FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

ANALYSIS OF AN SC-17M DESIGNED MAIN LANDING GEAR LOADING ACTION

[1]Sunny, O. U., [1]Obinnaya, N., [2]Japheth, G. C. , [3]Nnaemeka, J. A. and [4]Bello, Y.

[1]*Dept of Aircraft Engineering, Air Force Institute of Technology Kaduna. Nigeria*
sunnyokeminiuguzo@yahoo.com; *evobartho27611@gmail.com*
[2]*Dept of Mechanical Engineering, Nigerian Defence Academy, Kaduna. gideonchinerem@yahoo.com*
[3]*Dept of Mechanical Engineering, Air Force Institute of Technology Kaduna. Nigeria.*
necojohnsona@yahoo.com
[4]*Dept of Mechatronics Engineering, Air Force Institute of Technology Kaduna. Nigeria.*
belloyekinnitopa@gmail.com

Sunny O. U., Obinnaya N., Japheth, G. C. , Nnaemeka J. A. and Bello Y. (2022): Analysis of An Sc-17m Designed Main Landing Gear Loading Action. *Journal of Engineering and Engineering Technology /16(1), 20-26*

Received 02-07-21 **Accepted:11-02-22**

Abstract
The concept of the SC-17M aircraft design was initiated to address the shortfalls on the DO-228 and Hawker Beechcraft King Air 350i aircraft. Utilizing the EASA design certification standard, an SC-17M landing gear design has been carried out. Detailed study of sub-part C of the certification standard aided the application and determination of the necessary loads on the landing gear. The comprehensive design employed 300M steel as the best structural material to be used in the fabrication of the landing gear. The maximum bending moment in the shock absorber and wheel axle were calculated and validated with the use of Strand7 software stress analysis modelling. The reserve of strength calculated showed that the landing gear was able to withstand the applied loads without experiencing any failure.

Key words: Landing gear, loads, wheel spin-up, spring-back, braked roll, tail down

Introduction

The aircraft undercarriage as the landing gear is one of the primary systems incorporated to aircraft fuselage or wing. It provides structural support to the aircraft for different ground operations. It provides means to absorb unusual loads incurred during landing and ground operations. The landing gear can be classified in different forms: it can be classified based on the method of retraction where we have retractable and fixed wheel landing gear. It can also be classified based on the surfaces it land. These include Wheel, Skids, Skis and Pontoon/Float landing gear. Lastly it can be classified based on its configuration: Tail wheel/conventional landing gear, Tandem and Tricycle type landing gear (Abbe and Udu, 2018).
However, the concept of SC-17M aircraft was initiated to address the shortfalls on the DO-228 and Hawker Beechcraft King Air 350i. The shortfalls on the DO-228 were as a result of its high failure rates, increased maintenance demand and the aircraft dispatch reliability and turn-around time dwindled. Due to the problem of DO-228 and the Hawker Beechcraft King Air 350i. The aircraft is pressurized and incorporated to it was a glass cockpit design and state of the art cabin management system which enhanced it luxury requirements. The king air 350i has a low failure rate and minimal maintenance need which makes it to be outstanding in air operations but causes drawback in terms of capacity due to the incorporated nine number of seat configuration unlike the DO-228 which is Nineteen seats. Also, the absence of extended range tanks and confined fuselage space rendered it not wholly fit to meet the new role assigned to it for "intelligence surveillance reconnaissance purpose" (Rod, 2019).

The SC-17M designed landing gear requirements are detailed down in the CS-23 which is the regulatory requirement applicable to the size of the aircraft. The aircraft is a twenty seat maximum turboprop aircraft with minimum and maximum cabin altitude of 7000 feet and 35000 feet and a range of 2500 km. The aircraft ramp mass is 5796 kg, maximum take-off mass of 5700 kg and operating empty mass of 3567 kg. The aircraft is a high wing regional turboprop of a similar layout to its competitors: the DO-228 and King air 350i. The aircraft is 17 m fuselage length, 2.16 m external diameter, 2.06 m external height and 20.2m wing spa

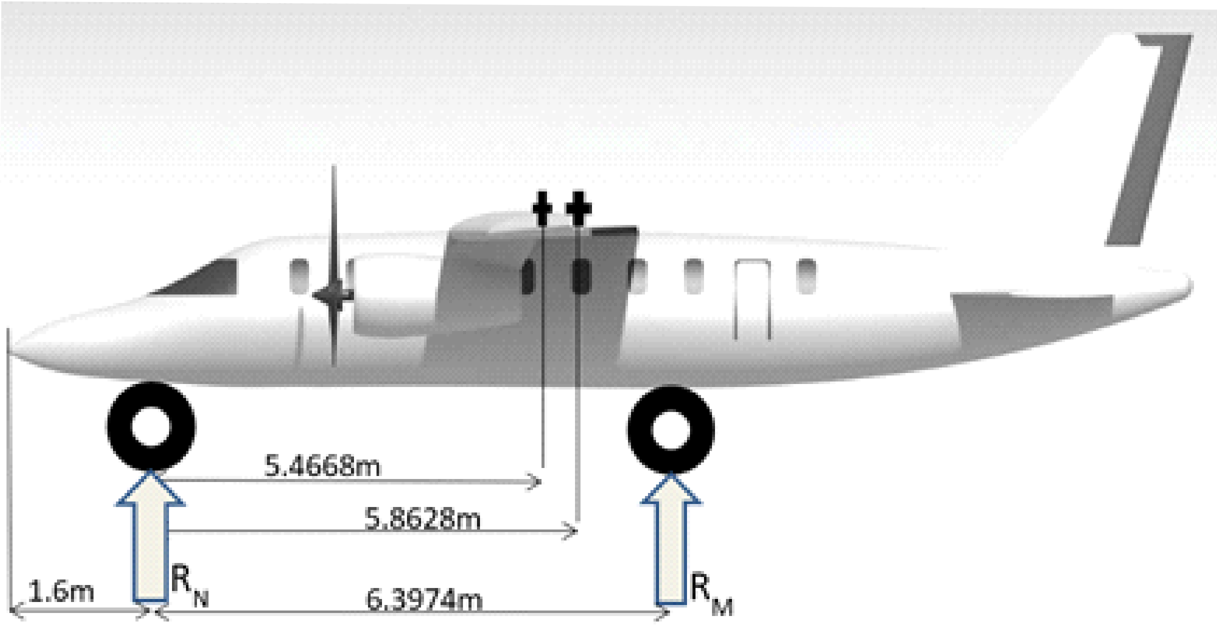


Figure 1: An SC-17M aircraft

The tricycle landing gear type was considered in this study. The layout of the gear is of two types: Firstly, one has the location of the center of gravity (CG) forward of the main landing gear with a steerable or caster nose wheel thereby maintaining horizontal fuselage installation while the other has the center of gravity aft of the main gear with tail dragger gear. The later has inclined fuselage installation that is the fuselage floor is inclined. Hence, the study focused on the gear with forward CG and steerable nose wheel because of its high pilot visibility and eliminating the problem of hydroplaning as seen in tail dragger type during landing (Abbe, 2018).

Materials and Methods

There are numerous materials for aerospace application ranging from metals, plastics, composites and ceramics material. The choice of materials depends on the area of application, the required material strength and stiffness, its resistance to corrosion, wear, crack growth propagation and fatigue life. The aircraft landing gear is designed with safe life philosophy such that its life span is the same as that of the aircraft and it is unlikely to fail while in service. The materials used in this work includes 300M steel, Strand7 software, landing gear design hand books, a computer set and the conventional methods are listed below in cases (EASA, 2013).

I.Standard Certification Governing Equations

Case 1 Limit Landing. CS-25.473(a).2 specify landing at maximum landing weight and descent velocity of 3.05 m/s.

Case 2: Limit Aborted Take-off. CS-25.473(a).3, this case specifies aborted take-off occurring at maximum take-off weight and vertical velocity of 1.83 m/s.

The kinetic energy (1) represents the total energy absorbed by the landing gear system

$$KE_{case1,2} = \frac{M_L \times v_V^2}{2} \quad \text{...........................(1)}$$

When two-point landing is considered, each unit of the main gear will absorb half of this energy since only two struts are being designed for.

In calculating the maximum vertical reaction on each of the two struts, a reaction factor λ of which represent the ratio of the maximum vertical reaction to the static load on the strut. This is presented in equation (2).

$$(R_M)_{max} = \frac{\lambda \times M_L \times g}{2} \quad \text{........................(2)}$$

The reaction per tire is calculated using equation (3):

$$R_{T(case1,2)} = \frac{(R_M)_{max}}{2} \quad \text{....................(3)}$$

With this vertical reaction on the tire, the tire deflection can be calculated considering the tire stiffness calculated above, using equation (4).

$$\delta_{T(case\ 1,2)} = \left(\frac{R_T}{K_T}\right)^{\frac{1}{1.1}} \quad \text{.....................(4)}$$

i. Shock Strut Deflection

The energy absorbed is given as the product of the shock strut efficiency, its maximum load and maximum deflection and the tire efficiency, its maximum load and maximum deflection. From this

 https://doi.org/10.51459/futajeet 2022.16.1.339

relationship, the shock absorber deflection can be determined assuming tire efficiency, shock absorber efficiency and shock absorber reaction factor, using equation (5)

$$\delta_{MS(case\ 1,2)} = \frac{1}{\eta_{MS}}\left(\frac{V_v^2}{2\lambda g} - 2\eta_{MT}\delta_T\right) \quad (5)$$

I. Total Gear Deflection

The total gear deflection $\delta_{MS(case\ 1,2)}$ is the sum of the tire deflection and shock absorber deflection. Also, one inch of travel is added to protect the mechanism from bottom out, using equation (6).

$$\delta_{MG(case\ 1,2)} = \delta_{MS} + \delta_T + 25.4 \quad (6)$$

I. Overall Landing Gear Efficiency

The overall landing gear efficiency $\delta_{MG(case\ 1,2)}$ is the ratio of the sum of the products of shock absorber defection and its efficiency and the tire deflection and its efficiency to the sum of the shock absorber deflection and the tire deflection, using equation (7).

$$\eta_{MG(case\ 1,2)} = \frac{\eta_{MS}\times\delta_{MS}+\eta_{MT}\times\delta_T}{\delta_{MS}+\delta_T} \quad (7)$$

I. Main Gear Reaction-Tail down/Two Point Level Attitude

For tail down attitude, each of the main landing gear unit will absorb half of the kinetic energy during the impact. The formula below is used to determine the main gear reaction for two-point landing attitude, using equation (8).

$$R_{M(case\ 1,2-2point)} = \frac{M_L V_v^2}{4\times\eta_{MG}\times\delta_{MG}} \quad (8)$$

I. Main Gear Reaction (Three Point Attitude Case 1)

This part of case 1 and 2 will take into account the energy absorbed by the main gear for forward and aft center of gravity the SC-17M aircraft. The equation below as stated is used to determine the reaction at the main gear for both forward and aft CG, calculated using equation (7). (Uguzo, 2010)

$$R_{M(case\ 1,2-3point)} = \frac{M_L V_v^2}{4\times\eta_{MG(case\ 1)}\times\delta_{MG(case\ 1)}}\cdot\left[\frac{L_N-\mu H}{L_M+L_N}\right] \quad (9)$$

Where μ *is ground friction coefficient given as* 0.25
H *is center of gravity height*

Case 3: Level Attitude Wheel Spin-Up and Spring-back. CS-23.479(b) stated that the drag component simulating the force needed to accelerate tire and wheel up to landing speed (spin-up) must be combined with vertical ground reaction. It states also that the forward acting horizontal load which result from rapid reduction of the spin-up drag (spring-back) must also be combine with vertical ground reaction assuming wing lift and tire sliding coefficient of 0.8 and drag load must not be less than 25% vertical reaction.

Case 4: Tail down Landing Condition. CS-23.483 specified that the aircraft should be at level attitude and contact ground on one side of the main gear unit. The ground reaction is assumed to be the same as that described in CS-23.479.

Case 5: Side Load Condition. CS-23.485 Subparagraph (a) state that the aircraft is assumed to be in a level attitude and shock absorber and tire are in their static position. Subparagraph (b) states that the limit vertical load factor must be 1.33 with vertical ground reaction divided equally among the main wheels. Subparagraph (c) prescribe side load inertial factor to be 0.83 with side ground reaction divided among the wheels such that 0.5 and 0.33 of the reaction will act inboard and outboard and drag load assumed to be zero.

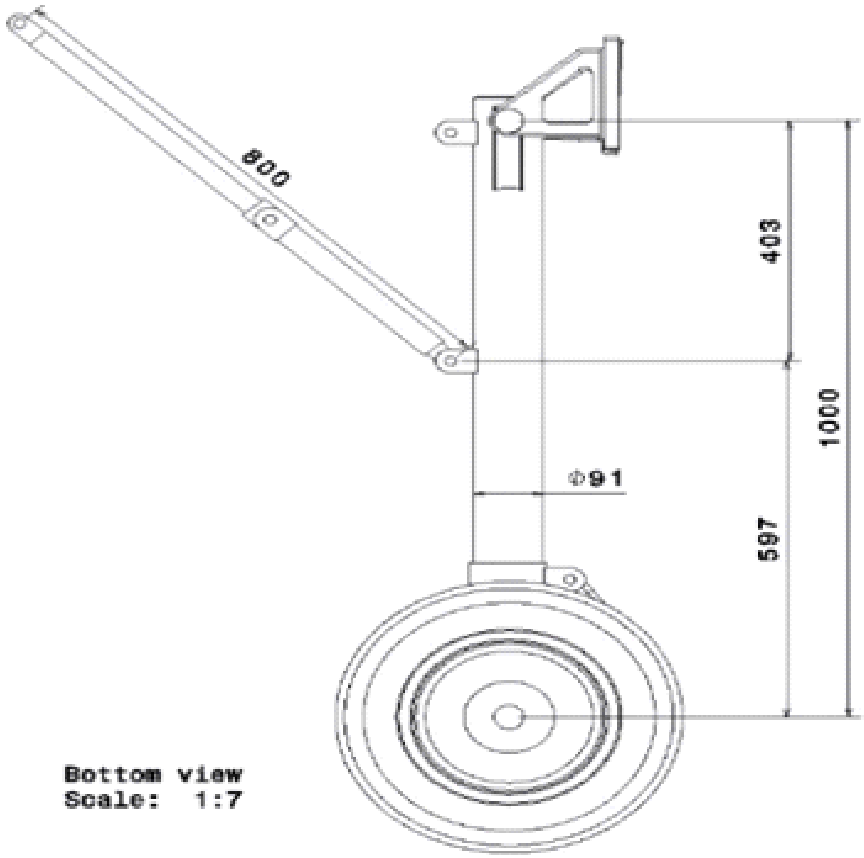
Case 6: Braked roll conditions. Subparagraph (a) of CS-23.493 specified that the limit vertical load factor must be 1.33 and subparagraph (c) prescribe drag reaction equal to vertical reaction times 0.8 coefficient of friction applied at ground contact point with each wheel.

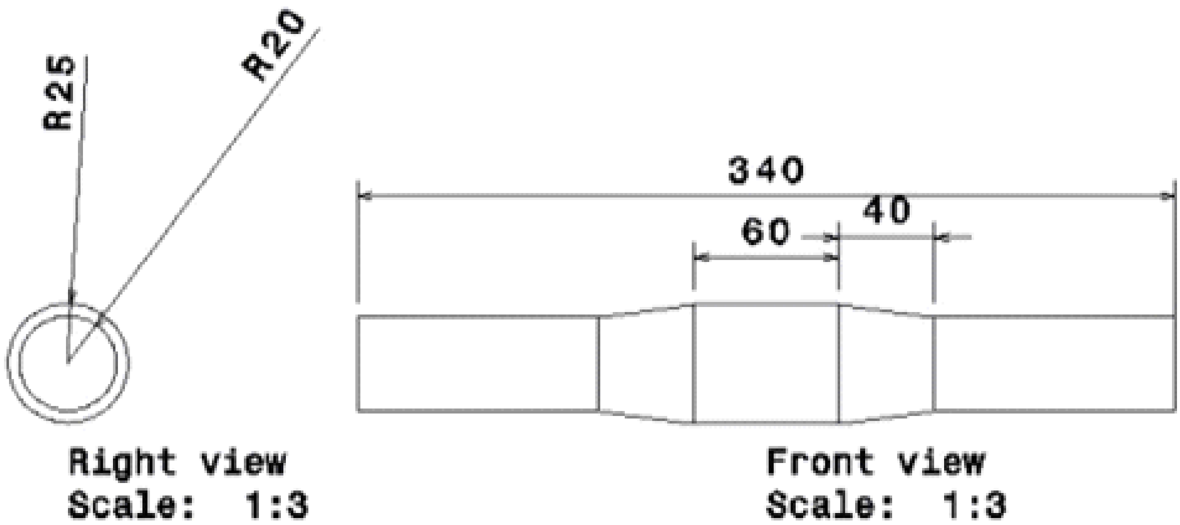
Case 7: Jacking Load. CS-23.507 stated that the aircraft must be designed to withstand load applied when on jack. A vertical load factor of 1.33 times the static reaction must be applied. Also load factor of 0.4 time's vertical load for forward, aft and lateral load should be applied.

Case 8: Towing Loads Conditions. CS-23.509(a) states that a vertical load of 1.0 to act at CG, the struts and tire are in static position. CS-23.509 sub-paragraph (b) states that for towing points not on landing gear but on a plane of symmetry of the aircraft, the drag and side tow load components for the auxiliary gear applies while for towing points located outboard of the main gear, the drag and side tow load for the main gear applies. CS-23.509(d) prescribed the towing loads for main gear and auxiliary gear towing points considering the maximum weight of the aircraft.

Case 9: Ground Load; Unsymmetrical Loads on Multiple-wheel units. CS-23.511(a) Pivoting Loads. This sub-paragraph assumed that the aircraft is pivoted about one side of the main gear with brakes on pivoting unit locked. It prescribed that the load corresponding to the limit vertical load factor of 1 and a coefficient of friction of 0.8 be applied to the main gear and its supporting structure. And CS-23.511(b) Unequal tire Loads. The loads pertaining to CS-23.471 through 23.483 are to be distributed in 60/40% manner to the dual wheels and tire in each unit. And CS-23.511(c) Deflated tire loads. 60% of load calculated for CS-23.471 to 23.483 be applied to each wheel of main gear unit. Also 60% of the drag and side loads and 100% of limit vertical loads under 23.485 and 23.493 be applied to each wheel in the dual wheel landing gear unit (Garth, 2018).

I. Design Specifications





i. Material Properties

Table 1: Material Properties

MATERIAL		PROPERTIES				DENSITY
		Ftu (MPa)	Fty (MPa)	Fcy (MPa)	E (MPa)	ρ Kg/m^3
ALUMINUM	2024-T4	393.0	289.6	262.0	73776.5	2778.0
	7075-T6	537.8	489.5	482.7	71018.5	2778.0
TITANIUM		789.9	868.8	910.1	110320.0	4444.4
STEEL	17-7PH	1220.4	1034.3	1103.2	199955.0	7667.0
	300M	1930.6	1586.0	1703.1	199955.0	7917.0
NICKEL		1068.7	689.5	689.5	213745.0	8333.0
GLASS FIBER		551.6		413.7	34475.0	1806.0
KEVLAR		1103.0		275.8	82740.0	1389.0
CARBON		1172.2		965.3	151690.0	1556.0

From Table 1, Kevlar has higher structural efficiency than other structural material because of its weight to strength ratio. The efficiency is the ratio of the ultimate tensile strength of material to the density or the ratio of the young modulus to the density. This shows that the composite and aluminum can be applied in fuselage construction and other structural components not subjected to adverse tension and compression. The 300M steel has the highest ultimate tensile, yield and compressive strength. Because of the mechanical properties of the 300M steel, it was chosen for SC-17M landing gear application.

3. Results and Discussion

Table 2: The Load Summary for Both Case-1 and case-2 (landing and Aborted Take-off)

Attitude	CG Position	case	Limit load (N)	Ultimate load (N)
Tail down	N/A	1	42603.6513	63905.4770
		2	48929.0056	73393.5084
Three points	FORWARD	1	33086.0601	49629 0901
		2	37790.0572	56685.0858
	AFT	1	35723.3547	53585.0321
		2	40802.3082	61203.4622

Table 2 shows that the highest kinetic energy absorbed by the undercarriage system occurs at tail down attitude implying that the main undercarriage absorbed all the kinetic energy without assistance of the nose gear.

Table 3: Wheel Spin-Up and Spring-back (Case 3)
As stated in CS-23. 479.b, the drag must not be less than 25% of vertical reaction and the forward acting horizontal load is 0.8 of the drag. The relationship is shown in the table below.

Load	Load factor (R_M)	Limit load (N)	Ultimate load
Vertica l	-	48929.0056	73393.5084
Drag	0.25	12232.2514	18348.3771
Forward acting	0.20	9785.8011	14678.7017

Table 4: Tail down Landing Condition (Case 4)
As specified in CS-23.483 the aircraft should be at level attitude and contact ground on one side of the main gear unit. The vertical reaction will be the maximum limit load calculated in case-2

Case 2	Limit load (N)	Ultimate load(N)
Tail down attitude	48929.0056	73393.5084

Table 5: Side Load Condition (Case 5)
CS-23.485 Subparagraph (a) state that the aircraft is assumed to be in a level attitude and shock absorber and tire are in their static position. Subparagraph (b) states that the limit vertical load factor must be 1.33, with vertical ground reaction divided equally among the main wheels. Subparagraph (c) prescribe side load inertial factor to be 0.83 with side ground reaction divided among the wheels such that 0.5 and 0.33 of the reaction will act inboard and outboard and drag load assumed to be zero.

Load	Load factor (R_M)	Limit load (N)	Ultimate load (N)
Vertical	1.33	65075.5775	97613.3662
Side	0.83	40611.0747	60916.6120
Drag	-	-	-
Inboard Reaction	0.50	24464.5028	36696.7542
Outboard Reaction	0.33	16146.5719	24219.8578

Table 6: Braked Roll Conditions (Case 6)
Subparagraph (a) of CS-23.493 specified that the limit vertical load factor must be 1.33 and subparagraph (c) prescribe drag reaction equal to vertical reaction times 0.8 coefficient of friction applied at ground contact point with each wheel.

Load	Load factor (R_M)	Limit load (N)	Ultimate load (N)
Vertical	1.33	65075.5775	97613.3662
Drag reaction	0.80	39143.2045	58714.80067

Table 7: Jacking Load (Case 7)
CS-23.507 stated that the aircraft must be designed to withstand load applied when on jack. A vertical load factor of 1.33 times the static reaction must be applied. Also load factor of 0.4 times vertical load for forward, aft and lateral load should be applied.

Load	Load factor (R_M)	Limit load (N)	Ultimate load (N)
Vertical	1.33	65075.5775	97613.3662
Forward	0.40	19571.6022	29357.4034
Aft	0.40	19571.6022	29357.4034
Lateral	0.40	19571.6022	29357.4034

Table 8: Towing Loads Conditions (**Case 8**)
CS-23.509(a) states that a vertical load of 1.0 to act at CG, the struts and tire are in static position. CS-23.509 sub-paragraph (b) states that for towing points not on landing gear but on a plane of symmetry of the aircraft, the drag and side tow load components for the auxiliary gear applies while for towing points located outboard of the main gear, the drag and side tow load for the main gear applies. CS-23.509(d) prescribed the towing loads for main gear and auxiliary gear towing points considering the maximum weight of the aircraft W.

Tow Point	Position	Magnitude (W)	Load (N)
Main gear		0.225	12581.325
Auxiliary gear	Swiveled forward	0.300	16775.100
	Swiveled aft	0.300	16775.100
	Swiveled 45^0 from forward	0.150	8387.550
	Swiveled 45^0 from aft	0.150	8387.550

 https://doi.org/10.51459/futajeet 2022.16.1.339

Table 9: Ground Load; Unsymmetrical Loads on Multiple-wheel Units (Case 9)

Case	1	2	3	4	5	6
Vertical load	42603.65	48929.00	48929.00	48929.00	65075.58	65075.58
60% Vertical	25562.19	29357.40	29357.40	29357.40	39045.35	39045.35
60% Drag	-	-	7339.35	-	-	23485.92
Forward	-	-	5871.48	-	-	-
Inboard	-	-	-	-	14678.70	-
Outboard	-	-	-	-	9687.94	-

Conclusion

In this study, the preliminary SC-17M landing gear design have been carried out where it was discovered that sub-part C of the certification standard aided the application and determination of the necessary loads on the landing gear. The detail design employed 300M steel as the best structural material as used in the design of the landing gear. The maximum bending moment in shock absorber and wheel axle were calculated and validated with the use of strand7 software that aided the stress analysis of the landing gear. It was also revealed that the reserve of strength calculated showed that the landing gear is able to withstand the applied loads without experiencing any failure.

Acknowledgement

The Department of Aircraft Engineering, Air Force Institute of Technology (AFIT) Nigeria is acknowledged for her various supports.

Reference

Abbe, G.E. (2018). Loading Action, Landing Gear Loads, UK: College of Aeronautics Aerospace Vehicle Design Cranfield University.

Abbe, G. E and Udu, A. G. (2018). Surveillance/Commuter Aircraft SC-17M Project Specification Kaduna : Air Force Institute of Technology.

EASA, (2013). CS-23 as Amended, United Kingdom: European Aviation Safety Agency .

Garth P (2018). Aerospace Structure, South Wares Australia: Mechanical and Manufacturing Engineering, University of South Wares Australia.

Rod, C. (2009). Main Landing Gear Design for the A-8 Hummingbird , UK: Cranfield University .

Uguzo S. O. (2010). A-9 Dragonfly Nose Landing Gear Design , UK: School of Engineering, Aerospace Vehicle Design Crandfield University .