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ENGINEERIG AIRCRAFT DESIGN REPORT

TOPIC: SADC AERIAL SAFARI

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NOMENCLATURE

R:	radius of turn [m]
AR:	Aspect ratio
Cl:	Lift coefficient
C_{Do}:	Zero-lift drag coefficient
Cl_{max}:	Maximum lift coefficient
D:	Total drag [kg]
g:	Gravitational acceleration: 9.81 m/s^2
M:	Mach number
Vs:	Stall velocity [m/s]
n:	load factor
W	weight [kg]
h:	Obstacle height [m]
Sref:	Wing reference area [m^2]
T:	Thrust [kg]
b:	Span [m]
t/c:	Thickness to chord ratio
V_{mc}:	Velocity of minimum control [m/s]
V_{so}:	Stall speed in the landing configuration [m/s]
µ:	Density of air at sea level: 1.225 kg/m^3
σ:	Relative density
Cm_0:	Moment coefficient at 0 degrees
λ:	Taper ratio of the wings

ABBREVIATION

KCAS: Knots Calibrated Air Speed

KTAS: Knots True Air Speed

NACA: National Advisory Committee for Aeronautics

SEP: Specific Excess Power

SFC: Specific Fuel Consumption

The SSS: The SADC super Safari

2. EXECUTIVE SUMMERY

The Southern African Development Community is a region that consist of 15 most Southern countries that came together to achieve economic development, security and peace for its people using region integration, trade and social connections [6]. Most of the countries under SADC region have amazing natural landmarks and wildlife and this present opportunity for the tourism sector. The tourism industry in this region has established itself over the years through itineraries that use a car or boat for transportation and more often offer packages for one country. The main purpose of this design report is to retrofit an old aircraft that will be able to travel from Skukuza to the Victoria Falls, Okavango Delta, Skeleton Coast and Table Mountain to explore and view these magnificent features. [7]

The solution is generated by studying old popular passenger aircrafts in Africa then retrofit the cabin and power-plant to meet user requirements and specification. Changing the Cabin involves upgrading seats and maximise space for comfort and luxury. Changing the power-plant translates into increasing flight performance such as climb, range, range and cruise. The mission profile is significant in developing performance and characterises of the selected aircraft.

The selected aircraft for upgrade is the Cessna 208 Caravan and it is fitted with a Honeywell TPE 331-12JR turboprop engine [10] and the cabin seat capacity is increased by reducing number of seats to six and use the Aurora interior seats designed by WipAire Seat Inc. [14]. This concept failed to meet range requirements because fuel payload was at 70% however the concept was revised and it met all requirements and specification by 96% after increasing fuel payload to 100%.

3. MISSION PROFILE

The flight mission is divided into two flight plans in order to refuel and comfort break for the tourist at Camp Okavango Airport.

3.1. Flight Plan A:

The flight mission take-off is at Kruger National park Airport [South Africa] and loiter at Victoria Falls [Zimbabwe] at 1500ft to view the water fall attraction. The next view attraction is at Okavango Delta [Botswana] where the aircraft will loiter at 1000ft and thereafter land at the Camp Okavango Airport for refuelling and comfort break. The first flight mission covers 2000km including loitering before refuel. Figure 1.[9]

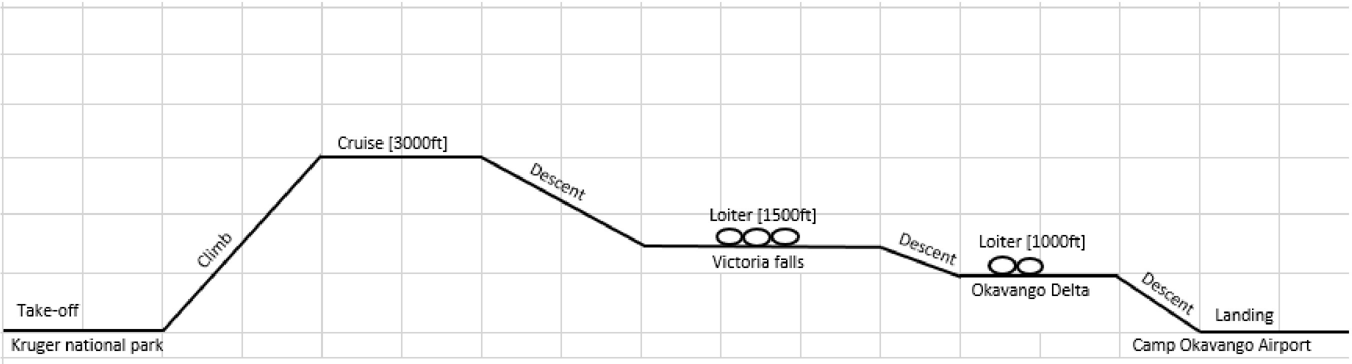


Figure 1: Flight plan A

3.2. Flight Plan B:

The flight mission take-off is at Camp Okavango Airport [Botswana] and loiter at Skeleton coast [Namibia] to view the skeleton attraction on the coast. The next view attraction is at Cape Town Table Mountain where the aircraft will loiter and manoeuvre the mountain at 6000ft and thereafter land at the Cape Town International Airport. The second flight mission covers 1990km including loitering before landing at Cape Town International Airport. Figure 2. [9]

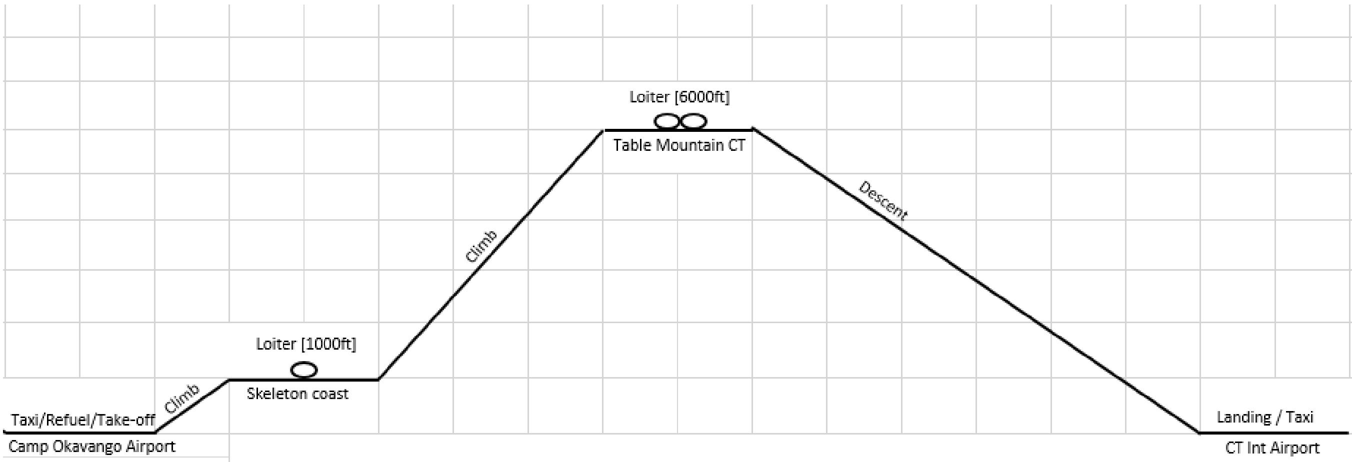


Figure 2: Flight plan B

The mission profile presents requirement and constrains for cruise performance because at low altitude density is high and at high altitude density is low which consequently affects the drag and lifting capabilities for the aircraft. The mission profile requires the aircraft to have range capability of more than 2000km before refuelling.

4. LITERTURE SURVEY

4.1. Aircraft retrofitting

The aerospace industry must contend with stricter requirements for cost-benefit, pollution [emission, noise] as well as well as rising passenger expectations for comfort and luxury. Bush planes or aircraft used for wildlife in South Africa are often old aircraft which can benefit from new technologies and upgrades in regards to performance and comfort. Contemporary aircraft are expensive to buy and maintain compared to old aircraft however old aircrafts are likely less costly but not efficient. Retrofitting presents an opportunity for old aircraft to improve performance and comfort without compromising the structural integrity of the aircraft. This project focuses on retrofitting the engine, cabin and wing design to upgrade passenger comfort and improve performance for SADC Safari tourism purposes. [4]

4.2. Airport field specifications

The airport specified by the mission profile are commonly used by small aircraft because the runway length is usually small which affects field performance requirements for landing and take-off. The purpose of this survey is to determine runway length for the specified airports which inform field performance requirements.[9]

Airport name	**Runway length**	**Altitude above sea level**
Skukuza International airport	1550 m	1020 ft.
Camp Okavango airport	1260 m	3150 ft.
Cape Town International Airport	3201 m	151 ft.

Table 1: Airport runway data

The field performance should be less than 1200 m for landing and take-off in order to complete the mission.

4.3. Engine retrofit

There are currently two companies certified to retrofit the standard Cessna 208 Caravan namely Blackhawk Aerospace and Texas Turbines Conversions Inc. [10]. The Blackhawk engine upgrade claims to improve performance by 28% increase in available horsepower, 37% increased climb rate and take 2 weeks to install [11]. The Texas Turbines Conversions promises shorter take-off distance, quitter flyover and better climb and cruise performance with less fuel burn [ref]. Refer to Table 3 for specification.

Specification	Standard Cessna 208	Blackhawk Aerospace	Texas Turbines
Engine name	Pratt & Whitney PTGA-114A	Pratt & Whitney PT6A-42A	Honeywell TPE 331-12JR
Horsepower	675 shp	850 shp	900 shp
Torque	1865 ft-lbs	2480 ft-lbs	2971 ft-lbs
Max gross weight	8750 lbs	n/a	9062 lbs
Empty weight	5000 lbs	n/a	5100 lbs
Max payload	3750 lbs	n/a	3962 lbs
Take-off distance	1405 ft	n/a	825 ft
Landing distance	950 ft	950 ft	950 ft
Climb rate	925 ft/min	1267 ft/min	1559 ft/min
Endurance	5.1 hrs	n/a	4.5 hrs
Max range (max cruise)	1600 km	n/a	1690 km
Max cruise speed	175 kts	195 kts	198 kts

Table 2: Existing Caravan engine retro-fits

Table 3 compares engine upgrade performance parameters and the Pratt & Whitney PT6A-42A engine has less aircraft performance output and information [13].

4.4. Cabin retrofit

The standard passenger only Cessna 208 Caravan comes with 5 rows of two seats with a walking passage in the middle. The standard passenger cabin design is designed to optimise passenger payload and typical used short flight application. The seats are narrow to for comfortable seating See Figure 4.

Figure 3: Standard passenger cabin

The alternative standard passenger cabin Caravan version has 4 rows of seats a walking passage between the seats and a lavatory at the back. The lavatory add as a comfort feature by sacrificing the last row of seats. The lavatory standard version is preferred for long flight application however the seats are not luxury grade. Figure 5 shows executive cabin layout for a Cessna Caravan which includes luxury comfortable seats, food tray and screen. This cabin layout is preferred for long distance, executive class passengers and it caters for 6 passengers. [14]

Figure 4: Executive cabin layout

Cabin design is a significant part of retrofitting the Cessna Caravan because comfort and feature necessity has to be optimised for instance there is no need to have display screens since the flight mission involves sightseeing however a food tray could add value for passenger experience provided the itinerary includes snacks or meals.

‘

4.5. SADC flight regulations for tourism purposes

The pilot will have to be in possession of flights permits from the country's Civil Aviation Authorities i.e. SACAA, ZCAA, BCAA, NCAA. The flight permits are obtained prior to the flight by submitting the complete (a) flight schedule, (b) entry point and exit point and (c) lead passenger details [pilot]. It should be less costly for the pilot to obtain entry to the SADC region for tourism purposes because the countries on the mission are part of the Africa Continental Free Trade Area. The trade agreement allows African countries to trade amongst each other without cross border tariffs. The flight plan presents a business case opportunity for investors who wish to explore the SADC tourism market.[7]

Low flying aircraft may course noise pollution which can disadvantage wildlife spotting hence it's advisable to use an aircraft with less noise for low flying flight missions. Capitalising on reducing engine noise will give tourists a higher wildlife spotting chances which add to more value on the flight experience. There is currently no detailed regulation that prescribed what decibel range/noise intensity of engine sound is allowed for low flying aircraft in wildlife environment however to increase customer experience for wildlife spotting a low noise or silent engine could be beneficial.[7]

4.6. Other air vehicle solution

Hot air balloon is an air vehicle that is attached with wicker basket which carries passengers and is propelled by combusted fuel which becomes the hot air that fills the balloon for lift. The balloon uses wind speed at different altitude to control up and down steering and cannot be steered into direction without changing altitude. The hot air balloon that are commonly used for tourism purposes because of the viewing experience but for less than 40 km radius exploration and the speed is very slow 8-10 mph Figure 5.

Figure 5: Hot air balloon

Helicopters are a type of aircraft that uses overhead rotors to provide lift and propulsion and they are controlled using empennage and blade pitch, Helicopters can take-off vertical, hover and manoeuvre easily around obstacles. Helicopters are design for short flight range of between 320 km to 700 km and the rotor blades are generally noisier than aircraft propellers. They generally used for rescue mission, sightseeing and tourisms because of their manoeuvrability and aerial viewing capacity see Figure 6.

Figure 6: Helicopter over Table Mountain

The above alternative solution are not considered for this design report because of their range and speed constraints for this mission profile however for a short flight plan they are competitive against convention aeroplanes.

5. TASK STATEMENT

The primary task for the design report is develop a concept aircraft that is used for touring Southern African landscapes for tourism purpose. The concept aircraft should be able to travel to Zimbabwe, Botswana and Namibia from South Africa giving tourists a comfortable bird's eye view of the natural landmarks and wildlife. The tourist attraction feature include wildlife in Kruger National Park, The Victoria Falls, Okavango Delta, Skeleton Coast and Table Mountain. The concept solution presents a business case for investors in tourism to diversify, broaden the tourism sector which consequently will strengthen developmental relationships within the SADC country members. One of the SADC goals is to improve trade and between countries integrate tourism industry offers a way of fulfilling this goal.

The concept solution should be a popular passenger aircraft in Africa that can upgraded to fulfil mission profile and user requirements and specification. The selected aircraft should be capable of low flying and provide aerial vision without any obstruction. The aircraft retrofit should focus on engine and cabin upgrade however the structural integrity of the aircraft should not be compromised. Retrofit the engine of an old common aircraft to improve its climb and cruise performance. Perform aircraft analyses and define the characteristic of flight parameters of the concept solution. Some of the aircraft characteristic include drag analyses, lifting capability, empennage stability and loitering capability. Retrofit aircraft cabin by upgrading seats and passenger space to provide luxury and optimised flight comfort.

6. FUNCTIONAL REQUIREMENT AND LIMITATIONS

These are the functions and capabilities that the retrofitted aircraft is expected to perform for the SADC Safari mission.

- Cabin furniture should be aesthetically pleasing and comfortable.
- The aircraft must complete mission profile and refuel once during the Safari tour.
- The aircraft should be able to manoeuvre land marks and give tourists best view experience.
- Aircraft noise must be regarded as some nature conservation areas may have noise restriction.
- The aircraft should perform efficiently for low altitude flight.

6.1. AIRCRAFT REQUIREMENTS AND SPECIFICATION

The aircraft requirements and constrains are derived from functional requirements and flight limitation. The retrofitted aircraft must satisfy these design expectation and criteria in order to be rendered a solution. [4]

6.1.1. Requirements

- Climb rate must be greater than 2000 ft/min.
- Minimum cruise flight range must be at least 2000 km.
- Take-off and landing distance of below 1200 m.
- High wing configuration.
- Radius of turn should be more than 120 m.
- Load factor of less than 3 during loitering.

6.1.2. Constraints

- Low flying capability.
- Low noise engine retrofit.
- Maintain aircraft structural integrity.
- Low maximum take-off weight.
- Luxury Cabin.

6.1.3. Criteria

- Aircraft should be popular in the African market.
- Aircraft first release should be at least 30 years old.
- Flight mission should adhere to area flight regulations.
- Engine retrofit with low fuel consumption.

7. AIRCRAFT SELECTION

The approach to selecting the aircraft is opting for the commonly used aircraft for Safari in Africa that have high passenger capacity, low maximum take-off weight and old release year. [13]

Aircraft	African Popularity	Passenger capacity	Weight MTOW	Year
Pilatus PC-12	Moderate	6-9	4740kg	1991
Cessna 210 Centurion	Highly	5-6	1814kg	1957
Cessna 208 caravan	Highly	9-13	3629kg	1981
Beechcraft Bonanza G36	Highly	5-6	1726kg	!947

Table 3: Common Safari aircraft

Declined: The Pilatus is not very popular in Africa and has high MTOW even though it has high passenger capacity.

Declined: The Cessna 210 Centurion is popular in Arica, low MTOW and has older year release however it has low passenger capacity.

Declined: The Beechcraft Bonanza G36 is popular in Africa, low MTOW and has older year release however it has low passenger capacity.

Selected: The Cessna 208 caravan is selected for retrofit because it is popular in Africa, has moderate MTOW, fairly old release year and highest passenger capacity. The Caravan also has high wing configuration which is a criteria for ground view impediment.

The Cessna 208 caravan Figure 3 is a high wing aircraft with conventional tail configuration powered by a single turboprop engine. The standard variant has non-retractable landing gear and four rows of 2 seats behind the cockpit seats.

Figure 7: Cessna 208 Caravan

8. DESIGN DEVELOPMENT

The retrofit design development is comprised of selecting the best available engine upgrade for the Cessna 208 and cabin design upgrades. After the retrofit development the standard Cessna 208 Caravan performance will be compared with the retrofitted Cessna and thereafter evaluated against the PRS. For the purpose of this project and reference, the retrofit Cessna 208 Caravan is named The SADC-Super-Safari or The SSS. [13]

8.1. CONCEPT DEVELOPMENT

8.1.1. Engine retrofit

The standard aircraft is retrofitted with the Honeywell TPE 331-12JR power-plant because it has 225 more horse power and 1106 ft-lbs more torque than the Pratt & Whitney PTGA-114A fitted on the standard Cessna 208 caravan. The Honeywell power-plant is certified for 76 decibels i.e. meets enhanced noise protection order. The Pratt & Whitney PT6A-42A power-plant retrofitted by Blackhawk Aerospace has less horse power and torque. [10]

Figure 8: Honeywell power-plant retrofit

The immediate distinction of the standard engine and the Honeywell is the number of blades where the standard power plant has three propeller blades and the Honeywell retrofit has four blades see Figure 6. Using a power-plant with more horse power and higher torque implies the aircraft has decreased endurance, increase cruise speed and climb rate and increase flight range. To meet the user requirement and specification the aircraft should cover more distance quicker and efficiently.

8.1.2. Cabin retrofit

The main assumption of cabin retrofit is that cabin seats retrofit should equal to weight of the standard cabin seats. Figure 7 and 8 shows the top view and front view sketch of a standard Cessna 208 and it can be seen that seat and leg space is 0.92m which does not allow for leg stretch. The width of the seat is around 0.47m which is narrow and it does not have arm rest for the long journey. [14]

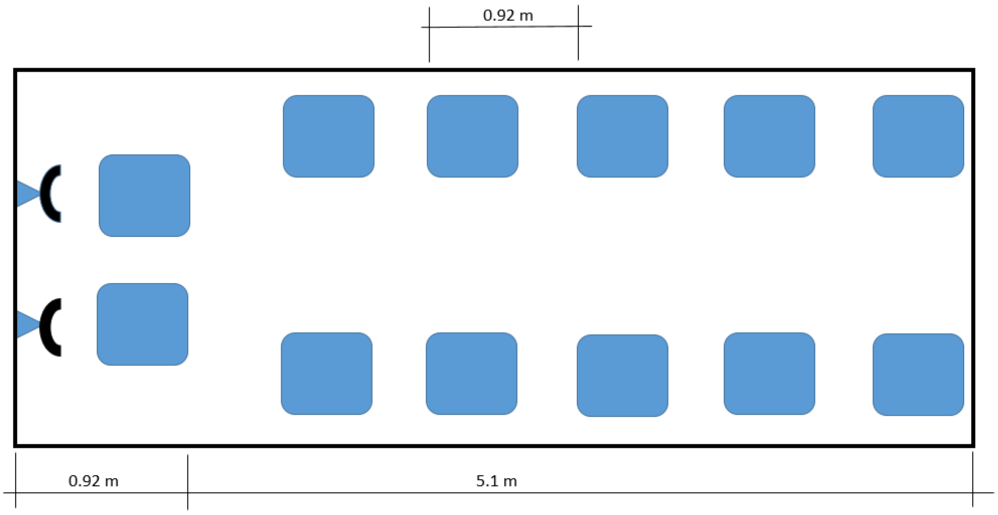


Figure 9: Standard interior cabin top view sketch

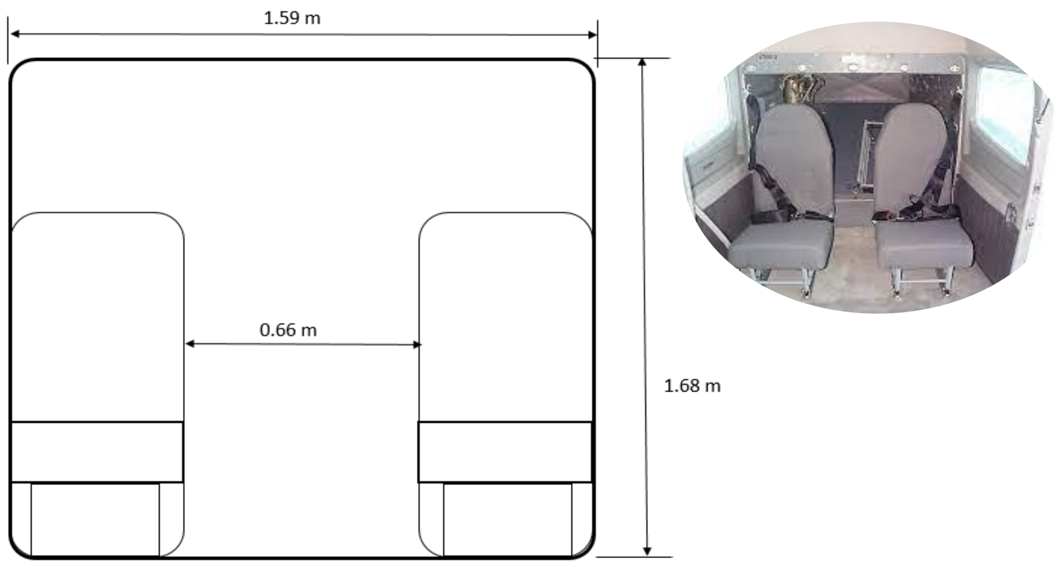


Figure 10: Standard interior cabin front view sketch

The SSS cabin is design to have 3 rows of seats that accommodate 6 passengers. The idea is to fit luxury comfortable seats with arm rest and also reserving a space for a food tray. Figure 9 and 10 shows the seat and leg space to be 1.5m and the width of the seat is 0.57m. The seats are fitted with head rest, arm rest and enough leg room to maximise comfort during flight. The seats are manufactured and customised by a company called Aurora interior by WipAire Inc.

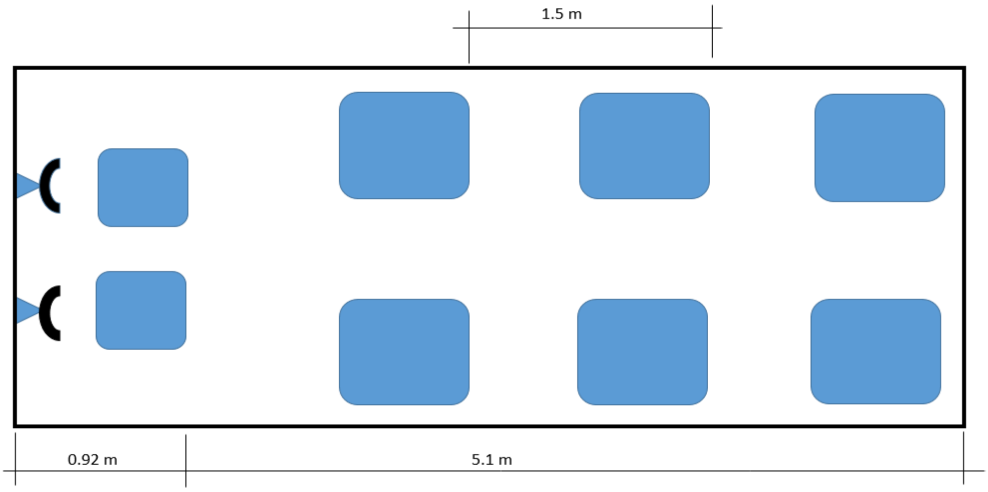


Figure 11: Retrofitted interior cabin top view

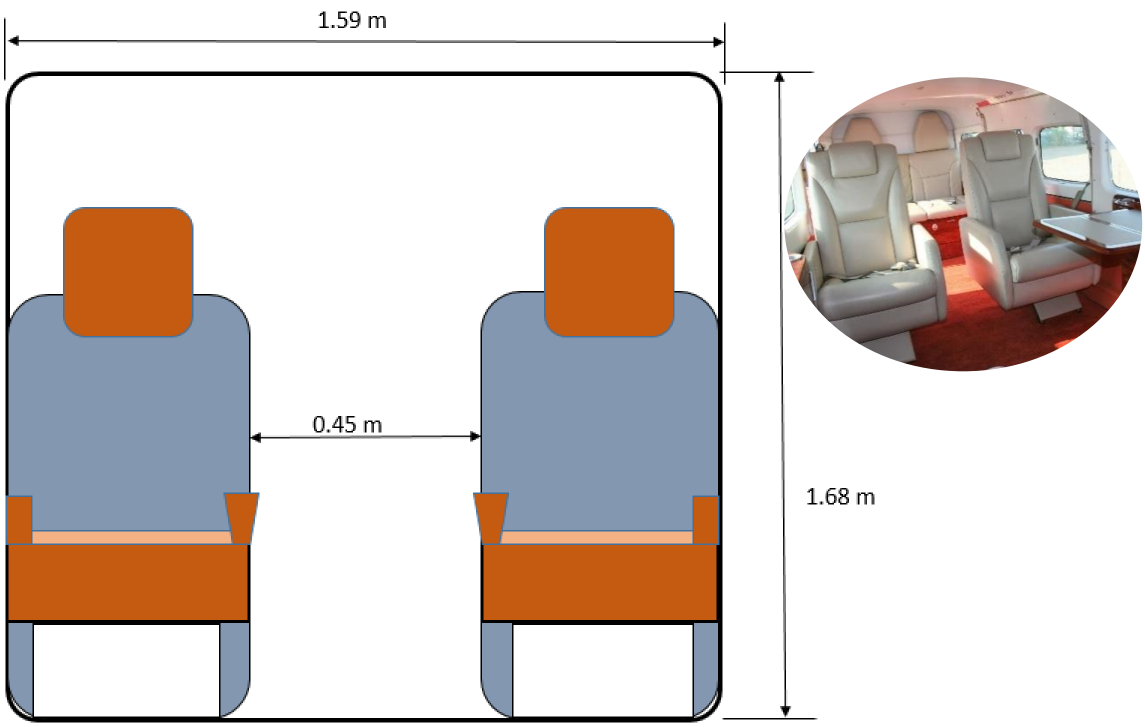


Figure 12: Retrofitted interior cabin front view

9. RETROFIT COST ANALYSIS

This section is comparative study of cost implications of retrofitting the cabin and power-plant see Table 4.

	Time	Cost	% expenditure
Engine retrofit	14 days	$675 000	31%
Cabin retrofit	8 days	&145 000	6.6%
Cessna 208 Caravan	n/a	$2 200 000	100%

Figure 13: Cost analysis

According Honeywell to retrofit the Cessna 208 Caravan will cost 31% of the brand new Cessna 208 aircraft and it will take two weeks to complete. The retrofitting process include overhauling, cleaning, installing new engine components, mounting the new engine, assembly and testing. Retrofitting the cabin will cost approximately 7% of the brand new Cessna cost and it takes over a week to complete. The cabin retrofit process comprises of old seats removal, cabin measurements, new seats customisation, cabin décor, installation and cleaning.

10.CONCEPT CHARACTERISTICS

10.1. Aircraft Weights

OEW: stands for basic weight of aircraft including crew, aircraft fluids i.e. water, engine oil, coolant, unusable fuel and operator equipment required for flight. [1]

MTOW: Maximum weight a pilot is permissible to attempt take off.

MLW: Maximum weight at which pilot is allowed to attempt landing.

Payload: Equation 1, sum of passenger weight and cargo weight where average passenger weight is assumed to be 85 kg and the cargo i.e. food and passenger accessories is assumed to be 75 kg.

$$Payload = cargo\ weight + total\ passenger\ weight \qquad [1]$$

Where for standard Cessna with 10 passengers:

$$Standard\ Payload = 75 + 10 \times 85 = 925\ kg$$

And for The SSS with 6 passengers:

$$Retroffited\ Payload = 75 + 6 \times 85 = 585\ kg$$

The fuel capacity for Cessna 208 Caravan is 1009 kg or 1257 litres and Equation 2 is the formula of calculating mission fuel payload in kilograms.

$$Fuel\ Payload = MTOW - OEW - Payload \qquad [2]$$

Aircraft weights	Standard Cessna in Kg	Retrofitted Cessna in Kg	% Increase
OEW	2145	2313	8%
MTOW	3629	4112	13%
MLW	3538	3538	0%
Payload	925	585	-37%
Fuel Payload	559	1214	117%

Table4: Aircraft weights

The 8% percentage increase on empty weight is accounted in by the retrofit engine and the 13% percentage increase on MTOW show increase on engine capability. The landing weight is expected to be same because of landing gear safety restriction for maximum weight it can carry and The SSS payload is expected to be less because it has four less passengers boarding the flight. The mission fuel for standard flight is almost half the allowable capacity because of high passenger payload hence it's preferred for short flight range. The SSS mission fuel is even above the aircraft fuel capacity hence in order to not burden lift on the aircraft the fuel is limited to what the mission requires. For mission take-off weight only 70% the fuel payload is loaded which makes the total mission weight to be approximately 3748 kg and the mission landing weight is 3141 kg.

10.2. Wing characteristics

Aircraft wings are a critical part of aircraft design because their main function is to lift the aircraft and also perform turns and control the flight. For this design scope only wing characterisation will be done because wing analysis is not part of the user requirement. The Cessna 208 has a strut braced conventional high wing configuration. The aerofoil is a NACA 23000 series with 26 m^2 reference area, 16 m span and a specified wing loading of 139.6 kg/m^2. Figure 11 estimates wing loading using Equation 3 for instance at 3629 kg the wing loading is 153.3 kg/m^2 which is slightly higher than the specified wing loading by 10 %. [2]

$$\frac{W}{S} = 10 \times (MTOW)^{0.333} \qquad [3]$$

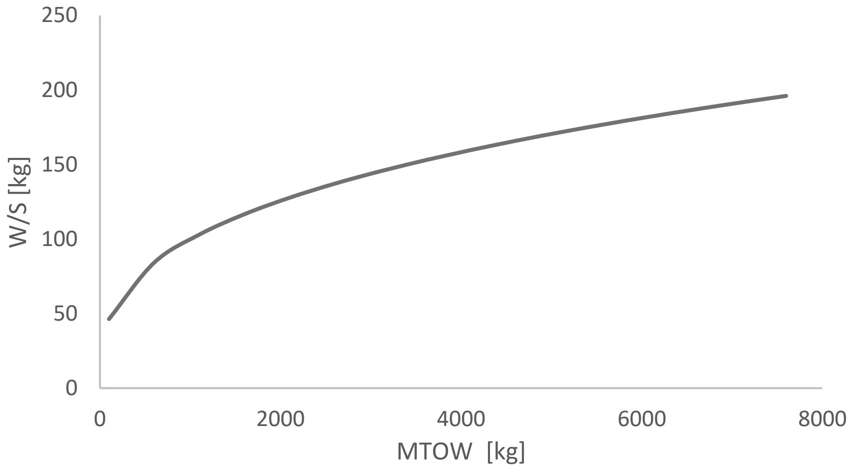


Figure 14: Wing load estimation

The wing weight estimation for an aluminium wing is estimated using the following Equation 4 and Figure 12 where aspect ratio is 9.8, t/c is 12% and wing wetted area is 37.5 m^2.

$$W_{wing} = 0.008548 \times \left(\frac{AR.MTOW.S_{wet}}{t/c.\cos\lambda_{\frac{1}{4}}}\right)^{0.6666} \qquad [4]$$

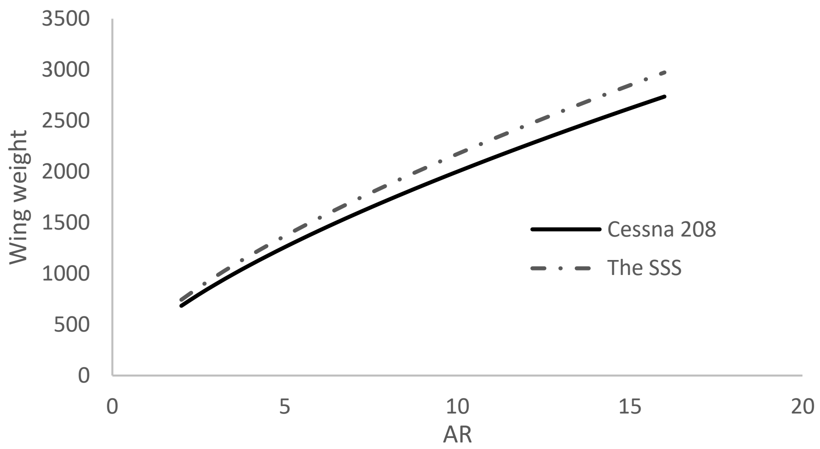


Figure 15: Wing weight vs aspect ratio

The estimated wing weight for the standard Cessna 208 is 1973 kg at 9.8 aspect ratio and the for The SSS is 2144 kg at AR = 9.8. The SSS estimated wing weight is higher because the MTOW is increased by 13%. For The SSS performance analysis AR is assumed to 8.5 in order to reduce wing weight to 1950 kg which is closer to the standard estimated wing weight.

10.3. Maximum lift coefficient and stall speed for take-off and landing.

The maximum lift coefficient is due to change in lift from flaps deflection and maximum clean lift coefficient for both landing and take-off scenario using the formulas below. The aircraft is assumed to be using NACA24012 aerofoil which has maximum clean lift coefficient of 1.4 and uses a single slotted flaps with $\frac{dC_{L\,max}}{d\delta_f}$ of 3.65. [2]

$$\Delta C_{L\,max} = \frac{dC_{L\,max}}{d\delta_f} . \delta_f . \frac{flap\ span}{wing\ span} \qquad [3]$$

$$C_{L\,max} = C_{L\,\max(clean)} + \Delta C_{L\,max} \qquad [4]$$

The $C_{L\,max}$ from the above equation is used to determine stall speeds using Equation 5 below.

$$V_s = \sqrt{\frac{2.M.g}{\rho.\sigma.S.C_{L\,max}}} \qquad [5]$$

		Take-off	Landing
Retroffited Cessna 208	Weight	3748	3141
Standard Cessna 208	Weight	3629	3538
	δ_f	20	40
	$\frac{flap\ span}{wing\ span}$	0.162	0.162
	$\Delta C_{L\,max}$	0.206	0.413
	$C_{L\,max}$	1.606	1.813
Retroffited Cessna 208	V_s	45.127	38.889
Standard Cessna 208	V_s	47.268	43.162

Table 5: Lift coefficients and Stall speeds

The standard Cessna 208 has higher stalls speeds than The SSS even though maximum lift coefficient is the make and this because the standard Cessna weighs more Equation 5. The Pilots hand book specified stall speed is 33m/s which is relative since for both scenario the weight is higher.

10.4. Clean take-off and landing zero lift drag coefficient

The zero drag coefficient is determined using book keeping drag method see APPENDIX A where C_{do} clean drag is determined to be 0.018 and the results for take-off and landing are below on Table 6. The table values are determined using the Equation 6,7,8,9. [2]

$$0.25S_{tyre} = 2D/q \qquad [6]$$

$$0.3S_{tyre} = 2D/q \qquad [7]$$

$$\Delta C_{do} = 1.1\sin(\alpha)^2 \frac{S_{flap}}{S_{wing}} \qquad [8]$$

$$\Delta C_{do} = \frac{C_{d0\,gearleg}}{S_{ref}} + \frac{C_{d0\,tyre}}{S_{ref}} \qquad [9]$$

	Take-off	Landing
α	20	40
$\frac{S_{flap}}{S_{wing}}$	0.162	0.162
$S_{gearleg}$	0.521	0.521
S_{tyre}	0.37	0.37
$D/q_{\,gearleg}$	0.0651	0.0651
$D/q_{\,tyre}$	0.0463	0.0463
$\Delta C_{d0\,flaps}$	0.0609	0.1145
$\Delta C_{d0\,gearleg}$	0.0025	0.0025
$\Delta C_{d0\,tyte}$	0.0018	0.0018
C_{d0}	0.0831	0.1367

Table 6: Cdo due to flaps deflection

The C_{do} for landing is higher than take-off because the flap angle deflection is higher or double the deflection angle at take-off Equation 8.

11.CONCEPT PERFORMANCE ANALYSIS

11.1. Drag polar set.

The drag polar set is determined using Equation 10 which shows lift vs drag coefficient at 95.2 m/s by varying lift coefficient see APPENDIX B.

$$C_d = C_{d0} + \frac{{C_l}^2}{\pi.AR.e} \qquad [10]$$

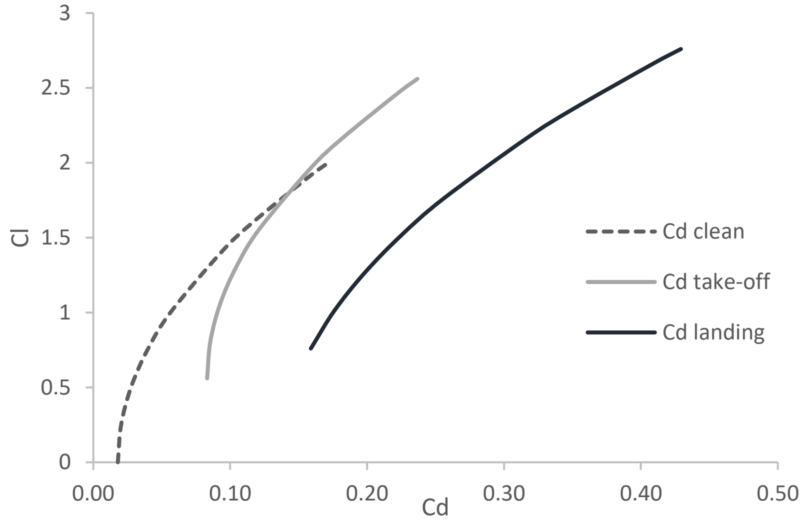


Figure 16: lift coefficient vs drag coefficient

11.2. Maximum power-plant thrust vs altitude for take-off

The Honeywell TPE 331-12JR turboprop engine has a maximum thrust variation with altitude is determined by multiplying thrust with T/T_o ratio APPENDIX D, engine efficiency [87.5%] and density ratio for every altitude because air density changes with altitude Figure 12. [2]

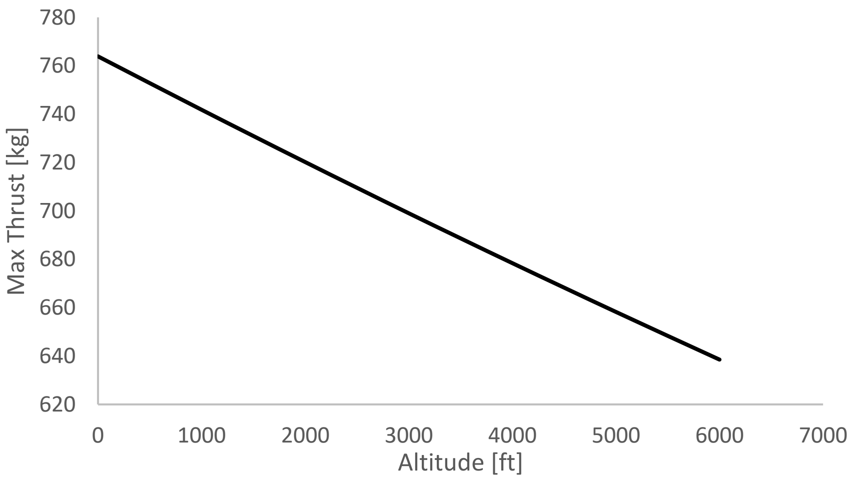


Figure 17: Maximum engine thrust vs altitude for take-off and climb

11.3. Field performance for take-off and Landing at Sea Level ISA and Kruger National Park Airport 38°.

11.3.1. Take-off

Equation 11 & 12 are formulas for calculating ground run and airborne performance at take-off.

$$S_{gr} = \frac{MTOW.V_{LO}^2}{g\ [(T_o - D_o) + (T_{LO} - D_{LO})]} \qquad [11]$$

$$S_{ga} = \frac{2.MTOW.\left(h + \frac{V_O^2 - V_{LO}^2}{2g}\right)}{g\ [(T_{LO} - D_i) + (T_{obs} - D_{obs})]} \qquad [12]$$

11.3.2. Landing

Equation 13 & 14 are used to determining airborne and ground run performance when the aircraft is landing.

$$S_{ga} = \frac{h}{\tan(\alpha)} \qquad [13]$$

Where alpha is 3° and obstacle height is 10.668 m.

$$S_{gr} = \frac{V_{TD}}{2g\mu_{brake}} \qquad [14]$$

Where tyre friction coefficient is 0.33 and V_{TD} > 1.15Vs i.e. (stall velocity).

Table 7 shows results for runway performance at take-off and landing and the variable for the above formulas are determined using APPENDIX C.

	Take-Off		Landing	
	ISA	KNP Airport 38°	ISA	CT int Airport 38°
Sgr [m]	594.5509	562.271	473.0168	646.041
Sga [m]	242.5307	261.169	203.5576	203.558
Sg [m]	**837**	**823**	**677**	**850**

Table 7: Runway Performance results

The take-off and landing performance meet the requirement of below 1200 m field performance. The published minimum required runway length for standard Cessna 208 is 762 m and this means for take-off The SSS is within limits and for landing its performing great since it requires less than the specified length. [1][2]

11.4. The SSS maximum thrust vs speed and altitude.

This performance analysis is done to exhibit how the engine performs relative to speed and altitude.

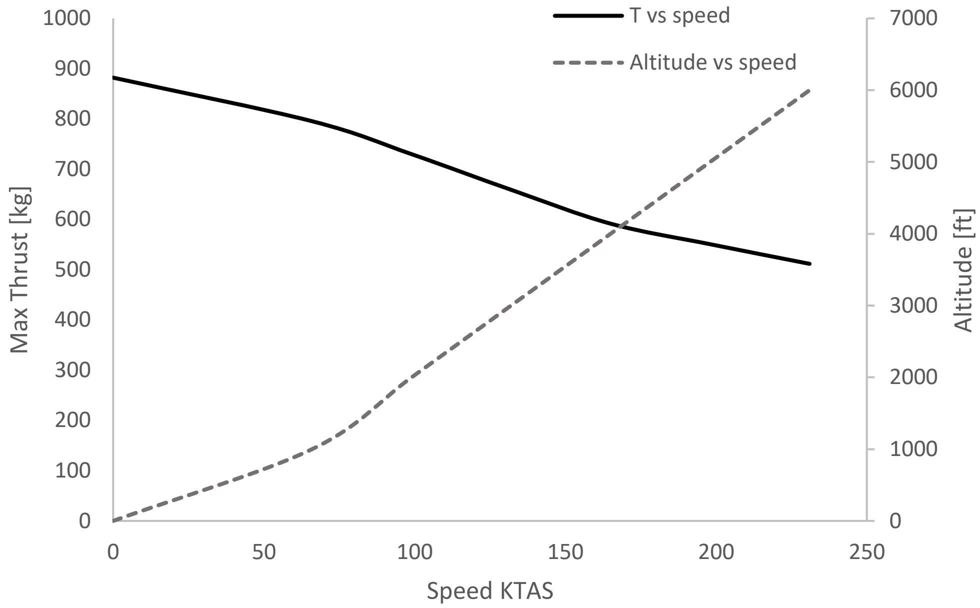


Figure 18: Speed vs thrust vs altitude

As speed increases with altitude, the thrust decreases and they intersect at 165 KTAS where Altitude is 4000 ft and thrust is 595 kg.

11.5. Climb Analysis

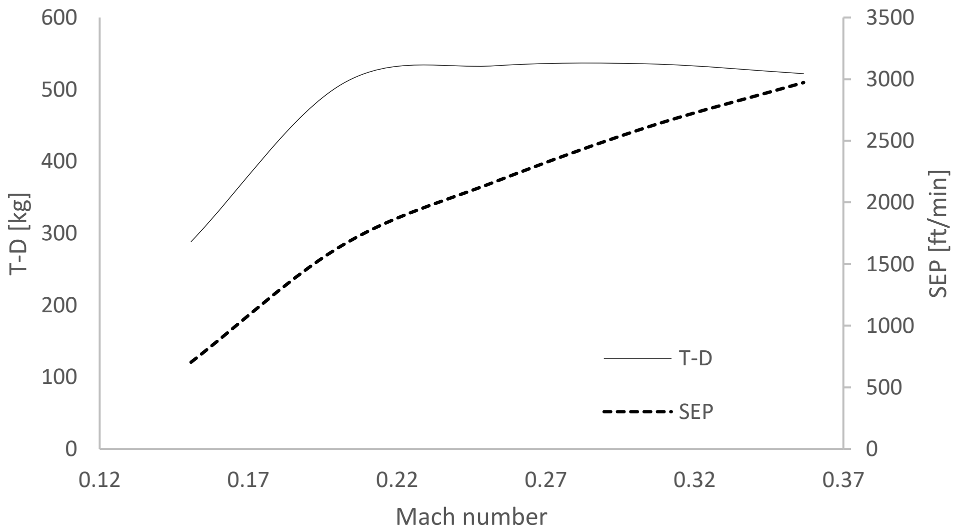


Figure 19: Climb SEP and T-D vs Speed

The best climb speed is at maximum SEP at 3322 ft/min where velocity is 118.8 m/s or 231 KTAS. The best climb speed for the standard Cessna 208 is at 120 KTAS at 975 ft/min which shows that the engine has better climb performance. The SSS has increase climb performance and the best climb angle of attack is 8.5° Equation 15.

$$\alpha_{climb} = \sin^{-1}\left(\frac{T-D}{MTOW}\right) \qquad [15]$$

Where excess thrust T-D is 555 kg and MTOW is 3748 kg.

11.6. Flight best cruise speed, range and Endurance performance.

The best cruise speed is found at maximum range and Figure 15 shows how range and endurance vary with speed for cruise. The variation of range with speed is determined using the Breguet-Range Formula Equation 16. [2]

$$Range = \frac{3600}{1853} \times \frac{\sqrt{C_l}}{C_d} \times \frac{2\sqrt{2}}{SFC} \times \frac{\left(\sqrt{W_1}-\sqrt{W_2}\right)}{\sqrt{3}\sqrt{\frac{\sigma\rho}{g}}} \qquad [16]$$

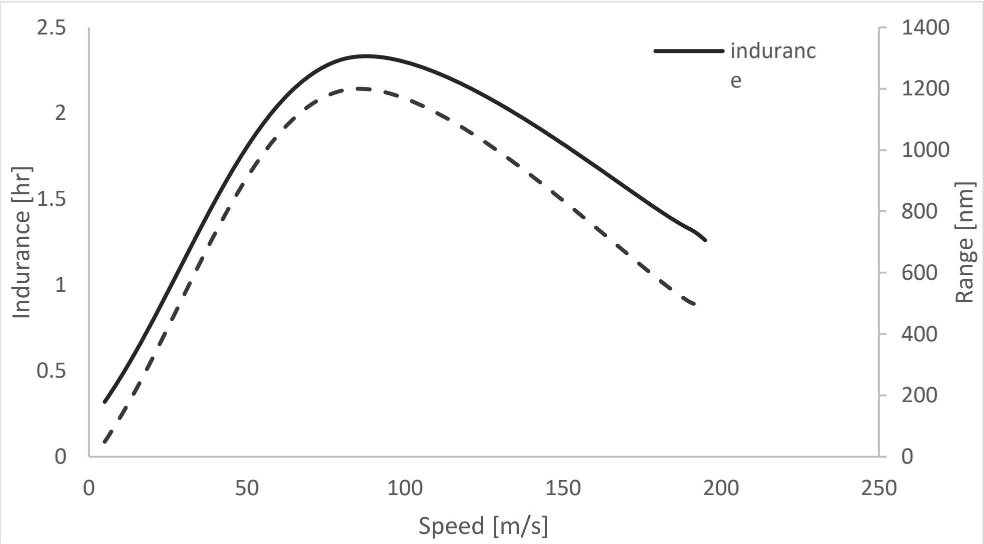


Figure 20: Cruise performance i.e. flight endurance, range

The best cruise speed is 83 m/s or 162 KTAS where range is 645 nm or 1195 km and the time it takes is 2.3 hours. The retrofit aircraft does not the meet minimum cruise range of 2000 km requirement and this can be attributed to fuel payload which affects the mission take-off weight. The SSS should be operated with maximum full payload to prove that fuel for the flight is not enough. This can be further justified by the fact that the standard Cessna 208 has maximum range of 1982 km at 186 KTAS.

12. CONCEPT WEIGHT REVISION

The process of investigating fuel short will affect all performance parameters that depend on weight however this is a significant iteration to meet product requirements specification. The first mission take-off weight was at 70% fuel payload and 20% fuel reserved for landing this mission fuel payload reduction proved to have impacted the performance of the aircraft. The iteration start with take-off with 100% fuel and landing with 10% fuel left.

		Take-off	**Landing**
Retroffited Cessna 208	Weight	4110	3023
Standard Cessna 208	Weight	3629	3538
	δ_f	20	40
	$\frac{flap\ span}{wing\ span}$	0.162	0.162
	$\Delta C_{L\ max}$	0.206	0.413
	$C_{L\ max}$	1.606	1.813
Retroffited Cessna 208	V_s	47.256	38.151
Standard Cessna 208	V_s	47.268	43.162

Table 8: Revised Lift coefficients and Stall speeds

The SSS take-off weight is increased and the landing weight is decreased which makes the stalling speeds for take-off to increase and for landing to decrease slightly. The zero drag coefficient, polar drag and thrust vs altitude analysis are not weight dependent hence no need to revise them. The field performance is affected because of stall speeds and lift induced drag.

	Take-Off		Landing	
	ISA	KNP Airport 38°	ISA	CT int Airport 38°
Sgr [m]	670.2628	854.937	518.7031	646.041
Sga [m]	285.8334	286.394	203.5576	203.558
Sg [m]	**956**	**1141**	**722**	**850**

Table 9: Revised Runway Performance results

The field performance for both landing and take-off has increase however it's still within runway requirements. The speed versus thrust and altitude relationship is also independent of weight but the climb and cruise performance is affected. Below is the revised climb and cruise performance Figure 16 &17.

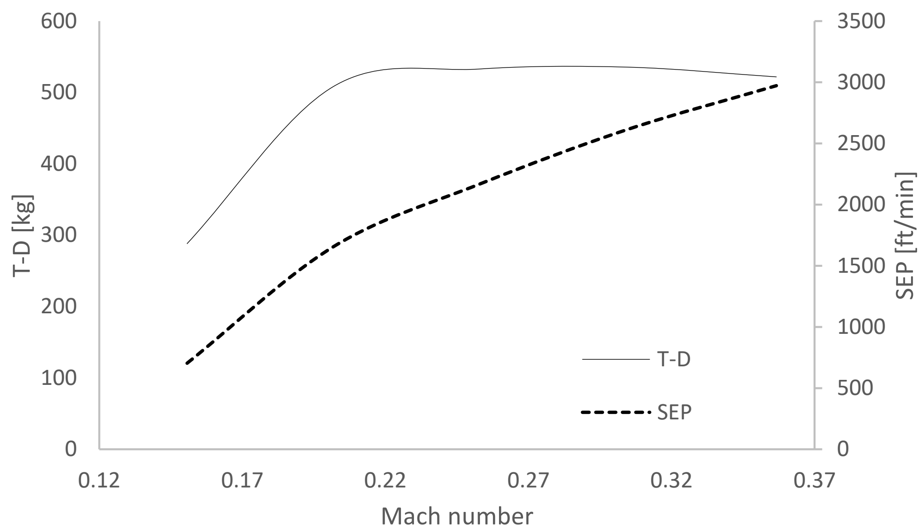


Figure 21: Revised Climb SEP and T-D vs Speed

The revised best climb speed is at maximum SEP at 2972 ft/min where velocity is 118.8 m/s or 231 KTAS. Even though the previous flight had better SEP than the revised flight plan its still an improvement compared to a standard Cessna 208. The revised SSS has increase climb performance and the best climb angle of attack is 7.3° Equation 15 where excess thrust is 522 kg and MTOW is 4110 kg.

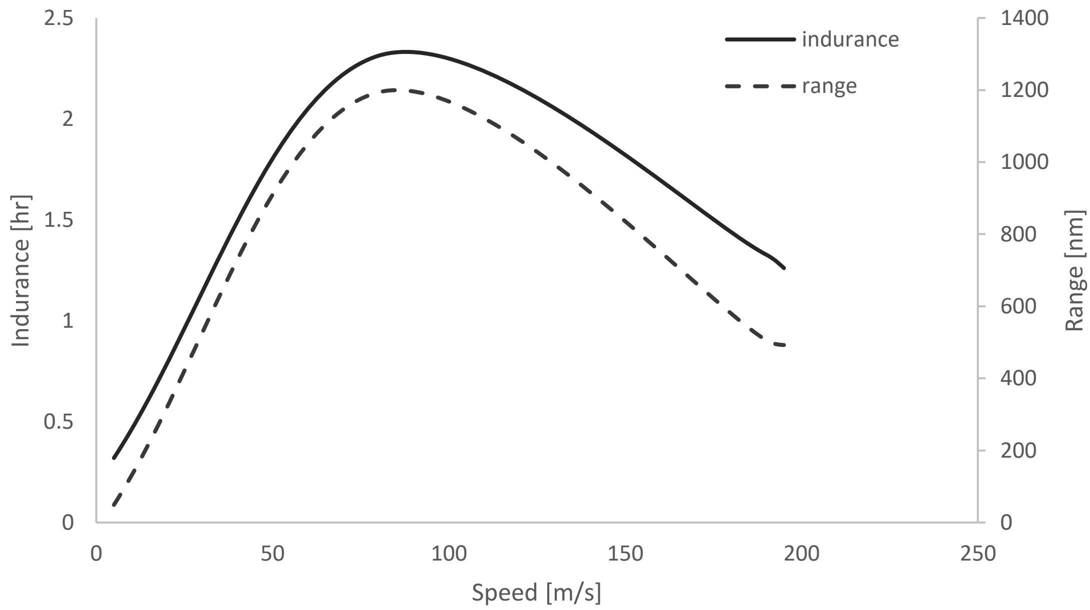


Figure 22: Revised cruise performance i.e. flight endurance, range

The revised SSS has the best cruise speed at 85 m/s or 165 KTAS where range in maximum at 1194 nm or 2211 km. The revised SSS has met the requirement for minimum cruise range and it takes 2.5 hours to achieve the maximum range. The revised SSS exceeds the standard Cessna 208 range of 1982 km by 229 km.

12.1. Loitering performance

According to the mission plan the aircraft should be able loiter at 1000 ft, 1500 ft and 6000ft with a load factor of less than 3.

altitude	speed	Cl	L	n	Radius of turn [m]	Bank angle
1000 ft	55	0.21	9724.85	2.37	143.79	65
1500 ft	55	0.2	8816.65	2.15	162.48	62
6000 ft	55	0.19	8375.81	2.04	173.66	61

Table 10: Loiter performance

The best speed for loitering is 107 KTAS because radius of turn is more than 120 m and load factor is close to 2 which means the flight will be comfortable when loitering to view landmarks and wildlife.

13. LANDING GEAR UPGRADE

The Cessna 208 Caravan comes with a non-retracting tricycle landing gear with a steerable front wheel and it supported by a strut that has shock absorptions capabilities Figure 23. The wheels use a four piston brake system that is applied using a hydraulic actuator. [5]

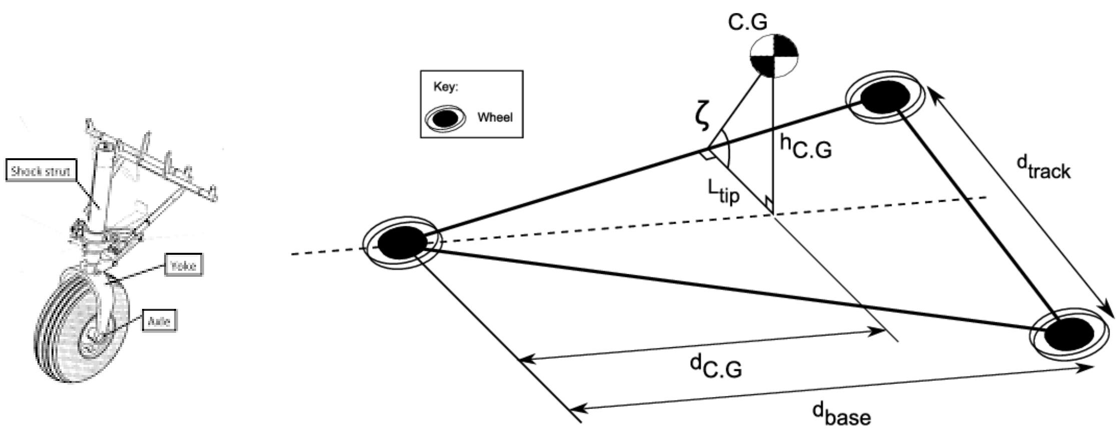


Figure 23: Tricycle landing gear configuration

The desired upgrade for landing gear is to make it retractable without compromising the airframe integrity. The available retractable landing gear solution for Cessna 208 Caravan is the WipAire 8000 float which is mounted with a retractable gear. This analyses seeks to determine whether using the float attached landing gear would reduce parasite since the floats have wetted area. Designing a retractable gear for this aircraft will not be viable because a gear cage will have to be built under the fuselage belly which consequently interfere with fuselage structures integrity.

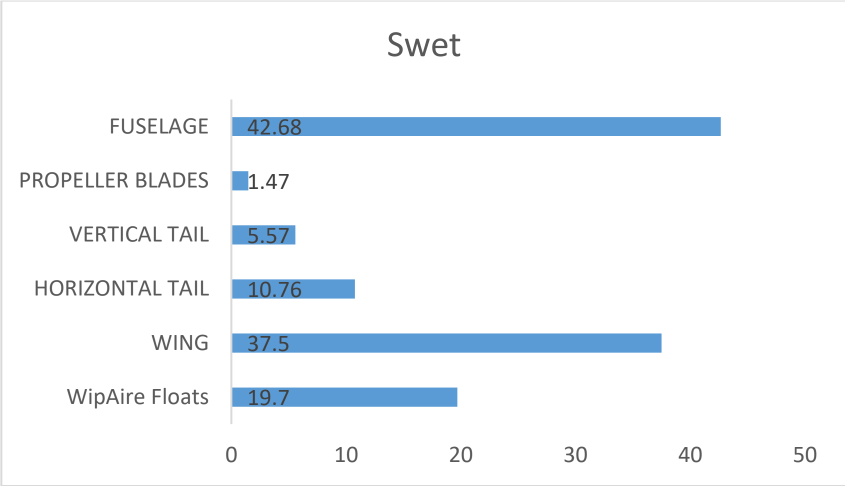


Figure 24: Components wetted area in [m^2]

The floats are a non-lifting body with wetted area of 19.7 m^2 which is more 89% more than the area of landing gears hence this is a clear indication that the retractable landing gear upgrade using WipAire 8000 float will increase zero coefficient drag drastically [14]. The float increases gross weight by 210 kg according to Caravan Pilots manual [5] and lastly the cost of mounting the float is $42 400 [15] and that is an extra 1.9% expenditure relative to a new Cessna 208 caravan. The motivation to use retractable landing gear is to reduce parasite drag and only existing solution comes with floats that increase drag, gross weight and cost of operation.

Figure 25: WipAire 8000 float on Caravan

14.EMPENNAGE

The SSS has a conventional tail configuration that is attached with vertical stabilizer, horizontal stabilizer, rudder and elevator. [3]

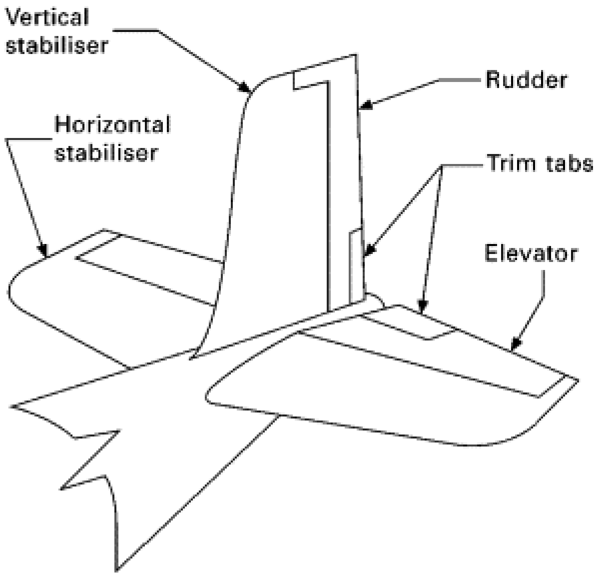
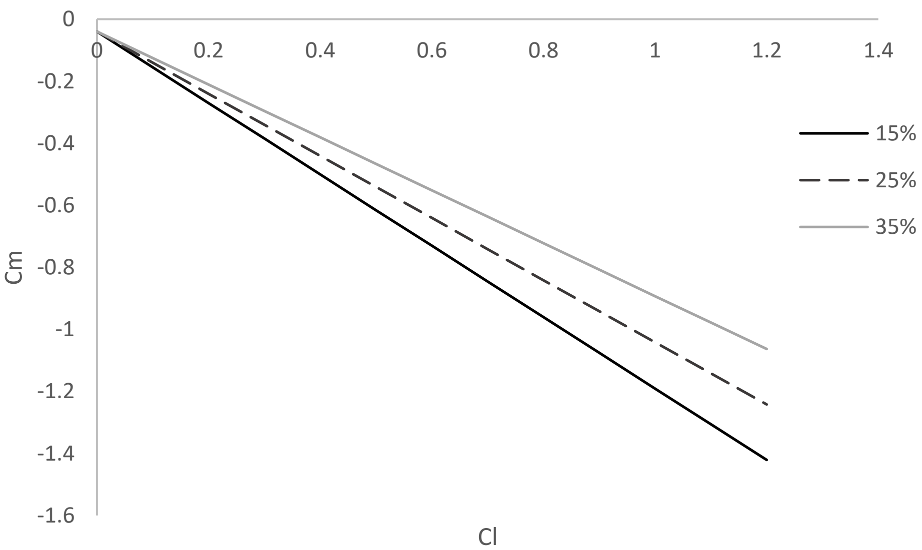


Figure 26: Empennage (conventional tail)

14.1. Aircraft flying qualities (longitudinal stability)

Figure 21 determines the safest flap deflection to trim the aircraft using Equation 17. This is done to show untrimmed coefficient about center of gravity for different OG positions where C_{mo} for NACA 23012 is –0.04. [3]

$$C_{Mcg} = C_{Mo} + (h - h_0)C_L - V_T C_{LT} \qquad [17]$$



15. CONCEPT EVALUATION

The 3D Pie chart shows the level of importance of the PRS section where requirement is allocated 60% level of important, constraints 35% and Criteria is 15%.

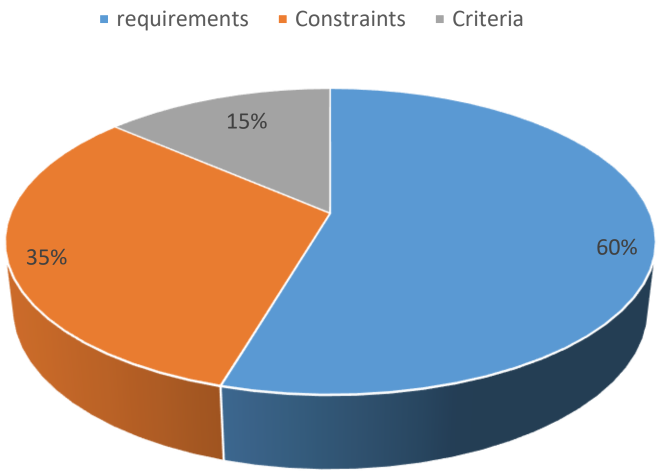


Figure 27: PRS level of importance

The requirements are evaluated using the table bar chart below which shows percentage increase or decrease for every value requirements and 100% stands for yes.

REQUIREMENTS	Value required	Results	%
Climb rate must be greater than 2000 ft/min.	2000	2972	48.6
Minimum cruise flight range must be at least 2000 km.	2000	2211	10.6
Take-off and landing distance of below 1200 m.	1200	1141	-4.9
High wing configuration. (100% or 0)	100	200	100.0
Radius of turn should be more than 120 m.(average)	120	160	33.3
Load factor of less than 3 during loitering. (average)	3	2.19	-27.0

Figure 28: Requirements evaluation

All user requirements are met where the chosen aircraft has high wing configuration and the engine retrofit increased climb rate, cruise range and radius of turn, and also have more radius of turn, load factor and within field performance. The requirements scored 60% because all requirements are met for evaluation and the Pie chart below shows which constraints were met and by what percentage.

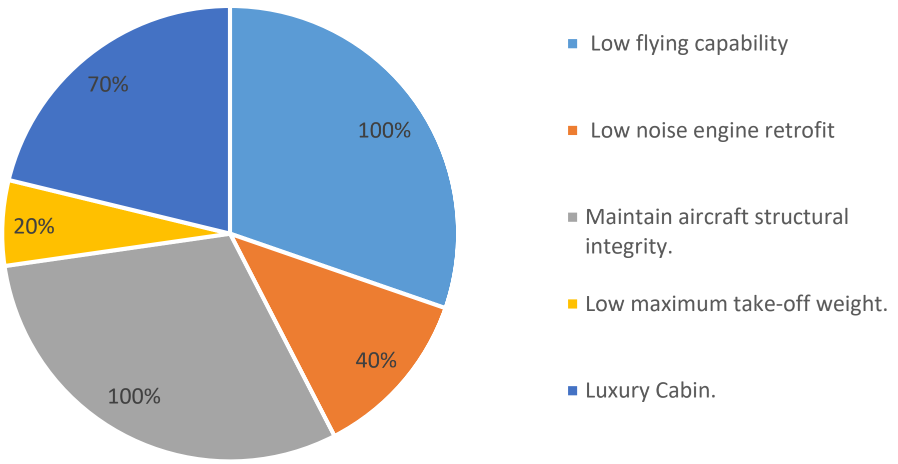


Figure 29: Constraints evaluation

The constraints scored 23.1% for evaluation. The low noise engine retrofit constraint has low scoring because there are currently no regulations that specifies restricted sound decibels however the new engine complies with the current improved noise requirements by EASA. The MTOW reduction scored the least because when fuel is reduced the aircraft does not meet range requirements hence the MTOW is not changed. The Pie chart below exhibit evaluation of criteria for the concept and it shows that the aircraft is popular, older than 30 years, low fuel consumption power-plant and flight regulations are adhered to on the mission plan.

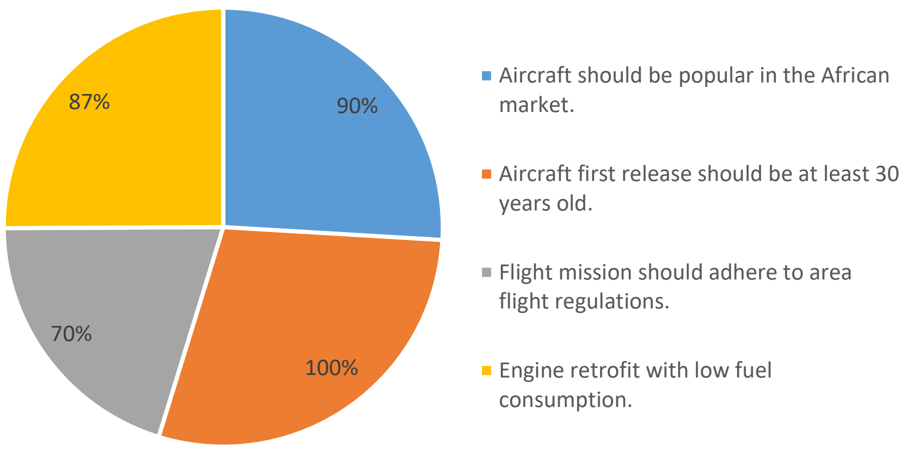


Figure 30: Criteria evaluation

The criteria scored 13% for evaluation and the overall concept score is 96.1% which means that The SADC SUPER SAFARI Cessna 208 Caravan engine and Cabin retrofit fulfilled 96.1% of the user requirements and specifications.

16.THE SADC SUPER SAFARI SPECIFICCATION

16.1. Flight V-N Diagram

The chart shows the limits of aircraft performance at SEA LEVEL by showing how much load factor can be safely achieved at different air speeds. The diamond point on the graph shows the slowest velocity at which this aircraft can pull a G i.e. load factor. Adhering to the requirements the maximum load factor is kept at 3. [2]

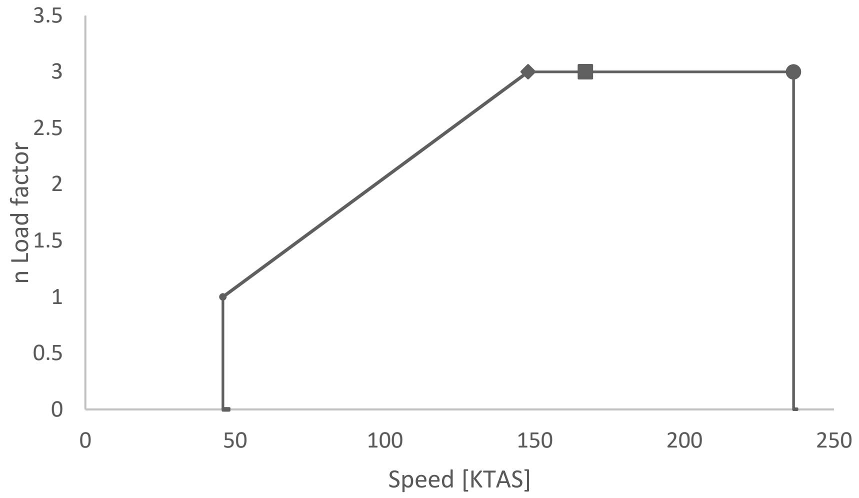


Figure 31: V-N diagram

16.2. Concept Detail Drawings

The drawings consist orthographic view, isometric view and exploded view which are drawn using Inventor CAD software. The dimensions of the aircraft are determined by measuring the dimensions of the aircraft on the Pilots Handbook using ratios of specified height and width over measured height and width. Sample calculation of scaling.

$$\text{Measured width} \times \text{height} = 104 \text{ mm} \times 40 \text{ mm}$$

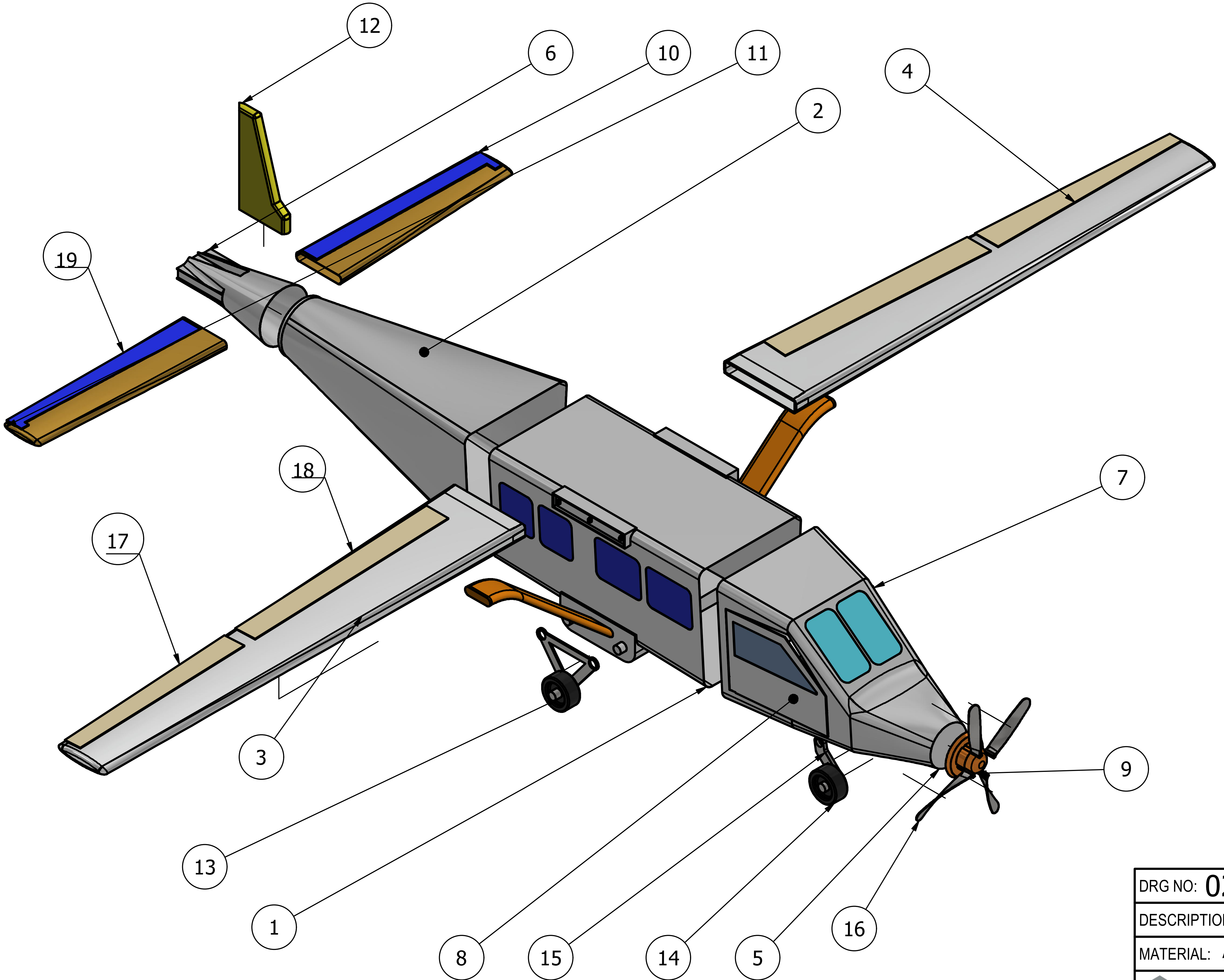
$$\text{Specified width} \times \text{height} = 11500 \text{ mm} \times 4500 \text{ mm}$$

$$\text{Width ratio: } 11500/104 = 110.577$$

$$\text{Height ratio: } 4500/40 = 112.5$$

$$\text{Average of ratios: } 111.5$$

Every measured dimension on the ruler is multiplied by this scale 111.5 to get the real approximate dimension for instance span was measure to be 140 mm and when multiplied by the scale the answer is 15 610 mm and the specified span is 16000 mm.



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Fusalage Centre
2	1	Fusalage Tail Section Main
3	1	NACA23012_Wing-Right
4	1	NACA23012_Wing-Left
5	1	Cockpi Section
6	1	Tail Section
7	1	Door_Left
8	1	Door_Right
9	1	Honeywell TPE 331-12JR
10	1	Horizontal Tail - Left
11	1	Horizontal Tail - Right
12	1	Vertical Tail Fin
13	2	Main Landing Gear
14	3	Wheel
15	1	Front Landing Gear
16	4	Propella Blade
17	2	Aileron
18	2	Single Slotted Flap
19	2	Elevator

NOTES:
SURFACE FINISH √ UNLESS OTHERWISE STATED.
DIMENSIONS IN mm.
DO NOT SCALE.
ALL THREADS MEDIUM FIT.

APPROVED:

STUDENT NO. 732537

DATE: 12 Sep 2022

DRAWN BY: Reloef Khoza

SHEET SIZE:

DRG NO: 02	REV NO.	SHEET 1 OF 1

DESCRIPTION: Exploded View

MATERIAL: Aluminium and Other Alloys

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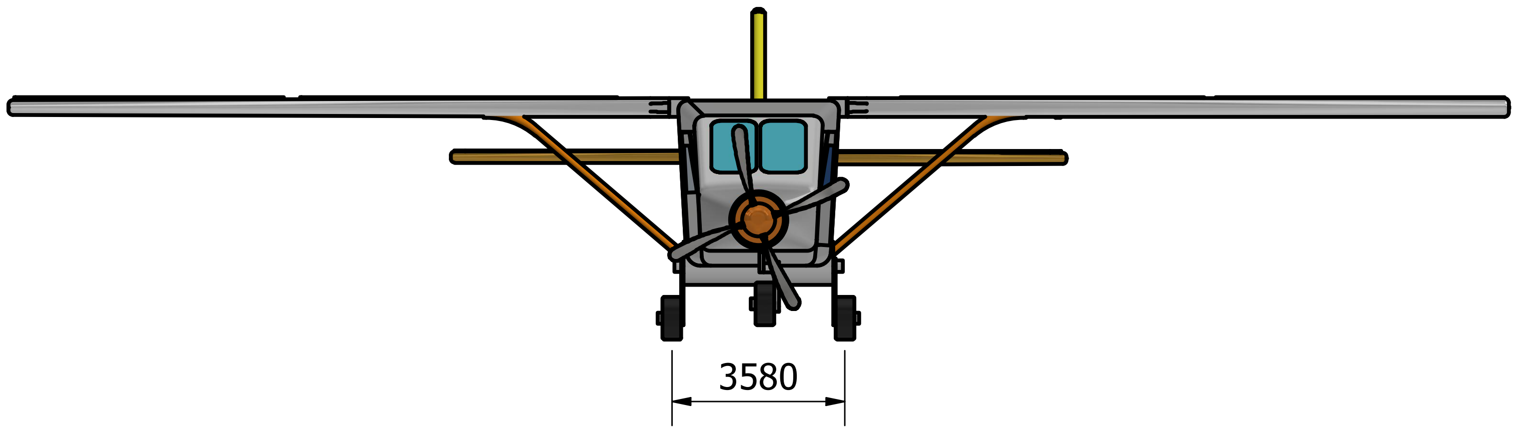
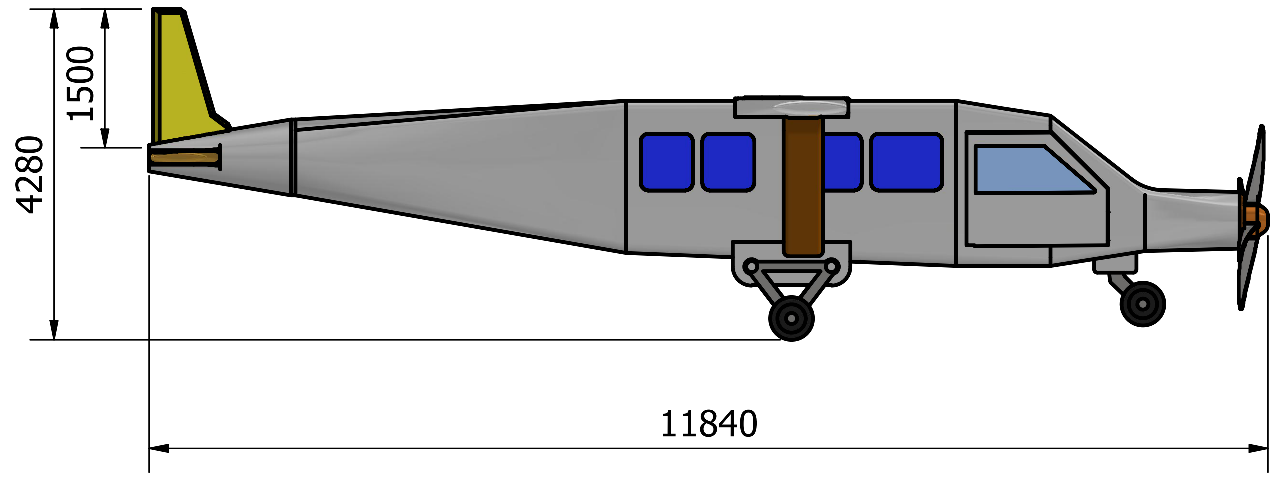
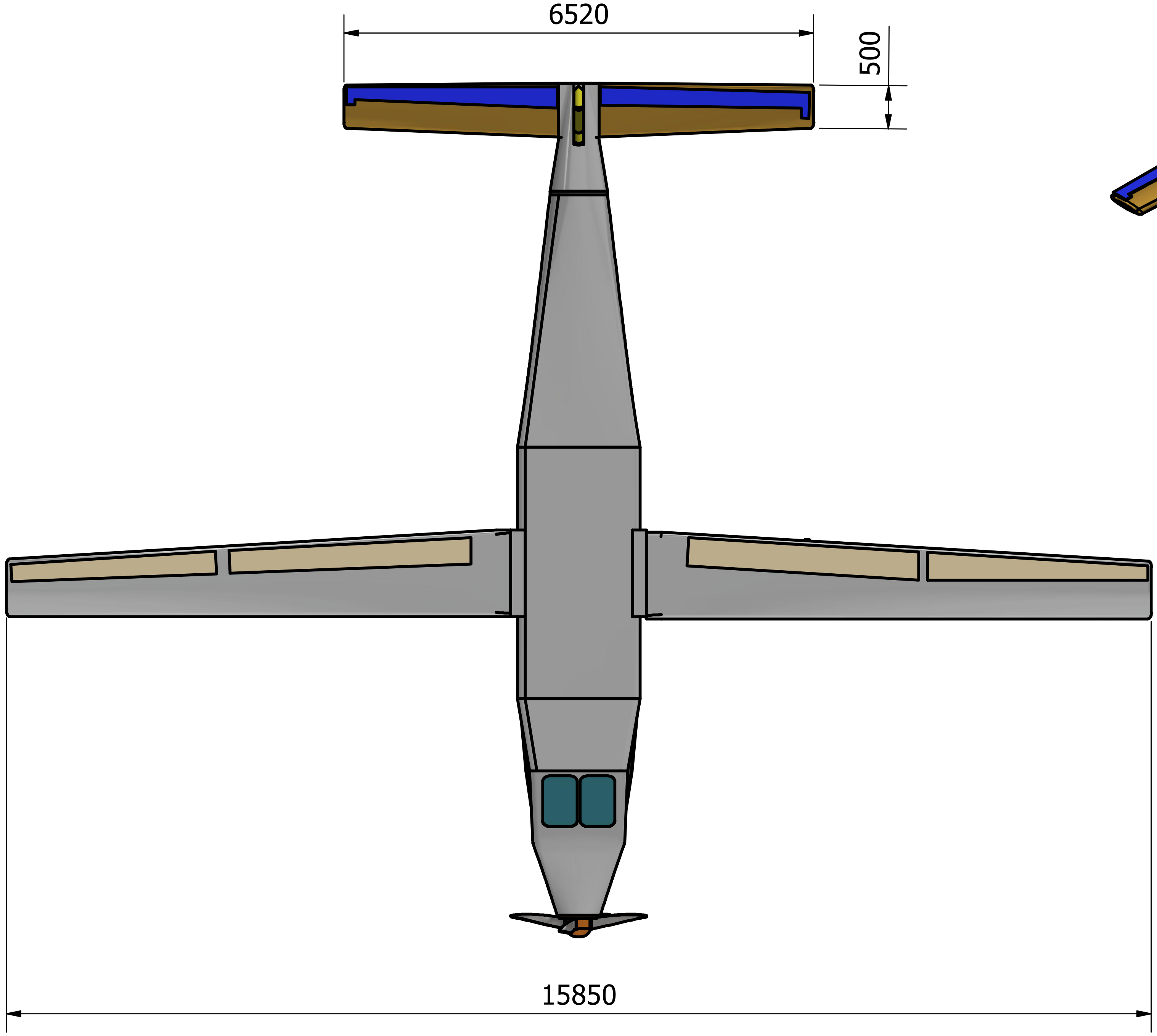
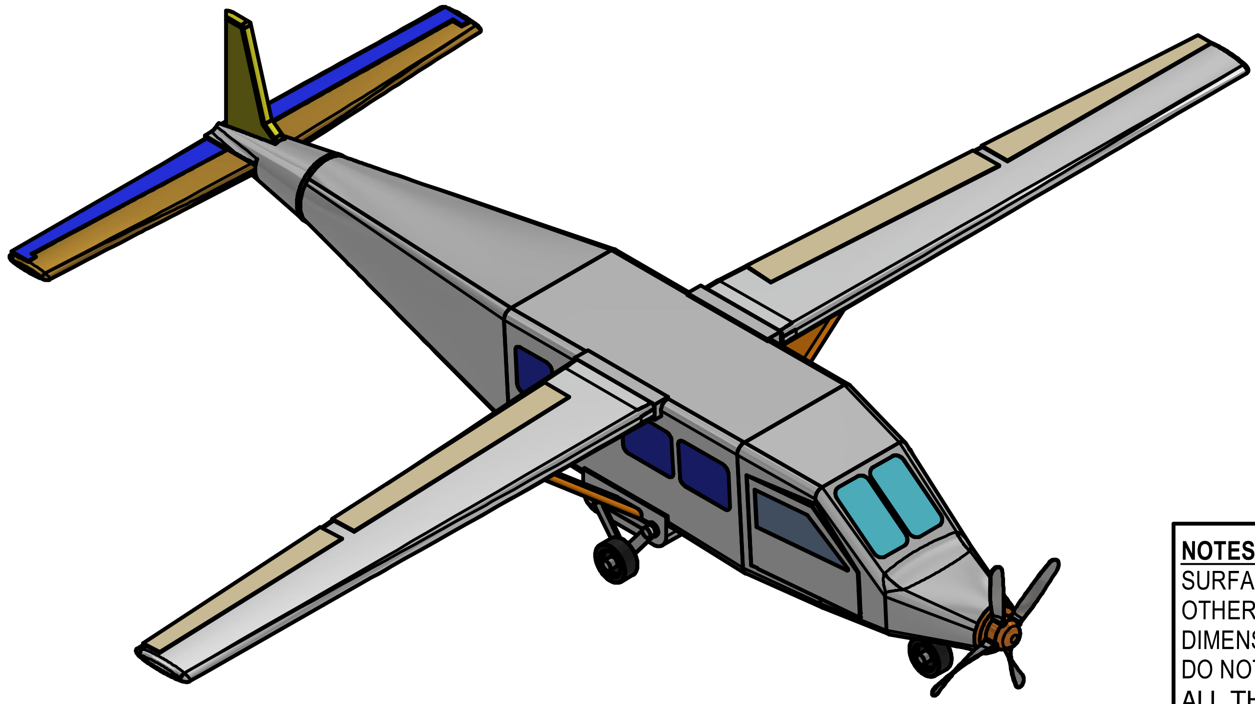
UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG.









NOTES:
SURFACE FINISH ∇ UNLESS OTHERWISE STATED.
DIMENSIONS IN mm.
DO NOT SCALE.
ALL THREADS MEDIUM FIT.

APPROVED:			
STUDENT NO. 732537			
DATE: 12 Sep 2022			
DRAWN BY: Reloef Khoza			
SHEET SIZE:			
DRG NO: 1	REV NO.		SHEET 1 OF 1
DESCRIPTION: Orthographic and Iso Views			
MATERIAL: Aluminium and Other Alloys			

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UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG.

17. CONCLUSION

The objective of this design report is to retrofit an old aircraft for SADC tourism purposes. The Cessna 208 Caravan was selected for engine and cabin retrofit because the standard model could not execute the flight mission. The cabin was improved for comfort and luxury by changing the seats type and configuration. The power-plant was improved by selecting a current available engine which improved climb performance, cruise range and endurance. From the orthographic view the engine can be seen to be mounted with 4 propeller blades which is an immediate proof that the engine is upgraded. The retrofit concept proved to be capable of comfortable loitering and stability. The concept evaluation reveals that the retrofit aircraft fulfils 96% of user requirements and mission specifications without tempering with the structural integrity of the aircraft.

18. RECOMMENDATIONS

- Optimise wing design to increase lift and reduce weight.
- Perform structural analysis of the aircraft to optimise structural weight.
- Perform CFD analysis of 3 propeller blades versus 4 propeller blades to show power increase due to propellers.
- Design food tray for the passengers using composite material.
- Perform FEM analysis for the landing gear.
- Generate a business case for THE SADC SUPER SAFARI tour.

19.References

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APPENDIX A

Book keeping drag.

Bodies of revolution form factors formula.

$$Q = 1 + \left(\frac{60}{(l/d)^3}\right) + 0.0025(l/d)$$

Lifting bodies form factors formula.

$$Q = 1 + l(t/c) + 100(t/c)^4$$

And to determine book keeping drag we use the following formula.

$$\frac{D}{q} = C_f * S_{wet} * Q$$

$$C_{d0} = \frac{\sum D/q}{S_{ref}}$$

Where S_{ref} is wing reference area.

ITEM	L/MAC	Re (flight)	Re(cut-off)	Cf	t/c OR l/d	Q	Swet	D/q
WING	1.49	4.4E+06	3.2E+06	0.0033	0.12	1.199536	37.5	0.14844258
HORIZONTAL TAIL	0.974	2.9E+06	2.0E+06	0.0035	0.09	1.094221	10.76	0.041208363
VERTICAL TAIL	1.32	3.9E+06	2.8E+06	0.0033	0.09	1.125361	5.57	0.020685261
PROPELLER BLADES	0.35	1.0E+06	6.7E+05	0.0034	6	1.292777778	1.47	0.006461303
FUSELAGE	11.5	3.4E+07	2.8E+07	0.0022	7	1.192427114	42.68	0.111964136
Sref = 26 sqrm, V= 95.2 m/s at cruise, altitude 6000ft. T=276.5K	**Use cut-off Re(f)>cut-off Re**			**0.017916166**			**0.328761643**	

The C_{d0} book keeping drag is 0.018.

APPENDIX B

Lift coefficient vs drag coefficient.

Cl clean at 95.2m/s	Cd clean	Cd take-off	Cl take-off	Cl landing	Cd landing
0	0.01792	0.083148771	0.56045	0.759621709	0.158908165
0.25	0.02032	0.085549298	0.81045	1.009621709	0.175896631
0.5	0.02752	0.092750879	1.06045	1.259621709	0.197686152
0.75	0.03952	0.104753514	1.31045	1.509621709	0.224276727
1	0.05632	0.121557203	1.56045	1.759621709	0.255668356
1.4	0.09320	0.158429299	1.96045	2.159621709	0.315881155
1.6	0.11624	0.181474359	2.16045	2.359621709	0.350596566
1.905	0.15730	0.222533933	2.46545	2.664621709	0.409453427
2	0.17155	0.236782502	2.56045	2.759621709	0.429245413
	no flaps	flaps	flaps		

APPENDIX C

Field performance inputs.

The KNP airport is at 1020 ft above sea level at a temperature of 38° and the density ratio at these conditions is 0.9682. [1]

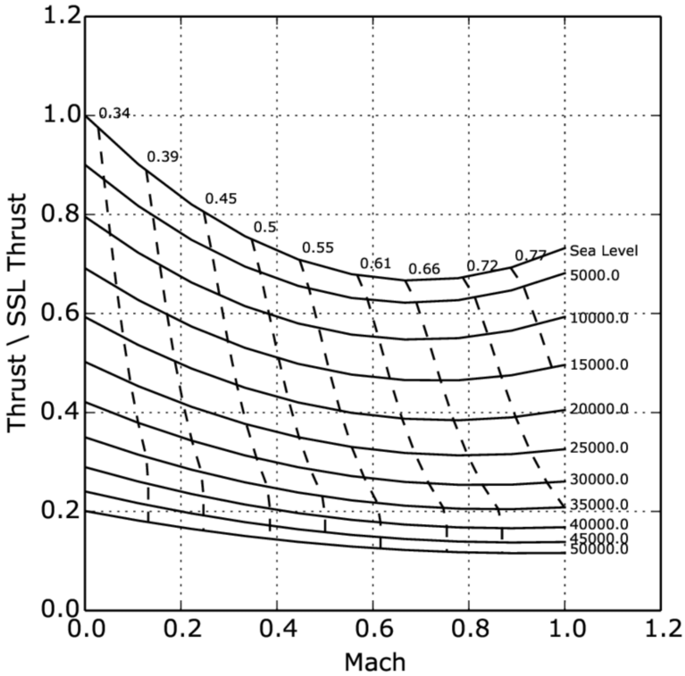
$V_{LO} = 1.1V_S$, $V_{obs} = 1.2V_S$ and

$$D_{LO} = \frac{1}{2g}\rho\sigma . S_{ref} . V^2 . C_d$$

	Ground Run		Airborne phase	
	ISA	KNP Air 38°	ISA	CT Int Air 38°
V_S [m/s]	42.57	49.75	42.57	41.91
V_{LO} [m/s]	46.83	54.73	n/a	n/a
V_{obs} [m/s]	n/a	n/a	51.0837357	58.03
T_o [kg]	900.00	900.00	n/a	n/a
D_o [kg]	93.70	93.70	n/a	n/a
D_{LO} [kg]	99.24	135.54	n/a	n/a
D_i [kg]	n/a	n/a	99.24	135.54
T_{LO} [kg]	702.00	693	702.00	693.00
T_{obs} [kg]	n/a	n/a	678.60	614.13
D_{obs} [kg]	n/a	n/a	295.05	320.25
MTOW [	3748.00	3748.00	3748.00	3748.00

APPENDIX D

The diagram is used to get T/T_o and SFC coefficient using Mach Number and Altitude for climb and cruise performance analysis. [2]



APPENDIX E

V-N diagram for SEA LEVEL FLIGHT using the following formulas. [3]

$$V_{stall} = V_s * \sqrt{n}$$

$$\blacklozenge\ V_{Amin} = 6.79\sqrt{n\frac{w}{s}}$$

$$\blacksquare V_{Cmin} = 7.67\sqrt{n\frac{w}{s}}$$

$$\bullet V_{Dmin} = 10.86\sqrt{n\frac{w}{s}}$$

Input data for V-N Diagram		
Speed	Load factor	
45.93302749	0	
45.93302749	1	
147.864745	3	
167.0283644	3	
236.4964846	3	
236.4964846	0	