ISTANBUL TECHNICAL UNIVERSITY ★ FACULTY OF AERONAUTICS AND ASTRONAUTICS

UNMANNED FIGHTER AIRCRAFT SHOCK ABSORBER DESIGN AND ANALYSIS

GRADUATION PROJECT

Melihcan BAŞKIR

Department of Aeronautical Engineering

Thesis Advisor: Prof. Dr. Ali Kodal

JULY, 2020

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Melihcan Başkır, student of ITU Faculty of Aeronautics and Astronautics student ID 110150052, successfully defended the **graduation** entitled "UNMANNED FIGHTER AIRCRAFT SHOCK ABSORBER DESIGN AND ANALYSIS", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

I present my endless thanks to my advisor Prof. Dr. Ali KODAL for his care, support and guidance in every sense throughout my thesis. I also would like to thank to Alanur Canbaz, who always encouraged me with her smile, support and being with me in any stresfull times I had and my dearest friends Emre Kara, Hasan Dalkılıç and Oğuz Özdoğan for their constant help during my university life. I express my gratitude to the BAYKAR family for sharing their knowledge and experience during my thesis study. Finally, I wholeheartedly thank my dear family for their unconditional love, spiritual, moral and financial support.

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ABBREVIATIONS

EASA	**:** European Aviation Safety Agency
FAR	**:** Federal Aviation Regulations
R&D	**:** Research and Development
UAV	**:** Unmanned Aerial Vehicle
UCAV	**:** Unmanned Combat Aerial Vehicle

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UNMANNED FIGHTER AIRCRAFT SHOCK ABSORBER DESIGN AND ANALYSIS

SUMMARY

In nowadays technology, activities on unmanned aerial vehicles in the aviation field have increased very intensely. With the development of autonomous systems, UAVs have made such great progress that every country has understood the importance of this technology, invested huge sums of money, started R&D studies and started best producing its own vehicles. Unmanned aerial vehicles have recently become a favorite because of their effectiveness in many areas such as exploration and surveillance of the operational area, border security, traffic control, trafficking monitoring, forest fires and natural disasters. UAVs take a more suitable place among other aircrafts in an economic aspect. The preparation, taking-off and post-landing maintenance of a fighter jet will be much costlier than UAV. One of the biggest advantages of unmanned aerial vehicles is that they have capability of staying in the air for much longer periods comparing to other manned aircraft. For these reasons, the studies for unmanned aerial vehicles have increased to a great extent.

The aircraft landing gear systems have crucial roles in terms of providing a suspension system during taxi, take-off and landing, reducing the loads coming from the ground to the airframe of the aircraft and enabling to the aircraft to stop and take-off. It is extremely important that the shock absorber of the landing gear system should function properly in order for the aircraft to land safely.

In line with this thesis, the types of unmanned aerial vehicle landing gear shock absorber, the components it possesses, the design criteria were mentioned. Based on this design criteria, the shock absorber was designed for the unmanned fighter aircraft consept. It was determined how much stroke and orifice diameter it should have. Based on the average weight value of the aircrafts that can be included in unmanned fighter aircraft class, the forces coming to the shock absorber were determined. Depending on this force, structural analysis of the shock absorber was carried out.

UNMANNED FIGHTER AIRCRAFT SHOCK ABSORBER DESIGN AND ANALYSIS

ÖZET

Günümüz teknolojisinde, havacılık sektöründe insansız hava araçları üzerine yapılan çalışmalar yoğun bir şekilde artmıştır. Otonom sistemlerin gelişmesiyle birlikte insansız hava araçları büyük gelişmeler katetmiştir. Her ülke bu teknolojinin önemine varmış. Onlarca paralar yatırım yapmış, araştırma geliştirme çalışmaları başlatmış ve en iyi kendi insansız hava araçlarını üretmeye başlamışlardır. İnsansız hava araçları operasyonel alanlarda keşif ve gözlem, sınır güvenliği, trafik kontrol, kaçakçılık gözetleme, orman yangınları ve doğal afetler gibi birçok alanda etkinliği nedeniyle son zamanlarda favori hale gelmişir. İHA'lar ekonomik açıdan da diğer uçaklar arasında daha uygun bir yer almaktadır. Bir savaş uçağının hazırlanması, kalkışı ve iniş sonrası bakımı bir İHA'ya göre çok daha maliyetli olacaktır. İnsansız hava araçlarının en büyük avantajlarından biri, diğer insanlı uçaklara kıyasla çok daha uzun süre havada kalma kabiliyetine sahip olmalarıdır. Bu nedenlerle, insansız hava araçlarına yönelik çalışmalar büyük ölçüde artmıştır.

Uçak iniş takımı sistemleri, taksi, kalkış ve iniş sırasında bir süspansiyon sağlama, yerden uçağın gövdesine gelen yükleri azaltma ve uçağın durmasını ve kalkışını sağlama açısından önemli rollere sahiptir. Uçağın güvenli bir şekilde inebilmesi için iniş takımı şok sönümleyici sisteminin düzgün şekilde çalışması son derece önemlidir.

Bu tez doğrultusunda insansız hava aracı iniş takımı şok sönümleyici çeşitleri, sahip olduğu bileşenler, tasarım kriterleri belirtilmiştir. Bu tasarım kriterlerine dayanarak, şok sönümleyici insansız savaş uçağı konsepti için tasarlanmıştır. Şok sönümleyicinin tasarımı için gerekli olan parametreler hesaplanmıştır. İnsansız savaş uçağı sınıfına dahil edilebilecek uçakların ortalama ağırlık değerine dayanarak, şok sönümleyiciye gelen kuvvetler belirlendi. Son olarak, bu kuvvete bağlı olarak şok sönümleyicinin yapısal analizi yapılmıştır.

1. INTRODUCTION

Landing gear system is one of the critical subsystems of an aircraft and and because of the structural configuration of the aircraft, they are usually configured together with the aircraft structure. One of the most important component of the landing gear that makes it a landing gear is the shock absorber. Shock absorbers are designed to absorb and distribute the kinetic energy of the landing effect. Thus, impact loads transmitted to the body reduced. Shock absorbers need to absorb not only the forces transmitted to the fuselage but also the loads coming to critical parts such as avionic units inside the aircraft. Different options have been used in the design of shock absorbers according to their intended use, requirements and technology of the age. Although the shock absorber designs look different from each other, all of them have certain parameters to be considered during the design phase. Some of these design conditions are specified in aviation regulations such as FAR, EASA.

In this study, the shock absorber design in the landing gear that can be used for unmanned combat aerial vehicle was theoretically implemented. The structural strength of the shock absorber designed was evaluated by analysis.

1.1 Purpose of Thesis

The aim of the project is to realize the theoretical design of the shock absorber in the landing gear, one of the critical sub-systems of the aircraft, for the unmanned combat aircraft configuration. Then, it is aimed to observe shock absorber's strength to the loads that the aircraft is exposed to by structural analysis.

1.2 Literature Review

With the onset of World War 1, the aircraft configurations began to have more wheel types and the landing gear struts were pretty sturdy to the fuselage and the bungee cords were wrapped around the axle, making a certain level of shock damping.

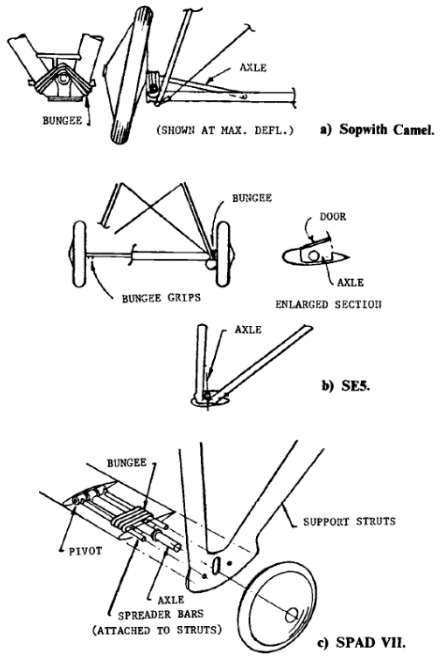

Figure 1.1 : Bungee chords enabling shock absorber.

For the first time in October 1906, this design was used on the 14-bis aircraft of Santos Dumont. With the effect of world war 2, the aviation field showed rapid development which also resulted in important progress on shock absorbers. Many types of shock absorbers such as restricted-flow hydraulic cylinders appeared. With the advancement of technology, retrectable landing gears began to be used. Weight of the aircrafts and sink speeds have increased more and more. This led to the need for aircrafts to absorb much more energy at the landing phase. Aircraft tires themselves provide a certain amount of shock absorpion. Due to size restrictions and low efficiency of the aircraft tires, the possible contribution to shock damping has been significantly reduced. Therefore, shock absorber variants such as rigid axle, solid spring, levered bungee and oleo-pneumatic have emerged. A typical rubber block shock absorber was used in the landing gear of the Ford Trimotor aircraft.

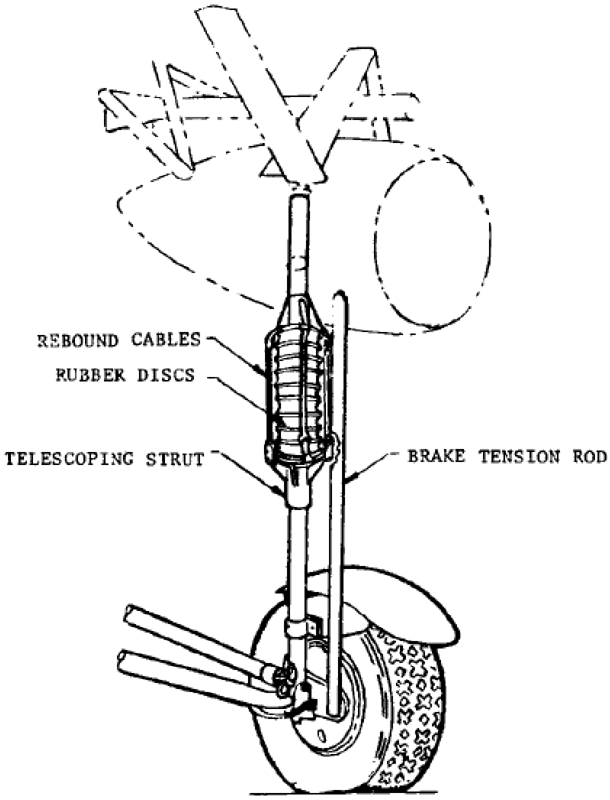

Figure 1.2 : Ford Trimotor rubber block shock absorber.

During 1915, the oleo pneumatic shock absorber was first designed and patented by Vickers Armstrong. Vickers' shock absorber was first used in a french aircraft company Breguet Aviation. Vickers' design was such that the oil was above the air. This design did not cause any problems until the landing gear became retrectable. Later on a free-floating piston was invented by Peter Hornill, creating a shock-absorber for retractable landing gears that could work at different angles, eliminating the disadvantage of the mix of oil and air. During the following years, oleo-type shock absorbers were widely used in aircraft around the world. Many types of shock absorbers have been designed towards today's years. However, although the general principles of all were the same, they differed in size, weight, performance, efficiency and demands.

2. SHOCK ABSORBER TYPES

Landing gear is one of the components that aircraft manufacturers spend most of their time intensely and detailed in its design from the very beginning of the design since it ensures that the aircraft will land and take off safely. On the other hand, it is one of the most prone to be one of the main causes of aircraft crashes. Therefore, it is vital that landing gears should perform its functions without any problems.

One of the most important design criteria in landing gear design is how the shock absorber system will be. There are many different shock absorber types which most important of them will be mentioned and decided which of these will be the best for unmanned fighter aircraft shock absorber design.

2.1 Rigid Axle Shock Absorber

Rigid axles were used in the early stages of aviation history. In the rigid axle shock absorber type, the wheels are connected to the airframe of the aircraft with rigid strut. Damping is very low in this shock absorber type because there is completely rigid connection between the tires and the fuselage of the aircraft and there is no flexibility. Therefore, the majority of the load exerted on the wheels at any hard touchdown is transmitted to the body. It is quite possible that the components inside the aircraft and the fuselage of the aircraft can be damaged. Engineers used air-inflated tires to absorb energy in this shock-absorber configuration. Although it does not provide enough shock absorption, its benefit cannot be denied.

Figure 2.1 : Rigid axle shock absorber.

2.2 Solid Spring Shock Absorber

Unlike rigid axle, the connection between the tires and the aircraft fuselage is made by flexible strut in the solid spring shock absorber design. In this configuration, the strut is positioned at an angle with the aircraft fuselage. Thus, vertical displacement takes place in the landing gear strut due to the load exerted on the tires at the touchdown moment. This enables the aircraft to make some certain of shock absorption. However, this lateral movement forces the wheels of the aircraft to move outwards and causes the wheel to wear out in time. Also, there is no element in this configuration to perform any damping function against shock-induced vibrations. Because of that this system can be resembled as undamped spring. The aircraft lands on to the ground by making some jumps. This causes landings to be severe. Although it has a number of disadvantages, it is popularly used in light aircraft. It does not contain any mechanically complex structure and it requires very little maintenance.

Figure 2.2 : Solid spring shock absorber.

2.3 Levered Bungee Shock Absorber

This shock absorber version is slightly more advanced model of solid spring shock absorber model. Because in this design, there is bungee chords between the fuselage and landing gear which enables to absorb shock-induced vibrations. Elastic chords in the form of rope wrapped around the landing gear transfers the impact loads on the wheels to the airframe of the aircraft in a way that reduces its impact and it prevents possible damage to the aircraft fuselage and other critic components inside the aircraft structure. Due to the forces acting at the first contact of the aircraft with ground, the landing gear flexes outward which tires wear out over time as in the solid spring shock absorber configuration [1]. This type of shock absorber was commonly used in early light aircrafts. Figure 2.3 shows an example of the levered bungee shock absorber.

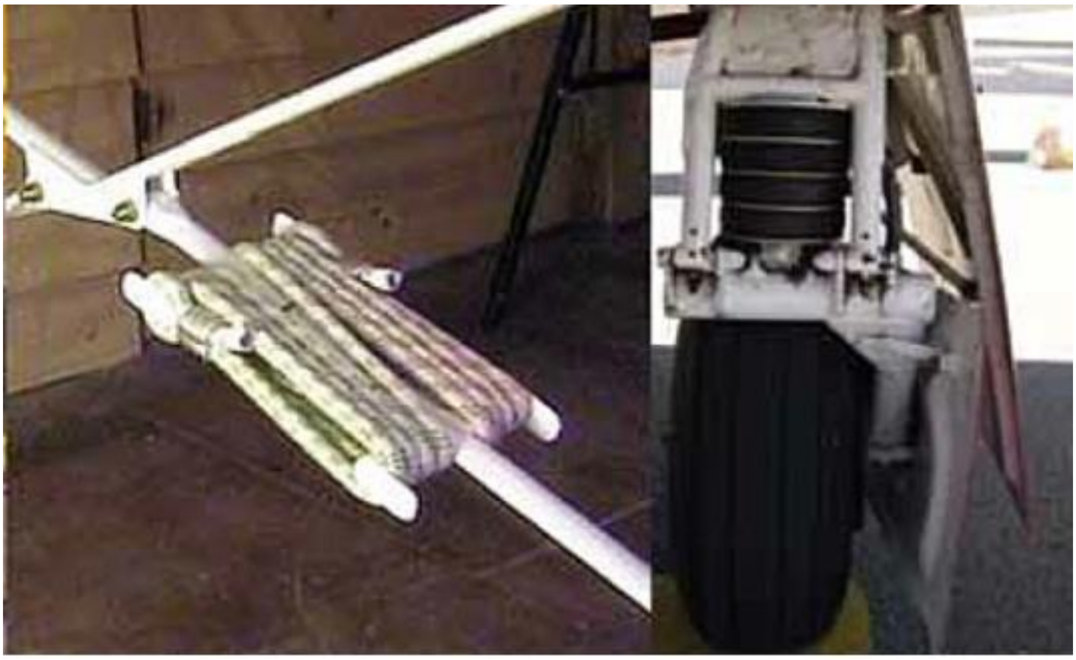

Figure 2.3 : Levered bungee shock absorber [2].

2.4 Oleo-Pneaumatic Shock Absorber

This type of shock absorber is the most widely used system from today's heavy passenger aircraft to lightweight medium-class unmanned aerial vehicles since it provides much more efficient shock absorption and damping compare to other shock absorber types. Oleo-pneaumatic shock absorber system based on the principle that the piston compresses the air inside the cylinder which air acts as a spring and the oil inside the lower chamber are forced to pass through the orifice which oil itself functions as a damping element. Nitrogen gas is used instead of air. Because nitrogen does not contain oxygen like air and is an inert gas. Therefore oxidation can not be occured inside the chamber[3]. This prevents the chambers from being corroded, thus extending the life of the shock-absorbing system much longer. Figure 2.4 shows the inside section of an oleo pneumatic shock absorber.

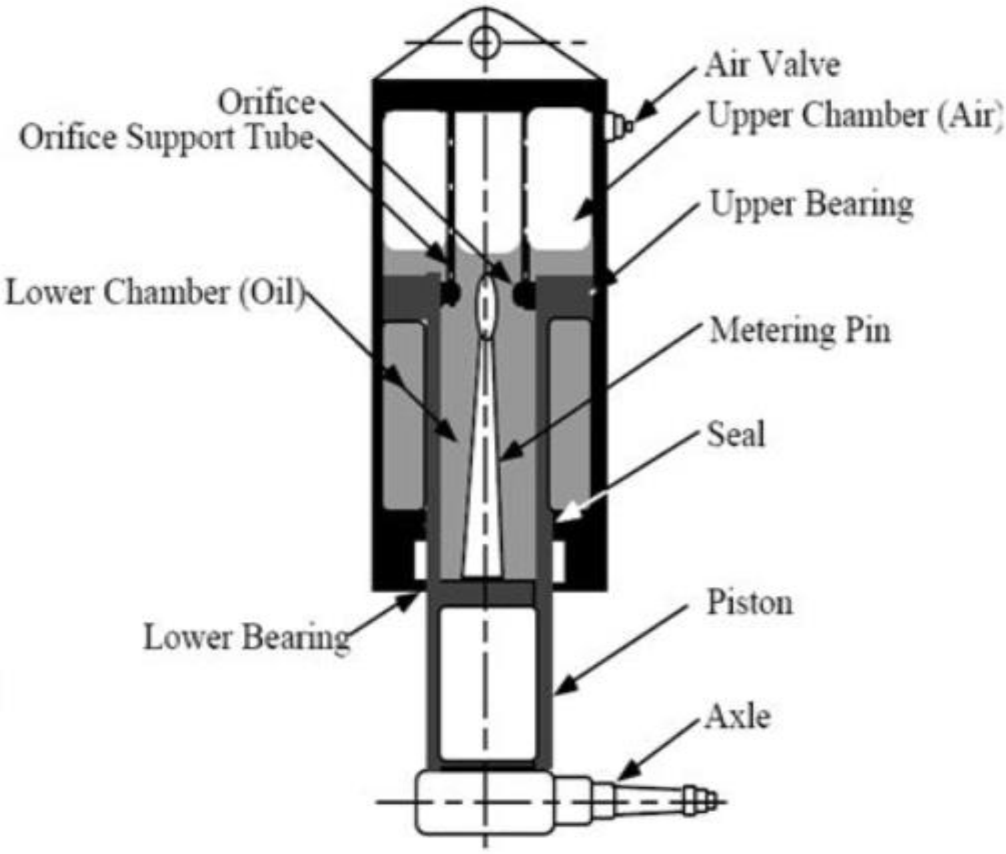

Figure 2.4 : Oleo-pneaumatic shock absorber [4].

When comparing the types of shock absorbers in the light of the above information, it will be the best choice to choose the oleo pneumatic shock absorber for the our UCAV configuration. As can be understood from the Figure 2.5, oleo pneumatic shock absorber has the highest efficiency compared to other types and is suitable for any application such as high aircraft weights and high sink speeds. Moreover, oleo pneumatic shock absorber has many advantages such as performance, low weight and small sizes compared to other types.

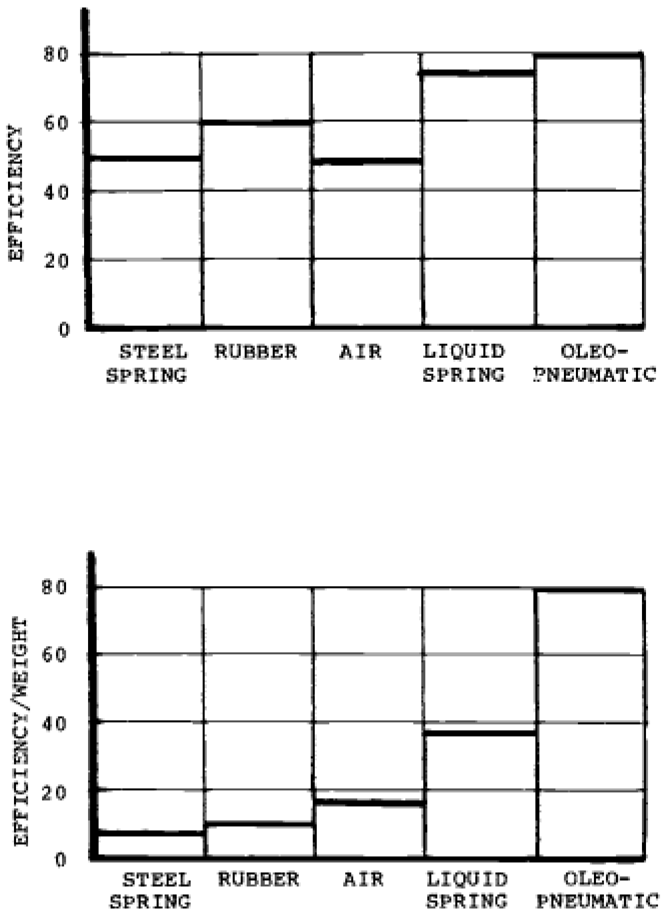

Figure 2.5 : Efficiency values according to shock absorber type [5].

In conclusion, it has been decided to use oleo pneumatic shock absorber for unmanned fighter aircraft shock absorber design because it has the highest efficiency over weight ratio.

3. OLEO PNEAUMATIC SHOCK ABSORBER DESIGN

3.1 Introduction

A typical oleo pneumatic shock absorber absorbs and dissipates shock loads by means of hydraulic oil and compressed air. Shock absorber works based on the principle of converting impact energy into heat energy with a sudden increase in pressure during compression. The upper part of the shock absorber consists of a cylinder and is mounted on the structural of the aircraft by a pin connection. On the other hand, the lower part consists of a piston and is connected to the wheels. According to the load change on the wheel, the piston can move freely in the cylinder in the direction of the stroke. The cylinder consists of two chambers and while the bottom chamber is filled with oil, the top one is usually filled with air or nitrogen gas. There is a hole called orifice that allows the passage between the two chambers. Thus, the oil passes through the orifice at the landing moment and provides the air to be compressed.

3.2 Parts

An oleo pneumatic shock absorber consists of many elements that dynamically interact with each other. It can be classified as an cylinder, piston consising of piston head and piston rod and eventually metering pin.

3.2.1 Cylinder

The cylinder surrounds the entire shock absorber and remains rigidly attached to the main strut of the landing gear during operation. The cylinder consists of two separate chambers. While the bottom chamber is filled with oil, the upper chamber is filled with air or nitrogen gas. The cylinder must withstand the pressures created by the gas and oil inside them due to dynamic and static loads during the landing.

3.2.2 Piston

The piston is placed in the outer cylinder in a way to move freely in the direction of its own axis. The piston has a critical role to absorb incoming shock loads. When the first contact of the aircraft wheels with the ground, the shock load forces the piston to move upwards, and the oil in the lower chamber passes through the orifice channel, allowing air to be compressed.

3.2.3 Metering pim

The metering pin plays a very critical role for the shock absorber. It determines the efficiency of the shock absorber. It takes part in determining in what ratio the oil will pass into the upper chamber of the cylinder. The metering pin is connected to the piston and in nowaday's oleo pneumatic shock absorbers, the metering pin usually has a tapered shape which crosses from the orifice. As the piston moves upwards, the orifice area will decrease and less oil will pass through orifice due to the increasing of the diameter of the metering pim at the orifice section. The figure below describes this situation. By changing the orifice area, an almost constant shock load is obtained under dynamic load. If this load could be made completely constant, the shock absorber would have a efficiency of hundred percent. However, this has not been achieved yet and the efficiency values are around 80-90 percent for oleo pneumatic shock absorbers [6].

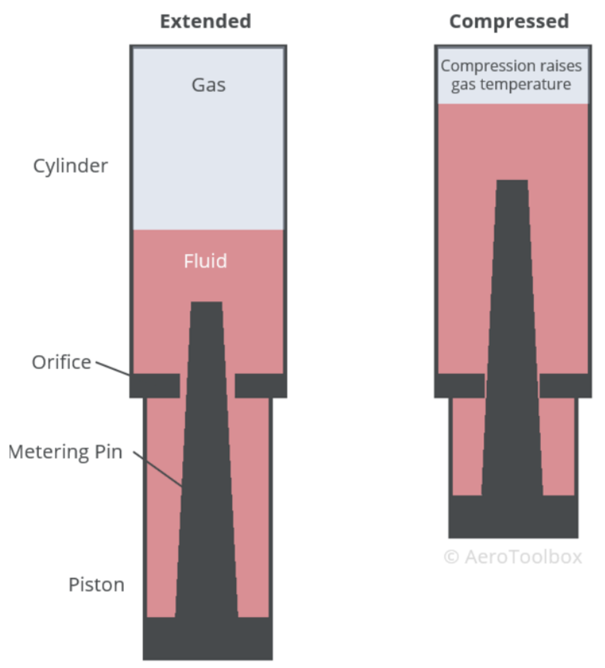

Figure 3.1 : The working principle of metering pim [7].

3.3 Design considerations

Designing a shock absorber requires iterative work in terms of optimizing parameters such as weight and size. Also, each aircraft is unique itself. In the initial design phase of a shock absorber, the sink speed of the aircraft, load factor, stroke and type of shock absorber has a direct effect. Since the shock absorber type has been determined for the UCAV, other parameters will be mentioned in this section.

3.3.1 Sink speed

Sink speed is defined as the vertical component of the aircraft's forward speed at the time of gliding [8]. Sink speeds are specified in the aviation regulations according to the categories of aircraft. In both the FAR 23 and FAR 25 regulations, the sink speed was determined to be 3 m/s. However, this value differs according to operation type for military aircrafts. If the military aircraft is landing on the runway, the sink speed is 3 m/s and 4 m/s for trainers. For the naval aircrafts, these value ranges from the 5 to 8 m/s. In addition, military aircrafts designed to have sink speeds of 4 or even 5 exist today like the Swedish Viggen and the Gripen aircrafts [9]. For the unmanned fighter aircraft, the sink speed was chosen as 4 m/s.

3.3.2 Load factor

Landing load factor or called as reaction factor can be described as the ratio of the maximum acceptable load on the shock absorber which is the sum of static and dynamic loads to the static load. The table shows the values of typical load factors for different aircraft categories. Since the type of the aircraft is unmanned fighter aircraft, the load factor was chosen as 4.

Table 3.1 : Landing load factors.

Aircraft type	N_{gear}
Large bomber	2.0-3.0
Commercial	2.7-3.0
General aviation	3.0
Air Force fighter	3.0-4.0
Navy fighter	5.0-6.0

3.3.3 Stroke

Stroke is the length of the displacement of the wheels in the vertical direction. When it is looked at the parameters determining the stroke length, the sink speed and the load factor come first. The stroke length may not be the same as the shock absorber stroke length. Since navy aircrafts have high sink speeds, the stroke length of the shock absorber is usually higher than the calculated sink value in order to keep the load factor within the appropriate limits.

3.4 Shock Absorber Design Equations

3.4.1 Stroke calculation

One of the most important parameters to be determined when designing the shock absorber is the stroke length. The principle of energy conservation will be used in calculating the stroke length. The kinetic energy in the vertical direction at the touchdown can be written as below.

$$E_t = 0.5(W_L)\left(\frac{v_z^2}{g}\right) \qquad \textbf{(3.1)}$$

Where:

E_t – touchdown kinetic energy of the aircraft

W_L – weight of the aircraft at landing

v_z – sink speed

g – gravitational acceleration

If potential energy is involved, the equation turns into the this.

$$E_t = 0.5(W_L)\left(\frac{v_z^2}{g}\right) + (W_L - L)(s_s + s_t) \qquad \textbf{(3.2)}$$

Where:

L – lift at landing

s_s – shock absorber stroke

s_t – tire deflection

The energy absorbed by the shock absorber and the tyres can be written as follows.

$$E_{absorbed} = W_L N_g \left(\eta_t s_t + \eta_s s_s\right) \qquad \textbf{(3.3)}$$

Where:

N_g – landing load factor

η_t – tire efficiency

η_s – shock absorber efficiency

From the conservation of the energy the total energy of the aircraft at the touchdown must be equal to total absorbed energy by the shock absorber and tires.

$$W_L N_g (\eta_t s_t + \eta_s s_s) = 0.5(W_L)\left(\frac{v_z^2}{g}\right) + (W_L - L)(s_s + s_t) \qquad \textbf{(3.4)}$$

If it is assumed that the lift generated by the aircraft during landig is equal to the weight of the aircraft and making the shock absorber stroke term alone, the equation becomes;

$$s_s = \left[\left(\frac{v_z^2}{2gN_g}\right) - \eta_t s_t\right] / \eta_s \qquad \textbf{(3.5)}$$

An additionally 0.0254 m is added to the calculated value for the safety against any unexpected situation.

$$s_{s_{design}} = s_s + 0.0254 \qquad \textbf{(3.6)}$$

In order to calculate the stroke length, it is need to know shock absorber efficiency, tire efficiency and tire deflection. The tire energy absorption efficiency is usually taken as 0.47. Since our shock absorber for the unmanned combat aircraft is the oleo-pneumatic with metered orifice, the efficiency was taken as 0.80 from the table 3.2.

Table 3.2 : Efficiency values for shock absorber types.

Type	Efficiency, •
Steel leaf spring	0.50
Steel coil spring	0.62
Air spring	0.45
Rubber block	0.60
Rubber bungee	0.58
Oleo-pneumatic	
-Fixed orifice	0.65-0.80
-Metered orifice	0.75-0.90
Tyre	0.47

When calculating the tire deflecion, it is assumed to deflect up to rolling radius. Therefore, tire deflection can be calculated as the half diameter of the tire minus rolling radius. In order to calculate tire deflection, it is needed to specify aircraft maximum take-off weight, how much static load will be exerted on the main landing gear and by utilizing from this values, the proper tire should be selected. The unmanned fighter aircraft will have maximum take-off weight of 8000 kg which is approximately 80000 N. The aircraft load factor was selected as 4 with the addition of 50 percent of safety factor according to EASA []. Total load exerted on the aircraft landing gear is 320000 N. At least 25 percent of the total load must be acting on to the front landing gear []. Accordingly, the maximum static load on one strut in the main landing gear was calculated as 120000 N. In line with this load, type VII 40x14 tire was selected from the table 3.3. Type VII tire was chosen because they are used for jet engine aircrafts unlike the type III which are used for piston engine aircrafts.

Table 3.3 : Tire data.

Size	Speed, mph	Max Load, lb	Infl, psi	Max Width, in.	Max Diameter, in.	Rolling Radius	Wheel Diameter	Number of Plies
Type III								
5.00–4	120	1200	55	5.05	13.25	5.2	4.0	6
5.00–4	120	2200	95	5.05	13.25	5.2	4.0	12
7.00–8	120	2400	46	7.30	20.85	8.3	8.0	6
8.50–10	120	3250	41	9.05	26.30	10.4	10.0	6
8.50–10	120	4400	55	8.70	25.65	10.2	10.0	8
9.50–16	160	9250	90	9.70	33.35	13.9	16.0	10
12.50–16	160	12,800	75	12.75	38.45	15.6	16.0	12
20.00–20	174 kt	46,500	125	20.10	56.00	22.1	20.0	26
Type VII								
16 × 4.4	210	1100	55	4.45	16.00	6.9	8.0	4
18 × 4.4	174 kt	2100	100	4.45	17.90	7.9	10.0	6
18 × 4.4	217 kt	4350	225	4.45	17.90	7.9	10.0	12
24 × 5.5	174 kt	11,500	355	5.75	24.15	10.6	14.0	16
30 × 7.7	230	16,500	270	7.85	29.40	12.7	16.0	18
36 × 11	217 kt	26,000	235	11.50	35.10	14.7	16.0	24
40 × 14	174 kt	33,500	200	14.00	39.80	16.5	16.0	28
46 × 16	225	48,000	245	16.00	45.25	19.0	20.0	32
50 × 18	225	41,770	155	17.50	49.50	20.4	20.0	26
Three-part Name								
18 × 4.25–10	210	2300	100	4.70	18.25	7.9	10.0	6
21 × 7.25–10	210	5150	135	7.20	21.25	9.0	10.0	10
28 × 9.00–12	156 kt	16,650	235	8.85	27.60	11.6	12.0	22
37 × 14.0–14	225	25,000	160	14.0	37.0	15.1	14.0	24
47 × 18–18	195 kt	43,700	175	17.9	46.9	19.2	18.0	30
52 × 20.5–23	235	63,700	195	20.5	52.0	21.3	23.0	30

3.4.2 Compression ratios

In order to define the behavior of the shock absorber, compression ratios must be determined in order to obtain the load stroke graph. The compression ratio can be defined as the pressure ratio from one point to the other during the stroke change of shock absorber. Three position are critical for shock absorbers which they are fully extended, static and fully compressed. Static to fully extended and fully compressed to static compression ratios are the important for the shock absorber load stroke graph. For the notation, 1 subscript indicates that the shock absorber is fully extended, 2 indicates static case, and 3 indicates fully compressed case. For larger aircrafts, the ratio 3:1 for the compressed to static and the ratio 4:1 for static to fully extended can be used as compression ratios at the design stage []. In general, in typical oleo pneumatic shock absorbers the internal pressure is 1800 psi (12415 kPa) []. This value was used in calculations. Piston area and displacement are both related with this static pressure.

$$A = \frac{F}{P_2} \tag{3.7}$$

$$D = sA \tag{3.8}$$

Where:

A – Piston area

F – Maximum static load on strut

D – Displacement volume

P_2 – Static pressure

3.4.3 Other sizing parameters

The stroke value of the shock absorber in the static case is the 66 percent of the total stroke from the fully extended for most aircraft types. The total length of the shock absorber can be approximately taken as 2.5 times of the total stroke []. Since the internal pressure and maximum static load acting on the shock absorber is known, the piston diameter can be calculated from the equation below.

$$d_{piston} = \sqrt{\frac{4F}{P_2 \pi}} \tag{3.9}$$

The cylinder diameter is usually 30 percent greater than the piston diameter for the oleo-pneaumatic shock absorbers.

$$d_{cylinder} = 1.3 d_{piston} \tag{3.10}$$

The orifice area can be calculated from the equation below, based on the experimental tests that were made for the orifice area being optimal.

$$A_{orifice} = \frac{0.3A}{r} \sqrt{\frac{As}{F}} \tag{3.11}$$

Where:

r – applicable load/static load

Since this formula was created according to the british unit system, the orifice area was calculated by converting the expressions in the formula to the british unit system.

As a result, all necessary calculations were made to design of the oleo-pneamatic shock absorber by utulizing from the equations above and the values in the table below are shown.

Table 3.4 : Design values for the oleo pneaumatic shock absorber.

Tire deflection, s_t	0.0864	m
Stroke, s_s	0.22948	m
Static position	0.07802	m
Piston Area, A	0.00967	m^2
Displacement Volume, D	0.00222	m^3
Piston diameter, d_{piston}	0.11096	m
Cylinder diameter, $d_{cylinder}$	0.14424	m
Total length, L	0.5737	m
Pressure at fully extended, P_1	3103.75	kPa
Pressure at fully compressed, P_3	37245	kPa

3.4.4 Load – Stroke curve

Load-stroke curves show how much energy the shock absorber absorbs against loads exerted on aircraft landing gear with the changing stroke value. By integrating the area under the load-stroke curves, it can easily be calculated how much energy the shock absorber absorbs at which stroke value. According to Boyle-Mariotte gas law, pressure and gas are inversely proportional to each other. Assuming that there is an isothermal compression, we can find the pressure in any stroke from the formula below.

$$P_1 V_1 = P_x V_x = const \qquad \textbf{(3.12)}$$

Where:

P_x – Pressure at any stroke x

V_x – Air volume at stroke x

Then, by multiplying the pressure found with the piston area, the load-stroke graph can be obtained. This isothermal compression represents the normal ground handling activities during touchdown. Similarly, polytropic compression curve can be obtained by utilizing from the isentropic to polytrophic relationship. Unlike isentropic compression, the polytropic compression load-stroke curve relates to dynamic behaviors such as landing impact.

$$P_x = P_2 \left(\frac{V_2}{V_1 - XA} \right)^n \tag{3.13}$$

Where n takes the value of 1.35 or 1.1, depending on whether the gas and oil are mixed in the shock absorber or not. If the oil and air do not mix during the compression , the value of n is 1.35 and if the oil and air are mixed, the value of n becomes 1.1. Thus, n value was chosen as 1.35 since the gas and oil are separated in our oleo pneaumatic shock absorber design. Finally, the matlab code was written for the cases of isentropic and polytropic compression in order to obtain load-stoke curves and their graphs are plotted.

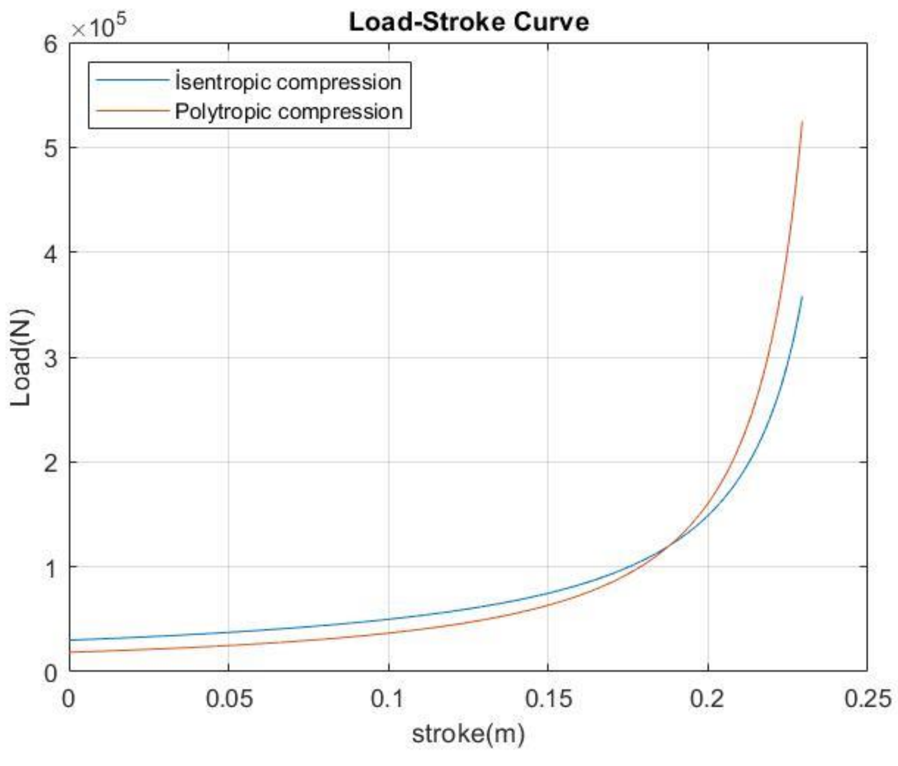

Figure 3.2 : Load-stroke curve of the oleo-pneaumatic shock absorber.

3.4.5 Final design

The 3D version of the oleo pneaumatic shock absorber for the unmanned combat fighter aircaft was designed in CATIA according to the values calculated from the shock absorber design equations. Figure 2.8 shows the cad design of the oleo pneaumatic shock absorber.

Figure 3.3 : Oleo pneaumatic shock absorber 3D design.

4. OLEO PNEAUMATIC SHOCK ABSORBER ANALYSIS

4.1 Material Selection

One of the most important parameters required to perform the analysis of any structural element is what the material of the part will be. Inserting the properties of the assigned materials into the analysis program correctly will increase the accuracy of the analysis results. Considering similar shock absorber types and strength/weight ratio of the materials , it was decided that the material of the shock absorber should be aluminum 7075 T6.

Table 3.5 : Aluminum 7075 T6 properties.

Density (g/cm^3)	2.81
Hardness, Brinell	150
Hardness, Rockwell A	53.5
Hardness, Vickers	175
Ultimate Tensile Strength (Mpa)	572
Tensile Yield Strength (Mpa)	503
Modulus Of Elasticity (Gpa)	71.7
Poisson's Ratio	0.33

4.2 Analysis Conditions

When performing an analysis, it is necessary to correctly determine the boundary conditions to get the correct results. Analysis performed in the ANSYS static structural workbench. With the analysis, it is aimed to determine whether the piston and cylinder can function without failure if the maximum load is applied to the shock absorber while in its static position. Accordingly, the connection of the shock absorber cylinder with the landing gear strut was determined as fixed support. In order to perform the analysis, the shock absorber cylinder and piston were assumed as a one part. So, bonded contact was given for the surfaces that the cylinder and the piston contact. Finally, the maximum static load coming to the shock absorber that we calculated was applied from the part where the shock absorber piston is connected with wheel. The load was applied in the vertical direction.

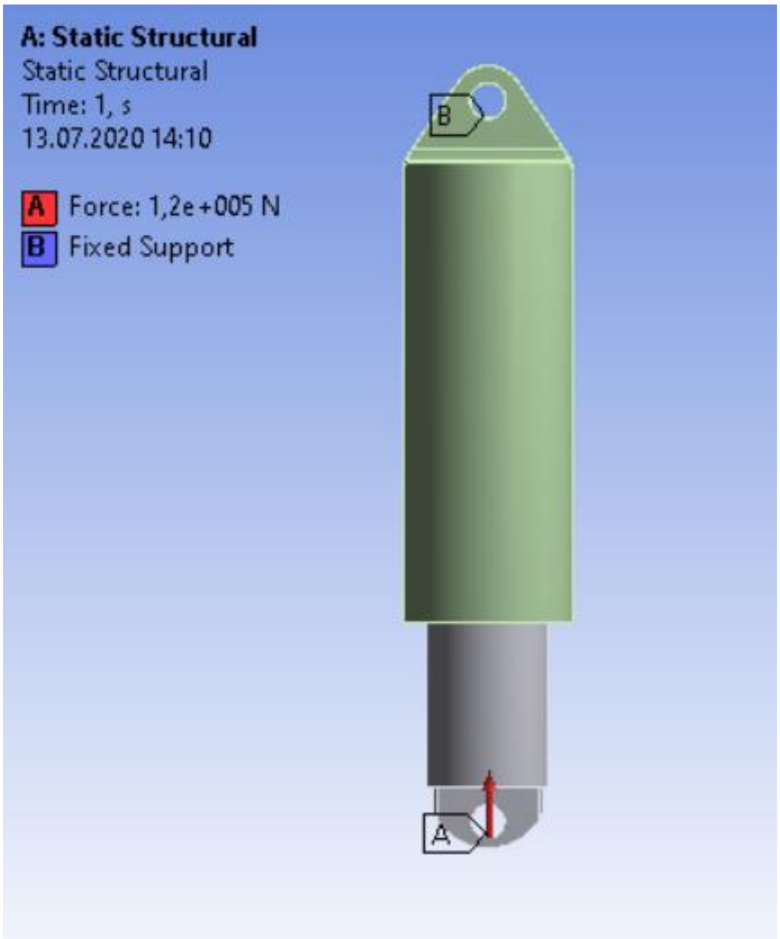

Figure 3.4 : Applied load and direction for the analysis.

4.3 Analysis Results

Total deformations, equivalent (von-Mises) stresses and maximum principal elastic strains on the shock absorber have been obtained with the analysis performed.

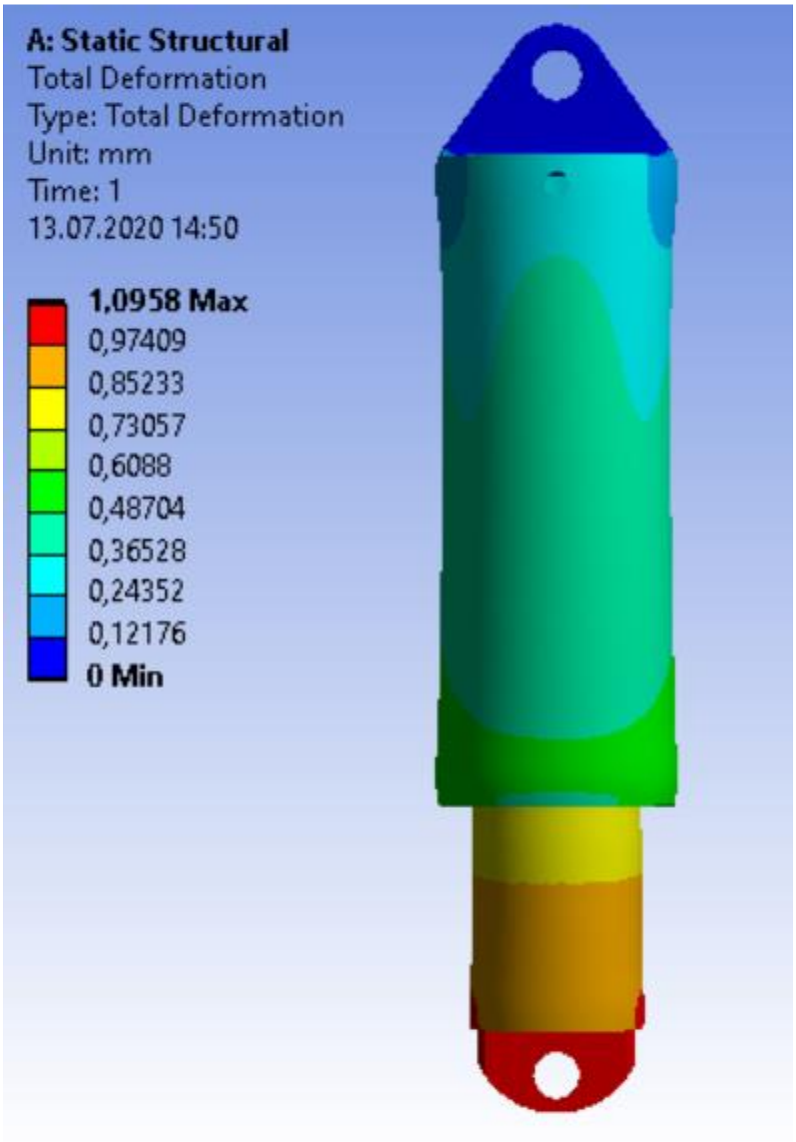

Figure 3.5 : Total deformation of the oleo pneaumatic shock absorber.

It would not be wrong to expect the most deformation to be bottom of the piston since the load was applied from the bottom of the piston, and the highest deformation is approximately 1.1 mm in the section where the load is applied.

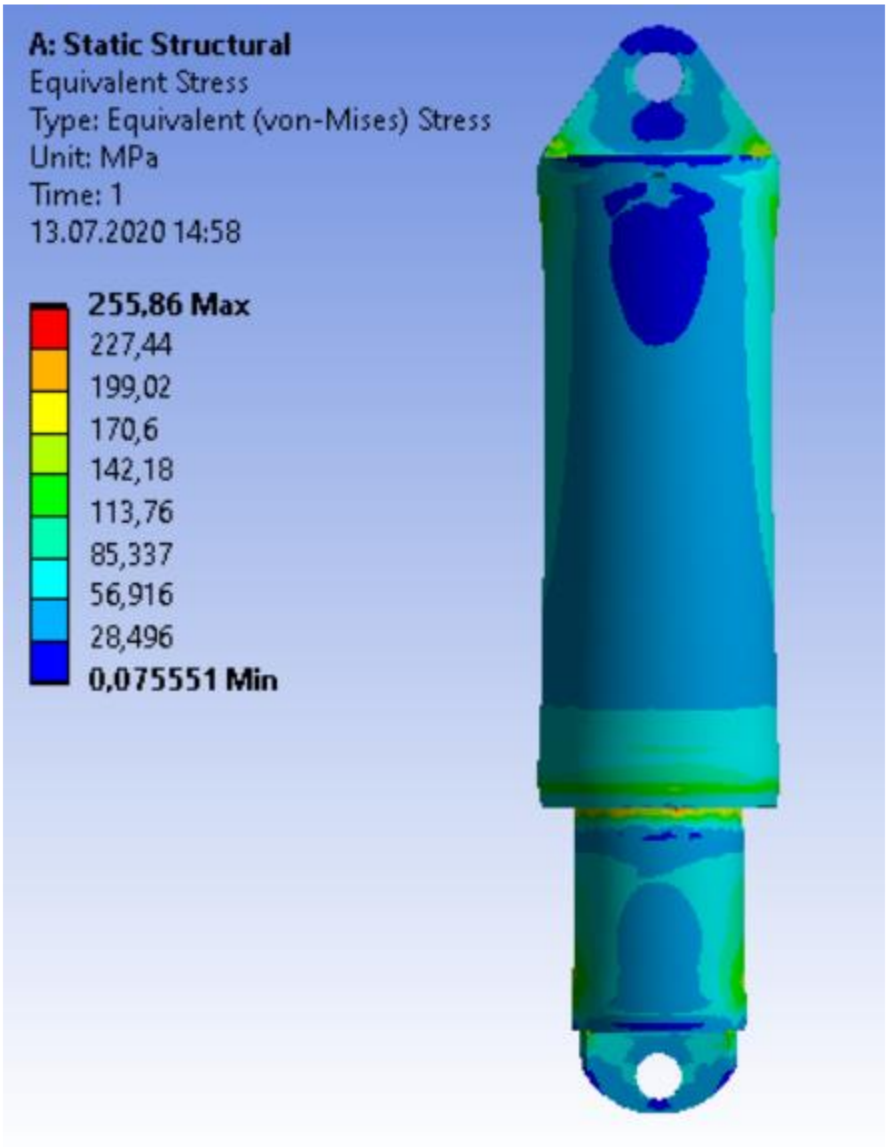

Figure 3.6 : Von-Mises stress of the oleo pneaumatic shock absorber.

When we examine the stress distribution according to the analysis of the shock absorber, it is seen that the maximum stress is at the bottom of the piston and the maximum stress value is 256 MPa. Since aluminum 7075 T6 has tensile yield strength of 503 MPa, it can be said that the shock absorber is in the safe zone.

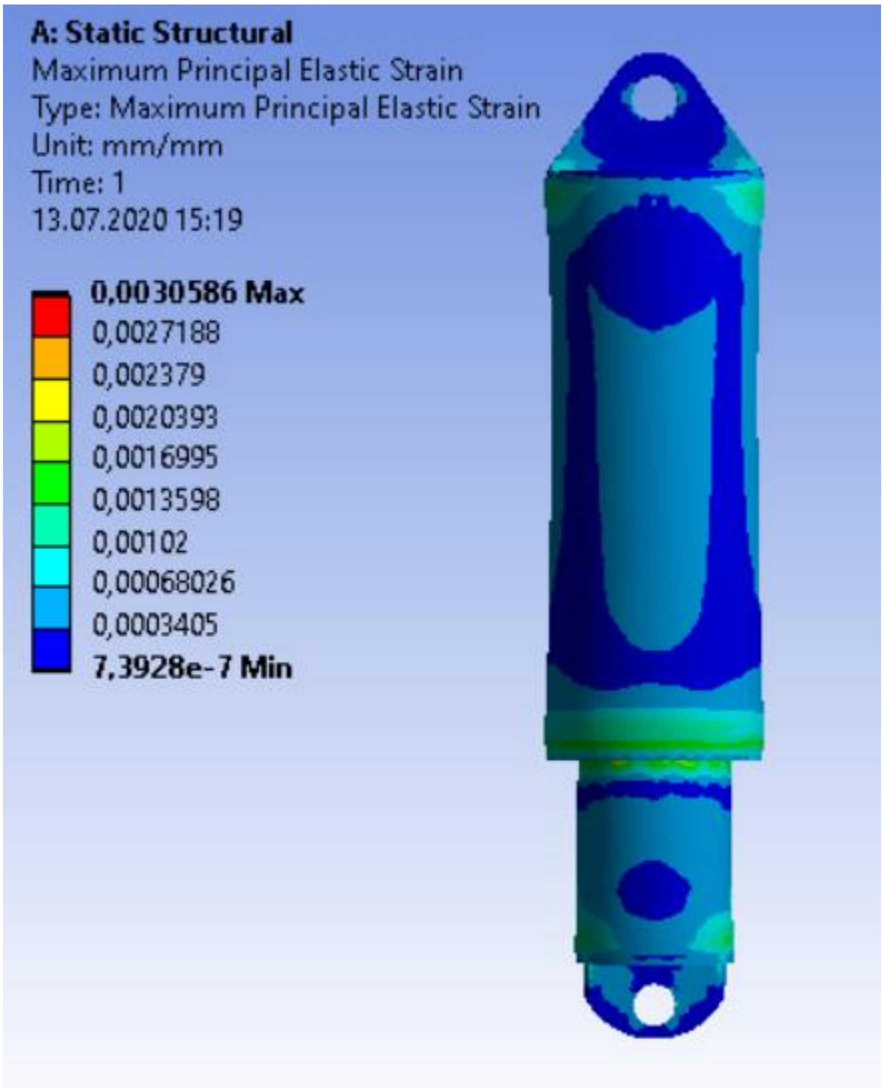

Figure 3.7 : Maximum principal elastic strain of the shock absorber.

Finally, the maximum elastic strain distribution of the oleo pneaumatic shock absorber was observed by the analysis performed. From the figure, it can be realized that the shock absorber has approximately maksimum elactic strain of 0.003 mm/mm.

5. CONCLUSIONS AND RECOMMENDATIONS

In this thesis, literature research has been done on shock absorbers and the types of shock absorbers from the past to nowadays have been mentioned. Among the types of shock absorbers mentioned, the one that can be used for unmanned fighter aircraft was selected. After mentioning the basic critical parameters to be considered while designing a shock absorber, all the equations required for the initial design were obtained. Load-stroke graph was plotted to observe the characteristic of the shock absorber. All the necessary values have been calculated from the shock absorber design equations in order to make 3D design for the unmanned combat aircraft that will weigh 8 tons. After the 3D design is completed, the material selection for the shock absorber has been made and the resistance against the loads to be exposed on the aircraft has been realized by structural analysis. It can be concluded that the shock absorber, which its dimensions have been calculated and designed, can perform its function without any failure under the maximum static loads.

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APPENDICES

APPENDIX A: MATLAB Code

```
clc;
clear;
clear all;

% Known Parameters
A = 0.00967;        % m^2
D = 0.00222;        % m^3
P_1 = 3103750;      % Pa
P_2 = 12415000;     % Pa
P_3 = 37245000;     % Pa

% Calculatin of Air Volume at full extension
% V_1 = P_3*(V_1-D)/P_1;
% V_1 = 12*(V_1-0.00222)
V_1 = 0.02664/11;
V_2 = P_1*V_1/P_2;
% Calculation of load for isentropic compression at any stroke x
F_ise = [ ];
n= 1;
for x = 0:0.00005:0.22948
    P_x_ise = P_1.*V_1./(V_1-A.*x);
    F_x_ise = P_x_ise.*A;
    F_ise(n) = F_x_ise;
    n= n+1;
end

% Calculation of load for polytropic compression at any stroke x
F_poly = [ ];
m = 1;
for x = 0:0.00005:0.22948
    P_x_poly = P_2.*(V_2./(V_1-A.*x))^1.35;
    F_x_poly = P_x_poly.*A;
    F_poly(m) = F_x_poly;
    m= m+1;
end

% Plotting Load-Stroke Curve
x =[0:0.00005:0.22948];
plot(x, F_ise)
grid on
hold on
plot(x, F_poly)
title('Load-Stroke Curve')
```

```
xlabel('stroke(m)')
ylabel('Load(N)')
legend({'İsentropic compression','Polytropic compression'},'Location','northwest')
```

APPENDIX B: Technical Drawing