Landing Gear Layout Design for Unmanned Aerial Vehicle

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Abstract

Aircraft landing gear mechanism serves several design purpose such as supporting the weight of aircraft, providing rolling chassis/taxiing and shock absorption function especially during takeoff and landing etc. The present study carried out to layout design of landing gear system for unmanned aerial vehicle (UAV) at conceptual design stage. The nose wheel tricycle landing gear has been the preferred configuration for UAV. The most attractive feature of this type of undercarriages is the improved stability during braking and ground maneuvers. The results of present study indicated that landing gear stability could be improved by longer wheel axle, stiffer damping mechanism and smaller wheel mass and lower aircraft sinking velocity. The present approach has been following the recommendations of the previous design of landing gear layout of other aircraft and international standard federal aviation regulations (FAR). More work to be done to prove the viability of this conceptual layout design. Detailed results needed further simulation study for validations.

Keywords: UAV, Landing gear stability, Shock absorber, Tip back angle, Landing gear load factor.

1 Introduction

This section contains the basic definition, classification and function of unmanned aerial vehicle and landing gear systems.

1.1 Unmanned aerial vehicle

An unmanned aerial vehicle (UAV) commonly referred to is a remotely piloted aircraft. UAVs come in two class: some are controlled from a remote location and others fly autonomously based on pre-programmed flight. There is a wide variety of UAV shapes, sizes, configurations, and characteristics.

UAVs perform a wide variety of functions. The majority of these functions are some form of remote sensing this is central to the reconnaissance role most UAVs fulfill, others functions include transport, research and development, to search for and rescue people in perilous locations etc. Nishant, Predator and Global hawk are importantly placed in the list of UAVs. The landing gear system required for those UAVs, which has conventional take-off and landing.

1.2 Landing Gear

Landing gear system is a major component of every aircraft. The landing gear serves a triple purpose in providing a stable support for aircraft at rest on the ground, forming a suitable shock-absorbing device and acting as a rolling chassis for taxiing during manhandling. It is the mechanical system that absorbs landing and taxi loads as well as transmits part of these loads to the airframe so that a majority of impact energy is dissipated. The main functions of the landing gear are as follows:

1. Energy absorption 2. Braking 3. Taxi control

The important types [1] of landing gear are as follows:

1. Tri-cycle type (nose gear in fuselage and main gear on wing)
2. Bicycle type (with or without outriggers)
3. Tail-gear type

In above-mentioned types of landing gear arrangement, the tricycle type with nose gear in fuselage and main gear on wing also called nose wheel landing gear has a series of unquestioned advantages over other layout of landing gear. In a general sense, the analytical solution of UAVs landing gear layout has received very little attention. One reason for this neglect is that its very wider classification and applications. The traditional landing gear design process for transport aircraft has described in textbooks "[1-4]". Therefore, in this paper nose wheel landing gear layout design for unmanned aerial vehicle has been described on basis of theoretical kinematics and international standard FAR.

2 Landing Gear Layout Design Parameters

This section represents a typical step by step approach that would be taken by the landing gear layout designer during conceptual design phase.

2.1 Main landing gear location

In the landing gear layout, the aircraft centre of gravity (c.g) location is needed to position the main landing gear such that ground stability, maneuverability and clearance requirements are met. The aerial vehicle has two c.g positions, forward c.g. corresponding to full fuel mass at the time of take-off and the aft c.g. when fuel has been used or at the time of landing.

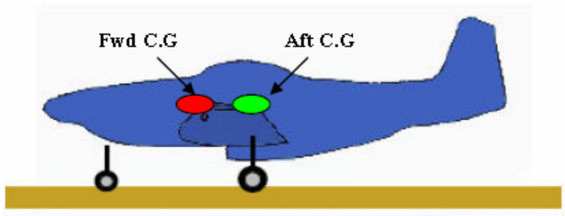

Fig. 1: Aerial vehicle with two c.g. positions.

The position of aircraft c.g. can be obtained by knowing the component weight and their positions. Mean aerodynamic chord calculation (MAC) calculation based in Fig. (2) and Eqs. (1-2).

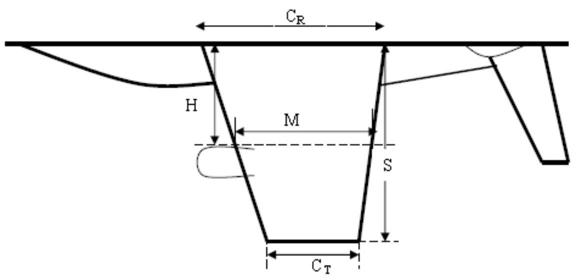

Fig. 2: Half 2-D plan view of UAV for calculation of MAC.

$$\text{MAC length (M)} = \frac{2}{3}\left[C_R + C_T - \frac{C_R C_T}{C_R + C_T}\right] \quad (1)$$

$$H = \frac{S\,(C_R - M)}{C_R - C_T} \quad (2)$$

The following steps are needed to position the main landing gear.

1a: Determination of mean aerodynamic chord of aircraft by using above Eqs. (1-2).

1b: Locate the forward and aft c.g. limit on the mean aerodynamic chord .

1c: Lines are drawn vertically from these forward and aft c.g. limits to locate the vertical position of the c.g. along these lines.

1d: Involves a recheck of the ensuing location of the main landing gear. It should be between about 50-55% of the MAC "[2]".

2.2 Load calculation on nose wheel and main wheel

The calculation of nose wheel and main wheel load are based on the diagram shown in Fig.(3) and the following as given relations and their constraints in Eqs. (3-5). The nose gear should be placed as far forward as to minimize its load, maximize flotation and maximize stability. Conversely, to allow for adequate nose wheel steering, a minimum normal force must act on the nose gear so that the appropriate level friction forces needed for steering can be generated.

Nose gear loads in the static condition generally vary about 6-20%, but these should be considered as extremes. A preferable range would be 8% with the c.g aft, increasing to 15% with the c.g. forward has been considering in present design calculations.

Max static main gear load (per strut)

$$= W\left(\frac{F-M}{2F}\right) \le (0.42\text{-}0.46)W \quad (3)$$

Max static nose gear load

$$= W\left(\frac{F-L}{F}\right) \le (0.08\text{-}0.15)W \quad (4)$$

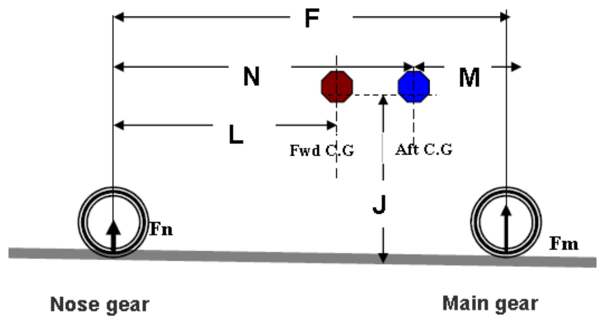

Fig.3: Diagram for Nose landing gear load calculation.

Min static nose gear load

$$= W\left(\frac{F-N}{F}\right) \ge (0.08)W \quad (5)$$

Max breaking nose gear load

$$= \text{Max static load} + 10J\left(\frac{W}{32.2F}\right) \quad (6)$$

Where W is the Take-off weight of aerial vehicle and other quantities are defined in Fig. (3). The equation (6) determines nose gear dynamic load, this is important for tire selection of landing gear "[4]".

2.3 Shock absorber stroke length calculation

The landing gears in most unmanned aircraft today are those making use of the solid steel spring or rubber and those making use of a fluid acting as spring with gas or oil, commonly known as the oleo-pneumatic landing gears. This technical paper has focused for conceptual layout design of oleo-pneumatic type shock absorber for both the main landing gears and the nose landing gear. The oleo-pneumatic shock absorber has been selected because it has the highest energy-dissipating efficiency among the various types of shock absorbers currently in use in the UAVs industry. It has efficiencies ranging as high as 0.7- 0.9.

Based upon the required sink speeds and load factors, the vertical wheel travel must be determined. Normal design in which the wheel and strut travel the same distance.

The first step is to determine the maximum loads accept able in the shock strut. This load comprises the static load plus the dynamic reaction load. When that load divided by the static load, the reaction factor N obtained. This is some time called to landing gear load factor or merely landing load factor. Its valued ranges from 2.0–3.0 for small utility aircraft or UAVs. Its permissible magnitude is determined by the airframe to accommodate those factors during landing impact.

Initially, the aircraft is assumed a rigid body with no relative acceleration between the c.g. and gear attachment point. Thus, the load factor at the c.g. is the same as the attachment. To understand fully the relationship between the load factor at the center of gravity Nc.g and the landing gear load factor N, consider a free body being acted upon by shock strut forces and lift, as

Shown in Fig. (4), Where Fs is the shock strut force and L, the lift. Thus

$$Nc.g = \frac{\text{Sum of all external forces}}{\text{Mass}} = \frac{F_s + L}{M} \tag{7}$$

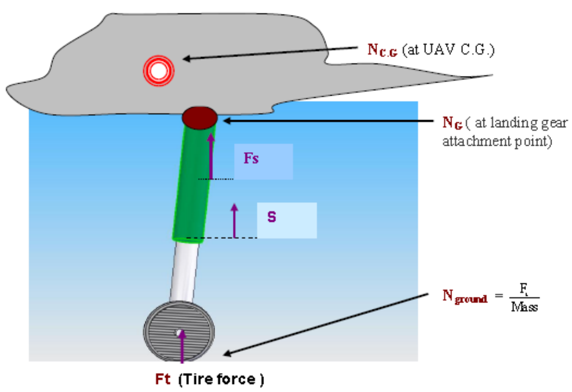

Fig. 4 Shock strut dynamics

When lift = weight W (as specified in FAR part25 for transport- type aircraft*)

$$\Rightarrow \frac{F_s}{M} + \frac{L}{\frac{W}{g}} = \frac{F_s}{M} + g$$

If, for convenience, the landing gear load factor N is defined as being equal to Fs/Mass, the gear load factor determine how much load ,the gear passes to the airframe, which affects the airframe structural weight as well as strength.

Then

Nc.g =1+N for FAR part 25 Aircraft

On utility and aerobatic aircraft, the rules of FAR part 23* apply and lift = 0.67w; i.e, W=l/0.67, as

$$Nc.g = \frac{F_s}{M} + \left(L \times \frac{0.67\,g}{L} \right) \tag{8}$$

Thus, for a given aircraft load factor, N will be higher for FAR Part23 aircraft than for FAR Part 25 aircraft. When the aircraft comes to rest on the ground, the lift is zero and the shock strut force is equal to the aircraft weight i.e. Fs =W Therefore

Nc.g =1+N for FAR part 23 Aircraft

The shock absorbers and tire act together to decelerate the UAVs from landing vertical velocity to zero vertical velocity. Therefore shock absorber and tire must also absorb the sum of the kinetic energy and potential energy of the aircraft; thus,

Tire Energy	Strut Energy	Kinetic Energy	Potential Energy

$$S_t \times n_t \times N \times W + S_t \times n_s \times N \times W = \frac{W\,V^2}{2\,g} + (W\text{-}L)(S+S_t) \tag{9}$$

Where St = Tire deflection under N times static load, ft

S = Vertical wheel travel, ft

n_t = Tire efficiency

n_s = Shock strut efficiency

N = Reaction

W = Aircraft weight

L = Lift

V = Sink speed

2.4 Lateral location of main gear

The tread and wheel base should to be determined. The relationship between the tread and wheel base is dictated by the turnover angle, which is determined as follows(Ref.Fig.5).

(1) Draw a top view showing the desired nose most forward C.G location

(2) Draw a side view showing the landing gear with shock absorbers and tire statically deflected and the C.G position.

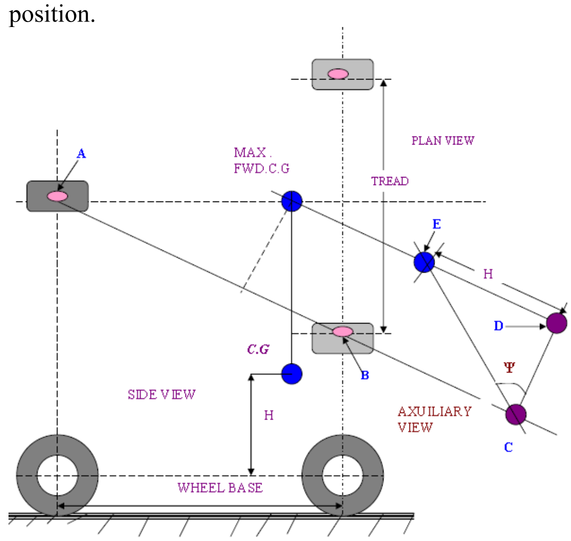

Fig. 5 Wheel track calculation based on turn over angle

(3) Establish line A-B Extend the line to a point "C".
(4)Through point, "C" draws a perpendicular to line A-B.
(5) Through the c.g. (in the plane view draw a line parallel to A-B and obtain point "D".
(6)From point "D" measure height of the c.g. (H) obtained from the side view and obtain point "E".
Ψ = 63deg for aircraft that are restricted to operate on smooth, hard surfaced runways. This values is based on a side friction coefficient of μ = 0.55 and the assumption that the aircraft will slide sideways instead of tipping over.

2.5 Tire selection

The tires are sized to be carried out the weight of the aircraft .Typically the main tires are carry about 90% of the total weight of the aircraft weight .Nose tires carry only about 10 % of the static load but experience higher dynamic loads during landing. In conceptual design stage we can find a tire size by using a statistical approach "[3]". Given below equations developed from data for rapidly estimating main tire size (assuming that main tire carry about 90% of aircraft weight). These calculated values for diameter and width should increase about 30% if the aircraft is to operate from rough unpaved runways. Nose tires can be assumed to be about 60- 100% the size of main tire.

Calculation of wheel diameter and width for main wheel Main wheels diameter or width (inch) =A $W^B{}_W$
W_W = weight on wheel. For general aviation aircraft,
A=1.51, B = 0.349 for calculation of diameter
A=0.715, B = 0.312 for calculation of width

3 Numerical Case Study

In this section we will discuss a case study of landing gear layout for following given dimensions

Table -1: Landing gear layout case study parameters

	Analysis Parameters	Value
1	Aircraft Take off weight	2000 kg
2.	Length of UAV	10 m (approx)
3.	Wing location	3.5 m (L.E) from nose of UAV
4	Wing span	21 m
5	Root chord	0.975m
	Calculated Data	
6	MAC position	4.34 m
7	C.G (vertical)	1.5m (From ground)
8	C.G shift	0. 10 times of MAC length
9	Tip chord	0.5 m
10	Aft C.G location	5.0 m from nose
11	MAC	0.74 m (7 cm max)
12	Fwd C.G position	4.90 m (Approx)from nose
13	Load factor	2.5

3.1 Load calculation

Nose gear loads calculation based on 8% with the c.g. aft, increasing to 15% with the c.g. forward.

Max nose gear load = 2000x15/100 = 300kg
Min nose gear load = 2000x8 /100 = 160 kg

Main gear load (per strut) = 850kg and 920 kg

3.2 Shock absorber stoke length calculation

For instance, let N =3, St =0.9 ft and V=15ft/s and assume 1 g wing lift such that L/W=1(at the time of landing) Then stroke length calculation as given in eq.(9)

$\Rightarrow$ $3(0.9 \times 0.47 + S \times 0.8) = 15^2 / 2 \times 32.2 + (1-1)$

$(S+0.9)$ $\therefore$ Stroke (S) = 11.10 inch

Table -2: Shock absorber stoke length

	Sink velocity (ft/s)	**Load factor** (g load)	**Stroke length** (Inch)
1.	15	3	11.10
2.	12	2.5	7
3.	10	2.0	5.3

For an initial layout, assume that a quarter to a third of the total stroke is used in moving from static to compressed thus for a 11.10inch stroke,3.7 inch is the distance from static to compressed and 7.4 inch that from static to extended.

3.3 Nose landing gear position

The length of landing gear must be set so that the tail does not hit the ground on landing. This is measured from the wheel in the static position assuming an aircraft angle of attack ($\alpha^0{}_{0.9}$) for landing which gives 90% of the maximum lift this range from about 3-8 deg for most types of aircraft.

Another hand the "tip back" angle is the maximum aircraft nose up attitude with the tail touching the ground and strut fully extended. To prevent the aircraft from tipping on its tail, the angle off (θ) the vertical from the main wheel position to the c.g. should be greater than the tip back angle or 15 deg whichever is larger. There is a rule-of–thumb which are correlate between alpha ($\alpha^0{}_{0.9}$) and theta (θ) as That is

$$\theta^0 = \alpha^0{}_{0.9} + 3^0$$

At conceptual design stage we have taken a range (3^0-8^0) of value alpha ($\alpha^0{}_{0.9}$)which are feasible for this solution than corresponding value of thita (θ) in that range is (6^0 –11^0) With known value of vertical c.g. height (H) from the level ground so corresponding (M) distance between Aft c.g. to main wheel position horizontally as shown previous Fig.6.

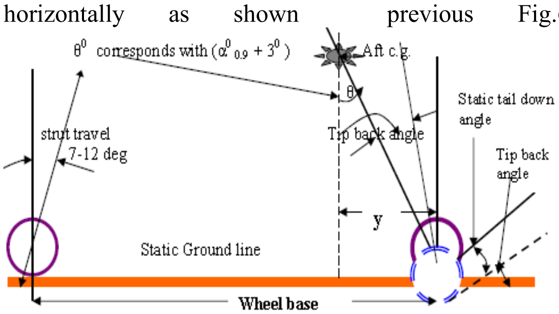

Fig. 6 Tricycle landing gear geometry

Suppose as ideal value $\alpha^0{}_{0.9}$ is 6 deg than corresponding value of θ is 9 deg an nose wheel carry 10% of MTOW than wheelbase can be calculated as

So value of M = H tan (θ) => 1.5 tan 9^0 = 0.237 m (where value of H = 1.5m approx) Load on nose wheel is 200 and corresponding load main wheel 900kg

Take moment about nose wheel

Max static main gear load (per strut) = W (F-M)/2F, where F is wheel base in meter

=> 900= 2000 (F-M) /2F

∴F = 10X.0.237 = 2.4m

Table- 2: Wheelbase corresponding given turnover Angle

SL No	$\alpha^0{}_{0.9}$ (Angle for0.9 CL max)	θ(Tip back angle) ($\theta^0 = \alpha^0{}_{0.9} + 3^0$)	M (Distance between Aft C.G and MLG	Percentage load on Nose gear of MTOW				
				8%	**9%**	**10%**	**11%**	**12%**
				Wheel Base (m)				
1	8	11	0.29	3.625	3.22	2.9	2.63	2.41
2	7	10	0.264	3.3	2.93	2.64	2.4	2.2
3	**6**	**9**	**0.237**	**2.96**	2.39	2.37	2.15	1.975
4	5	8	0.21	2.65	2.12	2.1	1.90	1.75
5	4	7	0.1841	2.3	1.85	1.84	1.62	1.53
6	3	6	0.1576	1.97	1.58	1.57	1.43	1.31

3.4 Lateral location of main landing gear

Calculation of lateral location of main landing gear, which is, depends upon turnover angle and C.G height. For a given C.G height, we can calculate the lateral location of main landing gear in a given feasible range of turnover angle. The turn over angle θ must not be more 63 deg for typical UAV to operate on smooth, hard surfaced runways. We can calculate the lateral separation of landing gear

For a given parameters C.G height H = 1.5 approx and value of D = 2.7 m and wheel base = 3 m

From given geometry in Fig. 5, we can calculate wheel track as given

Tan Ψ = H / K, Where CD =K ,Then

Tan50 = 1.5/K => K = 1.3

There fore sin Φ = K / D => Φ = 28 deg

(where D = 2.7 m)

Now TanΦ = Z / F => Z = tan 28 X F

=> Z = 0.53 x3 => Z =1.53 m

(F =4.115 m)

wheel track = 2 Z =2x1.53 = 3.2m
For a given wheel base F= 3m, M =2.37m, for different turnover angle wheel track as below

Table- 3: Wheel track corresponding given wheelbase

Parameter	1	2	3	4	5	6	7	8	9	10
Turn over angle (deg)	46	47	48	49	**50**	52	53	54	55	56
Wheel track(m)	3.7	3.5	3.4	3.25	**3.2**	2.9	2.8	2.7	2.57	2.46

We have calculated the wheel track for the turnover angle range from 45 deg to 55 deg

3.5 Tire sizing

Calculation of wheel diameter and width for main wheel. For general aviation aircraft and UAVs,

A=1.51, B = 0.349 for calculation of diameter "[4]".

D =AW^Bw for diameter calculation, max load per wheel of main landing gear = 1000 kg

Use log both sides logD = log A+ B log Ww

⇨ logD = log1.51 + 0.349 log 920

∴ D = 16.40 in

Tire dia range from (14-16.40 in)

Similar way for width (T) calculation of main wheel

T = AW^Bw, By using log both sides, log T = log A +B log Ww

Log T = log0.7150 +0.312 log 1000 kg

∴ Tire width (5.0-6.1in)

Calculation of tire diameter for nose wheel where nose wheel total (static +dynamic) Max load 650 kg (including 7% margin of safety) Nose wheel tire can be assumed to be about 60- 100% the size of the main wheel tires. Nose wheel tire detail tire size 13-16 in and tire width is around 4-6 in.

4.0 Results and Discussion

The results of the study also indicated that landing gear stability could be improved by longer wheel axle, smaller wheel mass and lower aircraft velocity. The nose wheel tricycle gear has been the preferred configuration for UAV. It leads to a nearly level fuselage when the aircraft is on the ground, important for payload safety.

The most attractive feature of this type of undercarriages is the improved stability during braking and ground maneuvers. Under normal landing attitude, the relative location of the main assembly to the aircraft *cg* produces a nose-down pitching moment upon touchdown. This moment helps to reduce the angle of attack of the aircraft and thus the lift generated by the wing.

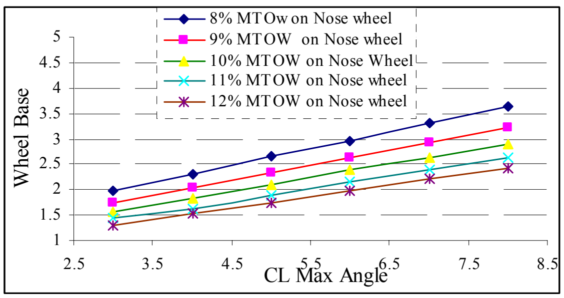

Fig. 7: Nose wheel Vs wheel base at constant angle

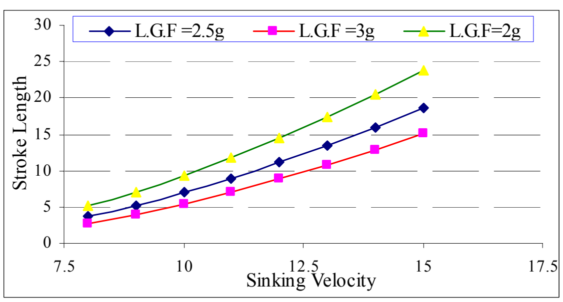

Fig. 8: Sink speed Vs vertical wheel travel

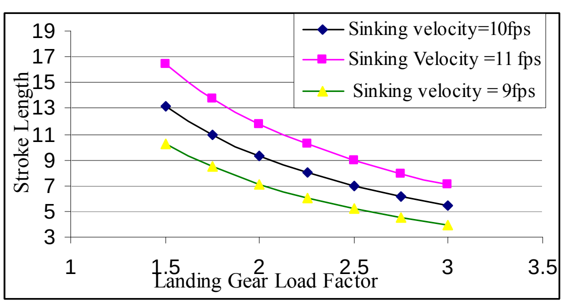

Fig. 9: Vertical wheel travel Vs load factor

In addition, the braking forces, which act behind the aircraft c,g., have a stabilizing effect and thus enable the external pilot to make full use of the brakes. These factors all contribute to a shorter landing field length requirement. While the shock absorber stroke is not a function of the aircraft weight, nevertheless it is vital to increase the size of the stroke to lower the landing load factors and thereby minimizing the structure weight due to landing loads. To accommodate this requirement, larger-section tires can be utilized. However, the penalty for this solution is the increase in aircraft weight and therefore reduced payload that would be too costly for UAVs.

5 Concluding Remark

Based on present study of landing gear layout design of UAVs the following concluding remark are drawn.

- Nose gear loads in the static position preferable or optimum range would be 8-12%.
- The wheel track of landing gear is approximately 25-30 % of wing span in UAVs cases.
- The stroke length of oleo –pneumatic shock absorber is approximately equal to touchdown sink speed.
- The strut length is about 2.5 to 3.0 times the stroke length.
- Nose wheel diameter is 60-100 % of main wheel dim in nose wheel landing gear.

Many more options could be decided to functionally and operationally improve the present conceptual design by using various computer simulation programs. These results needed experimental data to validate it.

References

[1] Roskam(1986), Airplane design part IV: Layout design of landing gear systems, Roskam aviation and engineering corporations

[2]Currey (1988). Aircraft Landing Gear Design: Principles and Practices 1st Edition, American Institute of Aeronautics and Astronautics.

[3]H.G Conway, “Landing gear design,” The Royal Aeronautical Society Chapman and Hall Ltd, 1958.

[4]Daniel P. Raymer (1992). Aircraft Design: A Conceptual Approach 1st Edition, American Institute of Aeronautics and Astronautics, Inc, p229-256.

[5] Joseph E. Shigley (1977). Mechanical Engineering Design 3rd Edition, McGraw Hill, Inc., p26, 34, 37-40, 43-45, 60, 94-120, 295-313.

[6]Department of Transportation, Federal Aviation Administration (1976). Airframe and Power plant Mechanics Airframe Handbook Revised 1st Edition, Aviation Maintenance Publishers, Inc., p341-405.

[7].Young ,D,E., “Aircraft landing gears-The past, present and future,” proceedings of the institute of mechanical engineers,vol 200,noD2,1986,pp. 75-92.

[8]S.F.N Jenkins, Landing Gear Design and Development, Proc. Instn. Mech. Engrs. Vol. 203, pp. 67-73.