بسم الله الرحمن الرحيم

Sudan University of Science and Technology

Faculty of Engineering

Aeronautical Engineering Department

RE-ENGINING FOR SAFAT-03

Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering. (BEng Honor)

By:

1. Ahmed Awadallah Ahmed.
2. Mohamed Azhary Hussain.
3. Mohamed Abdallah Mohamed.
4. Ebrahim Ayoup Mohamed Salih.

Supervised By:

Eng. Mohamed Mahdi

October, 2017

الاية

قال تعالي :

(قُلْ كُلٌّ يَعْمَلُ عَلَىٰ شَاكِلَتِهِ فَرَبُّكُمْ أَعْلَمُ بِمَنْ هُوَ أَهْدَىٰ سَبِيلًا * وَيَسْأَلُونَكَ عَنِ الرُّوحِ ۖ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا)

سورة الاسراء الاية ٨٤ و٨٥

Abstract

The engine is one of key factors to increasing the performance and improving the economics of aircraft. The most recent phenomenon in the industry, again engine driven, is a growing importance placed on the re-engining of in-service aircraft. The ever increasing cost of new aircraft the outstanding durability of aircraft now in service and the significant increase in both aircraft performance and economy provided by newly available engines makes re-engining a viable cost effective approach for the aircraft user.

This thesis a re-engining of SAFAT-03, which is a single engine propeller driven trainer aircraft, the re-engining is attracted from operational cost view point and economical aspects. The performance evaluation and installation of the engine as well as the weight and balance calculation have been covered in this work. The selected engine was AUSTRO AE 300. Which is a turbocharged 4 cylinders geared piston engine equipped with fuel injection system.

This work gives a predictable result, the engine power increased after 9000ft. by 32% and the specific fuel consumption **Reduced by 45%**. Beside the fuel type changed from Avgas to Diesel which is a lower cost making the new engine a cost effective solution for the SAFAT-03. The outcomes from these project are the SAFAT 03 applicable for AE300 and its gives better operation cost and more range and endurance. . After all the required submissions have been made, the CAA must verify these data. Only then does it issue an STC, which is an authorization to manufacture and install the modification.

التجريد

المحرك هو واحد من العوامل الرئيسية لزيادة الأداء وتحسين اقتصاديات الطائرات. من الظواهر المهمة والحديثة والتي تساعد في نمو الطائرات هي تطوير محركات الطائرات التي في الخدمة، الطائرات الجديدة ذات تكاليف عالية بخلاف الطائرات المسبق تصنيعها واثبتت متانتها في خدمتها. إن الزيادة الكبيرة في اداء الطائرات وتقليل تكاليفها يتحصل عليهما بواسطة المحركات الجديدة المتاحة؛ جعلت عملية تغيير المحرك Re-engining خيار يمكن تطبيقه بواسطة شركات الطيران او المصنعين لتقليل التكلفة.

هذه الأطروحة عبارة عن تغيير محرك صافات-٠٣، وهي طائرة تدريبية ذات محرك احادي المروحة ، عملية تغيير المحرك اعتبرت جازبة من جهة التكلفة التشغيلية والجوانب الاقتصادية. وقد تم تغطية تقييم الأداء وتركيب المحرك وكذلك حساب الوزن والتوازن في هذا العمل. كان المحرك الذي اختير واجريت عليه الدراسة AE300. وهو عبارة عن محرك مكبسي ذو ٤ اسطوانات مزود بشاحن توربيني ومجهزة بنظام حقن الوقود.

هذا العمل اعطي النتائج المتوقعة، حيث زادت قوة المحرك بعد ٩٠٠٠ قدم .بنسبة ٣٢٪ واستهلاك الوقود النوعي قلة بنسبة ٤٥٪. بجانب ان نوع الوقود قد تغير من avgas إلى diesel وهو أقل تكلفة مما يجعل المحرك الجديد حلا فعالا من حيث التكلفة للطائرة صافات-٠٣. النتائج من هذا المشروع جعلت الطائرة صافات ٠٣ تتقبل AE300ويعطيها أفضل تكلفة تشغيلية وتعطيها المزيد من المدى وزمن طيران اطول.

Acknowledgement

I would like to thank the many people who made this project possible. First of all, thanks to my teachers *Rania gurashi and Raheeg Osama*.

I am grateful for the efforts of many people at *Aeronautical Engineering Department* including, but not limited to teachers Ahmed Mukhtar *and Dr. Sakhr*.

Special thanks to my family Mother, Father, Sisters, and Brothers.

Dedication

I would like to dedicate my research to all those who helped me through this enlightening experience, and to my belovedness and to my teachers, father, mother and best friend,

My brother all within the span of this research. You have made countless sacrifices in the interest of this research and in the interest of my success.

Any and all success in this research is as much yours as it is mine.

There As much of a blessing as you have been throughout this research, you have been even more so throughout our five years together. A simple ‘thank you’ will not suffice; I am forever in debt to you for your selflessness and unwavering devotion.

Print clearance

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Engineering (BEng in Aeronautical Engineering).

Supervisor

Name:…………………………………………………………………

Signature:…………………………………

Date:…………………………………..

Table of Contents

الاية 2
Abstract 3
التجريد 4
Acknowledgement 5
Dedication 6
Print clearance 7
List of figures 12
List of tables 13
List of abbreviations 14
Chapter 1: INTRODUCTION 16
1.1 overview 16
1.2 Problem statement 16
1.3 proposed solution 17
1.5 New engine features 17
1.6 Goals and Objectives 17
1.7 Contribution 17
1.8 Scope of Work 17
1.9 Methodology 18
1.10 Time Frame 18
1.11 Flow Chart 20
Chapter 2: LITERATURE REVIEW 21
2.1 History of re-engining 21
2.2 Re-Engining Considerations 22

2.3 Performance of the aircraft 22
2.3.1Trim drag polar diagram 22
2.3.2Drag Breakdown Procedure 24
2.4 Piston Airplane Cruise Performance 25
2.4.1 Take-off Performance 26
2.4.2 Landing Performance 26
2.4.3 Rate of climb 27
2.4.4 Range 27
2.4.5 Endurance:- 27
2.5 Engine Performance: 27
2.5.1 Engine power related to RPM 28
2.5.2 Specific fuel consumption with RPM 29
2.5.3 Propeller performance 30
2.6 Regulation 31
2.6.1 Certification 31
2.6.2 The Supplemental Type Certificate 31
2.6.3 Fuel Environmental effect: 31
2.7 Operating cost: 32
2.7.1 Direct Operating Cost 32
2.8 Matching of the airframe 33
2.8.1 Engine mount 33
2.9 Cowling Requirement 34
2.9.1 Cooling by Cowling 35
2.9.2Cowling Inlets 35

2.10 Weight and Balance 36
2.10.1 Centre of Gravity 36
2.10.2 Location of CG 36
2.10.3 Computing CG Location 36
2.10.4 Expressing the CG as Percentage of the MAC 36
2.11 Performance Constrains 37
CHAPTER 3. METHODOLOGY 38
3.1 Why Re-engining SAFAT 03: 38
3.1.1 Reducing direct operating cost: 38
3.2 Engine selection: 38
3.2.1 Engine selection process algorithm 39
3.2.2 Engine selection criteria: 40
3.2.3 Table of selection 40
3.2.3 Maintenance cost 1
3.2.4 Comparing between the AE300 power and LYCOMING power 1
3.2.5 Fuel flow versus AE300 and LYCOMING IO 360 2
3.2.6 Comparison between Lycoming 360 and Austro AE300 characteristics 4
3.3 Performance calculation 5
3.3.1Range and Endurance 7
3.4 Weight and balance W&B 7
Chapter 4: RESULT AND DISCUSSION 10
4.1 Engine AE300 and mount conceptual design: 10
4.2 Result of Performance Calculation 15
4.2.1Trim drag polar diagram 15

4.2.2 Power required 17
4.2.3 Take-off distance 18
4.2.4 Maximum rate of climb 20
4.2.5 Flight Envelope 21
4.2.6 Endurance 22
4.2.7 Range 23
CHAPTER 5. CONCLUSION, FURTHE RWORK & RECOMMENDATION 24
5.1 Conclusion 24
5.2 Further work 24
5.2.1 STC program 24
5.3 Recommendation 25
5.3.1 Finalize new mount design 25
5.3.2 Design of new cowlings 25
References 27
Appendices 29
Appendix A 29
Appendix B 30
Appendix C 31

List of figures

Figure 1 Drag versus Flight Velocity.. 23

Figure 2 Engine Rpm and Maximum Continuous Power.. 28

Figure 3 Propeller Performance Chart 30

Figure 4 Engine Selection Process... 39

Figure 5 Maintenance Cost for AE300, Lycoming Io-360 and Continental....................... 1

Figure 6 Power Comparing According To Altitude 1

Figure 7 fuel flow for Lycoming IO-360... 2

Figure 8 Fuel flow for AE300.. 3

Figure 9 Shown table of fuselage sections in AAA... 5

Figure 10 shown 3D-model for SAFAT 03 with AE300... 6

Figure 11 Parameters in AAA.. 6

Figure 12 AE300 engine and mount integrated in SAFAT 03 10

Figure 13 AE300 engine and nose landing gear integrated in SAFAT 03 11

Figure 14 AE300 ENGINE and nose landing gear integrated in SAFAT 03 from side view 12

Figure 15 mount and nose landing gear for new engine.. 12

Figure 16 mount and nose landing gear for new engine from side view.......................... 13

Figure 17 the engine AE300 assembled in the mount with nose landing gear................. 13

Figure 18 engine mount and AE300 assembled in SAFAT 03.. 14

Figure 19 shown fuselage configuration in AAA software 14

Figure 20 angle off attack and elevator deflection angle relative to velocity................... 15

Figure 21 trim drag polar diagram... 16

Figure 22 power required vs velocity 17

Figure 23 take-off chart AE300 18
Figure 24 take-off chart Lycoming 19
Figure 25 max rate of climb vs altitude 20
Figure 26 flight envelope 21

List of tables

Table 1 AE300 versus Lycoming IO-360 4
Table 2 Weight and Balance 8
Table 3 percentage of MAC for AE300 9

List of abbreviations

C_{D_0} Zero-lift drag coefficient

C_D The total airplane drag coefficient

ρ Air density.

U_1 Steady state airspeed.

δ Pressure ratio.

a Speed of sound.

S Wing planform or reference area.

$C_{D_{wing}}$ Wing drag coefficient.

$C_{D_{fus}}$ Fuselage drag coefficient.

$C_{D_{emp}}$ Empennage drag coefficient.

$C_{D_{np}}$ Nacelle/pylon drag coefficient.

$C_{D_{flap}}$ Leading/trailing edge drag coefficient.

$C_{D_{gear}}$ Landing gear drag coefficient.

$C_{D_{cw}}$ Canopy/windshield drag coefficient.

$C_{D_{store}}$ Store drag coefficient.

$C_{D_{trim}}$ Trim drag coefficient.

$C_{D_{int}}$ Interference drag coefficient.

$C_{D_{misc}}$	Miscellaneous drag coefficient.
S_L	Take-off distance.
W	Aircraft weight.
G	Acceleration gravity.
$CLmax$	Maximum lift coefficient.
T	Thrust.
S_L	Landing distance.
TR	Thrust required.
μ	Coefficient of rolling friction.
D	Drag.
L	Lift.
R/C	Rate of climb
R	Range.
Ŋ	Propeller efficiency.
C	Specific fuel consumption.
W_o	Gross weight of aircraft.
W_1	Empty weight of aircraft.
E	Endurance

Chapter 1: INTRODUCTION

1.1 overview

SAFAT03 is a primary trainer single engine piston light aircraft used primly for training developed and manufactured in Sudan by SAFAT Aviation complex. The project is very promising and reserved a lot of interest in the international aviation events and air shows, it is a stepping stone for aviation industry in Sudan. The aircraft is powered by The Lycoming O-360 which is a family of four-cylinder, direct-drive, horizontally opposed, air-cooled, piston aircraft engine. The problem with those engines is their operating cost as they used the AVGAS fuel type, Avgas fuel prices now days are very high, so the fuel control using computer algorithm and feedback system and fuel injectors, namely FADEC(Full Authority Digital Engine Control) systems, but still the operation costs is considered relatively high.

The engine and propeller performance shall provide the required performance and flight characteristics of the aircraft, the propeller type and performance indicated by the propeller efficiency should be high enough to provide the nearly shaft horse power provided by the engine, the extracted power reduces by the consumed electrical generated and the other engines accessories like governor, oil pump, fuel pump, air condition and hydraulic pump/

1.2 Problem statement

Introducing new engine for SAFAT and comparing between the aircraft using the original engine and after modification in term of performance, stability and economical operation.

Re-engining the SAFAT 03 for reducing fuel consumption by providing FADEC system with the new alternative engine, reducing direct operating cost by utilizing the diesel fuel type which have lower price of Avgas [1] [2]. Provide better performance characteristics since the proposed engine uses the turbocharger, the turbocharger maintain the engine power not varied with altitude.

1.3 proposed solution

To enable the calculations of flight performance, the trimmed drag polar, engine performance charts, propeller performance charts, weight and balancing data (cg envelope) and atmospheric data shall be prepared. The trimmed drag polar diagram require a trim analysis with new cg using computational aerodynamics tools like DATCOM or AAA. The engine and propeller charts shall be obtained for the proposed engine by communicating the engine manufacture. The cg envelope correlate the cg with payload and empty weight that would varied from the base design by changing engine and propeller weight. Adding new systems components like FADEC.

1.5 New engine features

The proposed engine AE 300 (Australian origin) type is turbocharged diesel piston engine, control by FADEC, Alternative fuel, factory support, better fuel metering (E.F.I.), better ignition control (E.I.), Liquid cooling - better temp control, Geared operation - Higher torque and Lower vibration levels [3], The AE 300 hold a type certificate from EASA [4].

1.6 Goals and Objectives

Lower fuel consummation, higher altitude performance, Lower maintenance costs, Improve of aerodynamic of engine cowling and Reduce manufacturing costs.

1.7 Contribution

Decreasing direct operating cost of SAFAT 03 aircraft, provide better fuel efficiency and fuel consumption that satisfy the low emissions and climate change policies.

1.8 Scope of Work

Constructing trimmed drag polar diagram, contacting engine manufacturer to obtain the engine and propeller technical data sheet and the type certification issued by EASA, building atmospheric ISA model, determine the cg.

1.9 Methodology

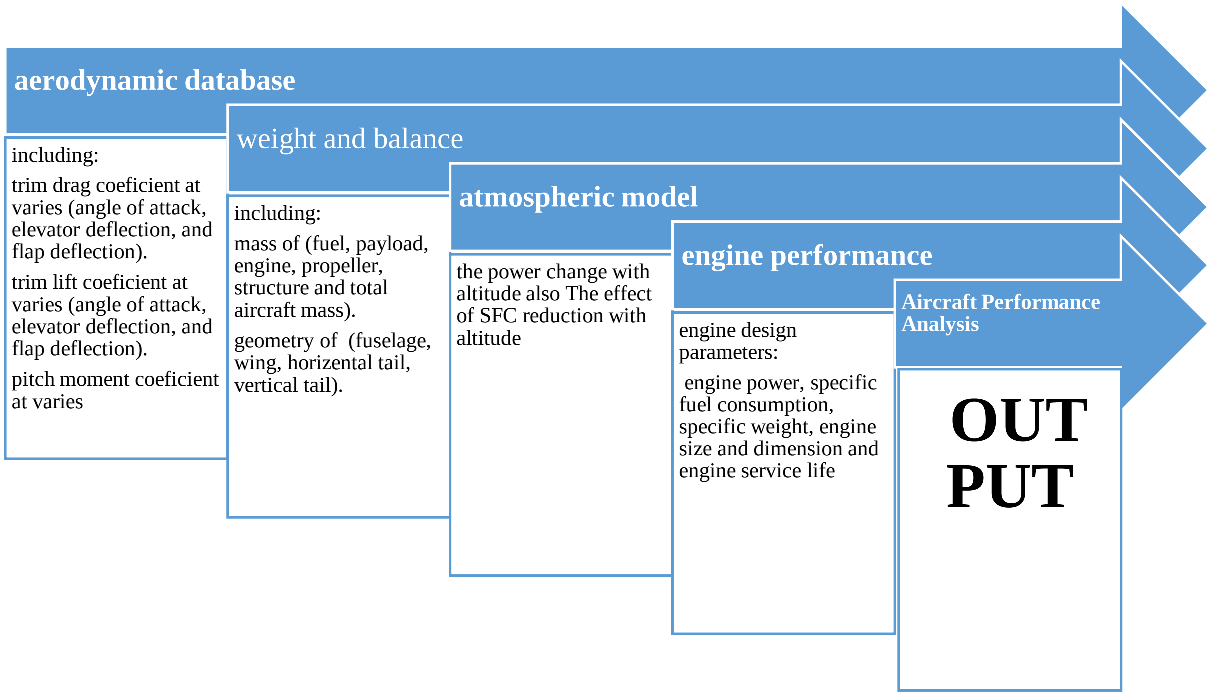
The work done in this thesis limited by the capabilities available now days in Sudan, the work is purely computational numerical and analytical. The trim drag polar will be obtained utilizing the AAA and DATCOM. The performance analysis is conducted by building in-house code by MATLAB. This code will enable to calculate level flight performance, take-off and landing performance.

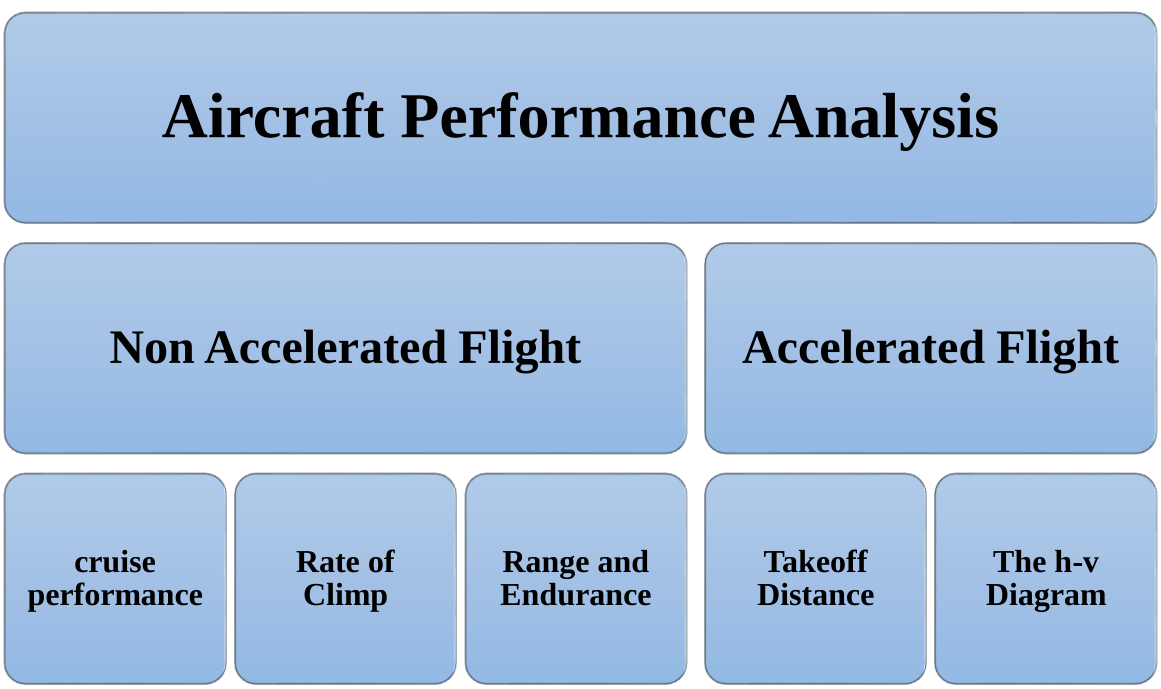
1.10 Time Frame

	MONTH 1				MONTH 2				MONTH 3				MONTH 4				MONTH 5			
Aerodynamic analysis of SAFAT03 using AAA		100 %																		
Trim analysis				100 %																
ISA						100 %														
Trim drag polar								100 %												
Engine technical specifications								100 %												
Cruise performance												100 %								

and construction h-v diagram																				
Take off performance																100 %				
Conceptual design of mount																	100 %			
Weight and Balance																	100 %			
Final report writing, documentation and design review																				100 %

1.11 Flow Chart





Chapter 2: LITERATURE REVIEW

2.1 History of re-engining

Re-engining of aircraft can happening several ways. These include an engine change or upgrade during the aircraft production run; an engine change plus a retrofit of existing aircraft; and re-engining after production is complete and the aircraft has been in service for a period of time. In the last 30 years there have been a number of aircraft programs, where during the course of the production run, new models of the same aircraft were re-engined to accept an improved engine not available at the program's inception. Examples of these programs include the McDonnell Douglas A4, B52 and the DA42NG.[5]

The Douglas A4 Skyhawk production started in 1956 using the 5658-20 engine. In the next seven years 1345 of those aircraft were produced. In 1961 production A4s were re-engined with the J52 engine, with remarkable performance improvements. Thrust was increased by almost 50% and aircraft range increased over 25%. The capability of the 'aircraft with the J52 was so improved that the A4 remained in production for another 18 years with about 1700 more aircraft produced.[5]

Another example of a change made to take advantage of increased thrust and lower SFC available from evolving engines is the B52. After five years in production with the J57 turbojet engine installed in over 600 aircraft, the B52, in 1961, was re-engined with the TF33 turbofan. The new engine increased take-off thrust by 16% and lowered SFC by 14%. These improvements increased aircraft range by more than 1400 miles.[5]

It should be noted that both the A4and B52 re-engining were measured in terms of improved performance. Any cost benefits were truly secondary. This type of re-engining happened before the drastic increases in fuel prices of the 1970s.It is also noteworthy that both theA4 and B52 are still in operational use and may well be until the year 2000.[5]

One of the biggest re-engining programs was that the DA42 using the IO-360 Lycoming engine. In 2008 production DA42 were re-engined with the AE 300 engine, after re-engining this called DA42 NG next generation, The DA42 NG, With its next generation turbo-diesel, 170 hp AE 300 engine by Austro Engine GmbH (AEG), With 26% more engine power and better high altitude engine performance than its predecessor, the DA42 NG will outperform across the board – take-off performance, climb performance, single engine performance and, of course speed. At the same time, the AE 300 offers up to 15% better specific fuel consumption at economy power setting, preserving the range, endurance and economy that has made the DA42 famous.

2.2 Re-Engining Considerations

Making re-engining decisions is more complex than making ordinary selection of new engine decisions. To make the re-engining possible three crucial considerations:

1. Performance of the aircraft
2. Regulation
3. Operating cost
4. Matching of the airframe

2.3 Performance of the aircraft

2.3.1Trim drag polar diagram

Drag force is the summation of all forces that resist against aircraft motion. The calculation of the drag of a complete aircraft is a difficult and challenging task, even for the simplest configurations. We will consider the separate sources of drag that contribute to the total drag of an aircraft. The variation of drag force as a function of airspeed looks like a graph of parabola. This indicates that the drag initially reduces with airspeed, and then increases as the airspeed increases. It demonstrates that there are some parameters that will decrease drag as the velocity increases; and there are some other parameters that will increase drag as the velocity increases. This observation shows us a nice direction for drag classification. Although the drag and the drag coefficient can be expressed in a number of ways, for reasons of simplicity and clarity, the parabolic drag polar will be used in all main analyses.[5]

The drag coefficient of an airplane can be written as:

$$C_D = C_{D_0} + \frac{C_L^2}{\pi e A} \qquad (1)$$

C_{D_0} The zero-lift drag coefficient

Trim drag It arises mainly as the result of having to produce a horizontal tail load in order to balance the airplane around its centre of gravity. Any drag increment that can be attributed to a finite lift on the horizontal tail contributes to the trim drag. Such increments mainly represent changes in the induced drag of the tail.[6]

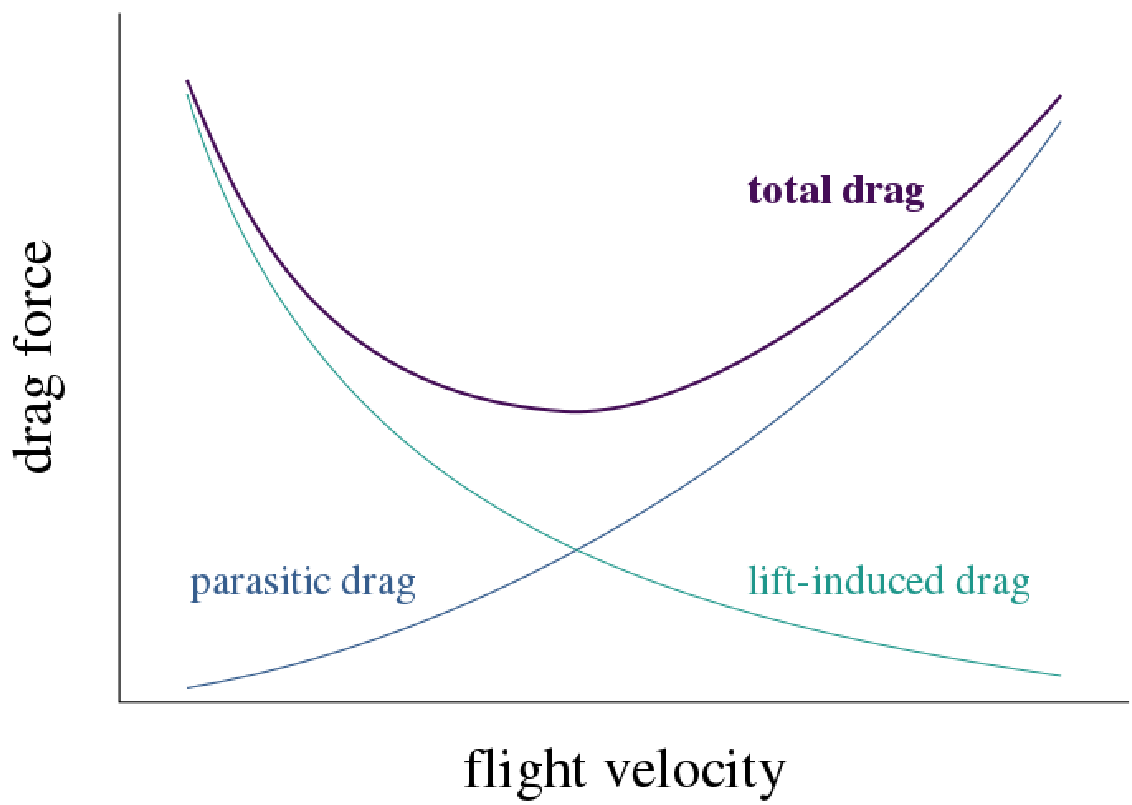


Figure 1 Drag versus Flight Velocity

2.3.2Drag Breakdown Procedure

Total airplane drag in Ibs is written as:

$$D = C_D \overline{q}\, S \tag{2}$$

Where: C_D= the total airplane drag coefficient

$\overline{q} = 0.5\, \rho\, (U_1)^2 = 1482\, \delta\, M^2$, also called free stream dynamic pressure, with:

$\rho =$ Air density.

$U_1 =$ Steady state airspeed.

$\delta =$ Pressure ratio.

$M = \frac{U_1}{a}$ = Mach number.

a = speed of sound.

S = the wing planform or reference area.

The total airplane drag coefficient is normally broken down into the following component:

$$C_D = C_{D_{wing}} + C_{D_{fus}} + C_{D_{emp}} + C_{D_{np}} + C_{D_{flap}} + C_{D_{gear}} + C_{D_{cw}}$$

$$+C_{D_{store}} + C_{D_{trim}} + C_{D_{int}} + C_{D_{misc}} \tag{3}$$

Where: $C_{D_{wing}}$ = wing drag coefficient.

$C_{D_{fus}}$ = Fuselage drag coefficient.

$C_{D_{emp}}$ = Empennage drag coefficient.

$C_{D_{np}}$ = Nacelle/pylon drag coefficient.

$C_{D_{flap}}$ = Leading/trailing edge drag coefficient.

$C_{D_{gear}}$ =Landing gear drag coefficient.

$C_{D_{cw}}$ =Canopy/windshield drag coefficient.

$C_{D_{store}}$ =Store drag coefficient.

$C_{D_{trim}}$ = Trim drag coefficient.

$C_{D_{int}}$ = Interference drag coefficient.

$C_{D_{misc}}$ = Miscellaneous drag coefficient.

This drag prediction methods apply only to flight cases where the boundary layer is mostly turbulent. If extensive laminar flow run are present (for example because of use of natural airfoils or because of use of "forced" laminar flow by suction). And also apply only to smooth surface. If surface roughness is present, the procedure of other method should be used in conjunction with this method. In chapter 3 will applying this method by details.[7]

2.4 Piston Airplane Cruise Performance

In analyzing piston airplane level cruise performance, one should recall that engine power output (power required, PR) may be considered closely proportional to fuel flow (FF), and vice versa. The constant of proportionality involves brake specific fuel consumption (BSFC) and propeller efficiency, and minor limitations to this approximation will be examined later. Since FF varies with PR, the latter can be used in lieu of FF.

A power required curve is a plot of P_R versus velocity for a given airplane at a given altitude. A power available curve is a plot of P_A versus velocity for a given airplane at a given altitude. The high speed intersection of the maximum power available and the power required curves determines the maximum velocity of the airplane.

2.4.1 Take-off Performance

$$S_{Lo} = \frac{1.44 * W^2}{g * \rho * S * CLmax * T} \qquad (4)$$

The lift-off distance is very sensitive to the weight of the airplane, varying directly as W^2 .if the weight is doubled, the ground roll of the airplane is quadrupled.

The lift-off distance is dependent on the ambient density ρ if we assume that thrust is directly proportional to ρ then

$$S_{Lo} \alpha \frac{1}{\rho^2}$$

This is why on hot summer days, when the air density is less than the cooler days, a given airplane requires a longer ground roll to get off ground. Also, longer lift-off distance are required at airports which are located at higher altitudes. The lift-off distance can be decreased by increase the wing area, increasing CLmax and increasing the thrust all of which simply make common sense.

2.4.2 Landing Performance

$$S_L = \frac{1.69 * W^2}{g * \rho * S * CLmax[TR + [D + \mu(W - L)]0.7VT]} \qquad (5)$$

During the landing ground roll, the pilot applying brakes, hence coefficient of rolling friction is that during braking, which is approximately μ=0.4 for a paved surface.

To shortening the ground roll utilized the thrust reverse. Also poly to shorten the ground roll is to decrease the lift to near zero by spoilers.

2.4.3 Rate of climb

$$R/C = \frac{excess\ power}{W} \qquad (6)$$

Clearly, rate of climb depends on raw power in combination with the weight of the airplane the higher the thrust, the lower the drag, and the lower the weight, the better the climb performance.

2.4.4 Range

$$R = \frac{\eta}{C}\frac{L}{D}\ln\frac{W0}{W1} \qquad (7)$$

For maximum rang fly at maximum $\frac{L}{D}$, have the highest possible propeller efficiency, lowest specific fuel consumption and highest ratio of gross weight to empty weight.

2.4.5 Endurance:-

$$E = \frac{\eta}{C}\sqrt{2 * \rho * S}\,\frac{Cl^{\frac{3}{2}}}{CD}\left(W1^{\frac{-1}{2}} - W0^{\frac{-1}{2}}\right) \qquad (8)$$

For maximum endurance fly at maximum $\frac{Cl^{\frac{3}{2}}}{CD}$, have the highest possible propeller efficiency, lowest specific fuel consumption, highest difference between W_o and W_1 , and fly at sea level where ρ is the largest value.

2.5 Engine Performance:

In any engine-airplane study it is necessary to generate engine performance over the range of important flight conditions especially cruise take-off, and landing) for a family of engines whose design parameters: engine power, specific fuel consumption, specific weight, engine size and dimension and engine service life.[8]

To steady engine Performance some parameters relationship must be obtained:

2.5.1 Engine power related to RPM

Increasing the power output of an engine, by increasing the engine speed. The strength and weight of the components used in an engine are the main factors limiting the power produced.

An increase in engine speed will also result in the burning of a greater weight of fuel in a given time, and will therefore result in the production of more power. However, the higher centrifugal forces, and other stresses set up in the engine, necessitate stronger components, with a disproportionate increase in weight. Again the strength of the materials is the limiting factor.[9]

The figures (2.5) shows the increasing in output shaft power identified in the performance data for use during periods of unrestricted duration. [3]

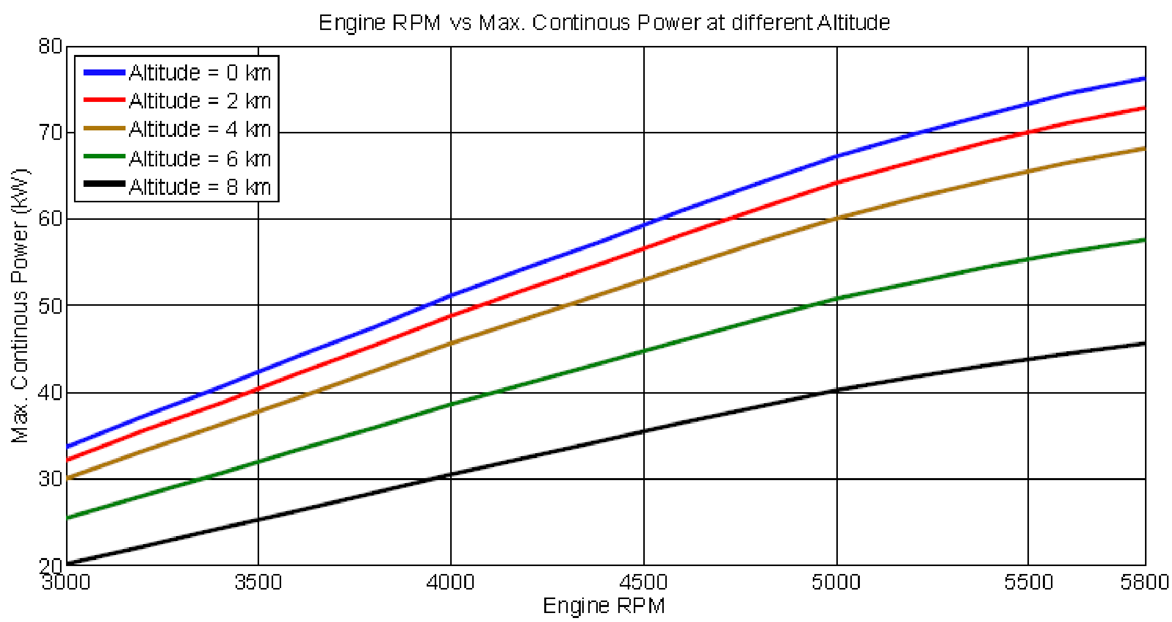


Figure 2 Engine Rpm and Maximum Continuous Power

2.5.2 Specific fuel consumption with RPM

The specific fuel consumption is a technical figure of merit for an engine which Reflects how efficiently the engine is burning fuel and converting it to power. For an internal combustion reciprocating engine, the specific fuel consumption c is defined as:[10]

c = weight of fuel burned per unit power per unit time

Or

$$c = \frac{\text{weight of fuel consumed for given time increment}}{(\text{power output})(\text{time increment})} \tag{9}$$

Variation of Specific fuel consumption with velocity and altitude

$$P \; \alpha \; dp_e \, RPM$$

In this equation P is the power that comes from the engine shaft; it is sometimes called shaft power. Considering the engine is mounted on an airplane. As the airplane velocity V is changed, the only variable affected in the equation is the pressure of the air entering the engine manifold, due to the stagnation of the airflow in the engine inlet. (Sometimes this is called a ram effect.) In effect, as V increases, this "ram pressure" is increased; it is reflected as an increase in p_e in the equation, which in turn increases P for the high-velocity propeller-driven fighter airplanes of World War II, this effect had some significance. However, today reciprocating engines are used only on low speed general aviation aircraft, and the ram effect can be ignored. Hence, we assume in this P is reasonably constant with V.[10]

2.5.3 Propeller performance

Theoretically the most efficient propeller is a large diameter, slowly turning single blade propeller. Here, think the Osprey or helicopters. In both cases, large diameter, slowly turning, compared to typical fixed wing aircraft, propellers are used. Generally, single bladed propellers are not used because of dynamic imbalance - think vibration. As a result, the general wisdom is that better propeller efficiency results from decreasing RPM. However, propeller efficiency is not only a function of RPM. It is also a function of propeller diameter and true airspeed. Generally these parameters are combined into a non-dimensional parameter called the advance ratio (J = V/ND), where V is the true airspeed in feet per second, N is the propeller rotational speed in revolutions per second and D is the propeller diameter in feet.[11]

Typical propeller performance curves are shown in figure (2.6) is used to study propeller performance [10]

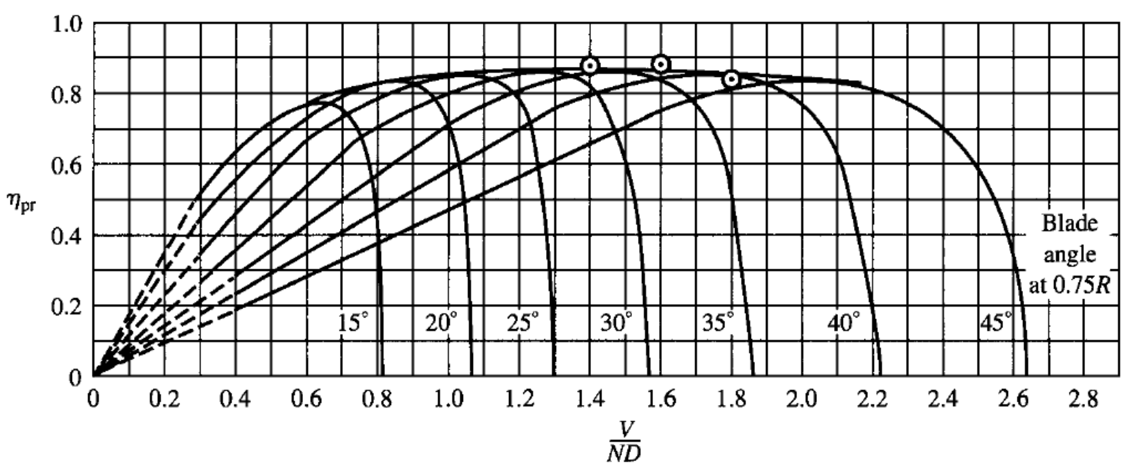


Figure 3 Propeller Performance Chart

2.6 Regulation

2.6.1 Certification

A type certificate is issued to signify the airworthiness of an aircraft manufacturing design or "type". The certificate is issued by a regulating body, and once issued, the design cannot be changed.

With respect to "cannot be changed": When an airframe wants to change something it has two options.

- Request a Supplemental Type Certificate (STC),
- Create an entirely different design with new Type Certificate (STC).

2.6.2 The Supplemental Type Certificate

A STC is a TC issued when an applicant has received FAA/EASA approval to modify an aircraft from its original design. An STC is a major change in type design not *great enough* to require an application for a new TC under FAR/EASA PART 21.19. An in our case would be installation of a power plant different from what was included in the original TC.

The work done during this task should be planned correctly taking to consideration instruction for continuous airworthiness requirements i.e flight manual, maintenance manual, operation manual and support during aircraft life cycle.

2.6.3 Fuel Environmental effect:

Tetraethyl Lead (TEL) emissions all forms of lead are toxic if inhaled or ingested. Lead can affect human health in several ways, including effects on the nervous system, red blood cells and cardiovascular and immune systems. Infants and young children are especially sensitive to even low levels of lead, which may contribute to behavioural and learning problems and lower IQ. Children have increased sensitivity due to their developing nervous systems. TEL is an organic compound that contains lead and, in small quantities, is very effective in boosting octane. The ban of TEL in automobile gas was phased in over a number of years and was largely completed by 1986 and resulted in significant reductions of lead emissions to the environment. TEL was not yet being banned for use in avgas, because no operationally safe alternative is currently available. Without the additive TEL, the octane levels would be too low for engines, and use of a lower octane fuel than required could lead to engine failure. As a result, the additive TEL has not been banned from avgas. Absent of led additives in diesel would help the general aviation industry make a transition to an unleaded fuel. (FAA Fact Sheet – Leaded Aviation Fuel and the Environment June 19, 2013 Henry J. Price) Carbon dioxide co2 emissions carbon dioxide effects directly Climate Change and increasing of global warming.

From CO2 perspective then diesels are less polluting than avgas engines, which is why in many places across the world people have been moving t:o diesel. Governments (many in Europe) have in some cases taxes diesel less to make it more attractive.

2.7 Operating cost:

This section provides estimates of variable and fixed aircraft operating costs. Aircraft variable operating costs are important factors in the evaluation of re-engining investment. The variable operating costs of aircraft affect aircraft operators directly and users of air service indirectly in the form of higher or lower prices. Fixed aircraft costs may also be important in evaluating the effects of re-engining, cause aircraft to be more productive, or cause aircraft to be out of service for extended periods of time.

2.7.1 Direct Operating Cost

DOC is the operational expense directly associated with a flight. This cost is allocated towards the flight planning process (positive or negative outcomes). DOC is summed up with both fixed and variable costing. For obvious accounting reasons, different airlines and their fleet manufacturers (Airframe and Power Plant) use different definitions on what their DOC is. In addition, airlines, charter companies, air taxis etc use different methods and approach to calculating DOC though some of the variables are constant. For instance Fuel, Crew, etc.

2.7.1.1 Contributing variables to DOC

- Depreciation, Insurance and Interest
- Fuel; the biggest, single line item in the cost
- Station and Ground Services; varies upon weight, class and size of fleet
- Flight and Cabin crew; varies upon weight, class and size of aircraft
- Airframe and Power-plant Maintenance – varies on what class and size airliner belongs to

2.8 Matching of the airframe

Study the ability of the aircraft to accommodate the new engine is depending on the stricture requirement, weight and balance and several performance constrains.

2.8.1 Engine mount

2.8.1.1 Conceptual Design for the Mount

The design determine the initial physical mount configuration. That initial design work depends upon certain basic information, including accurate 3D-CAD definitions of:

1. the firewall pickup points,
2. the engine attachment points,
3. the power plant top, front, rear and side profiles the desired location and orientation of the propeller centreline,
4. the top, front and side fuselage profiles

The engine is mounted to the aircraft in manner which allow the thrust to be transmitted to the main aircraft structure. In addition to support the engine weight and carrying any flight load. Due to the wide variation in the temperature of the engine casing, the engine is mounted so that casing can expand freely in both longitudinal and radial directions. Tubular mounts are used almost exclusively in light aircraft.

These mounts are built up of chrome-molybdenum (4130) steel tubing and are welded into single lightweight unit. The welding methods most often used are the oxy-acetylene and heli-arc processes.

Some engine mounts are designed to impart a downward or upward thrust (relative to the top longeron or waterline of the airframe) while others offset the engine slightly to the right or left. The determination of how much the thrust line should be offset and in what direction is a design problem best left to the designer.

2.8.1.2REQUIRMENTS OF MOUNT

1. High strength and low weight.
2. Stiff force element, UN deformed at the load acts.
3. The load on the knots should be minimum, therefore they should be located near the engine C.G, at small distance each other.
4. Easy of mount and dismount of the engine, and good accesses to element adjusting and servicing.
5. Minimum temperature stresses, for this reason the connection should of deferent temperature deformation part, free temperature expansion.
6. Free deformation of aircraft without any load to the engine case.

2.9 Cowling Requirement

1. Minimal aerodynamic drag in a system of the aircraft (at working engine or inoperative one; in view of an aerodynamic interference)

2. Rational organization of airflow for cooling an engine (propeller gear, cooler installations).

3. Good access to power plant at maintenance on ground.

4. Provision of fire safety (firewalls for fire

Isolation).

2.9.1 Cooling by Cowling

Many people still think a cowling is used only to streamline an airplane and to make it look good. Years ago, this is just about all the cowling did for an airplane. It rounded off the nose and hid the clutter of the engine compartment.

In time, what may best be described as an internal-flow cooling concept (also called pressure cowl cooling, ram air cooling, etc.) emerged. It changed the face of airplanes and the familiar protruding cylinders disappeared from view….along with a lot of parasite drag.

With the so called ram air or pressure cowl type of cooling system, a little air is made to do a lot of cooling rather than a lot of air cooling but little, and doing it unevenly at that.

2.9.2Cowling Inlets

The lack of data regarding the design and the cooling effectiveness of various kinds of cowling inlets is obvious. A look around any flight line will convince you that there is a lack of standardization a among the aircraft packed there.

The size and location of the cowling inlets depend upon the amount of air required to cool the engine at a given power setting, the velocity of the air, and the resistance imposed

2.10 Weight and Balance

2.10.1 Centre of Gravity

Every particle of an object is acted on by the force of gravity. However ,in every object there is one point at which a single force , equal in magnitude to the weight of the project and directed upward , can keep the body at rest , that is , can keep it in balance and prevent it from falling. This point is known as the center of gravity (CG).

2.10.2 Location of CG

Since the CG of a body is that point at which its weight can be considered to be concentrated, the CG of a freely suspended body will always be vertically beneath the point of support when the body is supported at a single point .To locate the CG therefore, it is necessary only to determine the point of intersection of vertical lines drawn downward from two separate points of support employed one at a time.

2.10.3 Computing CG Location

After the necessary dimensions and weights have been obtained, the empty weight and the empty weight CG can be calculated. Empty weight is the total of the three scale readings after subtracting the weight of rate items, plus or minus calibration errors. This weight is important for subsequent calculation of maximum weight and also is necessary factor in the determination of the CG.

2.10.4 Expressing the CG as Percentage of the MAC

The center of gravity may be expressed in terms of inches forward or to the rear of the datum line or as percentage of the mean aerodynamic chord (MAC). The MAC is established by the manufacturer, who defines its leading edge (LEMAC) and trailing edge (TEMAC) in terms of inches from the datum. The CG location and various limits are then expressed in percentages of the chord.

2.11 Performance Constrains

Top level requirements specify flight performances which dominate the engine to airframe matching process, the most relevant parameters involved are installed thrust and wing size. Constraints on these selection variables are derived from the following performance constraints:

The cruise speed or cruise Mach number occasionally in combination with an initial cruise altitude capability following the take-off with MTOW, ascending to the top of climb and acceleration to cruise speed. Climb gradients achievable after engine failure for several flight segments and aircraft configurations. Engine-out altitude capability, the altitude achievable in level flight with One Engine Inoperative. This requirement is relevant for airplanes having the capability to cross extensive uninhabited terrains and oceans. The take-off field length. The approach speed and/or the landing field length required.[9]]

CHAPTER 3. METHODOLOGY

This chapter covers the research framework, selection of the engine, methodology for the study. The study was based on a test of performance over the range of important flight conditions especially cruise take-off, and landing) for engines whose design parameters: engine power, specific fuel consumption, specific weight, engine size and dimension and engine service life.

3.1 Why Re-engining SAFAT 03:

As mentioned earlier, re-engining is done due to several reasons our main goal is to purpose a version or option of the aircraft relatively low operating cost and environmental friendly to meet local and global market needs in the most efficient way.

3.1.1 Reducing direct operating cost:

- using diesel fuel type which have lower price than Avgas
- Reduce fuel consumption

Improve Impact on the environment:

- Absent Tetraethyl Lead (TEL) emissions
- lower emissions

3.2 Engine selection:

We looked at a number of potential engine modifications as well as concepts for re-engining of current aircraft. The modifications or engine changes is not only on the basis of fuel savings alone. Some changes, however, bring significant operational improvements and maintenance benefits and should be considered also.

Depending on aircraft performance requirement the flawing Aircraft Diesel Engine Manufacturers for General Aviation offered by the market in our power rang in the competition of selecting an engine

3.2.1 Engine selection process algorithm

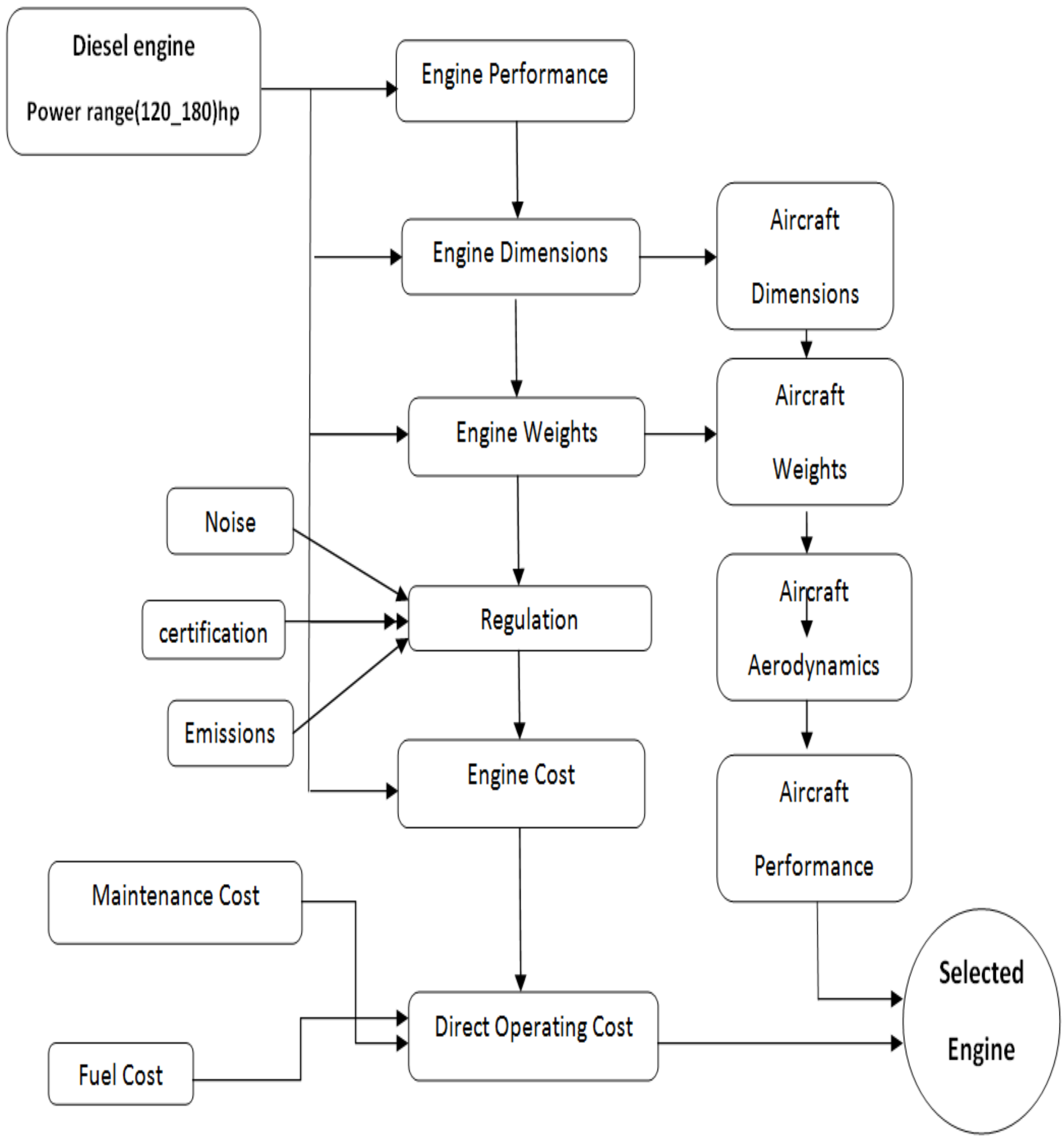


Figure 4 Engine Selection Process

3.2.2 Engine selection criteria:

Performance

Alternative fuel.

Fuel consumption

Weight and dimensions.

Regulation and certification

Influent on the environment

Engine cost

Maintenance costs.

Turbo charging.

Gear box drive engine.

Reliability

Durability

Safety

3.2.3 Table of selection

Table 1table of selection

ENGINE TYPE	POWER HP	FUEL TYPE	WEIGHT Kg	DIMENSION	CERTIFICATION	TBO	Constant	SFC	0rgan
Continental CD-155	155	Diesel	134	778 x 816 x 636	FAA	2100	yes	4.1* 10^-7	US
Austro ae300	168	Diesel	186	855 x 738 x 574	FAA& EASA	1800	yes	3.6* 10^-7	AUS

Lycoming IO-360	180	AVGAS	136	848x 832 x 515	FAA &EASA	2000	yes	6.6*10^-7	US

These characteristics combine offer a prospect of an Austro AE300 reciprocating engine being a viable alternative to Lycoming 360 engine.

3.2.3 Maintenance cost

ENGINE	OVERHAUL/ REPLACE COST[1]	MIDSTREAM COSTS[2]	PER HOUR/U.S.[3]	PER HOUR/ EUROPE
CONTINENTAL CD135	$35,520	$17,959	$47.70	$55.71
CONTINENTAL CD155	$42,180	$17,959	$51.01	$58.88
AUSTRO AE300	$23,647	$6945	$39.28	$42.84
LYCOMING IO-360	$25,000	$10,000	$55.10	$89.50

[1]Price for Continental engines is based on full replacement at 2100 hours. Austro price is based on published overhaul costs at 1800 hours, while Lycoming is Bluebook price for typical overhaul.
[2]Midstream costs include fluid and recommended filter changes for all engines and mid-time gearbox, alternators and timing chains for Continental engines. Austro engines require governor and accumulator overhauls.
[3]Fuel prices for U.S. were based on $4.07 for Jet A and $4.70 for 100LL, as of June 2016.

Figure 5 Maintenance Cost for AE300, Lycoming Io-360 and Continental

3.2.4 Comparing between the AE300 power and LYCOMING power

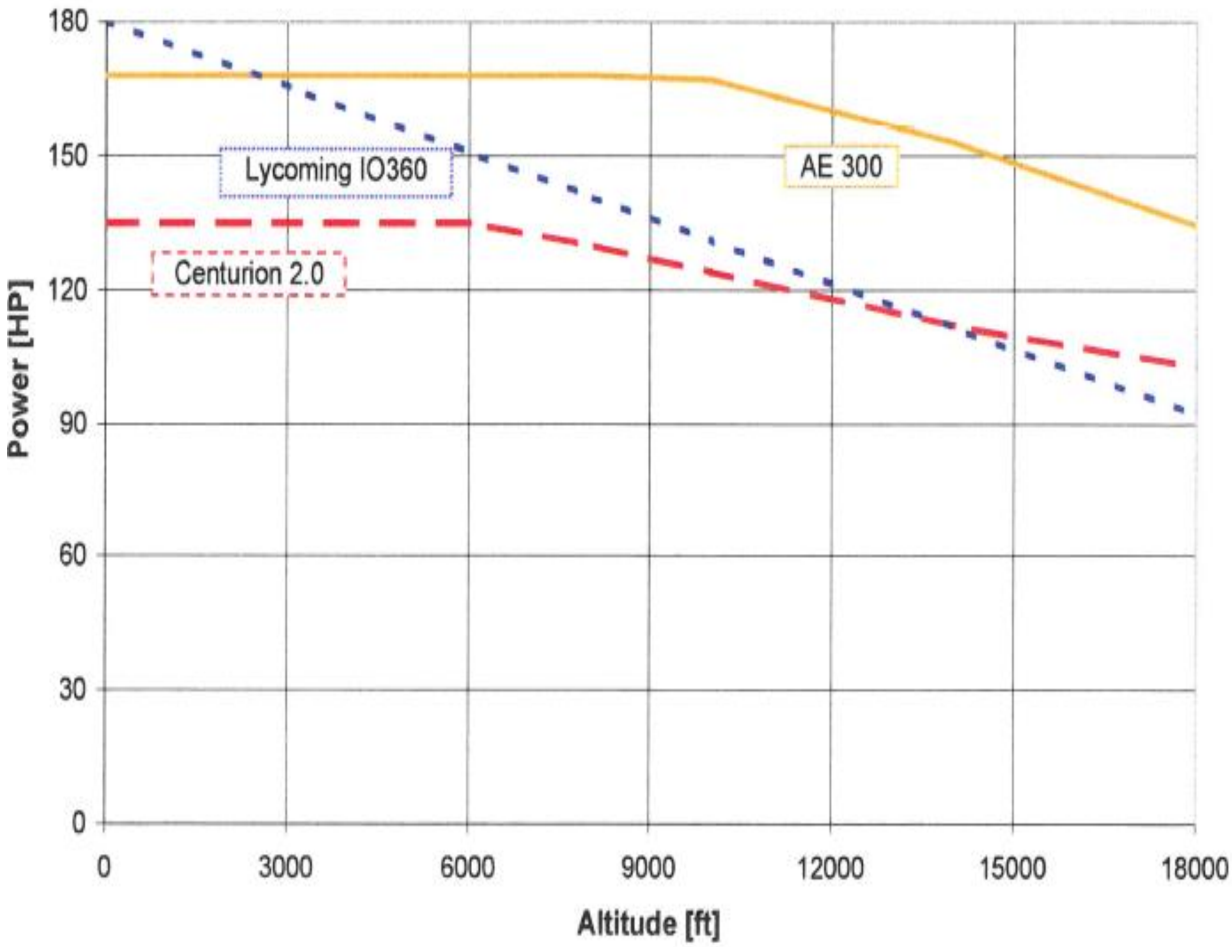


Figure 6 Power Comparing According To Altitude

Source: AE300 data sheet

3.2.5 Fuel flow versus AE300 and LYCOMING IO 360

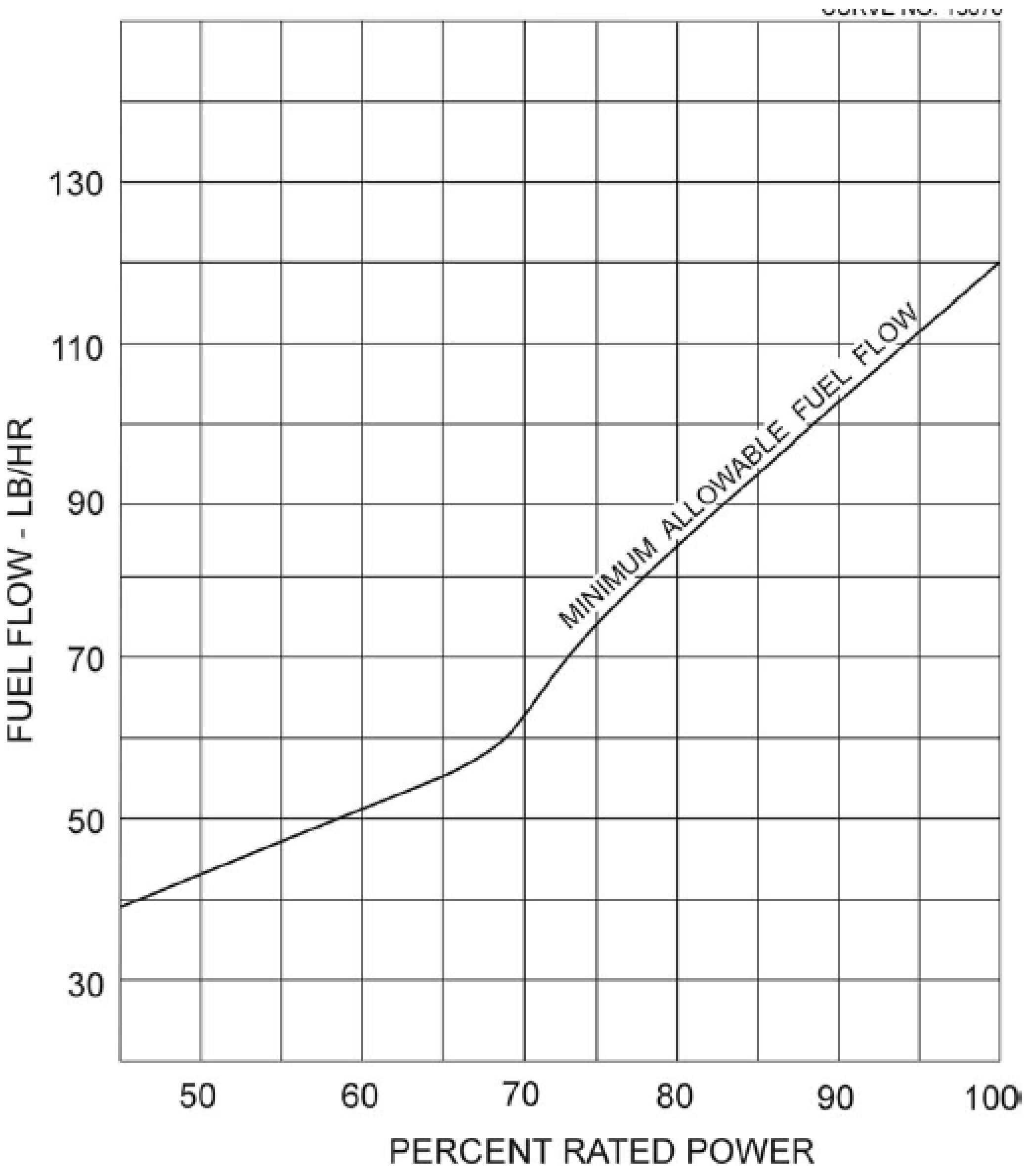


Figure 7 fuel flow for Lycoming IO-360

Source: Lycoming Operation Manual

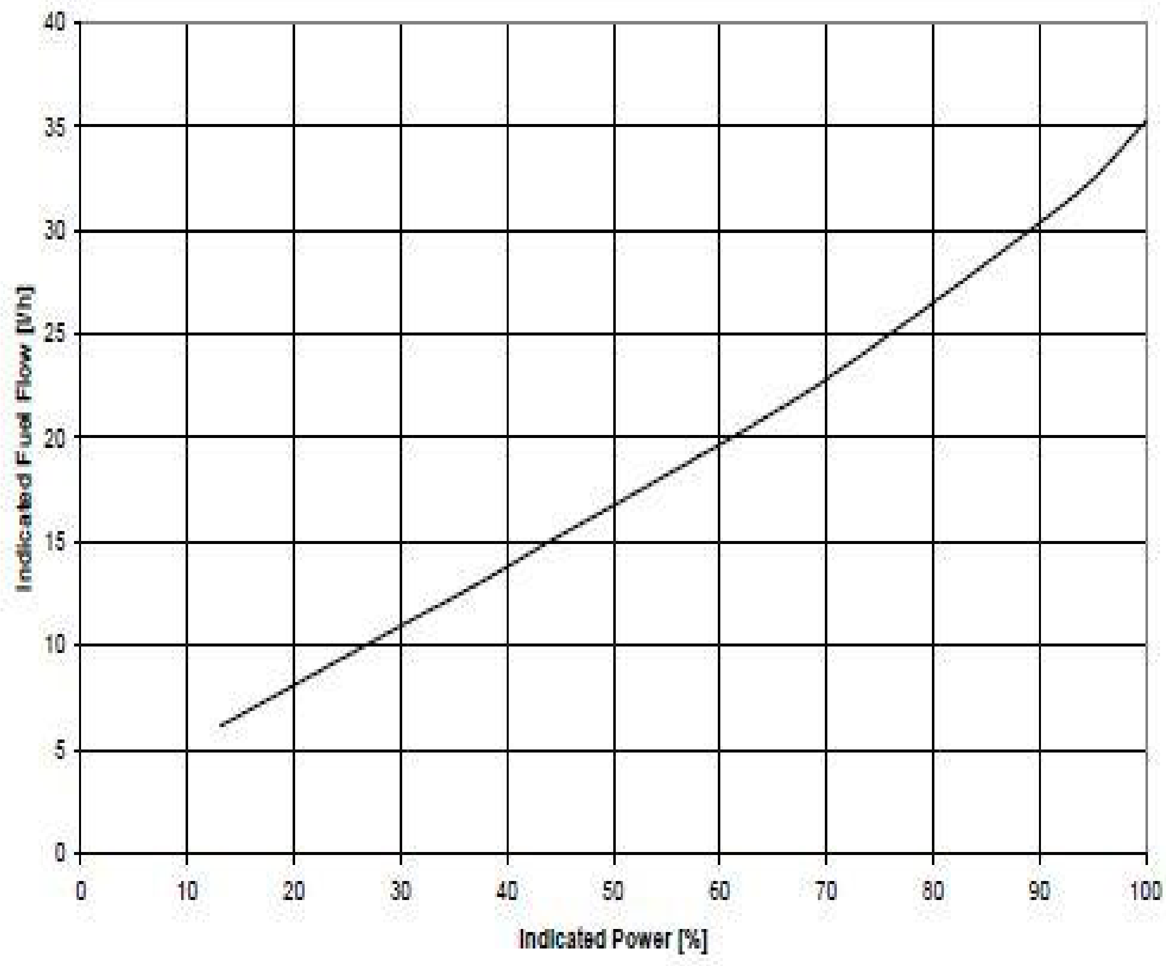


Figure 8 Fuel flow for AE300

Source: general information data from Austro Company

3.2.6 Comparison between Lycoming 360 and Austro AE300 characteristics

Table 2 AE300 versus Lycoming IO-360

	Austro AE 300	**Lycoming IO-360**
Horsepower(ph)	168	180
Weight(kg)	185 With system	136 Without system
NO of cylinders	In-line 4	Opposite-4
Length(in)	29	29.56
Width(in)	34	33.37
Height(in)	23	24.59
Type of fuel	Jet A1	Avgas
Propeller matching	constant speed	Constant speed
Fuel consumption (l/h)	35.1	41
Type of cooling	Liquid	air-cooled
Crank shaft material	Cast iron	Aluminum casting
Gearbox	Geared	Ungeared
Turbocharger	Turbocharged	Un-turbocharged

3.3 Performance calculation

To calculate the aircraft performance, must be building the aerodynamic data base of the aircraft; calculation done by using advance aircraft analysis software (AAA). The data needed to build aerodynamic data base: aircraft configuration such as, power plant, landing gear, structure, controls, and classification. After interring these data we get the final results.

Fuselage	x_{fus_1} m	z_{fus_1} m	z_{fus_3} m	Section	y_{fus_1} m	y_{fus_2} m	y_{fus_3} m	z_{fus_2} m	$y_{fus_{12}}$ m	$z_{fus_{12}}$ m	$\rho_{fus_{12}}$	$y_{fus_{23}}$ m	$z_{fus_{23}}$ m	$\rho_{fus_{23}}$	A_{fus_i} m^2	s_{fus} m
Section	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input	Output	Output
1	0.3240	0.1300	-0.2600	Nose	0.0000	0.2800	0.0000	0.0000	0.2800	0.1300	0.7740	0.2800	-0.2600	0.8380	0.20	1.6357
2	0.6160	0.1700	-0.3800	Nose	0.0000	0.4300	0.0000	0.0000	0.4300	0.1700	0.6990	0.4300	-0.3800	0.8090	0.40	2.3627
3	0.7660	0.2200	-0.4400	Nose	0.0000	0.4900	0.0000	0.0000	0.4900	0.2200	0.7090	0.4900	-0.4400	0.8020	0.55	2.7319
4	0.9160	0.2500	-0.4700	Nose	0.0000	0.5200	0.0000	0.0000	0.5200	0.2500	0.7600	0.5200	-0.4700	0.8250	0.66	2.9970
5	1.0660	0.2700	-0.4900	Nose	0.0000	0.5500	0.0000	0.0000	0.5500	0.2700	0.7380	0.5500	-0.4900	0.8010	0.72	3.1110
6	1.2160	0.3000	-0.5100	Nose	0.0000	0.5500	0.0000	0.0000	0.5500	0.3000	0.7350	0.5500	-0.5100	0.7950	0.76	3.1734
7	1.3660	0.3200	-0.5200	Nose	0.0000	0.5600	0.0000	0.0000	0.5600	0.3200	0.7210	0.5600	-0.5200	0.7890	0.80	3.2300
8	1.5160	0.3500	-0.5300	Nose	0.0000	0.5600	0.0000	0.0000	0.5600	0.3500	0.7400	0.5600	-0.5300	0.7910	0.84	3.3105
9	1.6660	0.4200	-0.5300	Center	0.0000	0.5600	0.0000	0.0000	0.5600	0.4200	0.7749	0.5600	-0.5300	0.7720	0.91	3.4289
10	1.8160	0.5100	-0.5200	Center	0.0000	0.5700	0.0000	0.0000	0.5700	0.5100	0.7620	0.5700	-0.5200	0.7730	1.00	3.5734

Figure 9 Shown table of fuselage sections in AAA

This sections export from aircraft 3d model in CATIA by division the fuselage to many sections and measuring the cross section areas, width and distance from reference line for each section. And then tabulated in excel file then export to AAA.

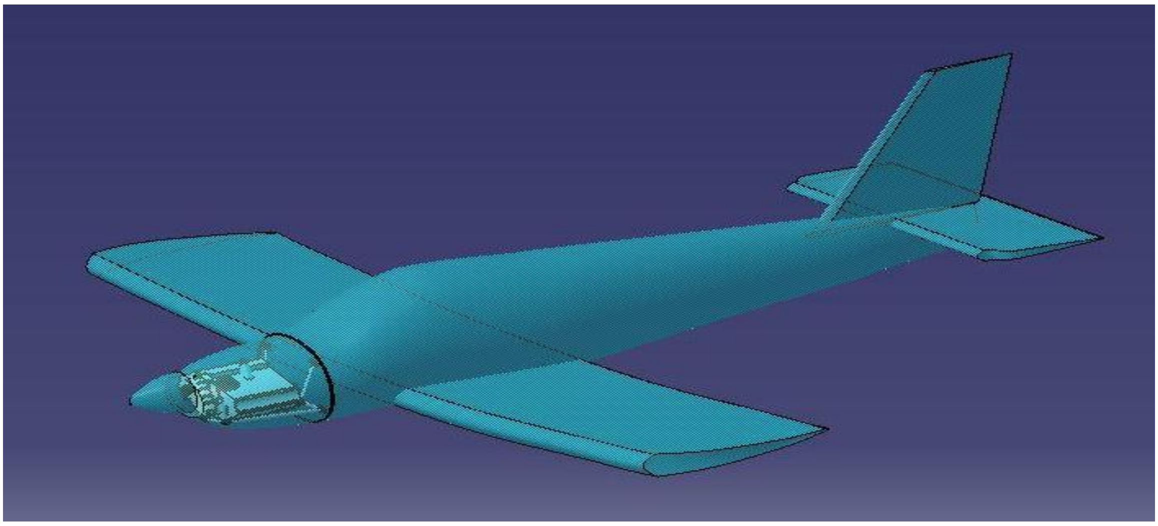


Figure 10 shown 3D-model for SAFAT 03 with AE300

Aerodynamic derivatives from AAA : ($Cl_{\propto}$, $Cm_{\propto}$, Cl_{δ_e}, Cm_{δ_e} , Cm_o , Cl_o , Cl_{max} , Cd_{δ_e}).

Input Parameters

X_{cg}	2.10 m	$X_{ac_{wf\ p.off}}$	2.31 m	$C_{L_{o_h}}$	-0.0336	$\bar{C}_{m_{o_{w\ clean}}}$	-0.0557
$C_{L_{o_{wf\ clean}}}$	0.4226	$\bar{c}_w$	1.55 m	X_{ac_h}	4.73 m	$\Delta C_{m_{w_{TE}}}$	0.0000
$C_{L_{o_{wf}}}$	0.4226	$\bar{C}_{m_{o_h}}$	0.0000	$\bar{C}_{m_{o_f}}$	0.0042	$\Delta C_{m_{o_{power}}}$	0.0079

Output Parameters

$\bar{C}_{m_{o_{wf\ clean}}}$	-0.0515	$C_{m_{o_{wf}}}$	-0.1093	$C_{m_{o_h}}$	0.0571	C_{m_o}	-0.0443
$\bar{C}_{m_{o_{wf}}}$	-0.0515	$\bar{C}_{m_{o_{no\ empen}}}$	-0.0515	$C_{m_{o\ p.off}}$	-0.0522		

Input Parameters

$\bar{x}_{cg}$	0.0413	$C_{L_{\alpha_{wf}}}$	0.0774 deg^{-1}	$\bar{x}_{ac_h}$	1.7410
$\bar{x}_{ac_{wf\ p.off}}$	0.1781	$C_{L_{\alpha_h}}$	0.0072 deg^{-1}	$\Delta C_{m_{\alpha_{power}}}$	0.0000 deg^{-1}

Output Parameters

$C_{m_{\alpha\ p.off}}$	-0.0228 deg^{-1}	C_{m_α}	-0.0228 deg^{-1}

Figure 11 Parameters in AAA

The results from AAA used in MATLAP code to calculate the variation of elevator deflection and angle off attack to build the trim drag polar diagram. All calculation accomplished by using MATLAB code to win more carefully results.

The power required from the engine it’s calculate from drag equation, drag force calculated in trimmed to obtain power required and determine maximum, minimum speed. Also used to estimate rate of climb through the excess power. Maximum rate of climb it’s varied with altitude as well calculated and plotted in graph.

Take-off performance calculation must be consider many parameters to take out exact distance to take-off, these parameters is: (run way altitude from sea level, head wind, tail wind, take-off weight and obstacle height).

Flight envelope it’s very important task to decide limiting speeds of the aircraft, it’s acquire in graph between altitude and velocity, the velocity calculated according to density in every altitude and power out from engine at same altitude.

3.3.1Range and Endurance

Range for aircraft with the new engine (AE 300):

$$R= \frac{\eta}{C} \frac{L}{D} \ln \frac{W0}{W1}$$

Endurance for aircraft with the new engine (AE 300):

$$E= \frac{\eta}{C} \sqrt{2 * \rho * S} \frac{Cl^{\frac{3}{2}}}{CD} (W1^{\frac{-1}{2}} - W0^{\frac{-1}{2}})$$

3.4 Weight and balance W&B

The new engine it’s accommodate gearbox and turbocharger this two equipment there is no find in the original engine these lead to shift in the centre of gravity therefore the weight and balance of the aircraft must be recalculated.

W&B have many method to calculate in this report will use the total moment (weight× arm) by the total weight, by changing the propulsion weight.

Table 3 Weight and Balance

Mass centre	**M [kg]**	**X [m]**	**Z [m]**	**M X**	**M Z**
Structure	365.821	-------	------	603.439	7.55077
Engine (AE300)	186	-0.64	-0.1	-119.04	-18.6
Propeller (MTV-6)	14	-0.95	-0.06	-13.3	-0.84
Engine mount	7.695	-0.1954	-0.18	-1.5036	-1.3851
Engine cowl	6	-0.42	-0.16	-2.52	-0.96
Other	1.9	-0.1	-0.27	-0.19	-0.513
Equipment and instruments	64.638	-------	-------	32.58227	-9.40561
Plus weight	21	-------	-------	11.91	-6
Full load	320	-------	-------	359.787	-52.25
Total mass	**987.054**	-------	-------	**871.165**	**-82.40294**

Plane empty = total mass – full load

$$\textbf{MAC}\ \% = \frac{\boldsymbol{CG - LEMAC}}{\boldsymbol{MAC}}$$

Table 4 percentage of MAC for AE300

Mass centre	**M**	$\sum$ **M X**	$\sum$ **M Z**	X_{cg}	Z_{cg}	**X%**
Plane empty	667.054	511.378	-30.153	0.7666	-0.0452	**24.5 %**
Plane fully equipped	987.054	871.165	82.4029	0.88259	-0.0835	**31.9 %**

Chapter 4: RESULT AND DISCUSSION

4.1 Engine AE300 and mount conceptual design:

The design determine the initial physical mount configuration. That initial design work depends upon certain basic information, including accurate 3D-CAD definitions of:

1. The firewall pickup points,

2. The engine attachment points,

3. The power plant top, front, rear and side profiles the desired location and orientation of the propeller centreline,

4. The top, front and side fuselage profiles.

The figures (12-18) shown conseptial design for engine mount and assemblies in the SAFAT-03.

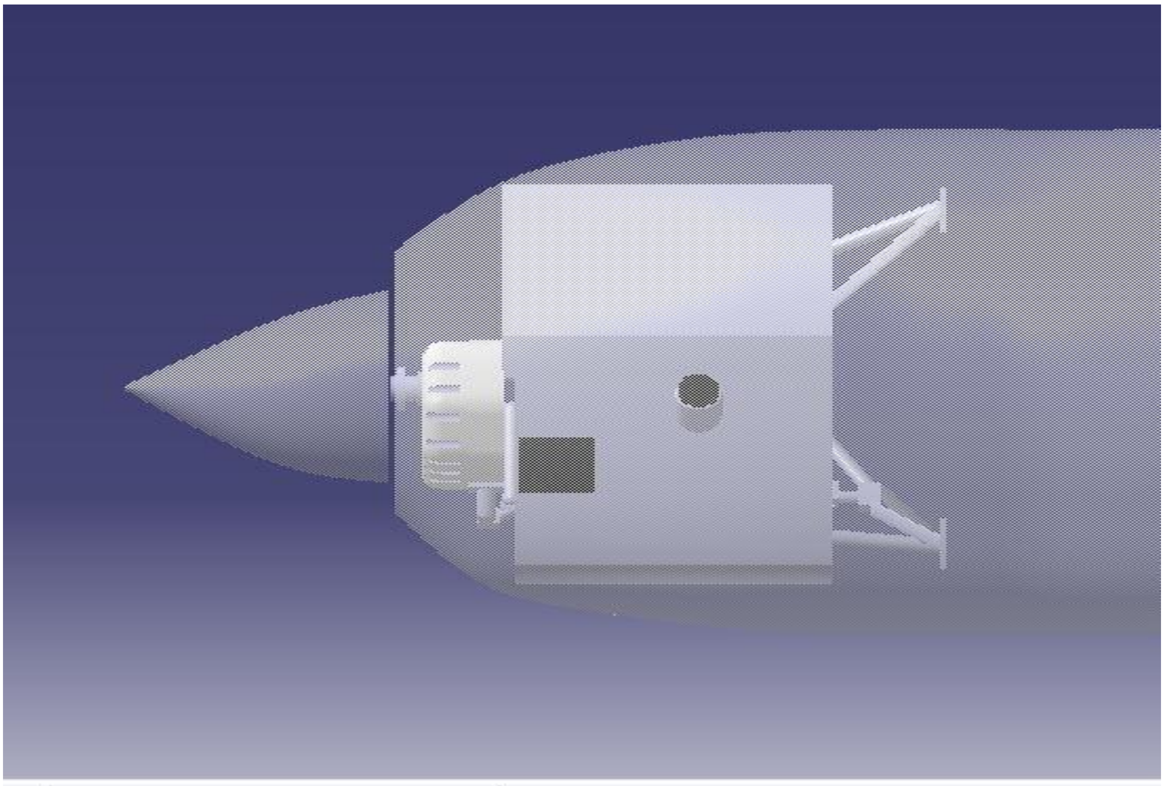


Figure 12 AE300 engine and mount integrated in SAFAT 03

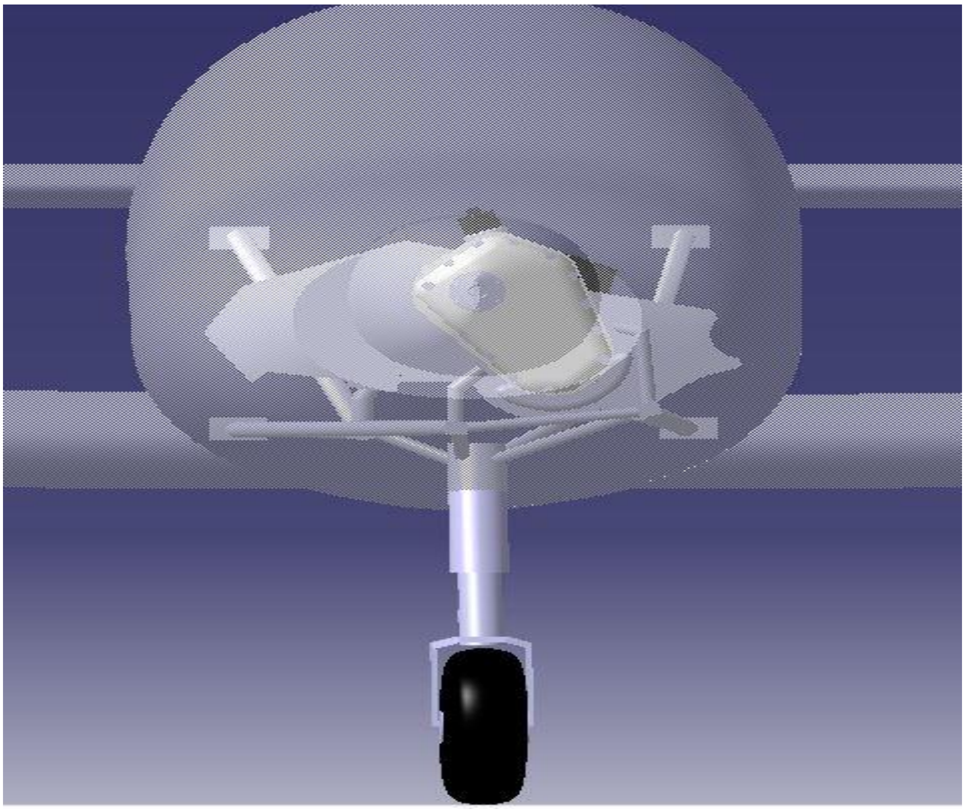


Figure 13 AE300 engine and nose landing gear integrated in SAFAT 03

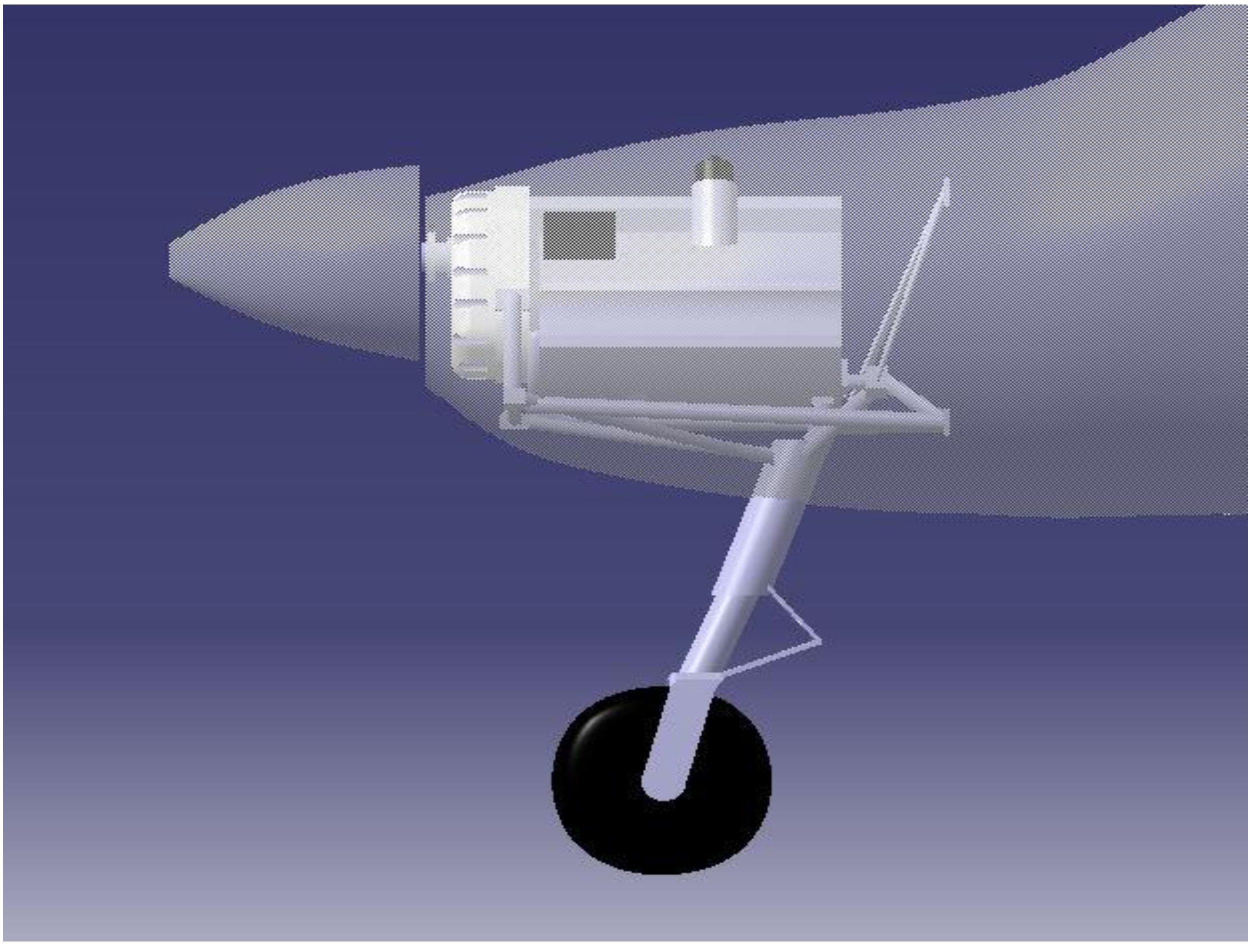


Figure 14 AE300 ENGINE and nose landing gear integrated in SAFAT 03 from side view

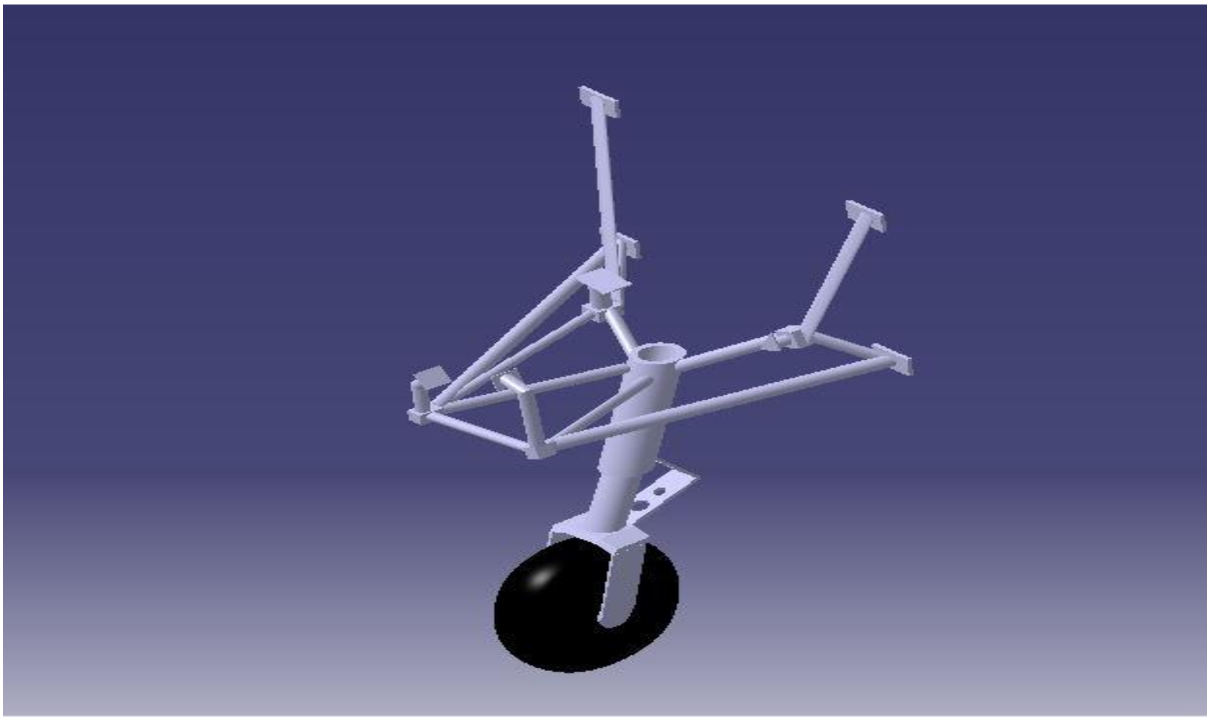


Figure 15 mount and nose landing gear for new engine

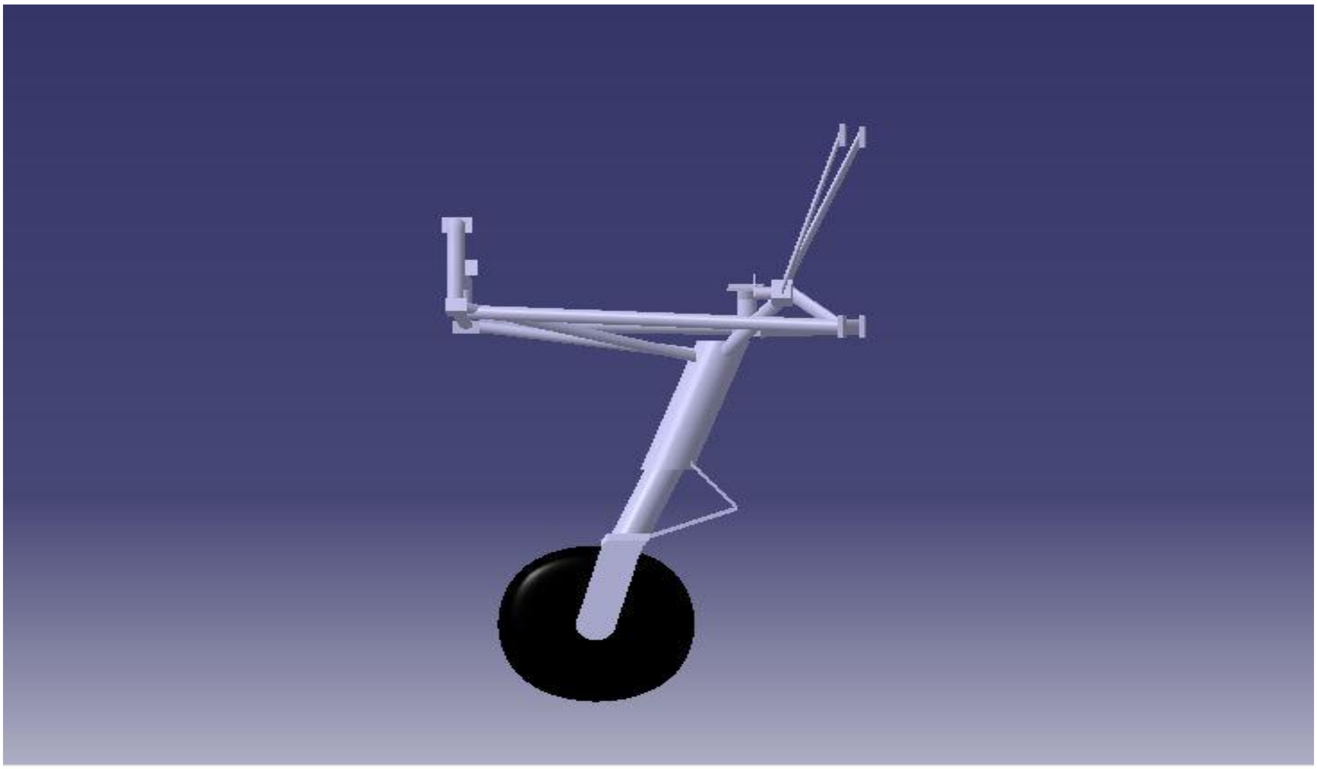


Figure 16 mount and nose landing gear for new engine from side view

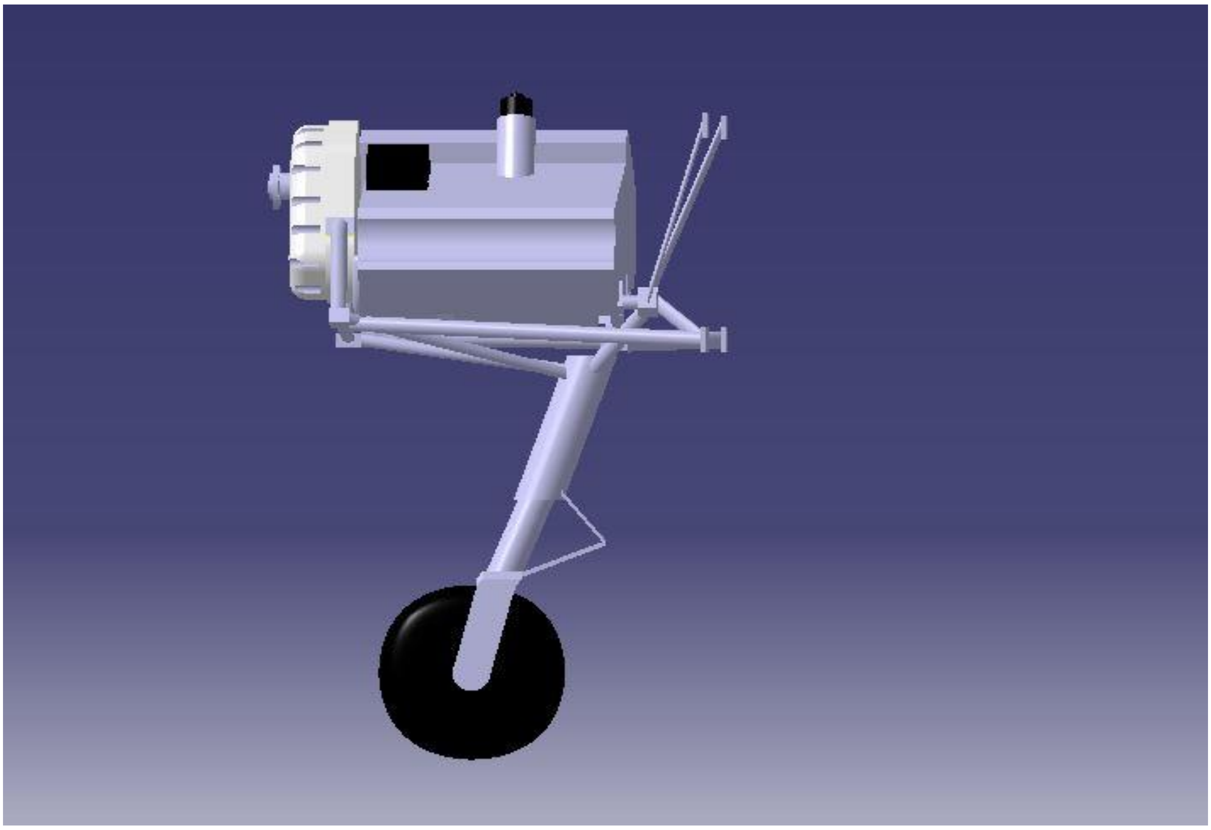


Figure 17 the engine AE300 assembled in the mount with nose landing gear

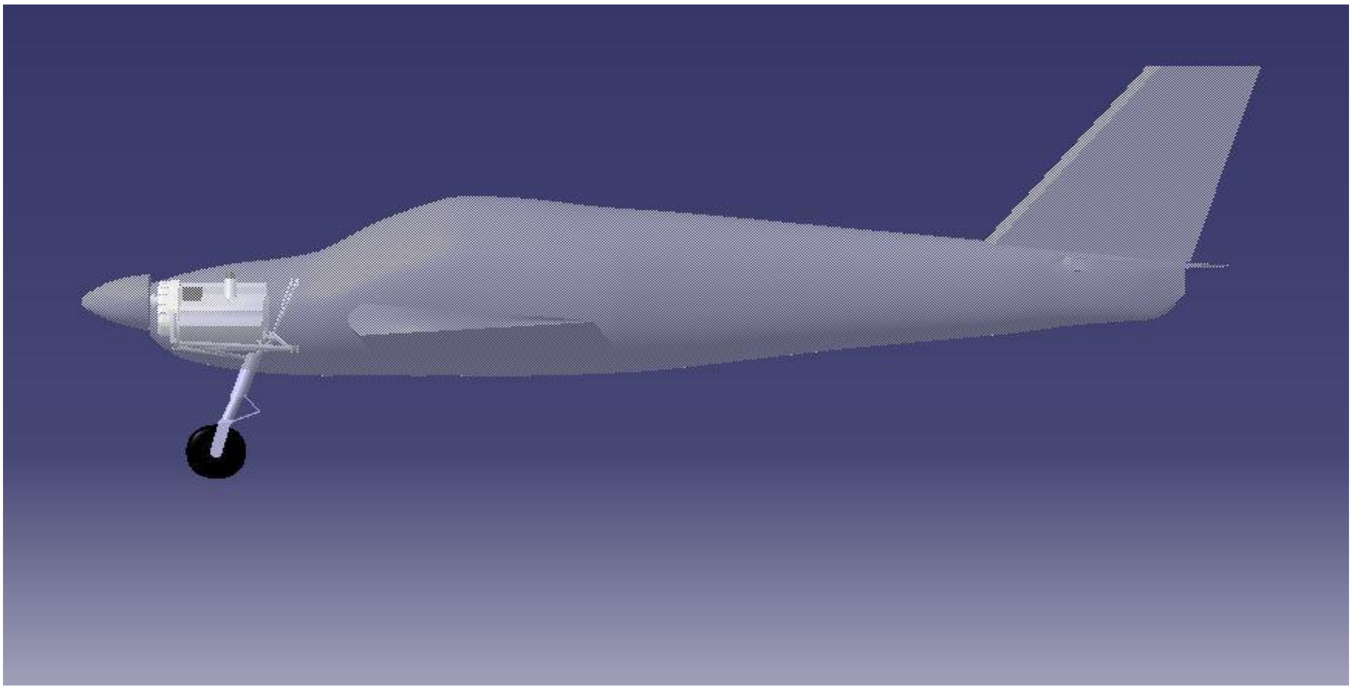


Figure 18 engine mount and AE300 assembled in SAFAT 03

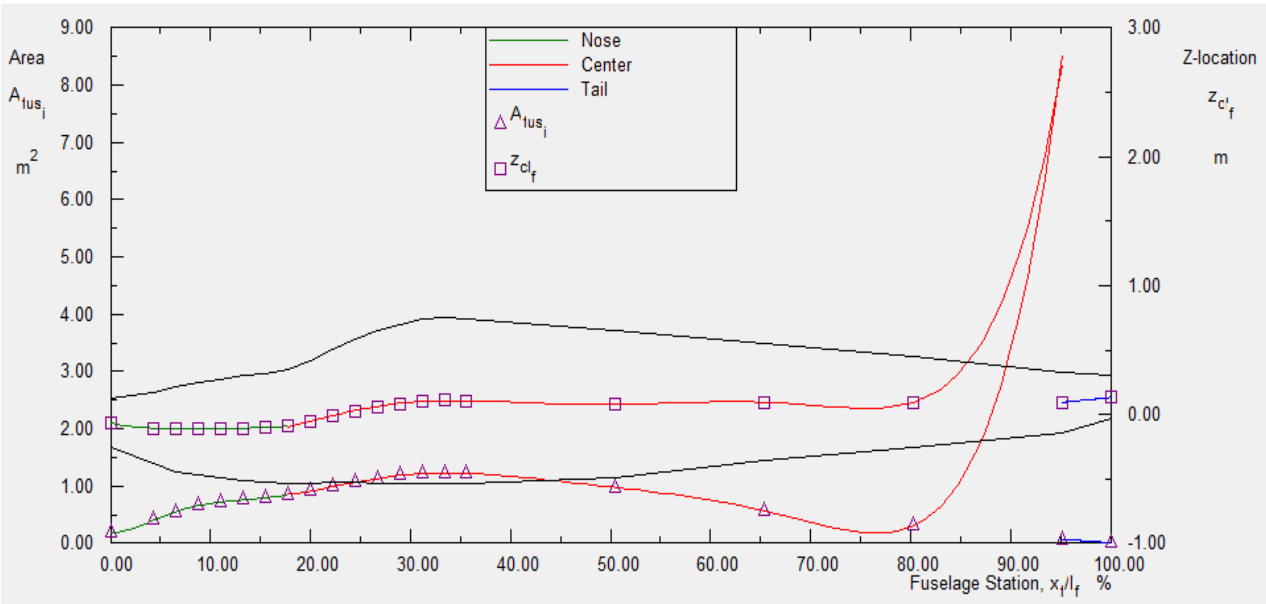


Figure 19 shown fuselage configuration in AAA software

4.2 Result of Performance Calculation

4.2.1Trim drag polar diagram

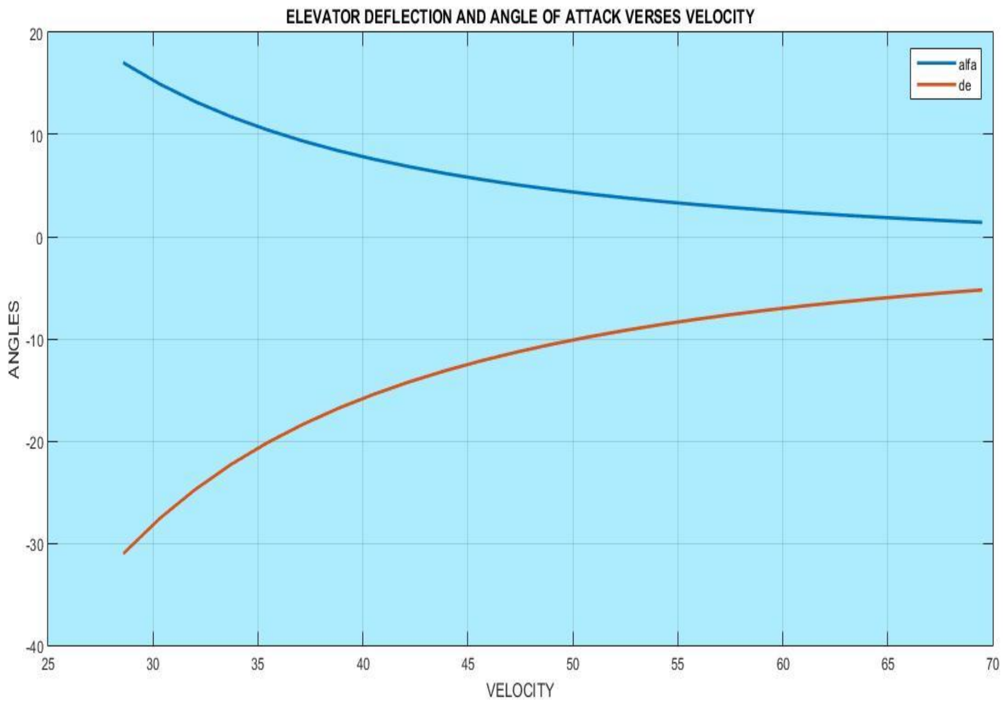


Figure 20 angle off attack and elevator deflection angle relative to velocity

The graphs compares the angle of elevator deflection and the angle off attack. It is clear that the angle off attack drop when thw elevator deflection goes up. Similarly the elevator deflection goes down when the angle off attack rise.

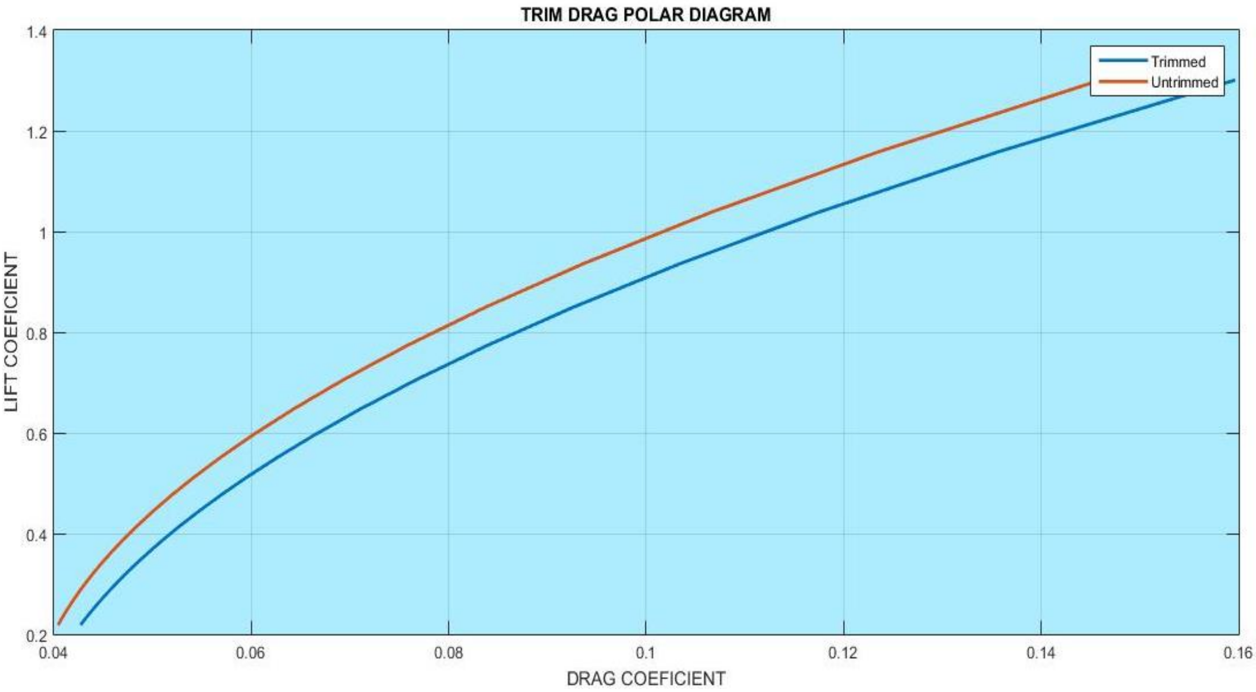


Figure 21 trim drag polar diagram

The graph compares who is higher drag either trimmed flight or untrimmed flight. It can be clearly seen that the drag increase when the lift increase in two cases.

The untrimmed lift coefficient it's big than trimmed due to the employed control surfaces lead to produce more drag. The relation between the lift coefficient and drag coefficient it's parabola, these from dependent of drag coefficient on squire of lift coefficient. So the drag coefficient goes up quickly at the begin of the curves due to the rate of increase of lift coefficient at low speed more than high speed.

Similarly the graphs climbs with the same degree of slope, it can be seen the lift coefficient at 0.8 the drag coefficient at trimmed it's 0.088 but at un-trimmed it's 0.078, these describe the drag coefficient increase with employed the control surfaces by 12%.

4.2.2 Power required

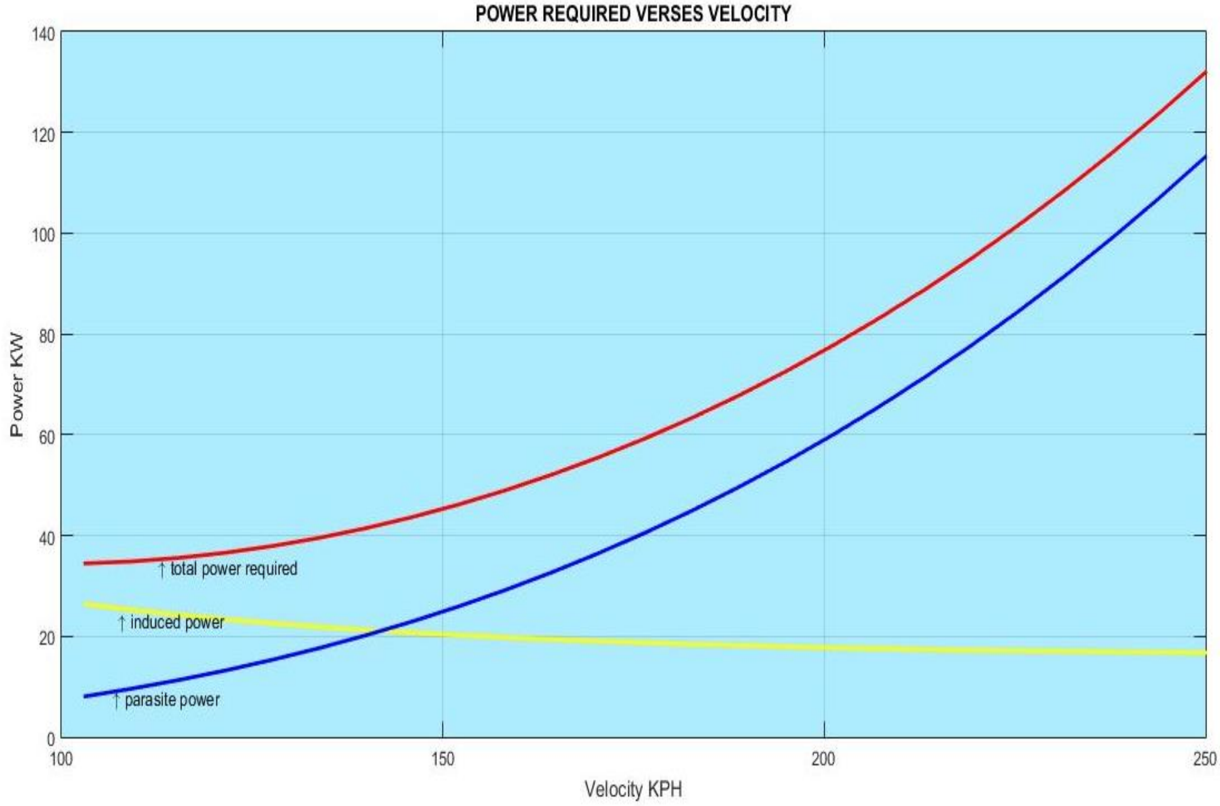


Figure 22 power required vs velocity

The graphs compares the induced power and parasite power with velocity. It's clear that that the total power required at low speed smallest than total power required at higher speed.

When the velocity excess the induced power reduced and the parasite power likewise rise quickly. The point of cross of induced and parasite power give's minimum power required, optimum velocity and maximum aerodynamic efficiency. After cross point the parasite power it's the dominate of the total power required.

4.2.3 Take-off distance

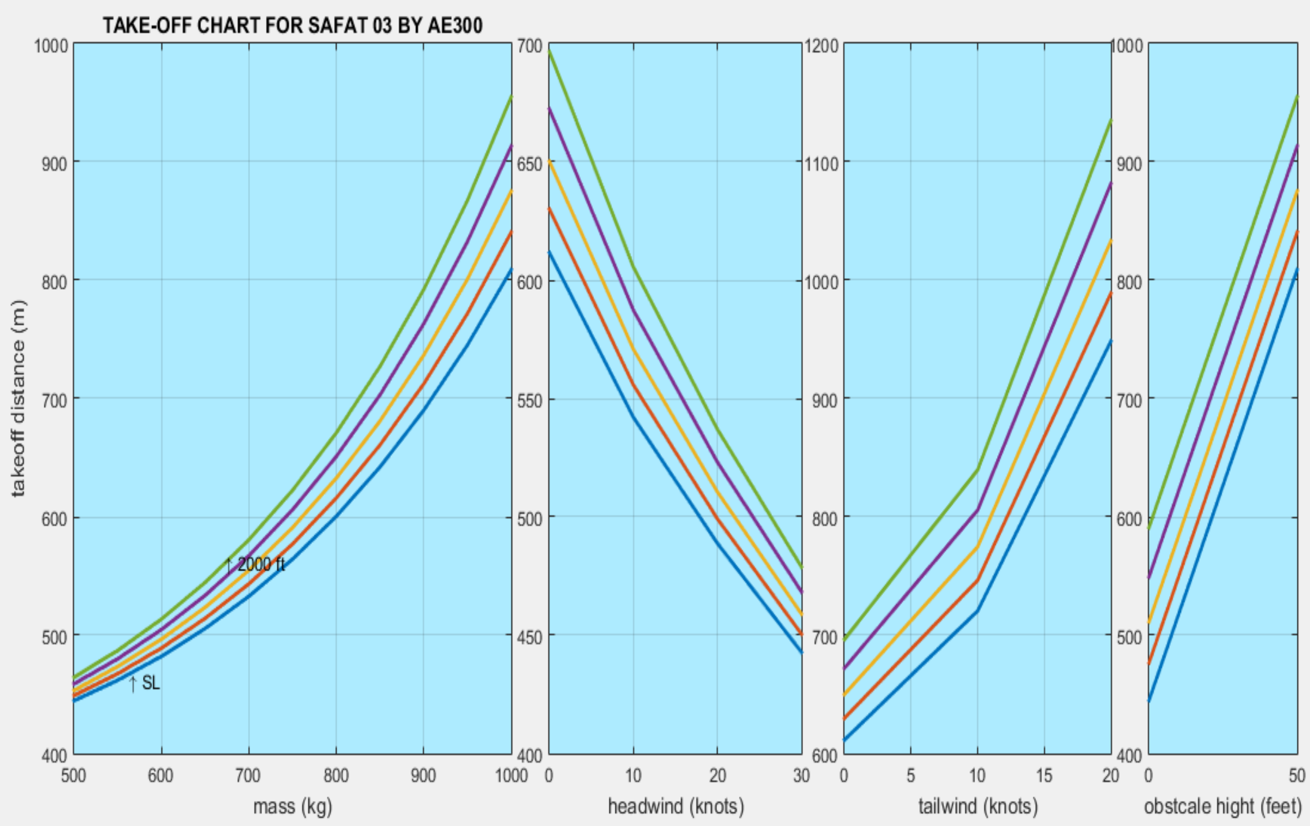


Figure 23 take-off chart AE300

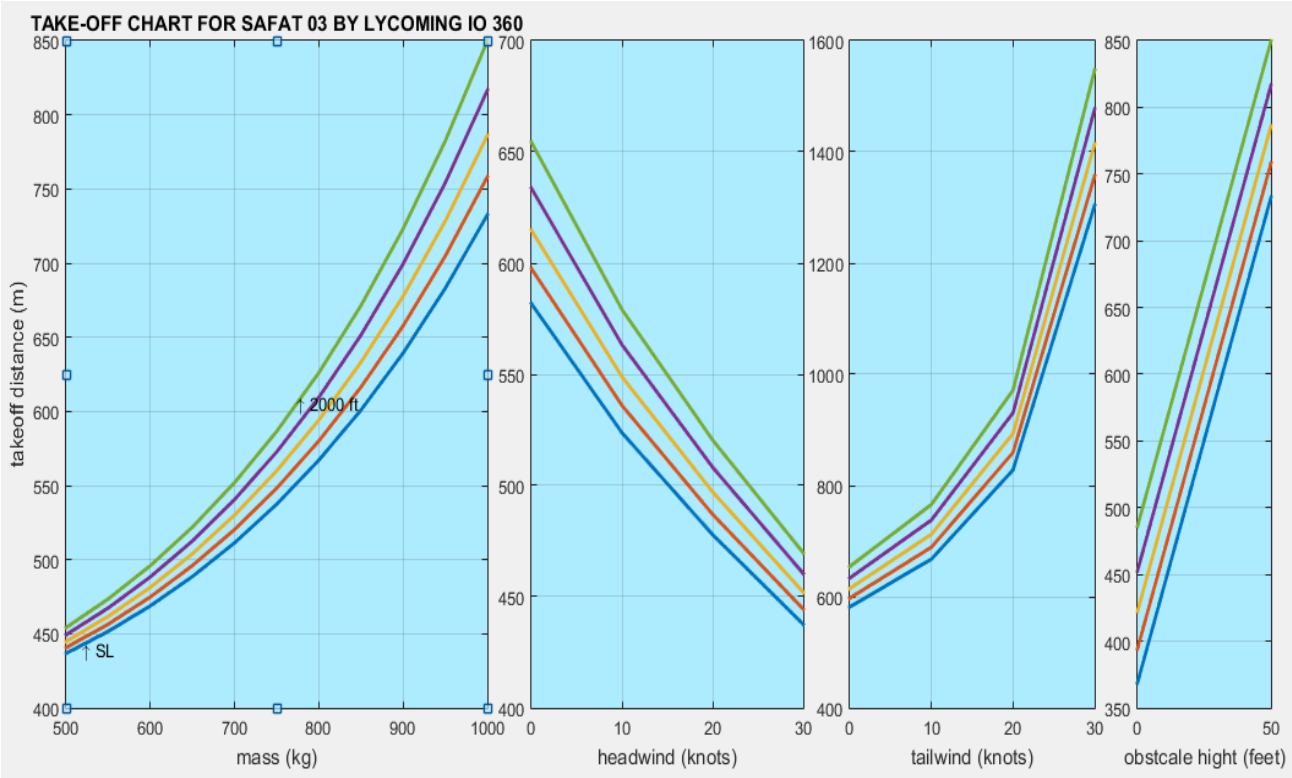


Figure 24 take-off chart Lycoming

The charts (23-24) compares between the take-off distance for SAFAT 03 with AE300 and LYCOMING IO 360. It can be clear seen the effect of power on take-off distance in chart (AE300) the distance it's more than distance by using IO 360. The rate of increase in the distance by using AE300 it's 11.7%.

The tailwind, take-off weight, obstacle height and altitude all these parameters when it increase the take-off distance increase, just the head wind when it goes up the distance decrease goes down.

4.2.4 Maximum rate of climb

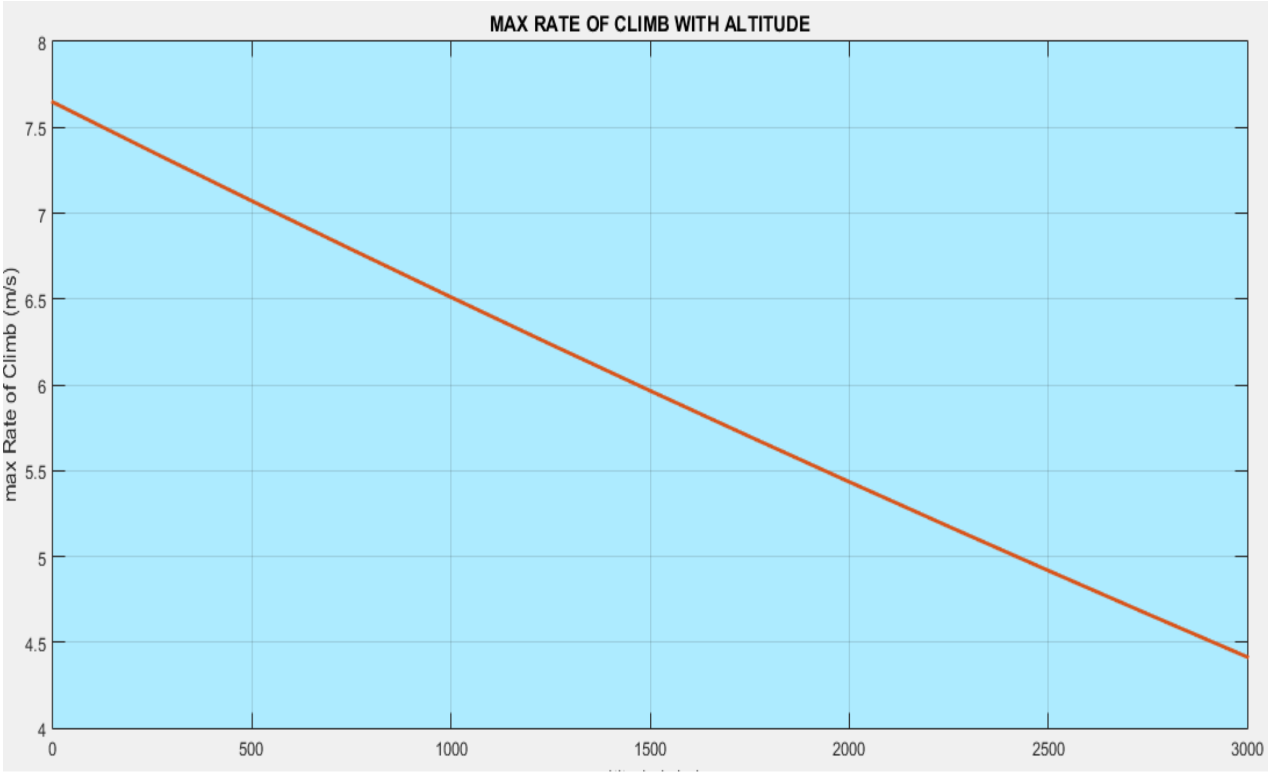


Figure 25 max rate of climb vs altitude

The graph reveals the max rate of climb declines gradually with altitude. It can be clearly seen the maximum max rate of climb at sea level. Even for turbocharged reciprocating engine assuming constant power available to weight ratio, in these case the increasing altitude lead to decrease the max rate of climb, these because the maximum velocity increase when altitude increase then lead to rise in power required.

4.2.5 Flight Envelope

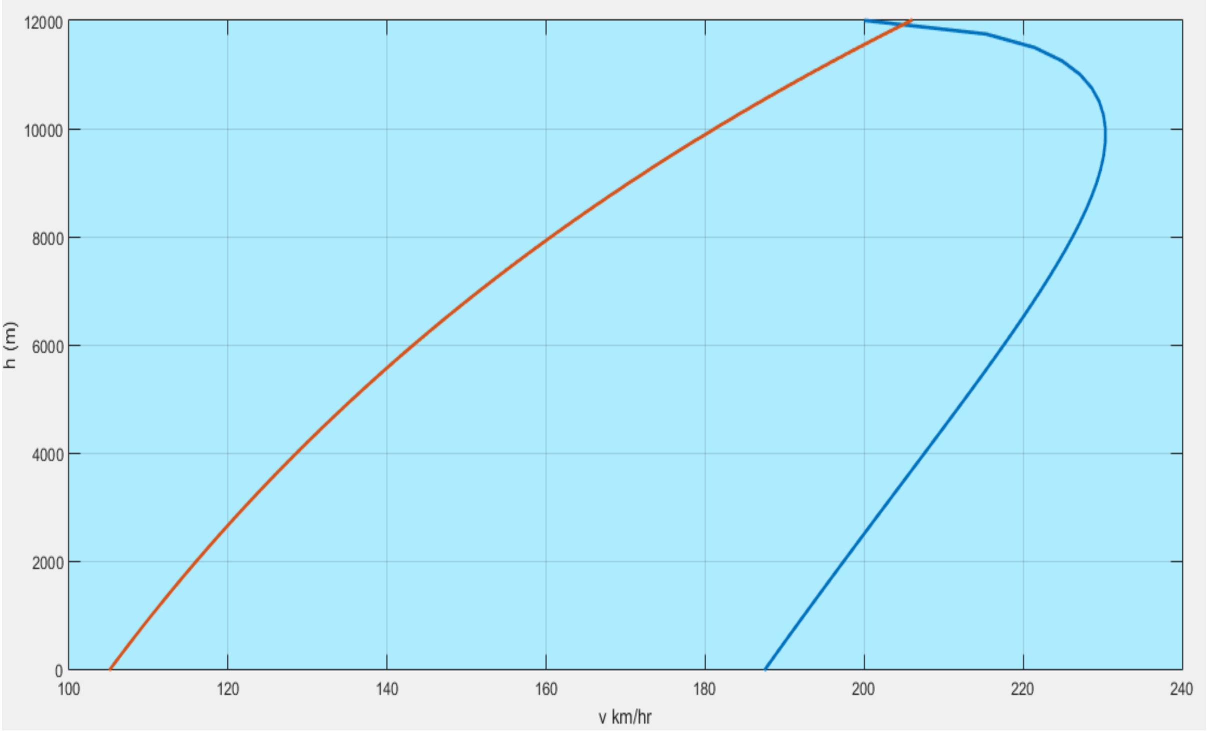


Figure 26 flight envelope

The graph describes min and max velocity varied with altitude. It can be clearly seen that the highest altitude its have equals velocities.

According to graph the min velocity rise quickly than growing in max velocity, this due to the dependent of the max velocity on the density simultaneously the min velocity depend upon stall speed and density.

4.2.6 Endurance

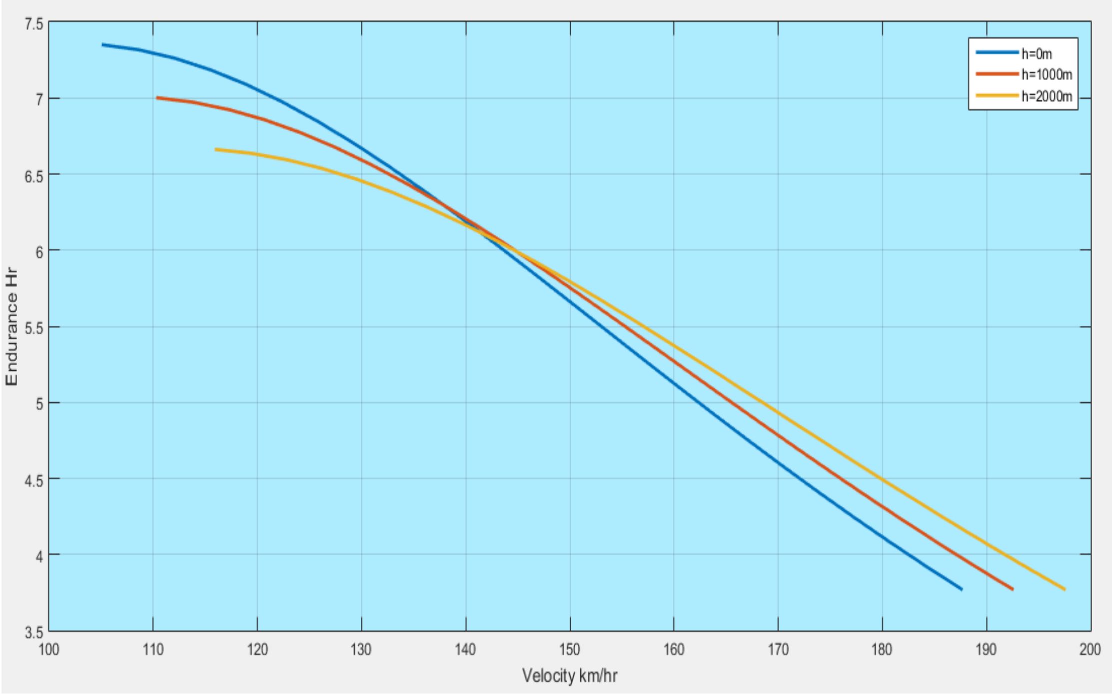


Figure 27 endurance vs velocity for vary altitude

The graph shows endurance of SAFAT-03 for three altitudes. It can clearly seen that the maximum endurance goes down with altitude increase, simultaneously the velocity rise.

Also it's describe when the aircraft flying by 140 km/hr. the endurance approximately same value for all altitude. The peak value is 7.35 hr. at sea level, and all the remaining altitudes have lower endurance.

4.2.7 Range

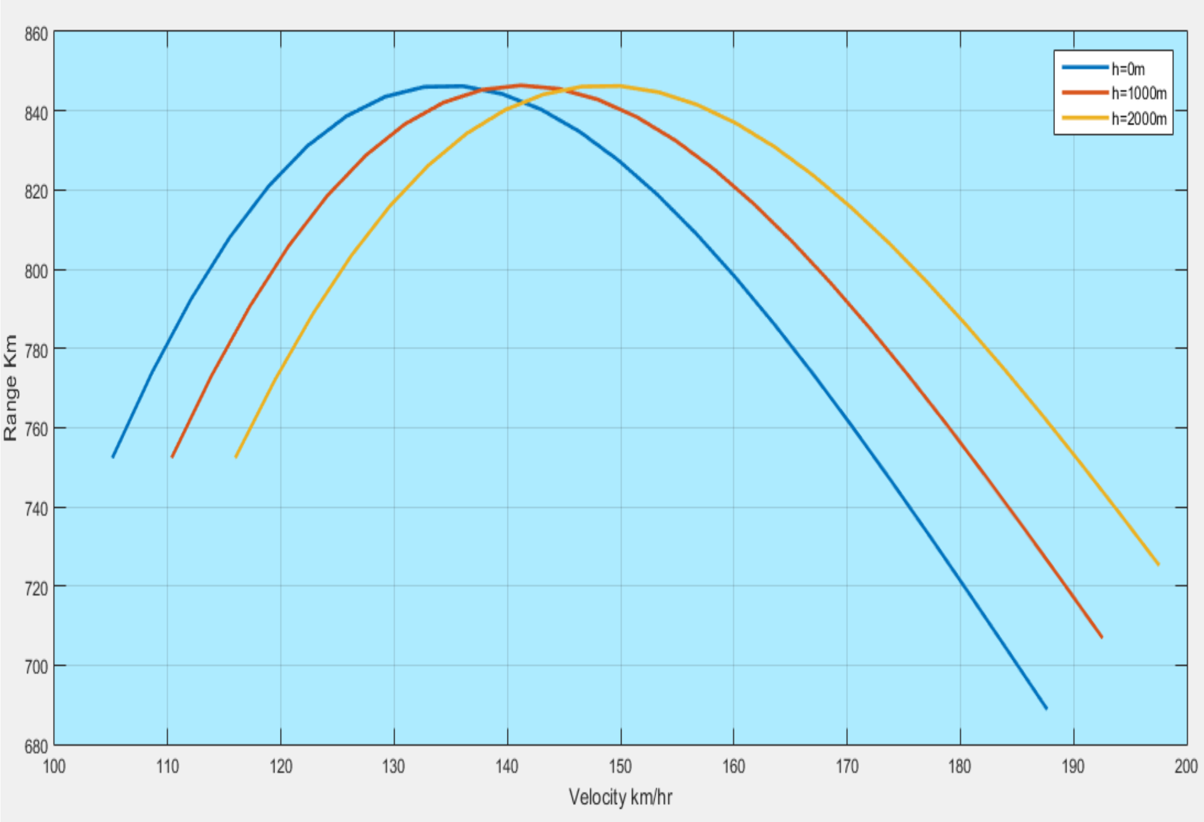


Figure 28 range vs velocity for vary altitude

The graph shows range of SAFAT-03 for three altitudes. It clearly seen that the max. range for all altitudes its constant, also its shown range in the velocity lower than140 km/hr. increase with increase velocity, and then decrease after these velocity.

CHAPTER 5. CONCLUSION, FURTHE RWORK & RECOMMENDATION

5.1 Conclusion

The project was able to meetup all objectives of it. The aim of the project was to optimize the performance of the SAFAT 03 at high altitude and reducing operating cost. The performance improved by re-engining the aircraft by new generation engine (AE300) these engine approximately have constant power with altitude but the Lycoming power decrease with increase the altitude. The fuel used in AE300 its lower price than that used in Lycoming, simultaneously the AE300 have a lower fuel consumption than Lycoming IO 360.

The engine selection was approach by choose many engines by power range (150-180) and then closeout that engines not applicable for that criteria was determined. The outcomes from these project the SAFAT 03 applicable for AE300 and its gives best operation cost and more range and endurance.

Any major modification in design have type certificate must be issue supplemental type certificate (STC) by specific program these program including flight test and ground testing these program done by manufacture.

5.2 Further work

The further work section is intended to offer ideas for further research related to this study and to provide insight into some potential implications of the findings. The three areas that will be addressed are certification, structure modifications, and performance.

5.2.1 STC program

SAFAT aviation complex must obtain a Type Certificate from the CAA in order to go into production. Any company that produces a product to modify aircraft must obtain a Supplemental Type Certificate from the CAA. There are many steps involved in the STC approval process. They include extensive technical analysis and thorough regulatory review. Substantial time is devoted to engineering, testing and actual flight. After all the required submissions have been made, the CAA must verify these data. Only then does it issue an STC, which is an authorization to manufacture and install the modification.

STC program require written material, drawings and test reports. These include: flight, ground and noise tests; engine, flap, tail and wing loads, shear, torque and moment of stress; fatigue, flutter and pivoting analysis; wind, inertial and braking variables. The aircraft must prove acceptable under every conceivable condition at all corners of the flight envelope. Once completed, this process ensures both performance and safety.

Also they have many significant effect of re-engining on some issue:

- Electrical load estimation for new engine.
- Generation of supported document for STC.
- Generation of instruction of continuous airworthiness ICA (flight manual, operation manual, etc.)
- And the effect of re-engining on gauges and instruments (fuel, oil, air, etc.).

5.3 Recommendation

5.3.1 Finalize new mount design

In our research we established a conceptual design for the mount, the design determine the initial physical mount configuration, , the next step is to determine whether the structure can support the loads it will see in service, with an adequate safety factor.

The resulting loads and moments are used in a Finite Element Analysis (FEA) package to determine the combined stresses generated in each element of the engine mount structure as well as the loads the engine mount assembly applies to the **airframe** in the flight condition being studied.

5.3.2 Design of new cowlings

Cowlings combine the cooling function of the cowl with the drag-reducing function into a rational design procedure, it is pointed out that certain factors must be determined by the engine manufacturers in order to achieve optimal cowling design

The shape of the cowling, drag that is subjected to, for an efficient cowling and for control of the air flow, the exit is the important part, engine cowling clearance. Also the propeller has an important effect on the flow at low air speeds.

5.3.3 Performance

The accelerated flight it’s not including in these report the next researcher calculate these terms:

- Level turn.
- Pull up and pull down manoeuvres.
- V-n diagram.
- Landing performance.

References

[1] "IATA," 20 5 2017. [Online]. Available: http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx.

[2] "100LL," 100LL, 20 5 2017. [Online]. Available: www.100ll.com.

[3] A. ENGINE, "AE300 ENGINE DATASHEET," AE, 2005.

[4] EASA, "TYPE CERTIFICATE DATASHEET FOR AE300," EASA, 2013.

[5] M. A. Zipkin, "Reengining The Key To Aircraft Renewal," *AIAA,* no. West Palm Beach, Folorida, p. 7, 1983.

[6] D. Müller, Aircraft Performance Analysis, Sadraey, 2009.

[7] S. M., aircraft performance analysis, VDM Verlag Dr. Müller,, 2009.

[8] D. J. Roskam, Airplane Design Part 6 Preliminary Calculation Of Aerodynamic, Thrust And Power Characteristics, Ottawa Kansas: Roskam Aviation and Engineering Corporation, 1987.

[9] NASA, 21 5 2017. [Online]. Available: WWW.NASA.COM.

[10] M. Haufe, Air Searvice Training Module 16 piston engine, Perth University.

[11] J. John D. Anderson, Aircraft Performance And Designe, McGraw-Hill companies, 1999.

[12] P. A. David F. Rogers, Cruise Propeller Efficiency Screen.

[13] E. Torenbeek, ADVANCED AIRCRAFT DESIGN, United Kingdom: A John Wiley & Sons, Ltd., Publication, 2013.

[14] TORENBEEK, AIRCRAFT DESIGN, LONDON: WILLEY, 1997.

[15] D. J. Roskam, AIRPLANE DESIGNE PART 1 PRELIMINARY SIZING OF AIRPLANE, Ottawa Kansas: Roskam Aviation and Engineering Corporation, 1985.

[16] M. R. B. Jr., “Piston Airplane Cruise Performance,” *Journal Of Aviation/Aerospace Education And Research*, vol. 4, 1993.

Appendices

Appendix A

```
clear all
clc
m=1000;
g=9.81;
W=m*g;
rho=1.225;
S=15.027;
CLA=0.0874;
CMA=-0.0228;
CLDE=0.0081;
CMDE=-0.0138;
CL0=0.147;
CM0=-0.04;
CLMAX=1.3;
CDDE=0.00044;
VST=sqrt(2*W/(rho*S*CLMAX));
Vmax=250/3.6;
U=linspace(VST,Vmax,25);
for i=1:length(U)
    CLTR(i)=2*W/(rho*S*U(i)^2);
    A=[CLA CLDE
       CMA CMDE];
    B=[CLTR(i)-CL0
       -CM0];
    C=inv(A)*B;
    alfa(i)=C(1)
    de(i)=C(2);
    CD(i)=0.03737+0.06421*CLTR(i)^2;
    CDTR(i)=0.03737+0.06421*CLTR(i)^2+CDDE*abs(de(i));
    CDO=0.03737;
    CDI(i)=0.06421*CLTR(i)^2+CDDE*abs(de(i));
    PR(i)=0.5*rho*U(i)^3*CDTR(i)*S;
    PRI(i)=0.5*rho*U(i)^3*CDI(i)*S;
    PR0(i)=0.5*rho*U(i)^3*CDO*S;
end
figure(1)
plot(U,alfa,U,de)
legend('alfa','de')
figure(2)
plot(CDTR,CLTR,CD,CLTR)
legend('Trimmed','Untrimmed')
figure(3)
plot(U*3.6,PR/1000,U*3.6,PRI/1000,U*3.6,PR0/1000)
table
text(109.2,34.85,'\uparrow total power required')
text(109.2,25.25,'\uparrow induced power')
```

```
text(103.1,8.075,'\uparrow parasite power')
xlabel('Velocity KPH')
ylabel('Power KW')
```

Appendix B

```
w=[500 550 600 650 700 750 800 850 900 950 1000];
s1=[436.81 451.66 468.85 488.65 511.39 537.4 567.1 600.88 639.31 682.92 732.5];
s2=[440.68 456.51 474.86 496.04 520.36 548.22 580.05 616.34 657.66 704.67 758.14];
s3=[444.86 461.75 481.36 504.02 530.08 559.96 594.13 633.15 677.63 728.29 786.02];
s4=[449.37 467.41 488.39 512.66 540.6 572.69 609.44 651.44 699.38 754.08 816.48];
s5=[454.21 473.52 495.99 522 552.03 586.53 626.09 671.36 723.12 782.25 849.81];
vhead=[0 10 20 30];
s6=[581.7357 523.706 477.8828 437.6096];
s7=[597.5 535.96 487.04 444.45];
s8=[614.74 548.83 497.11 452.02];
s9=[633.62 563.25 508.2 460.42];
s10=[654.32 579.09 520.44 469.73];
vtail=[0 10 20 30];
s11=[581.74 667.57 828.02 1303.97];
s12=[597.5 688.98 859.32 1356.81];
s13=[614.74 712.35 893.44 1414.61];
s14=[633.62 737.9 930.71 1477];
s15=[654.32 765.88 971.48 1547];
hob=[0 10 20 30 40 50];
s16=[368.88 441.62 514.3627 587.1044 659.8461 732.5878];
s17=[394.43 467.17 539.92 612.66 685.4 758.14];
s18=[422.31 495.05 567.79 640.53 713.28 786.02];
s19=[452.77 525.51 598.25 670.99 743.74 816.47];
s20=[486.1 558.84 631.59 704.32 777.07 849.81];
subplot(1,4,1);
plot(w,s1,w,s2,w,s3,w,s4,w,s5)
xlabel('mass (kg)')
ylabel('takeoff distance (m)')
text(500,453.4,'\uparrow SL')
text(500,464.5,'\uparrow 2000 ft')
grid on
subplot(1,4,2);
plot(vhead,s6,vhead,s7,vhead,s8,vhead,s9,vhead,s10)
xlabel('headwind (knots)')
grid on
subplot(1,4,3);
plot(vtail,s11,vtail,s12,vtail,s13,vtail,s14,vtail,s15)
xlabel('tailwind (knots)')
grid on
subplot(1,4,4);
plot(hob,s16,hob,s17,hob,s18,hob,s19,hob,s20)
xlabel('obstcale hight (feet)')
grid on
```

```
w=[1000 950 900 850 800 750 700 650 600 550 500];
s1=[808.74 745.25 690.11 642.18 600.52 564.32 532.91 505.7 482.21 461.99 444.67];
s2=[840.45 771.85 712.39 660.78 615.98 577.11 543.43 514.29 489.16 467.56 449.08];
s3=[875.12 800.899 736.67 681.02 632.79 591 554.83 523.59 496.68 473.57 453.4];
s4=[913.1 832.66 763.18 703.09 651.08 606.09 567.21 533.67 504.81 480.07 458.96];
s5=[954.78 867.45 792.16 727.17 671.02 622.52 580.66 544.6 513.62 487.1 464.5];
vhead=[0 10 20 30];
s6=[611.56 541.99 488.79 442.85];
s7=[629.96 555.69 499.13 450.49];
s8=[650.11 570.75 510.52 458.97];
s9=[672.21 587.28 523.08 468.38];
s10=[696.49 605.49 536.95 478.83];
vtail=[0 10 20];
s11=[611.56 720.53 948.28];
s12=[629.96 746.37 988.73];
s13=[650.11 774.65 1032.98];
s14=[672.21 805.63 1081.44];
s15=[696.49 839.63 1134.62];
hob=[0 10 20 30 40 50];
s16=[445.03 517.78 590.52 663.26 736 808.74];
s17=[476.74 549.48 622.23 694.97 767.71 840.45];
s18=[511.42 584.16 656.9 729.64 802.38 875.12];
s19=[549.4 622.14 694.88 767.62 840.36 913.1];
s20=[591.07 663.81 736.55 809.3 882.07 954.78];
subplot(1,4,1);
plot(w,s1,w,s2,w,s3,w,s4,w,s5)
xlabel('mass (kg)')
ylabel('takeoff distance (m)')
text(500,453.4,'\uparrow SL')
text(500,464.5,'\uparrow 2000 ft')
grid on
subplot(1,4,2);
plot(vhead,s6,vhead,s7,vhead,s8,vhead,s9,vhead,s10)
xlabel('headwind (knots)')
grid on
subplot(1,4,3);
plot(vtail,s11,vtail,s12,vtail,s13,vtail,s14,vtail,s15)
xlabel('tailwind (knots)')
grid on
subplot(1,4,4);
plot(hob,s16,hob,s17,hob,s18,hob,s19,hob,s20)
xlabel('obstcale hight (feet)')
grid on
```

Appendix C

```
clc
clear all
clear figure
%% engine modelling
```

```matlab
%% engine rpm vs powe watt
%% propeller data
P=123000;
CLmax=1.25;
W=1000*9.81;
b=9.8;
s=15.01;
e=0.85;
AR=b^2/s;
K=0.06421;
cd0=0.03737;
h=[0:250:3000];dth=1;npr=1;
%% FLight Envelope
for i=1:length(h)
    T(i)=288.15-0.0065*h(i);       % TEMPERTURE FOR ANY (h)
    rho(i)=1.225*(T(i)/288.15)^4.2561; %AIR DENSITY
    sigma(i)=rho(i)/1.225;
    Pshp(i)=P*npr%*npr*[1.132*sigma(i)-0.132];
    pv4(i)=0.5*rho(i)^2*s^2*cd0;
    pv3(i)=0;
    pv2(i)=0;
    pv1(i)=-0.5*rho(i)*s*dth*Pshp(i)*npr;
    pv0(i)=2*K*W^2;

    Poly_v=[pv4(i) pv3(i) pv2(i) pv1(i) pv0(i)];
    G=roots(Poly_v)
    for j=1:4
        if G(j)<0
            G(j)=nan;
        else G(j)>0;
            Vmax(i)=max(G);
            Vmin(i)=min(G);
        end
    end
    VStall(i)=sqrt(2*W/(rho(i)*s*CLmax));
        VMin(i)=max(VStall(i),Vmin(i));
end
figure(1)
plot(Vmax*3.6,h,VStall*3.6,h);grid;hold on
xlabel('v km/hr')
ylabel('h (m)')
% legend(Vmax,VStall)
%% Climb  performance
for i=1:length(h)
    T(i)=288.15-0.0065*h(i);       % TEMPERTURE FOR ANY (h)
    rho(i)=1.225*(T(i)/288.15)^4.2561; %AIR DENSITY
    sigma(i)=rho(i)/1.225;
    Pshp(i)=P*sigma(i);
    V(i,:)=linspace(VMin(i),Vmax(i),25);
```

```
    for j=1:25
        CLtrim(i,j)=2*W/(rho(i)*s*(V(i,j))^2);
        CD(i,j)=cd0+CLtrim(i,j)^2/(pi*e*AR);
        PR(i,j)=CD(i,j)*V(i,j)^3*0.5*rho(i)*s;
        npr(i,j)=0.85;
        PAv(i,j)=Pshp(i)*npr(i,j);
        RC(i,j)= (PAv(i,j)-PR(i,j))/W;

    end
    RCmax(i)=max(RC(i,:));
    invrocmax(i)=1/RCmax(i);

end
%% time to climb
p5=polyfit(h,invrocmax,2);
syms hh
tmclmb=p5(1)*hh^2+p5(2)*hh+p5(3);
min_time_to_climb=eval(int(tmclmb,h(1),h(end)));
disp(['tim to climb to  ',num2str(h(end)),' (m)= ',num2str(min_time_to_climb/60),' min'])

% %% plotting of results
% figure(2)
%
% plot(V(1,:)*3.6,PR(1,:),V(6,:)*3.6,PR(6,:),...
%     V(1,:)*3.6,PAv(1,:),V(6,:)*3.6,PAv(6,:));hold on
% xlabel('v km/hr')
% ylabel('Power (Watt)')
% legend('Req power h=0','Req power h=500',...
%     'Available power h=0','Available power h=500')
% figure(3)
% plot(V(1,:)*3.6,RC(1,:),V(6,:)*3.6,RC(6,:),...
%     V(11,:)*3.6,RC(11,:),V(16,:)*3.6,RC(16,:));hold on
% xlabel('v km/hr')
% ylabel('Rate of Climb m/s')
% legend('Rate of Climb h=0','Rate of Climb h=500',...
%     'Rate of Climb h=1000','Rate of Climb h=1500')
figure(4)
plot(h,RCmax);hold on
xlabel('h (m)')
ylabel('max Rate of Climb')

%% range and endurance calculations
WF=100*9.81;
W1=W-WF;
SFC=3*3.6*10^-7;          %S.F.C (N/N/S)

for i=1:length(h)
    T(i)=288.15-0.0065*h(i);      % TEMPERTURE FOR ANY (h)
    rho(i)=1.225*(T(i)/288.15)^4.2561; %AIR DENSITY
    sigma(i)=rho(i)/1.225;
```

```
    Pshp(i)=P;
    V(i,:)=linspace(VStall(i),Vmax(i),25);
    for j=1:25
        CL(i,j)=2*W/(rho(i)*s*V(i,j)^2);
        CD(i,j)=cd0+K*(CL(i,j)^2);
        npr(i,j)=0.85;
        R(i,j)=npr(i,j)*(CL(i,j)/CD(i,j))*(1/SFC)*log(W/(W-WF));
        E(i,j)=npr(i,j)*sqrt(2*rho(i)*s)*(CL(i,j)^(3/2)/CD(i,j))*(1/SFC)*((W1^-0.5)-(W^-0.5));
    end
end
figure(5)

plot(V(1,:)*3.6,R(1,:)/1000,...
    V(5,:)*3.6,R(5,:)/1000,...
    V(9,:)*3.6,R(9,:)/1000);hold on

xlabel('Velocity km/hr');ylabel('Range Km');hold on;grid on
legend(['h=',num2str(h(1)),'m'],['h=',num2str(h(5)),'m'],...
    ['h=',num2str(h(9)),'m'])
figure(6)

plot(V(1,:)*3.6,E(1,:)/3600,...
    V(5,:)*3.6,E(5,:)/3600,...
    V(9,:)*3.6,E(9,:)/3600);hold on

xlabel('Velocity km/hr');ylabel('Endurance Hr');hold on;grid on
legend(['h=',num2str(h(1)),'m'],['h=',num2str(h(5)),'m'],...
    ['h=',num2str(h(9)),'m'])
```