Nature of the Materials for Modern Airplane Parts

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Abstract

A materials engineer or mechanical engineer would be involved with the complexity of the design and selection of metals and alloys used in a high-temperature, aggressive environment. Airplanes industry has witnessed great developments to endure huge loads, reduce the costs and increase the security factors. This research has focused on the nature of raw materials that used in the airplane components. These materials either would be alloys or composites materials. The airplane is divided into ten parts. The significant parts of an aircraft structure for the present study are the wings, fuselage or hull, nose, tail, landing gear, pylon box, fuel tank, the engine and screens. Generally, the external surfaces of the civil airplanes are made of Aluminum alloys, while of the military airplanes are made of Titanium alloys. The internal parts of the plane has been made of iron alloys , while the engine parts has been made of anti- temperature materials such as Nickel alloys or special alloys like in combustion chamber , Nozzle and turbine, because these parts have faced a high degrees of temperature. The modern airplanes toward to use composite materials in the body structure and airfoil such as graphite-epoxy in Boeing 777, Kevlar-epoxy in Airbus A 320 and Nomex honey comb in F-15 Military. The calculation of airplane weight of Boeing 777 and Boeing 787 is done in this study. Results deal with the weight calculation indicated that the amount of reduction in mass of Boeing 787 by using the composites development in place of alloys is 3.8 Tons which is closest to that declared by Boeing Company.

Keywords Airplane, Engineering Materials, Alloys, Composites

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1. Introduction

The components of the airplane are varied according to its conditions and positions in the airplane. The materials of the airplane parts selection have submitted too many factors, like the load and the external conditions resistance to corrosion, the fatigue resistance, the weights and their positions in the plane. High quality and economic conditions will play a good role in the selection of materials for components of airplanes like the alloys and composites. Airplanes will be varied in the lifetime because the damaged parts either replaced or maintained. The modern civil airplane life is between (50000-150000) hour / fly while for military airplane the life is between (6000 -10000) hour / fly [1].

The wings are subjected to the highest levels, and also the most complex variation of stresses. The largest forced on the wing occur when the plan is airborne; hence, the wings must then support the whole weight of the aircraft. Each wing therefore acts as a cantilever with the maximum bending moment occurring at the wing roots. If the engines are mounted on the wings, the engine weight together with the weight of under carriage and fuel oppose the lift force and in a small way reduce its effects. The fuselage or the body is a long approximately cylindrical shell. The lower part of the body especially beneath the wings is subject to compression whilst the upper fuselage corresponding experiences tension. The landing gear functions once per flight as the weight of the whole aircraft hits the ground on touchdown. Whilst the vertical descent velocity value of more than (1 m/sec) is not high enough to rate as shock loading; the stresses are very high. The landing gear components must be manufactured from materials with highest levels of static strength [19].

Alloys are mixtures of elements which are suitable among each other in physical and chemical features, this is to create new components which have new features instead of the element that has one feature and lose the other. The elements of alloys are varied. The name of the alloys has belonged to elements with largest percentage in the alloy. The most common alloys are Iron, Aluminum, Titanium, Magnesium and Nickel alloys. An alloy is a metal composed of more than one element. Engineering alloys include the cast-irons and steels, aluminum alloys, magnesium alloys, titanium alloys, nickel alloys, zinc alloys and copper alloys. For example, brass is an alloy of copper and zinc [20]. See table (1) for the advantages and the deficiencies of some alloys.

The alloy name has submitted to the element with the highest percentage in the alloy such as Iron alloy which consists of: C (0.35), Ni (3.8), Cr (1.7), Mo (0.3) and the rest of the (100) is Iron; these numbers are the percent of the alloy. This alloy has significant feature which is the high resistance to the fatigue and cracks [1].

If there is a typical engineering material that is associated in the public's mind with modern engineering practice, it is structural steel. This versatile construction material has several characteristics, or properties, that we consider metallic [20]:

1 - It is strong and can be readily formed into practical shapes.

2 – It is extensive, permanent deformability, or ductility.

3 - Freshly cut steel surface has a characteristic metallic luster.

4 - Steel bar shares a fundamental characteristic with other metals.

In an alloy, the constituent elements are not meant to combine into larger molecules through chemical reactions, but are merely mixed together. When there are different ratios between two or more metals, the alloys produced have slightly different properties [20].

Table (1) Advantages and deficiencies of alloys [1]

	Alloy	Features	Deficiency	Treatment
1	Aluminum	Light Cheap	Dimpling Low strength Cracking	Anodizing - Painting
2	Iron	High strength Fatigue resistance	Corrosion Dimpling Heavy weight	Cadmium plating Phosphating -
3	Magnesium	Strong	Corrosion Cracking Dimpling	Anodizing Painting Conversion coating
4	Titanium	High temp resistance Light	Expensive	
5	Nickel	High strength High temp resistance	Expensive	

The composites are consisting of tiny elements and surrounds with binder fiber which is called (cloth) and the compass as (resin). Composites consist of fibers and resins and the value of the fiber is very tiny and consists from one of the following: Fiberglass, Kevlar and Carbon Fiber (Graphite). The first one is the most common and cheaper and has good physical features like (Bid 7725). Each fiber called a cloth and binder as resin which is plastic element has compasses features like: Polyester, Vinyl ester and Epoxy. Epoxy is easy to mix, but expensive. The composites materials are known by the two components like Kevlar-Epoxy, Graphite-Epoxy [21].

Composites are combinations of two materials in which one of the materials, called the reinforcing phase in the form of fibers, sheets, or particles and it is embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile, or tough, material [14]. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The downside is that such composites are often more expensive than conventional materials. In modern aircraft polymers are used for parts of the airframe, window protection and lightly stressed parts [9].

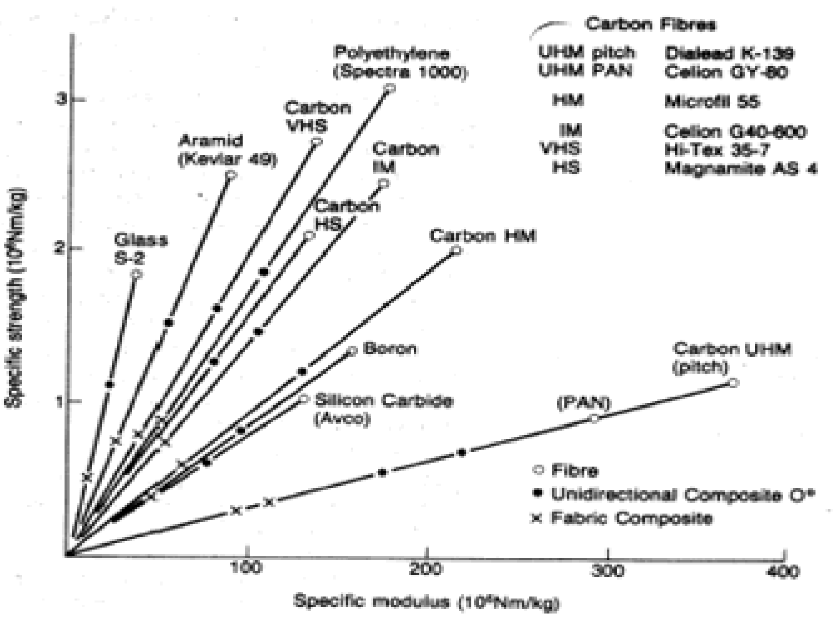

Figure (1) Properties of common reinforcing fibers [2]

2. Background

Glomb [17] describes a design for fiber-optic in advanced aircraft engine control. The recommended architecture is an engine contains fiber-optic interface. The study occurred in 19 positions on the aircraft.

Staley and Hunt [16] recognize that there are many possible drivers involved in the development and selection of materials for aircraft. They include, but are not limited to: low structural weight, high damage tolerance and durability, safety factors, cost, availability, manufacturability, reliability and maintainability. These drivers have evolved considerably since the beginning of the aircraft industry

Steven W. [8] explains the benefits of using the composite airframes especially in smaller airplanes. The reason is that composites don't fatigue like metal; don't corrode like aluminum; and composites can be molded and formed into shapes that are difficult and expensive to achieve using today's metal technology. Repairs of minor damage often can be accomplished in the field without a large outlay of money, using readily available materials.

Reznicek and et al [7] simulate an aircraft with significant shielding composite parts. The complicated composite is substituted by a homogenous dielectric layer with constant thickness instead of a fine metallic mesh on a laminate surface. The influence of replacing shielding composite parts by equivalents is investigated by observing the changes of the electric field distribution in the chosen areas.

3. Procedure of the Work

The study sets focus on the types of materials used in common airplanes either alloys or composites. Easily the airplane is divided into ten parts. The significant parts of an aircraft structure for the present study are the wings, fuselage or hull, nose, tail, landing gear, pylon box, fuel tank, the engine, screens and the surface controllers. In some cases, the materials explained according to its function as civil, military or transportation.

1- Body:

For civil aircrafts, (18Cr-8Ni) Iron alloys have been used for the internal surfaces of the body because of its high fatigue resistance. Aluminum alloys have been used for the external surfaces because of lightness and anti-corrosion property such as 7075-T6 (5.67 Zn, 2.5Mg, 1.6 Cu) and 2024-T3 (4.4Cu, 1.5Mg, 0.6Mn). But for the military aircrafts (6AL-4V) Titanium alloys has been used for the external surfaces [1].

In other hand, the using of composite materials being the common materials that used in accordance with these aircrafts [16]:

Boeing 777	Graphite-Epoxy	Fig (3-a)
Airbus A 320	Kevlar-Epoxy	Fig (3-b)
Atlas & F-15 Military	Nomex honey comb (DuPont)	Fig (3-c)

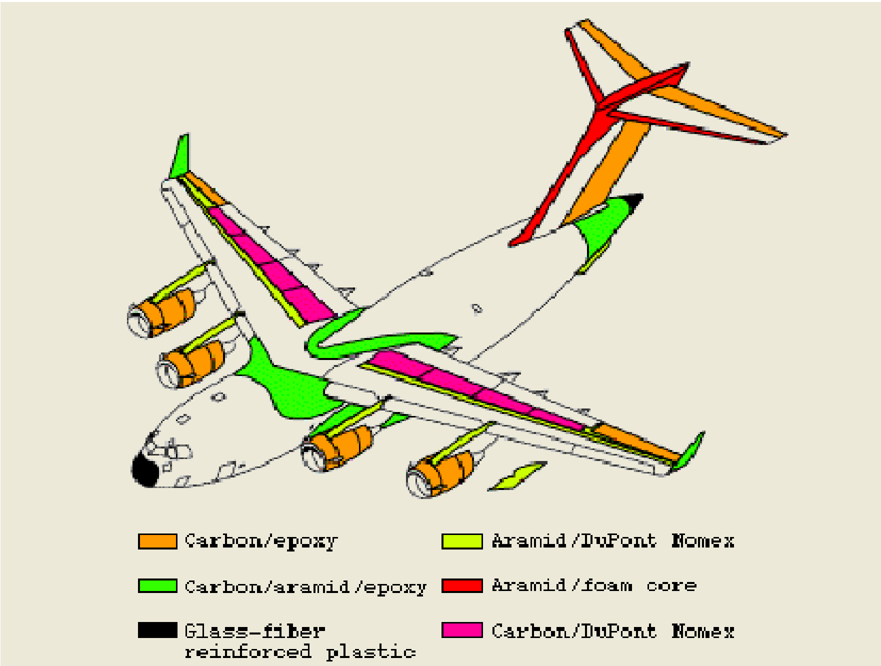

Figure (2) Composite materials used in airplane [11]

(a) Boeing **(b) Airbus** **(c) Atlas**

Figure (3) Bodies for some aircrafts [15]

2- Airfoil:

For the civil airplane, (7075-T6) Aluminum alloy has been used while (6AL-4V) Titanium alloys has been used for the military aircrafts. Aluminum-Zinc alloy has been used for painting Concord wings like Binary AL-Zn-Mg [18]. In the case of composites the Nomex honey comb became more suitable such as in F-15 [10]. The Beechcraft Starship, a twin-turboprop pusher design, was the first all-composite pressurized airframe ever certified. The wing structure used graphite/epoxy skins with Nomex honeycomb cores [8].

3- Under Carriage:

The Nickel alloy (0.35 C, 3.8 Ni, 1.7 Cu, 0.3 Mo) has been used because of its fatigue and stresses resistance [12].

4- Tail:

Aluminum alloy (6061-T6) has been used in the tail, but the edges has made from the compound plastic (CFRP) with fiber-glass. Nomex Honey Comb has been used in F-15 military Airplane [13].

5- Nose:

Magnesium alloy (MSR-B) has been used in Anglo- French military plane, or Aluminum - Lithium alloy has been used in modern airplane (concord) [1]. The modern airplanes have used the composites like Aramid (FRP) in Boeing [9].

6- Landing Gear:

Consists of the following alloys [1]:

Table (2) Types of alloys used in landing gear [1]

Contents	Alloys	Usage
1- Al DTD 5024	5.5(Zn) 2.5 (Mg) 0.5 (Cu) 0.5 (Mn)	Civil Airplane
2- Ti IMI 318	(6) Al (4) V	Military Aircraft
3- Steel S99	0.4 (C) 2.5 (Ni) 0.6 (Cr) 0.55 (Mo)	Transport Airplane

7- Pylon Box:

Since pylon box is allocated to save the engine, then using of the titanium alloy (6Al- 4V) is suitable for it [18].

8- Fuel Tank:

Almost, the tank is made from Aluminum alloy like (Al - Ni alloy) in Boeing 767 but a simulated chemical solution is added as a film to prevent pitting [23]. The fuel pump is made from an alloy resists the high temperature such as Titanium alloy [5].

9- Screens:

It consists of two layers of non-cracking plastic materials like one of the following [6]:

A- Poly Vinyl Butyral (Vinal)

B- Tri-Ethylene Glycol Di

C- Di Butyl Sebacate (D.B.S)

10- Engine:

The Engine of airplane which is an external type (open cycle) called also jet engine. It is consisted of the following parts:

A- Intake: This consists of diffuser and spike. It has been made of Aluminum because of its lightness [22].

B- Compressor: their parts have been made from Titanium alloy (6Al-4V) [1].

C- Combustor: Its walls have been made of Nickel alloy called 22-Hastelloy (20-22% Cr; 12.5-14.5% Mo; 2-6% Fe; 2.5-3.5% W; 55-60% Ni). Sometimes, Steel alloy (TS-2) has been used for the internal pad while the injector has been consisted of (Molybdenum, Copper and Tungsten) [4].

D- Turbine: has been made of Cobalt alloy (R30605-25) which consists of (Cobalt, Nickel, Chromium and Tungsten) or consists of Titanium alloy (6Al-4V). This alloy should be refractory of high temperature and exhausted gases [1].

E- Nozzle: has been made of Cobalt (6B-H) which consists of (Cobalt, Chromium and Tungsten) or consists of Titanium alloy or TZM alloys, which consists of (99% Mo, 0.5% Ti and 0.08% Zr) [1].

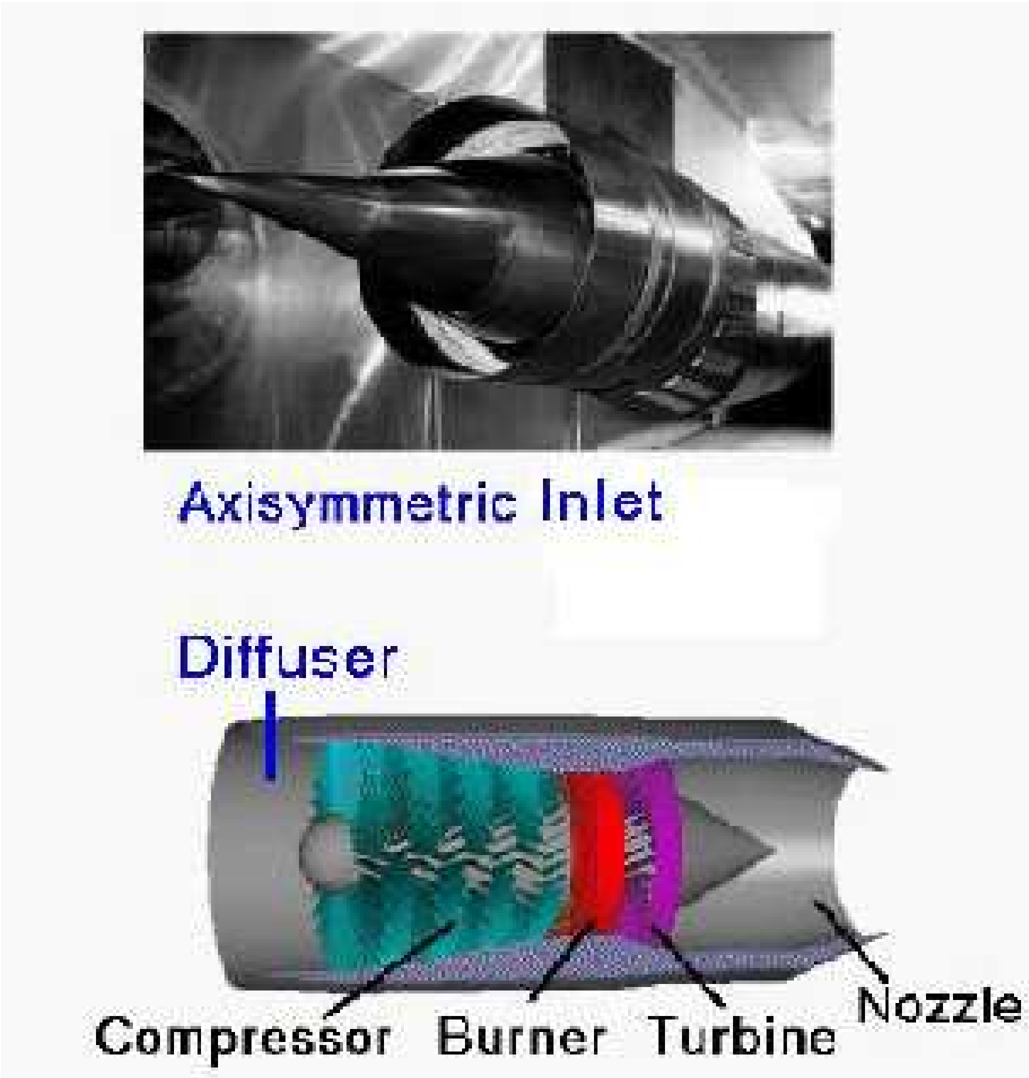

Figure (4) Jet engine [22]

4. The Calculation

The calculation of airplane weight of Boeing 777 and Boeing 787 is done in this study. The dimensions of Boeing 777 is based on the sketch of type (200LR) plane which mentioned in Boeing official web site, see figure (5), while the dimensions of Boeing 787 is depending on different references and comparisons.

The density of each component, which may be composite material or alloy, is taken from references. The mass of the component is calculated from the relation:

$$m = \rho \cdot V \qquad (kg)$$

Where:

ρ is the density of the component (kg/m^3)

V is the volume of the component (m^3)

The results of the calculations are shown in Table (3) for the calculation of component volume for Boeing 777. Table (4) shows the calculation of mass for Boeing 777. Table (5) shows the calculation of mass for Boeing 787 in the case of no composites development, while Table (6) shows the calculation of mass for Boeing 787 in the case of composites development. All calculations assumed empty plane and in absence of fuel, furniture and auxiliary parts.

The obtained results show that the reducing in the amount mass between Boeing 777 and Boeing 787 due to the small sizing of the new plane (Boeing 787) which is about 0.7 of the old plane (Boeing 777). The amount is about (40 Tons) and that is also referred in Boeing official web site. The results also show that the amount of reduction in mass of Boeing 787 by using the composites development in place of alloys, is 3.8 Tons. This amount is acceptable with that declared by Boeing Company which is about 3 Tons.

The differences between the calculated value and the actual values are due to:

1- The error in volume calculation.
2- The error in density estimation.

However, it can be said that the calculation gives good indication about how the composites reduce the overall plane weight.

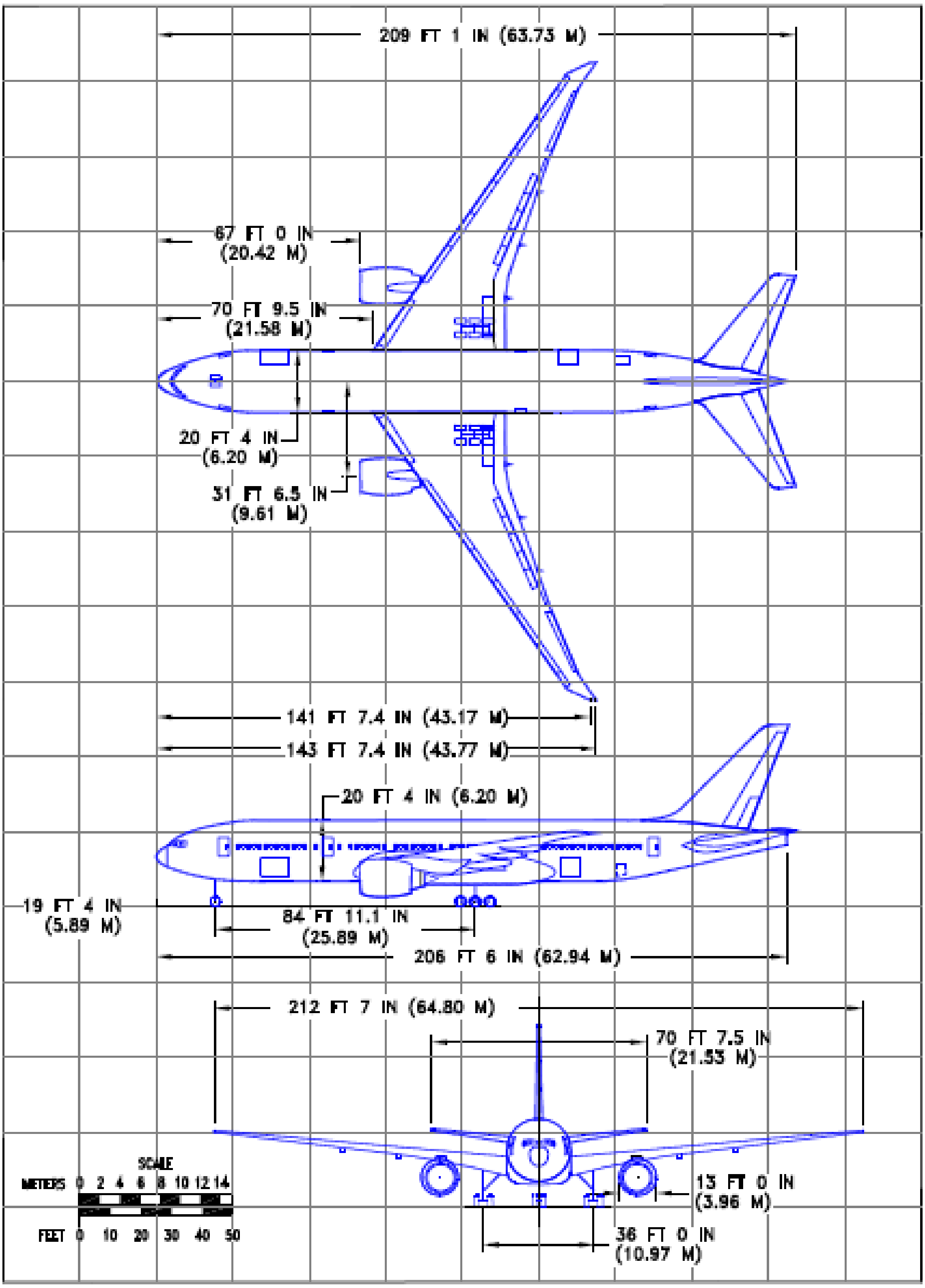

Figure (5) Layout of Boeing 777 [24]

Table (3) Calculation of component volume of Boeing 777

Item	Shape	No.	Dimensions	Thick. (m)	Volume (m3)
Body	Cylinder Cone	1 1	D=7 m L=50 m D=4 m L=7 m	0.015	19.5
Wings	Triangle	2	H=25 m B=12 m	0.020	6
Tails	Triangle	3	H=9 m B=6 m	0.020	1.6
Nose	Cone	1	D=4 m L=2 m	0.020	8.3
Pylon Box	Cylinder	2	D=3 m L=5 m	0.020	1.9

Table (4) Calculation of mass for Boeing 777

Item	V (m3)	Component	% V	Comp. Volume (m3)	Density (kg/m3)	Mass (Ton)
Body	19.5	Al(T6-7075)	72	14.04	2800	39.31
		Iron(18cr-8Ni)	14	2.73	7830	21.38
		Ti(6Al-4V)	9	1.76	4430	7.80
		Graphite-Epoxy	5	0.97	1500	1.46
Wings	6	Al(T6-7075)	85	5.10	2800	14.28
		Ti(6Al-4V)	8	0.48	4430	2.13
		Carbon-Nomex	2	0.12	1500	0.18
		Kevlar-Epoxy	5	0.3	1450	0.44
Tails	1.6	Al(T6-6061)	90	1.44	2790	4.02
		Carbon-Epoxy	10	0.16	1500	0.24
		Aramid-foam	0	0	1400	0
Nose	8.3	Mg (MSRB)	50	4.15	1350	5.60
		GFRP	50	4.15	1800	7.47
Pylon Box	1.9	Ti(6Al-4V)	90	1.71	4430	7.58
		Carbon-Epoxy	10	0.19	1500	0.29
Total Mass (Ton)						112.2

Table (5) Calculation of mass for Boeing 787 without composite development

Item	V (m3)	Component	% V	Comp. Volume (m3)	Density (kg/m3)	Mass (Ton)
Body	13.6	Al(T6-7075)	72	9.79	2800	27.41
		Iron(18cr-8Ni)	14	1.90	7830	14.88
		Ti(6Al-4V)	9	1.22	4430	5.40
		Graphite-Epoxy	5	0.68	1500	1.02
Wings	4.2	Al(T6-7075)	85	3.57	2800	9.99
		Ti(6Al-4V)	8	0.34	4430	1.51
		Carbon-Nomex	2	0.08	1500	0.12
		Kevlar-Epoxy	5	0. 12	1450	0.02
Tails	1	Al(T6-6061)	90	0.90	2790	2.51
		Carbon-Epoxy	10	0.10	1500	0.15
		Aramid-foam	0	0	1400	0
Nose	5.8	Mg (MSRB)	50	2.90	1350	3.92
		GFRP	50	2.90	1800	5.22
Pylon Box	1.3	Ti(6Al-4V)	90	1.17	4430	5.18
		Carbon-Epoxy	10	0.13	1500	0.20
Total Mass (Ton)						77.5

Table (6) Calculation of mass for Boeing 787 with composite development

Item	V (m3)	Component	% V	Comp. Volume (m3)	Density (kg/m3)	Mass (Ton)
Body	13.6	Al(T6-7075)	70	9.52	2800	26.66
		Iron(18cr-8Ni)	12	1.63	7830	12.76
		Ti(6Al-4V)	7	0.95	4430	4.21
		Graphite-Epoxy	11	1.50	1500	2.25
Wings	4.2	Al(T6-7075)	80	3.36	2800	9.41
		Ti(6Al-4V)	5	0.21	4430	0.93
		Carbon-Nomex	5	0.21	1500	0.32
		Kevlar-Epoxy	10	0.42	1450	0.61
Tails	1	Al(T6-6061)	70	0.70	2790	1.95
		Carbon-Epoxy	15	0.15	1500	0.23
		Aramid-foam	15	0.15	1400	0.21
Nose	5.8	Mg (MSRB)	50	2.90	1350	3.92
		GFRP	50	2.90	1800	5.22
Pylon Box	1.3	Ti(6Al-4V)	80	1.04	4430	4.61
		Carbon-Epoxy	20	0.26	1500	0.39
Total Mass (Ton)						73.7

5. Results and Conclusions

Generally, there are several results to be noted from the whole research

1- Results deal with the structure materials of the airplane indicated:

a. External parts (surfaces) should be made of light and anti-corrosion materials, so that Kevlar-Epoxy can be used instead of Aluminum alloys.

b. Internal parts (padding) should be made of strong materials, for example, Aramid (FRP) can be used instead of iron alloys.

c. Parts of engine should be made of refractory materials like Hastelloy or hybrids.
d. Fuel tank should be made of aluminum alloys.
e. Screens have made from composites like (Vinal).

2- Results deal with the weight calculation indicated that the amount of reduction in mass of Boeing 787 by using the composites materials in place of some alloys is 3.8 Tons. This amount is acceptable with that declared by Boeing Company which is about 3 Tons.
3- Development of the materials like hybrids which are employed where local variation of properties is required, perhaps in the vicinity of attachment or stress concentration, the Boeing-777 began to use it for the wing-to-body firing location [3].

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