MO)

This Part applies to the approval and operation of manufacturing organisations that manufacture specified products, parts or appliances, apply specified processes to products, parts or appliances; or carry out specified tests on products, parts or appliances.

In order to produce a type-certified production aircraft with a Type Holder Certificate (THC) issued the SACAA both the design organisation and manufacturing organisation need to obtain authority from the SACAA. Three points are notable in this regard:

(1) An organisation may only obtain DO Status (approval) from the SACAA if, in conjunction with its application for a DO licence, it approaches the SACAA with a design with the intention of obtaining a THC.

(2) Any components produced for the aircraft must be produced by an MO, where the design of the component must have been produced by a DO.

(3) Due to the processes and human resources prescribed in the manual of procedure, it is highly unlikely that a single entity could obtain both full DO and MO authority for production of an entire aircraft.

In order to produce a production-built non-type certificated aircraft, the following must be done:

1. Obtain the type holder certificate of airworthiness for the aircraft.
2. Construct and test the prototype of the aircraft.
3. Conduct a successful flight test programme.
4. Deliver a design for mass production.
5. Deliver the implementation plan for production.

2. Objectives

1. Synthesise a conceptual design that is compliant with the relevant aviation regulations to satisfy the requirements of the Blue Crane Development Agency.
2. Evaluate the performance of the conceptual aircraft by analysis of the flight envelope in hot/high conditions.
3. Develop a strategy for commercialising the aircraft, including a launch strategy and business plan.

3. Literature survey

3.1. Aircraft development

The analysis of competing aircraft included aircraft approved as microlight, ultralight, light sport and very light aircraft. Source data was obtained by processing data extracted from a survey of manufacturers [9]. This data was used to establish minimum competitive requirements. The majority of figures have been produced with a qualitative timeline for illustrative purposes.

The power utilisation was calculated using the published cruise speed and the maximum installed power. Each aircraft has a different engine and propeller combination and the cruise power might not have been the same for two similar aircraft. The best cruise speed might have been measured or calculated at different masses and flight altitudes. Manufacturers are not required to publish a type certificate with certified performance indices for aircraft in these categories. The aircraft sold as kit-aircraft will have slightly different build standards for each aircraft, this would mean that the manufacturer supplied performance may not be very accurate. Using the maximum available power would allow for a more consistent benchmark to be established, allowing for more direct comparison.

Figure 2 indicates a gradual increase in the power utilisation with time. The most efficient aircraft, the Pipistrel Sinus and Virus, are full composite aircraft that resemble powered gliders. The least efficient aircraft are; the Thunderbird (microlight), 2000 F-1 evo (high performance kit) and the Teddy (design based on the Piper J-3 Cub). The Jabiru aircraft utilise Jabiru engines with direct drive and the other aircraft use Rotax engines with a reduction gearbox. Since the inception of the LSA category aircraft performance has stabilised at over 1,05 kt/hp. For a competitive design the power utilisation needs to be a minimum of 1,05 kt/hp.

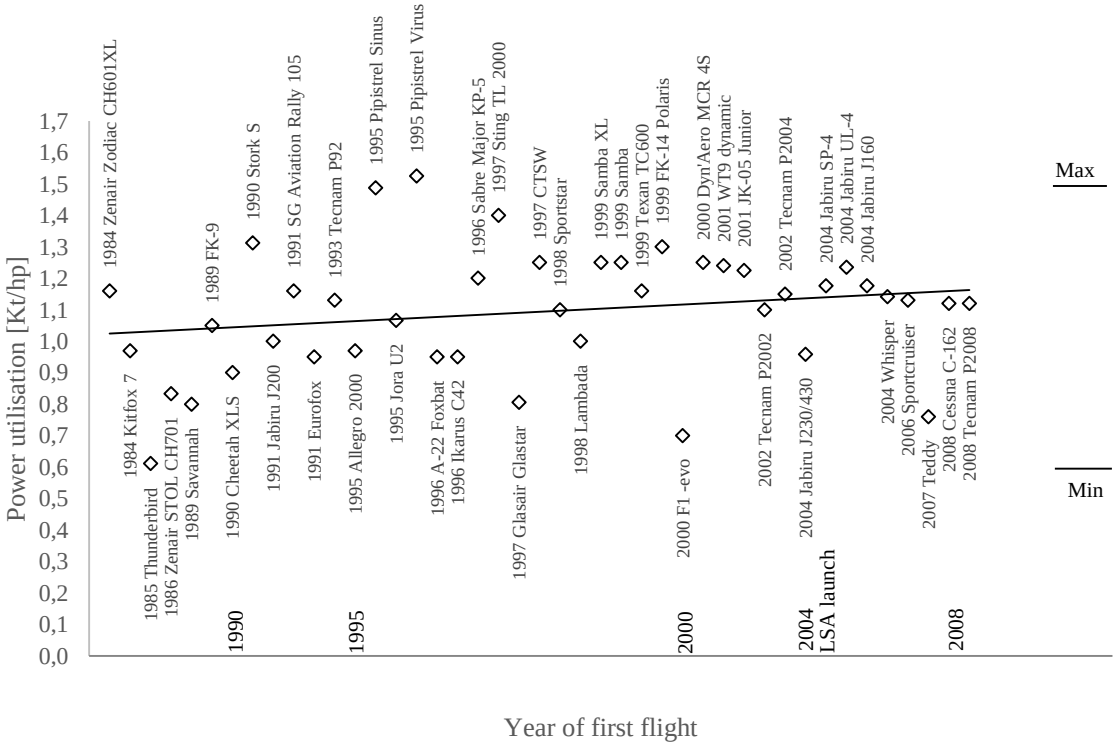


Figure 2. Evolution of power utilisation over time

The American Society for Testing and Materials (ASTM) consensus standards for LSA stipulate that the minimum payload for a two-seat LSA may not be less than 195kg for an aircraft fitted with a 100hp (75kW) engine [10]. The payload or useful load comprises the occupants, baggage and fuel. The published useful load for the different aircraft being considered has been plotted against the ratio of useful load to gross mass. Since a 450kg gross mass microlight and a 750kg very light aircraft might have the same useful load, but the useful load ratios will be different. Figure 3 illustrates the useful load and ratio of useful load to gross mass. The ASTM minima for LSA has been included. The Jabiru UL-4 is a composite aircraft with a gross mass of 500kg with a 85hp engine. The Cessna C-162 is an Aluminium aircraft with a gross mass of 600kg with a 100hp engine. Both the UL-4 and the C-162 have similar useful load capability. The Tecnam P92 ultralight has a very competitive useful load for an aircraft designed with a mixed steel/Aluminium primary structure. The Tecnam P2008 LSA has a similar useful load compared to the P92. It is not clear what the minimum useful load percentage is, however a typical useful load of at least 250kg for a steel or Aluminium aircraft would allow for the design to be competitive.

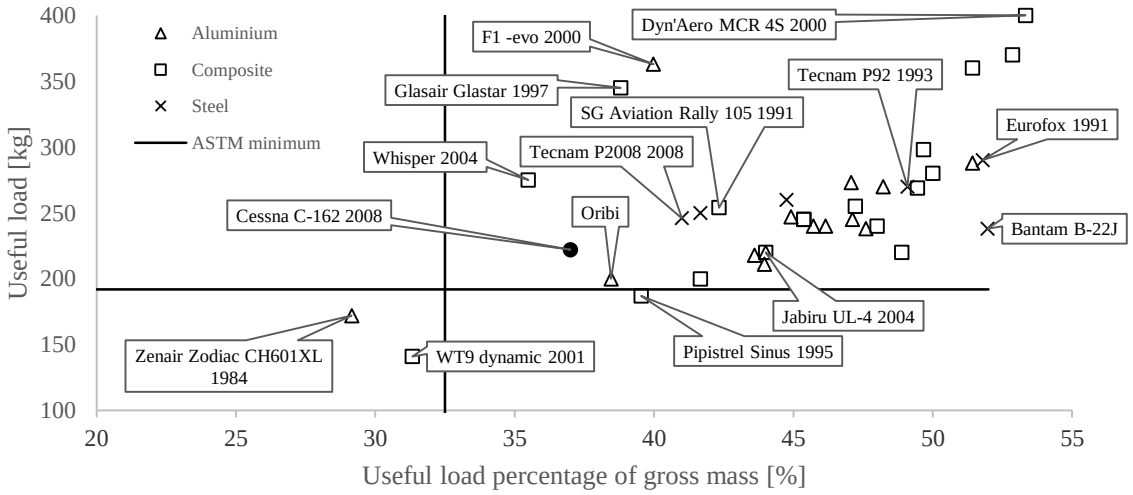


Figure 3. Useful load and useful load ratio of gross mass

The power loading performance indicator was calculated using the gross mass and maximum installed power. The gradual increase in power loading illustrated in Figure 4 indicates that modern aircraft in these categories are less powerful than earlier designs. The trend has stabilised with the inception of the LSA category. The two most powerful aircraft are not LSA. The WT9 is a composite aircraft with a gross mass of 450kg powered by a 100hp Rotax engine and the F1-evo is an Aluminium aircraft with a gross mass of 900kg powered by a 260hp Lycoming engine. For the design to be competitive, a power loading of 6,0kg/hp should not be exceeded for a LSA and 5,8kg/hp for an ultralight.

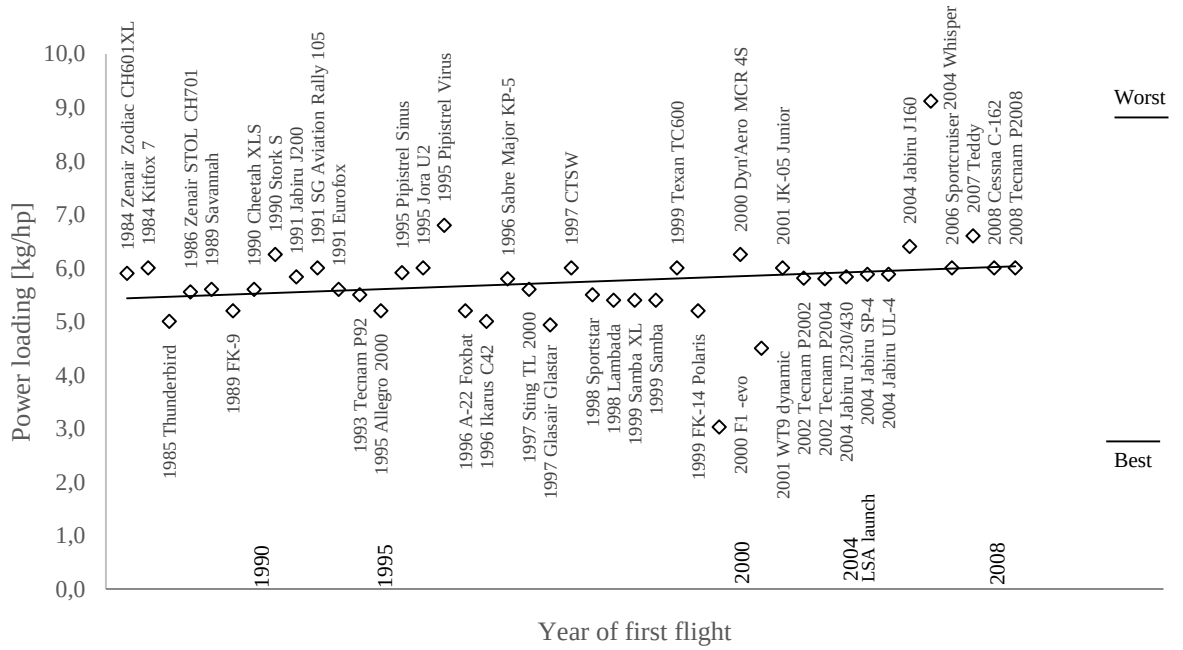


Figure 4. Power loading over time

The ratio of useful load to gross mass indicates a measure of the utility of the design. Aircraft with a 600kg gross mass; CTSW, Tecnam P2008, Texan, Sportcruiser and C-162 have been identified in Figure 5. The C-162 is the only aircraft not fitted with a Rotax engine. The Jabiru family has a restricted gross mass of 500kg, hence the higher ratio of useful load to gross mass when compared to the C-162. A competitive design would typically require a useful load in the range of 45-50% of the maximum take-off weight.

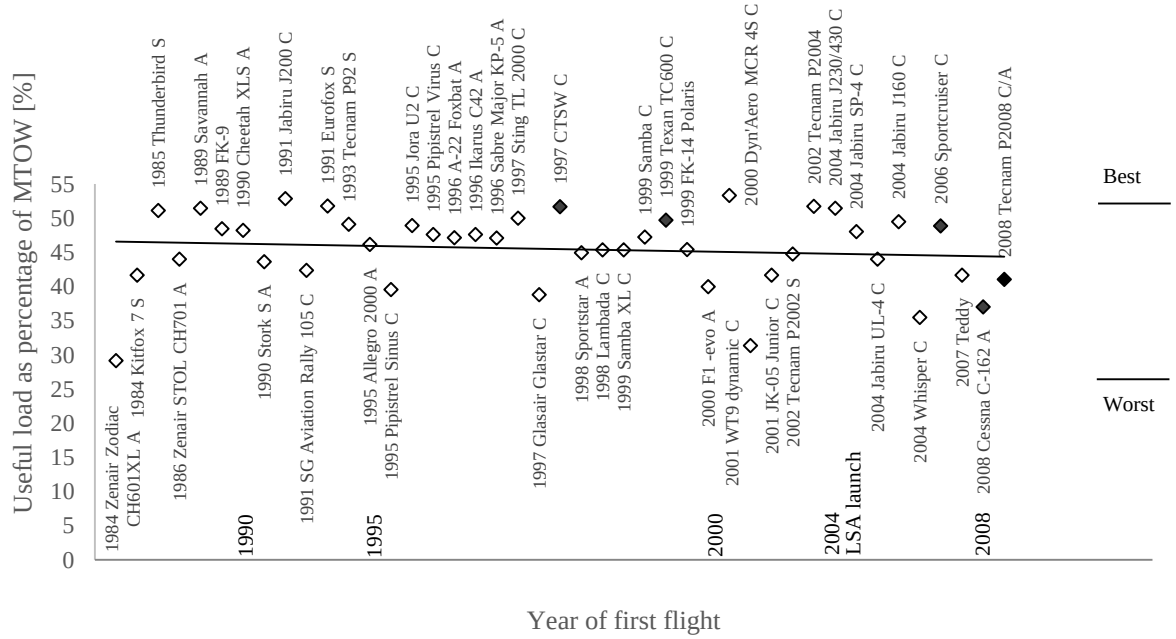


Figure 5. Useful load compared to useful load percentage of gross mass over time.

The useful load of the aircraft was investigated and compared to the minimum useful load prescribed by the ASTM consensus standards and is presented in Figure 6. The majority of aircraft have a useful load above the minimum level. The aircraft with the lowest useful load are microlight category aircraft

with lower gross mass than LSA. The aircraft with the highest useful load were not LSA. The Jabiru J200C and DynAero MCR 4S are four-seat light aircraft, hence the larger useful load. The Glasair Glastar is a two-seat aircraft with a gross mass of 890kg. The 600kg gross mass LSA aircraft have been highlighted. The C-162 has the lowest useful load of the LSA aircraft and is comparable with a Jabiru UL-4, an aircraft with a gross mass of 500kg. For the design to be competitive the useful load would need to be 250-300kg and between 45-50% of the maximum take-off weight.

With regards to the material used for primary structure. Each data point in Figure 6 has been labelled with an A, C or S corresponding to an Aluminium, composite or steel primary structure. The composite aircraft appear to outperform the C-162. The Tecnam P2008 has a hybrid structure of Aluminium and carbon fibre and was derived from the P92 and P2004. The P2008 is an LSA whereas the P92 and P2004 are classified as ultralights with versions sold as LSA. The useful load of 250-300kg for a competitive design is further reinforced.



Figure 6. Useful load for different primary structure over time.

The cruise speeds of the aircraft were analysed and are presented in Figure 7. The cruise speed displays a gradual increase with composite aircraft having higher cruise speeds that steel or Aluminium aircraft. The LSA aircraft have been highlighted for comparison. The CTSW, Tecnam P92, P2004, P2008 and C-162 are high-wing aircraft. The CTSW has a cantilevered wing whereas the C-162 and Tecnam P92 and P2008 have strutted wings. The Texan and Sportcruiser both feature cantilevered low wings. All LSA aircraft with 600kg gross mass can achieve 100 knots at cruise power settings. A competitive cruise speed of 110kt is required for the design to be competitive.

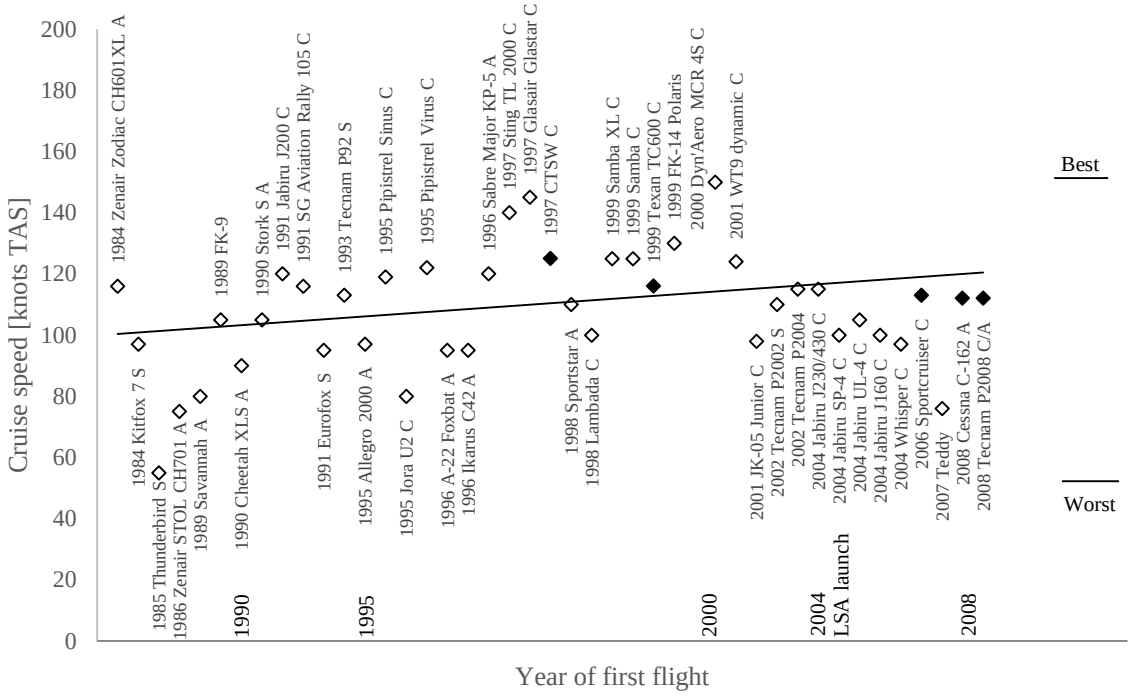


Figure 7. Cruise speed comparison over time.

3.2. Aircraft type by design standard

The Federal Aviation Authority has certified a total of 131 aircraft types from Aeronca, Ercoupe, Interstate, Luscombe, Piper, Porterfield, Quicksilver and Taylorcraft as certified Light Sport Aircraft [11]. These aircraft qualify as Light Sport Aircraft, but were not originally designed as such.

The ASTM produced a consensus standard for the specification and performance of a light sport aircraft. The consensus standards were focussed on encouraging the existing manufacturers of light un-regulated aircraft to design aircraft, produce documents, establish authority (for the design type) and declare compliance. This new standard would allow manufacturers of small light aircraft to enter production within a compliance framework less onerous than FAA regulations. The matrix of ASTM consensus standards is presented in Table 2.

Table 2. ASTM consensus standards [10]

Consensus Standard Topics	Aeroplanes
Design and Performance	**F2245-04 or -06**
Required Equipment	F2245-04 or -06
Quality Assurance	F2279-03 or -06
Production Acceptance Tests	F2279-03 or -06
Aircraft Operating Instructions	F2245-04 or -06
Maintenance and Inspection Procedures	F2483-05
Identification and Recording of Major Repairs and Major Alterations	F2483-05
Continued Airworthiness	F2295-03 or -06
Manufacturers Assembly Instructions [Kit builders only]	F2563-06
Wing Interface Documentation	N/A

ASTM F2245 has been updated on several occasions. Manufacturers have a six month overlap period with regards to the changes to the standard. This allows for aircraft that have started the certification process using the previous standard to introduce any changes to the design [12]. The revision history issued by the FAA follows:

- F2245-4 3 March 2005
- F2245-6 3 January 2007
- F2245-7a 28 July 2008
- F2245-9 15 October 2009
- F2245-10c 29 July 2011
- F2245-11 23 April 2012
- F2245-12d 11 June 2013
- F2245-13b 27 February 2014

The major version changes between F2245-10c and F2245-12d were [13]:

1. Operating manoeuvring speed V_O was introduced to protect the structure from damage due to an abrupt single input such as rapid full elevator deflection.
2. Maximum zero wing fuel weight W_{ZWF} was introduced to mitigate against optimistic assumptions for non-usable fuel remaining in the wing.
3. Minimum useful load definition was re-drafted based on the weight of the persons and consumable fuel for a flight time of 1 hour.
4. To prevent low control input forces, the minimum force required to obtain the limit manoeuvring load factor was set at a minimum of 70N for a clean aircraft with centre of gravity furthest aft.
5. Firewall thickness was reduced from 0.46mm to 0.38mm, the material remains specified as stainless steel.
6. The definition of suitable restraints was clarified as a pelvic and shoulder restraint.
7. Climb rate for aircraft intended for towing gliders was increased to 90m/min (295ft/min).
8. New airspeed indication system calibration requirements complying with light general aviation aircraft must be introduced. These were introduced due to a series of near-identical incidents with one type of light sport aircraft.
9. Fuel strainer requirements have been added as a result of an investigation led by the Air Accidents Investigation Branch (UK) into a fatal accident in June 2011, where a safety placard was left in the fuel tank and the fuel dissolved the adhesive thus allowing the safety label to block the drain hole. The fuel strainer requirements were specifically tailored to prevent foreign objects from entering the fuel lines [14].

The most important changes to specifications from the ASTM F2245 standard have been summarised in Table 3.

Table 3. Important changes to the ASTM F2245 standard.

Section	Pertaining to
4.5.1.2	Prolonged and (temporary) stick force application: Pitch – 23N (200N) Roll – 23N (100N) Yaw – 110N (400N)
5.1.2.1	Factors of safety: Castings – 3 Fittings – 1.8 Bearings – 3 Control surface hinges – 6.67 Push-pull control joints – 3.3 Cable control joints and seatbelt joints - 2
5.1.4	Each design requirement must be verified by conservative analysis or test (static, component, or flight), or both.
5.2.2.4	The maximum negative lift coefficient is specified as being 0.8. Even if the zero lift pitching moment coefficient is zero (symmetrical aerofoil) a value of at least ± 0.025 must be used.
5.2.3	Gust envelope uses same estimation method as FAR 23
5.2.9.1/2	Engine torque loads. Greater of two cases must be used: 1. Maximum power and propeller speed with 75% of the limit load factor applied. 2. Maximum continuous power with corresponding propeller speed with 100% of limit load factor applied.
5.2.9.3	Additional safety factor for direct drive engine-propeller combinations. Safety factors for four-stroke engines are based on number of cylinders: 1.33 – 5 or more cylinders 2 – 4 cylinders 3 – 3 cylinders 4 – 2 cylinders 8 – 1 cylinder
5.2.10	Side load on the engine must be 150% of the vertical limit load.
5.3.7	Ground gust hinge moments for control surfaces must be calculated at an airspeed of 38kts with a hinge moment coefficient of 0.75.

Table 3 demonstrates the typical level of detail specified in F2245. The primary content of F2245 may be summarised as follows:

1. The flight envelope is clearly defined. This is achieved by limiting the wing loading, centre of gravity limits, propeller diameter and rotation speed, climb rate, stability and control, manoeuvrability and flap geometry.
2. The structural loads may be calculated using empirical data, provided by ASTM, or by physical test to limit load. Deformation limits and factors of safety are prescribed. The limit load factor calculations for the gust induced load factors originate from the European light aircraft regulation and are in metric form. Loads for major systems such as the engine mount, landing gear, wing and control system are defined as a function of the flight envelope. Load case analysis has been simplified when compared to the regulations pertaining to general aviation certified aircraft. Pilot control forces are prescribed and as indicated previously, changes to the minimum control input forces have been made.

3. The design and construction guidelines do not limit exotic designs, since compliance is demonstrated by physical test rather than by analysis. Materials do not have to be conventional aerospace materials provided that no structural members fail during test. Apart from testing that the control system does not lock-up or jam during structural testing and that self-locking fasteners may not be used as hinges, the standards require the designer to use best practice during the design of the aircraft. No allowance is made for fatigue in the standards, instead, inspections on primary structure are prescribed by the manufacturer and are more frequent when compared to certified aircraft.
4. The powerplant and fuel system guidelines have been made stricter after several incidents and accidents were attributed to fundamental design problems with the systems. The latest F2245 document has new guidelines regarding fuel systems to increase safety.
5. The required equipment is prescribed, however each country stipulates minimum equipment in the country aircraft operating regulations. Geography and meteorology influence the equipment list. In order to obtain a type certificate from a country aircraft regulator, the equipment list in the pilot operating handbook must often be modified.
6. Additional standards are provided for aircraft intended for towing of gliders and banners, aircraft designed for flying at night and for aircraft intended for operating on water as float aircraft or as amphibious aircraft.

3.3. Aviation regulating authorities

The LSA market has shown substantial growth since the introduction of new designs. In the United States to date, approximately 50 different models of aircraft have already been approved under the special LSA regulation as ready-to-fly aircraft. Table 4 presents a summary of the United States aircraft register per aircraft type.

Table 4. United States aircraft register [15]

	2005	**2006**	**2007**	**2010**	**2015**	**2020**	**2006-10**	**2006-20**
	Actual			***Forecast***			***Forecast Annual Growth Rates***	
Light Sport Aircraft	170	400	2,700	5,600	10,500	13,200	93.4%	28.4%
Total GA	224,352	226,422	231,343	242,766	261,404	274,914	1.8%	1.4%
Percentage	<0.1%	0.2%	1.2%	2.3%	4.0%	4.8%		

Table 5 presents market share of LSA in the United States. The market share of 2700 LSA in 2007 can be compared to the market share of 2550 LSA in October 2013. The market had become saturated and the predicted market share of 10500 LSA in 2015 would not be achieved.

Table 5. Light Sport Aircraft market share (United States) [6].

Special Light-Sport Aircraft Market Shares to October 1, 2013				
	only fixed wing airplanes given a rank		Number	Market
Rank	Manufacturer	Main Model	of Aircraft	Share
1	Flight Design	CTLSi *	357	14.0%
2	Cessna • *(built in China)*	Skycatcher	275	10.8%
3	CubCrafters •	CarbonCubSS*	272	10.7%
4	Czech Sport Aircraft	SportCruiser *	205	8.0%
5	American Legend •	Legend Cub	185	7.3%
6	Tecnam	Sierra *	155	6.1%
7	Remos	GX NXT *	118	4.6%
8	Jabiru US †	J-230 *	103	4.0%
9	Evektor	SportStar	92	3.6%
10	Aeropro (Aerotrek in USA)	A240/A220	76	3.0%
11	TL Ultralight (SportairUSA)	Sting S4 *	75	2.9%
12	LSA America •	Allegro	52	2.0%
13	Rans •	S-7 Courier *	40	1.6%
14	ICP *(formerly Skykits †)*	Savannah *	30	1.2%
15	FP&A † (Aeroprakt)	Valor A-22 *	27	1.1%
16	Aero SP *(formerly Gobosh)*	AT-4	23	0.9%
17T	Magnaghi *(formerly III)*	Sky Arrow	22	0.9%
17T	Zlin (SportairUSA)	Savage (iCub)	22	0.9%
17T	Arion Aircraft •	LS-1	22	0.9%
20	Pipistrel	Alpha	17	0.7%
All other producers...			381	14.9%
		TOTAL SLSA AIRPLANES **	2,549	100.0%
Notes:	** Company has multiple models certified and counted here*			
	*** ELSA, Weight Shift, Powered Parachutes, Other types not counted*			
	• Designed or Manufactured in USA † Assembled in USA			
	—FAA database research by Jan Fridrich of the Czech LAA—			

Yearly LSA sales in the United States is presented in Figure 10 indicating the initial growth and subsequent decline in sales [6, 8]. The 2014 data only represents sales (Q1-Q3) for the top three selling LSA models, the Flight Design CT range, the Cub Crafters Carbon Cub and the Tecnam P92 and P2008 range. The LSA sales for 2014 is predicted to be similar to the annual sales of 2009-2014.

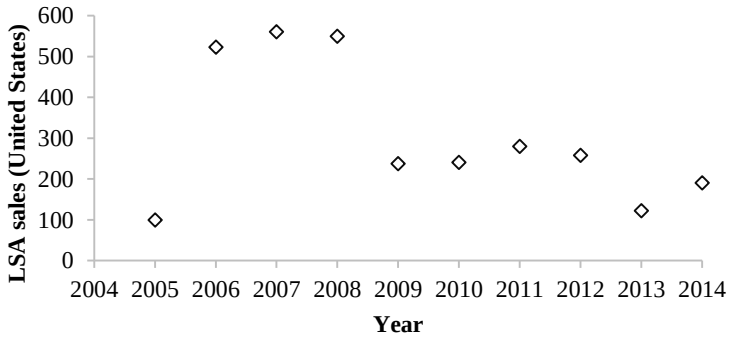


Figure 8. Light Sport Aircraft yearly sales in the United States of America.

South Africa:

Aviation in South Africa is regulated and overseen by the South African Civil Aviation Authority (SACAA), which is a part of the Department of Transport. The SACAA is responsible for certifying aircraft that apply for registration (type certification process) as well as for ensuring that Aircraft Maintenance Organisations (AMOs); Manufacturing, Processing and Testing Organisations (MPTs); Design Organisations; and Aviation Training Organisations (ATOs) are effectively inspected, approved and overseen, and that they perform their work within the framework of their approvals. The size of the industry overseen by this division can be summarized as follows: 10,730 aircraft (TCA and NTCA);

420 AMOs; 90 MPTs; 15 ATOs providing training to Aircraft Maintenance Engineers (AME); and at least 3,500 AMEs.

For the purposes of design and manufacturing of aircraft in South Africa, aircraft are put in two major categories, those which have been designed and manufactured under the standards that meet or exceed those of the International Civil Aviation Organisation (ICAO), otherwise known as Type Certified Aircraft (TCA) and those which are not compliant with ICAO standards, known as Non-Type Certified Aircraft (NTCA). A NTCA is an aircraft that does not qualify for the issue of a certificate of airworthiness in terms of Part 21 of the Civil Aviation Regulations (CARS) of 1997. It includes any TCA no longer qualifying. With the growth of the NTCA sector, regulatory provisions have been developed in an attempt to properly control and regulate this class of aircraft. NTCA standards are contained in the CARs:

- Part 24: certification and airworthiness of NTCA;
- Part 43: general maintenance rules;
- Part 94: recreation operation of the NTCA;
- Part 96: commercial use of NTCA.

Non-type certificated aircraft can be divided into five categories:

(a) Amateur or home- built aircraft: Specifically built in terms of the provisions of CAR Part 24. The owner performs most of the construction work themselves as a once-off project for the purpose of flying the aircraft themselves. Aircraft are classified as kit or plan-built.

(b) Production-built aircraft: The build standard and prototype (approved and constructed in terms of CAR Part 24) are available either fully-assembled or in kit form (< 51% of the airframe has been constructed and assembled) exclusively for non-commercial purposes. These aircraft must be constructed/assembled at SACAA approved manufacturing facilities in South Africa.

(c) Veteran aircraft: These aircraft are traditional aircraft that have lost their type certificate.

(d) Ex-military aircraft: All aircraft previously operated by military air forces.

(e) Any other aircraft not qualifying for the issue of a Certificate of Airworthiness (CAR Part 21).

NTCA aircraft are further divided into the following sub-groups – (a) aeroplanes, including microlight aeroplanes; (b) helicopters; (c) gyroplanes/ gyrogliders; (d) gliders; (e) manned captive and manned free balloons; (f) airships; (g) unmanned aerial vehicles; (h) hang-gliders including powered hang-gliders; (i) paragliders (powered paragliders and paratrikes); (j) parachutes; (k) model aircraft; and (l) rockets.

Along with the trends being experienced in the United States and European general aviation markets, South Africa has experienced a rapid growth in the NTCA market. At the end of 2008, there were 10,730 aircraft on the South African Civil Aircraft Register, of which 49% represented the sport and recreational NTCA aircraft. The South African civil aviation register is presented in Table 6.

Table 6. South African civil aviation register 1999-2008

	2000	2001	2002	2003	2004	2005	2006	2007	2008
TOTAL TCA	**4 190**	**4 247**	**4 311**	**4 496**	**4 695**	**4 901**	**4 985**	**5 132**	**5 497**
Aeroplane	3 679	3 718	3 769	3 898	4029	4149	4 204	4,271	4,474
Helicopter	511	529	542	598	666	752	781	861	1,023
TOTAL NTCA	**3 294**	**3 470**	**3 616**	**3 907**	**4 127**	**4 413**	**4 536**	**4 825**	**5 233**
NTCA - Amateur built	507	558	587	688	821	961	1 021	1 105	1 236
NTCA – Production Built	0	0	0	0	0	0	4	512	708
Sub-total: Amateur & Production Built Aircraft	***507***	***558***	***587***	***688***	***821***	***961***	***1 021***	***1 617***	***1944***
Amateur Built Microlight	1 926	2 014	2 118	2 226	2 232	2 326	2 356	2 023	2 065
Glider (incl. Motorised)	377	393	401	429	456	475	477	495	514
Amateur Built Gyrocopter/Helicopter	129	139	144	167	206	219	229	236	257
Limited/Research Aircraft	130	129	128	148	154	171	175	175	167
Veteran Aircraft	118	120	120	124	125	128	128	131	130
Other	160	171	173	184	193	210	224	246	284
TOTAL TCA and NTCA	***7 484***	***7 717***	***7 927***	***8 403***	***8 822***	***9 314***	***9 521***	***9 957***	***10 730***

Figure 11 outlines the growth in the NTCA class over the period 2000 - 2008. The market has increased by 59% over this period. Prior to 2006, it was not possible to determine how many of the NTCA aircraft were production built as these were included under the broader category of amateur built aircraft.

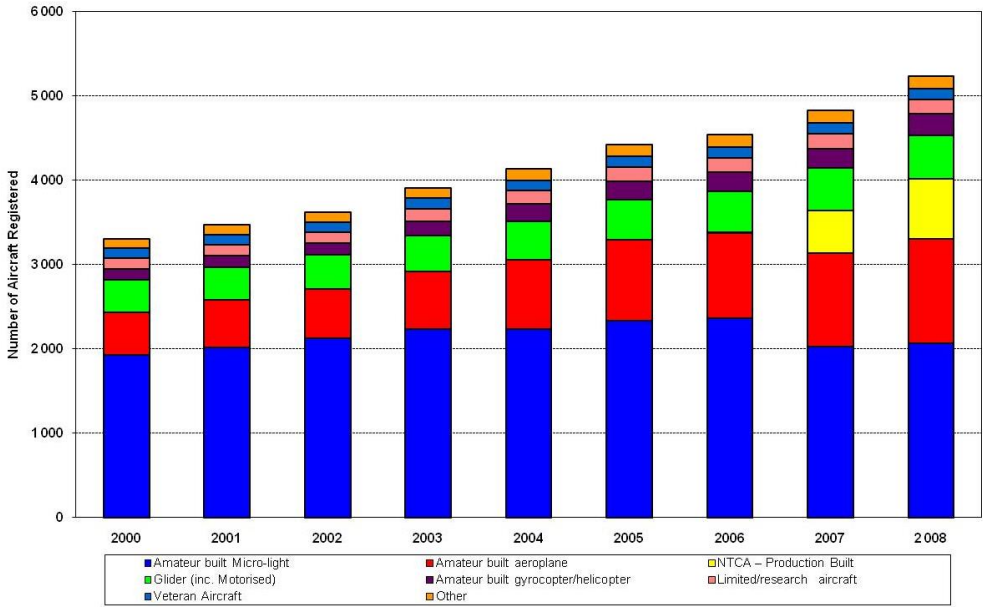


Figure 9. Non-type certificated aircraft 2000-2008

The amateur/production built category has increased from 15% to 37% of the total NTCA market between 1997 and 2008, with an average annual growth over this period of 17%. Amateur built microlights remain marginally the largest segment of the market at 39% of the NTCA register. In ghe year 2000 microlights represented 58% of the class of aircraft, but have had only a 2% average annual growth over this period.

Table 7 indicates that there has been a growth in recreational flying as the issuing of private pilot licences increased in line with the aircraft growth in this area of aviation. It is also notable that the number of student pilot licences has increased. In 2005 and 2006, the number of student learner pilots exceeded the number of microlight learners.

Table 7. Active pilots in South Africa

Category	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Others	3 891	3 474	4 187	4 575	4 901	5 500	5 434
Student	1 266	1 412	1 555	935	1 293	1 771	1 848
Microlight	918	1 526	1 222	1 300	1 629	1 580	1 561
Private	4 335	4 034	4 184	4 521	4 925	5 020	5 139
TOTAL	**10 410**	**10 446**	**11 148**	**11 331**	**12 748**	**13 871**	**13 982**

Canada:

Regulation of ultralight aircraft in Canada is covered by the Canadian Aviation Regulations. The definition of an "ultralight aircraft" includes advanced ultralight or basic ultralight aircraft, both of which have only two seats. A "basic ultralight aircraft" is designed and manufactured to have a MTOW not exceeding 544 kg, whereas the “advanced ultralight aircraft” is designed to have a maximum take - off weight 480 kg. Table 8 contains the Canadian aircraft register.

Table 8. Canadian aircraft register

	Normal	**Amateur Built**	**Basic Ultralight**	**Advanced Ultralight**	**Other**	**TOTAL**
Total	21,060	3,314	4,674 (14.9%)	968	12,405	**31,421**
Airplanes	17,978	2,934	4,674	968	1,231	**27,785**

United Kingdom:

- Very Light Aeroplanes (VLA) have a single engine with not more than two seats and a MTOW of not more than 750 kg.
- The definition of a microlight is an aircraft having no more than two seats and a MTOW of no more than:
  - 300 kg for a single-seater landplane (or 450 kg for a two-seater landplane); or
  - 330 kg for a single seater amphibian/floatplane, (or 495 kg for a two-seater).

Table 9 contains the aircraft register for the United Kingdom.

Table 9. United Kingdom aircraft register

Category	**2006**	**2007**	**2008**
Fixed wing MTOW <= 750 kg	3,077 (16.7%)	3,153 (15.8%)	3,186 (14.9%)
Microlights	4,254	4,392	4,447
Total	**18,445**	**19,890**	**21,331**

Australia:

In Australia a recreational aircraft must have a maximum all-up weight (MAUW) of 544kg or less and a maximum of two seats. In 2007, Australia had a market of 580 registered aircraft with a MTOW between 450kg and 544kg [16].

New Zealand:

In New Zealand microlight aircraft are separated into two classes, single and two seat aircraft.

Class 1: Single seat aircraft with a design maximum gross weight of 544 kg (landplanes) or 579kg (seaplanes/amphibians). Requires aircraft registration and annual condition inspections, but does not require a permit to fly.

Class 2: Two seat aircraft with a design maximum gross weight of 544 kg (landplanes) or 614kg (seaplanes or amphibians). Must meet minimum type acceptance standards or *via* a temporary permit to fly and flight testing regime. Requires aircraft registration, annual condition inspections, and a current permit to fly. New Zealand has 637 microlight class II on its aviation register.

Customer Analysis

Ultralight aircraft/Light Sport Aircraft are used extensively for flight training, recreation and various light commercial purposes. Customers therefore include:

- Flight Schools
- Private individuals
- Businesses
- Government/NGOs

Europe is currently the market leader with the Czech Republic playing a major role [3] and produced 588 ultralight aircraft (worth €40 million) in 2006, 170 more than in the previous year. TL Ultralight, a German manufacturing company, estimates that currently roughly 80% of the worldwide production of ultralight aircraft is located in the Czech Republic. Nearly 200 of the 560 ultralight aircraft registered in the United States in 2006 were produced in the Czech Republic. There are very few United States manufacturers of such ultralight aircraft.

The South African market share based on the 2009 register is shown in Figure 10.

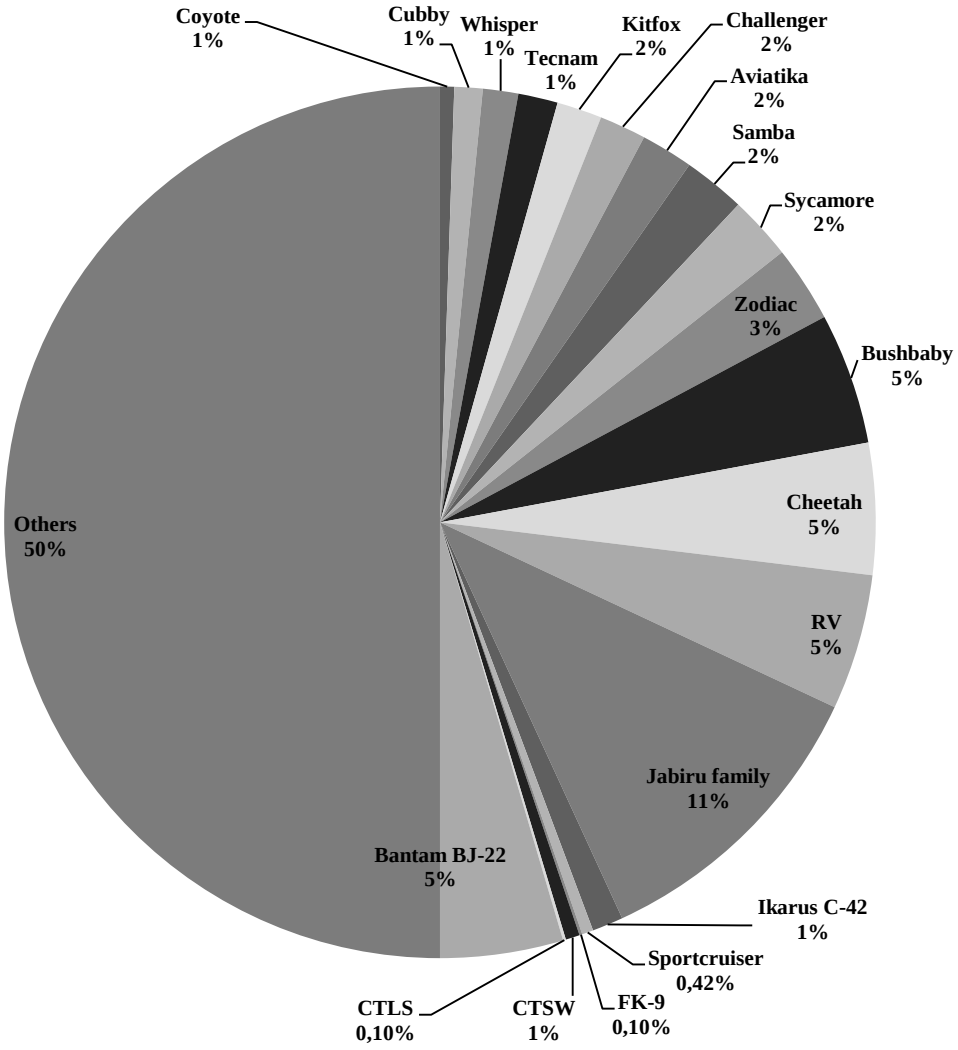


Figure 10. South African market share in the LSA category

A description of the most popular models on the market in South Africa is provided below.

- **Jabiru Aircraft Southern Africa**

  Jabiru Aircraft, a fully SACAA licensed MO and AMO, is the approved agent for the Australian designed Jabiru series of aircraft and engines. Jabiru has the highest number of NTCA registered in South Africa. Aircraft are sold either in kit form or fully built. Currently most financial institutions do not however finance the purchase of kits. The company offers customers the possibility of customising the aircraft including; the addition of photographic windows, extra fuel tanks and glass-fibre doors. Jabiru was one of the first design companies to obtain full private pilot's license (PPL) training status for the aircraft and claims that sales are increasing as PPL flight schools realise that the aircraft are affordable to operate.

- **Cessna - SkyCatcher**
  Cessna released their conceptual LSA in July 2006. The prototype production aircraft first flew in 2008. The aircraft achieved orders of 1200 aircraft [17]. Following a series of accidents during testing, manufacturing problems in China and increasing sales price the SkyCatcher production ended in December 2013 with production of only 275 airframes [17]. The aircraft was offered as an ideal aircraft for use at flight training schools.
- **FK Lightplanes: FK-9**
  FK-Lightplanes, a German company, markets the FK 9 MK IV. The aircraft was one of the fastest selling aircraft internationally, but has yet to achieve much market share in South Africa. The wings have a folding option, requiring no tools, for trailering and storage. The seats are adjustable, a feature not many LSA aircraft offer.
- **Microwings: (Cubby)**
  The Cubby is available in kit form, ready to fly or fully built but without engine, radio and instruments. The Cubby can be registered as a 3-axis microlight or an ultralight. The purchase price is comparatively low and operational costs are kept to a minimum due to the use of automotive fuel (MOGAS) as opposed to AVGAS. The Cubby is available in tri-gear or tail dragger. Price is dependent on the choice of engine.
- **Kitplanes for Africa: (Bush baby)**
  The Bush baby is a homebuilt kit aircraft which may be registered as a microlight or an ultralight. It has a low performance but is a safe entry level aircraft. The majority of Bush baby aircraft were built as a tail dragger to allow operation out of rough airfields. This configuration however makes the aircraft more challenging to fly in comparison to the tricycle aircraft, which is better suited for prepared runways.
- **Skystar Aircraft Company: (Kitfox Kits)**
  The Kitfox is a lightweight, two-seater sport aircraft with excellent STOL performance and the ability to operate from short and unimproved airfields. Various models include a larger aircraft designed to fit the needs of a growing segment of the marketplace that wanted a weekend cruiser, with pilots wanting a recreational aircraft with a greater useful load, certified engine, increased cabin space, and larger cargo capacity.
- **Wing ‘n tracks (Samba and Lambada)**
  The Samba is a competitively priced aircraft including a variable pitch propeller, two-metre wingtip extension, glider tow hook and a well-equipped panel and avionics suite. It can use unleaded MOGAS fuel, AVGAS or a mixture of both. The Lambada differs from the Samba, by using a shoulder-mounted wing and a T-tail empennage.
- **Rainbow Aircraft: (Cheetah)**
  The Cheetah has been approved by the SACAA for full PPL and hour building towards the CPL. The Cheetah is available in tail dragger form or with tricycle gear. The Cheetah XL features a bigger cabin with extra headroom. The company has also started selling the Cheetah as a kit.
- **Van’s Aircraft: (RV kit planes)**
  RV Aircraft are low-wing monoplanes. RVs are designed and built so they can be dismantled when necessary. All of the tail surfaces are removable. Wings are constructed independently and bolt to the fuselage, the landing gear attaches to the fuselage with a few bolts. The RV-12 is the only model compliant with the LSA regulations.

- **National Airways Corporation (NAC): Tecnam range**
  The Tecnam, P92, P2004 and P2008 are Italian manufactured LSA. The P92 was the first model released and featured simple design features such as a steel space-frame fuselage clad with Aluminium, conventional Aluminium strutted wing and an all-moving horizontal tail. The P2004 featured a wider cabin and cantilevered high-wing. The P2008 was derived from the P2004 and features a strutted Aluminium wing with a carbon fibre fuselage [18].
- **Microaviation: Bantam Microlight**
  The Bantam is classified as a microlight and is used in crop spraying and other commercial activities. The Bantam can be registered as an ultralight aircraft and can be used to build up PPL hours. Due to its quiet operation and short take-off and landing (STOL) capabilities the Bantam is used extensively in farming and nature conservation as well as by the Police Service for crime fighting and visible policing. The aircraft claims to have an incredible capability in windy conditions, outperforming other STOL aircraft that cost more than twice as much.
- **The Airplane Factory: Sling 2**
  The Sling is classified as a production-built Light Sport Aircraft. Development commenced in 2006. The aircraft is a side-by-side low-wing semi-monocoque design. Manufacturing methods include numeric controlled punching on the Aluminium components. The aircraft was flown around the World in 2009. In excess of 60 aircraft kits have been sold [19].

3.4. Target market size

South African flying schools were investigated to ascertain the size of the aircraft fleet used for flight training, the aircraft used for flight training and average age of the fleet. Growing fuel costs have increased the cost of flying, meaning that many flight schools have had to reduce operating costs. This could be done by purchasing aircraft with lower fuel consumption. Aircraft such as the Cessna 172 and Piper PA-28 are very popular training aircraft. The aircraft can be used as training aircraft or as hire and fly aircraft. They are certified and night rated. A total of 54 flying schools were surveyed. Data is presented in Table 10 and 11.

Table 10. Fleet of South African flying schools [20]

Manufacturer	Cessna			Piper		Jabiru		Comco Ikarus	Czech Aircraft works	Evektor	Urban Air
Aircraft type	150	172	182	PA-28	PA-38	430	160	C42	Sport cruiser	Sports star	Samba XL
Number in service	61	78	18	102	6	3	4	9	3	1	2

Table 11. Flying school analysis

Number of flight schools analysed	54
Total flight school fleet	290
Percentage of total light aircraft used by flight schools	21.21
Average age of aircraft (years)	21.22
Number of ultralight aircraft used for flight school training	22

According to Part 96 of the South African Civil Aviation Regulations, only production-built non-type certificated aircraft may be used for commercial operations such as flight training.

3.5. Atmospheric environment

Four airspeed definitions apply for aircraft:

1. Indicated airspeed as indicated by measurement from pitot static instrument.
2. Calibrated airspeed contains a correction for the location of the pitot static instrument installation. This accounts for changes in angle of attack, particularly in light aircraft.
3. Equivalent airspeed is a correction to the calibrated airspeed to account for compressibility.
4. True airspeed is a corrected equivalent airspeed to account for air density.

The South African climate poses different challenges compared to the European climate. Flying takes place year-round in South Africa, whereas in Europe it is limited to the summer months with occasional flying during good weather days in winter. The majority of South African aircraft are located at flying fields inland from the coast meaning that the flying happens at elevated altitude. During summer, when the temperatures are warm, the conditions are classified as hot and high. Hot refers directly to the temperature, high refers to the density altitude.

South Africa has very high levels of Ultra-Violet (UV) light. UV-B (315-400nm) penetrates the atmosphere to reach ground level and is capable of damaging skin [21]. UV-B indices are shown in Figure 11. CP represents Cape Point, CTI represents Cape Town, DA represents De Aar, PE represents Port Elizabeth, DBN represents Durban and PTA represents Pretoria.

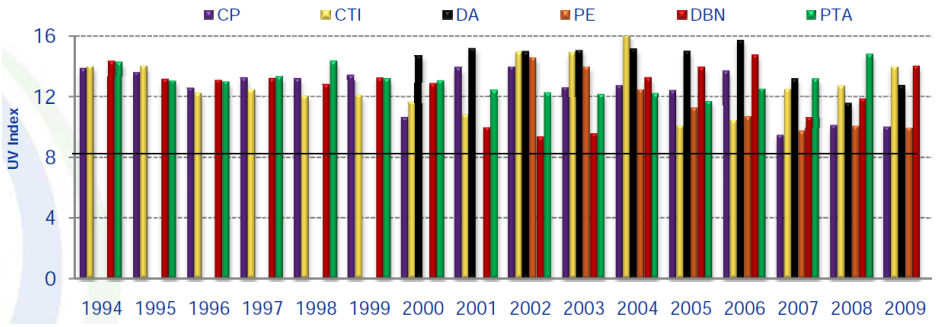


Figure 11. UV-B indices for South Africa 1994-2009 [22].

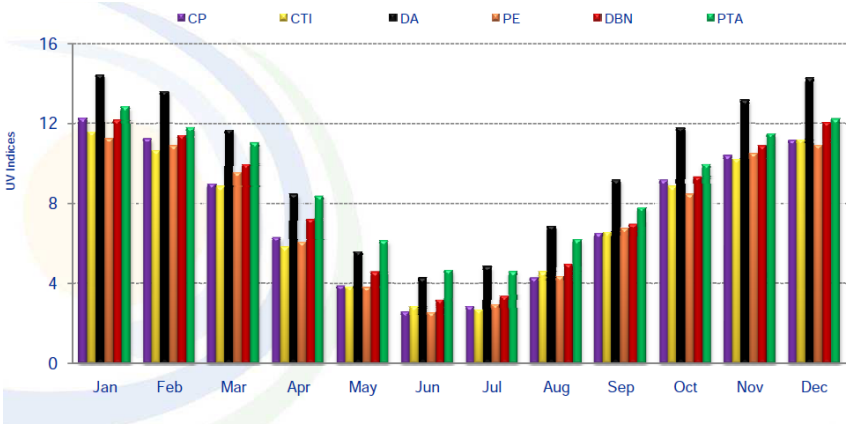


Figure 12. Monthly UV-B indices for South Africa 1994-2009 [22].

UV-B indices above 8 are considered very high. For a sunny climate at a South African latitude the index reaches 8 at approximately 11am and declines below 8 at approximately 3pm. A UV-B index of 11 or higher is categorised as extreme [23]. The exposure of light aircraft occupants to UV-B would be of concern. Flight instructors in South Africa would be exposed to good-weather flying conditions more frequently than European instructors. This would mean that consideration towards UV-B exposure would be justified for the design of the aircraft and for the safety and comfort of the occupants.

Aircraft components such as seals, composites materials, plastic components, coatings and adhesives deteriorate when exposed to UV. For a long service life in a country such as South Africa UV-stabilised components would have to be used if available.

3.6. Available propulsion units

Since the inception of the Light Sport Aircraft category in 2003, the Rotax 80-100hp 912 series has been the engine of choice in the majority of aircraft that entered serial production. The engine has been fitted to 320 aircraft types [24] with more than 40000 Rotax 912 series engines produced [25]. The 912 has air-cooled cylinder barrels and water-cooled cylinder heads. It is a geared, four cylinder horizontally-opposed, normally aspirated, spark ignition engine with altitude-compensating carburettors that produces a maximum of 100 brake horsepower at 5800 RPM. It may be fitted with a fixed pitch or ground-adjustable propeller.

The four-cylinder four-stroke engines suffer from a phenomenon unique to aircraft engines. Once an engine model is certified for a rated power output, the engine power may not increase or else the certification process must be repeated. What this means is that as the engine design matures, it may become more fuel efficient and more reliable, but may not become lighter or more powerful. Table 12 lists the history of the Rotax 912 80/100hp engine.

Table 12. Rotax 912 series history [25].

Year	Event
1984	912 series engine developed
1989	Type certificate for 912A awarded
1994	Type certificate for 912F awarded
1998	Type certificate for 100hp 912S awarded
2003	Design Organisation authority approved by EASA
2005	912 series compliant with ASTM consensus standards
2005	Production Organisation authority approved by EASA
2009	912 series time between overhaul increased from 1500 hours to 2000hours
2010	Production of 912/914 series achieved 40000 units
2012	912iS with fuel injection type certificate awarded

The Rotax 912 ULS and iS models are shown in Figure 13. The major difference between the engines is the fuel injection system and intake manifold.

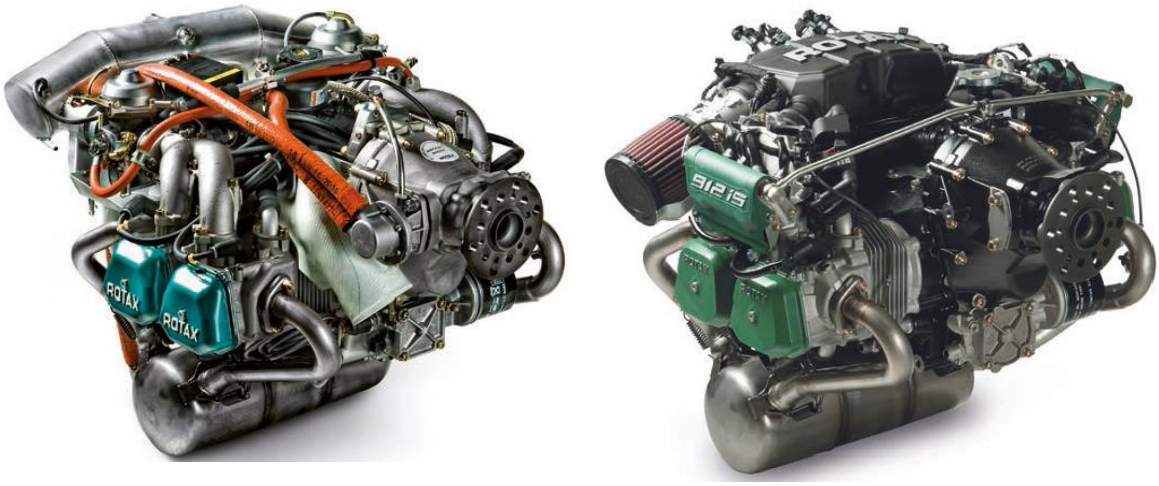


Figure 13. Rotax 912 ULS (left) and 912 iS (right) [25].

Two engines families were considered for the aircraft. The Jabiru J2200/J3300 and the Rotax 912. The Jabiru engine is an air-cooled engine based on Porsche engine technology, but suffers from thermal shock during descent when the engine is at idle. This leads to engine block fracture at the cylinder base. This is a very well-documented issue amongst operators and pilots are advised to make a power descent instead of a glide descent to keep engine temperature changes minimal. South African hot and high weather conditions exacerbate the probability of thermal shock. The Jabiru engines are direct drive, which means the power and torque produced can only drive propellers with small diameter and small activity factor. Jabiru has produced 3600 J2200 engines and 1700 J3300 engines [26].

The Australian Civil Aviation Safety Authority (CASA) released a draft instrument in November 2014 citing regulation 11.068 and 11.245. The instrument is in response to numerous engine failures and limits certain aircraft powered by Jabiru engines from [27]:

1. Carrying any passengers;
2. Flying over populous areas unless a suitable emergency landing area is within gliding distance; and
3. The aircraft may not be operated below 1000ft, except for climbing out from an airfield after take-off or approaching to land at an airfield.

This instrument has made Jabiru-powered aircraft unfit for flight training.

The Lycoming IO-233 was not considered due to the dry mass being significantly more than the Rotax or Jabiru engines. The quoted fuel consumption is presented in Figure 14.

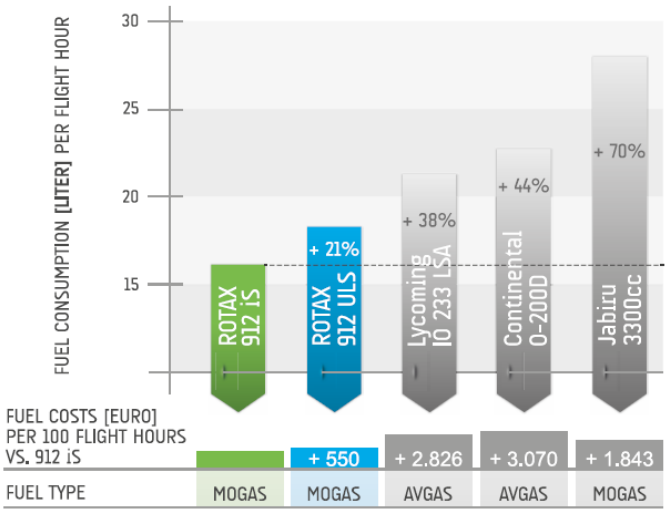


Figure 14. Rotax 912iS fuel consumption [25].

In terms of engine acquisition cost presented in Table 13, the Rotax 912 S and Jabiru J3300 are significantly cheaper than the fuel injected Rotax 912 iS and Lycoming engines.

Table 13. Comparison of engine acquisition cost in 2014.

Engine	Price in Rands (exchange rate of R11/1$)
Lycoming IO-233	R273 900 [28]
Continental O-200	R273 900 [28]
Rotax 912 iS	R277 750 [29]
Rotax 912 S	R213 800 [29]
Jabiru J3300	R204 600 [30]

The only viable engine for the aircraft is the Rotax 912 family if flight training is to be one of the target markets.

3.7. Cessna C-162 Skycatcher

The Cessna 152 (C-152) was a two seat light aircraft produced between 1977 and 1985 with 7584 airframes being produced [31]. The manufacturer stopped production in 1985 due to the liability claims against aircraft manufacturers. Production was not restarted. The aircraft was a popular choice for flight schools. After the introduction of the Light Sport Aircraft category, Cessna designed the model 162 (C-162) in accordance with the ASTM F2245 standard, the aircraft was named the Skycatcher.

The engine chosen for the C-162 was initially the Rotax 912 series. The aircraft received large orders shortly after its launch. Cessna then specified that the direct drive Continental O-200 engine be used instead. The engine produces the same 100hp that the Rotax 912 produces, but the engine is heavier than the Rotax and the fuel flow has been calculated as being higher for certain power settings [32, 33]. The reliability of an engine is normally specified as time between overhaul and in mean time between failures. The Continental engine has higher time specified between overhauls.

The ASTM standards specify the flight envelope in a fairly restrictive manner. Table 14 summarises the C-162 specifications compared to a Cessna 152.

Table 14. Comparison between C-162 and C-152.

Parameter	C-152	C-162
Airworthiness standard	FAR 23	ASTM F2245
Empty weight	444kg	379kg
Maximum take-off weight	726kg	600kg
Payload (occupants and fuel)	282kg	221kg
Engine	Continental O-200	Continental O-200
Wing span	9.97m	9.26m
Length	7.24m	6.73m
Wing area	15m^2	11.14m^2
Cruise speed	107kts	112kts
Maximum rate of climb	715ft/min	890ft/min
Wing loading (OEW-MTOW)	36-48kg/m^2	43-54kg/m^2

The two aircraft types have the same powerplant but are designed to different standards. The C-162 has a higher wing loading range and much lower payload. Stall speed and maximum speed are governed by the ASTM standard, which limits the thrust and wing loading to a prescribed target range. The C-162 has better cruise performance as it is lighter and smaller than the C-152, for the same installed power. To achieve the highest performance possible, its wing area has been reduced when compared to the C-152.

Figure 15 illustrates the design changes made between the C-152 and the C-162.

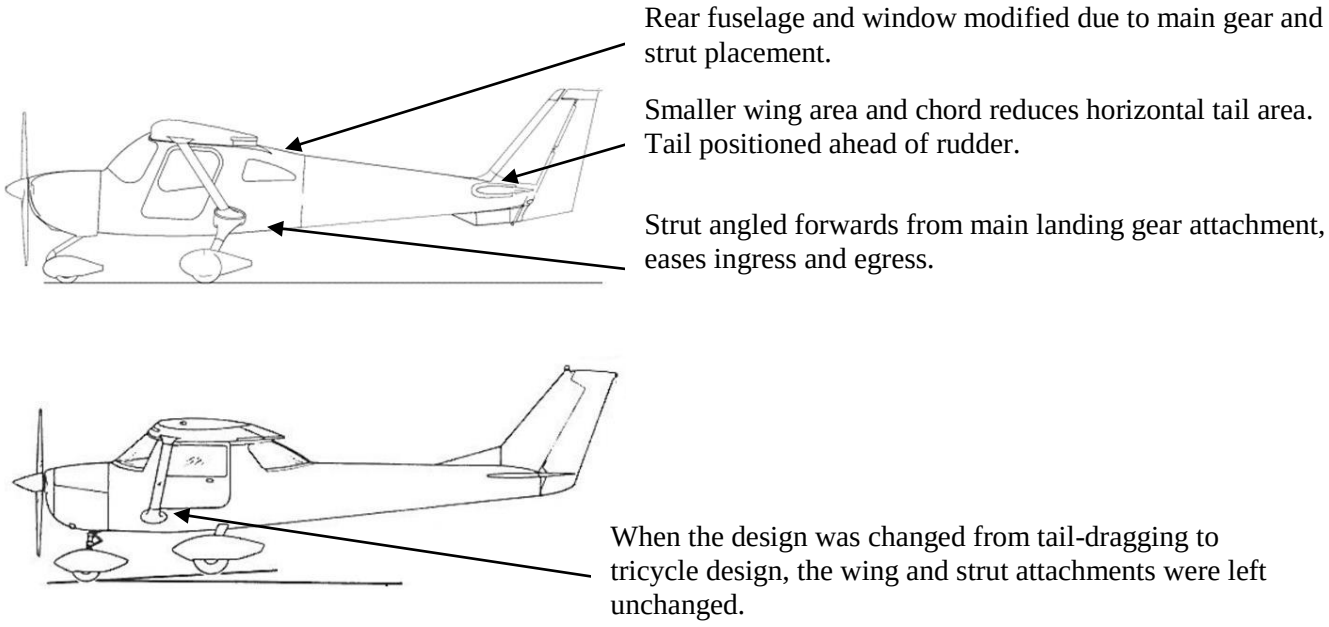


Figure 15. Side view comparison of C-162 (top) [34] and C-152 (bottom) [35]

Cessna has made four major design changes to the vertical stabiliser of the C-162 during its development. Figure 16 depicts the original Rotax-powered prototype.



Figure 16. Original Cessna 162 with Rotax 912 engine [36]

The prototype aircraft crashed during spin testing, failing to recover before impacting the ground. The aircraft was conducting spin testing for four configurations, during the final test for the second configuration the aircraft entered an uncontrolled flat spin. The pilot parachuted from the aircraft at a safe height [37].

The C-162 has a smaller wing chord, wing area and mass than a C-152. The horizontal and vertical tail volume coefficients used for the determination of the longitudinal stability and control characteristics are generally constant for aircraft with similar geometry and flight envelopes. The C-152 had a horizontal tail volume coefficient of 0.43 compared to 0.53 for the C-162. The primary reason for the increased coefficient for the C-162 is the higher wing loading. The directional stability and control was insufficient at low speed.

The first attempt at fixing the stability issue was to add a large dorsal fillet, pictured in Figure 17.



Figure 17. Cessna 162 with increased vertical stabiliser area [author].

Cessna later re-designed the vertical tail and increased the surface area, as seen in Figure 19.



Figure 18. Cessna 162 with re-designed vertical tail [36]

Cessna then added a ventral strake along the keel of the aircraft, pictured in Figure 19.



Figure 19. Cessna 162 with ventral strake [38]

The final tail configuration is depicted in Figure 20. This configuration included a larger vertical stabiliser with ventral strake and a rudder that extends below the fuselage. Cessna also increased wing thickness [39].



Figure 20. Final Cessna 162 tail design [40]

The stability issues regarding directional control were corrected by re-design of the vertical stabiliser, rudder and ventral strake. The parameters are listed in Table 15.

Table 15. Empennage comparison between C-152 and C-162.

Parameter	C-152	C-162
Aspect ratio	6.6	7.7
Mean aerodynamic chord	1.66m	1.27m
Horizontal tail area	2.56m^2	2.03m^2
Horizontal tail moment arm	4.2m	3.7m
Horizontal tail volume coefficient	0.43	0.53
Vertical tail area	1.4m^2	0.81m^2
Vertical tail moment arm	4.1m	3.94m
Vertical tail volume coefficient	0.039	0.031
Re-designed vertical tail area		1.25m^2
Vertical tail volume coefficient		0.048

The following factors clarify why the C-162 experienced stability and control issues:

1. The C-162 has a higher aspect ratio than a C-152. For a similar tail moment arm a more effective vertical tail is required. This can be achieved by changing the stabiliser and rudder design or by lengthening the tail moment arm.
2. The rear fuselage shape differs between the C-152 and the C-162. The centre of lift of the vertical tail on the original C-162 was 0.29m above the thrust line, the C-152 centre of lift was 0.61m above the thrust line. This reduction would lead to reduced coupling between yaw and roll on the C-162. The re-designed tail for the C-162 featured a distance between thrust line and centre of lift of 0.26m due to the addition of the ventral strake.
3. The C-162 was designed with a similar cruise speed to the C-152, powered by the same engine, but was designed to a different flight envelope standard. To best meet the flight envelope the aircraft baseline design had a higher wing loading.
4. The vertical tail volume coefficient of the C-152 was calculated as 0.039, the vertical tail volume coefficient calculated of the C-162 as 0.031. The enlarged vertical tail, with ventral strake had an increased volume coefficient of 0.048.

Cessna partnered with the Shenyang Aircraft Corporation in the People's Republic of China to produce the aircraft. Cessna cited production capacity issues and production cost savings for the partnership. Brand loyalty to locally produced United States aircraft led to a cancellation of orders. Cessna have sold a large number of these aircraft, but the commercial success of the programme was doubted publically by Cessna CEO Scott Ernest in 2013. He reflected that the C-162 had no future, citing the ASTM flight envelope requirements and the inferred design constraints and the impact they have had on a good aircraft design.

3.8. Tecnam P92 Echo

The Tecnam company was established in 1986 by the Pascale brothers after they left the Partenavia company (since renamed VulcanAir). The P92 was originally designed as an ultralight according to the European definition. The aircraft was designed for lightness, ease of accessibility and structural simplicity [41]. The fuselage is manufactured with a semi-monocoque tail cone that is affixed to an Aluminium-clad steel alloy spaceframe fuselage cabin. The wing is of conventional Aluminium alloy construction [42].

The aircraft first flew in March 1993 and featured two seats and a gross mass of 450kg. It was powered by a 80hp Rotax engine. In 1999 the P92 S was introduced with a re-designed wing, 100hp Rotax engine and increased gross mass of 550kg. The P92 may be purchased in versions that meet ultralight/microlight regulations, or in an ASTM compliant LSA version. Sales exceeded 1000 units in 2005 [43].

The P92 was further developed into the P2004 Bravo, the first Tecnam aircraft designed with a gross mass of 600kg. The P2004 featured a cantilevered wing without a strut, but maintained systems similarity with the P92. The P2004 has been discontinued. The P2008 first flew in 2008 and incorporates an Aluminium-alloy wing and empennage with a carbon-fibre fuselage [44].

The sales of Tecnam aircraft have been good with 86 LSA units sold from Q1 to Q3 in 2014 [8].

The design evolution from the ultralight P92 Echo light to the P2008 is shown in Figure 21 [18].



P92 Echo light (500kg) ultralight with simple cowling, straight-leg landing gear and trapezoidal rear window.



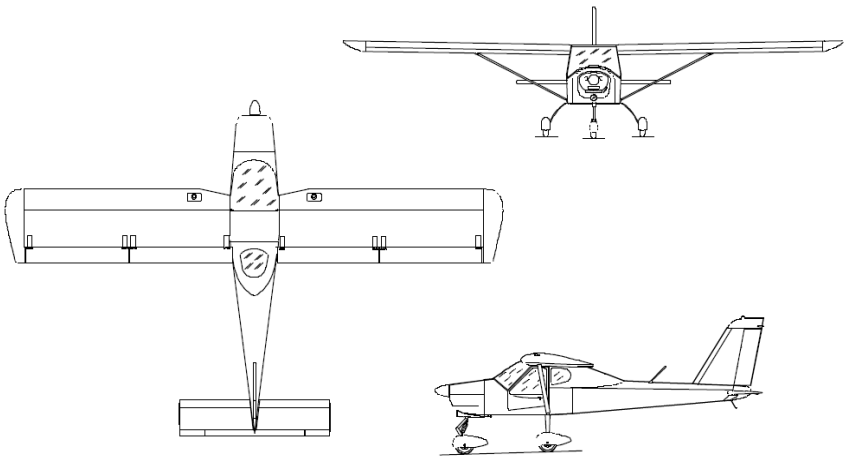
P92 Echo classic (600kg) LSA with a more aesthetic cowling, shrouded nose gear, curved main landing gear leg, vertical tail fillet and triangular rear window.



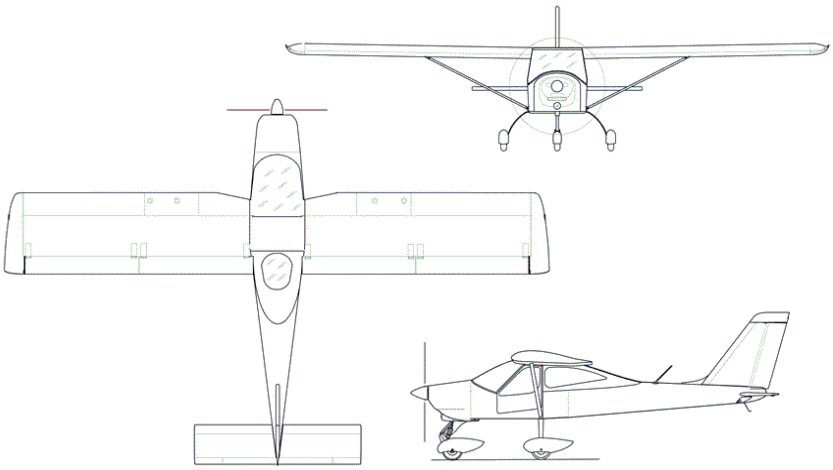
P2008 (600kg) LSA with refined fuselage, refined vertical tail and revised cokpit windows.

Figure 21. Tecnam aircraft range.

The P92 and P2008 have the same basic design features, even though the fuselages are constructed using different materials. The P92 is a lower cost all-metal aircraft suited to flight training. The P2008 is a higher cost aircraft suited to the recreational flyer. The major difference for the occupants is that the P2008 has a cabin width at shoulder height of 1.19m compared to 1.07m for the P92. The three-view images of the evolution of the aircraft may be seen in Figure 19.



P92 Echo light [42]



P92 Echo classic with contoured cowling, refined rear cockpit, winglets and vertical tail [18].



P2008 with wider cabin, refined cowling and re-designed fuselage. Wing is tapered, horizontal tail has faired tips [45]

Figure 22. Tecnam P92 and P2008 general views.

The critical geometry and performance for the P92 Echo classic, P2004 Bravo and P2008 has been summarised in Table 16 [44].

Table 16. Specification for the Tecnam P92, P2004 and P2008.

Parameter	P92 Echo classic	P2004 Bravo	P2008
Airworthiness standard	ASTM F2245	ASTM F2245	ASTM F2245
Empty weight	325kg	331kg	354kg
Maximum take-off weight	600kg	600kg	600kg
Payload (occupants and fuel)	275kg	269kg	246kg
Engine	Rotax 912 ULS	Rotax 912 ULS	Rotax 912 ULS
Wing span	9.4m	8.4m	8.8m
Length	6.5m	6.61m	6.93m
Wing area	13.4m^2	11m^2	11.5m^2
Cruise speed	110kts	116kts	112kts
Maximum rate of climb	1200ft/min	1200ft/min	1100ft/min
Wing loading (OEW-MTOW)	24-45kg/m^2	30-55kg/m^2	31-52kg/m^2

The P2004 was developed from an ultralight whereas the P2008 was a clean-sheet LSA design. From a performance perspective the P2008 has less payload, but offers the occupants more space and comfort.

The Cessna C-162 and Tecnam P2004 Bravo have been compared to each other. The aircraft specifications are stated in Table 17. The P2004 has a lower empty weight, higher payload and similar wing loading at gross weight. The P2004 is superior to the C-162 in useful load, maximum speed and features lower wing loading. The rate of climb of the C-162 is greater than that for the P2004, this should not be considered. Manufacturers do not often give the flying mass corresponding to the rate of climb. Mass has a large influence on rate of climb. Both aircraft have the same installed power yielding similar thrust. The C-162 would have lower lift-induced drag due to the greater wing aspect ratio.

Table 17. Comparison of the C-162 to the P2004.

Parameter	C-162	P2004 Bravo
Airworthiness standard	ASTM F2245	ASTM F2245
Empty weight	379kg	331kg
Maximum take-off weight	600kg	600kg
Payload (occupants and fuel)	221kg	269kg
Engine	Continental O-200	Rotax 912 ULS
Wing span	9.26m	8.4m
Length	6.73m	6.61m
Aspect ratio	7.7	6.4
Wing area	11.14m^2	11m^2
Cruise speed	112kts	116kts
Maximum rate of climb	890ft/min	1200ft/min
Wing loading (OEW-MTOW)	43-54kg/m^2	30-55kg/m^2

Tecnam has used their market sales and subsequent market share to venture into the type-certified aircraft category. The P92, P2008 and new P2010 are available in variants conforming to FAR.23 [18]. The P2010 competes with the Cessna 172 in the four-seat light aircraft category.

In conclusion, Tecnam has been able to design aircraft in the ultralight, LSA and light general aviation markets. The aircraft have the same characteristics and properties designed into the aircraft.

The Tecnam approach of designing a small ultralight with subsequent growth of the design has been successful. The sales reduction in LSA has allowed the company to sell ultralight and general aviation aircraft.

The characteristics and properties designed into the C-162 by the Cessna Company were not successful. Designing a LSA to meet every requirement of the ASTM consensus standard did not result in a good aircraft. Additional lessons gained from the Cessna C-162 is that it is unwise to change a powerplant once the design has been completed and to ensure that adequate control has been designed for. Conventional wisdom regarding vertical tail volume coefficients used for sizing LSA vertical tails needs to be reconsidered.

3.9. Summary of user requirements

The high-level user requirements developed for the aircraft from the design brief were grouped into four primary requirements:

1. Operation in terms of recreational and commercial operators was the primary requirement. Recreational operation requires less stringent maintenance, which may be conducted by the aircraft owner. The materials and manufacturing processes need to comply with production-built manufacturing standards for an aircraft to be rated as commercial operation compliant. An aircraft that could be operated in both types of operation would offer an advantage over many other aircraft.
2. Low production and operating costs was an important requirement. Designing an aircraft and manufacturing facility for low cost component manufacture, process and assembly would allow the aircraft to be competitively priced. The operating costs, both direct and indirect, would need to be minimised.
3. Environmental conditions affect aircraft performance, reliability and maintainability. The combination of high temperatures, dust content, humidity and UV can cause additional maintenance costs. The aircraft would need to have a competitive service life and maximise utilisation hours.
4. Competitive features or properties would need to be incorporated at a systems level. Good performance, stable flight characteristics, well-harmonised control and robust components that would enhance all high-level operation requirements, enhancing the operation of the aircraft by recreational or commercial operators. They would also reduce the production and operating costs. The features would also allow for the aircraft to be operated in any environment.

4. Design framework

4.1. Design technique

Creative design is enabled by constraining debilitating influences [46]. This is difficult to do when designing a group of interrelated systems, such as on an aircraft. Creative concepts can be developed by breaking a system down into components, or by starting with components and then developing a system [47, 48]. This infers that creative design can either start with a general concept ending with a specific concept, or that it may start with a specific concept and end with a general concept. The hypothesis that analysis is designing from the general to the specific may be thought of as deduction and analysis. This then implies that synthesis is designing from the specific to the general case and may be thought of as induction and synthesis [46]. When designing a system using the deduction and analysis method, uncertainty and disorder may be introduced. This is termed destructive deduction. The converse of destructive deduction is constructive induction. It follows that the human thought process of logical problem solving is often to break the problem into smaller elements and then to recompose them trying to find a solution. This cycle was termed destruction and creation [46]. Boyd used three theories to develop the cycle.

The first theory used to create this cycle dated from the 1931 work on the incompleteness and inconsistency of a system published by Godel [49]. He proved that any consistent system is incomplete and that consistency within a complete system can not be demonstrated. Using this result to analyse the consistency of a design system concept and the consistency of the performance of the concept in reality, when compared to performance prediction, is useful in the design of a system, but no perfect convergence can be achieved.

The second theory was the concept of consistency, proven by Heisenberg in 1927 [50]. The architect of destruction and creation infers that the uncertainty values represent the inability in determining the consistency of the system within the system. In itself this principle does not generally apply to the design of mechanical systems [46].

The third theory is the concept of entropy and the second law of thermodynamics as applied to the economic process. High entropy levels were compared to high levels of confusion and disorder. Entropy also increases within a closed system, hence the confusion and disorder would increase [51].

Combining the theories of Godel, Heisenberg and the second law of thermodynamics, it was proposed that the uncertainty and disorder generated by an inward-oriented system can be reduced by introducing or creating a new system. The three theories support the idea that any inward-oriented and continued effort to improve the match-up of a concept with reality would increase the mismatch [46]. This can be summarised as a design process where destructive deduction breaks a system into components where the uncertainty in the performance of the design would become reduced. The confidence in the design could be restored by recomposing the design into a system and comparing the performance to the prediction. This was termed a dialectic engine [46].

The process of destruction and creation may be used as a method for thought generation applied to a design process. Given a requirement or section of regulation, the creation of a compliant system to meet the requirement and satisfy the regulation may be as simple as creating a system using creative induction. The best system would be produced after the initial concept system has been broken down and re-formed with external-oriented effort using destruction and creation. This process would not apply

to simple mechanical components, but may be used to provide creative and novel systems that are compliant.

4.2. Aircraft design requirements

General design considerations were extracted from the Douglas Aircraft Company [52]. The considerations have been expanded:

1. The use of standard parts can dramatically reduce production costs. The majority of systems on a light aircraft should be sourced from suppliers.
2. Standard size parts should be used where possible. This implies that detailed consideration should be given to the fit, form and function of every component. Non-standard size material costs more per unit mass than standard size material.
3. Tolerances and limits must be factored into manufacture to reduce the assembly-related costs. The technical difference between a limit and a fit needs to be understood. Tolerance being the difference between the two limits.
4. The possibility of adjustment must be included in the design. Adjustments could be required because of the manufacturing process, modifications to the design or for alignment during the rigging of primary structure. Tolerances can be increased if adjustment is designed into the airframe.
5. Minimise the number of parts used for an assembly. The fewer components used results in easier assembly and for easier modification of the design to be made. This does not mean that single piece components need to be used, rather that components should be eliminated by using ingenuity.
6. The relative motion between components should be minimised. Motion introduces loading that may not have been fully designed for and can result in cracks or wear-related component life issues. Light aircraft may suffer from cracks if stiffener ends are not attached to ribs with a clip or suitable fastener.
7. The use of oversized bend radii for components must be included in the design for manufacture. This will allow for a thicker sheet to be used, if required, without affecting the structural design or manufacturing jigging.
8. Stock size sheet metal should be used. Joints should be designed where required.
9. Joggles should be used for all sheet metal joints. A joggle is a layered indent a single sheet thickness deep to allow for a smooth skin overlap. For sheet thinner than 0.8mm, the additional process cost does not usually offer any aerodynamic smoothness benefit.
10. Aluminium should not be used for mating components that need to rotate or translate. Aluminium fasteners should not be used where frequent removal is necessary.
11. Use should be made of both primary and secondary structure to improve the design. Failure of primary structure would endanger the safety or operation of the aircraft whereas failure of secondary structure would not endanger the safety or operation of the aircraft.
12. Control surface clearance should be designed into the airframe from the start. The clearance should factor in elastic deformation of the lifting surface and the control surface should be capable of free movement.
13. Drainage holes or passages should be included where necessary. Moisture condenses into water and accumulates at the lowest parts of airframe components.
14. Regarding the airframe, materials and structural design should be considered from a weight, strength and rigidity or stiffness perspective. In a light aircraft, where some components experience very small loads, the lightly loaded components may be designed for the correct load, but end up being flexible. Vibration of these flexible items could result in relative motion (point 6).

15. Fittings need to be considered at an early stage of the design when the primary and secondary structure is being designed. This can enhance the adaptability of the structure to accommodate modifications. Fittings should be manufactured with a low part count as a primary consideration. Prototype aircraft generally differ substantially from production aircraft regarding fittings. Prototype or experimental aircraft generally use machined fittings and production aircraft generally use forged fittings for high load applications. Fittings should be designed to accommodate an oversized fastener if required.
16. Eccentricity needs to be reduced to a minimum to reduce combined loads at fittings. Eccentric loads can be inadvertently introduced when using sheet stock manufactured into a component.
17. Stress concentrations need to be considered and included in the design of primary and secondary structure. Bend radii, fillet radii and tapering of fittings all reduce the stress concentrations.
18. Shear fittings need to be used for rivets and shear fasteners. Single and double shear fittings need to be designed with consideration given to eccentricity and stress concentrations.
19. Tension fittings should be used with care on light aircraft. Localised crushing of the structure underneath the fastener head may not be easily observed. This can cause the fastener to become loose. Correctly specified washers may be used to prevent this.

These design considerations were used in the design of the Douglas C-47/DC-3. The considerations may not, in their entirety, be applicable to a small aircraft. The incorporation of creative design techniques and the Douglas aircraft company design considerations form the basis of the design method applied here.

In the framework of the primary user requirements of; operation, cost, the environment and competitive features, the airworthiness standard governed by the South African Civil Aviation Regulations Part 24 was analysed.

Part 24.01.2 (2) states: “Only those aircraft, of which the type, the local or foreign manufacturing organisation, the local assembling organisation or agent, or the build standard has been approved by the Commissioner, may be built or imported and flown within the Republic.”

This was the primary driver behind the business case for the aircraft. Additionally;

Part 24.01.2 (5) states: “The design criteria and the build standard for an amateur- or production-built aircraft must –
(a) comply with the appropriate design criteria as prescribed in Document SA-CATS-NTCA;
(b) comply with any special conditions prescribed in terms of Regulation
24.02.4 by the Commissioner or, if applicable, the organisation designated for the purpose in terms of Part 149 of the CAR, 1997, as the case may be; and
(c) incorporate no feature or characteristic that makes the aircraft type unsafe for its intended use.”

This regulation is not prescriptive as the design criteria stipulated was originally developed for experimental aircraft. The ASTM F2245 would adequately satisfy the design criteria requirement. The F2245 consensus standards was summarised in §3.2.

The F2245 section 6 relating to design and construction is summarised in Table 18 [10].

Table 18. Summary of ASTM F2245 relating to design and construction.

Section	Summarised content
6.1 General	The integrity of any novel or unusual design feature having a bearing on safety shall be established by test.
6.2 Materials	Suitable and durable materials that have sufficient strength shall be used.
6.3 Fabrication methods	Manufactured parts, assemblies and completed aircraft shall be produced in accordance with the manufacturer's quality and production assurance and acceptance procedures.
6.4 Self-locking nuts	Not to be used on a fastener that is required to rotate.
6.5 Protection of structure	Structure must be protected against weathering, corrosion and wear. Must have adequate ventilation and drainage.
6.6 Accessibility	Items deemed critical shall be accessible for inspection, adjustment and maintenance.
6.7 Rigging	Rigging and de-rigging must be able to be performed by a person of average skill.
6.8 Proof of design	Fulfilment of the design requirements must be determined by conservative analysis, test, or a combination of both. Structural analysis alone may only be used for validation. Flight tests at specified mass and speeds are accepted proof.
6.9 Control system-operation test	All controls must be free from interference, jamming, excessive friction and excessive deflection with loads applied to the control surfaces.
6.10 Pilot compartment	Appropriate visibility, accessibility, the ability to reach all controls and conduct an emergency evacuation must be provided. Seat-belts or harnesses and their attachments must be designed for maximum load factor as stipulated.

The original design brief stated in §1.1 was grouped into the high level user requirements listed in §3.9. The requirements derived from the design brief have been shaded to indicate a relationship between the user requirements in Table 19.

Table 19. High-level design and user requirements.

Design requirement	**User requirements**			
Specification	**Operation**	**Cost**	**Environment**	**Features**
Wing				
Fuselage				
Engine (non-aviation grade petroleum)				
Range				
Endurance				
Landing gear				
Engine installation				
Two seat cockpit				
ASTM F2245 compliance				
Performance to satisfy international export market				

Each high-level user requirements was expanded to allow for the dialectic engine to be used for design of a competitive aircraft. Each specification was expanded relative to one of the four user requirements. The operational user requirements are summarised in Table 20.

Table 20. Operation requirement advantages.

Specification	**Operation requirement**
Wing	In-service damage in the flight training role can be easily repaired if wing is constructed using Aluminium.
Fuselage	Space-frame fuselage offers low weight for high useful load for recreational users, low empty weight for flight training.
Engine (non-aviation grade petroleum)	Operation from larger number of airfields as automotive fuel is widely available.
Range	Suitable range for a country such as South Africa.
Endurance	Long endurance for flight training.
Landing gear	Tricycle landing gear can be used by both recreational and commercial operators. It is easier for control of the aircraft during take-off, landing and taxiing.
Engine installation	Conventional tractor arrangement offers no additional complexity for users.
Two seat cockpit	Suits both recreational and commercial operators.
Performance to satisfy international export market	Minimum performance targets established from competitors.

The cost user requirements are summarised in Table 21. Manufacturing, assembly and maintenance costs have been considered, in addition to operating costs.

Table 21. Cost requirement advantages.

Specification	**Cost requirement**
Wing	Aluminium offers low material and manufacture cost compared to composite wing. Aerofoil profile can be changed without major cost implications.
Fuselage	Material and manufacturing processes differ to wing production. Space frames are generally welded. Manufacture of engine mount and landing gear would be similar, reducing facility costs.
Engine (non-aviation grade petroleum)	Lower fuel costs for all users, better fuel availability for recreational users
Landing gear	Lower maintenance cost associated with tricycle gear.
Engine installation	Tractor installation offers lower maintenance cost, simplified engine mount.
Performance to satisfy international export market	Efficient operation for both recreational and commercial operators.

The environmental user requirements are summarised in Table 22. The high temperatures, high density altitudes and high levels of UV have been considered.

Table 22. Environment requirement advantages.

Specification	Environment requirement
Wing	Needs to be designed for hot and high operation. Aluminium is not UV sensitive. Corrosion protection would increase longevity of the airframe.
Fuselage	Robust, space-frame allows for less complex fittings between primary and secondary structure.
Engine (non-aviation grade petroleum)	Maximum time-between overhaul for both commercial and recreational users.
Range	Range to allow operation in a country such as South Africa.
Endurance	High endurance for flight training.
Landing gear	Robust tricycle gear designed for higher true landing speed in hot and high conditions would offer occupants a smoother ride.
Engine installation	Tractor installation easier to cool in hot and high operation than unconventional layout.
Two seat cockpit	Comfort for recreational and flight training occupants in hot and high conditions with high UV indices.
Performance to satisfy international export market	Safe operation in hot and high conditions.

A wing designed to offer lower true air speed field performance than competitors would be advantageous to recreational and commercial operators. The lower speeds would lessen maintenance costs associated to the landing gear.

The feature user requirement has been summarised in Table 23. The high level user requirements do not incorporated actual technology, rather the features that would be desirable.

Table 23. Features requirement advantages.

Specification	Features requirement
Tricycle landing gear	Designed for low bounce.
Two seat cockpit	Introduce technology for flight training and recreational users.
Performance to satisfy international export market	Performance benefit when compared to competitor aircraft.

The design specification of the performance of the aircraft would lead to an aircraft satisfying the environmental and operational user requirements, the specifications were derived as follows:

Performance requirements:

1. Minimum power utilisation of 1,05kt/hp based on maximum installed power and cruise speed (see Figure 2.).
2. Minimum useful load of 250kg (see Figure 6.).
3. Maximum power loading of 5,8kg/hp for an ultralight and 6,0kg/hp for a LSA (see Figure 4.).
4. Minimum cruise speed of 110kts (see Figure 7.).

Performance Constraints:

1. Useful load may not exceed 45-50% of maximum take-off mass (see Figure 3.).
2. Design must comply with ASTM F2245 in the case of a LSA or SACAA Part 24 in the case of an ultralight.

Performance criteria:

1. Performance to exceed competitor performance in hot and high conditions.
2. Performance to suit both recreational and commercial operators.

This performance-based requirement specification would allow for a first pass high-level concept to be developed using the destruction and creation principles. The cost user requirement would be considered during the high-level design phase, with it being the primary user requirement during the detailed design phase. The feature user requirement would be incorporated during the entire design process.

4.3. SWOT analysis of business case

The user requirements were synthesised to decide whether the aircraft would be designed as an ultralight or as a LSA. The LSA market had shown growth with the majority of aircraft being designed and sold as production-built aircraft. The decision was made to design an ultralight that could be increased in gross mass, but that complied with the ASTM consensus standard. This would allow for the aircraft to be accepted by the SACAA and other authorities as an ultralight. This would shadow the business case of the Tecnam P92. The business case proposed included the establishment of the DO and a MO for the commercialisation of the aircraft. The business case was analysed using a high-level risk assessment and investigation into strengths, weaknesses, opportunities and threats to a business venture, as indicated in Table 24.

Table 24. Analysis of strengths, weaknesses, opportunities and threats

Strengths	**Weaknesses**
– Access to a South African University based design team through a SACAA approved Design Organisation. – First production-built South African Light Sport Aircraft customised for local conditions. – Maintenance and repair of South African production built Light Sport Aircraft made easier.	– No track record: will be first aircraft designed and produced by the venture. – Local labour as yet untrained. – Outsourcing strategy for marketing, hence potentially less direct control. – Dependence on imported engines. – Access to financing.

Opportunities	Threats
– Growing ultralight and LSA market in South African and internationally. – Potential change in South African regulations regarding non-type certificated aircraft. – Potential for inclusion of patents with novel features. – South African focus on aerospace industry growth strategy, AISI and NAC. – Support for after-purchase customisation by the Design Organisation.	– Currency fluctuations can impact on the variable cost and hence profitability. – Aviation market traditionally cyclical. Luxury goods particularly linked to economy/prime lending rate. – Many existing aircraft already in this category with competition from the Czech Republic, Italy and Australia. – Market entrance of strongly-branded Cessna 162 into market.

The proposed business case included mitigation against the threats identified and compensation for the weaknesses through the following strategies.

For compensation against weaknesses:

- The marketing plan identified flying schools as being early adopters in the general aviation industry. This would be the first segment of the market to be targeted. As soon as awareness and credibility was proven among flight schools, marketing and sales efforts would result in significant growth in sales of the aircraft within the second target market such as private customers. Positive word-of-mouth communication between flight schools would be anticipated and the purchase of the aircraft by referred customers would further improve the sales effort and the company's standing in the industry.

- The design team would be linked to first class universities having a reputation of excellence in this area. Furthermore, members of the design team are already well known in the South Africa aviation industry, being involved in air-crash investigations. Their expertise in this area would assist in providing customers with confidence in the design.

- The use of agents is standard practice in the industry. The appointed agents would serve primarily as regional distribution and contact points. The marketing strategy would however be driven by active marketing. It would be beneficial to secure more than one agent in South Africa and internationally, leading to reduced risk associated with the outsourcing strategy.

- The labour required for the manufacture of the aircraft would be similar to that required by the automotive industry, with some minor training, the skills are available in South Africa. The minority of work would be done by some artisans at supervisory level with the majority of work done by specialist technicians.

- There is potential for a South African designed and manufactured engine to be used in the future, which will provide further protection against the exchange rate, and will facilitate pricing of the

aircraft in South African Rands in the future. This would provide a competitive advantage against imported aircraft.

- The joint venture would leverage its funding requirements with the setting up of the Design Organisation as a national platform.

Minimising the effect of threats:

- The imported aircraft components would be priced in US dollars, hence providing a hedge against currency fluctuations.
- The joint venture would not only concentrate its marketing strategy on the luxury private aviation market, but will also focus on diversifying sales to flight training schools and businesses which utilise Light Sport Aircraft as part of their operational requirements. The cost effectiveness (which includes the link to a local manufacturing facility for repair and maintenance) of the aircraft in this context would provide a competitive advantage over imported aircraft.
- The innovative features, price and strategic alliances will provide the joint venture with a benefit when compared to existing products in the market. Several of these features would specifically be designed for the South African climate.
- Although there are many existing aircraft in the market, the market is fragmented. Only Jabiru, from Australia, has market share over 10%, all other companies having market shares of 6% or less. There is no real dominant supplier in the market.

4.4. Aircraft preliminary sizing

The design procedure used for this aircraft is shown in Figure 23. Due to the type of aircraft and operational use, the mass of the aircraft would be between 550 and 600kg for most flights. The environmental conditions and performance goals were used as the primary constraints to size the aircraft. The structural design of the aircraft would be used to determine the empty mass of the aircraft. The design would be acceptable if both the performance and payload targets were achieved.



Figure 23. Aircraft design procedure.

The user requirements and performance specifications were used to form the basis for the preliminary layout of the aircraft. The sizing was conducted using the dialectic engine principles [46].

The concept was initially created by conducting calculations within the regulatory framework to determine geometric limits and targets. The geometry for the cabin, engine bay, rear fuselage and vertical tail was constructed as a full-size line drawing. The design process used for sizing of the cabin is shown in Figure 24. Factors such as the door sills, ingress/egress, instrument panel, visibility and access to engine systems were key factors in the cabin arrangement, firewall and wing placement. This resulted in a centre of mass estimate that was used for the design of the wing, empennage, fuselage and landing gear. Similar processes were used for the other major systems of the aircraft.



Figure 24. Cabin design process.

Once the configuration was confirmed the geometry was transferred as coordinate points on to paper. Figure 25 shows one of the early iterations of the design. Office yarn and thumb tacks provided a suitable medium. The concept was iterated several times until the basic design satisfied the user requirements

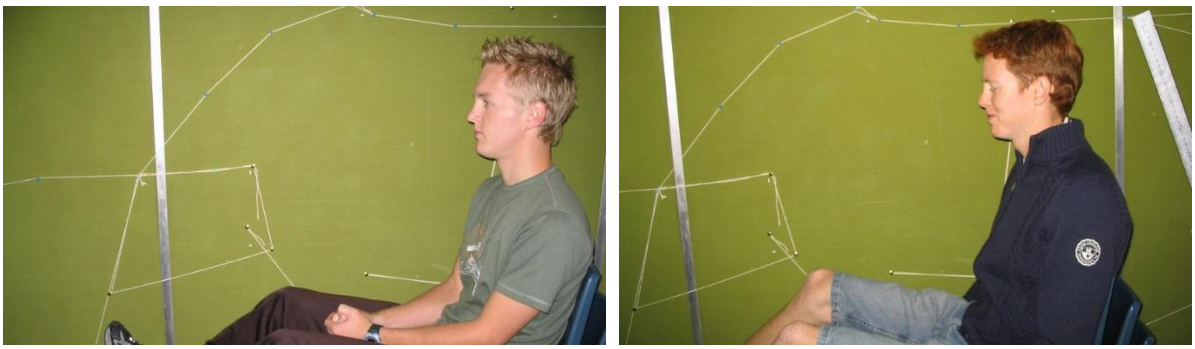


Figure 25. Full-size side view of an early concept being marked out.

The process of sizing the aircraft revolved around the four user requirements.

The fuselage was designed first since it is where the occupants spend the majority of the time. The cabin, including the occupants, seats, instrument panel, baggage and access were sized. Occupant geometry was considered and included both teenage pupil pilots (aged 16) and adults. For adults, the maximum height considered was 95th percentile height for Western Europe at 1880mm and the lowest height considered was the 5th percentile for Asia at 1540mm [53]. The cabin was crafted around two occupants with elbow and shoulder room for comfort. The cabin width was established at 1200mm between body-fuselage contact points. The occupants net body mass would account for 25-30% of the maximum gross mass. Existing aircraft in the ultralight category do not feature seat adjustment such as is common to automobiles. To accommodate a variety of human occupants the centre of gravity of the cabin needed to remain within certain practical limits. The notion that taller occupants having larger mass than shorter occupants was used to contour an occupant box. The box would contain a shorter, lighter occupant seated higher up in the cabin and closer to the instrument panel and controls. It would also contain a larger, heavier occupant seated farther back in the cabin and further from the instrument panel and controls. This resulted in angled seat rails and meant that motion of the centre of gravity would not be as large a challenge as on some competitor aircraft. Access was specified so that the door sills would be lower than the seat offering better ingress and egress. The cabin layout was designed to be comfortable for long flights in hot conditions. Legroom matching the corresponding occupant height was designed into the rail geometry. In terms of the operational and environmental user requirements, this high-level cabin design complied with the requirements.

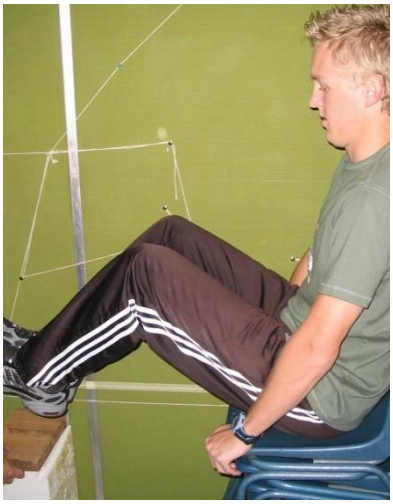
The student team working on various aspects of the design in fulfilment of vacation work requirements was used to size the cabin. Figure 26 depicts the differences in headroom and knee clearance with the instrument panel. The seating position was a comfortable position for the average height student.



Average height student | Above average height student

Figure 26. Sizing the cabin headroom using students [author]

The same students were used to investigate the legroom. The position indicated in Figure 27 was comfortable for the above average height student. The average height student was seated in the position set for below average height occupants. The legs would impact the instrument panel. If this was raised, the visibility would be reduced.



Average height student



Above average height student

Figure 27. Sizing the cabin legroom using students [author].

Figure 28 depicts an average height student in an ultralight cockpit. The small amount of legroom and foot-room for ingress and egress should be noted. The seats do not allow for adjustment, instead the occupant may use a cushion to raise the seating position. The knees are very close to the instrument panel and the student's left arm would be in contact with the door. The tubing connecting the left and right sides of the fuselage would be in the vertical peripheral vision.



Figure 28. Average height student in a Fly Synthesis Storch [author].

The styling of the interior was deemed as important for the recreational owner. Aircraft are a significant investment and not many aircraft manufacturers offer interiors that offer the same comfort levels as automotive manufacturers. Figure 29 shows the initial design of the cabin interior.

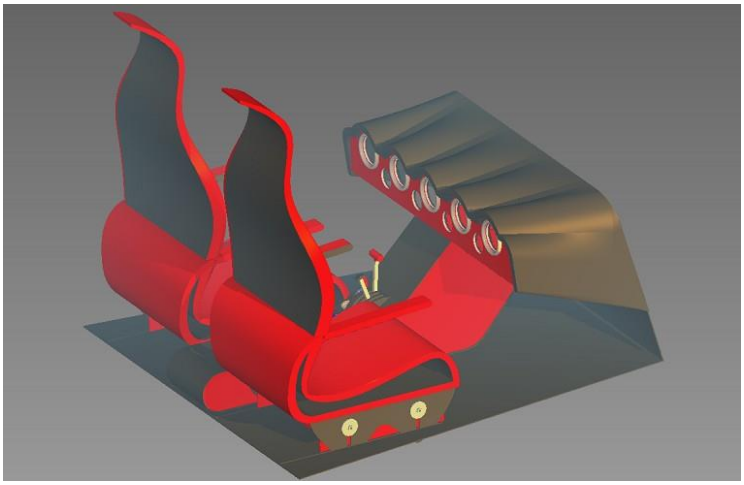


Figure 29. Initial concept of cabin design [S Gruber, vacation work student].

The propulsion system was considered as the next priority. The tractor arrangement was favoured over a pusher arrangement simply because the cabin was designed for a better environmental user requirement. A tractor propeller arrangement can be mounted with an un-aerodynamic fuselage behind it whereas a pusher arrangement needs to be mounted behind a fairly aerodynamic fuselage. Additional consideration was given to the operational user requirement and airfield surface quality. The tractor arrangement was much better for an aircraft for flight training and recreational use. The engine choices were given maximum height, width and length dimensions. These propulsion units were arranged in front of the cabin with consideration given to the view out the front of the cabin by occupants of different height at the corresponding comfortable seat positions. The engine was positioned with an angled firewall sloping forward from the instrument panel. This served several purposes. The majority of engine-related systems need to be on the hot side of the firewall and occupy significant volume. Slanting the firewall creates larger volume behind the engine above the thrust-line. Systems at this convenient height would be accessible more ergonomically. The slant also created less volume below the engine and created more volume in the cabin to allow for the rudder pedal placement to match the occupant height and associated seat positions. The reduced volume in the engine bay would not pose a problem since the exhaust is the only component located underneath the engine. In terms of the operational, environmental and feature user requirements, this combination of high-level cabin and propulsion design complied with the requirements.

The engine bay is depicted in Figure 30. The instrument panel and nose landing gear are visible.



Figure 30. Engine firewall position [author]

The aircraft consisted of a cabin and engine bay, with a layout that offered ergonomic features to satisfy the operational user requirement. The wing placement decision was considered next. Two-seat light aircraft can only be designed with a mid-fuselage mounted wing if the aircraft is of canard design with a pusher engine arrangement. The two types of wing mount for a light aircraft are a low wing configuration or high wing configuration. The low or high position refers to the position of the wing mounting on the fuselage.

The low wing option offered more disadvantages than a high wing option. The view of the ground is restricted to a greater degree during cruise and during manoeuvres and ground effect causes float on landing increasing the length of the landing roll. After performing destruction and creation on the wing system, a high-wing mount was selected. The justification was based on increased visibility of the ground during cruise satisfying the operational requirement. The high wing placement would the only configuration that would be suitable for operation on rough airfields.

The cabin design with seating that accommodated occupants in a more comfortable position allowed the high-wing to be mounted further aft than on traditional high-wing aircraft. This allowed for the occupants to have increased above-horizon visibility out of the cockpit compared to a traditional design. The inclusion of a strut would allow for a wing-fuselage joint that would increase headroom compared to a cantilevered wing. To improve the visibility in a turn manoeuvre, the wing was given a small amount of sweep to move the leading edge and wingtip out of view. The added benefit created by this feature was that the sweep could be changed during the design for manufacture phase to suit the centre of mass of the aircraft without affecting the wing joint or other systems.

In terms of the operational and environmental user requirements, this combination of high-level cabin wing placement satisfied the requirements.

With the cabin, engine bay and wing joint forming the front half of the aircraft concept, the landing gear was incorporated before completing the rear fuselage. The reason for this was that several aircraft were inspected and unsatisfactory design features were observed. Several aircraft systems such as the pitch and yaw control systems were positioned in ergonomically-poor locations. Upon inspection of the landing gear design, it was deduced that the systems were moved away from landing gear structure attachment positions at the expense of ergonomic design. With a space-frame fuselage the nose landing gear would influence the space-frame node points towards the front of the cabin. This would affect legroom and the profile of the front fuselage. The creativity permitted for the design of a control system is greater than that acceptable for design of landing gear or for the fuselage space-frame. The nose landing gear was designed as a steerable unit of trailing link design. The angled firewall meant that the gear leg could be mounted parallel to the firewall behind the engine. With a cabin design that allowed for occupants of differing height to be comfortably seated, the rudder pedals could be fixed in position and linked to the gear. Nose gear steering is not available on several ultralight aircraft and LSA models, differential braking is used for steering. The trailing link action mechanism was selected due to the energy-absorbing action. The types of surface commonly found on grass or compacted dirt runways often have grass tufts that can create large impact loads that can lead to damaged nose landing gear or components. The landing gear was also incorporated so that it was not part of the engine mount. The reason for this was to increase assembly ease and allow for engine maintenance or landing gear maintenance that would not involve much disassembly. Damage caused by a propeller strike would be isolated to the engine mount and damage caused by a hard landing would be isolated to the landing gear mount. An integrated engine mount and landing gear structure is depicted in Figure 31. The steering linkage is located near the lower part of the gear leg.

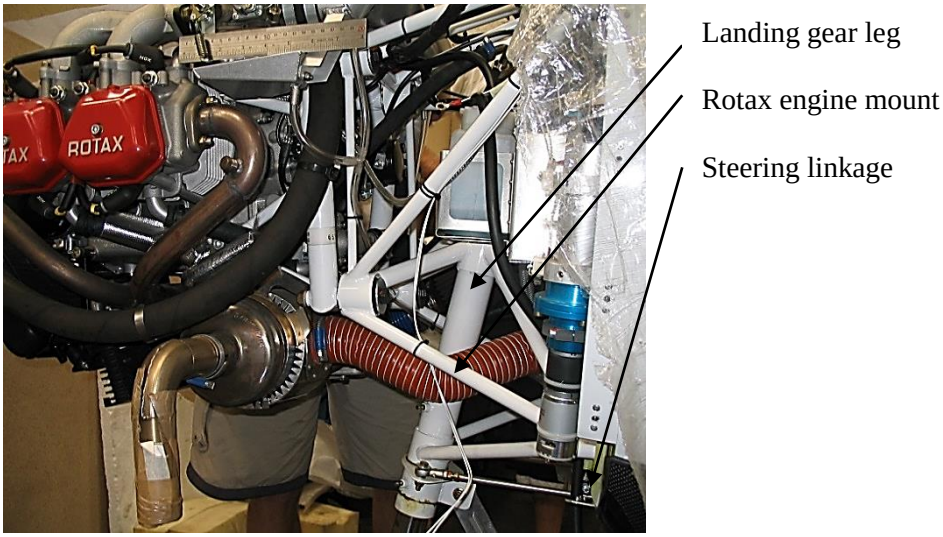


Figure 31. Integrated engine mount and landing gear leg [author].

The main landing gear position is determined by the centre of mass of the aircraft and influences the design of the horizontal tail. The position of the main gear also determines the load carried by the nose landing gear. A tricycle gear configuration was selected because initial flight training is primarily conducted on tricycle gear aircraft as the ground manoeuvring and cross wind handling during take-off and landing requires less skill. The main gear attachment position would determine the space-frame node positions behind the cabin. This would affect the door and cabin floor. The cabin, engine bay, wing joint and nose landing gear already formed the front half of the aircraft concept. The main landing gear was positioned aft of the theoretical centre of mass of the aircraft.

The conventional landing gear types used on ultralight and LSA are typically either the tubular-type using steel or Aluminium or plate-type using steel, Aluminium or composite materials. In addition to the type of landing gear, the method of load transfer is either a single landing gear component or a split-design with separate left and right units. The material specification was not important for the concept gear, the method of load transfer was investigated since landing gear needs to behave like a spring, absorbing loads with large deflections. Using the destruction and creation principle, the landing gear selected would be located behind the door due to the space-frame design, ease of assembly and ease of ingress and egress. The split-type and single piece landing gear load transfer characteristics were considered. The aircraft landing in hot and high conditions has a higher true air speed than indicated. Reduction in bounce on landing and lower maintenance in terms of failure required the inclusion of suspension in the landing gear design.

Several options were considered. The first concept included pivoting the gear leg with a spring and damper at the fulcrum. This type of design was used in the de Havilland DH-6 Twin Otter. The second concept incorporated a pivot point and pushrod arrangement as used in Formula 1 vehicles. The inclusion of suspension would constrain the design to a split-type arrangement, the concepts would introduce the loads in different directions. The pivoting design would introduce vertical loads whereas the pivot and pushrod design would introduce additional lateral loads. The design was iterated through the destruction and creation dialectic engine to refine the two concepts. The benefit gained by using the pivot and pushrod design was that the left and right landing gear units could be linked to act as a single bench type unit with left and right load transfer with response. The pivot type would be fully independent meaning that the suspension would absorb the load, but not necessarily make landing more comfortable. The pivot hinge axis could be rotated to move the landing gear ground contact point as a

form of adjustment in a similar manner to the inclusion of slight wing sweep. The combination of wing and landing gear adjustment would allow for the centre of lift to be adjusted for centre of mass limits and the main landing gear could be adjusted for adjustment of the nose landing gear load.

Traditional light aircraft have the strut positioned ahead of the door. With the cabin designed to be similar to that of an automobile, the strut hinders access to the cabin. The door would also have to be reduced in size to clear the strut. The solution was to move the fuselage strut mount to aft of the door. The Fk-9 pictured in Figure 32 has the strut and landing gear connecting to the same section of the fuselage. The occupant needs to climb over the strut to enter or exit the cockpit.



Figure 32. FK-9 indicating strut position [54].

The creative solution to this problem was to use the wing sweep advantageously. The sweep was originally incorporated to allow for the static margin to be adjusted during the design. The consequence of the sweep was additional improvement to the visibility out of the cockpit. The sweep coupled with the cabin design with movable seats allowed for better centre of mass control thus allowing for the position of the cabin to be placed for visibility. Another result of this arrangement would include giving the strut forward sweep. The forward sweep of the strut would be reduced by the wing sweep. The strut placement of the Cessna 162 is shown in Figure 33.



Figure 33. Cessna C-162 indicating strut position and strut sweep [55].

The position of the main landing gear is shown in Figure 34. The wing strut attaches at the same position.

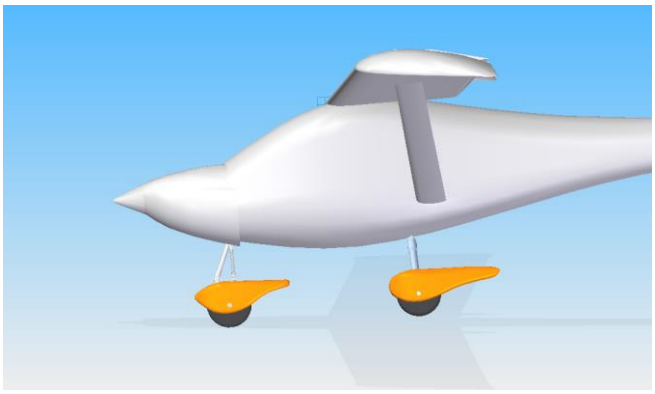


Figure 34. Side view of initial concept illustrating strut and landing gear positions.

Figure 34 shows the unobstructed view from the occupant position towards the wingtip. Entry to the cabin would be performed ahead of the strut.

The front half of the fuselage now consisted of the cabin, engine bay, wing placement and the nose and main landing gear. The empennage consisting of the horizontal and vertical tail surfaces was conceptualised next. When considering aircraft recognition the general impression, size and shape principles are used by aircraft spotters and birders to recognise aircraft and birds. In ultralight and LSA, the cowling and empennage are the primary references to aircraft identification as all high-wing aircraft appear similar. Function is a primary requirement for good design and aesthetics is the primary influence for good sales. The horizontal tail was designed before the vertical tail for the reason that assembly would be done in that order. The horizontal tail types commonly used on ultralights and LSA are either fixed stabiliser with an elevator or the all-moving type. The fixed type of horizontal tail was not considered as the design would be more maintenance intensive with a larger number of hinges and attachment points when compared to the all-moving type. The space-frame fuselage construction would be better suited to a hinged all-moving surface. The trim drag for the same amount of lift would be reduced and greater pitch authority is available.

The flight envelope of a LSA has a regulated minimum safe airspeed that is less than a certified light aircraft, with a similar cruise speed. Pitch authority at low speed needs to be high. The all-moving horizontal tail was designed with a servo tab that would allow for trim adjustments. This arrangement is known as link-balanced tab [56]. The position of the horizontal tail was constrained by the distance from the main landing gear and rotation angle. The lift required from the horizontal tail is inversely proportional to the distance between the tail and the main landing gear. The height of the tail above the ground is determined by a defined rotation angle to prevent contact with the ground. The rotation angle specified for the preliminary design was 16°. This would be slightly higher than the stall angle of the aircraft at low speed with flaps deployed. The height was originally set above the rotation angle at a convenient height for assembly, inspection and maintenance. The distance aft of the main landing gear was not defined until the vertical tail had been conceptually designed.

An example of a hinged all-moving horizontal tail fitted to an ultralight is shown in Figure 35. The counter-weight is indicated. The design is functional with easy access for assembly, inspection and maintenance, but it is neither aesthetic nor aerodynamic. The important control components of the tail are exposed to the environment. For a user keeping the aircraft indoors when not in use, this would not

be a concern. For a user keeping the aircraft outdoors, the exposure of the control linkages to the environment would be a concern.

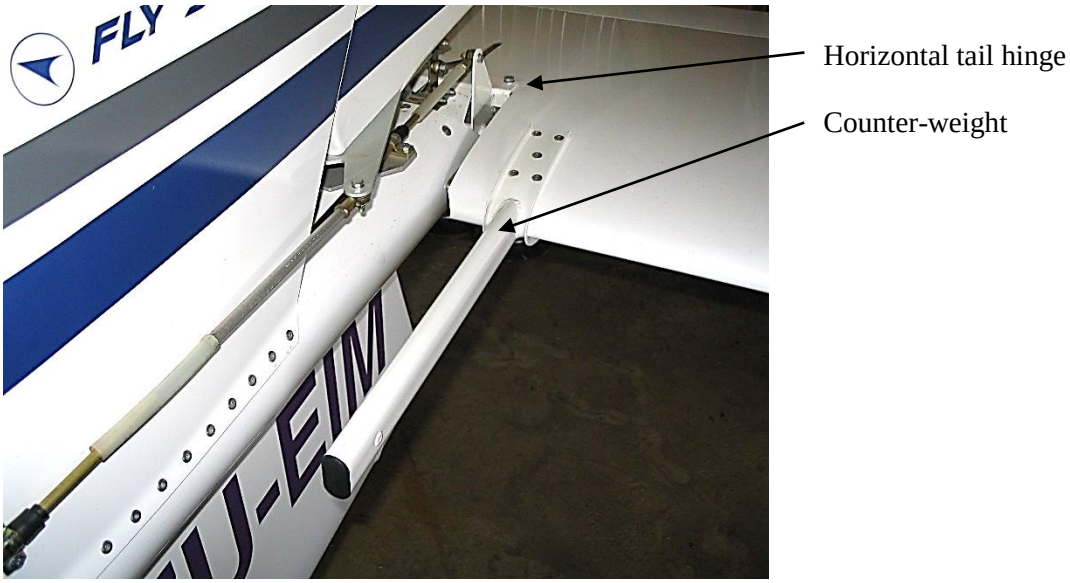


Figure 35. All-moving horizontal tail attachment [author].

The vertical tail is one of the most recognisable and distinguishing components on an aircraft. The vertical tail needs to be large enough to give control authority at the low-speed envelope, have a high aesthetic index as a component and contribute a high aesthetic appeal to the rear fuselage. The vertical tail configuration selected was conventional with respect to the design being a fixed stabiliser with hinged rudder. The taper ratio was manipulated to lower the height of the lift centre of the vertical tail. The very first concept resembled the tail design used on the Jabiru aircraft. The next tail concepts had a curved leading edge to introduce a shape not common to ultralight and LSA aircraft. The tail was also located above the fuselage. The first Cessna C-162 accident preliminary report finding was used with the destruction and creation method to modify the concept. The curved vertical stabiliser was modified to a tapered trapezoidal stabiliser without changing the rudder shape. This was done to ease manufacture. The aspect ratio of the unit was increased to steepen the lift curve slope. The concept resulted from breaking the trapezoidal tail into a trapezium and two triangles. The height of the aerodynamic centre of lift was lowered nearer to the fuselage. The increased stabiliser and rudder area below the tail would be similar to the solution finally used by Cessna on the C-162. The vertical tail design may be described as a swept, tapered vertical tail with both a dorsal and ventral strake. The tail was positioned behind the horizontal tail to allow for a full-span horizontal tail with a common attachment location to the space-frame for reduced assembly complexity.

The horizontal and vertical tail assembly was positioned at the preliminary length constraint at the height required for rotation clearance. The rear fuselage was then contoured to create a rear fuselage boom.

The vertical tail was the aircraft component that was modified the most. The second generation vertical tail is depicted in Figure 36.



Figure 36. Second iteration of vertical tail shape.

The aircraft Cartesian geometry was extracted from the full size side view and the CAD model was updated when changed were made. Figure 37 depicts the initial versions of the high-level concepts and Figure 38 shows the final version of the initial high-level concept.

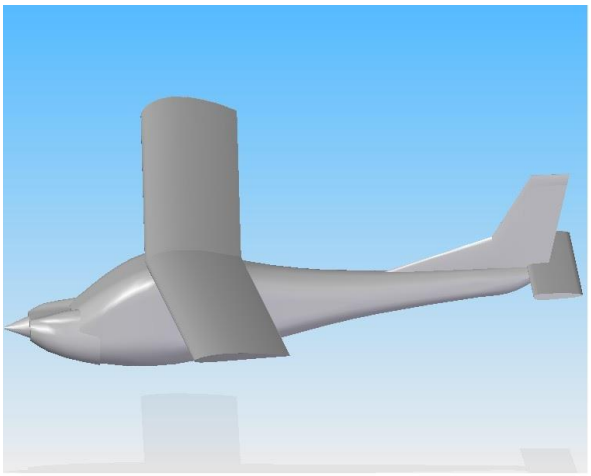


Figure 37. Initial concept indicating wing sweep.

The final high-level concept is shown in Figure 38.



Figure 38. Final high-level concept with second vertical tail concept

The aircraft was now ready for refinement of the initial design.

4.5. Aircraft refinement

Each assembly or system was developed from a high-level concept into low-level component detail. This development was done in parallel to advance the design with minimal risk of a single system having a major negative influence on other systems. The four user requirements provided the focus for the mid-level design. For all assemblies, only minor modifications were required from the initial high-level design.

The wing assembly included the wing, strut, ailerons and high lift devices. The wing was not as important as the cabin during the first design pass. The wing was given priority during the second pass.

The original wing was designed using a NACA 4412 section profile. The profile features a fairly flat lower ordinate locus allowing for lower complexity jigs to be used during assembly. The profile features a high maximum lift coefficient and mild stall. To reduce the cost of the wing, the profiles of the flaps and ailerons were made congruent for manufacturing cost reduction. The manufacturing process was used as the primary influence for this. For the flaps, single-slotted flaps were selected to provide a sufficient increase to the maximum section lift coefficient, ensuring lower stall speed at high density altitudes. The destruction and creation principle resulted in a larger wing area than used by competitors. This lower wing loading and flap system would result in take-off and landing speeds that would be lower than other aircraft operating in hot and high conditions. The lower take-off and landing speeds would reduce landing gear loads.

The common practice with single-slotted flaps is to hinge the device on a mechanism that protrudes below the lower wing surface. The principle of destruction and creation was used to solve the problem of trying to fit the flap extension mechanism within the profile. This introduced an element of novelty, at least amongst light aircraft. A guide rail that was enclosed within the geometric perimeter of the aerofoil was designed to support the flaps. The flap guide was shaped to give translation and rotation without it being full Fowler motion. The application was novel, but not novel enough to pursue with an international patent co-operation treaty application. The provisional patent was developed in South African patent 2010/00868 and may be found in Appendix A. The flap guide is shown in Figure 39.

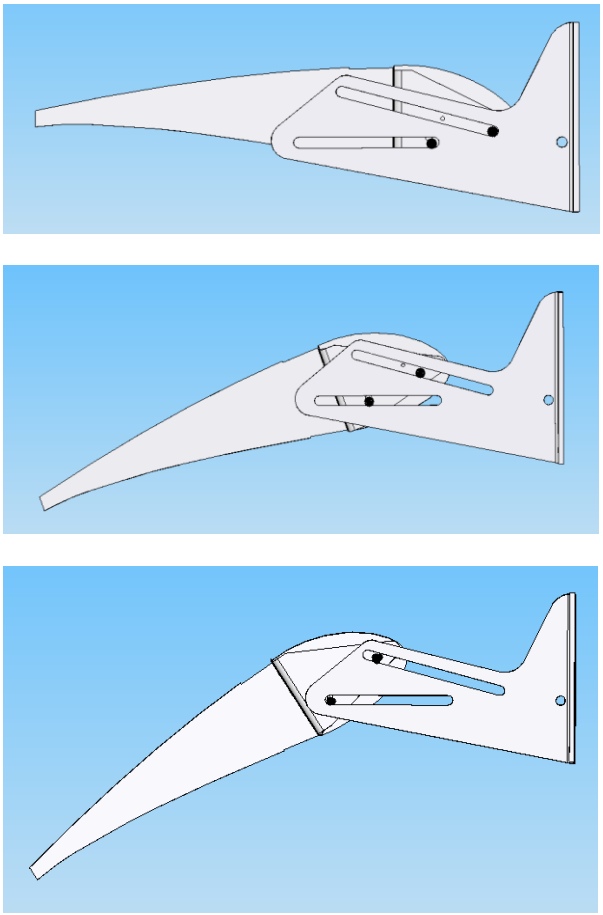


Figure 39. Flap extension

The wing featured a strut to allow for a lighter wing structure at the fuselage joint. The joint was designed to offer very good visibility, the strut would allow a cut-out in the leading edge of the wing at the wing joint, giving the occupants upwards visibility.

An aerodynamic assessment of the NACA 4412 and the NASA 0317 was conducted to determine the suitable aerofoil profile. The lift and pitching moment coefficient data for a NACA 4412 is shown in Figure 40. The lift coefficient data for a NASA 0317 is shown in Figure 41 and combined lift and pitching moment data is shown in Figure 42. The data was compared at a Reynolds number of $4x10^6$ which approximated cruise flight conditions of 100kts.

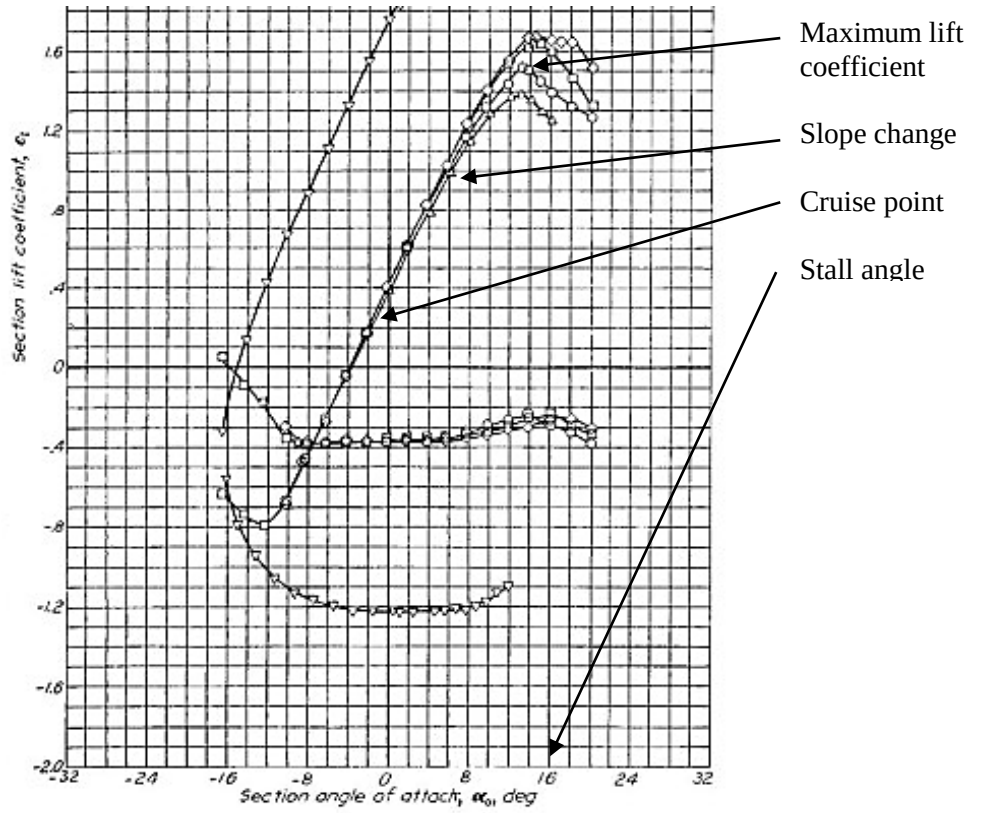


Figure 40. NACA 4412 lift and pitching moment data [57].

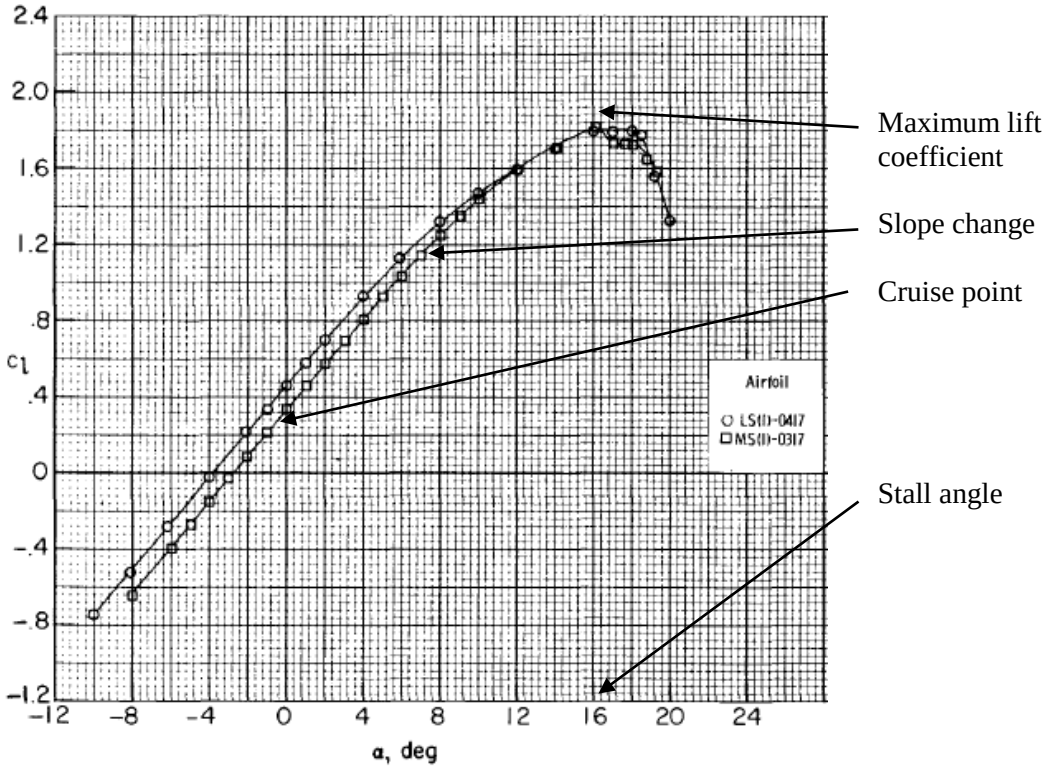


Figure 41. NASA 0317 lift curve data [55].

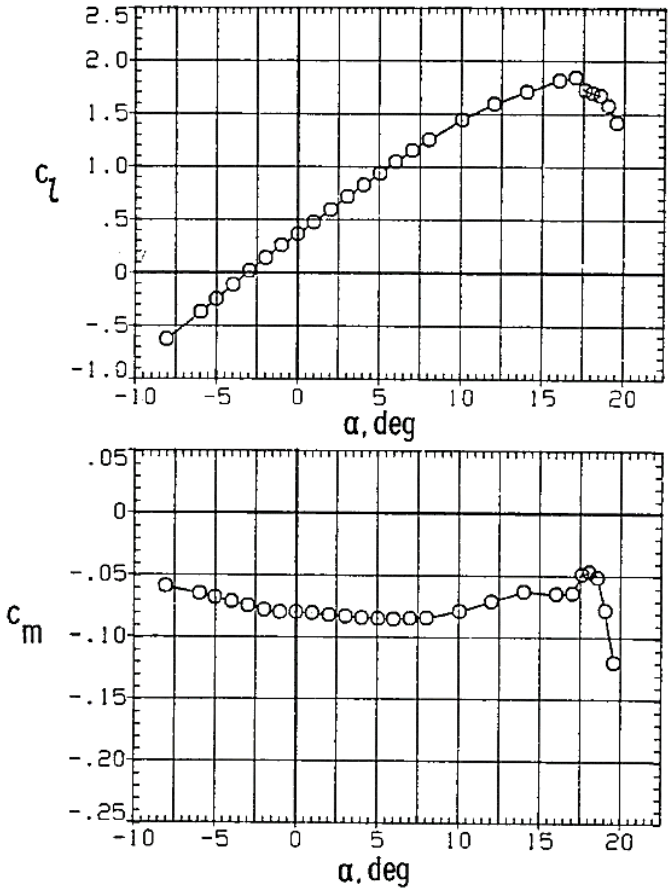


Figure 42. NASA 0317 Lift and pitching moment coefficients at Re = $4x10^6$ [55].

When comparing the 2-D lift coefficient data at a Reynolds number of four million, corresponding to cruise speed of 100kts, the comparison is presented in Table 25.

Table 25. Comparison of 2D aerofoil data.

Parameter	NACA 4412 [57]	NASA 0317 [55]	Conclusion
2D lift curve slope	0.106/deg	0.114/deg	NASA 0317 has better lift curve slope.
C_{Lmax} clean	1.52	1.8	NASA 0317 has 18% higher maximum lift coefficient.
C_L at 0°	0.4	0.32	NASA 0317 produces a cruise lift coefficient at angle of attack of approximately 0°.
Stall angle	13°	16°	NACA 4412 stalls at a lower angle.
Thickness ratio	12%	17%	NASA 0317 is 5% thicker or 50mm thicker per metre chord.
Aerodynamic centre	24.5%	26.8%	NASA 0317 aerodynamic centre further aft by 23mm per metre chord.
Pitching moment slope at 0°	Flat	Negative	NASA 0317 produces stronger relative nose down moment with increasing angle of attack.
C_M at 0°	-0.09	-0.075	NASA 0317 produces approximately 17% less nose down pitching moment.
3D lift curve slope (DATCOM method)	0.08819/deg	0.09349/deg	NASA 0317 has better 3D lift curve slope.

The NASA 0317 was selected due to the aerodynamic properties; steeper lift curve slope, higher maximum lift coefficient, higher stall angle, aft aerodynamic centre position, negative pitching moment slope, lower cruise pitching moment and higher 3D lift curve slope. The higher lift curve slope, higher lift coefficient and higher stall angle would compensate for micro imperfections during manufacture of the aircraft. Therefore the aircraft could be designed for a lower maximum lift coefficient than the maximum available and the aircraft could still attain good performance. This safety margin would allow for the ASTM prescribed stall speed to be attained with greater certainty. The thicker section would allow for the flap mechanism to be fully contained within the section. The thicker wing would allow for a less complicated fuel tank to be developed and would result in a lighter wing. Figure 43 shows the cross-section of the wing.

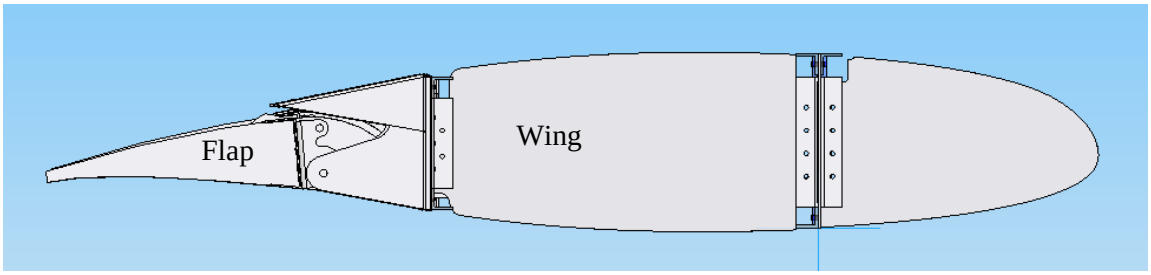


Figure 43. Wing cross section

The wing was designed as a stressed semi-monocoque two-spar torsion box, manufactured from Aluminium alloy. The primary spar would be a built up section using a shear web and sparcaps, with machined end fittings to attach to the cabin. The high lift single slotted flaps and the ailerons would attach to the rear spar and will be of the same critical chord length. The wing assembly is shown in Figure 44.

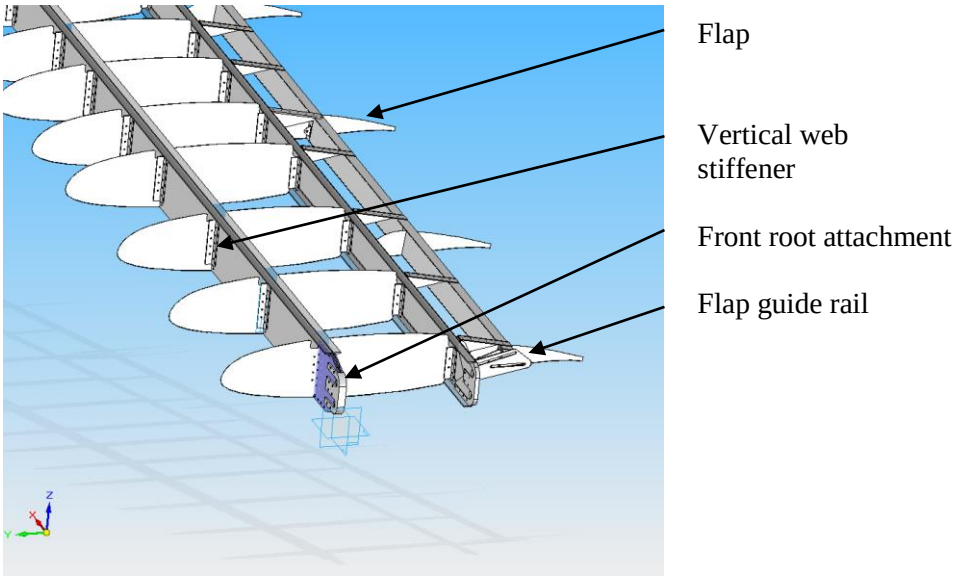


Figure 44. Wing assembly.

The pitching moment slope for the NASA 0317 is non-linear. The maximum value occurs at an angle of attack of 7°. This is advantageous from a flight training perspective, resulting in slightly different pitch stick loads when compared to a competing ultralight or LSA. For the recreational user the lower wing loading would require a lower magnitude of lift coefficient range to be used for manoeuvres, the

trim system incorporated would not make the pitch control uncomfortable. The lower wing loading also reduces the cruise lift coefficient so that the wing is almost at an angle of attack of 0°. The aircraft was designed with an all-moving horizontal tail with link-balanced tab, this would allow for adequate control with the increased pitching moment caused by the higher lift coefficient resulting from speed reduction or increased load factor at a constant speed.

The cabin included the wing strut attachment, instrument panel, windows, doors and baggage area. The cabin was, initially, the most important system from a user perspective. With the wing designed, the cabin and its features needed to be integrated with the wing. To increase the field of view out of the cockpit, the instrument panel was lowered and angled upward to lower the height of the panel. The angle was based on the most comfortable angle for reading a book. This would also assist pilots flying with progressive lens spectacles. The parallax read-error would be reduced by this inclination and the instrument panel could be styled similarly to a modern automobile or recreational vehicle such as a high-powered boat. The wing was positioned with a sweep of 3˚. During physical testing, this sweep angle made an improvement to the view. The cabin featured some elements that offered improvement over competing aircraft. The structural tubes connecting the wing root joint to the engine were angled to move the tubes into peripheral view that was found less intrusive to the most common visual targets, the horizon and lower lateral view of the ground.

The doors were made as large as the space-frame structure would allow. The firewall angle was revised for additional legroom. The cabin design of adjustable seats and an angled rail was revised for the field of view for a short or tall person to remain almost identical while attempting to limit the associated centre of mass movement. The aerodynamic centre location of the NASA 0317 being further aft than a NACA 4412 would be advantageous for the geometry selected for the cabin. The instrument panel was arranged in a left and right side instrument cluster. The cluster would have the basic six instruments; airspeed indicator, altimeter, vertical speed indicator, artificial horizon and turn and bank indicator. The other instruments and switches would be housed in a central console. The wide cabin design would accommodate a 150mm wide console. The instrument panel was profiled to be different to other instrument panels. The profile was hollowed out in the centre of the panel and was tilted up towards the occupants, due to the panel being lower. Figure 45 shows the refined concept.

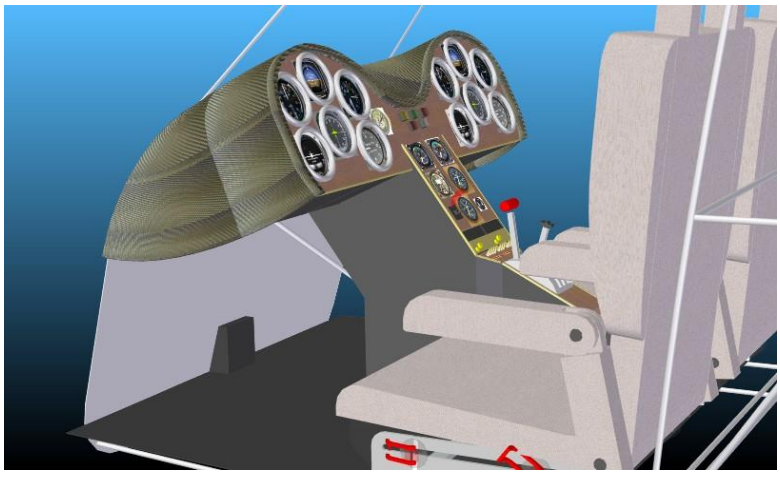


Figure 45. Second iteration of the instrument panel and cabin design.

With the electronic flight instrument system (EFIS) being offered to light aircraft manufacturers, the panel and console was refined to house a combination of one or two EFIS units. The analogue flight instruments were incorporated to improve the aesthetics of the panel. Figure 46 shows the third iteration of the panel and console design with a single EFIS and analogue back-up instruments.

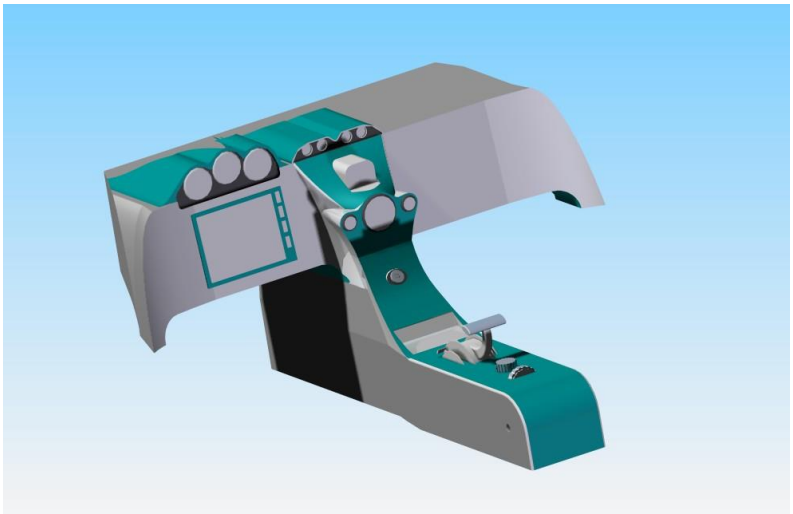


Figure 46. Third iteration of the instrument panel and console design.

The final design featured a single EFIS on the left side for the pilot in command with a standard set of analogue instruments in the centre of the panel. The profile of the panel was lowered directly in front of the occupants and raised in the centre to emphasise the console design. The lowest cost version of the panel would incorporate the six analogue instruments only. The empty space on the panel would contain a storage receptacle or a second EFIS. Figure 47 shows the final design.



Figure 47. Final instrument panel and console design.

Baggage stowage volume was designed into the cabin directly behind the seat. Due to the cabin layout and the swept wing, the baggage location would be closer to the centre of mass than on other aircraft. The problem with the common wing strut and landing gear attachment was that access to the baggage compartment would be from inside the cabin or from behind the landing gear. The wider cabin design allowed for a gap between the seats to be incorporated so occupants could access the baggage during flight. The narrow centre console, similar to that installed in an automobile would incorporate a receptacle for beverages and food.

In summary the aircraft cabin would feature the following:

- Two removable seats containing foam padding upholstered in a variety of material.
- Adjustable seat rails, ergonomically adjustable to comfortably suit all 95% percentile adult humans.
- Adjustable four-point seat belts.
- A neutrally finished interior with customisable back-lit instrument panel.
- Folding armrests fitted on the seats.
- Glare shield with mood lighting and LED map light.
- Centre console containing instruments, air-conditioning, engine instruments and map storage.
- Baggage storage volume of 0.4m^3 behind seats, accessible from the cabin or via exterior door.
- Baggage net to prevent articles from shifting in flight.

The cabin layout was iterated to improve the design. The 2-D cabin with 3-D wing and strut is shown in Figure 48. The student in the figure would have a view out of the window down towards the ground without a strut in the line of sight. The panel is low enough for the occupant to have good forward visibility out of the cabin.

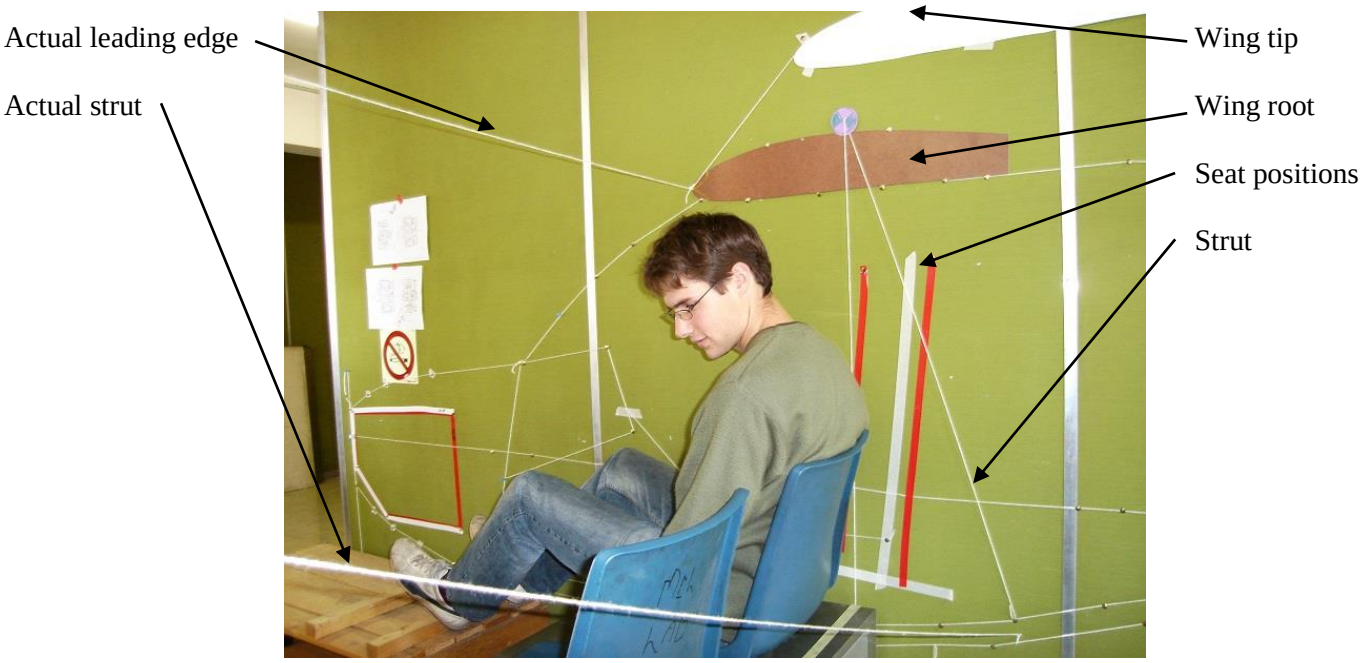


Figure 48. Refined cabin concept [author].

The engine bay firewall was positioned to provide 600mm between the firewall and the door frame. This was introduced following determination of the engine moment arm from the centre of mass. The distance would allow for the space-frame tubing to be positioned to maximise the visibility out of the cockpit. The design would not have any tubing behind the windscreen. The nose landing gear loads are carried through the cabin in other designs. This reduces visibility. The aircraft depicted in Figure 49 has a centrally mounted strut that attaches the nose landing gear to the wing joint.



Figure 49. Ultralight aircraft with nose gear structure within the cabin.

The FK-9 has reinforcement tubes that are inside the windscreen as well, as shown in Figure 50.



Figure 50. FK-9 cabin with visible reinforcement strut [author].

The flight controls were designed to consist of dual full-control sticks, providing movement to the elevator and ailerons. Not all ultralight and LSA feature dual control sticks. Some have a single stick in the centre of the aircraft. The rudder pedals provide the nose landing gear and rudder with movement and will be fitted with differential toe brakes. An electric flap system will be included between the occupants on the control panel. Electric trim systems will be used.

The basic engine bay concept was developed to accommodate the Rotax 912 series. The annotated schematic of a typical design may be seen in Figure 51.

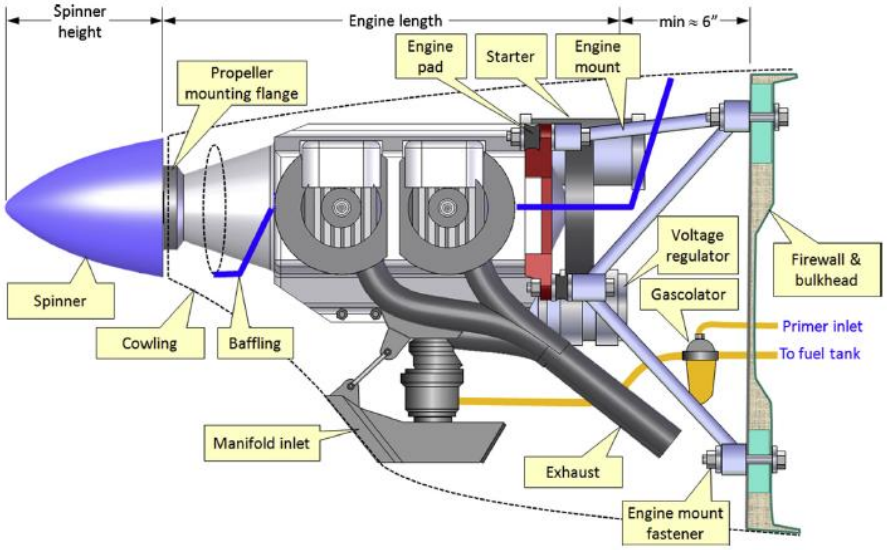


Figure 51. Typical light aircraft engine installation [58].

The concept engine bay differed to a conventional layout in several ways. The upper surface of the cowling was aligned with the sloped instrument panel to give the occupants an unobstructed forward view. This meant that all intakes and inlets needed to be on the lateral or lower sides of the cowling. The Rotax 912 engine has air-cooled cylinders and liquid cooled cylinder heads. This allows the engine to be operated safely at a reduced power setting after a cooling system failure. In addition to the radiator circuit for the cylinder head, the oil needs to be cooled with its own radiator. The advantage of the sloped firewall was that the air volume inside the cowling could be reduced. This reduction would be due to the shorter distance between radiator inlet and exhaust under the engine. This compact assembly would be possible because the nose gear was designed as a separate part, independent to the engine mount. The design is shown in Figure 52.

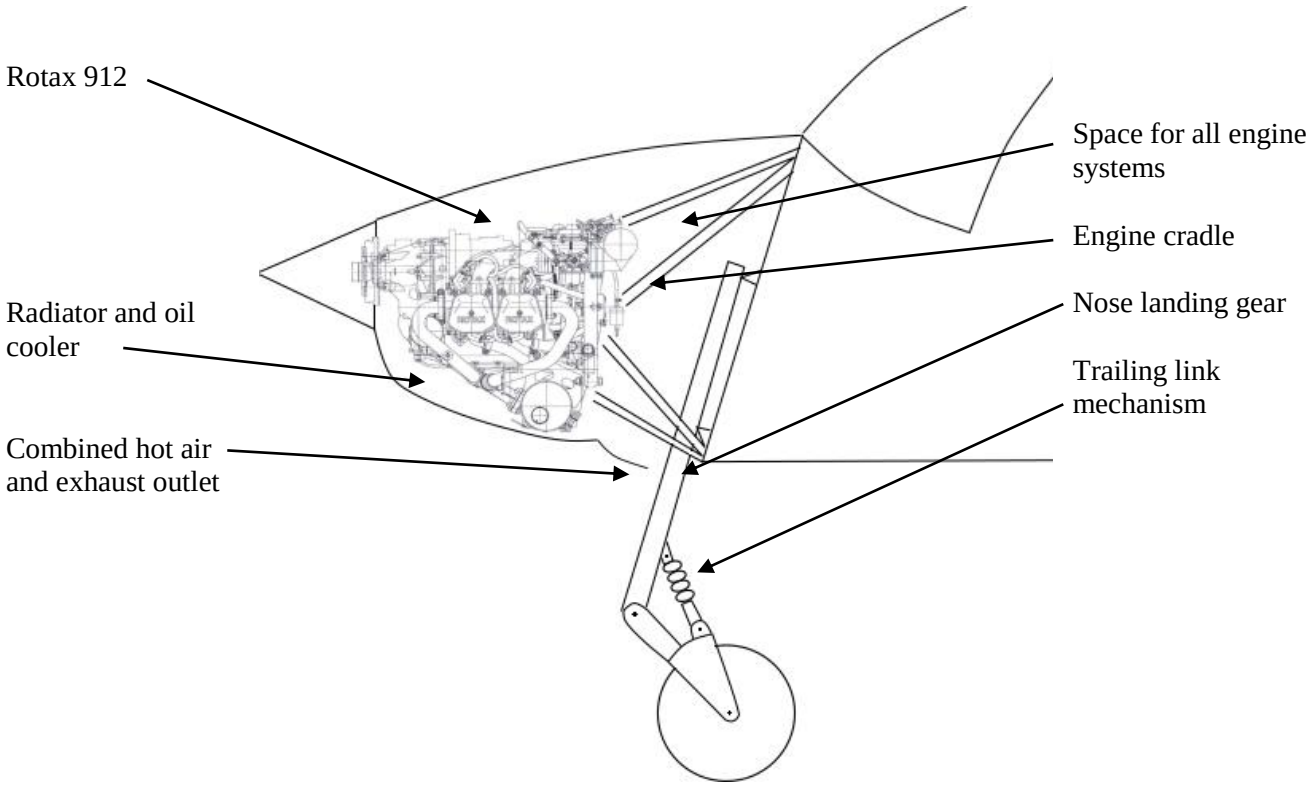


Figure 52. Engine bay concept

The nose landing gear concept, depicted in Figure 52 was designed not to attach to the engine mount, even though it shares attachment points on the fuselage space-frame. The trailing link design was favoured due to type of grass tufts present at South African airfields. The device was designed as steerable with load arresters designed into the control linkage to absorb impact load, such as those transferred to the gear during take-off and landing on rugged grass runways.

During the development of the engine bay several ideas were synthesised. A device of novel value was designed featuring a propeller spinner that would assist engine cooling by forcing additional air into the cowling using a spring-loaded fan arrangement. The fan would be sprung closed when engine rotational speed was low and when flight speed was high. When engine rotational speed was high and flight speed was low, the fan would open due to low dynamic pressure and high centripetal acceleration. The novelty was limited to the device and not to the method, the patent was not pursued for this reason and for the fact that the device was inherently more susceptible to damage from a bird strike. The device would also be difficult to maintain. The provisional patent *SA 2007/04439* may be found in Appendix B.

The main landing gear was designed as independent left and right units, the units were designed as symmetrical, making them left-right interchangeable to reduce manufacturing costs. The landing gear was designed with a pivot point and a spring damper to allow operation on unimproved airfield surfaces. The strut would be attached to the fuselage aft of the main landing gear. This would allow for an inclination angle of the landing gear hinge axis relative to the longitudinal axis to be incorporated. The initial concept is depicted in Figure 53.

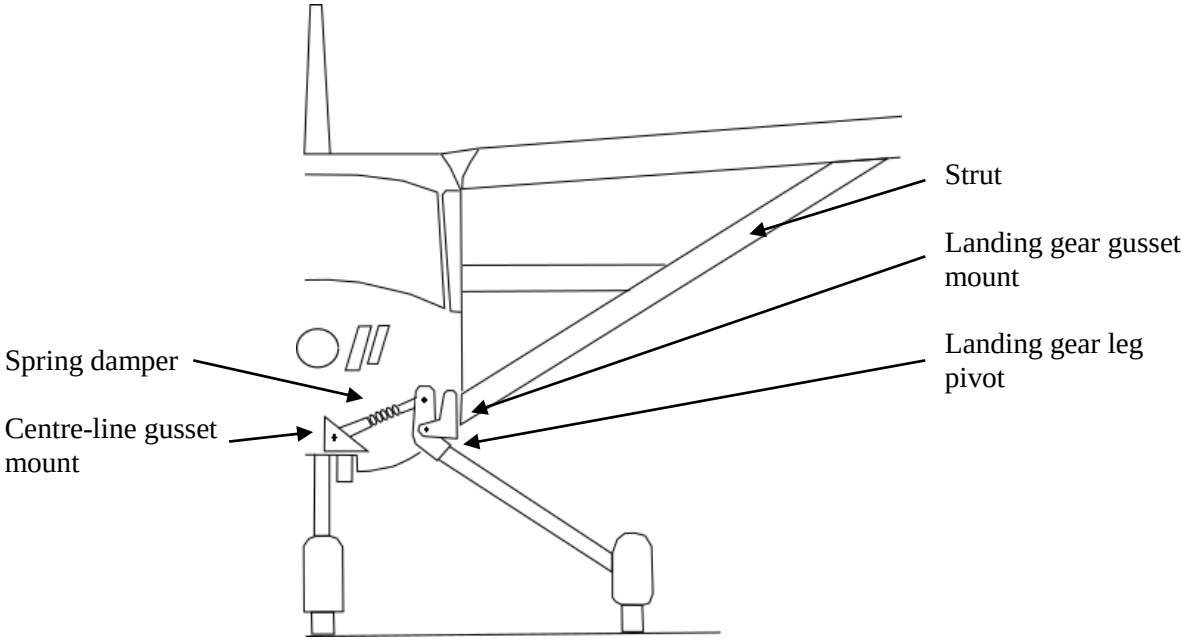


Figure 53. Left side main undercarriage concept.

The all-moving horizontal stabiliser was of conventional design and featured a servo-tab to reduce stick control force loads. The trim would be adjusted using a commercially-available electric trim unit designed as part of the control linkage.

The vertical tail was the final structural component of the aircraft that was designed. This was done to ensure that it would offer sufficient directional stability and have a high aesthetic index. The tail was designed to extend below the fuselage to offer positive restorative control during a spin. The taper ratio was increased to bring the aerodynamic centre towards the predicted drag axis.

The first iteration of the fuselage space frame is shown in Figure 54. The frame featured a heavily triangulated side structure, single node wing attachment and triangular baggage hatch. The design did feature large doors, but was heavier than expected.

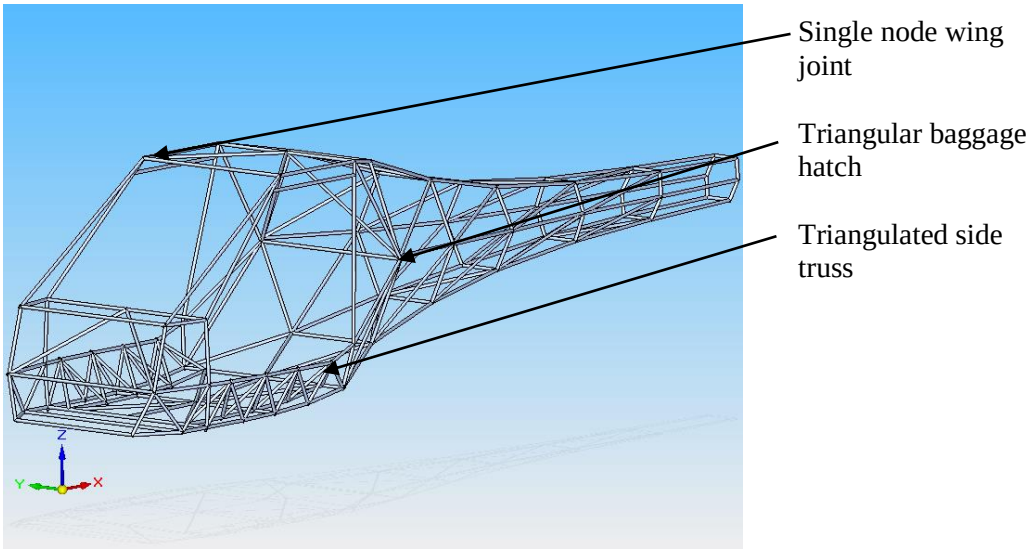


Figure 54. Initial fuselage space-frame design

The space-frame design was improved by removing the fuselage side truss structure and placing a central structure under the console. The space-frame behind the engine was triangulated. The weaker fuselage sides were reinforced by the larger door sill structure. This allowed for less tube to be used for the cabin structure. The final fuselage cabin structural concept is shown in Figure 55. The door sill tubes were positioned farther forward than competitors and were lofted at a flatter angle. This increased the visibility in the lateral plane through the door with a slight reduction in peripheral visibility when looking straight ahead.

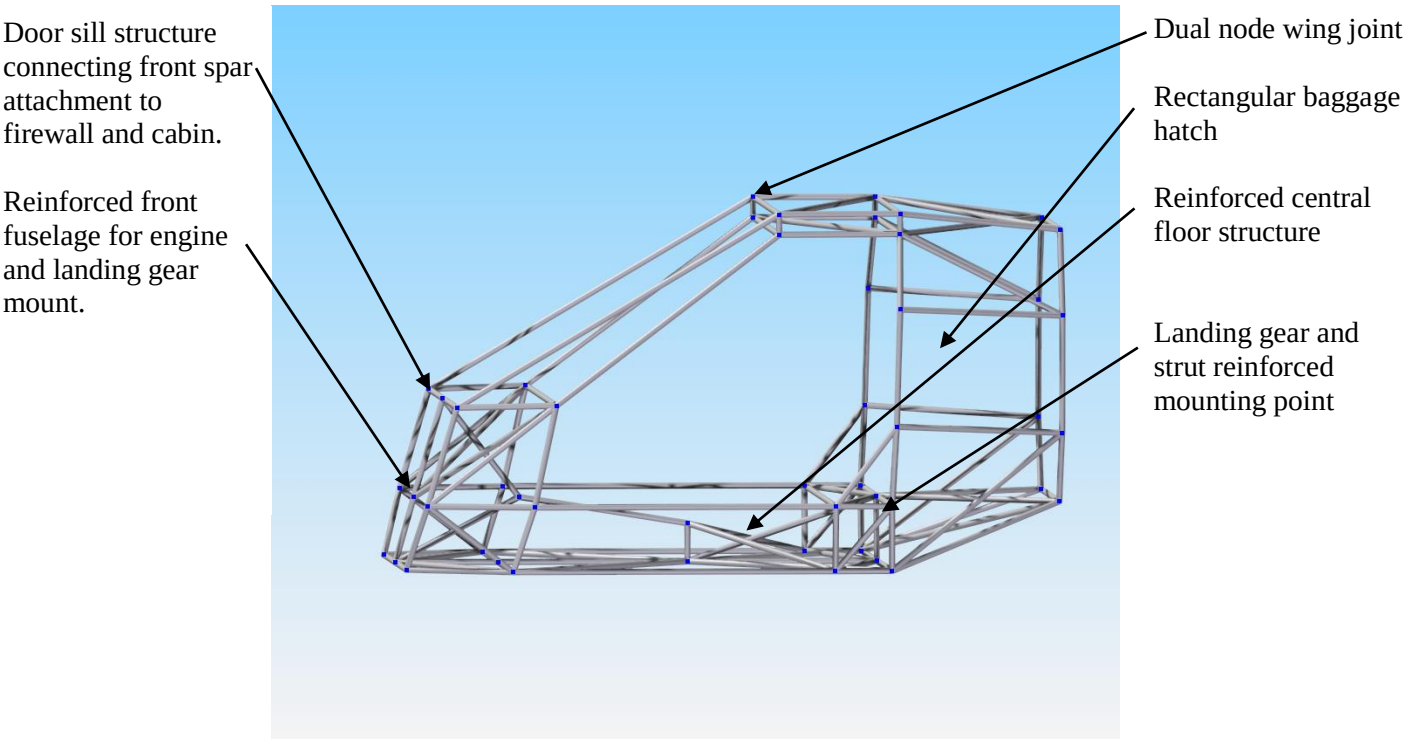


Figure 55. Final cabin space-frame structural concept.

The front fuselage structure is shown in Figure 56. The triangulation of the nose landing gear is visible. The emergency airframe parachute, known as a ballistic recovery parachute system (BRS) has been made available for use on ultralight aircraft. The device uses a rocket to extract a parachute to bring an aircraft down in the event of structural failure, loss of control or engine failure over terrain unsuitable for a forced landing. The BRS systems need to be attached to the airframe such that the centre of mass is between the front and rear attachments. A variety of harness types are available. Composite airframes need to be constructed with channels containing the embedded cables. The cables then tear through the skin when the BRS is used. Aluminium semi-monocoque airframes need to be designed with an un-riveted lap joint covering the cables. The cables then bend the overlap without destruction of the joint. This requires the use of a hat-stiffener. Space-frame fuselages simply need lug attachments on the structure for the cables and the cables need to be contained in a sheath to prevent fretting of the cables or space-frame. The BRS was incorporated into the fuselage behind the occupants, above the baggage compartment. The attachment points for four harness cables are indicated in Figure 56.

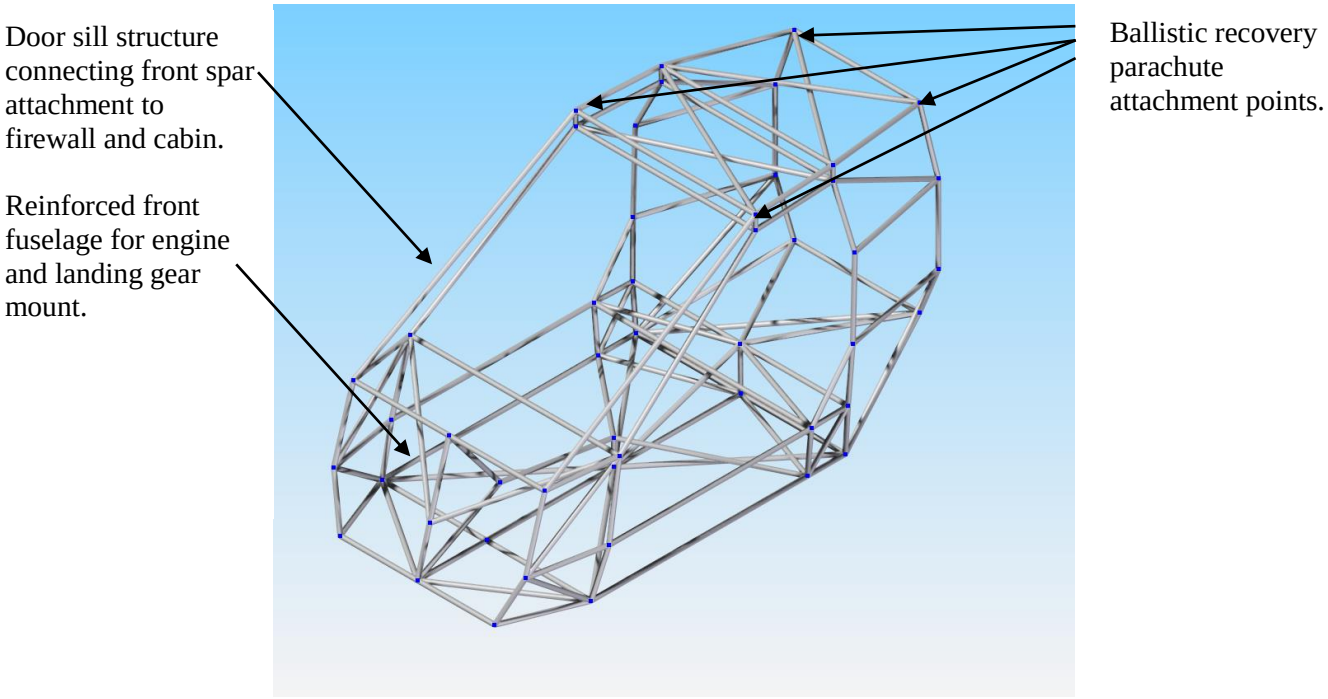


Figure 56. Isometric view of final cabin structural design.

The forward visibility out of the cabin may be seen in Figure 57. The door sill structure attaches to the cabin and firewall at the widest position possible.

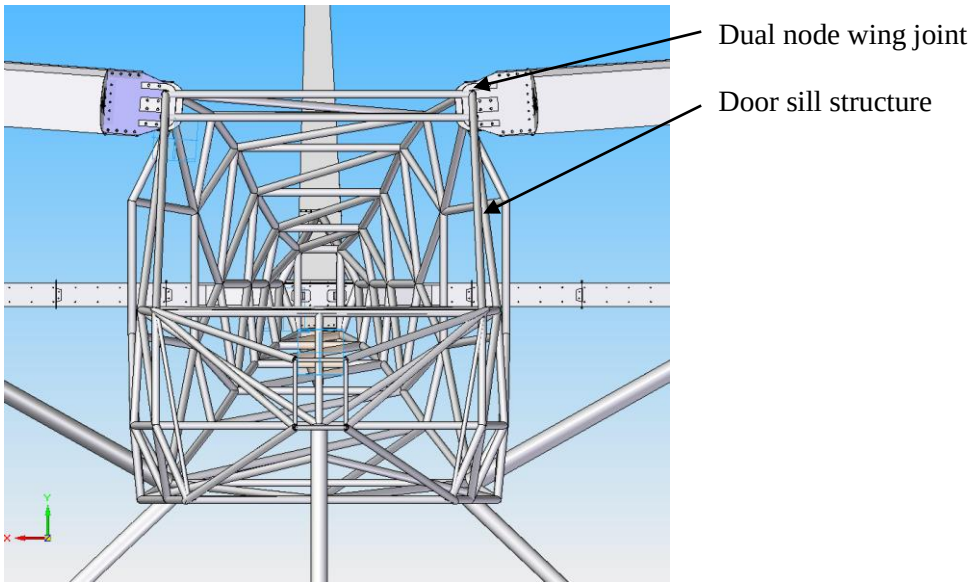


Figure 57. Visibility out of the cabin in the forwards direction.

Figure 58 shows the left wing joint.

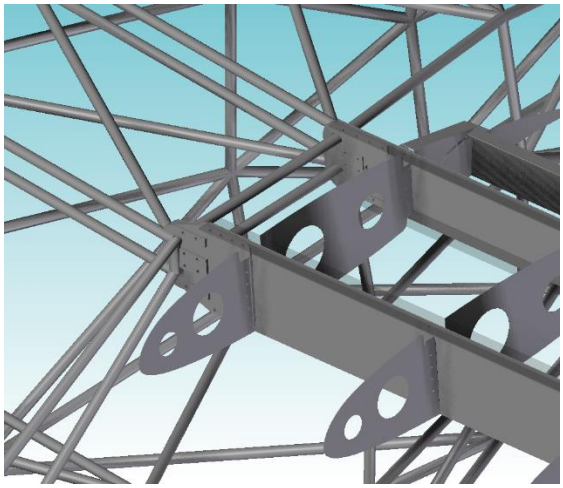


Figure 58. Wing attachment joint.

The space-frame structural concept presented in Figure 59 shows the large doors and wing sweep.

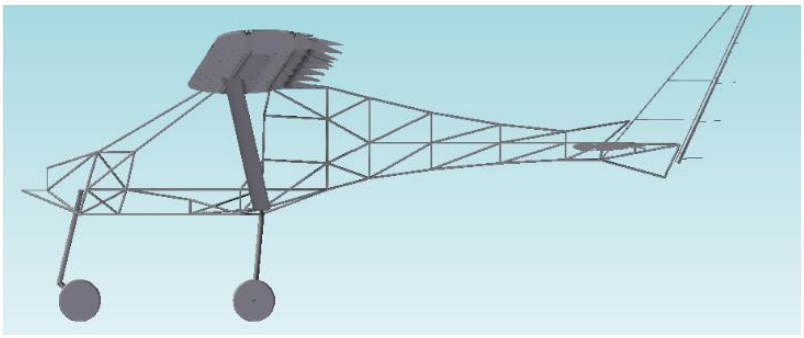


Figure 59. Side view of structural concept.

The visibility in a turn was a major requirement for the recreational and commercial operation. The visibility from the cockpit for both occupants is shown in Figure 60. The occupants are marked on the figure. The door sill structure does not block the view of either occupant into the turn.

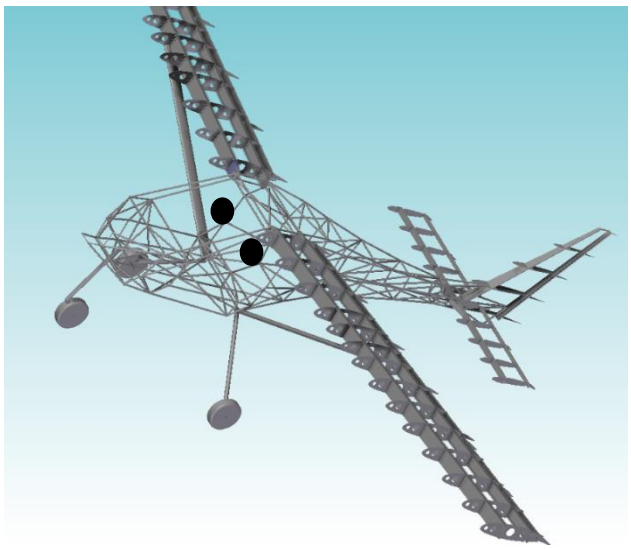


Figure 60. Occupant view during turn manoeuvre.

A novel wingtip was originally developed for this aircraft. The original intention was for a winglet that could be set at any fixed angle by the pilot. The design developed into one suited for commercial aircraft to assist in the early destruction of the wake vortices during take-off and landing phases. To achieve this, the design was able to rotate about several axes in an oscillatory manner. The winglet could also be fixed at any position. Provision was made for the winglet to oscillate randomly and sinusoidally. Following various iterations of the high-level concept design, translation along the chord line was introduced to along for the device to be used for more effective vortex manipulation leading to breakdown. The device would work at the edge of any lifting surface and control surface. A United States patent has been granted for this novel idea. Application *PCT/IB2010/055708* may be found in Appendix C.

4.6. Maintenance considerations

The initial target client for the aircraft would be the flying schools. The South African Civil Aviation Regulations require all non-type certificated aircraft operating in the commercial sector, such as at a flight training school, to be maintained according to the same standard as a type certificated aircraft [59]. The maintenance scheme recommended by a manufacturer must include an approved maintenance schedule (AMS) and a maintenance control manual (MCM). The AMS provides a checklist for regular scheduled maintenance. The MCM provides guidance on the maintenance responsibilities, functions and obligations of the operator.

The considerations given to maintenance during the design were factored into the systems during the design process. The considerations are listed per system:

1. Wing assembly:
    a. The wing strut attachment to the wing needed to be watertight without any surface for water to collect. The attachment needed to be accessible for average size hands and hand tools. Provision needed to be made at the strut position for the wing to be supported during removal of the strut.
    b. The fuel tanks posed an access problem. On traditional aircraft the pilot may stand on the strut to refuel the aircraft or conduct routine inspection or maintenance on the tanks. With the strut removed access to the fuel filler cap and fuel tank would be difficult.
    c. The flaps and ailerons were supported on internal hinges. The hinges for the ailerons and guide rails for the flaps would be accessible through maintenance panels on the lower wing surface. The hinge brackets or guide rails would be disconnected and the flap with hinge attached would be removed. This would make removal less time consuming than the dis-assembly of hinges.
    d. The front spar attachment would be accessible from the cabin, the rear spar attachment would be accessible from outside the cabin. For ergonomic reasons this was deemed easier that having both inside or outside the cabin. Access to the rear spar would also allow for inspection of the ballistic parachute system and cable harnesses.

2. Empennage assembly:
    a. The all-moving horizontal tail would be accessible for maintenance through inspection panels above and below the hinge on the fuselage. Removal of the unit would be achieved by removal of the upper portion of the vertical tail and rudder. The space-frame fuselage would terminate at the tail joint.
    b. The control linkages for the rudder and horizontal tail would run along the lower fuselage space-frame members. Access could be gained from the baggage compartment and the inspection hatches at the tail.
3. Engine bay:
    a. The engine cowling was designed so that the upper cowling could be removed for basic maintenance and the lower cowling would only be removed when required. The angled firewall would ensure that all engine-related systems would be directly behind the upper part of the engine at convenient working height.
4. Landing gear assembly:
    a. The nose landing gear would be accessible for maintenance with the upper cowling removed. Nose landing gear removal would be accomplished after removal of the entire cowling to expose the fasteners attaching the gear. The nose and main landing gear wheels and tyres were specified as being the same to reduce part count and to allow for wheel commonality. Grease points would be located on the upper surfaces to allow for simple greasing.
    b. The main landing gear would be accessible with removal of the fairing over the strut and gear attachment. The jack-point would be located under the strut attachment to allow for the person conducting maintenance to have more legroom and to reduce accidental impact with maintenance equipment such as jacks. The rear seat mounts would be accessible from this maintenance panel. Additional panels would be included behind the seats under the baggage compartment for access to the main landing gear mechanism.
5. Cabin assembly:
    a. The front spar wing joint would be accessible from the seats of the aircraft for removal of the wings.
    b. The control mechanism for the ailerons was designed with a joint at the rear spar joint, this would be accessible from outside the aircraft in the same hatch used for removal of the rear spar. The flap actuator would be housed within the wing and could be accessed through the maintenance panel used for inspection of the flap guide rail.
    c. The instruments would be removed by removing the panel face. This would expose the lattice structure to which the instruments are attached.
    d. The rudder and control stick control linkages would be accessed by removal of the floor panels. The floor was designed with sufficient depth to allow average size hands to access the linkage joints, the linkages would be suspended in the floor space.

4.7. Summary of preliminary design

The final sizing of the aircraft was completed and led to an aircraft that had a lower wing loading than competing LSA. This would give the LSA good performance in hot and high conditions while making it a very good performing ultralight if operated at a reduced maximum take-off mass.

The final orthographic view of the concept aircraft may be seen in Figure 61.

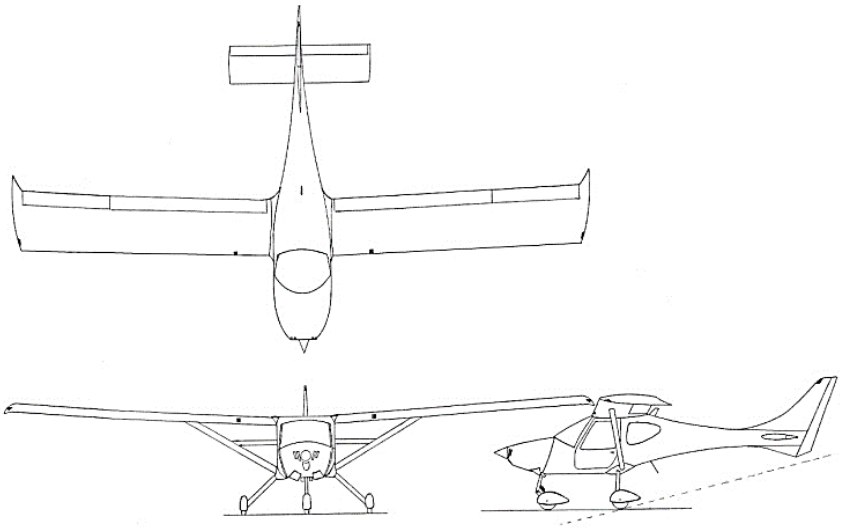


Figure 61. Final 3-view of the aircraft.

The specifications for the aircraft are listed with the same data from the C-162 and P2004 as the current direct competitor products in Table 26. The empty mass of 315kg compares favourably to the competitors. The rate of climb values are presented for a mass of 600kg (900ft/min) and 550kg (1000ft/min).

Table 26. Specifications for the aircraft and C-162 and P2004.

Parameter	Aircraft	C-162	P2004 Bravo
Airworthiness standard	ASTM F2245	ASTM F2245	ASTM F2245
Empty mass	315kg	379kg	331kg
Maximum take-off mass	600kg	600kg	600kg
Payload (occupants and fuel)	335kg (310kg)	221kg	269kg
Engine	Rotax 912 ULS 100hp	Continental O-200	Rotax 912 ULS
Wing span	11.2m	9.26m	8.4m
Length	6.7m	6.73m	6.61m
Aspect ratio	10.18	7.7	6.4
Wing area	12.32m^2	11.14m^2	11m^2
Cruise speed	105kts	112kts	116kts
Maximum rate of climb	900-1000ft/min	890ft/min	1200ft/min
Wing loading (OEW-MTOW)	24-49kg/m^2	43-54kg/m^2	30-55kg/m^2

4.8. Drag coefficient determination

The wing of the aircraft was larger than that of the competitors and had a higher aspect ratio. This allowed for the zero-lift coefficient to be lower than the competitors, the higher aspect ratio and lower wing loading would result in a lower coefficient of drag than the competitors. The larger wing area would unfortunately result is a slightly higher drag magnitude at higher speeds, but would result in lower drag than the competitors at lower speed during take-off, climb and during manoeuvring.

Preliminary performance data for the aircraft has been calculated based on the standard aircraft configuration without optional wheel spats operating in windless International Standard Atmosphere (ISA) conditions. The performance would vary within statistical limits with individual aircraft, factors such as aircraft configuration, atmospheric conditions and Air Traffic Control (ATC) would also affect the performance.

The parasite drag or zero-lift drag coefficient C_{D_0} for a light aircraft is comprised of the skin friction drag, form or pressure drag and interference drag. Skin friction drag is a function of the surface roughness of the aircraft component and the skin friction coefficient C_f. The surface roughness is generally estimated using metrology guidelines and differs for Aluminium skin (round and flush rivets), composite and fabric covering. The skin friction coefficient is determined using the Reynolds number for the aircraft component. The cut-off Reynolds number, determined as the transition between laminar and turbulent flow is compared to the flight Reynolds number, at cruise speed. Two cases generally exist for determination of skin friction coefficient. If the flight Reynolds number is less than the cut-off Reynolds number, the skin friction coefficient is determined using flight Reynolds number. If the cut-off Reynolds number is less than the flight Reynolds number, the cut-off Reynolds number is used. Figure 62 shows the skin friction coefficient as a function of Reynolds number for flow over a flat plate. Skin friction coefficient reduces with increasing Reynolds number.

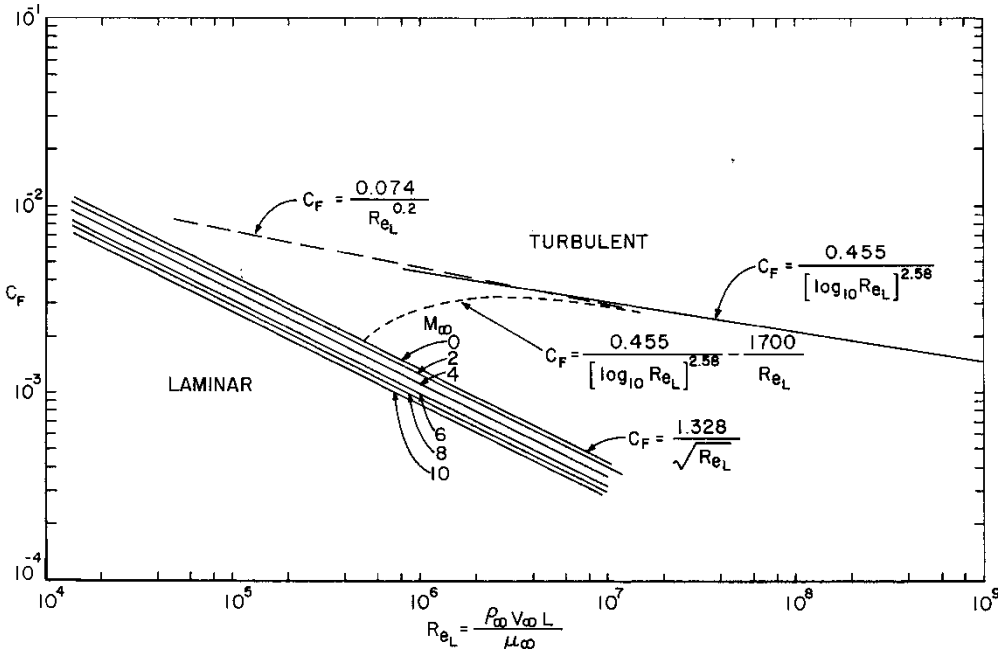


Figure 62. Skin friction coefficient [60]

Roskam [61] developed an equation for C_f where,

$$C_f = \frac{0.455}{\left(\log_{10} R_{e\,cut-off}\right)^{2.58}(1+0.144.M^2)^{0.58}} \quad 1$$

Due to the log-log relationship of the skin friction coefficient lines, the following equation was derived for a small range of Reynolds numbers applicable to light aircraft;

$$Re_{cut-off} = 31.3713 \times \left(\frac{L}{k}\right)^{1.067} \quad 2$$

where L is the characteristic length and k is the skin roughness. k and L must be specified in SI units, generally metres.

The pressure drag contribution is characterised by a form factor Q [61] and differs for a lift producing surface and a body of revolution.

$$Q_{lifting\ surface} = 1 + L\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4 \quad 3$$

The form factor for lifting surface would be used for the wing, empennage and any excrescences that resembles an aerofoil. The t/c is the aerofoil thickness ratio, L is a function of the pressure distribution over the aerofoil and differs between equivalent NACA four and six series profiles.

$$Q_{body\ of\ revolution} = 1 + \frac{60}{\left(\frac{l}{d}\right)^3} + 0.0025\left(\frac{l}{d}\right) \quad 4$$

The form factor for a body of revolution would be used for any component that does not resemble an aerofoil. Components such as the fuselage, wheel spats, aerials or Pitot tube would be considered bodies of revolution. The l/d term is the finesse ratio of the body of revolution.

The bookkeeping drag estimation method involves the summation of the component form factor, skin friction coefficient and wetted area into an equivalent frontal parasite drag area, defined as D/q. The C_{Do} may then be obtained by dividing the equivalent frontal parasite drag area by the reference wing area. This yields a parasite drag coefficient that can be added to the induced drag coefficient. Aircraft components may be added or subtracted from the overall equivalent frontal parasite drag area as required. To add a component to the airframe, the frontal area and parasite drag coefficient of the item needs to be known. These can be summed to a micro equivalent frontal parasite drag area that may be directly added to the macro equivalent frontal parasite drag area. Once that is divided by the wing reference area the C_{Do} of the airframe with the addition is then given by:

$$C_{Do} = \frac{\Sigma[Q.C_f.S_{wet}]}{S_{ref}} = \frac{D}{q.S_{ref}} \quad 5$$

The total clean aircraft drag coefficient is thus;

$$C_D = C_{Do} + \frac{C_L^2}{\pi.AR.e} \quad 6$$

The geometry of the major external components of the aircraft are presented in Tables 27-33. These measurements and wetted areas were used to calculate the zero-lift coefficient of drag.

Table 27. Wing geometry.

Wing	**Specification**
Mean aerodynamic chord	1.1m
Chord tip	1.1m
Chord root	1.1m
Taper ratio	1.0
Semi-span	5.6m
Panel area	6.16m^2
Area of fuselage	2.64m^2
Thickness ratio	0.17
Pressure distribution factor	1.2
Wetted area	22m^2

The wetted area of the wing was calculated with the exclusion of the roof section of the fuselage. The strut geometry listed in Table 28 includes a parasite drag coefficient for an elliptical cylinder. The flow over an ellipse is not the same as for a cylinder. The angle of attack range was used to create an average C_D for the strut. The D/q for the strut would be the sum of total frontal area and the drag coefficient.

Table 28. Wing strut geometry.

Struts	**Specification**
Thickness	0.04m
Length	2m
Parasite coefficient of drag [62]	0.3
Frontal area	0.16m^2

The wetted area of the fuselage was obtained using a method of summation of trapezoidal areas. The method developed required two orthographic views of the fuselage. The two base dimensions were obtained from the two orthographic views of the same fuselage station. These base dimensions were converted into an equivalent diameter for an ellipse of the same circumference. This provided the base dimension for one of the parallel edges of a trapezium. The procedure was repeated at another span station to provide the dimension for the other parallel edge of the trapezium. The linear distance between span stations provided the height of the trapezium. The area could then be easily calculated. The method was derived for calculating complicated wetted areas for a variety of second and third generation jet fighters. The wetted areas were compared to the values obtain by Roskam [61]. The method achieved very good correlation. The additional advantage of dividing the fuselage into a lot of small sections is that changes can easily be incorporated into the design. The summarised fuselage geometry is presented in Table 29.

Table 29. Fuselage geometry.

Fuselage	**Specification**
Length	6m
Mean diameter	1.2m
Finesse ratio	5.0
Wetted area	16.22m^2

The wetted areas for the horizontal and vertical empennage was calculated in the same way as for the wing. The geometry is presented in Table 30 and 31.

Table 30. Horizontal empennage geometry.

Horizontal empennage	**Specification**
Mean aerodynamic chord	0.65m
Chord tip	0.65m
Chord root	0.65m
Taper ratio	1.0
Semi-span	1.35m
Panel area	0.878m^2
Area deduction due to fuselage	0.117m^2
Thickness ratio	0.12
Pressure distribution factor	2
Wetted area	3.393m^2

Table 31. Vertical empennage geometry.

Vertical empennage	**Specification**
Mean aerodynamic chord	0.840m
Chord tip	0.32m
Chord root	1.15m
Taper ratio	0.28
Semi-span	1.18m
Panel area (including rudder behind fuselage)	1.12m^2
Thickness ratio	0.12
Pressure distribution factor	2
Wetted area	2.240m^2

The equivalent frontal parasite drag area for the wheels and tyres was calculated by using the frontal drag coefficient of a short cylinder with rounded edges resembling a square ellipsoid from the front. The configuration used did not have wheel spats. Most aircraft used for flight training do not use spats. The geometry for the wheels and tyres is presented in Table 32.

Table 32. Tyre and wheel geometry.

Wheels	**Specification**	
	Nose	**Main**
Width	0.13m	0.13m
Diameter	0.36m	0.36m
Parasite coefficient of drag	0.5	0.5
Frontal area	0.0374m^2	0.0749m^2

The landing gear leg equivalent frontal parasite drag area was calculated using the same procedure used for the wing struts. The geometry is presented in table 33.

Table 33. Landing gear structure geometry.

Landing gear legs	**Specification**	
	Nose	**Main**
Diameter	0.05m	0.05m
Length	0.8m	1.2m
Parasite coefficient of drag	0.3	0.3
Frontal area	0.016m^2	0.048m^2

The form factor, flight Reynolds number, cut-off Reynolds number and skin friction coefficient were determined for the cruise condition of 105KCAS. The equivalent parasite drag areas were determined from the product of skin friction coefficient, wetted area and form factor. The wing, empennage, strut and fuselage calculation is presented in Table 34. The strut equivalent parasite drag area was determined directly from the parasite drag coefficient and frontal area.

Table 34. Bookkeeping drag breakdown of the wing, empennage and fuselage of the aircraft.

Component	**Q (form factor)**	**k (skin roughness) [m]**	**$Re_{cut-off}$**	**C_f (skin friction coefficient)**	**S_{wet} [m^2]**	**D/q [m^2]**
Wing	1.288	$0.787x10^{-6}$	$0.831x10^6$	$4.591x10^{-3}$	22.0	0.1301
Horizontal empennage	1.261	$0.787x10^{-6}$	$0.474x10^6$	$5.117x10^{-3}$	3.39	0.0219
Vertical empennage	1.261	$0.787x10^{-6}$	$0.623x10^6$	$4.851x10^{-3}$	2.24	0.0137
Fuselage	1.493	$0.787x10^{-6}$	$5.08x10^6$	$3.328\ x10^{-3}$	16.22	0.0806
Wing struts	n/a	$0.787x10^{-6}$	$24.2x10^3$	$9.965\ x10^{-3}$	n/a	0.0039

The landing gear drag breakdown is presented in Table 35. The equivalent parasite drag area was determined directly from the parasite drag coefficient and frontal area of each component. The calculation was done for an aircraft not equipped with wheel spats.

Table 35. Bookkeeping drag breakdown of the landing gear of the aircraft.

Component		**D/q [m^2]**
Wheels and tyres	Nose	0.018
	Main	0.037
Landing gear	Nose	0.012
	Main	0.036

The interference drag created adverse pressure gradients in the location of the wing and empennage joints and at the strut attachment was estimated at 10%. The excrescence drag due to lights, latches, hinges, skin overlays, pitot tubes, aerials, rivets, exhaust pipes and cowling gaps was estimated at 10%. These two drag contributors are independent of angle of attack. The relative contribution is not as important as the net contribution. Glide tests conducted on the Airplane Factory Sling 4 indicated that the combined contribution of interference and excrescences was approximately 25% after deduction of the elevator trim drag [63]. Flight data was extracted (from another project) and used to determine the zero-lift drag coefficient of the Skyworx SW-18. The combined contribution of interference and excrescences was determined to be 20%. The fabric skin led to a higher skin friction coefficient. This aircraft has the skin friction properties of the Sling so 20% was used to allow for the strut. The final zero-lift drag coefficient is presented in Table 36.

Table 36. Zero-lift coefficient of drag determination.

C_{D_0} calculation	**Input**	**D/q [m^2]**
Interference	10%	0.0359
Excrescences	10%	0.0359
Total D/q		0.3594
Zero-lift drag coefficient		0.0359

The published zero-lift drag coefficient for the Cessna 150 is 0.0327 [61]. This is expected since the C-150 has a larger wing than the aircraft. The aircraft efficiency for the aircraft and the Cessna 150 is shown in Figure 63. The aircraft has a better lift/drag ratio at higher lift coefficients.

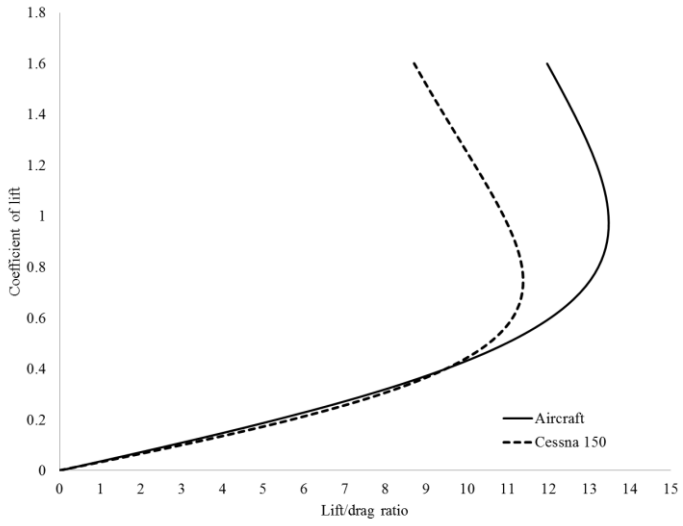


Figure 63. Aircraft lift/drag ratio.

4.9. Aircraft mock-up for marketing purposes

Once the design of the primary structure was complete, students were employed to build a full-scale mock-up of the aircraft. The budget and expenditure is presented in Table 37. The aircraft was launched in Somerset East and at Africa Aerospace and Defence 2010. The project was funded by the Blue Crane Development Agency and Industrial Development Corporation. The project was completed under budget.

Table 37. Budget for the mock-up project

Item	Budget	Expenditure
Design	R 20 280	R 20 280
Students - vacation work	R 24 624	R 24 624
Material	R 55 000	R 33 331
Per diem Somerset East	R 4 760	R 4 830
Per Diem AAD 2010	R 11 550	R 9 056
Vehicle fuel costs SE	R 2 416	R 2 371
Vehicle fuel costs AAD	R 4 528	R 3 984
Vehicle rental AAD	R 11 918	R 12 657
Trailer rental	R 2 900	R 3 600
Sub-Total	R 38 072	R 36 498
TOTAL	**R 137 976**	**R 114 734**

The aircraft was manufactured from 1010 grade steel alloy square tube to allow for inexperienced students to profile the tubes more easily prior to welding. The surfaces including the wings, flaps, ailerons and both tail surfaces were constructed using polyurethane foam, finished with glass fibre and gel-coat. The construction of the fuselage and wing is shown in Figure 64.



Figure 64. Fuselage and wing manufacture

For the fuselage, the steel frame was covered in two-component expanding polyurethane foam, used for taxidermy. Sections of foam sheet were then bonded to the expanding foam before being sanded and finished in glass fibre and gel-coat.



Figure 65. Cowling before and after sanding

The aircraft mock-up was displayed in Somerset East, at the Africa Aerospace and Defence 2010 and at the Industrial Development Corporation, a funder of the project.



Figure 66. Mock-up on display at Africa Aerospace and Defence 2010



Figure 67. Upgraded mock-up displayed at the Industrial Development Corporation



Figure 68. Marketing image of the side view.

4.10. Aircraft business case

Two full business plans were done for the aircraft as it developed. The latter one is attached as Appendix D. The summary of the business case is presented.

At the time the closest performing competitors were the FK- 9, Tecnam P92, P2004 and the Cessna 162 Skycatcher. These aircraft are priced above R 780,000. The pricing and market analysis indicated that Cessna sold more Skycatcher aircraft than the higher performing FK-9. In addition, the best-selling aircraft was the Jabiru J170, which had average ratings in terms of construction, operation and ownership criteria. This analysis seems to indicate that the higher performance end of the market, there is a degree of compromise between pricing and performance.

The Jabiru J170 also sold better than lower priced, medium performance aircraft such as the Bush Baby, Cheetah, Zodiac and Ikarus C-42. This would imply that at the lower end of the price market, performance remains an important consideration.

The conclusion of this analysis is that there are two market segments in which the aircraft could compete:

- Against the high performance, high price aircraft such as the Tecnam P92, P2004 and Cessna Skycatcher by offering a more competitively priced aircraft with similar performance.
- Against the lower priced, medium performing aircraft such as the Zodiac and Bush Baby by offering a higher performing aircraft for a competitive price.

The aircraft was named SkyWake, the name and logo were registered as trademarks and the aircraft design was registered [64]. The pricing is summarised in Figure 69. The SkyWake was pitched at being the cheapest LSA in the market. If operated in the ultralight aircraft category the aircraft would be cheaper than the best-selling Jabiru J170. The aircraft would be slightly more expensive that the fabric covered Cheetah XLS, but with a 30kt higher cruise speed.

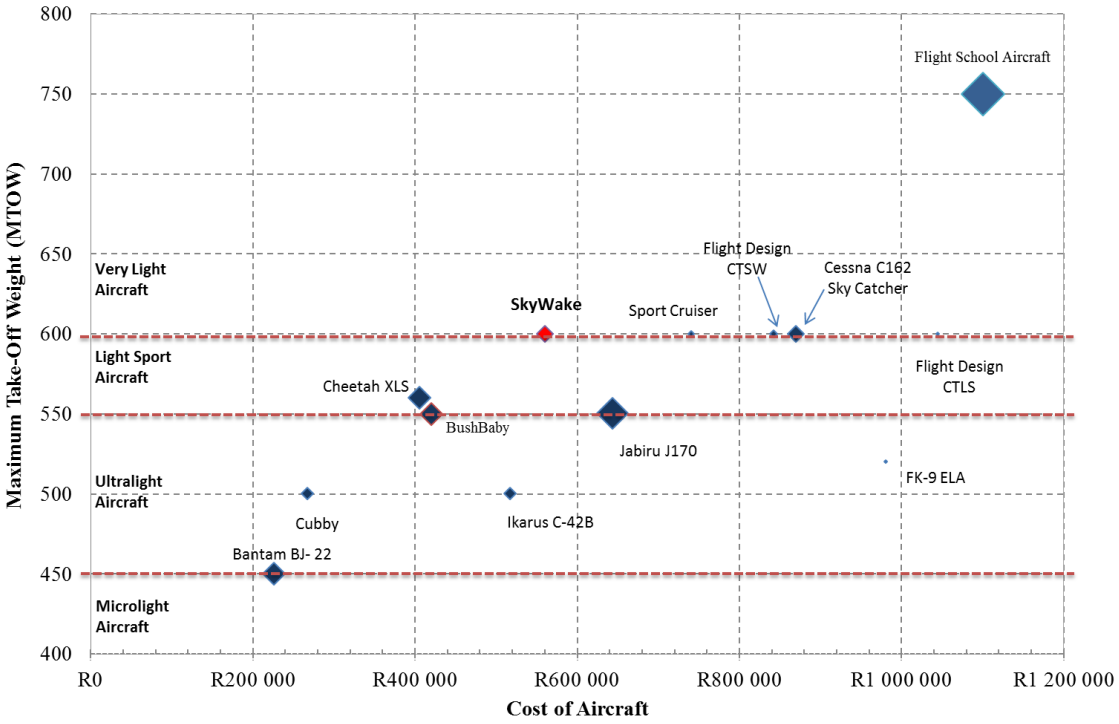


Figure 69. Pricing in the market [65]

The sales forecast and cash flow breakdown analysis presented in Figure 70 was based on a sales forecast based on the market share analysis [65].

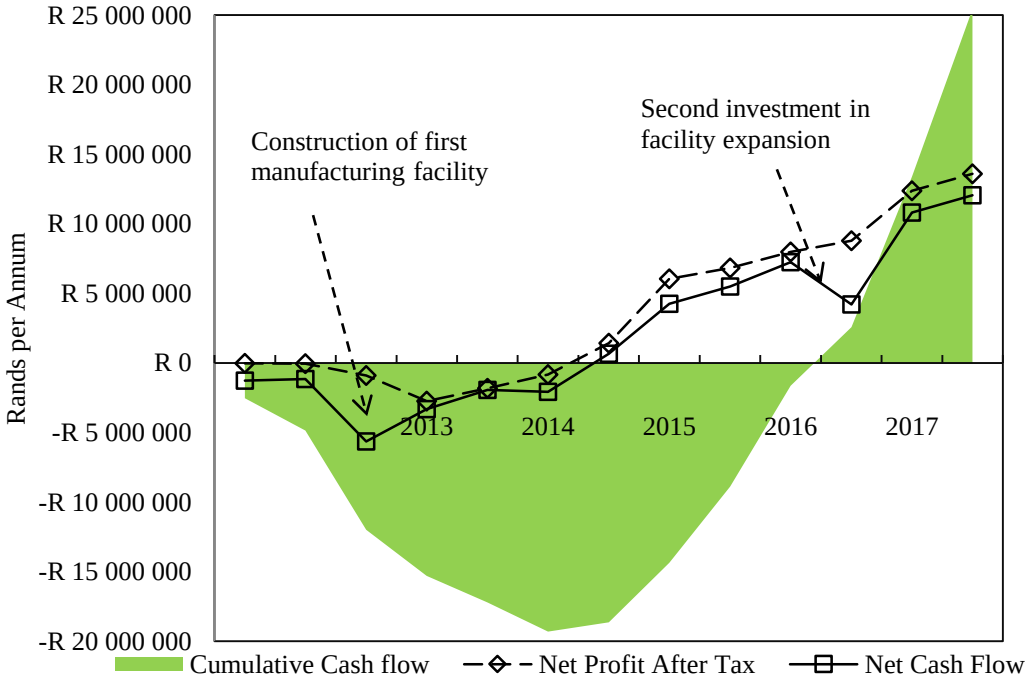


Figure 70. Cash flow breakeven analysis [65]

The profit per aircraft was calculated based on the net difference between the cost per aircraft and the net selling price. Figure 71 indicates the total cost per aircraft and the predicted bi-annual sales.

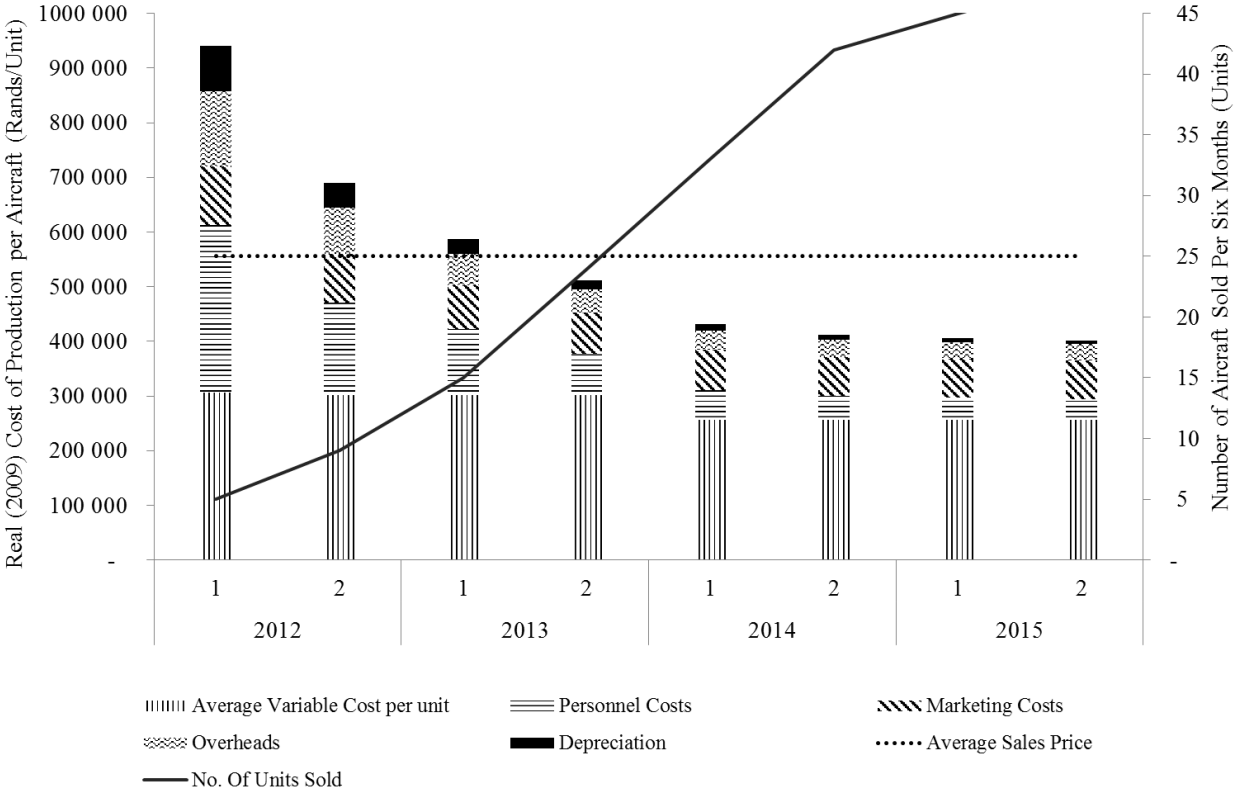


Figure 71. Cost per aircraft [65]

The components for the aircraft were sourced from suppliers of the components. The contribution to airframe cost is presented in Figure 72. The largest contributor to airframe cost was the Rotax engine.

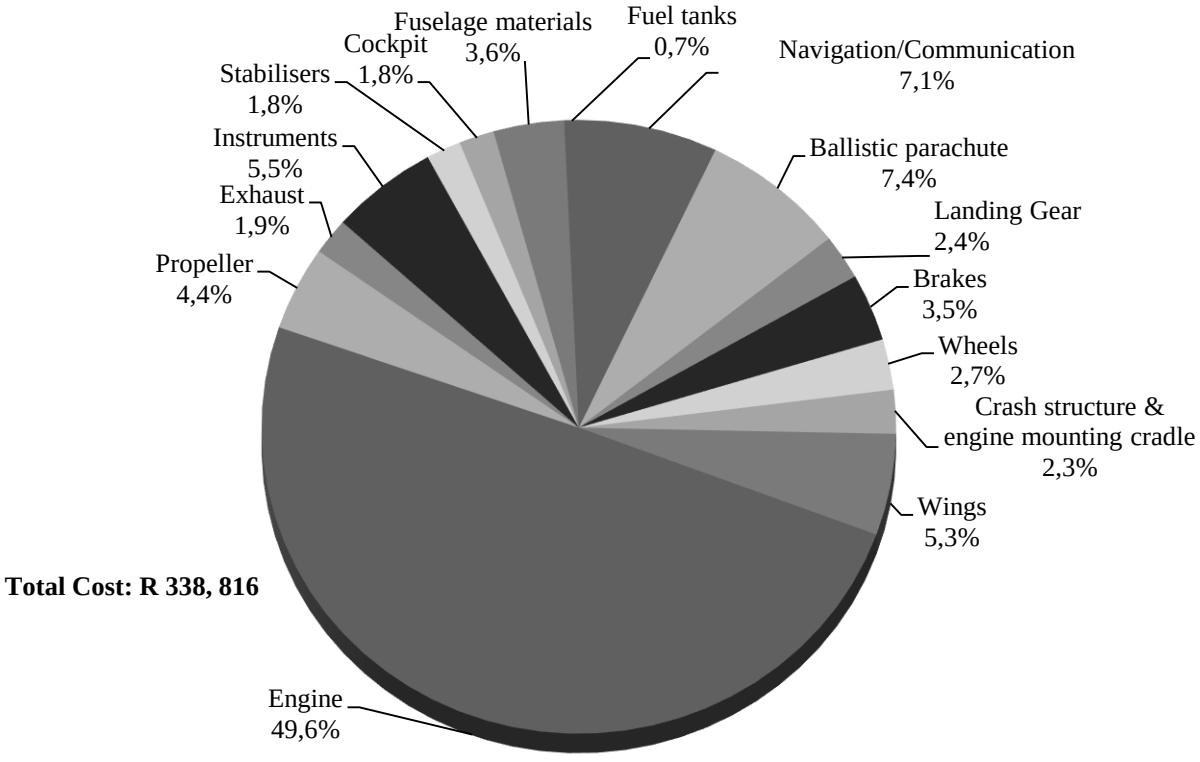


Figure 72. Material component cost breakdown in 2009 [65].

The breakdown of instrument costs is presented in Table 38. The instruments are for a complete set of analogue gauges and indicators. This would be the typical minimum instrument equipment required for the aircraft to be used for flight training, which is classified as commercial activity. Recreational users could specify lower cost instruments. The EFIS was not included, but would cost approximately R50 000 [66].

Table 38. Instrument cost breakdown [65].

Instruments	**Total**	**R 42 505**
Engine	Oil pressure	R 1 966
	Oil Temperature	R 478
	Ammeter	R 190
	Tachometer	R 1 286
Flight Instruments	Altimeter	R 3 103
	Air Speed indicator	R 1 064
	Artificial horizon	R 3 978
	Direction indicator	R 3 761
	Vertical speed indicator	R 1 645
	Compass	R 553
	Slip indicator	R 481
Navigation/Communication	Nav/Com	R 24 000

The cost of the components for the fuselage is presented in Table 39. The cockpit equipment was sourced from suppliers to ultralight kit builders. The BRS was included in the aircraft as mandatory. The unit was fairly heavy, to keep the centre of mass in the correct position heavy safety items were not made optional. The material costs for the landing gear components were obtained from suppliers of wheels, tyres and brakes [67].

Table 39. Fuselage component cost breakdown [65].

Fuselage	**Total**	**R 82 570**
Cockpit	Seatbelts	R 580
	Seats	R 2 000
	Fire extinguisher	R 295
	First aid kit	R 200
BRS	Ballistic parachute system	R 25 000
Lighting		R 3 000
Fuel tanks		R 2 500
Landing gear	Gear	R 8 000
	Brakes	R 12 000
	Wheels	R 8 000
	Spats	R 1 000
Material costs	Fuselage and engine cradle	R 7 792
	Tail Boom	R 3 384
	Fuselage skin	R 3 119
	Cowling, doors	R 4 200
	Windows and Windscreen	R 1 500

The cost of the material for the landing gear, spats and material for the fuselage was based on quotations obtained from manufacturers during the research phase of the business plan.

The material cost for the wing is presented in Table 40. The cost was calculated after calculating the thickness of the wing, flap and aileron skins and ribs. The cross-sectional area of the stiffeners was calculated. Using standard thickness sheet of standard size the number of sheets of Aluminium was determined. The total length of stiffener material was determined by constraining all stiffeners to the same profile. The strut was positioned to manipulate the shear force and bending moment reaction loads such that the stiffener area could be standardised for front and rear shear webs without a large mass penalty.

Table 40. Wing material cost [65]

Wing	**Total**	**R 18 038**
Material costs	Struts (Streamline Tubing)	R 5 875
	Wings	R 10 663
	Fillets and Wingtips	R 1 500

The cost of the material required for manufacture of the horizontal and vertical tail assemblies is presented in Table 41. Standard thickness Aluminium sheet of standard size was used for the two empennage surfaces.

Table 41. Empennage material cost [65].

Vertical Stabiliser	**Total**	**R 2 410**
Material costs	Vertical Stabiliser	R 2 410
Horizontal Stabiliser	**Total**	**R 3 593**
Material costs	Horizontal Tail	R 3 593

The Rotax 912s engine was selected for the aircraft. The engine system cost is presented in Table 42. The engine and propeller combination was specified without option for a cheaper unit so that the aircraft would qualify for production–built approval from the SACAA. The cost for the exhaust was sourced from the same manufacturer as the fuselage.

Table 42.Basic engine system cost [65].

Engine	**Total**	**R 189 700**
Rotax 912 ULS		R 167 000
	Propeller	R 15 000
	Exhaust	R 6 500
	Battery	R 1 200

The bill of material may be found in Appendix E.

There were many components that were not included in the cost. These items included; control linkages, internal haberdashery and finishes, fasteners, rivets, engine mount, wire harness and paint. These items were factored into the labour cost since they would be manufactured by the company. The electronic trim actuator for the horizontal tail was not included in the cost because the unit would be developed for the aircraft.

The cost sensitivity was analysed against the estimated total investment amount of R15 million and is presented in Figure 73. The highest impact index parameters were selling prices and variable cost. These would have a larger impact than the exchange rate. The majority of components would be sourced from suppliers in the Unites States of America, the engine would be sourced from Austria. A local supplier was found for the initial purchase of engines, instruments and materials. Once the company was launched, the company would import directly.

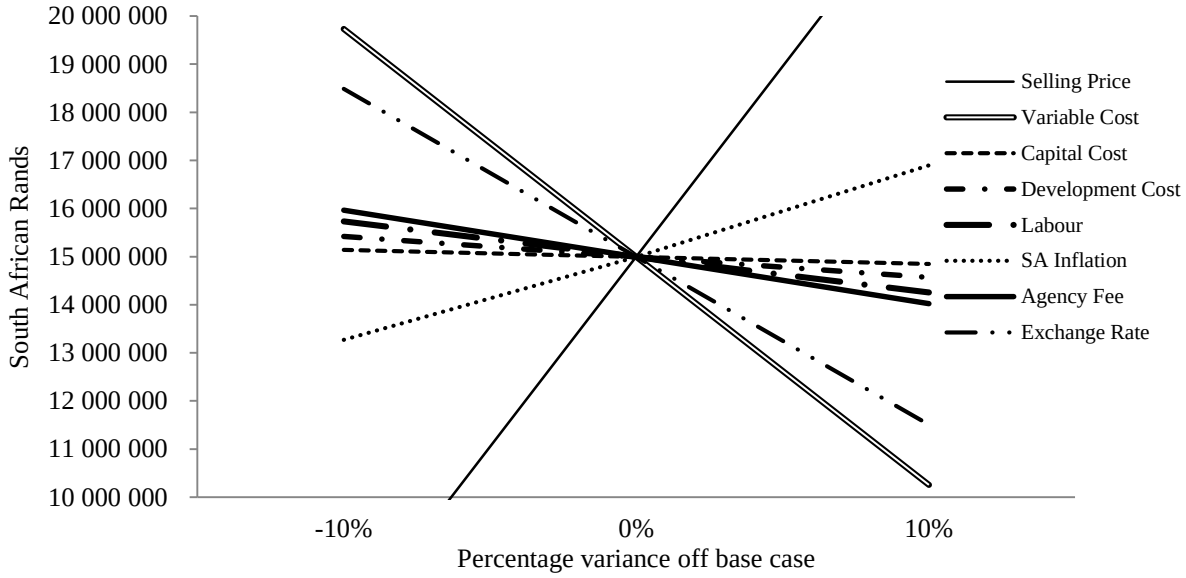


Figure 73. Cost parameter sensitivity [65]

Lastly a manufacturing facility was designed with production bays rather than an assembly line. The wings and empennage would be manufactured in a sheet-metal section. The engine mount, landing gear and fuselage would be manufactured in a steel-tube section. The sheet-metal processing would involve cutting, forming and bending, tube processing would involve notching and profiling. A composite materials section was included for manufacture of the interior, wingtips and fairings. All components would share a paint section. The electrical section would be where the wire harness and assembly of the instrument panel would occur. Ergonomics were considered in the design of the plant layout.

Material processing would occur next to the assembly area for the component. Assembly would take place in an open space adjacent to the front of the plant. Included in the plant layout was a design office and provision was made for all the responsible persons required by the SACAA for DO and MO approval. The plant was sized for initial production rates. The second facility shown in Figure 70 would be a duplicate facility without the office space.

The initial tooling investment was estimated at R340 000 with full production manufacturing labour costing R108 000 per month for the 18 employees. The report for the proposed manufacturing facility with equipment list may be seen in Appendix F. Figure 74 indicates the floor plan required for the facility to manufacture the aircraft.

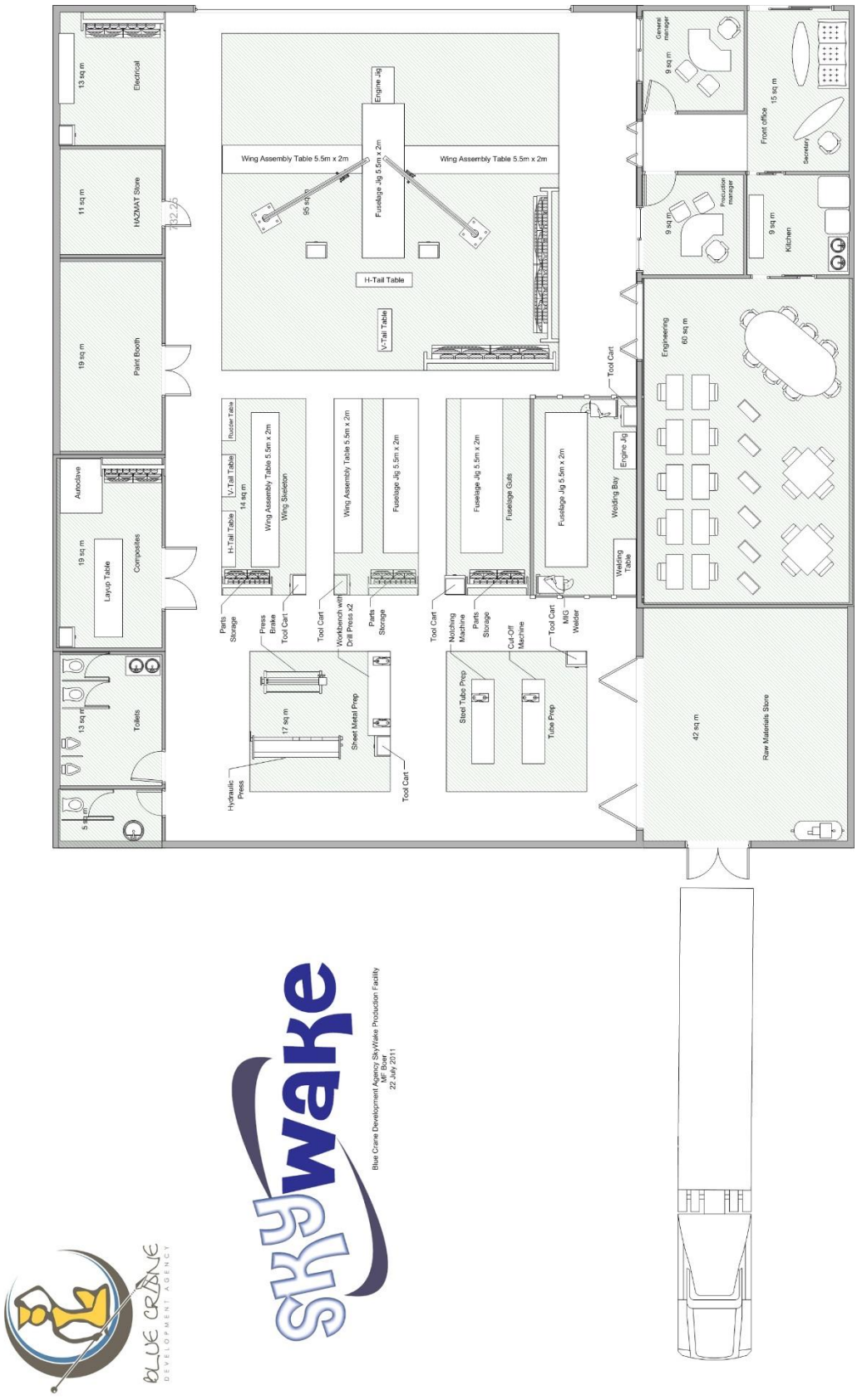


Figure 74. Aircraft assembly facility.

5. Detailed design

The design of this aircraft was undertaken as a commercial activity by the University. The design analysis was limited to software permitted for such use such as the Microsoft Office suite. The University procured a single commercial license for Solid Edge version 19 for production of manufacturing drawings. This was done at the conclusion of the design. The use of any numerical simulation was not permitted due to the restrictions imposed by academic software licenses, which do not allow their use on work for commercial gain. To analyse the space-frame fuselage, the results from another LSA that was re-designed as an academic and educational research project is presented. The method followed was the same used for this aircraft. The analysis was done with a student version of the Prokon package, a finite element solver specifically designed for use in Civil Engineering applications.

5.1. Airworthiness regulation

The design of the aircraft needed to comply with the 1997 South African Civil Aviation Regulations:

Part 24.01.2 relating to airworthiness requirements of NTCA states:

"(5) The design criteria and the build standard for an amateur- or production-built aircraft must –

(a) comply with the appropriate design criteria as prescribed in Document SA-CATS-NTCA;

(b) comply with any special conditions prescribed in terms of Regulation 24.02.4 by the Commissioner or, if applicable, the organisation designated for the purpose in terms of Part 149 of the CAR, 1997, as the case may be; and

(c) incorporate no feature or characteristic that makes the aircraft type unsafe for its intended use.

(6) Production-built aircraft may not be delivered to the public by a manufacturer or agent unless the aircraft has been registered in the name of the new owner: Provided that this restriction shall not apply in the case of the sale of a plan according to an approved build standard, in which case the provisions of sub-regulation (4)(a) applies." [68].

Due to the aircraft being designed as a LSA, the ASTM F2245 was used for compliance as the design criteria. The build standard required for an amateur-built aircraft differs from that for a production-built aircraft. The owner of an amateur-built aircraft assumes responsibility for the build standard whereas the company (MO) assumes responsibility for the build standard of production-built aircraft. The build standard for a prototype aircraft of a production-built aircraft will be different to the final build standard accepted by an aviation authority for the design to be approved as a production-built aircraft. This process allows for the development costs to be reduced. The analysis of the airworthiness of the aircraft was the focus of the work in this report. For the build standard to be developed, the aircraft components would be tested before the build standard could be confirmed.

5.2. Analysis of performance

5.2.1. Field performance

Field performance of an aircraft consists of several phases of flight. The take-off distance includes the ground run and airborne phases. The ground run consists of acceleration from the initial stationary position to lift-off velocity under maximum power. The airborne phase consists of an accelerated climb from lift-off velocity to obstacle velocity with a height gain to clear an obstacle of specified height. Within the ASTM standards the reference speeds are slightly different to FAR23 reference speeds. The reference take-off speed is not prescribed, the reference speed most appropriate is V_{Sl} which is defined as the minimum controllable flying speed for the aircraft in a given configuration. The configuration could vary according to the pilot's choice of flap deflection for take-off. Flap deflection for take-off is optional for most light aircraft. The ground run reference speed would need to be greater than V_{Sl} for the take-off aircraft configuration. The airborne phase reference speed was given as $1.3V_{Sl}$ as a minimum.

The landing distance includes an airborne phase with a constant velocity power glide from a specified obstacle height to a short flare manoeuvre before impact and a ground roll phase where the aircraft decelerates using brakes to a stationary position. The reference speed at the obstacle height must be no less than $1.3V_{SO}$ where V_{SO} is the minimum controllable airspeed in the landing configuration.

5.2.2. Thrust estimation

Propeller engine thrust can be derived from the power coefficient and the propeller advance ratio. The power coefficient is a function of the engine power, air density, propeller rotation speed and propeller diameter. The power coefficient is a useful coefficient if the engine properties are known. The commonly available data such as rotation speed and power can be used to calculate the C_P. [61]

$$C_P = \frac{P}{\rho.n^3.d^5} \qquad 7$$

Where P is power in W, n is propeller revolutions per second and d is propeller diameter in metres. Advance ratio is a measure of forward flight speed against the rotational speed of the propeller. [61]

$$J = \frac{V}{n.d} \qquad 8$$

where V is in m/s. [61]

The propeller efficiency η_P for a given flight condition may be determined from the intersection of power coefficient and advance ratio using Figure 75. The chart may also be used for determining the blade angle that would achieve the required efficiency at the desired speed.

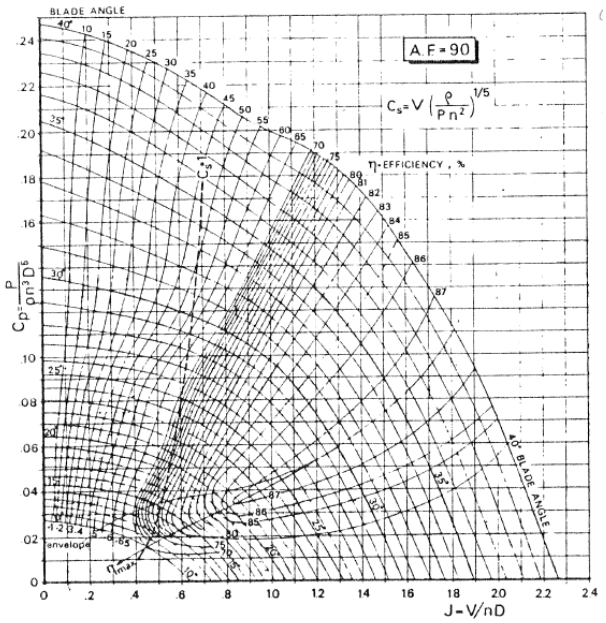


Figure 75. Propeller efficiency curve. [71]

This propeller efficiency is the ideal propeller efficiency. Using the thrust equation, the ideal thrust may be calculated. [61]

$$T = \frac{\eta_P . P}{V} \qquad 9$$

where T is in N and velocity V is in m/s.

The propeller slipstream interacts with the aircraft structure behind the propeller. Roskam proposed a correction method for the scrubbing of air over the fuselage and empennage [61]. Based on flight test data from a Piper J-3 Cub, the equation was modified for excrescences typically found on light aircraft such as door handles, door hinges and sharp changes in surface geometry. The final form being; [61]

$$F_{scrubbing} = 1 - 1.558\left(\frac{\sigma.0.015.S_{wet}}{d^2}\right) \qquad 10$$

Thus $\eta_{P\,real} = \eta_P . F_{scrubbing}$, where S_{Wet} is in m^2 and d is in m.

The method used for the prediction of static thrust was to use the C_P and the relationship of power coefficient to thrust coefficient to determine a static thrust. The equation was derived from Roskam [61]:

$$T_{static} = 227.56\left(\frac{C_P}{C_T}\right)\left(\frac{P}{n.d}\right) \qquad 11$$

where P is in Hp.

The activity factor for a Cessna 150 (AF=77 [61]) was used since the propeller rpm, diameter and power was similar. The static thrust predicted using this method was corrected for scrubbing.

5.2.3. Effect of high-lift devices

The method of calculating the lift contribution from a trailing edge flap used a span ratio of flap span to the wing span and a flap factor based on the type of flap used. The equation being: [61]

$$\Delta C_{L\,flap} = \frac{\partial C_{L\,max}}{\partial \delta_{flap}} . \delta_{flap} . \frac{b_{flap}}{b_{wing}} \quad 12$$

Where the $\frac{\partial C_{L\,max}}{\partial \delta_{flap}}$ factor was approximated at 2.2/Rad because the flap geometry selected was not the pure rotation of a simple or plain flap. The flap translated and rotated, but not with the same motion as a single slotted flap. The lift contribution method described by Roskam [61] differs in that the method uses area ratio instead of flap ratio. For the same net lift coefficient, the $\frac{\partial C_{L\,max}}{\partial \delta_{flap}}$ factor was calculated.

The drag contribution from the flaps was developed from the Roskam method. The flap parasite drag due to its deflection from the reference chord line of the wing was added to the induced drag from the lift coefficient produced by the flap deflection using the induced term in equation 6. The parasite drag was calculated using flat plate drag theory where:

$$C_{Do\,flap} = 1.1 \left(sin\left(\delta_{flap}\right)\right)^2 \left(\frac{S_{flap}}{S_{wing}}\right), \text{ modified from [61].} \quad 13$$

Induced drag from the wing was added to this contribution and this was summed with the zero-lift coefficient of drag of the aircraft. For any flap deflection, the drag coefficient would be:

$$C_D = C_{Do\,clean} + C_{Do\,flap} + \frac{{C_{L\,flap}}^2}{\pi . AR_{flap} . e_{flap}} + \frac{\left(C_{L\,wing} - C_{L\,flap}\right)^2}{\pi . AR . e} \quad 14$$

Where the first three terms would be constant for a given flap deflection. The take-off ground run equation was derived from Dommasch [69] and is denoted S_{GR}.

$$S_{GR} = \frac{M . {V_{LO}}^2}{g . (T_o + T_{LO} - D_o - D_{LO})} \quad 15$$

Where T_o and T_{LO} are the thrust values corresponding to static and to lift off conditions. D_o is the rolling friction and D_{LO} is the parasite aerodynamic drag at lift off velocity.

The take-off airborne phase is denoted S_{GA}. The drag during the airborne phase would include parasite drag and lift-induced drag.

$$S_{GA} = \frac{M . \left(h + \frac{\left({V_{OBS}}^2 - {V_{LO}}^2\right)}{2.g}\right)}{(T_{LO} + T_{OBS} - D_{LO} - D_{OBS})} \quad 16$$

Where T_{LO} and T_{OBS} are the thrust values corresponding to lift off and obstacle reference speeds. D_{LO} and D_{OBS} are the drag values at lift off and obstacle reference speeds inclusive of lift-induced drag.

5.2.4. Specific excess power

Climb is generally defined as flight at constant indicated airspeed or flight at constant dynamic pressure. Because normally aspirated engine power decreases linearly with air density as a function of the stoichiometric energy and since the true airspeed increases with increasing altitude at constant indicated airspeed, the climb rate decays with altitude. The same indicated airspeed at two different altitudes will result in the lift and drag coefficients being comparable even though the true air speed and Mach numbers will differ. This is true for slow aircraft flying at speeds less than Mach 0.3.

Rate of climb is also referred to as an energy level. Energy levels were first used to characterise combat aircraft by Col. John R. Boyd (USAF) [70]. Climb rate is dependent on the thrust loading and wing loading. Purely ascending and descending rates are useful performance indices, as are the climb and descent angles.

Climb angle is calculated from the net propulsion thrust, whereas climb rate is calculated from the product of the net propulsive thrust and velocity. Specific excess power (SEP) has been defined by Boyd [70] as the product of net propulsive force and velocity divided by the mass. The lowest SEP is obtained at maximum mass. [70]

$$SEP = \frac{(T-D).V}{M} \qquad 17$$

SEP may be used for determining the climb, descent, level-altitude acceleration and deceleration performance. It may also be used for determining the turn climb, descent, level-altitude acceleration and deceleration performance. The manoeuvre envelope can be divided into two main categories, climb and turn. The SEP chart links turn rate to load factor, turn radius and energy level as a function of velocity for any altitude, configuration and mass. The SEP chart contains a substantial amount of information that is useful. The turn rate lines must be plotted for constant load factor with termination at stall speed and dive speed. The turn radius lines must be cross-plotted using the turn rate lines as intersection points. The radius lines terminate at stall speed and at maximum limit load factor. The lines of constant SEP must be plotted with intersections of turn rate and radius. [61]

$$R = \frac{V^2}{g.\sqrt{n^2-1}}. \qquad 18$$

provides the turn radius in metres, note that it is not dependant on mass

$$\omega = \frac{g.\sqrt{n^2-1}}{V} \qquad 19$$

provides the turn rate in Rad/s and is also independent of mass.

Substituting the lift equation into the induced portion of the drag equation and then substituting equation 17 into equation 19, the following equation has been derived.

$$\omega = \frac{180.g}{V.\pi}\sqrt{\left[\left(T - \frac{SEP.M}{V}\right)\frac{K}{q.S} - K.C_{Do}\right].\left[\frac{q.S}{M}\right]^2 - 1} \qquad 20$$

where, $q = \frac{\rho.V^2}{2.g}$ and $K = \pi.AR.e$

This equation produces lines of constant SEP and allows for the parameters affecting SEP to be optimised. This was not necessary for this type of aircraft. The higher aspect ratio of the design allowed for better SEP states at lower speeds than the competitors.

The equation used to determine the time required to accelerate or decelerate over an increment of velocity is provided by: [70]

$$t = \frac{V_i.\Delta V}{g.SEP} \qquad 21$$

where V_i is initial velocity, ΔV is the difference in velocity.

Before considering the ASTM standard specifications, the flight envelope was developed to meet the performance requirements. The determination of the maximum sea level flight speed was conducted at a mass of 600kg. The thrust curve lines were generated using the method described. A variety of different engines were included to compare them to the Rotax. The Rotax engine would allow for a maximum level flight speed of 115kts, less than the 120kts ASTM maximum. The thrust for the different engine and drag data for SkyWake is shown in Figure 76. The units for thrust and drag are in kilograms because the SEP equation uses kilograms as input.

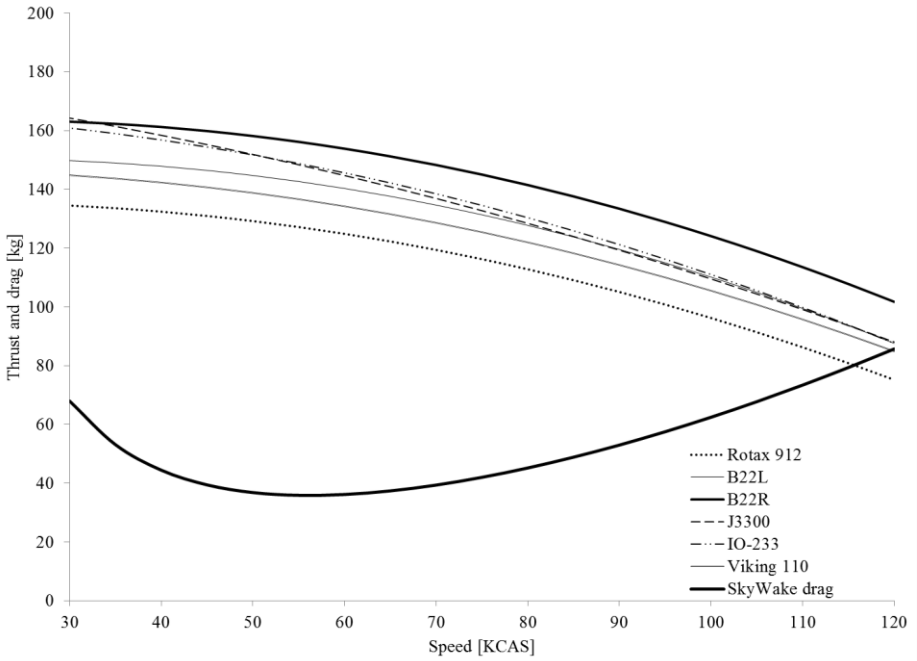


Figure 76. Maximum power thrust curves for different engines at sea level

The cruise speed was calculated for a mass of 600kg at sea level. The power setting used for the Rotax engine was 75% of maximum corresponding to 75hp at 4300rpm. The engine thrust for several engines was plotted for comparison. The cruise speed is shown in Figure 77 and was determined as 106kts, yielding a power utilisation of 1.06kt/hp at maximum power and 1.41kt/hp at cruise power. This exceeded the performance requirement of 105kt/hp.

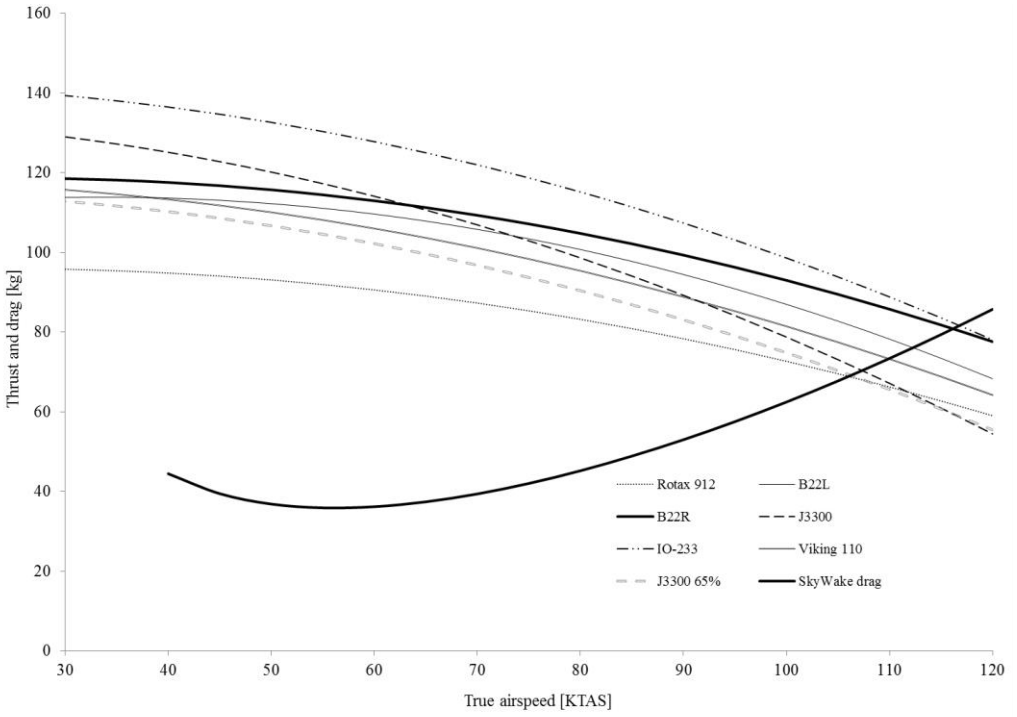


Figure 77. Cruise power thrust curves for different engines at sea level.

The Rotax 912 maximum thrust and cruise thrust data was overlaid on a clean drag curve for the aircraft, shown in Figure 78.

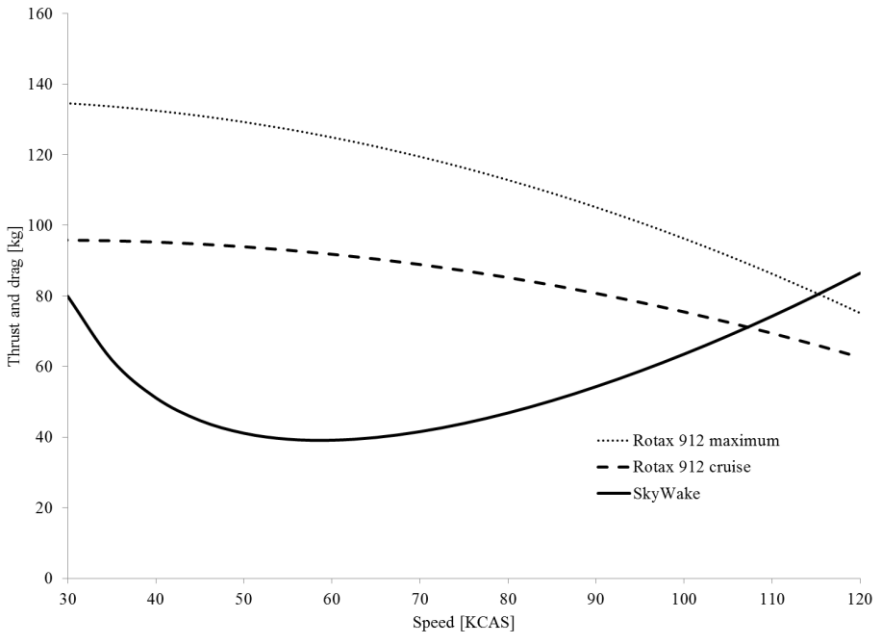


Figure 78.Maximum and cruise power thrust curves for different engines at sea level.

SEP charts were completed using the conditions specified in the captions of Figures 79-81, in order to demonstrate the energy and manoeuvre envelope. The SEP line indicating 0ft/min is the zero-energy line. This represents the steady state energy level. For sea level at 600kg mass as shown in Figure 79, the maximum level flight speed is seen as 115KCAS. The peak turn performance is a load factor of 2.5g, corresponding to a turn rate of 38°/s and a turn radius of approximately 52m. The maximum energy level is 900ft/min, which is achievable between 68-74KCAS.

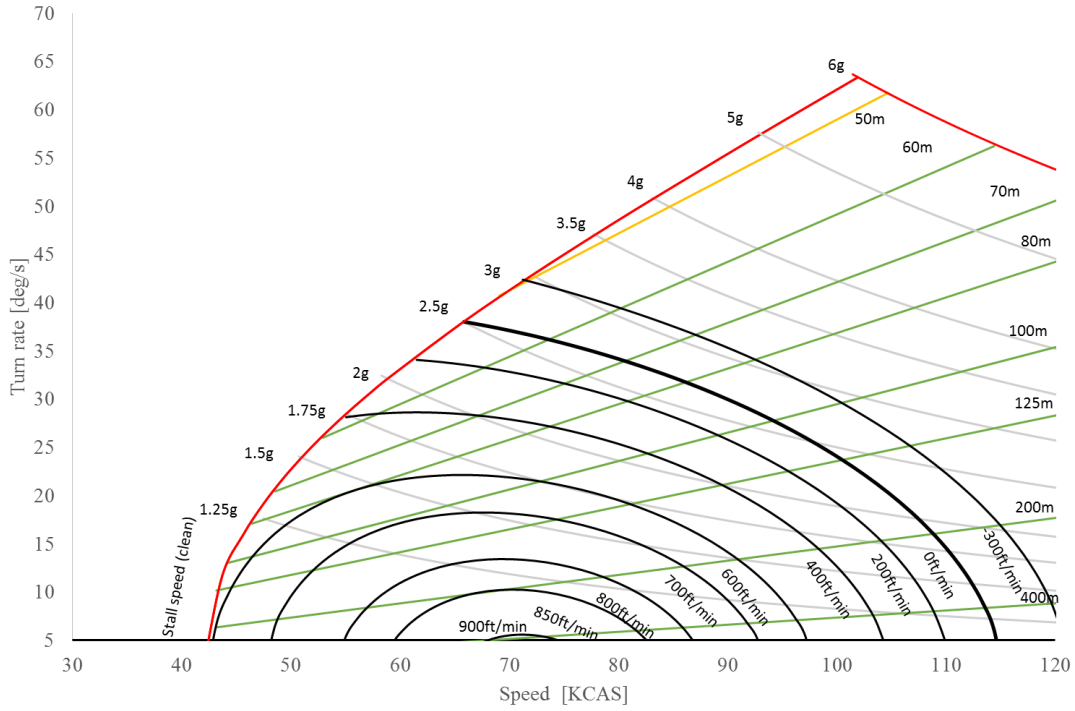


Figure 79. SEP at sea level at 600kg take-off mass

During a typical training flight the aircraft would not operate at maximum take-off mass. Figure 80 shows the sea level performance at a mass of 550kg. The maximum speed is approximately the same, this is due to the low wing loading resulting in a minimal change in induced drag at high speed. The maximum energy level has increased to 1000ft/min. The 900ft/min energy level is now available between 54-87KCAS. The maximum sustained turn performance parameters have all increased, with a peak load factor of 2.75g. This is due to the increase in energy level and reduction in stall speed.

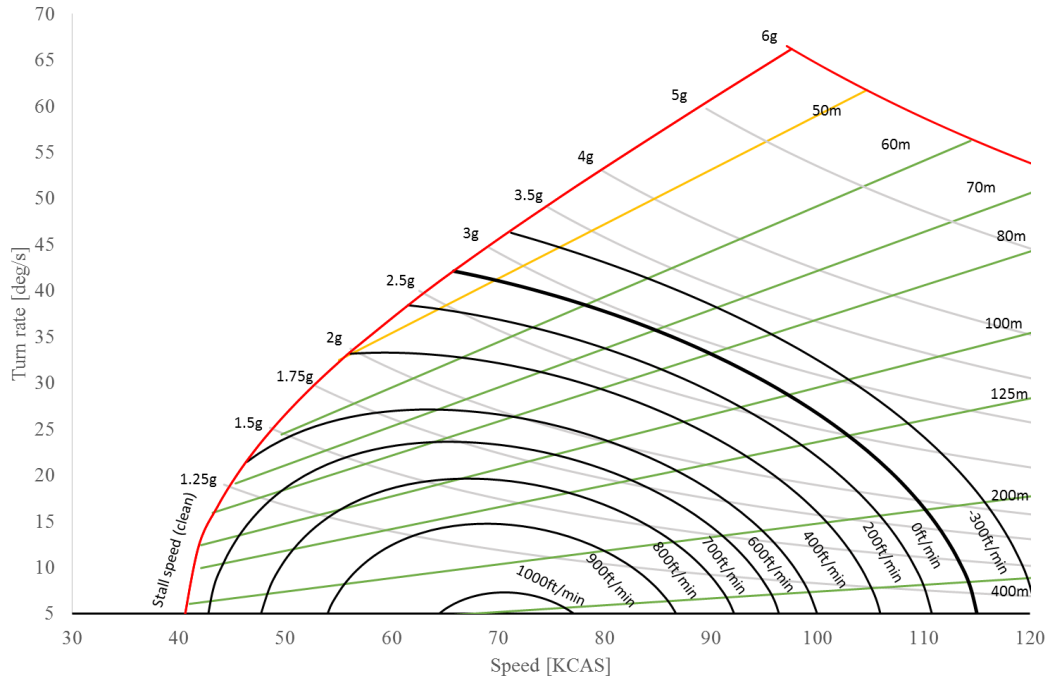


Figure 80. SEP at sea level at mass of 550kg

The aircraft performance at maximum mass of 600kg at an altitude of 10000ft was determined as shown in Figure 81. The maximum speed has reduced to 99KCAS, which is approximately 115KTAS. As expected the energy levels are reduced. The maximum energy level is 600ft/min between 55-72KCAS. The maximum sustained turn performance is a 2g turn at 59KCAS with a turn radius of 75m and turn rate of 28°/s.

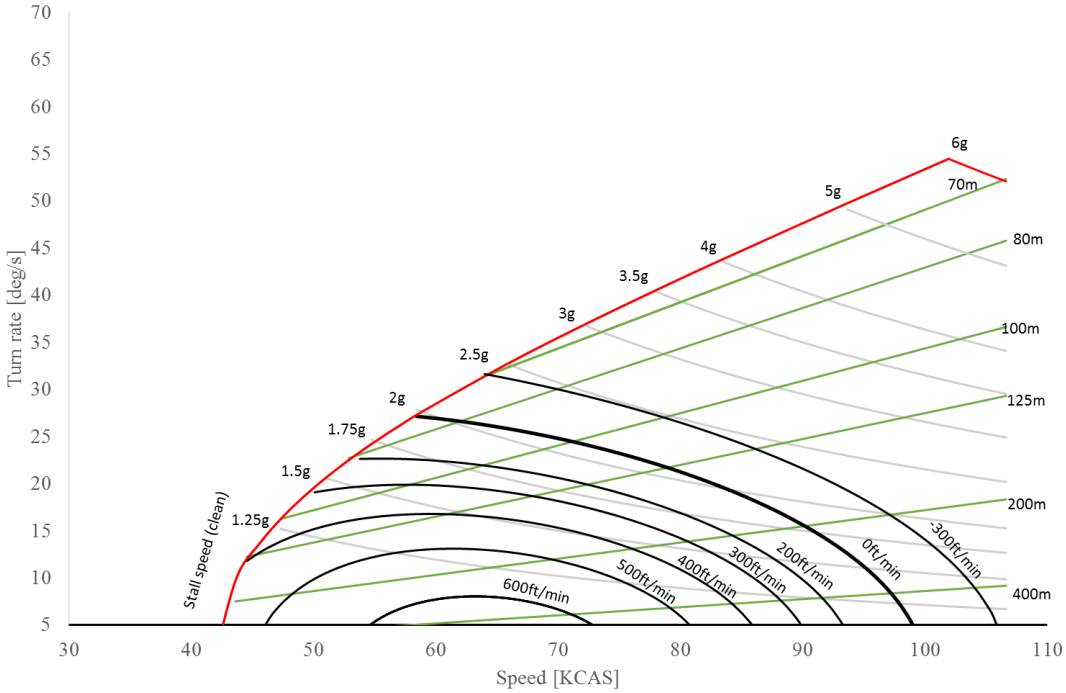


Figure 81. SEP at 10000ft at mass of 600kg

The energy levels for the Cessna-162, Tecnam P2004 and the aircraft concept were analysed to determine if the design did demonstrate higher energy levels and a better flight envelope than the competitors. The SEP value chosen was 500ft/min. The aircraft geometric characteristics were used with identical parasite drag coefficients since the zero-lift coefficient of drag did not have a large effect on the result. The aircraft thrust was also assumed as the same since the aircraft have the same installed power and have similar wetted areas in the scrubbing zone. Low wing loading and high wing aspect ratio provided better energy levels at low speed. This is shown in Figure 82.

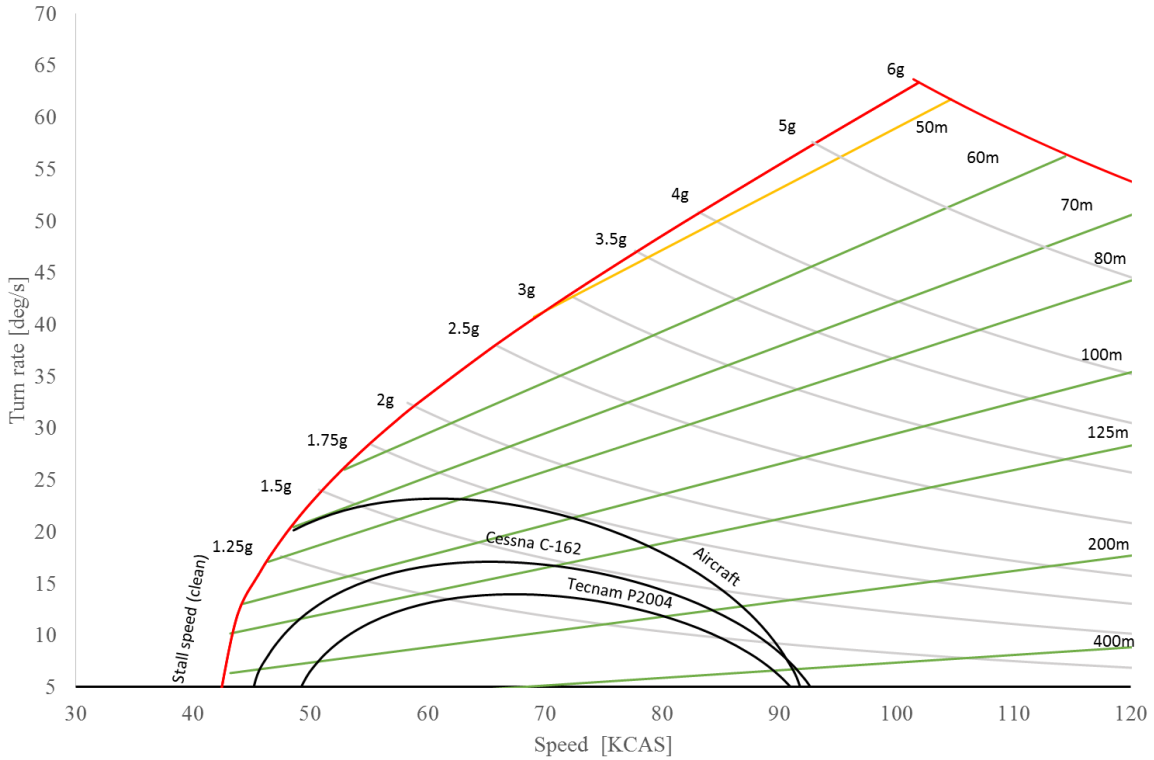


Figure 82. Turn performance for three aircraft at SEP =500ft/min.

The maximum energy levels for the Cessna-162, Tecnam P2004 and the aircraft concept were also analysed to determine if the design did demonstrate higher energy levels and to check if the maximum speeds were realistic. The SEP value chosen was 0ft/min. The maximum speed of the aircraft was expected to be slightly less than the competitors due to the larger wing. The maximum speed of the Cessna C-162 was calculated as 116.6KCAS. The flight manual indicates that the maximum speed is 118KCAS [34]. The discrepancy was deemed acceptable for this type of aircraft. This is shown in Figure 83.

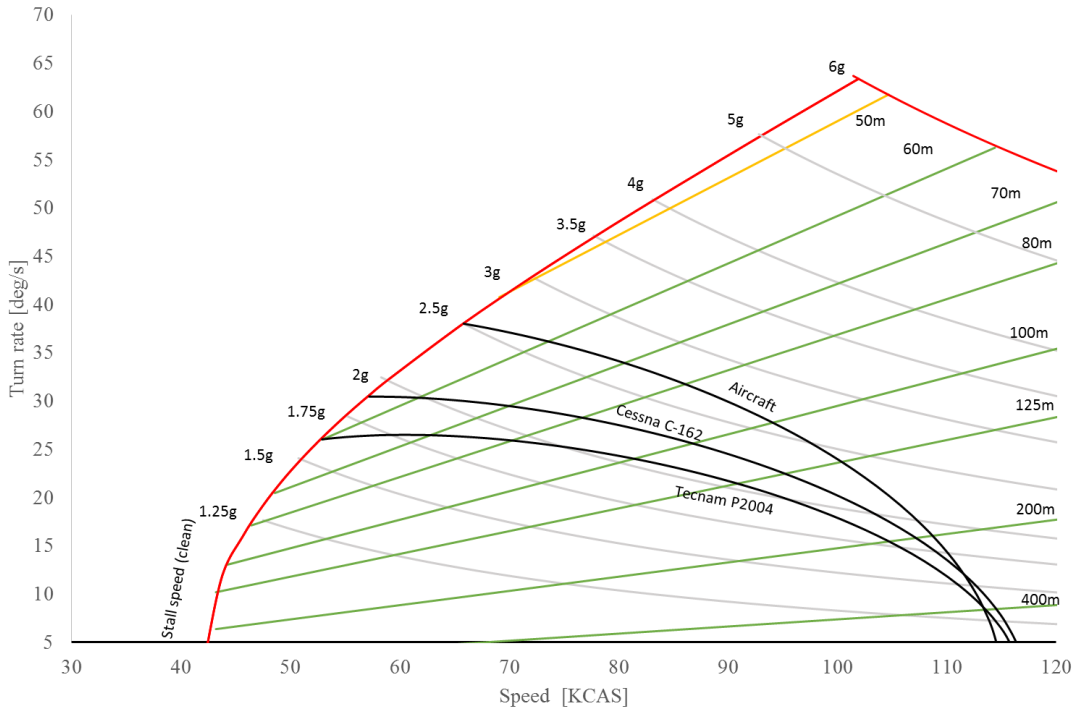


Figure 83. Turn performance for three aircraft at SEP =0ft/min.

The glide SEP chart was developed for this aircraft and features turn radius, turn load factor and sink rate with velocity. The chart indicates sink rate at zero power for any possible turn combination of radius and load factor. The engine would have to arrest the sink rate in terms of additional SEP to maintain altitude. The infinite radius line corresponds to a 1g glide at constant speed. This figure would be used during flight tests to determine the drag coefficients including trim drag.

Figure 84 shows the data for the glide SEP at a mass of 600kg at sea level. For a final approach turn in clean configuration at a speed of 70KCAS, the turn would be a 1.6g manoeuvre with a sink rate of approximately 700ft/min. The pilot would be in trouble when comparing that data point to the SEP chart (refer to Figure 79). At 1.5g at 70KCAS the maximum energy available is approximately 630ft/min. If the pilot was in the gliding turn and applied full power the net energy would be -70ft/min. The pilot could resolve the situation by unloading the load factor. The glide SEP and climb/acceleration SEP charts are useful for determining energy levels during manoeuvres.

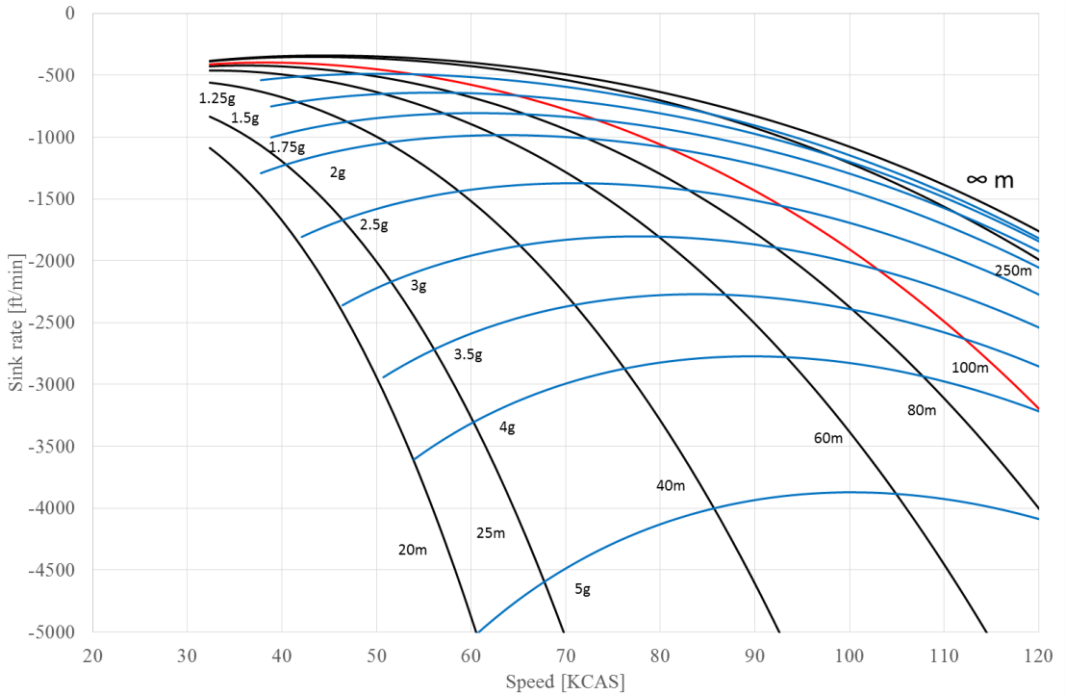


Figure 84. Engine-off sink rate at sea level at 600kg mass

Figure 85 shows the glide performance at altitude at maximum mass. The same manoeuvre stated above would result in a gliding turn at 70KCAS with a sink rate of -1200ft/min at 100m turn radius with a load factor of 2g. The higher load factor is due to the higher true air speed. Referring back to Figure 81, the maximum energy level if the pilot applied full power would be approximately 50ft/min. The net sink rate would be -1150ft/min.

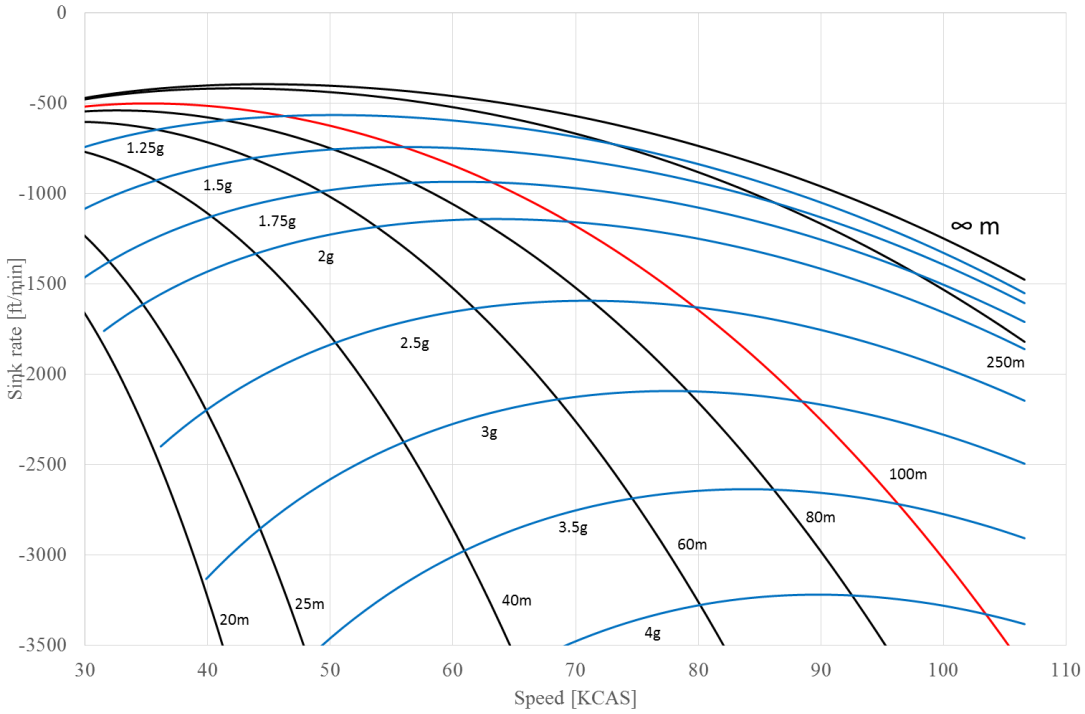


Figure 85. Engine-off sink rate at 10000ft at mass of 600kg

The glide SEP for the Cessna C-162 and the aircraft concept is shown in Figure 86. The aircraft has a better glide ratio than the C-162 at speeds less than 85KCAS. The aircraft has significantly lower sink rate than the C-162 at a load factor of 2g.

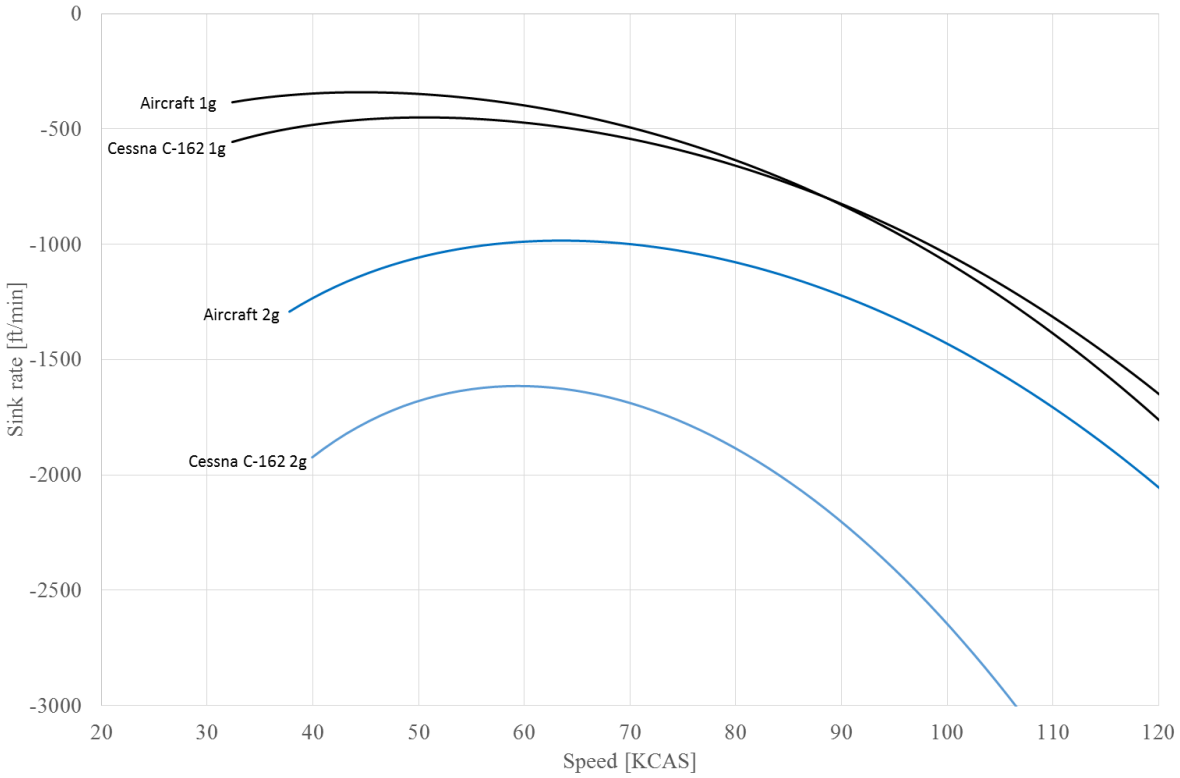


Figure 86. Engine-off sink rate for 1g and 2g flight at sea level for a mass of 600kg.

Comparing the performance of the aircraft to the original performance requirement. The minimum power utilisation of 1.05kt/hp was exceeded. The power loading of 6.0kg/hp was achieved with a 100hp powerplant. The minimum cruise speed performance requirement of 110KCAS was not met. The design produced was focussed on the criteria of good hot and high performance and a flight envelope that exceeded that of the competition. This resulted in a design with a high aspect ratio and lower wing loading, this reduced the cruise speed to 106KCAS. This predicted cruise speed was with the aircraft operated without drag-reducing wheel spats. The aircraft did have better performance for the aircraft cost than any other LSA and had better energy and manoeuvre performance than more expensive LSA.

For the business case the launch strategy was developed, a mock-up aircraft was designed and built and the design of a manufacturing facility was completed. A structural wing testing facility was designed and constructed at the University. The strategy to achieve design and manufacturing organisation approval was developed and presented to the Innovation Fund. The application was rejected because the proposal covered the cost of the aircraft and manufacturing facility as well as costing for an airfield and industry. It was deemed too ambitious.

5.3. Airworthiness compliance

The stall speeds have been calculated for a range of flap deflections at different masses. The total flap span was 6.1m (54% of wing span) and was modelled as a single slotted device. The maximum permitted stall speed of 45kts was achievable in the clean configuration. The target stall speed of 36KCAS was selected because this would result in a stall speed of 40.8KTAS in Johannesburg at a temperature of 30°C. This would be less than the maximum stall speed and would lead to reduced landing gear loads and better SEP energy levels than any competitor aircraft at 45KCAS. The maximum coefficient of lift was underestimated (refer to aerofoil selection in §4.5) and the flap contribution was also underestimated. The device was modelled as having a higher lift contribution than a simple flap, but not as much as a single slotted flap would contribute [71].

The principle of adjustment was used since the maximum coefficient of lift is easily reduced during development of an aircraft if required. It is not easily increased. The stall velocities for different mass and flap deflections are presented in Table 43. The shaded values are combinations of mass and flap deflection resulting in a stall velocity that is higher than 36KCAS and were not considered for operation. The nose-down pitching moment C_M has been derived using the pitching moment from wind tunnel data [55] and the ASTM F2245 pitching moment approximation for a quarter chord moment coefficient.

Table 43. Stall speed with flap deflection for different flying masses.

			Mass	400	450	500	550	600
Flap deflection [deg]	Flap C_L	Net C_L	Net C_M	Stall velocity [KCAS]				
0	0.00	1.60	-0.08	35.0	37.1	39.2	41.1	42.9
5	0.12	1.72	-0.13	33.7	35.8	37.7	39.6	41.3
10	0.25	1.85	-0.18	32.6	34.6	36.4	38.2	39.9
15	0.37	1.97	-0.23	31.6	33.5	35.3	37.0	38.6
20	0.49	2.09	-0.28	30.6	32.5	34.2	35.9	37.5
25	0.62	2.22	-0.33	29.7	31.6	33.3	34.9	36.4
30	0.74	2.34	-0.38	29.0	30.7	32.4	33.9	35.5
35	0.87	2.47	-0.43	28.2	29.9	31.5	33.1	34.6

The parasite drag coefficient was calculated and a clean drag polar was derived for an aircraft without wheel spats. The polars for different flap deflection angles is shown in Figure 87. The take-off setting of 10° and maximum setting of 35° were of importance in the ASTM calculations. Relatively good lift to drag ratios were made possible because of the high flap span and single-slotted design.

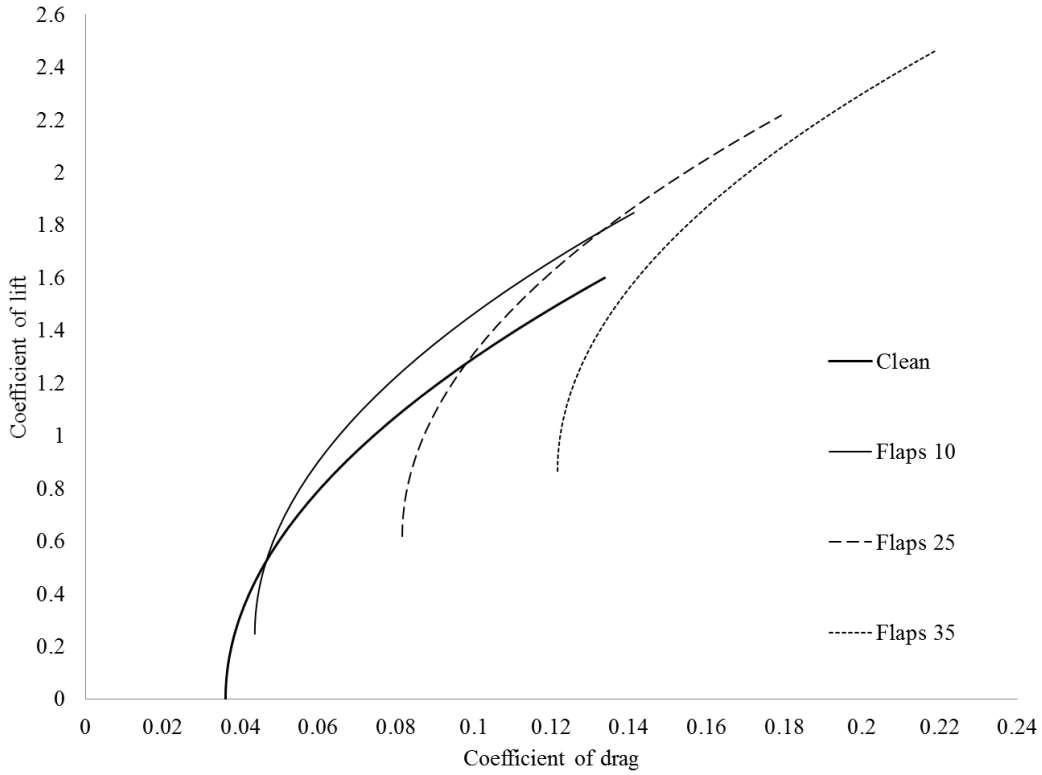


Figure 87. Drag polar set for the aircraft with different flap deflections.

The lift, drag and pitching moment data due to flap deflection was required for compliance calculations for subpart 4 of ASTM F2245 as it relates to take-off, landing and low-speed control.

5.3.1 Airworthiness compliance with ASTM F2245 subpart 4

The ASTM compliance calculations have been summarised with an explanation of the method used. Table 44 relates to sub-part 4 of ASTM F2245 regarding flight

Table 44. ASTM F2245 sub-part 4 compliance checks.

Compliance criterion	**Determined from**	**Estimated value**	**Accepted**
V_{SO} wings level stall speed in landing configuration	Flight test	34.6KCAS using 35° flap deflection, at 600kg refer to Table 43.	Y
V_{LO} take-off speed	Calculation	44KCAS using 10° flap deflection at 600kg. This was calculated as 110% of stall speed. For C_L values refer to Table 43.	Y
Ground roll distance	Calculation	118m at 600kg, 10° flap deflection and thrust values from Figure 78. C_L = 1.53, C_D = 0.0689, D_o = 15kg, D_{LO} = 27kg, T_O = 173kg, T_{LO} = 135kg. Using equation 15.	Y
Distance to clear a 50ft obstacle	Calculation	168m at 600kg, 10° flap deflection and thrust values from Figure 78. T_{LO} = 135kg, T_{OBS} = 130kg, D_{LO} = 42.7kg, V_{OBS} = 52KCAS, D_{OBS} = 39kg. C_{LOBS} = 1.09. Using equation 16.	Y
Rate of climb at best climb speed	Calculation	915ft/min at 71KCAS from SEP chart in clean configuration. Exceeds 312ft/min minimum requirement	Y
Climb gradient at best climb angle	Calculation	Gradient is 1/6.9 at 52KCAS. Exceeds 1/12 requirement.	Y
Balked landing climb gradient	Calculation	The reference speed of 52KCAS happens to be the same as best climb angle speed due to low wing loading, value of 1/6.9 exceeds 1/30 minimum requirement.	Y

Compliance criterion	Determined from	Estimated value	Accepted
Longitudinal control	Calculation and flight test	Horizontal tail volume coefficient of 0.411. The all-moving type would produce more lift than a standard type. At V_{SO} the C_M = -0.43 using the ASTM approximation with wind tunnel C_{MO}. The C_M available from the horizontal tail is +0.41 per unit C_L. With thrust acting as a positive pitching moment and the cabin centre of mass position making the static margin small. Flight tests would allow for V_{SO} to be determined as per ASTM F2245 4.4.1. The maximum flap deflection might need to be reduced to 30°. The wind tunnel data from Abbott [57] suggests a C_M with flaps of -0.3 would be more realistic. The thrust line is below the wing drag line. During slow flight at V_{SO} the wing contributes 26kg of drag, this is 74% of the total aircraft drag. The thrust of approximately 135kg would contribute a nose up pitching moment. At V_{LO} the C_M = -0.18 using the ASTM approximation. The C_M available from the horizontal tail is + 0.41 per unit C_L. The horizontal tail provides sufficient authority. At the worst case for unstick speed at V_{SO} with flap deflection limited to 30°, the total nose down rotation moment due to mass and pitching moment is 1.67kNm, the nose up pitching moment due to the horizontal tail is 1.97kNm with a C_L of 1.0 at the tail at a deflection of -15°. The lift curve of the horizontal tail was calculated as 0.069/deg using the DATCOM method.	Design compliance could be obtained by limiting the pitching moment[1].
Directional control	Calculation and flight test	Vertical tail volume coefficient of 0.032 excludes the fillet. The value is similar to the original C-162. The aircraft has 38% more vertical tail area at a similar moment arm. The higher aspect ratio wings reduce the volume coefficient. The higher aspect ratio wing with sweep may assist the aerodynamic coupling that opposes a spin. The high aspect ratio means the ailerons centre is located 5.45m from the centre of mass. The critical rear centre of mass position is constrained by the cabin geometry.	The aileron gap may be modified if required. The rudder size could be increased if necessary.

[1]the flap deflection could be limited to reduce the overall pitching moment at minimum flight speed should pitch control authority be minimal. This would not affect performance greatly as the low wing loading still allows for a low stall speed.

Compliance criterion	Determined from	Estimated value	Accepted
Lateral control	Calculation and flight test	Aileron volume coefficient of 0.059. Aileron span of 3.6m combined with a chord of 0.3m. The higher aspect ratio wing means the ailerons are further outboard than on other aircraft. The chord and aerofoil profile will be the same as for the flaps. 3 degrees of dihedral has been included for static lateral stability. The design of the ailerons is the Frise type. The aileron gap was selected to introduce adverse yaw into a turn with the differential aileron deflection. Meaning that if the aircraft was rolled to the left, the aircraft would yaw left slightly.	Y, ailerons size is adequate.

The longitudinal stability and control authority was estimated for the centre of mass range of 20-32% mean aerodynamic chord. The increase in nose-down pitching moment due to flap extension was included in the estimation. The downwash factor was calculated using the method described by Brandt [74] and Etkin [75]. The downwash factor of 0.003/deg was included in the calculation. Figure 88 presents the coefficient of moment with respect to the centre of mass as a function of the coefficient of lift. The forward, intermediate and aft centre of mass positions were used in conjunction with a zero deflection angle for the horizontal stabiliser. For the forward (20% MAC) and intermediate (25% MAC) conditions, the aircraft has an increasing nose-down pitching moment coefficient. For the aft (32% MAC) condition the aircraft demonstrates a decreasing nose-down pitching moment coefficient. The coefficient of moment tends to zero near stall for the aft centre of mass condition. The airfoil section exhibits a strong nose-down pitching moment tendency near stall, this, as shown in Figure 42. This was not considered for this estimation, since the horizontal stabiliser provides adequate pitch authority.

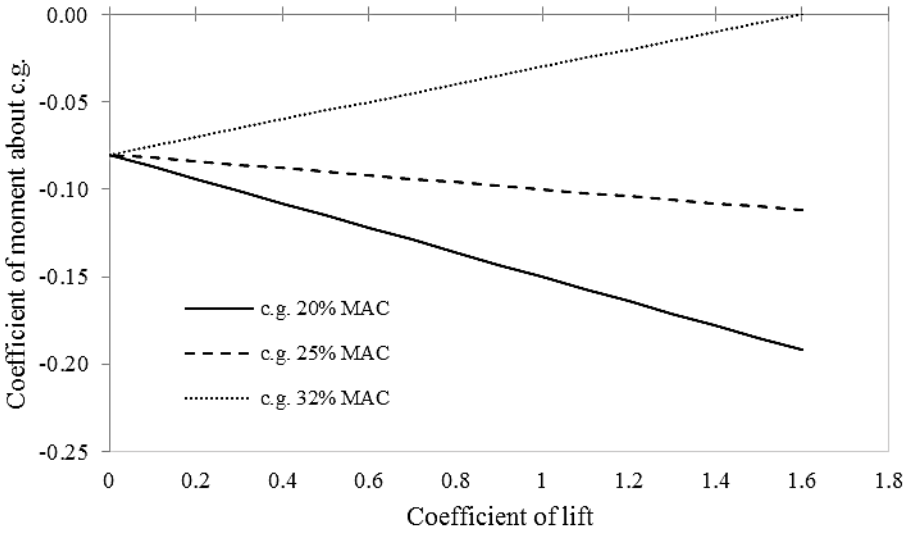


Figure 88. Coefficient of moment for various centre of mass positions.

Figure 89 shows the coefficient of pitching moment as a function of the lift coefficient for the forward centre of mass position (20% MAC). The aircraft is considered trimmed when the coefficient of moment is zero. The aircraft is trimmed using a total horizontal stabiliser deflection range of 4 degrees.

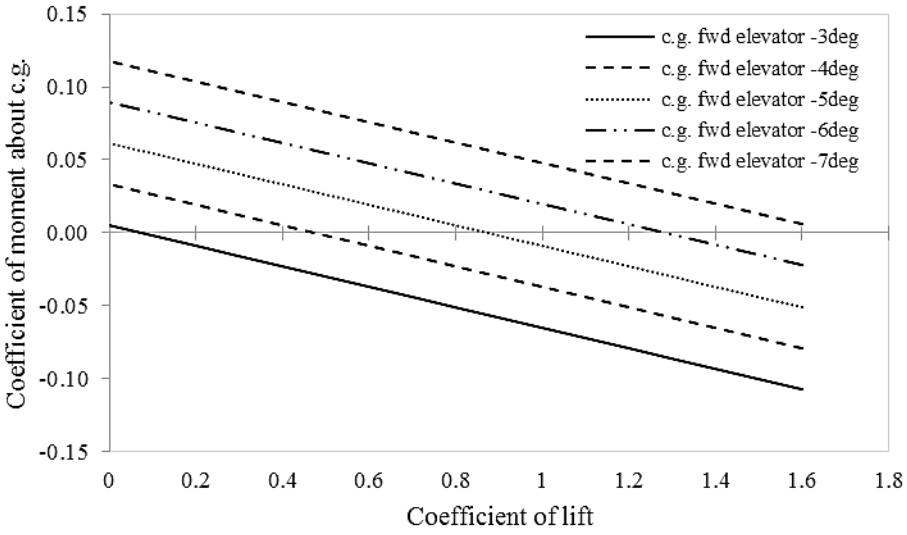


Figure 89. Coefficient of moment at forward centre of mass position.

Figure 90 shows the coefficient of pitching moment as a function of the coefficient of lift for the aft centre of mass position (32%). The aircraft is trimmed using a total of 2.5° of horizontal stabiliser deflection. This may seem very small, but the pilot only controls the tab of the stabiliser and the control harmony was carefully examined for this aircraft.

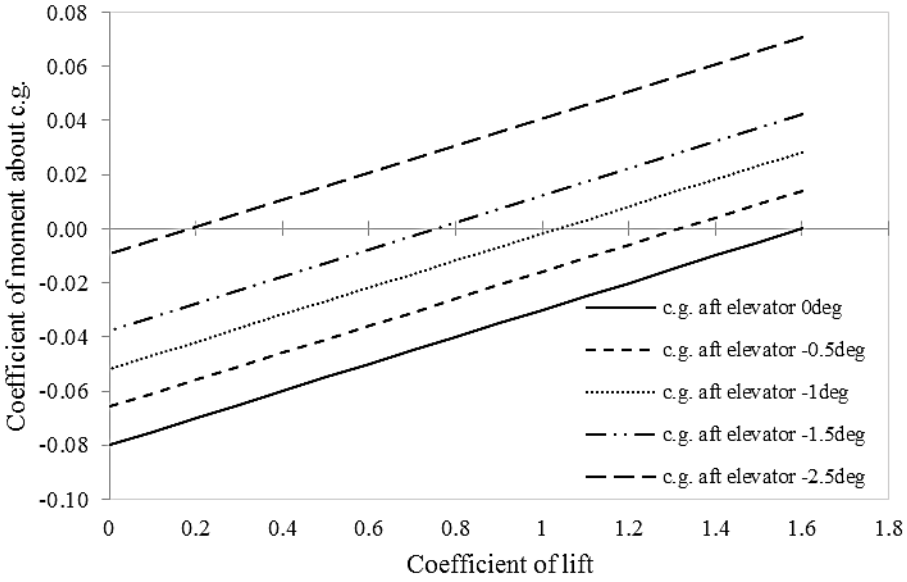


Figure 90. Coefficient of moment for aft centre of mass position.

The horizontal stabiliser deflection angle required for trimmed flight in the clean configuration was calculated for four centre of mass positions. Due to the all-moving horizontal stabiliser design, the stabiliser is always deflected downwards, except when the coefficient of moment tends to zero. At manoeuvre speeds of 80KCAS and greater, the required deflection range of the stabiliser is small, hence justifying the electronic trim system.

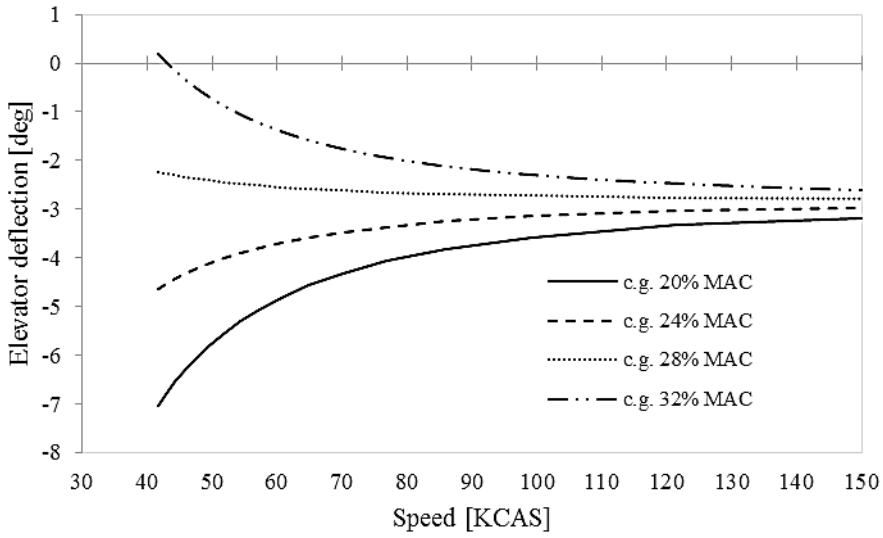


Figure 91. Stabiliser (elevator) deflection required for trimmed flight.

The deflection of a high-lift control surface increases the nose-down pitching moment of an aircraft. The four flap deflection cases were 0°, 10°, 25° and 35°. The flap retraction speed was determined by analysis of the drag polars and lift/drag ratios. Figure 92 shows the coefficient of pitching moment as a function of lift coefficient with flap deflection and various centre of mass positions. The pitching moment coefficient no longer tends towards zero for the aft centre of mass position. All three lines indicate much large pitching moment magnitudes, as expected.

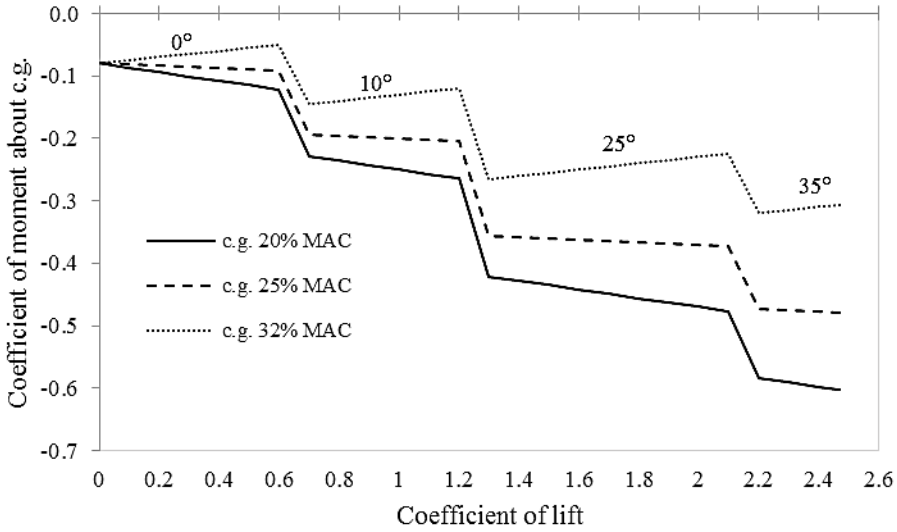


Figure 92. Coefficient of moment with flap deflection at various centre of mass positions.

The coefficient of pitching moment for flap deflection at the forward centre of mass position was calculated for the range of lift coefficients. The horizontal stabiliser deflection range, required for trim, has increased to 17°. As shown in Figure 93, the aircraft can be trimmed at maximum mass for any flap deflection.

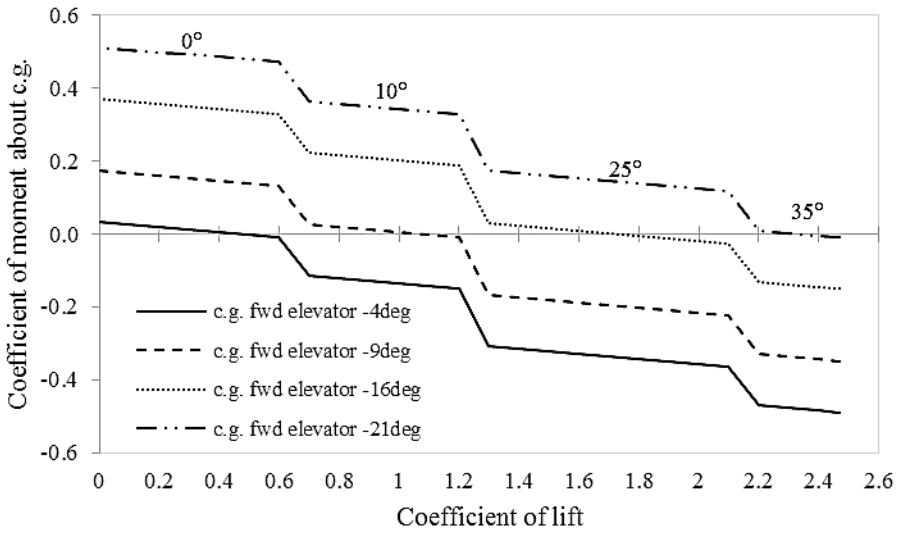


Figure 93. Coefficient of moment with flap deflection at forward centre of mass position.

The coefficient of pitching moment for flap deflection at the aft centre of mass position was calculated for the range of lift coefficients. The horizontal stabiliser deflection range, required for trim was estimated at 8.5°. As shown in Figure 94, the aircraft can be trimmed at maximum mass for any flap deflection.

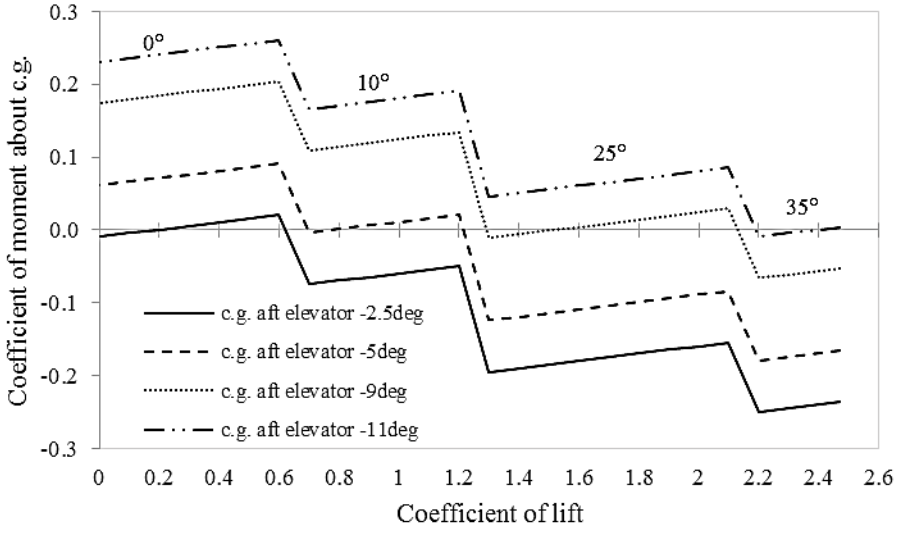


Figure 94. Coefficient of moment with flap deflection at aft centre of mass position.

The final pitch authority compliance check was that the required horizontal stabiliser deflection required for flight should be less than the deflection available. Figure 95 shows the stabiliser deflection required for trimmed flight across the design speed range for flap deflections at four centre of mass positions. This demonstrates that the aircraft has positive and negative pitch authority for the design flight envelope.

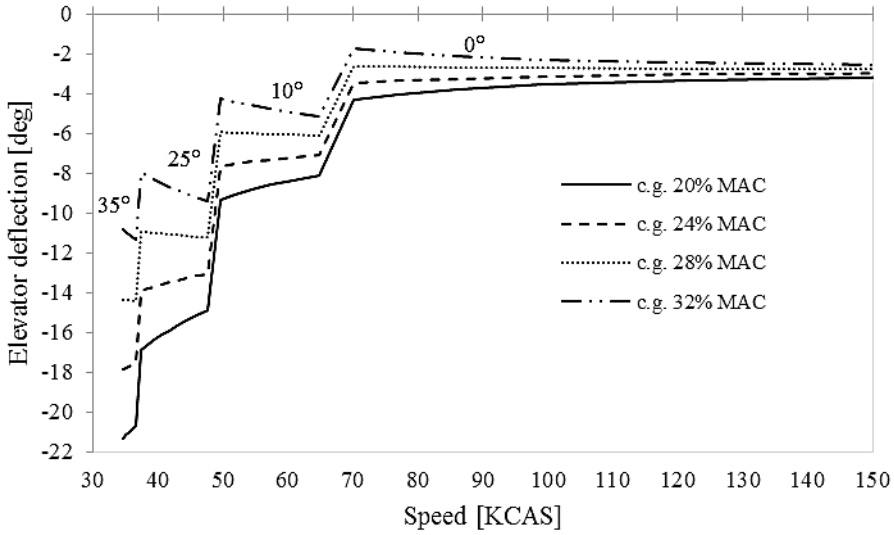


Figure 95. Stabiliser (elevator) deflection required for trim with flap deflection at various centre of mass positions.

The important design aspect included in this aircraft was the small deflection range required at manoeuvre speeds.

5.3.2 Airworthiness compliance with ASTM F2245 subpart 5

Figure 96 shows the flight envelope velocity-load factor diagram. It was derived from the ASTM F2245, with explanation in Table 45. The lift coefficient at V_A for level cruise flight was calculated as 0.4. The energy level available at that speed at maximum mass and maximum power is 700-800ft/min. The flap velocity-load diagram is also shown in the same figure. The aircraft stall speeds for clean and landing configuration at maximum mass is shown. The ASTM prescribed stall speed is 45kts. This aircraft stalls below that requirement meaning that flaps are not necessary for landing from a regulation perspective. In the event of a flap extension failure the landing gear would not be over-stressed due to high touch-down speeds. The low wing loading resulted in a lower V_A and a higher energy level at the reference speed.

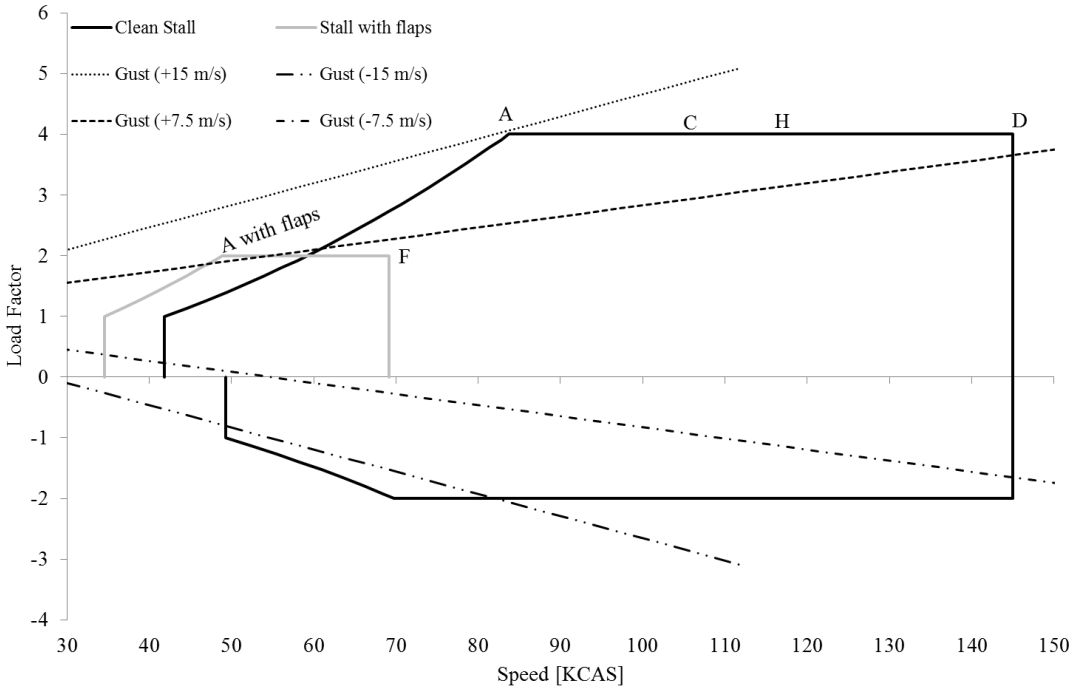


Figure 96. Velocity-load factor diagram for mass of 600kg.

The reference speeds are required for the compliance calculations for sub-part 5. Table 45 relates to sub-part 5 of ASTM F2245 where structural loads are determined. Several conflicts were discovered. The ASTM F2245 is not very prescriptive and, in some instances, refers to ASTM F2245 Appendix X1 – the simplified design load criteria for light sport airplanes. This appendix contains non-mandatory information, some of which conflicts the F2245 consensus standard. The conflicts are discussed where they occur.

Table 45. ASTM F2245 sub-part 5 compliance checks.

Compliance criterion	**Determined from**	**Estimated value**	**Accepted**
Maximum flap speed	Calculation	$1.4V_S$ in the clean configuration is 60.1KCAS, $2.0V_{SO}$ in the landing configuration is 69.2KCAS. The ASTM stipulates that the greater value must be used. The design flap speed is therefore 69.2KCAS.	Y
Manoeuvring speed	Calculation	V_A determined as 85.8KCAS using ASTM F2245 5.2.4.1. V_A was calculated to be 95KCAS using the method described in ASTM F2245 Appendix X1. V_A used is 85.8KCAS due to the lower wing loading of the aircraft and higher maximum lift coefficient.	Y
Design cruise speed	Calculation	V_C must not be less than 104KCAS based on maximum wing loading according to ASTM F2245. The minimum required cruise speed calculated according to ASTM F2245 Appendix X1 1.2.5.2 was 107.5KCAS. The appendix also states ”V_{Cmin} need not	Y

		exceed values of $0.9V_H$ actually obtained for the lowest weight category for which certification is desired". Using this, V_C need not be greater than 90% of maximum level flight speed V_H. V_H is 115KCAS, therefore $0.9V_H$ is 103.5KCAS. Due to this conflict the regulation would take precedence over the appendix. It is suspected that due to the aircraft wing loading being lower than competitors the conflict is due to the constants in the ASTM equations being based off data from the first LSA. The calculated cruising speed has been determined as 106KCAS. V_C would be 103.5KCAS in this case. This would be the minimum required cruise speed.	

Compliance criterion	**Determined from**	**Estimated value**	**Accepted**
Design dive speed	Calculation	V_D must be 140% of the minimum required cruise speed. The V_D is thus based on 140% of $0.9V_H$ resulted in V_D of 144.9KCAS. There is no defined never-exceed velocity for this category of aircraft.	Y
Positive limit manoeuvring load factor	Regulation	N_1 of 4g used. N_3 calculated as 4g based on wing loading. The low wing loading ensured that N_1 and N_3 would be equal. N_1 is the positive limit load factor at V_A, N_3 is the positive limit load factor at V_C.	Y
Negative limit manoeuvring load factor	Regulation	N_2 of -2g used. N_4 calculated as -2g based on wing loading. The low wing loading ensured that N_2 and N_4 would be equal. N_2 is the negative limit load factor at V_A, N_4 is the negative limit load factor at V_C.	Y
Loads on the flap	Calculation	N_{1flap} = 2g, N_2 = 0 for any deflection up to the V_F of 69.2KCAS. Gust intensity of 7.5m/s must be applied with flap fully down at V_F. Load per flap without gust, lift = 618N, drag = 61N and net force = 621N. These were determined using the standard lift and drag methods applied solely to flap geometry. Load per flap with gust, lift = 846N, drag = 104N and net force 852N. These were calculated with an angle of attack and velocity change due to the gust and the standard lift and drag method applied solely to the flap geometry.	Y
Gust intensities	Regulation	At V_C 15m/s gusts must be applied in both up and down directions. At V_D 7.5m/s gusts must be applied, in both directions.	Y
Rolling conditions	Calculation	Roll control deflection loads must be combined with two thirds of N_1 loads. Torsion loads due to the pitching moment of the deflected ailerons must be accounted for in the *unsymmetrical flight loads*.	Y

Compliance criterion	Determined from	Estimated value	Accepted
Engine torque	Calculation	Engine torque would be one of the loads for the design of the front fuselage and engine mount. The worst torque load case would be determined by examining two ASTM F2245 load cases. Maximum limit torque based on take-off power and propeller speed acting with 75% of vertical loads due to N_1 . This was computed as an engine torque of 122Nm at 3g. Limit torque based on maximum cruise power and propeller speed acting with vertical loads due to N_1. This was computed as 125Nm at 4g. For a four cylinder four-stroke engine a factor of two must be used on limit torque. The design maximum torque load would thus be 250Nm.	Y
Engine side load	Calculation	Limit load factor of 1.5 used, this load may be assumed to be independent of other load conditions. Any engine mount designed to withstand the vertical, longitudinal and torque loads stipulated would be able to withstand more than 150% of the engine mass in a lateral direction. This load would be 883N for an engine weighing 60kg.	Y
Control system loads	Regulation	The control system stops for the load applied at the grip on the control stick must be designed for 445N for pitch and for 180N for roll. The rudder pedals must be designed for 580N acting on a single pedal in the forwards direction and 580N applied to both pedals in the forward direction.	Y
Dual control system pilot loads	Regulation	A dual system must be designed for both pilots applying 75% of the control system loads in opposite directions. This would be necessary for an aircraft used for flight training.	Y
Ground gust conditions	Calculation	The equation specified in ASTM F2245 5.3.7 resulted in the following ground gust moments: Ailerons = 39Nm Rudder = 3.7Nm Horizontal stabiliser = 110Nm All control surfaces should have stops to withstand the greater of the forces due to pilot force, 125% of surface load or ground gust loads.	Y

Compliance criterion	Determined from	Estimated value	Accepted
Average limit control surface loading	Regulation	Based on ASTM F2245 Figure X1.4 and X1.5 the surface loads were determined. The load distributions specified in Table X1.2 resulted in the following loads: Ailerons = 900N/m^2 resulting in a vertical load of 283.5N on each aileron. Vertical stabiliser = 1100N/m^2 resulting in a horizontal load of 982N. Horizontal stabiliser = 1250N/m^2 resulting in a symmetrical load case of 1097N total load and an unsymmetrical load of 1097N on one side and 713N on the other side[1]. Flaps = 1200N/m^2 resulting in a vertical load of 1647N upwards and 412N downwards. Tabs = 1500N/m^2 resulting in a load of 1520N for the servo tab on the horizontal stabiliser.	Y
Horizontal tail manoeuvring loads	Calculation	At V_A of 85.8KCAS the maximum deflection of the horizontal tail in upwards and downwards deflections must be used. At V_D of 144.9KCAS the deflection of the horizontal tail must be one third of maximum. Gust loads previously described apply.	Y
Vertical tail manoeuvring loads	Calculation	At V_A of 85.8KCAS the maximum deflection of the rudder in both directions must be used. At V_D of 144.9KCAS the deflection of the rudder must be one third of maximum. Gust loads previously described apply.	Y

[1] The asymmetrical tail load is applied during a structural test where the combined loading is applied to the fuselage. The asymmetric load case for the horizontal and vertical tail surfaces must be applied simultaneously.

Compliance criterion	Determined from	Estimated value	Accepted
Supplementary load conditions for stabilising surfaces	Regulation	Using the higher of the horizontal tail manoeuvring loads, 75% of the horizontal and vertical tail loads must be applied simultaneously. The fuselage and stabilising surfaces must also be designed for the higher of the horizontal and vertical tail manoeuvring loads where 100% load is applied on one side and 70% applied to the other side of the tail.	Y
Symmetrical flight loads	Calculation	At V_A of 85.8KCAS the loads due to N_1 must be used to calculate the loads. N_2 must be used for the negative g load case. At V_D of 144.9KCAS the loads due to N_1 must be used to calculate the loads. N_2 must be used for the negative g load case. In the absence of better data a maximum lift coefficient of 1.35 must be used. The maximum lift coefficient of 1.8 was used based on wind tunnel data for the section (see §4.5, Table 25). The aerodynamic loads may be applied normal to the relative wind and a safety factor of 1.05 must be applied to the loads. Flap loads at V_{Aflap} and at V_F must be used with the load factor stipulated as 2g.	Y
Unsymmetrical flight loads	Calculation	At V_A of 85.8KCAS the wing and carry-through structures must be designed for 100% of the N_1 load on one side of the aircraft and 70% of N_1 load on the other side. At V_A or V_C the wing and carry-through structures must be designed for a combination of loads resulting from 75% of N_1 loads on both sides with maximum torsion due to the ailerons. The additional pitching moment for the up aileron is $C_{M+} = 0.17$ and for the down aileron $C_{M-} = -0.28$. Using ASTM F2245 Appendix X1.3.3.4 the critical aileron deflection case was determined. Using a total aileron deflection of 45° the value of *K* was determined as 0.897. V_C of 106KCAS would be used for aileron torsion loads.	Y

<table>
<tr><th>Compliance criterion</th><th>Determined from</th><th>Estimated value</th><th>Accepted</th></tr>
<tr><td>Aileron manoeuvring loads</td><td>Calculation</td><td>At V_A of 85.8KCAS the maximum deflection of the ailerons must be used.

At V_D of 144.9KCAS the deflection of the ailerons must be one third of maximum.</td><td>Y</td></tr>
<tr><td>Landing gear loads (level landing with nose wheel off the ground)</td><td>Calculation</td><td>Drop height was calculated at 288.5mm using the ASTM equation and the aircraft wing loading.

The load factor on the wheels n_j was calculated as 3g giving a total landing gear deflection at full load of 300mm, including tyre and landing gear leg.

The vertical load on each main gear was calculated at 8.84kN.

The level landing inclination was stipulated at 14°.</td><td>Y</td></tr>
<tr><td>Landing gear loads (level landing inclined reactions)</td><td>Calculation</td><td>The centre of mass height was estimated at 1.18m above the ground and 0.15m ahead of the main landing gear.

Main wheel load of 6.05kN each inclined at 14° to vertical.

Nose gear load of 5.56kN inclined at 14° to vertical.</td><td>Y</td></tr>
<tr><td>Landing gear loads (braked loads and side loads)</td><td>Regulation</td><td>The loads matrix was derived from ASTM F2245 Figure 3 and 4.
<table>
<tr><th></th><th></th><th colspan="3">Direction</th><th colspan="3">Magnitude</th></tr>
<tr><th>Load name</th><th>Load number</th><th>x</th><th>y</th><th>z</th><th>Fx</th><th>Fy</th><th>Fz</th></tr>
<tr><td>Braked roll</td><td>1</td><td>-1</td><td></td><td></td><td>0.54W</td><td></td><td></td></tr>
<tr><td></td><td>2</td><td></td><td>1</td><td></td><td></td><td>0.67W</td><td></td></tr>
<tr><td rowspan="6">Side load</td><td>3</td><td></td><td></td><td>1</td><td></td><td></td><td>0.33W</td></tr>
<tr><td>4</td><td></td><td>1</td><td></td><td></td><td>0.67W</td><td></td></tr>
<tr><td>5</td><td></td><td></td><td>1</td><td></td><td></td><td>0.5W</td></tr>
<tr><td>6</td><td></td><td>1</td><td></td><td></td><td>0.67W</td><td></td></tr>
<tr><td>7</td><td></td><td>-1</td><td></td><td></td><td>1.34W</td><td></td></tr>
<tr><td>8</td><td></td><td></td><td>-1</td><td></td><td></td><td>0.83W</td></tr>
</table>
Where x, y and z denotes the longitudinal, directional and lateral axes respectively. The sign indicates the direction relative to the axis. W denotes the weight of the aircraft. For example, load 1 is a load of 3178N towards the rear of the aircraft.

Any shock absorber is assumed to be in the static position.</td><td>Y</td></tr>
</table>

Compliance criterion	Determined from	Estimated value	Accepted
Tie down points	Regulation	Tie down points must be designed for the maximum open area wind speed of 38kts.	N, tie down points were not designed.
Parachute system loads	Regulation	Must comply with ASTM F2316.	N, parachute loads were not specifically designed for given the space-frame design.

5.3.3 Airworthiness compliance with ASTM F2245 subpart 7

Table 46 relates to sub-part 7 of ASTM F2245 regarding the powerplant. Consideration was given to the compliance, but because the aircraft progressed no further than a mock-up the systems were not designed in detail. The design would be modified as necessary if the project progresses.

Table 46. ASTM F2245 sub-part 7 compliance checks.

Compliance criterion	Determined from	Requirement
Installation	Regulation	The powerplant installation must be easily accessible and withstand the applicable load factors.
Fuel system	Regulation	Tanks must be protected from wear, vibration and must withstand inertial loads due to manoeuvres. The tanks must be vented and withstand a pressure of 24.5kPa.
Fire prevention	Regulation	Firewall must be of stainless steel no thinner than 0.46mm or mild steel (with corrosion protection) no thinner than 0.46mm.

5.4. Analysis of structure

As mentioned at the beginning of §5.3 commercial software was not permitted for use in the design of this aircraft due to licensing restrictions. A method was developed for the re-design of an LSA as a non-commercial research project. The method was verified and improved before being applied to the current design. The method as applied to the research project is presented here as the results for the current design are embargoed due to the software licence restrictions.

The research aircraft was a re-design of a South African home-built aircraft. The original aircraft was developed from Piper Cub wings and Piper Super Cub fuselage and empennage components. Instead of using steel alloy tube the aircraft was constructed using wood. The aircraft externally resembled a Super Cub, but had a low useful load due to the high empty mass. The re-design was to produce a design using low-strength steel tube. The tube was constrained to AISI 1010 mild steel tubing by the research proposer. The ASTM standards do not limit the use of this material. The original Piper aircraft that the design was based on used AISI 4130 Chrome-Molybdenum tube and was certified under FAR 23.

To improve the design of the fuselage, the fuselage space-frame node points were moved to accommodate new contours for the door and roof. These could be achieved because the wing was also being re-designed to make use of a single strut instead of two struts. The wing structure was modified

to have a single highly-loaded main web with a strut and a lightly-loaded rear web. The empennage was designed with a trapezoidal shape at the request of the proposer. The re-designed fuselage is shown in Figure 97.

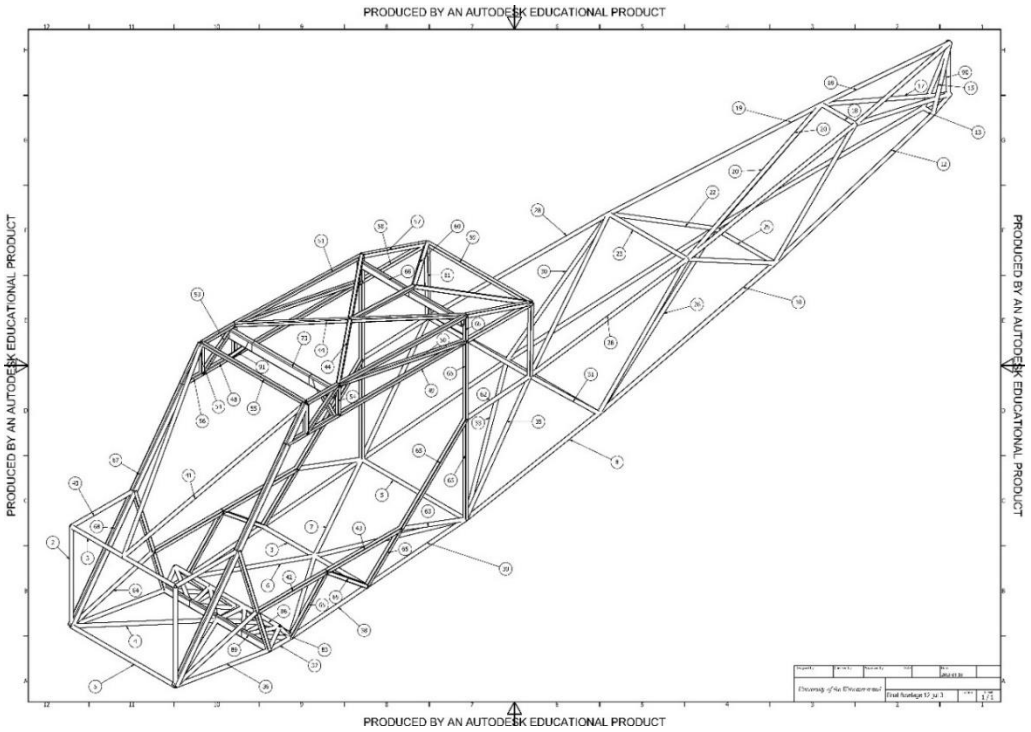


Figure 97. Fuselage of a research project aircraft.

The ASTM F2245 was used to check the design and check the compliance with the consensus standards. For the most important components of the aircraft, the original Piper Super Cub was analysed using F2245. The loads were compared to the loads calculated for SkyWake. The loads were comparable since the research aircraft had a mass of 600kg and a wing area of over 16m^2. The aircraft did not have flaps. The space-frame is shown in Figure 98.

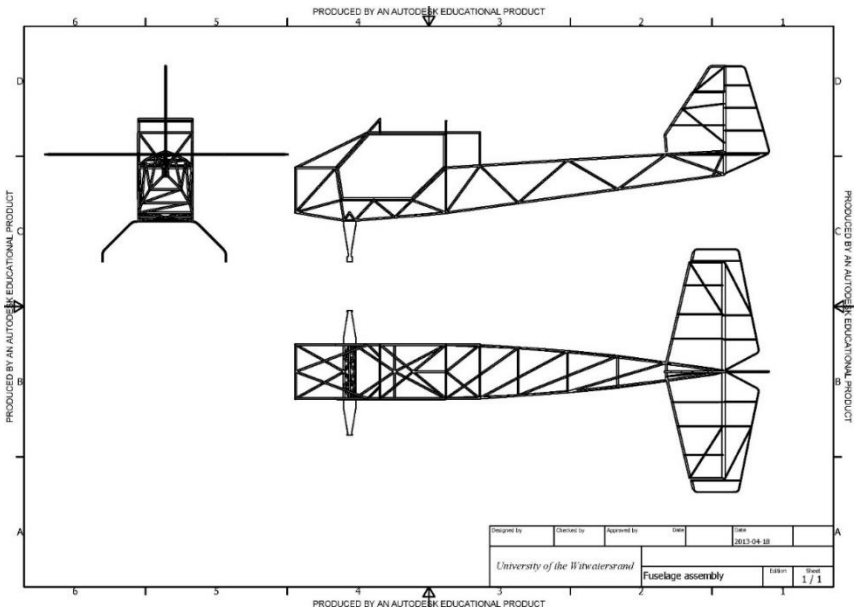


Figure 98. 3-view of the space frame and empennage.

Prokon software was used to analyse the structure. The academic license allowed the use of 50 nodes. The entire fuselage and empennage is shown in Figure 99. Each node was input from a spreadsheet. The properties of each tube, represented by a nodal link, was input.

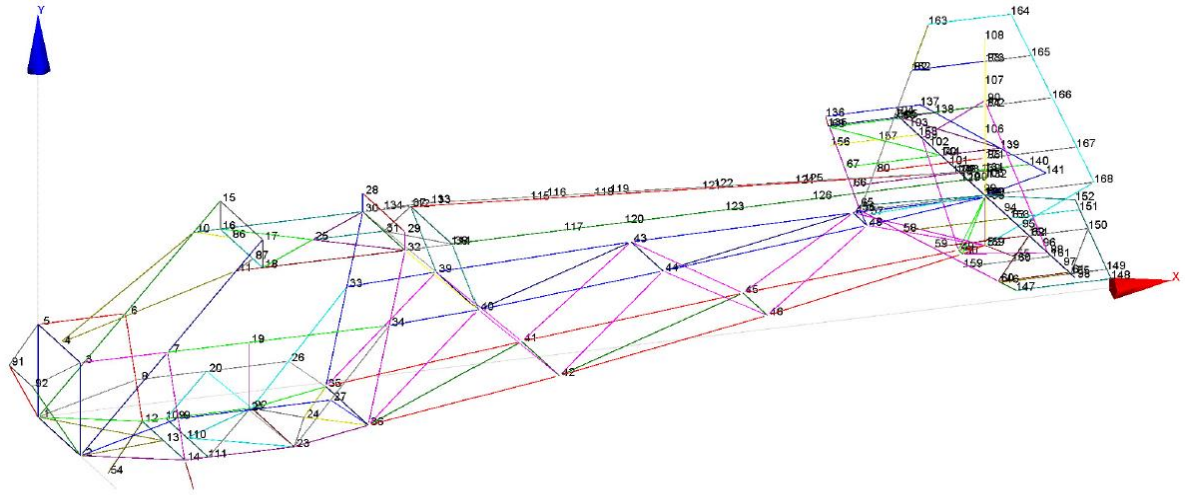


Figure 99. Nodes for the fuselage space-frame.

Different tube sizes were used in the design to reduce the mass of the fuselage, the reduced strength of the 1010 tube would have a negative effect on wall thickness. The tubes in tension would have to be thicker than if a stronger grade material was used. The output loads from Prokon were used with a sort function in a spreadsheet to select the correct tube for the section. The tubes used for this design are presented in Table 47. Pipe 7 is solid rod used for empennage bracing.

Table 47. Tube options for the design.

Pipe	Outer diameter	Wall thickness	Cross section area	Yield stress	Force yield	Young's modulus	Moment of area
No	mm	mm	mm^2	N/mm^2	kN	N/mm^2	mm^4
1	10.9	.9	28.27	305	8.62	$2.07x10^5$	356.29
2	19.1	0.7	40.46	305	12.34	$2.07x10^5$	1714.90
3	19.1	0.9	51.46	305	15.70	$2.07x10^5$	2135.88
4	19.1	1.6	87.96	305	26.83	$2.07x10^5$	3395.54
5	22.2	0.9	60.22	305	18.37	$2.07x10^5$	3421.49
6	22.2	1.6	103.55	305	31.58	$2.07x10^5$	5525.78
7	4	0	12.57	305	3.83	$2.07x10^5$	12.57
8	19.1	1.2	85.92	305	26.21	$2.07x10^5$	4608.89
9	19.1	2	136.80	306	41.86	$2.07x10^5$	6758.15
10	19.1	2	212.80	305	64.90	$2.07x10^5$	38134.05
11	25.4	2.5	356.00	305	108.6	$2.07x10^5$	114165.37

The load case for symmetrical horizontal tail load combined with vertical tail load is presented. For this load case both sides of the horizontal tail were loaded with 100% of the stipulated load vertically downwards and 100% of the vertical tail load was applied towards the positive z-axis. This corresponds to ASTM F2245 X2.4. The fuselage was constrained by the cabin-wing joint. The load case is shown in Figure 100.

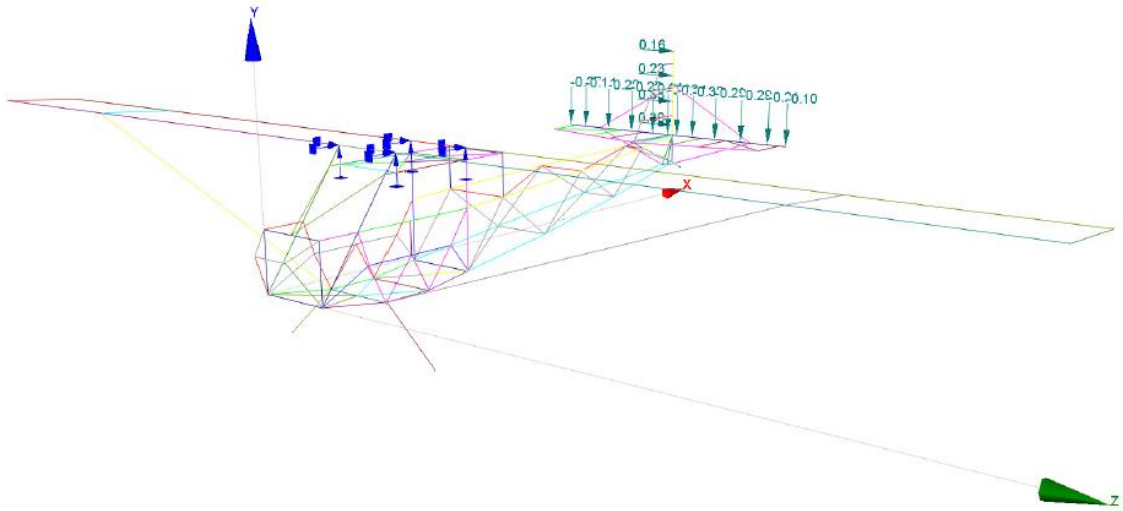


Figure 100. Applied loads to empennage.

The load in each member was determined and the tensile and buckling failure criteria were used. For buckling, the Johnson and Euler conditions were tested. Table 48 presents the data for this load case. The nodal length of each tube was used. For these loads the safety factors are all acceptable. Proof of compliance would still be done by practical test as required by SACAA Part 24.01.2 (6).

Table 48. Results for empennage load case.

Nodes	Length [mm]	Force in member [kN]	Pipe number	F yield [kN]	Tensile Safety factor	F critical [kN]	Compressive Safety factor
36-42	1112	8.61	3	15.7		12.31	1.43
42-46	1245	6.2	2	12.3		7.88	1.27
2-48	727	3.54	3	15.7	4.43		
39-43	1088	7.46	2	12.3		10.32	1.38
43-47	1230	6.06	2	12.3		8.08	1.33

The load case for symmetrical wing load is presented. For this load case both wings were loaded with 100% of the stipulated load vertically upwards and the loads at the wing joint and strut joint were applied to the fuselage. The fuselage was constrained by the cabin-wing joint in the vertical direction only. The loads applied corresponded to 7g. Table 49 presents the data for this load case.

The compressive safety factors that are less than one have been highlighted. The reason for inclusion was that this was part of the structural design process. When a safety factor that was problematic was found, the structure was put through the destruction and creation loop since the majority of the tubes were longer than a single nodal length. The lower fuselage keel tubes were 6m long and ran from the firewall to the tail to reduce the number of joints. If a load was problematic the option of local reinforcement was preferred to specifying a larger tube. The benefit of having structural members in convenient locations for attachment of all the aircraft systems means that almost all tubes in the fuselage would have a lug, gusset or finger plate welded to them. For any highly stressed tube with a welded attachment bracket, the tube would be analysed for the resulting combined loading.

Table 49. Results for symmetrical wing load case.

Nodes	Length [mm]	Force in member [kN]	Pipe number	F yield [kN]	Tensile Safety factor	F critical [kN]	Compressive Safety factor
9-14	253	6.9	8	26.2		13.10	1.90
1-8	580	6.48	8	26.2	4.04	13.10	
1-13	692	17.55	3	15.7		7.85	**0.45**
8-20	410	7.2	3	15.7	2.18	7.85	
1-12	608	14.9	4	26.8		13.41	**0.90**
22-48	492	10.4	4	26.8		13.41	1.29
22-26	492	8.9	8	26.2		13.10	1.47
2-14	608	3.55	4	26.8		13.41	3.78
21-23	326	5.24	8	26.2	5.00	13.10	
23-27	304	6.3	8	26.2		13.10	2.08
27-34	580	6.96	8	26.2		13.10	1.88
26-33	580	9.72	8	26.2		13.10	1.35
1-6	743	21.5	8	26.2	1.22	13.10	
2-7	743	3.4	8	26.2	7.71	13.10	
39-50	214	1.31	4	26.8		13.41	10.24
38-48	214	3.59	4	26.8	7.47	13.41	
14-39	170	16.27	8	26.2	1.61	13.10	
13-39	170	13.88	8	26.2	1.89	13.10	
13-38	160	25.5	8	26.2	**1.03**	13.10	
41-50	170	16.62	8	26.2	1.58	13.10	
41-49	170	19.35	8	26.2	1.35	13.10	
12-38	170	23.55	10	64.9	2.76	32.45	
12-48	130	16.31	4	26.8		13.41	**0.82**
40-48	170	22.95	8	26.2	1.14	13.10	
16-19	150	11.39	8	26.2		13.10	1.15
4-10	1046	10.75	4	26.8		22.11	2.06
6-10	588	13.37	8	26.2	1.96	13.10	
4-11	1049	9.84	4	26.8	2.73	21.99	
19-42	370	9.06	8	26.2		13.10	1.45
15-17	670	9.73	11	108.6		54.29	5.58
40-49	160	22.95	8	26.2	1.14	13.10	

For the SkyWake aircraft a total of 93 nodes with 150 members were used for the analysis of the cabin structure between the firewall and rear fuselage attachment point. The rear fuselage had 42 nodes with 111 members. The method used was less elegant than that presented for the research aircraft. The load cases were applied using simplified truss theory. The critical load cases were tested until a maximum load for that member was observed. The member was sized for that applied load. Given the size of the model, not all load cases were tested. ASTM F2245 Appendix X2.1 stipulates that at V_A the vertical load must be 4W with a tangential forward load of W applied. At V_D a vertical load of 4W and tangential rearwards load of 0.2W must be applied. At the negative load factor manoeuvre point a vertical load of 2W must be applied downwards and a tangential forwards load 0.4W applied with flaps extended. W being the maximum weight of the aircraft in Newtons. These loads would be applied during static testing.

The primary concern was the maximum loads applied from the nose landing gear and engine mount and the loads from the wing and main landing gear. The fuselage space-frame appears very different to that of the Piper Cub design, but the wing and strut load combination were the same order of magnitude and the tube specified was similar in dimension. The method of validation used during the aircraft re-design project involved comparison of the tube specified for a particular member of the fuselage with the tube specified for that member on the original aircraft. The comparison included an analysis of the buckling properties of round AISI 4130 tubes against the square AISI 1010 tubes. The forces obtained for each fuselage space-frame member resulted in a fuselage that was equivalent to the original aircraft. The fuselage was slightly heavier than the original due to the thicker tube wall thickness of the lower strength tube. This formed the basis for the analysis of the SkyWake fuselage.

The material chosen was AISI 4130 Chrome-Molybdenum tube. For the cabin section there were only 18 tubes that had lengths longer than 500mm. The maximum stress obtained in any member was 367MPa, the conservative yield stress used for 4130 steel tube was 560MPa [85]. The minimum tube outer diameter used was 1/2in (12.7mm) and the maximum outer diameter used was 1 1/4in (31.5mm) tube. The thicknesses varied between 0.72-1.25mm. All tube was of nominal size. Due to the use of 4130 steel tube in many racing vehicle, aircraft engine mount and kit aircraft application, the most readily available tube sizes are imperial. The decision was made to standardise the tubes as imperial.

To accommodate changes in the design the tubes were over-specified and large diameter tubes were preferred for rigidity. Wall thickness could be varied to withstand local buckling or to reduce the mass of tubes in tension. The tube length for the cabin totalled 64.5m and the tubes had a combined mass of 24.9kg. The initial fuselage cabin structure side view is shown in Figure 101. The cabin includes the original engine mount attachment. The tail boom would be a separately manufactured structure that would join the rear of the cabin. The side view of the cabin only shows the nodal network down the side of the aircraft. The lower keel truss can be seen on the top view in Figure 102 This was done to reduce the structure across the floor of the cabin and to absorb the high strut and main landing gear loads.

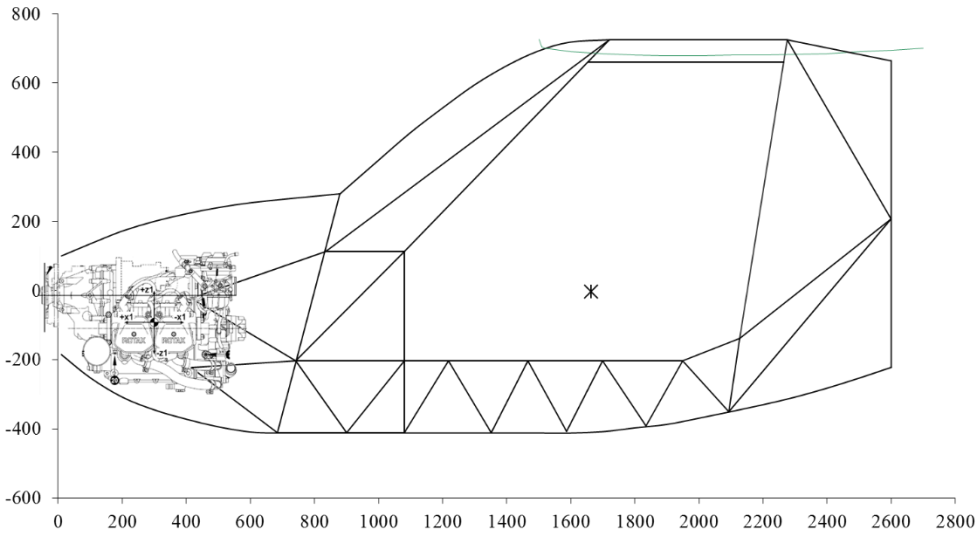


Figure 101. Original fuselage cabin structure side view.

The top view of the cabin is shown in Figure 102. The high number of tube members is apparent. The redundancy in the structure is high. The difficulty in welding the tubes was the primary reason for changes made to the design. The cost of manufacturing a fuselage with a very high number of nodes is significant. The tube profiling, jigging, welding and painting would require a large amount of time and this would create a manufacturing bottle-neck, since the aircraft could only be assembled once the cabin was complete.

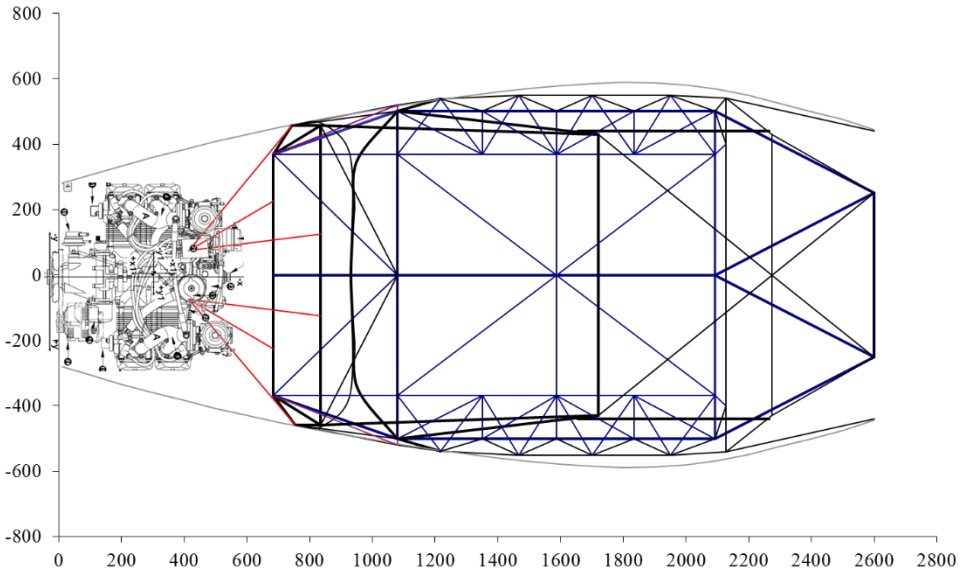


Figure 102. Original fuselage cabin structure top view.

The design was only drawn in CAD once a single professional license had been obtained. The final cabin structure is shown in Figure 103. The engine loads were transferred to the wing and lower fuselage. The side truss was removed in favour of a loaded structure within the centre console. The rear door profile was given a gentle curve to contrast the straight lower and front edges.

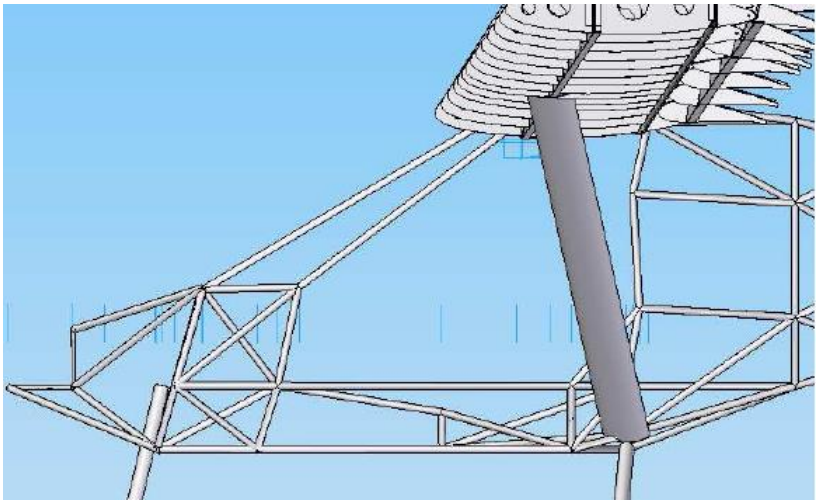


Figure 103. Final fuselage cabin structure side view

The rear fuselage was designed as a separate space-frame that would attach to the cabin. ASTM F2245 Appendix X2.4 stipulates that the worst case of bending and torsion resulting from the empennage be applied to the fuselage. These loads were applied from the tail to the fuselage and resulted in lower forces being applied to the structure than for the cabin structure. The maximum length of any member was 880mm, with a maximum stress of 207MPa obtained for the highest load member. The tubes used for this section were 1/2in (12.7mm) for the smallest diameter tube and 3/4in (19.05mm) for the largest. The tube thicknesses varied between 0.72-0.9mm. The total tube length for the rear fuselage was 52.9m and the combined mass was calculated as 15.2kg. The initial rear fuselage is shown in Figure 104. The fuselage consisted of six tubes in a hexagonal arrangement with triangulation.

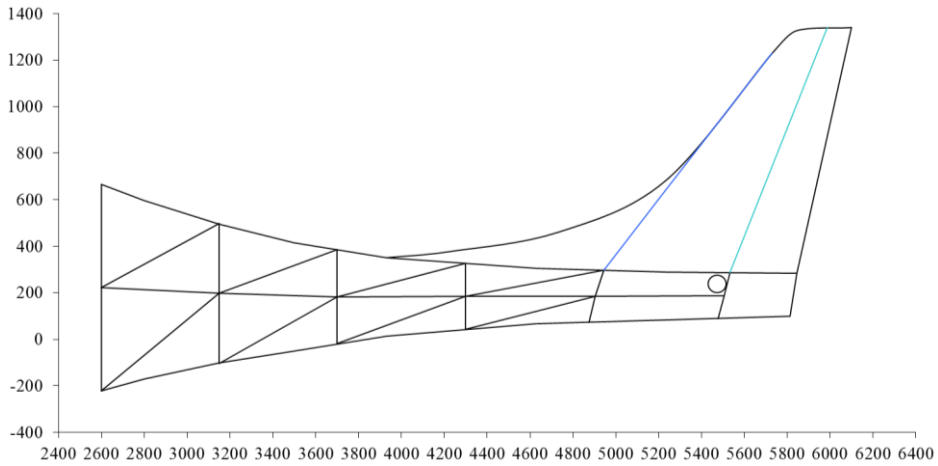


Figure 104. Initial rear fuselage structure side view.

The structure between the first and second bulkhead in the rear fuselage was modified to accommodate the changes made to the cabin. The attachment of the vertical tail was designed using a three-point attachment. The space-frame would attach to the vertical stabiliser front web above and below the horizontal stabiliser. The rear attachment would be a single point attachment. The final rear fuselage is shown in Figure 105. The number of tubes used for the rear fuselage remained unchanged as the design evolved. The combined SkyWake fuselage space-frame had a total mass of 40.1kg. For the Super Cub aircraft fuselage shown in Figure 89, the mass for the tube was calculated as 47.4kg for the first iteration and 45.8kg after refinement. This was considered reasonable since the tube did not have a high yield stress.

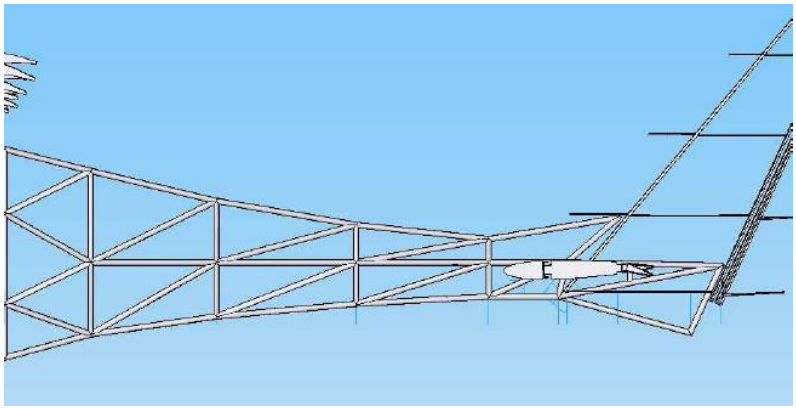


Figure 105. Final rear fuselage structure side view.

The tube sizes used for the fuselage have been listed in Table 50. The fuselage tube wall thickness was constrained to three sizes to reduce welding defects and changes to tube profiling grinding wheels. In some instances tubes with the same outer diameter have been specified with different wall thicknesses. The 19.05mm tube has been specified as the major load-carrying tube for the fuselage. The three thicknesses allowed for a slight weight reduction.

Table 50. Tube sizes used for SkyWake.

Structure	Number of tubes	Outer diameter [mm]	Wall thickness [mm]	Total tube mass [kg]
Tail boom	11	11.13	0.71	0.32
	60	12.7	0.89	6.49
	30	19.05	0.71	5.67
	9	19.05	0.89	2.27
Fuselage	23	11.13	0.71	1.74
	50	11.13	0.89	3.19
	4	12.7	0.89	0.54
	13	14.29	1.25	2.47
	42	19.05	0.89	7.64
	3	19.05	1.25	0.67
	2	22.2	1.25	0.76
	12	25.4	1.25	7.15

The isometric view of the rear fuselage and tail assembly is shown in Figure 106.

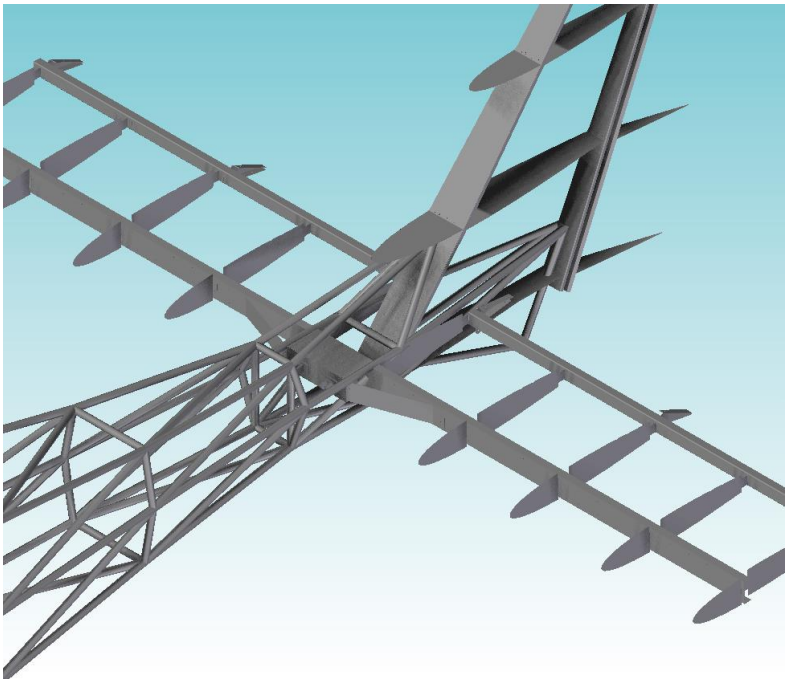


Figure 106. Rear fuselage and empennage assembly isometric view.

The vertical tail was designed as a two-spar semi-monocoque structure. The structure was analysed using a shear flow analysis common for the analysis of the wing and horizontal tail. The largest design loads were applied to the structure. The loads were calculated using three approximations.

The distributed loads according to Schrenk's approximation were compared to loads calculated from lift calculations with an assumed maximum lift coefficient at the reference speed. These loads were compared to the loads derived from the ASTM load estimation method. The loads from Schrenk's method and for the lift calculations were comparable. The ASTM loads would be applied during static tests with bag masses or by whiffle tree. The cellular division of the vertical tail for the shear flow analysis is shown in Figure 107.

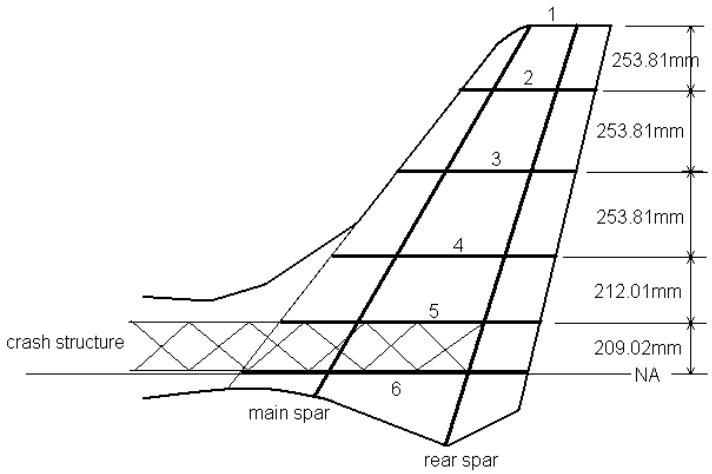


Figure 107. Structural division of the vertical tail.

The front web thickness required to satisfy shear and buckling requirements was determined to be 0.8mm. The applied load of 5.33kN was calculated at V_D and was applied to the stabiliser. The rear web was required to be 0.8mm thick. The skin used was 0.5mm thick. The material thickness was increased so that the front and rear webs could be integrally stiffened with stiffeners manufactured using the same material used for the horizontal tail. The front web was increased to 1.6mm with a 1.6mm thick stiffener and the rear web was thickened to 1.6mm with a 1.6mm thick stiffener. The material mass for the vertical tail was calculated as 5.2kg for the stabiliser. The total mass for the entire tail was calculated at 10kg including a push-rod control system specified for 120mm rudder pedal travel with a control gearing of 4.73 Rad/m.

The horizontal tail was designed using a two-spar semi-monocoque structure with a single carry-through web and load box in the centre. The left and right stabilisers would be separated to allow rotation about the hinge point through the space-frame fuselage. The loads were calculated at unstick speed and at V_A and V_D. The thickness of the front carry-through web was specified as 2mm with 1.6mm stiffeners. The rear web was specified at 1.6mm thick with 1.6mm stiffeners. The ribs and skin were specified as 0.5mm thick. The factor of safety for the web was 8.9 for the shear stress of 30.8Mpa. The factor of safety for the critical compressive load in the web stiffeners was calculated as 2.53 for the compressive stress of 87.7MPa. The mechanism for the tab was modelled and is shown in Figure 108. L_1 represents the chord of the stabiliser. The length of L_2 would be adjusted by the electronic trim actuator to manipulate the angle of the tab, denoted as R'α. For the zero trim setting R'α would be the same as elevator angle α. The centre of gravity limits used were between 20%-32% mean aerodynamic chord. These were set as outer limits for the conceptual design. The aircraft would not have a large centre of gravity range as the cabin was designed to constrain the position of the passengers. The pitch authority provided by the horizontal tail was calculated for these large limits.

The limits would be reduced during the proving flight phase of testing. The limit of travel for the trim actuator would be controlled by adjusting L_3 and h_1.

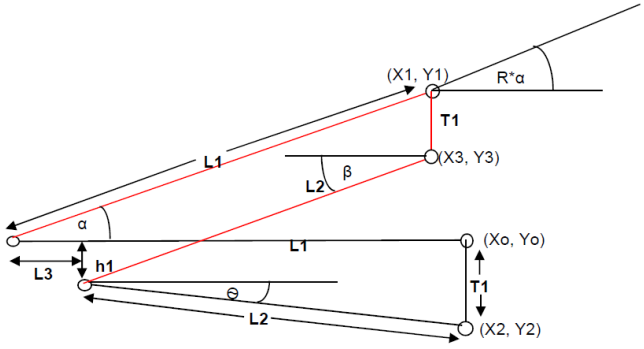


Figure 108. Horizontal tail trim mechanism diagram.

The wing was analysed using Schrenk's approximation at the reference speeds stipulated by the ASTM standards. The strut was positioned on the main web. The lateral position from the fuselage was determined by calculating the overall shear force and bending moment on the wing for different strut positions. The location of the strut at a distance of 1.7m from the wing joint and 2.32m from the centre-line resulted in lower root reaction loads and lower bending loads for the wing. The reactions in 3 axes were calculated at the front web fuselage joint, rear web fuselage joint and at the strut attachment. The bracket attaching the strut to the wing was designed as a reinforced plate that introduced the loads across the entire web. Due to the angle of the strut to the axis of the strut, the ribs and web were stiffened to resist the strut moment. The strut mounting bracket was a machined Aluminium plate with maximum thickness of 10mm. The front web was specified as 2.3mm thick and the rear web as 1.6mm thick. Five web stiffeners were used for the wing. Three for the front web and two for the rear. The stiffener cross section was standardised as 22.2mm x 3.2mm Aluminium 6061 angle. The vertical web stiffeners were specified as the same section angle. The total number of 0.5mm thick ribs specified for each wing was 14 with each rib being attached to the web with a vertical stiffener on both sides of the web.

The ring ribs were modelled as shown in Figure 109. Standard shear flow analysis was used. For the maximum applied load at V_D the shear stress in the front web was calculated as 27.5MPa and the shear stress in the rear web was calculated as 28.1MPa. The factor of safety for the main web was determined to be 10.0 for the front web and 9.8 for the rear web. The peak point load was at the strut attachment. The front web factor of safety reduced to 5.3 for this load application. The critical buckling case for the web stiffeners was in compression. The factor of safety was calculated as 1.12 for the front web stiffeners and 1.29 for the rear web stiffeners based on a crippling stress of 360MPa. The rivets specified for the web-stiffener had diameter of 4.8mm. The rivet shear stress of 177MPa would support a shear load of 3.2kN. The spacing determined for the skins was 23.6mm and for vertical stiffeners the spacing was calculated at 19.5mm. The rivets were specified as solid rivets for the ribs, webs and stiffeners. The skins would be attached with pop rivets on the underside and solid rivets on the upper surface. Round head rivets were specified since the aircraft was a low-speed aircraft and the manufacturing costs associated with countersunk rivets are high. The total mass for the webs, skins and stiffeners for the wing (neglecting the flaps fuel tanks and ailerons) was calculated as 30.7kg per wing. The Super Cub aircraft wings were constructed of Aluminium primary structure with fabric covering. They were larger in area, with a USA 35B profile and weighed 31kg each.

The wings did not feature flaps, the low wing loading and larger centre of mass limits, due to the tandem seating arrangement, meant that the additional pitching moment created by flaps would require a larger horizontal tail. The SkyWake wings were comparable in mass and featured Aluminium primary structure, Aluminium skin and flaps. For a wing of similar span and slightly less area, this initial mass estimate was reasonable.

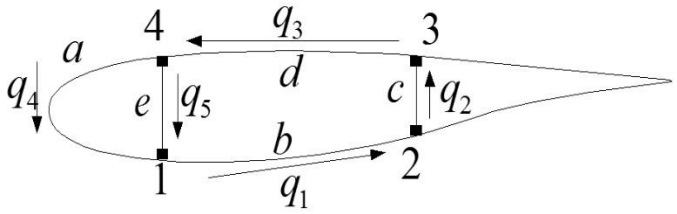


Figure 109. Wing rib structural analysis.

The wing cross-section is shown in Figure 110. The front web has three stiffeners. Two are located to absorb the compressive load on the upper surface and a single stiffener absorbs the tensile load on the lower surface. The lower stiffener is located behind the web as the strut attaches on the front of the web. The two stiffeners used for the rear web are attached on the front of the web. The vertical stiffeners are indicated. The aileron hinge point and push-rod attachment that enable Frise motion are also shown.

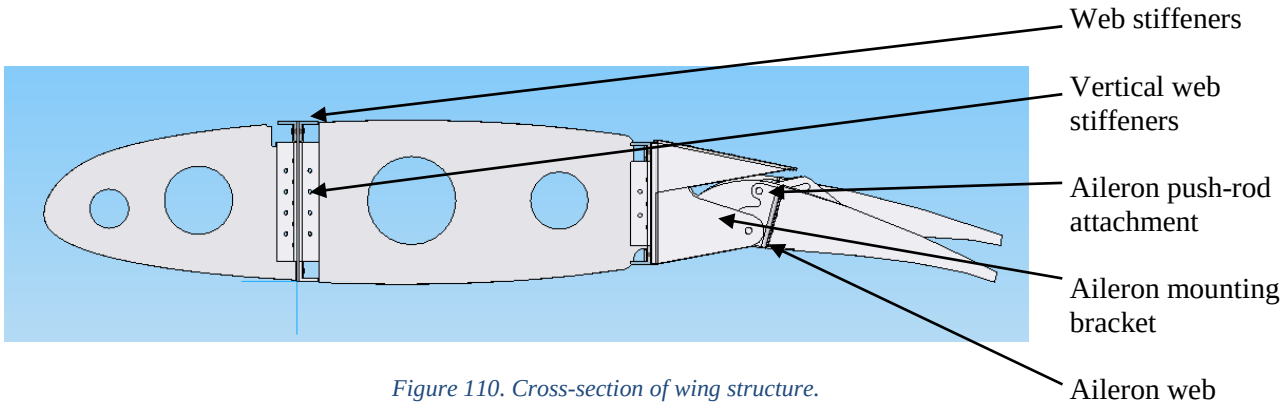


Figure 110. Cross-section of wing structure.

The main landing gear was designed to offer better comfort and low bounce performance. The analysis used to design the landing gear leg was initially a static load analysis given the maximum landing load factor n_j of 3g. The combined load applied at the axle mount of each main gear leg was 8.84kN. The leg was specified as a heated-treated AISI 4340 tube with a yield stress of 834MPa [72]. The outer diameter was calculated as 2in (50.8mm) with a 1/4in (6.35mm) wall thickness. The peak static bending moment resulted in a maximum stress of 631MPa. The horizontal static reaction load required from the spring damper was calculated as 64kN for an axle deflection of 300mm. The load on the pivot was calculated as 111kN.

To analyse the landing gear the model used for vertical loads is shown in Figure 111. F_1 and V represent the forces aligned with the gear leg, forces F_2 and F_3 represent loads aligned with the aircraft. The ASTM provide a maximum load factor for the design of the landing gear. The landing gear may be designed for this load case where static analysis may be used. Alternatively the impact may be modelled to calculate the forces. The analysis of the loads generated during a hard landing is not trivial. For this aircraft the static case was used for the stress analysis.

The spring damper was specified to resist the maximum displacement under static load. The vibration response of the system was calculated by assuming spring constants for the tyre, leg and spring of 190kN/m, 1760kN/m and 209kN/m respectively. The total spring constant equivalent was calculated as 94kN/m. The overall damping constant was determined to be 1000Ns/m. This was determined from high-speed video of aircraft landings and the assumption that the deflection for a perfectly smooth landing was 40mm. The impact needed to be damped after 5 oscillations and approximately 1.5s. The landing gear was analysed assuming the aircraft itself was a rigid body. The spring damper combination would be adjusted on a structural prototype.

The ASTM consensus standards do not prescribe calculations for spin-up loads. The landing gear is testing with the drop test and static tests are required for the loads calculated in Table 45.

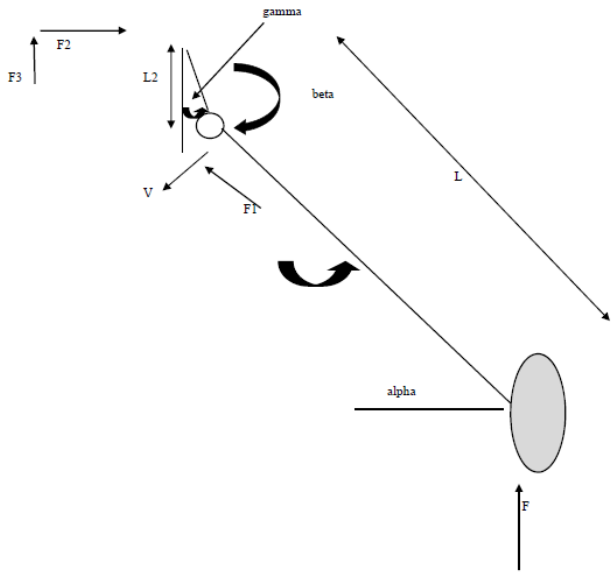


Figure 111. Landing gear vertical load model.

The mass of the material contributing to the empty mass of the aircraft is presented in Table 51.

Table 51. Empty mass breakdown of the aircraft.

Component	Mass [kg]	Comment
Fuselage space-frame	40.1	Conservative as the mass was calculated based on nodal tube length. Compares favourably to the mass for the research aircraft (see Figure 97).
Fuselage skin	15	Includes Aluminium skin, glazing and cowling
Flight instruments	12	Includes the flight instrument panel.
Wing	100	Includes skin, ribs, webs, stiffeners, struts, flaps, ailerons and paint.
Engine	80	Includes Rotax 912 ULS and battery.
Landing gear (main)	20	Includes wheel, leg, stub axle, brake and spring damper.
Landing gear (nose)	8	Inclusive of wheel, axle, spring damper and steering mechanism.
Horizontal tail	14	Includes stabiliser, tab and control linkage (2.3kg).
Vertical tail	10	Includes stabiliser, rudder and control linkage (2kg).
Interior	15	Includes carpeting, console and seats.
Total empty mass	315	

The aircraft empty mass of 315kg allows for a total payload of 235kg to be carried when operating as an ultralight at a take-off mass of 550kg and for a payload of 285kg to be carried when operated as a LSA. This exceeds the requirement of 250kg by a sufficient margin.

With reference to the user requirements:

1. The aircraft was designed for recreational and commercial operations. The materials specified for the aircraft would enable the design to follow a maintenance schedule similar to current trainer aircraft. The design was conservative with regards to structure. The space-frame fuselage would allow for equipment installation to be adapted for different user requirements.
2. The aircraft was designed for low production and operating costs. The manufacturing facility for the aircraft was conceptually designed for low cost component manufacture and assembly that allowed for the aircraft to be competitively priced.
3. The aircraft was designed for typical South African hot and high environmental conditions. Consideration was given to aircraft performance, reliability and maintainability. The performance of the aircraft was assessed on maximum available energy levels, where a definite advantage over the competitors was designed into the aircraft.
4. The aircraft was designed with competitive features and properties that were incorporated at a systems level. Three patents were filed using ideas that were generated for the design. The flap system guide rail being the only patent included in this design. The flap system would eliminate flap mechanism outside the aerofoil profile reducing drag and the chance of cranial or facial impact with the mechanism.
5. The aircraft was designed to meet the requirements of ASTM F2245.

A micro air-conditioning unit was designed to fit adjacent to the ballistic parachute and duct cool air down the centre console. A small food and beverage receptacle was included in the console to be cooled by the cool air. The design has not been included in this report.

With reference to the business requirements, two business plans were created. The first business plan was written assuming the design was to be developed by the Blue Crane Development Agency. The second business plan was written based on a business model where the University of the Witwatersrand would apply for CAA Part 147 Design Organisation approval and the company would apply for Part 148 Manufacturing Organisation approval. The business plans were presented to venture capital consortia and to the following funders (Aerosud, Denel, the Innovation Fund, Industrial Development Corporation, Department of Science and Technology, Department of Trade and Industry, the Employment Creation Fund and the United Nations). The Industrial Development Corporation, Blue Crane Development Agency and University of the Witwatersrand funded the construction of a mock-up of the aircraft. A funding proposal was written for a University-housed DO, this was supported by the National Aerospace Centre. Funding has been awarded to the project from the Eastern Cape government, the priority was to establish the Somerset East airport and industrial park. Should the project be completed on time without budget overrun, this project would be funded in the second phase of the funding. The industry growth plan was named the Somerset East Bureau of Aeronautics (SEBuAer).

5.5. Aircraft development

In terms of the South African regulations regarding the developmental design of an aircraft, SACAA Part 24 was viewed by the aviation community and by the regulating authority as problematic. The regulations for non-type certificated aircraft were never developed for the mass-production of production-standard aircraft. They were written for home-built experimental aircraft, vintage, veteran and ex-military aircraft. Several issues with the regulation language, intent and interpretation were observed by both the industry and the SACAA. The Recreation Administration of South Africa approached the University to investigate changes to the regulations to enable the industry to be regulated based on approvals and type-acceptance basis rather than on a certification process. The regulations were examined and this lead to a proposal to the administrative body responsible for the oversight of non-type certificated aircraft. The regulations were re-drafted [68] in conjunction with industry and regulator participation and the response from industry has been very positive.

The process required to build an amateur-built aircraft with the intention of obtaining a production-built type certificate is illustrated in Figure 112, developed from [72]. The processes for assessing the airworthiness were based on the experienced gained from this project and the understanding of the ASTM standards for LSA. The processes would also need to be developed to assess the airworthiness against FAR 23. That project is in its early stages.

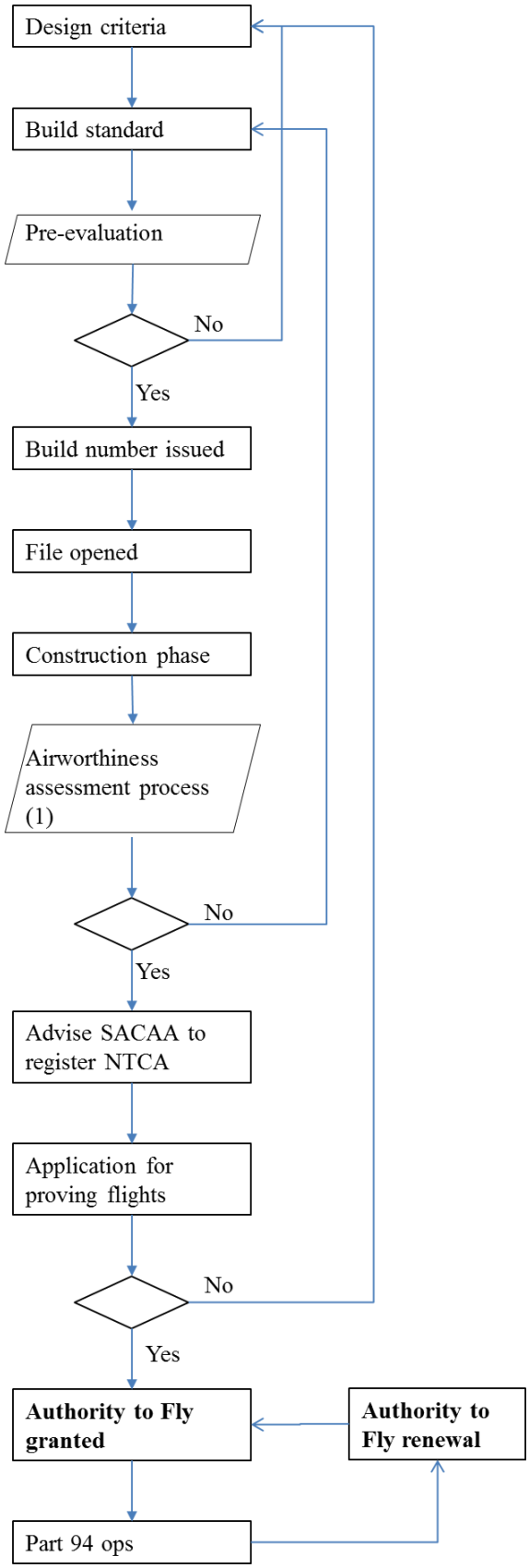


Figure 112. Process developed for the Recreation Aviation Administration of South Africa.

The static testing requirement for a new design intended for production-built approval was clarified. The new regulation pertaining to testing follows:

"Part 24.01

(6) In the case of-

(i) Amateur built aircraft, static tests, as required, are to be carried out on the aircraft prior to its first flight or after a structural modification, referred to in Regulation 44.03.14, according to Document SA-CATS-NTCA.

(ii) Production built aircraft, in the absence of static test documentation from an appropriate authority acceptable to The Director for Civil Aviation, static tests, as required, are to be carried out on the aircraft prior to its first flight or after a structural modification, referred to in Regulation 44.03.14, according to Document SA-CATS-NTCA." [68]

While funding for the aircraft was being sourced, the testing equipment required to test the aircraft was designed. The projects were suitable as final year design projects. The design inputs and user requirements were developed by students with the aim of developing a centre for aircraft structural testing at the university. Funding was sourced from the National Aerospace Centre and from the University to build some of the testing equipment. The structural testing designs completed include:

1. Engine bay test apparatus where the front end of the aircraft would be attached to a small, light rolling stock wagon for high speed testing on unused rail track. The engine bay could be tested at flight speed in very hot conditions in summer and very cold conditions in winter. The apparatus was generated with the use of destruction and creation.
2. Landing gear testing apparatus was designed to test landing gear individually as the first design. The second iteration was a gantry that could reproduce a variety of impact not tested in the ASTM F2245 drop test. The aircraft would be supported by the ballistic parachute attachment points. The aircraft could be dropped at different pitch and lateral angle combinations. The aircraft could also be dropped at any angle combination with a lateral velocity created by allowing the aircraft to swing during the drop. This apparatus was also created using destruction and creation.
3. Landing gear load cells were designed that would allow for realistic tyre slip during the drop testing. This would allow for realistic data to be extracted for the gear to be optimised. The traditional drop test does not allow the tyres to slide laterally as they would on a real aircraft during a landing.
4. Wing structural testing facility was designed for load application to a variety of different wing geometries. This facility was designed to test rear fuselages as well. In addition to testing the wing, the ailerons and flaps can be loaded during the test as well with independent whiffle trees. This project received funding and is being constructed in the University laboratory. The SkyWake wing can be seen attached to the whiffle tree in Figure 113.

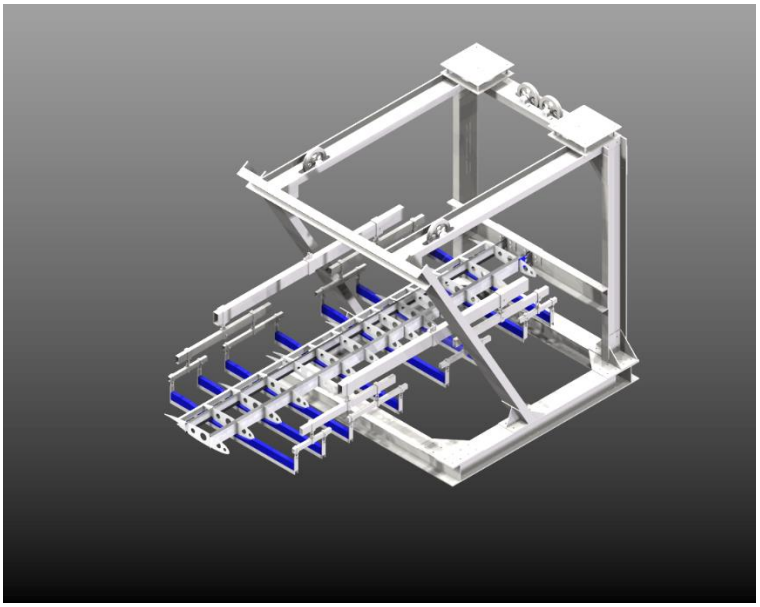


Figure 113. Rendered view of the National Aerospace Centre whiffle tree

As part of the development of new Civil Aircraft Regulations related to the airworthiness of non-type certificated aircraft, the maintenance requirements were found to be problematic and contradictory for some aircraft types. Part 44 was developed specifically for the maintenance of non-type certificated aircraft. Extracts comparing the regulations are presented.

1997 regulations: *43.02.2 (3) Any person may carry out maintenance on an amateur built aircraft or a production-built aircraft, or any component thereof, if such person –*

(a) is authorised by the Commissioner or by the organisation designated for the purpose by the Commissioner in terms of Part 149, as the case may be, to carry out the maintenance; or

(b) carries out the maintenance under the direct supervision of a person authorised by the Commissioner or by the organisation referred to in subregulation (a). [59]

This regulation was problematic regarding an owner-builder of an aircraft. The build standard of a kit aircraft would vary with each builder. The 2011 regulations gave clarity in terms of the supervision necessary and for an owner-builder maintaining his/her aircraft. The substitution of parts complying with a material specification was also clarified. This would allow for Design Organisation approval to be gained by small enterprises that manufactured non-critical aircraft accessories.

***2011 regulations**: 44.01.4(1) A person may carry out maintenance on an amateur built aircraft or a production-built non-type certificated aircraft, or any component thereof, if such person-*

(a) is appropriately rated or approved on type by The Director for Civil Aviation, or the organisation designated for the purpose in terms of The Act, as the case may be, to carry out maintenance; or

(b) carries out the maintenance under the prescribed supervision of a person authorised by The Director of Civil Aviation or by the organisation referred to in sub-regulation (a). A dual check of the maintenance carried out must be performed by a person referred to in sub-regulation (a); or

(c) is the owner of the aircraft provided that an appropriately rated approved AMO, AME or Approved Person, rated in accordance with Regulation 66.4, performs a dual check on the maintenance which was carried out; or

(d) is an appropriately rated approved AMO, AME or Approved Person, rated in accordance with Regulation 66.4.

(2) Components and parts intended to be used on non-type certificated aircraft may be fabricated by a person or organisation not licensed in terms of Part 66 or Part 145 of these Regulations. The owner of the aircraft must provide The Director for Civil Aviation, or the organisation designated for the purpose in terms of The Act, as the case may be, with evidence that the components or parts meet the minimum specification for the component or part as specified by the Original Equipment Manufacturer. An appropriately rated approved AMO, AME or Approved Person, rated in accordance with Regulation 66.4 shall sign off the component or part in the appropriate logbook. [72]

The regulation of modifications was over-regulated, as such many aircraft were left in a modified stated without a certificate of airworthiness. The 1997 regulation effectively required an engineering report for a very trivial modification of an aircraft.

***1997 regulation**: 43.02.15 (1) No person shall, without the prior written approval of the Commissioner, carry out any modifications, including changes to equipment or the installation thereof, which affect, or are likely to affect, the serviceability of the aircraft, or the safety of its occupants or of any other persons or property.*

(2) Before the approval of the Commissioner is considered for a modification as referred to in subregulation (1), the owner of the aircraft, or any other person who applies for the modification, shall

(a) furnish the Commissioner with such information, data, calculations, reports on tests, drawings or wiring diagrams relating to the design, and proof of effectiveness or airworthiness of such modification, as the Commissioner may require; and

(b) be accompanied by the appropriate fee as prescribed in Part 187.

(3) Notwithstanding the provisions of subregulations (1) and (2), such modifications as may from time to time be recommended by the manufacturer of the type of aircraft or equipment concerned, may be carried out if the modifications are carried out in accordance with the said manufacturer's recommendations. [59]

The difference between an aircraft used for recreation, experimentation or for commercial gain was clarified in the 2011 regulations. Two categories of modification were introduced. A minor modification was defined as being a modification to an aircraft that did not change any load condition. The regulation was primarily created to allow owner-builders of non-type certificated aircraft to experiment. Any person owning a production-built aircraft would need approval from the authority, because these aircraft could be used for commercial activity.

2011 regulation *(1) A person may carry out any modifications, including changes to equipment or the installation thereof, which affect, or are likely to affect, the serviceability of the aircraft, or the safety of its occupants or any other persons or property. In the case of-*

(a) a minor modification, as defined in Part 1 of these Regulations, to-

(i) an amateur built aircraft, a notification of the modification must be submitted to The Director for Civil Aviation, or the organisation designated for the purpose in terms of The Act, as the case may be, once the modification has been performed.

(ii) a production built aircraft, a notification of the modification must be submitted to The Director for Civil Aviation, or the organisation designated for the purpose in terms of The Act, as the case may be, within 30 days of the modification being performed. All subsequent modifications shall be an amendment to the build standard.

(b) a major modification, as defined in Part 1 of these Regulations, to amateur built and production built aircraft, an application for the approval of the modification and authority to fly, as prescribed in Document SA-CATS-NTCA, must be submitted to The Director for Civil Aviation, or the organisation designated for the purpose in terms of The Act, as the case may be, before the modification has been performed.

(2) The application as specified in sub-regulation (1) must be accompanied by the appropriate fee as described in Part 187.

(3) All approved modifications shall be entered into the appropriate logbook(s).

(4) An appropriately rated approved AMO, AME or Approved Person, rated in accordance with Regulation 66.4 shall sign in the appropriate logbook(s) that all procedures, as stated in the application for modification, were adhered to and that he or she is satisfied with the quality of the work which was carried out. [72]

The major modification was distinguished from a minor modification. The process allowing for a modification to be approved has been developed and is illustrated in Figure 114.

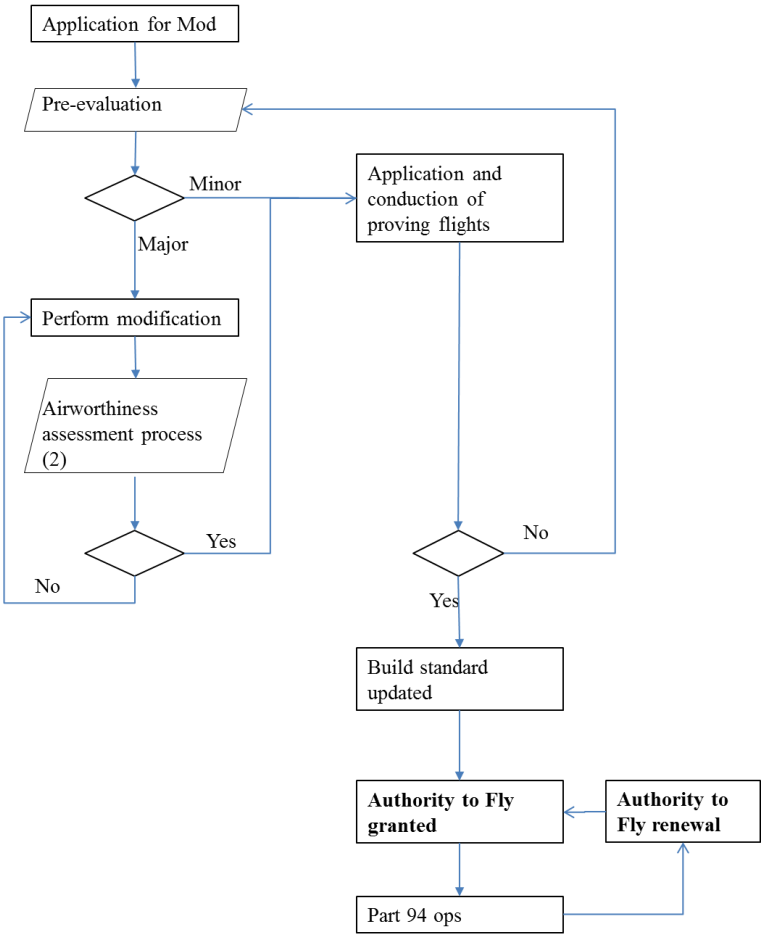


Figure 114. Process for modifications developed for the Recreation Aviation Administration of South Africa.

This process is expected to make the possibility of modifying an amateur-built aircraft significantly easier. The airworthiness assessment process was developed using the structural analysis methods and experience gained during the design of SkyWake. These new processes would allow for a designer to experiment with aircraft performance and structure. This would allow for an experimental home-built aircraft to be developed into a factory produced production-built aircraft. This would allow the industry to grow.

6. Discussion

The intention of the Light Sport Aircraft category of aircraft and its associated airworthiness consensus standards, as described in §1.3, was to promote and nurture general aviation. Student pilots would be able to afford to fly these aircraft before graduating on to type certified aircraft fitted with similar, but certified equipment. These new aircraft would have similar performance to type certified aircraft. Flight schools could purchase these aircraft and they would be used as the preferred flight training platform, replacing expensive legacy aircraft. The operational and insurance costs were intended to be lower than older, traditional, type certified trainer aircraft. Private pilots could purchase these aircraft for recreational use since the cruise speed and aesthetics would be comparable to certified aircraft. New companies could enter the market with new airframes, avionics, engines, components and systems being brought to market without the prohibitive FAR 23 certification costs that have made certified aircraft expensive.

The aircraft in this study was designed as an ultralight that would meet the Light Sport Aircraft design specifications established by the ASTM. The standards were incomplete when initially published and have been modified on several occasions to improve the safety of LSA. The flight envelope defined by the ASTM placards the minimum and maximum flight speeds. Should a manufacturer design a very light structure with a 80hp engine to minimise purchase price, the aircraft would not be capable of achieving a cruise speed of 100KCAS nor would it be capable of transporting a payload of 250kg. The aircraft would also not be competitive against more expensive aircraft fitted with a 100hp engine. If the manufacturer were to use an engine with more than 100hp, the aircraft would exceed the placard speeds and would not be compliant with the ASTM specifications, by exceeding the stipulated flight envelope. The baseline design that would meet the lower placard speeds, with adequate performance at the maximum flying mass, would limit the designer to a 100hp engine. The limits placed on the design by the ASTM consensus standards constrain the aircraft, so that most aircraft of a certain wing configuration would be very alike in terms of appearance and performance. Several vintage aircraft such as the Piper Cub could be made to comply with ASTM F2245, meaning that the aircraft could still be produced for the LSA market. This aircraft would fly slowly with a very low wing loading and very low airframe complexity. The Piper Cub would only be fitted with basic flight instruments due to the narrow cabin width, the maximum speed would be less than 100KCAS, but the aircraft would have adequate performance for a vintage design for a limited target market. The new category of modern LSA aircraft would feature a higher flying speed, higher wing loading and higher airframe complexity. This, in combination with the excellent performance would allow for the aircraft to suit both recreational and commercial operating roles. Any new design would have to offer the market some initial competitive benefit to gain sales. The new design would have to be designed with new technology such as EFIS flight instruments, LED lighting and electric trim to offer additional benefits to the user.

The design as described in §1.1 was conceived to give critical mass to a rural airfield development. The proposer of the design had some criteria that the new aircraft needed to meet. These criteria were based on a basic assessment of existing aircraft in the microlight and ultralight categories. The most suitable aircraft type was a conventional aircraft in the ultralight category, which would be designed as a non-type certificated aircraft. The ultralight category includes a variety of sub-categories as mentioned in §1.2. The aircraft would need to be designed according to the vague SACAA Part 24 airworthiness standards for type approval in South Africa to be awarded. The basic requirements for gaining type approval were discussed in §1.5 and the design and manufacturing organisation approvals necessary for the aircraft to be approved as a production-built aircraft were investigated.

The good sales figures for the new LSA category in both the recreational and commercial markets, in addition to a common consensus standards for the design of the aircraft, would allow for the aircraft to be designed to a common international standard, something the SACAA Part 24 did give guidance on. Light aircraft production in South Africa was investigated. The only aircraft produced in South Africa as presented in Table 1 that would meet some of the criteria was the Airplane Factory Sling, which at the time this design was started, did not exist.

Performance parameters were investigated to refine the proposed criteria. The flight cruise speed was specified at a minimum of 1.05 kt/hp. The payload minimum was set at 250kg to accommodate two adults, baggage and fuel. The aircraft power loading target was stipulated at not more than 6kg/hp. The competitive cruise speed was determined to be 110KCAS. The market-leading ultralight and LSA aircraft performance was explored with the engines available for use on these aircraft. The Rotax 912 series was selected as the most suitable engine. The engine selection was described in §3.6.

The market-leading aircraft based on pre-sales orders was investigated in §3.7. The C-162, manufactured by Cessna, gained substantial sales with the prototype aircraft. The design resembled a legacy aircraft of the same manufacturer. The company made changes to the powerplant to satisfy local demand for a legacy engine. The manufacturing was moved from an existing factory to an international factory. The performance appeared to be market-leading, but a series of accidents resulted in a drop in sales. The aircraft was designed from the start as an ASTM compliant aircraft. The accidents were all due to loss of directional control. An investigation showed that vertical tail surfaces sized using the conventional vertical tail volume coefficients for typical light general aviation aircraft would result in insufficient directional control and stability. The C-162 required a major modification to the vertical tail to improve the directional control.

The dwindling sales of the aircraft resulted in production being terminated. This has resulted in the Piper Cub being the only production United States-designed LSA. The C-162 aircraft was intended to infiltrate flight schools worldwide. Cessna has now been left without any aircraft that is smaller and cheaper than the C-172. It has also left the company without a successful high-wing very light aircraft since the company ended production of the C-152 in 1985.

The Tecnam family of ultralight and LSA aircraft was examined in §3.8. The P92 series evolved from an austere ultralight into a very well-equipped LSA. The sales have been consistently good, resulting in product and company growth. The company has begun to offer certified aircraft as well that compete with Cessna and Piper aircraft. This growth was explored given the airfield development project goal. The evolution of the design was explored because Cessna failed to develop growth once the aircraft entered production. The Tecnam design approach of modification of an initial ultralight design into a LSA was adopted as the lowest risk to market entry. This approach was also selected as the ASTM specification was yet to be adopted by the SACAA. The design complexity of the Tecnam design has increased with product evolution. The initial aircraft appears as being manufactured to a cost constraint rather than a performance constraint. The later aircraft appear to be designed for good performance and comfort rather than for simple, low-cost manufacturing. The P92 Echo classic, P2004 Bravo and P2008 were compared. The P2004 was the evolution of the ultralight P92. The P2008 is a clean sheet LSA design with a lower useful load compared to a P2004, but superior performance to the C-162.

The SkyWake design was focussed on self-developed user requirements with proposer-developed criteria and specifications. To achieve the required specifications, qualitative goals were researched before being turned into quantitative targets. Economic goals had to be satisfied by transforming quantitative targets into performance specifications. At the commencement of this project the C-162 appeared to have the correct quantitative targets and the P92 appeared to be an average aircraft in the ultralight category. The P92 has been evolved into the leading ultralight and Tecnam is the leading LSA manufacturer. The criteria for the design were based, initially, on the perception of the ideal solution.

For the performance the primary criteria used was energy, or more explicitly, the specific excess power. By using energy the competition could be beaten in climbing turns, descending turns, level turns and gliding turns. This could be achieved without compromising the aircraft with regards to any of the other user requirements. This approach to the design of a clean-sheet aircraft of this type has novelty.

The most important theoretical tool used in the design process was the principle of destruction and creation. The notion of deconstructing a design, equation, problem, drawing, system or regulation into base elements and then construction an alternative seems to contradict the standard method of aircraft design prescribed by the majority of authors. For the alternative solution to be successful, the constructed solution needs to be continually assessed against the requirement. The destruction and creation method was not meant to be randomly applied to a complex situation. The approach needed structure. Having correctly prioritised user requirements, structure was provided for the dialectic engine to work. The destruction and creation loop was also used for the creation of concepts with broad capability. For this aircraft the simultaneous destruction and creation loops were structured for operation, cost, environment and competitive features in order of decreasing priority. Each component or system was designed using this method.

Other contributing influences such as the Douglas Aircraft Company general guidelines for design and manufacture were used as constraints to continually assess the concepts during development. Three novel ideas were patented that resulted directly from this design process. A novel propeller spinner was developed to assist with engine cooling during high heat, high power slow manoeuvres. The spinner was an assembly of petal blades retained by a spring. By balancing centripetal force and dynamic pressure the petals would open and act as a fan ahead of the propeller. A South African provisional patent was filed for this invention. The second innovative design was a flap guide rail that was fully housed inside the aerofoil shape. The flap motion was a mixture of translation and rotation. The device would lower the excrescence drag. A South African patent was awarded for this device. The third design was a winglet originally derived to offer a tailored position for the reduction in induced drag. The winglet could be positioned at angle of attack, yaw and cant. The device was further developed to oscillate in a sinusoidal manner and in a random manner to assist in destabilising the wingtip vortices during the roll-up phase. Translation along the longitudinal axis was included for a Patent Cooperation Treaty application. This device was proven to work during wind tunnel tests. US 8,894,018 B2 was awarded in November 2014. Only the flap design was incorporated into the design. The patents were filed to give the design funding applications some intellectual property. The patents are appended as Appendices A, B and C.

The user requirements were used to refine the original requirements. The major systems of the aircraft were designed from the general to the specific. The high-level concepts for the wing, fuselage, landing gear, engine installation and cockpit were generated to best meet the original proposed criteria. The design was developed combining elements of these high-level concepts.

The design of this aircraft was conducted within a framework of fundamental design concepts. The individual concepts that were amalgamated to create aircraft systems at different levels in the system were not unique. In most cases the concepts had not yet been incorporated into an aircraft of this type by other manufacturers. By utilising scientific and operational knowledge of physics, materials and structural elements of an aircraft, the individual concepts could be synthesised into a unique overall concept. For this aircraft the layout of the cabin influenced every other major component of the aircraft. The layout was developed within the architecture of a destruction and creation framework. The physical size and mass of different occupants was used to position the occupants. This allowed for maximum visibility and ergonomic comfort. It also allowed for the change in centre of mass of the cabin to be constrained. The instrument panel and doors could be positioned using the seating as practical geometric limits. The engine was positioned and engine systems were ergonomically placed after incorporating an angled firewall. The wing and landing gear was incorporated before the inclusion of the rear fuselage and empennage.

These components were then designed in isolation before being integrated back into the design. Most components of the aircraft started as creative features where qualitative limits of operation morphed them into a standard configuration. The dialectic engine was used to develop the design and to solve problems encountered where individual qualitative limits could not be mutually satisfied. The flight envelope was identified as the problem that resulted in the demise of the C-162. The C-162 was designed for a high speed envelope and its resulting low speed envelope was not what the market wanted. The Tecnam approach to good low speed envelope and an acceptable high speed envelope has resulted in a commercial success. The Tecnam design sacrificed top-end speed for better all-round performance.

The basic sizing of the aircraft was completed using several teams of students during the university vacation periods. The students conducted research into very specific aspects of the design. The students were then used to size the physical aircraft as demonstrated in §4.4. The students were used to give live feedback during the destruction and creation process. The additional creative input was that less than 5% of the students involved were pilots, the feedback was thus based on opinion of the design without any prejudice or preference. Short and tall students were used to size the cabin. Students would represent the younger generation of aspiring student pilots, an aircraft design project that involved students was within the spirit of the developmental goals of the proposer. Other older pilots were brought in to give their opinion of the design once the design had evolved. The only large changes made to the design during this preliminary sizing was a change in wing aerofoil from a NACA4412 to a NASA 0317. This lightened the wing, provided more space for the flap guide-rail and resulted in lower stall speed with negligible increase in drag. The increase in manufacturing cost due to the larger surface area of the internal wing components was offset by the increase in rivet spacing, resulting in a more ergonomic environment when working with the wing.

The aircraft was then refined with a different set of students. The exceptional students from the first contingent were used to defend the original design that they had helped with, against scrutiny from the new students. Minor changes were introduced only if the change improved the design against the user requirements for two cases. Firstly the individual change needed to improve the design in isolation. Secondly the change needed to improve the design after all other systems were engineered to accommodate the change. This meant that changes were only incorporated if the resulting aircraft was better than the baseline. This process was useful in that each student worked on a small portion of the aircraft but was exposed to the entire aircraft as it evolved.

The refinement of the aircraft, covered in §4.5, verified that the initial conceptual aircraft had fewer negative features than some of the popular competitor aircraft. The wing joint resulted in unobstructed vision, the strut position and door position meant easier access as indicated in Figures 32, 49 and 50.

Maintenance considerations were used in conjunction with the Douglas Aircraft Company guidelines to design sub-systems at a high-level prior to the compliance calculation checks made against the ASTM specifications. This was done because a sub-system can readily be made compliant, whereas a complete system requires more time to be made so.

The initial business case for the aircraft was re-considered as a result of the dialectic engine being used on the entire airfield development. The original idea as proposed by the airfield developer was for an aircraft that would be used for flight training in the Eastern Cape. The company would sell the initial production aircraft to the flight school and rely on word-of-mouth sales from satisfied student pilots, flight instructors and sight-seeing flight customers. By combining the goals of the developer with the goals of a university and the global LSA sales goals, the project was re-scoped further. The business plan presented in this report is appended as Appendix D and only covers the aircraft, launch strategy and manufacturing facility. Extensive planning was done to create a new aircraft industry in South Africa. The aircraft design would, therefore, need to be a commercially successful production-built non-type certificated aircraft. This would enable the owner of the design to gain both design and manufacturing organisation approval, this would allow for product evolution to occur as Tecnam has demonstrated. The manufacturing organisation would be an all-inclusive light industry park located at the airfield with manufacturing companies producing aerospace components in addition to other products such as microlights, parachutes, gliders, racing cars and wind turbines. The design organisation would be a separate company with the university participating in research, development, and design with testing capability. This would allow for spin-off companies to be incubated using the university and industry-linked design and manufacturing hub. The multiple manufacturing organisations and single design organisation would begin producing a variety of aerospace products using the assembly facility for this aircraft to create an industrial hub. For this aircraft several manufacturing facility designs were developed. The sales forecast and business plan required an investment of R15 million for the project.

The best method of demonstrating the three dimensional aesthetics, design features, ingress and egress is to build a model of the aircraft. The decision to manufacture a low-cost full-size mock-up of the aircraft was made once the refinement of the design had been completed. Twelve students, led by a student that had done vacation work during the first round of student involvement, built a mock-up in a twelve week period. The students had no practical experience in welding, metalwork, foam work or in composites manufacturing. The mock-up was presented along with the completed business plan to a variety of potential customers, investors and manufacturers. The aircraft was pitched as being the cheapest LSA in the market with performance comparable with the market leading aircraft. It was therefore pitched as having the best performance in the flight training role at speeds of 70-85KCAS as demonstrated in Figures 82 and 83. The lower wing loading and higher aspect ratio were used to demonstrate the good performance in hot and high conditions. The construction of the mock-up was summarised in §4.9.

The performance was calculated using methods developed by the leading authors in the field of aircraft design. Some of the methods were modified for use on aircraft in this category based on flight test data obtained from LSA aircraft. The thrust model was originally used to evaluate the performance changes resulting from a 20% increase in power on a Parker Teenie two. The method resulted in good correlation. The method was refined during the re-design of the Super Cub, described in §5.4. The

inclusion of scrubbing to correct the ideal thrust for the aircraft fuselage, wing and empennage in the propeller slipstream was verified using flight data for that aircraft. The aircraft was fitted with a 120hp Jabiru engine. The thrust model was further verified by a student during his final year research report on performance enhancements to the Sling. The method of drag estimation has been verified on the projects listed. Two of the aircraft were Aluminium semi-monocoque low-wing monoplane aircraft with mass ranges of 300-700kg and flight speeds of 80-130KCAS. The high-wing aircraft was a fabric covered aircraft. The parameters with high levels of uncertainty used to predict the zero-lift drag coefficient, were better understood during these projects. The skin friction and form factor for light aircraft were investigated to resolve the discrepancy between calculated drag coefficient and flight test drag coefficient. The drag coefficient calculation method was described in §4.8.

The specific excess power during climb and during manoeuvres was assessed as the most important performance parameter considering the combined user requirements. The performance of this aircraft in this regard exceeds that of the P92 and C-162. The zero specific excess power level of the SkyWake was verified by estimation of the maximum level flight speed. The verification was achieved by modelling the P-92 and C-162. The maximum level flight speeds for the two competitors was accurate, the C-162 maximum speed was 1.4KCAS less than advertised as seen in Figure 83. At a speed range of 70-110KCAS, the SkyWake demonstrates a higher maximum energy level. This means that the Aircraft can perform tighter manoeuvres than the competitors and can out accelerate them. If the aircraft was used to tow a banner or a glider, the higher energy level would allow the aircraft to absorb the extra drag without reducing the climb rate significantly. New performance graphs for aircraft were developed to assess the engine-out glide energy levels of an aircraft. The aircraft would be safer to conduct flight training in than a current market-leading LSA as described using Figures 82 and 83. The performance analysis of this aircraft has resulted in several new graphical methods of performance comparison.

The compliance calculations have been summarised, with only the important portions of the consensus standards appearing. The compliance checks were developed for the SkyWake once the design was undergoing refinement. The checks were theoretical when applied to a conceptual aircraft. To verify the checks, the re-designed Super Cub project was used. The verification was based on load calculation and specification of structure for the load, then comparing the specified structural member to the member used on the original aircraft. The method was tested and modified, where necessary, before being used to check the compliance in a second iteration of the compliance analysis. The only concerns were with pitch authority and with directional control. With regards to the pitch authority provided by the horizontal tail, the all-moving design provides adequate pitch control from un-stick speed to minimum controllable flight speed. The aircraft pitching moment was analysed and elevator angle required for trim is within the elevator travel limits as shown in Figure 95. Should flights demonstrate that the pitch authority at low speed is inadequate, the flap deflection would be reduced. The low wing loading and large flap resulted in a stall speed that was less than that required by the consensus standards. The reduction in flap deflection would be preferred to enlargement of the horizontal tail. This is an example of a change that would affect every other system on the aircraft. The enlargement of the tail would result in more parasite drag, greater fuselage loads and a centre of mass shift. As additional mitigation, the rear fuselage and horizontal tail structure was over-designed to allow for growth in surface area. Aerodynamic fixes such as vortex generators would only be used for measurement purposes.

With regards to the directional control, the aircraft was designed with a highly tapered high aspect ratio vertical tail. The volume coefficient is similar to that of the C-162. The final version of the vertical tail fitted to the C-162 has features common to this aircraft, where the final shape was completed before the final C-162 configuration was published. The tail features a large ventral section that is not filleted. The

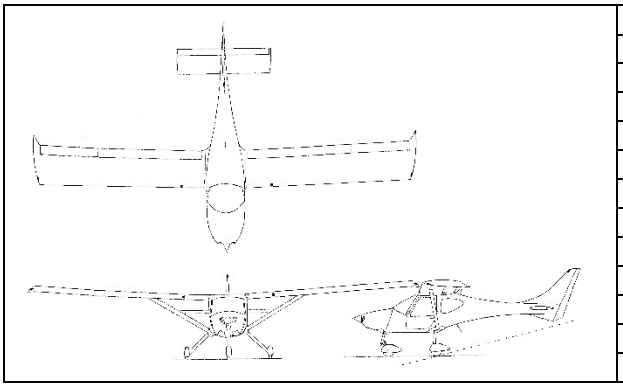
dorsal section has a fillet with a full-span rudder. The actual tail area is larger than that fitted to the C-162. The major difference between this design and the C-162 is the fuselage cross-section, the C-162 is a rounded square and the SkyWake design features a rounded hexagon. The blanketing effect of the fuselage shape on the vertical tail may have led to the poor directional control on the C-162. The control surface loads were calculated using Schrenk's approximation and by using flat plat lift theory to gauge a worst case set of loads. The ASTM recommended control surface loads were directly proportional to wing loading. The low wing loading of this design means that the loads expected at the control surfaces should be less than stipulated for the worst case load set. The structure was then designed for the worst case loads. Based on measurement during the prototype proving flights, the structure could be lightened, if necessary. This approach may require a large modification workload, but that was preferable to a high expense burden during the design phase. The cost of a single finite element modelling software license was approximately equivalent to two fully manufactured fuselages.

The structural components covered in the report summarised the work done on the aircraft. The structure was analysed using fairly simple methods that could be done with the use of a spreadsheet. The fuselage was divided into a cabin and rear section. The cabin design was changed substantially as described in §5.4. The rear fuselage was refined slightly. The tube size and mass estimate for the fuselage was compared to the re-designed Super Cub, the design was comparable. The models for load estimation were either self-derived as in the case of the landing gear or else followed a standard procedure such as the shear-flow analysis in a semi-monocoque box beam for the wing and empennage. All components designed for the aircraft were originally drawn on paper. This was done to save the cost of a CAD licence during the design. With additional funding, a single licence seat was purchased and the paper drawings were drawn in CAD. Many minor changes to components were made at this stage. The Douglas Aircraft Company guidelines were consulted during the drawing phase. Part count was reduced for the wing and horizontal empennage by making every wing rib identical, every aileron and flap rib was also made identical and the stabiliser and tab ribs were made identical. The aesthetics and functionality of the vertical tail justified the taper, the ribs were therefore different.

The aircraft evolved from an ultralight into a LSA. The performance, operational, environmental and cost user requirements were successfully achieved using a standard design procedure with unorthodox systems being combined into an orthodox design offering better energy performance than the competitors. The design was used to develop a business plan for the aircraft and for a development plan to create an industry. The project was gaining critical mass following the construction of a mock-up of the aircraft. Since then the global economy has experienced a down-turn and the LSA market has stabilised at lower than expected annual sales, meaning that a new market entrant is unlikely to be successful. Although the project may never progress, funding was secured for an innovative wing structural testing facility. Funding is being sourced to construct a wing, empennage and fuselage for structural research. The methods, models, intellectual property and know-how derived from this project is being used on other projects currently. More knowledge is being added to the methods.

The SkyWake 3-view and specification is given in Table 52.

Table 52. SkyWake specification summary



Parameter	SkyWake
Airworthiness standard	ASTM F2245
Empty mass	315kg
Maximum take-off mass	600kg
Payload	335kg
Engine	Rotax 912 ULS 100hp
Wing span	11.2m
Length	6.7m
Aspect ratio	10.18
Wing area	12.32m^2
Cruise speed	105kts
Maximum rate of climb	900-1000ft/min
Take off ground run	118m

The work conducted for the regulatory authority on the airworthiness and maintenance regulations and technical standards resulted in a largely improved Part 24 where the airworthiness requirements for amateur built, production built, veteran, vintage and ex-military aircraft was clarified. The airworthiness assessment for each type of aircraft is now specific to the aircraft type. This replaced the older generic approach to airworthiness that was too strict in some instances. The new regulations also give owners that made illegal modifications to an aircraft an opportunity to achieve an airworthiness certificate. The maintenance of non-type certificated aircraft was originally derived from Part 43. This approach resulted in some safety concerns for non-type certificated aircraft used for commercial activity. Part 44, a new part of the regulations was created specifically for all non-type certificated aircraft. The part makes allowance for non-type certificated aircraft use in commercial activity. The part also cleared up minor and major modifications. The substitution of parts with appropriate fit, form and function was included if the part conformed to the general specifications of the original part.

The structural test facility would be very useful to a regulatory authority since the whiffle tree method is more accurate than the traditional sand-bag test. The facility would enable FAR23 tests to be conducted for aircraft certification. The ability to conduct such tests would assist small companies to gain design organisation approval from the regulator. Aircraft originally designed as amateur designed and built aircraft could be tested as part of a research project at low cost. The design could then be improved with the objective of gaining a type certificate in the case of a certified aircraft or gaining type acceptance in the case of a non-type certificated aircraft. This would allow aircraft to progress from amateur-built to production built in accordance with the regulations. The facility would thus act as a design incubator.

7. Conclusion

A conceptual aircraft was synthesised. The synthesis, described in §4.4 included high-level, mid-level and low-level detailed design. The design was then refined in §4.5. Maintenance considerations were introduced in §4.6 and a business plan was produced §4.10 to demonstrate the feasibility of the design. The flight envelope was derived according to the appropriate ASTM F2245 consensus standard as described in §5.3 and the aircraft flight loads were determined in accordance with the method prescribed. The major components of the aircraft were designed to be compliant with the additional system loads calculated using the consensus standards in §5.4.

The flight envelope of the aircraft was developed and the aircraft was tailored to demonstrate superior energy levels to the competitors. The energy levels were assessed in §5.2 for climbing, gliding and turning manoeuvres. A method for evaluating engine-out manoeuvring glide performance was developed and shown in Figures 84 and 85. The conceptual aircraft had better performance than the competitors at any speed between stall speed and the cruise speed recommended by the ASTM as shown in Figure 83. The low speed performance was better due to the lower wing loading and higher aspect ratio offered by the wing. The high speed cruise performance was slightly less than the competitors but the time taken to accelerate to the maximum speed was less than for the competitors. The cruise speed was marginally less than the competitors, but the combination of energy performance and purchase price mitigated this. The pitch stability was investigated with flap deflection in §5.3, adequate longitudinal control was demonstrated. Deficiencies in the vertical tail design used on the market leading competitor was described in §3.7. The vertical tail of the aircraft was designed for improved directional control over that of the competitors.

The mass specifications for the aircraft were an empty mass of 315kg, payload fraction of 55.8% of maximum take-off mass of 600kg. The geometry of the wing allowed for improved manoeuvre performance with aspect ratio of 10.18 and wing area of $12.32m^2$, resulting in a wing loading of $48.7kg.m^{-2}$. The cruise speed was determined to be 105KCAS with a maximum speed of 114KCAS. The maximum rate of climb energy level was estimated at 1000ft/min using a performance model that predicted the performance of the market leading competitor with 1.2% error. The aircraft demonstrated superior engine on and engine off performance as show in Figures 82 and 86 respectively.

A strategy for developing an aircraft industry was developed. The manufacturing facility for the aircraft was designed and costed in detail. The business plan in §4.10 and Appendix D included a market survey, sales forecast, investment requirement, operational costs and launch strategy. A mock-up of the aircraft was constructed as described in §4.9. Three design features were patented, as described in §4.5 to assist with fund-raising. Funding for a structural testing facility was received, the facility that received funding would allow for the wing, flap and aileron structures to be validated.

7.1. Aircraft energy levels, transient energy rates and tumble mechanics

The analysis of energy levels used in the design of the aircraft resulted in the ability to determine the maximum energy levels of a light aircraft for level altitude manoeuvres such as a turn or level altitude acceleration. The maximum energy levels were also used to determine rate of climb at constant speed. The zero-thrust energy levels were used to determine sink rate in a turn, glide rate and could be used for level altitude deceleration. The analysis of energy levels for a given steady state altitude and airspeed is useful for a light aircraft in the event of airshow display authorisation or in an accident investigation.

The analysis of transient energy was identified as a future research field. Transient energy would enable the changes in speed, altitude and position to be determined during a manoeuvre. The future energy state of an aircraft is function of the current energy level and rate of energy gain or loss. An example would be a light aircraft at stall. The level altitude recovery would require the pilot to apply full power and lower the nose as the speed increased. The altitude loss recovery with full power applied would result in greater acceleration due to the combination of horizontal energy and vertical energy contributing to the change in energy level. From an energy rate perspective the altitude loss recovery results in a faster transient between energy states. To complicate the altitude loss recovery, if the aircraft was put into a turning manoeuvre during the recovery, the horizontal energy level would decrease due to load factor and vertical energy level would increase for the same reason. To achieve the same energy state as for the original altitude loss recovery, a different end state would result.

To apply this analysis to a light aircraft would not result in information that would improve understanding of aircraft or safety. The analysis would be very useful to airshow pilots performing tumble manoeuvres. The analysis of energy levels and rates during stalled or near-stalled manoeuvres would allow for safe speed and altitude margins to be made. Pilots skilled in aerobatics understand energy and energy levels. The transients are not well understood, particularly when a manoeuvre exit energy level and energy rate is not as expected by the pilot. The result has been many instances of controlled flight into terrain where the pilot needed extra energy and altitude ran out before that could be achieved.

The SEP charts for aircraft have only been produced for aircraft using stall as a lower reference speed. With aerobatic aircraft, many aircraft are controllable post-stall with the pilots using the propeller slipstream with elevator and rudder to control the aircraft. This regime of flight and the associated energy levels will be investigated.

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Appendices

Appendix A – Provisional patent specification for the wing flap

Appendix B – Patent application for the propeller spinner

Appendix C – US patent for the winglet

Appendix D – Business plan

Appendix E – Bill of sheet metal material

Appendix F – Prototype costing for the SkyWake aircraft

APPENDIX A

SA Provisional Application 2009/00359

PROVISIONAL SPECIFICATION

Applicant: University of the Witwatersrand,
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Christopher Bodill
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James Reeves
Amit Bholla
Sean Mowatt
Jonathan Nash

Title: Improved Airfoil Deployment Mechanism.

BACKGROUND TO THE INVENTION:

Light aircraft have mechanisms to adjust the position of the second element of an airfoil external to the wing such that they cause excrescence drag when retracted. Figures 1 and 2 show this type of prior art mechanism.

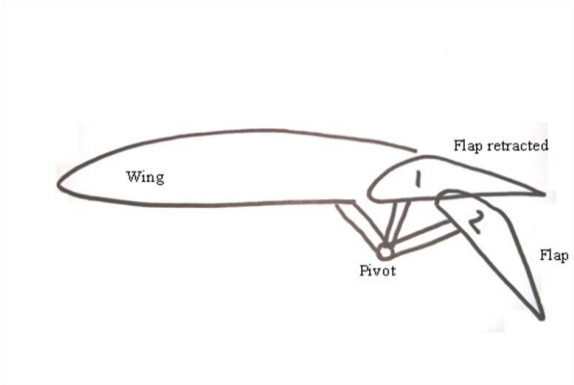


Figure 1. Conventional device for a single slotted flap.



Figure 2. Commonly used external pivot mechanism for single slotted flap systems.

SUMMARY OF THE INVENTION:

According to the invention, there is provided an internal mechanism for the translation and rotation of the second element or flap of an airfoil into a position to increase the coefficient of lift of the airfoil by allowing airflow over the upper surface of the flap.

Preferably the internal mechanism comprises of a horizontal translation guide and a dual guide rail to induce rotation of the flap. These guides are internal to the elements of the airfoil, not creating excrescence drag.

Further, the internal mechanism comprises of a horizontal translation guide and a dual guide rail with multiple rollers to induce rotation of the flap whilst maintaining an optimum gap between the wing and the flap.

DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION:

The device is an internal mechanism intended to deploy the second element of a conventional airfoil using horizontal translation and a dual-guide rail to induce rotation with the purpose of increasing the coefficient of lift of the airfoil. The geometric locus of the flap is similar to that commonly regarded as a single-slotted flap. Figure 3 depicts the wing assembly, incorporating the device.

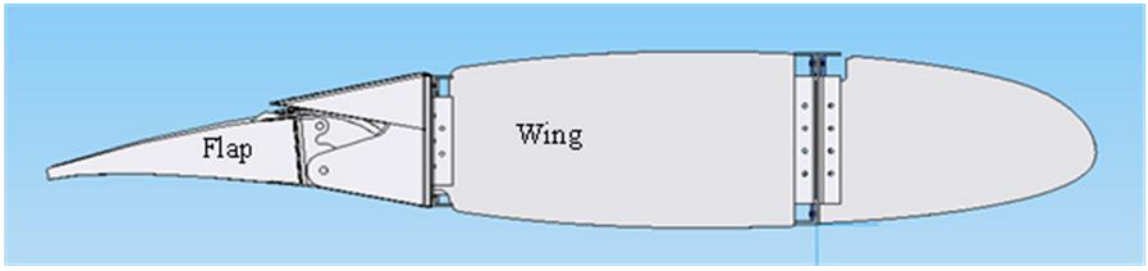
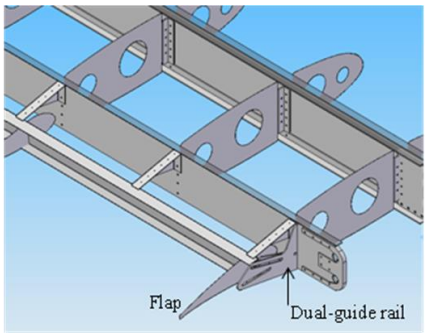


Figure 3. Flap guide rail



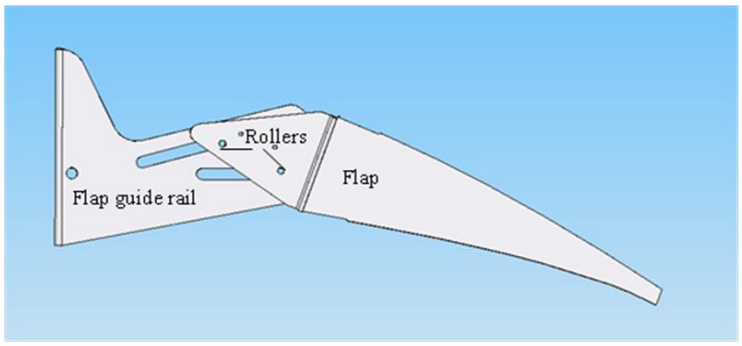
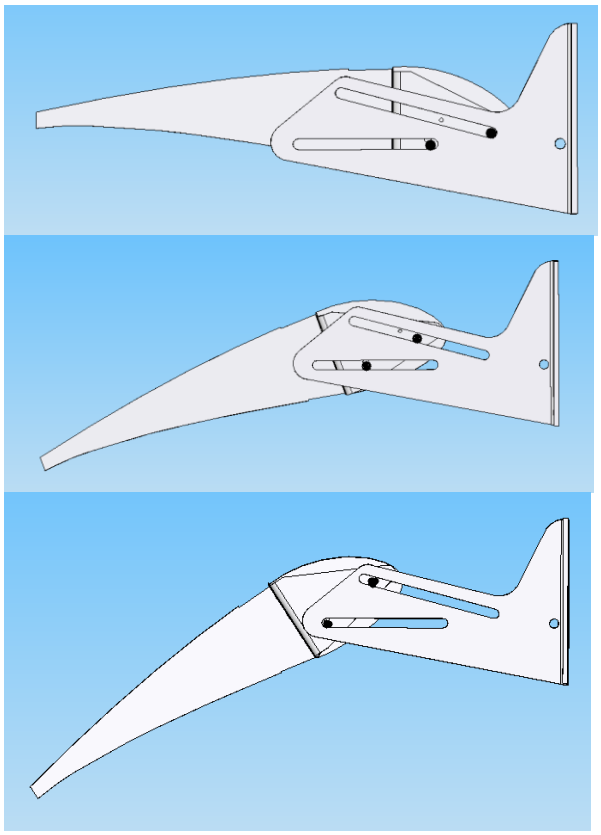


Figure 4. General arrangement of the device

The mechanism is contained within the first and second elements of the airfoil, thereby eliminating excrescence drag. The effect of a high lift device is to increase the coefficient of the lift of the airfoil, whilst increasing drag to a lesser extent. The coefficient of lift is proportional to the camber (curvature) of an airfoil, increasing the relative angle between the first and second element increases the camber. The increase in the coefficient of lift may be calculated from first principles using Kutta-Joukowsky, thin airfoil or lifting line

theory. The device offers an insignificant improvement to the coefficient of lift but reduces the coefficient of drag by eliminating the external pivot mechanism.

There are several options for the actuator system, including hydraulic, pneumatic and electrical actuators. The movement of the flap is shown in Figure 5.



Flap retracted

Flap extended for Take-off

Flap extended for landing

Figure 5. Three primary flap deployment positions

The rollers may be seen in Figure 5, represented as dots. The curvature of the guide rails keeps the flap at the correct angle and allow for the air gap to be optimized.

The drag when retracted would be substantially less than the conventional systems employed, shown in Figures 1 and 2.

This flap mechanism would be unique in its robustness and modular construction, making it suitable for installation in a multitude of aircraft.

APPENDIX B

PROVISIONAL SPECIFICATION

Applicant: University of the Witwatersrand,
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Inventors: Michael Boer
Anthony Hoffe
Andre Cachucho
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Terence Herron
Jonathan Nash

Title: An Improved Spinner for Propeller Engines.

BACKGROUND TO THE INVENTION:

Propeller engines, such as used on aircraft, have a spinner to guide air into a positioned air intake for the cooling of the engine. Figure 1 shows a conventional spinner installed on an aircraft engine (the conically shaped component covering the propeller hub, with the air intake duct below the spinner).



Figure 1: A conventional spinner installed on an aircraft engine.

A problem with such conventional spinners is that they do not assist in providing air for cooling, especially under high-power low-speed, conditions where typical engine installations can overheat. This commonly occurs during take-off and climb.

SUMMARY OF THE INVENTION:

According to the invention, there is provided a spinner for a propeller engine on which vanes are positioned to enhance the acceleration of the flow of air into the engine air intake.

The vanes are positioned to be axi-symmetric, so that the propeller engine is balanced, and the contours of the vanes are such that air is accelerated into the air intake of the engine when the rotational speed of the spinner exceeds the forward velocity of the propeller.

According to one aspect of the invention, two or more vanes are planar, axi-symmetric, such that the vanes are emerge radially from the spinner axis.

According to another aspect of the invention, the planar vanes above are positioned such that the outer edge is curved in the direction of rotation of the spinner.

According to yet another aspect of the invention, the vanes are not planar, but curved such that a concave surface of the vanes moves in the direction of rotation of the spinner, effecting an acceleration of the flow of air over the spinner.

According to another aspect the invention, there is provided a spinner for a propeller engine on which hinged petals are positioned to increase the momentum of the flow of air into the engine air intake. The cambered petals form a semi-enclosed spinner when at low rotational speed and at high forward velocities.

The petals are positioned to be axi-symmetric, so that the propeller engine is balanced, and the contours of the petals are such that air is accelerated into the air intake of the engine when the rotational speed of the spinner exceeds the forward velocity of the propeller.

Further to this aspect of the invention, two or more petals are planar, axi-symmetric, such that the petals emerge radially from the spinner shaft.

Preferably for this aspect of the invention, the planar petals above are positioned such that the chord line of the petals form a positive angle of attack to the oncoming air in the direction of rotation of the spinner.

According to yet another embodiment of this aspect of the invention, the petals are not planar, but curved such that a cambered surface of the vanes moves in the direction of rotation of the spinner, effecting an acceleration of the flow of air over the spinner. Again, the cambered petals form an enclosed spinner when at low rotational speed and at high forward velocities.

Further, the invention is a spinner substantially as described herein.

PREFERRED EMBODIMENT OF THE INVENTION.

The device of the first embodiment of this invention is a fixed rotational component attached to an aircraft propeller and is intended to accelerate air into a positioned air intake with the purpose of imparting velocity to the air flowing over the spinner. The axis-symmetric body employs carefully positioned vanes to accelerate the air. The general term for such a smooth axis-symmetric body is a spinner. Figure 2 depicts the general arrangement of the spinner.

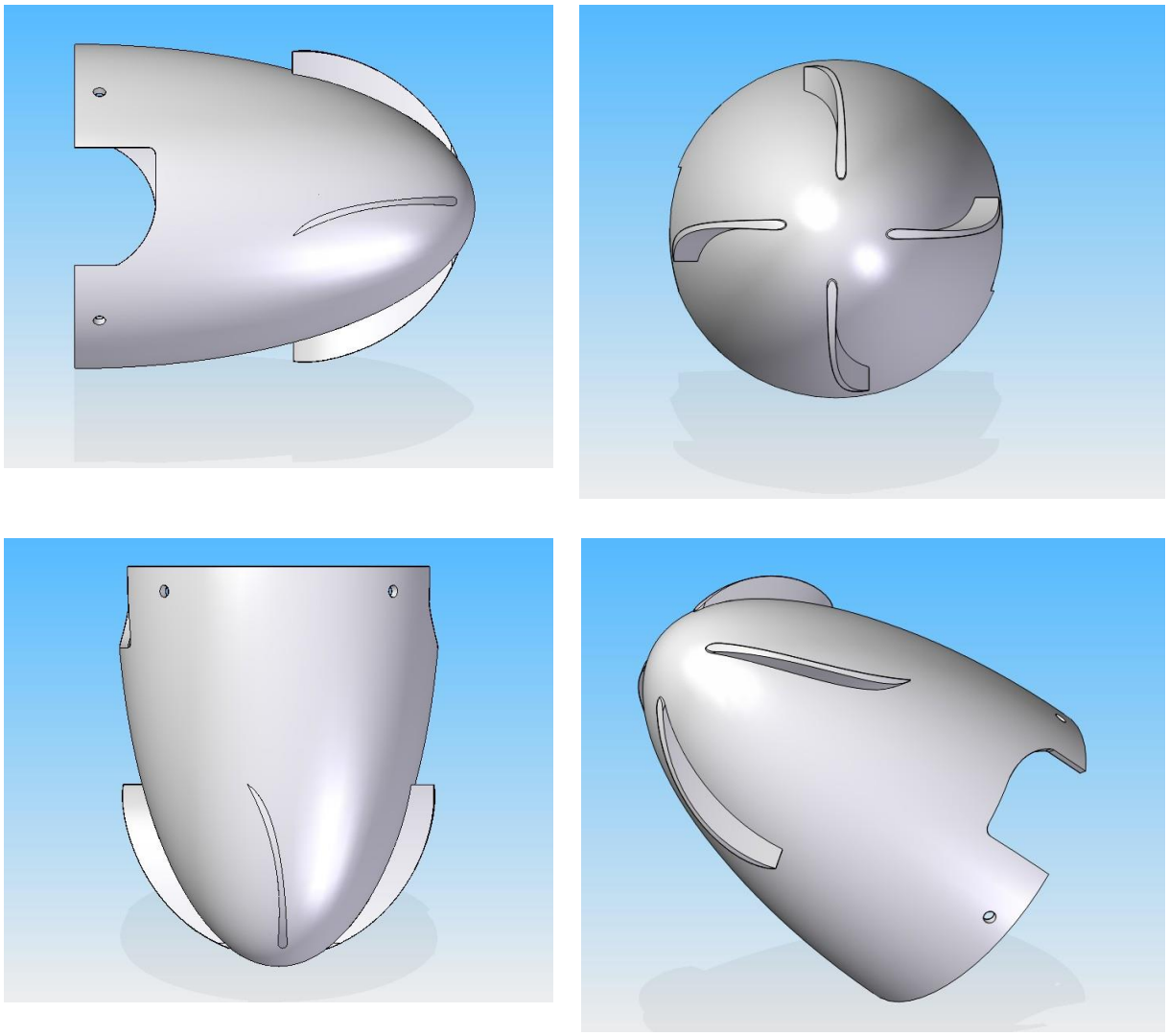


Figure 2. General arrangement of a preferred embodiment of the spinner of the first embodiment of the invention.

The device aims to accelerate airflow over the spinner to increase the mass flow rate of air, allowing for more efficient heat dissipation from a standard heat exchanger. The vanes on the spinner could be regarded as an un-ducted fan.

The contour of the vanes needs to be carefully matched to the propeller rotational speed and the forward velocity of the aircraft. The contour should only accelerate air under conditions where the rotational speed of the spinner exceeds the forward velocity of the aircraft. This would occur under high-power low-speed conditions.

The spinner of this first embodiment would be the first spinner to offer enhanced cooling properties for a liquid or liquid/air cooled engine. The spinner could easily be adapted for a multitude of propeller driven aircraft.

The device of the second embodiment of the invention, a novel variation of the first embodiment, consists of a shaft connected to the propeller hub, for which the front end of the shaft has machined lugs which act as pivot points for the petals. The petals are connected to the shaft at the pivot points and are connected to the slider by means of small pushrods, connected to lugs on the inner surfaces of the petals. The slider acts against a compression spring as centripetal force, due to the rotation, exerts a force on the petals, causing them to open. Figure 3 depicts the general arrangement of the spinner.

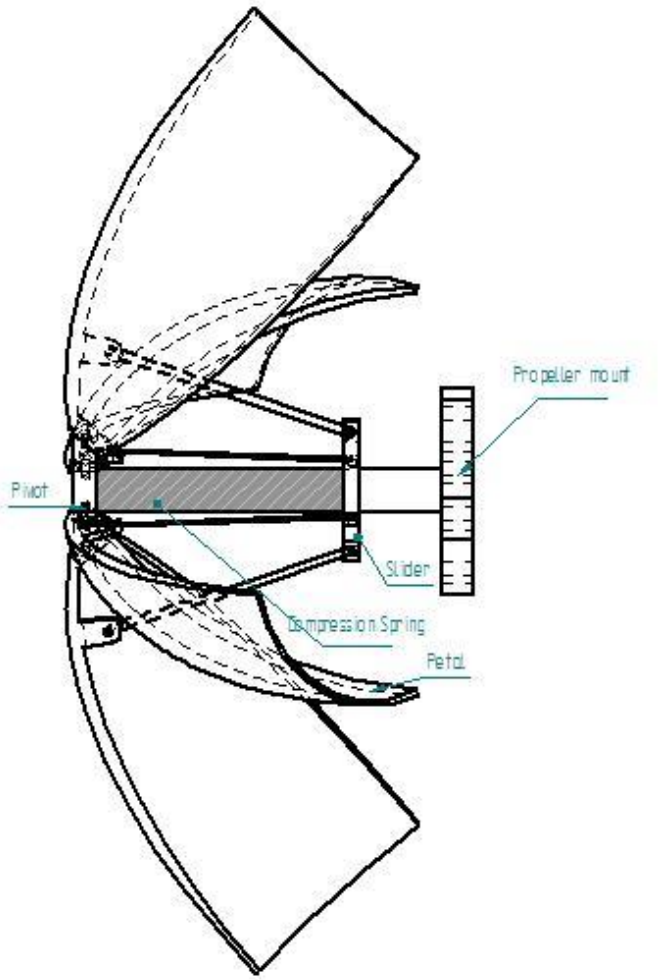


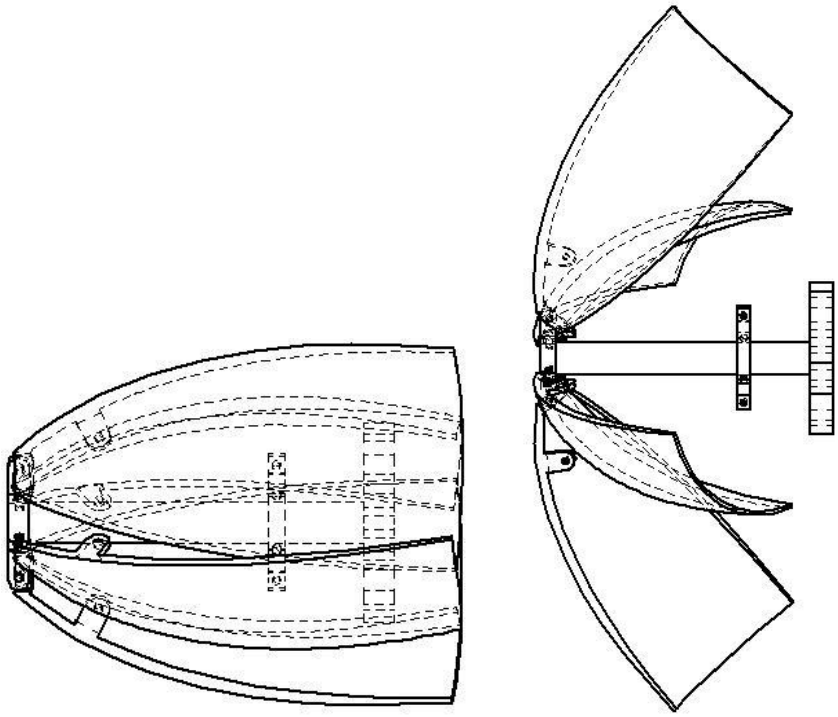
Figure 3. General arrangement of the second preferred embodiment of the spinner of the invention.

The contour of the petals, including camber and twist, needs to be carefully matched to the propeller rotational speed and the forward velocity of the aircraft. The combination of

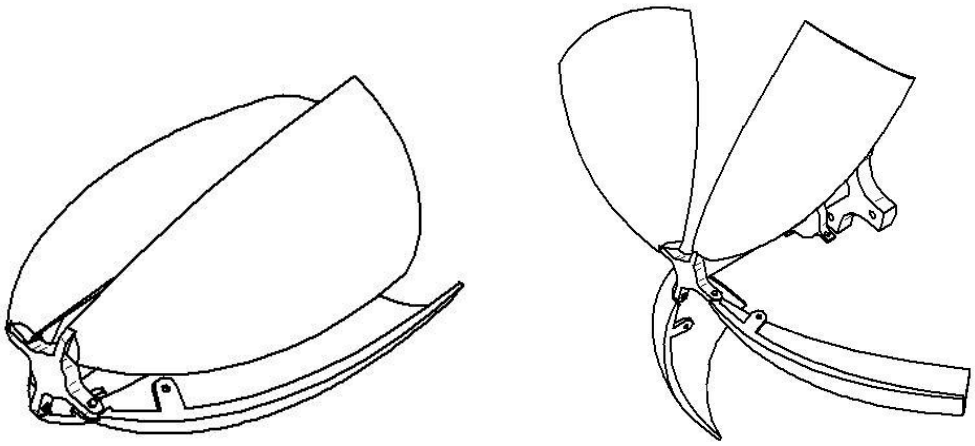
rotational centripetal force, thrust generated by the petal and aerodynamic drag needs to be determined to specify the spring. The compression spring needs to have non-linear stiffness, since the loads are proportional to the square of the velocity, which may require a combination of springs, The contour should only accelerate air under conditions where the rotational speed of the spinner exceeds the forward velocity of the aircraft. This would occur under high-power low-speed conditions.

The petals on the spinner could be regarded as an un-ducted fan.

Figure 4 gives different views of the second embodiment of the invention, in order to illustrate the concepts.



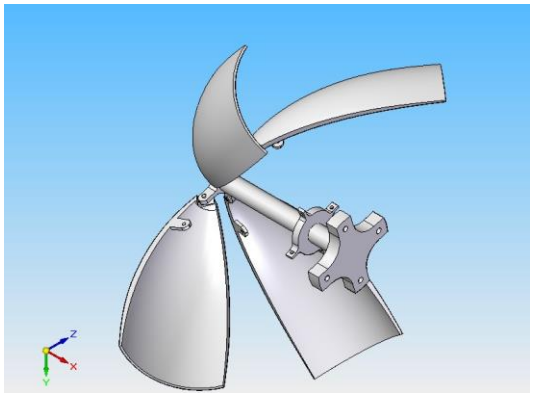
(a) Side view, spinner closed (b) Side view, spinner open

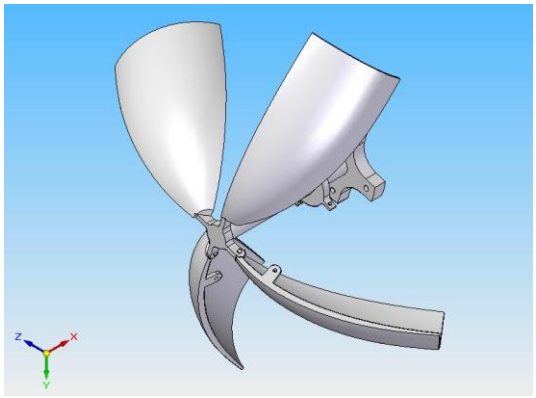


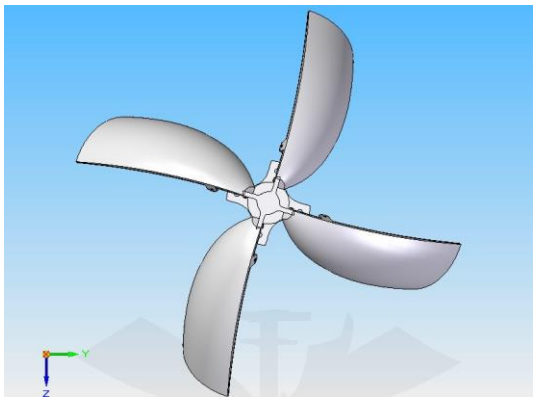
(c) Isometric view, spinner closed (d) Isometric view, spinner open

Figure 4: Views of the second preferred embodiment of the invention from different perspectives.

Some other images….







US008894018B2

(12) **United States Patent**
Boer et al.

(10) **Patent No.: US 8,894,018 B2**
(45) **Date of Patent: Nov. 25, 2014**

(54) **METHOD FOR REDUCING IN FLIGHT WAKE VORTICES AND AN AIRCRAFT WINGTIP ARRANGEMENT USED IN SUCH METHOD**

(75) Inventors: **Michael Frederick Boer**, Lyndhurst (ZA); **Anthony Charles Hoffe**, Parktown North (ZA)

(73) Assignee: **University of the Witwatersrand**, Johannesburg (SA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 126 days.

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§ 371 (c)(1),
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PCT Pub. Date: **Jun. 16, 2011**

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(30) **Foreign Application Priority Data**

Dec. 10, 2009 (ZA) 2009/08787

(51) **Int. Cl.**
B64C 23/06 (2006.01)

(52) **U.S. Cl.**
CPC ***B64C 23/065*** (2013.01); *Y02T 50/164* (2013.01)
USPC **244/199.4**; 244/199.3

(58) **Field of Classification Search**
USPC 244/198, 199.1, 199.2, 199.3, 199.4, 244/201, 203
See application file for complete search history.

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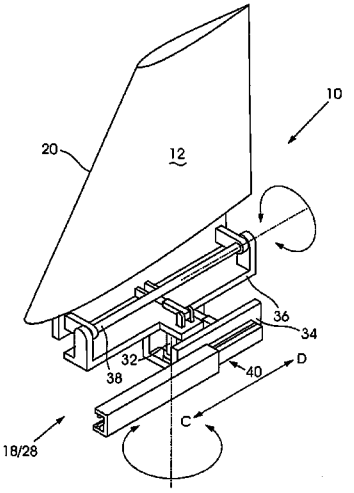
Primary Examiner — Benjamin P Lee
(74) *Attorney, Agent, or Firm* — Wiggin and Dana LLP; Gregory S. Rosenblatt; Jonathan D. Hall

(57) **ABSTRACT**

This invention discloses a method to break down, destabilize, or destroy an in flight wake vortex shed from an aircraft's wing. The wingtip has a winglet mounted to an extremity of the wing, and means for actuating displacement of the winglet relative to the wing. The winglet is displaced from a stationary position, in which the in flight wake vortex is stable, to a continuous moving condition, in which the winglet is displaced to a secondary temporary stationary position, remote from the initial stationary position, and having any angle relative to a plane extending through a vertical, longitudinal, or lateral axis of the aircraft to alter the winglet's angle of attack, and persisting in the moving condition as long as required to break down, destabilize or destroy the in flight wake vortex. The invention includes a wingtip arrangement for use in the method and an aircraft including the wingtip arrangement.

14 Claims, 7 Drawing Sheets



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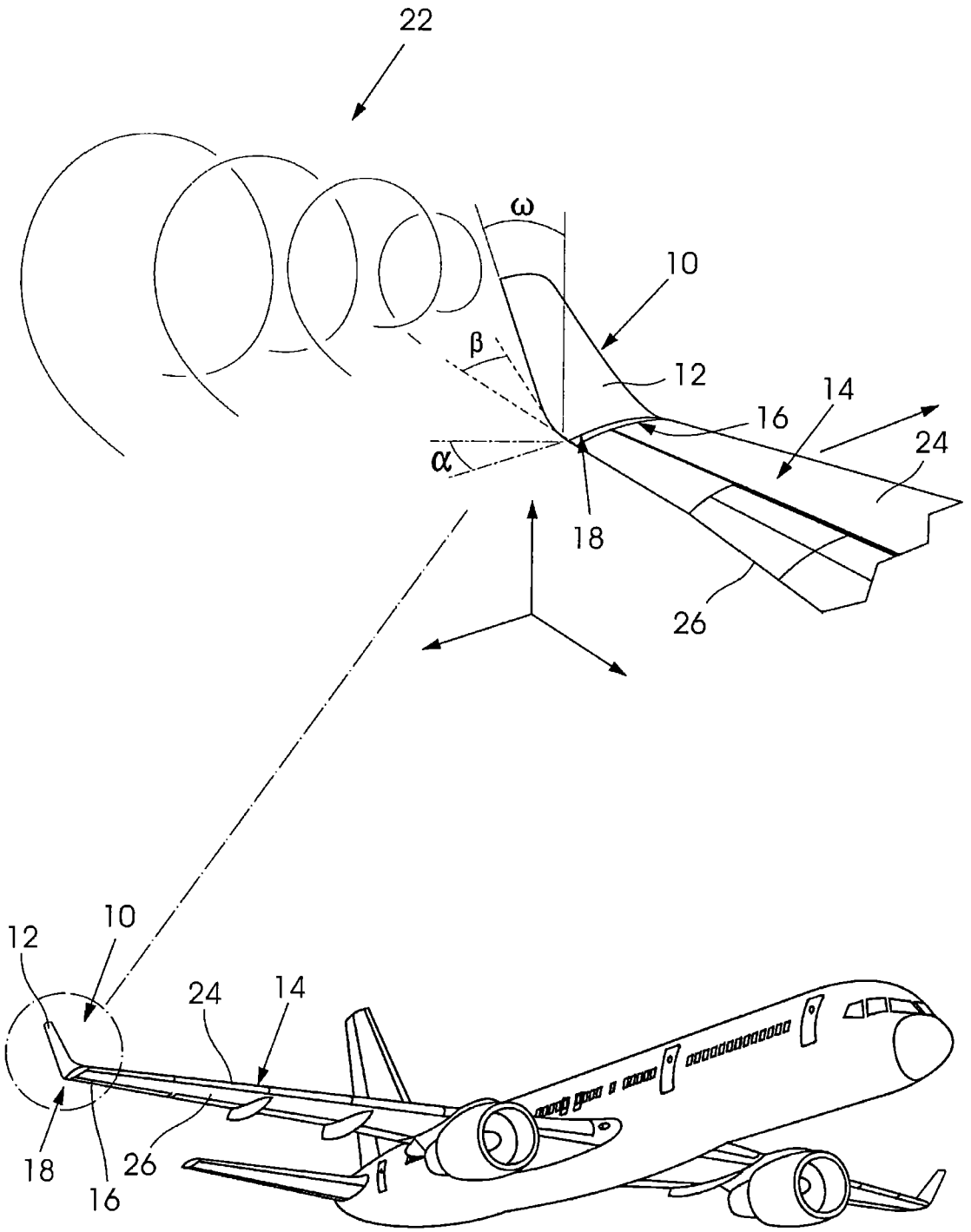


FIGURE 1

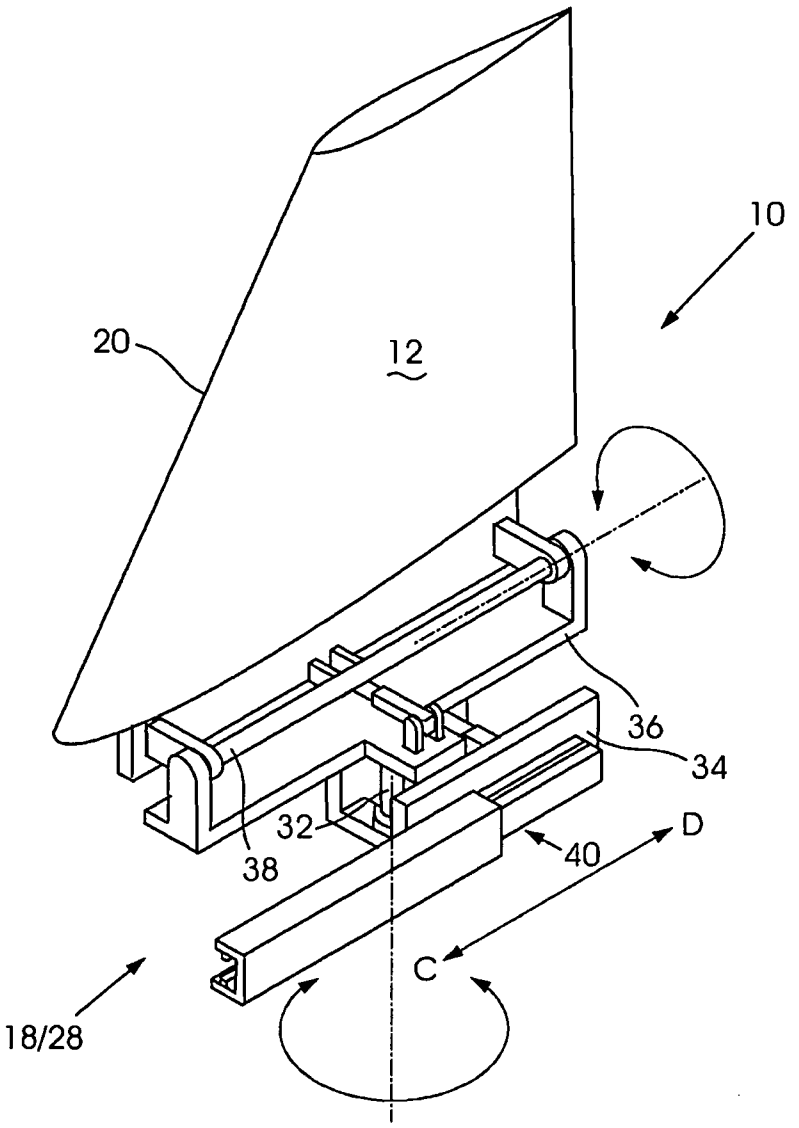


FIGURE 2

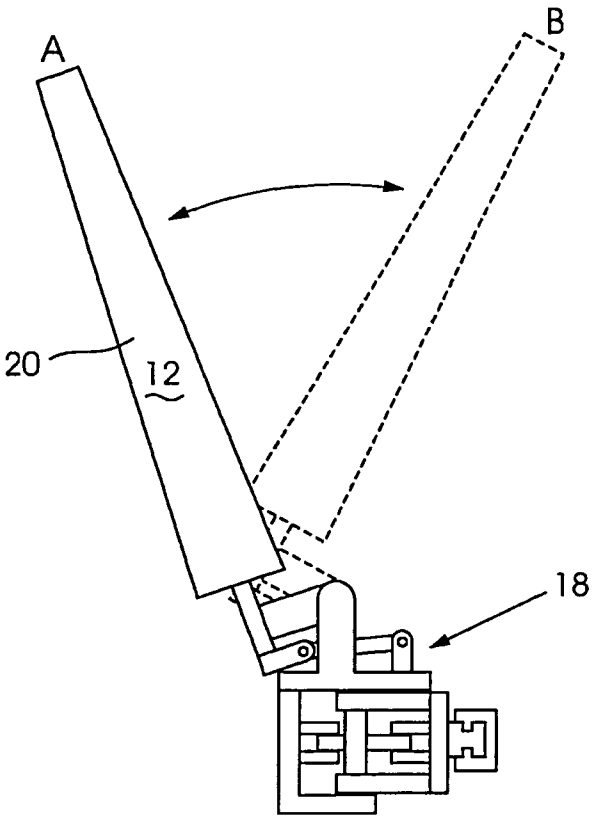


FIGURE 3

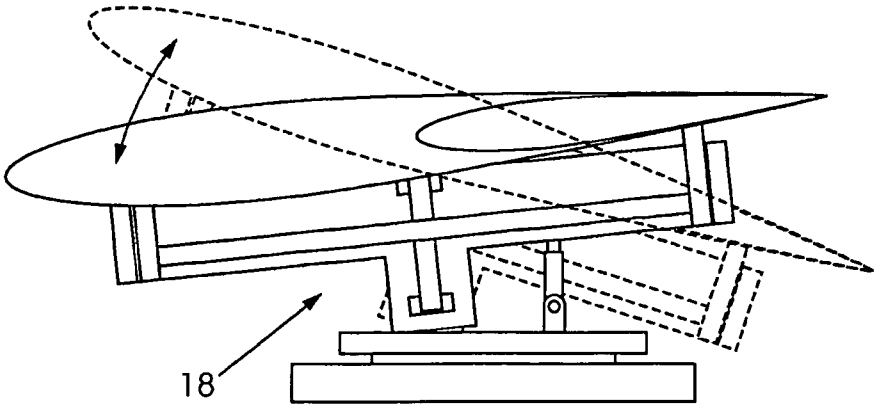


FIGURE 4

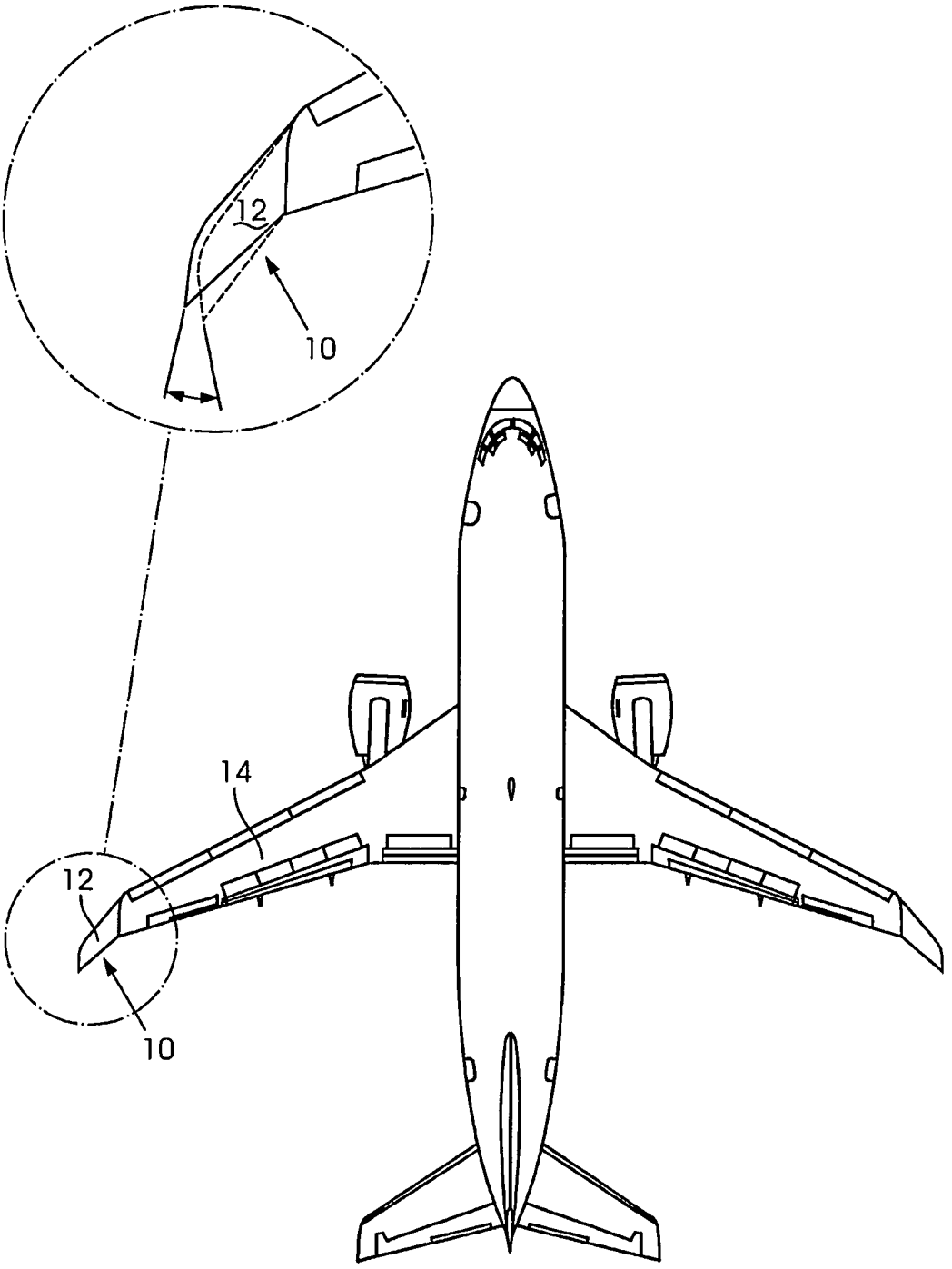


FIGURE 5

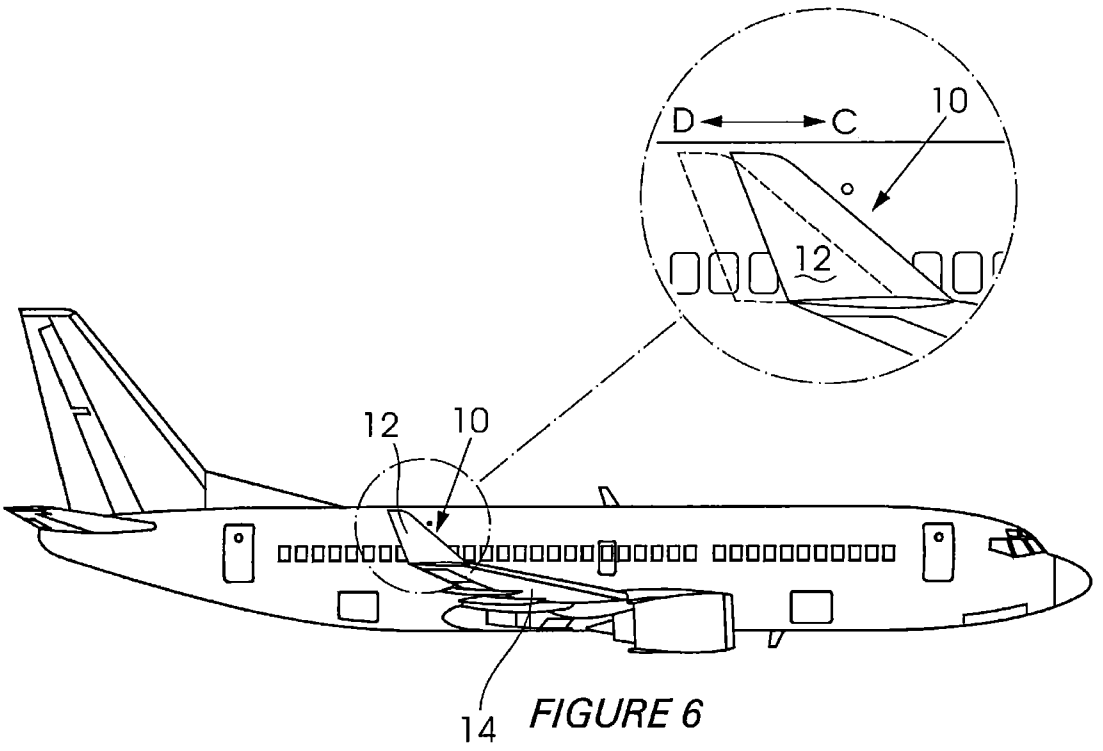


FIGURE 6

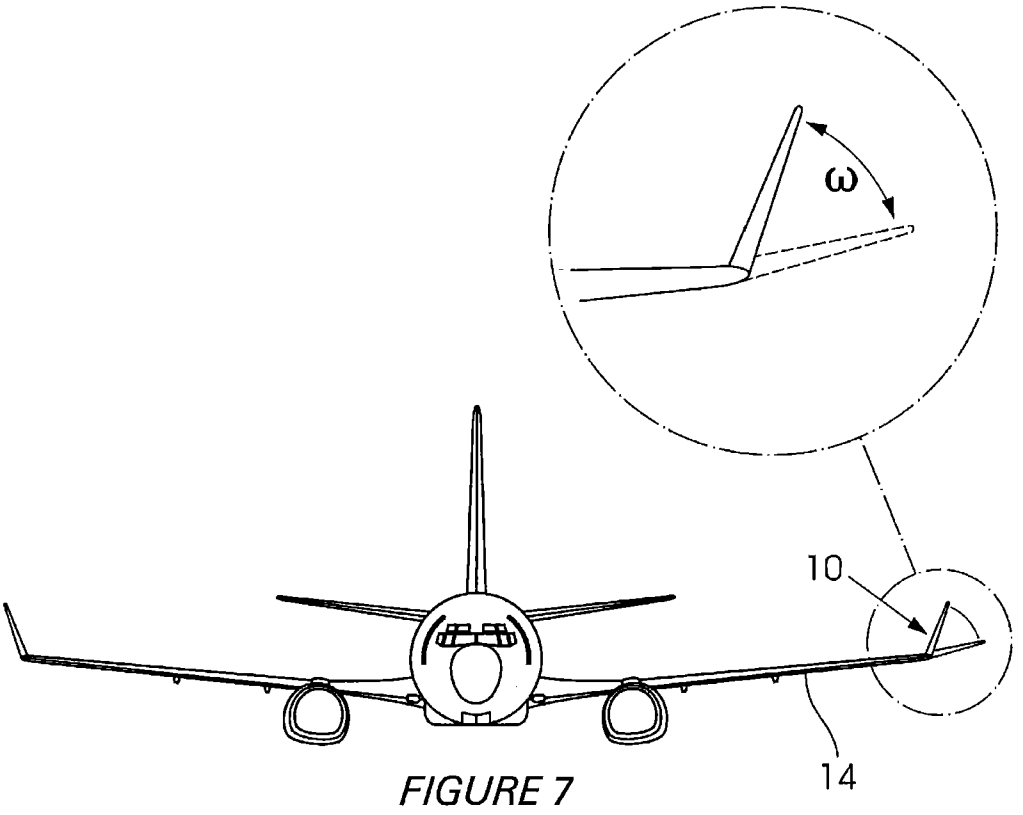


FIGURE 7

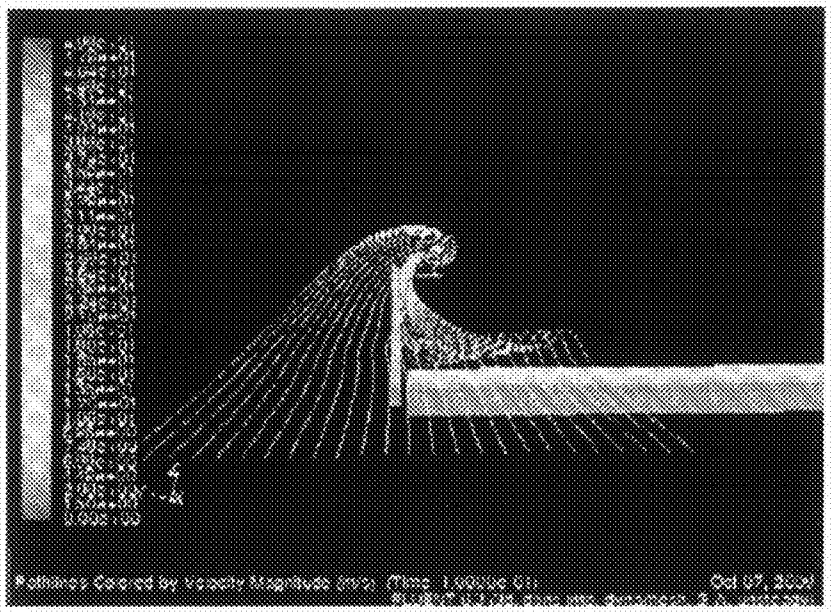


FIGURE 8

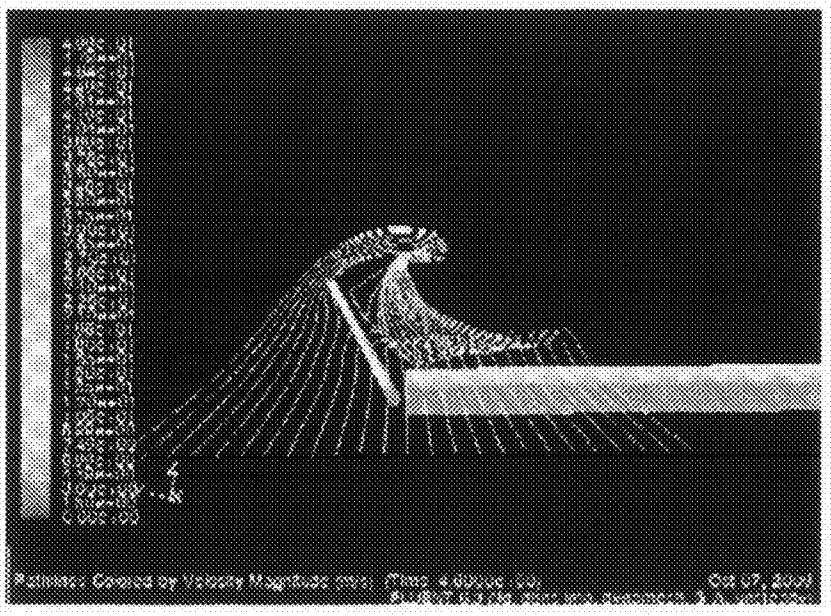


FIGURE 9

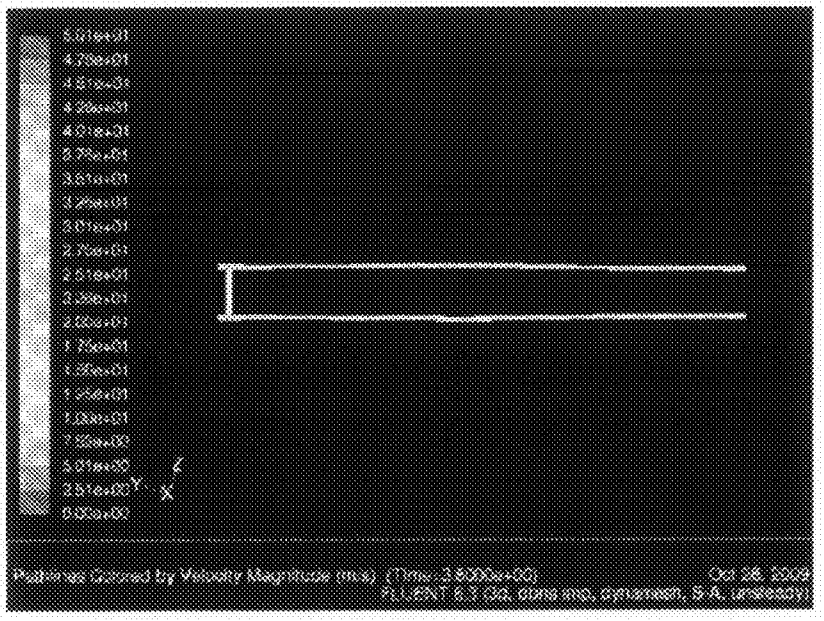


FIGURE 10

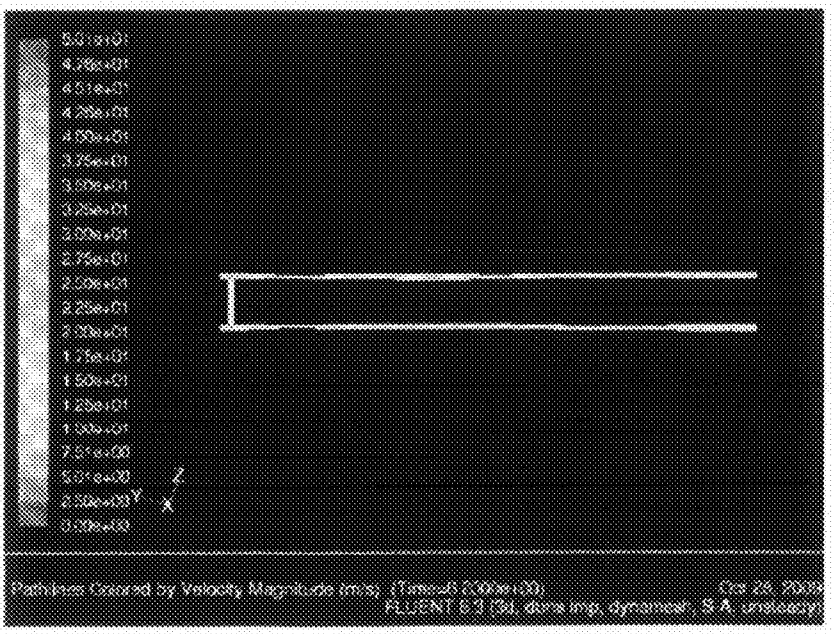


FIGURE 11

METHOD FOR REDUCING IN FLIGHT WAKE VORTICES AND AN AIRCRAFT WINGTIP ARRANGEMENT USED IN SUCH METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the National Stage of International Application No. PCT/IB2010/055708, filed Dec. 10, 2010, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to aeronautics. In particular, the invention relates to a method to break down, destabilize, or destroy an in flight wake vortex shed from an aircraft's wing and to an aircraft wingtip arrangement that can be used in such method of reducing in flight wake vortices by using same.

BACKGROUND TO THE INVENTION

Aircraft wings produce aerodynamic lift by creating a pressure distribution over the aerofoil section with a resultant force perpendicular to the flight trajectory. Because the wing is not infinitely long the pressure distributions over the upper and lower surfaces of the wing meet at the wingtip. The result is an intense rotational flow known as a lift-induced wingtip vortex. This vortex is shed from the wingtip and interacts with the airflow over the wing, known as downwash. In doing so the vortex becomes what is termed a wake vortex.

Wake vortices may linger in the air for several minutes before breaking down due to natural instabilities present in rotational flow. Aircraft flying through a wake vortex may experience loss of control or structural failure due to the severe turbulence induced by the vortex. Because the wake vortex is dangerous to other aircraft and because it takes a long time to break down naturally, long distances are required between aircraft approaching an airport, reducing the number of aircraft an airport can accommodate.

This inventions seeks to, at least in part, address these problems.

SUMMARY OF THE INVENTION

According to the invention there is provided a method to break down, destabilize, or destroy an in flight wake vortex shed from an aircraft's wing having a wingtip arrangement with at least one winglet movably mounted to an extremity of the aircraft's wing, and actuating means connected to the winglet for actuating in use displacement of the winglet relative to the aircraft's wing, the method comprising:

actuating the actuating means to displace the winglet from an initial stationary position, in which the in flight wake vortex shed from the wing is stable, to a continuous moving condition, in which the winglet is displaced to at least one secondary temporary stationary position, remote from the initial stationary position, and having any angle relative to a plane extending through a vertical, longitudinal, or lateral axis of the aircraft so as to alter the winglet's angle of attack; and

persisting in the continuous moving condition as long as it is required to break down, destabilize or destroy the in flight wake vortex.

There is also provided for the moving condition to comprise oscillation or reciprocation of the winglet.

There is further provided for the moving condition to comprise rotation of the winglet about an axis parallel to the lateral, vertical, or longitudinal axis of the aircraft.

Further features of the invention provide for the moving condition to comprise linear translation of the winglet along an axis parallel to the longitudinal axis of the aircraft. Alternatively, the moving condition comprises linear translation of the winglet along an axis parallel to the longitudinal axis of the aircraft, which linear translation coincides with rotation, reciprocation, or oscillation of said winglet about an axis parallel to either the longitudinal, lateral, or vertical axis of the aircraft.

There is also provided for the actuating means to comprise a hinge arrangement operatively connected to switching means operable to regulate winglet displacement timing. Preferably, the switching means comprises at least one solenoid.

There is further provided for the hinge arrangement to comprise a first hinge that extends parallel to the vertical axis of the aircraft, the first hinge being disposed between a first base plate and a second base plate, the first base plate being connectable to the extremity of the wing while the second base plate operatively accommodates the winglet thereby allowing the winglet to in use follow a curvilinear path about the vertical axis of the aircraft.

Alternatively, there is provided for the hinge arrangement to comprise a second hinge that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge, the second hinge being operatively connected to the second base plate and operable to accommodate the winglet thereby allowing the winglet to in use follow a curvilinear path about either the longitudinal or vertical axis of the aircraft.

Further alternatively, there is provided for the hinge arrangement comprises a third hinge disposed between a third base plate to which the winglet is connectable and the second base plate, the third hinge extending parallel to the lateral axis of the aircraft and substantially perpendicular to the second hinge, the third base plate being operable to accommodate the winglet thereby allowing the winglet to in use follow a curvilinear path about the lateral, longitudinal, or vertical axis of the aircraft.

The invention also provides for a guide means to be connected to any of the first to the third base plates to permit translational displacement of the hinge arrangement along an axis parallel to the lateral, longitudinal, or vertical axis of the aircraft. Preferably, the guide means is a rail adapted to slidably receive any of said base plates.

Finally, the invention includes a suitable power source and control circuitry for controlling displacement of the winglet. Additionally, two wingtip arrangements, located at extremities of two opposing wings, can be controlled and displaced in such a way that vortices generated from respective wings have a destructive and destabilizing effect on each other.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example with reference to the accompanying non-limiting drawings, wherein:

FIG. **1** shows a schematic bottom perspective view of an aircraft having a wingtip arrangement for use in a method according to an embodiment of the invention;

FIG. **2** shows a schematic top perspective view of the wingtip arrangement of FIG. **1**;

FIG. **3** shows a schematic front view of the wingtip arrangement of FIG. **1** as it is displaced between position A and position B about an axis parallel to a longitudinal axis of the aircraft;

FIG. **4** shows a schematic side view of the wingtip arrangement of FIG. **1** as it is displaced about an axis parallel to a lateral axis of the aircraft;

FIG. **5** shows a schematic side view of the wingtip arrangement of FIG. **1** as it is displaced about an axis parallel to a vertical axis of the aircraft;

FIG. **6** shows a schematic side view of the wingtip arrangement of FIG. **1** as it is linearly displaced along an axis parallel to a longitudinal axis of the aircraft;

FIG. **7** shows a schematic front view of the wingtip arrangement of FIG. **1** as it is displaced about an axis parallel to a longitudinal axis of the aircraft;

FIG. **8** shows a front view with winglet at 0° of a Computational Fluid Dynamics (CFD) diagram of the winglet of FIG. **1** as it oscillates about an axis parallel to the aircraft's longitudinal axis;

FIG. **9** shows a front view with winglet at 30° of a Computational Fluid Dynamics (CFD) diagram of the winglet of FIG. **1** as it oscillates about an axis parallel to the aircraft's longitudinal axis;

FIG. **10** shows a top view illustrating vortex formation and the start of sinusoidal motion of the wake vortex; and

FIG. **11** shows a top view illustrating vortex formation and progression of sinusoidal motion down the vortex.

DETAILED DESCRIPTION OF THE DRAWINGS

The description below is not intended to limit the invention in any way and is provided only to describe specific embodiments of the invention.

In the drawings, like numerals generally indicate like components, unless otherwise indicated.

Referring to FIG. **1**, reference numeral **10** generally refers to a wingtip arrangement in accordance with the invention. The Wingtip arrangement **10** includes a winglet **12**, movably mounted to an extremity **16** of an aircraft wing **14**, and actuating means **18** connected to the winglet **12** for actuating in use displacement of the winglet **12** relative to the wing **14**.

Displacement of winglet **12**, as best shown in FIGS. **2** and **3**, alters the angle that a leading edge **20** of winglet **12** makes with oncoming airflow (also referred to as the angle of attack). In essence, winglet **12** is displaced from an initial stationary position A to a moving condition, as can be seen from FIG. **3**.

With the winglet **12** in its initial stationary position A, an in flight wake vortex **22** flowing off, or shed from, the wing **14** is stable. The wake vortex refers to air with an intense rotational flow caused by the wing **14** not being infinitely long thereby forcing pressure distributions, which flow over upper and lower surfaces **24**,**26** of wing **14**, to meet at extremity **16** before being shed from extremity **16** and before interacting with airflow over wing **14** (known as downwash). The result of the interaction is an intense vortex termed a wake vortex.

The winglet **12**, in its moving condition, is displaced to a selected angle to destabilize said in flight wake vortex. The angle α may be any angle relative to a plane extending through a vertical, longitudinal, or lateral axis of the aircraft. To illustrate this, the winglet **12** is shown oscillating or reciprocating between a second stationary position B and the initial stationary position A. Typically, A and B are remote from each other and winglet **12** is only temporarily either in position A or in position B. The second stationary position B allows winglet **12** to form a yaw angle a (shown in FIG. **1**), rake angle β (shown in FIG. **1**), and/or cant angle ω (shown in FIGS. **1** and **7**) different to that of winglet **12** in the initial stationary position A. It will be appreciated that in other embodiments of the invention (not shown) the moving condition includes rotation of winglet **12** about an axis parallel to either the lateral axis of the aircraft, as shown in FIG. **4**, or vertical axis of the aircraft, as shown in FIG. **5**.

In another embodiment of the invention, as shown in FIGS. **2** and **6**, the moving condition includes linear translation of the winglet **12** along an axis C-D running parallel to the longitudinal axis of the aircraft, thereby permitting backward and forward movement of winglet **12** along axis C-D. Although not shown in the drawings, it is also envisaged that the moving condition may include translation of the winglet **12** along a curvilinear path behind wing **14**.

Alternatively, the moving condition includes linear translation of winglet **12** along axis C-D, which translation coincides with rotation, reciprocation, or oscillation of winglet **12** about an axis parallel to the longitudinal, lateral, or vertical axis of the aircraft. It is thus possible to move the winglet **12** in any direction as it moves back and forth along axis C-D. This moving condition ensures that winglet **12** oscillates sinusoidally thereby increasing airflow irregularities present in the wake vortex leading to predictable breakdown of the vortex.

Breakdown of wake vortex **22** can also occur by the interaction between two vortices generated from either wing. This can lead to destructive interference and aid in causing instabilities within the vortices. Therefore, it is envisaged that displacement of two wingtip arrangements **10** located at extremities **16** of two opposing wings may be used and controlled in such a way that vortices generated from respective wings **14**, which both are equal in strength, but rotate in opposite directions, have a destructive and destabilizing effect on each other. The same results is believed to be achievable when a vortex from the aircraft's right horizontal stabilizer interacts with the wake vortex from the right wing, for example, since the vortices rotate in opposite directions and are of non-uniform strength.

The actuating means **18**, as best shown in FIG. **1**, includes a hinge arrangement **28** operatively connected to switching means operable to regulate winglet displacement timing. Preferably, the switching means comprises a solenoid.

The hinge arrangement **28** may also have a second hinge **38** that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge **32** and which is connected to the second base plate **36**. The second hinge **38** may also accommodate the winglet **12** and allows same to, in use, follow a curvilinear path about the longitudinal axis of the aircraft. Displacement of winglet **12** about hinge **32** and hinge **38** at the same time is thus also possible.

The hinge arrangement **28** may also have a second hinge **38** that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge **32** and which is connected to the second base plate **36**. The second hinge **38** may also accommodate the winglet **12** and allows same to, in use, follow a curvilinear path about either the longitudinal axis of the aircraft. Displacement of winglet **12** about hinge **32** and hinge **38** at the same time is thus also possible.

The hinge arrangement **28** may also have a third hinge (not shown) disposed between a third base plate (not shown), to which the winglet **12** is connected, and the second base plate **36**. The third hinge then extends parallel to the lateral axis of the aircraft and substantially perpendicular to the second hinge **38**. The third base plate may be adapted to accommodate winglet **12** to allow winglet **12** to, in use, follow a curvilinear path about the lateral, longitudinal, or vertical axis of the aircraft.

A guide means **40**, best shown in FIG. **2**, is connectable to any of the first to the third base plates and permits linear translational displacement of the hinge arrangement **28** away from extremity **18**. Thus, winglet **12** is linearly movable, along an axis parallel to the lateral, longitudinal, or vertical axis of the aircraft. Preferably, the guide means is a rail **40** adapted to slidably receive any of said base plates. More preferably, said translational movement occurs only along an axis parallel to the longitudinal axis of the aircraft.

It will be appreciated that the winglet **12** will be equipped with a suitable power source and control circuitry for controlling displacement of the winglet.

Preliminary Computational Fluid Dynamics (CFD) has been done on winglet **12** oscillating about an axis parallel to the aircraft's longitudinal axis. The CFD shows that these oscillations can cause sinusoidal motion to be exhibited in the trailing vortex.

FIGS. **8** and **9** show front views of the wing **14**, showing the winglet **12** moving through an angle of 30°, starting at the vertical, or neutral, position. FIGS. **10** and **11** show top views of vortex formation and motion of the wake vortex. Looking at these two figures, the sinusoidal motion can clearly be seen as the wave moves along each vortex. This was done over a distance of 10 m and so no destruction of the vortex can be seen yet, but due to the fact that the sinusoidal motion exists in the vortex core this early on, namely during the plateau phase, suggests that instability will occur sooner than normal and result in early destruction of the vortex.

A method of reducing in flight wake vortices in which the wingtip arrangement **10**, as described above, is actuated and displaced to destabilize an in flight wake vortex shed from an extremity of an aircraft's wing is believed to hold great benefit since the combined motion of winglet **12** will cause wake vortices created behind the aircraft to be broken down soon after formation, resulting in the distances required between aircraft departing and approaching an airport to be reduced. This will increase the hourly number of flights operating at an airport.

While preferred embodiments of the invention are shown and described, it will be understood that it is not intended to limit the extent of the invention, but rather it is intended to cover all modifications and alternate methods, including: methods and processes for manufacturing a wingtip arrangement falling within the spirit and the scope of the invention.

The wingtip arrangement **10** and associated method of use thereof, thus, provide a neat and cost effective solution to current problems associated with wake vortex formation.

The invention claimed is:

1. A method to break down, destabilize, or destroy an in flight wake vortex shed from an aircraft's wing having a wingtip arrangement with at least one winglet movably mounted to an extremity of the aircraft's wing, guide means that extends parallel to a vertical, longitudinal or lateral axis of the aircraft, and actuating means connected to the winglet for actuating in use displacement of the winglet relative to the aircraft's wing, the method comprising:

actuating the actuating means to displace the winglet, linearly along the guide means, from an initial stationary position, in which the in flight wake vortex shed from the wing is stable, to a continuous moving condition, in which the winglet is displaced to at least one secondary temporary stationary position, remote from the initial stationary position, and having any angle relative to a plane extending through a vertical, longitudinal, or lateral axis of the aircraft so as to alter the winglet's angle of attack; and

persisting in the continuous moving condition as long as it is required to break down, destabilize or destroy the in flight wake vortex.

2. The method of claim **1**, including continuously oscillating or reciprocating the winglet.

3. The method of claim **1**, including:

rotating, reciprocating, or oscillating the winglet about an axis parallel to either the longitudinal, lateral, or vertical axis of the aircraft while the winglet is linearly displaced along the guide means.

4. The method of claim **3**, including:

providing a hinge arrangement having a first hinge that extends parallel to the vertical axis of the aircraft, the first hinge being disposed between a first base plate and a second base plate, the first base plate being connectable to the extremity of the wing while the second base plate operatively accommodates the winglet; and

actuating the first hinge to effect rotation, oscillation, and/or reciprocation of the winglet about the vertical axis of the aircraft.

5. The method of claim **3**, including:

providing a hinge arrangement having

a first hinge that extends parallel to the vertical axis of the aircraft, the first hinge being disposed between a first base plate and a second base plate, the first base plate being connectable to the extremity of the wing; and

a second hinge that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge, the second hinge being operatively connected to the second base plate and operable to accommodate the winglet; and

actuating the second and/or first hinge to effect rotation, oscillation, and/or reciprocation of the winglet about either the longitudinal or vertical axis of the aircraft.

6. The method of claim **3**, including:

providing a hinge arrangement having

a first hinge that extends parallel to the vertical axis of the aircraft, the first hinge being disposed between a first base plate and a second base plate, the first base plate being connectable to the extremity of the wing;

a second hinge that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge, the second hinge being operatively connected to the second base plate; and

a third hinge disposed between a third base plate, to which the winglet is connectable, and the second base plate, the third hinge extending parallel to the lateral axis of the aircraft and substantially perpendicular to the second hinge; and

actuating the first and/or second and/or third hinges to effect rotation, oscillation, and/or reciprocation of the winglet about either the longitudinal, vertical axis, or lateral axes of the aircraft.

7. The method of claim **6**, including linearly displacing any of the first to the third base plates along guide means to permit translational displacement of the winglet along an axis parallel to the lateral, longitudinal, or vertical axis of the aircraft, which translational winglet displacement occurs either in conjunction with, or separate from, rotation, oscillation, and/or reciprocation caused by any of the first to third hinges.

8. The method of claim **7**, wherein the guide means is a rail adapted to slidably receive a base plate.

9. The method of claim **1**, including displacing the winglet and causing the flight wake vortex shed from the aircraft's wing to exhibit generally sinusoidal motion.

10. The method of claim 1, including:

providing actuating means in the form of a hinge arrangement including a suitable power source, control circuitry for controlling displacement of the winglet, and switching means operable to regulate displacement timing.

11. A method to break down, destabilize, or destroy an in flight wake vortex shed from an aircraft's wing, which method includes:

providing a wingtip arrangement having a winglet movably mounted to an extremity of each of the aircraft's respective wings, guide means that extends parallel to a vertical, longitudinal or lateral axis of the aircraft, and actuating means connected to said winglets for actuating in use displacement of the winglets relative to the aircraft's wing;

actuating the actuating means to displace the respective winglets, linearly along the guide means, from an initial stationary position, in which in flight wake vortices shed from the respective wings are stable, to a continuous moving condition, in which the winglets are displaced to any angle relative to a plane extending through a vertical, longitudinal, or lateral axis of the aircraft so as to alter the winglets' respective angles of attack; and

persisting in the continuous moving condition as long as it is required to break down, destabilize or destroy the in flight wake vortices of said winglets so that wake vortices generated from respective wings have a destructive and destabilizing effect on each other.

12. A wingtip arrangement for an aircraft wing comprising:

at least one winglet movably mountable to an extremity of the wing; and

actuating means in the form of a hinge arrangement connected to the winglet for actuating in use displacement of the winglet relative to the wing so as to alter the winglet's angle of attack, the hinge arrangement having

a first hinge that extends parallel to the vertical axis of the aircraft, the first hinge being disposed between a first base plate and a second base plate, the first base plate being connectable to the extremity of the wing;

a second hinge that extends parallel to the longitudinal axis of the aircraft and substantially perpendicular to the first hinge, the second hinge being operatively connected to the second base plate and operable to accommodate the winglet; and

a third hinge disposed between a third base plate, to which the winglet is connectable, and the second base plate, the third hinge extending parallel to the lateral axis of the aircraft and substantially perpendicular to the second hinge;

so that upon actuation of the first and/or second and/or third hinges, rotation, oscillation, and/or reciprocation of the winglet is affected about either the longitudinal vertical or lateral axis of the aircraft.

13. The wingtip arrangement of claim 12, wherein any of the base plates is connected to guide means, preferably in the form of a rail, to permit translational displacement of the winglet along an axis parallel to the lateral, longitudinal, or vertical axis of the aircraft, which translational winglet displacement occurs either in conjunction with, or separate from, said rotation, oscillation, and/or reciprocation caused by any of the first to third hinges.

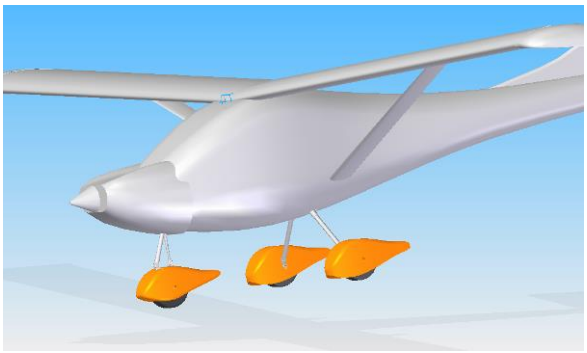
14. An aircraft including the wingtip arrangement of claim 12.

* * * * *

APPENDIX D

PLAN – AIRSPIRE™ (PTY) LTD

Launch of SkyWake™



AUGUST 2009

wits enterprise
THE NEW EDGE IN KNOWLEDGE MANAGEMENT

WITS COMMERCIAL ENTERPRISE (PTY) LTD

Written by:
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ABBREVIATIONS

AME	Aircraft Maintenance Engineer
AMO	Aircraft Maintenance Organisation
AP	Approved Person
ATO	Aviation Training Organisations
BCDA	Blue Crane Development Agency
BCRM	Blue Crane Route Municipality
SACAA	Civil Aviation Authority
CAR	Civil Aviation Regulations
CAS	Calibrated (Computed) Air Speed
CEO	Chief Executive Officer
CGE	Computable General Equilibrium
DEAET	Department of Economic Affairs, Environment and Tourism
DO	Design Organisation
dti	Department of Trade and Industry
EAA	Experimental Aircraft Association
E-LSA	Experimental Light-Sport Aircraft
GP	Gross Profit
JAR	Joint Airworthiness Requirement
FAA	Federal Aviation Authority
FAJ	Floor Assembly Jig
IDC	Industrial Development Corporation
IDZ	Industrial Development Zone
LSA	Light Sport Aircraft
MAUW	Maximum All-Up Weight
MO	Manufacturing Organisation
MOA	Memorandum of Association
MPTO	Manufacturing, Processing and Testing Organizations
MPL	Microlight Pilot's License
MTOW	Maximum Take-Off Weight
NACoE	National Aerospace Centre of Excellence
NASA	National Aeronautics and Space Administration
NTCA	Non-Type Certified Aircraft
NPV	Net Present Value
PDI	Previously Disadvantaged Individual
PPL	Private Pilot's License
SA	Single engine certified aircraft
SABS	South African Bureau of Standards
SPV	Special Purpose Vehicle
STF	Structural test facility
STOL	Short Take Off and Landing
ULM	Ultralight Motorised
US	United States of America
Wits	University of Witwatersrand

EXECUTIVE SUMMARY

1 COMPANY OVERVIEW

1.1 Introduction

Wits Enterprise intends to create a new company, Airspire™ (Pty) Ltd, to commercialise innovative Light Sport Aircraft (LSA). The first aircraft, trademarked as SkyWake™, will be launched in Q3 2012 with first sales anticipated in Q1 2013. In South Africa, Light Sport Aircraft are defined as two-seat aircraft with 3-axis control having a maximum take-off mass of 600kg with a stall speed not exceeding 65km/h. New regulations governing Light Sport Aircraft were promulgated in the US in 2004. LSA are fast becoming the best selling aircraft amongst recreational flyers due to the good performance and range associated with the newly designed purpose-built aircraft. The operating costs are significantly less than existing recreational aircraft such as the popular Cessna C150/2 and Piper PA-28 families.

The University of the Witwatersrand's School of Mechanical, Industrial and Aeronautical Engineering (SMIA) houses significant resources, expertise and know-how in the aeronautical environment. The SMIA has expertise in aircraft design, performance estimation, competitive engineering design, analysis and testing of metallic and composite structures, numerical simulation and the analysis of aerial vehicles. The SMIA offers the only accredited undergraduate degree in Aeronautical Engineering in Africa. The SMIA also has specialised research groups with focus on fluid flow, thermodynamics, composite materials, applied mechanics, flight mechanics and aerodynamics.

Wits Enterprise now proposes the establishment of a Light Sport Aircraft manufacturing and marketing business. This business, Airspire™ (Pty) Ltd will be built on either a LSA design licensed from the Blue Crane Development Agency (BCDA) (discussions in this regard are currently underway), or alternatively through the creation of a new LSA design developed by the SMIA. The design for the aircraft will be registered with the South African Civil Aviation Authority (SACAA) and production of the aircraft prototype will follow. The appropriate regulatory activities required to obtain "Authority to Fly" from the SACAA and to accredit the organisation as a manufacturing organisation will be implemented.

The launch of SkyWake™ will pave the way for the introduction of further Light Sport and Recreational Aircraft which will incorporate additional innovations currently being researched and patented by Wits, with further development of innovative design solutions. Airspire™ will thus be positioned to continue to bring innovative design features, compliant with international standards, to the market to meet the growing demand for this category of aircraft.

1.2 Mission Statement

"Airspire™ will be the first South African Manufacturing Organisation to design and manufacture innovative and affordable Light Sport Aircraft, specifically tailored for the African aviation enthusiast."

1.3 Strategic Objectives

Airspire™ will:

1. Bring to market the first "Proudly South African" designed and manufactured, innovative, and affordable production-built Light Sport Aircraft for the aviation enthusiast.
2. Introduce a range of state-of-the-art Light Sport Aircraft through the introduction of patented innovations developed by the South African Design Organisation.
3. Create an export market for the South African aircraft which will be designed to meet the international class of Light Sport Aircraft regulations.
4. Facilitate the establishment of a SACAA certified South African Design Organisation.
5. Facilitate the growth of an aircraft manufacturing industry through the creation of jobs and the development of scarce and higher levels of skill, relevant to the requirements of the aerospace industry.

1.4 Organisational Strategy

The South African Civil Aviation Authority states that only those aircraft of which the type, the local or foreign manufacturing organization, the local assembling organization or agent, or the build standard has been approved by the Commissioner, may be built or imported and flown within the Republic. In addition, no organisation shall design any product or a change thereof, except under the authority of, and in accordance with the provisions of an approved design organisation. In order to comply with these regulations, two types of organisations are required: (1) a Manufacturing Organisation (MO) and (2) a Design Organisation (DO). These organisations will jointly ensure that SkyWake™ will apply to have its build standard approved and become type certified.

Airspire™, will be established as a Manufacturing Organisation (MO) and comply with Part 148 - Manufacturing Organisations as set by the South African Civil Aviation Authority (SACAA). Approval as a MO is required in order to (i) manufacture specified products, parts or appliances; (ii) apply specified processes to products, parts or appliances; or (iii) carry out specified tests on products, parts or appliances.

In parallel, Wits Enterprise is working together with other interested parties to create a Design Organisation according to the standards, rules, requirements, methods, specifications, characteristics and procedures for a DO set up by the SACAA. The DO will support Airspire™'s products in production by offering technological improvement, manufacturing advancements and market driven innovation. It is envisaged that the DO will have the necessary skills and competence to engineer new aircraft, modify existing aircraft and design aircraft components for manufacture, design and manufacture of prototype aircraft, flight proving and certification. [The formation of this DO is the subject of a separate proposal and business plan].

The need to establish a DO has been identified as critical to the success of any aircraft design initiative in South Africa. South Africa is emerging as a risk-sharing partner in the manufacture of sizeable aircraft structural components however, its design participation is very limited and very few organisations in South Africa have obtained DO status from the SACAA. The DO will provide the first steps towards a substantial design expertise and resource base in South Africa. The DO will incubate new conceptual designs; generate detailed designs and commercialisation strategies that are predicted to be commercially viable projects in the context of a South African aviation industry. The DO will hence be established in the interests of establishing a national centre of expertise in design of relevance for human capital development and the creation of employment and wealth in the engineering based aviation field.

In addition to the DO, a Structural Test Facility (STF) will be established by Wits University. The STF will be established as a publically-accessible commercially viable facility capable of testing commercial, home-built and new aircraft with maximum take-off weight initially limited to 1000 kg. The STF will be staffed, at least initially, by the SkyWake™ design team working for the DO. The STF would be set up midway through the DO incubation period, allowing for early SACAA approval of the SkyWake™, the Light Sport Aircraft to be manufactured by Airspire™ and which forms the subject of this business plan. SkyWake™ will be the first aircraft to obtain NTCA type certification from this DO. [The formation of this STF is the subject of a separate proposal and business plan].

Airspire™ will be owned by Wits Enterprise. Should the sale of any shares in the company be required, for example to raise funds for the development of the prototype, this will be negotiated on a case-by-case basis. Different classes of shares could be considered, but this will depend on the needs of any potential future shareholders and the requirement of the company to raise capital over successive rounds.

1.5 Product Description and Position in the Market

The emergence of ultralight aviation has its beginnings more than 25 years ago as flying became more and more expensive. General aviation (defined as all aircraft not flown for commercial or military purpose) is cyclical, with periods of growth followed by decline. New improved aircraft marked each period of growth. Due to the oil-crisis progressing into the late 1970's a pronounced decline in the industry began and the number of pilots began to decrease, partly contributed to by increasing aircraft manufacturing costs. This lasted throughout most of the 1980's and into the mid-1990's.

During the late 1970's and early 1980's many people wanted to fly affordably and this led to the emergence of ultralights in the field of general aviation. In the 1970's people started to put small engines and landing gear on foot launched hang gliders. These aircraft developed rapidly becoming faster and more manoeuvrable. These first generation Ultralights were essentially hang gliders with small engines added to them for self-launching, with wire-braced wings, and were steered by shifting the pilot's weight under the wing. Second generation ultralights began to appear in the mid-1970s and were designed as powered aircraft, although they still used wire braced monoplane wings. The third generation utlralights, launched in the early 1980's, had strut-braced wings, a structurally efficient fuselage and nearly all used 3-axis control systems, as used on standard aircraft.[1]

Ultralights/Light Sport Aircraft hence occupy a niche between microlights and type certified light aircraft within the general aviation industry. This class of aviation has rapidly grown internationally to become a safe and affordable recreational aviation activity and is considered to be the fastest growing segment of the general aviation industry. In most affluent countries, ultralights now account for about 20% of the civil aircraft fleet.[2]

As a result of the transformation of these lightweight aircraft into high performance aircraft, capable of very respectable speed and range, many international aviation authorities set up definitions that could be subject to minimum regulation. It should be noted that the weight and speed limits for this class of aircraft are rarely the same between any two countries.

In 2004, the US Federal Aviation Authority (FAA) approved a new sport pilot certification program and aircraft category called Light Sport Aircraft (LSA), with the aim of making aviation even more accessible and affordable[3]. The LSA is a small two-person aircraft with a maximum take-off mass of 600 kg and may be purchased pre-constructed or as a kit. The aircraft are fuel efficient and have lower maintenance costs than larger aircraft. The sport pilot license or certificate is easier to obtain requiring only 20 hours to qualify as a sport pilot versus the 40 – 45 hours for a private pilot's license.

Airspire™'s first entry level aircraft, SkyWake™, will have a number of innovative features to distinguish it from its competitors. These features will be tailored to meet specific needs and provide benefits identified as being important in the market for this category of aircraft, particularly within the African flying conditions. The planned aircraft will comply with international regulations, thus opening the export market for South African-developed aircraft and creating a skills pool in the field of Light Sport Aircraft aviation.

1.6 Strategic Context

This emerging market represents an opportunity for South Africa in its implementation of an aviation Industry as it seeks opportunities for job creation and skills development. The timing of this project coincides with South Africa's identification of the aerospace industry as a high-priority sector expected to follow a growth and consolidation path similar to that experienced by the automotive industry. The government, in its commitment to the well-being of the industry, has created three synergistic initiatives.

1 http://en.wikipedia.org/wiki/Ultralight_aviation
2 Overview of the General Aviation Industry: Sport Aviation Study. Wilbur Smith Associates
3 FAR Part 103

- The **National Aerospace Centre of Excellence (NACoE),** a Department of Trade and Industry (dti) programme, is a collaboration between government, industry, academia and research institutions and is hosted by Wits. NACoE is the first Industrial Centre of Excellence under the Industrial Policy framework.
- The **Aerospace Industry Support Initiative (AISI)**, a dti initiative co-ordinated by the CSIR, aimed at repositioning the South African Aerospace Industry as a future growth industry. The CSIR and the dti aim to upgrade the South African Aerospace Industry and integrate the industry into global supply networks.
- The **Advanced Manufacturing Technology Strategy (AMTS),** a Department of Science and Technology initiative, is a national strategy focussing on the automotive and aerospace industries.

2 TECHNOLOGY

2.1 Introduction

The University of Witwatersrand (Wits) initiated development of an African ultralight design (MTOW < 550kg) in 2003. An analysis of market needs in regards to ultralight/Light Sport Aircraft in the South African market was undertaken and research conducted into pilots' wishes and needs. Work on a South African designed aircraft was subsequently initiated by final-year students at Wits. The aircraft was designed to compete directly against the Australian Jabiru series, a popular aircraft in the South African market. In addition, the aircraft was designed specifically for South Africa's harsh interior climate and instead of being composite and incorporated a stressed aluminium wing with a steel-alloy space frame fuselage. The design was, however, not pursued since the overall design was rendered obsolete by the introduction of the LSA regulations in 2004. The experience gained with regard to the market analysis, research, design process and methodology followed, and performance modelling was invaluable and contributed significantly to the knowledge base existing at Wits.

In 2006, Wits Commercial Enterprise (Pty) Ltd (Wits Enterprise), the intellectual property commercialisation company of the University of Witwatersrand, and the University of the Witwatersrand's School of Mechanical, Industrial and Aeronautical Engineering (SMIA) was contracted by the Blue Crane Development Agency (BCDA) to produce a conceptual design for a Light Sport Aircraft (LSA). The design project was completed in March 2008.

Wits Enterprise now proposes the establishment of its own Light Sport Aircraft manufacturing and marketing business to build either the LSA design licensed from the BCDA (discussions in this regard are currently underway), or alternatively through the creation of a new LSA design developed by the SMIA. Several improvements and enhancements to the original BCDA design have been identified and provisional patents submitted. These are: (1) a single-slotted flap mechanism to eliminate the hinge mechanism resulting in reduced drag; and (2) a spinner thruster which will result in a performance increase and improve the airflow into the cowling for engine cooling. A full South African patent application has been filed for (2). These may be incorporated into the first generation Light Sport Aircraft, trademarked SkyWake™, to be produced by Airspire™.

The design for the aircraft will be registered with the South African Civil Aviation Authority (SACAA) and production of the aircraft prototype will follow during the course of 2010. The appropriate regulatory activities required to obtain "Authority to Fly" from the SACAA and to accredit the organisation as a manufacturing organisation will be implemented. Airspire™ will launch SkyWake™ in 2012 as its first aircraft in this market.

2.2 Nature of the Technology

The market opportunity to be addressed by Airspire™ is two-fold. Firstly, a robust Light Sport Aircraft tailored specifically to African operating conditions has not yet been designed. Secondly, the South African Civil Aviation Authority (SACAA) has recently adopted a slightly modified version of the Federal Aviation Authority's LSA regulation, CAR Part 24: Non-Type Certificated Aircraft. African countries are then expected to follow South Africa's lead. The intent is, therefore, to design an aircraft that matches expected international trends, with the performance to beat leading competitors, particularly in inland African conditions, and is suited to South African and African markets.

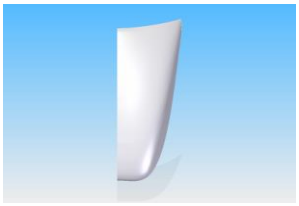
To some extent the regulation limits the degree of innovation and performance enhancement that can be addressed. The cost incurred to certify a completely innovative structural design would not be conducive to commercial success. The regulatory authorities have placed a limit on the minimum structural mass, so even if an innovative structure could be used, any reduction in weight would be limited, making the cost of innovation unjustifiable. The innovation to be contained in SkyWake™ is hence constrained to the user-

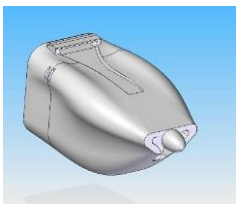
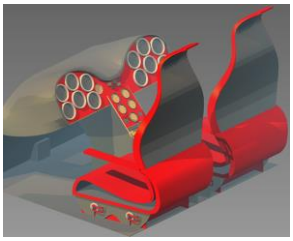
interface and non-structural assemblies, offering several novel features that provide clear benefits to the operator in comfort and performance.

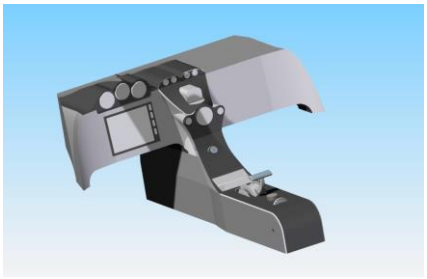
Analysis of market needs in regards to the ultralight/Light Sport Aircraft market in South Africa was undertaken by Wits University. Research was conducted into pilots' wishes and needs. Many non-pilots were interviewed to determine optimum control and system placement. The cockpit arrangement was then refined after a full size mock-up was built. The embodiment of the aircraft was also researched and the majority of pilots expressed preference for low cost, good performance and good comfort. The ergonomic interface was researched by measuring body geometry and the results were compared to historic data obtained from the SABS and NASA. Work undertaken by a final year student in 2007 has confirmed that the identified design features and improvements would be accepted by the majority of pilots.

Performance has been specifically tailored for hot and high altitude African conditions; the aircraft has excellent take-off and landing performance, exceeding the performance of its competitors. Competitive design methodology will, for example, allow for the use of standard materials, such as high-strength steel and aluminium alloys, in the aircraft structure. Competitors use carbon/glass reinforced plastic which offers better stiffness and surface finish, but is not damage tolerant nor does it lend itself to modification based on customer requirements. The metallic structure will be fully recyclable whereas composite materials are not currently. SkyWake™ will be designed with an aluminium clad tubular space frame crash structure and tail boom with an aluminium semi-monocoque strut-supported wing and all-moving tab-balanced aluminium tail.

TABLE 1: Competitive features and benefits to be included in the Airspire™ prototype design

COMPONENT	FEATURE	BENEFIT
Landing Gear	• Tricycle landing gear. • Steerable trailing-link nose landing gear. • Spring-damped main landing gear.	• Robust landing gear suitable for the roughest landing strips in South Africa. • Reliable mechanism. • Energy absorbing with low-bounce characteristics. • Good ground handling.
Automatic Gill Flaps	• Gill flaps operated by an electronically controlled servo-motor - unique in the LSA class.	• Modelled for the different types of engine that will be fitted. • Gill flaps control the amount of air for cooling of the engine, automatic gill flaps would reduce the pilot workload.
Wingtip 	• The tab will be unique in both the general aviation and the LSA class. • The wingtip-mounted trim tab will allow for level flight to occur without the constant stick-load experienced in traditional aircraft. • Research is being conducted into the influence of a vortex shedding device which would cause instability and subsequent destruction of the wingtip vortices.	• Reduces pilot workload. • Would increase safety when flying in formation, towing gliders and banners and reduce the following distance required in a circuit.

COMPONENT	FEATURE	BENEFIT
Adaptable Structure	• A modular wing box will allow the wing span to be increased or decreased from the standard span. • The fuselage has been designed as a modular assembly, allowing for modifications to be made.	• Allowing for tailored aircraft models with either extra payload or better cruise speed. • Allows medium speed flight training in hot conditions. • Allows the fitment of surveying, surveillance and specialist equipment making the aircraft versatile.
Tail	• An aesthetically appealing all moving horizontal stabiliser has been designed • Electronic trim system. • A conventional and aesthetic vertical tail design has been used, with rudder control linked to the nose-wheel.	• Has been sized for good control authority at low speed with good high speed trim characteristics. • Ease of flight control. • Provides easy ground manoeuvring
Cowling	• Inspiration for the shape comes from classic sports cars such as the Ferrari Dino and Jaguar E-Type. • Air intake will be designed to capitalise on the ram-air effect.  *SkyWake™ cowling*	• It will be both aesthetically pleasing and aerodynamically clean. • The pressure-recovery used by the intake will be unique in the LSA class allowing for a slight boost in power.
Interior Layout	• The design of the cockpit seats, inspired by sports car interiors, will be completely adjustable. The height, angle and longitudinal position of the seat and arm-rests can be adjusted.  *SkyWake™ Cockpit* • The design will offer a choice of tinted colours to change the colour of cabin light. • Photographic windows will allow the pilot to have uncompromised view out of the aircraft.	• Increases safety and enhances the pilot's flying experience. • Scientific studies have shown that this feature has a beneficial effect on fatigue resistance, which is lowered by vibration and constant noise in aircraft.

COMPONENT	FEATURE	BENEFIT
Interior Layout (cont'd)	• Air conditioning will be offered as a standard feature. • Use of heat-pipe technology would allow an air-conditioning unit to be fitted with negligible reduction of engine power. • The vertical instrument panel will be tilted for reduced parallax read-error.  *Instrument Panel concept*	• Provides additional pilot comfort • Leads to minimal read-error  *Conventional instrument panel of the Fly Synthesis Storch*

Additional features offering competitive advantage include:

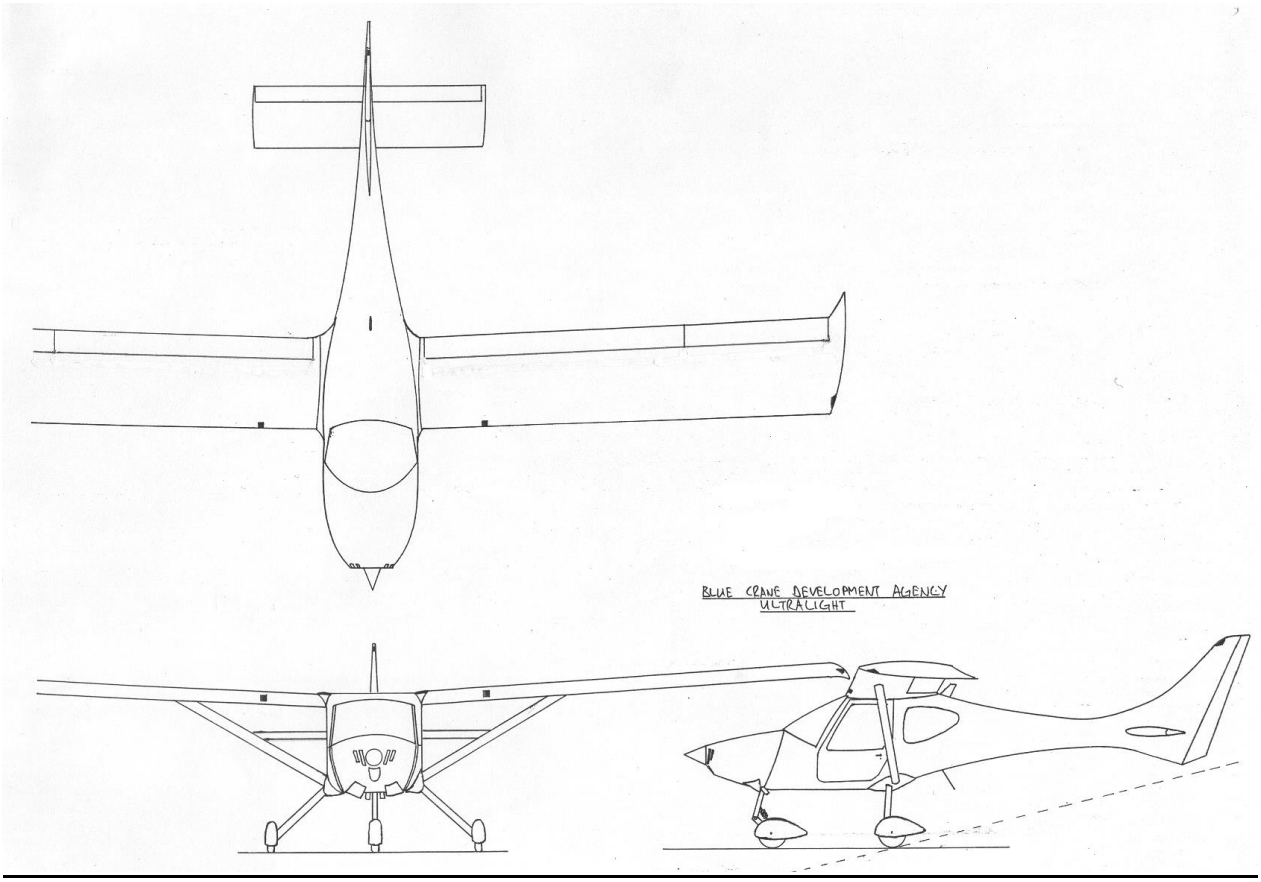
- A ballistic parachute will be supplied as standard in all aircraft. The ballistic parachute has become standard equipment in Europe and the US as a safety device. A ballistic parachute is simply an airframe parachute that is deployed during an emergency.
- The customer will have a choice as to the external colour and external enhancements.
- The customer may also select the instrument suite and general arrangement of the instrument panel.
- Engine:
  To suit a variety of pilot's needs and budget, the aircraft will be available with an option of different engines in the 60 - 75 kW (80 - 100 Hp) categories. In the future, a South African aviation engine (currently in development) may be chosen.
  - Rotax (imported ex Austria) engines are the worldwide recognised standard for ultralight aircraft. The 60-75 kW engines are respected for their reliability and customer service. The four-cylinder engines feature air-cooled cylinders and liquid-cooled cylinder heads.
  - The Jabiru (imported ex Australia) 2,200cc and 3,300cc Aircraft Engines are air cooled engines in the 60-90kW category and are the less expensive than Rotax engines.
  - Adept Airmotive have developed a high performance South African piston engine for aviation use. The engine under development is, however, not suitable for use in LSA since it produces more than 200kW. Adept Airmotive have indicated that a 3-cylinder LSA engine may be developed and should that materialise, the LSA will be adapted to use the engine when it is available.

2.3 Technology Analysis

The SkyWake™ has been designed as an Ultralight according to the South African definition, a Light Sport Aircraft according to the US definition and Very Light Aircraft according to the European definition. The definitions follow in section 3 of the business plan. The SkyWake™ will be a factory-built all metal, single piston engine high-wing monoplane seating two persons, including the pilot. The seating is configured as side-by-side. Allowance for luggage has been made behind the seats. The SkyWake™ will be equipped per South African SACAA regulations to meet day VFR flight requirements. The major features of SkyWake™ are as follows:

1. The wing structure is a built-up two-spar strut-braced semi-monocoque Aluminium alloy structure. The airfoil is a NASA 0317 low speed laminar-flow section. The wing is equipped with single-slot flaps and frise-type ailerons. The wing has been designed to allow for operating weights of between 550-600kg depending on the country of registration.

2. The horizontal tail featuring a Camm-type balanced tab all-moving stabiliser, manufactured using two built up spars and is of semi-monocoque Aluminium alloy construction.
3. The fuselage is a 4130 steel alloy tubular welded structure clad in Aluminium and incorporates a 600mm crash-crumple-zone.
4. The nose landing gear is steerable and incorporates a trailing link spring-damper.
5. The main landing gear consists of independent pivoted legs with fuselage mounted spring-dampers.



3-View of SkyWake™

TABLE 2: General Specifications of SkyWake™

Engine	Rotax 912 S
Power output	100HP at 5800rpm
Propeller	Composite two-blade fixed pitch propeller
Service ceiling	15000ft
Maximum gross weight	600kg
Standard empty weight	315kg
Maximum useful load	255kg
Usable fuel capacity	85 litres
Overall height	2.5m
Overall length	6.7m
Wing span	11.2m
Shoulder height cabin width	1.2m

Preliminary performance data for the proposed SkyWake™ design has been calculated based on the standard aircraft configuration with optional wheel spats operating in windless International Standard

Atmosphere (ISA) conditions. Field performance, including take-off and landing phases, has been calculated using a level hard dry surface. The performance will vary within statistical limits with individual aircraft. Factors such as aircraft configuration, atmospheric conditions and Air Traffic Control will affect the performance.

TABLE 3: Estimated performance of SkyWake™

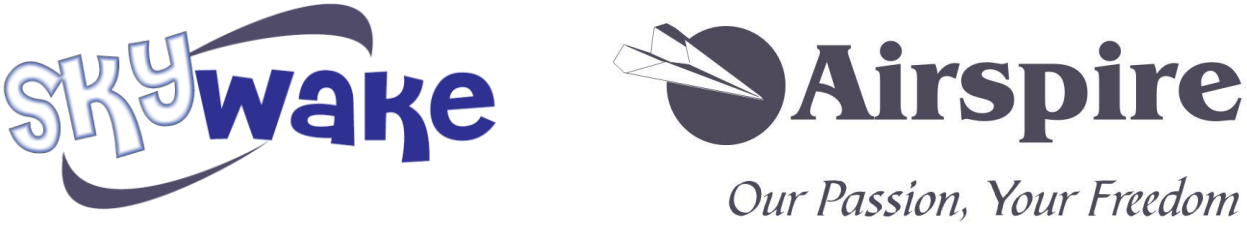
Take-off distance, sea level ground run	70m
Take-off distance, sea level to clear 50ft obstacle	118m
Maximum climb rate, sea level	1200ft/min
Maximum speed, sea level	120KTAS
Cruise range and endurance, 1000ft MSL	525nm, 5hrs
Cruise speed, 1000ft MSL	105KTAS
Landing distance, sea level ground roll	60m
Landing distance, sea level to clear 50ft obstacle	205m*
Take-off distance, 5000ft MSL (ISA +20°C) ground run	121m
Take-off distance, 5000ft MSL (ISA +20°C) to clear 50ft obstacle	176m
Maximum climb rate, 6500ft MSL	800ft/min
Maximum speed, 6500ft MSL	110KTAS
Maximum range and endurance, 6500ft MSL	287nm, 2.7hrs
Cruise speed, 6500ft MSL	103KTAS
Landing distance, 5000ft MSL (ISA +20°C) ground roll	68m
Landing distance, 5000ft MSL (ISA +20°C) to clear 50ft obstacle	215m*

(Estimated performance shown for SkyWake™ with 30min fuel reserve, flying weight of 550kg)
* Calculated at 3 degree glide slope.

2.4 Intellectual Property

Wits Enterprise has filed the name Airspire™ for trademark registration in class 42: Engineering design and services. The chosen name for the aircraft to be produced according to the design is SkyWake™ and this name has also been submitted by Wits Enterprise for registration in class 12: Aircraft. Logos for both Airspire™ and SkyWake™ have been developed.

FIGURE 1: Logos for SkyWake™ and Airspire™



Wits Enterprise has developed the design specifications for two novel aspects which may be included in the design of SkyWake™. The provisional patents for these innovations have been registered by Wits Enterprise. The patent details are appended in Appendix 1. The first patent describes a propeller spinner used to increase cooling airflow and provide a small amount of thrust. The second patent describes a flap mechanism that is not used in current LSA. The mechanism offers very little drag for a small weight penalty.

In the future, the DO would support products in production by offering technological improvement, manufacturing advancements and market driven innovation. Design methodology would be kept confidential and clearly marked as sensitive. The only information that will enter the public domain will be the design general arrangement (3-view), and this will be protected by registration of the design. The structures will be statically tested and the test reports remain the property of the SACAA. The test methods followed are internationally standardised.

Within the framework of contract research undertakings and taking cognisance of the requirements of the Intellectual Property Rights from Publicly Financed Research and Development bill, any IP generated will be the property of the University, and the exclusive rights to the commercialisation of this technology will be assigned to Airspire™.

2.5 Anticipated Time to Commercialisation

The project plan is to either license the BCDA LSA design (discussions are currently underway) or to alternatively create a new LSA design for the development of the prototype aircraft. The timing outlined below is associated with the latter scenario.

TABLE 4: Anticipated Time to Commercialisation of SkyWake™

hase		**Time**	**Start Date**	**End Date**
I.	Conceptual/Detailed Design	3 months	1 January 2010	31 March 2010
II.	Mock-up and detailed design	9 months	1 April 2010	31 December 2010
III.	Prototype and Ground Testing	10 months	1 January 2011	31 October 2011
IV.	Prototype and Flight Testing	9 months	1 October 2011	30 June 2012
V.	Certification	3 months	1 July 2012	30 September 2012
VI.	Launch of SkyWake™		September 2012	

3 INDUSTRY and MARKET ANALYSIS

3.1 Industry Analysis[4]

There are several types of aircraft qualifying as ultralights. These aircraft can be used for sport and recreation, flight training, rental, and glider-towing. The different categories are described below.

- **Weight Shift (Trike) -** are first generation ultralights controlled by weight shift. Most use a hang glider-style wing, below which is suspended a three wheeled structure containing the engine and aviators. Trikes can use internal combustion engines or a pedal system to produce thrust.
- **Glider -** rely on rising air and very efficient aerodynamic properties to keep them aloft. Whilst some do have engines, the engine's role is to raise the glider to an altitude suitable for gliding, at which point the engine is turned off. Gliders with no engine rely on tow-aircraft, winches and occasionally land vehicles for launching purposes.
- **Powered parachutes -** includes a frame with engine, propeller and wheels. The powered parachute is a popular form of recreational sport flying, due to its relatively low cost of start-up and up-keep.
- **Powered paragliding -** in which the pilot wears a small motor on his back and runs into the air with lift from a parafoil wing. This form of flying offers low and slow flying capability, 'open' feel, portability, low equipment and maintenance costs, and safety aspects.
- **Gyroplane -** are similar to small, one-seater helicopters, except that instead of spinning its winged rotor by motor, the gyroplane uses the principle of autorotation to keep its rotor spinning and the aircraft in flight.
- **Lighter-than-Air Sport Aircraft -** rely on filling a balloon with gas that is less dense than air, allowing the balloon to rise to and maintain a particular altitude.

Most countries now require an ultralight pilot's license/certificate however internationally there is no common set of ultralight rules. The safety regulations used to approve ultralights vary between countries, the strictest being the United Kingdom, Italy, Sweden and Germany, while they are almost non-existent in France and the United States. This disparity between regulations is a major barrier to international trade and overflight, as is the fact that these regulations are invariably sub-ICAO (International Civil Aviation Organisation), which means that they are not internationally recognised.[5]

For example, ultralight aircraft in the United Kingdom and New Zealand are generally called microlight aircraft and in France and Italy they are called ultralight motorised (ULM). Some countries further differentiate between weight shift and 3-axis aircraft, calling the former microlight and the latter ultralight. It should be noted however that the US definition of an ultralight is significantly different from that in most other countries and can lead to some confusion. The US "ultralight" is a single seat vehicle with an empty weight of less than 115 kg and a top speed of 102 km/h. The introduction of the FAA "Light-Sport Aircraft" (LSA) regulations in 2004 introduced a category of aircraft in the US which more closely resembles other countries' ultralight categories. For Light Sport Aircraft a sport pilot certificate is required, which is similar in requirements to other countries' ultralight license. [The introduction of this category of aircraft will be discussed below.]

The European aviation community is working on regulations that are intended to resolve the non-standard definition of the LSA within a reasonable time frame.

The build quality and airworthiness of ultralight aircraft (LSA category in the US) now rivals that of certified light aircraft. It is possible that some aircraft can satisfy both sets of requirements and can hence be available for registration as either ultralight or certified status. In recent years there has been a dramatic rise in the number of general aviation pilots flying high performance ultralights due to the lower costs. Ultralight pilots are permitted to perform some of the simple maintenance tasks, resulting in a lower cost of operation, although the pilot must then follow the ultralight regulations such as avoiding densely populated urban areas and not flying at night. Many older pilots have been willing to trade these operational

4 Overview of the General Aviation Industry: Sport Aviation Study. Wilbur Smith Associates
5 http://en.wikipedia.org/wiki/Ultralight_aviation

restrictions for the lower operational costs, and as a result many ultralights are now flown by experienced general aviation pilots or ex-commercial pilots. In addition, further growth in this market has been driven by the fact that ultralight pilots are not required to pass periodic physical examinations, as is the case for general aviation pilots.

Thus, although ultralights (microlights in some countries) started out in the early 1980's as slow, lightweight and uncomplicated aircraft, many have evolved into fast, sophisticated machines. The ultralight aircraft have thus internationally rapidly transformed into high performance aircraft, capable of very respectable speed and range. These aircraft are now often referred to as recreational aircraft.

Data published by the General Aviation Manufacturers Association (GAMA) in the *2008 General Aviation Statistical Databook & Industry Outlook* indicating growth factors for several sectors is depicted below.

TABLE 5: Federal Aviation Authority Forecast.

Growth Factor	***1st rank (percentage growth)***	***2nd rank / (percentage growth)***	***3rd rank (percentage growth)***	***4th rank (percentage growth)***
Annual sales	Light Sport Aircraft (9.9%)	Turbo-jet aircraft (5.6%)	Piston engine rotorcraft (4.7%)	Experimental home-built aircraft (2.2%)
Annual hours flown	Light Sport Aircraft (12.1%)	Turbo-jet aircraft (7.7%)	Piston engine rotorcraft (5.0%)	Experimental home-built aircraft (2.5%)
Pilot population	Light Sport Pilot License (13.7%)	Rotorcraft Pilot License (2.1%)	Student Pilot License (1.0%)	Commercial Pilot License (0.5%)

3.2 Market Place Analysis

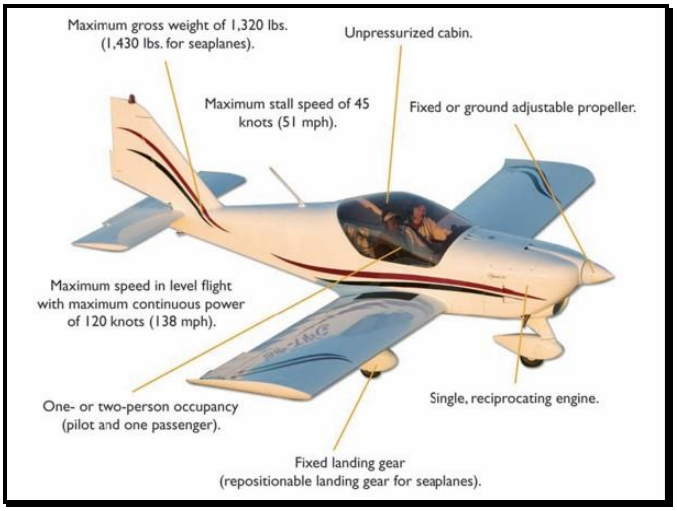
3.2.1 United States:

With the recognition of a declining pilot population and the implications to air travel, in 2004 the FAA generated an entirely new category specifically designed to address the desire of people wishing to fly aircraft primarily for recreational purposes. The Light Sport Aircraft (LSA) regulation is a comprehensive package addressing all aspects of the operation of Light Sport Aircraft for recreational purposes, including a new pilot certificate, a new flight instructor certificate, maintenance rules, and medical and aircraft certification. This new category of the sport aviation market effectively reduces the barriers to becoming a pilot in the US as it substantially lowers capital investment and operating costs. These aircraft are cheaper to purchase, are more fuel efficient and have a lower maintenance cost than larger aircraft. Pilots are not required to hold a medical certificate, but need only to carry a valid US driver's license to meet the medical eligibility requirements. The basic sport pilot certificate requires a minimum of 20 hours training and a driver's license medical certificate.

The Light Sport Aircraft is not a new concept. Aircraft within this category have existed since the 1930's, the most famous example of a vintage aircraft complying with the 2004 S-LSA regulation is the Piper J-3 Cub. The 2004 regulation serves only to provide a standard for performance and safety, whilst limiting absurd designs.

Light Sport Aircraft (LSA) can be manufactured and sold ready-to-fly under new LSA certification. Aircraft under this certification may be used for sport and recreation, flight training, and aircraft rental. They can also be licensed as Experimental Light Sport Aircraft (E-LSA) if kit-built. Both US and foreign manufacture of LSAs are authorised. The design limitations imposed on the LSA producers are depicted in the diagram below.

FIGURE 2: Light Sport Aircraft Regulations[6]



It is anticipated that this sport pilot and aircraft classification will enlarge the aviation market among those who are already pilots, attract a significant number of new pilots to general aviation as well as convert existing pilots downgrading to cheaper aircraft.

The LSA market has shown substantial growth since the introduction of new designs. In the US to date, approximately 50 different models of aircraft have already been approved under the special LSA regulation as ready-to-fly aircraft.

TABLE 6: The US Aircraft Register[7]

	2005	2006	2007	2010	2015	2020	2006-10	2006-20
	Actual			***Forecast***			***Forecast Annual Growth Rates***	
Sport Aircraft	170	400	2,700	5,600	10,500	13,200	93.4%	28.4%
Total GA	224,352	226,422	231,343	242,766	261,404	274,914	1.8%	1.4%
Percentage	<0.1%	0.2%	1.2%	2.3%	4.0%	4.8%		

3.2.2 South Africa:

Aviation in South Africa is regulated and overseen by the South African Civil Aviation Authority (SACAA), which is a part of the Department of Transport. The SACAA is responsible for certifying aircraft that apply for registration (type certification process) as well as for ensuring that Aircraft Maintenance Organizations (AMOs); Manufacturing, Processing and Testing Organizations (MPTs); Design Organizations; and Aviation Training Organisations (ATOs) are effectively inspected, approved and overseen, and that they perform their work within the framework of their approvals. The size of the industry overseen by this division can be summarized as follows: 10,730 aircraft (TCA and NTCA); 420 AMOs; 90 MPTs; 15 ATOs providing training to Aircraft Maintenance Engineers (AME); and at least 3,500 AMEs.

For the purposes of design and manufacturing of aircraft in South Africa, aircraft are put in two major categories, those which have been designed and manufactured under the standards that meet or exceed those of the International Civil Aviation Organisation (ICAO), otherwise known as Type Certified Aircraft (TCA) and those which are not compliant with ICAO standards, known as Non-Type Certified Aircraft (NTCA). A NTCA is an aircraft that does not qualify for the issue of a certificate of airworthiness in terms of Part 21 of the Civil Aviation Regulations (CARS) of 1997[8]. It includes any TCA no longer qualifying. With

6 http://www.eaa.org/sportpilot/sourcebook.pdf
7 Source: 2000-2005, FAA General Aviation and Air Taxi Activity (and Avionics) Surveys.
8 As amended

the growth of the NTCA sector, regulatory provisions have been developed in an attempt to properly control and regulate this class of aircraft. NTCA standards are contained in the CARs:

- Part 24: certification and airworthiness of NTCA;
- Part 94: operation of the NTCA;
- Part 96: commercial use of NTCA.

NTCA can be divided into five categories.

(a) Amateur- or home- built aircraft: Specifically built in terms of the provisions of CAR Part 24. The owner performs most of the construction work themselves as a once-off project for the purpose of flying the aircraft themselves. Aircraft are classified as kit or plan-built.

(b) Production-built aircraft: The build standard and prototype (approved and constructed in terms of CAR Part 24) are available either fully-assembled or in kit form (< 51% of the airframe has been constructed and assembled) exclusively for non-commercial purposes. These aircraft must be constructed/assembled at SACAA approved facilities in South Africa.

(c) Veteran aircraft: These aircraft are traditional aircraft that have lost their type certificate.

(d) Ex-military aircraft: All aircraft previously operated by military air forces.

(e) Any other aircraft not qualifying for the issue of a Certificate of Airworthiness (CAR Part 21).

NTCA aircraft are further divided into the following sub-groups – (a) aeroplanes, including microlight [9] aeroplanes; (b) helicopters; (c) gyroplanes/ gyrogliders; (d) gliders; (e) manned captive and manned free balloons; (f) airship; (g) unmanned aerial vehicles; (h) hang-gliders including powered hang-gliders; (i) paragliders (powered paragliders and paratrikes); (j) parachutes; (k) model aircraft; and (l) rockets.

Along with the trends being experienced in the US and European general aviation markets, South Africa has experienced a rapid growth in the NTCA market. At the end of 2008, there were 10,730 aircraft on the South African Civil Aircraft Register, of which 49% represented the sport and recreational NTCA aircraft.

TABLE 7: South African Civil Aircraft Register: 1999 - 2008

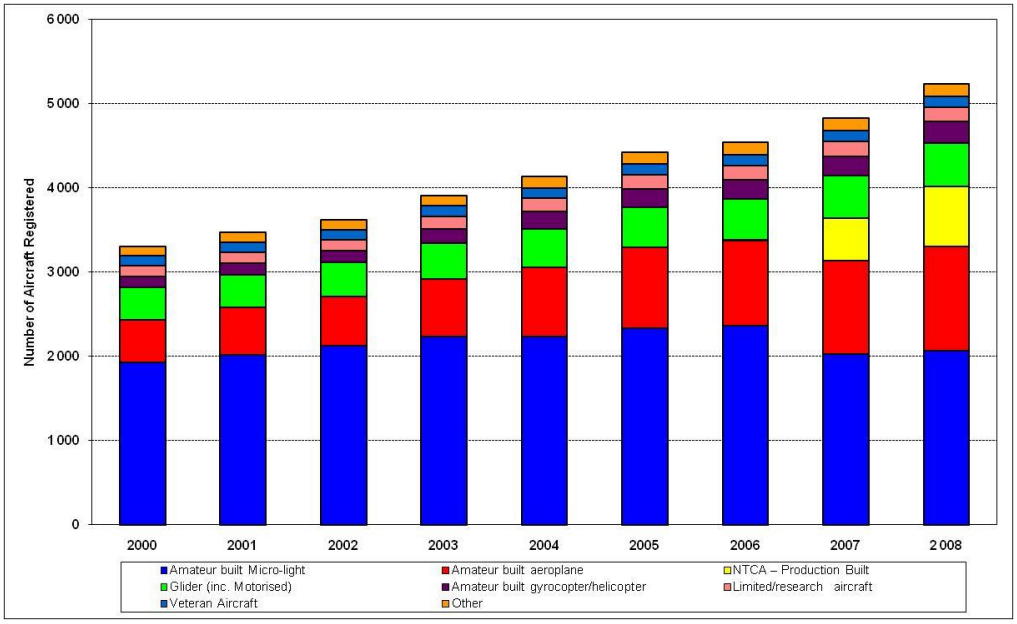
	2000	2001	2002	2003	2004	2005	2006	2007	2008
TOTAL TCA	**4,190**	**4,247**	**4,311**	**4.496**	**4,695**	**4,901**	**4,985**	**5,132**	**5,497**
Aeroplane	3 679	3 718	3 769	3 898	4029	4149	4 204	4,271	4,474
Helicopter	511	529	542	598	666	752	781	861	1,023
TOTAL NTCA	**3 294**	**3 470**	**3 616**	**3 907**	**4 127**	**4 413**	**4 536**	**4 825**	**5 233**
NTCA - Amateur built	507	558	587	688	821	961	1 021	1 105	1 236
NTCA – Production Built	0	0	0	0	0	0	4	512	708
Sub total: Amateur & Production Built Aircraft	***507***	***558***	***587***	***688***	***821***	***961***	***1 021***	***1 617***	***1944***
Amateur Built Microlight	1 926	2 014	2 118	2 226	2 232	2 326	2 356	2 023	2 065
Glider (incl. Motorised)	377	393	401	429	456	475	477	495	514
Amateur Built Gyrocopter/Helicopter	129	139	144	167	206	219	229	236	257
Limited/Research Aircraft	130	129	128	148	154	171	175	175	167
Veteran Aircraft	118	120	120	124	125	128	128	131	130
Other[10]	160	171	173	184	193	210	224	246	284
TOTALTCA and NTCA	***7 484***	***7 717***	***7 927***	***8 403***	***8 822***	***9 314***	***9 521***	***9 957***	***10 730***

9 Microlight aircraft are further defined as having restricted minimum flying speed and the maximum take-off mass, with a MTOW of 450kg for a two-seater and a minimum flying speed at MTOW less than 65km/h.

10 Other includes hot air balloons, gyrocopters, amateur built helicopters

Figure 3 outlines the growth in the NTCA class over the period 2000 - 2008. The market has increased by 59% over this period. Prior to 2006, it was not possible to determine how many of the NTCA aircraft are production built as these were included under the broader category of amateur built aircraft.

FIGURE 3: Non-Type Certified Aircraft 2000 - 2008



The amateur/production built category has increased from 15% to 37% of the total NTCA market between 1997 and 2008, with an average annual growth over this period of 17%. Amateur built microlights remain marginally the largest segment of the market at 39% of the NTCA register. In 2000 microlights represented 58% of the class of aircraft, but have had only a 2% average annual growth over this period.

Table 7 indicates that there has been a growth in recreational flying as the issuing of private pilot licences increased in line with the aircraft growth in this area of aviation. It is also notable that the number of student pilot licences has increased. In 2005 and 2006, the number of student learner pilots exceeded the number of microlight learners.

TABLE 8: Number of Active Pilots in South Africa

	2000	2001	2002	2003	2004	2005	2006
Others	3 891	3 474	4 187	4 575	4 901	5 500	5 434
Student	1 266	1 412	1 555	935	1 293	1 771	1 848
Microlight	918	1 526	1 222	1 300	1 629	1 580	1 561
Private	4 335	4 034	4 184	4 521	4 925	5 020	5 139
TOTAL	**10 410**	**10 446**	**11 148**	**11 331**	**12 748**	**13 871**	**13 982**

3.2.3 Canada:

Regulation of ultralight aircraft in Canada is covered by the Canadian Aviation Regulations. The definition of an "ultralight aircraft" includes advanced ultralight or basic ultralight aircraft, both of which have only two seats. A "basic ultralight aircraft" is designed and manufactured to have a MTOW not exceeding 544 kg, whereas the “advanced ultralight aircraft” is designed to have a maximum take -off weight 480 kg.

TABLE 9: The Canadian Aircraft Register

	Normal	Amateur Built	Basic Ultralight	Advanced Ultralight	Other	TOTAL
Total	21,060	3,314	4,674 (14.9%)	968	12,405	**31,421**
Airplanes	17,978	2,934	4,674	968	1,231	**27,785**

3.2.4 United Kingdom:

- Very Light Aeroplane (VLA) has a single engine with not more than two seats and a MTOW of not more than 750 kg.
- The definition of a microlight is an aircraft having no more than two seats and a MTOW of no more than:
  - 300 kg for a single-seater landplane (or 450 kg for a two-seater landplane); or
  - 330 kg for a single seater amphibian/floatplane, (or 495 kg for a two-seater).

TABLE 10: The UK Register certification summary 1 Jan 2004

	2006	2007	2008
Fixed wing MTOW <= 750 kg	3,077 (16.7%)	3,153 (15.8%)	3,186 (14.9%)
Microlights	4,254	4,392	4,447
Total	**18,445**	**19,890**	**21,331**

3.2.5 Australia:

In Australia a "Sport/Recreational aircraft" must have a maximum all-up weight (MAUW) of 544 kg or less and a maximum of two seats. Australia has in the order of 580 registered aircraft with a MTOW between 450 kg and 544 kg.

3.2.6 New Zealand:

In New Zealand microlight aircraft are separated into two classes, single and two seat aircraft.

Class 1: Single seat aircraft with a design maximum gross weight of 544 kg (landplanes) or 579 kg (seaplanes/amphibians). Requires aircraft registration and annual condition inspections, but does not require a permit to fly.

Class 2: Two seat aircraft with a design maximum gross weight of 544 kg (landplanes) or 614 kg (seaplanes or amphibians). Must meet minimum type acceptance standards or *via* a temporary permit to fly and flight testing regime. Requires aircraft registration, annual condition inspections, and a current permit to fly. New Zealand has 637 microlight class II on its aviation register.

3.3 Customer Analysis

Ultralight aircraft/Light Sport Aircraft are used extensively for flight training, recreation and various light commercial purposes. Customers therefore include:

- Flight Schools
- Private individuals
- Businesses
- Government/NGOs

3.4 Competitor Analysis

The Europeans are currently the market leaders with the Czech Republic playing a major role[11] producing 588 ultralight planes (worth €40 million) in 2006, 170 more than in the previous year. TL Ultralight, a German manufacturing company, estimates that currently roughly 80% of the worldwide production of ultralight aircraft is located in the Czech Republic. Nearly 200 of the 560 ultralight aircraft registered in the US in 2006 were produced in the Czech Republic. There are very few US manufacturers of such ultralight aircraft.

There is an enormous diversity and range of ultralight and Light Sport Aircraft on the market in South Africa, available either in kit or fully built form. Fully built aircraft are assembled locally from imported components; there are hence no fully South African manufactured aircraft. The design features of the aircraft models are broad. Some are modern versions of designs that have been proven in classic aircraft, while others are imports from Europe and Australia where lighter aircraft have been in the marketplace for more than a decade. Some of the more popular aircraft and their manufacturers are profiled in the following table.

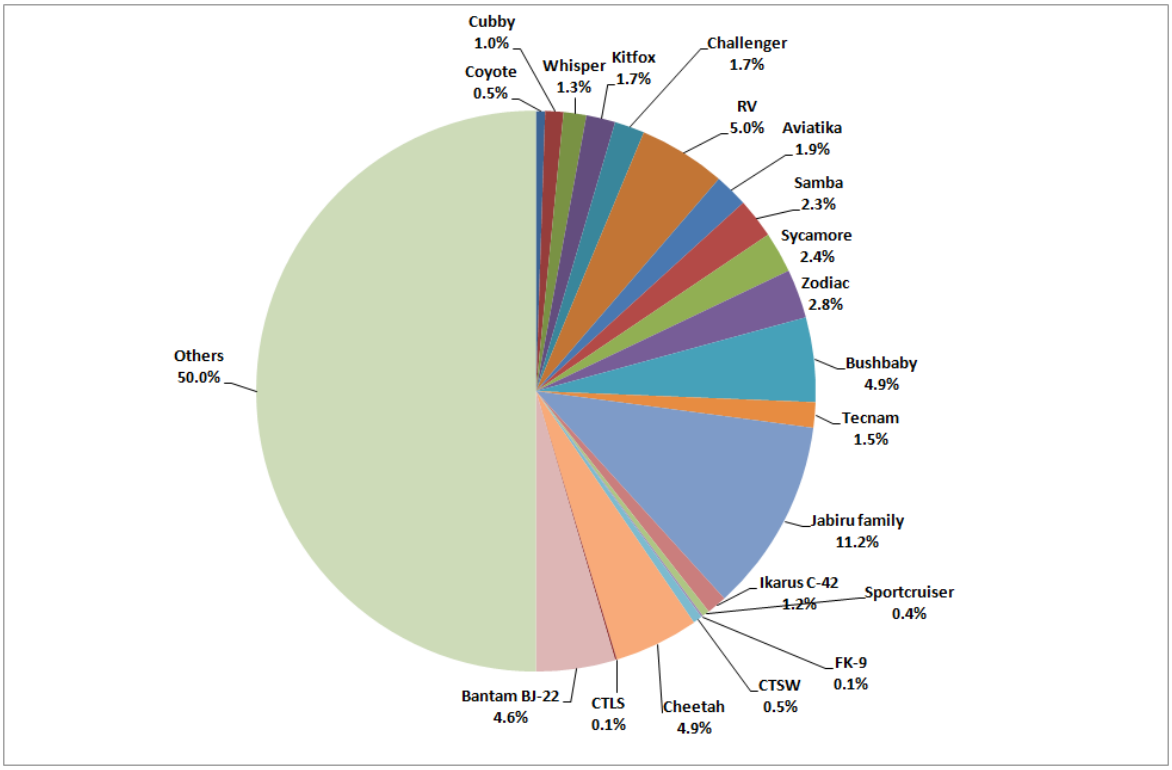
TABLE 11: South African Ultralight Manufacturers[12]

Manufacturer	*Aircraft model*	*Technical Description*	*Photo*
Rainbow Aircraft	Cheetah XLS (Ultralight-production built))	High wing braced monoplane with aluminium tubular structure, clad with Dacron.	
Davies Aircraft Corporation	Thunderbird (Microlight-production built)	Enclosed cabin high-wing braced two-seat aircraft. Dacron clad.	
Whisper Aircraft	Whisper (Motorglider-production built)	High aspect ratio exposed-motor glider.	
The Airplane Factory	D-6 Sling (Light Sport Aircraft-kit built)	Low-wing two-seat Aluminium semi-monocoque structure.	
Micro Aviation SA	Bantam BJ-22 (Microlight-production built)	Semi-enclosed cabin high-wing braced two-seat aircraft. Dacron clad.	

The diagram below indicates the market share, by company, as at the end of 2008 according to the SACAA register.

11 http://www.aero-friedrichshafen.com/html/en/home/home.php?lid=9653
12 All images taken from manufacturer's websites.

FIGURE 4: The South African NTCA Market (1944 aircraft in 2008)



A description of the most popular models on the market in South Africa is provided below. The attached **Appendix 2** outlines a comparison of the specification of some of these aircraft.

- **Jabiru Aircraft Southern Africa**
  Jabiru Aircraft, a fully SACAA licensed MO and AMO, is the agent for the Australian designed Jabiru series of aircraft and engines. Jabiru has the highest number of NTCA registered in South Africa. Aircraft are sold either in kit form or fully built. (Currently most financial institutions do not however finance the purchase of kits). The company offers customers the possibility of customising the aircraft e.g. through addition of photographic windows, extra carry on fuel tanks and glass-fibre doors. Jabiru was one of the first to obtain full private pilot's license (PPL) training status for the aircraft and claims that sales are increasing as PPL flight schools realise how affordable the aircraft are to run.
- **Cessna - SkyCatcher**
  Cessna released their conceptual LSA in July 2006. The prototype production aircraft has just started its test flight program and over 800 Cessna C162 SkyCatchers have been ordered globally. Production is in China.
- **FK Lightplanes: FK-9**
  FK-Lightplanes, a German company, markets the FK 9 MK IV. The aircraft is one of the fastest selling aircraft internationally, but has yet to achieve much market share in South Africa. The wings have a folding option, which require no tools, for trailering and storage. The seats are adjustable.
- **Microwings: (Cubby)**
  The Cubby is available in kit form, ready to fly or fully built but without engine, radio and instruments. The Cubby can be registered as a 3-axis microlight or an ultralight. The purchase price is low and operational costs are kept to a minimum due to the use of automotive fuel (MOGAS) as opposed to AVGAS. The Cubby is available in tri-gear or tail dragger. Price is dependent on the choice of engine.
- **Kitplanes for Africa: (Bush Baby)**
  The Bushbaby is a homebuilt kit aircraft which may be registered as a microlight or an ultralight. It has a low performance but is a safe entry level aircraft. The majority of Bushbabys are tail draggers as the aircraft was designed to operate out of rough fields. This configuration however makes the

aircraft more challenging to fly in comparison to the tricycle aircraft, which is better suited for prepared runways.

- **Skystar Aircraft Company: (Kitfox Kits)**
  The Kitfox is a lightweight, two-seater sport aircraft with excellent STOL performance and the ability to operate from short and unimproved airfields. Various models include a larger aircraft designed to fit the needs of a growing segment of the marketplace that wanted a "Weekend Cruiser" i.e. pilots wanting a recreational aircraft with greater useful loads, certified engines, increased cabin space, and larger cargo capacity.
- **Wing 'n tracks (Samba and Lambada)**
  The Samba is a competitively priced aircraft including a variable pitch propeller, two-metre wingtip extension, glider tow hook and a well-equipped panel and avionics suite. It can use unleaded MOGAS fuel, AVGAS or a mixture of both. The Lambada differs from the Samba, the differences with a shoulder mounted wing and a T-tail.
- **Rainbow Aircraft: (Cheetah)**
  The Cheetah has been approved by the SACAA for full PPL and hour building towards the CPL. The Cheetah is available in tail dragger form or with tri-cycle gear. The Cheetah XL features a bigger cabin with extra headroom. The company has also started selling the Cheetah as self-build kits.
- **Van's Aircraft: (RV kit planes)**
  RV Aircraft are low-wing monoplanes. RVs are designed and built so they can be dismantled when necessary. All of the tail surfaces are removable. Wings are constructed independently and bolt to the fuselage, the landing gear attaches to the fuselage with a few bolts.
- **National Airways Corporation (NAC): Tecnam range**
  The Italian Tecnam, P92 Echo Super, has a spacious cabin, bigger instrument panel, smaller wing surface and highly efficient single-slotted flaps in comparison to the others. The Sierra has an all-moving horizontal stabiliser and a tapered wing which improves aerodynamic efficiency. The P92 2002 has a retractable gear reducing drag and making this aircraft a good performer.
- **Microaviation: Bantam Microlight**
  The Bantam is classified as a microlight and is used in crop spraying. The Bantam can be registered as an ultralight aircraft and can be used to build up PPL hours. Due to its quiet operation and STOL capabilities the Bantam is used extensively in farming and nature conservation as well as by the Police Service for crime fighting and visible policing. The aircraft claims to have an incredible capability in windy conditions, outperforming other STOL aircraft that cost more than twice as much.

A comprehensive technical analysis of SkyWake™ compared to its nearest competitors [13] the FK-9 ELA and the Jabiru J 170, as well as the Cessna SkyCatcher is attached as Appendix 2. In summary, the FK-9 is the nearest competitor in terms of design specification. The SkyWake™ has been designed with a wing approximately 2% larger in area than the FK-9 offering 20% less lift induced drag, attributable to the geometry. The SkyWake™ produces 8% less total drag at 110km/h than the FK-9 and 1% less drag at 184km/h. SkyWake™ has been designed to have the best performance at its maximum flying weight.

The SkyWake™ has been compared to the FK 9 ELA, Jabiru 170 and Cessna SkyCatcher using a weighting scheme (refer to Appendix 2a for further details of this comparison). Each criterion has a highest possible score of 100%. As can be seen, SkyWake™ scores very well in all categories. Performance wise, SkyWake™'s closest competitors are the FK- 9 ELA and the SkyCatcher, with the best being the FK9.

13 As determined by detailed technical analysis by the School of Mechanical and Aeronautical Engineering.

General Criteria	Specific Criteria	Cessna SkyCatcher	FK 9	Jabiru 170	SkyWake
Construction	Damage tolerance, corrosion resistance and degree of modification	67%	58%	50%	92%
Operation	Landing gear, flight performance, equipment and performance at altitude with elevated temperature	55%	70%	52%	92%
Ownership	Parts availability, degree of customisation and cabin layout	55%	40%	55%	100%
OVERALL RATING		**3**	**2**	**4**	**1**

3.5 Pricing Analysis

Prices of the different models are as varied as are the models themselves, ranging from R 364,000 (Cheetah XLS) to R 838,000 (Flight Design CTLS). The cost of the average light sport is estimated to be roughly a quarter of the cost of a new type certified four-seater single-engine, such as a Cessna and less than half the cost of a type certificated two-seater.

Figure 5 demonstrates the pricing analysis demonstrating the comparative aircraft sales - marker size is proportional to sales. Aircraft registered to the flight schools are also indicated in this graph for comparative purposes, although being in a higher weight and cost category. The graph also included prices of a microlight aircraft (Bantam) and lower weight ultralight kit aircraft such as the Cubby and Bush Baby. The SkyWake price is the average price (of three models that will be marketed – refer to section 4.3 below).

Performance wise (refer to table above) SkyWake™'s closest competitors are the FK- 9 ELA and the SkyCatcher. Both of these aircraft are priced above R 780,000. The pricing and market analysis indicates that the Cessna SkyCatcher sells more aircraft than the higher performing FK-9. In addition, the best selling aircraft is the Jabiru J170, which based on the analysis in section 3.4 above, has average rating in terms of construction, operation and ownership criteria. This analysis seems to indicate that the higher performance end of the market, there is a degree of compromise between pricing and performance.

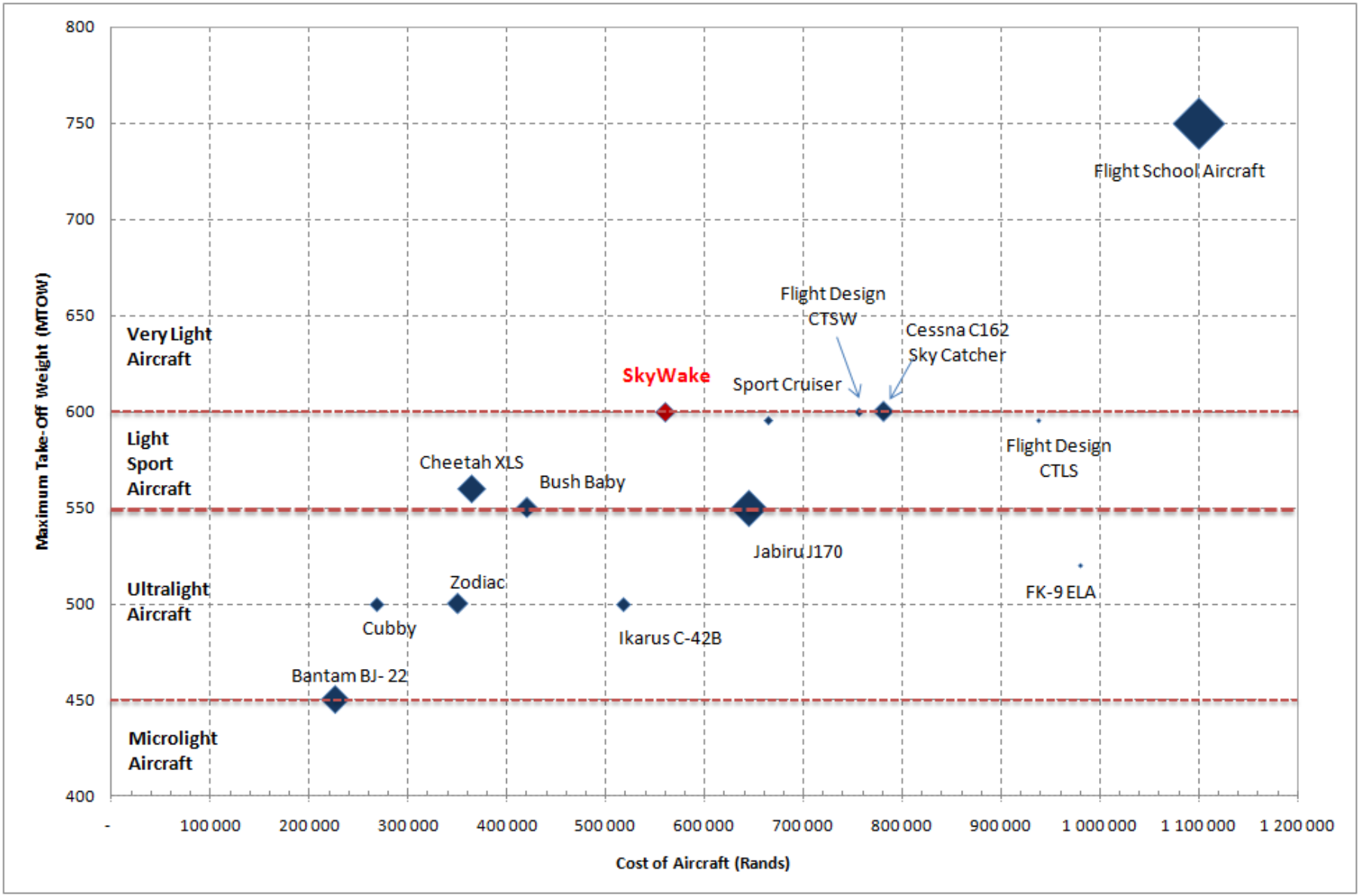
At the same time, the Jabiru J170 also sells better than lower priced, medium performance aircraft such as the Bush Baby, Cheetah, Zodiac and Ikarus. This would imply that at the lower end of the price market, performance remains an important consideration.

The conclusion of this analysis is there are two market segments in which SkyWake could compete:

- Against the high performance, high price aircraft such as the Cessna SkyCatcher.
  - ⇒ **Offer is a more competitively priced high performing aircraft**
- Against the lower priced, medium performing aircraft such as the Zodiac and Bush Baby.
  - ⇒ **Offer** is a higher performing aircraft for a competitive price.

Airspire will introduce more than one model of the SkyWake™ design to accommodate this positioning in the market.

FIGURE 5: Pricing Analysis - South African NTCA



4 MARKETING PLAN

The LSA/ultralight market is becoming recognised as the future of general aviation. It is anticipated that this market sector will not only rejuvenate the general aviation industry by encouraging new students to enter flight training, but will also provide flight schools with a highly competitive alternative to the current fleet of Cessnas and Pipers that they are now utilising, allowing them to upgrade their fleets with modern, safe and more affordable aircraft. LSA aircraft have demonstrated 55-65% reduced fuel burn when compared to two-seat legacy aircraft such as the Cessna 152 and Piper Super-Cub.

It is always a challenge for any manufacturer to enter a highly competitive market; however Wits University has carefully researched the market needs and has tailored the company's first entry level aircraft, SkyWake™, to meet specific needs identified in the market for ultralight aircraft. SkyWake™ will incorporate a number of unique aspects in comparison to its competitors in the LSA category. The performance of the aircraft has been tailored to the rugged climate of the plateau regions and comfort of the occupants has been maximised. Also of importance is the fact that it will comply with international Light Sport Aircraft regulations in order to satisfy the international export market. This product will thus open the export market for South African developed aircraft.

It is believed that these innovative features incorporated in the SkyWake™ design will offer a competitive advantage allowing Airspire™ to reach sales of 50 aircraft within 3 years of launch.

4.1 Marketing Objective

The company's marketing strategy is centred around the objective of SkyWake™ becoming the leader in the South African ultralight market within the first five years of operation, and obtaining market share in the expanding international LSA market.

1. 20% of all new sales in the production/amateur built aeroplane category within 5 years, and 25% within 7 years.
2. To convert 7.5% of microlight sales into SkyWake™ sales within 4 years.
3. To enter into the export market within 3 years.
   - Market share of up to 1.2 5% of new aircraft sales are projected in Northern Hemisphere countries and in Australia/New Zealand.
4. The target is to have sold 125 aircraft by the end of year 3 and over 330 by the end of year 5.

4.2 Product Positioning

"Airspire™ will be the first company to bring to market a "Proudly South African" designed and manufactured innovative Light Sport Aircraft for the aviation enthusiast in Africa."

Airspire™ will leverage its competitive edge, based on product innovations/features and price competitiveness. The major competitive edges are:

1. The design of a high performance Light Sport Aircraft designed specifically for the South African climate and unique flying conditions.
2. The luxurious interior of the aircraft and the ability for the customer to tailor the colour and fittings to suit their taste at an affordable price.

Acquisition cost is one of the principal factors which restricts the purchase of new aircraft, second only to the cost associated with aircraft operation and maintenance. The vision for Airspire™ is thus to introduce the option for an aircraft priced such that it offers significantly improved reliability and

operational efficiency, coupled with a comfortable cabin, reliable power plant and customised novel features.

4.3 Pricing Strategy

Analysis of the pricing of the best-in-class ultralight aircraft in South Africa as depicted in Figure 5 above has demonstrated that the aircraft representing the closest competition in terms of both price AND performance is the Jabiru J170 priced at R 644,344. The FK-9 retails for R 981,000. As has been demonstrated in the competitive analysis above, SkyWake™ offers potential customers better value for money in terms of performance as well as additional features such as customised seating, air-conditioning, ballistic parachutes, and other innovative features.

SkyWake™, as the first Light Sport Aircraft to be launched by Airspire™, will be within a price range of R 520,000 to R 600,000 (delivered to agent's airfield). This price hence allows for an agency fee to be received by the marketing company. The prices are[14]:

- **Entry level**: Conventional instruments & Jabiru J 330 engine
  Cost: R 520,000 (US$ 74,286)
- **Middle range**: Glass cockpit instruments & Jabiru J 330 engine
  Cost: R 550,000 (US$ 78,571)
- **Top of the range:** Glass cockpit instruments & Rotax 912 S engine
  Cost: R 600,000 (US$ 85,714)

Prices will be fixed in US$ to protect Airspire™ against currency fluctuations. Approximately 78% of the variable cost of manufacture is priced in US$, hence currency exchange rates could potentially have a major impact on the profitability of the business.

4.4 Market Segments

Figure 6 outlines the 3 main market segments in which Airspire will compete for sales with its models of the SkyWake™ aircraft.

Market Segment 1: Flight Schools

The first market segment targeted will be flight schools and the young, aspiring pilots trained by them. NTCAs may be used for flight training provided the flying school is the holder of the appropriate aviation training organization approval (issued in terms of Part 141 of the CARs). SkyWake™ will provide the schools with a safe, affordable aircraft, as an alternative to certified aircraft such as Cessna and Piper aircraft, which will help flight schools establish and expand their business. A number of flying schools have been identified as initial targets and some research was conducted. This research indicated that the average age of the aircraft used by the 54 schools analysed is over 21 years. These aircraft will shortly have to be replaced. Already, nearly 8% of the flight school aircraft are LSAs.

Number of flight schools analysed	54	
Total flight school aircraft fleet	290	
Percentage of SA aircraft used by flight schools[15]	21.21	%
Average age of aircraft	21.22	Years
Number of LSA currently used as training aircraft	22	

14 At an exchange rate 2009 of SA Rand 7.00/US$

15 Single engine certified aircraft fleet used by flight schools (e.g. Cessna 152)

The SkyWake™ top of the range aircraft is targeted at this market segment. This aircraft has glass cockpit instruments & the higher performance engine, the Rotax 912 S.

Market Segment 2: Private and Business Pilots

Subsequent to achieving market presence through selecting and entering this early adopter market, the company will be able to extend its service to its secondary target groups. Within this market segment, SkyWake™ will compete against the higher priced, high performance aircraft such as the FK-9 and Cessna SkyCatcher. Its closest competitor is the medium priced, medium performance Jabiru J170. (Refer to analysis in section 3.4).

Airspire™ will target the following market segments in South Africa:

- Private Pilots – recreational flying. There are 2 categories of potential purchasers, aspiring young pilots as well as the high net worth individuals
- Private Pilots – businesses, government and non-governmental organisations (e.g. farms, construction companies, sight-seeing organisations etc.) in terms of part 96 of the CARs - Commercial Operation of NTCAs.
- "Communal" aircraft bought by a few parties with a common interest. Each owner would own a share in the aircraft. This has become popular amongst recent flight school graduates in the US.

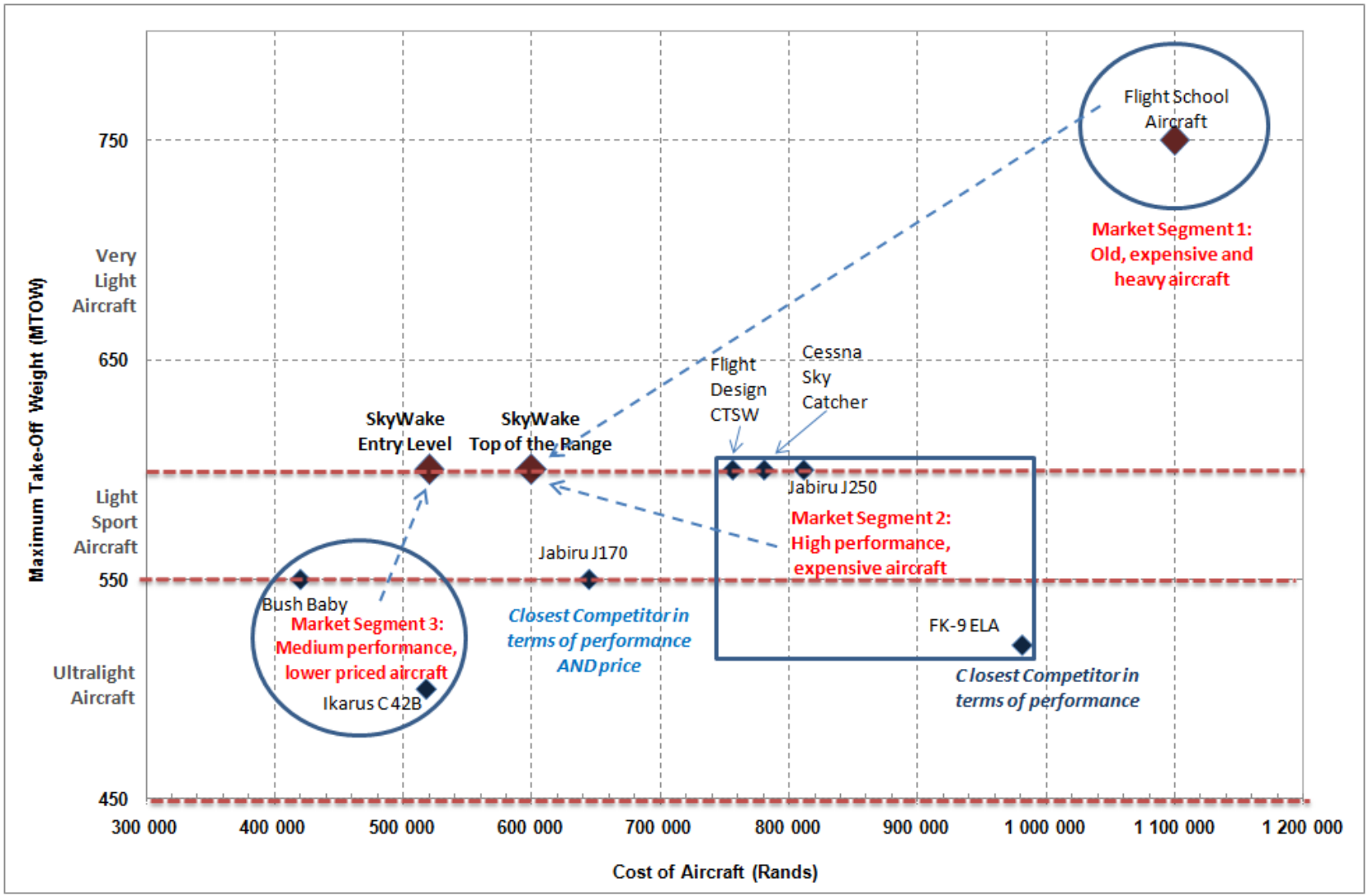
The Middle and Top Range SkyWake™ are likely to be the most popular models in this market segment.

Market Segment 3: Private and Business Pilots

With an appropriately priced model (entry level model), SkyWake™ intends to capture market share from the following aircraft market segments:

- Pilots purchasing the lower priced, medium performance aircraft such at the Cheetah XLS and the Bush Baby. Whilst both are available in kit form, they are also sold as fully complete models. Other aircraft in this segment include the Ikarus.
- South African microlight pilots – upgrading to an affordable Light Sport Aircraft. Pilots with MPL licenses may fly any aircraft with a MTOW of less than 600kg in South Africa. Data contained in Figure 3 indicates that in recent years growth in the microlight market segment has been stagnating. Although this market segment is still the dominant NTCA sector, the homebuilt/amateur built market is capturing significant market share.

FIGURE 6: Marketing Positioning Analysis - South African NTCA



4.5 Sales and Marketing Activities

4.5.1 Launch Plan:

During 2011, whilst the prototype is under construction, letters, brochures, a web-site and presentations will be designed in order to prepare for the initial sales effort. The company will run a training course for all appointed marketing agents to enhance their product and sales expertise.

The "Approval to Fly" process will start in July 2011 followed by the formal sales process with the initial contacts made at the Air Shows. The official product launch will be during the biannual African Aerospace and Defence Exhibition (AADE), to be held in September 2010 at the Ysterplaat Air Force Base, Cape Town. Airspire™ will be represented with its own booth and its first aircraft, co-locating with the Design Organisation.

Marketing activities after launch include ensuring that Airspire™ has a continuing presence at the air shows.

The product launch and the initial sales effort will be supported by a press conference prior to the trade show. In addition, an advertising and public relations campaign will be started using a professional public relations agency.

Publicity would also be generated by the aircraft setting a South African endurance record.

4.5.2 Phase 1: South Africa:

Appointment of Regionally Located Specialised Sales Agents:

Airspire™ will carefully select and appoint official distributors, in South Africa and abroad, to market SkyWake™. Marketing companies are generally located at airfields around the country. Over a period of time, 3 marketing companies will be appointed and will cover Gauteng, Western Cape and KwaZulu Natal. An additional location in the Eastern Cape will also be considered.

Selection of the marketing agent will be based on its technical skills, presence at airfields and air shows and on their ability to provide customers with the appropriate after-sales service. Each marketing company appointed will be provided with an aircraft, which will be run and operated at its own cost that will be used for flight demonstration.

Marketing and sales efforts are anticipated to result in significant growth of sales of SkyWake™ amongst private customers as soon as awareness and credibility is proven among flight schools and new pilots. Positive word-of-mouth communication between flight schools and the purchase of SkyWake™ by "reference customers" will further improve the sales effort and the company's standing in the industry.

Maintenance Contracts:

A competitive advantage will be provided through Airspire™ entering into a maintenance agreement with flying schools which have purchased SkyWake™ aircraft. It is a SACAA requirement that all NTCA aircraft are maintained such that they are airworthy at the commencement of any flight. All NTCAs must therefore undergo an annual inspection not later than 365 days after the previous inspection and this must be carried out by an Approved Maintenance Organisation (AMO). Following completion of this maintenance an appropriately rated Approved Person (AP) or Approved Maintenance Engineer (AME) may then issue the Authority to Fly. This provides a competitive

advantage over imported aircraft which often need to be sent back to the country of origin should the aircraft not pass the inspection.

Exposure at Major South African Airshows:

Airshows are viewed as being major launch and marketing platforms for the sale of new aircraft as evidenced by the fact that leading companies in the industry time their product development to match the cycle of the aviation trade exhibitions in order to present their new products (termed premieres) and innovations. Airspire™, and its agents, will maintain an ongoing visible presence through the Experimental Aircraft Association (EAA) and other air shows held around the country during the course of the year. Interested customers will be identified at these air shows and will be followed up by the marketing agents. Upon definite interest by the customer, product presentations will be held at the customer's closest airfield. Depending on the interest of the customer, a demonstration flight will be performed on a route chosen by the customer.

The first major marketing event for Airspire™ will be the biannual African Aerospace and Defence Exhibition (AADE), to be held in September 2010 at the Ysterplaat Air Force Base, Cape Town. This is South Africa's **ONLY** international Aerospace Exhibition/Air Show, featuring aircraft from fighters to model aircraft from more than 400 exhibitors from over 30 countries. The show draws more than 22,000 professional trade visitors from Africa and beyond. The public days featuring some of the world's most advanced aircraft draw over 90,000 spectators. This exhibition is therefore an expanded showcase for local, regional and global exhibitors who supply civil, military and security products, systems, components and services to customers in Africa and around the world. Airspire™ will be represented with its own booth and its first aircraft.

Some further air shows already identified include the following:

- April – Margate air show (This Air Show is particularly popular amongst private pilots)
- May – Rand Airport Show (Gauteng's only Air Show)
- June – Klerksdorp (This is an EAA airshow, popular with private flyers)
- July – Durban Wings Club Air show
- August – African Bush Pilots Fly-In Barberton
- October – Mafikeng Airshow
- November – Overberg Fly-In, Bredasdorp

Direct Identification of Potential Clients through extensive Market Research activities:

Through Airspire™ market research conducted, potential customers - including private individuals, flight schools, and government organisations - have been identified including contact persons and information on the individual/organisation's specific travel needs. Marketing of aircraft generally does not generally proceed *via* direct marketing channels; however contact with specifically targeted customers will be initiated. These potential customers will be provided with a sales brochure, press reprints and customized information detailing the exact benefits for the customer's identified specific aviation needs. The sales brochure will also describe the product offer and the pricing. Depending on definite interest by the customer, product presentations will be held at the customer's closest airfield and a demonstration flight performed.

Associations with Aircraft Financing Companies:

Airspire™ will form associations with the relevant aircraft financing companies in South Africa. Examples include WesBank Aviation Finance, the aviation finance arm of WesBank which provides specialist aircraft finance solutions to the general aviation industry. The bank has entered into formal or informal arrangements with most of the respected suppliers of aircraft in South Africa. Aviation Finance Solutions (Pty) Ltd offers aviation financing expertise to all current and prospective aircraft

owners. Dennis Jankelow & Associates is an organisation providing an insurance programme for aircraft owners. This includes an in-depth technical inspection by an Aircraft Assessing Company of the aircraft to one of 5 predetermined levels. These strategic partnerships are hence an important component in the sales efforts.

4.5.3 Phase 2: Export Market:

Phase 2, export marketing outside of South Africa will begin in the second half of year 3 once the SkyWake™'s brand is established. Market penetration into the South African market sectors will be followed by extensive sales efforts in the export market, particularly the USA, UK, Canada, Australia and New Zealand. These markets have been identified as being those with the greatest growth potential, and hence ability to absorb new innovative products into the market. There is also potential in Africa for flight schools. Airspire™ will identify marketing agents in the selected countries through which the sales and marketing effort will be championed.

The annual US AirVenture Oshkosh air show organised by the US EAA is attended by more people and by more aircraft than any other air show in the world. More than 750,000 aviation enthusiasts including international visitors attend AirVenture annually. The air show also includes talks by influential people in aviation, as well as a large area with booths where aircraft, aircraft parts, aircraft services, and aircraft memorabilia are traded. The other major yearly air show organized by the EAA is "Sun 'n Fun", held in Florida. Both EAA airshows feature a LSA mall and showcase events highlighting new products and the unveiling of new aircraft. Sales and technical consultants attend to potential customers.

The annual US Sport Aviation Expo is held at the Sebring regional airport in Florida during January. In 2009 the event was deemed highly successful even though the US was in a financial recession. Many different LSA were showcased and sold.

In Europe, the two largest air and aerospace trade shows are the Farnborough Air Show (England), held in even years, and the Le Bourget Air Show (France), and held in odd years. In addition to displays for the general public, these two shows have important showcases and display halls for professionals. They are two of the few occasions when aerospace companies announce deals.

Aero Friedrichshafen is the largest European Sport Aviation show, being held in Germany during April. The event mimics the US Sport Aviation Expo.

Asian Aerospace, previously the third largest exhibition in the world, will be held in Hong Kong from 2008. The Singapore air show has taken place in Singapore since 2008. The air show, advertised to be Asia's largest air show, is held in February in even years, at a convention centre purpose-built for aviation and aerospace exhibitions.

4.6 Distribution Strategy

The location of Airspire™ in Somerset East, Eastern Cape is relatively close to Port Elizabeth such that potential customers can visit the manufacturing facility and observe SkyWake™ being assembled should they be interested.

The sales strategy involves using agents based at various small airports around South Africa. Aircraft will hence be delivered to the customers at these airports. Common practice is that most local customers will fly the aircraft themselves out of these airports. The aircraft is signed over to the owner at the agent's airfield. The owner then flies the aircraft home.

The aircraft would be flown to the agency's airfield directly from the manufacturing facility. Sales in Johannesburg would be made at Grand Central Airport, a small privately-owned airfield which is open to public air traffic. It is located in Midrand, halfway between Johannesburg and Pretoria in South Africa. Prior permission to land at Grand Central is not required for light aircraft pilots, a radio call is sufficient. Grand Central is a fully-equipped airfield and is open 24 hours a day. It is also the base of numerous flying schools for both fixed-wing aircraft and helicopters. There are 2 or 3 fixed base operators on the airfield which provides maintenance and repair facilities for light aircraft. This is a small airfield that is restricted to light aircraft only.

A van and trailer would also be available to transport an aircraft to an airfield for delivery. A team of at least 2 people would be required to transport the aircraft, put the wings on and complete a pre-delivery check (fuel, lights and control systems).

SkyWake™ has been designed to fit into a 6m container (tail off) for shipping. Shipping is normally an extra. Ferry or shipping would be an extra cost. Customers in Africa would either collect the aircraft from the factory or pay a ferry pilot to deliver the aircraft.

Distribution costs of 2.5% of turnover have been assumed, which will cover insurance for the transport of the aircraft and the cost of the ferry pilot.

4.7 Sales Forecast

The sales forecast is based on careful modelling of market potential on the one hand and an assessment of the company's sales capacity on the other hand. These projections are based on only those countries for which marketing information could be obtained.

The sales forecast is detailed in the table below with the first aircraft being sold in 2013. Market growth is assumed as follows:

- The South African NTCA production/amateur built market category: 15% per annum for 5 years (refer to section 3.2.2 followed by 10% per annum
- The South African microlight category: 2% (refer to section 3.2.2).
- US market: projections according to section 3.2.1 (FAA projections)
- United Kingdom: Market growth 2.5%
- Canada, Australia and New Zealand: Conservative market growth of 2% per annum

It is assumed that sales are split equally between the three different SkyWake™ models.

The table below outlines the sales forecast for the first 5 years of operation.

TABLE 12: SkyWake™ Sales Forecast

Year	2009	2010	2011	2012	2013		2014		2015		2016		2017		2018	
					1	2	1	2	1	2	1	2	1	2	1	2
TOTAL NUMBER OF AIRCRAFT REGISTERED (refer to section 3.2)																
South African Market																
Fixed Wing	1 944	2 571	2 957	3 400	3 655	3 910	4 203	4 497	4 834	5 171	5 430	5 688	5 973	6 257	6 570	6 883
Microlight	2 065	2 148	2 191	2 235	2 258	2 280	2 303	2 326	2 349	2 372	2 396	2 419	2 444	2 468	2 493	2 517
US	2 700	5 600	6 580	7 560	8 050	8 540	9 030	9 520	10 010	10 500	10 770	11 040	11 310	11 580	11 850	12 120
CANADA	4 674	4 908	5 153	5 411	5 546	5 681	5 823	5 965	6 114	6 264	6 420	6 577	6 741	6 906	7 078	7 251
United Kingdom	3 186	3 266	3 347	3 431	3 474	3 517	3 561	3 605	3 650	3 695	3 741	3 787	3 834	3 882	3 930	3 979
Australia/New Zealand	1 217	1 342	1 479	1 631	1 712	1 798	1 888	1 982	2 081	2 186	2 295	2 410	2 530	2 657	2 789	2 929
MARKET SHARE (refer to section 4.1)																
South Africa																
Fixed Wing					2.0%	3.5%	5.0%	8.0%	9.5%	11.0%	16.0%	17.0%	18.5%	20.0%	21.1%	22.2%
Microlight						5.0%	5.5%	5.9%	6.4%	6.8%	7.3%	7.5%	7.5%	7.5%	7.5%	7.5%
US										1.0%	1.2%	1.4%	1.7%	2.0%	2.0%	2.0%
CANADA												1.0%	1.2%	1.4%	1.7%	2.0%
United Kingdom																
Australia/NZ													1.0%	1.3%	1.7%	1.8%
NUMBER OF AIRCRAFT SOLD					**5**	**9**	**15**	**24**	**33**	**42**	**45**	**48**	**59**	**65**	**76**	**80**
South Africa																
Fixed Wing					5	8	14	23	32	37	41	43	52	56	66	69
Microlight						1	1	1	1	1	1	1	1	1	1	1
US										4	3	3	4	5	5	5
CANADA												1	1	2	2	3
United Kingdom																
Australia/NZ													1	1	2	2
CUMULATIVE NUMBER OF AIRCRAFT SOLD					**5**	**14**	**29**	**53**	**86**	**128**	**173**	**221**	**280**	**345**	**421**	**501**

5 DESIGN AND CERTIFICATION OF SKYWAKE™

As discussed above, the design, manufacture, approval, and maintenance of NTCA aircraft are controlled and enforced by the SACAA through rules and regulations contained in the Civil Aviation Regulations (CARs) of 1997. With the growth of the NTCA sector, along with international trends, the SACAA has developed regulatory provisions in order to properly control and regulate this class of aircraft. The CARs control certification and airworthiness, operation and the commercial use of NTCAs. In addition, separate parts of the CARs (applicable to both NTCAs and type certified aircraft) control the design of all products, parts and appliances as well as the licensing of design, manufacturing, and maintenance organisations.

The plan for the industrialisation of the business is thus largely dictated by the need to comply with the regulatory environment. Of importance are those NTCA regulations that pertain specifically to production-built aircraft i.e. aircraft of which the prototype has been constructed and approved in terms of SACAA regulations for the issue of a certificate of airworthiness and which are made available either fully-assembled or in kit form.

The relevant parts are:

Part 24 - *Airworthiness Standards: NTCA Aircraft*

This Part was signed by the Minister for promulgation in July 2007. The airworthiness, aircraft documentation, maintenance, inspection and type approval processes are described within the Part.

Part 147 - *Design Organisations* for Products, Parts and Appliances.

The Design Organisation (DO), to be established by WE, will be established in compliance with this Part. SkyWake™ will form the first NTCA prototype to obtain a certificate to fly through this DO and will hence form the platform through which the DO obtains its certification.

Part 148 - *Manufacturing Organisations*

This Part applies to the approval and operation of manufacturing organisations (MO) that manufacture specified products, parts or appliances; (apply specified processes to products, parts or appliances; or carry out specified tests on products, parts or appliances.

In order to produce a production aircraft with a Type Holder Certificate (THC) from the SACAA both the DO and MO need to obtain approval from the SACAA. Two points are notable in this regard:

(1) An organisation may only obtain DO Status (approval) from the SACAA if, in conjunction with its application for a DO licence, it approaches the SACAA with a design with the intention of obtaining a THC.

(2) Any components produced for the aircraft must be produced by an MO, where the design of the component must have been produced by a DO.

The intent is to obtain SACAA certification of Airspire™ as a Manufacturing Organisation. In terms of NTCA regulations, Airspire™ will be required to contract with a DO in order to obtain type certification for its prototype aircraft, SkyWake™, and to facilitate the mass production of SkyWake™. The responsibilities of the DO in terms of the commercialisation of SkyWake™ are as follows:

1. To obtain the type holder certificate (THC) of airworthiness for SkyWake™.
2. To construct and test the prototype of SkyWake™.
3. To conduct a successful flight test programme.
4. To deliver a design for mass production.
5. To deliver the implementation plan for production.

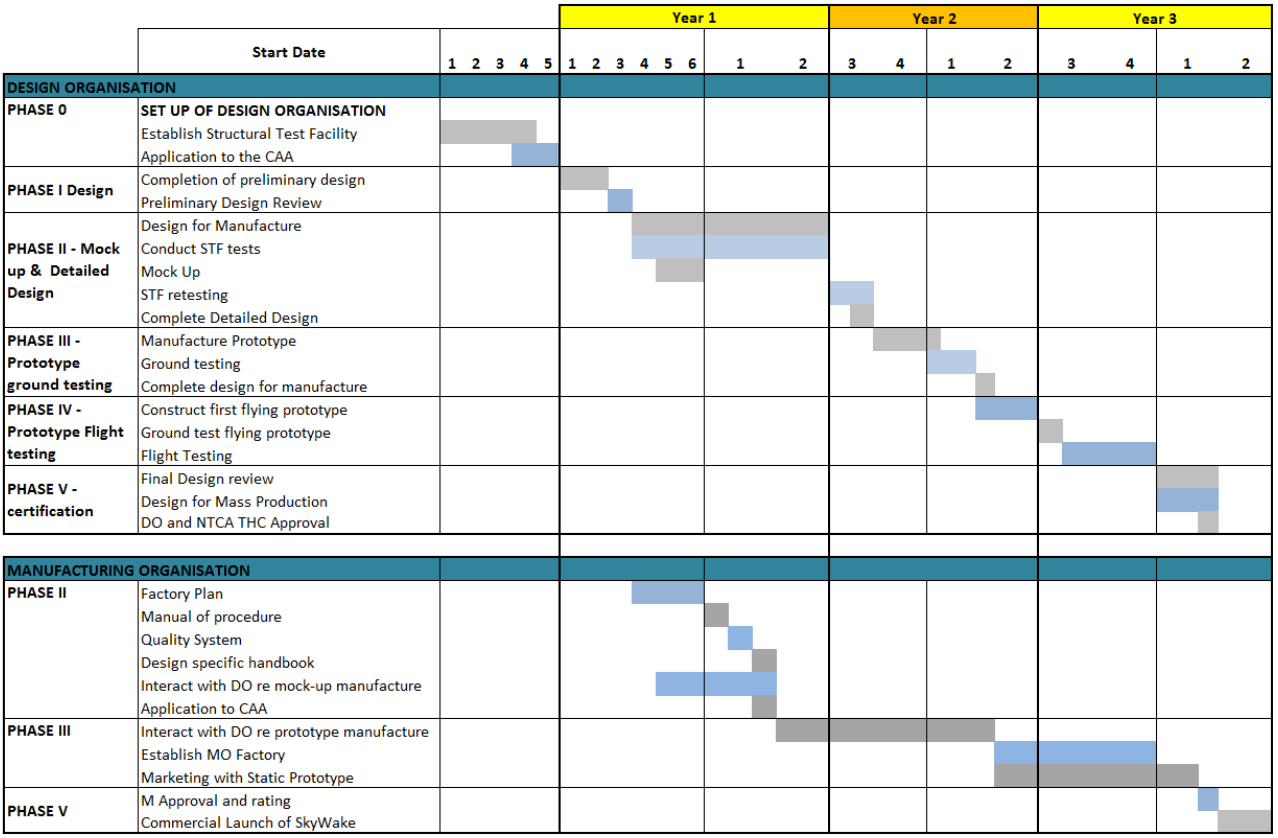
[Full details as to the establishment of the DO, including a summary of the regulatory requirements for its accreditation form the subject of a separate proposal.]

The establishment and commercialisation of Airspire™ is outlined in the figure below and will be conducted in 5 phases over a total time period of 36 months. [A more detailed project plan indicating the activities to be completed in this regard is attached as Appendix 3].

TABLE 13: Project Plan Time Table

Phase		Time	Start Date	End Date
I.	Conceptual/Detailed Design	3 months	1 January 2010	31 March 2010
II.	Mock-up and detailed design	9 months	1 April 2010	31 December 2010
III.	Prototype and Ground Testing	10 months	1 January 2011	31 October 2011
IV.	Prototype and Flight Testing	9 months	1 October 2011	30 June 2012
V.	Certification	3 months	1 July 2012	30 September 2012
VI.	Launch of SkyWake™		September 2012	

FIGURE 7: Implementation of Airspire™ (Pty) Ltd and the Manufacture and Marketing of SkyWake™



5.1 Phase I: Design of a New Light Sport Aircraft

5.1.1 Completion of the Preliminary Design

The user requirements of a LSA for the South African market based on the potential customers, regulations and current constraints have been defined. The specification of the aircraft i.e. performance goals, geometry and engine, performance and handling characteristics have been established. The possible concepts have been identified and a preferred concept for development has been selected.

Preliminary Design

- Refined sizing of preferred concept to increase performance/reduce weight
- Design examined/establish confidence
- Update embedded technology
- Initial cost estimates

This activity will be completed by the DO under contract by Airspire™.

5.2 Phase II: Mock up and Detailed Design

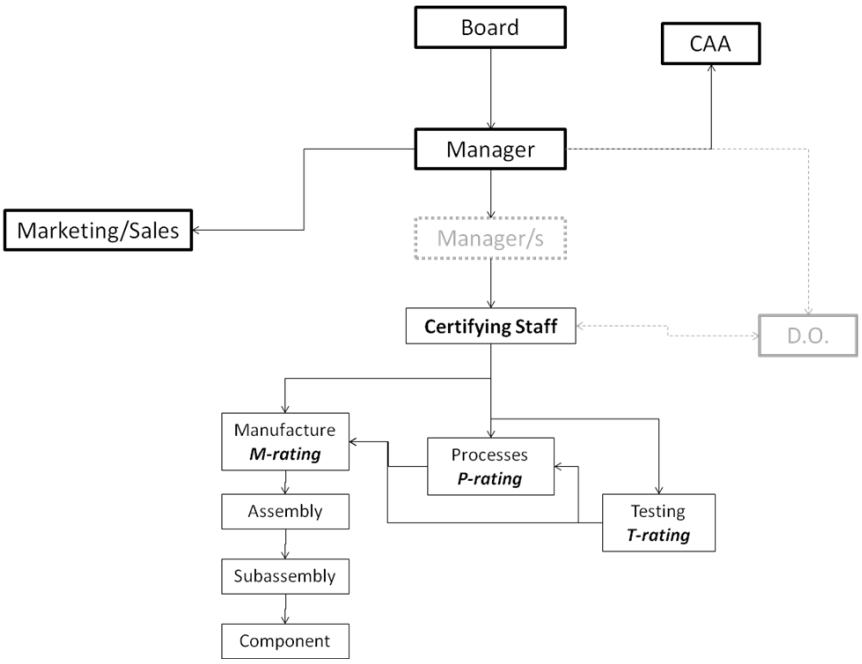
5.2.1 Application to Civil Aviation Authority:

The SACAA regulations state that in order to build and fly aircraft in South Africa, both the type of aircraft and the Manufacturing Organisation must be approved by the SACAA. Under the terms of these regulations (part CAR Part 148), Airspire™ will apply for a manufacturing ("M") rating which qualifies it for the manufacture of specified products, parts or appliances. The requirements for the MO are:

- The organisation structure is prescribed and includes a layered management structure (as per Figure 11 below).
  - The upper management tier is accountable to the commissioner of the SACAA.
  - The lower management tier is responsible for the certification of each component manufactured, processed or tested.
- The MO must produce two specific documents according to the SA-CATS-MORG (South African Civil Aviation Technical Standards for Manufacturing Organisations)
  - A Manual of Procedure (MOP) which requires the company to demonstrate that it has the facilities, working conditions, equipment and tools, processes and associated materials, personnel numbers and competence, in order to fulfill its responsibilities.
  - A Quality Control (QC) system which outlines how the organisation will ensure that each completed aircraft conforms to the approved design data and is in condition for safe operation for the issuing of authorised release certificates to certify airworthiness or conformity.
- The MO must ultimately be in receipt of all approved data from the DO to determine conformity with the applicable design data; and have a procedure to ensure that approved data is correctly incorporated in its production process.
- The MO must be able to conduct structural tests of completed assemblies and must be sufficiently staffed with manufacturing and certification staff with adequate management to competently perform actions described in SA-CATS-MORG.

A MO approval is issued for an unlimited duration. It remains valid unless the company fails to demonstrate compliance with the applicable requirements or there is evidence that the company cannot maintain satisfactory control of the manufacture or that it no longer meets the requirements of the CARs.

FIGURE 8: Organogram of Manufacturing Organisation according to SACAA regulations



5.2.2 Performance, handling and strength tests:

These tests must be conducted in compliance with the provisions of SA-CATS-NTCA. These aspects of the certification process will be performed by the Structural Test Facility (STF) to be established by Wits University.

The following tests will be performed by the STF in terms of the regulatory process for the approval of a new prototype production built aircraft such as SkyWake™:

1. Proof of engineering design analysis:
   (i) The design criteria basis in terms of which the aircraft must:
   - Be able to withstand the maximum loads (static test programme) to be expected.
   - Withstand ultimate (limit) loads multiplied by a specified safety factor.
   - Have no unsatisfactory features of design and construction.
   - Use approved aircraft components (where possible).
   - Undergo a test sequence of the complete power plant installation.

   (ii) A schedule of how compliance with the design criteria basis is proposed;
   (iii) A predicted performance analysis prior to commencing of proving flights;
   (iv) An aerodynamic analysis appropriate to the type of aircraft;
   (v) A structural analysis appropriate to the type of aircraft; and
   (vi) An analysis of the power plant/s and of the systems appropriate to the type of aircraft.
2. The empty mass of the aircraft (including the mass of equipment and instruments necessary for the safe operation of the aircraft) and its centre of gravity must be determined.
3. Static tests must be carried out before the aircraft's first flight and be witnessed by a designated airworthiness representative. The primary aircraft structure shall be tested to the limit loads for which the aircraft will be registered.

5.2.3 Completion of Detailed Design:

The next step to be completed in order to obtain a complete detailed design of the chosen aircraft, both structurally and aerodynamically, are as follows.

– Drawings released
– Only minor modifications
– Final cost estimates

5.3 Phase III: Prototype and Ground Testing

5.3.1 Manufacture of Prototype Aircraft:

An application must be made to the SACAA for a build number before the construction of the prototype can commence. The application must be accompanied by a copy of the design criteria for the aircraft as prescribed in SA-CATS-NTCA.

The aircraft must be manufactured by an organization approved, or which will be applying for approval, by the Commissioner in compliance with the provisions in terms of SA-CATS-NTCA. At various stages of construction, the aircraft shall be inspected by an Approved Person (AP) with the appropriate inspection rating for the type of aircraft, in order to prevent the possibility of undesirable features. When the aircraft is completely assembled, with engine, essential instruments and equipment in place, the aircraft shall again be made available for inspection by the AP.

5.4 Phase IV: Prototype and Flight Testing

5.4.1 Certificate of Airworthiness:

An application must be submitted for a “Proving Flight Authority” which includes the submission of the complete build standard of the prototype - a package defining the dimensions, materials and processes used in the construction of the aircraft - together with associated documents showing that the design complies with established design criteria.

A minimum of 40 hours of flight time is required, with an appropriately rated test pilot carrying out the final flight test on the aircraft. The SACAA may also require the aircraft to be inspected by an authorised person.

During the period of validity of the Proving Flight Authority, normally a maximum of six months, the manufacturer may make modifications and repairs as required. However, should a major modification or repair be required, certain proving flights may need to be repeated.

An Authority to Fly follows successful completion of the proving flights.

5.5 Phase V: Type Holder Certification

5.5.1 Engineering Design for Mass Production:

After successful completion of the proving flights with the prototype and based on the results of these flights, the engineering design for mass production shall include the following:

1. Recorded, validated performance and aerodynamic analysis for complete flight and mass envelope.
2. Recorded, validated and detailed structural analysis.
3. Validated and detailed production status engineering design for each part, component and assembly of the aircraft.
4. Recorded, validated and proven power plant and systems analysis for the production status power plant/s and systems.

5.5.2 Issue of Type Holder Certificate:

In summary, following completion of the above process, the following documentation must be provided by the MO to the SACAA:

1. Proof of compliance with the outlined technical standards.
2. A copy of the Authority to Fly issued for the prototype aircraft.
3. Proof that the applicant has been or may be approved as a MO and that the aircraft will be manufactured according to the approved build standard.

Following the successful provision of this documentation, the applicant will be issued with a production-built NTCA type certificate as prescribed in Document SA-CATS-NTCA.

6 ESTABLISHMENT of AIRSPIRE™ – MANUFACTURING ORGANISATION

6.1 Location

The production facility and the company headquarters will be located at Somerset East Airfield in the Eastern Cape. The facility will handle the production of SkyWake™, including final assembly of all structural components and parts, aircraft system assembly and installation, completion of the interior, and painting.

6.2 Regulatory Compliance

Section 5.3.2 above outlines the requirements for Airspire™ to comply with SACAA regulations for a Manufacturing ("M") rating

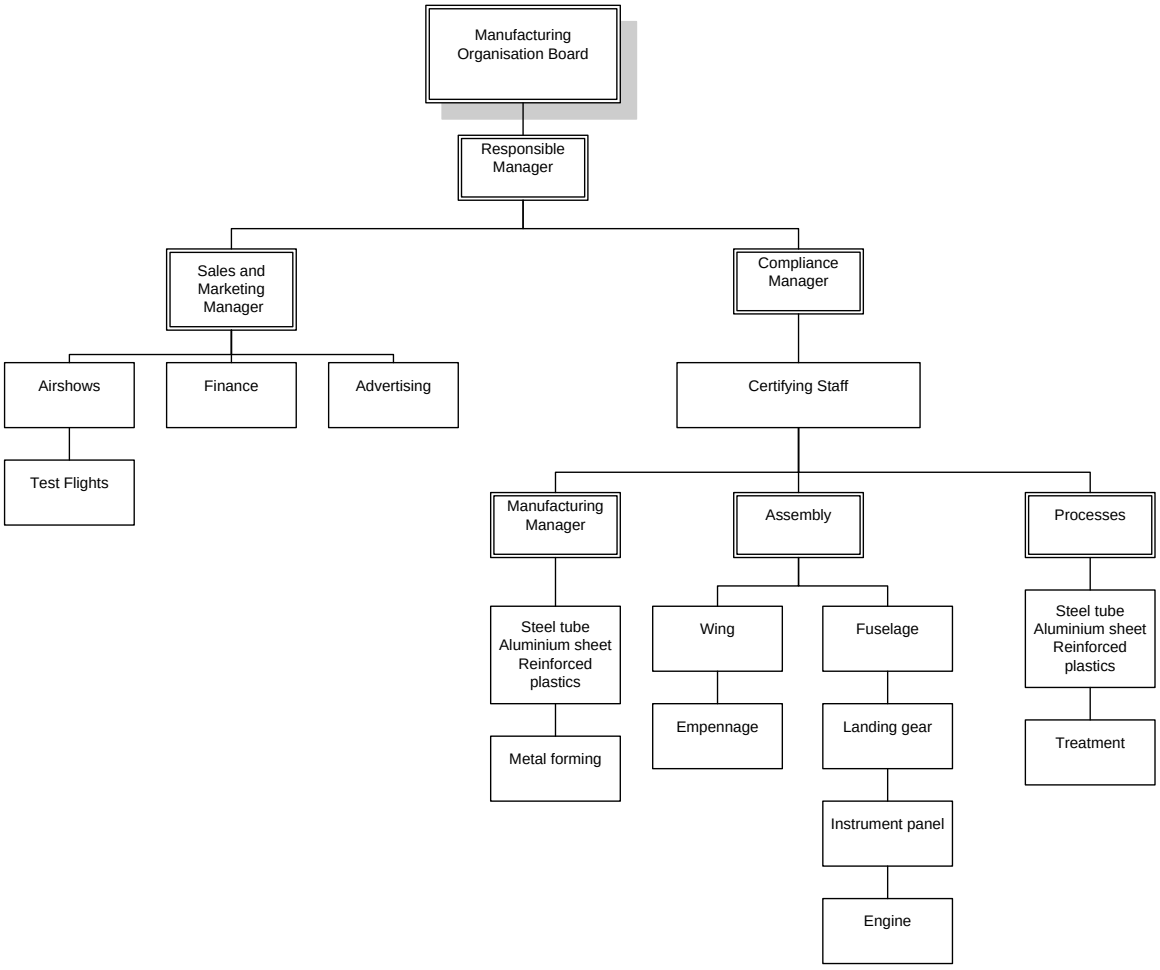
6.3 Insurance Coverage

Insurance is currently being discussed during the drawing up of the license agreement between Wits Enterprise (Pty) Ltd and the Blue Crane Development Agency for the commercialisation of SkyWake™.

6.4 Organisational Structure

The structure of the MO is as illustrated in the diagram below. The dotted lines illustrate the personnel that will interact with the DO.

FIGURE 9: Organogram of Airspire™



The manufacturing organisation, according to Part 148 of the CARs must have the following personnel:

1) ***Responsible Manager***, accountable to the Commissioner, with overall responsibility within the organisation to ensure that all production is performed to the required standards and that the production organisation is continuously in compliance with the data and procedures identified in the manual of procedures. This person will be the company CEO. It is essential that the CEO has both a technical grasp of the industry as well as business expertise. Ideally, the main attribute for this position is a pilot with technical knowledge and business background.
2) A ***Compliance Manager*** nominated to ensure that the organisation is in compliance with the CARs and who has been identified together with the extent of their authority. In this respect, such person or persons must be directly responsible to the manager identified above. This person can be trained by Wits University with regard to all the relevant technical details. An engineering degree or technical diploma would be required as well as previous experience in manufacturing technology, quality control and non-destructive testing.
3) ***Certifying Staff***, defined as those personnel who are authorized by the manufacturing organisation to sign the documents issued under the scope or terms of its approval. The knowledge, background (including other functions in the organisation), and experience of the certifying staff shall be appropriate to discharge their allocated responsibilities. This person can be trained by Wits University with regard to all the relevant technical details. An engineering degree or technical diploma would be required as well as previous experience in manufacturing technology, quality control and non-destructive testing.

6.5 Design of Manufacturing Facility

The manufacturing facility for SkyWake™ will be designed according to the following requirements, constraints and criteria.

Requirements:

- The facility must be able to handle 2 – 8 aircraft per month whilst still catering for customisable aspects of the aircraft.
- The facility will be equipped with facilities to be able to deal with customised interiors and paint finishes.
- The speed of the build – lead time will be on par, if not less than average of competing aircraft manufacturers.
- The quality of finish will not be compromised even when production is at the maximum.
- The cost will be kept to a minimum in order to make it competitively priced.

Criteria:

- The facility will be as automated as possible to ensure consistency in manufacturing.
- The number of skilled labourers will minimised, whilst ensuring that there are enough skilled employees to make the process of constructing and fabricating as efficient as possible without sacrificing build quality of the aircraft.
- The facility will be made as efficient as possible at a reasonable cost.
- All manufacturing operations and waste disposal operations will be as clean and as environmentally friendly as possible.
- Provisions for manufacturing facility growth are to be considered if the demand for the aircraft increases. This will also incorporate the expansion of the product range to other items e.g. ballistic parachutes.

In 2008 the design of a manufacturing facility for a LSA aircraft as envisaged in this business plan was undertaken and updated in 2009[16]. Following a literature study to obtain an understanding of the design and layout of a LSA manufacturing facility, different layouts of existing and conceptual LSA manufacturers were

16 Alberto Cipolat under supervision by Professor DR Snaddon and Mr MF Boer, MECN4006 – Research Project: Facility to manufacture a Light Sport Aircraft.

analysed. SkyWake™'s assembly sequence, together with metal forming and other major operations which govern the requirements for machinery, moulds, and equipment for the facility, was then determined. The most suitable layout was selected according to the criteria outlined above.

Assembly lines are used for manufacturing, each consisting of a sequence of production steps. There are six major sub-assemblies: 1) fuselage/body, 2) tail assembly, 3) wings, 4) landing gear assemblies, 5) power plant, and 6) flight control systems/instruments. A series of floor assembly jigs will be used to hold, support, and locate the individual work pieces or sub-assemblies until they can be riveted, bonded, or bolted in place. Some jigs are permanently installed, while others are on rollers so they can be moved to the assembly line when needed at a pace determined by the production rate. Specific features of the chosen design for SkyWake™'s manufacturing facility are:

- A cellular layout wherein each cell is equipped with the machinery and tooling that will allow it to perform a specific set of processes allowing for a more compact and less wasteful system.
- The empennage assembly area and wing, flap and aileron assembly area are side by side as the components being assembled in these 2 areas follow a similar sequence. Thus, when production rates are low, one of these areas can manufacture all of these components, hence decreasing labour costs.
- The composites and plastics cells, as well as the engine cell are located close to an exterior wall, allowing for adequate ventilation.

6.6 Capital Cost

The capital cost of the facility, excluding the building itself, is estimated to be in the order of R 1.779 million as outlined in the table below. The overall area of the manufacturing facility required is approximately 900 m^2. This accommodates a production rate of up to eight aircraft per month.

TABLE 14: Machinery Costs

	Quantity	Cost/Unit[17]	Cost
EQUIPMENT			
Press Brake	1	406,798	406,798
Tube Profiling Machine	1	450,000	450,000
Horizontal Band Saw	1	250,000	250,000
Paint Booth and Mixing room	1	324,900	324,900
Hydraulic Press	1	250,000	250,000
Hand Drill	5	2,548	12,743
Rivet Hammer	4	2,164	8,656
Welding Equipment	1	11,950	11,950
MOULDS	4	**6,250**	**25,000**
WORK AREAS			**20,000**
HEAVY LIFTING/TRANSPORT			**4,104**
Engine Crane	2	2,052	**4,014**
Trolley (for fuselage)	3	**1,250**	**3,750**
TOTAL COST			**1,779,761**

A value for the facility has as yet not been determined as this is dependent on factors such as location and size of the entire facility (not just of the manufacturing section).

17 Exchange Rates: 1 Euro = R 11.86 and 1 US Dollar = 8.17

A second manufacturing facility, to produce an additional 96 aircraft per annum, will be constructed in Year 6 (2017) as the sales volumes are projected to reach maximum capacity.

6.7 Labour Requirements of the Manufacturing Facility

Although the industry assembles a complex and high-tech product, its assembly process is relatively labour intensive. Production of aircraft is carried out at relatively low rates relative to most manufacturing industries. Furthermore, a large proportion of an aircraft is hand-made due to the fact that manufacturers are cautious about the expensive damage that could be caused by a malfunctioning machine.[18]

The production process requires expertise in reading blueprints, proficiency in the use of several different tools, and the ability to anticipate and solve various assembly problems to meet demanding technical standards. Many employees are thus involved in managing and inspecting the process. For these personnel, well-developed technical skills are essential. In addition, many more technical non-production workers are required. Overall, staff required to manufacture SkyWake™ will comprise precision production, craft, and repair workers, professional and technical workers as well as less skilled jobs such as operators, fabricators, and general labourers.

Labour costs have been estimated based on values for less skilled, through to highly skilled workers. The most specialised workers (e.g. welder, paint booth operator and specialised machinery operators) are paid the most. The table below displays the estimated labour costs for the facility based on the assumption that it operates 8 hours a day and 5 days per week producing a maximum of 8 aircraft monthly.

TABLE 15: Number of Operators and Labour Costs at Full Capacity (8 aircraft per month)

Cell	Operator Task	Operators	Rate (R/Hour)[19]	Daily Cost
Space Frame Construction	Crash boom, tail boom & engine mounting cradle welding	2	100	1,600
Metal Preparation	Press	1	25	200
	Tube cutting and profiling	1	70	560
Stores	Receive, record, pack, handout materials	1	20	160
GFRP	Moulding	1	25	200
ABS plastic	Forming	1	25	200
Engine	Filling, connecting, testing	1	80	640
Inspection bays 1 & 2	Inspect components & sub-assemblies	1	25	200
Paint booth	Masking, priming and painting	1	50	400
Instrument panel	Instrument unpacking, preparing, instrument panel assembly & testing	2	25	400
Skin covering	Drilling, installing of components & securing skin	2	25	400
Wing, aileron & flap	Assembly	2	25	400
Empennage	Assembly	1	25	200
Primary Assembly	Assemble sub-components	2	25	400
Total		**19**		**5,960**
MONTHLY TOTAL				**119,200**

18 Productivity in aircraft manufacturing: Monthly Labour Review, June, 1993 by Alexander Kronemer, J. Edwin Henneberger

19 Labour rates based on an interview held by A. Cipolat with M Bandini (September 2008)

7 BUDGET

The budget below is in South African Rands over a three year period which will deliver a flying prototype with certificated structure.

Manhour Costs/Salaries:

Salary component budgeted for the team of part-time design engineers required during the incubation of the Design Organisation. The design team comprises 7 postgraduates working. An allocation has also been made for student stipends. The experience gained will improve skills. An advisory panel of experts will review the project monthly, providing advice and feedback as necessary.

Prototype Costs:

Raw materials would be required at the commencement of the project, with decreasing demand for new material during the second year. The material includes all metal, composites, electrical, electronic sub-assemblies and interior equipment. Several sets of full flight instruments would be required for the prototype, flight simulator and certification equipment. An engine will be required during each year for ground testing, airframe testing and for the prototype. The budgeted amount includes all auxiliary equipment, propeller, battery and engine silencer. Four high-specification computers will be purchased during the first year, regular maintenance and minor upgrades are accounted for in year two. Fuel will be required for ground testing and flight testing. The fuel allowance includes all fluids required for engine use, including oil and anti-corrosion products. Machinery will be required during the first year for production of various components; less machinery will be required during the following year, as production processes are finalised. The larger assemblies will be manufactured under contract by suitably accredited manufacturers

Running and Other Costs:

Additional office space for the design team will be leased from the SMIA for the duration of the project and until the company moves into the offices at the Manufacturing Facility. Other costs encompass expenses associated with patent, trademark and design registration, drafting of contracts and agreements, legal fees, and overhead costs (as per the University's external work policy guidelines). The project management and administration will be handled by the project leader in conjunction with Wits Enterprise.

Testing Costs:

Wind tunnel tests would be carried out using the School's low-speed tunnels and equipment. The tunnel results would be used to confirm flight test results and used to enhance the design. Results from Finite Element Analysis (FEA) for structural analysis and Computational Fluid dynamics (CFD) for aerodynamic analysis are required prior to certification.

Commercialisation Costs:

The marketing strategy would only be commenced once construction of the prototype is completed, and flight testing initiated. A company CEO will be recruited in April 2012. A budget allocation has been made for marketing and commercialisation activities – these include consultant costs, travel, web-site development, literature and brochure printing, mailing campaigns, establishment of linkages with market players, building of awareness of the project's outputs and maintaining an awareness of the market (attendance of Air Shows, procurement of market surveys etc.).

7.1 Phase I: Design of SkyWake™

TABLE 16: Budget for Phase I: Design of a new Light Sport Aircraft

Rands (nominal – inflation 8% per annum)	**2010**	**2011**	**2012**
Manhours			
Design of New Light Sport Aircraft	193 882		
Preliminary Design Review	69 854		
Other Costs			
Travel	8 640		
Printing	2 592		
Phone	7 776		
Stationary	1 890		
Logistics	2 970		
Rental	45 360		
Patent expenses	270 000		
Project management	75 807		
	678 771	**0**	**0**

7.2 Phase II: Mock-up and Detailed Design

TABLE 17: Budget for Phase II: Mock-up and Detailed Design

Rands (nominal – inflation 8% per annum)	**2 010**	**2 011**	**2 012**
Manhours			
Application to the Civil Aviation Authorities	25 091		
Utilisation of the Structural Test Facility	1 154 531		
Design for Manufacture	210 719	227 576	
Other Costs			
Travel	8 640	9 331	
Printing	2 592	2 799	
Phone	7 776	8 398	
Stationary	1 890	2 041	
Logistics	2 970	3 208	
Rental	45 360	48 989	
Patent expenses	270 000	174 960	
Project management	75 807	63 370	
	1 805 375	**540 672**	**0**

7.3 Phase III: Prototype and Ground Testing

TABLE 18: Budget for Phase III: Ground Testing

Rands (nominal – inflation 8% per annum)	**2 010**	**2 011**	**2 012**
Manhours			
Phase 3 - Prototype and ground testing		155 551	
Other Costs			
Prototype		816 480	

Rands (nominal – inflation 8% per annum)	**2 010**	**2 011**	**2 012**
Engine		116 640	
Fuel		34 642	
Wind Tunnel testing		5 832	
Machinery		58 320	
Computational Fluid Dynamics		34 992	
Apparatus		116 640	
Finite Element Modelling		34 992	
Travel		9 331	
Printing		2 799	
Phone		8 398	
Stationary		2 041	
Logistics		3 208	
Rental		48 989	
Patent expenses		174 960	
Project management		63 370	
		1 689 452	

7.4 Phase IV: Prototype and Flight Testing

TABLE 19: Budget for Phase IV: Flight Testing

Rands (nominal – inflation 8% per annum)	**2 010**	**2 011**	**2 012**
Manhours			
Prototype and Flight testing			249 524
Other Costs			
Prototype			881 798
Engine			125 971
Fuel			34 642
Consultant Costs			62 986
Certification			251 942
Insurance			535 378
Travel			10 078
Printing			3 023
Phone			9 070
Stationary			2 204
Logistics			3 464
Rental			52 908
Project management			86 333
		0	**2 309 322**

7.5 Phase V: Type Holder Certification

TABLE 20: Budget for Phase V: Certification

Rands (nominal – inflation 8% per annum)	**2 010**	**2 011**	**2 012**
Manhours			
Design review and certification			192 056
Other Costs			
Travel			10 078
Printing			3 023
Phone			9 070
Stationary			2 204
Logistics			3 464
Rental			52 908
Project management			81 113
	0	**0**	**353 916**

7.6 Phase VI: Launch of SkyWake™

TABLE 21: Launch of SkyWake™

	2010	**2011**	**2012**
Travel			22 675
Exhibitions / shows etc.			125 971
Market development /research			50 388
Web-site development			62 986
Recruitment Costs			75 583
Printing and literature costs			100 777
Office set up costs			
Furniture			151 165
Laptops and computers			75 583
Software			37 791
TOTAL BUDGET			**680 244**

7.7 Total Budget

TABLE 22: Total Implementation Budget for Development and Launch of SkyWake™ - a new Light Sport Aircraft

	2009	**2010**	**2011**	**2012**
Phase I: Preliminary Design	Set up of Design Organisation – No cost to Airspire™	678 771	0	0
Phase II: Mock up and Final Design		1 805 375	545 505	0
Phase III: Ground Testing			1 689 452	0
Phase IV: Flight Testing			0	2 304 102
Phase V: NTCA and MO Certification		0	0	353 916
Phase VI: Launch				680 244
TOTAL BUDGET		**2 484 147**	**2 234 958**	**3 338 263**

TOTAL BUDGET (including inflation): R 8.057 million

8 FINANCIAL PLAN

The following Financial Statements are attached as appendices:

APPENDIX 4: Cash Flow Statement
APPENDIX 5: Income Statement
APPENDIX 6: Balance Sheet
APPENDIX 7: Discount Cash Flow

8.1 Product Costing

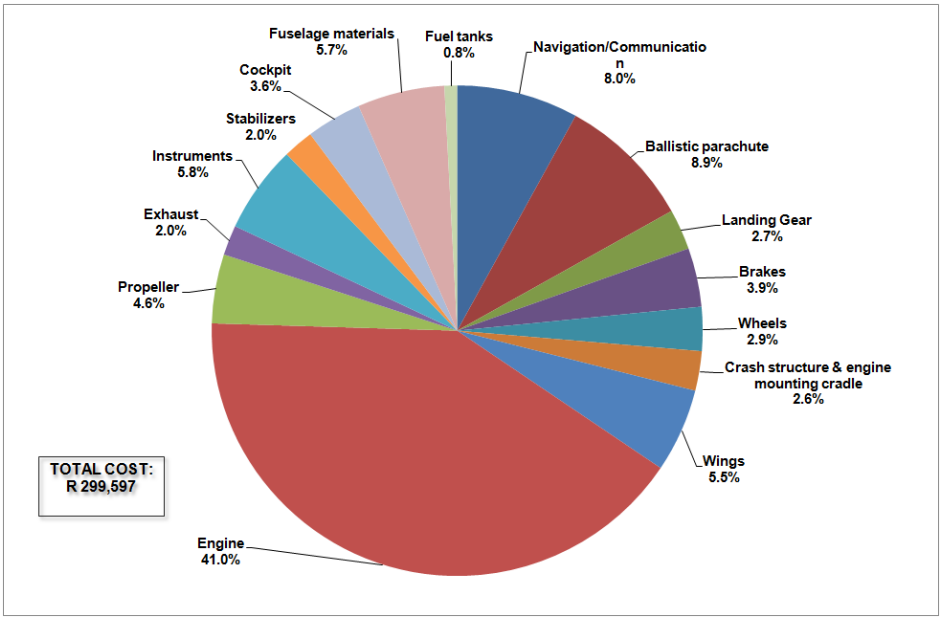
8.1.1 Variable Costs:

The design project completed in 2008 by a student in the Wits SMIA determined a very basic bill of raw materials and costing for the manufacture of the LSA. The variable cost of manufacture, as currently determined, of the SkyWake™ middle of the range aircraft with Jabiru 3300 engine and with navigation system is R 310,816 (see table below). The Rotax 912S engine costs R 167,000 hence putting the top of the range variable cost at R 343,816. The entry level cost of manufacture without a glass-cockpit instrument system is R 286,816. The engine contributes between 40.7 – 46.1% of the variable cost of manufacture of the aircraft. Both engines are currently imported. Overall, between 73 – 79% of the variable cost of the aircraft models are imported.

TABLE 23: Gross Margins for SkyWake™ Range of Aircraft

	Entry Level	Mid Range	Top of Range
Sales Price	520,000	550,000	600,000
Variable Cost	275,597	299 597	329 597
Gross Margin	244 403	250 403	270 403
Gross Margin %	45.1%	45.5%	47.0%
Imported Component	79%	73%	75%

FIGURE 10: Breakdown of Variable Cost of Manufacture of SkyWake™ "Mid Range" Aircraft



It is estimated that the variable cost of manufacture can be reduced by at least 15% as economies of scale in production are reached. The costs of individual raw material components can be reduced due to bulk purchasing.

TABLE 24: Variable Cost of Production for SkyWake™ (middle of the range)

Total		US $	SA Rands
Instruments		**$5 901**	**41 310**
Engine	Oil pressure	$272	1 905
	Oil Temperature	$63	443
	Ammeter	$29	201
	Tachometer	$177	1 239
Flight Instruments	Altimeter	$414	2 897
	Air Speed indicator	$139	974
	Artificial horizon	$519	3 636
	Direction indicator	$489	3 423
	Vertical speed indicator	$223	1 561
	Compass	$83	581
	Slip indicator	$64	450
Navigation/Communication		$3 429	24 000
Fuselage		**$13 328**	**93 295**
Cockpit	Seatbelts	$83	580
	Seats	$286	2 000
	Fire extinguisher	$90	630
	First aid kit	$29	200
Ballistic parachute		$3 800	26 600
Lighting		$1 070	7 490
Fuel tanks		$357	2 500
Landing gear	Gear	$1 143	8 000
	Brakes	$1 659	11 615
	Wheels	$1 098	7 685
	Spats	$143	1 000
Material costs	Crash structure and engine mounting cradle	$1 113	7 792
	Tail Boom	$483	3 384
	Fuselage skin	$446	3 119
	Cowling, doors	$600	4 200
	Windows and Windscreen	$214	1 500
	Fitting	$714	5 000
Wing		**$2 362**	**16 535**
Material costs	Struts (Streamline Tubing)	$763	5 341
	Wings	$1 385	9 694
	Fillets and Wingtips	$214	1 500
Stabilisers		**$858**	**6 003**
Material costs	Vertical Stabilizer	$344	2 410
Material costs	Horizontal Tail	$513	3 593
Engine		**$20 351**	**142 455**
Engine	Jabiru J3300	$17 403	121 818
	Propeller	$1 948	13 636
	Exhaust	$844	5 909
	Battery	$156	1 091
GRAND TOTAL		**$42 800**	**299 597**

8.1.2 Fixed Costs

Fixed costs include the following:

- **Labour:**
  - Chief Executive Officer: R 650,000 per annum
  - Compliance Officer: R 400,000
  - Certification Manager: R 350,000
  - Marketing Manager: R 450,000
  - Personal Assistant: R 150,000 per annum
  - Bookkeeper (part-time): R 200,000 per annum
  - Direct labour (See 5.4.3 above): R 119,200 per annum per 96 aircraft produced)
- **Agency Fee:** 10% of turnover annually
- **Insurance Costs**: 3% of turnover annually
- **Maintenance on Plant & Equipment**: 1.5% of net asset value
- **Distribution Costs:** 2.0% on turnover annually.
- **Rental:** R 55/m^2 per annum. First facility of 900m^2 and second facility after 5 years a further 900m^2.
- **General Admin costs:** R 39,000 per month

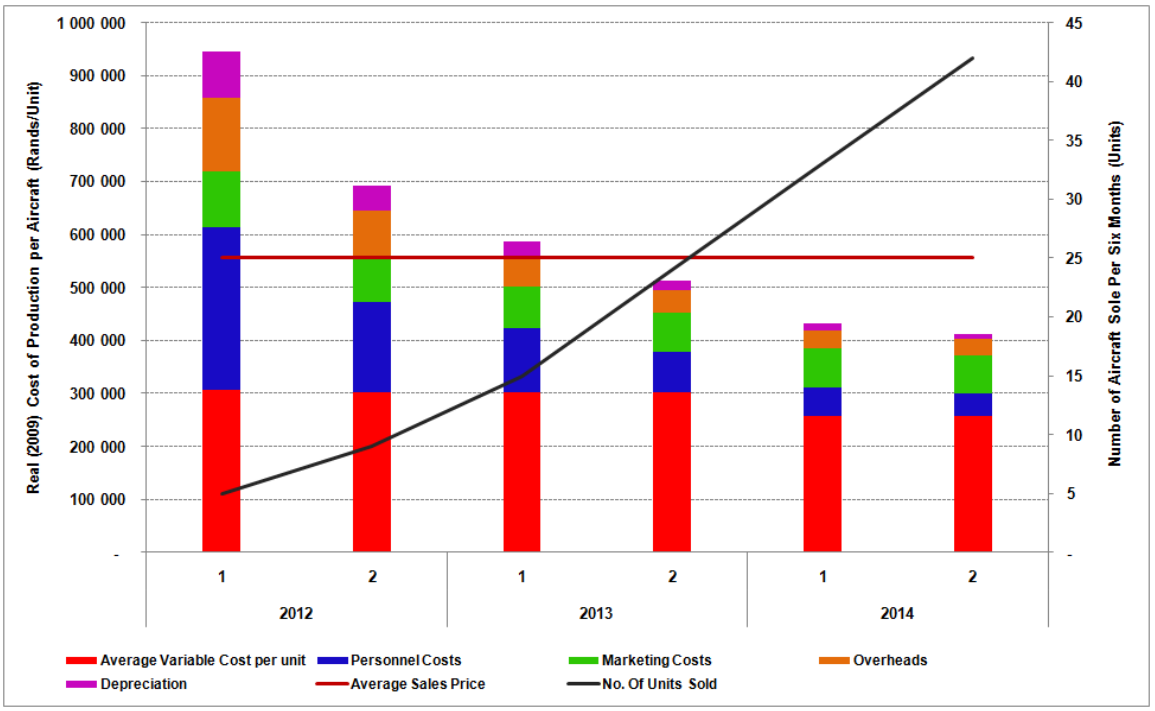
Admin consumables	7 200
Audit fee	40 000
Bank Charges	9 600
Cleaning materials	6 000
Electricity	150 000
IT and Support	36 000
Legal Fees	18 000
Office repairs and maintenance	15 000
Printing	18 000
Postage and courier fees	18 000
Staff training	60 000
Subscriptions	6 000
Telecommunications	84 000
TOTAL	**467,800**

- **Marketing Costs**:
  - Local and international travel: R 20,000 per month
  - Advertising and entertainment: R 30,000 per month
  - Shows and exhibitions: R 120,000 per annum
- **Depreciation:** Straight line over 10 years on aircraft provided for marketing purposes. The development costs of the prototype are also capitalised and depreciated over 10 years.

8.2 Cost of Production

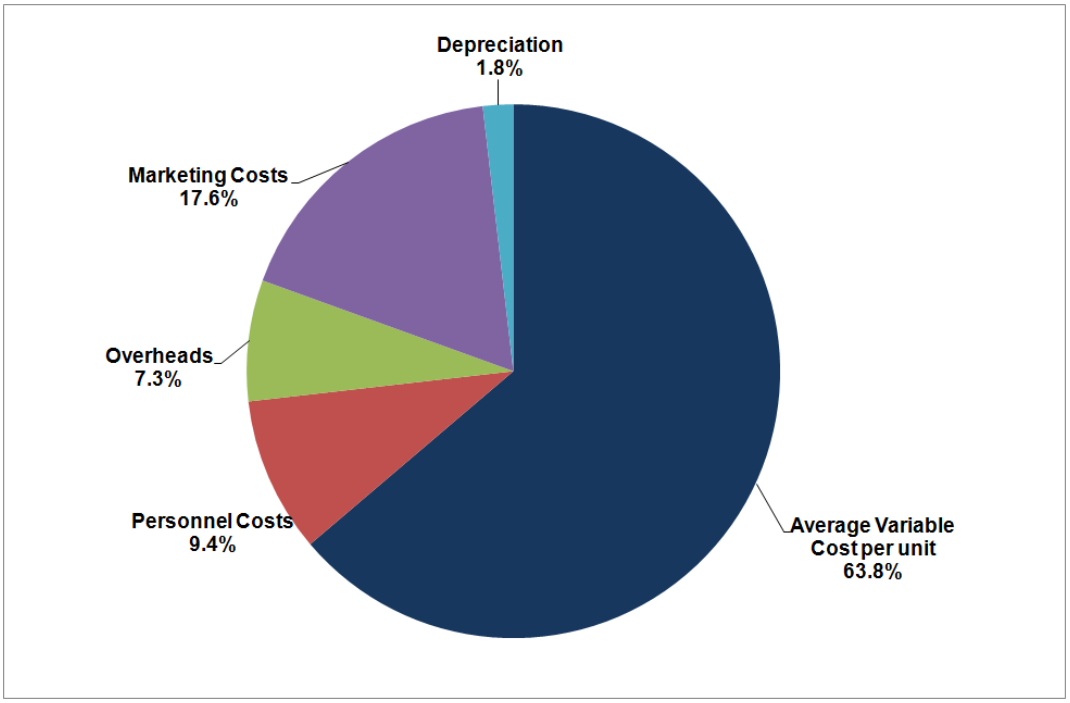
Figure 11 compares the total cost of production, including depreciation, against the sales price for the top of the range model. This graph indicates the economies of scale effect in years 1 to 4, with turnover exceeding the cost of production in the second half of year 2. The company's breakeven sales are 19 aircraft.

FIGURE 11: Airspire™ Fixed and Variable Costs vs Sales Price



The graph below shows the breakdown of the production cost in 2014, when the company reaches economy of scale. This graph clearly shows that the variable cost of production is the major contributor towards the production cost (of which the engine contributes between 40.7 – 46.1%).

FIGURE 12: Total Average Production Cost in 2014



8.3 Economic Assumptions

Key economic assumptions upon which the financial statements are based include the following:

- Income tax is paid at 28%.
- SA Inflation is 8% - constant for the life of the project.
- US Inflation is 2.5% - constant for the life of the project.
- SA Rand/US$ 2009 is R 7.00/US$
- The forward R/$ exchange rate is calculated on the differential in SA and US inflation rate i.e. purchasing power parity is assumed.
- The project's capital is depreciated over 10 years in the calculation of tax.
- Prime interest rate: 11%

8.4 Financial Assumptions

BALANCE SHEET:

- The investment is assumed as a combination of debt and equity (10:90).
- New aircraft for marketing are produced and used by Airspire™ at variable cost in Q1 2012, Q1 2013 and Q1 2014.
- A second investment in a manufacturing facility is undertaken in 2017 funded by a long-term loan.

INCOME STATEMENT:

- No dividend policy included as yet.
- Interest is paid at 2% below prime on debt incurred.

CASH FLOW:

- Working Capital is calculated as follows:
  - Creditors Days: 60
  - Debtors Days: 30
  - Inventory: 90
- Discount factor/Risk adjusted cost of capital calculated as follows:
  Weighted Average Cost of Capital (WACC) = Cost of equity x (percentage equity) + Cost of Debt x (percentage debt) x (1 – tax rate)
  - Cost of debt = prime interest rate = 11%
  - Cost of equity = Risk Free Rate + Market Premium
  - Risk free rate = R 153 = 7.27%
  - Market Premium = 6%[20]

  Discount Factor/Risk Adjusted Cost of Capital = WACC + risk factor
  - Risk Factor = 20%[21]
  - Calculated Risk Adjusted Cost of Capital = 32.7%
- Terminal value calculation Gordon's constant growth model formula as follows:

  $P_0 = D_1 / (k – g)$ where
  - P_0 = Terminal value
  - D_1 = cash flow in year 1
  - g = growth rate = 8% (equivalent to inflation)
  - k = risk adjusted cost of capital

20 Report by PriceWaterHouse: Business enterprise valuation survey 2003 stating market premium average of 6%.
21 Assumed

8.5 Financial Budget

The full investment budget required to commercialise SkyWake™, including the development of the design, construction of the manufacturing facility, and support during the first 2 years of operation is outlined in the table below. A full investment totalling R 18.801 million is required.

TABLE 25: Financial Investment in Airspire™ Startup/Launch

ITEM	Rands
Development Expenses	7 377 123
Launch Costs	680 244
Van and trailer	476 171
Marketing Aircraft	467 758
Labour	4 882 114
Working Capital	2 696 476
Facility	2 241 028
TOTAL	**18 801 569**

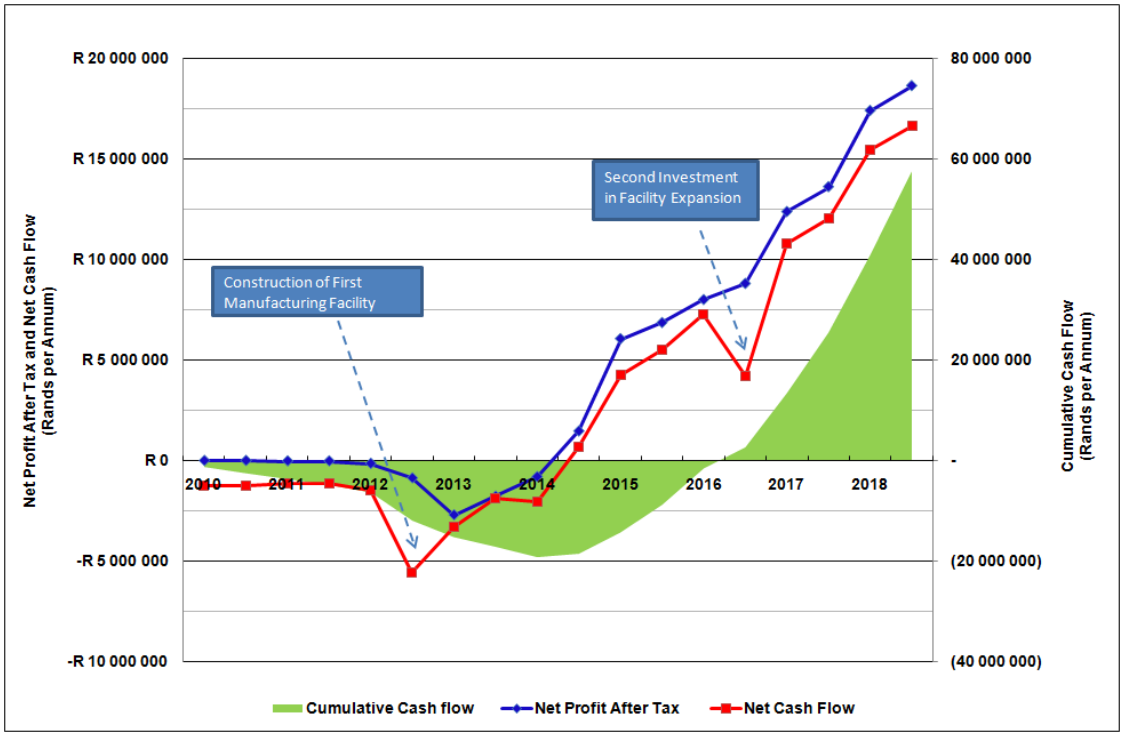
Assumptions:

- Support of Working Capital: Q1 2012 – Q2 2013
- Support of Labour: Q4 2012 – Q4 2013
- Purchase of new aircraft for marketing at variable cost in Q1 2013.
- Purchase of van and trailer for transport of aircraft to agent's site.
- Launch costs: refer to section 7.6 above.

8.6 Financial Analysis

The figure below shows Airspire™ earnings after tax, net cash flow and cumulative net cash flow.

FIGURE 12: Airspire™ Breakeven Cash Flow and Net Profit Analysis



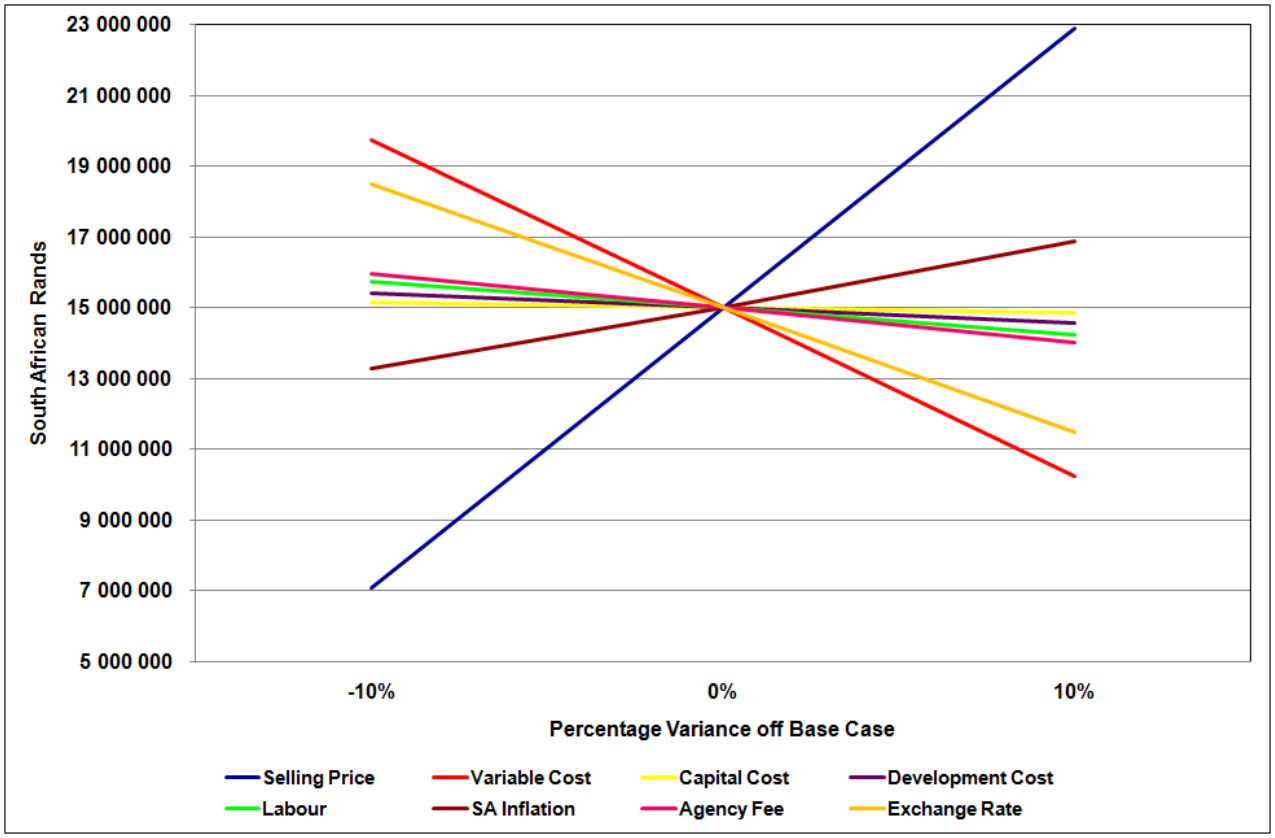
Key financial indicators are outlined in the table below. This table compares results with and without the Phase 2 investment in Q3/4 2016.

TABLE 26: Financial Results

	Base Case Phase 1 and 2	Base Case Phase 1 only
NPV (Rands)	14.99 million	6.724 million
IRR (%)	56	47
Peak Cash Outflow (Rands)	(19.24 million)	(19.24 million)
Peak Cash Outflow (Year)	Q1/2 2014	Q1/2 2014
Breakeven (Year)	Q3/4 2016	Q3/4 2016

The graph below indicates a sensitivity analysis of some of the main variables over a range of ± 10%. This indicates that the factors with the most impact are that of sales price, variable cost and exchange rate.

FIGURE 13: Sensitivity Analysis



- **Sales Price**: The pricing of the 3 SkyWake™ models is however supported by the analysis contained in Figures 5 and 6 above. The marketing strategy and positioning of the aircraft is associated with this pricing strategy. [The top range model is very competitively priced against is closest benchmark, Jabiru 170, which is the highest selling aircraft in the South African market (R 600,000 *vs* R 644,000).] Airspire™ believes that this pricing risk is mitigated against by its flexibility in the range of aircraft models offered to the market. Airspire™ has the ability to select the engine to be included as well as the inclusion or exclusion of glass cockpit instruments. (See sections 2.2 and 4.3)

- **Variable Cost:** Section 8.2 describes how the variable cost is the largest component of the aircarft's manufacturing costs. Of the raw materials used, the item with the single largest ability to impact the variable cost is the engine – both engines used are currently imported. Once a local engine e.g. from Adept Airmotive is procured, this risk will decline. Furthermore, Airspire™ will work to reduce the variable cost further by investigating bulk purchasing as well as more competitive sources of parts locally.
- **Exchange Rate**: The impact of exchange rate is due to the high percentage of imported components (particularly the engine) in the manufacture of SkyWake™, and is linked therefore to the overall impact of variable cost on the project. The impact of exchange rate on sales price will be managed by pricing annually in US dollars. The procurement of the engines and other imported parts will be managed by securing forward cover on foreign currency where possible.

9 BUSINESS RISKS

9.1 SWOT Analysis

STRENGTHS	WEAKNESSES
– Access to South African University based design team through DO to be established. – First production-built South African Light Sport Aircraft customised for local conditions. – Maintenance and repair of South African production built Light Sport Aircraft made easier. – Potential for inclusion of patents with novel features. – Affordably priced in comparison to the top of the range imported models.	– No track record: will be first aircraft designed and produced by Airspire™. – Local labour as yet untrained. – Outsourcing strategy for marketing, hence potentially less direct control. – Dependence on imported engines. – Access to financing.
OPPORTUNITIES	**THREATS**
– Growing light sport aviation/ultralight market in South African and internationally. – Potential change in SA legislation along FAA introduction of LSA class. – South African focus on National Aerospace industry: (NACoE)	– Currency fluctuations can impact on the variable cost and hence profitability. – Aviation market traditionally cyclical. Luxury goods particularly linked to economy/prime lending rate. – Many existing aircraft already in this category with competition from Czech Republic and Australia and entrance by strongly branded Cessna into market.

9.2 Risk Management Strategy

Airspire™ will mitigate against the identified threats and compensate for the weaknesses through the following strategies:

Weaknesses:

- The marketing plan has identified flying schools as being early adopters in the general aviation industry. This is hence the first segment of the market to be targeted. As soon as awareness and credibility is proven among flight schools, marketing and sales efforts will result in significant growth in sales of the aircraft with secondary target market i.e. private customers. Positive word-of-mouth communication between flight schools is anticipated and the purchase of SkyWake™ by "reference customers" will further improve the sales effort and the company's standing in the industry.
- The design team will be linked to first class universities which have a reputation of excellence in this area. Furthermore, members of the design team are already well known in the South Africa aviation industry, being involved in aircrash investigations. Their expertise in this area is hence already well established providing customers with confidence in the design.
- The use of agents is standard practice in the industry. The appointed agents will serve primarily as regional distribution and contact points. The marketing strategy will however be driven by the Airspire™ marketing. It is intended to secure more than one agent in South Africa and internationally, hence mitigating against the outsourcing strategy.

- The labour required for the manufacture of aircraft is similar to that required by the automotive industry, with some minor training, the skills are available in South Africa.
- There is potential for a South African designed and manufactured engine to be used in the future, which will provide further protection against the exchange rate, and will facilitate pricing of the aircraft in South African Rands. This will provide a competitive advantage against imported aircraft.
- Airspire™ will leverage its funding requirements with the setting up of the Design Organisation as a national platform.

Threats:

- SkyWake™ will be priced in US dollars, hence providing a hedge against currency fluctuations.
- Airspire™ will not only concentrate its marketing strategy on the luxury private aviation market, but will also focus on diversifying sales to flight training schools and businesses which utilise Light Sport Aircraft as part of their operational requirements. The cost effectiveness (which includes the link to a local manufacturing facility for repair and maintenance) of SkyWake™ in this context will provide a competitive advantage over imported aircraft.
- The innovative features, price and strategic alliances will provide Airspire™ with the edge to compete against existing players in the market. Several of these features are specifically designed for South African conditions and climate.
- Although there are many existing aircraft in the market, the market is incredibly fragmented. Only Jabiru, from Australia, has market share over 10%, all other companies having market shares of 6% or less. The market is also experiencing dramatic growth and there is no real dominant supplier in the market.

Appendix 2: Competitor Analysis: Performance comparison

		Cessna 162 SkyCatcher	**B&F Technik FK 9 mk IV**	**Jabiru J170[22]**	**SkyWake™**
Construction	Wing	Aluminium Semi-Monocoque	Hybrid Aluminium Ceconite	Full Composite	Aluminium Semi-Monocoque
	Fuselage	Aluminium Semi-Monocoque	Steel alloy spaceframe covered with Ceconite	Full composite	Steel alloy spaceframe covered with aluminium
	Landing gear	Tapered steel tube, un-damped	Metal/Carbon fibre composite, un-damped	Steel, un-damped	Steel tube, spring-damped
	Empennage	Aluminium Semi-Monocoque	Aluminium Semi-Monocoque	Composite	Aluminium Semi-Monocoque
Engine	Type	Continental O-200D	Rotax 912 series	Jabiru J2200	Rotax 912 series
	Power	100hp	80 or 100hp	80hp	80 or 100hp
	Propeller	Composite two-blade fixed pitch	Composite three-blade ground-adjustable	Wood-composite Two-blade fixed pitch	Composite three-blade ground-adjustable
Weight	Empty weight	377kg	268kg	295kg	240-260kg
	Useful load	222kg	252kg	245kg	260-280kg
	Gross weight	599kg	520kg	540kg	520kg
	Fuel load	73kg	80kg	108kg	70-90kg
Dimensions	Wingspan	9.14m	9.85m	8.12m	10.5-11m
	Length	6.95m	5.85m	5.78m	6.1-6.2m
	Cabin width	1.12m	1.09m	1.14m	1.15-1.2m
	Wing area	9.96m^2	11.3m^2	8.04m^2	11-12m^2
	Aspect ratio	8.39	8.6	8.2	9.6
Performance	Stall speed (Clean)	N/A	35kts	45 (49)kts	35kts
	Cruise speed	112kts @ 77% power	104kts @ 75% power	100kts @ 75% power	100-105kts @ 75% power
	Maximum speed	118kts	125kts	115kts	115-120kts
	Range	470nm	700nm	1030nm	Approx 500-650nm
	Take-off	381m	220m		

22 Previously Jabiru J160C

	distance				
Calculated data[A]	Cruise coefficient of lift	0.29	0.257	0.406	0.248
	Induced drag coefficient	0.004	0.0031	0.008	0.0025
	Induced drag glide ratio	1:73	1:83	1:51	1:99
	Wing Loading	60.1kg/m^2	46 kg/m^2	67.2 kg/m^2	45 kg/m^2
	Wing chord	1.1m	1.15m	1.0m	1.1m
	Reynolds' cut-off number	2.7e6	2.86e6	2.5e6	2.7e6
	Skin friction coefficient	0.00375	0.0037	0.0038	0.00375
	Coefficient of parasite drag	0.024	0.027	0.024	0.027
	Coefficient of drag	0.028	0.030	0.032	0.0295
	Glide ratio	1:10.4	1:8.5	1:12.7	1:8.4
	Power required to fly	76Hp*	75Hp*	50Hp[B]	75Hp*

[A] Data calculated using standard performance analysis determination

[B] 50Hp significantly less than the 60Hp specified for cruise, data not verified

* Data within 1% of manufacturer's data, performance verified

The performance was compared and the results follow with explanation:

The SkyWake™ at a gross mass of 600kg has been added since the aircraft may be flown with a Microlight Pilots' license at a take-off mass of 520kg and on a Private Pilot's license at 600kg.

1. Aircraft Drag Polar

The drag polar is a curve relating the lift of an aircraft the drag generated. The slope of the curve is non-linear and is primarily affected by the wing geometry.

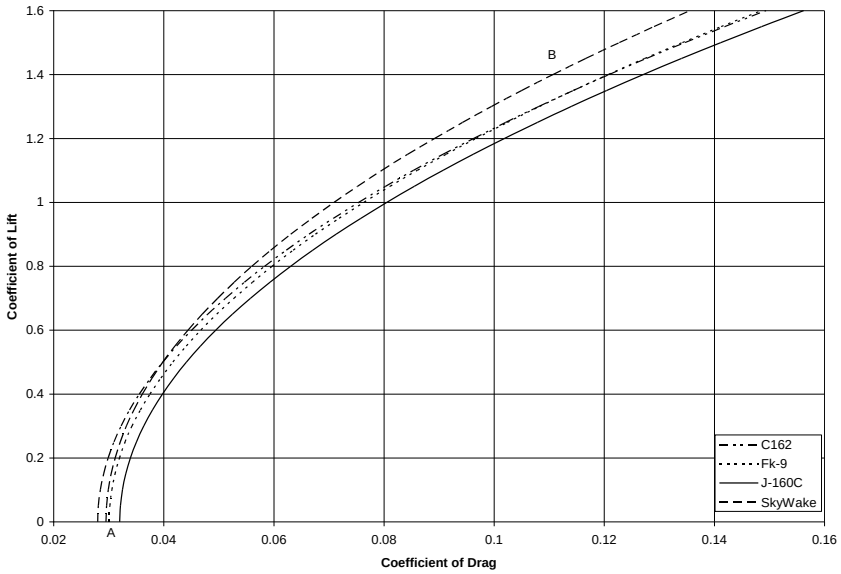


Fig 1: Drag Polar

At point A, where the aircraft is at maximum speed the coefficient of lift required is very small. The SkyWake™ does not have the lowest drag, however at point B, at lower speeds; the SkyWake™ produces the lowest amount of drag. The 520kg and 600kg version of SkyWake™ will have the same polar slope.

2. Aircraft Glide Ratio

The glide ratio is the slope that the aircraft will glide; a glide ratio is simply the ratio of lift divided by drag. A glide ratio of 10 means that the aircraft will be able to fly horizontally for 10m for a height loss of 1m. The higher the glide ratio, the more efficient the aircraft.

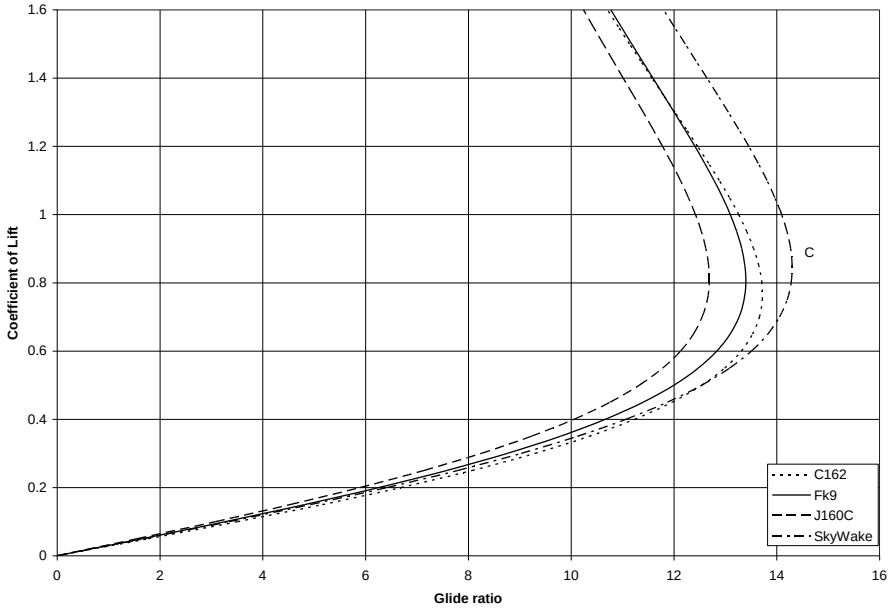


Fig. 2: Glide ratio

At point C the SkyWake™ has the highest glide ratio and thus the best lift to drag ratio, the fuel flow will thus be the lowest.

3. Glide ratio with speed

The glide ratio depicted above is non dimensional. The following figure depicts the glide ratio with forward speed.

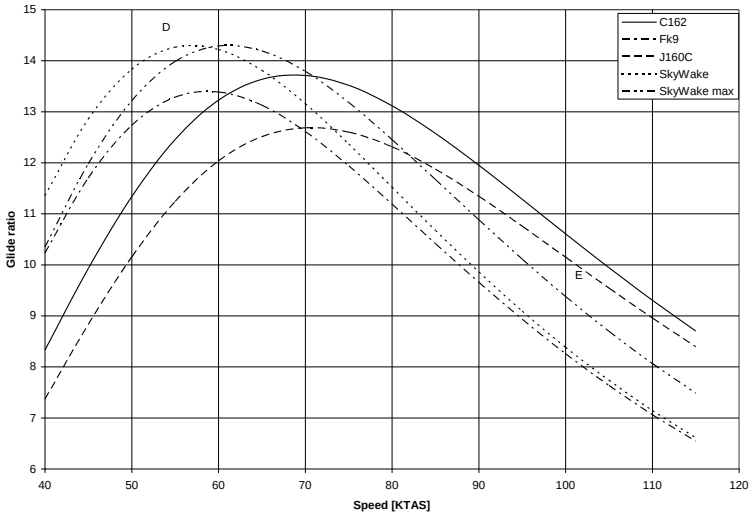


Fig. 3: Glide ratio with speed

At point D, the SkyWake™ clearly has the best glide ratio, at point E the C162 has the higher ratio, the C162 also has poor take-off and stall performance. The 600kg SkyWake has a better glide ratio at higher speeds than the 520kg model.

4. Power required to fly

The power required to fly is derived from the drag polar and is an indication of best operating speed. It is the minimum power required to fly, and excess power may be used for manoeuvring.

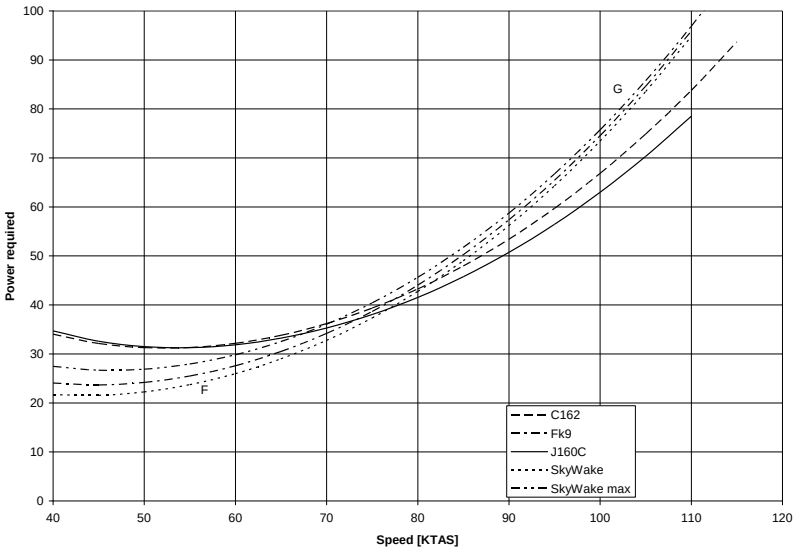


Fig. 4: Power required to fly

At point F, the SkyWake™ requires the least amount of power while at point G it requires slightly more power to fly. At medium speeds (80 Knots or less) for low-level flight the SkyWake™ will use less power and hence less fuel. As expected the 600kg version of SkyWake™ requires more power at low speeds and less power at high speeds than the 520kg model.

5. Angle of Attack

The flying angle of attack is a measure of wing area relative to the aircraft's weight; this is known as wing loading. The Jabiru has the smallest wing area and hence the largest wing loading. The figure below demonstrates that the Jabiru requires a higher angle of attack during flight. The SkyWake™ and FK-9 are similar. The 600kg version of SkyWake™ flies at a slightly higher angle of attack.

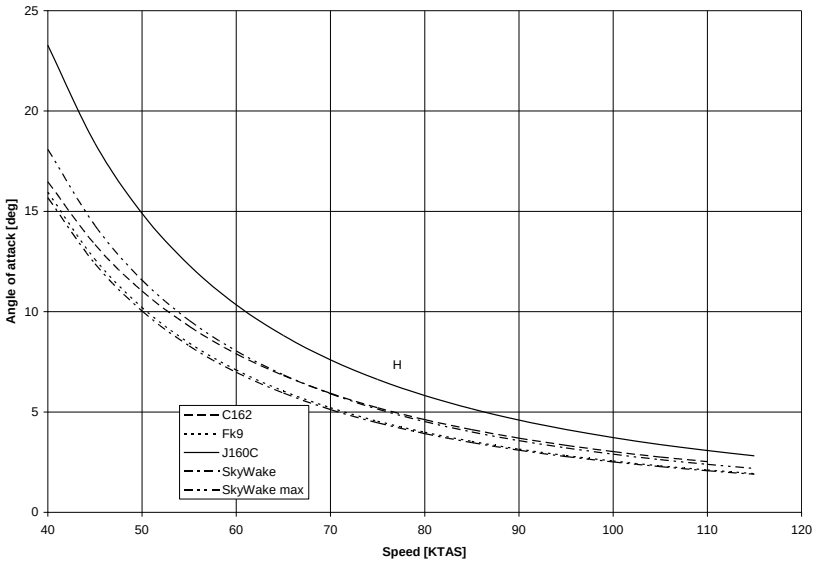


Fig 5: Angle of Attack

APPENDIX 2A

		Cessna SkyCatcher	FK-9 mark IV	Jabiru J 170	SkyWake
Construction		**67%**	**58%**	**50%**	**92%**
Damage tolerance		3	2	1	4
Corrosion resistance		2	3	4	3
Degree of modification		3	2	1	4
Operation		**55%**	**70%**	**52%**	**92%**
Landing gear	Low bounce characteristics	3	3	3	4
	Energy absorption	2	1	3	4
	Robustness	3	2	1	4
	Ground handling	2	3	1	4
Stall speed		2	3	1	4
Manoeuvrability		2	3	1	4
Fuel flow		2	4	3	3
Controllability		3	4	2	4
Payload		1	3	2	4
Empty weight		1	4	2	3
Cruise speed		4	2	3	2
Range		2	3	4	3
Take-off distance		1	3	2	4
Tailored flight instruments		3	1	2	4
Safe operation at hot/high conditions		2	3	1	4
Ownership		**55%**	**40%**	**55%**	**100%**
Parts availability		3	1	2	4
Customisation	Interior	1	2	3	4
	Exterior	3	1	2	4
Cabin layout		1	3	2	4
Training of maintenance staff		3	1	2	4
	Overall Rating	57%	62%	52%	93%
	Price	869 700	981 000	644 344	600 000

APPENDIX E – Bill of materials

Component	Quantity Required per Aircraft	Manufacturing Functions
Ailerons		
Aileron - Elevator Stick Crank (3mm)	4	Cut holes/profile 3mm plate/De-burr/ Corrosion protection
Aileron Bracket 3mm - Left	1	Cut holes/Profile 3mm plate/de-burr/Corrosion protection/Bend 3mm plate 90°
Aileron Bracket 3mm - Right	1	Cut holes/Profile 3mm plate/de-burr/Corrosion protection/Bend 3mm plate 90°
Aileron Bracket 4mm - Left	2	Cut holes/Profile 4mm plate/de-burr/Corrosion protection/Bend 4mm plate 90°
Aileron Bracket 4mm - Right	2	Cut holes/Profile 4mm plate/de-burr/Corrosion protection/Bend 4mm plate 90°
Aileron Bracket Support - Left (0.5mm)	3	Cut holes/Profile 0.5mm plate/de-burr/corrosion protection/bend 0.5mm plate 90°
Aileron Bracket Support - Right (0.5mm)	3	Cut holes/Profile 0.5mm plate/de-burr/corrosion protection/bend 0.5mm plate 90°
Aileron Hinge Bracket 3mm - Left	1	Cut holes/Profile 3mm plate/de-burr/corrosion protection/bend 3mm plate 90°
Aileron Hinge Bracket 3mm - Right	1	Cut holes/Profile 3mm plate/de-burr/corrosion protection/bend 3mm plate 90°
Aileron Hinge Bracket 4mm - Left	2	Cut holes/Profile 4mm plate/de-burr/corrosion protection/bend 4mm plate 90°
Aileron Hinge Bracket 4mm - Right	2	Cut holes/Profile 4mm plate/de-burr/corrosion protection/bend 4mm plate 90°
Aileron Rigging Pulley Support Bracket - Bottom (3mm)	2	Cut holes/Profile 3mm plate/de-burr/corrosion protection/bend 3mm plate 90° & 134°
Aileron Rigging Pulley Support Bracket - Top (2mm)	2	Cut holes/Profile 2mm plate/de-burr/corrosion protection/bend 2mm plate 97° & 134°
Aileron Spar - Left (1.5mm)	1	Cut holes/Profile 1.5mm plate/de-burr/corrosion protection/bend 1.5mm plate 97° & 79°/ NDT
Aileron Spar - Right (1.5mm)	1	Cut holes/Profile 1.5mm plate/de-burr/corrosion protection/bend 1.5mm plate 97° & 79°/ NDT
Aileron Front Rib (0.5mm)	6	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Aileron Rear Rib (0.5mm)	6	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Differential Deflection Crank For Ailerons (3mm)	2	Cut holes/Profile 3mm plate/de-burr/Corrosion protection/Bend 3mm plate 90°
Crank Mounting Bracket (Aileron) At Twin Tube (1.5mm)	2	Cut holes/profile 1.5mm plate/de-burr/corrosion protection/bend 1.5mm plate 90°
Sheet Metal skin (0.5mm)	2	Form leading edge/Cut to appropriate size/Cut holes/de-burr/corrosion protection
Vertical Stabiliser		
Rib 1 Aft (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°

Rib 1 Mid (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 2 Aft (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 2 Front (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 3 Aft (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 3 Mid (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 3 Front (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 4 Aft (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 4 Mid (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 4 Front (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 5 Aft (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Rib 5 Mid (0.5mm)	1	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Spar Cap (1.6mm)	2	Cut holes/Profile 1.6mm plate/de-burr/Corrosion protection/Bend 1.6mm plate 90°/ bend entire 1745mm 178°
Spar Front (1.5mm)	1	Cut holes/Profile 1.5mm plate/de-burr/Corrosion protection/NDT
Spar Rear (1.6mm)	1	Cut holes/Profile 1.6mm plate/de-burr/Corrosion protection/Bend 1.6mm plate 90°
Vtail Control System Crank (3mm)	2	Cut holes/Profile 3mm plate/de-burr/Corrosion protection/Bend 3mm plate 90°
Sheet Metal Skin/leading edge (0.5mm)	1	Form leading edge&panels/Cut to appropriate size/Cut holes/de-burr/corrosion protection/cut inspection panel holes/reinforce periphery of inspection panel holes/attach anchor nuts to which inspection panels can be screwed
Rudder		
Bracket Rudder (3mm)	1	Cut holes/de-burr/corrosion protection/profile 3mm plate/bend 3mm plate 90°
Rudder Spar (1.6mm)	1	Cut holes/Profile 1.6mm plate/de-burr/Corrosion protection/Bend 1.6mm plate 90°
Rudder Rib (0.5mm)	5	Cut holes/Profile 0.5mm plate/de-burr/Corrosion protection/Bend 0.5mm plate 90°
Bracket Rudder Long (3mm)	1	Cut holes/de-burr/corrosion protection/profile 3mm plate/bend 3mm plate 90°
Sheet Metal Skin (0.5mm)	1	Form leading edge&panels/Cut to appropriate size/Cut holes/de-burr/corrosion protection
Horizontal Stabiliser		
Horizontal Tail Crank (3mm)	2	Cut holes/de-burr/corrosion protection/profile 3mm plate
Horizontal Tail Tab Inner End Plate (2mm)	1	Cut holes/de-burr/corrosion protection/profile 2mm plate/bend 2mm plate 90°

Horizontal Tail Tab Outer End Plate (2mm)	1	Cut holes/de-burr/corrosion protection/profile 2mm plate/bend 2mm plate 90°
HTail Control Linkage Mount (3mm)	2	Cut holes/de-burr/corrosion protection/profile 3mm plate/bend 3mm plate 90°
HTail Front Rib-O (0.5mm)	8	Cut holes/de-burr/corrosion protection/profile 0.5mm plate/bend 0.5mm plate 90°
HTail Middle Rib-O (0.5mm)	10	Cut holes/de-burr/corrosion protection/profile 0.5mm plate/bend 0.5mm plate 90°
HTail Front Spar (2mm)	1	Cut holes/de-burr/corrosion protection/profile 2mm plate/NDT
Htail Rear Spar (1.6mm)	1	Cut holes/de-burr/corrosion protection/profile 1.6mm plate/bend 1.6mm plate 86°/NDT
Htail Spar Cap (1.6mm)	2	Cut holes/de-burr/corrosion protection/profile 1.6mm plate/bend 1.6mm plate 90°
HTail Hinge Box Front Plate (1.5mm)	1	Cut holes/de-burr/corrosion protection/profile 1.5mm plate
Htail Hinge Box Front Spar Cap (1.6mm)	2	Cut holes/de-burr/corrosion protection/profile 1.6mm plate/bend 1.6mm plate 90°
Htail Hinge Box Bracket (4mm Base) 5mm (Vertical)	Unknown	Cut holes/ profile 4mm & 5mm plate/deburr/corrosion protection
Htail Hinge Box Panel (0.5mm)	2	Cut holes/de-burr/corrosion protection/profile 0.5mm plate
Htail Hinge Box Triangulation Bracket (2mm)	2	Cut holes/de-burr/corrosion protection/profile 2 mm plate/ bend 2mm plate to 160°
Htail Rear Spar Tab Hinge Mount (2mm)	2	Cut holes/de-burr/corrosion protection/profile 2mm plate/bend 2mm plate 90°
O-Horizontal Tail Tab Inner End Plate (2mm)	1	Cut holes/de-burr/corrosion protection/profile 2mm plate/bend 2mm plate 90°
O-Horizontal Tail Tab Outer End Plate (2mm)	1	Form leading edge/Cut holes/de-burr/corrosion protection/profile 2mm plate/bend 2mm plate 90°
Sheet metal skin/leading edge (0.5mm)	1	Form leading edge/Cut holes/de-burr/corrosion protection/cut inspection panel holes/reinforce periphery of inspection panel cut-outs/attach anchor nuts to which inspection panels can be screwed
Elevators		
Elavator&Actuator Hinge Bracket A (3mm)	2	Cut holes/profile 3mm plate/de-burr/corrosion protection
Elavator&Actuator Hinge Bracket B (3mm)	2	Cut holes/profile 3mm plate/de-burr/corrosion protection
Elavator&Actuator Hinge Bracket C (3mm)	2	Cut holes/profile 3mm plate/de-burr/corrosion protection
Elevator PushRod Crank A (3mm)	2	Cut holes/Profile 3mm sheet metal/ De-burr/corrosion protection
Elevator PushRod Crank B (3mm)	2	Cut holes/Profile 3mm sheet metal/ De-burr/corrosion protection
2 × 2mm Spacer (2mm)	Numerous	Cut hole/Profille 2mm sheet metal /De-burr/corrosion protection
4-3 Geared Elevator Pushrod Crank (3mm)	6	Cut holes/Profile 3mm sheet metal /De-burr/corrosion protection
4 × 2mm Spacer (2mm)	Numerous	Cut hole/Profille 2mm sheet metal /De-burr/corrosion protection
64mm Bush (ID 12mm OD 16mm)	Unknown	Form leading edge/Cut to appropriate size/Cut holes/de-burr/corrosion protection

Elevator Rib (2mm)	6	Cut holes/Profile 2mm plate/de-burr/Corrosion protection/Bend 2mm plate 90°
Sheet metal skin (0.5mm)	2	Form leading edge/Cut to appropriate size/Cut holes/de-burr/corrosion protection
Wing		
Front Wing Rib (0.5mm)	28	Cut holes/profile 0.5mm plate/de-burr/corrosion protection/bend 0.5mm plate 90°
Middle Wing Rib - O (0.5mm)	28	Cut holes/profile 0.5mm plate/de-burr/corrosion protection/bend 0.5mm plate 90°
Rear Wing Rib - O (2mm)	28	Cut holes/profile 2mm plate/de-burr/corrosion protection/ bend 2mm plate 90°
Front Spar (2.3mm)	2	Cut holes/profile 2.3mm plate/de-burr/corrosion protection/NDT
Front Spar Cap 1 (3.175mm)	3	Cut holes/profile 3.175mm plate/de-burr/corrosion protection/ bend 3.175mm plate 90°
Front spar Cap 2 (3.175mm)	3	Cut holes/profile 3.175mm plate/de-burr/corrosion protection/ bend 3.175mm plate 90°
Rear Spar (1.5mm)	2	Cut holes/profile 1.5mm plate/de-burr/corrosion protection/ NDT
Front Spar Stiffener (3.175mm)	56	Cut holes/profile 3.175mm plate/de-burr/corrosion protection/ bend 3.175mm plate 90°
Front Spar Attachment Bracket (22mm)	2	Cut holes/profile 22mm plate/de-burr/corrosion protection/NDT
Front Spar Attachment Plate double milled (5mm)	2	Cut holes/profile 5mm plate/de-burr/corrosion protection/NDT
Front Spar Attachment Plate single milled (5mm)	2	Cut holes/profile 5mm plate/de-burr/corrosion protection/NDT
Rear Spar Attachment Bracket (12mm)	2	Cut holes/profile 12mm plate/de-burr/corrosion protection/NDT
Rear Spar Attachment Plate (5mm)	2	Cut holes/profile 5mm plate/de-burr/corrosion protection
Hinge Plate Doubling Plate (3mm)	6	Cut holes/profile 3mm plate/de-burr/corrosion protection
Hinge Crank (1.5mm)	2	Cut holes/profile 1.5mm plate/de-burr/corrosion protection
Sheet metal skin/leading edge (0.5mm)	2	Form leading edge/Cut to appropriate size/Cut holes/de-burr/corrosion protection/cut inspection panel holes/reinforce periphery of inspection panel cut-outs/attach anchor nuts to which inspection panels can be screwed
Flaps		
Flap Actuator bracket 2.3mm	4	Cut holes/profile 2.3mm plate/bend 2.3mm plate 90°/de-burr/corrosion protection
Flap Bracket Support - Left 0.5mm	14	Cut holes/profile 0.5mm plate/bend 0.5mm plate 90°/de-burr/corrosion protection
Flap Bracket Support - O (0.5 mm)	14	Cut holes/profile 0.5mm plate/bend 0.5mm plate 90°/de-burr/corrosion protection
Flap Rib Front (0.5mm)	18	Cut holes/profile 0.5mm plate/bend 0.5mm plate 90°/de-burr/corrosion protection
Flap Rib Rear (0.5mm)	18	Cut holes/profile 0.5mm plate/bend 0.5mm plate 90°/de-burr/corrosion protection

Flap Rib Bracket 3mm - Left	1	Cut holes/profile 3mm plate/bend 3mm plate 90°/de-burr/corrosion protection
Flap Rib Bracket 3mm - Right	1	Cut holes/profile 3mm plate/bend 3mm plate 90°/de-burr/corrosion protection
Flap Rib Bracket 4mm - Left	2	Cut holes/profile 4mm plate/bend 4mm plate 90°/de-burr/corrosion protection
Flap Rib Bracket 4mm -Right	2	Cut holes/profile 4mm plate/bend 4mm plate 90°/de-burr/corrosion protection
Flap Track Bracket 3.17mm Left	1	Cut holes/profile 3.17mm plate/bend 3.17mm plate 90°/de-burr/corrosion protection
Flap Track Bracket 3.17mm Right	1	Cut holes/profile 3.17mm plate/bend 3.17mm plate 90°/de-burr/corrosion protection
Flap Track Bracket 4mm Left	2	Cut holes/profile 4mm plate/bend 4mm plate 90°/de-burr/corrosion protection
Flap Track Bracket 4mm Right	2	Cut holes/profile 4mm plate/bend 4mm plate 90°/de-burr/corrosion protection
Flap Spar (1.5mm)	4	Cut holes/profile 1.47mm plate/bend 1.47mm plate 79°/de-burr/corrosion protection/NDT
Sheet metal skin/leading edge (0.5)	2	Form leading edge/Cut holes/de-burr/corrosion protection/cut inspection panel holes/reinforce periphery of inspection panel cut-outs/attach anchor nuts to which inspection panels can be screwed
Wing Strut		
Tubing	2	Cut to appropriate length/cut holes/ de-burr/corrosion protection
Strut Mounting Bracket 10mm	2	Cut 10mm plate/cut hoes/de-burr/ NDT
Strut Fairing	2	Cut Fairing to appropriate size/form fairing/ de-burr/cut holes/attach to tubing

Report

detailing

PROTOTYPE COSTING FOR SKYWAKE

22 July 2011
DRAFT 1

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Introduction

South Africa has always had a very small aerospace industry. The large state-assisted companies did develop aerospace products, but only for military purposes. Since 1994 other companies have been established exclusively to manufacture small components for international civil aerospace companies. Several small companies have started to produce small recreational aircraft including microlights, gliders and sport aircraft. These companies work in isolation, have no research and design capability, have limited ties to universities and, as a result, cannot grow into international markets or develop world-class products.

The Blue Crane Development Agency (BCDA) in Somerset East, Eastern Cape and the University of the Witwatersrand (Wits) has design of a highly competitive Light Sport Aircraft (LSA) has been completed and construction of the prototype needs to commence. The aircraft will attain Civil Aviation Regulation Part 24 certification once flight-tested. The aircraft design was managed and supervised by staff within the University, with the majority of the design work being completed by students involved with the student development model.

The LSA will allow for a Manufacturing Organisation (MO) to be established and approved. The Manufacturing Organisation will be able to manufacture the LSA and other aircraft and aviation related products. The organisational structure of MO has been designed for strategic establishment of the aerospace industry and the seamless interaction with the universities will allow for many new aircraft designs to be undertaken. Additionally, the three goals of the Industry Participation Action Plan II (IPAP) for aerospace are to develop rural areas, increase skills and promote manufacture. This project would exceed expectations for all three goals. To date, R9.5Mil has been invested in the project, including a R8.8Mil academic donation by Wits University. To establish a facility to build the two prototypes and establish a toolset and skills set, capable of supporting future aviation projects, requires an investment of R1.6Mil.

Bill of materials

Instruments		**R 42,505**
Engine	Oil pressure	R 1,966
	Oil Temperature	R 478
	Ammeter	R 190
	Tachometer	R 1,286
Flight Instruments	Altimeter	R 3,103
	Air Speed indicator	R 1,064
	Artificial horizon	R 3,978
	Direction indicator	R 3,761
	Vertical speed indicator	R 1,645
	Compass	R 553
	Slip indicator	R 481
Navigation/Communication	nav/com	R 24,000
Fuselage		**R 82,570**
Cockpit	Seatbelts	R 580
	Seats	R 2,000
	Fire extinguisher	R 295
	First aid kit	R 200
Ballistic parachute		R 25,000
Lighting		R 3,000
Fuel tanks		R 2,500
Landing gear	Gear	R 8,000
	Brakes	R 12,000
	Wheels	R 8,000
	Spats	R 1,000
Material costs	Crash structure and engine mounting cradle	R 7,792
	Tail Boom	R 3,384
	Fuselage skin	R 3,119
	Cowling, doors	R 4,200
	Windows and Windscreen	R 1,500
Wing		**R 18,038**
Material costs	Struts (Streamline Tubing)	R 5,875
	Wings	R 10,663
	Fillets and Wingtips	R 1,500
Vertical Stabiliser		**R 2,410**
Material costs	Vertical Stabilizer	R 2,410
Horizontal Stabiliser		**R 3,593**
Material costs	Horizontal Tail	R 3,593
Engine		**R 156,700**
	Jabiru J3300	R 134,000
	Propeller	R 15,000
	Exhaust	R 6,500
	Battery	R 1,200
GRAND TOTAL		**R 305,816**

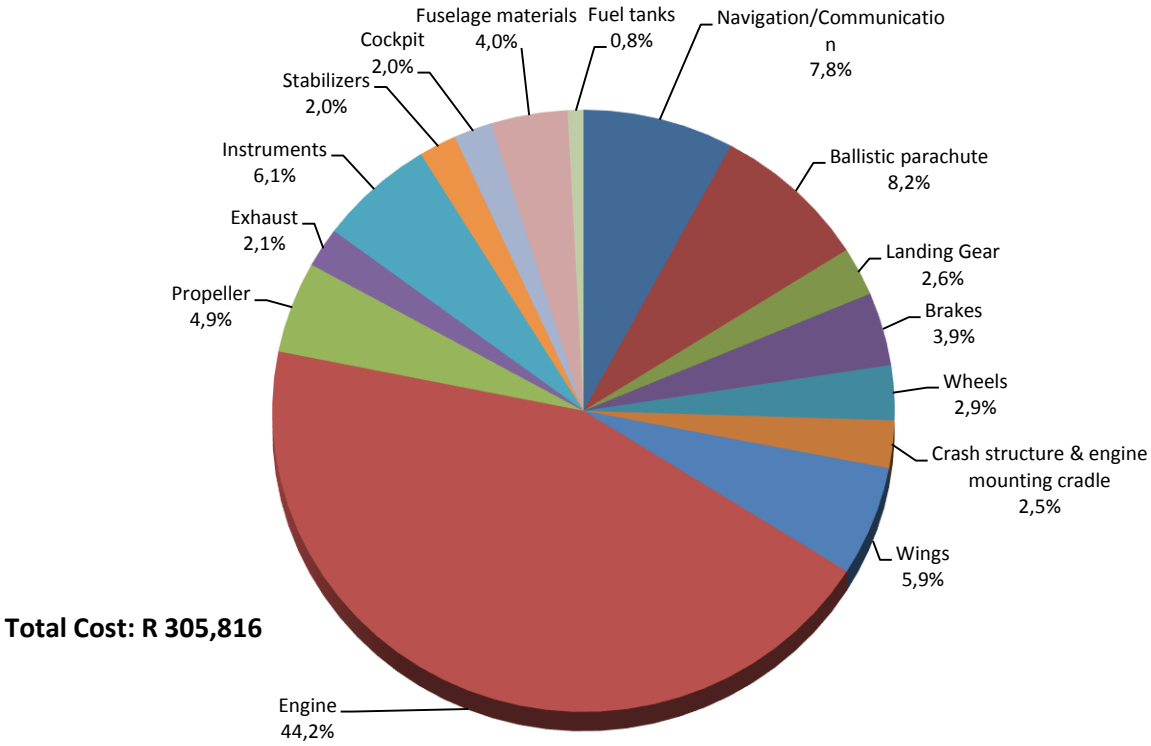

Figure 1. Contributive materials costing

Wits University is establishing a structural testing facility, which is being partly funded by the National Aerospace Centre, a dti initiative. The facility will be used to test a non-flying prototype of the aircraft that is identical to the flying version, just without an engine. Once the testing is complete, a flying prototype will be built.

Organogram

The organogram proposed is in line with international practice and is required by the Civil Aviation Authority.

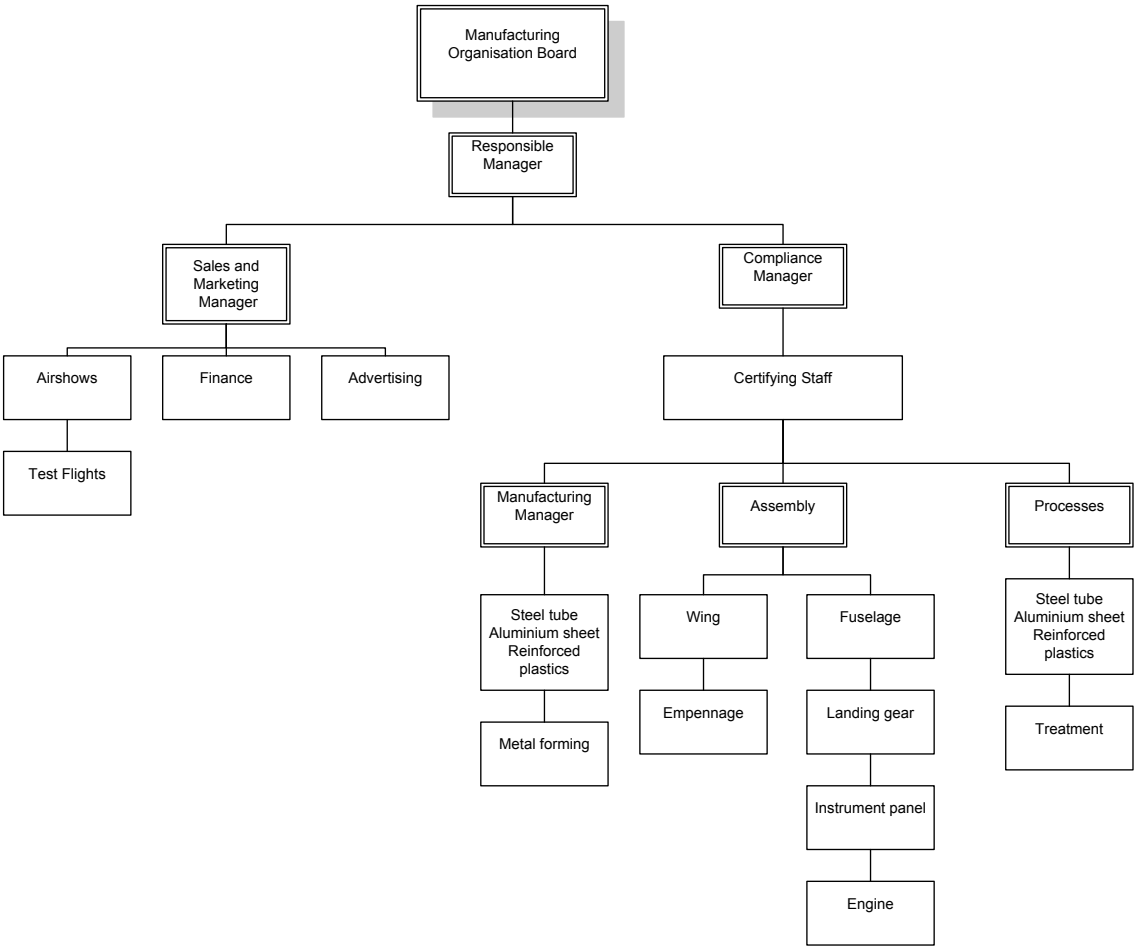

Figure 2. Manufacturing Organisation organogram

The roles and responsibilities of the key people is described;

1) ***Responsible Manager***, accountable to the Director for Civil Aviation, with overall responsibility within the organisation to ensure that all production is performed to the required standards and that the production organisation is continuously in compliance with the data and procedures identified in the manual of procedures. This person will be the company CEO.
2) A ***Compliance Manager*** nominated to ensure that the organisation is in compliance with the Civil Aviation Regulations and who has been identified together with the extent of their authority. In this respect, such person or persons must be directly responsible to the manager identified above. An engineering degree or technical diploma would be required as well as previous experience in manufacturing technology, quality control and non-destructive testing.

Labour requirements at the manufacturing facility

Although the industry assembles a complex and high-tech product, its assembly process is relatively labour intensive. Production of aircraft is carried out at relatively low rates relative to most manufacturing industries. Furthermore, the aircraft are almost 100% hand-made due to the fact that manufacturers are cautious about the expensive damage that could be caused by a malfunctioning machine.

The production process requires expertise in reading blueprints, proficiency in the use of several different tools, and the ability to anticipate and solve various assembly problems to meet demanding technical standards. Many employees are thus involved in managing and inspecting the process. For these personnel, well-developed technical skills are essential. In addition, many more technical non-production workers are required. Overall, staff required to manufacture SkyWake™ will comprise precision production, craft, and repair workers; professional and technical workers as well as less skilled jobs, such as operators, fabricators, and general labourers.

Labour costs have been estimated based on values for low skilled, through to highly skilled workers. The most specialised workers (e.g. welder, paint booth operator and specialised machinery operators) are paid the most. The table below displays the estimated labour costs for the facility based on the assumption that it operates 8 hours a day and 5 days per week producing a maximum of 8 aircraft monthly.

Table 1. Labour rates

Production cell	Operator Task	Operators	Rate (R/Hour)	Daily Cost
Space Frame Construction	Crash boom, tail boom and engine mounting cradle welding	2	100	1,600
Metal Preparation	Press	1	25	200
	Tube cutting and profiling	1	70	560
Stores	Receive, record, pack, handout materials	1	20	160
GFRP	Moulding	1	25	200
ABS plastic	Forming	1	25	200
Engine	Filling, connecting, testing	1	80	640
Inspection bays 1 & 2	Inspect components and sub-assemblies	1	25	200
Paint booth	Masking, priming and painting	1	50	400
Instrument panel	Instrument unpacking, preparing, instrument panel assembly and testing	1	25	200
Skin covering	Drilling, installing of components and securing skin	2	25	400
Wing, aileron and flap	Assembly	2	25	400
Empennage	Assembly	1	25	200
Primary Assembly	Assemble sub-components	2	25	400
Total		**18**		**5,960**
MONTHLY TOTAL				**107,280**

Tooling costing

Equipment	No.	Needed?	Cost(Rands)
Machinery			
Hydraulic Press	1	n	R -
Router Multicam 3000 Series 1	1	n	R -
Band Saw Cosen Automatic Band Saw	1	n	R -
Cut-Off Machine	1	y	R 1,500.00
Press Brake	1	y	R 225,000.00
20 Tonne Hydraulic Press	1	y	R 4,000.00
Notching machine Otmar Tube Notcher	1	y	R 4,000.00
Welder TA 200 Amp	1	y	R 11,000.00
Gas Regulator	1	y	R 450.00
Autoclave	1	y	R -
Subtotal			**R 245,950.00**
Riveting Equipment			
Rivet Squeezer	2	y	R 1,190.00
Solid shank rivet gun set (incl. bucking bars)	2	y	R 4,480.00
Blind rivet gun	2	y	R 8,400.00
Rivnut speed driver	1	y	R 1,400.00
Subtotal			**R 15,470.00**
Fastening Equipment			
Manual spanner set (Imperial sizes)	1	y	R 450.00
Air wrench	2	y	R 900.00
Torque wrench	1	y	R 500.00
Ratchet Set	3	y	R 450.00
Imperial socket set	2	y	R 1,000.00
Cleco pliers	2	y	R 61.60
Clecos		y	R -
Screwdriver set	3	y	R 300.00
Offset screwdriver set	1	y	R 61.25
Soldering Iron Ellies 40W	1	y	R 650.00
Wire crimping tool	2	y	R 479.50
Swaging tool	1	y	R 910.00
G-clamp set	1	y	R 800.00
Tool clamp set	2	y	R 2,200.00
Bench vice	2	y	R 1,800.00
Cable tie gun kit	1	y	R 385.00
Safety wire pliers	2	y	R 350.00
Subtotal			**R 11,297.35**

Moving Equipment				
Manual 2 ton crane	1	y	R	1,700.00
Load Leveler	2	y	R	600.00
Chain Block 1 tonne 3m lift	4	y	R	1,600.00
Slings	1	y	R	-
Restoration Rotator	4	y	R	-
Dolly	2	y	R	-
Tow Bar	1	y	R	700.00
Subtotal			**R**	**4,600.00**

Material removal tools				
Pneumatic hand drill	2	y	R	990.00
Drill Bit set (Imperial sizes)	1	y	R	200.00
Drill Press	1	y	R	1,795.00
Bench grinder	1	y	R	575.00
Tool grinder	1	y	R	269.00
Small angle grinder	1	y	R	300.00
De-burring tool	3	y	R	315.00
Electrical wire stripper	2	y	R	120.00
Control cable cutter	1	y	R	1,050.00
Hand operated tube cutter	1	y	R	245.00
Fine tooth hacksaw	1	y	R	75.00
Side cutters	1	y	R	40.00
Tin Snips	2	y	R	80.00
Hand file set	1	y	R	145.00
Stanley Knife	2	y	R	120.00
Allen Key Set	2	y	R	120.00
Subtotal			**R**	**6,439.00**

Inspection and Alignment Equipment				
Multimeter	2	y	R	500.00
Vernier (digital)	3	y	R	885.00
Micrometer (digital)	2	y	R	990.00
Internal Micrometer	1	y	R	2,000.00
Sheet metal micro	1	y	R	1,274.00
Set square	2	y	R	260.00
V-block set	1	y	R	500.00
Tape Measures	4	y	R	160.00
Laser level	2	y	R	1,000.00
Spirit Levels	2	y	R	300.00
Control cable tensiometer	1	y	R	1,820.00
Instrument Calibration System	1	y	R	7.00
Subtotal			**R**	**9,696.00**

Miscellaneous			
Hand fuel tube bender (RDB-25)	1	y	R 1,400.00
Compressor (screw compressor)	1	y	R 20,000.00
Hole finder	1	y	R 210.00
Centre Punch	1	y	R 45.00
Sealant dispensing gun	1	y	R 3,850.00
Fire Extinguisher	4	y	R 1,400.00
Ladders	2	y	R 1,130.00
Battery Charger	1	y	R 195.00
Engine Fluids Drip Tray	1	y	R 210.00
Hand crank fuel pump	1	y	R 1,400.00
Tyre Inflator	1	y	R 150.00
Label Maker	1	y	R 900.00
Fire Proof Cabinets (1830x915x459)	1	y	R 6,000.00
Work Benches (lkgoodwin.com)	2	y	R 7,000.00
Scales	1	y	R 560.00
Subtotal			**R 43,890.00**

PPE			
Welding Mask	2	y	R 990.00
Welding Gloves	2	y	R 2.00
Welding Aprons	2	y	R 2.00
Work Gloves	6	y	R 6.00
Overalls	6	y	R 6.00
Safety Boots	6	y	R 6.00
Safety Goggles	6	y	R 6.00
Dust Mask	6	y	R 6.00
Ear Plugs	6	y	R 6.00
Painting Mask	1	y	R 1.00
Painting Overalls	1	y	R 1.00
Subtotal			**R 1,032.00**

TOTAL	**R 338,374.35**

Factory layout

The hangar presently in existence at the Somerset East airfield will be equipped according to the production facility layout

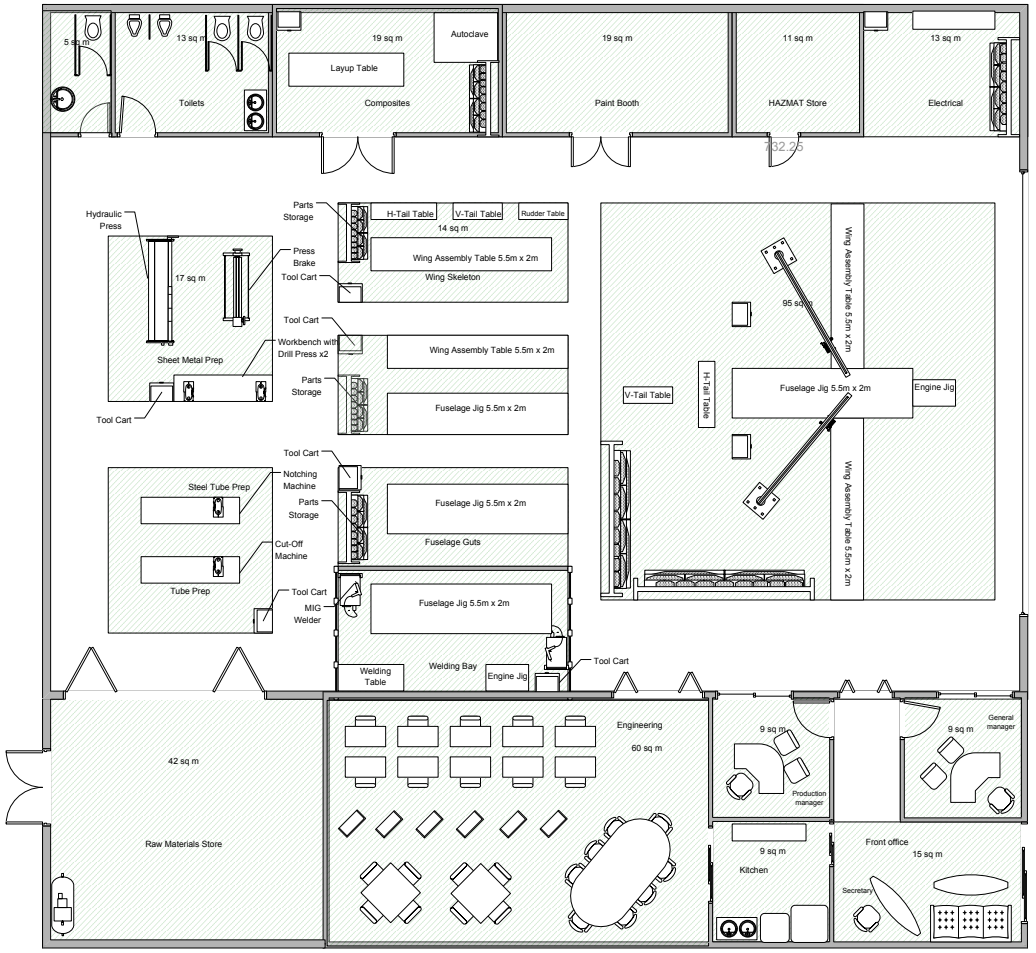

Figure 3. Production facility layout

Budget

The budget has been drawn up using the data provided above. The values have been rounded with several percent contingency margin. The labour has been calculated at 7 months full-time, which would be spread over a period of 7-12 months. The total funding ***required*** is R 1 620 000.

Contribution received	**Amount required for 12 month period**
LSA design	R 240 000
Wits University (19000 manhours)	R 4 750 000
Wits University facilities	R 4 000 000
Mock up	R 135 000
Hangar building	R 400 000
Total funding received	**R 9 525 000**
Contribution required	
Materials for structural testing prototype	R 200 000
Materials for flying prototype	R 320 000
Tooling for established facility	R 340 000
Labour for contract work	R 756 000
Total funding required	**R 1 616 000**
Total project value	**R 11 141 000**
Leverage ratio (received / required)	**5.9**