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CONCEPTUAL DESIGN OF AN AIRCRAFT FOR AUSTRALIAN OUTBACK CONDITIONS *

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Abstract The conceptual design of a general aviation aircraft, specifically designed for use on the large Australian pastoral properties, was carried out. The unique operational and environmental conditions in Australia for this class of aircraft were considered when formulating the specification. The specification led to the proposal of two aircraft, one was a tractor arrangement, *Kookaburra I* and the other was a pusher arrangement, *Kookaburra II*. Standard sizing techniques were employed to match the major aircraft characteristics to the required performance. Detailed mass and drag analyses confirmed the initial estimates. Investigation of the longitudinal and lateral stability verified the suitability of the tail arrangement which also showed good spin recovery characteristics. Both aircraft configurations provided several advantages over the competition. These included, good visibility, improved crashworthiness, true STOL performance at gross weight in 40° Celsius temperatures and flexible interior design to maximise payload capability. Finally a preliminary cost estimate was carried out for the aircraft. It was estimated that to produce the airframe in Australia would result in a price of around $AUS 120,000. It was estimated that this may be reduced to around $AUS 76,000 by producing the airframe in India or another "Third World Country" with aerospace expertise.

Introduction

The conceptual design of a general aviation aircraft, specifically designed for use on the large pastoral properties in Australia, was carried out. Many of these large properties are located in the remote areas of northern and central Australia. In these regions the climate and operating environment pose particular design problems which are discussed.

It is important to gain an understanding of the distribution of Australia's population, location and distribution of rural industry and the environmental conditions that are prevalent in these regions. It is these factors that have led to the widespread use of aircraft in these regions. The market is to some extent unique and well established and will exist for the foreseeable future.

Population

By world standards Australia has a small population, particularly in relation to the area of the country. Australia had a population of 15.1 million in 1981[1], which is a stark contrast to the population of the United Kingdom or the USA as summarised in Table 1. The population distribution of Australia is given in Table 2. The relative size of each of these countries is illustrated in Figure 1.

It is the areas with population densities under 1 person per km^2 in which aircraft are an important part of everyday life. In areas with over 64 km^2 per person the population is too sparse to support rural service towns or the customary service network. Many basic service functions are provided on the very large cattle stations, which each occupy between 4,000 and 20,000 km^2 and employ between 10 and 100 people. This concentration of population is sufficient for some propereties to have weekly air services, flying doctor clinics and twice yearly provision of bulk stores. In regions with population densities of between 64 km^2 to 8 km^2 per person, properties range in size between 80 and 300 km^2 and are mainly family run businesses. One day access to a small town with limited facilities is generally available to these properties. Larger towns with a reasonable range of services are not within single day access and a return trip may often take a minimum of 3 days. It is the properties and areas described above that are of

Country	Area (km^2)	Population (1981)	Pop. Density (per km^2)
Australia	7,687,000	14,926,800	2
Cont. USA	7,827,000	226,504,290	30
UK & NI	244,102	56,286,000	230

Table 1: Population Comparison

Population Breakdown		
Settlement	Area	Population
Closely Settled	1.6%	79.0%
Moderately Settled	15.7%	17.7%
Sparsely Settled	82.7%	3.3%

Table 2: Australian Population Breakdown

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*This work was carried whilst studying at Cranfield University

[1] This was the date of the last census in Australia and United Kingdom

Figure 1: Relative Size of Australia, USA and the United Kingdom

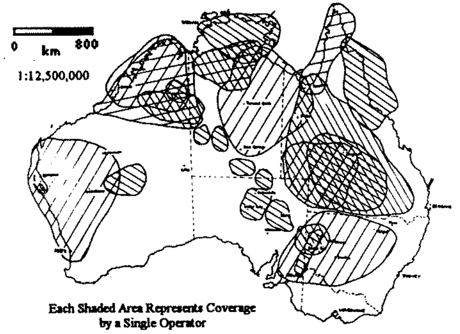

Figure 2: Aircraft Operating Regions

interest and this is the market for which this aircraft was designed. The remoteness and size of the properties are factors dictating the use of aircraft on a daily basis. Whilst tracks are available on many properties travel by vehicle is slow. To gain an insight into the daily operations of aircraft in these regions a questionnaire was formulated and sent to over 120 properties in Australia. The data received from these questionnaires was used to plot regions of aircraft usage on a map and this is shown in Figure 2.

Environment and Climate

Australia is located in the subtropical high pressure belt which results in clear, dry air and plentiful sunshine for much of the year. This, combined with the low altitude and greatest east west extent of the country above the Tropic of Capricorn, makes it the hottest continent in terms of duration and intensity of heat [1]. Frosts are common in the cooler months, however, these are rarely severe or prolonged. Only a small proportion of Australia is cold enough to receive appreciable snow falls.

The highest average temperatures generally occur in January over most of the continent and exceed 39°C over much of the northwest. Temperatures in excess of 50°C are common in western NSW, northern WA and the NT during the summer months due to sunny cloudless days and the hot northerly winds from the interior. The lowest average temperatures occur in midwinter. The average minimum temperatures fall below 6°C in inland regions south of the tropics. The relative humidity on the coast tends to be higher than that in the inland regions. This is due to the high level of water evaporating from the adjacent oceans. In the northern regions the summer humidity is relatively high, averaging over 80% in Darwin in January.

The global (short wave) radiation levels[3] in Australia are over twice the levels experienced by the United Kingdom and are often in excess of 900 mWh cm^{-2} day^{-1}. The total average annual hours of sun for the United Kingdom is under 1600 which contrasts with the 4000 hours received in the centre of Australia. A high level of solar illuminance indicates a high level of ultraviolet (U.V.) radiation which is important when considering material selection during the design process.

Impact on Aircraft Design Aircraft performance is very dependent on the physical properties (density and temperature) of the air in which it flies. The standard ISA atmosphere is designed for the atmospheric conditions normally found in temperate latitudes such as Europe and North America. For Australia, however, it is more appropriate to consider atmospheric conditions approaching those of the Tropical Maximum Atmosphere to cater for the weather conditions in Northern Australia. The design temperature was taken as 40°C, to ensure performance in these conditions. Degradation in the performance of the aircraft was accepted at temperatures in excess of 40°C and at altitudes above sea level.

The environmental factors have a large influence on aviation materials and performance. The main environmental factors to be considered for an aircraft designed for Australia include air temperature and humidity, solar activity and insolation, atmospheric electricity, precipitation - type and amount, ground strength and composition, dustiness, salinity of soil and water, biological factors, and wind.

The effects of temperature and humidity are combined in their impact on the aircraft. One of the worst conditions for attack on aircraft materials are those of high temperature and high humidity [2] which are characteristic of the tropical north of Australia.

High temperature lowers the performance of the aircraft with the engine thrust or power output being lowered as the temperature increases. In addition the available lift decreases with increasing temperature. These result in a longer take off and landing run, a decrease in the rate of climb, lowering in payload capacity and an increase in fuel consumption due to the lower engine output and consequently the engine must work harder.

Engine overheating is a problem associated with high temperatures. This may cause problems during flight as well as on the ground. The effect of high temper-

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[3] Global radiation includes the energy reaching the ground directly from the sun plus that received indirectly from the sky, scattered back down by clouds, dust and other aerosols.

ature is felt throughout the troposphere and temperatures may still be around 30°C at 1000m when the ground temperature is around 40°C!!

Australia is a country of very high solar illumination and the action of solar rays and the associated U.V. radiation have a dramatic effect on paint and varnish coatings. The coatings lose elasticity and crack allowing the weather to attack the bare materials. Cabin glazing is most subject to destruction under dry, hot, conditions. Microcracks form as a result of the crystallisation of acrylate under the action of the solar rays and this is typical damage in aircraft operated under these conditions for a period of 3 years [2]. Cabin glazing may also go yellow due to the action of the U.V. radiation. Other effects are the thinning of lubrication oils and greases and the effect of dust and sand once it has become trapped in hinges and bearings.

Design Specification

A questionnaire was formulated and forwarded to over 120 aircraft owners in these remote regions, by my parents and brother, to whom I am greatly indebted to for their time and assistance. Of those sent out around 50% were returned and analysed in conjunction with the airworthiness requirements of ref [3] to generate the specification.

This type of aircraft is a true bush aeroplane and is distinct from other classes of general aviation aircraft. These aircraft are a necessity to isolated communities and fulfill the role of a Four Wheel Drive (4WD) vehicle on smaller farms such as those in Europe. The aircraft is used as an everyday work vehicle to transport machinery and equipment and to check stock, fences and water, as well as for shopping, emergency evacuation and holiday travel.

Major design drivers were the operational and environmental conditions present in these regions. These had to be met in addition to compliance with all the statuatory aircraft design criteria.

From an inspection of the Australian civil aircraft register the Cessna 172 was the most popular aircraft in use on the properties. This was confirmed from the surveys returned where 51% of the aircraft were Cessna 172's; 16% were Cessna 182's and 9% were Cessna 150's. The aim was to improve on the performance characteristics of the Cessna aircraft whilst satisfying the other criteria determined from the author's knowledge of aircraft operations in these areas and the data from the questionnaire's. The preliminary specification generated was:

- High Wing - gives good visibility of stock and the ground, gets wing out of the way of low shrubs and rocks deflected by the wheels. Gives more storage space under the wings when housed in hanger/garage. A cantilever wing would be better from a clearance point of view however it has structural disadvantages.
- Improve Visibility - use of more transparencies around the doors and maybe over the roof. This was to aid visibility from the pilot's seat during operations.
- Take Off - 200 metres was aimed for. The current average from the survey was 348 m and 200m was an improvement over the quoted distances for the 172 - 264m and the 182 - 215m.
- Landing - 150 metres was aimed for. The current average from the survey was 296 m and the quoted distances for the 172 is 158m and for the 182 is 180m.
- Climb Rate at Sea Level - for compliance with BCAR 23 the minimum climb rate is 500 ft/min. The value quoted for the 172 is 880ft/min and the aim is to achieve at least 900 ft/min.
- Stall Speed - 50 knots or less was the target with the flaps extended.
- Range - the range was set at 600nm with a reserve capacity for 30 mins flying.
- Duration - the duration of flight was set to 5 hours minimum.
- Capacity - 4 persons plus payload. The occupants were assumed to be 90kg each and a minimum requirement of an additional 100kg of payload and 7kg of ancillary equipment to cover the pilot's equipment such as charts, manuals etc.
- Speed - cruise speed of around 140 kts which was an improvement over the 172 - 126kts and the 182 - 136kts.
- Undercarriage - Fixed undercarriage of the tailwheel type. Tailwheel undercarriage is lighter, has less drag and is better for rough field operations. Tricycle undercarriage was proposed as an option. Large tyres for rough field operations.
- Engine - Unleaded petrol or diesel were the preferred fuels due to their widespread use on the properties. Overheating needed to be considered.
- Fuel Consumption - under 8 gallons per hour at economical cruise, if possible.
- Handling - well harmonised controls, docile stall and non acrobatic general utility category.
- Maintenance - removable covers and openings large enough for easy access.

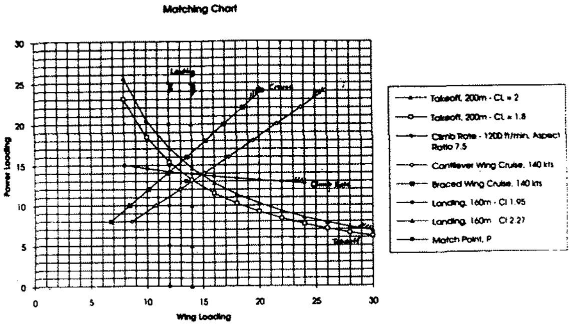

Figure 3: Matching Diagram

- Construction - conventional aluminium alloys to ease repairability and to minimise life cycle costs. Composites are not so well adapted to high solar illumination and ultraviolet radiation.

- Other considerations - simplicity and accident survivability are important; stretchability needs to be considered.

- Cost - ideally around $AUS80,000, however, this may be a little too optimistic.

From this specification the preliminary sizing was carried out.

The Design Process

The basic design philosophy followed was that of reference [4]. Initial sizing and weight estimation was carried out using the method of Loftin [5].

The values of the lift coefficient, lift to drag ratio, specific fuel consumption and propeller efficiency were all taken from data for similar aircraft. Using this data in conjunction with the specification the wing area, take-off power required and maximum lift coefficients in the clean, take-off and landing configurations were estimated. An analysis of the following performance criteria: stall speed, take off field length, landing field length, cruise and/or maximum speed, and climb rate resulted in a range of values for the wing loading, power loading, and maximum lift coefficient within which certain performance requirements were met. The combination of the highest wing loading and the lowest thrust loading which satisfied the requirements resulted in the lowest weight and cost of aircraft. The match point is shown in Figure 3 and the relevant boundaries are indicated on this diagram.

Later in the design process a detailed mass breakdown was used to verify the initial estimate. The final design details for the aircraft are contained in Table 3.

Configuration Design Two arrangements were selected which satisfied the following important requirements namely, good visibility, high wing for clearance, rough field operations, tail obstacle clearance, and ease of manufacture and maintenance. Their subsequent development was carried out considering a number of prime design considerations, short take off and landing, rough field operations, good visibility, and take off at maximum gross weight and 40°C.

Design Parameter	Units	Value
Lift Coefficient		
Clean	-	1.5
Take-Off	-	2.0
Landing	-	2.3
Wing Loading	lbs/ft^2	13.8
Wing Aspect Ratio	-	7.5
Wing Area	ft^2	261
Power Loading	lbs/hp	12.6
Take Off Power (min)	hp	284
Cruise Speed	kn	140
Stall Speed	kn	45
Take Off Distance	m	200
Landing Distance	m	150
Climb Rate	ft/min	1,200
Climb Gradient	-	1:15
"g" limits	m/s^2	$\pm 4g$
Gross Weight	lbs	3,600
Fuel	lbs	510
Payload Weight	lbs	400

Table 3: Kookaburra Design Parameters

Aircraft design is a parallel process and a decision in one area often has carry on effects in many other areas. The design of each component is thus inextricably related to the design of each and every other component. No one item can be designed in total isolation and the reasons for certain design decisions are detailed below.

Both aircraft arrangements were named after the well known Australian bird, the Kookaburra. The conventional tractor aircraft, Kookaburra I, offered with either taildragger or tricycle undercarriage. The pusher arrangement, Kookaburra II, was only offered with the tricycle undercarriage. Some of the major design features and considerations of these two arrangements are listed below.

Kookaburra I - Tractor Arrangement

- Thrustline is typically on or close to the aircraft centreline which influences stability.

- Tractor aircraft tend to be less stable than pusher arrangements

- Heavy engine up front tends to shorten forebody and allows a smaller tail area and improved weathercock stability

- Tractor arrangement is advantageous for engine cooling and the propeller is placed in undisturbed air

- Aircraft, however, flies in the propwash and the skin friction is thus higher.
- Normal arrangement - many aircraft of this type around and it is generally an accepted arrangement.
- Forward visibility is somewhat limited
- Higher noise level in cockpit although the slower revving engine used should assist in keeping this to a minimum
- Engine mounted on fuselage and structural attachments are fairly easy to arrange.

Kookaburra II - Pusher Configuration

- Thrust line is a long distance from centreline which means more control input required for pitch control between power on and off
- Pusher tends to be stabilising in static longitudinal and directional stability and the empennage may be smaller than for a similar tractor aircraft
- Pusher can reduce the skin friction drag as the aircraft is flying in undisturbed air
- Shorter fuselage means a reduction in wetted area
- Air flow into prop allows a much sharper closing angle on the fuselage without flow separation.
- Less cabin noise as the prop noise, exhaust etc are aft of the cabin. Windscreen is not buffeted by the prop wash
- Damage to prop may be more of a problem when stones are thrown up from runway
- More unusual arrangement
- Much better pilot visibility
- Cooling of engine may suffer a little.
- Rough field operations and clearances may pose some problems
- Engine may not be suitable for a pusher installation
- Engine is mounted high on fuselage and attachment may be more complex
- Clearance of the propellers from the fuselage is important to reduce noise and acoustic fatigue
- Propeller needs to be around 1/2 of the local chord aft of the wing trailing edge to prevent excitation by the trailing vortices

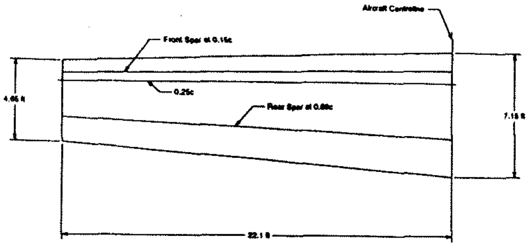

Figure 4: Wing Dimensions

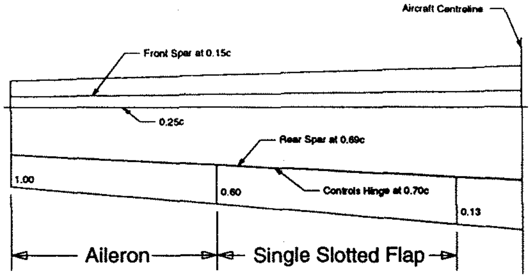

Figure 5: Flap and Aileron Disposition

Wing Location A high wing was selected as it gave a much better field of view downwards from the cockpit than the low winged configuration. The wing clearance above the ground was ideal for rough fields where small trees, shrubs etc. would cause problems for a low wing aircraft. The flaps and ailerons were also up out of harms way. Access to the rear cargo doors was better than on a low wing aircraft which was a major advantage. Finally, a high wing augments dihedral and provides a more laterally stable aircraft and this would be advantageous for the handling characteristics. The high wing would enable equipment to be stored under the wings when the aircraft is hangared - an important consideration when covered space is at a premium.

The high wing would protects the occupants from the sun thus aid in keeping the cabin cooler. The large shaded area under the wing gives somewhere to work whilst out in the field and in the event of an emergency landing may prove to be a lifesaver.

Single slotted flaps were selected to give the required lift increments for take off and landing. Single slotted flaps were not too complicated in design and arrangement yet gave quite good performance. The flap area ratio was selected to satisfy the increments in lift coefficient required from the flaps for take off and landing. The flap arrangement had to be compatible with the

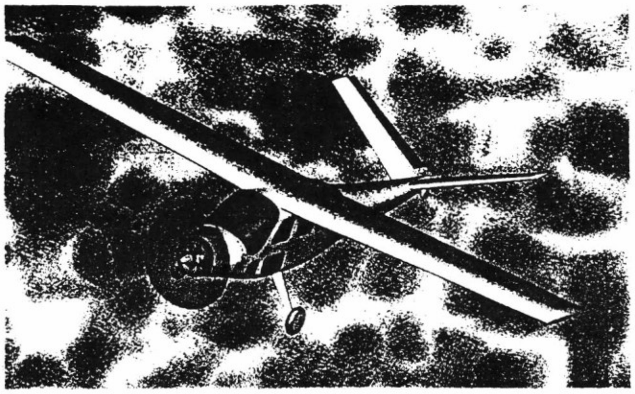

Figure 6: Kookaburra I - Taildragger

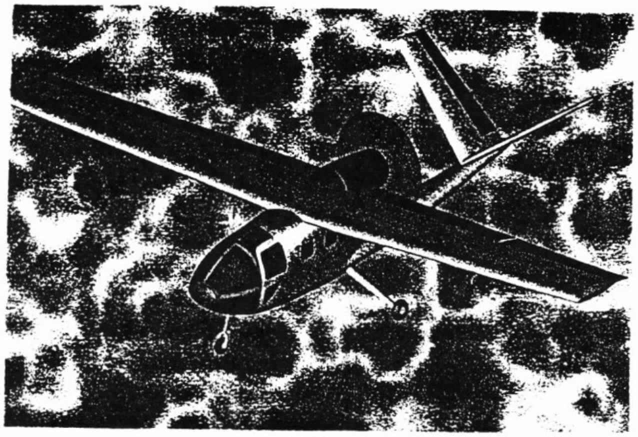

Figure 7: Kookaburra II - Pusher

requirement for roll control via the ailerons and typical aileron parameters for the chord and span ratios were selected from similar aircraft.

It was decided to carry the fuel in the wings to keep the centre of gravity in an advantageous position. The initial calculations indicate that there was ample volume in the inboard sections of the wing to achieve this. The fuel would be carried in separate tanks one installed in each of the wings. This would reduce the manufacturing complexity of producing wet wings with the consequent sealing and flow balancing problems.

The position of the spars was chosen to be compatible with the control surfaces and the front spar was located at 0.15c and the rear spar at 0.695c.

At this preliminary stage the design data was taken from an inspection of similar aircraft using the methods in ref [4]. The wing planform design is shown in Figure 4 the arrangement of the high lift and roll control surfaces are given in Figure 5.

Fuselage and Cockpit Layout In the early stages of the design the aircraft layout drawings consisted of hand drawn scale sketches for both aircraft arrangements. These sketches were used through the entire design process to calculate the cabin layout, the cg location and weight breakdown, the detailed drag estimation, and for locating the undercarriage.

Once the sizing and the layout were determined the aircraft were drawn on the Unigraphics II CAD package (UG) to produce the shaded images as shown in Figures 6 and 7 and the three view drawings in Figures 8 and 9. The use of CAD was valuable during the design stages as it enabled the three dimensional shape to be investigated and gave experience at lofting the fuselage and getting the interfaces to fit. Sizes of components and their relative locations and joins could be visually examined in three dimensions and the space available for people and equipment could be likewise examined. It was possible to move individual objects around and effect design changes with a minimum of effort.

The cabin and cockpit of both aircraft were required to house: 4 passengers (including the pilot), a 200 kg payload and a maximum payload volume estimated at 40

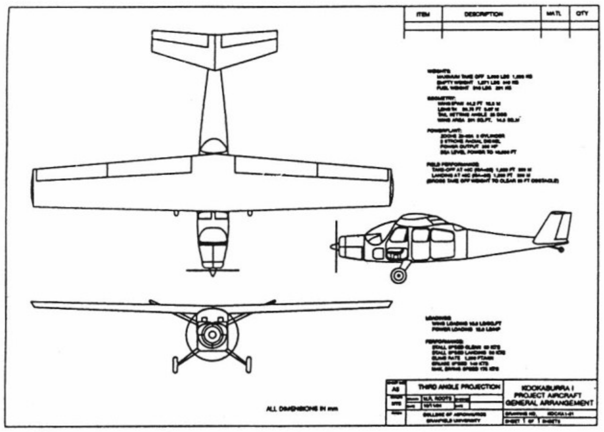

Figure 8: Engineering Drawing - Kookaburra I

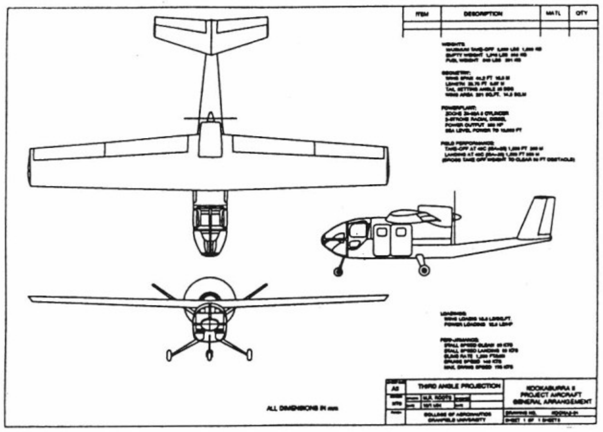

Figure 9: Engineering Drawing - Kookaburra II

ft^3. A two abreast seating arrangement was adopted for both of the Kookaburra aircraft. This was the most common for aircraft in this category and consisted of two cockpit and two passenger seats arranged in a conventional two by two arrangement. The cockpit and cabin area must accommodate the passengers and payload in reasonable comfort, a requirement which has a big influence on the sizing of the fuselage. The design person for the aircraft was a 97.5 percentile man (188 cm or 6ft 2in tall).

The aircraft was unpressurised due to the operational envelope and the aircraft size . This enabled slab sides to be used in the design with the consequent ease of manufacture and repairability built in. Slab sides enabled the best use to be made of the internal space in the aircraft and gave the passengers more head, shoulder and leg room. To keep the production costs low as much single curvature as possible was used in the skin panels. Single curvature panels make repairs simpler, cheaper and of course quicker - an advantage in the life costs of the aircraft. In selecting the overall cross section a comparison was made with similar aircraft. The general layout of Kookaburra I and Kookaburra II are given in Figures 8 and 9 respectively.

Better visibility from the cockpit than exists in the competition aircraft was one of the design criteria. This involved the use of more transparencies and placing them where they assist the pilot in getting a better view. For the tractor arrangement forward visibility was improved by the use of a large single piece windscreen. The pilot was placed reasonably far forward in the cockpit to give improved visibility in turns. Side view was enhanced by the addition of windows in both the upper and lower sections of the front doors. Small windows were included in the front footwells improving the forward and downward visibility in level flight and turns. Transparencies were considered for the roof area, however, at this stage have been neglected. Windows that can be opened in flight were considered useful for the purposes of shooting and baiting. The arrangement proposed was to have the upper window section of the front doors as a drop window, which gave a large opening for carrying out the required operation. An added advantage of this arrangement was its secondary function as an emergency exit.

The pusher aircraft had visibility which was far superior to that of the competition. The cockpit glazing consisted of a large helicopter style bubble canopy. This transparency runs from the pilot's seat forward resulting in superb vision even in a turn. The canopy was composed of several sections thus lowering the manufacturing costs and making replacement of damaged panels cost efficient.

The doors were arranged to enable easy access to and from the aircraft for the crew, passengers and the cargo. The pilot and co-pilot have doors adjacent to their seats thus making access to the cockpit easy. The passengers and cargo would be loaded via the large double doors situated on both sides of the rear fuselage. Ease of loading would be facilitated by the cargo area being in close proximity to the ground. The cargo area was designed to be flexible in its uses. The rear seats were designed to be easily removable yet secure in crash conditions. The removal of the seats exposes a much greater volume for the payload. The floor in this area was provided with many tie down points to maximise the flexibility. The large rear door was designed to slide open and not swing. This was selected for security in flight as a rearward opening door is unstable and a large door swinging open in flight could prove disastrous. Another advantage of this door arrangement was the ability to open the door in flight to enable food drops etc. to be made to stranded animals in times of flood.

Empennage The "V" or butterfly tail has been used on a number of aircraft in the past. This arrangement was selected for this aircraft due to the need to keep the tail away from low shrubs and obstacles on rough fields, especially in the case of the tail dragger arrangement. The butterfly tail manages this by having the surfaces angled upwards and an additional benefit is the creation of storage space under the tail when it is hangared.

There were a number of potential benefits to be gained from the vee tail arrangement. These include, lower drag because the vee-tail only has two tail junctures, less tendency for rudder lock, higher location of tail surfaces leading to a reduction in elevator deflection required at take-off and landing, and fewer tail surfaces to manufacture. Disadvantages also exist with this arrangement and these need to be investigated fully in later design stages, possible interaction of elevator and rudder control forces, and greater loads on the tail and fuselage and this may lead to an increase in weight. Vee-tails, however, appear to have better spin recovery characteristics than conventional tail arrangements [6]. This is possibly due to the absence of horizontal tail surfaces blanketing the fin.

The initial tail setting angle of the pusher aircraft was calculated to be 25°. The subsequent stability analysis indicated that an angle of 35° was required and was taken as the final design value.

Stability and Control A preliminary investigation of the static longitudinal and lateral directional stability was carried out for both arrangements. A 10% static margin [4] was required for the longitudinal stability and this was easily achieved for both configuration. The method of reference [12] was used for calculation of the the lateral stability. For the tractor aircraft the tail setting angle of 25° was found to be satisfactory. For the pusher arrangement it was found necessary to increase this setting angle to 35°.

Propulsion System The aircraft would be operated mainly between 50 and 10,000 ft altitude at speeds between 50 and 140 knots and for this type of operation a piston engine was ideal.

In general the tractor is a more accepted aircraft configuration and more engines are available off the shelf to satisfy this requirement. There are, however, advantages and disadvantages for both the tractor and pusher arrangements.

A tractor arrangement is somewhat better from both an aerodynamic (propeller) and structural (engine attachement) viewpoint. The ability to mount the engine close to the aircraft centreline results in small trim changes between power on and power off. Disadvantages of the tractor arrangement include the proximity of the propeller to the ground and to possible damage. The cabin noise may be higher due to its proximity to the propeller and exhaust.

A pusher configuration may produce a reduction in the cabin noise as the major noise sources are aft of the cockpit. Pushers tend to be stabilising and the consequence is that the tail area may be able to be reduced. A high engine mounting results in the propeller being out of the way of damage from stones and other foreign objects.

Design of the engine installation would be more difficult for a pusher. If the prop is too close to the fuselage there may be problems with acoustic fatigue and the fuselage may transmit these vibrations, as sound, to the cockpit. The thrust line is a reasonable distance from the centreline of the aircraft and trim changes may be significant between the power off and power on cases. Access to the engine for maintenance may be more difficult due to its high location. Due to the high operating temperatures in Australia engine cooling may be more of a problem with the pusher due to reduced cooling air flow. No information was available from the manufacturer as to the suitability of the engine selected for a pusher installation.

The required power was estimated to be 284 hp for takeoff. It has been reported that aircraft often lack power [7] and some reserve is required to give the pilot a small margin for error. Consequently engines with power outputs of between 280 and 310 hp were selected from reference [8]. From the engines examined the Zoche (Germany) ZO-02A - eight cylinder radial two stroke diesel engine was selected. The power (300bhp) was sufficient for the aircraft, and it was much lighter (118kg) and more compact than the competitors. Diesel fuel is cheaper than other fuels, is more readily available and is much less flammable. Diesel engines have direct fuel injection and consequently have no need for carburettor heaters. There are no magnetos and no engine electrical ignition system, vapour lock is eliminated with diesel fuel - a problem with certain other fuels in hot temperatures. The low parts count and the general ruggedness of diesel engine components should be an advantage in keeping maintenance costs low and achieving high reliability.

The less stringent cooling requirements of the diesel engine, combined with a good inlet design may go a long way to alleviating the overheating problems reported whilst both taxiing and flying. Inlet and cowling design was carried out using the methods proposed in reference [9] and [10]. Information on the engine was sought from the manufacturer, however, very little was obtained and the cooling and performance of the engine in Australian conditions needs to be checked.

Propeller Selection Preliminary design of the propeller was carried out and a three bladed propeller of diameter 1.98 m was selected. This gave adequate ground clearance for the tractor aircraft and clearance for the pusher aircraft from the fuselage. Constant speed and fixed pitch propellers were considered and the constant speed prop was selected. The additional cost, complexity and weight were considered justifiable as the flight conditions of the aircraft vary significantly. The aircraft needs to perform well in take off and landing as well as high speed cruise and in low speed configurations whilst loitering. The use of a fixed pitch propeller is too much of a compromise for the variety of operation of this type of aircraft.

Landing Gear The aircraft is a high wing configuration and consequently mounting the undercarriage on the wing was not considered. This arrangement would result in a "leggy" construction with increased drag and the need to increase the wing structure to take the high landing loads.

The aircraft was designed to operate in hot and dusty conditions where the maintenance facilities are often remote. These factors influenced the selection of a fixed undercarriage and the simplicity of fixed gear should have benefits in the reduction of life cycle costs. The drag penalty was considered worth the saving in weight due to the relatively low cruise speed of 140 knots.

For the tractor aircraft both conventional or taildragger and tricycle undercarriages were proposed. The taildragger is more suited to soft rough field operations, however, flying training in recent years has taken place mainly on tricycle undercarriage aircraft. Consequently the majority of pilots have little or no experience with conventional landing gear arrangements. As a consequence the tricycle undercarriage was proposed to satisfy the market forces.

Several respondents to the survey had lost nosewheels

when landing - this is a real possibility and relatively easy to do when operating from rough strips.
The visibility over the nose of the taildragger aircraft is poor during ground operations however this is not a significant problem when very little taxiing is required.
The tailwheel aircraft undergoes less pitching changes of the wing leading edge during the take off run and the take off is thus reduced on rough fields.
The tricycle gear option was proposed for the tractor aircraft and was the only option used for the pusher aircraft. Whilst a taildragger version of the pusher was feasible it would result in the cockpit being quite high off the ground and the pilot access would be compromised.
The advantages of the tricycle arrangement were the good visibility over the nose during ground operations. The aircraft is more stable but not immune to ground looping and the steering is good. The nosewheel is very vulnerable to damage from hitting foreign objects on the runway. This can be compensated for by beefing up the nosewheel arrangement, however, there is a weight and drag penalty as a result.
The main landing gear design was of a simple conventional arrangement. The main gear was designed to be relatively light and cheap and the legs were of flat spring for minimal maintenance. The main wheels were low pressure tyres suitable for soft and rough field operations.
The undercarriage designs could be met within reasonable cg limits. The location and track of the arrangements provided suitable angles to minimise the risk of tipping over.

Other Design Requirements and Features

Airconditioning was considered essential for this aircraft to make the work environment pleasant for the operators. The importance is higher in the case of the pusher which has a large greenhouse on the front of it. It would be undesirable to have the airconditioning required for ventilation of the cabin. Windows which could be opened are an advantage in this operational environment for cooling of the cabin area when the airconditioning is not in use.

Materials and Manufacturing Considerations

Composites were not considered suitable for this aircraft due to the operational environment and repairability aspects. Composites are not ideal contenders for regions of very high solar illumination or high humidity and the combination of these two factors is worse [2]. Impact damage to composites is not readily visible and may result in significant loss in strength. Repairability is a difficult area and this is especially of concern in remote areas where there are no advanced facilities for laying up and curing repairs and little experience in repairs to composites. The fatigue life of composites is difficult to predict and with an aircraft which is expected to have a service life of 30 years this is an important consideration.
An all metal construction was proposed and the corrosion protection of the structure is an area that needs careful attention. Metals tend to be consistent in their properties and the manufacturing processs used do not result in a variation of material properties with operator skill. The aircraft was designed with a minimum number of components of double curvature - this cuts down on the manufacturing costs and makes the repair of damaged panels more straightforward. The repair of metal panels is well understood and arranging for repairs to be carried out in the remote areas of operation should not provide any problems. Metal structures are impact resistant and impacts that do cause damage do so in a visible way.

Crashworthiness Crashworthiness was a prime consideration due to the statistics received from the questionnaire (27% of owners had been involved in aircraft accidents).
The human body can withstand for 0.10 sec, longitudinal accelerations of ± 45g on the chest or back, lateral accelerations up to ± 11.5g and vertical accelerations along the spine of ± 10g [11]. Consequently fitting aircraft with full shoulder harnesses which can withstand 40g for a 40kg upper torso should increase survivability in impacts. Seat materials are available which can absorb the energy of loads for the vertical accelerations mentioned. It is important to pay careful attention to the attachment of the seats and harnesses to the structure. This combined with an aircraft forebody capable of withstanding 20g for 0.10 sec have been shown to be methods of greatly improving impact survival [11].
Both aircraft would be designed with a crash box around the occupants. Designing the wings to fold forward at around 15-20g and the engine to separate at similar levels would reduce the deceleration loads significantly. Bevelling of the front firewall on its lower edge would reduce the tendency to plough the ground in impacts where the landing gear (especially for for tricycle undercarriages) was lost or damaged.
With these design features incorporated and relatively low landing speeds the impact forces should be able to be reduced and crash survival increased. This is an area that needs more investigation and careful consideration in the detailed design stages.

Cost Analysis

The cost of the aircraft is a very important consideration and one that can make or break the company producing it. With a large number of second hand aircraft being available at reasonable cost the job of selling

Second Hand Aircraft	
Aircraft	Price Range $US (1994)
Cessna 120/140	7,800 - 12,500
Cessna 150	6,000 - 18,000
Cessna 152	12,000 - 28,000
Cessna 172	12,000 - 60,000
Piper Cherokee 140	12,000 - 18,000
Piper Archer	32,000 - 65,000
Beech Sundowner	17,000 - 39,000

Table 4: Second Hand Aircraft

Aircraft Cost Estimates		
Method	Number of Aircraft Produced	Cost $US
Raymer	1000	338,373
Roskam	1000	393,605
Raw Data	1000	122,000

Table 5: Aircraft Production Cost Estimation

would be even more difficult. Typical second hand aircraft prices from the American market [13] are quoted in Table 4.

An estimate of the cost of the aircraft was required to compare it to the prices for second hand aircraft. Initially the methods of Roskam, ref [4] and Raymer [14] were used. Both these methods were based on the Rand Report [15] and it was found that the aircraft used for this report were military and consequently did not represent general aviation aircraft. Estimated costs from both methods are given in Table 5.

Prices for light single engine general aviation aircraft between 1982 and 1992 were obtained from reference [16]. This data was used to draw a number of graphs to try to correlate the aircraft cost to some parameter such as take off weight or wing loading. The results from two of the analyses can be found in Figures 10 and 11. Using this data estimated an aircraft cost of between $US96,250 and $US180,000. Clearly these methods gave some difficulty in estimating the aircraft price due to the large amount of scatter in the raw data.

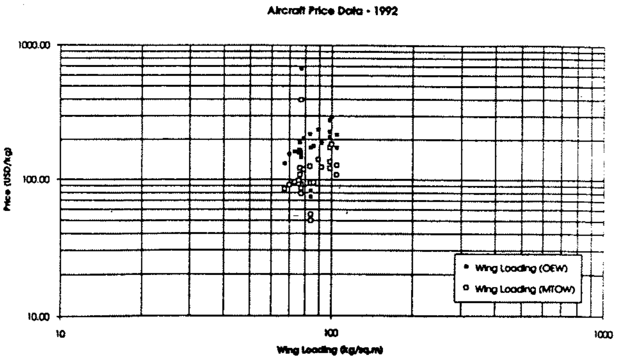

Figure 10: Single Engine Aircraft Costs - Wing Loading versus $US per kg

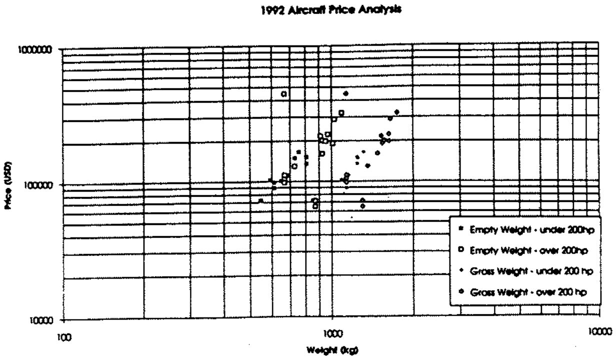

Figure 11: Single Engine Aircraft Costs - Aircraft Weight vs $US per kg

Another aircraft cost estimation method was proposed based on engine price. It would appear that the engine of single engine aircraft represents between one third and one half of the total aircraft cost. Thus with an engine costing $US40,000 the aircraft could be expected to cost between $US80,000 and $US120,000. An average was taken from all the figures based on light aircraft and the cost estimate for this aircraft was around $US122,000 (approx. $AUS135,000). This value is tabulated along with aircraft price estimates from Roskam [4] and Raymer [14] in Table 5.

Reference [17] gives data on the learning curves for production of the Cessna 172 and for the 100th aircraft this was approximately 1,150 hours. It was assumed that the airframe was the only manufactured component and that the cost of the purchased items was similar to that for a Cessna 172 [17] which in 1989 was $AUS54,464. Taking the aircraft production cost to be $AUS135,000 then the manufactured components would cost approximately $AUS81,000. Certification costs may amount to $AUS1.07 million [17] and these would be in addition to the cost of the aircraft manufactured parts. These costs need to be considered together in a net present value analysis to determine the profitability and break even point for this aircraft. This was considered beyond the scope of this investigation at this time.

It has been reported [18] that the direct costs of producing aircraft in India is one third to one fifth the cost of producing the same in the Western World. The labour cost on a per pound of aircraft component manufactured is $AUS 0.90 - this is for very skilled labour. The cost of an experienced Engineer is around $AUS 650 per month and access to CAD and other advanced engineering tools is relatively easy. India (and for that matter countries in the old eastern block) have a vast amount of experience in producing aircraft and aircraft components. It would be necessary to arrange for the raw materials to be shipped to the manufacturing company in India and for the completed product to be shipped out. The assembly could be carried out in India or the completed components could be shipped back to Australia for assembly.

Taking the cost estimated above for the manufactured components of the aircraft the cost in India of producing the same airframe would be in the range of $AUS16,200 and $AUS27,000. The resulting aircraft could be expected to be produced for approximately $AUS76,000.

Conclusion

Two aircraft were proposed as a result of this conceptual design study. Both aircraft were designed to satisfy the specification and to operate in the harsh Australian environment.

Both aircraft provided better visibility than the competition and were designed with the operating conditions in mind. The vee-tail was adopted to give better clearance from obstructions when landing. Large cargo doors provided excellent access for loading freight and passengers. A flexible interior layout with removable seats and a large number of load restraint points were important design features for these aircraft. The aircraft appear to have satisfactory control characteristics and an adequate centre of gravity range.

The cost of producing the aircraft in Australia was estimated to be $AUS135,000. This could be reduced to approximately $AUS 76,000 by producing the aircraft in a country with aircraft production experience and low labour rates. Overall the objectives were met and the two proposed aircraft offer superior performance and flexibility over the competition.

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