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Preliminary Design of Retractable Landing Gear System for SAFAT03 Aircraft

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أستهلال

قال الله سبحانه وتعالى:

(وَقُلِ ٱعْمَلُواْ فَسَيَرَى ٱللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَٱلْمُؤْمِنُونَ ۖ وَسَتُرَدُّونَ إِلَىٰ عَٰلِمِ ٱلْغَيْبِ

وَٱلشَّهَٰدَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ)

سورة التوبة الاية 105

Dedication

To my parent, brother and sister.

To My little family.

To Every researcher and designer.

Dedicated to you.

Acknowledgement

"He who doesn't thank people doesn't thank Allah almighty "

*I express my deep sense of gratitude to **Dr: Hisham Ahamed Ali** for his guidance and support during exceptional circumstance*

*I would like also to extent my acknowledge to **Sudan aircraft design center** to provide my all technical data*

*And I send my sincere gratitude to far east to **expert Mr: Heruo hirnaldas** who did not skimp on his high experience in field of landing gear*

Thank you all for your unwavering support

Abstract

Landing gears are used during take-off and landing process of aircrafts, there are two types of landing gears fixed and retractable. This thesis investigates the possibility of convert fixed landing gear of two seat light aircraft safat03 to retractable so can increase capabilities of safat03. The main objective is to deign mechanism to retract safat03 landing gear completely inside its body, and make model to test retraction process. Initially, according to safat03 fixed landing gear drawings, retractable mechanism is designed base on three point's path generation method. After that retractable mechanism model is done by catia software and simulated to check intersection with structure. Then electrical rotary actuators are proposed as consequence of conceptual loads calculation on main landing gear retractable mechanism. Furthermore, Landing gear and mechanism are scaled down five times, and manufactured by three dimension printer. Then stepper motor is selected to rotate the scale down model, and light emitting diodes (LED) are used to simulate landing gear lights as in cockpit. Therefore, stepper motor and LEDs are controlled via Arduino microcontroller. Evaluation of retractable mechanism kinematics simulation shows obviously interference between landing gear and structure. Also observations of scale down model demonstrates retractable mechanism moves according to prescribe path. Finally this thesis focuses on kinematic design of retractable mechanism of main landing gear. As well as, conducts test of main landing gear by made scale down model. Despite this study don't cover all aspects of design, but from kinematic perspective convert saftat03 to retractable landing gear needs big modification in wing and fuselage structure of safat03 aircraft.

المستخلص

عجلات الهبوط تستخدم أثناء عمليات الأقلاع والهبوط في الطائرات , ويوجد نوعين من عجلات الهبوط, ثابته وعجلات هبوط قابلة للطي. هذه الاطروحة تتحقق من إمكانية تحويل عجلات الهبوط الثابتة للطائرة الخفيفة ذات المقعدين صافات 03 إلى عجلات هبوط قابلة للطي مما يزيد من إمكانياتها. الهدف الرئيس هو تصميم آلية طي تُحرك عجلات هبوط الطائرة صافات 03 كليا داخل جسمها. وعمل نموزج لإختبار عملية الطي. في البداية حسب رسومات عجلات الهبوط الثابتة للطائرة صافات 03 تم تصميم آلية طي بناءً على طريقة توليد المسار ذو الثلاث نقاط . بعد ذلك تم عمل مجسم لالية الطي بواسطة برنامج الكاتيا, وتمت محاكاته لفحص التداخل مع الهيكل. ثم تم اقتراح مشغلات دواره كهربائية نتيجة لحساب الاحمال الابتدائي على آلية الطي. بالاضافه الى ذلك تم تصنيع عجلات الهبوط والية الطي بواسطة طابعة ثلاثية الأبعاد بتصغير عجلات الهبوط والية الطي خمس مرات. ثم تم اختيار محرك خطوه لتشغيل النموزج المصغر . وأُستُخدمت الثنائيات الباعثة للضوء لمحاكاة إضاءة عجلات الهبوط كما في قُمرة القيادة. لذلك المحرك الخطوة و الثنائيات الباعثة للضوء تم التحكم فيهما بواسطة متحكم أردينو. التقيم الكينماتيكي لآلية الطي أظهر تداخل واضح بين عجلات الهبوط والهيكل. كما أثبت المراقبة للنموزج المصغر أن آلية الطي تتحرك حسب المسار المحدد. أخيرا ركزت هذه الاطروحة على التصميم الكينماتيكي لالية الطي , بالاضافة إلى إجراء إختبار لعجل الهبوط الرئيسي بتصنيع نموزج مصغر له. بالرغم من أن هذه الاطروحة لم تغطي كل نواحي التصميم إلا انه ومن الناحية الكينماتيكية فان تحويل عجلات هبوط الطائرة صافات03 إلى عجلات هبوط قابلة للطي يحتاج إلى تعديل كبير في هيكل الطائرة صافات 03 وهيكل الجناح.

TABLE OF CONTENTS

Chapter	Title	Page
	أستهلال	I
	DEDICATION	II
	ACKNOWLEDGEMENT	III
	ABSTRACT	IV
	المستخلص	V
	CONTENTS	VI
	LIST OF TABLES	X
	LIST OF FIGURES	XI
	ABBREVIATIONS	XIII
1	**INTRODUCTION**	2
	1.1 Preface	2
	1.2 Problem Statement	3
	1.3 Objective	3
	1.4 Proposed Solutions	3
	1.5 Methodology	3
	1.6 Thesis layout	4
2	**LITERATURE REVIEW**	7
	2.1 Background	7
	2.2 Landing gear arrangement and type	7
	2.2.1 Fix and retractable landing gear.	8
	2.3 Components of nose landing gear type	9

2.3.1 Landing gear storage bay 9
2.3.2 Retraction Mechanism Elements according to aircraft standard (ARP1311 10
2.4 Landing Gear Control System Diagnostics 15
2.5 Kinematics of Four-bar linkage mechanism 18
2.5.1 Kinematic mechanism terminology 19
2.6 Forces on The landing gear 22

3 LANDING GEAR RETRACTABLE MECHANISM DEIGN FOR SAFAT03 26
3.1 Introduction of SAFAT03 26
3.2 SAFAT 03 Landing gear mechanism design 27
3.2.1 Assumption of main landing gear mechanism 27
3.2.2 Method description 28
3.2.3 Three Dimension Modelling of MLG mechanism 33
3.3 Mechanism calculation 35
3.3.1 MLG Configuration drag force calculation 35
3.3.2 Main Landing Gear Actuator Force when LG is retracting (Up) 36
3.4 Actuators selection 37
3.4.1 AMETEK actuator 37
3.4.2 CIRCOR actuator 38
3.5 Landing Gear Retraction Flow Chart 39
3.6 Landing Gear Extension Flow 41

4 **SCALE DOWN MODEL OF MAIN LANDING GEAR** 44
4.1 MLG Scale down manufacturing parts 44
4.1.1 MLG strut assembly 44
4.1.2 Lower side brace 45
4.1.3 Upper side brace 45
4.1.4 MLG assembly 46
4.1.5 MLG stand 46
4.2 Scale down Retraction system components 48
4.2.1 Arduino Uno 48
4.2.2 Arduino Software 48
4.2.3 Stepper motors 48
4.2.4 ULN2003 driver 50
4.3 Assumption of model 51
4.4.1 Selector lever 51
4.4.2 Landing gear down and locked indicator 52
4.4.3 Landing unsafe indicator 52
4.4.4 Amber light on handle 52
4.5 Flow chart of scale down MLG gear retraction 53
4.6 Flow chart of scale down MLG gear extension 54
4.7 Sketch code of MLG scale down model 56
4.8 Landing gear Scale down model simulation 56

5 **RESULTS AND DISCUSSION** 59

5.1 Retraction Mechanism angle at LG full extract 59

	5.2 Retraction Actuator power consumption	60
	5.3 Landing gear interference with structure	60
	5.4 Scale down model performance	62
	5.5 Retraction angle	62
	5.6 Compression between scale down model and real model of MLG retraction design	64
6	**CONCLUSION AND RECOMMENDATION**	67
	6.1 Conclusion	67
	6.2 Recommendation	68
	REFERENCES	69
	APPENDICES	71-82

OF TABLES

TABLE NO	TITLE	PAGE
2.1	Compression between fixed and retractable landing gear	8
2.2	LG control system components for airbus 330	17
2.3	Shows the lower pairs of kinematic	20
2.4	Loads acting on the system during retraction and extension	24
3.1	Nose gear technical characteristic	26
3.2	Main gear technical characteristics	27
4.1	28byj stepper motor specification	49
4.2	List of devices used in scale down model	51
5.1	Main different between real and scale down model of MLG	64

LIST OF FIGUIRE

FIGURE NO.	TITLE	PAGE
2.1	Landing gear configuration types	7
2.2	Landing gear storage bay	10
2.3	Landing gear indication and warning architecture	16
2.4	Main landing gear retraction cycle	17
2.5	Position control strategy	18
2.6	Four bar linkage	19
2.7	Landing gear's forces	22
2.8	Direction of retraction for NLG and MLG	24
3.1	Front view of safat03 wing structure and fix link point	28
3.2	MLG path motion	28
3.3	Generation of input link (O_2a)	29
3.4	Generation of circle (1) and circle	30
3.5	Generation of point (b)	31
3.6	Mechanism with termary link	31
3.7	Landing gear mechanism links dimension	32
3.8	MLG retraction mechanism	33
3.9	MLG install on wing structure	33
3.10	MLG at full retraction and extension position	34
3.11	MLG retraction angle	34
3.12	MLG surface area	35
3.13	MLG drag force	36
3.14	AMETEK rotary actuator	38

3.15	CIRCOR rotary actuator	38
3.16	Landing retraction flow chart	39
3.17	LG extension flow chart	41
4.1	MLG assembly	44
4.2	MLG lower side brace	45
4.3	MLG upper side brace	45
4.4	MLG assembly with upper and lower side brace	46
45	Landing gear stand	47
4.6	Real model of landing gear stand assembly with MLG and motor	47
4.7	Scale down MLG retraction components on bread board	50
4.8	Flow chart of scale down MLG	53
4.9	Flow chart of scale down MLG	55
4.10	IDE window	56
4.11	Scale down landing gear circuit in protus	57
5.1	Retraction mechanism angle at LG full extend	59
5.2	Landing gears strut interfere with wing rib	60
5.3	Strut interference with wing main spare	61
5.4	Strut interfere with wing structure at full retraction	61
5.5	MLG real model during retract and extend position	62
5.6	Clearance between shaft and retraction mechanism	63

Abbreviations

ARP	: Aircraft Recommended Practice
CG	: Centre of Gravity
CAD	: Computer Aid Design
DC	: Direct Current
DOF	: Degree Of Freedom
EASA	: European Aviation Safety Agency
FHA	: Functional Hazard Assessment
FMEA	: Failure Mode and Effect Analysis
FTA	: Fault Tree Analysis
FWD	: Forward
GND	: Ground
LED	: Light Emitting Diode
LG	: Landing Gear
LGCU	: Landing Gear Control Unite
LCGH	: Landing Gear Control Handel
MIL	: Military Standard
MLG	: Main Landing Gear
MRS	: Manual Release System
NLG	: Nose Landing Gear
PSSA	: Preliminary System Safety Analysis
UAV	: Unmanned Arial Vehicle
WOW	: Weight On Wheel

Chapter one

Introduction

Chapter One

Introduction

1.1 Preface

Landing gear is the structure that supports an aircraft on the ground and allows it to taxi, take-off, and land. Landing gear retraction mechanism typically includes a couple of mechanical members and piston-cylinder or electrical actuator. The direction of retraction inward, outward, forward, and backward is decision which must be made prior to considering more details on aircraft design. The criteria for the selection of type of landing gear retraction mechanism include mechanism weight, volume, cost, maintenance, and power transmission system. There are variety of design options, two of which convenient retraction systems are hydraulic and electrical, in general, a hydraulic system is more expensive and heavier than electric.

In fact, landing gear design tends to have several interferences with the aircraft structural design. Landing gear divided to two type fixed landing gear which not include the retraction mechanism and another type is retractable landing gear which including the retraction mechanism and will be addressed on this thesis.

Retraction mechanism of landing gear will be designed and suitable actuator will be selected to drive landing gear inside safat03 body.

Also the scale down prototype will be produced to show real operation of landing gear and will be controlled via stepper motor with ARDUINO micro-controller and LED will be used to refract the position of landing gear.

1.2 Problem Statement

Safat03 is light aircraft used fixed landing gear which has more drag and reduced from capabilities of safat03. Therefore convert landing gear of safat03 to retractable can increase capabilities and can upgrade safat03 to upper level.

1.3 Objective

To design retractable mechanism to stow safat03 landing gear completely inside body.

To select suitable electrical actuator to drive landing gear.

To conduct real test by manufacturing scale down model.

1.4 Proposed Solutions

Design mechanism to retract safat03 landing gear into aircraft body, and used electrical actuator to preform retraction and extension motion.

1.5 Methodology

To improve capabilities of safat03 aircraft landing gear of it will be investigated to convert it to be retractable. First of all, landing gear data such as drawing, safat03 structure arrangement, and landing gear specification are gathered. All these data were collected from technical reports of safat03. Left main landing gear was used as case study to design retractable mechanism for it, and later can just refract the design to right main landing gear.

Retractable mechanism was designed for safat03 left main landing gear according to three synthesis path generation method. This method is graphical methods, but in this thesis improved it by using AUTOCAD software to achieve method steps. Then retractable mechanism was modeled by CATIA software, and simulated to trace path of landing gear during retraction and extension, also kinematic analysis is done to evaluate interference between landing gear and safat03 structure when landing gear is fully retract. Moreover, the retraction angle which stow landing gear inside safat03 body is identified from CATIA simulation. Then conceptual loads was calculated in most critical position of landing gear retractable mechanism. According to that, suitable electrical actuators were selected.

Retractable mechanism and left main landing gear were scaled down five times less than real model. Then kinematics stand was design to install scaled down landing gear on it. Left main landing gear, retractable mechanism and kinematics stand were manufactured by 3D printer to conduct real simulation of landing gear retraction.

A unipolar stepper motor was selected to rotate left main landing gear on kinematic stand, and LEDs are used to state the landing gear situation while extension, transit or retraction. So Arduino UNO was used to control stepper motor and LEDs. After that the code was writing using ARDUINO IDE 1.8.8 software. Then circuit was simulated using PROTEUS software.

Finally scale down model and stepper motor and LEDs were assembled and conducted test, observation was presented against safat03 structure.

1.6 Thesis layout

Chapter one give brief information about this thesis start from problem of fix landing gear, and main objective of this thesis, beside methodology that follow to convert landing gear to retractable.

At beginning of chapter two there is background about landing gear, after that show in detail the previous studies which related to landing gear such as landing gear type, components, and retraction, beside standard steps should follow when design retractable landing gear, finally this chapter review the concept of four bar linkage which will use to design retraction mechanism.

Chapter three show steps of retractable landing gear mechanism for safat03 aircraft, also the simulation of landing gear during retract and extract, after that the conceptual force which expose on landing gear mechanism was calculation, at end of this chapter the appropriate actuators were selected based on previous calculation.

Chapter four describe scale down model of landing gear ,and how will manufacturing ,also shows the electronic components that used to control retractable mechanism during extract and retract process.

Chapter five discuss the result that obtained from converting the LG to movable and its effects on aircraft structure, and also observation from scale down model performance.

Lastly chapter six conclude all work done in this thesis, as well as give recommendation for the most important outcomes of this thesis.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Background

Author in [1] Reviewed the history of landing gear deign from first wheeled landing gears appeared shortly after the Wright Brothers 'maiden flight in December 1903. Santos-Dumont's had a wheeled landing gear, this airplane made the first flight in Europe in October 1906.

Also author in [1] shows the development of retractable landing gear since period between World Wars I and II, landing gear design was improving as fast as airframe design, the earliest retractable landing gear found on the Bristol (England), then Lockheed's Model 8D Altair which first flew in 1930, had a fully retractable landing gear.

2.2 Landing gear arrangement and type

Sadraey in study [2] classified Landing gear (LG) according to functions, so the LG may be performed through the application of various landing gear types and configurations. In general, there are many of configurations for a landing gear as showmen in figure (2.1) below:

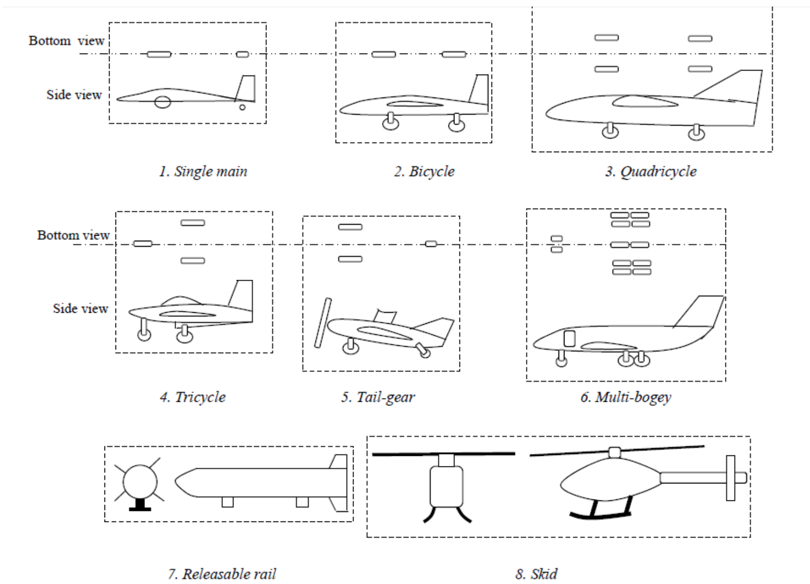


Figure 2.1: landing gear configuration types [2]

Tricycle is the most widely used landing gear configuration in recent aircraft. Figure (2.1) in 4 shows the side and top views of the tricycle landing gear, which consist of main landing gear (MLG) located aft center of gravity (CG) of aircraft, and carries much of the aircraft weight and load, the main landing gear (MLG) normally has two wheels are locate in the same distance from the CG in the x-axis and the same distances in y-axis (left and right sides); thus both are carrying the same load. The forward gear is called nose landing gear (NLG) is far from CG (compared with main gear); hence it carries much smaller load. The share of the main gear from the total load is about 80 to 90 percent of the total load, so the NLG is carrying about 10 to 20 percent. This arrangement is sometimes called nose gear.

2.2.1 Fix and retractable landing gear

Table 2.1: Compression between fixed and retractable landing gear [2]

No	Item	Fixed (un-retractable) Landing Gear	Retractable Landing Gear
1	Cost	Cheaper	Expensive
2	Weight	Lighter	Heavier
3	Design	Easier to design	Harder to design
4	Manufacturing	Easier to manufacture	Harder to manufacture
5	Maintenance	Easier to maintain	Harder to maintain
6	Drag	More drag	Less drag
7	Aircraft performance	Lower aircraft performance (e.g. maximum speed)	Higher aircraft performance (e.g. maximum speed)
8	Longitudinal stability	More stable (stabilizing)	less stable (destabilizing)
9	Storing bay	Does not require a bay	Bay must be provided
10	Retraction system	Does not require a retraction system	Requires a retraction system
11	Fuel volume	More available internal fuel volume	Less available internal fuel volume
12	Aircraft structure	Structure in un-interrupted	Structural elements need reinforcement due to cutout

Table (2.1) shows the compression between fixed and retractable landing gear, obviously fixed landing gear has many advantages especially for light aircraft which is simple design and light weight, therefore convert safat03 to retractable will increased cost, weight and may need modification on structure.

2.3 Components of nose landing gear type

The main components of tricycle landing gear (nose type) are:

1. Main landing gear strut, which is main part withstand load on MLG
2. Nose landing gear strut which is main part withstand load on NLG
3. Brake system
4. Steering system
5. Retraction system
6. Shock absorber
7. Tire and wheel

- The focusing on this project will be in retraction system

2.3.1 Landing gear storage bay

In study [2] also Reviewed another design aspect of the landing gear that what to do with landing gear after take-off operation. In general, there are four alternatives as follows:

1. Landing gear is released after take-off.
2. Landing gear hangs underneath the aircraft.
3. Landing gear is fully retracted inside aircraft (e.g. wing, or fuselage).
4. Landing gear is partially retracted inside aircraft.

Each of these four alternatives has various advantages and disadvantages which must be evaluated prior to decision making.

Major options for main landing gear home as figure below

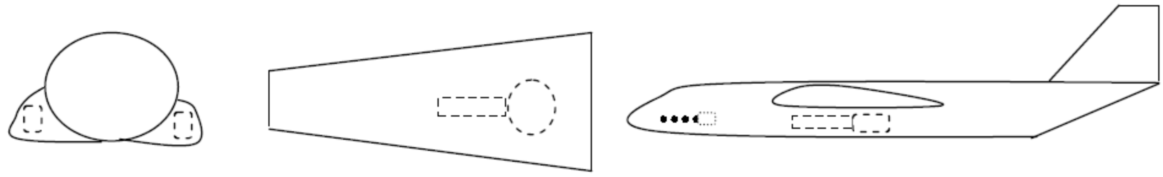


Figure 2.2: Landing gear storage bay [2]

1. Fuselage-podded

A podded bay configuration tends to increase aircraft frontal area that causes additional aerodynamic drag.

2. In the wing

Landing gear bay in the wing requires a wing cutout that leads in stronger spars. The best candidate for a bay in the wing is the room between main spar and rear spar (Some GA aircraft retract the main gear into the wing (e.g. Cessna 525)).

3. The wing-fuselage junction

Most low wing transport aircraft (such as Boeing 767 and Airbus 320) retract the main gear into the wing-fuselage junction in a high-wing configuration, retracting and locating landing gear in the fuselage makes the strut shorter. In general, a retracted position inside aircraft will chop up aircraft structure which consequently increases aircraft weight.

2.3.2 Retraction Mechanism Elements according to aircraft standard (ARP1311):

Aircraft landing gear standard in [3] , shows safety design and most common reliable design, ARP1311 is specialist in landing gear aspect, and the next paragraphs will briefly review most important elements of LG retraction according to ARP1311.

2.3.2.1 Down-Locks

All retractable landing gear should have mechanical down-locks capable of sustaining the extended position of the gear under all loading conditions (air, ground, inertia, etc.) for which the gear is designed, and the structural deflections resulting therefrom. Engagement of the down-lock should be automatic upon completion of the gear extension, whether this extension is accomplished either by a normal or emergency procedure. Release of the down-lock from its

Engaged state should occur automatically upon applying power to affect landing gear retraction and after removal of ground safety provisions. The down-lock should be designed and protected to avoid the risk of malfunction due to corrosion, ice, and dirt accumulation. The design of the down lock should not permit the lock to be loaded by ground loads or cause the lock to move due to either structural deflection, vibration, or any other means for which the gear is designed. When the

down-lock has been "engaged", it should not change from that state as a result of any remote system function.

2.3.2.2 Down-Lock Position Verification

Means should be provided to inspect the position of lock components whose operation is sensitive to manufacturing tolerances such as over-center type linkage locks. If over-center type linkage locks are used, a positive means should be provided to measure or verify, during the rigging process, that the linkage pivot centers are in line or over-center per the design requirements. If internal locking actuators are used, a visual indication of lock condition should be provided.

2.3.2.3 Down-Lock Status Indication

Provision should be made for a means whereby the down-lock status ("engaged" or "less than fully engaged") may be indicated in the cockpit. Such means should be incapable of falsely indicating an "engaged" state.

2.3.2.4 Weight on Wheel Indicators

Provision should be made to indicate that the gear is being compressed (due to landing surface contact). This is to provide a signal to systems such as the antiskid system, which may require such indication. Indicator installations should not be affected by corrosion, ice, de-icing or cleaning fluids, and mud or dirt accumulation.

2.3.2.5 Up-Locks

All retracting landing gears should have a means for sustaining the retracted state of the gear, either in conjunction with, or independently from, its stowage bay doors after retraction is complete, and until "gear down" is selected. Engagement of the up-locks should be automatic upon completion of the raising of the gear and, if interconnected, the closing of the doors. Release of the up-lock from the engaged state should result from cockpit selection of "gear down". The up-lock should be designed and protected to avoid the risk of malfunction due to corrosion, ice, and dirt accumulation. Hydraulic and/or electric power should not be required to restrain the landing gear in the up and locked position.

2.3.2.6 Up-Lock Status Indication

Provision should be made for means whereby the state of the up lock(s) either "engaged" or "less than fully engaged" may be indicated to the cockpit via the landing gear control system.

2.3.2.7 Gear Retraction and Extension

Sizing of the retraction actuator (geometry and effective pressure areas) should be considered in the early stages of landing gear design. Trunnion moments of retraction are established by the evaluation of the air loads, landing gear dead weight, and acceleration forces based upon retraction time requirements, and, in some instances, negative due to rapid ascent of the aircraft. For gear extension, all gears (nose and mains) should "free fall" and be capable of being powered down in the event of an emergency. In cases where rearward retracting gears are found to be absolutely necessary, an independently powered extension device must be used.

2.3.2.8 Gear Control Action

All retractable landing gear should fully retract and complete their stowage and up-locking function in response to a single control action from the cockpit. Also, they should revert to the down and locked state in response to another single control action. Where a series of actions such as a down-lock release, truck assembly trimming, gear raising, and door actuation constitute the total retraction or extension cycle, all necessary sequencing should be accomplished either by positive mechanical means, or, if dependent upon electrical and/or hydraulic system(s), then system malfunction should be incapable of generating damage, or precluding return to the "gear down" state by both normal and emergency procedure.

2.3.2.9 Gear Control Reversal

At all stages within the retraction and lowering cycles, the gear actuation should be responsive to a reversal of control selection. In the event that the retraction or lowering cycle is temporarily arrested or reversed by the occurrence of briefly applied dynamic or aerodynamic loads in excess of design operating values, the normal motion should resume thereafter without the need for further control action from the cockpit.

2.3.2.10 Lost Motion Mechanisms

When lost motion mechanisms are adopted, studies should be made to ensure that the limited freedom of movement cannot occur to the detriment of the landing gear or its supporting structure.

2.3.2.11 Ground Safety Locking

Means should be provided to physically preclude gear retraction when, or if hydraulic pressure is separately applied to each leg while the aircraft is on the ground. Such means should be independent of provisions to preclude "gear-up" selection in the event that any leg is in a loaded state. They should be provided with a warning indication that can easily be seen on a walk-around inspection.

2.3.2.12 Landing gear handle

The main function of the control handle is to provide electric command to the landing gear control valve to retract and extend the landing gear.

Landing gear position command is initiated by the Landing Gear Control Handle (LGCH) located on the landing gear control panel.

Movement of the handle down commands landing gear extension. Movement of the handle up commands landing gear retraction.

The control handle is locked in up and down position by a locking sleeve (pull to release). The selector lever is also locked by a solenoid latch in down position in order to prevent retraction of the landing gears during aircraft on the ground. The solenoid lock function will be automatically released when the coil is energized while aircraft in flight mode.

2.3.2.13 Landing gear control unite (LGCU)

The landing gear control unit has a function to provide control the relevant signals of the landing gear system, landing gear indication and warning circuits.

The Landing Gear Control Unit consists of two digital channels. Each channel performs both the landing gear control and indication function.

Each channel of the LGCU is designed to be fail-safe and can operate with full functionality if the other channel is not available. For safety critical functions, the unit uses a dual lane configuration with one lane being used for control and the other lane being an independent monitor for the control lane. The monitor lane has the ability to shut down the landing gear and in the case of a failure in the system affecting a critical function.

2.3.2.14 **Manual Release System**

The Manual Release System (MRS) is a mechanism by which the main and nose landing gear legs can be extended in the event of the primary extension system failed. The MRS handle is mechanically linked to the MLG unlocks, NLG up lock, and dump valve through a cable system. It allows the landing gears to free fall. The main landing gears are powered into down and locked position by means of the free fall assister.

2.4 Landing Gear Control System Diagnostics

Author in [4] built a set of health management methods including system real-time monitoring, accurate fault diagnosis and prognosis of major components which are suitable for the aircraft landing gear extension and retraction control system, aircraft landing gear extension and retraction control system, as one of the most important aircraft systems on-board, could directly affect the flight safety Based on the function hazard assessment (FHA), and fault tree analysis (FTA) of the aircraft landing gear extension and retraction control system, each of the catastrophic events, all the root causes and their effects were identified. Synchronously, all the components which are related to the catastrophic events were found.

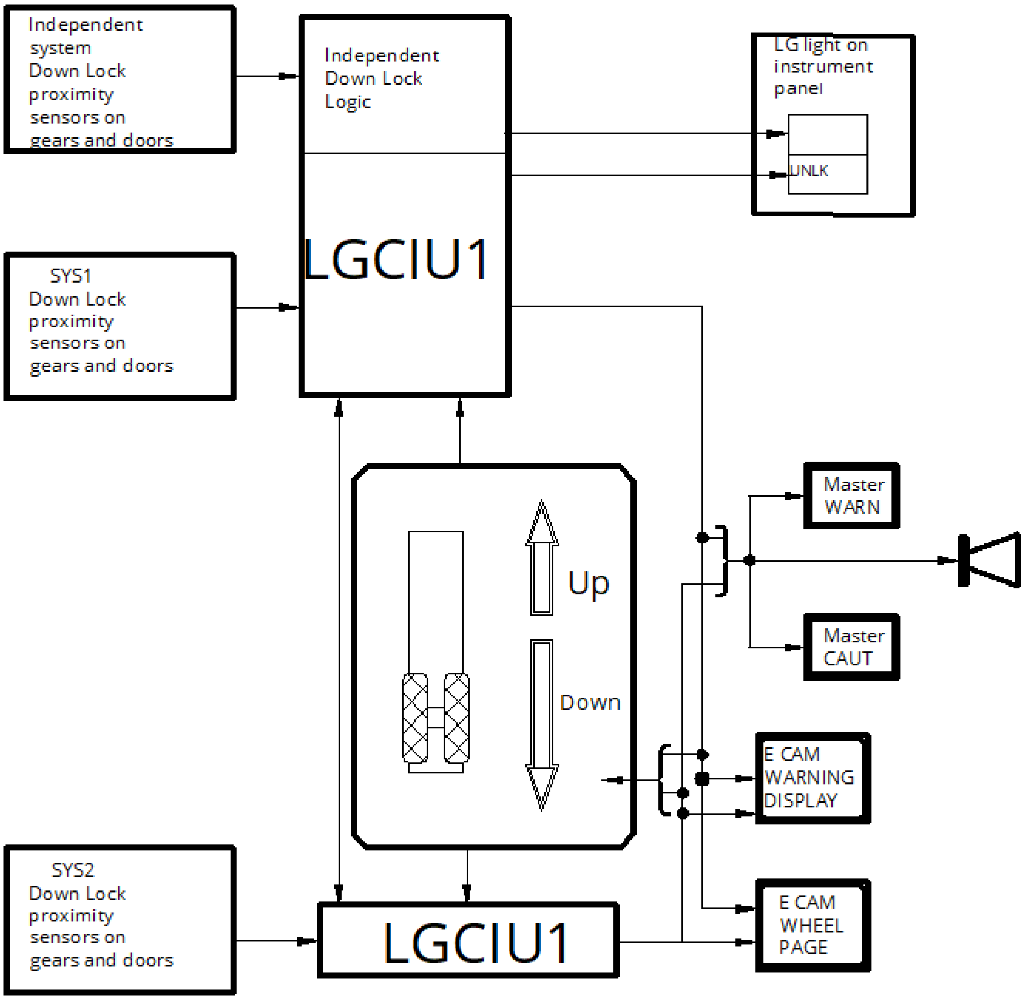


Figure 2.3 Landing gear indication and warning architecture [4]

The landing gear position indication and warning function is another important function. The gears and doors position could be indicated by landing gear indicator panel and the ECAM wheel page. The landing gear position indication is still provided by landing Gear Control and Interface Unit one (LGCIU1) even when the LGCIU2 is controlling the cycle. According to the hazard class of a failure, warnings and cautions will be performed in many modes such as aural warning, master light, local warning and etc., when a fault is detected. Landing gear indication and warning architecture is showing in figure (2.3), the components of landing gear extension and retraction control system as in table below

Table 02.2: LG control system components for Airbus 330

Item	Components	Item	Components
1	L/G Lever	5	Gear selector valve
2	LGCIU1	6	Proximity sensors
3	LGCIU1	7	Gravity extension switch
4	Door selector valve	8	Gravity extension motor

The landing gear extension/ retraction control system has three main functions, the first one is normal operation function which controlled by the landing gear lever located on the center instrument panel, secondly, the indication function that the position of gears and doors are shown on the center instrument panel, finally, the gravity extension function which controlled by two selectors on the center instrument panel, the system architecture was introduced based on the three functions respectively.

Study in [5]investigate the location of sensors and retractable cycle, the main landing gear actuator control is achieved by local control systems (Active standby) with internal sensing for snubbing and under/over end of travel position sensors. The locations of the end of travel hall sensors are identified in Figure (2.4).

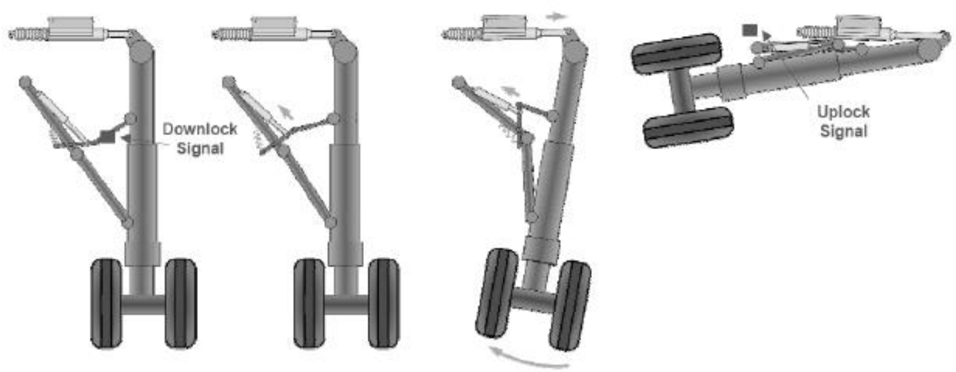


Figure 2.4 : Main Landing Gear Retraction Cycle

Position control will be achieved through counting of motor commutation hall sensor states, hall sensors are available to detect when the actuator has reached the desired position to stop accelerating to the maximum rate of speed and also when to begin decelerating to the end of travel position, this is shown in Figure (2.4). The motor also contains thermocouples to avoid operation at overly high temperatures. External aircraft proximity sensors are used to indicate up lock and down lock positions. Figure (2.5) illustrates a retraction cycle of the main gears, demonstrating the direction of travel for the retraction and locking actuators, the landing gear retraction mechanisms also contain snubbing devices used to suppress high voltage transients in the electrical systems. The range of these sensors is also indicated in Figure (2-5).

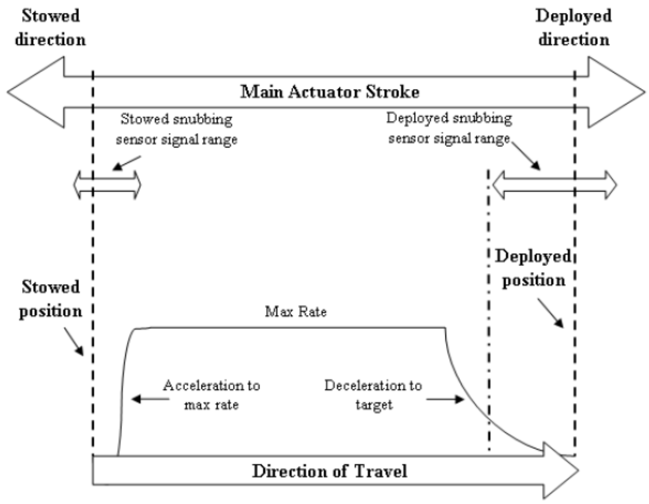


Figure 2.5: Position Control Strategy

2.5 Kinematics of Four-bar linkage mechanism

Hamilton and Fred In [6] explained principle of four bar linkage which is the retractable landing gear based upon it, a four-bar linkage using three members connected by pivots, the fourth bar is the aircraft structure, Study of mechanism is very important to determine the suitable motion an all parameter of landing gear retraction and extension

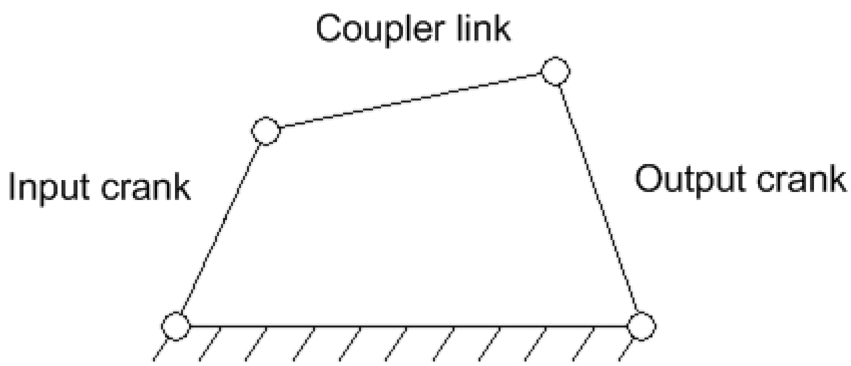


Figure 2.6: Four bar linkage [6]

2.5.1 Kinematic mechanism terminology

- **Kinematic:** mean that subjects which deal with only geometric aspect of motion without consideration of force
- **Mechanism inversion**: when link which was originally fixed is allowed to moved and another link becomes fixed the mechanism is said inverted, the inversion does not change the motion of it is link relative to each other but change their absolute motion or Kinematic inversion refers to the process of considering different links as the frame in a given kinematic chain. Thereby different and possibly useful mechanisms can be obtained. The slider crank, the turning-block and the swinging-block mechanisms are mutual inversions, as are also drag-link and "crank-and-rocker" mechanisms.
- **Planer motion(translation)** when a rigid body move that the position of each straight line of the body is parallel to all of it is other position
- **Degree of freedom (D.O.F):** Is the number of independent pair variable needed to completely define the relative movement between all links

$$f = 3(n-1) - 2j - h \tag{1}$$

Where:

f: is degree of freedom (DOF)

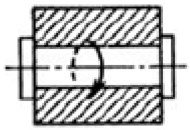
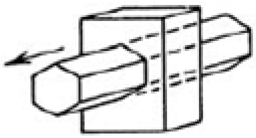
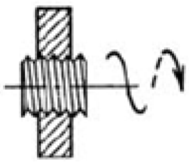
n: total number of link including fix link

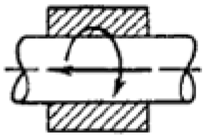
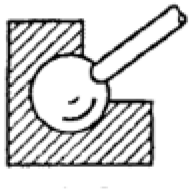
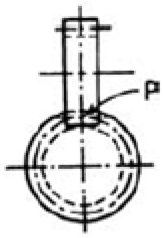
j: total number of lower pairs

h: total number of higher pairs (if exist)

•**Kinematic pairs**: classification to lower pairs and higher

Table 2.3: Shows the lower pairs of kinematic [6]

Name of lower pairs		**Number of DOF**
Revolute		1
Prismatic		1
Screw		1
Cylindrical		Two degree of freedom one translation

		One rotation
Spherical		Three rotation degree of freedom
Planer		Three degree of freedom

- **Link**: each rigid body contributing for kinematic pair is referred to as link.

- Mechanism must be having one link fixed

- **Redundant degree of freedom**: mean some links moves without transmitting any other motion links

- **Number of synthesis**: determine the number of link, revolute and prismatic

- minimum number of binary link is four which called four bar linkage

- **Dimensional synthesis of linkages**: Mean determine kinematic dimensions so that satisfy some prescribed motion characteristic.

• **Motion generation**: Design a link so that a rigid body (say the coupler of a 4bar linkage) can be guided in a prescribed manner, this guidance may or may not be coordinated with the input movement or

• **Function generation**: To maintain a prescribed relationship between the output and input motions (In "function generation" the input and output motions of a mechanism are linear)

• **Path generation**: Appoint on the floating link (say the coupler of a 4R linkage) is to be guided along a prescribed path the movement along the path may or may not be coordinate with the input movement (a point of a floating link traces a prescribed path with reference to the frame)

2.6 Forces on The landing gear

In [7] Costesèque and Caroline Reviewed Forces applied on the side leg (strut) of LG and distributed throughout the entire aircraft, when the landing gear is deployed, the drag has most impact on the system, while during the landing, the airplane weight is the largest force on the legs. As seen in figure (2.7) below, the drag force hit the legs, wheels and doors of the system.

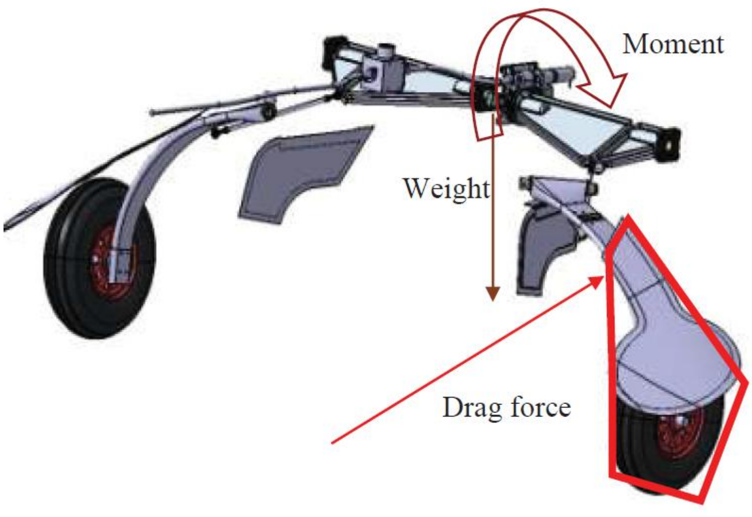


Figure 2.7: Landing gear's forces

The weight is located in the Centre of the system. The red area is the surface to estimate and include in the calculation of the forces. Outside this area, the geometry is not directly impacted by the drag force. This area includes the door of the landing gear, the leg and the wheel. The connecting system and rotation system are outside the red area, inside the fuselage. As the system is being patented, the description cannot be more detail and the figure (2.7) is presenting a simplified solution that help visualize the system and air loads,

As the legs will go out of the fuselage, the red area will increase its surface. With the help of the CAD software Pro/Engineer, it is possible to estimate the surface area for each angle. The angle 0° means the system is fully out of the fuselage. At 180°, the system is fully in the fuselage. The angles chosen for the study are 0°, 40°, 60°,80°,90°,100°,120°,130°,150° and 180°. Angles have been chosen to have enough points to draw curves. Once the surface (red part in figure (2.7)) is calculated for each angle and for one leg, it is then possible to calculate the drag force see equation (2):

$$F = 0.5 \times C_p \times V^2 \times A \qquad (2)$$

Where:

A: The area, V^2: The flow velocity, ρ: The air density and C_p: The drag Coefficient.

Here the flow velocity is the speed of the airplane, as we only Consider the drag force.

In this case the coefficient is set to 1 and the air density is 1.225 kg/m3.

This study used ANSIS software to analysis the force on landing gear leg (strut) and test it.

Study in [8] calculated the load on hydraulic actuator, figure (2.8) shows the direction of NLG and MLG during extension and retraction.

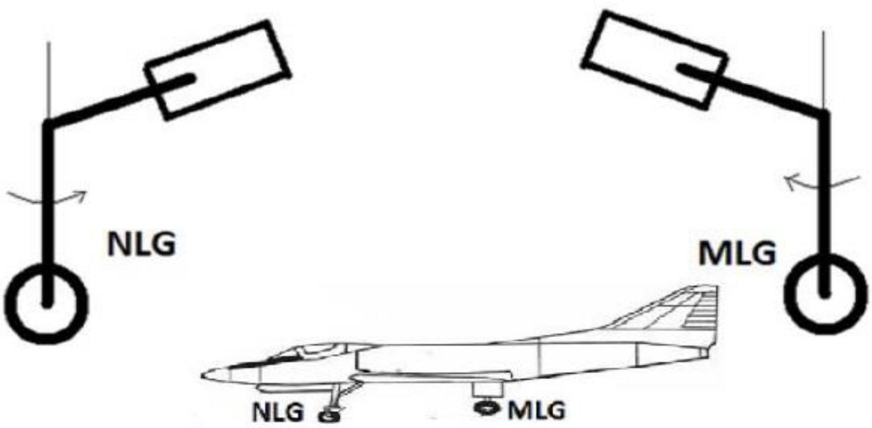


Figure 2.8: Direction of Retraction for NLG and MLG

Table (2.4) below shows the effect of operational loads on nose and main landing gears. The drag load is calculated by taking the frontal area of strut.

Table 2.4: Loads acting on the system during retraction and extension

Landing gear	**Retraction**	**Extraction**
Nose landing gear(NLG)	Inertia Load - Drag Load	Inertia Load + Drag Load
Main landing gear (MLG)	Inertia Load + Drag Load	Inertia Load - Drag Load

This chapter gives background about landing gear types, and advantages and disadvantages of fixed and retractable landing gear, also all components of retraction landing gear is presented on this chapter even components that recommended from aircraft standard, Also way to calculate force on landing gear mechanism is presented.

Chapter Three

Landing Gear Retractable Mechanism Deign For SAFAT03

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Landing Gear Retractable Mechanism Deign for SAFAT03

3.1 Introduction of SAFAT03

SAFAT03 is light aircraft has two seats used to training beginner pilot, the type of landing gear is fix tricycle landing gear (nose landing gear), the design report of safat03 in [9] showed the specification of SAFAT03's landing gear (LG) and specification of it tables (3.1 and 3.2) shows the landing gear specification of SAFAT03.

Table 03.1: Nose gear technical characteristic [9]

No	Parameter	Specification
1	Shock absorber type	Oleo-pneumatic
2	Kinematics	telescopic with locking in position "down"
3	Oil type	MIL-H-5606
4	Pneumatic, dimensions	5.00-5 6PR DUNLOP
5	Absorber air pressure on 20°C	6.3 bar
6	Tire pressure	2 bar
7	Vertical speed at landing impact	
	Absorbed maximum energy	3.048m/s
	Absorbed reserve energy	3.658m/s
8	Shock absorber stroke for maximum energy	h_{max} = 186 mm
9	Absorbed kinetic energy	
	Maximum	1520 J $_{-50J}$
	Reserve	2188 J $_{-70J}$
10	Nose gear mass (with tire and oil)	16.6 kg

Table 3.2: Main gear technical characteristics [9]

No	**Parameter**	**Specification**
1	Shock absorber type	Oleo-pneumatic
2	Kinematics	lever
3	Oil type	MIL-H-5606
4	Pneumatic, dimensions	6.00-6 6PR DUNLOP
5	Absorber air pressure on 20°C	16 +1 bar
6	Tire pressure	2.2 bar
7	Vertical speed at landing impact	
	Absorbed maximum energy	3.048m/s
	Absorbed reserve energy	3.658m/s
8	Shock absorber stroke for maximum energy	h_{max} =112 mm
9	Absorbed kinetic energy Maximum	2200 J $_{-50J}$
	Reserve	3168 J $_{-70J}$
10	Main gear mass (with tire and oil)	22.7 kg

3.2 SAFAT 03 Landing gear mechanism design

The objective to design suitable mechanism to retract main landing gear inside the aircraft body with minimum modification on structure, the MLG of SAFAT03 will take as case study.

3.2.1 Assumption of main landing gear mechanism

- The input motion is rotary motion.
- Method to determine suitable mechanism is path generation with three position synthesis to give prescribed motion
- The fixed point (O_4) will be the turning hinge line of main landing gear and point O_2 will locate under point O_4 to be inside the wing figure (3.1) below shows location of fixed point on wing structure.

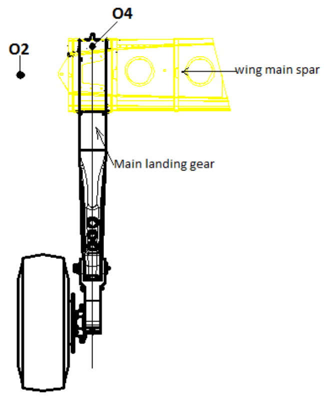


Figure 3.1: Front view of safat03 wing structure and fix link point

3.2.2Method description

This method is used to determine the dimension of retractable links, its graphical method and we used AUTOCAT to facilitate method, steps of three position synthesis are:

1.Select the fixed point O_2 and O_4 corresponding to frame shape and space available, previous Figure (3.1) shows the propose location of points O_2 and O_4.

2.Obtain three points 1, 2, and 3 in MLG path as figure (3.2), radius of MLG path is 150mm.

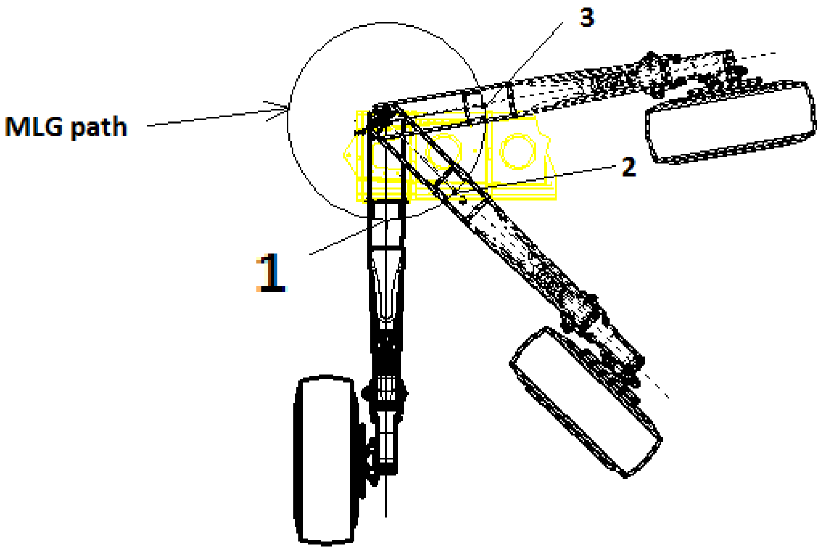


Figure 3.2: MLG path motion

3.On MLG path circle obtain point A horizontally with point O_2 , joint point A and O_2 to obtain line (O_2 A), Next figure (3.3) illustrates construction of line (O_2 A).

4.Select first point (1) which previous obtain in step (2) let name it Point (C)

5.Joint point (A) and point (C) to get line (AC)

6.Used AUTOCAD software to draw steps 3, 4 and 5 as shows in figure (3.3).

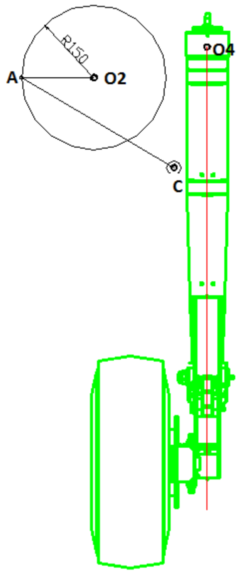


Figure 3.3: Generation of input link (O_2A)

7.Draw circle (1) by radius O_2 A (O_2 is the center of this circle) and draw anther circle (2) at point (C) by radius CA copy circle 2 twice and take point (C) as base point and copy to point (2) and (3), See figure (3.4).

8.Circle 2 and their copies must be intersecting circle 1, otherwise, change the length and find other location for lines (O_2A) and (AC) until those circles intersected circle O_2A figure (3.4) illustrate that.

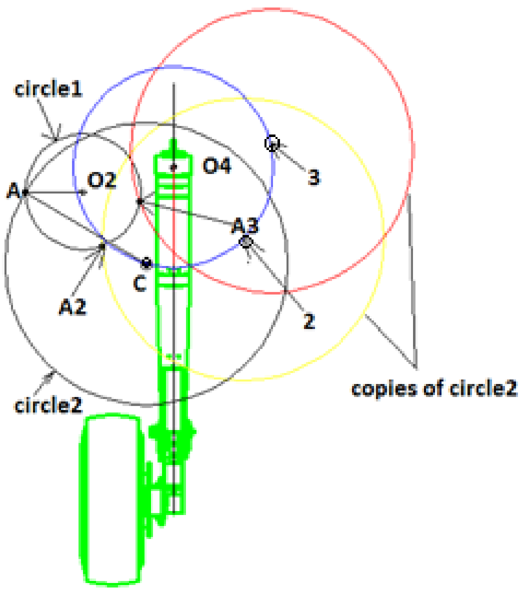


Figure 3.4: Generation of circle (1) and circle (2)

9. Note that the circles (2) intersected circle (1) at two points, that mean each points can satisfy the prescribed path, so assume the line (O_2 A) rotate counter clockwise.

10. Joint point (A_2) and point (2), and point (A_3) and point (3) A_2 , that mean the position of point A according to point (2) in MLG strut path, by another word A_2 mean the location of point A if point C moved to location of point (2).

11. Now used inversion of kinematic to obtain the position of point B (graphically method used tracing paper but here used AUTOCAD)

12. Press move icon select line (A_2,2) and point O_4 then select point 2 as base point and copy to point (C)

13. Press rotate select previous objects and select point (C) as base point, then reference rotate angle, select end point of line(A_2,2) then select point (A) to rotate.

- line (A_2, 2) will congruent completely to line (A, C) and that what mean tracing the object(A_2,2) and point O_4 to point C, by other word assume fixed point C and point O_4 is free so generate $O_{4,2}$

14. Repeat step (12&13) typically, except select object(A_3,3) and point O_4 to generate $O_{4,3}$

15. Press three point curve icon on AUTOCAD and select point o_4, $o_{4,2}$, $o_{4,3}$ respectively, The center of this curve represent the position of point (B) as in figure (3.5).

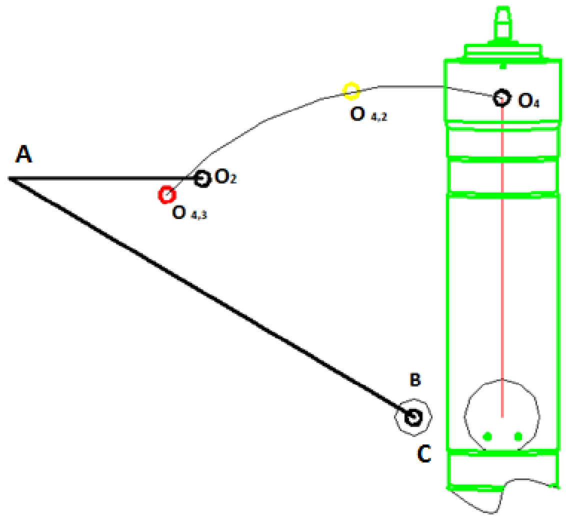


Figure 3.5: Generation of point (B)

• Note that the point (B) congruent on point (C) that mean the coupler link of four bar link is binary, to clarify this point let assume the center of curve (o_4, $o_{4,2}$, $o_{4,3}$) as in figure (3.6) below so the point will (B)will be as below.

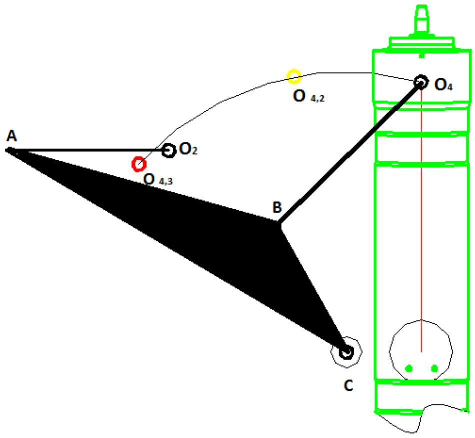


Figure 3.6: Mechanism with termary link

Joint (O2 A) (A, C) (A, B) (B O_4) (C, B) so Link A, C, B is termary (consist of three lower revolute pairs) link transfer motion to MLG.

The final mechanism which satisfy the path of MLG will be as in figure (3.7) below

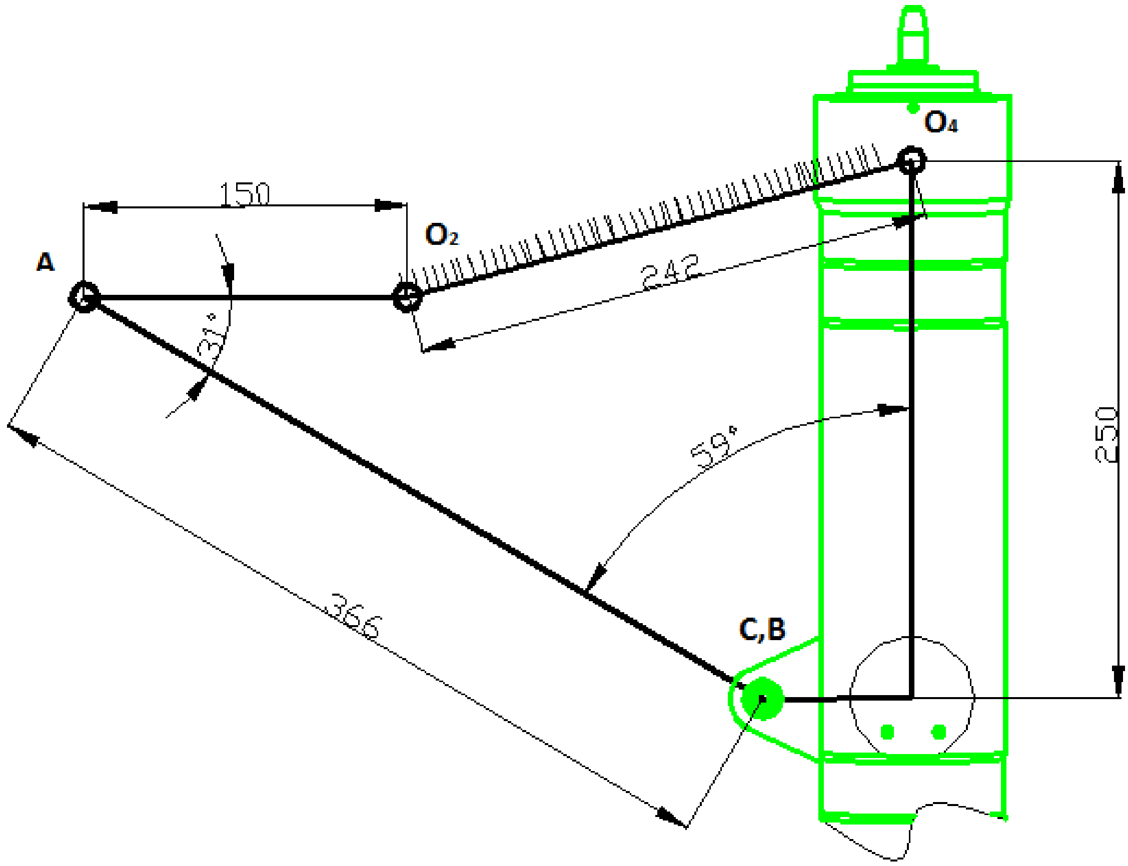


Figure 3.7: Landing gear mechanism links dimension

•Link O_4, O_2 is binary (consist of two lower revolute pairs) link and represent the fix link.

•Link O_2, A is binary link and represent the input motion link (install to servo motor or rotary actuator) or called input bell crank.

3.2.3 Three Dimension Modeling of MLG mechanism

After determine the length of mechanism, the model of mechanism is generating by CATIA CAD software.

- The thickness of mechanism is assumed

Figures below shows the components of main landing gear retraction mechanism point O_4 represent the hinge point of landing gear.

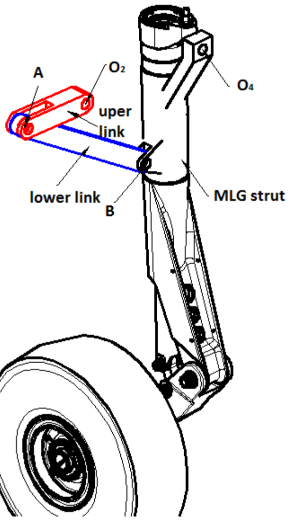


Figure 3.8: MLG retraction mechanism

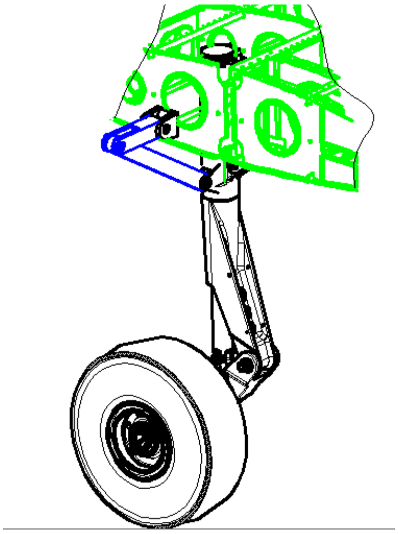


Figure 3.9: MLG install on wing structure

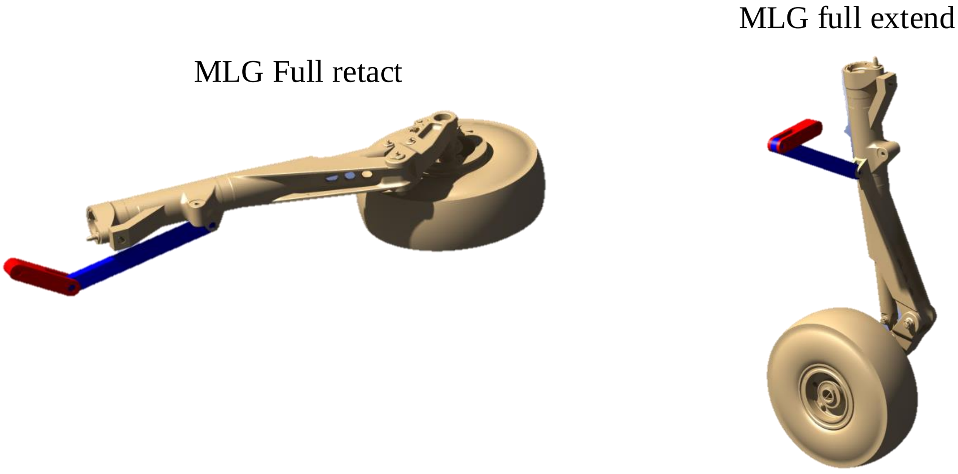


Figure 3.10: MLG at full retraction and extension position

The max retraction angle is 150° to stow the landing gear completely inside wing, figure (3.11) shows the displacement of servo link according to wing fix frame the simulation was done by CATIA DMU kinematics

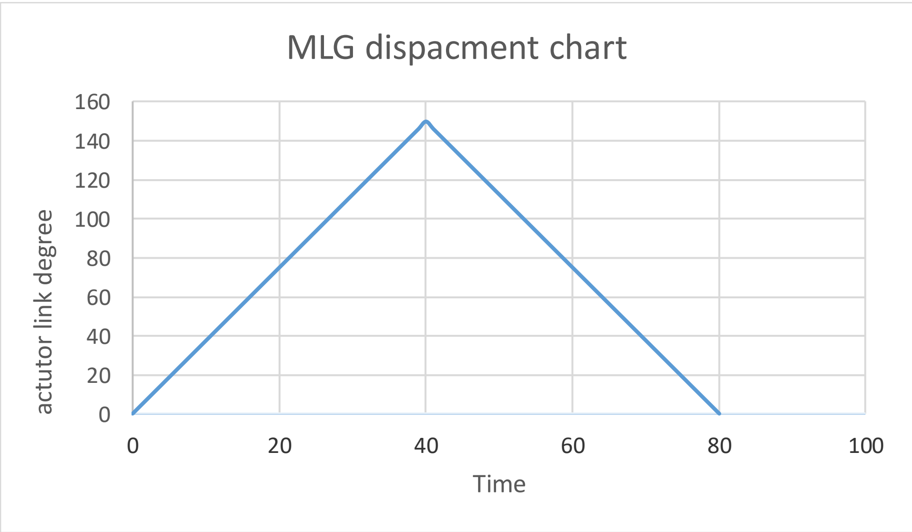


Figure 3.11: MLG retraction angle

3.3 Mechanism calculation

This conceptual calculation of force that expose on landing gear during retraction and extraction, the calculation of this force is so complicated so on this thesis we assume many assumption to select conceptual motor only ,so this calculation will need more detail if need to select actual load on LG mechanism.

Assume main forces acting on LG is drag force acting on center of pressure, weight of landing gear acting on center of gravity.

3.3.1 MLG Configuration drag force calculation

Assume Surface area of MLG (S_{ML}) as in figure (3.12)

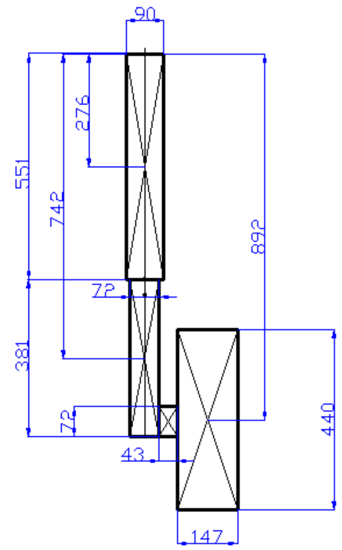


Figure 3.12: MLG surface area

$$S_{ML} = [(90x551) + (72x381) + (43x72) + (147x440)] = 144798 \text{ mm}^2 \quad (3)$$

Center of pressure calculation of MLG(R3)

$$R_3 = \frac{[\,[(90x551x276) + (72x381x742) + (43x72x892) + (147x440x892)]}{[(90x276) + (72x381) + (43x72) + (147x440)} = 652.6 \text{ mm} \quad (4)$$

Drag force on MLG (D)

$$D = \frac{1}{2} C_D \ \rho \ V_p^2 \ S_{ML} \quad (5)$$

Where:

C_D =drag coefficient=0.9

ρ =air density=1.225 kg/m3

V_p= aircraft speed during LG retraction= 140 km/h=39 m/s

S_{ML}=main landing gear surface area (m^2)

$$D = \frac{1}{2} \times 0.9 \times 1.225 \times (39)^2 \times 0.145 = 121.5 \ N$$

3.3.2 Main Landing Gear Actuator Force when LG is retracting (Up)

Assume the drag force acting as figure (3.13)

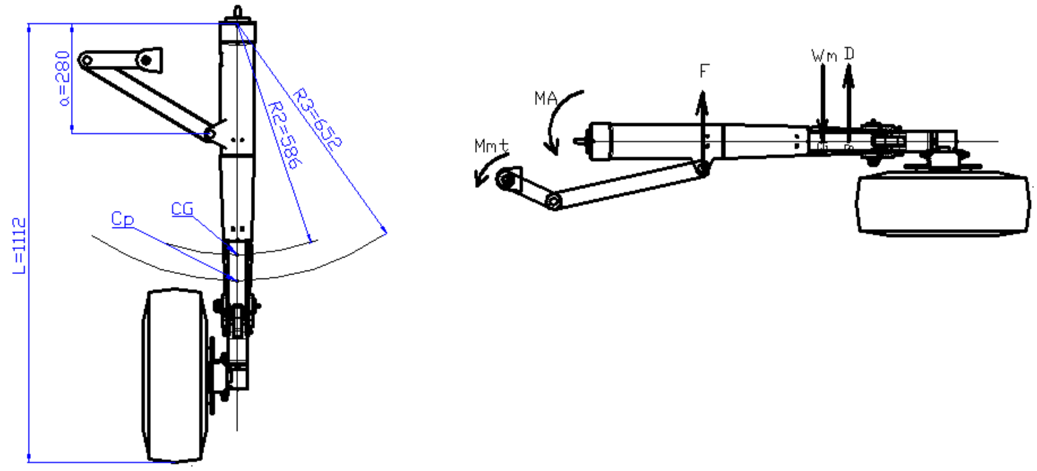


Figure 3.13: MLG drag force

$$M_A = (W_M \times R_2) - (D \times R_3) + friction\ force \quad (6)$$

Where:

M A: Moment of landing gear

W_M: weight of left main landing gear

D: drag on left main landing gear

Neglected the friction force

$$M_{A\,ML\,left} = (22.7x9.81\ \times 0.586) - (121.5 \times\ 0.652)$$
$$= 51.3\ Nm$$

$$M_A = F \times a \qquad (5)$$

$$F = \frac{51.3}{0.28} = 183.2\ N$$

$$M_{mt} = F \times b \qquad (7)$$

Where: M_{mt} : moment on servomotor, F: Force on servomotor

b: Moment length

$$M_{mt} = 196.4 \times 0.35 = 68NM$$

3.4 Actuators selection

So according to torque calculated in previous step 68Nm, the next paragraph shows is suitable rotary actuator which can be used for SAFAT 03 landing gear.

3.4.1 AMETEK actuator

[10]The AMETEK PDS engineering team is known for its impressive track record of designing, developing and qualifying Rotary Actuators used in various Aerospace and Defense applications - Business, Commercial and Military jets, Helicopters and UAV's. Our durable Rotary Actuators consist of permanent magnet stepper or DC Brushless motor designs. Each actuator design can be customized to include position feedback using potentiometers and micro switches allowing for use in a variety of applications, including flight controls, cabin and cargo doors, fuel valves, cargo locks, aileron trim and winch hoists.

Figure 3.14: AMETEK rotary actuator [10]

Features and Benefits:

- 28V DC brushed or brushless motor designs, Integral electronic control
- Custom designed to customer's output shaft and mounting requirements
- Rotary torque up to 600 ft-lbs (813.8 Nm).
- Limit switches, rotary potentiometers and opto-switches available for control
- Certified on flight critical applications

3.4.2 CIRCOR actuator

[11]Another option is CIRCOR AEROSPACE & DEFENSE

Type electric: Movement rotary

Applications: for aircraft

Torque Min.: 96.6 Nm (71.25 ft.lb), Max.: 271.16 Nm (200 ft.lb)

Figure 3.15: CIRCOR rotary actuator [11]

3.5 Landing Gear Retraction Flow Chart

Figure (3.16) show the sequence of landing gear retraction process.

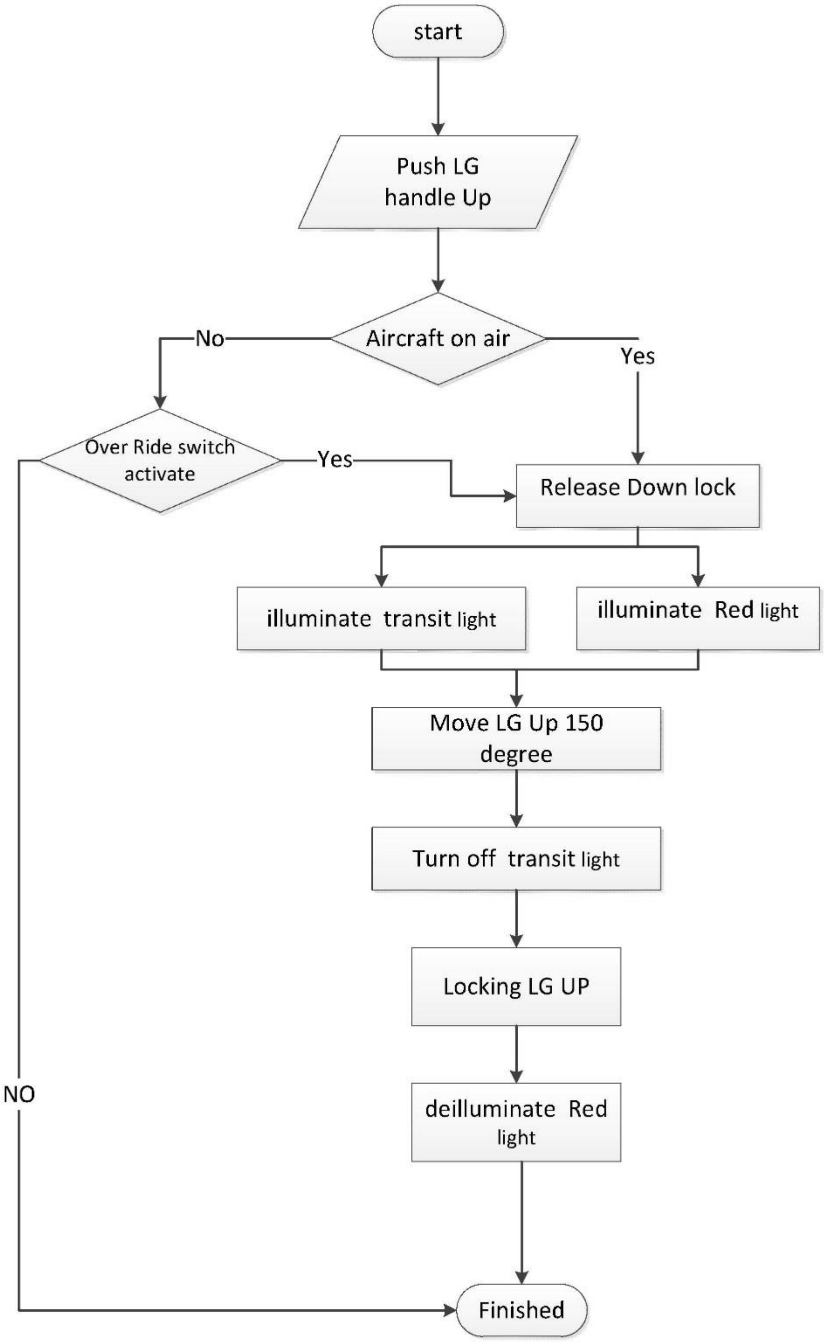


Figure 3.16: landing retraction flow chart

1. When the pilot lift the landing gear handle up the landing gear control unit first check if aircraft on ground or on air by weight on wheel sensors, if aircraft at ground and if the over-ride switch not activate (the over-ride switch will activate when need to check the landing gear for maintenance purpose) so the command is cancelled finished the sequence of retraction.

Most of aircraft will lock the handle lever when the aircraft on ground by solenoid safety switch take signal from WOW sensors.

2. When the aircraft on air or over-ride switch activate the landing gear sequence will start by release the lock of down position

3. Then the landing gear will start moving up and at same time red light will illuminate to indicate the LG now in unsafe, and the transition light will turn ON to inform pilot now landing gear is moving up.

4. The landing gear retraction motor will rotate counter clockwise 150^{o} to full stow landing gear inside fuselage and wing

5. After that the transit light will turn off

6. Then will lock the landing gear on up position

7. Finally turn the red light off to show landing gear on safe up position

3.6 Landing Gear Extension Flow Chart

When the pilot pulls the landing gear handle lever down the landing gear control unit first check if aircraft on ground or on air by weight on wheel sensors

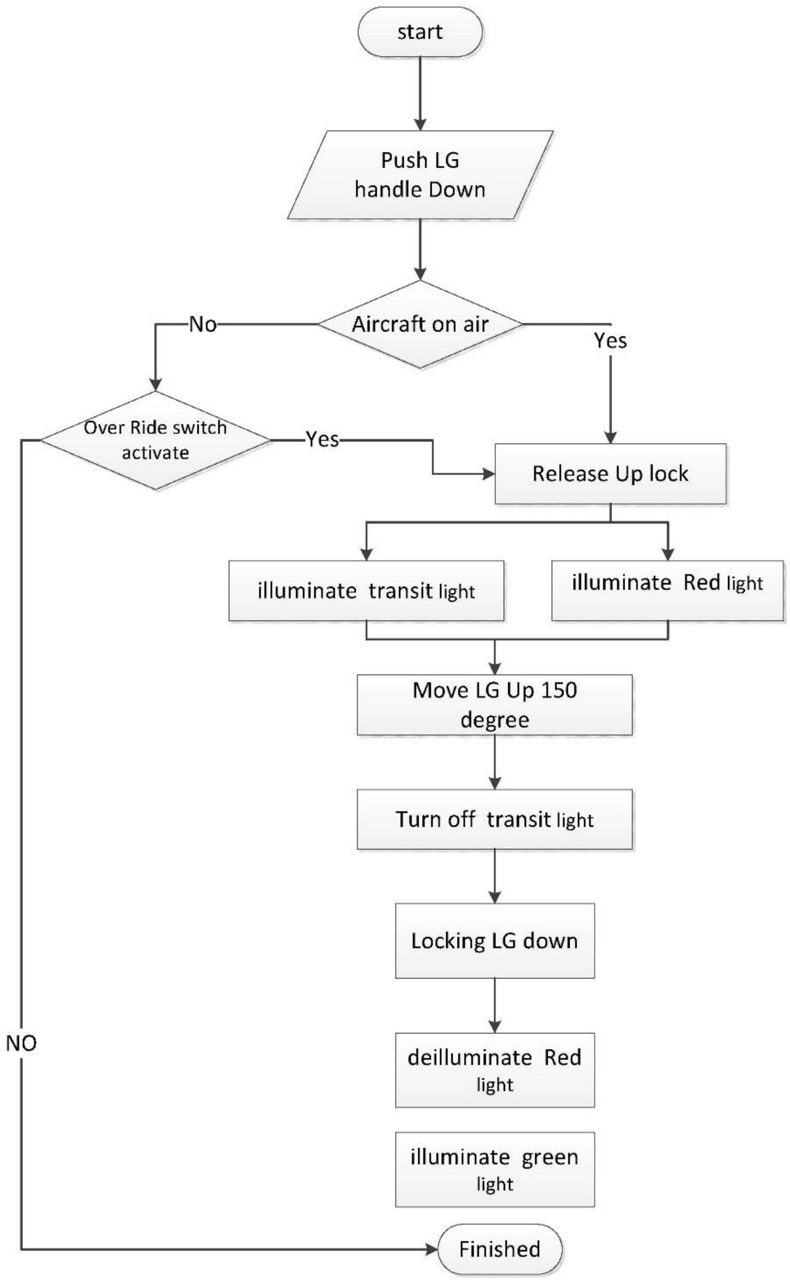


Figure 3.17: LG extension flow chart

1. If aircraft at ground and if the over-ride switch not activate (the over-ride switch will activate when need to check the landing gear for maintenance purpose) so the command is cancelled finished the sequence of retraction.

- Most of aircraft will lock the handle lever when the air craft on ground by solenoid safety switch take signal from WOW sensors.

2. If aircraft on air or override switch activate the landing gear up lock will release and illuminate the red light to show the landing gear in unsafe position, also the transit light will turn on.

3. Then landing gear extraction motor will rotate clockwise 150^{o} to full extent the landing gear, then the transit light will turn off

4. After that will lock the landing gear on down position and de-illuminate the red light.

5. Finally illuminate green light to show the landing gear is down and locked

This chapter describe SAFAT03 aircraft, and explain in detail all steps of retractable mechanism design for main landing gear, after that conceptual load calculation is done to select suitable electrical actuators, finally follow chart that shows all process of retract and extent landing gear is done.

Chapter Four

Scale Down Model Of Main Landing Gear

Chapter Four

Scale Down Model of Main Landing Gear

In this chapter will scale down the main landing gear (MLG) of SAFAT03 by factor 1:5 and manufacture by 3D printer for all MLG components then design stand to see the motion of MLG by stepper motor and control via Arduino micro controller, there are assumptions of scale down model are below

4.1 MLG Scale down manufacturing parts

4.1.1 MLG strut assembly

Figure (4.1) shows the MLG assembly, there are two revolute attachment points one attached to stand and another attached to lower side brace of retraction mechanism

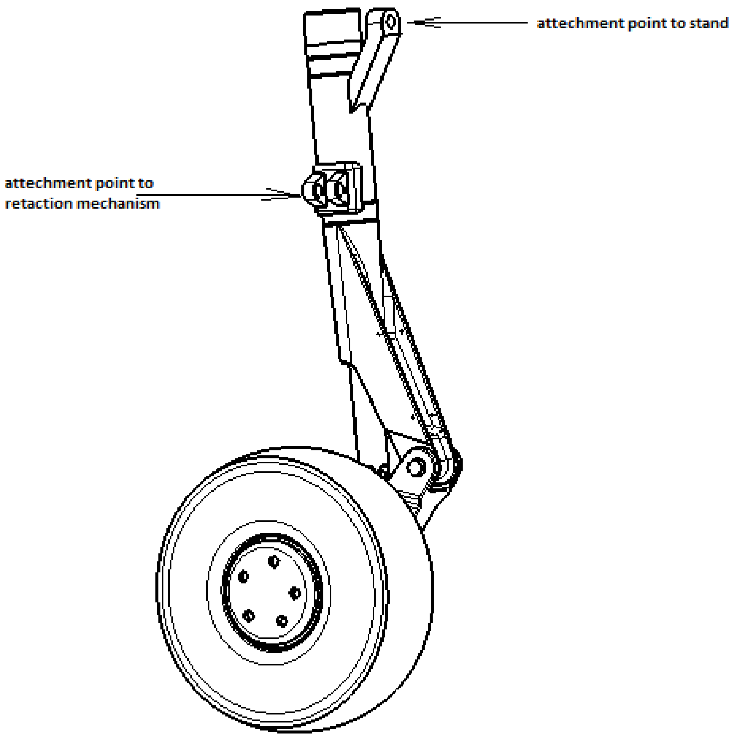


Figure 4.1: MLG assembly

4.1.2 Lower side brace

Lower side brace is one part of retraction mechanism, the lower side brace consists of two revolute joint one of them is angle chamfer edge to prevent friction between it and upper side bras during retraction process and the another revolute joint attached on MLG

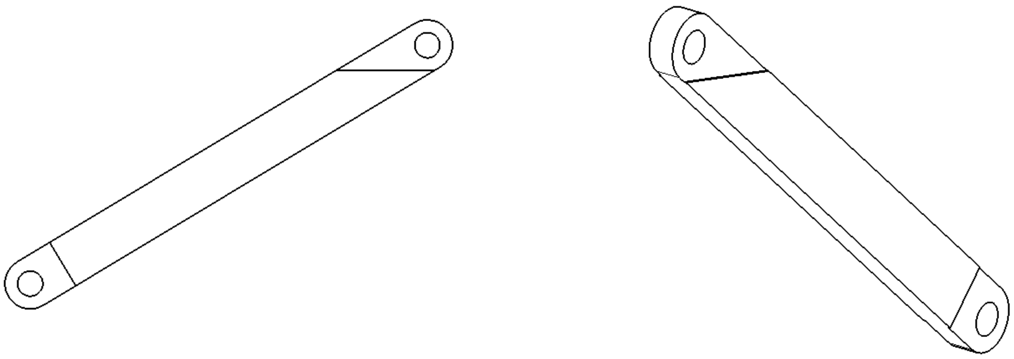
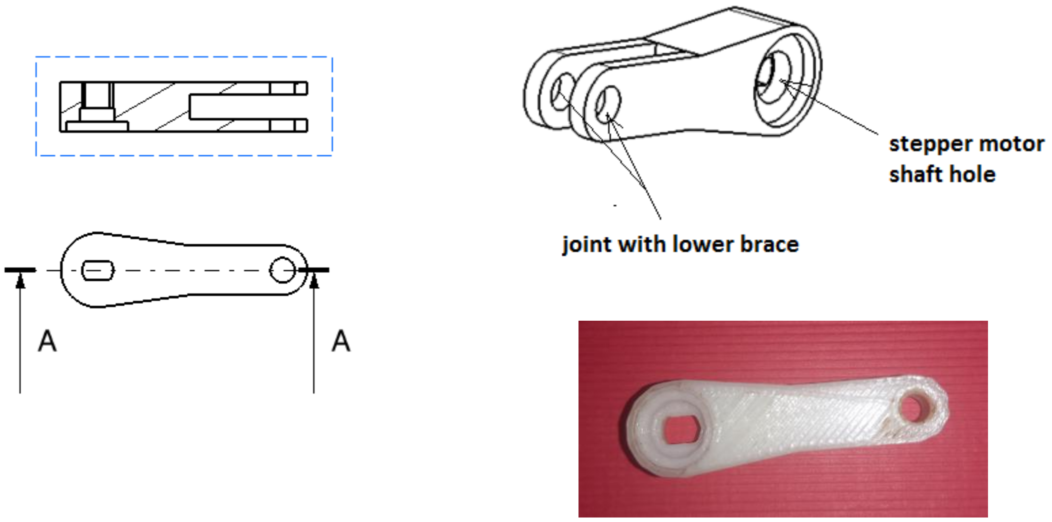


Figure 4.2: MLG Lower Side brace

4.1.3 Upper side brace

The another part of retraction mechanism is upper side brace this part transfer motion from stepper motor shaft to lower side brace figure (4.3) shows the side brace

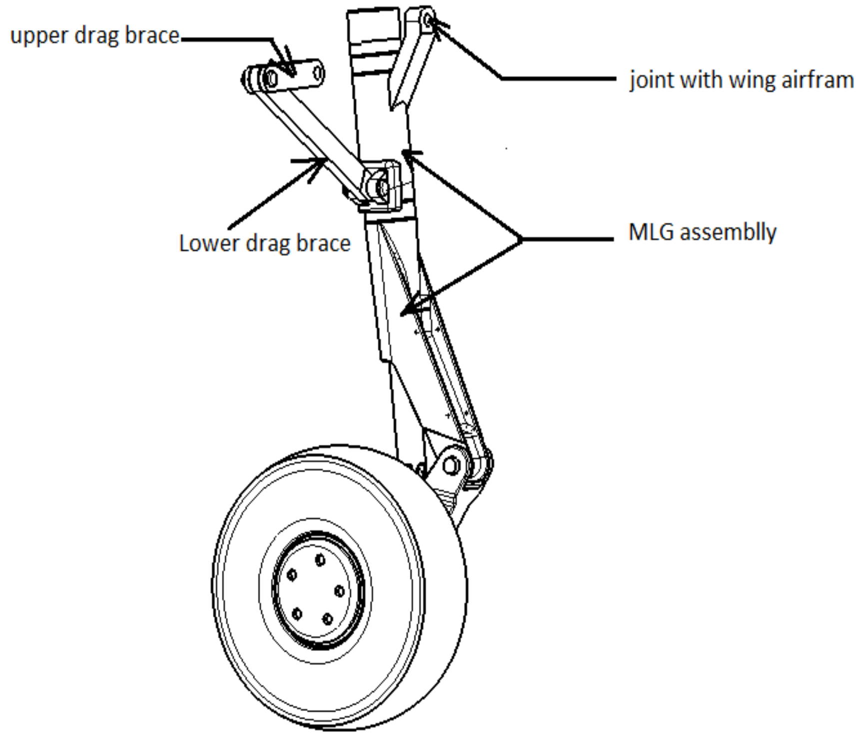


Real model

Figure 4.3: MLG upper Side brace

4.1.4 MLG assembly

Figure (4.4) shows the assembly of MLG with lower and upper side brace all part joint with pins made from PLA by 3Dprinter also



MLG manufactured by 3Dprinter

Figure 4.4: MLG assembly with upper and lower side brace

4.1.5 MLG stand

The MLG stand design to install all MLG assembly on it beside the stepper motor, this stand is representing the aircraft structure and attachment points of MLG, as in figure (4.5) the stand has small shaft attached to MLG, also there is compartment to install stepper motor via bolt and nut

- Dimension between shaft and compartment of steeper motor is take according to real design except scaled by same factor 0.2

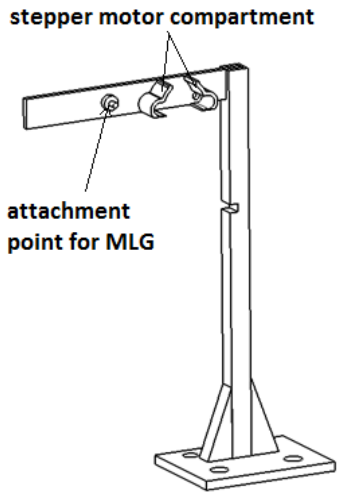


Figure 4.5: Landing gear stand

Figure (4.6) shows the assembly of MLG, retraction mechanism and stepper motor on stand.

•All parts were manufactured by 3D printer with PLA filament.

•The wheel removed to give good view of another component

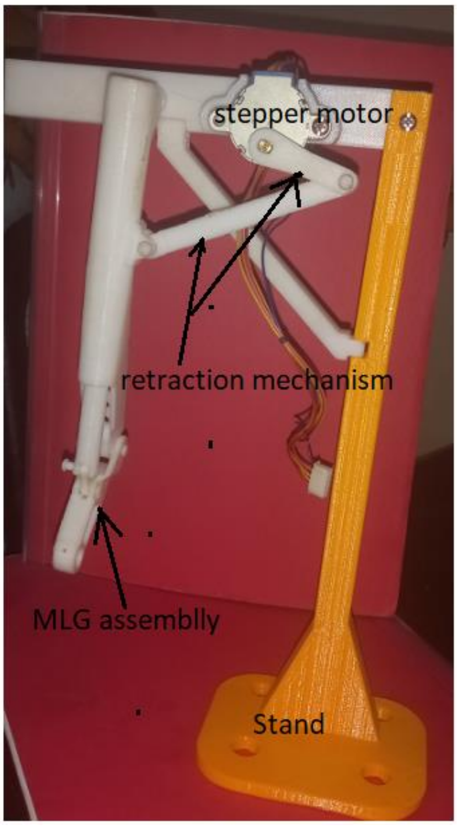


Figure 4.6: Real Model of Landing gear stand assembly with MLG and motor

4.2 Scale down Retraction system components

4.2.1 Arduino Uno

Arduino is an open source programmable circuit board that can be integrated into a wide variety of maker space projects both simple and complex. This board contains a microcontroller which is able to be programmed to sense and control objects in the physical world. By responding to sensors and inputs, the Arduino is able to interact with a large array of outputs such as LEDs, motors and displays. Because of its flexibility and low cost, Arduino has become a very popular choice for makers and maker spaces looking to create interactive hardware projects.

One of the most popular Arduino boards out there is the Arduino Uno. While it was not actually the first board to be released, it remains to be the most actively used and most widely documented on the market. Because of its extreme popularity, the Arduino Uno has a ton of project tutorials and forums around the web that can help you get started or out of a jam.

4.2.2 Arduino Software

In [12] Arduino **I**ntegrated **D**evelopment **E**nvironment (IDE). The IDE enables you to write and edit code and convert this code into instructions that Arduino hardware understands. The IDE also transfers those instructions to the Arduino board (a process called uploading).

4.2.3 Stepper motors

In [13] drone bot workshop web site explained stepper motor , a stepper's purpose is to rotate through a precise angle and halt. The speed and torque of the rotation are secondary concerns. As long as the stepper rotates through the exact angle and stops, its mission is accomplished. Each turn is called a step, and common step angles include 30°, 15°, 7.5°, 5°, 2.5°, and 1.8°.

Due to their simplicity and precision, steppers are popular in electrical devices. Analog clocks, manufacturing robots, and printers (2D and 3D) rely on steppers for motion control. An important advantage is that the controller doesn't have to read the stepper's position to determine its orientation. If the stepper is rated for 2.5°, each control signal will turn the rotor through an angle of 2.5°. For many applications, we want the step angle to be as small as possible. The smaller the motor's step angle, the greater its angular resolution. Another important figure of merit is torque, particularly holding torque. A stepper is expected to hold its position when it comes to a halt, and holding torque identifies the maximum torque it can exert to maintain its position.

- **28 BYJ-48 unipolar stepper motor**

The 28BYJ-48 is a 5-wire unipolar stepper motor that moves 32 steps per rotation internally but has a gearing system that moves the shaft by a factor of 64. The result is a motor that spins at 2048 steps per rotation.

Specification of 28BYJ-48 stepper motor

Table 4.1: 28BYJ stepper motor specification

Parameter	**Value**
Rated voltage	5VDC
Number of Phase	4
Gear ratio	**1:64**
Stride Angle	5.625° /64
Self-positioning Torque	>34.3mN.m

Steps calculation

Stride angle = 5.625\64 , So step angle =5.625*2=11.25

full step per REV for 28BY is 360\11.25= 32, full retraction angle =150º so 150\11.25=13.3 steps, put the gear ration = 1:64 so 13.3*64=853 steps

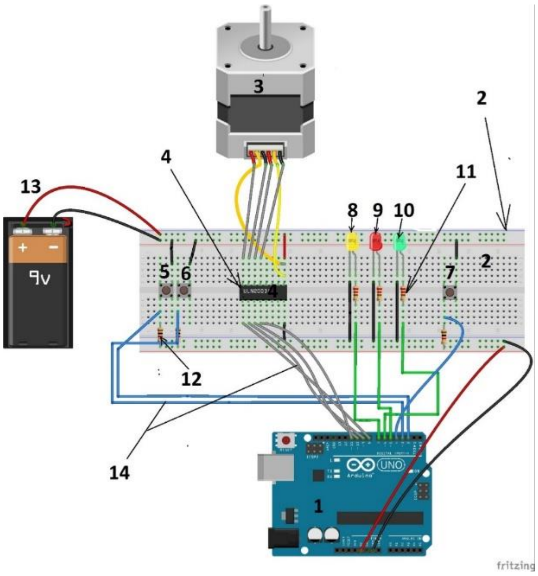
4.2.4 ULN2003 driver

The ULN2003 Darlington transistor array. The board has a connector that mates perfectly with the motor wires so it is very easy to use. There are also connections for four 5-volt digital inputs as well as power supply connections.

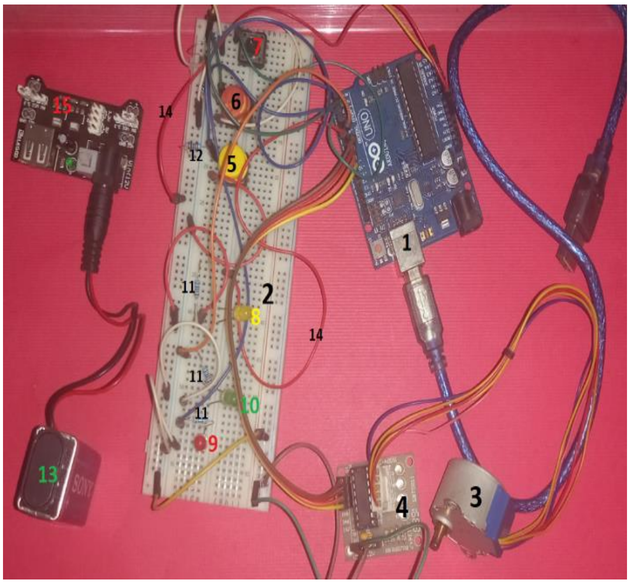
•On the subject of power supplies one very important thing to note is that you should

❖ NEVER use the 5-volt power from your Arduino to power this (or any) stepper motor no matter how tempting it is. Even though the 28BYJ-48 doesn't draw much current it will induce electrical "noise" onto its power supply lines and this could damage your Arduino. Always use a separate power supply to power your stepper motors!

Figure (4.7) shows the breadboard diagram for all components that used in retraction system



Retraction components circuit



Real components connecting on bread board

Figure 4.7: Scale down MLG retraction components on bread board

Table 4.2 shows the list of all component that use in scale down model

Table 4.2: list of devices used in Scale down model

N O	Name	No off
1	Arduino UNO	1
2	Bread board	1
3	Unipolar stepper motor	1
4	ULN2003A driver	1
5,6,7	5-push button(up switch)	3
	6- push button (down switch)	
	7-push button (ground safety)	
8,9,10	8- LED (for transit light)	3
	9- LED (for unsafe position)	
	10- LED (for down position)	
11	220 resistors	3
12	1k resistor	3
13	9v battery	1
14	Jumper wires	-

4.3Assumption of model

- Scale down factor 1:5
- Used push bottom switch instead of landing gear handle lever
- Used red Led to indicate the unsafe position of LG and green Led to indicate the down position of LG and yellow for transit light
- The total angle is 155^o

4.4 LG control and indicators on Scale down model

Air craft standard organize the all indicators on cockpit, the certification specifications for light aircraft (CS-23) which published from European aviation safety agency (EASA) explain in detail about indicators so according to that The LG control panel consist of

4.4.1 Selector lever

If pushed up means released down lock and applied actuator to retract LG If pull selector lever down that mean released up lock and applied actuator to extend LG [14]

•Here in this scale down model will used two push button one for MLG up and another for MLG down

4.4.2 Landing gear down and locked indicator

Advisory light green, illuminated associated LG are down and locked [14]

•Here in this scale down will used green LED illuminate when MLG is down and locked.

4.4.3 Landing unsafe indicator

Advisory light is red, so when illuminate that mean LG not locked up or down

Here will used red LED.

4.4.4 Amber light on handle

There is light on handle illuminates concurrent with red unsafe light to indicate LG in transit Here in this scale down will used yellow LED to indicate MLG in transit [14]

4.5 Flow chart of scale down MLG gear retraction

Figure (4.8) shows the flow chart of scale down model of MLG

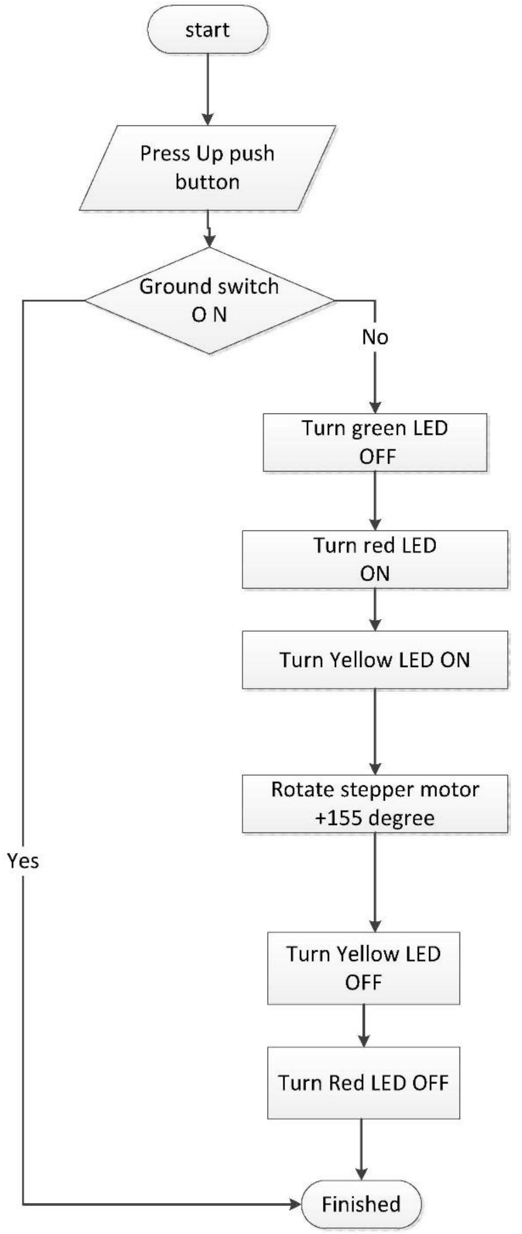


Figure 04.8: Flow chart of scale down MLG

when press the push button (used as switch to retract MLG) and if the ground switch not activate that mean the aircraft on board So Arduino turn the green LED off and red LED will illuminate (that mean the MLG now in unsafe position) and turn the yellow LED ON (transit light) in same time the stepper motor will beginning rotate 155^o (this full angle to retract the MLG) after the stepper motor complete rotation that mean the MLG now is full retract so the yellow LED will turn off after that the MLG will locked in up position so red LED will turn off so MLG statue is full retract and locked

4.6 Flow chart of scale down MLG gear extension

According to Figure (4.9) when press the down push button (used as switch to extract MLG) and if the ground switch not activate that mean the aircraft on board So turn the green LED off and red LED will illuminate (that mean the MLG now in unsafe position) and turn the yellow LED ON (transit light) in same time the stepper motor will beginning rotate 155^{o}cunter clockwise (this full angle to retract the MLG) after the stepper motor complete rotation that mean the MLG now is full retract so the yellow LED will turn off and MLG will locked in down position after that red LED will turn off and green LED will illuminate so MLG statue is full retract and locked

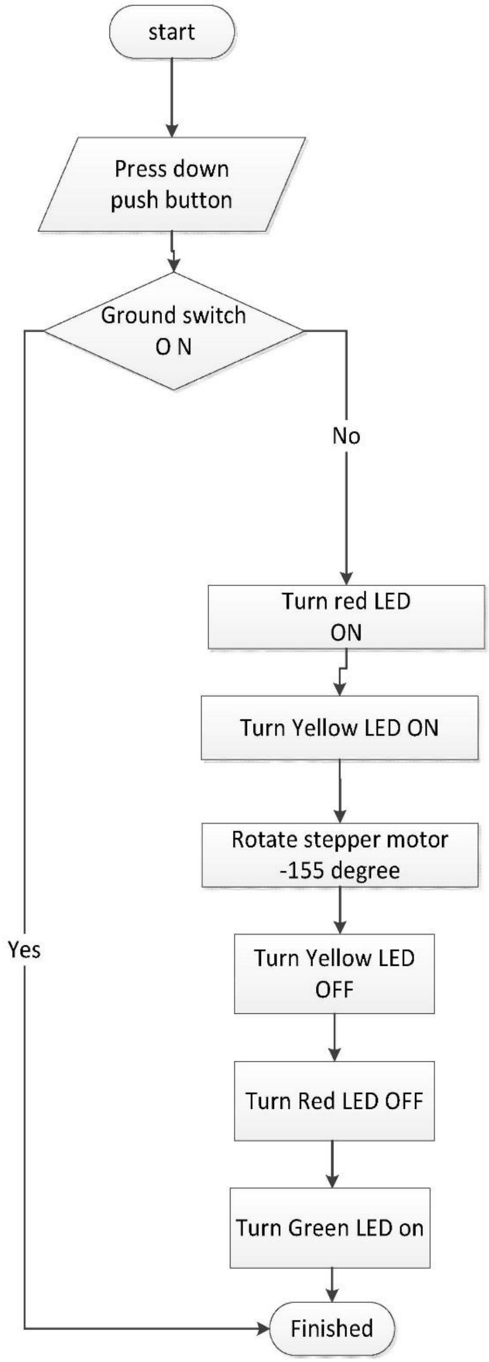


Figure 4.9: Flow chart of scale down MLG

4.7 Sketch code of MLG scale down model

The code is write according to previous flow charts by Arduino Integrated Development Environment (IDE) figure (4.10) shows the window of IDE software.

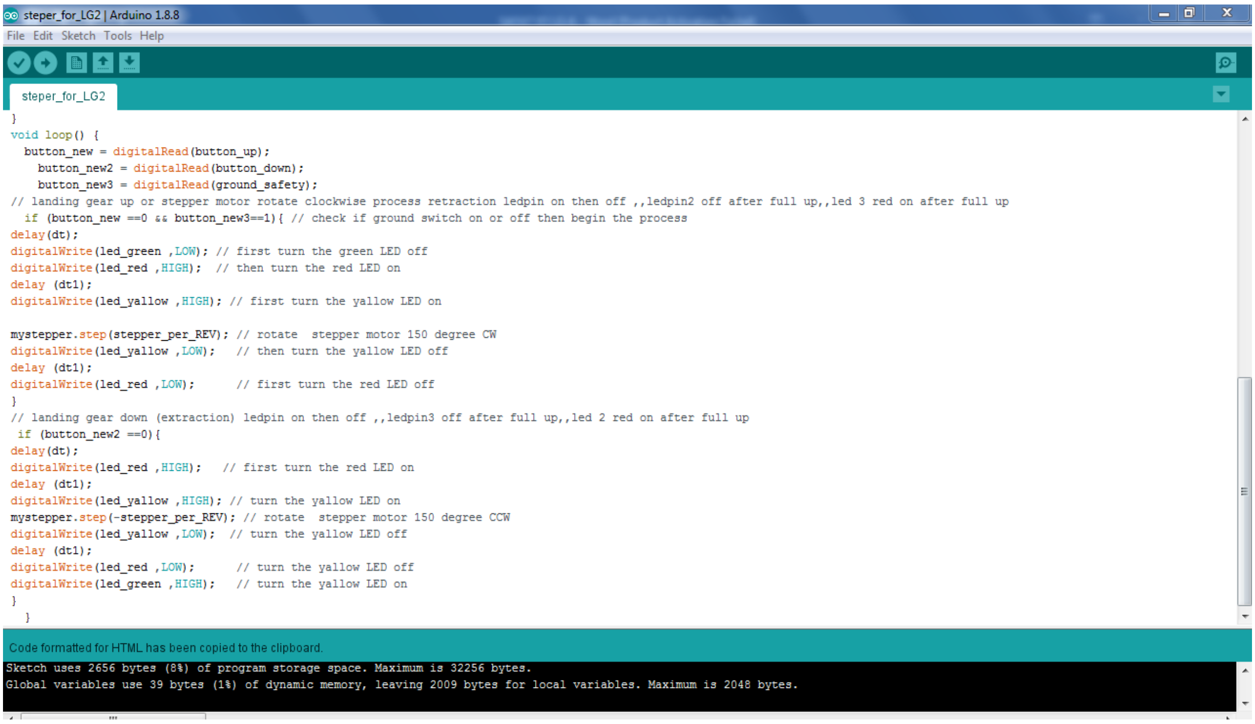


Figure 4.10: IDE window

The lock system assumes to be self-lock on stepper motor so in code the LEDs will illuminate sequence

4.8 Landing gear Scale down model simulation

All components of scale down model is drown in PRODUS software as in figure (4.11) uploading code into Arduino uno and simulate to see the proper work of this circuit

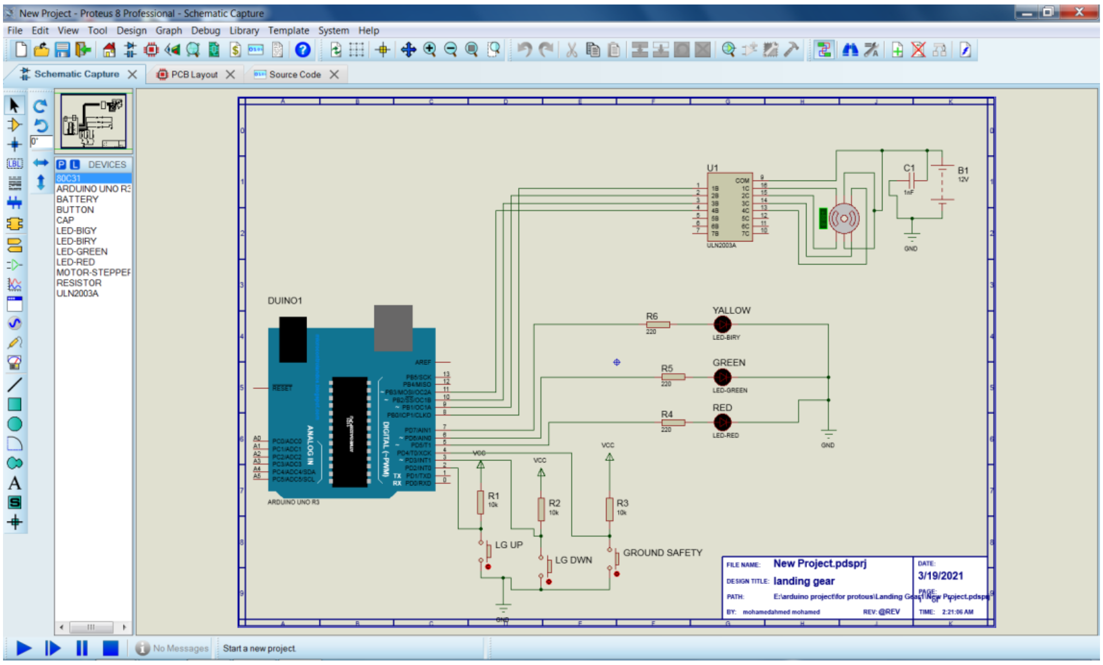


Figure 4.11 Scale down landing gear circuit in PROTUS

Chapter Five

Results and Discussion

Chapter Five

Results and Discussion

5.1 Retraction Mechanism angle at LG full extract

Purpose of retraction mechanism in this study to retract landing gear, and used as side brace to sustain the side force during landing phase (especially the retraction direction in same side force (lateral direction)), in most design the retraction mechanism if used the side brace the lower and upper part will be co-linear (co axial) when the landing gear is full extent , this position will give self-mechanical lock, by another word this design is give lock position when landing gear is full extract so can easy install mechanical lock or lock system ,while in this study is used the two parts (1and 2) in figure(5.1) of side brace not co linear (there is angle less than 180^{o}) so this will make the locking system is very complicated so for that we suppose the actuator shroud be self-lock and this will generate another problem that should have high reliable actuator to sustain this side force.

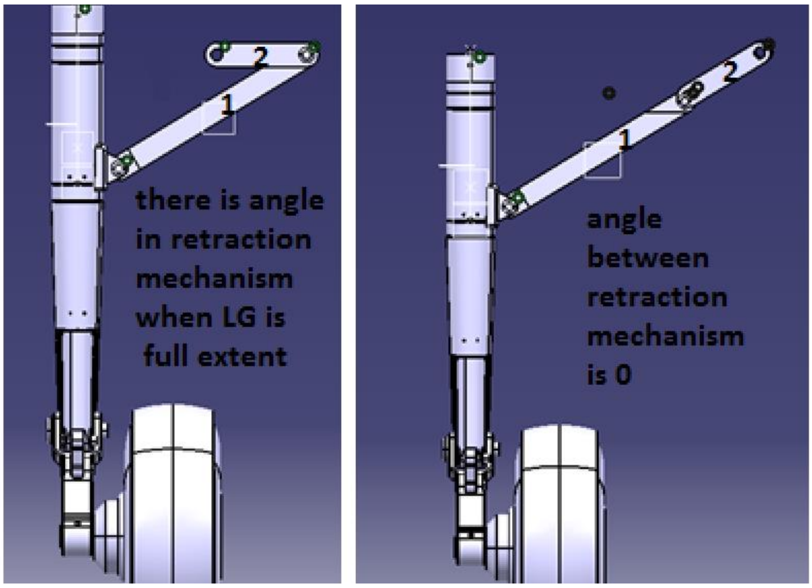


Figure 5.1: Retraction mechanism angle at LG full extend

5.2 Retraction Actuator power consumption

The actuator was selected is electrical and according to load calculation the torque required the retract LG is $68NM$ so this will need high power from engine and alternator the engine power and alternator is will not enough to operate LG actuator and preformed SAFAT 03 properly.

5.3 Landing gear interference with structure

During retraction process the LG was interfere with many parts of structure as in figures below

- When landing gear begin move to up position the strut of landing gear was cut the wing rip as show in figure (5.2), also the lower brace cut the other rib

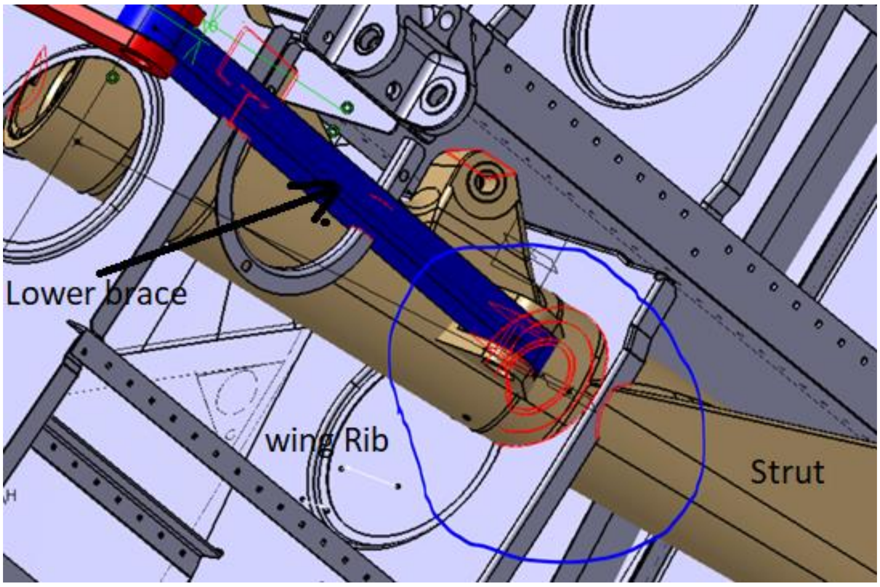


Figure 5.2: Landing gears strut interfere with wing rib

- When landing gear almost complete fully retract, the strut cut main spare of wing as show in figure (5.3), this situation is unacceptable from structure perspective

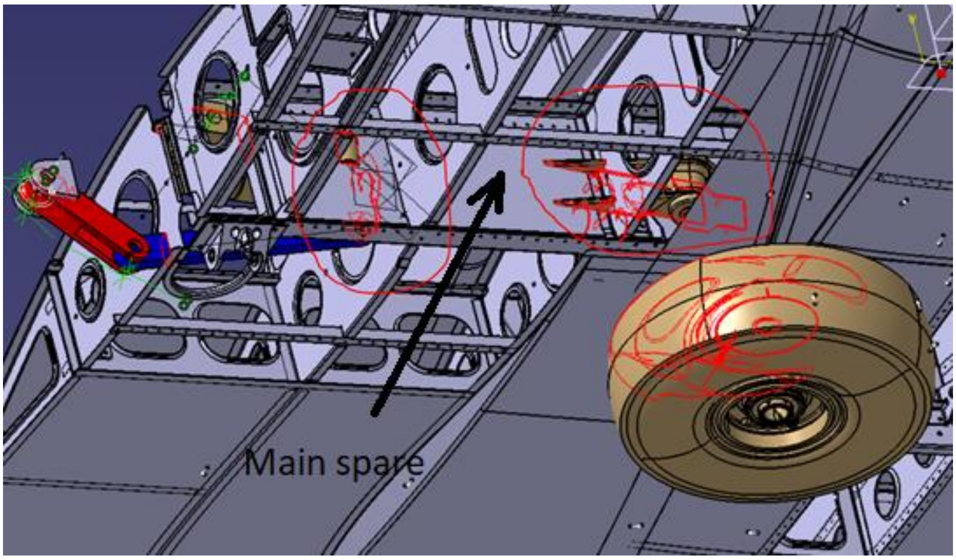


Figure 5.3: strut interference with wing main spare

- when landing gear is fully retract the wheel also cut the main spare and part of lower skin, and also its clear the lower brace interface with wing rib as show in figure (5.4)

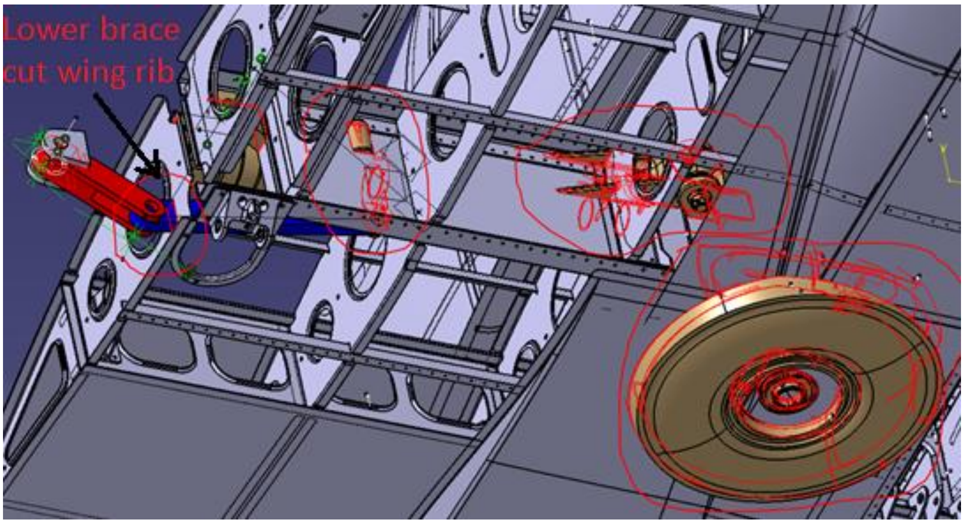


Figure 5.4: Strut interfere with wing structure at full retraction

Also in figure above shows the wheel was not retract completely inside the safat03 body.

All figures above showed landing interfered with wing structure in many location during retraction process, therefore, structure specialist should be consulted to study the effect of this interference on the structure of aircraft.

5.4 Scale down model performance

The scale down model was manufactured to test to the mechanism of landing gear and evaluate the angle of retraction, figure (5.5) shows the performance of MLG model during retraction and extraction, as shown in figure the wheel was removed because is very heavy and stepper motor can't move MLG with wheel.

Retractable position

Extension position

Figure 5.5: MLG real model during retract and extend position

5.5 Retraction angle

From CATIA simulation the max rotation angle of upper bras is 150° to stow LG completely inside the safat03 body ,while in real model 155° is max angle to full retract of LG, because there is some clearance between the stepper motor shaft and upper brace part, figure (5.6) shows the clearance between stepper motor shaft and upper part of retraction mechanism, so when stepper motor shaft start rotate the upper part of retraction mechanism didn't move immediately, because the shaft rotate free then connect with mechanism upper part, for that reason the real rotation angle in this model is 155° instead of 150°.

Also in figure (5.6) the angle between upper and lower part of retraction mechanism is not 180°, so the stepper motor should be lock the mechanism during this position, otherwise, the MLG will move while the aircraft landing and this will lead to catastrophic accident.

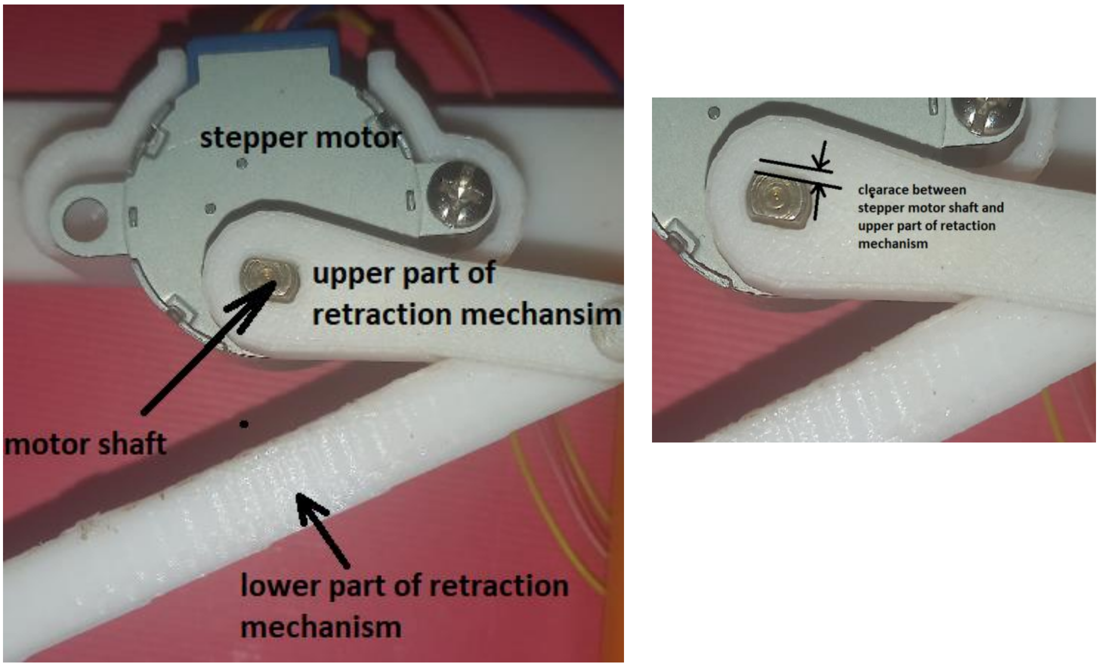
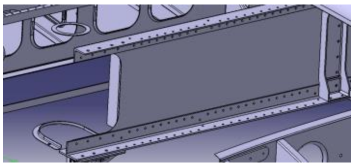
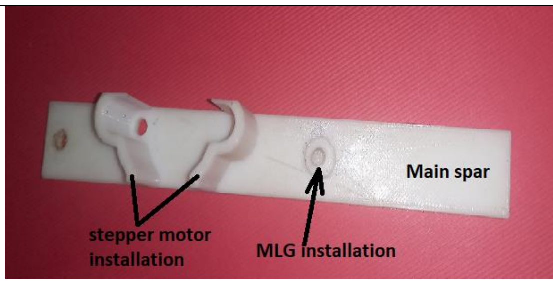
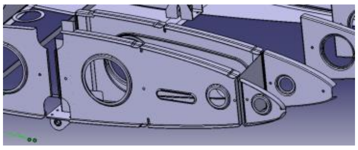


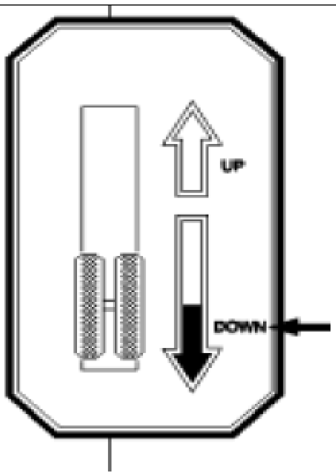
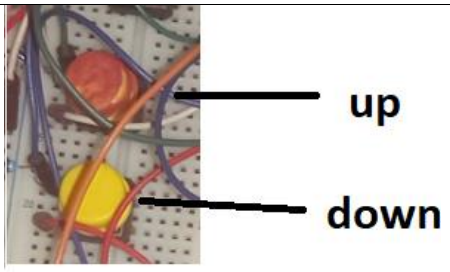
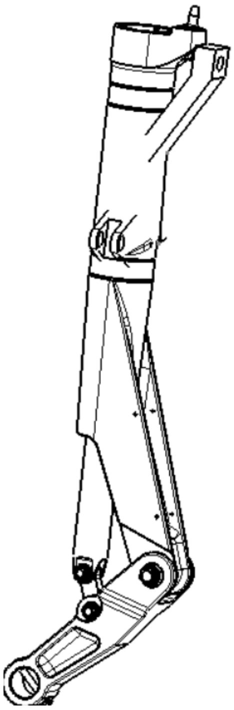
Figure 5.6 clearance between shaft and retraction mechanism

5.6 Compression between scale down model and real model of MLG retraction design

There are many assumptions when need to design and manufacturing scale down model, so these assumptions make some differences between real model and scale down model, table below shows the most these differences.

Table 5.1: main different between real and scale down model of MLG

	Full scale MLG model	**Scale down model of MLG**
Main spar	 Main spar in safat03 aircraft	
Ribs	 Ribs in safat03 aircraft	Not considered
Safety switch	In real model used safety switch activate by weight of aircraft to prevent retract LG on ground	 push button as safety switch . This button used instead of safety switch ,when press it the MLG model will not move

LG handle	 Real landing gear should be as in figure above, like lever move up and down	 Two button switch used on for LG up position and anther for down position
MLG		 Almost same as full scale MLG except the articulated arm don't move.

Chapter Six

Conclusion and Recommendation

Chapter Six

Conclusion and Recommendation

6.1Conclusion

Landing gear is substantial part in aircraft so should be analysis according to specific aircraft because each plane has unique LG design for this reason the landing retraction system was design according to safat03 configuration and focus only on aspect that related to retraction systems and consider real data such as space available ,weight, structure arrangement and wing configuration, retraction mechanism was design to stow landing gear inside wing and fuselage with minimum modification on structure, to accomplish this retraction the electrical rotary actuator was selected according to force exposed on LG, the actuator is high torque and aero actuator (high reliability) and assumed to be self –lock.

The MLG of saft03 was take as case study and retraction mechanism establish via general path graphical method and AUTOCAD 2D used to get high result of graphical method , then CATIA software used to modeling the mechanism and simulate it to get the retraction angle and evaluate the motion path if intersect with structure.

The model was manufacturing from PLA by 3d printer by scale five times smaller than real model and design stand which suitable to attached MLG and retraction mechanism on it, more over to see the real motion the stepper motor was install on stand to retract and extract the MLG scale down model , also the LED was used just to illuminate according to LG status, all these was control via Arduino microcontroller, the data on this scaled model took from real model such as retraction angle and retraction direction

The lock system of MLG is suppose self-lock so will not mention in this study so.

6.2 Recommendation

For certification issue this design should be review against aircraft regulation to evaluate the modification on it compare to real LG so maybe this will be major change.

The safety analysis is most important on aircraft design to evaluate the retraction system from safety aspect and to know if system is case any classification of accident (catastrophic, major, manor, no effect) to design redundancy system if the reliability of system is low or may the system need some modification on design

The strength analysis of retraction system should be contact to evaluate the sustainability of mechanism and to verify the sizing of retraction mechanism and the effect of LG bay on aircraft structure

The monitoring system should be design according to cockpit arrangement.

Design of NLG retraction mechanism with consideration of steering system this will be complicated because need to designate the retraction mechanism during steering and engage it when need to lift nose landing gear up so this need centering came to shift with steering mechanism if the AC touch the ground and alignment the nose wheel when landing gear on board.

The weight of retraction mechanism should be evaluating to see if the landing gear weight will be acceptable for SAFAT 03 landing gear
Power consumption by actuator should be evaluated to see if alternator and battery will be enough for landing gear electrical load

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Appendices

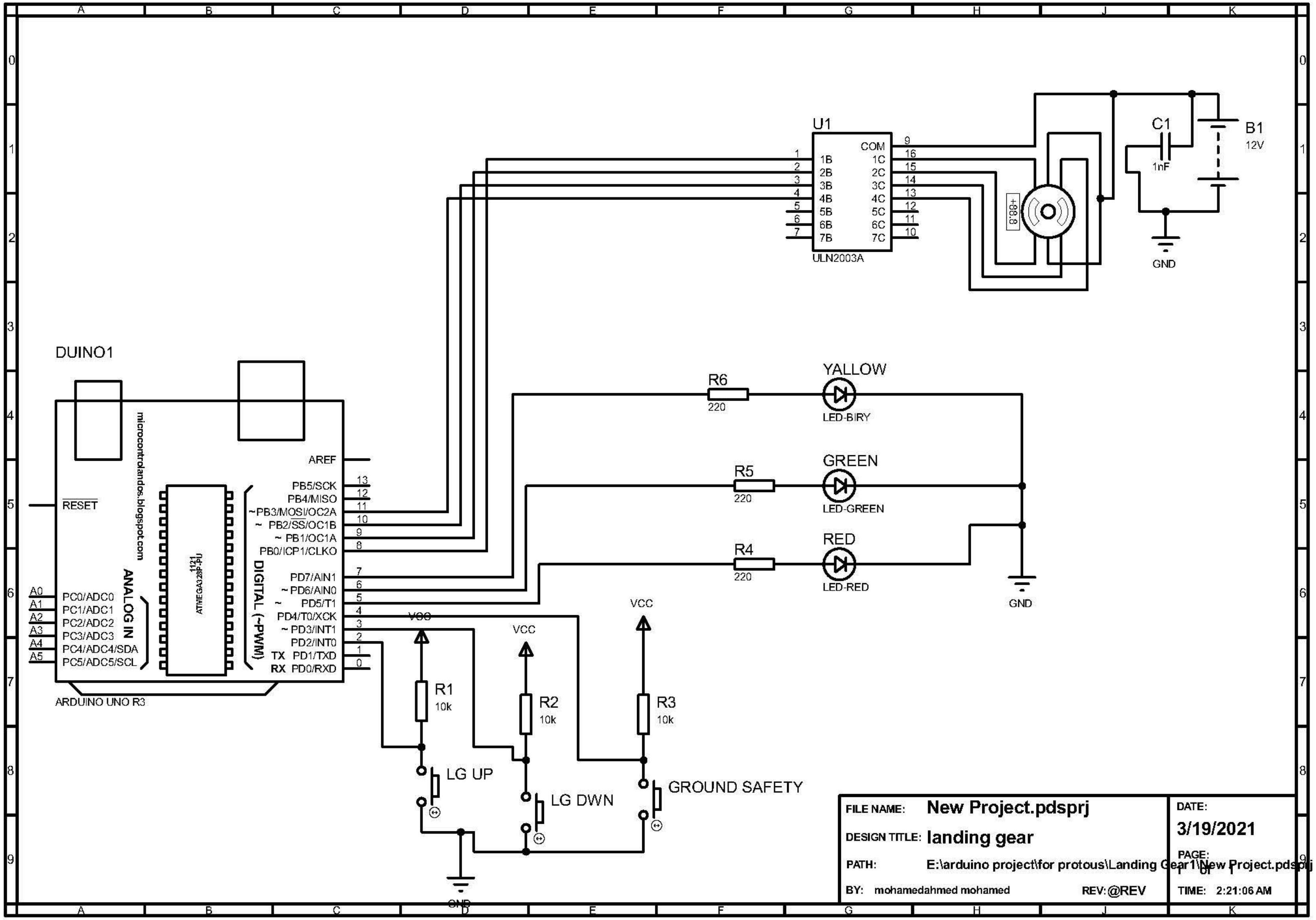
Appendix A: code of MLG scale down model

```
#include <Stepper.h>
/*
- turn the 28By stepper motor 150 degree when press button
1
- turn the 28y in oppsite direction when press button 2
- and contol LED to illuminate according to stepper motor
position
- the stride angle 5.625\64 step angle =5.625*2=11.25
- full step per REV for 28BY is 360\11.25= 32
- we need stepper motor rotate 150 angle so the step will
be 150\11.25=13.3 so and
have 64 gear ratio so 13.3*64=853 steps
*/
int stepper_per_REV =853;
int motor_speed =5;
int dt =500; // delay for pushbutton debounce
int dt1=1000;
int button_up =2; //conect push button to pin 2
int button_down =3; //conect push button to pin 3
int ground_safety =4; //conect push button to pin 4
int led_yallow =7; // illuminate when landing gear moving
connect to pin 7
int led_green =6; // illuminate when landing gear down and
lock connect to pin 6
int led_red =5; // illuminate when landing gear in unsafe
position conect to pin
5
int button_new; //this constant to read the value on button
up
```

```
int button_new2; //this constant to read the value on
button down
int button_new3; //this constant to read the value on
ground safety
int motor_stat =0;
Stepper mystepper(stepper_per_REV,8,10,9,11);
void setup() {
// put your setup code here, to run once:
pinMode(button_up,INPUT);
pinMode(button_down,INPUT);
pinMode (ground_safety,INPUT);
pinMode (led_yallow ,OUTPUT);
pinMode (led_green ,OUTPUT);
pinMode (led_red ,OUTPUT);
mystepper.setSpeed(motor_speed);
}
void loop() {
button_new = digitalRead(button_up);
button_new2 = digitalRead(button_down);
button_new3 = digitalRead(ground_safety);
// landing gear up or stepper motor rotate clockwise
process
if (button_new ==0 && button_new3==1){ // check if ground
switch on or off then begin the process
delay(dt);
digitalWrite(led_green ,LOW); // first turn the green LED
off
digitalWrite(led_red ,HIGH); // then turn the red LED on
delay (dt1);
digitalWrite(led_yallow ,HIGH); // first turn the yallow
LED on
mystepper.step(stepper_per_REV); // rotate stepper motor
150 degree CW
```

```
digitalWrite(led_yallow ,LOW); // then turn the yallow LED
off
delay (dt1);
digitalWrite(led_red ,LOW); // first turn the red LED off
}
// landing gear down (extraction)
if (button_new2 ==0){
delay(dt);
digitalWrite(led_red ,HIGH); // first turn the red LED on
delay (dt1);
digitalWrite(led_yallow ,HIGH); // turn the yallow LED on
mystepper.step(-stepper_per_REV); // rotate stepper motor
150 degree CCW
digitalWrite(led_yallow ,LOW); // turn the yallow LED off
delay (dt1);
digitalWrite(led_red ,LOW); // turn the yallow LED off
digitalWrite(led_green ,HIGH); // turn the yallow LED on
}
}
```

Appendix B: Main landing Gear circuit



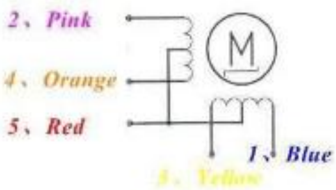
Appendix C: data sheets of component

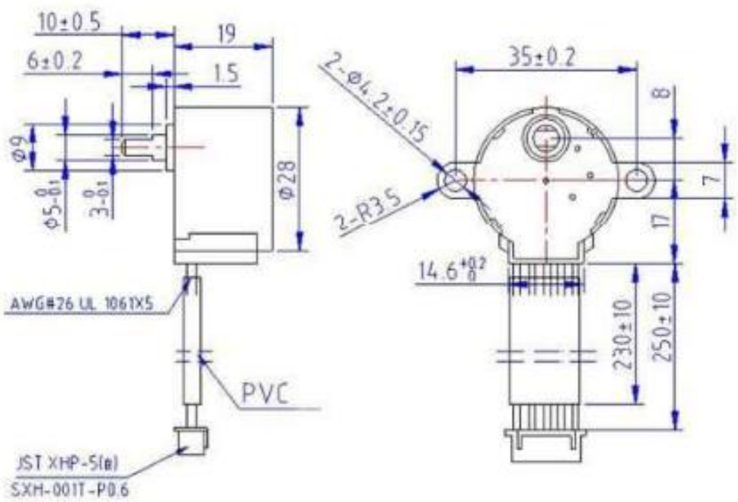
Appendix C1: 28BYJ-48-5V stepper motor data sheet

28BYJ-48 – 5V Stepper Motor

The 28BYJ-48 is a small stepper motor suitable for a large range of applications.

Rated voltage :	5VDC
Number of Phase	4
Speed Variation Ratio	1/64
Stride Angle	5.625°/64
Frequency	100Hz
DC resistance	50Ω±7%(25℃)
Idle In-traction Frequency	> 600Hz
Idle Out-traction Frequency	> 1000Hz
In-traction Torque	>34.3mN.m(120Hz)
Self-positioning Torque	>34.3mN.m
Friction torque	600-1200 gf.cm
Pull in torque	300 gf.cm
Insulated resistance	>10MΩ(500V)
Insulated electricity power	600VAC/1mA/1s
Insulation grade	A
Rise in Temperature	<40K(120Hz)
Noise	<35dB(120Hz,No load,10cm)
Model	28BYJ-48 – 5V





Appendix C2: Arduino ONU technical specification

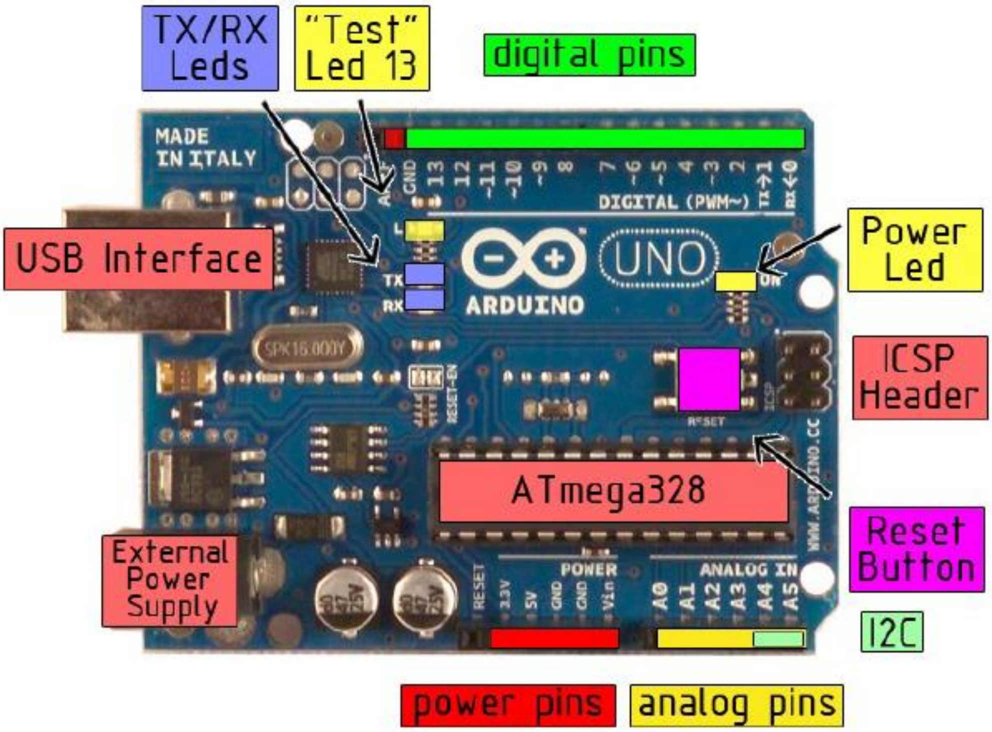
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



AppendixC3: LED data sheet

5mm LED RL5-R5015

SPECIFICATIONS

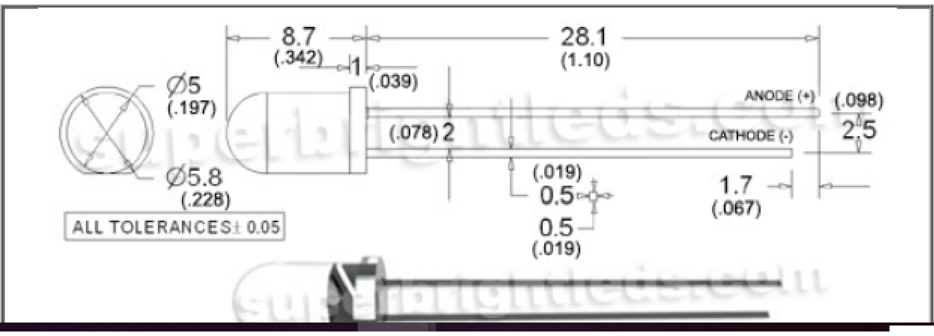
Part Number: RL5-R5015 - Super-Red LED (AlGaInP)

absolute maximum ratings: (TA=25°C)

PARAMETER	SYMBOL	RATING	UNIT
Power Dissipation	PD	150	mW
Continuous Forward Current	IF	50	mA
Peak Forward Current (1/10th duty cycle, 0.1ms pulse width)	IFM	100	mA
Reverse Voltage	VR	5.0	V
Operating Temperature	TA	-25~+85	°C
Storage Temperature	TSTG	-40~+85	°C
Reverse Current (VR=5V)	IR	10	µa
Lead Soldering Temperature (3mm from body) 260C (for 3 seconds)			

optoelectric characteristics:

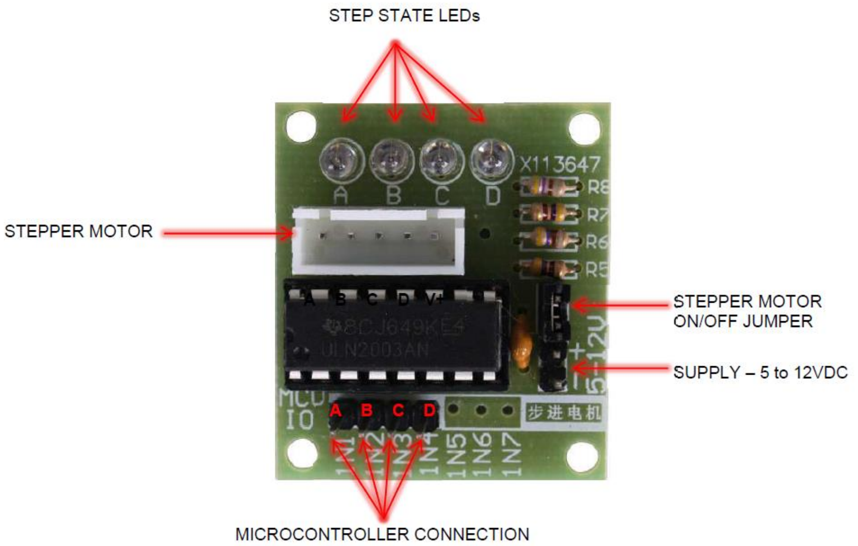
PARAMETER	SYMBOL	MAX	TYP	UNIT	TEST
View Angle of Half Power	2ø1/2	±3deg	15	Degree	
Forward Voltage	VF	2.5	2.0	V	IF=20mA
Peak Emission Wavelength	ÿ P		631	nm	IF=20mA
Dominant Emission Wavelength	ÿ D	±3nm	624	nm	IF=20mA
Spectral Line Half Width (FWHM)	Dl		13.49	nm	IF=20mA
Luminous Intensity	IV	±20%	5000	mcd	IF=20mA



Appendix C4:ULN2003 data sheet

4 Phase ULN2003 Stepper Motor Driver PCB

The ULN2003 stepper motor driver PCB provides a direct drive interface between your microcontroller and stepper motor. The PCB provides 4 inputs for connection to your microcontroller, power supply connection for the stepper motor voltage, and ON/OFF jumper, a direct connect stepper motor header and 4 LEDs to indicate stepping state.



Operation

The driver board accepts a four bit command from any microcontroller and in turn applies the necessary power pulse to step the motor. At the heart of the driver is a ULN2003AN integrated circuit. The board can supply between 5V to 12V to the motor from an independent power supply. It also has a bank of LED's that correspond to the input signals received from the controller. They provide a nice visual when stepping.

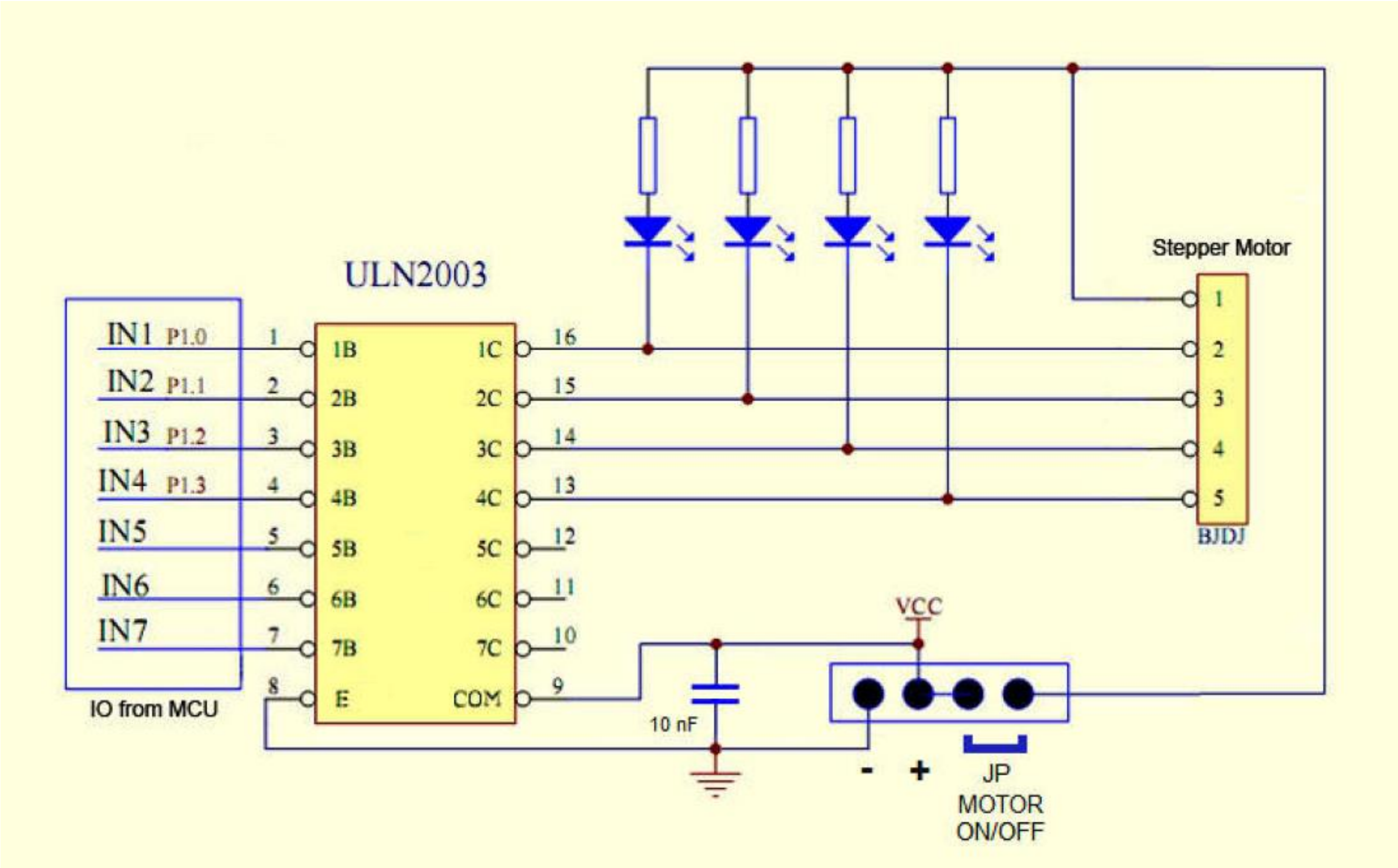
Some typical stepper motor details:

- Model: 28KYJ-48
- Voltage: 5VDC
- Phase: 4
- Step Angle: 5.625°(1/64)
- Reduction ratio: 1/64

It takes 4096 steps to rotate the spindle 360°. It is impossible to see a single step. When testing it pays to have something distinct on the spindle to show it is turning.
Physically connecting a microcontroller to the driver board is straight forward. Pick a free GPIO pin on an expansion header and run a wire from it to one of the input pins on the driver board. The driver board requires power. Make sure your power supply has sufficient power to drive the stepper motor. It is usually a good idea to use a separate power source to the one that is driving the microcontroller. Having wired a GPIO pins to the driver board you can test the interface. Set the GPIO pin high and the corresponding LED on the driver board will illuminate. Set it low and the LED turns off.

Typical Connections

Signal Name	**Microcontroller Pin**	**Driver Board Pin**
VDD_5V		+
GND	GND	-
GPIO1	PORTA.0	IN1
GPIO2	PORTA.1	IN2
GPIO3	PORTA.2	IN3
GPIO4	PORTA.3	IN4


ULN2003
Stepper Motor
IN1 P1.0
IN2 P1.1
IN3 P1.2
IN4 P1.3
IN5
IN6
IN7
IO from MCU
1B
2B
3B
4B
5B
6B
7B
E
1C
2C
3C
4C
5C
6C
7C
COM
BJDJ
VCC
10 nF
-
+
JP
MOTOR
ON/OFF

Appendix C5:Bread board power supply data sheet

CircuitAttic.com MB-V2 Datasheet | May 1, 2014

Breadboard Power Supply

Product Specifications:

- Locking On/Off Switch
- LED Power Indicator
- Input voltage: 6.5-9v (DC) via 5.5mm x 2.1mm plug
- Output voltage: 3.3V/5v
- Maximum output current: 700 mA
- Independent control rail output. 0v, 3.3v, 5v to breadboard
- Output header pins for convenient external use
- Size: 2.1 in x 1.4 in
- USB device connector onboard to power external device

Appendix C6: 9V battery data sheet

Start of an Era

The Ultralife Lithium 9V battery was launched in 1991 as the world's longest lasting lithium 9V battery.

The battery is based on lithium-manganese dioxide chemistry which leads to high energy density and voltage that remains very stable throughout the discharge.

Since the initial launch, there have been over 100 million units sold worldwide. The battery immediately gained acceptance into critical markets such as smoke detectors, security sensors, and medical telemetry.

The Next Generation

ThinCell™ Technology

The redesigned 9V battery utilizes the Ultralife ThinCell™ technology, where three individual thin foil cased cells are combined to create a 9V battery. Ultralife has been producing ThinCell™ technology cells for over 15 years.

New Size

The first major improvement was dimensionally. The U9VL-J-P is smaller than the predecessor and is equivalent to size as a standard carbon zinc or alkaline size battery and conforms to the ANSI 1604 specification.

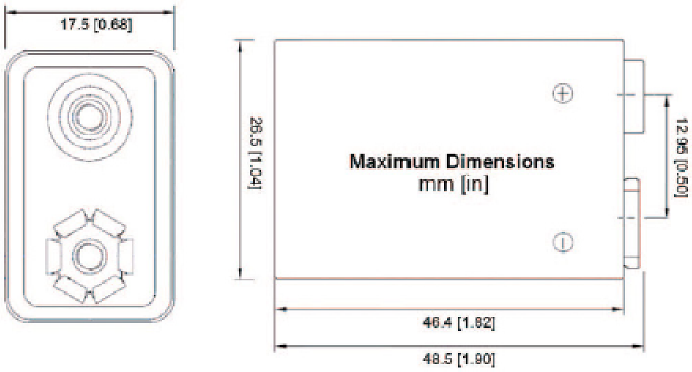
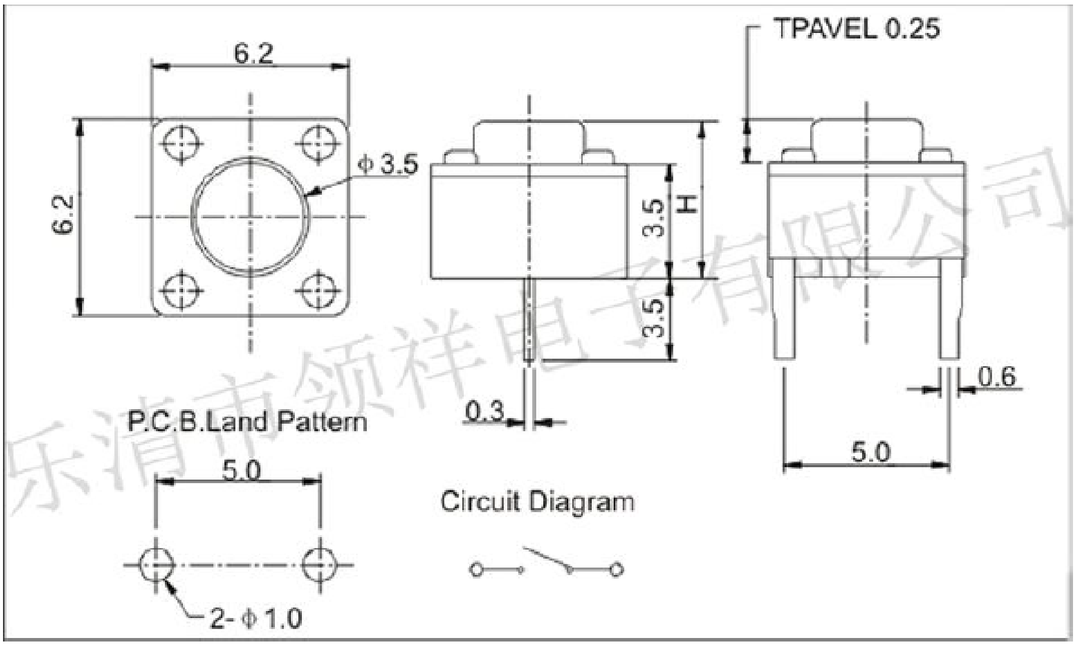


Figure 1: U9VL-J-P Dimensions

Appendix C7: push button data sheet



Specification of tact switch series

Temperature	-30~+70℃
Rated Load	DC 12V 0.5A
Insulation Resistance	>=100M Ω
Contact Resistance	=<0.03 Ω
Withstand Voltage	AC 250V(50Hz)/min
Actuating Force	150~300G
Life	100000 number of times