ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

REGIONAL JET DESIGN OPTIMIZATION BY GENETIC ALGORITHM

M.Sc. THESIS

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Department of Aeronautics and Astronautics Engineering

Aeronautics and Astronautics Engineering Program

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

GENETİK ALGORİTMA YÖNTEMİ İLE BÖLGESEL YOLCU UÇAĞI TASARIM OPTİMİZASYONU

YÜKSEK LİSANS TEZİ

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MAYIS 2014

Gökhan DAĞLI, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID 511111148, successfully defended the **thesis** entitled "**REGIONAL JET DESIGN OPTIMIZATION BY GENETIC ALGORITHM**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

The aircraft history has been developing fastly in very different areas such as military and civil applications. The airliners and aircraft manufacturers directed to produce and use the most possible efficient aircraft by the increment of global transportation demand. To meet the demand the designers has envisaged new methods like optimization. There are many branches of the optimization methods and one of these methods is Genetic Algorithm. In the thesis, an optimization process to design the lowest weight or maximum ranged aircraft by using the Genetic Algorithm.
The optimization process is carried out by a simply prepared interface. The aircraft is designed using the variables, constraints and design parameters and the results of the aircraft and comparison with other aircrafts can be seen on interface.
Firstly, I would like to specially thank my academic advisor, Prof. Aydın Mısırlıoğlu for his technical instructions and experience. I have owed to TUBITAK BIDEB for their financial and mental support to my Master of Science education and thesis process for three years.
Last, but certainly not least, I am very grateful to my dear family for bringing me up with their unconditional love and giving me the best possible education in my youthhood so that I could be successful in my higher education and to my fiancee, Özlem for her support in my pursuit of Master degree.

May 2014 Gökhan DAĞLI

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ABBREVIATIONS

RJ : Regional Jet
STOL : Short Take-off and Landing
BAE : British Aerospace
CRJ : Canadair Regional Jet
ERJ : Embraer Regional Jet
L_F : Fuselage Length
L_T : Tail Arm (The distance between wing aerodynamic center to tail aerodynamic center)
W : Fuselage width
b : Wing Span
c_r : Wing root chord
c_t : Wing tip chord
S : Wing area
AR : Wing aspect ratio
Λ : Wing sweep angle
λ : Wing taper ratio
b_{ht} : Horizontal tail span
b_{vt} : Vertical tail span
S_{ht} : Horizontal tail area
S_{vt} : Vertical tail area
Λ_{ht} : Horizontal tail sweep angle
Λ_{vt} : Vertical tail sweep angle
AR_{ht} : Horizontal tail aspect ratio
AR_{vt} : Vertical tail aspect ratio
T_{max}/W_{TO} : Maximum thrust to maximum take-off weight ratio
Pax : Passenger Number
W_{dry} : Engine dry weight
SFC : Specific Fuel Consumption
OPR : Overall Pressure Ratio
BR : Bypass Ratio
GA : Genetic Algorithm
W_{TO} : Maximum take-off weight
W_{empty} : Empty weight
W_{crew} : Crew weight
$W_{payload}$: Payload weight
W_{fuel} : Fuel weight
V_{cruise} : Cruise velocity
c_j : Specific fuel consumption
L/D : Fineness ratio
W_f : Final weight of cruise
W_i : Initial weight of cruise
r_i **and** c_j : Penalty parameters

G_i and L_j	: Constraints
C_{Lmax}	: Maximum lift coefficient
t/c	: Thickness ratio
N_{en}	: Number of engine
c_{mean}	: Mean aerodynamic chord
V_v	: Vertical Tail volume coefficient
V_h	: Horizontal Tail volume coefficent
L_{radome}	: Radome length
V_{fuel}	: Fuel volume
ρ	: Density
T	: Temperature
a	: Speed of sound
e	: Oswald efficiency factor
c_{fe}	: Friction factor
C_D	: Drag coeffiecient
M_{ff}	: Fuel Fraction
W_{tfo}	: Trapped fuel weight
S_{e_sht}	: Control surface area to tail area ratio
F_w	: Fuselage width at tail connection
C_T	: Tail type
W_w	: Wing weight
W_{hort}	: Horizontal tail weight
W_{fus}	: Fuselage weight
W_{mlg}	: Main landing gear weight
W_{nlg}	: Nose landing weight
W_{prop}	: Propulsion system weight
W_{fuel_sys}	: Fuel system weight
W_{pneu}	: Pneumatic weight
W_{antice}	: Anti-ice system weight
W_{av}	: Avionics system weight
W_{hg}	: Handling gear system weight
W_{sc}	: Surface controls weight
N_z	: Load factor
S_{cs}	: Control surface area to wing area ratio
d_f	: Fuselage width
N_{seat}	: Seat number at a row
w_{seat}	: Seat width
w_{aisle}	: Aisle width
L	: Fuselage length without radome and cone
L_{fc}	: Cone length
L_{fn}	: Radome length
S_f	: Fuselage wetted area
W_{nac}	: Nacelle weight
W_e	: Engine weight
W_{hy}	: Hydraulics system weight
N_{ft}	: Fuel tank number
UAV	: Uninstalled Avionics
M	: Mach number
p_{norm}	: Normalized variable, $0 \leq p_{norm} \leq 1$
p_{lo}	: Smallest value of a variable

$\mathbf{p_{hi}}$	**:** Highest value of a variable
$\mathbf{p_{quant}}$	**:** Quantized version of p_{norm}
$\mathbf{q_n}$	**:** Quantized version of p_n
N	**:** Current population size
n	**:** Rank of the chromosome
MFUW	**:** Max. Fuel Weight

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REGIONAL JET DESIGN OPTIMIZATION BY GENETIC ALGORITHM

SUMMARY

With the development of the aviation industry, the interest on the air transportation has increased by years. The reasons like shorter cruise time and more affordable tickets raise the demand on the air transportation. This situation leads to search the innovations and designs by the airliners and manufacturers to provide less cost, farther range stations, less time and more comfortable journey. Today, the importance of the regional jets has increased because many stations whose passenger capacity is lower than the aircrafts capacity that airliners have or whose pists are not enough for the aircrafts to take-off or land have been opened to service to include them to air transportation network. A regional jet (RJ) is an aircraft class that has approximately 80-120 passenger capacity but generally cruises at similar speeds and altitudes of larger transporters.

The aircraft design process depends on the many variables and constraints. In this process, it is high possibility that the other variables will be bad when a variables has its best value. Therefore, all variables and constraints should be controlled when the aircraft design optimization is carried out and this is not possible by hand because the number of the variables and constraints could be too much. The optimization provides to design an aircraft more systematically. In the thesis, the method of the optimization is Genetic Algorithm. The optimization process is carried out by solving the objective function that depends only on a variable that is maximum take-off weight or range. The optimization uses the design parameters, variables and constraints that are specified by user.

Genetic Algorithm is applied by using the single point crossover, mutation rate, selection rate and population size. Every variable has a special code constituted by zeros and ones called binary coding. After encoding process of the variables, each variables are implemented in the objective function for each iterations to get the cost value. Objective function is a function that gives the variable that will be optimized by using the other variables. The analytical equations are used to calculate the fuel, empty, payload and crew weights to do the optimization. Then, the new populations are created by help of the mutation rate and crossover to find the new cost values until the stopping criteria is satisfied and the minimum value for maximum take-off weight or the maximum value for range optimization is taken. Finally, according to the solution values the specifications of the aircraft can be derived.

An interface is prepared for the optimization process. The interface lets the user to select the variable that will be optimized. Later, the user enters the design parameters, selects each range of the variables, which constraint will be taken and what will be the range of the selected constraints, population size, mutation rate and selection rate and finally run the solution. The results and the comparison of the designed and other aircrafts can be seen on the interface.

By this work, a regional aircraft that the design parameters are specified can be designed easily. The code and interface can be improved introducing the other types of the crossover options and making the multi optimization.

GENETİK ALGORİTMA YÖNTEMİ İLE BÖLGESEL YOLCU UÇAĞI TASARIM OPTİMİZASYONU

ÖZET

Havacılık sanayisinin gelişmesiyle birlikte havayolu taşımacılığına olan ilgili de gün geçtikçe artmaktadır. Özellikle yolculukların daha kısa sürmesi ve giderek ekonomik olması hava taşımacılığındaki talebe ivme kazandırmıştır. Yolcu uçak üreticileri gerek yolcuların gerekse de havayolu şirketlerinin taleplerini karşılamak amacıyla arayışlara girmişler, asgari maliyetlerle, daha uzaklara daha kısa zamanda ve daha konforlu yolculukları sağlayabilecek tasarımlar yapmak için çalışmalara başlamışlardır.

Günümüzde, havayolu taşımacılığının her yere ulaşması amacıyla açılan hatlarda, havayollarının filolarındaki uçakların yolcu sayıları, talep edilen yolcu kapasitesinin çok üstünde olması veya eldeki uçakların boyutlarından dolayı ilgili noktalara iniş-kalkış yaparken yaşadığı ve/veya yaşayacağı sorunlardan dolayı bölgesel yolcu uçaklarının önemi artmıştır. Daha kısa mesafelerde ekonomik olacak, daha küçük havaalanlarına iniş kalkış yapabilen, konforlu ve maliyeti düşük, ortalama 80-120 yolcu kapasitesine sahip uçaklar bölgesel yolcu uçağı olarak adlandırılır. Bugün dünyada, Embraer, Bombardier gibi sektörün lider konumundaki firmaların yanında, Japonya, İran gibi yolcu uçağı tasarımı ve üretim sürecine yeni dahil olmak isteyen ülkeler, gerek üretiminin büyük,uzun menzilli, geniş gövdeli yolcu uçaklarına göre kolay olması gerekse de markete daha çok hitap etmesi nedeniyle bölgesel yolcu uçaklarını üretmekte veya üretmeyi planlamaktadırlar.

Uçak tasarım süreci, birçok değişkene ve kısıtlamaya bağlı olan bir süreçtir. Bu süreçte herhangi bir değişkenin olabilecek en iyi değeri alması sağlanırken diğer değişkenlerin kötü değer alması yüksek ihtimaldir. Bu bakımdan, uçak tasarımı yapılırken, bütün değişkenler ve kısıtlamalar kontrol altında tutulmalıdır. Değişken ve kısıt sayısı çok fazla olduğu için, bunu elle yapmak mümkün değildir. Optimizasyon, uçak tasarımının istenen düzeyde yapılabilmesine olanak sağlamaktadır. Optimizasyon birçok farklı yöntem kullanılarak yapılabilirken, tezde, optimizasyon Genetik Algoritma kullanılarak yapılmıştır. Genetik algoritma temel olarak biyolojide kullanılan, gen, kromozom ve populasyon gibi terimlere dayanan, doğadaki çoğalma ve farklılaşma olaylarını temel alan optimizasyon yöntemidir. Uçak tasarımı farklı disiplinlerin aynı anda çözüldüğü (Multidisciplinary Design Optimization), yani optimizasyon sürecinin aynı anda birbirini etkileyen farklı değişken fonksiyonlarıyla yapılması daha uygun olsada; tezde tek bir değişkene bağlı olarak yazılan objektif fonksiyonun çözülmesiyle yapılmıştır. Bu değişken fonksiyonu, azami kalkış taşıma ağırlığı ve menzildir. Her iki çözümde de kullanıcı tarafından aralıkları verilen 18 farklı tasarım değişkeni, çözümün mantıklı ve istenilen değerlerde olmasını sağlayan yine kullanıcı tarafından kontrol edilebilen kısıtlamalar ve tasarlanması istene uçağın hangi fiziksel özelliklerde olacağı ve kullanıcının belirlediği performans isterleri kullanılmıştır. Tasarlanmak istenen hava

aracının hangi kabin özelliklerine sahip olacağı ve temel performans isterleri belirlendikten sonra bahsi geçen 18 değişkenin aralıklarına ve kullanılan kısıtlamalara göre hava aracı tasarlanmakta yani sınırları çizilen bölgedeki en iyi hava aracı bulunmaktadır.
Genetik algoritmada, değişkenler belirlenen gen (bit) sayısı ile temsil edilirler. Tezde bütün değişkenleri kapsayan yaklaşık 134 bitlik kromozom bir uçağı temsil etmektedir. Populasyon sayısı ya da büyüklüğü, populasyondaki bu kromozom gibi ilk durumda kaç adet farklı uçağın olduğunu göstermektedir. Genetik Algoritma uygulanırken kullanılan çeşitli teknikler vardır. Örneğin doğada var olan çaprazlama, mutasyon ve seçim gibi olaylar genetik algoritmada da kullanılmaktadır. Çaprazlama yöntemi olarak tezde, tek nokta çaprazlama (Single point crossover) yöntemi uygulanmıştır. Tek nokta çaprazlama yönteminde genlerden oluşan iki kromozomun belirlenen bir noktasından geride kalan kısımları yer değiştirilerek yeni bireyler elde edilir. Elde edilen bireyler çaprazlamadan önceki kromozomlara göre farklı özellikleri taşırlar bu şekilde çözüm için her adımda yeni değerler elde edilmesine olanak sağlar. Genetik algoritmada kullanılan bir diğer doğa olayı da mutasyondur. Mutasyon kromozomlardaki herhangi bir veya birden fazla genin değişmesi olarak modellenir. Belirlenen mutasyon oranına göre, kromozom üzerindeki genlerle oynanır ve yeni farklı özellikteki bireyler meydana getirilir. Çözüm sürecinde kullanılan diğer yöntemler seçim oranı ve populasyon büyüklüğüdür. Seçim oranı değer (objektif) fonksiyonunda değerleri elde edilen kromozomların sıralanmasından sonra hangilerinin bir sonraki adıma aktarılacağını belirler. Her bir değişken, bit kodlama sistemine göre kodlanmıştır. Bazı genetik algoritma çözümlerinde değişkenler bazı eşitlikler yardımıyla bit sistemine dönüştürülürken, tezde kodlama sistemi çözümün başında rastgele atanmış; kodlarla temsil edilen değişkenler, önce bir fonksiyon yardımıyla gerçek değerlerine dönüştürülmüş, daha sonra ise gerçek değerler belirlenen objektif fonksiyonda yerine konularak objektif fonksiyonun değeri yani o iterasyon için hesaplanan değer çekilmiştir. Objektif fonksiyon, belirlenen değişkenler kullanılarak elde edilmek istenen değişkeni veren bir fonksiyondur. Her iki optimizasyon seçeneğinde de hava aracının yakıt, boş, paralı yük ve mürettebat ağırlıkları analitik denklemler yardımıyla hesaba katılmıştır. Daha sonra mutasyon oranı, çaprazlama seçenekleri kullanılarak oluşturulan yeni populasyonlar yardımıyla aynı işlem yakınsama kriteri sağlanana kadar devam ettirilir ve olabilecek azami kalkış ağırlığı için asgari değer, menzil içinse azami değer alınır. Bu değerleri veren değişkenlere göre de tasarlanan hava aracının boyutları ve temel özellikleri belirlenmektedir.
Bütün bu optimizasyon süreci için, bir arayüz yazılmıştır. Arayüzde kullanıcı öncelikle hangi değişkene göre tasarım yapacaksa onu seçer. Daha sonra, sırasıyla tasarım parametrelerini, değişkenlerin aralıklarını, hangi kısıtlamaların olacağını ve değerlerini, optimizasyonun populasyon büyüklüğünü, mutasyon oranını ve seçim şartları gibi değerleri girdikten sonra da çözümü elde eder. Çözümden elde edilen sonuçlar liste halinde arayüzde gözükmektedir. Genetik algoritmanın ve arayüzün işlevselliği faal halde olan ve özellikleri bilinen Embraer E-195 uçağının tasarım parametreleri girilerek kontrol edilmiş ve küçük sapmalar dışında aynı uçağın kanat açıklığı, kuyruk özellikleri ve hava aracının boyu ağırlığı gibi temel değerler elde edilmiştir. Daha sonra tasarımı istenilen özelliklerde faal olarak uçmuş, uçan ve uçma aşamasında olan uçakların toplanmasıyla elde edilen veriler yardımıyla, ortalama bir uçağın isterleri ve performans parametreleri ile değişken ve kısıt değerleri belirlenerek program çalıştırılmış ve optimizasyon sonucunda yeni bir bölgesel yolcu uçağı elde edilmiştir. Hazırlanan arayüzde hava aracının diğer

uçaklarla karşılaştırmada gözükmektedir. Tezde ayrıca, farklı mutasyon, seçim ve populasyon sayıları için yedi farklı çözüm her iki optimizasyon yöntemi için yapılmış ve sonuçlar karşılaştırılarak bu tekniklerin çözüme etkisi gözlenmiştir. Sonuçlara göre özellikle yüksek mutasyon oranı çözümü kötüleştirmektedir.

Yapılan bu çalışma ile istenilen şartlardaki bir bölgesel yolcu uçağı basit olarak tasarlanabilmektedir. İleriki çalışmalarda arayüz ve kod farklı çaprazlama seçenekleri ile birlikte ve çoklu değişkene bağlı olacak şekilde geliştirilebilir. Ayrıca optimizasyon disiplinlerarası bir hale getirilerek ve bu disiplinlerde elde edilen çözümü denetleyecek basit analiz kodları ile denetleyerek gerçek ve kapsamlı bir uçak tasarım çözüm programı oluşturulabilir. Elde edilecek bu gelişmiş kod içerisine yerleştirilecek bir çizim programı ile üretilen hava aracının çizimi 3 boyutlu olarak da alınabilir. Bu yöntemle birlikte, teorik denklemler ve istatistiki bilgiler harmanlanmış olacak ve günümüzde kullanılabilecek istenilen değerler içerisinde en uygun uçak hızlı bir şekilde tasarlanabilecektir.

1. INTRODUCTION

A regional jet (RJ) is an aircraft class that has approximately 80-120 passenger capacity but generally cruises at similar speeds and altitudes of larger transporters. Regional Jets serves on short-haul flights and combine the lower potential lines to the larger hubs. By the development of the aviation industry, the borders of the air transport have extended and this has leaded to build new airports that some of them are sufficient for large aisle aircrafts but some of them are not. In addition, usage of Regional Jets provides to balance between the economical expectations of airliners and meeting the demand of people at small markets [1].

The aircraft manufacturers have started to think how to design and produce new, more cost efficient generation of regional aircraft to meet the demand of airlines that work to handle oil prices while trying to optimize their passenger traffic and route networks. The countries that want to enter the aviation industy such as India, Russia, China and Japan chose the regional jet design and manufacture. Turkey also wants to build a small sized and low-ranged transport jet. Because reginonal jet design and manufacture is a vital step for market and for experience [2].

While many airlines are renew their fleet with higher capacitied aircrafts in search of lower costs, there are an evolution process within the regional aircraft industry. The existence of regional jets in the market will decrease from 13% to 6% during the next 20 years, while the overall number of regional aircraft continues to rise [2]. For instance, Bombardier projects that until 2031 the fleet of 20 to 149-seat aircraft will grow by 51% [3]. In 2008 annual report Boeing projected a world-wide total market from 2007 through 2027 valued at $3200 billion for a total of 29400 aircraft, of which nearly ten percent would be regional jets [4]. The statistics shows the development and the demand of the regional jets at next decade. For this reason the design and manufacture of the regional jets by the optimum solution is very significant (Figure 1.1).

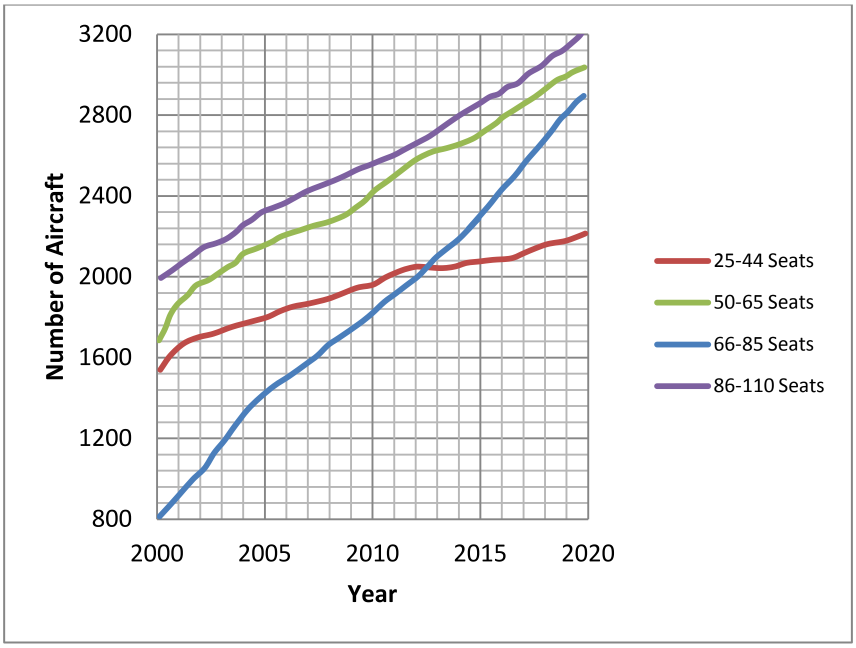


Figure 1.1: Number of in-service Regional Aircraft Forecast [5]

1.1 History

In the first years of aviation, approximately all aircrafts had a short range so they can be called “regional”. By the production of the larger aircrafts, short range aircrafts lost their popularity and airlines carried the passengers between their hubs by large airplanes. By the mid-1950s, demand for more economical designs led to the production of the small sized aircrafts such as Avro 748, Fokker F27 and Handley Page Dart Herald [1].

By the 1970s despite the first generation regional airliners became older; there is not much new design. In 1978, one of the developments came to the regional aircraft industry is the production of De Havilland Canada types such as the Dash 7 which was tailored more to the short-range and STOL (Short Take-off and Landing) role than as a regional airliner [6].

The aviation industry took a vital step in the late 1990s with design and manufacturing of the modern regional jet. By the late 1990s in the United States, 11 airlines operated or had orders for approximately 320 RJs.

By October 2000, major U.S. passenger airlines and their regional carriers had bought almost 500 RJs. This represents a significant increase in RJ aircraft since 1997, when only 89 RJs were in service. This situation leaded to comments that stated to the aviation industry is changing by directing the airlines' strategy to regional aircrafts [7].

The earliest example of a regional jet is the BAe 146, produced by BAE Systems. However, like the Dash 7, the BAe 146 was turned to a very specific market, from small hubs to another small hub where excellent take-off performance were significant. By the time, this design proved to be big for this market, and its four engines caused higher maintenance costs than twin-engine designs. This blank is filled by Bombardier's twin-engine Canadair Regional Jet, which became a best-seller. The CRJ's range is enough to fly mid-range routes which were previously served by larger aircraft such as the Boeing 737 and DC-9 [8]. However, when Fokker bankrupted, the regional-jet market has affected badly in the air industry but Bombardier created a new model, CRJ200 which changed the fate of the market. Because this aircraft turned out to be more efficient and popular. It transformed the economics of the medium-distance, low-density routes operated by regional airlines, which had flown mostly noisy and slow turboprops. The successful launches of Bombardier's and then Embraer's jets were followed by Fairchild Dornier, an American-German firm. All of these companies than started to work on bigger models with 70-110 seats, overlapping with the smallest jets made by Boeing and Airbus [5].

The success of the CRJ led to new regional jet designers to compete with Bombardier. The one of successful examples is the Embraer ERJ 145, which has seen excellent sales and has competed strongly with the CRJ. The ERJ's success led to a totally new version, the Embraer E-Jets series, which Bombardier answered them by Bombardier C Series. The CRJ and ERJ success also played a minor part in the failure of Fokker, whose Fokker 100 found itself squeezed on both sides by new models of the Boeing 737 and Airbus A319 on the "large" side and the RJs on the "small side" [5].

In 2005, increasing fuel prices and airline bankruptcies pushed the companies to renew their route plans and this cause to abandon the regional jet strategy. Furthermore, RJs increasingly were assigned to operate long range flights that are provide by larger jets and this cause to uncomfort and terrible journeys for passengers [9]. In late 2005, Bombardier suspended its CRJ-200 production line and the regional jet concept have begun to change from narrow and small to larger and bigger with better economics, like Bombardier's 70-seat CRJ-700 and the 70-110-seat E-Jet series. Especially the E-Jets became a level that can compete with Boeing 737 and Airbus A320 in cabin comfort while offering ranges of over 3700 kilometers [10].

The Sukhoi Superjet 100, a 60 to 95-seat jet developed by the Russian aerospace firm Sukhoi with help of Ilyushin and Boeing entered service in 2011 and the Antonov An-148 entered service in 2009 [11].

The modern fleet of new generation regional jets has capacity range from as few as 32 seats to more than 100 seats. In reality, today's regional airline industry is defined less by aircraft size than by the real mission the carrier serves: that is, supporting airlines that serve at larger hubs.

During the last few years the market of regional jets that has been dominated by such as Bombardier and Embraer has noticeably grown since at least three more countries have launched their own projects of regional aircraft. Such companies as Comac, Sukhoi Civil Aircraft and Mitsubishi Aircraft have put additional pressure on the leading companies by developing their regional jets like ARJ21, MRJ90 and SSJ100 [7] (Figure 1.2).

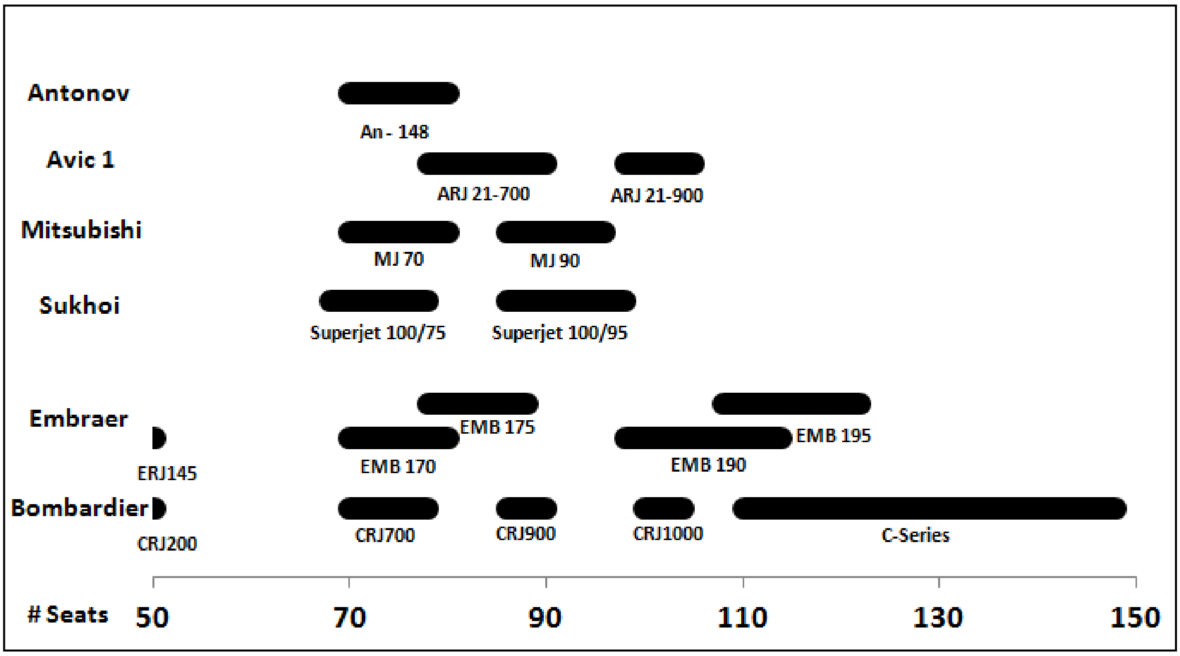


Figure 1.2: Regional Jets Seating Capacities [7]

2. LITERATURE REVIEW

2.1 Regional Jet Data

As stated in the introduction section, there are many regional jets in the world in a wide range. In this thesis, passenger capacity of the relevant regional jet will be about 90-120, so table shows the aircrafts that are in or close to this range (Table 2.1-10) [12-21]. Some of these aircrafts are not classified in the regional jet category because of their passenger capacity or cruise conditions. However, regional jet notion is changing by the years and there is no specific definition of this class. Two examples of these aircrafts are Boeing B737-600 and Airbus A318 (Figure 2.1). The reason why these aircrafts were included in the list is that they could be served as a regional jet.

Figure 2.1: Airbus A318 [22]

The list was preapared by the official data given by the manufacturers; nevertheless, some kind of information is missing in these data and the possible significant data for the aircrafts like taper ratio, sweep angle was predicted with the geometry and dimensions given by manufacturer. There are old and also newly manufactured aircrafts that have finished the test processes yet. The biggest aircraft in the list is Airbus A318, and the smallest one is Bombardier CRJ1000. There are two Embraer aircrafts in this range, but just Embraer E195 (Figure 2.2) takes place in the list.

Regional jet data is used to specify the minimum and maximum values of constraints and variables when the Genetic Algorithm is applied according to largest, smallest and average value of the related parameter in the list.

Figure 2.2: Embraer E-195 [10]

Table 2.1: Regional Aircraft Data Overall and Fuselage Dimensions [12-21]

AIRCRAFT	MANUFACTURER	OVERALL				FUSELAGE	
		L_F (m)	L_F (ft)	L_T (m)	L_T (ft)	W (m)	W (ft)
A318-100	AIRBUS	31.5	103.2	16.5	54.0	4.0	13.0
AN-158	ANTONOV	30.8	101.2	17.1	56.1	3.2	10.5
BAE RJ 100	BRITISH AEROSPACE	31.0	101.7	16.3	53.5	4.1	13.5
B717	BOEING	37.8	124.0	17.1	56.0	3.3	11.0
B737-600	BOEING	31.2	102.5	15.1	49.7	3.8	12.3
CRJ1000	BOMBARDIER	39.2	128.4	19.8	64.9	2.9	9.7
CS100	BOMBARDIER	35.0	114.8	17.3	56.7	3.7	12.2
ARJ21-900	COMAC	36.4	119.3	16.8	55.2	3.6	11.9
E -195	EMBRAER	38.7	126.8	16.3	53.4	3.4	11.2
FOKKER 100	FOKKER	35.5	116.6	17.6	57.9	3.3	10.8
MRJ90	MITSUBISHI	35.8	117.5	18.4	60.3	3.0	9.7
SJ100	SUKHOI	29.0	95.3	14.8	48.5	3.5	11.4
Average		34.3	112.6	16.9	55.5	3.5	11.4
Min		29.0	95.3	14.8	48.5	2.9	9.7
Max		39.2	128.4	19.8	64.9	4.1	13.5

Table 2.2: Regional Aircraft Data Engine, Tail and Wing Configurations [12-21]

AIRCRAFT	Engine	Tail Configuration	Wing Configuration
A318-100	CFM56-5B8	Conventional	Low
AN-158	D-436	T	High
BAE RJ 100	LF-507	T	High
B717	BR715-A1-30	T	Low
B737-600	CFM56-7B18	Conventional	Low
CRJ1000	CF34-8C5A1	T	Low
CS100	PurePowerTM PW1524G	Conventional	Low
ARJ21-900	CF34-10A	T	Low
E -195	CF34-10E	Conventional	Low
FOKKER 100	Tay 620	T	Low
MRJ90	PurePower PW1217G	Conventional	Low
SJ100	PowerJet SaM146	Conventional	Low

Table 2.3: Regional Aicraft Data Wing Specifications [12-21]

AIRCRAFT	WING								
	b (m)	**b (ft)**	**c_r (m)**	**c_t (ft)**	**S (m^2)**	**S (ft^2)**	**AR**	**Λ (der)**	**λ**
A318-100	34.1	111.8	6.1	20.0	122.4	1317.5	9.5	25.0	0.31
AN-158	28.6	93.7	4.7	15.4	87.3	939.9	9.3	30.0	0.34
BAE RJ 100	26.3	86.4	4.2	13.9	77.3	832.1	8.9	15.0	0.46
B717	28.5	93.3	5.4	17.7	93.0	1001.0	8.7	25.0	0.21
B737-600	34.3	112.6	5.7	18.8	125.0	1345.5	9.4	25.0	0.22
CRJ1000	26.2	85.9	5.7	18.7	77.4	833.1	8.8	30.0	0.29
CS100	35.1	115.1	5.8	18.9	112.3	1208.8	11.0	30.0	0.29
ARJ21-900	27.3	89.5	5.5	18.2	79.9	859.6	9.3	25.0	0.29
E -195	28.7	94.2	5.0	16.4	96.0	1033.0	8.6	25.0	0.33
FOKKER 100	28.1	92.1	5.6	18.4	93.5	1006.4	8.4	17.5	0.25
MRJ90	29.2	95.8	5.8	19.0	89.8	966.1	9.5	24.0	0.25
SJ100	27.8	91.2	5.5	17.9	83.8	902.0	9.8	30.0	0.25
Average	29.5	96.8	5.4	17.8	94.8	1020.4	9.3	25.1	0.29
Min	26.2	85.9	4.2	13.9	77.3	832.1	8.4	15.0	0.21
Max	35.1	115.1	6.1	20.0	125.0	1345.5	11.0	30.0	0.46

Table 2.4: Regional Aircraft Data Tail Spans and Areas [12-21]

AIRCRAFT	TAIL							
	b_{ht} (m)	**b_{ht} (ft)**	**b_{vt} (m)**	**b_{vt} (ft)**	**S_{vt} (m^2)**	**S_{vt} (ft^2)**	**S_{ht} (m^2)**	**S_{ht} (ft^2)**
A318-100	12.5	40.9	6.6	21.7	21.5	231.4	31.0	333.7
AN-158	9.1	29.9	5.0	16.4	23.3	250.5	20.0	215.7
BAE RJ 100	12.0	39.2	5.3	17.2	24.7	265.9	27.8	299.1
B717	11.2	36.8	5.0	16.5	24.0	258.2	29.5	317.8
B737-600	14.4	47.1	7.8	25.5	26.4	284.2	32.8	353.1
CRJ1000	8.7	28.6	3.3	10.7	12.0	129.3	16.3	175.9
CS100	11.0	36.0	5.6	18.4	21.2	228.6	21.8	235.0

Table 2.4 (cont.): Regional Aircraft Data Tail Spans and Areas [12-21]

AIRCRAFT	TAIL							
	b_{ht} (m)	b_{ht} (ft)	b_{vt} (m)	b_{vt} (ft)	S_{vt} (m^2)	S_{vt} (ft^2)	S_{ht} (m^2)	S_{ht} (ft^2)
ARJ21-900	11.2	36.7	4.5	14.6	21.6	232.6	29.3	315.0
E-195	12.1	39.6	5.5	18.0	14.0	150.7	31.9	343.0
FOKKER 100	10.0	32.9	3.9	12.8	16.0	172.4	21.7	233.8
MRJ90	11.0	36.1	5.5	18.0	17.1	184.1	22.1	238.2
SJ100	10.0	32.9	5.4	17.6	15.7	169.1	19.6	211.0
Average	11.1	36.4	5.3	17.3	19.8	213.1	25.3	272.6
Min	8.7	28.6	3.3	10.7	12.0	129.3	16.3	175.9
Max	14.4	47.1	7.8	25.5	26.4	284.2	32.8	353.1

Table 2.5: Regional Aircraft Data Tail Sweep Angles and Aspect Ratios [12-21]

AIRCRAFT	TAIL			
	Λ_{ht} (der)	Λ_{vt} (der)	AR_{ht}	AR_{vt}
A318-100	35	40	5.0	2.0
AN-158	35	40	4.1	1.1
BAE RJ 100	20	35	5.1	1.1
B717	35	45	4.3	1.1
B737-600	35	35	6.3	2.3
CRJ1000	30	40	4.6	0.9
CS100	35	40	5.5	1.5
ARJ21-900	35	40	4.3	0.9
E-195	30	30	4.6	2.2
FOKKER 100	26	40	4.6	1.0
MRJ90	30	40	5.5	1.8
SJ100	35	40	5.1	1.8
Average	32	39	4.9	1.5
Min	20	30	4.1	0.9
Max	35	45	6.3	2.3

Table 2.6: Regional Aircraft Data Weights [12-21]

AIRCRAFT	MTOW		MFUW		MTOW/S	
	kg	lb	kg	lb	kg/m^2	lb/ft^2
A318-100	68000	149780	19159	42200	555.6	113.7
AN-158	43700	96256	x	x	500.5	102.4
BAE RJ 100	44225	97412	x	x	572.1	117.1
B717	49895	109901	11162	24586	536.7	109.8
B737-600	65090	143370	x	x	520.7	106.6
CRJ1000	40823	89919	8887	19575	527.4	107.9
CS100	52615	115892	x	x	489.0	100.1
ARJ21-900	47180	103921	10624	23401	590.8	120.9
E-195	52290	115176	x	x	544.9	111.5
FOKKER 100	45810	100903	10731	23637	489.9	100.3
MRJ90	40955	90209	16805	37015	456.3	93.4

Table 2.6 (cont.): Regional Aircraft Data Weights

AIRCRAFT	MTOW		MFUW		MTOW/S	
	kg	lb	kg	lb	kg/m^2	lb/ft^2
SJ100	45880	101057	12690	27952	506.2	103.6
Average	49705	109483	12865	28338	524.2	107.3
Min	40823	89919	8887	19575	456.3	93.4
Max	68000	149780	19159	42200	590.8	120.9

Table 2.7: Regional Aircraft Data Performance Specifications [12-21]

AIRCRAFT			Max. Thrust	
	T_{max}/W_{TO}	# Engine	kN	lbf
A318-100	0.29	2	96.08	21600
AN-158	0.35	2	74.99	16859
BAE RJ 100	0.29	4	31.14	7000
B717	0.37	2	91.18	20500
B737-600	0.27	2	86.74	19500
CRJ1000	0.32	2	64.54	14510
CS100	0.40	2	103.64	23300
ARJ21-900	0.33	2	75.87	17057
E-195	0.35	2	88.96	20000
FOKKER 100	0.27	2	61.60	13850
MRJ90	0.38	2	75.62	17000
SJ100	0.34	2	76.82	17270
Average	0.33	2	77.26	17371
Min	0.27	2	31.14	7000
Max	0.40	4	103.64	23300

Table 2.8: Regional Aircraft Data Cruise Performance and Cabin Specifications [12-21]

AIRCRAFT	Altitude		Ope. Speed	Range		Pax	Crew	Seat No
	(m)	(ft)	(M)	(km)	(nm)			
A318-100	12130	39797	0.82	5741	3100	132	4	6
AN-158	11600	38058	0.79	2500	1350	99	4	5
BAE RJ 100	9450	31004	0.72	2760	1490	110	4	6
B717	10424	34199	0.77	2621	1415	117	4	5
B737-600	12200	40026	0.79	5649	3050	130	4	6
CRJ1000	12497	41001	0.78	3004	1622	100	4	4
CS100	12495	40994	0.78	5463	2950	110	4	5
ARJ21-900	10670	35007	0.78	3334	1800	105	4	5
E-195	12497	41001	0.82	4074	2200	116	4	4
FOKKER 100	11285	37024	0.74	3111	1680	107	4	5
MRJ90	11885	38993	0.78	2389	1290	92	4	4
SJ100	11885	38993	0.78	2948	1592	98	4	5
Average	11585	38008	0.78	3633	1962	110	4	5
Min	9450	31004	0.72	2389	1290	92	4	4
Max	12497	41001	0.82	5741	3100	132	4	6

Table 2.9: Regional Aircraft Data Cabin Dimensions [12-21]

AIRCRAFT	Seat Width		Aisle Width		Seat Pitch	
	(m)	(ft)	(m)	(ft)	(m)	(in)
A318-100	0.46	1.51	0.48	1.57	0.76	30
AN-158	0.44	1.44	0.48	1.57	0.76	30
BAE RJ 100	0.43	1.41	0.32	1.05	0.86	34
B717	0.52	1.71	0.48	1.58	0.81	32
B737-600	0.43	1.41	0.51	1.67	0.76	30
CRJ1000	0.44	1.44	0.41	1.35	0.79	31
CS100	0.47	1.54	0.41	1.35	0.81	32
ARJ21-900	0.46	1.51	0.49	1.59	0.79	31
E-195	0.46	1.51	0.50	1.64	0.79	31
FOKKER 100	0.44	1.44	0.48	1.57	0.81	32
MRJ90	0.47	1.54	0.46	1.51	0.74	29
SJ100	0.47	1.54	0.51	1.67	0.81	32
Average	0.46	1.50	0.46	1.51	0.79	31
Min	0.43	1.41	0.32	1.05	0.74	29
Max	0.52	1.71	0.51	1.67	0.86	34

2.2 Engine Data

The engine data has the all engine that belong to the aircrafts that were given in the regional jet list (Table 2.10). There are twelve engines and the data are not fully filled because of the some data is missing and some engines have tested recently and performance information is not shared by the manufacturers (Figure 2.3).

Table 2.10: Engine Data [23-30]

Engine	Manufacturer	Type	W_{dry} (lb)	T_{max} (lbf)	T_{max} (kN)	SFC (lb/lb/h)	OPR	BR
CFM56-5B8	CFM International	Turbofan	5250	21600	96	-	32.6	6.00
D-436	Ivchenko-Progress	Turbofan	3200	16859	75	0.63	21.9	4.95
LF-507	Lycoming - Honeywell	Turbofan	1385	7000	31	0.41	13.8	5.30
BR715-58	Rolls-Royce	Turbofan	6155	20500	91	0.61	32.0	4.70
CFM56-7B18	CFM International	Turbofan	5216	19500	87	0.63	32.8	5.50
CF34-8C5A1	General Electric	Turbofan	2500	14510	65	0.68	28.0	5.00
PurePower PW1524G	Pratt & Whitney	Turbofan	-	23300	104	-	-	12.00
CF34-10A	General Electric	Turbofan	-	17057	76	-	-	-
CF34-10E	General Electric	Turbofan	3700	20000	89	0.64	29.0	5.00
Tay 620	Rolls-Royce	Turbofan	3310	13850	62	0.69	16.2	3.04
PurePower PW1217G	Pratt & Whitney	Turbofan	-	17000	76	-	-	9.00
PowerJet SaM146	Snecma - NPO Saturn	Turbofan	3770	17270	77	0.63	28.0	4.43

Figure 2.3: CFM-56-7B-18 Engine [31]

2.3 Genetic Algorithm

Optimization is a process that finds a best or optimal solution for a problem. The optimization problems are centered on three factors: an objective function that is to be minimized or maximized; variables and constraints. The aim of the optimization problem is finding the variables that provide good solution for the objective function while satisfying the constraints. One of the optimization methods is the Genetic Algorithm that is based on the evolutionary strategy (Figure 2.4). GA searches the design space from a population created by bit string, gene, chromosome and regenareted by mutation and crossover methods similar to the evolution [32].

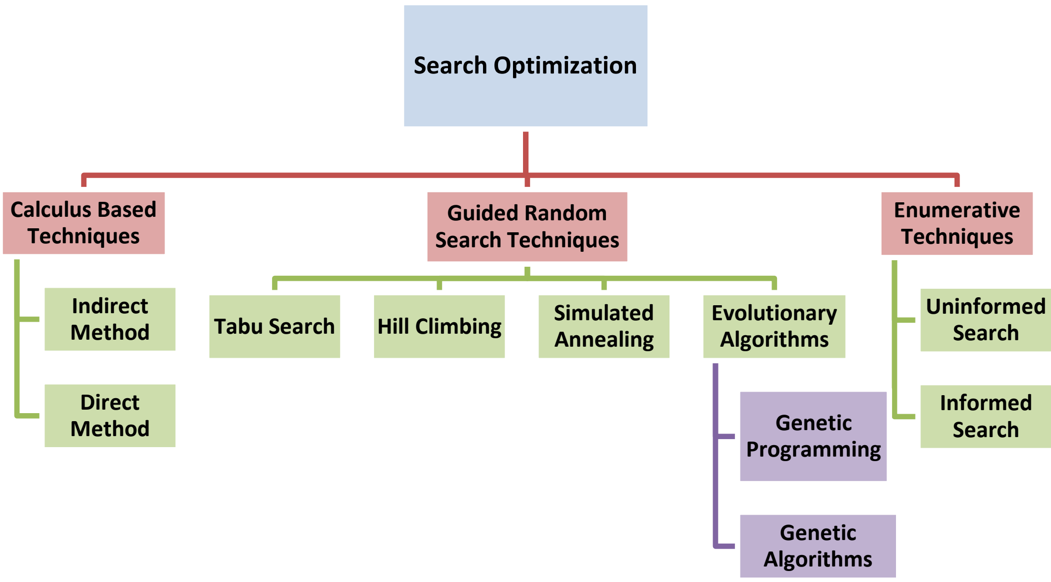


Figure 2.4: Optimization Methods [33]

The Genetic Algorithm was evaluated from the mechanics of biological evolution and they are adaptive heuristic search algorithm. It means that there is no certainity whether the result of using them is correct or not and the way which they use to find the solution, can be different each time [34]. Genetic Algorithm is very beneficial and efficient technique for optimization of business, science and engineering problems. GAs can be used in highly complex search spaces and it is very effective when the algorithm search the solution, because the algorithm does not make any assumption whatever the shape of the fitness function. In addition, Genetic algorithm is more robust than conventional artificial intelligence systems. Therefore, the GA does not break easily when there is a slight change in the inputs.

Genetic Algorithm is not too fast but it can be used in a large search space. There are many applications and fields that it is used: Optimization problems, robotics, machine learning, signal processing, design problems, automatic programming, economics, immune systems, ecology and population genetics [35].

Scientists studied the Genetic algorithm to develop an optimization tool for engineering problems by using the evolution terminology firstly in the 1950s and the 1960s. The idea in this system was to search a population of candidate solutions to a specific problem by using some methods such as natural genetic variation and natural selection [36].

In the 1960s, Rechenberg (1965, 1973) introduced a method he used to optimize real−valued parameters for devices such as airfoils and then Schwefel (1975, 1977) improved this method. Fogel, Owens, and Walsh (1966) developed a technique in which possible solutions to a specific problem were represented as finite−state machines whose state−transition diagrams were mutated randomly to evolve them and selecting the fittest. All of these methods form the base of evolutionary computation [36].

Genetic algorithms (GAs) were invented by John Holland and were developed by Holland and his students at the University of Michigan in the 1960s and the 1970s. In contrast with the other techniques stated above, Holland's first aim was to understand processes in nature and to design artificial systems similar to the natural systems and then to import this into computer systems. Holland mentioned this process in his book by defining the genetic algorithm as a brief summary of biological evolution.

Holland also gave a theoretical outline for adaptation of artificial systems to natural systems under the GA. Holland's GA is a technique depends on the chromosomes, genes and mutation and crossover processes. Holland's introduction of a population−based algorithm with crossover, inversion, and mutation was a major innovation. Because Rechenberg's evolution strategies started with a population of two individuals, one parent and one offspring, the offspring was a mutated version of the parent. Fogel, Owens, and Walsh's evolutionary programming used only mutation to provide variation [36].

In the last years, there has been interaction among researchers studying various evolutionary computation methods so there is no border between these methods and all of them stand on the Holland’s GA. Today, there are many algorithms similar to Genetic algorithm to solve the wide range of problems developed by the researchers [36].

2.4 Aircraft Design

Aircraft Design has approximately a hundred year history from Sir George Cayley to today. In 1700s and 1800s, Sir George Cayley studied on the basic aircraft design and made models like gliders to understand the importance of lift, propulsion, dihedral. After George Cayley, Otto Lilienthal took the flag in late 1800s and he stated that the control is very vital for an aircraft until he died in a glider accident. At the same time with Otto Lilienthal, another researcher, Octave Chanute carried the all information he knowed about the aviation from Europe to America and his knowledge helped the Wright Brothers when they revealed their successfully flight aircraft. In 1903, the Wright Brothers achieved first heavier than air sustained flight. Then the engineers had begun to use the aircraft similar to the Wright Brothers’ aircraft such as Ryan Monplane (1927). Then designers have improved the aircraft (Figure 2.6). Firstly, they made retractable landing gear, fully cantilevered wing, for body they used the monocoque construction, and wing flaps. As the problems like weight, control, aerodynamic and structure, they met very complex situation. When they reducing the drag, they met the structure problem and when they solved the problem this time weight problem came up [37].

Figure 2.5: Messerschmitt Me 262 [37]

During the Second World War, the aircraft industry had leveled up especially with the huge improvement in engine technology. The jet engine took place instead of piston engine and the fighter aircraft were developed (Figure 2.5). After the war, this technology was applied for commercial aircraft and in 1957, a four wing mounted engine, swept wing Boeing 707 was produced.

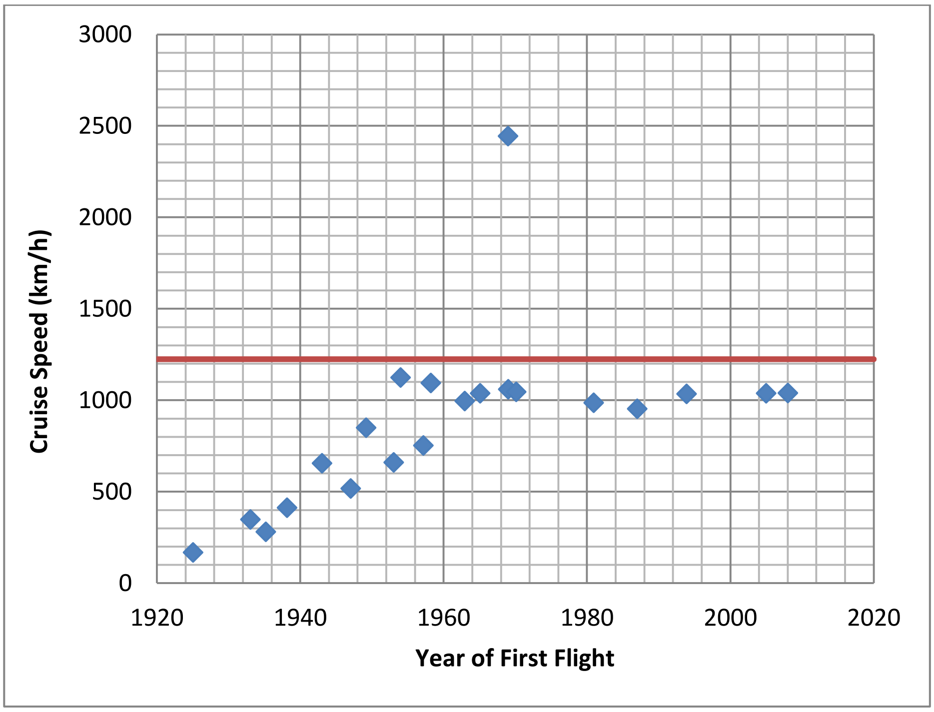


Figure 2.6: Cruise Speed Development of the Transport Aircrafts by Years (Red line: Speed of Sound - 1225 km/h) [37]

Today, there are hundreds of thousands of aircraft are in the sky and the aircraft design is an approved method for engineers. Many equations define the all forces and components of the aircraft and their effects to each other such as Daniel Raymer's book: "Aircraft Design: A Conceptual Design".

Aircraft design is a very complicated process because several disciplines are involved at the same time: aerodynamics, structures, performances, propulsion, costs. At first glance, the definition of the best aircraft design is very simple: the fastest, the lightest, the cheapest, the most enduring, and the most efficient airplane. Unfortunately, when an engineer design an aircraft it is not possible but it could be very good from one point shown as Figure 2.7. For instance, if an aircraft is very comfortable, so these aircraft has less efficient engine or maybe it is very heavy or if an aircraft has very good aerodynamic shape but meanwhile it is not allow to transport. Therefore, the design process of the aircraft should be decided carefully according to what type of aircraft will be designed and which quantity should be best to provide the best solution. The figure of merits of the quantities such as weight, flight controls, structures, manufacturing, aerodynamics, noise and propulsion characteristics should be specified in a objective function for the relevant aircraft type [38].

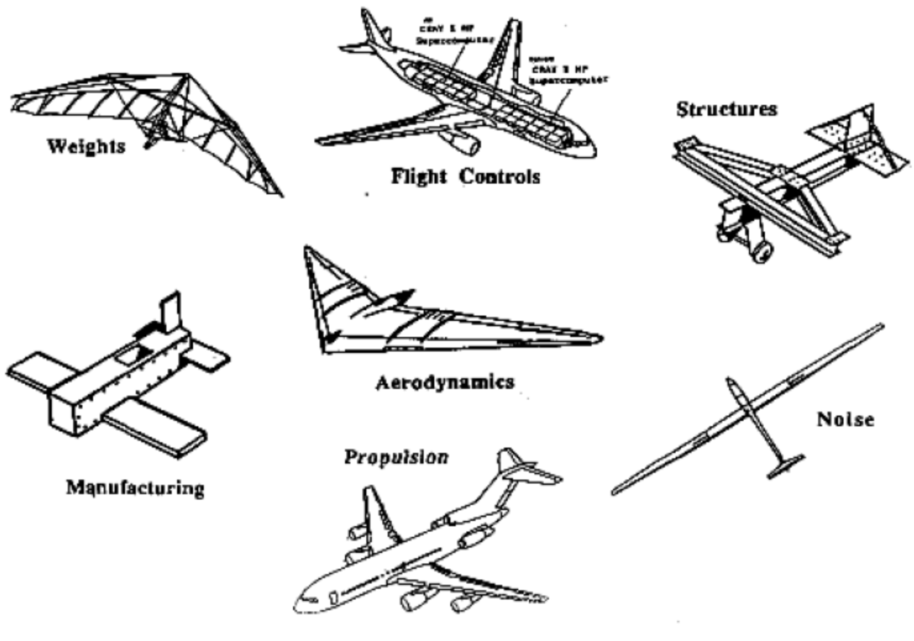


Figure 2.7: Aircraft Optimization Target [38]

Once the most important quantity has been decided, the other parameters that affect that quantity and the relation with that should be defined. The engineer solves the problem for the specified equation for quantity by a method. There are too many parameters to completely specify an airplane, so a combination of approximation, experience and statistical information on similar aircraft has to be used to reduce the number of design variables. Two approaches to optimization are commonly used: 1) Analytical: this approach is very useful for fundamental studies but requires great simplification; 2) Numerical: in most aircraft design problems, the analysis involves iterations, table look-ups or complex computations. In these cases, direct search methods are employed: grid searching, random searches, nonlinear simplex and gradient methods. In aircraft design, problems are often constraint-bounded when many constraints are active at the optimum. [38].

Today, the engineers no longer seeks the best aerodynamic or the best structural solutions, but rather the optimal solution, that is called multidisciplinary optimization (MDO). Alonso, Martins and Reuther used gradient methods to find the optimal solution but determining the numerical derivatives is computationally very expensive [39]. When the objective function is not continuous, the gradient-based methods cannot be immediately applied. In this case, Genetic Algorithm (GA) is coming forward in many science fields when all other conventional algorithms seem to fail [38].

3. STATEMENT OF THE PROBLEM

First and the most important aim of the thesis is to design the lowest possible weighted regional jet and after that the longest range in the specified region by some requirements such as passenger capacity, stall speed, cruise speed, cabin parameters etc. and by some constraints such as wing loading, tail volume coefficients etc. In order to apply the optimization process, Genetic Algorithm was used. The objective functions of the problem are maximum take-off weight and Breguet range equation.

$$W_{TO} = W_{empty} + W_{crew} + W_{payload} + W_{fuel} \quad \textbf{(3.1)}$$

$$Range = \frac{V_{cruise}}{c_J} \left(\frac{L}{D}\right)_{cruise} \ln \frac{W_{\mathrm{f}}}{W_{\mathrm{i}}} \quad \textbf{(3.2)}$$

First equation expresses the aircraft maximum take-off weight W_{TO}. In the equation, there are four terms empty weight W_e, payload weight $W_{payload}$, crew weight W_{crew} and fuel weight W_f. The empty weight is determined by the component build-up method that is to calculate the weight of each part of the aircraft by an equation based on the specified variables. Payload and crew weight are calculated with respect to the inputs for the numbers of passenger and crew. Finally, the fuel weight is defined by the mission profile of the aircraft. In the thesis, the mission profile contains warm-up, take-off, climbing, and cruise, descending, loiter, and fly to alternate and landing segments of the flight. Each segment of the mission profile gives the weight fraction calculated by the equation based on the variables that is the ratio the weight at the end of the segment to the weight at the start of the segment.

Second equation expresses the aircraft range R, that is, maximum distance that aircraft can fly. At the right side of the equation, V is the cruise velocity, SFC is the specific fuel consumption at cruise speed and altitude, L is the airplane lift, D is the airplane drag, W_i is the initial airplane weight and W_f is the final airplane weight [38].

The variables and the constraints for two equations firstly were defined and the relation between the objective function and the variables were described in the Genetic Algorithm. To limit the results, the constraints were implemented by penalty function whose details will be given in the next section. To minimize the weight and to maximize the range the Genetic Algorithm code was used and an interface was designed to make the calculation easily. This interface let the user to select the range of each variable, which constraint will be open and then to calculate the solution with the results and comparison parts of the designed aircraft.

Genetic Algorithm that used in the thesis is based on population of possible solutions that was created from the chromosomes that are comprised from the bit strings. The coupling was made by the single point crossover method.

4. GENETIC ALGORITHM

Genetic algorithms are the main element of the evolutionary computing and they are inspired by Darwin's theory about evolution. GAs are the ways of solving problems by simulating the natural systems' behavior like selection, crossover, mutation and accepting to provide a solution to the problem. There are some terms that are used in the GAs similar to the genetics: chromosome, gene, individual, population, fitness function, mutation and selection.

- Gene: a single encoding of part of the solution space, i.e. either single bits or short blocks of adjacent bits that encode an element of the candidate solution.
- Chromosome: a string of genes that represents a solution, sometimes called individual.
- Population: the number of individuals that are presented with same length of chromosome available to test.
- Fitness function: a function that assigns a value to the individual, called also cost or objective function.
- Mutation: changing a random gene in an individual.
- Selection: Selecting individuals for creating the next generation.

The basic process of the Genetic Algorithm starts with generating random population of chromosomes (Figure 4.1). These chromosomes consist of group of genes that each gene represents a variable according to the bit string. For instance, a variable is represented by 5 bit, the other one by 8 bit so the chromosome has 8+5=13 bits and two variables. The number of bits that will represent the variable are decided according to encode-decode process and the real value of the variable [33].

Secondly, all members of the population have a fitness value after evaluating the fitness function by relevant chromosome. After that, the fitness values of each individual are sorted depends on the fitness function type, for example if the aim of the problem is to find minimum then the sorting process is done from minimum fitness value to maximum value.

After sorting process has finished, the algorithm starts to create a new population by selecting two parent chromosomes from the previous population according to sort. To form new offspring (children), the parents are crossovered by specified crossover probability. New offspring can be mutated at a selected position in the chromosome by a mutation rate.

Finally, the fitness function is evaluated by using the new population and each chromosome will have a fitness value. If the results are satisfactory with the stop conditions, then the process stops.

The crossover and the mutation are very effective on Genetic Algorithm's performance and they are very significant.

Encoding – Decoding Process: Basically, this process turns real values to string of bits that are 0 and 1, by specified bit length and when the process is finished, turns bit strings to the real values. For example, one variable function, say 0 to 15 numbers, numeric values represented by 4-bit binary string (Table 4.1) [33].

Table 4.1: Encoding - Decoding Process

Numeric Value	4 - bit string	Numeric Value	4 - bit string	Numeric Value	4 - bit string
0	0000	6	110	12	1100
1	0001	7	111	13	1101
2	0010	8	1000	14	1110
3	0011	9	1001	15	1111
4	0100	10	1010		
5	0101	11	1011		

Reproduction, crossover and mutation are the most important parameters of the Genetic Algorithm. In addition to these, population size is another vital parameter. Population size means how many chromosomes are in the population. If there are only few chromosomes, then GA will search the solution in a small region. On the other hand, the increment in the population size causes to slow down of the algorithm. There is an optimum value for the population size and this depends on the type of encoding and the problem.

The reproduction or selection process can be done by five methods: Roulette wheel selection, Boltzmann Selection, Tournement Selection, Rank selection and Steady

State Selection. For example, Roulette wheel selection is used for selecting potentially useful solutions for recombination that is the selection of the luckiest individual that is decided by the ratio of its value to the sum of the fitness values of the all individuals. In the thesis, rank weighted selection was applied. This approach is problem independent and finds the probability from the rank, n, of the chromosome:

$$P_n = \frac{N - n + 1}{\sum_{n=1}^{N} n} \tag{4.1}$$

For example, for the N = 4 chromosomes, to select the chromosome the cumulative probabilities are calculated. Then a random number between zero and one is generated and starting from the top of the list, the first chromosome with a cumulative probability that is greater than the random number is selected for the mating pool. For instance, if the random number is r = 0.577, then 0.4 < r < 0.7, so chromosome-2 is selected (Table 4.2) [40].

Table 4.2: Rank Weighting Selection

n (Rank)	Chromosome	P_n	$\sum_{i=1}^{n} P_i$
1	00110010001100	0.4	0.4
2	11101100000001	0.3	0.7
3	00101111001000	0.2	0.9
4	00101111000110	0.1	1.0

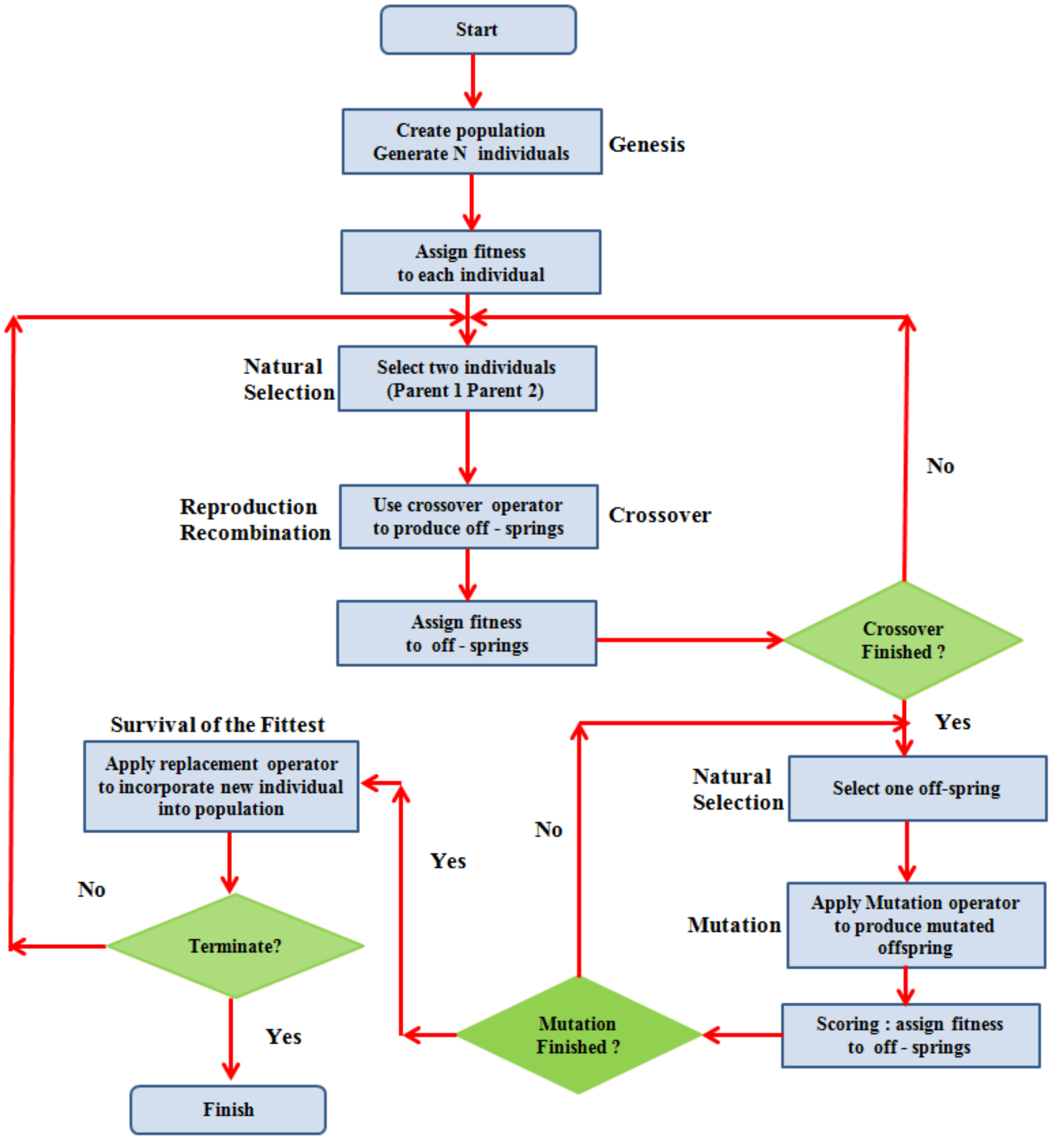


Figure 4.1: Genetic Algorithm Flow Chart [33]

The crossover process combines two parents to produce a new chromosome (Figure 4.2). This is done to create a new child that has better quality than its parents have. There are many crossover types such as: one point, two point, uniform, arithmetic and heuristic crossovers. In the thesis, the one point crossover method was used. One point crossover, selects one location to make the alteration. The left of the parent one stays same but after this location changed with the right side of the parent two and this is the same for the parent two.

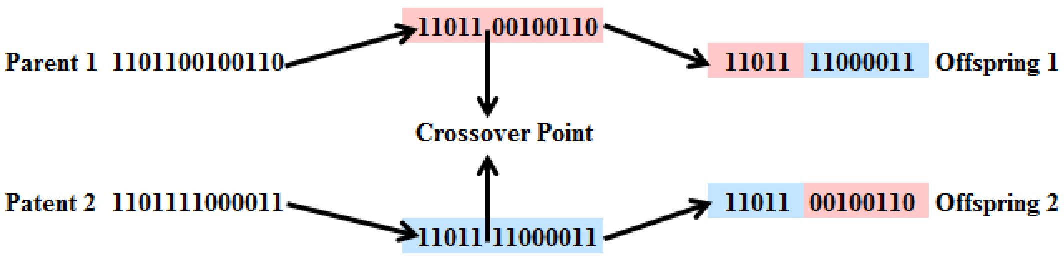


Figure 4.2: Crossover Process

After the crossover, mutation takes place by changing one or more gene values in a chromosome from its initial state. This means new genes added to the pool that provides better solution for that population than before. Mutation is an important part of the optimization due to prevent the population from stagnating at any local optimum value.

4.1 Penalty Function

To handle the constraints that is inequality or equality situations, the penalty functions are used in the Genetic Algorithm. Penalty functions were originally proposed by Richard Courant in the 1940s and were later expanded by Carroll and Fiacco & McCormick [41]. The idea of penalty functions is to transform a constrained optimization problem into an unconstrained one by adding, subtracting or multiplying a certain value to, by or from the objective function based on the amount of constraint violation present in a certain solution. There are several methods to handle constrained optimization problems that can be grouped in four major categories: Methods based on penalty functions, Methods based on a search of feasible solutions, Methods based on preserving feasibility of solutions and Hybrid methods.

Death Penalty, Static Penalty, Dynamic Penalty, Annealing Penalty, Adaptive Penalty, Segregated GA and Co-evolutionary Penalty are the methods based on penalty functions.

Repairing unfeasible individuals, superiority of feasible points, behavioral memory are the methods based on a search of feasible solutions.

The GENOCOP system, searching the boundary of feasible region, homomorphous mapping are the methods based on preserving feasibility of solutions [41].

Exterior and interior methods are the two methods as stated penalty functions. The exterior methods move the infeasible solution to the feasible region. In the case of interior methods, the penalty term is chosen such that its value will be small at points away from the constraint boundaries and will tend to infinity as the constraint boundaries are approached. The external penalty functions of the form:

$$\phi(\vec{x}) = f(\vec{x}) \pm \left[\sum_{i=1}^{n} r_i \; x \; G_i + \sum_{j=1}^{p} c_j \; x \; L_j \right] \qquad \textbf{(4.2)}$$

where φ(x) is the new objective function to be optimized, G_i and L_j are functions of the constraints and r_i and c_j are positive constants and called penalty parameters. The purpose of a penalty parameter is to make the constraint violation of the same order of magnitude as objective function value. Equality constraints are usually handled by converting them into inequality. The most common form of G_i and L_j is:

$$G_i = max\,[0,\; g_i(\vec{x})]^{\beta} \qquad \textbf{(4.3)}$$

$$L_j = \left| \, h_j(\vec{x}) \right|^{\gamma} \qquad \textbf{(4.4)}$$

where β and γ are normally 1 or 2 [42]. In the thesis, this value was selected as 2. The values of the r_i and c_j are specified according to the feasible region for the solution. Each parameter for each constraint was defined by several attempts to improve the accuracy of the solution. In the thesis static penalty function was used for each constraints and the penalty function parameters were selected by several trials. The details for the penalty parameters will be given in the next section [43].

The solution of the objective function depends on penalty parameters. To steer the search towards the feasible region, different values of parameters have to be tried. This process takes long time to find any reasonable solution. For instance, different values of r_i depending on the level of constraint violation can be used [44].

The inclusion of the penalty parameter alters the objective function. The optimum of objective function may not be near the actual constrained optimum when small values of R_j is added so the distortion is small. On the other hand, The optimum of objective function may be closer to the actual constrained optimum when large values of R_j is added but this time the distortion may be so huge that objective function may have artificial locally optimal solutions because of the interactions among multiple constraints. To avoid such locally optimal solutions, classical penalty function approach works in sequences, where in every sequence the penalty parameters are increased in steps and the current sequence of optimization begins from the optimized solution found in the previous sequence. By this way, a controlled search is possible and locally optimal solutions can be avoided. In the code, this process is provided at the start of the process by hand [44].

4.2 Variables and Constraints

The optimization of the aircraft process is based on the variables and constraints. The optimization consists of two separate methods: Possibly the lowest maximum take-off weight and the furthest range. For each method, the variables and constraint were specified. The interface that was prepared for optimization provides user to select the range for variables and which constraint will be used and which value will be given to constraints. In the Table 4.3, minimum and maximum allowable limits and number of bits for each variable are shown. The length of the bit string is determined from the range of these variables and the degree of accuracy required. The user can change these values in this range. All variables except the maximum lift coefficient and maximum take-off weight are used in all optimization process. The maximum lift coefficient is only be included in the minimum weight problem while the maximum take-off variable is only be involved in the maximum range problem.

Table 4.3: Optimization Variables

	Design Variables	**Admissible values**	**Unit**	**Number of Bits**
Wing	Max. Lift Coefficient	$1.4 < C_{Lmax} < 3$		10
	Area	$700 < S < 1500$	ft^2	10
		$65 < S < 140$	m^2	
	Aspect Ratio	$7 < AR < 12$		8
	Thickness Ratio	$0.10 < t/c < 0.20$		8
	Taper Ratio	$0.1 < \lambda < 0.7$		8
	Sweep Angle	$15 < \Lambda < 40$	degree	8
Horizontal Tail	Area	$160 < S_{ht} < 380$	ft^2	8
		$14.86 < S_{ht} < 35.3$	m^2	
	Aspect Ratio	$3 < AR_{ht} < 8$		8
	Sweep Angle	$15 < \Lambda_{ht} < 45$	degree	8

Table 4.3 (cont.): Optimization Variables

	Design Variables	Admissible Values	Unit	Number of Bits
Vertical Tail	Area	$100 < S_{vt} < 320$	ft^2	8
		$9.3 < S_{vt} < 29.7$	m^2	
	Aspect Ratio	$0.5 < AR_{vt} < 3.5$		8
	Sweep Angle	$25 < \Lambda_{vt} < 50$	degree	8
Tail	Arm	$40 < L_T < 75$	ft	8
	Type	Conventional - T Tail		1
	Thickness Ratio	0.10 < t/c< 0.20		8
Engine	Number	$2 < N_{en} < 4$		1
Fuselage	Length	$80 < L_f < 150$	ft	8
		$24.4 < L_f < 45.7$	m	
	Thrust to Weight Ratio	0.1 < T/W < 0.4		8
	Max. Take-off Weight	$80000 < W_{TO} < 150000$	lbs	8
		$36320 < W_{TO} < 68100$	kg	

There are twelve constraints to limit the solution (Table 4.4). All of these constraints can be involved or none of them can be included according to the user's demand by selecting "open" or "closed" options on the interface (Table 4.5). The fuel volume and take-off weight calculation are only applicable for maximum take-off weight optimization process.

The constraint of calculation of the fuel volume states that, fuel volume calculated from the geometrical parameters should be bigger than the fuel volume calculation from the fuel weight because the fuel tank volume can be greater than needed or used fuel. And the constraint of calculation of maximum take-off weight mentions that the weight calculated from the multiple of the wing loading and wing area should be equal or larger than the weight that was calculated by component build up method because the component build up method is statistical method and some components could be missing.

Maximum take-off weight constraint:

$$W_{TOF1} = \mathrm{W_{TOF}}/\mathrm{S}\ \mathrm{x}\ \mathrm{S} \quad \textbf{(4.5)}$$

$$W_{TOF2} = W_{empty} + W_{crew} + W_{payload} + W_{fuel} \quad \textbf{(4.6)}$$

Fuel volume constraint:

$$V_{fuel\_weight} = V_f \qquad \textbf{(4.7)}$$

$$V_{fuel\_geometry} = 0.54\ x\ \frac{S^2}{b}\ x\ (t/c)\ x\ \frac{(1+\ \lambda +\ \lambda^2)}{(1+\ \lambda)^2} \qquad \textbf{(4.8)}$$

Wing root chord:

$$c_r = 2\ x\ \frac{S}{b\ x\ (1+\ \lambda)} \qquad \textbf{(4.9)}$$

Mean aerodynamic chord:

$$c_{mean} = \frac{2}{3}\ x\ c_r\ x\ \frac{(1+\ \lambda +\ \lambda^2)}{(1+\ \lambda)} \qquad \textbf{(4.10)}$$

Horizontal and vertical tail volume coefficient constraint:

$$v_v = \frac{L_t\ x\ S_{vt}}{b\ x\ S} \qquad \textbf{(4.11)}$$

$$v_h = \frac{L_t\ x\ S_{ht}}{c_{mean}\ x\ S} \qquad \textbf{(4.12)}$$

Table 4.4: Optimization Constraints

Constraint	**Admissible values**
Wing Loading kg/m^2 (lb/ft^2)	342.1<W/S (70<W/S)
Wing Loading kg/m^2 (lb/ft^2)	781.9<W/S (W/S<160)
Wing - Tail Weight Relation	$W_{tail}<W_{wing}$
Wing - Fuselage Weight Relation	$W_{wing}<W_{fuselage}$
Radom Length	$0<L_{Radom}$
Fuel Volume Calculation	$V_{fuel\_weight}<V_{fuel\_geometry}$
Fuselage Length	$L_{fuselage\_without\_cone\&radome}<L_{fuselage}$
Take-off Weight Calculation	$W_{TOF2}<W_{TOF1}$
Vertical Tail Volume Coefficient	$0.02<V_v$
Vertical Tail Volume Coefficient	$V_v<0.10$
Horizontal Tail Volume Coefficient	$0.7<V_h$
Horizontal Tail Volume Coefficient	$V_h<1.6$

Table 4.5: Constraints and Penalty Parameters

Constraint	Optimization Method	Penalty Parameter
Wing Loading	Max TOW / Range	1.00e+05
Wing Loading	Max TOW / Range	1.00e+05
Wing - Tail Weight Relation	Max TOW / Range	1.00e+01
Wing - Fuselage Weight Relation	Max TOW / Range	1.00e+03
Radom Length	Max TOW / Range	1.00e+01
Fuel Volume Calculation	Max TOW	1.00e+03
Fuselage Length	Max TOW / Range	1.00e+03
Take-off Weight Calculation	Max TOW	1.00e+03
Vertical Tail Volume Coefficient	Max TOW / Range	1.00e+03
Vertical Tail Volume Coefficient	Max TOW / Range	1.00e+02
Horizontal Tail Volume Coefficient	Max TOW / Range	1.00e+03
Horizontal Tail Volume Coefficient	Max TOW / Range	1.00e+02

5. AIRCRAFT DESIGN EQUATIONS

The optimization consists of two objective functions: Range equation (Breguet) and Maximum Take-off weight equation. All variables are written in a function that gives the desired objective function. Maxiumum take-off weight is divided into empty, fuel, payload and crew weight. Payload weight and crew weight is calculated according to the desired specification values. The weight of a passenger and a crew is taken 175 lbs (approximately 80 kg) and baggage weight is 30 lbs (approximately 15 kg). The fuel weight is determined by mission profiles and the empty weight is calculated by component build up method expect the weights of flight controls, APU, hydraulics, electrical, furnishing,air conditioning and handling gear [45].

5.1 Maximum Take-off Weight

$$W_{TO} = W_{empty} + W_{crew} + W_{payload} + W_{fuel} \tag{5.1}$$

5.1.1 Crew weight

Crew weight is calculated by multiplying the weight of officers plus their baggage by the number of the crew.

$$W_{crew} = Crew\ x\ (175 + 30\ )\ (lbs) \tag{5.2}$$

5.1.2 Payload weight

Payload weight is calculated by multiplying the weight of a passenger plus his baggage by the number of the passenger.

$$W_{payload} = Passenger\ x\ (175 + 30\ )\ (lbs) \tag{5.3}$$

5.1.3 Fuel weight

Fuel weight is determined by mission profile that consists of engine start up-warm up, taxi, take-off, climb, cruise, loiter, descent, fly to alternate, landing and taxi segments. In addition, trapped fuel and oil that is taken as 0.5% of the maximum take-off weight is added to the fuel weight. Each segment has its weight ratio that is the ratio of the first weight at the start of the segment to the final weight at the end of the segment.

Engine start up - warm up, taxi, take-off, climb, landing and taxi weight fractions are taken as constants. Cruise, loiter and fly to alternate segments are calculated by range and endurance equations based on the variables.

5.1.3.1 Mission profile

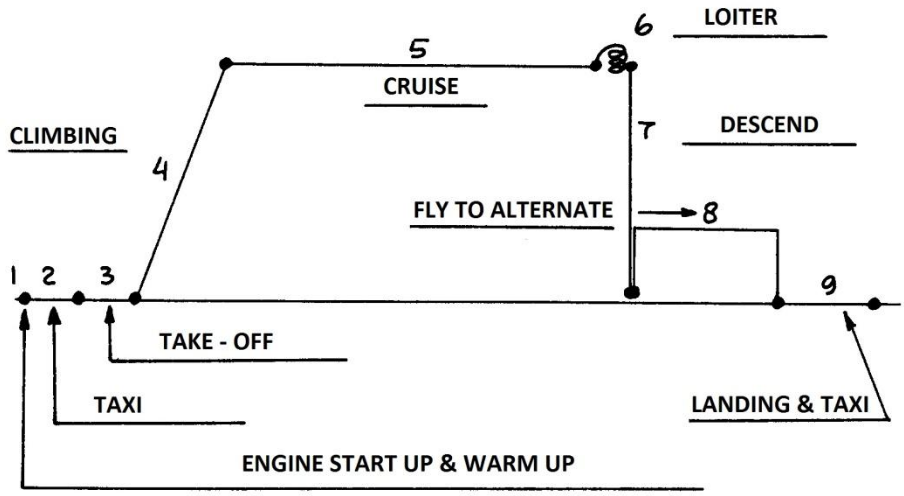


Figure 5.1: Mission Profiles

Mission profile is scheduled for the aircraft that will be optimized and numbers was given to the steps of the mission profile as can be seen in Figure 5.1.

5.1.3.2 Engine start up & warm up

Roskam (1985) states that the transport aircraft loses weight approximately 1% of the total weight (p. 12) [45].

$$W_1/W_{TOF} = 0.99 \quad \textbf{(5.4)}$$

5.1.3.3 Taxi

Roskam (1985) states that the transport aircraft loses weight approximately 1% of the start weight of the segment (p. 12) [45].

$$W_2/W_1 = 0.99 \quad \textbf{(5.5)}$$

5.1.3.4 Take – off

In contrast to first two segments, the transport aircraft loses weight approximately 0.5% of the start weight of the segment during take-off [45].

$$W_3/W_2 = 0.995 \quad \textbf{(5.6)}$$

5.1.3.5 Climb

According to Roskam (1985), a transport aircraft loses weight about 2% of the start weight of the segment during the climb (p. 12) [45].

$$W_4/W_3 = 0.98 \quad \textbf{(5.7)}$$

5.1.3.6 Cruise

Cruise weight fraction is calculated by several equations using given parameters such as cruise altitude, cruise Mach number, specific fuel consumption according to the selected engine. Firstly, the density of the atmosphere at cruise altitude, the temperature based on the standart atmosphere conditions and the sound speed are calculated. Then, lift coefficient is found using the lift equation by taking the weight at the start of the cruise operation that is drived by substracting the lost weight segments before the cruise. To calculate the drag, parasite drag is derived from the equation that uses wing thickness ratio and friction coefficient for the transport aircrafts given by Raymer [46]. The induced drag is added to the parasite drag by using the Oswald span efficiency that is computed with Wing Aspect Ratio and sweep. Finally, Breguet Range equation is applied with L/D ratio, desired Range value, cruise speed and specific fuel consumption.

Density:

$$\rho = 0.002377\ x\ \left((1 - 7x10^{-6})x\ h\right)^{4.21}\quad (slug/ft^3) \qquad \textbf{(5.8)}$$

Temperature at specified altitude:

$$T = 518.4 - 0.003564\ x\ h\ \ (R) \qquad \textbf{(5.9)}$$

Speed of sound:

$$a = \sqrt{\gamma RT} \qquad \textbf{(5.10)}$$

Cruise velocity:

$$V = M\ x\ a \qquad \textbf{(5.11)}$$

Lift coefficient:

$$C_{L_{cruise}} = \frac{(W_4/S)}{0.5\ x\ \rho\ x\ V_{cruise}^2} \qquad \textbf{(5.12)}$$

$$W_4/S = (W_{TOF}/S)\ x\ (W_4/W_3)\ x\ (W_3/W_2)\ x\ (W_2/W_1)\ x\ (W_1/W_{TOF}) \qquad \textbf{(5.13)}$$

Oswald efficiency factor:

$$e = 4.61\ x\ \left(1 - 0.045x(AR^{0.68})\right)\ x\ (cos(\Lambda)^{0.15} - 3.1) \qquad \textbf{(5.14)}$$

$$K = \frac{1}{\pi\ x\ AR\ x\ e} \qquad \textbf{(5.15)}$$

Friction coefficient:

$$C_{fe} = 0.003 \qquad \textbf{(5.16)}$$

Drag Coefficient:

$$C_{D0} = C_{fe}\ x\ \left(0.8\ x\ \left(1.977 + 0.52\ x\ (t/c)\right)\right) \qquad \textbf{(5.17)}$$

$$C_{D_{cruise}} = C_{D0} + K \, x \, C_{L_{cruise}}{}^{2} \tag{5.18}$$

$$\left(\frac{L}{D}\right)_{cruise} = \frac{C_L}{C_D} \tag{5.19}$$

$$W_5/W_4 = \frac{1}{e^{Rx\, c_j/\left(V\, x\, \frac{L}{D}\right)}} \tag{5.20}$$

5.1.3.7 Loiter

Similar to the cruise, the weight fraction of loiter segment is derived from the endurance equation by using L/D, specific fuel consumption for loiter and endurance time that is specified at the start of the design. The specific fuel consumption for loiter can change according to the aircraft so the value is taken as 85% of the cruise fuel consumption by taking the average value of loiter fuel consumption values to cruise fuel consumption values at Raymer's (1992) table for low and high bypass ratio turbofan engines (p. 19) [46]. For L/D value, as same as the cruise, both lift and drag coefficients are calculated. The weight of the aircraft to find the lift coefficient is the weight which in the start of the loiter step and the loiter velocity is taken as 93% of the cruise speed because of root square of 0.866 (p. 22) [46].

$$V_{loiter} = V_{cruise} \, x \, 0.93 \tag{5.21}$$

$$c_{j_{loiter}} = c_{j_{cruise}} \, x \, 0.85 \tag{5.22}$$

$$C_{L_{loiter}} = \frac{(W_5/S)}{0.5 \, x \, \rho \, x \, V_{loiter}^2} \tag{5.23}$$

$$W_5/S = (W_{TOF}/S) \, x \, (W_5/W_4) \, x \, (W_4/W_3) \, x \, (W_3/W_2) \, x \, (W_2/W_1) \, x \, (W_1/W_{TOF}) \tag{5.24}$$

$$C_{D_{loiter}} = C_{D0} + K \, x \, C_{L_{loiter}}{}^{2} \tag{5.25}$$

$$\left(\frac{L}{D}\right)_{loiter} = \frac{C_L}{C_D} \tag{5.26}$$

$$W_6/W_5 = \frac{1}{e^{Ex\, c_j/\left(\frac{L}{D}\right)}} \quad \textbf{(5.27)}$$

5.1.3.8 Descent

Roskam (1985) states that the transport aircraft loses weight approximately 2% of the start weight of the descent process (p. 12) [45].

$$W_7/W_6 = 0.98 \quad \textbf{(5.28)}$$

5.1.3.9 Fly to alternate

The weight fraction of the fly to alternate divison is determined by Breguet Range equation. According to Roskam (1985), fly to alternate segment will occur at about 10000 feet altitude and by maximum 250 knots speed (p. 57) [45]. To make the process systematically the velocity is taken 30% percent of the cruise velocity. Specific fuel consumption will be higher than the cruise so is taken 150% of the cruise fuel consumption. According Roskam (1985) while the specific fuel consumption of fly to alternate process is taken 0.9 lbs/lbs/hr, the specific fuel consumption of the cruise process is 0.5 lbs/lbs/hr so the ratio of these values is 1.8 and so in the thesis this ratio is taken 1.5 (p. 54) [45]. The weight of the aircraft to find the lift coefficient is the weight which in the start of the segment. The range that aircraft can fly is given in the design specification.

$$V_{fly\ to\ alternate} = V_{cruise}\ x\ 0.3 \quad \textbf{(5.29)}$$

$$c_{j_{flytoalternate}} = c_{j_{cruise}}\ x\ 1.5 \quad \textbf{(5.30)}$$

$$C_{L_{flytoalternate}} = \frac{(W_7/S)}{0.5\ x\ \rho\ x\ V_{fly\ to\ alternate}^2} \quad \textbf{(5.31)}$$

$$\frac{W_7}{S} = \frac{W_{TOF}}{S} x \frac{W_7}{W_6}\ x\ \frac{W_6}{W_5} x\ \frac{W_5}{W_4} x\ \frac{W_4}{W_3} x\ \frac{W_3}{W_2}\ x\ \frac{W_2}{W_1}\ x \frac{W_1}{W_{TOF}} \quad \textbf{(5.32)}$$

$$C_{D_{flytoalternate}} = C_{D0} + K\ x\ \left(C_{L_{flytoalternate}}\right)^2 \quad \textbf{(5.33)}$$

$$\left(\frac{L}{D}\right)_{fly\ to\ alternate} = \frac{C_L}{C_D} \quad \textbf{(5.34)}$$

$$W_8/W_7 = \frac{1}{e^{Rx\ c_j/\left(\frac{L}{D}\,x\,V_{flytoalternate}\right)}} \quad \textbf{(5.35)}$$

5.1.3.10 Landing and taxi

According to Roskam (1985), a transport aircraft loses weight about 0.8% of the start weight during the landing (p. 12) [45].

$$W_9/W_8 = 0.992 \quad \textbf{(5.36)}$$

5.1.3.11 Fuel fraction

Fuel fraction is the ratio between the preliminary weight of the aircraft to the end weight. The difference states used fuel during the operation. To calculate the all of the fuel weight the trapped fuel and oil also should be added to the used fuel weight. Trapped fuel is 0.5% of maximum take-off weight. To introduce the fuel weight to optimization process, wing load and wing area variables are used [45].

$$M_{ff} = \frac{W_9}{W_{TOF}} = \frac{W_9}{W_8}\,x\,\frac{W_8}{W_7}\,x\,\frac{W_7}{W_6}\,x\,\frac{W_6}{W_5}\,x\,\frac{W_5}{W_4}\,x\,\frac{W_4}{W_3}\,x\,\frac{W_3}{W_2}\,x\,\frac{W_2}{W_1}\,x\,\frac{W_1}{W_{TOF}} \quad \textbf{(5.37)}$$

$$W_{tfo} = 0.005\,x\,(W_{TOF}/S\ \ x\,S) \quad \textbf{(5.38)}$$

$$W_{Fuel} = W_{tfo} + M_{ff}\,x\,(W_{TOF}/S\ \ x\,S) \quad \textbf{(5.39)}$$

5.1.4 Empty weight

Empty weight estimations are made using the statistical equations by component build-up method that is the weight of each component of the aircraft except flight controls, APU, hydraulics, basic electrical systems, furnishing, air conditioning, is derived by an equation [46].

$$W_{empty}=W_{w}+W_{hort}+W_{vert}+W_{fus}+W_{mlg}+W_{nlg}+W_{prop} + W_{fuel\_sys}+W_{pneu}+W_{antice}+W_{av}+W_{hg}+W_{sc} \quad \textbf{(5.40)}$$

5.1.4.1 Wing

Wing loading, wing area, aspect ratio, thickness ratio, taper, sweep angle are variables that is used during the wing weight calculation. Ultimate load factor and ratio between control surface to wing area are taken as 1.5 x 2.5=3.75 and 0.25 respectively [46].

$$W_{wing}=0.0051 \text{ x } (W_{TOF}/S \text{ x } S \text{ x } N_z)^{0.557} \text{ x } S^{0.649} \text{ x } (t/c)^{-0.4} \text{ x}(1+\lambda)^{0.1} \text{x } (\cos(\Lambda))^{-1} \text{x}(S \text{ x } S_{csw})^{0.1} \quad \textbf{(5.41)}$$

5.1.4.2 Horizontal tail

Wing loading, wing area, horizontal tail aspect ratio, horizontal tail area, tail arm, horizontal tail sweep angle are variables that is used during the horizontal tail weight calculation. Ultimate load factor, ratio between control surface to horizontal tail area, tail motion factor and fuselage width at horizontal tail intersection are taken as 3.75, 0.25, 1 (not moving horizontal tail) and approximately 10 ft respectively [46].

$$b_{ht} = \sqrt{AR \ x \ S_{ht}} \quad \textbf{(5.42)}$$

$$W_{hort}=0.0379 \text{ x } K_{uht} \text{x } (1+F_w/b_{ht})^{-0.25} \text{ x } (W_{TOF}/S \ x \ S)^{0.639} \text{ x } (N_z)^{0.10} \text{ x } S_{ht}^{0.75} \text{ x}(0.3x \ (L_t)^{-0.296}) \text{ x } (\cos(\Lambda))^{-1} \text{x}\left(1+ S_{e\_sht}\right)^{0.1} \text{x } (AR_{ht})^{0.166} \quad \textbf{(5.43)}$$

5.1.4.3 Vertical tail

Wing loading, wing area, vertical tail aspect ratio, vertical tail area, tail arm, vertical tail sweep angle, vertical tail thickness ratio and tail type are variables that is used during the vertical tail weight calculation. Ultimate load factor is taken as 3.75 [46].

$$W_{vert}=0.0026 \text{ x } (1+C_T)^{0.225} \text{ x } (W_{TOF}/S \text{ x } S)^{0.556} \text{ x } (N_z)^{0.536} \text{ x } S_{vt}^{\ 0.5}$$

$$\text{x } (L_t)^{0.375} \text{x } (\cos(\Lambda))^{-1} \text{x } (AR_{vt})^{0.35} \text{ x } \left(\frac{t}{c_{vt}}\right)^{-0.5} \qquad \textbf{(5.44)}$$

5.1.4.4 Fuselage

Wing loading, wing area, taper, sweep angle and fuselage length are variables that is used during the fuselage weight calculation. Number of seats at a row, seat width, aisle width and seat pitch are the constants specified by design parameters. Fuselage depth is assumed as 1.25 time of total of all of the seat and aisle widths. Fuselage length without radome and tail cone is determined by passenger, seat number at a row and seat pitch. Roskam (1985) states that fuselage cone length is derived from the fuselage depth by multiplying with 3 (p. 110) [47]. Fuselage radom length is total fuselage length minus cone and fuselage length without cone and radome. Fuselage wetted area is also calculated using fuselage depth, fuselage length without radome, radome length and cone length. Door constant (K_{door}) and landing gear mount type constant (K_{lg}) are taken 1 (no cargo door) and 1.12 (landing gear mounted to fuselage) respectively.

Fuselage width:

$$d_f = (N_{seat} \ x \ w_{seat} + \ w_{aisle}) \ x \ 1.25 \qquad \textbf{(5.45)}$$

Fuselage length without radome and tail cone:

$$L = \frac{pax}{N_{seat}} \ x \ pitch \qquad \textbf{(5.46)}$$

Fuselage tail cone length:

$$L_{fc} = 3 \ x \ d_f \qquad \textbf{(5.47)}$$

Fuselage radome length:

$$L_{fn} = L_f - L_{fc} - L \quad \textbf{(5.48)}$$

Fuselage wetted area:

$$S_f = 0.75\ x\ \pi\ x\ d_f\ x\ L_{fn} + 0.72\ x\ \pi\ x\ d_f\ x\ L_{fc} + \pi\ x\ d_f\ x\ L \quad \textbf{(5.49)}$$

Wing Span and fuselage weigth constant:

$$b = \sqrt{AR\ x\ S} \quad \textbf{(5.50)}$$

$$K_{ws} = 0.75\ x \frac{(1 + 2\ x\ \lambda)}{(1 + \lambda)}\ x\ b\ x \frac{\tan(\Lambda)}{L_f} \quad \textbf{(5.51)}$$

$$W_{fus} = 0.328\ x\ K_{door}\ x\ K_{lg}\ x\ (W_{TOF}/S\ x\ S\ x N_z)^{0.5}\ x\ (L_f)^{0.25}\ x\ (S_f)^{0.302}\ x\ (1 + K_{ws})^{0.04} x \left(\frac{L}{d_f}\right)^{0.1} \quad \textbf{(5.52)}$$

5.1.4.5 Main landing gear

Wing loading and wing area are variables that are used during the main landing gear weight calculation [48].

$$W_{mlg} = 40 + 0.16\ x\ (W_{TOF}/S\ x\ S)^{0.75} + 0.019\ x\ (W_{TOF}/S\ x\ S)^{1.5} + 1.5 x\ 10^{-5}\ x (W_{TOF}/S\ x\ S) \quad \textbf{(5.53)}$$

5.1.4.6 Nose landing gear

Wing loading and wing area are variables that are used during the nose landing gear weight calculation [48].

$$W_{nlg} = 20 + 0.1\ x\ (W_{TOF}/S\ x\ S)^{0.75} + 2 x\ 10^{-6}\ x (W_{TOF}/S\ x\ S)^{1.5} \quad \textbf{(5.54)}$$

5.1.4.7 Propulsion system

Propulsion system weight is the sum of the engine with cover and nacelle group. Number of engines and thrust to weight ratio are variables that are used during the propulsion system weight calculation. Engine weight is taken from the design parameters that are selected from the engine data [48].

$$W_{prop} = 1.357\ xW_e\ x\ N_{en} \tag{5.55}$$

$$W_{nac} = 0.055\ x\ (T/W)_{TOF}\ x\ N_{en} \tag{5.56}$$

$$W_{prop\_sys} = W_{prop} + W_{nac} \tag{5.57}$$

5.1.4.8 Surface control systems

Wing loading and wing area are variables that are used during the surface control systems weight calculation [48].

$$W_{prop} = 0.64\ x(W_{TOF}/S\ \ x\ S)^{\ 2/3} \tag{5.58}$$

5.1.4.9 Fuel systems

Number of engines is the only variable that is used in the fuel systems weight calculations. To derive the fuel volume, the density of the kerosene and to make calculation fuel tank number is taken eight [48].

$$\rho_{kerosene} = 50.4\ \ lb/ft^3 \tag{5.59}$$

$$V_f = {}^{W_{fuel}}/_{\rho_{kerosene}} \tag{5.60}$$

$$W_{fuel\,systems} = 80\ x\left(N_{en} +\ N_{ft} - 1\right) + 15\ x\ \left(N_{ft}\right)^{0.5} x\ \left(V_f\right)^{0.333} \tag{5.61}$$

5.1.4.10 Pneumatic systems

Number of engines is the only variable that is used in the pneumatic systems weight calculations. Engine weight is taken from the design parameters that are selected from the engine data.

$$W_{pneumatic} = 49.19\ x(N_{en} x\ W_e\ /1000)^{0.541} \quad \textbf{(5.62)}$$

5.1.4.11 Anti – ice

Wing loading and wing area are variables that are used during the anti – ice systems weight calculation [46].

$$W_{anti\ ice} = 0.002\ x\ (W_{TOF}/S\ \ x\ S) \quad \textbf{(5.63)}$$

5.1.4.12 Handling gear

Wing loading and wing area are variables that are used during the handling gear weight calculation [46].

$$W_{handling\ gear} = 0.0003\ x\ (W_{TOF}/S\ \ x\ S) \quad \textbf{(5.64)}$$

5.1.4.13 Avionics

To calculate the avionics weight, uninstalled avionics weight is used and that is specifically ranged in 800-1500 lbs and 1500 lbs is chosen [46].

$$W_{avionics} = 1.73\ x\ UAV^{0.983} \quad \textbf{(5.65)}$$

5.2 Range

Range optimization depends on cruise velocity, cruise fineness ratio, cruise specific fuel consumption and finally weight values before and after the cruise operation. Cruise velocity and cruise specific fuel consumption are the same with maximum take-off weight optimization.

$$Range = \frac{V_{cruise}}{c_J} \left(\frac{L}{D}\right)_{cruise} \ln \frac{W_5}{W_4} \quad \textbf{(5.66)}$$

5.2.1 Initial weigth

Initial weight is calculated using the only variable maximum take-off weight and weight fractions before the cruise segment: engine start up and warm up, taxi, take-off and climb.

$$W_4 = W_{TOF} x \frac{W_4}{W_3} x \frac{W_3}{W_2} x \frac{W_2}{W_1} x \frac{W_1}{W_{TOF}} \quad \textbf{(5.67)}$$

5.2.1.1 Engine start up & warm up

Roskam (1985) states that the transport aircraft loses weight approximately 1% of the total weight (p. 12) [45].

$$W_1/W_{TOF} = 0.99 \quad \textbf{(5.68)}$$

5.2.1.2 Taxi

Roskam (1985) states that the transport aircraft loses weight approximately 1% of the start weight of the segment (p. 12) [45].

$$W_2/W_1 = 0.99 \quad \textbf{(5.69)}$$

5.2.1.3 Take-off

According to Roskam (1985), in contrast to first two segments, the transport aircraft loses weight approximately 0.5% of the start weight of the segment during take-off (p. 12) [45].

$$W_3/W_2 = 0.995 \quad \textbf{(5.70)}$$

5.2.1.4 Climb

According to Roskam (1985) a transport aircraft loses weight about 2% of the start weight of the segment during the climb (p. 12) [46].

$$W_4/W_3 = 0.98 \quad \textbf{(5.71)}$$

5.2.1.5 Cruise L/D

Cruise fineness ratio is determined as the same as the maximum take-off optimization process.

$$\rho = 0.002377\ x\ \left((1 - 7x10^{-6}\ )x\ h\right)^{4.21} \quad (slug/ft^3) \quad \textbf{(5.72)}$$

$$T = 518.4 - 0.003564\ x\ h\ \ (R) \quad \textbf{(5.73)}$$

$$a = \sqrt{\gamma RT} \quad \textbf{(5.74)}$$

$$V = M\ x\ a \quad \textbf{(5.75)}$$

$$C_{L_{cruise}} = \frac{(W_4/S)}{0.5\ x\ \rho\ x\ V_{cruise}^2} \quad \textbf{(5.76)}$$

$$W_4/S = (W_{TOF}/S)\ x\ (W_4/W_3)\ x\ (W_3/W_2)\ x\ (W_2/W_1)\ x\ (W_1/W_{TOF}) \quad \textbf{(5.77)}$$

$$e = 4.61\ x\ \left(1 - 0.045x(AR^{0.68})\right)\ x\ (cos(\Lambda)^{0.15} - 3.1) \quad \textbf{(5.78)}$$

$$K = \frac{1}{\pi\ x\ AR\ x\ e} \quad \textbf{(5.79)}$$

$$C_{fe} = 0.003 \quad \textbf{(5.80)}$$

$$C_{D0} = C_{fe}\ x\ \left(0.8\ x\ \left(1.977 + 0.52\ x\ (t/c)\right)\right) \quad \textbf{(5.81)}$$

$$C_{D_{cruise}} = C_{D0} + K\ x\ C_{L_{cruise}}{}^2 \quad \textbf{(5.82)}$$

$$\left(\frac{L}{D}\right)_{cruise} = \frac{C_L}{C_D} \quad \textbf{(5.83)}$$

5.2.2 Final weigth

Final weight is calculated using the empty, payload and crew weights that are same with first optimization process and using the weight fractions after the cruise segment: loiter, descent, fly to alternate, landing and taxi.

$$W_5 = \left(W_E + W_{pay} + W_{crew} + W_{tfo}\right)x\ \frac{W_9}{W_8}\ x\frac{W_8}{W_7}x\frac{W_7}{W_6}x\ \frac{W_6}{W_5} \qquad \textbf{(5.84)}$$

5.2.2.1 Loiter

Loiter weight fraction is calculated by endurance time, specific fuel consumption that are selected by design parameters and fineness ratio for loiter that is taken as 16 [47].

$$c_{j_{loiter}} = c_{j_{cruise}}\ x\ 0.85 \qquad \textbf{(5.85)}$$

$$\left(\frac{L}{D}\right)_{loiter} = 16 \qquad \textbf{(5.86)}$$

$$W_6/W_5 = \frac{1}{e^{Ex\ c_j/\left(\frac{L}{D}\right)}} \qquad \textbf{(5.87)}$$

5.2.2.2 Descend

Roskam (1985) states that the transport aircraft loses weight approximately 2% of the start weight of the descent process.

$$W_7/W_6 = 0.98 \qquad \textbf{(5.88)}$$

5.2.2.3 Fly to alternate

The weight fraction of the fly to alternate divison is determined by Breguet Range equation. According to Roskam (1985), fly to alternate segment will occur at about 10000 feet altitude and by maximum 250 knots speed (p. 57) [45]. To make the process systematically the velocity is taken 30% percent of the cruise velocity. Specific fuel consumption will be higher than the cruise so is taken 150% of the cruise fuel consumption. According Roskam (1985) while the specific fuel consumption of fly to alternate process is taken 0.9 lbs/lbs/hr, the specific fuel consumption of the cruise process is 0.5 lbs/lbs/hr so the ratio of these values is 1.8 and so in the thesis this ratio is taken 1.5 (p. 54) [45]. The weight of the aircraft to find the lift coefficient is the weight which in the start of the segment. The range that aircraft can fly is given in the design specification.

$$V_{fly\ to\ alternate} = V_{cruise}\ x\ 0.3 \quad \textbf{(5.89)}$$

$$c_{j_{flytoalternate}} = c_{j_{cruise}}\ x\ 1.5 \quad \textbf{(5.90)}$$

$$C_{L_{flytoalternate}} = \frac{(W_7/S)}{0.5\ x\ \rho\ x\ V_{fly\ to\ alternate}^2} \quad \textbf{(5.91)}$$

$$\frac{W_7}{S} = \frac{W_{TOF}}{S} x \frac{W_7}{W_6}\ x\ \frac{W_6}{W_5} x \frac{W_5}{W_4} x \frac{W_4}{W_3} x \frac{W_3}{W_2}\ x\ \frac{W_2}{W_1}\ x \frac{W_1}{W_{TOF}} \quad \textbf{(5.92)}$$

$$C_{D_{flytoalternate}} = C_{D0} + K\ x\ \left(C_{L_{flytoalternate}}\right)^2 \quad \textbf{(5.93)}$$

$$\left(\frac{L}{D}\right)_{fly\ to\ alternate} = \frac{C_L}{C_D} \quad \textbf{(5.94)}$$

$$W_8/W_7 = \frac{1}{e^{Rx\ c_j/\left(\frac{L}{D} x\ V_{flytoalternate}\right)}} \quad \textbf{(5.95)}$$

5.2.2.4 Landing and taxi

According to Roskam (1985) a transport aircraft loses weight about 0.8% of the start weight during the landing (p.12) [45].

$$W_9/W_8 = 0.992 \quad \textbf{(5.96)}$$

5.2.2.5 Trapped fuel

Trapped fuel is 0.5% of maximum take-off weight. [45]

$$W_{tfo} = 0.005\ x\ (W_{TOF}/S\ \ x\ S) \quad \textbf{(5.97)}$$

5.2.2.6 Empty weight

Empty weight process in the range optimization is the same as the maximum take-off optimization process.

5.2.2.7 Payload and crew weight

Payload and crew weight process in the range optimization is the same as the maximum take-off optimization process.

6. CODE AND INTERFACE

The optimization process for the maximum take-off weight and range problems are done with a code written by using the Genetic Algorithm with penalty functions.

6.1 Genetic Algorithm Code

The Genetic Algorithm code has three functions: Main Optimization Function, Binary to Real Values Function and Objective Function. Main Optimization Code uses Binary to Real Values and Objective Functions.

Main optimization Function uses number of variables, iteration numbers, minimum cost value, population size, mutation rate, selection ratio and number of bits for each variable as inputs. After inputs are taken, according to the selection ratio, a part of population is kept and lower and upper values of variables are specified. To start the process first population should be created so a population size x number of bits matrix is created randomly by 0 and 1 values. Secondly, population matrix is involved in binary to real values function to convert 0s and 1s to contionus values in the range between lower and upper values of the variables. Then real values are used in objective function to derive the cost. After that, cost values for each population is calculated and cost values are sorted, as minimum is the first for the maximum take-off weight and, as maximum is the first for the range optimization. Thirdly, population is divided to make mating and crossover process followed by mutating. After the new population is created again binary to real function is used and the cost value is calculated for second iteration. This process goes on until the maximum iteration reach or minimum or maximum cost value reach to an extreme value. Finally, there will be a cost value for each iteration and code selects the most appropriate value from the solutions. The code will be available in the appendix part.

6.1.1 Binary to real values function

Binary to real values function plays key role during the optimization. The GA works with the binary encodings, but the cost function often requires continuous variables.

Therefore, this function converts binary-coded populations to real values called decoding to derive the cost value. Quantization is a method that models the values that are at a specific range and categorizes the models into subranges that are not in the same range. Then each value is assigned to a subrange. The difference between the actual function value and the quantization level is known as the quantization error. Increasing the number of bits would reduce the quantization error. The mathematical formulas for the binary encoding and decoding of the n^{th} variable, p_n, are given as follows [40]:

For encoding,

$$p_{norm} = \frac{p_n - p_{lo}}{p_{hi} - p_{lo}} \tag{6.1}$$

$$gene[m] = round\left\{p_{norm} - 2^{-m} - \sum_{p=1}^{m-1} gene[p]2^{-p}\right\} \tag{6.2}$$

For decoding,

$$p_{quant} = \sum_{m=1}^{N_{gene}} gene[m]2^{-m} + 2^{-(M+1)} \tag{6.3}$$

$$q_n = p_{quant}\ x\ (p_{hi} - p_{lo}) + p_{lo} \tag{6.4}$$

6.1.2 Constraint implementation

All constraints are written as inequality equations and the equations are normalized by dividing the one side of the equation to other side and making that less than or equal to zero. By this way each constraint can be called inequality and they can be multiply with the same penalty parameters. For instance wing loading, W/S is should be lower than 160 lb/ft^2 so the inequality is $(W/S) \leq 160$ and that is written:

$$\frac{(W/S)}{160} - 1 \leq 0 \tag{6.5}$$

6.2 Interface

The interface comprises the six main parts: design parameters, engine, variables, constraints, solution and results. The optimization process begins with design parameters and goes on the order that given in the interface from left to right. When the user click on the design parameters part there will be seen two options: TOW means maximum Take-off weight Optimization and Range means maximum range that aircraft can cruise (Figure 6.1 - 6.21).

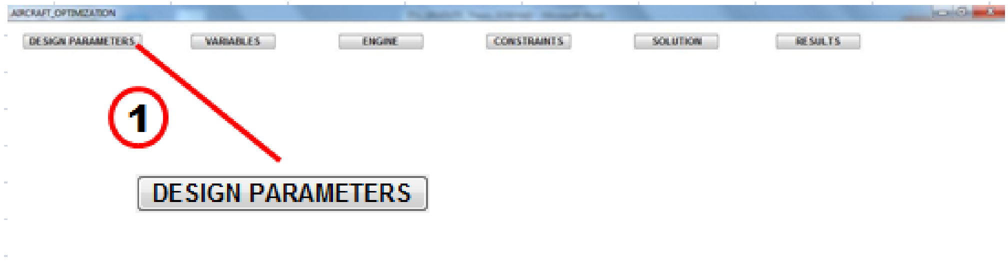


Figure 6.1: First Step of the Aircraft Optimization

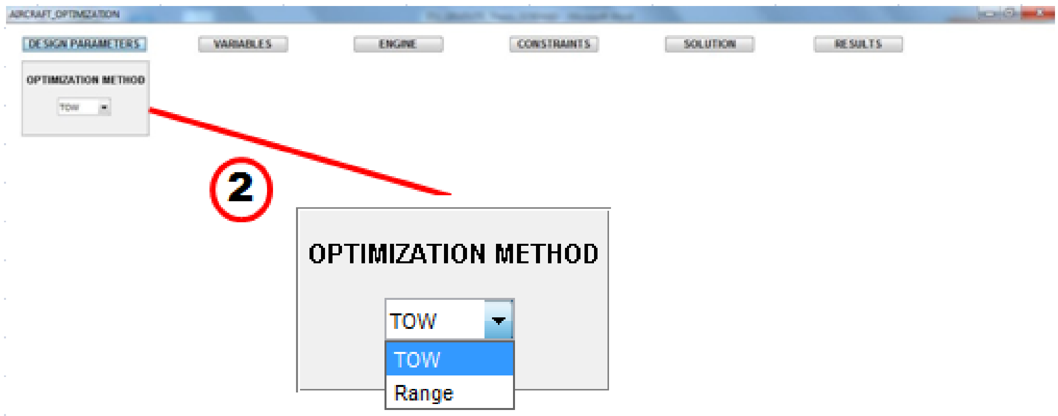


Figure 6.2: Second Step of the Aircraft Optimization

After selection of the method, the design parameters for the relevant optimization problem will be appear and the values will be wanted.

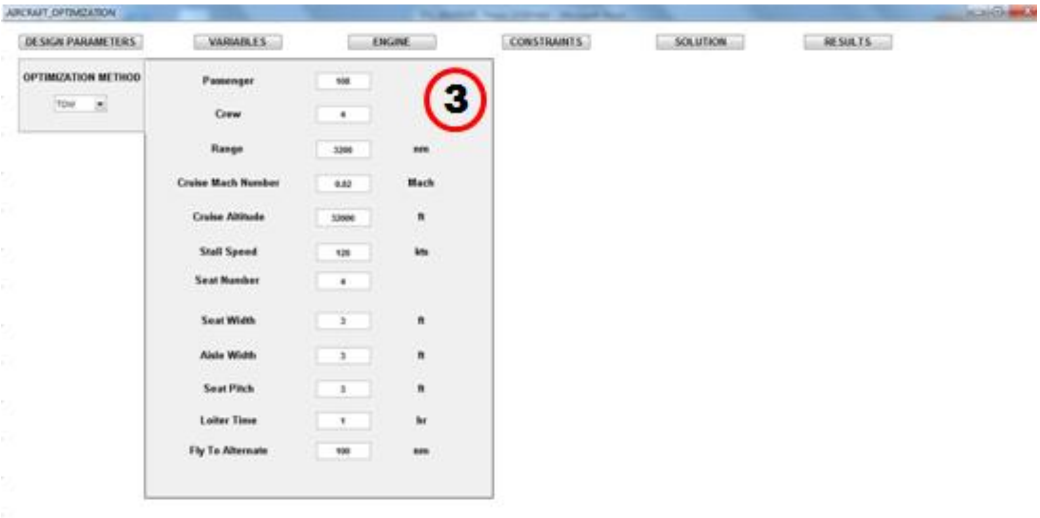


Figure 6.3: Third Step of the Aircraft Optimization

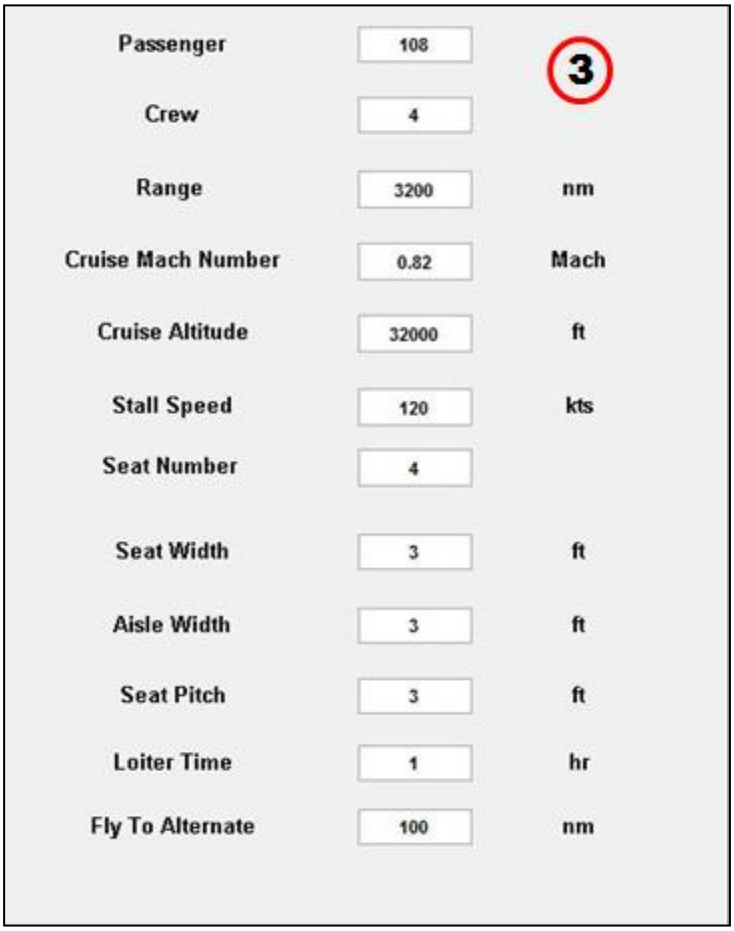


Figure 6.4: Inputs of Aircraft Optimization

The next step is selection of the values of variables. There are two parts to specify the range of each variable by selecting the values from the popup menu.

Figure 6.5: Fourth Step of the Aircraft Optimization

Figure 6.6: Fifth Step of the Aircraft Optimization

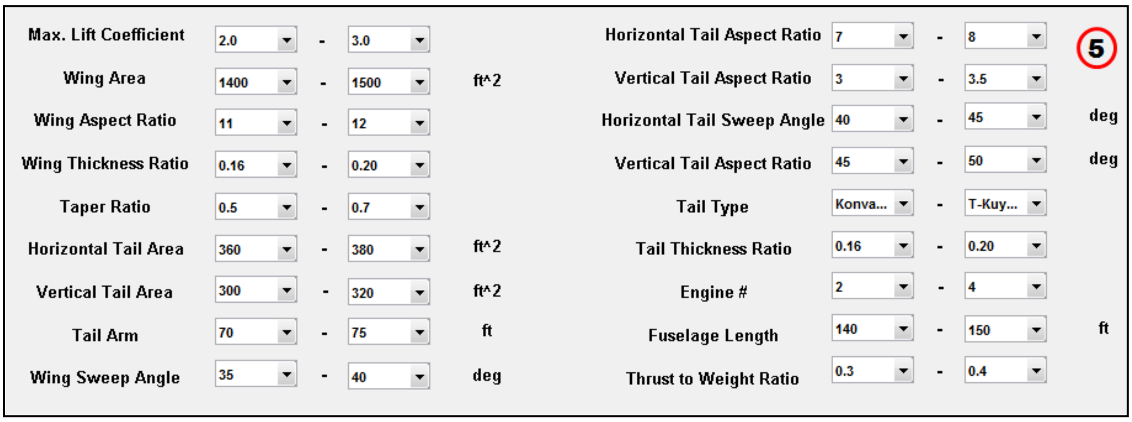


Figure 6.7: Variables of the Aircraft Optimization

The sixth step is engine tab and engine selection from the menu. There are five engine data in the menu that have already been used by different regional jets and selection of engine will show the the specification of the engine.

Figure 6.8: Sixth Step of the Aircraft Optimization

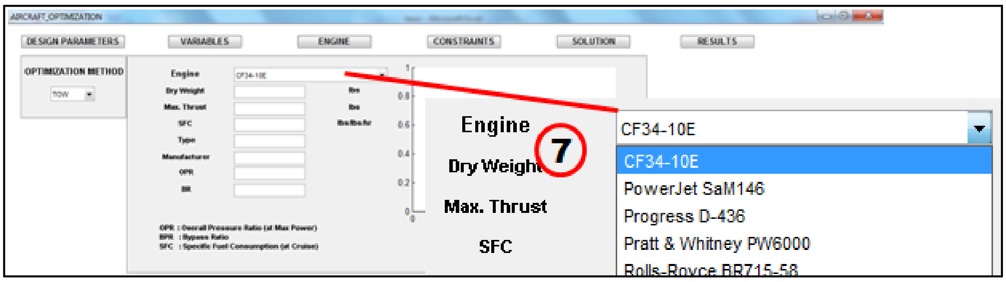


Figure 6.9: Seventh Step of the Aircraft Optimization

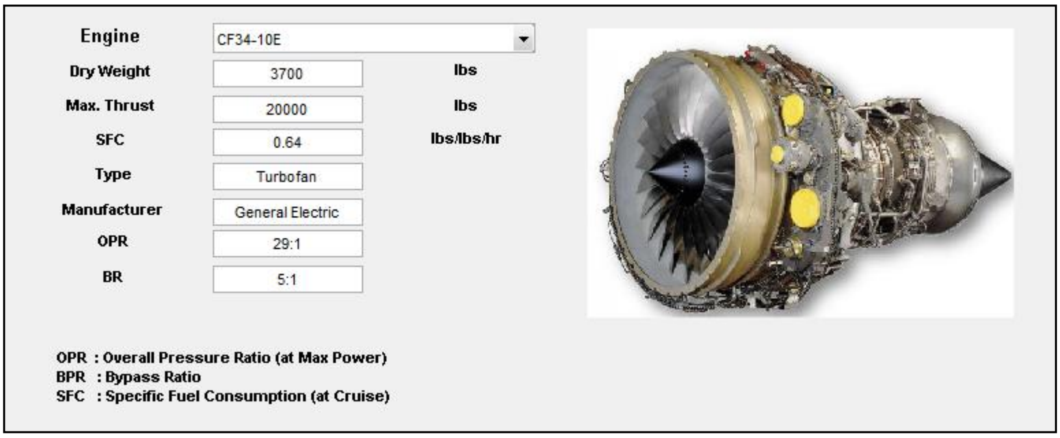


Figure 6.10: Engine Selection of the Aircraft Optimization

The next step is selection of the constraints. The user can select all or none of the contstraints by choosing the “open” or “closed”. Some constraints have limit values and these values can be selected from the popup menu.

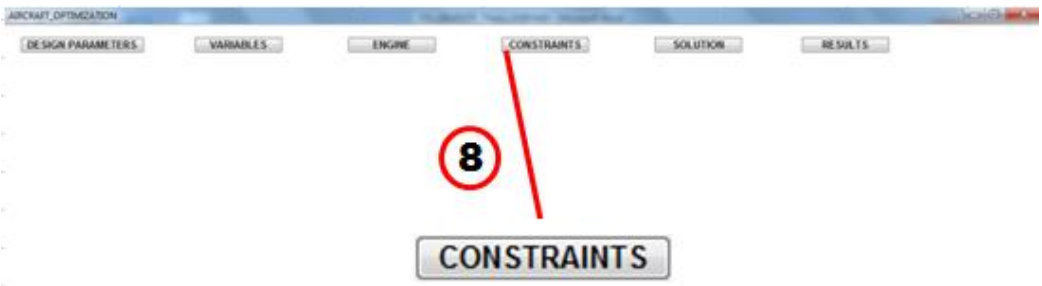


Figure 6.11: Eighth Step of the Aircraft Optimization

Figure 6.12: Ninth Step of the Aircraft Optimization

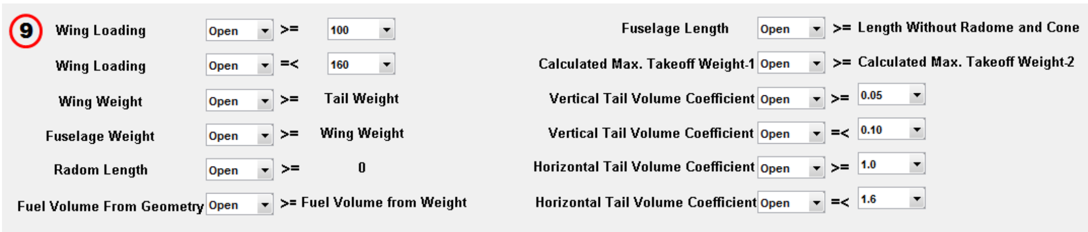


Figure 6.13: Constraints of the Aircraft Optimization

To derive the optimization process, the solution part will be the next step. Optimization conditions such as population size, mutation rate is specified then the optimization solution could be carried out. The first solution is the maximum take-off weight and range. The maximum take-off weight is given with the main components: payload, crew, fuel and empty weight. The graphic gives the cost and generation values for the best and population average solution for each iteration.

Figure 6.14: Tenth Step of the Aircraft Optimization

Figure 6.15: Optimization Conditions and Run of the Solution

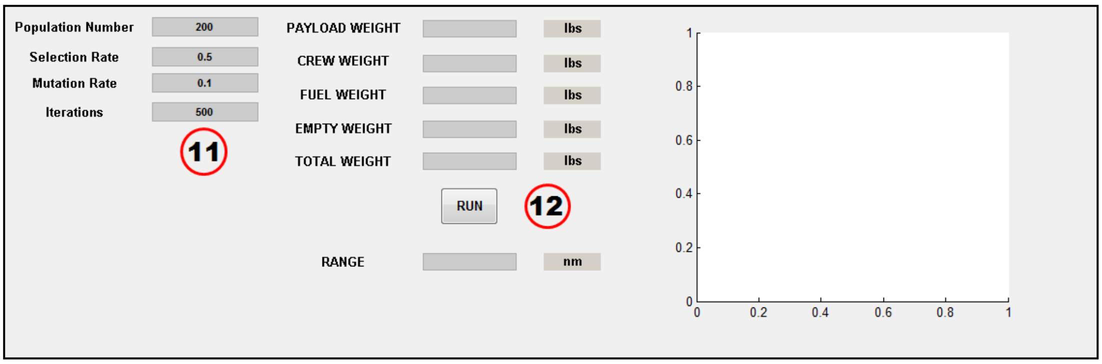


Figure 6.16: Run of the solution and first results for the design

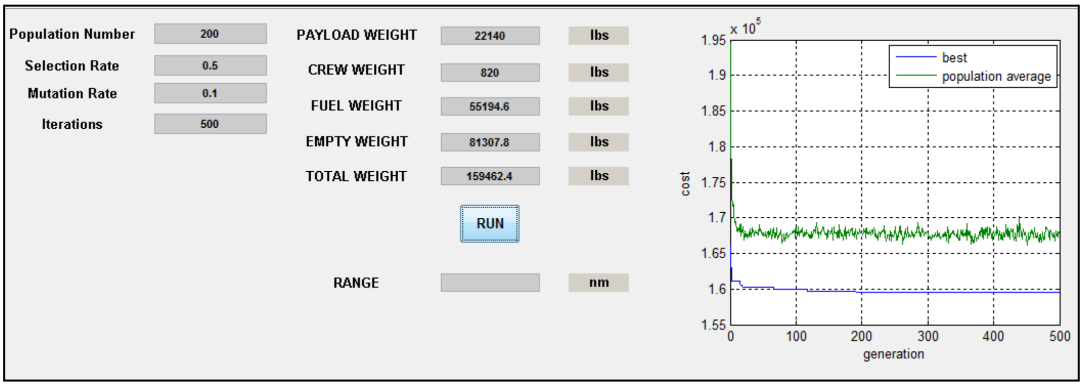


Figure 6.17: The graphical and numerical results of optimization

The final step is the results segment. In this part, the solution of the optimization problem is given by the variables of the all variables and fineness ratios with two graphics. In the graphics, there are two views of the Embraer E-195 and the optimized aircraft to compare the dimensions, length, wingspan, tail span etc.

Figure 6.18: Thirteenth Step of the Aircraft Optimization

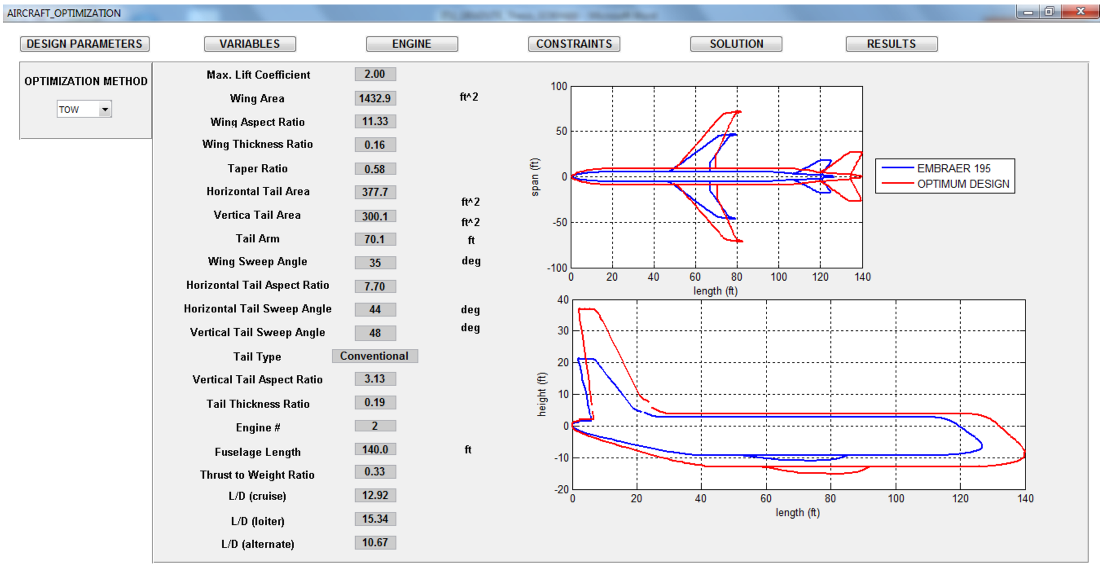
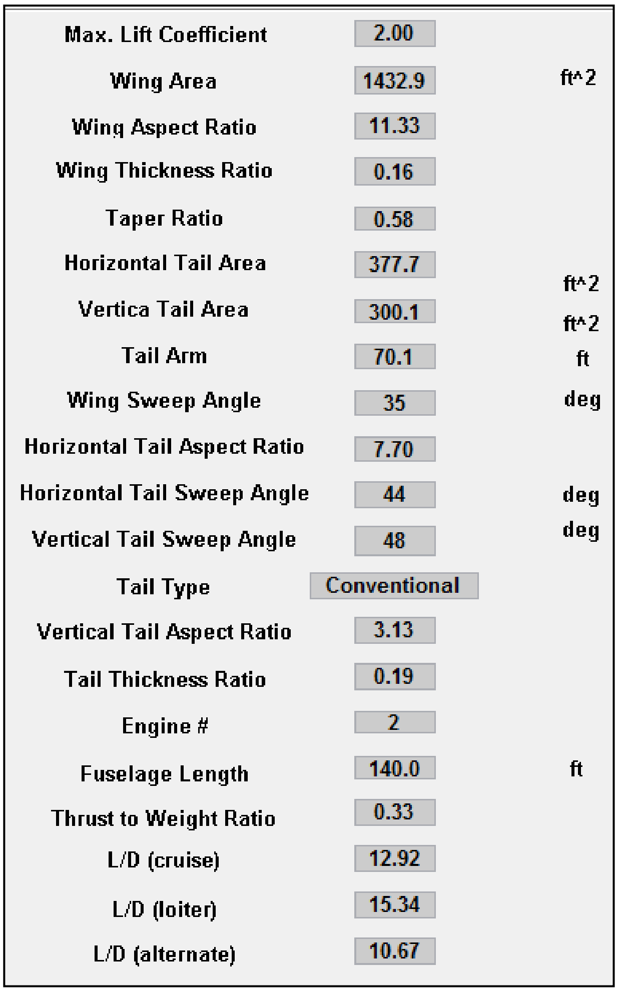


Figure 6.19: Detailed Optimization Results



Max. Lift Coefficient	2.00	
Wing Area	1432.9	ft^2
Wing Aspect Ratio	11.33	
Wing Thickness Ratio	0.16	
Taper Ratio	0.58	
Horizontal Tail Area	377.7	ft^2
Vertica Tail Area	300.1	ft^2
Tail Arm	70.1	ft
Wing Sweep Angle	35	deg
Horizontal Tail Aspect Ratio	7.70	
Horizontal Tail Sweep Angle	44	deg
Vertical Tail Sweep Angle	48	deg
Tail Type	Conventional	
Vertical Tail Aspect Ratio	3.13	
Tail Thickness Ratio	0.19	
Engine #	2	
Fuselage Length	140.0	ft
Thrust to Weight Ratio	0.33	
L/D (cruise)	12.92	
L/D (loiter)	15.34	
L/D (alternate)	10.67	

Figure 6.20: The view of the variables after optimization

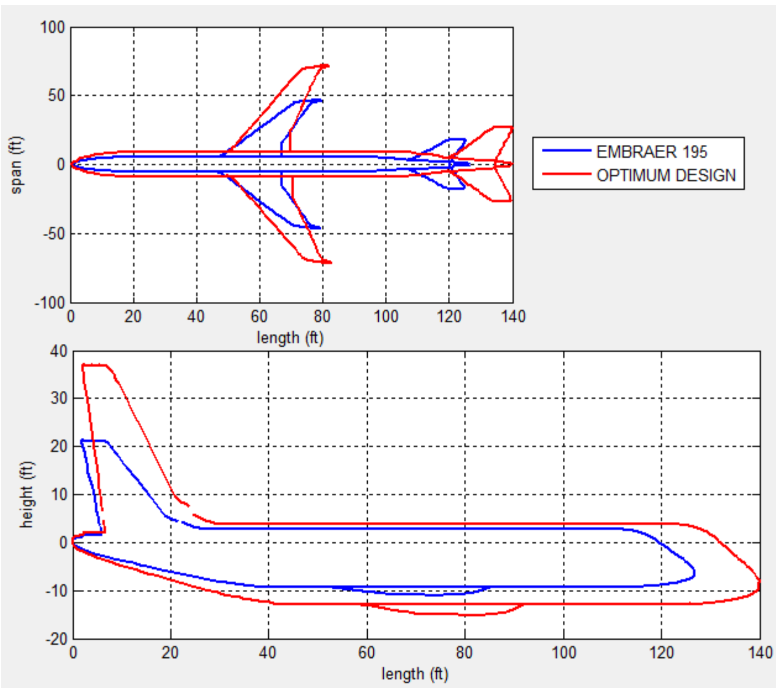


Figure 6.21: Comparison of the design and Embraer E-195

6.3 Code Validation

To satisfy the reliability of the code, necessary values for interface were entered by using Embraer E-195 specifications. The variables, constraints and the engine are the same with the optimization process given in the results segment. Some values of variables for E-195 are out of range that is specified for optimization problem so for these values the range was enlarged or carried. The validation was done for two optimization method and results showed the code is suited with real values by small differences (Figure 6.22 - 6.25). Maximum take-off weight for weight and range optimizations are very close to real values for wing and vertical tail dimensions while horizontal tail dimensions are slightly different from the real values (Table 6.1).

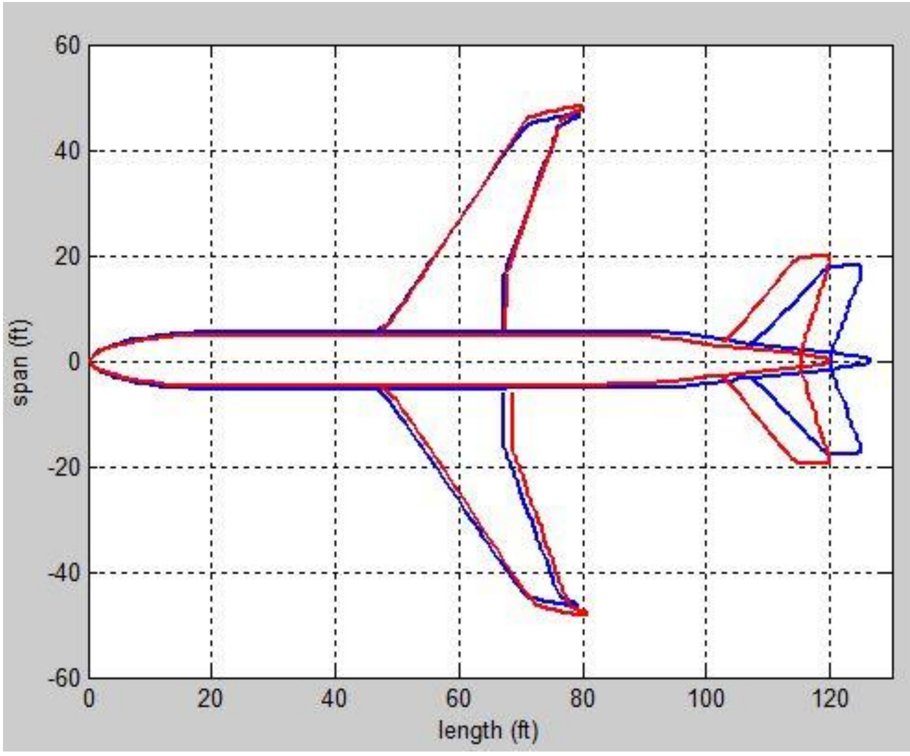


Figure 6.22: Code Validation MTOW Optimization: Optimized Aircraft (red) versus Embraer E -195 (blue) Top view

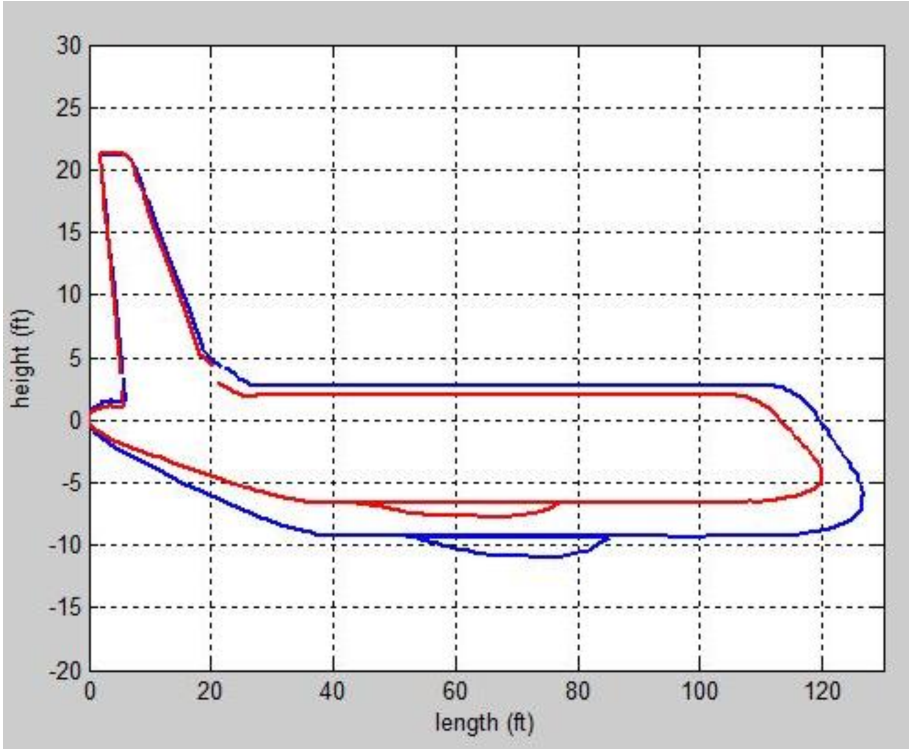


Figure 6.23: Code Validation MTOW Optimization: Optimized Aircraft (red) versus Embraer E - 195 (blue) Side view

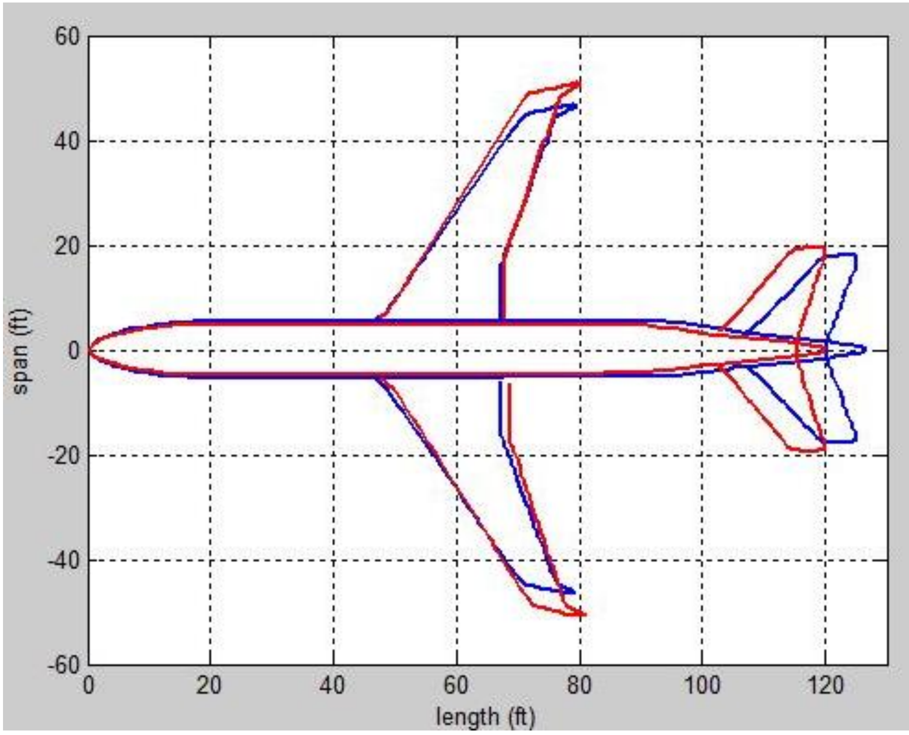


Figure 6.24: Code Validation Range Optimization: Optimized Aircraft (red) versus Embraer E-195 (blue) Top view

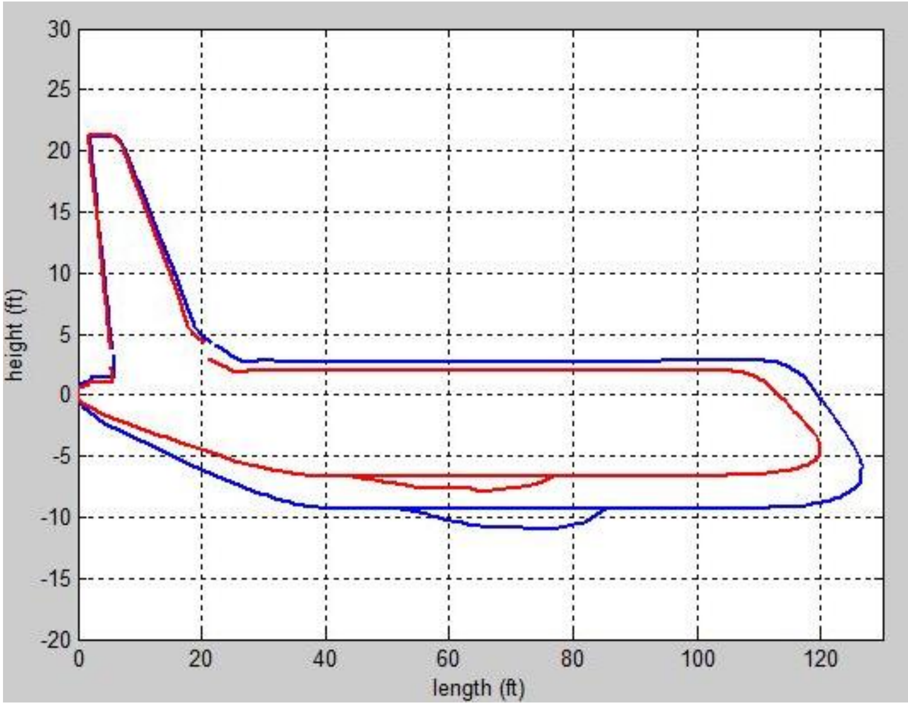


Figure 6.25: Code Validation Range Optimization: Optimized Aircraft (red) versus Embraer E-195 (blue) Side view

Table 6.1: Code Validation Results Comparison

	MTOW Opt.	Range Opt.	E-195	
C_{Lmax}	2.001	1.867	2.000	
S	1000.2	1100.0	1033.0	ft^2
	92.9	102.2	96.0	m^2
AR	9.00	9.00	8.60	
Λ	0.34	0.32	0.33	
S_{ht}	348.6	346.3	343	ft^2
	32.4	32.2	31.9	m^2
S_{vt}	148.4	146.2	150.7	ft^2
	13.8	13.6	14.0	m^2
L_t	55.1	55.0	53.4	ft
	16.8	16.8	16.3	m
Λ	25	25	25	degree
AR_{ht}	4.48	4.40	4.60	
AR_{vt}	2.11	2.13	2.20	
Λ_{ht}	31	30	30	degree
Λ_{vt}	32	30	30	degree
Engine number	2	2	2	
L_f	120.0	120.0	126.8	ft
	36.6	36.6	38.7	m
T/W	0.33	0.40	0.30	
Tail	Con	Con	Con	

Table 6.1 (cont.): Code Validation Results Comparison

Payload Weight	23780	23780	23780	lbs
	10796	10796	10796	kg
Crew Weight	820	820	820	lbs
	372	372	372	kg
Fuel Weight	39257.6	39329.0	27470	lbs
	17823.0	17855.4	12471.4	kg
Empty Weight	52770.6	51071.0	63106.0	lbs
	23957.9	23186.2	28650.1	kg
Max. TOW	116628.2	115000.0	115176.0	lbs
	52949.2	52210.0	52289.9	kg
Range	2200.0	2144.0	2200.0	nm
	4074.4	3970.7	4074.4	km

7. RESULTS

The solution of optimization problem and specified parameters of the aircraft is given. The optimization process is carried out using two separate ways with same values to control the solutions and obtain the same results. The design parameters, variables and constraints were selected according to the average values of each variable given in the regional aircraft data shown in Table 7.2. For optimizations, General Electric CF34-10 Engine is selected. The optimization process contains seven cases due to understand the effects of mutation rate, selection ratio, population size and iteration numbers (Table 7.1). There are five graphics: top and side view of designed aircraft, the top and side view comparison of Embraer E-195 with designed aircraft and cost versus generation graph.

Table 7.1: Optimization Run Cases

Case	Selection Rate	Mutation Rate	Population Size	Iteration Number
1	10%	10%	200	500
2	50%	10%	200	500
3	90%	10%	200	500
4	50%	90%	200	500
5	50%	50%	200	500
6	50%	10%	500	500
7	50%	10%	200	5000

Besides the specified average data some parameters are missing such as stall speed, lift coeffiecient, loiter time, fly to alternate range and thickness ratio for tail and wing. The stall speed is chosen 125 knots according to the average maximum take-off value [49]. Fly to alternate and loiter time values are selected as 100 nm and an hour [47].

Table 7.2: Regional Aircraft Data Average Values

Design Parameter		
Passenger Capacity	109.67	
Range	1961.58	nm
	3631.77	km
Mach	0.82	
Cruise Altitude	38007.98	ft
	11584.83	m
Seat number	5	
Seat width	1.50	ft
	0.46	m
Aisle width	1.51	ft
	0.46	m
Seat pitch	2.60	ft
	0.79	m
Variables		
MTOW	109482	lbs
	49705	kg
S	1020.4	ft^2
	94.8	m^2
AR	9.26	
λ	0.29	
S_{ht}	272.6	ft^2
	25.3	m^2
S_{vt}	213.1	ft^2
	19.8	m^2
L_t	55.5	ft
	16.9	m
Λ	25.10	degree
AR_{ht}	4.92	
AR_{vt}	1.46	
Λ_{ht}	31.75	degree
Λ_{vt}	38.75	degree
Engine number	2	
L_f	112.6	ft
	34.3	ft
T/W	0.33	
Constraint		
W/S	107.26	lb/ft^2
	524.16	kg/ m^2

The value of lift coefficient is determined by using stall speed, the maximum take-off and wing area of the regional aircraft data at sea level (Table 7.3).

Table 7.3: Average Lift Coefficient

Aircraft	S (m^2)	MTOW (kg)	C_{Lmax}
A318-100	122.4	68000	2.19
AN-158	87.3	43700	1.97
BAE RJ 100	77.3	44225	2.25
B717	93.0	49895	2.11
B737-600	125.0	65090	2.05
BOM CRJ1000	77.4	40823	2.08
BOM CS100	112.3	52615	1.85
COMAC ARJ21-900	79.9	47180	2.33
EMBRAER E-195	96.0	52290	2.15
FOKKER 100	93.5	45810	1.93
MITSUBISHI-MRJ90	89.8	40955	1.80
SUKHOI SJ100	83.8	45880	2.16
Average (ρ=1.225 kg/ m^3 and V_{stall}=64 m/s)			2.07

7.1 Maximum Take-off Weight Optimization

All values given in the table are selected or entered in the interface according to the average values listed above and run the algorithm by several time to obtain the results for different cases (Table 7.4).

Table 7.4: Maximum Take-off Weight Optimization Values

Design Parameter		
Passenger Capacity	110	
Range	2000	nm
	3704	km
Mach	0.82	
Cruise Altitude	38000	ft
	11582	m
Seat number	4	
Seat width	1.50	ft
	0.46	m
Aisle width	1.51	ft
	0.46	m
Seat pitch	2.60	ft
	0.79	m
Loiter time	1	h
Fly to Alternate	100	nm
	185	km

Table 7.4 (cont.): Maximum Take-off weight Optimization Values

Variables			
	Min	Max	
C_{Lmax}	2.00	2.40	
S	1000.0	1100.0	ft^2
	92.9	102.2	m^2
AR	9.00	10.00	
t/c	0.10	0.14	
λ	0.30	0.40	
S_{ht}	260.0	280.0	ft^2
	24.2	26.0	m^2
S_{vt}	200.0	220.0	ft^2
	18.6	19.5	m^2
L_t	50.0	60.0	ft
	15.2	18.3	m
Λ	25.00	30.00	degree
AR_{ht}	4.00	5.00	
AR_{vt}	1.00	2.00	
Λ_{ht}	30.00	35.00	degree
Λ_{vt}	35.00	40.00	degree
Tail Type	Conventional	T	
t/c (tail)	0.16	0.20	
Engine number	2	4	
L_f	110.00	120.00	ft
	33.53	36.58	m
T/W	0.30	0.40	

Constraints				
W/S	$\geq$	90	lb/ft^2	Open
		440	kg/m^2	
	$\leq$	130	lb/ft^2	Open
		635	kg/m^2	
W_w	$\geq$	W_t		Open
W_f	$\geq$	W_w		Open
L_{fn}	$\geq$	0		Open
$V_{fue\text{-}geo}$	$\geq$	$V_{fue\text{-}weight}$		Open
L_f	$\geq$	L		Open
TOW_1	$\geq$	TOW_2		Open
V_v	$\geq$	0.05		Open
	$\leq$	0.10		
V_h	$\geq$	0.80		Open
	$\leq$	1.30		

For seven cases, the results of maximum take-off weight based optimization is shown in Table 7.5 and Table 7.6. The aircraft weight is specified approximately 47-48 tons and the empty weight of the aircraft is about half of the total weight. As expected, the process tried to select the lowest values for wing area and lift coefficient due to lower the weight. The results shows conventional tail and two engines is the most suitable values for lowest aircraft. L/D ratios for three mission profiles gave realistic results according to the selected engine and flow conditions. The interesting result for optimization is fuel weight. With comparison of fuel weights of aircraft that data were given shows the fuel weight is more than expected. This situation could be results of the assumptions that were done for the fuel consumptions and velocities for loiter and fly to alternate segments that could cause to burn more fuel.

Constraint control is the key process for optimization problem shows how much the solution satisfy the limits. MTOW Optimization satisfied ten constraints over twelve. The vertical tail volume coefficient is very close to bound but there is a remarkable difference between fuel volume calculations from geometry and weight. This result can be changed by using different fuel. Therefore, the fuel volume constraint can not be a good constraint but provides to control the solution.

The cost–generation graphs shows that increasing the mutation rate causes to increase the difference between the best result with population average. In contrast to cases that mutation rates are high, the lowest difference between best cost and population range is for cases that selection rate is 0.5 and for lowest mutation rates. Increasing the mutation rate also has negative effect on optimization process by increasing the weight (Figure 7.1).

Top and side views of the designed aircraft for different cases are not show big difference but the wing position and tail size difference can be seen (Figure 7.2-7.3).

Comparison with Embraer E-195 notices that the designed aircraft has short fuselage length, approximately same aisle width but less height. However, the optimized aircraft has bigger wings but smaller vertical tail while about the same sized horizontal tail (Figure 7.4-7.5).

Table 7.5: Maximum Take-off Weight Optimization Results

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	
C_{Lmax}	2.000	2.002	2.008	2.000	2.000	2.001	2.000	
S	1000.9	1000.2	1003.0	1010.3	1004.6	1000.1	1000.2	ft^2
	93.0	92.9	93.2	93.9	93.3	92.9	92.9	m^2
AR	9.02	9.10	9.01	9.18	9.21	9.01	9.01	
t/c	0.14	0.14	0.14	0.13	0.14	0.14	0.14	
λ	0.31	0.30	0.31	0.38	0.40	0.33	0.31	
S_{ht}	279.2	264.9	276.7	261.1	265.1	269.5	278.3	ft^2
	25.9	24.6	25.7	24.3	24.6	25.0	25.9	m^2
S_{vt}	202.2	200.4	206.8	212.7	210.6	208.7	201.6	ft^2
	18.8	18.6	19.2	19.8	19.6	19.4	18.7	m^2
L_t	51.6	50.1	53.4	53.8	50.2	53.0	50.3	ft
	15.7	15.3	16.3	16.4	15.3	16.2	15.3	m
Λ	25	25	25	25	25	26	25	deg
AR_{ht}	4.78	4.83	4.30	4.67	4.36	4.97	4.66	
AR_{vt}	1.62	1.18	1.22	1.29	1.25	1.17	1.04	
Λ_{ht}	32	32	31	32	35	34	34	deg
Λ_{vt}	36	35	39	36	37	36	38	deg
Tail Type	Con	Con	Con	Con	Con	Con	Con	
t/c (tail)	0.18	0.20	0.19	0.16	0.20	0.18	0.19	
Engine number	2	2	2	2	2	2	2	
L_f	110.1	110.1	110.4	110.7	110.9	110.2	110.0	ft
	33.6	33.6	33.7	33.7	33.8	33.6	33.5	m
T/W	0.36	0.36	0.30	0.34	0.34	0.34	0.31	
Payload Weight	22550	22550	22550	22550	22550	22550	22550	lbs
	10238	10238	10238	10238	10238	10238	10238	kg
Crew Weight	820	820	820	820	820	820	820	lbs
	372	372	372	372	372	372	372	kg
Fuel Weight	33421	33444	33707	33805	33609	33458	33379	lbs
	15173	15184	15303	15348	15259	15190	15154	kg
Empty Weight	48548	48551	48959	49493	49047	48632	48346	lbs
	22041	22042	22227	22470	22267	22079	21949	kg
Max. TOW	**105339.4**	**105365.0**	**106036.2**	**106667.9**	**106025.8**	**105459.6**	**105095.0**	lbs
	47824.1	**47835.7**	**48140.4**	**48427.2**	**48135.7**	**47878.7**	**47713.1**	kg
L/D (cruise)	13.24	13.23	13.20	13.20	13.20	13.21	13.25	
L/D (loiter)	15.45	15.44	15.40	15.41	15.41	15.42	15.46	
L/D (fly alternate)	11.41	11.40	11.36	11.37	11.37	11.38	11.42	

Table 7.6: Maximum Take-off Weight Optimization Constraint Control

Constraint				Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
W/S	≥	90	lb/ft^2	105.24	105.34	105.72	105.58	105.54	105.45	105.07
	≤	130	lb/ft^2	105.24	105.34	105.72	105.58	105.54	105.45	105.07
W_w	≥	W_t		7768.5 ≥ 664.9	7812.3 ≥ 646.4	7832.0 ≥ 636.5	8105.5 ≥ 620.3	7958.6 ≥ 653.9	7788.3 ≥ 660.6	7761.2 ≥ 682.9
W_f	≥	W_w		10427 ≥ 7769	10429≥ 7812	10475 ≥ 7832	10509 ≥ 8106	10492≥ 7959	10434 ≥ 7788	10419 ≥ 7761
L_{fn}	≥	0		10.42	10.45	10.73	11.00	11.28	10.57	10.34
$V_{fue\text{-}geo}$	≥	$V_{fue\text{-}weight}$		650.81 ≥ 663.12	643.68 ≥ 663.58	649.98 ≥ 668.79	615.34≥ 670.74	625.76≥ 666.85	647.10 ≥ 663.84	648.94 ≥ 662.28
L_f	≥	L		110.1 ≥71.5	110.1 ≥71.5	110.4 ≥71.5	110.7 ≥71.5	110.9 ≥71.5	110.2 ≥71.5	110.0 ≥71.5
TOW_1	≥	TOW_2		106947 ≥105339	106979 ≥105365	107600 ≥106036	107951 ≥106668	107342 ≥106026	106915 ≥105460	106872 ≥10595
V_v	≥	0.05		0.11	0.11	0.12	0.12	0.11	0.12	0.11
	≤	0.10		0.11	0.11	0.12	0.12	0.11	0.12	0.11
V_h	≥	0.80		1.25	1.15	1.28	1.24	1.19	1.25	1.21
	≤	1.30		1.25	1.15	1.28	1.24	1.19	1.25	1.21

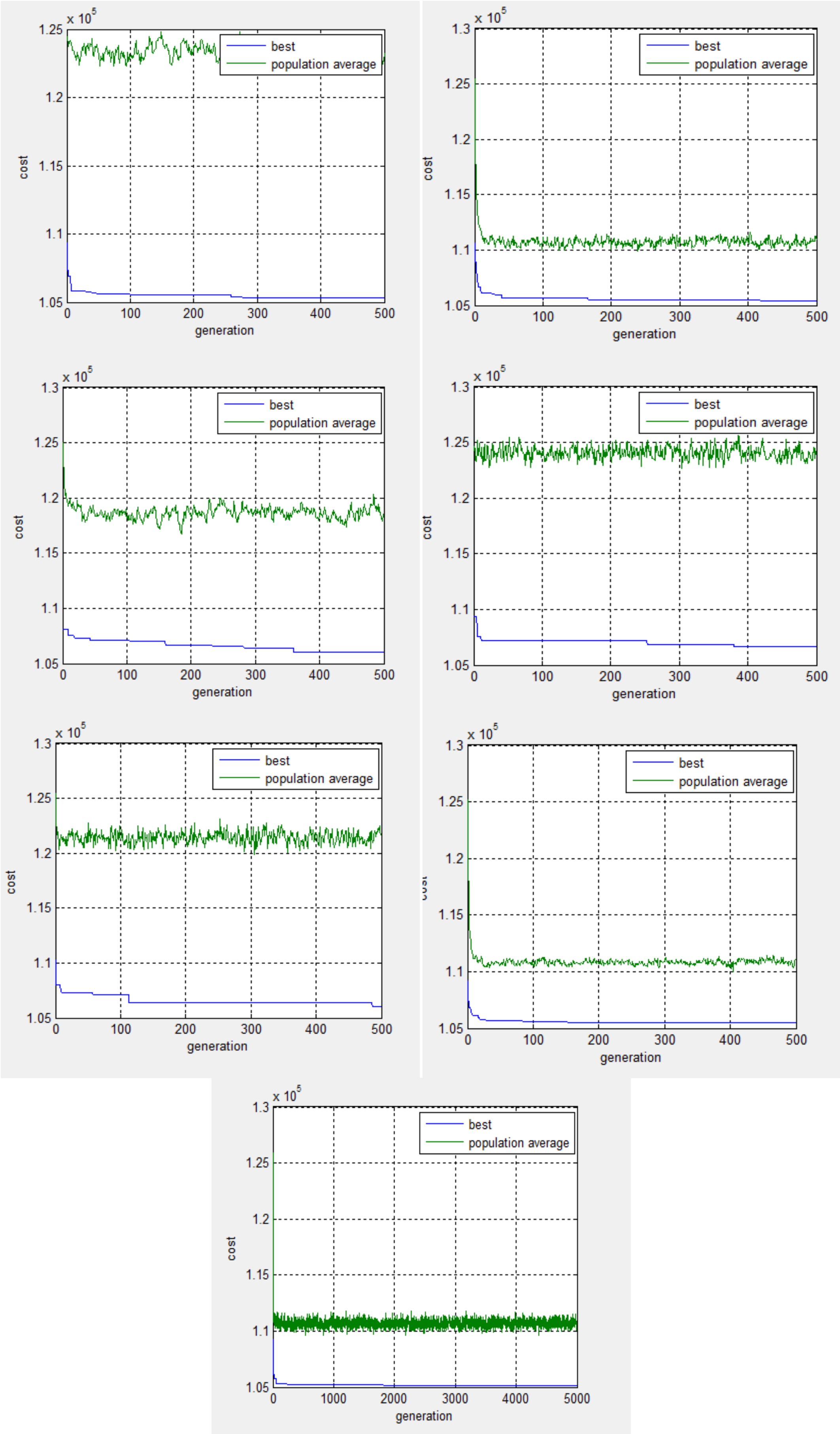


Figure 7.1: Cost-Generation Graphics Case 1 to Case 7

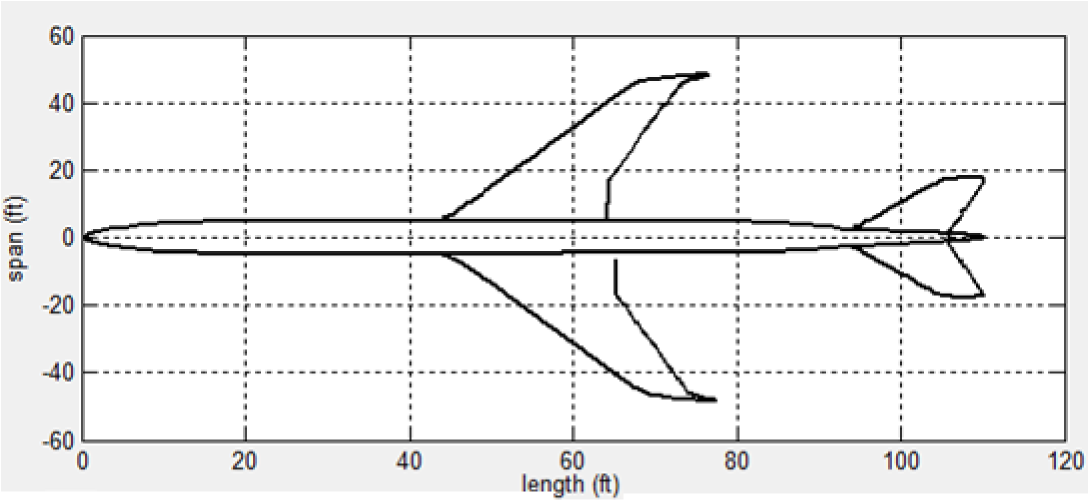


Figure 7.2: Optimized Aircraft Top View for Max. Take-off Weight Optimization (Case 2)

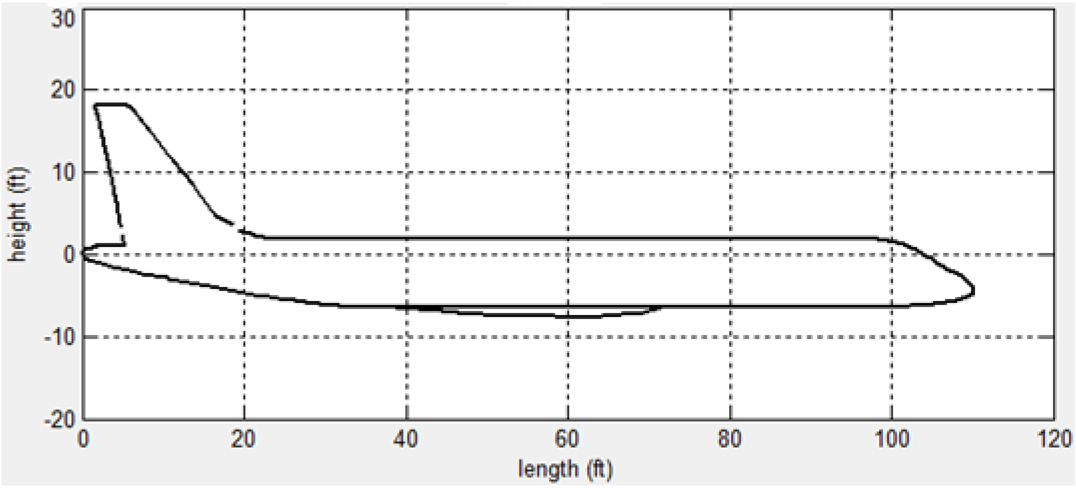


Figure 7.3: Optimized Aircraft Side View for Max. Take-off Weight Optimization (Case 2)

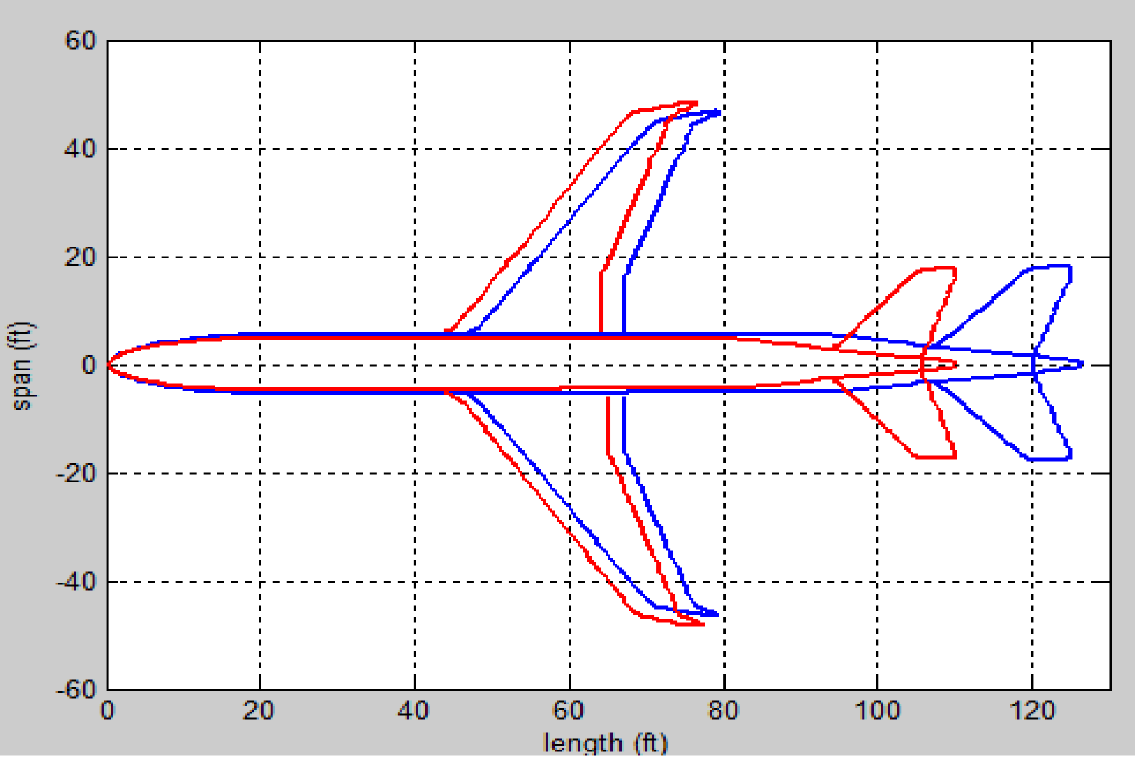


Figure 7.4: Optimized Aircraft (red) versus Embraer E-195 (blue) Top view (Case 2)

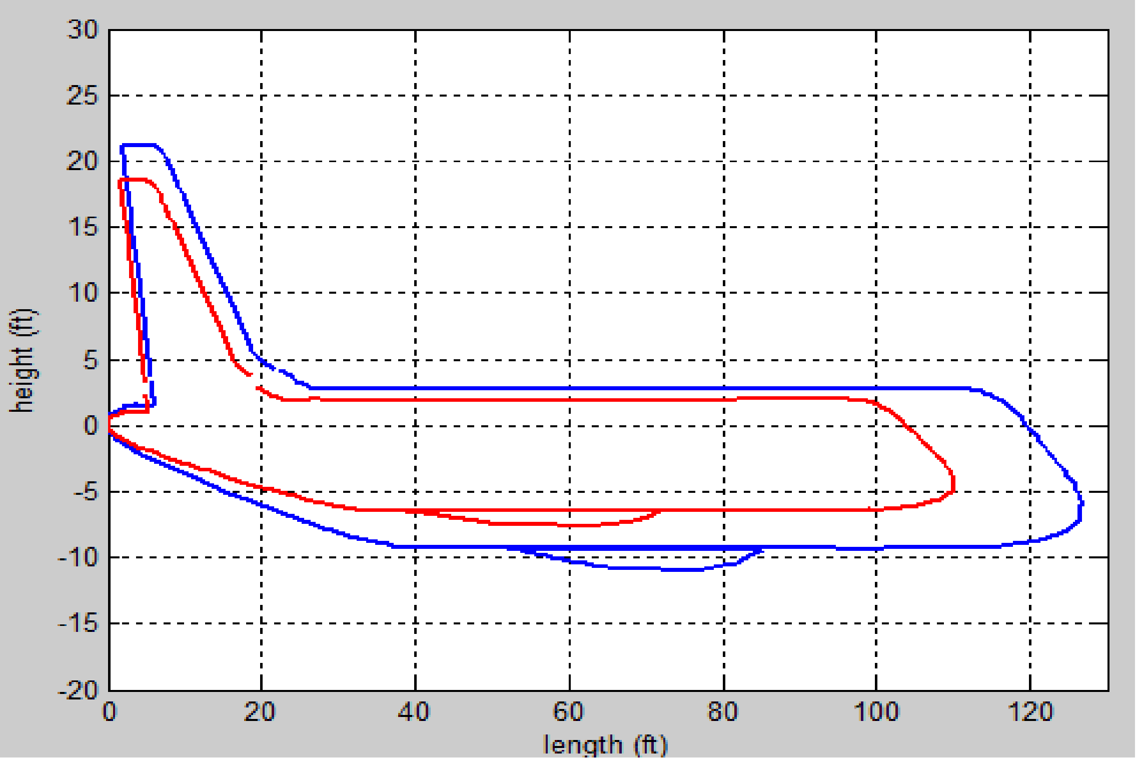


Figure 7.5: Optimized Aircraft (red) versus Embraer E-195 (blue) Side view (Case 2)

7.2 Range Optimization

All values given in the table are selected or entered in the interface according to the average values listed above and run the algorithm by several time to obtain the results for different cases (Table 7.7).

Table 7.7: Range Optimization Values

Design Parameter			
Passenger Capacity	110		
Mach	0.82		
Cruise Altitude	38000		ft
	11582		m
Seat number	4		
Seat width	1.50		ft
	0.457		m
Aisle width	1.51		ft
	0.460		m
Seat pitch	2.60		ft
	0.792		m
Loiter time	1		h
Fly to Alternate	100		nm
	185.2		km
Variables			
	Min	**Max**	
MTOW	105000	110000	lbs
	47670	49940	kg
S	1000.0	1100.0	ft^2
	92.9	102.2	m^2
AR	9.00	10.00	
t/c	0.10	0.14	
λ	0.30	0.40	
S_{ht}	260.0	280.0	ft^2
	24.2	26.0	m^2
S_{vt}	200.0	220.0	ft^2
	18.6	19.5	m^2
L_t	50.0	60.0	ft
	15.2	18.3	m
Λ	25.00	30.00	degree
AR_{ht}	4.00	5.00	
AR_{vt}	1.00	2.00	
Λ_{ht}	30.00	35.00	degree
Λ_{vt}	35.00	40.00	degree
Tail Type	Conventional	T	

Table 7.7.(cont): Range Optimization Values

Variables				
t/c (tail)	0.16	0.20		
Engine number	2	4		
L_f	110.0	120.0	ft	
	33.5	36.6	m	
T/W	0.30	0.40		
Constraints				
W/S	$\geq$	90	lb/ft^2	Open
		440	kg/m^2	
	$\leq$	130	lb/ft^2	Open
		635	kg/m^2	
W_w	$\geq$	W_t		Open
W_f	$\geq$	W_w		Open
L_{fn}	$\geq$	0		Open
L_f	$\geq$	L		Open
V_v	$\geq$	0.05		Open
	$\leq$	0.10		
V_h	$\geq$	0.80		Open
	$\leq$	1.30		

For seven cases, the results of range based optimization is shown in Table 7.8 and Table 7.9. The aircraft weight is specified approximately 49-50 tons and the empty weight of the aircraft is again about half of the total weight. As expected, the process tried to select the highest values for maximum take-off weight due to increase the distance that aircraft will cruise. The results shows conventional tail and two engine is the most suitable values for range. The optimized range value is different from the maximum take-off weight optimization which has 2000 nm range. The range is optimized about 2500 nm, 500 nm more than first optimization. This value is vital for an aircraft. The maximum weight difference between two optimization process is around 2500 kg and this difference comes from the fuel weight as can be seen in the results. This fuel weight can cause the range deviation. Again with comparison of fuel weights of aircraft that data were given shows the fuel weight is more than expected. This can be from the assumptions that were for the fuel consumptions and velocities for loiter and fly to alternate segments by causing the more fuel burn. Although the other aircraft specifications are similar to the first optimization results, wing area for range optimization is slightly different because optimization derives heavier aircraft.

Constraint control is the key process for optimization problem shows how much the solution satisfy the limits. Range Optimization satisfied all constraints. The vertical tail volume coefficient slightly passed the limit for case 5.

The cost–generation graphs shows that increasing the mutation rate causes to increase the difference between the best result with population average. In contrast to cases that mutation rates are high, the lowest difference between best cost and population range is for cases that selection rate is 0.5 and for lowest mutation rates. Increasing the mutation rate also has negative effect on optimization process by increasing the weight (Figure 7.6).

Top and side views of the designed aircraft for different cases are not show big difference but the wing position and tail size difference can be seen (Figure 7.7–7.8).

Comparison with Embraer E-195 notices that the designed aircraft has short fuselage length, approximately same aisle width but less height. However, the optimized aircraft has bigger wings with smaller vertical tail while about the same sized horizontal tail (Figure 7.9–7.10).

Table 7.8: Range Optimization Results

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	
Max. TOW	109961.0	110000.0	109961.0	110000.0	110000.0	110000.0	110000.0	lbs
	49922.3	49940.0	49922.3	49940.0	49940.0	49940.0	49940.0	kg
S	1069.8	1067.1	1074.5	1040.8	1061.6	1072.9	1064.7	ft^2
	99.4	99.1	99.8	96.7	98.6	99.7	98.9	m^2
AR	9.04	9.07	9.06	9.02	9.05	9.00	9.01	
t/c	0.14	0.14	0.14	0.14	0.14	0.14	0.14	
λ	0.36	0.37	0.35	0.39	0.38	0.32	0.31	
S_{ht}	279.9	277.5	263.5	270.3	271.5	279.8	280	ft^2
	26.0	25.8	24.5	25.1	25.2	26.0	26.0	m^2
S_{vt}	206.4	201.3	207.1	206.7	208.6	208	203.1	ft^2
	19.2	18.7	19.2	19.2	19.4	19.3	18.9	m^2
L_t	51.1	50.3	50.8	52.3	50.5	51.3	51.1	ft
	15.6	15.3	15.5	15.9	15.4	15.6	15.6	m
Λ	25	25	25	25	26	25	25	deg
AR_{ht}	4.80	4.25	4.65	4.24	4.54	4.91	4.72	
AR_{vt}	1.26	1.00	1.47	1.67	1.31	1.00	1.08	
Λ_{ht}	34	34	31	34	35	34	35	deg
Λ_{vt}	36	37	35	38	38	39	37	deg
Tail Type	Con	Con	Con	Con	T	Con	Con	
t/c (tail)	0.20	0.20	0.17	0.18	0.16	0.20	0.18	
Engine number	2	2	2	2	2	2	2	
L_f	110.0	110.0	110.2	110.8	110.3	110.1	110.0	ft
	33.5	33.5	33.6	33.8	33.6	33.6	33.5	m
T/W	0.33	0.36	0.37	0.36	0.38	0.37	0.32	
Payload Weight	22550	22550	22550	22550	22550	22550	22550	lbs
	10238	10238	10238	10238	10238	10238	10238	kg
Crew Weight	820	820	820	820	820	820	820	lbs
	372	372	372	372	372	372	372	kg
Fuel Weight	38652	38698	38270	38213	38263	38660	38815	lbs
	17548	17569	17375	17349	17371	17552	17622	kg
Empty Weight	47939	47932	48321	48417	48367	47970	47815	lbs
	21764	21761	21938	21981	21959	21778	21708	kg
Range	**2542.9**	**2543.3**	**2492.7**	**2444.2**	**2465.6**	**2547.0**	**2558.6**	nm
	4709.5	**4710.2**	**4616.5**	**4526.7**	**4566.3**	**4717.0**	**4738.5**	km
L/D (cruise)	13.45	13.43	13.47	13.25	13.33	13.48	13.43	
L/D (loiter)	16.00	16.00	16.00	16.00	16.00	16.00	16.00	
L/D (fly alternate)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	

Table 7.9: Range Optimization Constraint Control

Constraint				Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
W/S	≥	90	lb/ft^2	102.79	103.09	102.34	105.69	103.62	102.52	103.31
	≤	130	lb/ft^2	102.79	103.09	102.34	105.69	103.62	102.52	103.31
W_w	≥	W_t		8321.6≥ 694.5	8333.2≥ 681.4	8364.5≥ 641.9	8189.4≥ 657.5	8407 ≥ 679.6	8347.7≥ 698.8	8235.8≥ 700.9
W_f	≥	W_w		10575 ≥ 8322	10577≥ 8333	10587≥ 8365	10614≥ 8189	10596≥ 8407	10578 ≥ 8348	10573 ≥ 8326
L_{fn}	≥	0		10.34	10.34	10.57	11.12	10.65	10.42	10.34
L_f	≥	L		110.0 ≥71.5	110.0 ≥71.5	110.2 ≥71.5	110.8 ≥71.5	110.3 ≥71.5	110.1 ≥71.5	110.0 ≥71.5
V_v	≥	0.05		0.10	0.10	0.10	0.11	0.10	0.10	0.10
	≤	0.10		0.10	0.10	0.10	0.11	0.10	0.10	0.10
V_h	≥	0.80		1.14	1.13	1.06	1.19	1.12	1.12	1.13
	≤	1.30		1.14	1.13	1.06	1.19	1.12	1.12	1.13

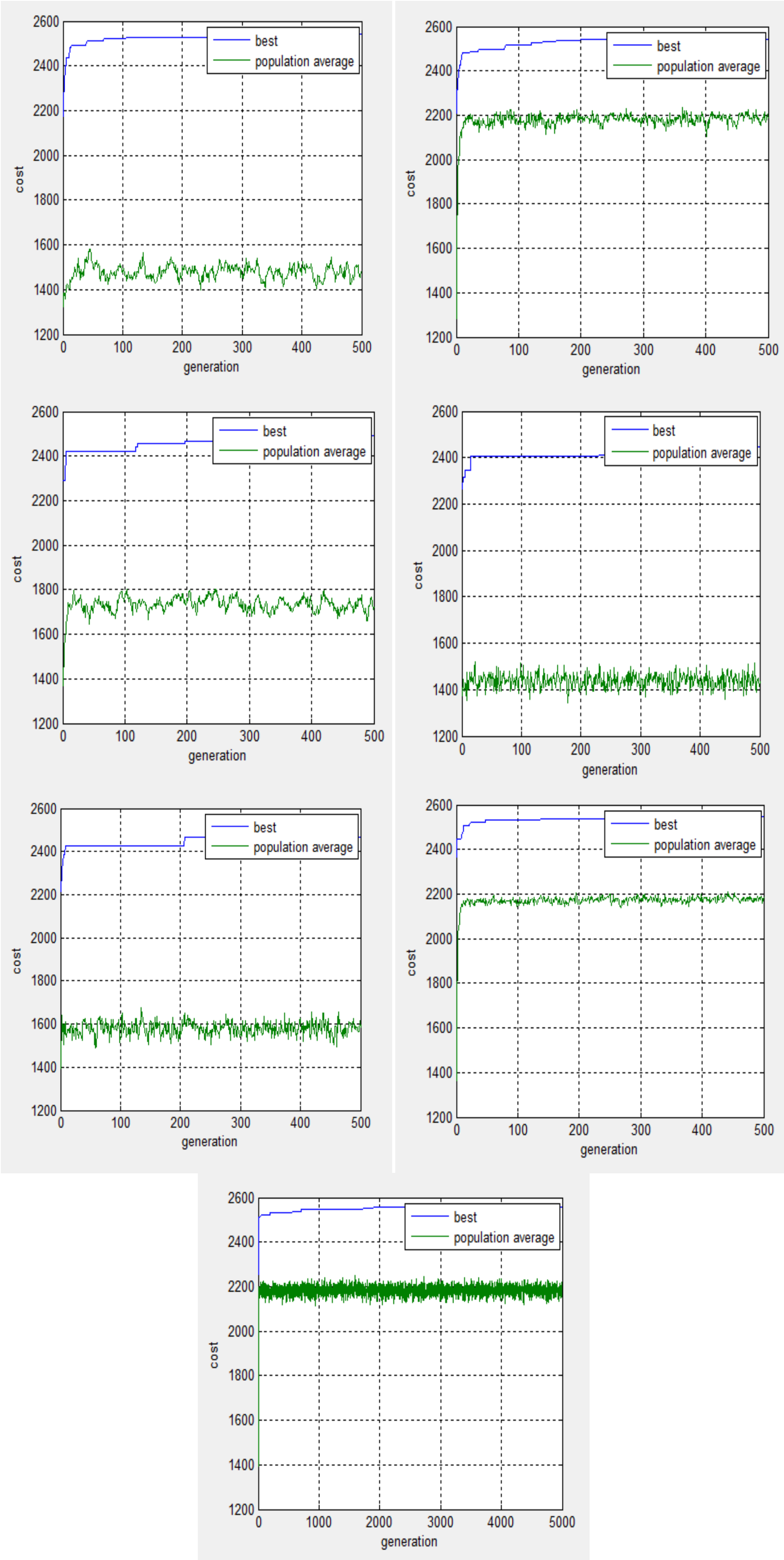


Figure 7.6: Cost-Generation Graphics Case 1 to Case 7

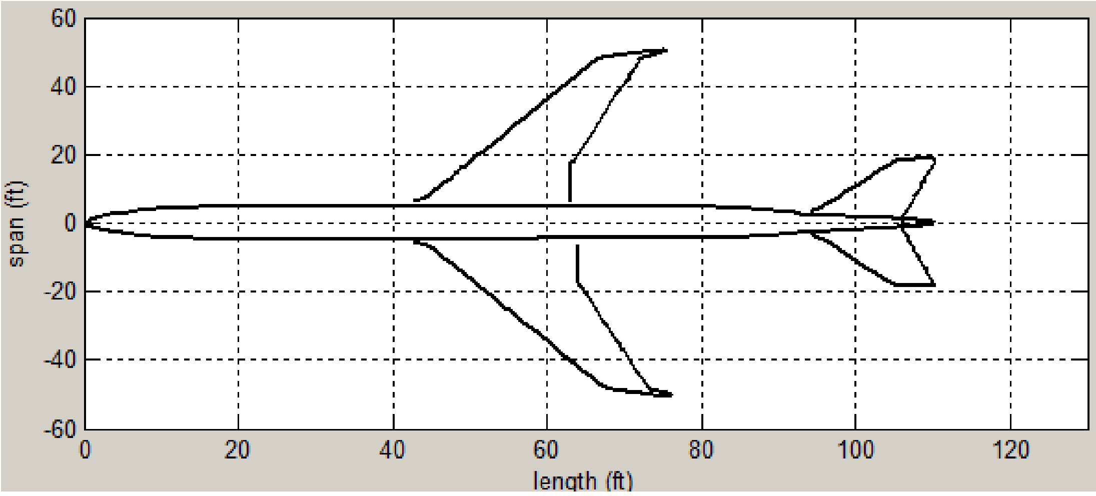


Figure 7.7: Optimized Aircraft Top View for Range Optimization (Case 2)

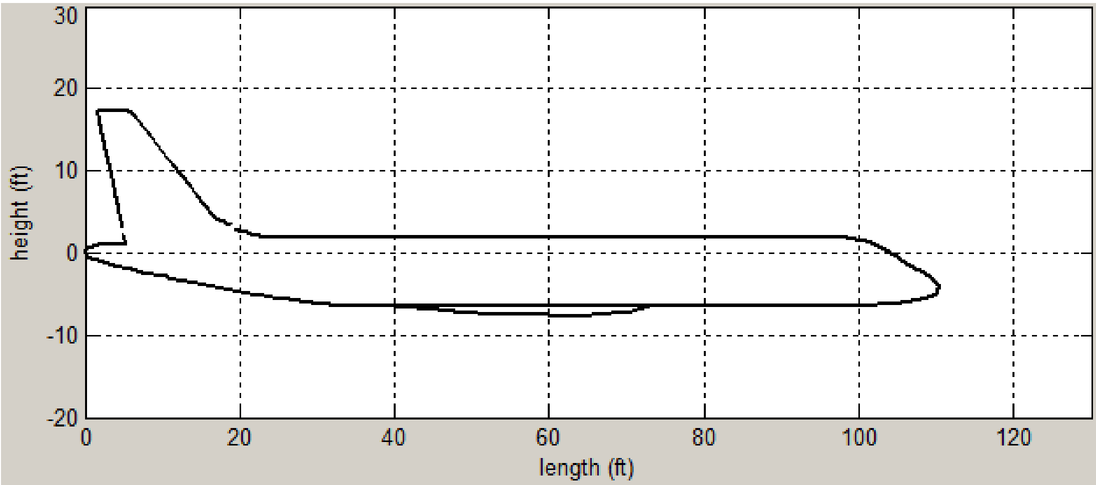


Figure 7.8: Optimized Aircraft Side View for Range Optimization (Case 2)

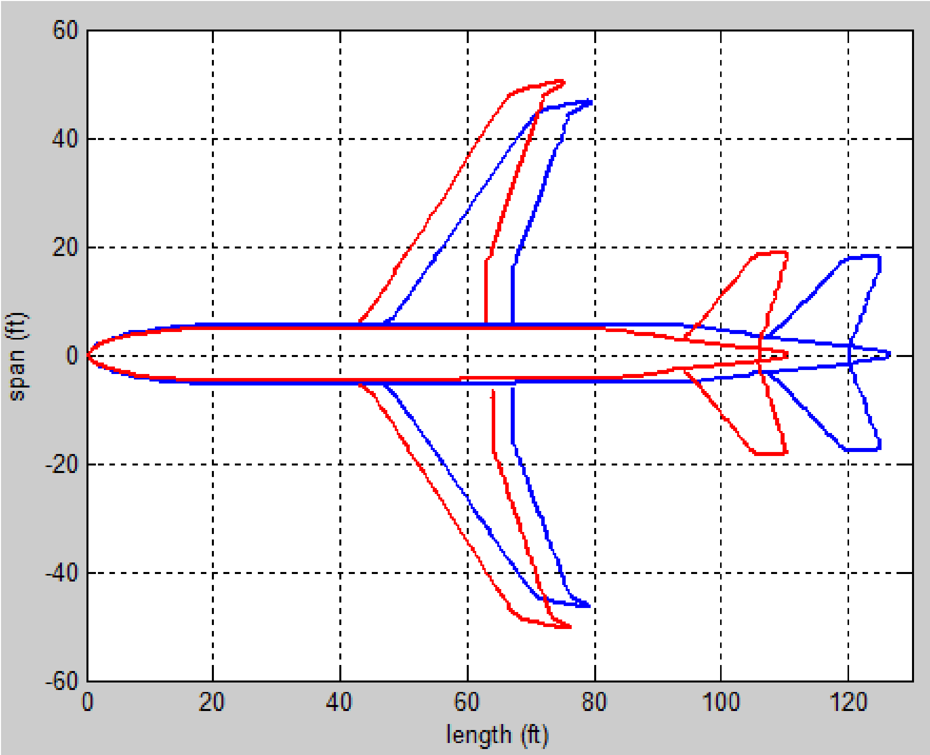


Figure 7.9: Optimized Aircraft (red) versus Embraer E-195 (blue) Top view (Case 2)

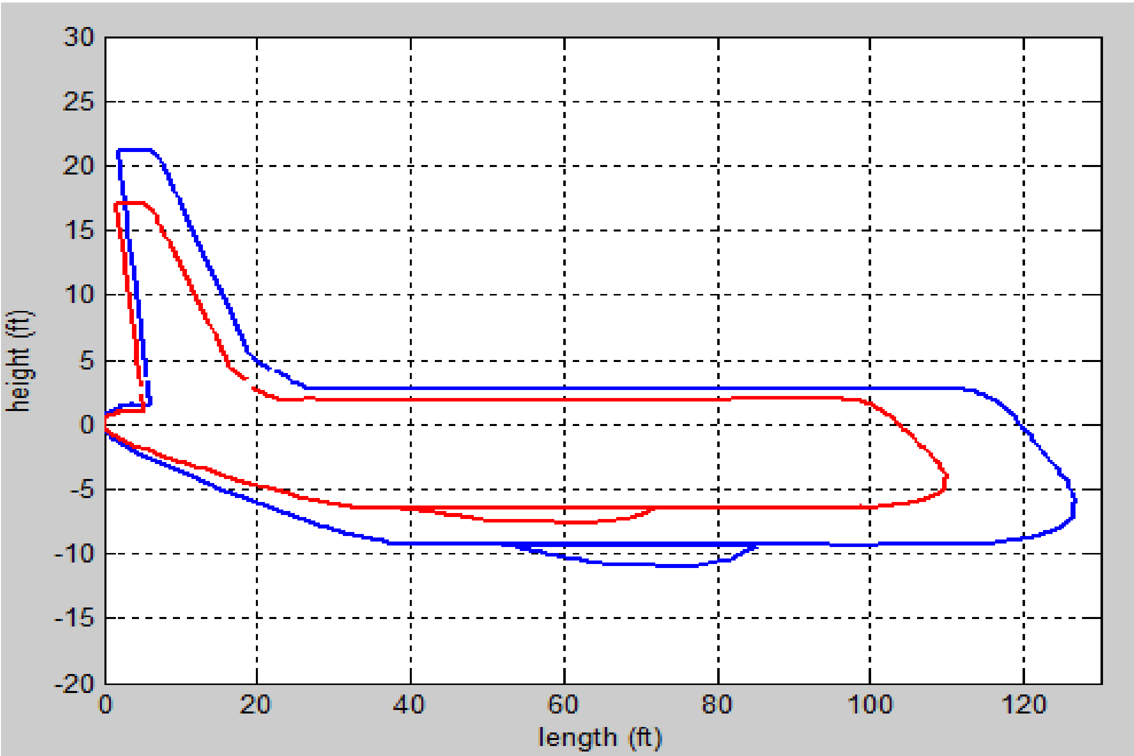


Figure 7.10: Optimized Aircraft (red) versus Embraer E-195 (blue) Side view (Case 2)

Table 7.10: Comparison of Optimization Results with Theoretical Results

Parameter	MTOW Opt.	Range Opt.	ROSKAM	Unit
C_{Lmax}	2.002	1.929	2.000	
S	1000.2	1067.1	997.3	ft^2
	92.9	99.1	92.7	m^2
AR	9.10	9.07	7.97	
λ	0.30	0.37	0.28	
S_{ht}	264.9	277.5	290.5	ft^2
	24.6	25.8	27.0	m^2
S_{vt}	200.4	201.3	117.4	ft^2
	18.6	18.7	10.9	m^2
L_t	50.1	50.3	60.6	ft
	15.3	15.3	18.5	m
Λ	25	25	28	deg
AR_{ht}	4.83	4.25	4.75	
AR_{vt}	1.18	1.00	1.35	
Λ_{ht}	32	34	28	deg
Λ_{vt}	35	37	43	deg
Engine number	2	2	2	
L_f	110.1	110.0	102.9	ft
	33.6	33.5	31.4	m
T/W	0.36	0.36	0.37	
c_{jcru}	0.63	0.63	0.50	lbs/lbs/hr
c_{jlt}	0.54	0.54	0.60	lbs/lbs/hr
c_{jalt}	0.95	0.95	0.90	lbs/lbs/hr
Payload Weight	22550	22550	22550	lbs
	10238	10238	10238	kg
Crew Weight	820	820	820	lbs
	372	372	372	kg
Fuel Weight	33444	38698	25394	lbs
	15184	17569	11529	kg
Empty Weight	48551	47932	57751	lbs
	22042	21761	26219	kg
Max. TOW	105365.0	110000.0	106565.0	lbs
	47835.7	49940.0	48380.5	kg
Range	2000.0	2543.3	2000.0	nm
	3704.0	4710.2	3704.0	km
L/D (cruise)	13.23	13.43	16.00	
L/D (loiter)	15.44	16.00	18.00	
L/D (fly to alternate)	11.40	10.00	10.00	

The comparison of results of two optimization processes and theory were given in Table 7.10. The lift coeffiecient for MTOW and Roskam are very close while Range optimization value is not too far from them.This situation is also valid for wing area. There is remarkable difference between optimized results and theory for vertical and horizontal tail and lift arm. Finally the most important result comparison are weights. Although the theory and maximum take-off weight optimization gave the same maximum take-off weight, the empty weight and fuel weight differs by huge value. This can be a result of different specific fuel consumption and L/D values. Another vital point is that theory and optimization gave the similar Maximum Take-off weight while the specific fuel consumptions for optimization solutions are higher than the theoretical solutions. This means that optimization solutions have lower structural weights according to the theory. Therefore, the optimization method is more successful than theoretical solutions to find lowest weighted aircrafts.

8. CONCLUSIONS

The optimization process is a short and systematic way to design an aircraft with desired parameters in a feasible region bounded by constraints. Genetic algorithm is very useful method to apply optimization process. During the thesis, an interface based on genetic algorithm was prepared to carry out the optimization by two different way: maximum take-off weight and range. Genetic algorithm uses rank weighted selection, mutation rate and single point crossover. The weight and range of the aircraft was calculated by theoretical equations. The specific fuel consumption and engine data is determined according to the selection of the user from the interface; for solutions that was given in the thesis were calculated using the GE CF34-10A engine. The results were overlapped with each other except some values such as range and take-off weight which are the main aim of the optimization but these solutions can be accepted because of assumptions especially for fly to alternate and loiter L/D, velocity and specific fuel consumptions. In addition to that, penalty parameter is very important for an optimization and in the thesis static penalty parameters that were specified by trying each one to carry the solution to feasible region causes to deviations. Despite the possible unstabilities of penalty parameters each optimization problem provided the constraint successfully.

The optimized regional jet approximately has 50 tons maximum take-off weight with half of this value will be empty weight with about 2000-2500 nm. range. An aspect ratio is 9 and the wing area is 92-99 m^2 so aircraft will have 30 m. wing span. Unlike the Embraer E-195, the optimized aircraft will have about 34 m. (110 ft) length. Conventional tail and two engines is the most applicable design. The aircraft has 125 knots stall speed with C_{Lmax} equals to 2. The cabin of the optimized aircraft will have 4 seats in a row, 31 inch pitch, with 110 passenger capacity. The drawings of the optimized aircraft were given in the appendix.

9. FUTURE WORK

Despite the optimization problems and genetic algorithm code gives good results, many developments can be applied. First, the aircraft design equation can be improved by adding new parameters, new constraints and new equations. The optimization process can be carried out not with just a parameter; it can be multi objective optimization instead of running separately the problems. The genetic algorithm code can be improved by adding different selection and crossover opportunities and these conditions can be shown on the interface to create many options to user to select and run the optimization. In the thesis penalty parameters are static penalties, there are many developed penalty algorithms that can control the solution easily and without any intervention and one of these algorithms can be added.

For interface, the results can be exported to a text file with a shortcut. More aircraft and engine data can be implemented in the code and the solution can be compared. Maybe after these upgrades, a drawing program can be used to model the optimized aircraft.

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APPENDICES

APPENDIX A: Drawing of the Optimized Aircraft

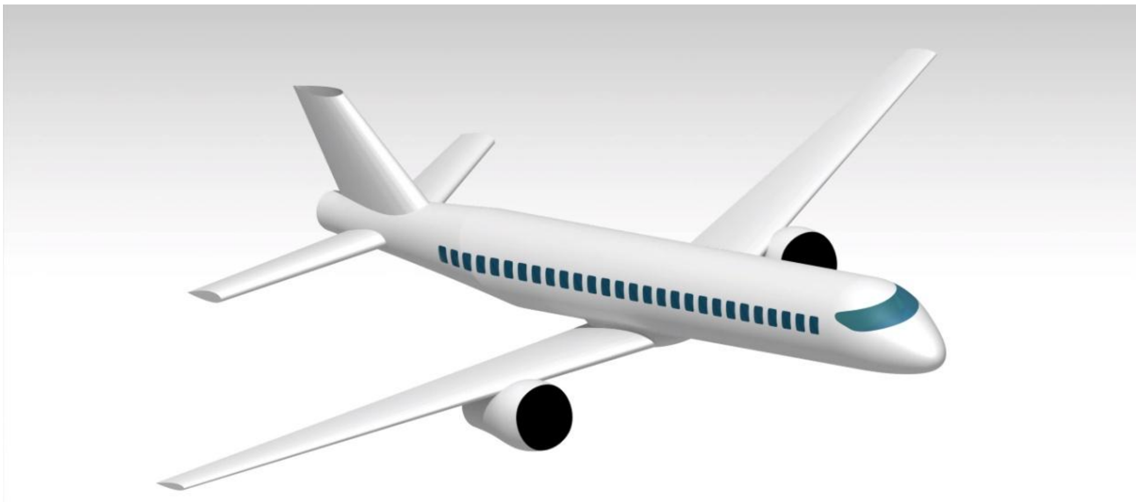


Figure A.1: Optimized Aircraft isometric view

Figure A.2: Optimized Aircraft cabin layout isometric view

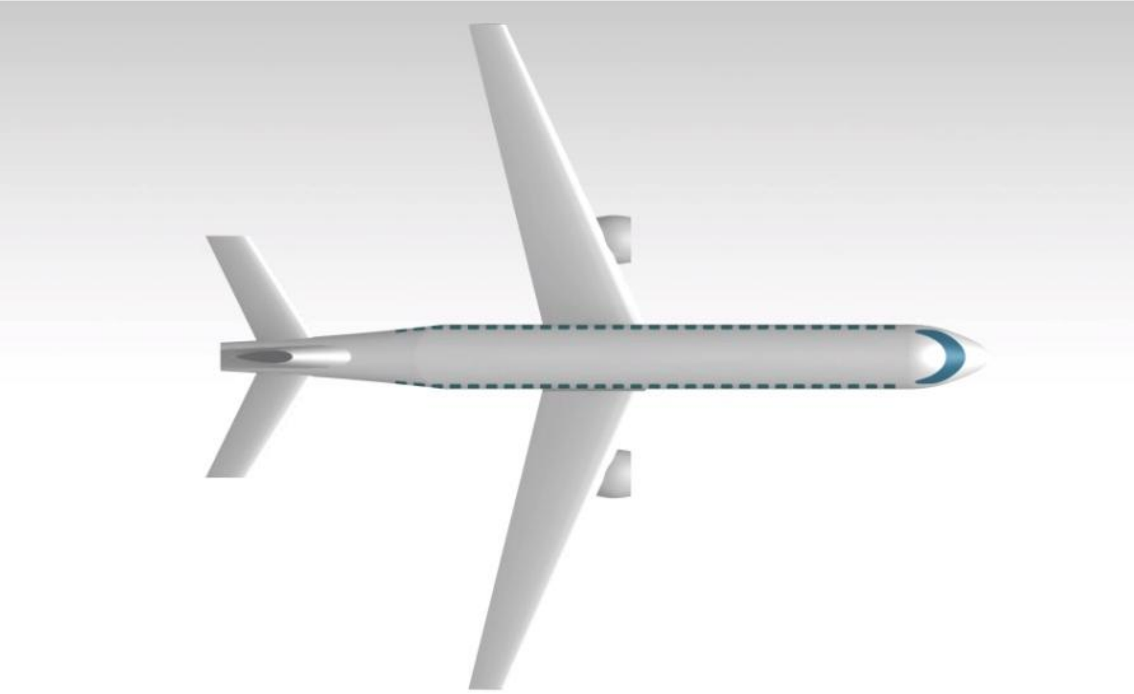


Figure A.3: Optimized Aircraft top view

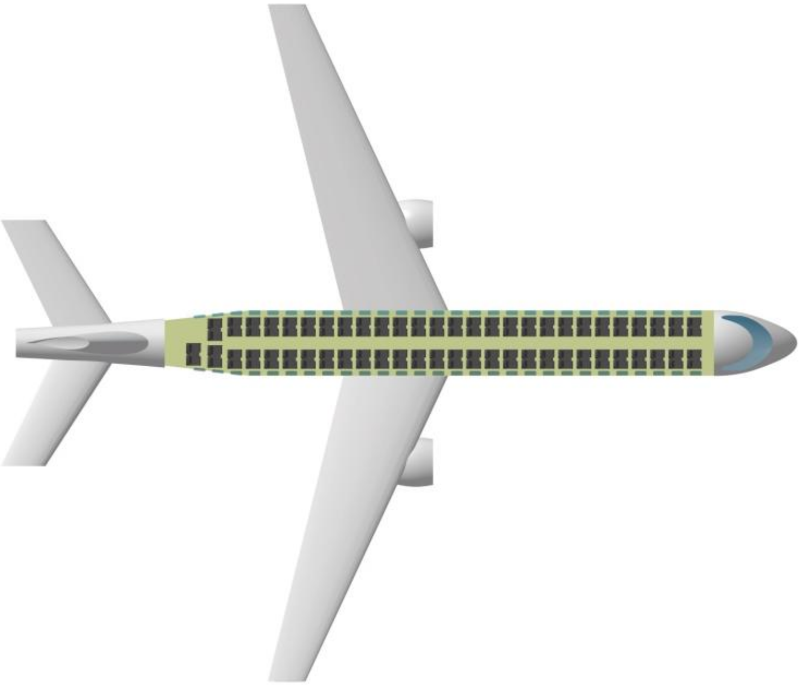


Figure A.4: Optimized Aircraft cabin layout top view

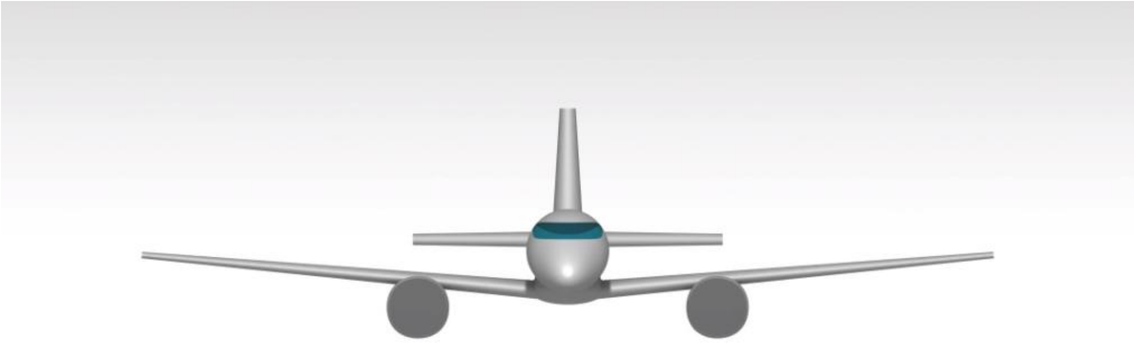


Figure A.5: Optimized Aircraft front view

APPENDIX B: Genetic Algorithm Code : Max. Take off Optimization

```
%Aircraft Optimization by Genetic Algorithm Single Point Crossover
%15.12.2013
% objective function 1 : take off weight optimization
OF1='TOW';
% number of optimization variables
nvar=18;
%Stopping criteria
%max number of iterations
maxit=str2double(get(handles.itsay,'String'));
%minimum cost
mincost=-9999999;
%population size
popsize=str2double(get(handles.popsay,'String'));
%mutation rate
mutrate=str2double(get(handles.mutor,'String'));
%population selection rate
selection=str2double(get(handles.SR21,'String'));
% number of bits for each variable
%     CLmax S   AR t/c taper Sht Svt Lt sweep ARht sweepht sweepvt    CT-TT
ARvt t/cvt Nen Lf T_W
nbits=[10    10   8   8  8     8   8  8    8    8       8       8         1
8    8    1   8  8 ];
% total number of bits in a chromosome
Nt=sum(nbits);
%population members that will survive
keep=floor(selection*popsize);
%Handling values of variables
pp1=get(handles.CLmaxmin,'Value');
switch pp1
    case 1
         CLmax1=2.0;
...
end
pp2=get(handles.CLmaxmax,'Value');
switch pp2
    case 1
         CLmax2=3.0;
...
end
pp3=get(handles.Smin,'Value');
```

```
switch pp3
    case 1
         S1=1400;
...
end
pp4=get(handles.Smax,'Value');
switch pp4
    case 1
         S2=1500;
...
end
pp5=get(handles.ARmin,'Value');
switch pp5
    case 1
         AR1=11;
...
end
pp6=get(handles.ARmax,'Value');
switch pp6
    case 1
         AR2=12;
...
end
pp7=get(handles.t_cmin,'Value');
switch pp7
    case 1
         tc1=0.16;
...
end
pp8=get(handles.t_c_max,'Value');
switch pp8
    case 1
         tc2=0.20;
...
end
pp9=get(handles.tapermin,'Value');
switch pp9
    case 1
         taper1=0.5;
...
end
pp10=get(handles.tapermax,'Value');
switch pp10
    case 1
         taper2=0.7;
...
end
pp11=get(handles.Shtmin,'Value');
switch pp11
    case 1
         Sht1=360;
...
end
pp12=get(handles.Shtmax,'Value');
switch pp12
    case 1
         Sht2=380;
...
end
pp13=get(handles.Svtmin,'Value');
switch pp13
    case 1
         Svt1=300;
...
end
pp14=get(handles.Svtmax,'Value');
switch pp14
    case 1
```

```
        Svt2=320;
...
end
pp15=get(handles.Ltmin,'Value');
switch pp15
    case 1
        Lt1=70;
...
end
pp16=get(handles.Ltmax,'Value');
switch pp16
    case 1
        Lt2=75;
...
end
pp17=get(handles.sweepmin,'Value');
switch pp17
    case 1
        sweep1=35;
...
end
pp18=get(handles.sweepmax,'Value');
switch pp18
    case 1
        sweep2=40;
...
end
pp19=get(handles.ARhtmin,'Value');
switch pp19
    case 1
        ARht1=7;
...
end
pp20=get(handles.ARhtmax,'Value');
switch pp20
    case 1
        ARht2=8;
...
end
pp21=get(handles.sweephtmin,'Value');
switch pp21
    case 1
        sweepht1=40;
...
end

pp22=get(handles.sweephtmax,'Value');
switch pp22
    case 1
        sweepht2=45;
...
end
pp23=get(handles.sweepvtmin,'Value');
switch pp23
    case 1
        sweepvt1=45;
...
end
pp24=get(handles.sweepvtmax,'Value');
switch pp24
    case 1
        sweepvt2=50;
...
end
pp25=get(handles.CT_TTmin,'String');
switch pp25
    case 'Konvansiyonel'
        T1=0;
```

```
end
pp26=get(handles.CT_TTmax,'String');
switch pp26
    case 'T-Kuyruk'
         T2=1;
end
pp27=get(handles.ARvtmin,'Value');
switch pp27
    case 1
         ARvt1=3;
...
end
pp28=get(handles.ARvtmax,'Value');
switch pp28
    case 1
         ARvt2=3.5;
...
end
pp29=get(handles.t_cvtmin,'Value');
switch pp29
    case 1
         tcv1=0.16;
...
end
pp30=get(handles.t_cvtmax,'Value');
switch pp30
    case 1
         tcv2=0.20;
...
end
pp31=get(handles.Nenmin,'Value');
switch pp31
    case 1
         Nen1=2;
end

pp32=get(handles.Nenmax,'Value');
switch pp32
    case 1
         Nen2=4;
end
pp33=get(handles.Lfmin,'Value');
switch pp33
    case 1
         Lf1=140;
...
end
pp34=get(handles.Lfmax,'Value');
switch pp34
    case 1
         Lf2=150;
...
end
pp35=get(handles.T_Wmin,'Value');
switch pp35
    case 1
         TW1=0.3;
...
end
pp36=get(handles.T_Wmax,'Value');
switch pp36
    case 1
        TW2=0.4;
...
end
% upper and lower limits of the variables.
%    CLmax  S   AR  t/c taper  Sht  Svt  Lt  sweep  ARht  sweepht  sweepvt
CT-TT ARvt  t/cvt Nen  Lf  T_W
```

```
up= [CLmax2 S2 AR2  tc2 taper2 Sht2 Svt2 Lt2 sweep2 ARht2 sweepht2 sweepvt2
T2   ARvt2 tcv2  Nen2 Lf2 TW2];
low=[CLmax1 S1 AR1  tc1 taper1 Sht1 Svt1 Lt1 sweep1 ARht1 sweepht1 sweepvt1
T1   ARvt1 tcv1  Nen1 Lf1 TW1];
% handling the design parameters
global crew1
crew1=str2double(get(handles.crew2,'String'));
global pax1
pax1=str2double(get(handles.pax,'String'));
global Vstall1
Vstall1=str2double(get(handles.Vstall,'String'));
global R_cr1
R_cr1=str2double(get(handles.range,'String'));
global h11
h11=str2double(get(handles.h1,'String'));
global M_cr1
M_cr1=str2double(get(handles.Mcr,'String'));
global Nseat1
Nseat1=str2double(get(handles.nseat,'String'));
global w_seat1
w_seat1=str2double(get(handles.wseat,'String'));
global w_aisle1
w_aisle1=str2double(get(handles.waisle,'String'));
global pitch1
pitch1=str2double(get(handles.pitch,'String'));
global E_lt1
E_lt1=str2double(get(handles.loiter11,'String'));
global R_al1
R_al1=str2double(get(handles.edit103,'String'));
%handling the constraints
global g1_11
global g1_111
pp37=get(handles.O1,'Value');
switch pp37
    case 1
        pp371=get(handles.G1,'Value');
        g1_111=1; %open selection activate the cons.
switch pp371
    case 1
        g1_11=100;
...
end
    case 2
        g1_11=1e+150;
        g1_111=0;  %closed selection de-activate the cons.
end
global g2_111
pp38=get(handles.G2,'Value');
switch pp38
    case 1
        g2_111=1;
    case 2
        g2_111=0;
end
global g3_111
pp39=get(handles.G3,'Value');
switch pp39
    case 1
        g3_111=1;
    case 2
        g3_111=0;
end
global g4_111
pp40=get(handles.G4,'Value');
switch pp40
    case 1
        g4_111=1;
    case 2
```

```
        g4_111=0;
end
global g5_111
pp41=get(handles.G5,'Value');
switch pp41
    case 1
        g5_111=1;
    case 2
        g5_111=0;
end
global g6_11
global g6_111
pp42=get(handles.G12,'Value');
switch pp42
    case 1
        pp421=get(handles.O12,'Value');
        g6_111=1;
switch pp421
    case 1
        g6_11=0.10;
...
end
    case 2
        g6_11=1e+150;
        g6_111=0;
end
global g7_11
global g7_111
pp43=get(handles.G7,'Value');
switch pp43
    case 1
        pp431=get(handles.O7,'Value');
        g7_111=1;
switch pp431
    case 1
        g7_11=1.6;
...
end
    case 2
        g7_11=1e+150;
        g7_111=0;
end
global g8_111
pp44=get(handles.G8,'Value');
switch pp44
    case 1
        g8_111=1;
    case 2
        g8_111=0;
end
global g9_111
pp45=get(handles.G9,'Value');
switch pp45
    case 1
        g9_111=1;
    case 2
        g9_111=0;
end
global g10_11
global g10_111
pp46=get(handles.G10,'Value');
switch pp46
    case 1
        pp461=get(handles.O10,'Value');
        g10_111=1;
switch pp461
    case 1
        g10_11=160;
```

```
...
end
    case 2
        g10_11=1e+150;
        g10_111=0;
end
global g11_11
global g11_111
pp47=get(handles.G11,'Value');
switch pp47
    case 1
        pp471=get(handles.O11,'Value');
        g11_111=1;
switch pp471
    case 1
        g11_11=1.0;
...
end
    case 2
        g11_11=1e+150;
        g11_111=0;end
 global g12_11
global g12_111
pp48=get(handles.G12,'Value');
switch pp48
    case 1
        pp481=get(handles.O12,'Value');
        g12_111=1;
switch pp481
    case 1
        g12_11=0.05;
...
end
    case 2
        g12_11=1e+150;
        g12_111=0;
end
%ENGINE
global We1
global c_j_cr1
pp49=get(handles.popupmenu40,'Value');
switch pp49
    case 1
        We1=str2double(get(handles.we,'String'));
        c_j_cr1=str2double(get(handles.cj,'String'));
    case 2
        We1=str2double(get(handles.we,'String'));
        c_j_cr1=str2double(get(handles.cj,'String'));
    case 3
        We1=str2double(get(handles.we,'String'));
        c_j_cr1=str2double(get(handles.cj,'String'));
    case 4
        We1=str2double(get(handles.we,'String'));
        c_j_cr1=str2double(get(handles.cj,'String'));
    case 5
        We1=str2double(get(handles.we,'String'));
        c_j_cr1=str2double(get(handles.cj,'String'));
end
c1=low';
cc1=c1(:,ones(popsize,1));
r_1 = cc1(:)';
min_var = r_1';
c2=up';
cc2=c2(:,ones(popsize,1));
r_2 = cc2(:)';
max_var = r_2';
%Creating initial population
%counter
```

```
iga=0;
%random population of 1s and 0s.
pop=round(rand(popsize,Nt));
%convert binary to continuous values
par=gadecode(pop,min_var,max_var,nbits);
%calculates population cost using OF1
cost=feval(OF1,par);
%min cost in element 1
[cost,ind]=sort(cost);
%sort population with lowest cost first
par=par(ind,:);
pop=pop(ind,:);
%minc contains min of population
minc(1)=min(cost);
%meanc contains mean of population
meanc(1)=mean(cost);
%Iteration process
while iga<maxit
iga=iga+1;
%Pair and mate
%number of matings
M=ceil((keep)/2);
%weights chromosomes based upon position in list
prob=flipud((1:keep)'/sum((1:keep)));
%probability distribution
odds=[0 cumsum(prob(1:keep))'];
pick1=rand(1,M);      % mate #1
pick2=rand(1,M);      % mate #2
% ma and pa contain the indicies of the chromosomes that will mate
ic=1;
while ic<=M
for id=2:keep+1
if  pick1(ic)<= odds(id) &&  pick1(ic)>odds(id-1)
ma(ic)=id-1;
end
if pick2(ic)<=odds(id) &&  pick2(ic)>odds(id-1)
pa(ic)=id-1;
end
end
ic=ic+1;
end %while
%Performs mating using single point crossover
ix=1:2:keep;                                         % index of mate #1
xp=ceil(rand(1,M)*(Nt-1));                           % crossover point
pop(keep+ix,:)=[pop(ma,1:xp) pop(pa,xp+1:Nt)];       % first offspring
pop(keep+ix+1,:)=[pop(pa,1:xp) pop(ma,xp+1:Nt)];     % second offspring
%Mutate the population
nmut=ceil((popsize-1)*Nt*mutrate);                   % total number of
mutations
mrow=ceil(rand(1,nmut)*(popsize-1))+1;               % row to mutate
mcol=ceil(rand(1,nmut)*Nt);                          % column to mutate
for ii=1:nmut
pop(mrow(ii),mcol(ii))=abs(pop(mrow(ii),mcol(ii))-1); % toggles bits
end
% The population is re-evaluated for cost
par(2:popsize,:)=gadecode(pop(2:popsize,:),
min_var((nvar+1):(nvar*popsize),:),max_var((nvar+1):(nvar*popsize),:),nbits)
; % decode
cost(2:popsize)=feval(OF1,par(2:popsize,:));
% Sort the costs and parameters
[cost,ind]=sort(cost);
par=par(ind,:);
pop=pop(ind,:);
minc(iga+1)=min(cost);
meanc(iga+1)=mean(cost);
% Stopping criteria
if iga>maxit || cost(1)<mincost
break
```

```
end
[iga cost(1)];
end %iga
%Write the optimized max. take off value
bWTOF=sprintf('%0.1f',cost(1));
set(handles.WTOF, 'String',bWTOF);
%handle the weight components
[f1,W_pay1,W_crew1,W_Fuel1,WE1, L_D_cr1,L_D_lt1,L_D_al1,df1]=TOW(par(1,:));
%Write the optimized values
set(handles.WPAY, 'String',W_pay1);
set(handles.WCREW, 'String',W_crew1);
set(handles.WFUEL, 'String',W_Fuel1);
set(handles.WEMP, 'String',WE1);
%handle and write L/D values
b1119=sprintf('%0.2f',L_D_cr1);
b1120=sprintf('%0.2f',L_D_lt1);
b1121=sprintf('%0.2f',L_D_al1);
set(handles.LDcru, 'String',b1119);
set(handles.LDloi, 'String',b1120);
set(handles.LDal, 'String',b1121);
%handle values of all variables.
b111=sprintf('%0.3f',par(1,1));
b112=sprintf('%0.1f',par(1,2));
b113=sprintf('%0.2f',par(1,3));
b114=sprintf('%0.2f',par(1,4));
b115=sprintf('%0.2f',par(1,5));
b116=sprintf('%0.1f',par(1,6));
b117=sprintf('%0.1f',par(1,7));
b118=sprintf('%0.1f',par(1,8));
b119=sprintf('%0.0f',par(1,9));
b1110=sprintf('%0.2f',par(1,10));
b1111=sprintf('%0.0f',par(1,11));
b1112=sprintf('%0.0f',par(1,12));
b1114=sprintf('%0.2f',par(1,14));
b1115=sprintf('%0.2f',par(1,15));
b1116=sprintf('%0.0f',par(1,16));
b1117=sprintf('%0.1f',par(1,17));
b1118=sprintf('%0.2f',par(1,18));
if par(1,13)<0.5
    b1113='Conventional';
    else
       b1113='T Tail';
end
%write values of all variables.
set(handles.R1, 'String',b111);
set(handles.R2, 'String',b112);
set(handles.R3, 'String',b113);
set(handles.R4, 'String',b114);
set(handles.R5, 'String',b115);
set(handles.R6, 'String',b116);
set(handles.R7, 'String',b117);
set(handles.R8, 'String',b118);
set(handles.R9, 'String',b119);
set(handles.R10, 'String',b1110);
set(handles.R11, 'String',b1111);
set(handles.R12, 'String',b1112);
set(handles.R13, 'String',b1113);
set(handles.R14, 'String',b1114);
set(handles.R15, 'String',b1115);
set(handles.R16, 'String',b1116);
set(handles.R17, 'String',b1117);
set(handles.R18, 'String',b1118);
% cost and iteration graph
iters=0:length(minc)-1;
plot(handles.axes1,iters,minc,iters,meanc);
xlabel(handles.axes1,'generation');ylabel(handles.axes1,'cost');
legend(handles.axes1,'best','population average')
grid(handles.axes1,'on')
```

```
%EMBRAER E-195 top view
AAA=textread('E195_GOVDE.txt');
xxx=AAA(:,1)/0.3048;
yyy=(AAA(:,2)-AAA(1,2))/0.3048;
AAA2=textread('E195_SOL_KANAT.txt');
xxx2=AAA2(:,1)/0.3048;
yyy2=(AAA2(:,2)-AAA(1,2))/0.3048;
AAA3=textread('E195_SAG_KANAT.txt');
xxx3=AAA3(:,1)/0.3048;
yyy3=(AAA3(:,2)-AAA(1,2))/0.3048;
AAA4=textread('E195_KUYRUK.txt');
xxx4=AAA4(:,1)/0.3048;
yyy4=(AAA4(:,2)-AAA(1,2))/0.3048;
%optimized aircraft top view
LLF=par(1,17);
SSS=par(1,2);
ARR=par(1,3);
SSSh=par(1,6);
ARRh=par(1,10);
SSSv=par(1,7);
ARRv=par(1,14);
LLT=par(1,8);
bbb=sqrt(ARR*SSS);
bbbh=sqrt(ARRh*SSSh);
bbbv=sqrt(ARRv*SSSv);
%graphic coordinates
xxx11=xxx*LLF/max(xxx);
yyy11=yyy*df1/(max(yyy)-min(yyy));
xxx44=xxx4*LLF/max(xxx4);
yyy44=(yyy4)*bbbh/(max(yyy4)-min(yyy4));
xxx22=(xxx2-min(xxx2))+(min(xxx44)-LLT);
yyy22=yyy2*bbb/2/(max(yyy2)-min(yyy2));
xxx33=(xxx3-min(xxx3))+(min(xxx44)-LLT);
yyy33=yyy3*bbb/2/(max(yyy3)-min(yyy3));
h(:,1)=plot(handles.axes2,xxx,yyy,'b',xxx2,yyy2,'b',xxx3,yyy3,'b',xxx4,yyy4,
'b','LineWidth',2);
% hold(handles.axes2,'on')
h(:,2)=plot(handles.axes2,xxx11,yyy11,'r',xxx22,yyy22,'r',xxx33,yyy33,'r',xx
x44,yyy44,'r','LineWidth',2);
hold(handles.axes2,'off')
% set(h(:,1), 'Color','b')
set(h(:,2), 'Color','k')
xlabel(handles.axes2,'length (ft)');ylabel(handles.axes2,'span (ft)');
axis(handles.axes2,[0 120 -60 60])
% legend(handles.axes2,h(1,:),{'EMBRAER 195','OPTIMUM
DESIGN'},'location','eastoutside');
grid(handles.axes2,'on')
figure(1)
plot(xxx,yyy,'b',xxx2,yyy2,'b',xxx3,yyy3,'b',xxx4,yyy4,'b','LineWidth',2);
hold('on')
plot(xxx11,yyy11,'r',xxx22,yyy22,'r',xxx33,yyy33,'r',xxx44,yyy44,'r','LineWi
dth',2);
hold('off')
% set(h(:,1), 'Color','b')
% set(h(:,2), 'Color','k')
xlabel('length (ft)');ylabel('span (ft)');
axis([0 130 -60 60])
% legend(handles.axes2,h(1,:),{'EMBRAER 195','OPTIMUM
DESIGN'},'location','eastoutside');
grid('on')
%EMBRAER E-195 side view
AAA21=textread('E195_YAN.txt');
[za1 ind]=min(AAA21(:,1));
ka1=AAA21(ind,2);
xxx21=AAA21(:,1)/0.3048;
yyy21=(AAA21(:,2)-ka1)/0.3048;
AAA22=textread('E195_DUS_KUYRUK.txt');
xxx212=AAA22(:,1)/0.3048;
```

```
yyy212=(AAA22(:,2)-ka1)/0.3048;
AAA33=textread('E195_WING_BOX.txt');
xxx215=AAA33(:,1)/0.3048;
yyy215=(AAA33(:,2)-ka1)/0.3048;
%optimized aircraft side view
xxx213=xxx21*LLF/max(xxx21);
yyy213=yyy21*df1/(max(yyy21)-min(yyy21));
xxx214=xxx212*LLF/max(xxx21);
yyy214=yyy212*bbbv/(max(yyy212)-min(yyy212));
xxx216=xxx215-max(xxx215)+max(xxx212)+LLT;
yyy216=yyy215*df1/(max(yyy21)-min(yyy21));
%plot(handles.axes4,xxx21,yyy21,'b',xxx212,yyy212,'b',xxx215,yyy215,'b','Lin
eWidth',2);
% hold(handles.axes4,'on')
plot(handles.axes4,xxx213,yyy213,'k',xxx214,yyy214,'k',xxx216,yyy216,'k','Li
neWidth',2);
hold(handles.axes4,'off')
xlabel(handles.axes4,'length (ft)');ylabel(handles.axes4,'height (ft)');
axis(handles.axes4,[0 120 -20 30])
grid(handles.axes4,'on')
figure(2)
plot(xxx21,yyy21,'b',xxx212,yyy212,'b',xxx215,yyy215,'b','LineWidth',2);
hold('on')
plot(xxx213,yyy213,'r',xxx214,yyy214,'r',xxx216,yyy216,'r','LineWidth',2);
hold('off')
xlabel('length (ft)');ylabel('height (ft)');
axis([0 130 -20 30])
grid('on')
%gadecode function converts binary chromosome
%to contionus variables
function f=gadecode(chrom,lo,hi,bits)
% chrom = population
% lo = minimum parameter value
% hi = maximum parameter value
% bits = number of bits/variable
[M,N]=size(chrom);
nvar=(length(lo)/M);                % number of variables
quant=(0.5.^((1:max(bits))'));      % quantization levels
quant=quant/sum(quant);             % quantization levels normalized
t=0;
for j=1:nvar
    k=t+1;
    t=t+bits(1,j);
    f(1:M,j)=(chrom(1:M,k:t)*quant(1:bits(1,j))).*(hi(j,1)-lo(j,1))+lo(j,1);
end
function [f,W_pay,W_crew,W_Fuel,WE,L_D_cr,L_D_lt,L_D_al,df]=TOW(x)
%TOW function is the objective function that will be optimized.
%Max. take off weight is divided into 3 main parts:
% Payload and crew, empty and fuel weight.
%PAYLOAD & CREW WEIGHT
%175 lbs per person + 30 lbs baggage
global crew1
crew=crew1;
global pax1
 pax =pax1;
W_pay      = (pax*175 + pax*30);              %[lbs]
W_crew     = (crew*175 + crew*30);            %[lbs]
%PARAMETERS
%stall speed
global Vstall1
Vstall=Vstall1;
%all variables
CLmax=x(:,1); S=x(:,2); AR=x(:,3); t_c_r=x(:,4); taper=x(:,5); Sht=x(:,6);
Svt=x(:,7); Lt=x(:,8); sweep=x(:,9); ARht=x(:,10); sweepht=x(:,11);
sweepvt=x(:,12);  CT_TT=x(:,13);   ARvt=x(:,14); t_cvt=x(:,15);
Nen=x(:,16);   Lf=x(:,17); T_W=x(:,18);
%wing loading
W_S=(0.5*0.0024*((1.688*Vstall).^2).*CLmax); %[lb/ft^2]
```

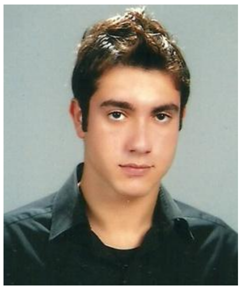
```
%FUEL WEIGHT
%Mission profiles:
%engine startup/warm up
W1_W_TO=0.99;
%taxi
W2_W_1=0.99;
%Take - off
W3_W_2=0.995;
%Climb
W4_W_3=0.98;
%Cruise
%from table 2.2
%Range
global R_cr1
R_cr=R_cr1;                                                  %[nm]
%Altitude
global h11
h1=h11;                                                       %[ft]
%Density
rho1=(0.002377*((1-7*(10^(-6))*h1)^4.21));                   %[slug/ft^3]
%Temperature
T=15-6.5*h1*0.3048/1000;                                      %[C]
T2=(T + 273.15) * 9/5;                                        %[R]
%Sound of speed
%288K = 518.40°R
%R=1716 ft-lb/slug/°R
a=sqrt(1.4*1716*T2);
%Cruise Mach number
global M_cr1
M_cr=M_cr1;
V_cr=M_cr*a*0.3048/0.51;                                      %[kts]
%Specific Fuel Consumption
global c_j_cr1
c_j_cr=c_j_cr1;                                               %[lbs/lbs/hr]
%Lift Coefficient
CL_cr=W_S*W1_W_TO*W2_W_1*W3_W_2*W4_W_3./(0.5*rho1*((1.688*V_cr).^2))
%Oswald Effiiency Factor
%Raymer s.299 p.157 e.12.50
e=abs(4.61*(1-0.045*(AR.^0.68)).*((cos(sweep*pi/180)).^0.15)-3.1);
K=1./(pi*AR.*e);
%Drag Coefficient
%Sexposed= Sref - cr*Wf,
%according to excel data Sref_mean=94.80; cr_mean=5.42; Wf_mean=3.48
%so approximately Sexp=%20Sref (raymer s.150 p.83)(1-0.2=0.8)
Cfe=0.0030;             %(raymer s.280 p.140)(Civil Transport)
CD0=Cfe*(0.8*(1.977+0.52*(t_c_r))) ;
CD_1=CD0 + K.*(CL_cr.^2);
%Prandtl Compressibility Correction
CD_cr=CD_1/sqrt(1-M_cr*M_cr);
L_D_cr=CL_cr./CD_cr;
W5_W_4=1./exp((R_cr*6076.12)/(V_cr*1.688)*(c_j_cr/3600)./L_D_cr);
%Loiter
global E_lt1
%Loiter time
E_lt=E_lt1;
%average value - 0.85 Raymer s.17 table 3.3
c_j_lt=c_j_cr*0.85;             %[lbs/lbs/hr]
% raymer square root of 0.866 equals to 0.93.
V_lt=V_cr*0.93;
%Lift coefficient
CL_lt=W_S*W1_W_TO*W2_W_1*W3_W_2*W4_W_3.*W5_W_4./(0.5*rho1*((1.688*V_lt).^2))
%Drag Coefficient
CD_2=CD0 + K.*(CL_lt.^2);
CD_lt=CD_2/sqrt(1-M_cr*M_cr*0.93*0.93);
%Fines ratio
L_D_lt=CL_lt./CD_lt;
W6_W_5=1./exp(E_lt*c_j_lt./L_D_lt);
% Descent
```

```
W7_W_6=0.98;
% Fly to alternate
%Range
global R_al1
R_al=R_al1;               %[nm]
%Altitude is taken 10000 ft for fly to alternate.
h2=10000;                                                  %[ft]
rho2=(0.002377*((1-7*(10^(-6))*h2)^4.21));            %[slug/ft^3]
T3=15-6.5*h2*0.3048/1000;                                  %[C]
T4=(T3 + 273.15) * 9/5;                                    %[R]
%R=1716 ft-lb/slug/°R,
%288K = 518.40°R
alt=sqrt(1.4*1716*T4);
%Fly to alternate Mach is taken 30% of the cruise Mach number
M_al=M_cr*0.3;
V_al=M_al*alt*0.3048/0.51;
%Aircraft will burn fuel more than cruise.
c_j_al=c_j_cr*1.5;                  %[lbs/lbs/hr]
%Lift coefficient
CL_al=W_S*W1_W_TO*W2_W_1*W3_W_2*W4_W_3.*W5_W_4.*W6_W_5*W7_W_6./(0.5*rho2*((1
.688*V_al).^2));
%Drag coefficient
%Compressibility Effects Neglected due to M is lower than 0.3
CD_3=CD0 + K.*(CL_al.^2);
CD_al=CD_3;
%Fines ratio
L_D_al=CL_al./CD_al;
W8_W_7=1./exp(R_al/V_al*c_j_al./L_D_al);
% Landing and taxi
W9_W_8=0.992;
%Fuel fraction
Mff=W1_W_TO*W2_W_1*W3_W_2*W4_W_3*W5_W_4.*W6_W_5*W7_W_6.*W8_W_7*W9_W_8;
% trapped fuel and oil
Mtfo=0.005;
W_tfo=(W_S.*S).*Mtfo;
W_F_used=(1-Mff).*(W_S.*S);
W_Fuel=W_F_used+W_tfo;
%EMPTY WEIGHT
%flight controls, APU, hydraulics, electrical, furnishing,air
conditioning,%handling gear are not calculated.
%Wing Span
b=      sqrt(AR.*S);
%Ultimate load factor
Nz=     1.5*2.5;
%Control surface area to lifting surface area: %25 wing area
Scsw_r= 0.25;
%Not moving h.tail
Kuht=   1;
%fuselage width at horizontal tail intersection
Fw=     10;        %[ft]
%Horizontal tail span
Bh=     sqrt(ARht.*Sht);
%Elevator to tail ratio
Se_Sht= 0.25;
%wing weight
wing=0.0051*((W_S.*S*Nz).^(0.557)).*(S.^(0.649)).*(AR.^(0.5)).*(t_c_r.^(-
0.4)).*((1+taper).^(0.1)).*(cos(sweep/57.3).^(-1)).*((S*Scsw_r).^(0.1));
%horizontal tail weight
ht=0.0379*Kuht*((1+Fw./(Bh)).^(-
0.25)).*((W_S.*S).^0.639)*(Nz^0.10).*(Sht.^(0.75)).*(Lt.^(-
1)).*((0.3*Lt.^(0.704)).*(cos(sweepht/57.3)).^(-
1))*((1+Se_Sht)^0.1).*(ARht.^(0.166));
%vertical tail weight
vt=0.0026*((1+ CT_TT).^(0.225)).*((W_S.*S).^(0.556))*(Nz^0.536).*(Lt.^(-
0.5)).*(Svt.^(0.5)).*(Lt.^(0.875)).*(cos(sweepvt/57.3).^(-
1)).*(ARvt.^(0.35)).*(t_cvt.^(-0.5));
%no cargo door
K_door=1;
```

```
%landing gear mounted on fuselage
Klg=1.12;
%Number of seats at a row
global Nseat1
Nseat=Nseat1;
%one seat width
global w_seat1
w_seat=w_seat1;          % [ft]
% aisle width
global w_aisle1          % [ft]
w_aisle=w_aisle1;
% fuselage depth
df=(Nseat*w_seat+w_aisle)*1.25;     %[ft]
%distance between two seat
global pitch1
pitch=pitch1;            %[ft]
% fuselage length without radom and cone.
L=pax/Nseat*pitch;       %[ft]
% fuselage cone length roskam part 2 p. 122
Lfc=3*df;                %[ft]
% fuselage radom
Lfn=Lf-Lfc-L;            %[ft]
%fuselage wetted area
Sf=0.75*pi*df*Lfn + 0.72*pi*df*Lfc + pi*df*L;          % [ft^2]
Kws=0.75*(1+2*taper)./(1+taper).*(b).*tan(sweep/57.3)./Lf;
%fuselage weight [lbs]
fus=0.328*K_door*Klg*((W_S.*S*Nz).^0.5).*(Lf.^(0.25)).*(Sf.^(0.302)).*((1+Kw
s).^0.04).*((L/df)^0.10);
%main landing gear weight [lbs]
%Torenbeek pdf s.283
mlg=40+0.16*((W_S.*S).^(0.75))+ 0.019*((W_S.*S))+1.5*(10^(-
5))*((W_S.*S).^(1.5));
%nose landing gear weight [lbs]
%Torenbeek pdf s.283
nlg=20+0.10*((W_S.*S).^(0.75))+ 2*(10^(-6))*((W_S.*S).^(1.5));
% engine weight  (lbs)
% aircraft estimation in interactive design process-Torenbeek
global We1
We=We1;
Wprop=1.357*(We).*Nen;
Wnac=0.055*(T_W).*Nen;
Wprop_sys=Wprop+Wnac;
% surface controls weight torenbeek s.283
Wsc=0.64*((W_S.*S).^(2/3));
%kerosene weight
rho_ker=50.4;                     %lb/ft^3
%fuel volume
Vf=W_Fuel/rho_ker;
%number of fuel tanks
Nft=8;
%fuel system weight-torenbeek s.286
Wfu_sys=80*(Nen+Nft-1)+ 15*(Nft.^0.5).*(Vf.^0.333);
% pneumatic system weight
starter=49.19*(Nen*We/1000).^0.541;
%anti - ice system weight
Want_ice =0.002*(W_S.*S);
%handling gear weight system
Whg=0.0003*(W_S.*S);
%uninstalled avionics
UAV=1500;     %lbs
avionics=1.73*(UAV^0.983);
WE=wing + ht + vt + fus +  mlg + nlg + Wprop_sys + starter + avionics + Wsc
+ Wfu_sys + Want_ice + Whg;
%%CONSTRAINTS
%Tank Volume
VF=0.54*(S.^2)./b .* (t_c_r) .* (1+taper + taper.^2)./((1+taper).^2);
%Tail Volume Coefficient
%root chord [ft]
```

```
Cr=2*S./(b.*(1+taper));
%mean aerodynamic chord [ft]
mean_c=Cr*(2/3).*(1+taper+taper.^2)./(1+taper);
% vertical tail volume coefficient
vv=(Lt.*Svt)./(b.*S);
% horizontal tail volume coefficient
vh=(Lt.*Sht)./(mean_c.*S);
global g1_11
global g1_111
g1_1111=-W_S/g1_11+1;
g1=g1_1111*g1_111;
global g2_111
g2_1111=-wing./ht+1;
g2=g2_1111*g2_111;
global g3_111
g3_1111=-fus./wing+1;
g3=g3_1111*g3_111;
global g4_111
g4_1111=-Lfn;
g4=g4_1111*g4_111;
global g5_111
g5_1111=-Lf/L+1;                  % Roskam Part - 2 P.122- 11.86
g5=g5_1111*g5_111;
global g6_11
global g6_111
g6_1111=vv/g6_11-1;               % Raymer p.64
g6=g6_1111*g6_111;
global g7_11
global g7_111
g7_1111=vh/g7_11-1;                % Raymer p.64
g7=g7_1111*g7_111;
global g8_111
g8_1111=-VF./Vf +1;
g8=g8_1111*g8_111;
global g9_111
g9_1111=-(W_S.*S)./(WE + W_pay + W_crew + W_Fuel)+1;
g9=g9_1111*g9_111;
global g10_11
global g10_111
g10_1111=W_S/g10_11-1;
g10=g10_1111*g10_111;
global g11_11
global g11_111
g11_1111=-vh/g11_11+1;                     % Raymer p.64
g11=g11_1111*g11_111;
global g12_11
global g12_111
g12_1111=-vv/g12_11+1;                     % Raymer p.64
g12=g12_1111*g12_111;
p=(1e+5)*(g1.^2)....
+(1e+1)*(g2.^2)....
+(1e+3)*(g3.^2) ....
+(1e+1)*(g4.^2) ....
+(1e+3)*(g8.^2) ....
+(1e+3)*(g5.^2)....
+(1e+3)*(g9.^2) ....
+(1e+2)*(g12.^2) ....
+(1e+3)*(g6.^2 + g7.^2) ....
+(1e+2)*(g11.^2)....
+(1e+5)*(g10.^2);
WE=WE+p;
f=WE + W_pay + W_crew + W_Fuel
```

CURRICULUM VITAE



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