RESEARCH
Vol. 15, February, 2018

ISSN 2319–7757
EISSN 2319–7765

Indian Journal of Engineering

Redesign of Air Bettle Aircraft Nose Landing Gear

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Article History
Received: 04 January 2018
Accepted: 20 February 2018
Published: February 2018

Citation
Enigbe OS, Uguzo SO, Lawal MS, Thomas S. Redesign of Air Bettle Aircraft Nose Landing Gear. *Indian Journal of Engineering*, 2018, 15, 19-28

ABSTRACT

The content of this re contains the first attempt at redesigning the Nose Landing Gear of the Air Bettle-18 (ABT 18) to an Unmanned Aerial Vehicle. The nose landing gear is an in-line single-wheeled nose gear of tricycle configuration. It features a single acting oleo-pneumatic shock absorber with a total vertical axle travel of 0.2547m. Steering is achieved by the used of Electro-Mechanical servo-actuator with a 60^0 effective steer angle. This nose gear is non-retractable and is fixed to the bulkhead of the aircraft via the trunnion. Its static closure is 69.90% of the total stroke. The nose landing gear meets a lot of the requirements as defined by Project Specification and EASA CS-23 but will require additional work to be completely compliant. The design philosophy for the ABT-18 Nose Landing Gear is safe life with primary material being Steel AISI 4340.

Keywords: Shock absorber, Unmanned Aerial Vehicle, Landing Gear

1. INTRODUCTION

The ABT 18; a low winged monoplane trainer aircraft with a non-retractable landing gear entered into service with the Nigerian Air Force [1]. Over the course of its operation it presented maintenance, safety and reliability challenges, some of which include (but were not limited to):

1. Nose Landing Gear buckling.
2. High Cylinder Head temperature.
3. Low fuel octane rating.
4. Old Avionics System.

To keep the aircraft in continued service and improve performance, it became necessary to modify this aircraft into an Unmanned Aerial Vehicle (UAV) with an overall improvement in aircraft performance across all systems [2]. This proposed UAV is intended to communicate with a Ground Control Station (GCS) forming an Unmanned Aerial System (UAS) with improved 'automatic intelligence'. The increasing intelligence of UAS means the proposed UAV can be deployed in several roles considered dull, dirty, covert and/or environmentally critical [3]:

The modification of this monoplane into a UAV is a group design project (GDP) carried out at the Air Force Institute of Technology (AFIT). The project was split into the following groupings:

1. Structures.
2. Systems and
3. Avionics.

The aim of this project is to redesign the Nose Landing Gear (NLG) for the ABT 18 (Standard Version) UAV that will be of optimum weight and structurally sound enough to handle all static and dynamic loads over the course of its operation in the Nigerian air space.

To achieve the aim, the author intends to:

1. Evaluate the current nose landing gear subassembly. Its configuration, connection to airplane, components materials, failure modes and similarities with other aircraft will be critically appraised.
2. Redesign of the nose landing gear to meet the following:

a. a. Airworthiness Requirements in concordance with EASE Certification Specification (Part 23) and the Project Specification requirements.

b. Landing Gear Structural Integrity with Weight Minimization.

The landing gears were designed using a safe life design philosophy. Reason (as with most aircraft landing gears) being catastrophic failure elimination: This design approach will look at the complete elimination of catastrophic fatigue failure or greatly reduce the probability of such failure occurring. The landing gears will have a 'minimum life' and will be replaced when life limit has elapsed. This could make the gears of considerable weight and thus, minimum weight (while being able to handle all loads) becomes all the more important to achieve.

2. ANALYSIS

This section is split into two:

1. Evaluation and
2. Redesign.

2.1. EVALUATION OF ABT 18 NOSE LANDING GEAR

It is required to understand fully the reason(s) why the current landing gear in its configuration fails as it does. This is needed to justify a redesign. The purpose of doing this is to collect necessary data, analyze and then confer conclusions based on data collected. This section also covers a comparative study between the landing gears of ABT-18 and similar aircraft. Based on the visual inspection of the undercarriages, these are the information/observations gotten:

CONFIGURATION: Tricycle with nose landing gear attached to the engine bulkhead via a truss-like tube structure.

COMPONENTS: The major components of the nose landing gear are listed below

1. Steel tube.
2. Aluminum Fork.
3. Tyre and Wheel subassembly.

The entire wheel assembly is connected to an aluminum fork (for swiveling) fastened to the extruded steel tube. This assembly is connected to the engine bulkhead via a tubular truss-like structure (mount). The steel tube is faired to reduce aerodynamic drag seeing as the undercarriages were designed to be non-retractable. The entire nose landing gear assembly is connected to the engine bulkhead via the mount.

Upon speaking with the technical crew that handles the maintenance of the ABT 18 (Standard Version) at 333 Logistics it was learnt that the nose landing gear buckled when it experienced hard landing by trainee students/personnel. This failure needs to be corrected if there is to be improved structural integrity of the nose landing gear. For the singular reason of poor shock absorption, a redesign is justified. Nevertheless, the Experimental Failure Investigation on the ABT 18 Nose Landing Gear [4] as published by the International Journal Metallurgical and Material Science and Engineering (IJMMSE) contains more information about the NLG failure as a function of material selected. Major highlights from their research are listed below.

1. Material used, based on compositional analysis, is a medium carbon steel of the tough grade. This falls below the standard requirement (high strength spring steel) as used in most aircraft.
2. Failure mode was impact fatigue failure initiated at the inclusions present in the microstructure leading to crack propagation through the matrix and eventual fracture.

To achieve the primary objectives, comparative analysis of landing gear configuration, shock absorption and steering has to be carried to enable the best cost-to-benefit gear selection. The factors of shock absorber efficiency, weight, cost (manufacturing and maintenance) and the desires of the customers were considered.

A large percentage of air vehicles, from those manned to those unmanned have an undercarriage configuration that is nose wheel tricycle configuration. The advantages of using this configuration are well documented. The spring steel tube has to be replaced with a hydraulic shock absorbing strut for better energy absorption and dissipation. The steering is achieved by differential braking of the MLGs. NLG Steering actuation by use of servo controlled mechanical linkages will be implemented [4].

2.2 REDESIGN OF ABT-18 NOSE LANDING GEAR

The design procedure followed is as documented by [6] requiring that the following be analyzed, calculated and/or selected:

1. Longitudinal positioning of landing gears.
2. Preliminary tyre and wheel selection.
3. Shock absorber design.
4. Steering system design.

2.2.1. LONGITUDINAL POSITIONING AND STATIC LOAD DISTRIBUTION

Positional layout of the landing gear relative to the fuselage (Center of Gravity) is the first job any undercarriage designer must carry out. According to [5] there are no set/defined regulations guiding landing location and as such best practices as prescribed from his experiences and documentations by [6], [7] will serve as a guide. It is important to note also that adequate load distribution between NLG and MLG is essential in avoiding structural and operational problems.

Having decided the configuration of the landing gear, some landing gear geometry has to be determined to position the gears as shown in Fig 1. Parameters such as wheel track, wheel base, height and distance between main gear and the aircrafts center of gravity are important as regards load distributions. These parameters have been defined in the Project Specification [2] and it is within the limits imposed that the following calculations were made.

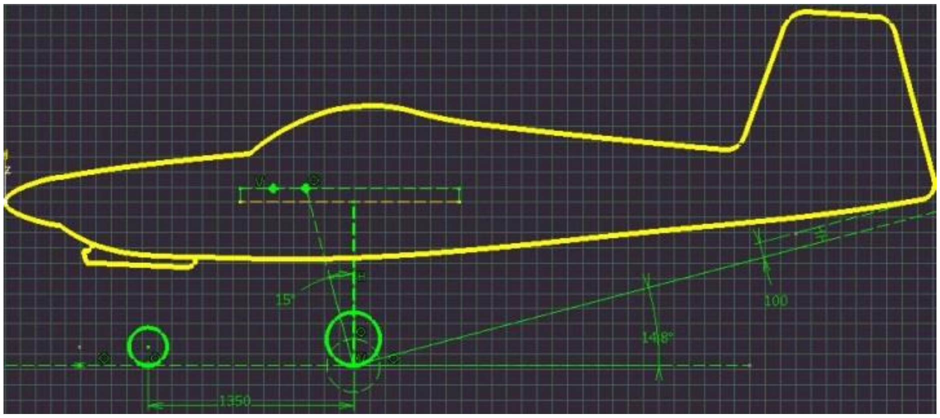


Figure 1 Initial Side view layout of Landing Gears

The NLG load at fore CG is calculated thus: $R_N^{MAX} = \frac{W * L_M^{MAX}}{WB}$ where all parameters are as described in Table 2

Table 1 NLG Static reaction (Modified)

WB (m)	R_N^{MAX} (N)	% NLG LOAD	R_M^{MIN} (N)	%MLG LOAD
1.8	2410.07	29.22	5837.32	70.77

Table 2 Data Extract from Project Specification [2]

PARAMETERS			
DESCRIPTION	SYMBOL	VALUES	UNITS
Aft CG Distance to Nose Datum	X_{ACG}	1.9434	M
Fore CG Distance to Nose Datum	X_{FCG}	1.739	M
MLG distance to aft CG	L_m^{min}	0.3216	M
MLG distance to fore CG	L_m^{max}	0.5260	M
Design Take-Off Weight	W	8247.3927	N
Wheel Base	WB	1.35	M
MLG Distance to Nose Datum	X_{MLG}	2.265	M

From Table 2 it is observed that the NLG carried 29.22% of static load-being above the ideal range (6-20) % as described by[6]. Nevertheless this load percent couldn't be reduced because no further increase in wheel base was possible. Having established the static load distribution the preliminary tyre and wheel selection is done next.

2.2.2. PRELIMINARY TYRE AND WHEEL SELECTION

The major parameters calculated for were the rated speed, rated load, inflation pressure and tyre deflection. The tyre data book referenced in [8] and the summary of the results obtained are shown in the tables below. Strict adherence to the procedures outlined by [6] was followed.

Table 3 Rated Speed

MAXIMUM TYRE VELOCITY		
SYMBOL	VALUES	UNITS
V_T	30.19	m/s
V_T	67.54	Mph

Table 4 Nose Tyre Rated Load and Corresponding Dimensions

SELECTED NOSE TYRE DATA (GOODYEAR EXTRACT)										
S/N	RATED LOAD (N)	INFLATION PRESSURE (psi)	SIZE	PLY RATING	RATED SPEED (mph)	WEIGHT (lb.)	NOMINAL DIAMETER (mm)	NOMINAL WIDTH (mm)	SLR (m)	TYPE
1	1200	55	5.00-4	6	120	4.3	330	127	0.14986	TYPE III
2	1150	29	5.00-5	6	120	6.7	355	155	0.14351	TYPE III

3	**1100**	**55**	**16*4.4**	**4**	**210**	**8.3**	**401**	**110**	**0.17526**	**TYPE III**

Table 5 Deflection of NLG Tyre Selected

NOSE TYRE DEFLECTION FOR SELECTED TYRE		
SYMBOLS	**VALUES**	**UNITS**
D_M	**0.355**	**M**
SLR	**0.144**	**M**
δ_{T}	**0.034**	**M**
K_T	**211056.06**	**$N/m^{1.1}$**
R_N^{MAX}	**2410.07**	**N**
RATED LOAD	**5115.45**	**N**
δ_{TSN}	**0.0172**	**M**

Table 6 Nose Tyre Pressure

NOSE TYRE PRESSURE				
S/N	**RATED LOAD**	**RATED PRESSURE**	**N^T_L**	**P_{CN}**
1	**1200**	**55**	**914.32**	**41.91**
2	**1150**	**29**	**914.32**	**23.06**
3	**1100**	**55**	**914.32**	**45.72**

Figure 2 CAD Model of Selected Tyre

The corresponding wheel parameters[8] are shown below.

Table 6 Corresponding Wheel Diameter for Selected Tyre

CORRESPONDING WHEEL DATA FOR SELECTED TYRE				
S/N	**WHEEL SIZE**	**WIDTH BETWEEN FLANGES**	**RIM DIAMETER**	**FLANGE HEIGHT**
1	**6.00-6**	**5.00**	**6**	**0.75**

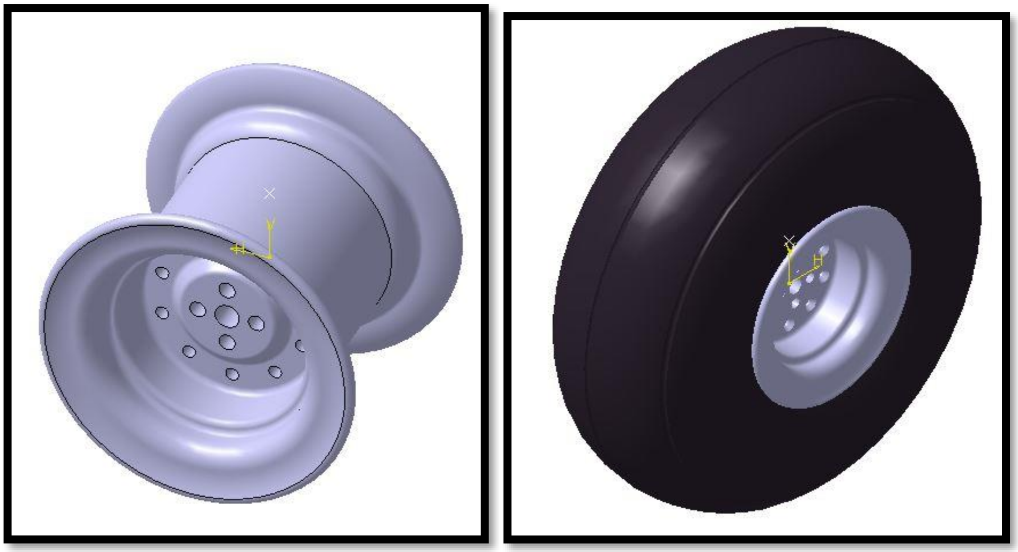


Figure 3 CAD Models of Tyre-Wheel Assembly

2.2.3. SHOCK ABSORBER DESIGN

After carrying out a dynamic loading action as prescribed by the EASA CS-23 Specification, the oleo-pneumatic shock absorber was designed. The EASA CS-23 outlines the load envelope concerning landing and ground maneuvering for the NLG. Loads due to landing, taxi, take-off, towing and jacking are spelled out in this document (Young, 2004)[5].

CS-23 LOAD ENVELOPE				
V_N=V_{2N} and V_{STATIC}=R_N^{MAX}				
S/N	**LOADING CASES**		**LIMIT LOAD**	**ULTIMATE LOAD**
1	**Level Landing with Spin-Up**	**V=**	**11753.69**	**17630.54**
		D=	**9402.95**	**14104.43**
		S=	**0.00**	**0.00**
2	**Tail down Landing**	**V=**	**14692.12**	**22038.17**
		D=	**0.00**	**0.00**
		S=	**0.00**	**0.00**
3	**Braked roll**	**V=**	**5413.21**	**8119.81**
		D=	**4330.56**	**6495.85**
		S=	**0.00**	**0.00**
4	**NLG Supplementary Load: Aft Loads**	**V=**	**5422.66**	**8133.99**
		D=	**4338.13**	**6507.19**
		S=	**0.00**	**0.00**
5	**NLG Supplementary Load: Forward Loads**	**V=**	**5422.66**	**8133.99**
		D=	**-2169.06**	**-3253.60**
		S=	**0.00**	**0.00**
6	**NLG Supplementary Load: Side Loads**	**V=**	**5422.66**	**8133.99**
		D=	**0.00**	**0.00**
		S=	**3795.86**	**5693.79**

7	**NLG Supplementary Load: Steerable NLG**	V=	3253.60	4880.39
		D=	0.00	0.00
		S=	0.00	0.00
8	**Jacking Loads**	V=	3253.60	4880.39
		D=	1301.44	1952.16
		S=	1301.44	1952.16
9	**Towing Loads (Forward, Aft: Swivel Forward, Aft): 5,6,7,8**	V=	2474.22	3711.33
		D=	0.00	0.00
		S=	0.00	0.00
9	**Towing Loads (Forward, Aft: Swivel 45^0 Forward, Aft): 9,10,11,12**	V=	1237.11	1855.66
		D=	0.00	0.00
		S=	0.00	0.00

The piston was sized thus: $A_p = \frac{V_N}{P_2} = \frac{22038.71}{1034550} = 0.00215637\ \mathrm{m}^2$ where the most critical load was used to size the piston.

The corresponding piston diameter $D_P = \sqrt{\left(\frac{4A_P}{\pi}\right) = \left(\frac{4*0.00215637}{\pi}\right)} = 0.05208\ \mathrm{m}$

Concerning load/stroke analysis shown in Fig 4 is a single stage with one air chamber that permits no mixing was selected. The load stroke analysis is done to ascertain the load, pressure and volume as the shock absorber starts to deflect from a fully extended position to its fully depressed position as shown in Fig 5.

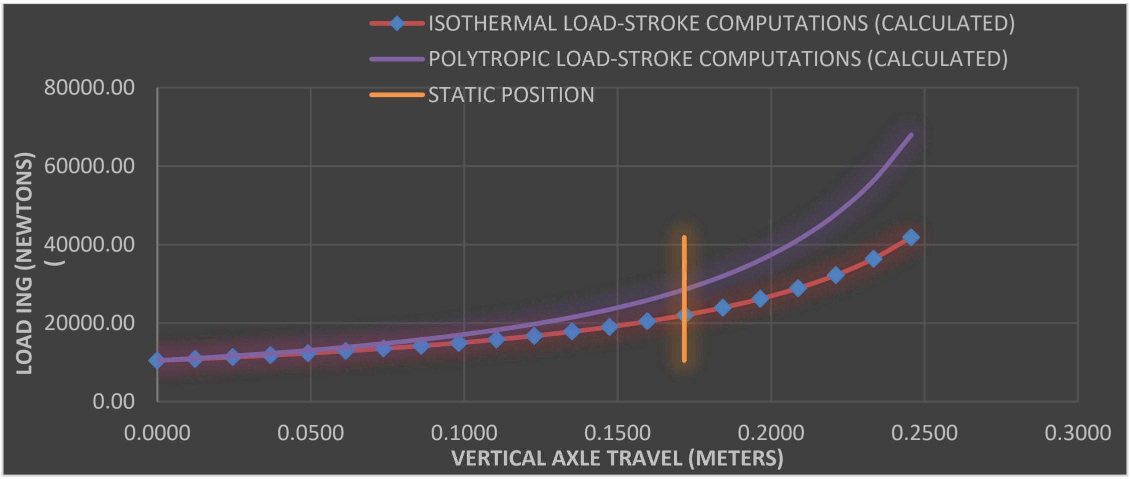


Figure 4 Load-stroke analysis

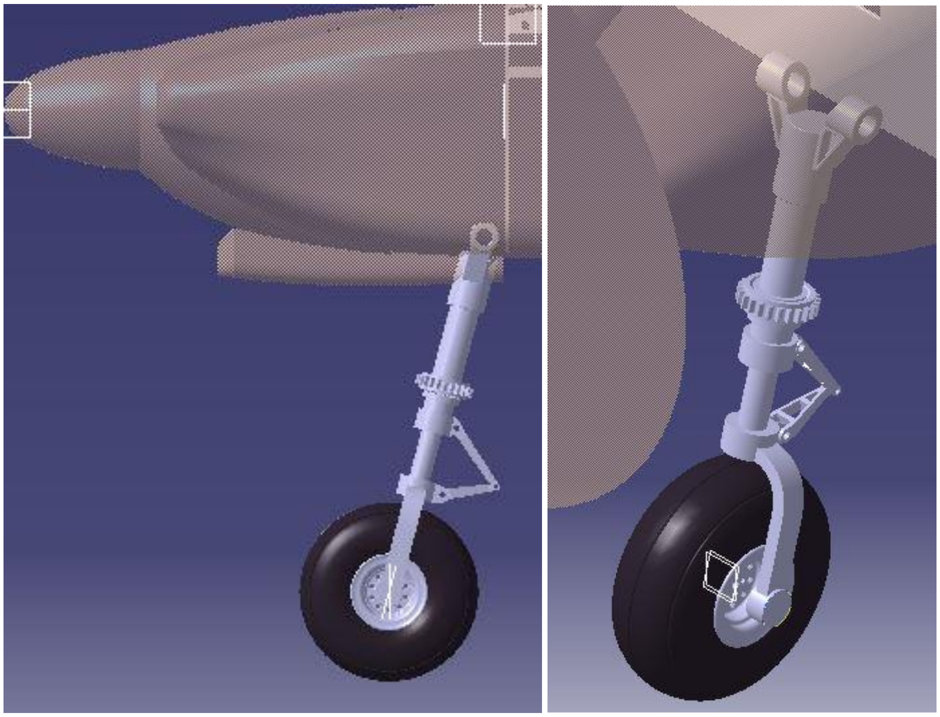


Figure 5 Side view of redesigned NLG

2.2.4 STEERING SYSTEM DESIGN

The actuation system consists of direct drive worm screws geared to an internal and external toothed collar that mates with grooves on the shock cylinder as shown in Fig 6.

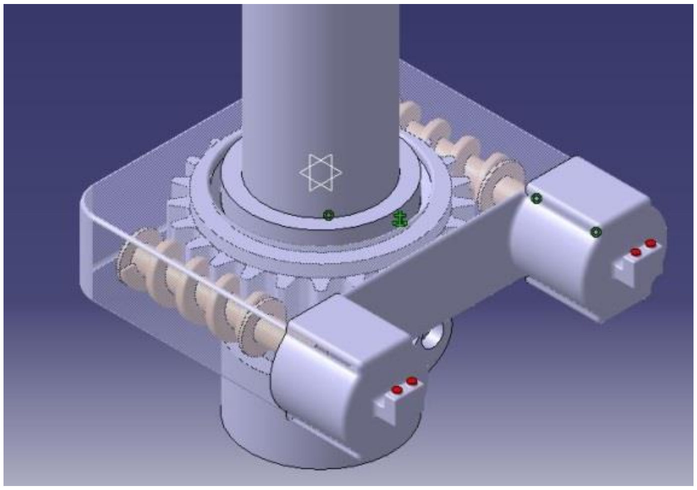


Figure 6 Model of Steering System

3. RESULTS

Concerning detailed stressing a different approach is taken and is based on the application of eye-bar theory to dynamic landing of NLG of a trainer aircraft [9]. In as much as hand calculation would have aided in result comparison the author ran out of time and as such the entire result is based on a single source: Simulation Multiphysics shown below in Fig 7.

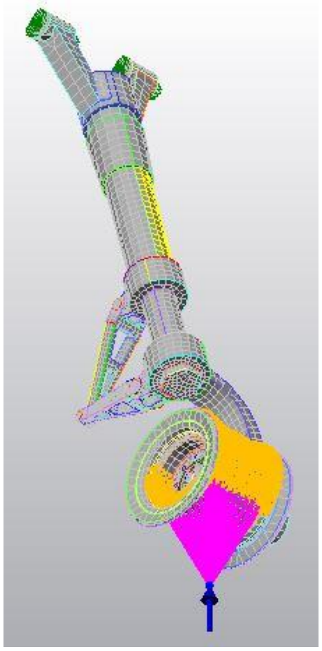
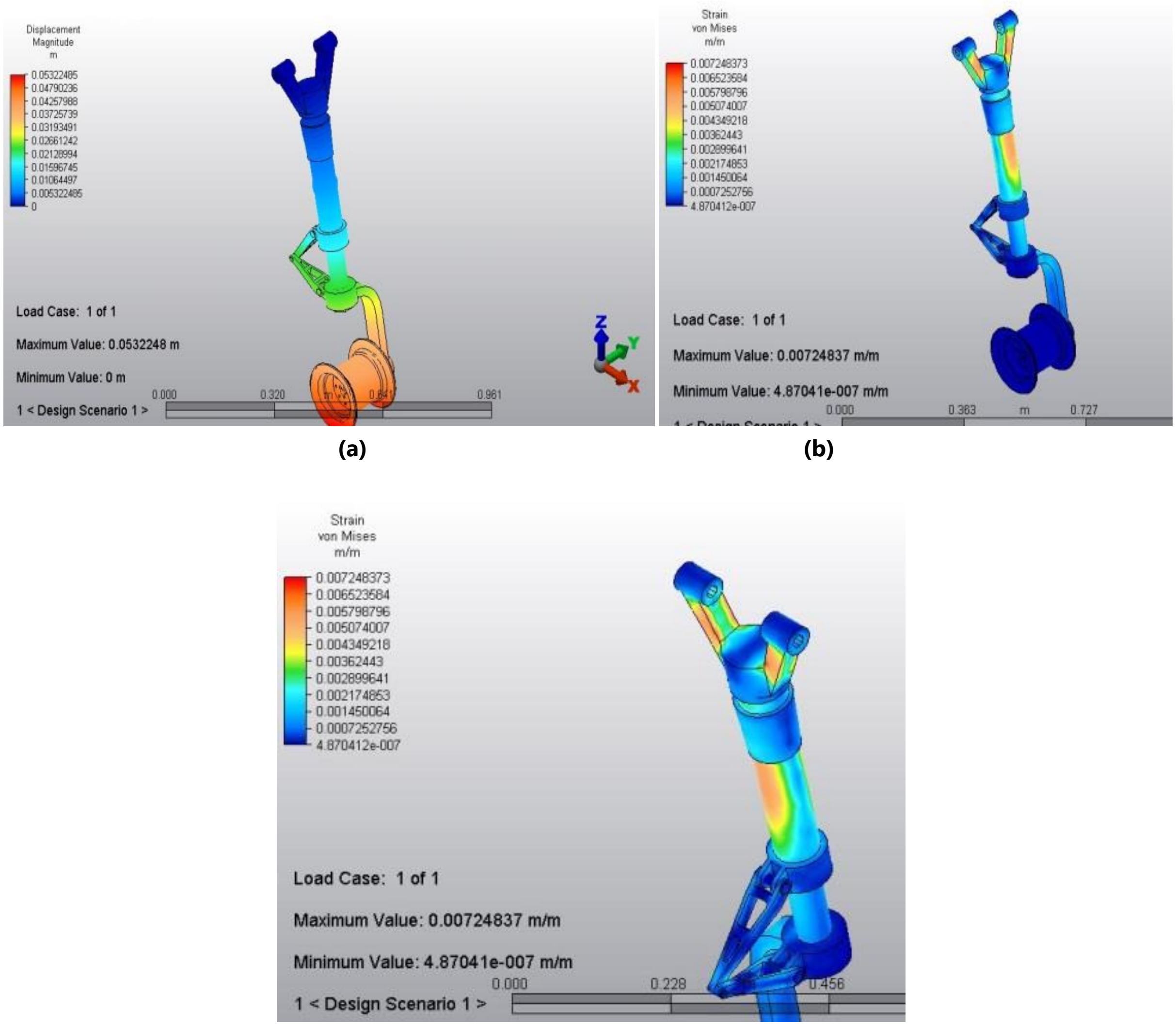


Figure 7 Model imported into Simulation Multiphysics



(a) **(b)**

(c)

Figure 8 Results: Displacement (a), Von Mises Stress (b), Von Mises Strain (c)

The model was imported into Simulation Multiphysics with the tyre suppressed and a load path created to simulate load transfer from tyre to the wheel's bead seat. Constraints, loads, contacts and materials were applied and the model meshed. The simulation was then run to generate results shown below in Fig 8.

4. CONCLUSION

The Nose Landing Gear for the proposed ABT-18 UAV is angled at 12^0 to the directional plane with a 29.22% static load distribution. The tyre was sized based on the nose braking load with an overall diameter of 0.355 m. The shock absorber is single acting with simple orifice design. Total stroke of shock absorber is 0.245 m. The steering power (electrical) required per DC Motor is about 540 W. CS-23 provided the load envelope and ultimate load factor for design with Steel AISI 4340 (300M Steel) as major material. A mechanical event simulation is highly advised to be done and compare hand calculations with simulated results.

ACKNOWLEDGMENT

This project was funded by the Nigerian Air Force Institute of Technology.

Funding: This research was funded by the Nigerian Air Force Institute of Technology, Nigeria.

Conflicts of Interest: The authors declare no conflict of interest.

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