DESIGNING UNIVERSAL YOKE STRUCTURE OF SUSPENSION AND RELEASE SYSTEM WITH TOPOLOGY OPTIMIZATION FOR FIGHTER AIRCRAFTS

TAŞIMA VE BIRAKMA SİSTEMİ PARÇASI ÇOK AMAÇLI KELEPÇE YAPISININ AVCI UÇAKLAR İÇİN TOPOLOJİ OPTİMİZASYONU İLE TASARIMI

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ABSTRACT

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In the aviation industry, a design with a sensitive and low margin is more important than any vehicle production. Within the scope of this study, the design road map of a product intended to be used in fighter aircraft is explained and it is aimed to bring an example study to the literature of our country. Due to the maneuvers of the fighter aircraft and the environmental conditions, it was desired to find out which loads were affected on this structure. Weapon systems were selected as sample application, duties and working principles of the suspension and release systems were explained in detail. General literature and studies about ejector release units and weapons were examined, information was given about structural design and lightening studies. Then, loads on the ejector release unit and weapon due to the movements and environment of the fighter aircraft were calculated. In addition, the forces required to safely separate these weapons from the aircraft were explained and included in the process. A multi-purpose and compatible yoke structure has been considered for the purpose of carrying air-air and air-surface weapon with the same release system, which has not been applied before. The yoke structure is modeled in the SolidWorks program according to the requirements.

The material selection from alternatives is aimed to be realistic in terms of our country's literature and opportunities. In the ABAQUS program, design spaces and constraints were selected and analyzed using the finite element method under different multi load cases of beyond vision missile and 1000lb bombs. Necessary weight reduction and topology optimization studies were carried out with the TOSCA module in the analysis program. The surface smoothing process was applied to this yoke structure which was optimized and lightened after the design. Different yoke design alternatives that can be considered separately for bombs and missiles were also subjected to relevant loads and the resulting stress values were examined, compared with the current results of the optimization geometry, and the multi-purpose designed structure was evaluated to be efficient. This structure, which was calculated as 705 grams after optimization, decreased to the desired weight level. In the case of maximum loading, 2 as a safety factor has been chosen for the material yield value. Since the yield strength of the material 17-4PH H1025 is 1170 Mpa, the analysis results should be less than 585 Mpa. As a result, the maximum stress in the yoke calculated as 521 MPa and this strength remained below the limit. It was concluded that this geometry would not create a risky situation for safe flight and seperation after designing with topology optimization.

Keywords: Flight Loads, Yoke Structure, Suspension and Release Systems, Finite Element Method, Topology Optimization

ÖZET

TAŞIMA VE BIRAKMA SİSTEMİ PARÇASI ÇOK AMAÇLI KELEPÇE YAPISININ AVCI UÇAKLAR İÇİN TOPOLOJİ OPTİMİZASYONU İLE TASARIMI

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Havacılık sanayisinde hassas ve hata payının az olduğu bir tasarım her araçta olduğundan daha fazla önem arz etmektedir. Bu çalışma kapsamında avcı uçaklarında kullanılmak istenen bir ürünün tasarım yol haritası anlatılıp, örnek bir çalışmayı ülkemiz literatürüne kazandırmak amaçlanmıştır. Tasarlanmak istenen bu yapının uçağın hareketleri ve ortam şartları sebebiyle hangi yüklerin etkisi altında kaldığı bulunmak istenmiştir. Silah sistemleri örnek uygulama olarak seçilmiş, taşıma ve bırakma sistemlerinin görevi ve çalışma prensibi detaylıca anlatılmıştır. Salan ve silahlar hakkında genel literatür ve yapılmış çalışmalar incelenmiş, yapısal tasarım ile hafifletme çalışmaları hakkında bilgi verilmiştir. Ardından, uçağın hareketleri ve içinde bulunduğu ortam sebebiyle takılı olan mühimmat ile salan sisteminin maruz kaldığı yükler hesaplanmıştır. Ayrıca bu mühimmatların uçaktan güvenli şekilde ayrılması için gereken kuvvetler de anlatılarak işleme katılmıştır. Daha önce uygulaması bulunmayan, hava hava ve hava yer mühimmatlarını aynı salan sistemiyle taşıma amacı doğrultusunda çok amaçlı ve uyumlu bir kelepçe yapısı düşünülmüştür. Kelepçe yapısı SolidWorks programında gereksinimlere uygun modellenmiştir.

Seçenekler arasından malzeme seçimi ülkemiz literatürü ve imkanları açısından gerçekçi olması hedeflenmiştir. ABAQUS programında tasarım bölgeleri ve sınırlandırmalar seçilmiş, görüş ötesi füze ve 1000lb bombanın farklı yük senaryoları altında sonlu elemanlar yöntemi kullanılarak analiz edilmiştir. Gerekli ağırlık azaltma ve topoloji optimizasyonu çalışmaları analiz programı içerisindeki TOSCA modülü ile yapılmıştır. Tasarım sonrası ortaya çıkan optimize edilerek hafifletilmiş bu kelepçe yapısına yüzey yumuşatma işlemi yapılmıştır. Bomba ve füzeler için ayrı ayrı düşünülebilecek farklı kelepçe tasarım alternatifleri yine ilgili yüklere maruz bırakılarak ortaya çıkan gerilme değerleri incelenmiş, optimizasyon geometrisinin mevcut sonuçları ile karşılaştırılmış ve çok amaçlı tasarlanan yapının verimli olduğu değerlendirilmiştir. Optimizasyon sonrası 705 gram hesaplanan bu yapı istenen ağırlık seviyesine inmiştir. Maksimum yükleme durumunda malzeme akma değeri için güvenlik katsayısı 2 seçilmiştir. Malzeme 17-4PH H1025'in akma dayanımı 1170 Mpa olması sebebiyle, analiz sonuçları 585 Mpa'dan küçük olmalıdır. Sonuç olarak kelepçe maksimum 521 MPa ile yorulma dayanımı sınırın altında kalmış, topoloji optimizasyonu sonrası güvenli uçuş ve ayrılma için bir risk oluşturmayacağı kanaatine varılmıştır.

Anahtar Kelimeler: Uçuş Yükleri, Kelepçe Yapısı, Taşıma ve Bırakma Sistemleri, Sonlu Elemanlar Yöntemi, Topoloji Optimizasyonu

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Melih Kaan Bal

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

g	Acceleration due to gravity, ft/sec^2
$\ddot{\omega_x}, \ddot{\Phi}$	Roll acceleration, rad/sec^2
$\dot{\omega_x}$	Roll rate, rad/sec
$\ddot{\omega_y}, \ddot{\Theta}$	Pitch acceleration, rad/sec^2
$\dot{\omega_y}$	Pitch rate, rad/sec
$\ddot{\omega_z}, \ddot{\Psi}$	Yaw acceleration, rad/sec^2
$\dot{\omega_z}$	Yaw rate, rad/sec
C_D	Drag Coefficient
C_L	Lift Coefficient
C_M	Moment Coefficient
$I_{xx,yy,zz}$	Store moment of inertia, in-lbs^2 at store c.g
$I_{xz,xy,yz}$	Store product of inertia, in-lbs^2 at store c.g
L_{ref}	Reference length, inch
$M_{x_{inertia}}$	Net roll moment
$M_{y_{inertia}}$	Net pitch moment
$M_{z_{inertia}}$	Net yaw moment
$P_{x_{inertia}}$	Net axial force
$P_{y_{inertia}}$	Net side force
$P_{z_{inertia}}$	Net normal force
S_{ref}	Reference area, in^2
W_s	Weight of the store, lbs
a_x	Aircraft axial acceleration, g's

a_y	Aircraft side acceleration, g's
a_z	Aircraft normal acceleration, g's
n_{x_s}	Force and aft load factor
n_{y_s}	Side load factor
n_{z_s}	Normal load factor
ΔX	Aircraft fuselage station, ft
ΔY	Aircraft butt line, ft
ΔZ	Aircraft waterline, ft
Li	Distances between CG and lugs, inch
Si	Distances between CG and sway braces, inch
α_A	Aircraft angle of attack, degrees
β_A	Aircraft angle of sideslip, degrees
q	Dynamic pressure, lbs/ft^2

Abbreviations

AIM	Air Intercept Missile
AISI	American Iron and Steel Institute
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ASIM	Aircraft Stores Interface Manual
BRU	Bomb Release Unit
CG	Center of Gravity
ERU	Ejection Release Unit
HDERU	Heavy Duty Ejection Release Unit
LAU	Launcher
LDERU	Light Duty Ejection Release Unit
MIL	Military
MK	Mark
NATO	North Atlantic Treaty Organization
SARE	Suspension and Release Equipment
SIMP	Solid Isotropic Material with Penalization
STD	Standard
USA	United States of America

1 INTRODUCTION

1.1 Problem Definition

Suspension and release equipment are systems that are between the weapon and the aircraft structure, developed to captive carry weapon during any flight maneuver and to release/launch it from the aircraft with pneumatic, pyrotechnic or electromechanical propulsion systems when commanded.

Since they are in the mass group in the fuselage and wings of aircraft, they are required to be as low as possible. Weapon suspension and release equipment are expected to withstand a variety of loads as they are critical mission equipment.

Due to the weight of the carried weapon and the capacity of the compatible weapon diameter, suspension equipment is preferred differently for air to air and air to surface operations.

1.2 Motivation

The main goal of this thesis is to introduce a basic method that can be used by anyone who wants to develop any product on the fighter aircraft and can be used in the calculation of the forces on this related product, especially for the literature of our country. Developing competition in the aviation industry, the integration of different platforms on the battlefield, reveals the need to use the volume efficiently by designing the aircraft more and more every day. When it comes to the fighter aircraft, it is also important that the products to be designed will be exposed to which loads under which conditions. It has been evaluated that it is critical to ensure the safe suspension and separation of the weapon systems, which are the main purpose of combat aircraft, the suspension and release system, which is a difficult example, has been chosen and how to reduce the weight, which is very important in the aviation industry, has also been demonstrated using the optimization method. In addition, while designing this product, it is aimed to be suitable for different purpose weapons, which has not been seen in the literature before.

It is aimed to design and optimize yoke structure, which is mentioned in the literature as a part of the weapon suspension and release equipment, by applying changes in the geometry of universally suitable for the diameters of both air to surface and air-to-air weapon without the need for separate sway braces with the demonstration of design process and methods for the first time and contribute to the literature of our country as a guideline.

For this purpose, first, reaction forces will be found from calculated ejector forces for different weapons in the literature which have various weight classes, load and moment calculations will be computed for one or more weapon during various maneuvers for a selected generic fighter aircraft, the reaction forces on the sway braces will be calculated. In line with information obtained, static analyses will be carried out in the ABAQUS program with the finite element analysis for a yoke structure that drawn according to the need. The effects on the stress intensity and weight will be examined and compared with equivalent geometries according to the weight and topology optimization studies with ABAQUS TOSCA.

1.3 Challenges

In order to design a structure on the aircraft, the physical conditions of the region where it will be located must be known, and for this purpose, the loads and environmental impacts must be calculated. In order to make all these calculations, an aircraft with available information should be used, and if it is planned to be designed, it should be compared to known aircraft.

The same difficulty exists when the structure to be designed is part of the suspension and release system. The information of the weapon to be ejected and carried should be known from literature or calculated in the static test rig.

During the calculation of the impact of the weapon on the suspension and release equipment, a sample must be found and its similarity with the new release system must be known.
Within the scope of this study, points mentioned below can be expressed as difficulties to find information especially using open source;

- Generic fighter aircraft
- Generic suspension and release system
- Generic weapon

2 LITERATURE SURVEY

2.1 Literature of Weapon Systems

When the military aviation literature is examined, it is seen that the studies carried out are shared with limited publications. It is considered that the reason for the limited publications is that most of the topics are evaluated within the scope of national knowledge and that they are critical for the development of the defence industry.

Schoppert tried to determine the reaction forces coming from the carried weapons to a designated suspension and release equipment and compared them with ground-flight tests [1]. Xiao-guang et al. [2] have tried to optimize and design hydraulic and control systems in missile launch systems and examined parameters such as wind, launch forces and launch angle.

In their work, XieJian et al. [3] focused on the influence and direction of the wind and the impact of these variables on missile launch. Sindura and Thangadurai calculated the total load on all structural parts of a specified suspension and release equipment, including aerodynamic forces from the carried weapon, and optimized the design [4].

The main task of the fighters is to ensure that carried weapon is released to the target safely and effectively when necessary. It is necessary to design weapon systems that can be used for many years and can be compatible with the forecast conditions of the future. Its importance increases as it is costly to replace later.

In this thesis, MAU-12 ejector release unit was preferred to shape the study in terms of performance data. This ejector release unit, which has proven itself, has been used in our country for many years. The 1964 MAU-12 performance analysis study, which was later opened to the public by the American air force weapons laboratory, was used to understand working principles of these systems [5]. Many articles presented at the Aircraft-Store interface symposiums held in the early 2000s also clearly reflect the MAU-12 performance characteristics [6] [7].

Considering that there will be similar needs and requirements in aviation in the future, there are similar suspension and release equipment optimization and design studies that have been developed within the scope of the F-35 multi-purpose and multinational joint new generation fighter aircraft design project. The BRU-67/68 ejector release units have a semi-automatic sway brace that moves with the piston, while the LAU-147 also has a sway brace combined with the piston designed for a single missile [8] [9]. Apart from open source documents on this subject, there is not enough information about the field samples and the working principles cannot go beyond the estimate. Only the equipment weights, dimensions, suitable weapons, piston lengths and speeds are shared. Unfortunately, there is no structural information within our knowledge.

There are past studies in the USA only on automatic sway brace and there is no movement feature with the piston [10] [11]. Although there are some past studies in the USA on the design of large contact pistons, these designs are not about the sway brace; it is specific to a weapon [12]. The closest study to the scope of the thesis is the classic quad sway brace system combined with a piston. This study, which may have been used in BRU 67/68, is from 2007 [13].

Figure 2-1 Suspension and Release Equipment for F-35 Fighter

It is estimated that the UVKU-50U / UVKU-50L launchers in the new generation Russian fighter Pak Fa/Su-57 have automatic sway brace mechanisms that move with the piston. However, there is not much information available except from open source photographs [14]. Apart from these, a study on the design of the sway brace in Russia has been carried out in recent years [15].

Figure 2-2 Suspension and Release Equipment for PAK FA Fighter

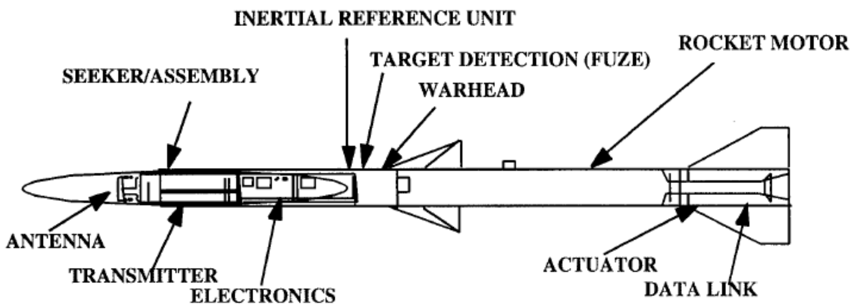
Table 1 Specifications of Mentioned Products

	MAU-12	BRU-67	BRU-68	LAU-147	UVKU-50U	UVKU-50L
Dimensions (in)	32x6x3	32x11x4	36x11x4	37x7x4	~100x8x5	~60x8x5
Weight (lb)	70	68	88	64	-	-
Max Store Class/ Type	5000lb Bomb	1000lb Bomb	2000lb Bomb	350lb Missile	1500lb Bomb and Missile	660lb Missile
Stroke Velocity(fps)	Max 30	Max 20	Max 20	Max 25	-	-

Purchase of the mentioned sample suspension and release equipment are not possible for confidentiality reasons. These technologies are developed within the competence of each country. Beyond these issues, at the point of using indigenous weapons in a locally developed fighter aircraft, a suspension and release equipment design that can withstand the mentioned conditions is a necessity in terms of independence of the defence industry and it has to be carried out and developed together with major projects. Within the scope of the thesis, it is important to work in terms of being a forward-looking project that we can use in possible national fighter aircrafts, which designed, with national and domestic facilities in our country.

2.2 Literature of Aircraft Weapons

There are many air to air and air to surface weapons, which used in fighter aircrafts. The aircraft's mission profiles determine which weapon to carry. There are major popular weapons and related studies in the literature used by NATO countries. In our country, it is known that these missiles and bombs are in the inventory. In this section, firstly, the past studies about weapons will be mentioned and then the used weapons will be discussed in detail. The reason for this is that these weapons will be mentioned frequently during the narration stage of the designed structure. Watson prepared performance simulations for the AIM-120 advanced medium range air-to-air missile to reduce the flight test cost for the F-18 fighter. In this context, AIM-120 AMRAAM specifications are given [16].



PARAMETERS	AIM-120A/B	AIM-120C
LENGTH	144 IN	144 IN
DIAMETER	7 IN	7 IN
WING SPAN	21 IN	17.5 IN
CONTROL SURFACE SPAN	25 IN	17.5 IN
WEIGHT (NOM)	345 LBS	345 LBS
CG (NOM)	79.8 IN	79.8 IN

Figure 2-3 AIM-120 AMRAAM

Baker et al. [17] compared the AIM-9M short-range air-to-air missile, AIM-120C AMRAAM, and fuel tank separation analysis with the flight test results, used in the F/ A-22 fighter aircraft for the same purpose.

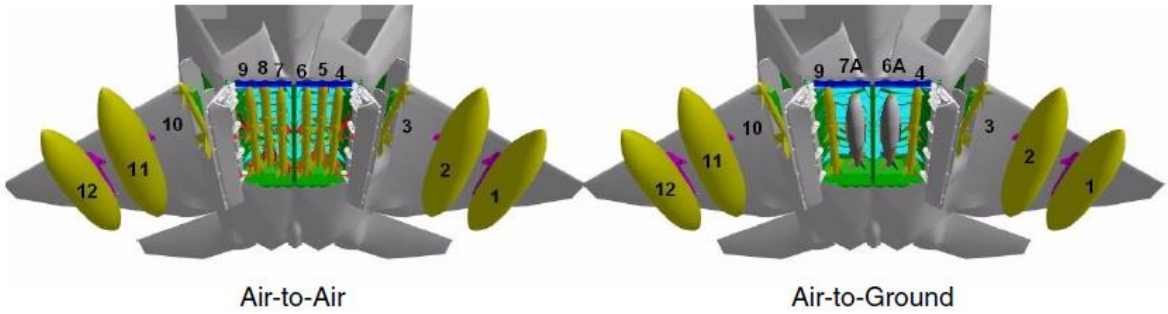


Figure 2-4 F/A-22 Weapon Configuration

In their work, Kummer et al. [18] have performed the seperation analysis of the GBU-39 small diameter air to ground bomb from the F-22A fighter aircraft and mentioned the certification process of the suspension and release equipment.

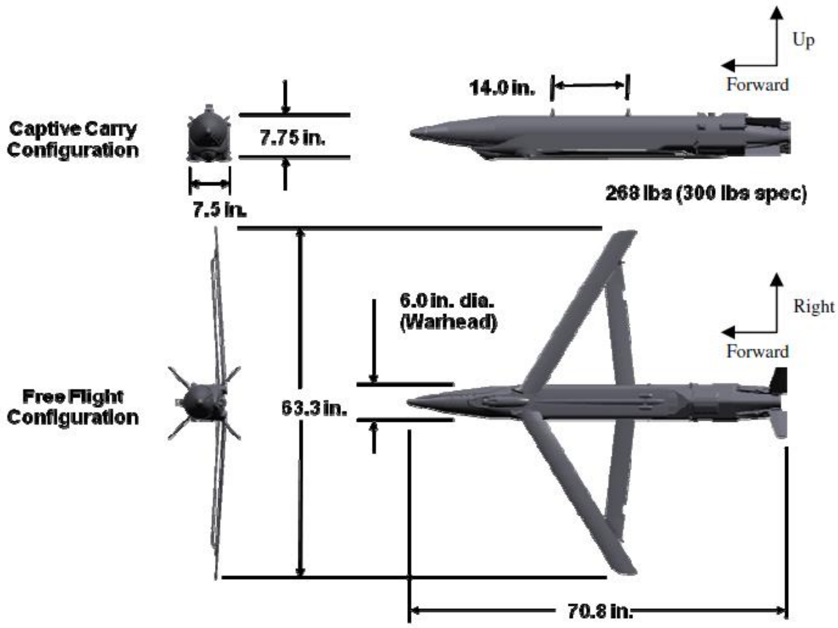


Figure 2-5 GBU-39 Specifications

Pairlie et al. [19], subjected a 1/8 scaled-down model of the air-ground dumb bomb MK-82 to the wind tunnel test to investigate its behaviour in the transonic region. Shilo later developed the six degree of freedom dynamic flight model for the real size of the same bomb. Taking into account the moments and forces that the bomb is subjected in separation and afterwards, it is processed in the study with aerodynamic data. Specifications and drawings of the bomb were shared [20].

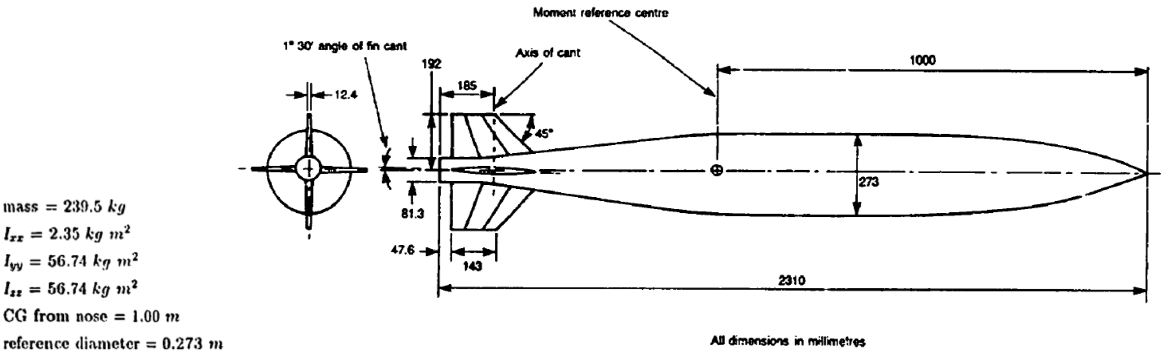


Figure 2-6 MK-82 Drawing

2.3 Suspension and Release Equipment

With the use of aircrafts in a warfare environment, besides scouting duties, the needs of suppressing ground defence troops and attacking ground forces also emerged. Pilots solved this sudden need by throwing light bombs with their hands. However, the desire to work more than expected and to increase the number of weapons caused this war tactic to become more orderly. The size and types of aircraft that will perform these tasks have also changed with the change of the target types, mission types, weapon types and weights. New equipment had to be developed for the carry and release of these modernized weapons. Modern equipment that carries these weapons are systems that are also described as suspension and release equipment.

Suspension and release equipment is a system that carries and releases the weapon by attaching it to the lugs on the weapon with 14 or 30-inch distance hooks as required by the standard. It generates gas pressure with its cartridge or pneumatic trigger and drives the mechanism owned by the system. It releases the hooks from the lugs and then releases weapon with the pistons it has.

Suspension and release equipment in today's technology are used on attack helicopters, light attack aircraft, heavy bombers and combat aircraft. The most important criterion that is taken into consideration when designing these systems is the weight of the carried equipment. Initially, only the method of storing and releasing a large number of bombs caused the need for an internal weapon bay. However, over time, the method of carrying these weapons in internal bays has emerged with the increase of supersonic aircrafts and importance of low visibility.

2.3.1 Working Principle

Ejector release units from suspension and release equipment generally consist of five subsystems;

- Gas Source
- Sway brace
- Lock Mechanism
- Piston Mechanism
- Hook Mechanism

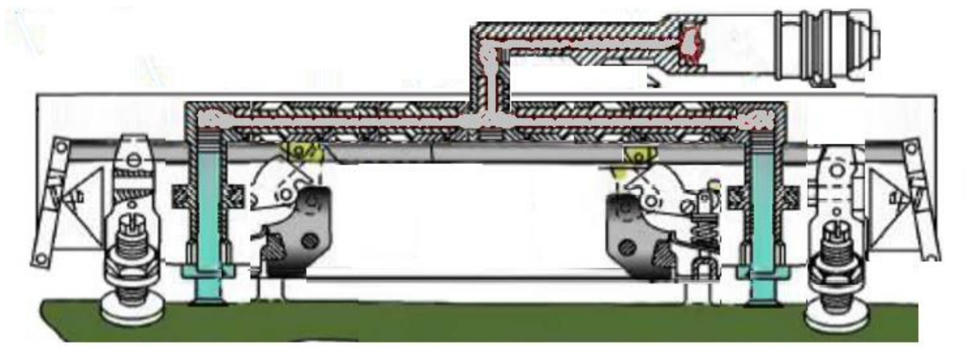


Figure 2-7 Ejector Release Unit Subsystem Representation

Gas sources of the suspension and release equipment vary according to the working principle of the equipment. If the equipment used is pyrotechnic, the gas source of the system is explosive cartridges in the suspension and release equipment. With this method, if hot gas is supplied to the system, the cartridges burst inside the equipment and the gas pressure is transmitted to the required interfaces. However, this system poses a problem in terms of continuity since there is a need for cleaning after each shot.

If the used equipment is working with a pneumatic system, the gas source of the system is the supplied gas pressure. In systems where this method is preferred, cold gas stored in the accumulator of suspension and release equipment. When the task is to be executed, it is transferred to the required interfaces. This system is more convenient than the pyrotechnic system in terms of continuity.

Figure 2-8 Pneumatic and Pyrotechnic Ejector Release Unit

The gas that comes out of the gas source during the execution reaches the orifice. Orifice distributes the gas from the pipeline through various holes in its system in order to drive the subsystems. These orifice holes are used to adjust the order of the pistons hitting weapon, to deliver the gas to activate the pistons and to drive the hook mechanism.

The gas separated from the orifice first comes to the hook mechanism and makes the mechanism driven. According to the type of mechanism, after the hook system are driven, respectively, the hook mechanism releases the hooks from the lugs in order to release the weapon.

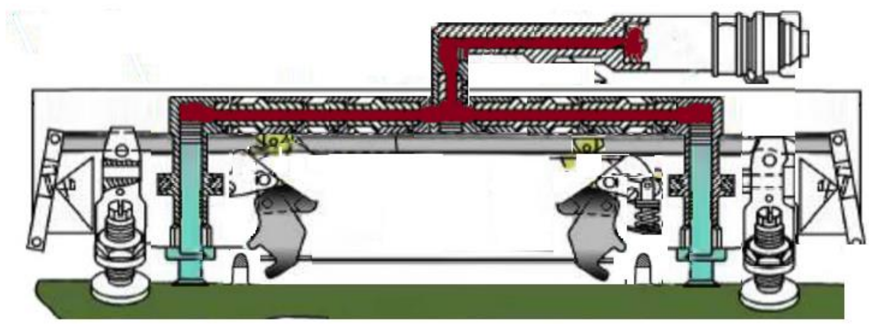


Figure 2-9 Movement of Hooks Representative

These suspension hooks are designed to carry and release the lugs specified by various standards with mechanism movements [4]. These hooks are locked so that they do not become free in various flight conditions.

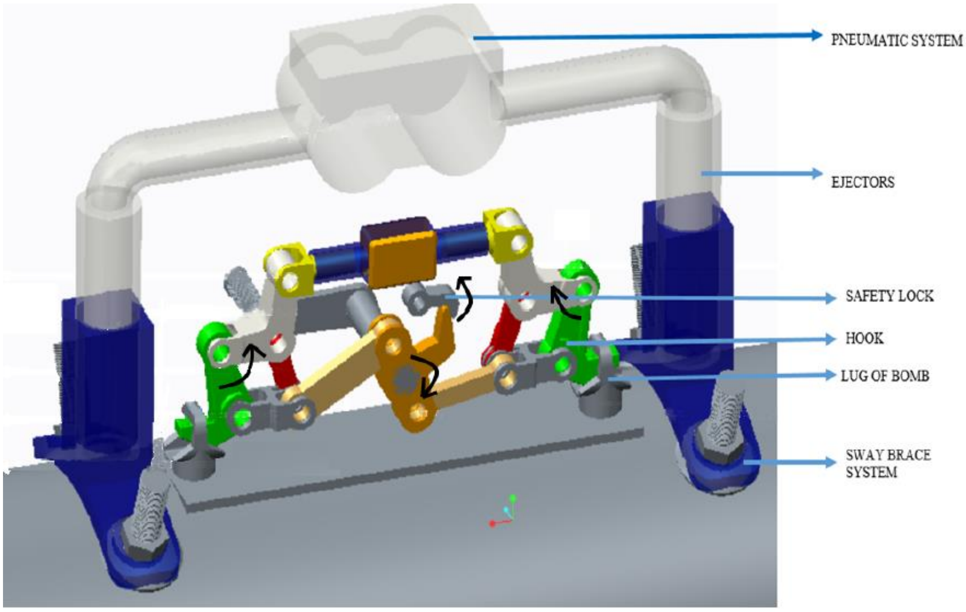


Figure 2-10 Mechanism Example with Hooks, Lugs and Swaybraces

With the spring system in the hook mechanism, it returns to its original position and locks, than closes the path where the gas will travel through the hole whose size is not changed. Gas, which has no way to go, travels through the gas pipeline to drive the piston by going to the orifice holes. The size of these changed holes determines how much force should be hit according to the center of gravity of the carried weapon.

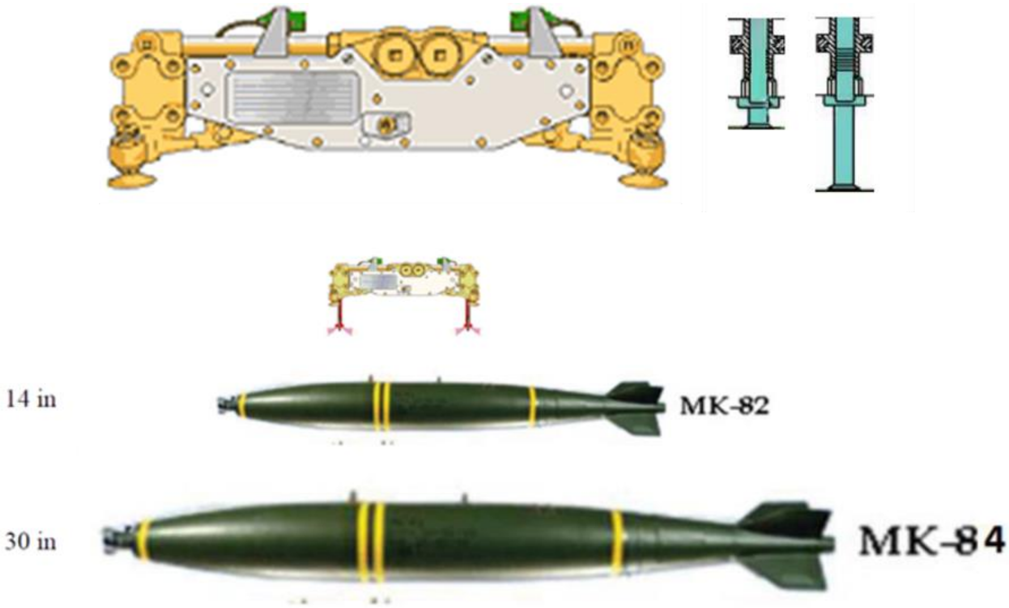


Figure 2-11 Piston Mechanism Working Principle Representation

Due to the spring system inside the piston mechanism and the air discharge hole it has, it returns to its first position after completing the duty.

2.3.2 Different Types of SARE

The weight of the carried weapon determines whether Light Duty Ejection Release Unit (LDERU) or Heavy Duty Ejection Release Unit (HDERU) is selected as suspension and release equipment.

If the carried weapon is under 1000lb weight or 1000lb class, it is carried by using 14-inch lugs on the weapon using LDERU or HDERU suspension and release equipment.

Figure 2-12 LDERU Example

If the carried weapon is more than 1000lb weight or 1000lb class, it is carried by using 14 inch or 30 inch lugs on the weapon using HDERU suspension and release equipment.

Figure 2-13 HDERU Example

If the weapon to be launched is a missile, minor changes must be made so that the system remains similar. Missiles are normally designed to be fired from rail launchers. Rail launchers are systems that allow the missile to go after fired and stop holding it. But to release these missiles out of internal weapon bays, they need to be pushed down like a bomb. This method can be used not only in these cases but also under the wing as in the Russians. It is seen that they use this method to minimize the effect of plum on the plane.

Figure 2-14 Rail Launcher Examples

But there are several reasons why missile vertical ejection launcher are not common. The first is that missiles are not certified for vertically released. Another reason for this is the low number of aircraft that will require this.

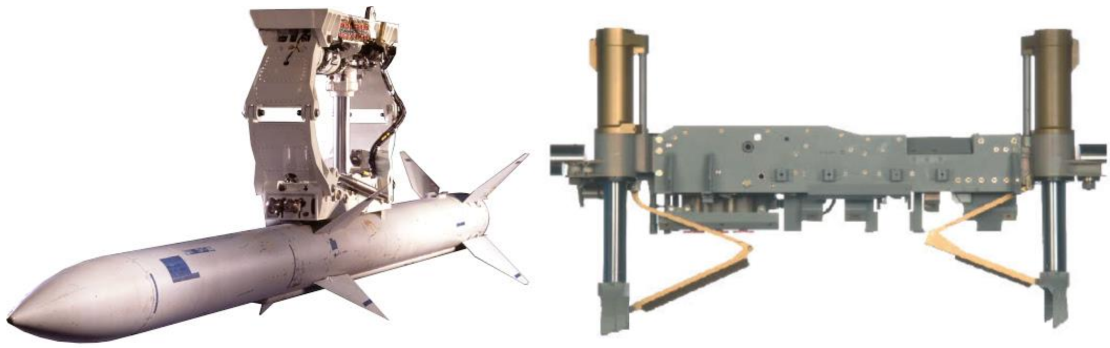


Figure 2-15 Missile Vertical Ejection Launchers Examples

2.3.3 Necessity of Sway Braces and Yoke Structure

In classic air to ground weapon suspension and release equipment, after the weapon is suspended, it must be fixed with sway brace at four points by the ground personnel. The time lost for the placement of the weapon appears to be a problem, especially to loading of the internal weapon bays.

Figure 2-16 Sway Brace and Usage

While the sway brace structure is used to fix the weapon, the piston system is used to provide safe separation by hitting the weapon from two fine points. During the launching of the weapon with a piston, the weapon is dragged downward with a telescopic piston piece in one axis, while the sway brace loses its function, and these parts remain on the releasing system. In this case, there is a chance to move of the weapon on the longitudinal axis. It is necessary to avoid that kind of movements, which may occur on the lateral axis and cause it to come out of its trajectory.

Figure 2-17 Piston and Usage

Air to air weapon, namely missile systems with vertical launch, as mentioned earlier, are used. Modern medium and long-range air-to-air missiles belonging to NATO countries have few variations. The body diameters of these missiles were adjusted to be the same. The surfaces of the pistons that hit weapon in vertical ejection launchers were designed to fit the surface of these missiles and to wrap it. For this reason, this yoke structure combining piston and sway brace is not adjustable for different diameters.

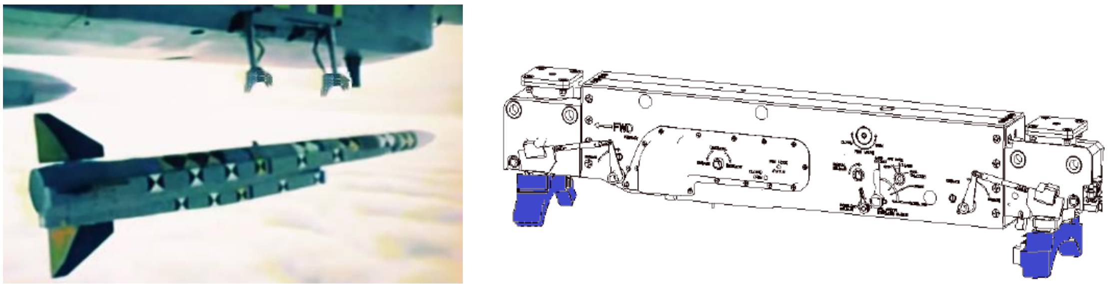


Figure 2-18 Yoke Structure and Usage

It is aimed to integrate the sway brace parts with the piston system in order to launch the missile or a general-purpose bomb with a common structure, safely and as desired under difficult conditions. They are also intended to move together and be adjustable to suit weapons with different diameters. In this way, the possibility of shifting to different axes is eliminated since the weapon is limited.

With this study, the sway brace structures are reduced to the number of pistons. It is aimed to tighten the sway braces with a single movement, thus reducing manual work. Combining the piston system with the more advanced sway brace system restricts the movements of the weapon, allowing safer separation, and since the number of sway brace is reduced, fixing the weapon does not waste time as much as before.

A common type of suspension and release equipment is not available by NATO, and in this study, the application of the yoke structure to the air surface weapons will be investigated and it will be aimed to contribute to the national literature in this regard.

2.4 Brief Literature of Topology Optimization

When the past literature is analysed especially for our country, it is very clear the intensive usage of the topology optimization in their studies and this leads their workings.

Topology optimization is also used in aircraft structures and parts in the aviation field. Yaban compared topological optimization and sizing analysis of the pressure bulkhead, which is an aircraft part. He made the optimum mass distribution with the evolutionary optimization algorithm that author wrote. It has been stated that with the optimization of topology, a more homogeneous load distribution is achieved and there is a weight reduction [21].

Wong tried to optimize the design of commercial landing gear assemblies under dynamic forces. The desired weight reduction and cost savings targets were achieved by trying different methods. Two different approaches were used to evaluate the topology results. In the first study, the geometry that emerged as a result of the topology was taken directly and a peak stress increase of 74% and a weight saving of 67% were achieved. However, there was no cost recovery due to complex geometry. In the second study, as the focus was on cost and weight savings, this design was able to achieve 6% weight, 36% cost savings and an overall stress increase of 60%, respectively. Since the structure was corrected, the cost decreased but the weight did not decrease as desired [22].

Yiğitbaşı tried to lighten an aircraft structure fitting using topology optimization and demonstrated the feasibility of its manufacture with additive technics. At the end of the study, it is aimed to show that a topology optimization of a sample aircraft part can be done by using the data obtained by tests with lighter and more complex structures that operate in a similar way. Two optimization studies were performed for the part from different directions. With optimization, it has been shown that similar performance can be achieved with a 40% lighter design [23].

Tamkan aimed to reduce the boarding step to the optimum weight by using different materials and including the effect of the Lattice structure. The importance of reducing weight and cost in the aviation industry was emphasized in this study and the idea that new production techniques paved the way for optimization studies was advocated. As a result of the study, it was seen that the designs that were optimized and the existing structures were compared and success was achieved. It is concluded that the lattice design provides 46% lighter than aluminum design and 3% lighter than 3D woven design, while discharging the same performance requirements [24].

Erol worked to lighten the upper torque arm of the landing gear of a designated large body aircraft using topology optimization. As safety is one of the important issues in the aviation field, it is concluded that the optimized part is mitigated by examining the forces acting on the torque arm at selected high loads. After the verification analysis of the geometry formed after optimization was completed in Solidworks and sT Inspire, two designs with 22.95% and 41.8% gain were obtained, respectively. It is stated that the road followed within the scope of the study can be followed in many systems, especially aircrafts [25].

There are many studies on vehicle structural parts in literature. In his study, Işık included topology optimization of the flange yoke structure that provides the connection in the cardan shafts. An analysis model has been created by using the analysis methods of the existing part and a similar forked flange part on the market, design variables and boundary conditions have been determined. Based on the resulting topology, the new geometry of the forked flange part was modelled and the production of the new forked flange geometry was confirmed. As a result of topology optimization, it was stated that the weight of the structure was reduced by around 12% [26].

Hatipoğlu discussed the optimization of the compressor bracket that one of engine elements with OptiStruct software. The aim is to provide the targeted frequency value and reduce the mass. In order to get more real results, the mesh model of the engine was created and placed in the analysis in the same way to the bracket. Stress analysis was made and interpreted using the HyperWorks program. The forces coming in case of maximum loading, taking 60% smaller than the material's yield value, were taken into consideration. As a result of the analysis, the desired maximum value was found as 51 MPa and it was found that it was approximately 35% less than the desired value. Because of the optimization, the targets were met and it was stated that it would be possible to start mass production in the future [27].

Polavarapu worked at the automotive front seat backrest frame and its compliance with legal standards and resistance to forces that may occur during an accident with its topology optimization. The most appropriate strength rib positioning was performed under multiple load conditions and as a result, it was stated that there was an average reduction in weight of 12.95 percent [28].

Çalışkan, made an optimization work on the leaf spring bracket used in a commercial vehicle. The part is intended to meet the specified structural strength criteria. While trying to keep the hardness values constant, the weight was reduced and fatigue analysis was successfully provided. Due to manufacturing constraints, 3 different designs have been studied. In terms of geometry, different alternatives have been created such that the lightest and most manufacturable design, the design that occurs after the displacement constraint is added, and the final design, which is an extra lightened version of the second design. It is stated that the final design is 18.25% lighter than the current design [29].

Enginar, has decided to replace a specified vehicle rim used in many vehicles as a result of shape and topology optimization. The maximum stress value was reduced by 23 MPa, resulting in a 5.7% gain, which is predicted to significantly increase the life time. The weight value was reduced by 0.46 kg, resulting in a gain of 2.7%, which is said to contribute positively to the raw material cost. Because of reaching the weight and maximum stress values of the models, the optimum design that provides the desired fatigue tests has emerged [30].

3 THEORY

3.1 Load Calculation for Aircraft Equipment

The critical issue in the design of the sway brace is the safe carriage than safe separation. It is necessary to calculate which forces and moments our design should be based on. It provides information about how much force is applied to the weapon with different maneuvers with the desired dimensions, and the forces acting on these structural parts. For this purpose, MIL-STD-2088B BRU and MIL-STD-8591 aircraft-weapon interface and methods in the standard were applied respectively in this study [31] [32].

The inertial force and maximum reaction force calculations in the appendixes of the MIL-STD-8591H version have been used in some aspects by being enriched in today's conditions. For this purpose, firstly using the FORTRAN program and then MATLAB, calculations are made with the following equations, and the reaction forces occurring in various maneuver and motion situations can be listed.

When calculating reaction forces, the forces are calculated on two main headings as inertial load and aerodynamic load. During the movements of the aircraft, both inertial movements and aerodynamic forces arise from contact with air. Although the validity of the calculation methods of aerodynamic forces used in the standards can be used at the time they are written, the need to be updated in the current situation has emerged. For this purpose, aerodynamic calculations will be made more realistic in terms of today's fighter aircraft, as used in the following documents. The scope of the study has been determined with some limitations and acceptances.

Physical characteristics in the study are important values for calculating the desired values. A flexible use can be achieved by using the features of parametric aircraft and suspension and release systems. Thus, when necessary, the forces required for different aircraft and fighter systems can be calculated. In this study, the information of the generically named systems was taken from a reliable open source, then verified by the Aircraft Stores Interface Manual (ASIM) reference, it will not be shared directly [33].

Inertial Loads are the subject that should be handled first within the scope of the study. The weight of the weapon to be carried, the location of weapon on aircraft and the performance of the aircraft are the parameters affecting the inertial loads. In this context, the maneuver the aircraft is doing within the scope of the operational action plan directly affects the load values to be calculated. These maneuvers are summarized as high-level flight, arrested, landing and catapulting, and the critical loads that will occur in the CG of the weapon are mentioned separately. Load factor envelopes are limited to the latest version of the 8591 standard.

In this thesis, the weapon considered for the internal weapon bay has been taken into consideration. The aerodynamic load effects arising from the contact of air on the aircraft with during maneuvers should be considered as another study item. In addition, the irregular situation due to cavity problems during ejection from weapon bay was also left within the scope of the study. The movements that come from the standard and that the aircraft performs in certain maneuvers are directly used within the scope of the thesis. However, the calculation of the aerodynamic loads effect from similar studies in terms of similar surfaces of the weapon will be done anyway as mentioned and will be added if it is observed to have made a serious change.

3.1.1 Physical Characteristics for Store

With the information-sharing platform called ASIM, a wide range of information is shared within the scope of weapon, suspension and release systems and aircrafts used by NATO countries. The weights of the weapon, the mass moments of inertia, the distances between the sway braces of the generic systems to be used in the calculation of the forces, the distance of the points where the weapon will be hung, to the CG of the weapon, the angle of the sway braces with the aircraft obtained from these sources are compared and used. ASIM, which is used as a reference to contribute to the work of cooperating countries within the scope of aircraft-store integration, assists with new weapon, new suspension and release equipment and new aircraft designs.

Table 2 Source of Specifications

Weight of store	ASIM, Store Characteristics, Bombs
Mass moment of inertia X-axis	
Mass moment of inertia Y-axis	
Mass moment of inertia Z-axis	
Distance between lugs	ASIM, Store Characteristics and Suspension Equipment
Distance store CG to fwd lug X-direction	
Distance store CG to aft lug X-direction	
Distance store CG to fwd lug Y-direction	
Distance store CG to aft lug Y-direction	
Distance store CG to fwd lug Z-direction	
Distance store CG to aft lug Z-direction	
Distance between forward and aft sway brace pads	
Distance store CG to fwd sway brace pad X-direction	
Distance si re CG to aft sway brace pad X-direction	
Distance store CG to near sway brace pad Y-direction	
Distance store CG to far sway brace pad Y-direction	
Distance store CG to right sway brace pad Z-direction	
Distance store CG to left sway brace pad Z-direction.	
Angle between radius of curvature of store and Z-axis	ASIM, Suspension Equipment
Rotation around the X-axis for stores mounted at a roll angle W.R.T. the aircraft axis system.	

3.1.2 Inertial Load Equations

Six acceleration and load value affecting the center of the weapon are found by ready values of weapon and the generic aircraft, adding into the equations below. In this way, any desired value can be found easily.

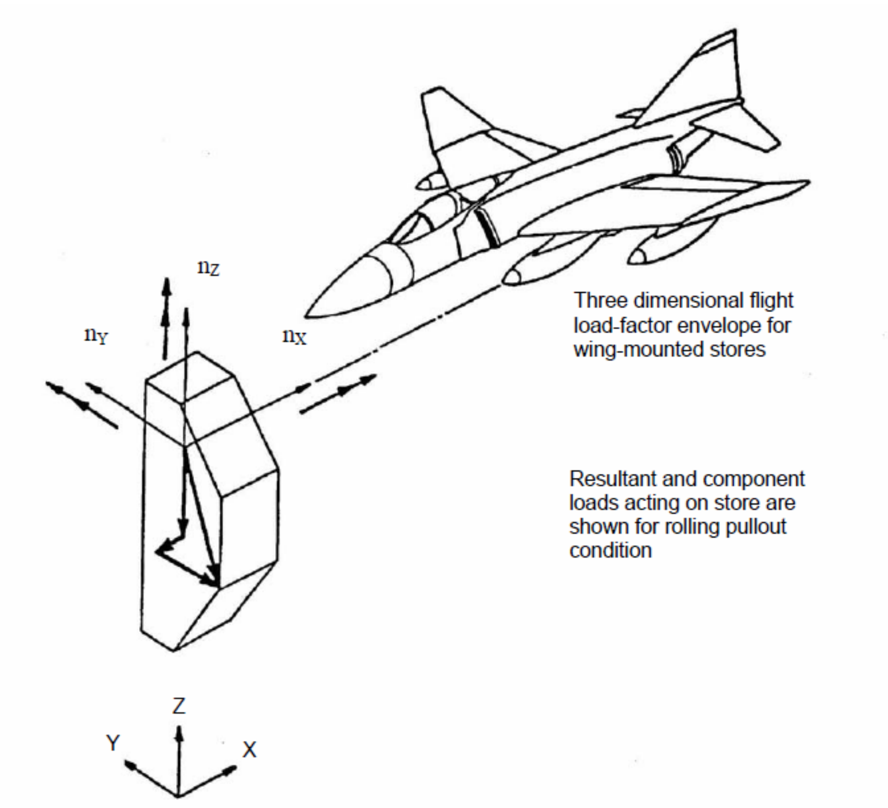


Figure 3-1 Axis of Three Dimensional Flight

After load factors are calculated with the following equations, they become inertial loads that affect their center with the characteristics of the weapon. Peak angle rates and peak angular acceleration values corresponding to the maneuvers envisaged by the fighter are taken from the table. The distance between the CG of the generic fighter and the CG of the weapon is added to the equation. With the linear acceleration, the load factor is found for each axis [32].

$$n_{x_s} = -a_x + \frac{1}{g}\left[\ddot{\omega}_z \Delta Y - \ddot{\omega}_y \Delta Z + \left(\dot{\omega_y}^2 + \dot{\omega_z}^2\right)\Delta X - \dot{\omega}_x \dot{\omega}_y \Delta Y - \dot{\omega}_x \dot{\omega}_z \Delta Z\right] \tag{3.1}$$

$$n_{y_s} = -a_y + \frac{1}{g}\left[\ddot{\omega}_x \Delta Z - \ddot{\omega}_z \Delta X + \left(\dot{\omega_x}^2 + \dot{\omega_z}^2\right)\Delta Y - \dot{\omega}_x \dot{\omega}_y \Delta X - \dot{\omega}_y \dot{\omega}_z \Delta Z\right] \tag{3.2}$$

$$n_{z_s} = -a_z + \frac{1}{g}\left[\ddot{\omega}_y \Delta X - \ddot{\omega}_x \Delta Y + \left(\dot{\omega_y}^2 + \dot{\omega_x}^2\right)\Delta Z - \dot{\omega}_x \dot{\omega}_z \Delta X - \dot{\omega}_y \dot{\omega}_z \Delta Y\right] \tag{3.3}$$

$$\Delta X = X_{store\ cg} - X_{aircraft\ cg} \tag{3.4}$$

$$\Delta Y = Y_{store\ cg} - Y_{aircraft\ cg} \tag{3.5}$$

$$\Delta Z = Z_{store\ cg} - Z_{aircraft\ cg} \tag{3.6}$$

Table 3 Aircraft Limit Conditions from STD 8591

Condition	Dynamic pressure q (psf)	Aircraft angles (deg)		Linear acceleration (g)			Peak angle rates 1/ (rad/sec)			Peak angular accelerations 1/ (rad/sec^2)		
		Attack α_A	Sideslip β_A	a_x	a_y	a_z	$\dot{\omega}_x$	$\dot{\omega}_y$	$\dot{\omega}_z$	$\ddot{\omega}_x$	$\ddot{\omega}_y$	$\ddot{\omega}_z$
1. Pullout	2500	5	0	±1.5	±1.0	+7.0	-	-	-	±0.25	±0.5	0
2. Pullout	1000	13	0	±1.5	±1.0	+8.5	-	-	-	±0.5	±0.5	0
3. Pullout	500	25	0	±1.5	±1.0	+10.0	-	-	-	±0.5	±0.5	0
4. Rolling-pullout	650	6	±2	±1.5	±0.5	+7.0	±5.0	-	-	±11.0	±3.0	±2.0
5. Rolling-pullout	2500	3	±1	±1.5	±0.25	+6.5	±4.5	-	-	±13.0	±1.0	±1.0
6. Rolling-pullout	2500	2	±1	±1.5	±0.25	+6.0	±4.5	-	-	±17.0	±1.0	±1.0
7. Barrier engagement (land)	150	0	0	-4.0	±1.0	+2.0	-	-	-	0	±6.0	±4.0
8. Max sink rate landing	150	0	0	-1.0	±1.0	+4.0	-	-	-	0	±4.0	±2.0
9. Bank-to-bank roll	2500	3	±1	±1.5	±1.0	+6.0	-	-	-	±13.0	±0.5	±1.0
10. Rudder-kick release (1g)	400	2	±10	±1.5	±1.5	+1.0	-	-	-	±1.0	0	±1.5
11. Pushover	2500	-2	0	±1.5	±1.0	-1.0	-	-	-	0	0	0
12. Pushover	1800	-4	0	±1.5	±1.0	-3.0	-	-	-	0	0	0
13. Pushover	1000	-6	0	±1.5	±1.0	-6.0	-	-	-	±0.5	0	0

This load factor found, along with the weight of the weapon, gives us loads to the CG of the weapon in each axis. The aircraft's peak angle rates which taken mostly as '0' and peak angular acceleration information and the inertia of the weapon are used and angular accelerations applied to the CG are found in each axis [32] .

$$P_{x_{inertia}} = n_{x_s} W_s \tag{3.7}$$

$$P_{y_{inertia}} = n_{y_s} W_s \tag{3.8}$$

$$P_{z_{inertia}} = n_{z_s} W_s \tag{3.9}$$

$$\begin{aligned} M_{x_{inertia}} = &-I_{xx}\ddot{\omega}_z + \left(I_{yy} - I_{zz}\right)\dot{\omega}_y\dot{\omega}_z + I_{yz}\left(\dot{\omega}_y^2 - \dot{\omega}_z^2\right) \\ &+ I_{xz}\left(\ddot{\omega}_z + \dot{\omega}_x\dot{\omega}_y\right) + I_{xy}\left(\ddot{\omega}_y - \dot{\omega}_z\dot{\omega}_x\right) \end{aligned} \tag{3.10}$$

$$\begin{aligned} M_{y_{inertia}} = &-I_{yy}\ddot{\omega}_y + (I_{zz} - I_{xx})\dot{\omega}_z\dot{\omega}_x + I_{xz}\left(\dot{\omega}_z^2 - \dot{\omega}_x^2\right) \\ &+ I_{xy}\left(\ddot{\omega}_x + \dot{\omega}_y\dot{\omega}_z\right) + I_{yz}\left(\ddot{\omega}_z - \dot{\omega}_x\dot{\omega}_y\right) \end{aligned} \tag{3.11}$$

$$\begin{aligned} M_{z_{inertia}} = &-I_{zz}\ddot{\omega}_z + \left(I_{xx} - I_{yy}\right)\dot{\omega}_x\dot{\omega}_y + I_{xy}\left(\dot{\omega}_x^2 - \dot{\omega}_y^2\right) \\ &+ I_{yz}\left(\ddot{\omega}_y + \dot{\omega}_x\dot{\omega}_z\right) + I_{xz}\left(\ddot{\omega}_x - \dot{\omega}_y\dot{\omega}_z\right) \end{aligned} \tag{3.12}$$

Within the scope of the study, the limits of envelopes in the reference source are considered as the worst case. Since this product draws the envelope boundaries that it must bear during the design, the corner points of the closed area are used in the code and 3 force and 3 acceleration values come from the coefficients in the tables. These forces and moments are same with aircrafts X, Y and Z axis respectively [32]. As an assumption of taking body rigid reduces complexity. Small deformations on acceleration calculation like Coriolis and centripetal neglected in this study because of flexibility and worst case calculations [1].

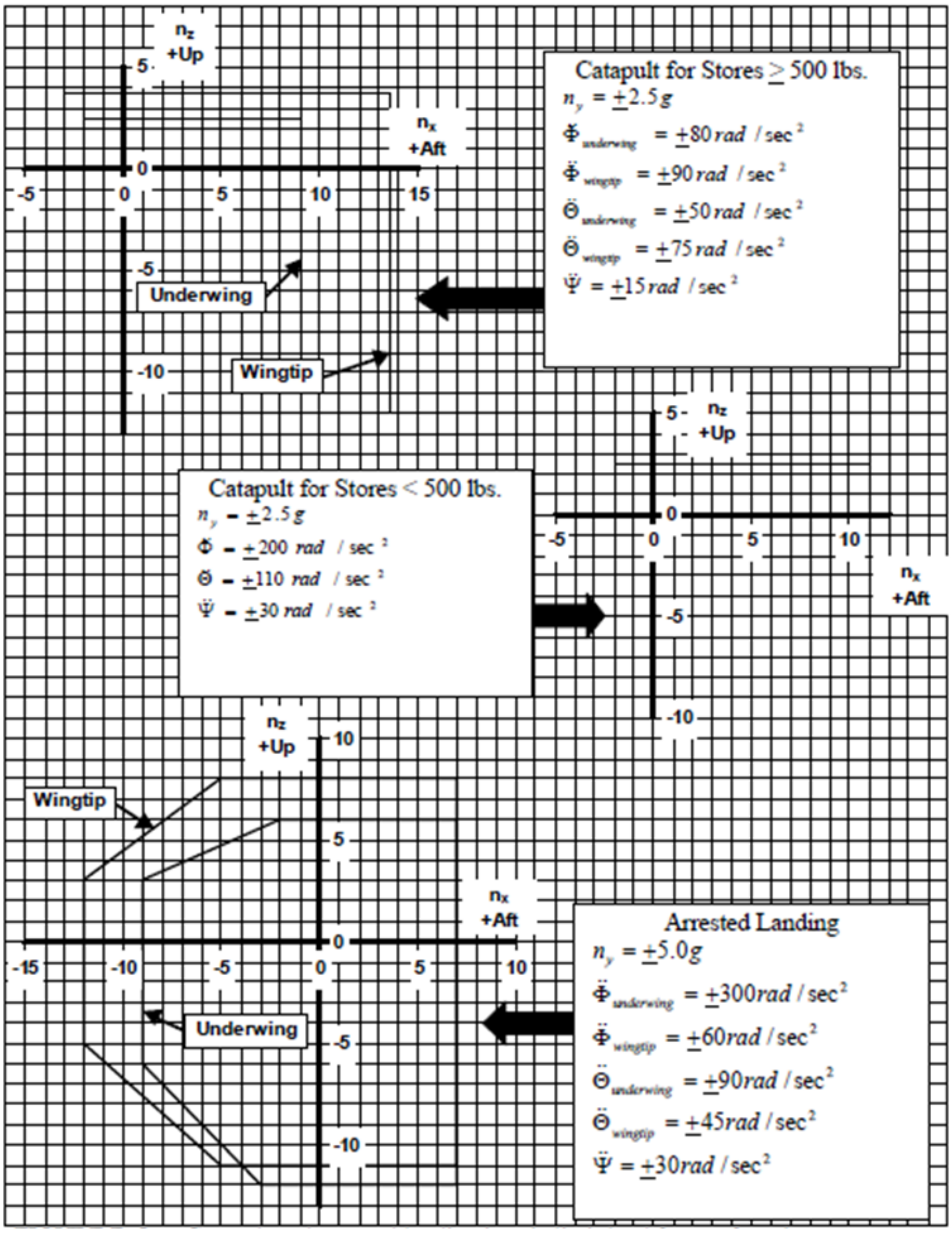


Figure 3-2 Inertia Limit Load Factors of Catapult and Arrested Landing at Wings

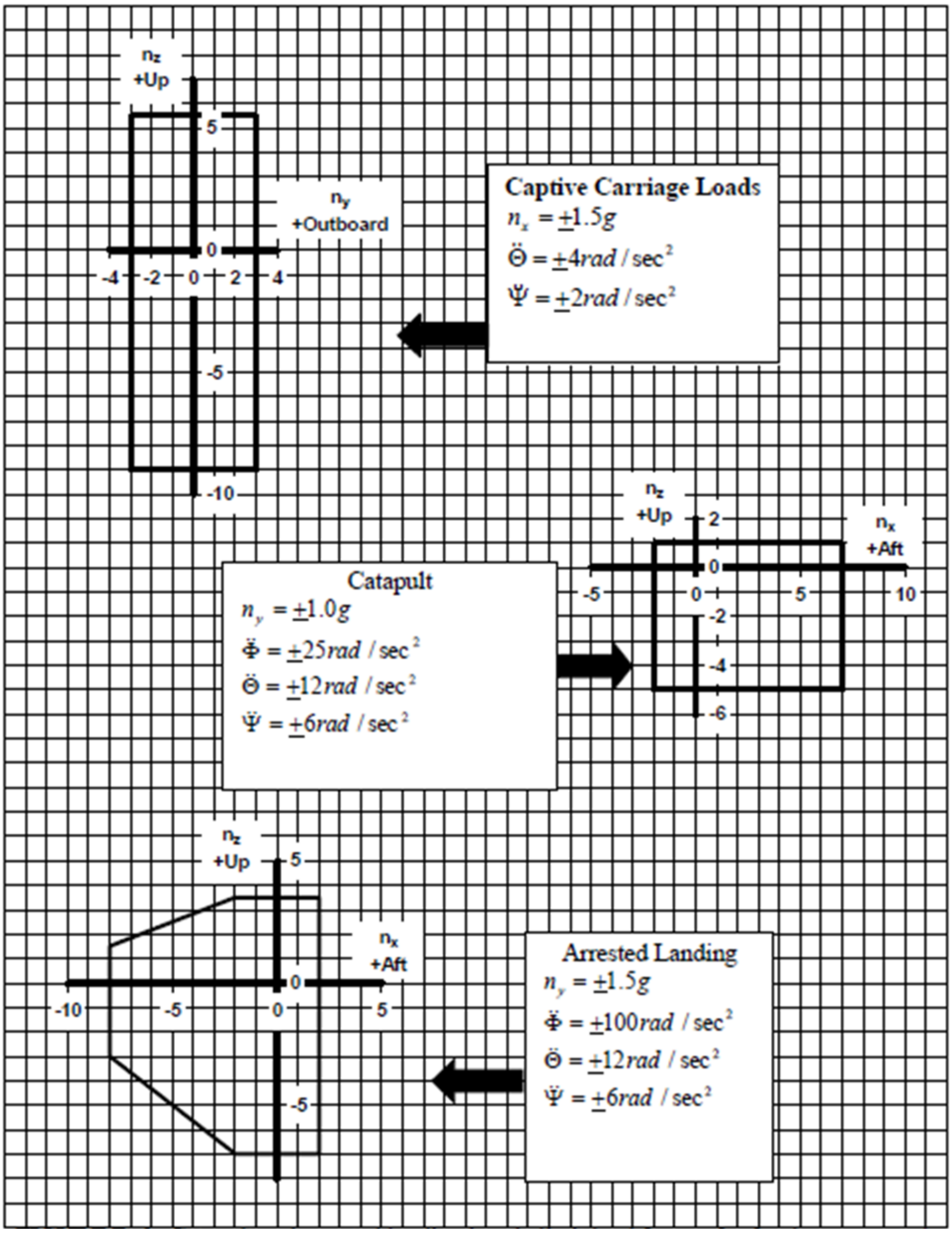


Figure 3-3 Inertia Limit Load Factors of Catapult and Arrested Landing at Fuselage

3.1.3 Aerodynamic Load Equations

Since aerodynamic forces are more complicated to calculate, many predictions have been made on weapon. Although verification and correction studies have been performed with flight tests and ground tests, taking realistic values requires precise work. The effects of aerodynamic forces for the arrested landing, catapulting and flight situations mentioned were evaluated. It has been observed in studies that the aerodynamic effect is negligible due to the worst-case scenario in cases other than flight. In the case of flight, situations where the aerodynamic force effect is high are not generally found in the most scenarios. Therefore, it has been evaluated that there is no effect in calculating the max load, but it will be beneficial to try to calculate it anyway.

Calculation equations of the angle of attack and sideslip of the aircraft in the load envelopes are given. The required values are found by using the figure 4-2 and 4-3 if the aircraft type is similar and by the table 3 according to the similarity of the detailed maneuvering situations. It is stated in 8591 standard that realistic aerodynamic calculations should be calculated in accordance with real flight and ground test data.

The aerodynamic loads mentioned consist of lift moment and drag forces. Due to the shape and surfaces of the weapon, these forces also act on the plane. Lift and drag forces occur around all axes around the aerodynamic center of the weapon, causing rotational acceleration around CG. After the preliminary design, detailing the aerodynamic calculations becomes more critical. The list of values required for performing the calculations mentioned in 8591H is given below.

- Dynamic pressure
- Weapon Frontal Area
- Weapon Length
- Drag coefficient
- Weapon angle of sideslip
- Weapon angle of attack
- Lift coefficient slope
- Pitch moment coefficient
- Side force coefficient slope
- Yaw moment coefficient slope

Aiming to find flight data in the preliminary design process is an optimistic move. For this reason, as mentioned before, calculation is started by selecting maneuvers in the corners of the flight envelope, where angle of slip in and angle of attack are maximum. Dynamic pressures are also among the values specific to these maneuvers. All the remaining coefficients are found by comparing the weapon to a certain shape and using the generic general coefficients of that shape, as specified.

Aerodynamic forces and moments are achieved by combining the coefficients taken from references with weapon and data in maximum situations. The studies show that there is no need to examine the flutter effect in carrying weapon lighter than 2000lb because of their structural nonlinearities. Suspension and release equipment, weapon and the vibration values of the pylon trio are therefore excluded and evaluated as an opportunity for future studies [1].

Points (1) and (2) (symmetric pullup):

α_A=0 to α_{max} degrees

β_A=±0.2 β_{max} degrees

Points (3) and (4) (symmetric pushover):

α_A=0 to -0.6 α_{max} degrees

β_A=±0.2 β_{max} degrees

Point (5) (rolling pushover):

α_A= +α_R to (-0.4 α_{max} +α_R) degrees

β_A=±β_{max} degrees

Point (6) (rolling pullout):

α_A= +α_R to (0.8 α_{max} +α_R) degrees

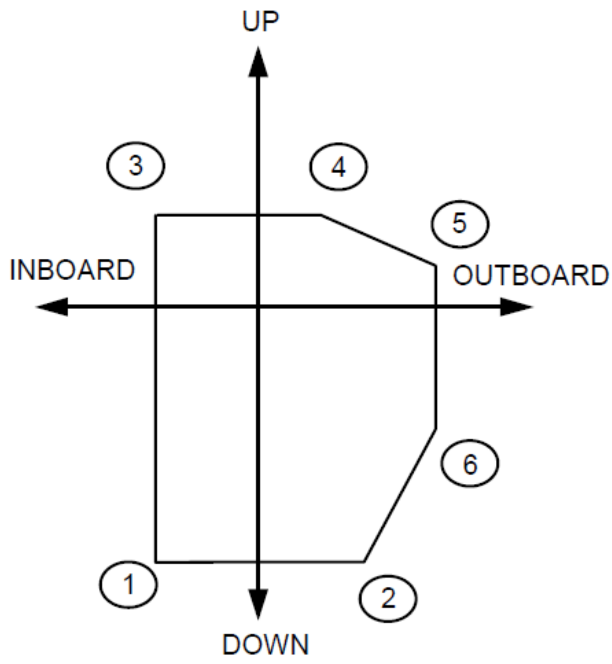


Figure 3-4 Angles of Attack and Sideslip for Load Envelopes

To reduce the error rate of the results in force and moment, it was recalculated in the equations written above using the aerodynamic coefficients found and calculated using the MISSILE DATCOM program for the MK82 500lb weapon [34]. This method has been applied for preliminary design and is another method of using angle of attack and sideslipler. In the studies carried out on errors to be made in calculations with Datcom, 1: 3 reduced model of the same weapon was introduced into the wind tunnel and these aerodynamic coefficients were compared [35]. There are also drag coefficient calculations for this weapon on various aircraft [36]. Similar results were obtained by calculating the aerodynamic coefficients of weapon of certain shape and weight using different methods. During the preliminary design, it was observed that it did not have any direct effect on the design since it was lower in size than the existing inertial loads.

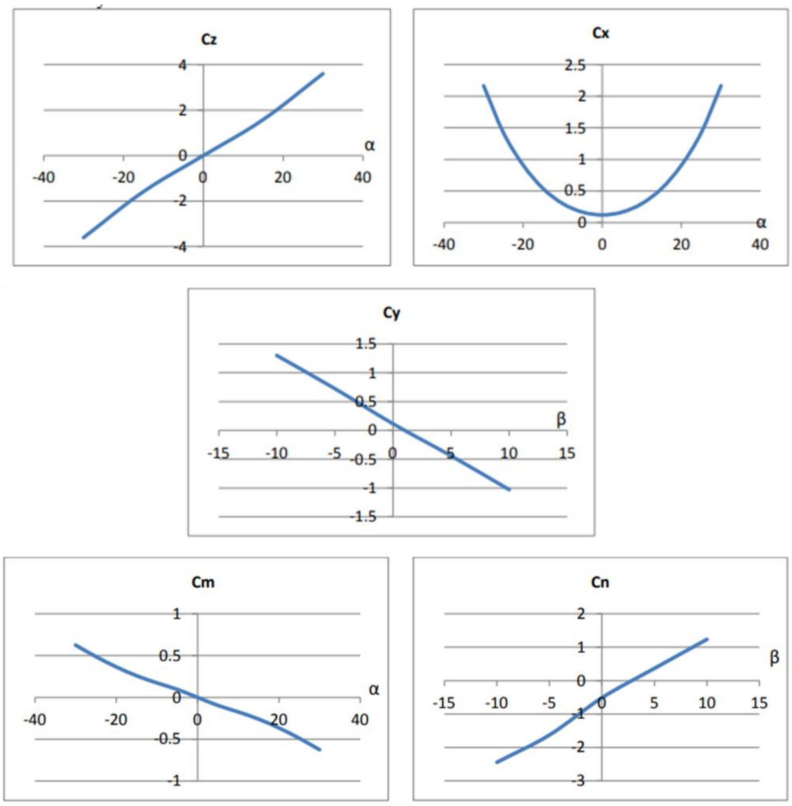


Figure 3-5 Lift, Drag, Side Force, Pitch and Yaw Moment Coefficients Plots

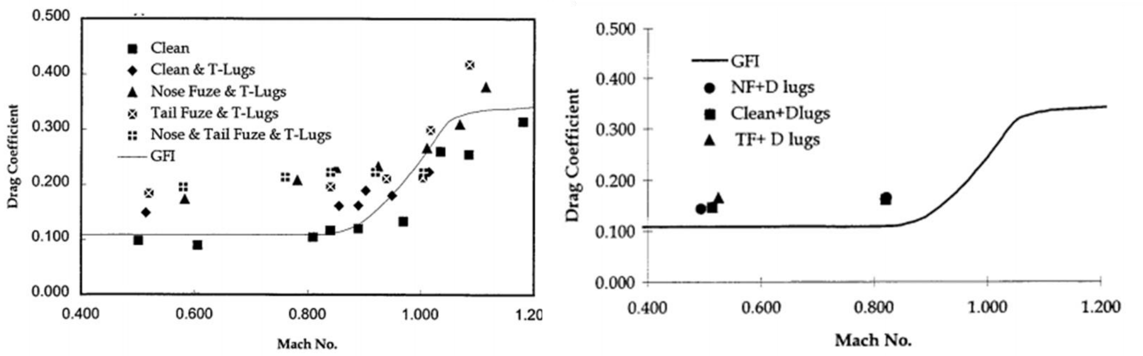


Figure 3-6 Drag Coefficients and Mach Plots

In order to find aerodynamic forces and moments, the correctness of the equations written under the standard 8591H is discussed. The study conducted in this context examined the lift, drag, moment coefficients in detail under the title of aerodynamic forces [1]. Drag coefficient dealt with a wider range, by dividing it into subsonic and supersonic. As a result, we come across equations as follows;

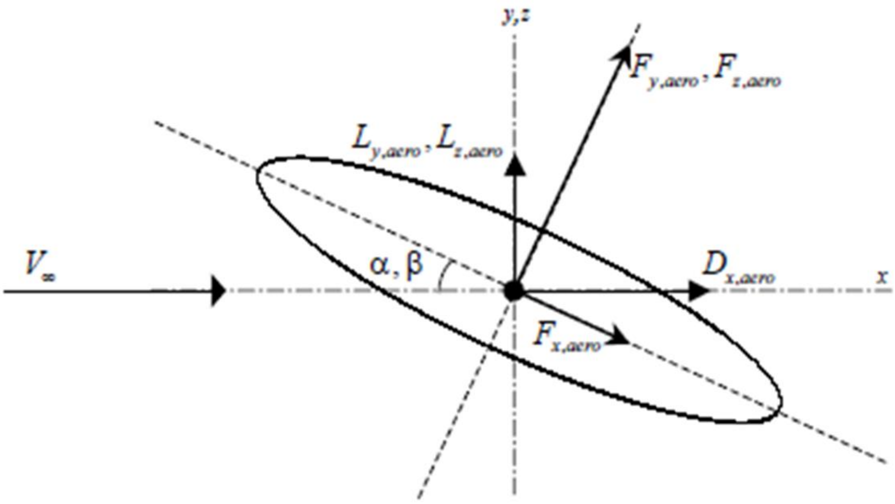


Figure 3-7 Flight Aerodynamic Forces for Stores

The program mentioned in the study was used in the program and the corrections were made by comparing the results with the code written within the scope of the thesis.

$$F_{x,aero} = D_{x,aero,\alpha} \cos\alpha - L_{x,aero}\sin\alpha + D_{x,aero,\beta}\cos\beta - L_{y,aero}\sin\beta \tag{3.13}$$

$$F_{y,aero} = D_{x,aero,\beta}\sin\beta - L_{y,aero}\cos\beta \tag{3.14}$$

$$F_{z,aero} = D_{x,aero,\alpha}\sin\alpha - L_{z,aero}\cos\alpha \tag{3.15}$$

$$M_{x,aero} = qS_{ref}L_{ref}C_{M,roll} \tag{3.16}$$

$$M_{y,aero} = qS_{ref}L_{ref}C_{M,pitch} \tag{3.17}$$

$$M_{z,aero} = qS_{ref}L_{ref}C_{M,yaw} \tag{3.18}$$

The aerodynamic and inertial load moments are handled together and the maximum reaction forces applied to the sway braces together with the physical characteristics mentioned earlier are found. For this purpose, it is necessary to establish the equations with the sway braces at the front and back and the dimensions of the selected generic field. Within the scope of this study, it has been accepted that sway brace pads are exposed to compression loads only, and lugs to tension loads only on vertical axis. This is accepted as it is desired to have maximum conditions and forces at these contact points for suspension and release situations. These assumptions were made in the same way for the worst cases in the studies of this field. The following sign convention table has been prepared to avoid errors due to the positioning of each piece on the right or left.

Table 4 Loads and Moments Directions for Reaction Forces at Sway Braces

Loads	**Forward Sway Brace**		**Aft Sway Brace**	
	Left	Right	Left	Right
$\mathbf{P_x}$	-	-	+	+
$\mathbf{P_y}$	-	+	-	+
$\mathbf{P_z}$	+	+	+	+
$\mathbf{M_x}$	-	+	-	+
$\mathbf{M_y}$	+	+	-	-
$\mathbf{M_z}$	+	-	-	+

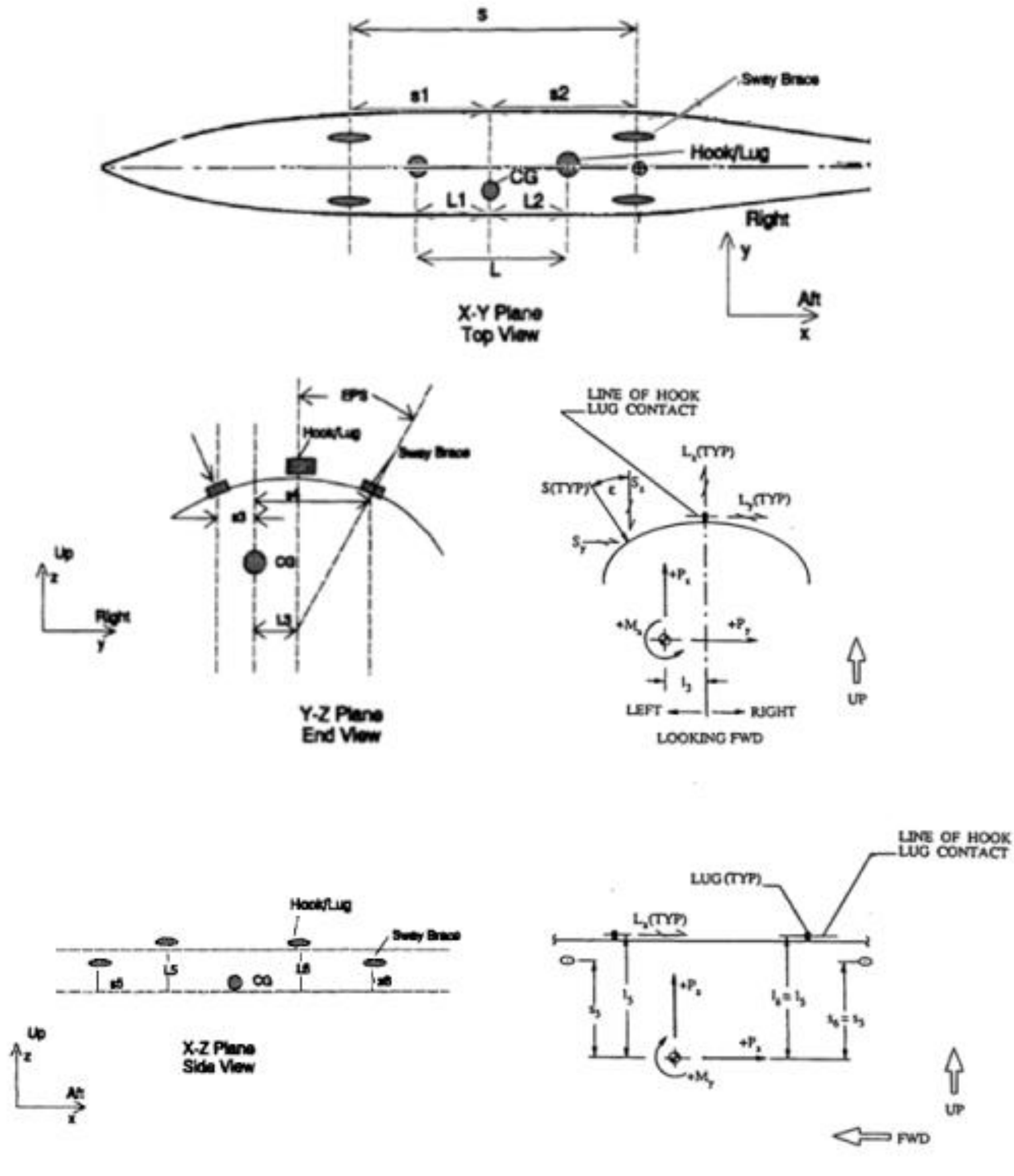


Figure 3-8 Top, Side and End views of Sway brace and Weapon Interfaces from [37]

As seen in the figures, the equations for front sway braces were established with free body diagrams for every axis and related areas and the calculation was started [37]. The aim here is to create an equation with the effects of forces and moments in various axes on the points where the weapon is fixed. As shown above, a weapon on the equipment has four contact points; two lugs and two swaybraces. The forces and moments coming to the center of the weapon are reflected in the equation and shortened by using the distances to the mentioned 4 contact points.

$$S_y = S_z \tan \varepsilon \tag{3.19}$$

$${S_z}^2 + {S_y}^2 = S^2 \tag{3.20}$$

$$S_z = AP_x + BP_y + CP_z + DM_x + EM_y + FM_z \tag{3.21}$$

$$S = \frac{S_z}{\cos \varepsilon} \tag{3.22}$$

$$A = \frac{L5}{2(S1 + L2)} + \frac{L3}{S \tan \varepsilon} \tag{3.23}$$

$$B = \frac{S2L5}{SK} \tag{3.24}$$

$$C = \frac{S2}{S}\left(\frac{1}{2} + \frac{L3}{K}\right) \tag{3.25}$$

$$D = \frac{S2}{SK} \tag{3.26}$$

$$E = \frac{1}{2}\frac{1}{(S1 + L2)} \tag{3.27}$$

$$F = \frac{1}{\mathrm{S}\tan \varepsilon} \tag{3.28}$$

$$H = (L5 - S5) \tan \varepsilon \tag{3.29}$$

$$K = H + L3 + S3 \tag{3.30}$$

3.2 Force Calculation for Specific Weapon Release

The effects of weapon on CG due to inertial and aerodynamic forces during the maneuvers performed by the fighter were evaluated in the previous section. The force required to separate and remove the weapon from the releasing system is another determining value that must be calculated to design the interface structure of the piston, which is the driving part of the releasing system. When weapon is desired to be left in the air, this interface will be subjected to the impact force and will do the fixing and dropping function together.

If weapon is to be ejected from a launcher that is not yet known, studies on a weapon whose characteristics are known should be examined. In military academic articles, it is seen that general-purpose bombs generally takes place in the aircraft-store interface studies. These weapons are referred to as dumb bombs. Thanks to the target adjustments on the aircraft, the distance to the target is carefully examined.

The critical factor in releasing from the suspension and release systems is the weight. It can easily be said before the research that higher forces will be required to drop heavy weapon. The important point here is that the weapon must come out at determined speeds to effectively separate from the launcher. The connection of the weight with the force should be considered with this detail.

The most accurate way to calculate an ejector release unit performance data is in-flight and static ejection tests. However, since these methods are generally expensive, it is more logical to use a performance estimation model that has been proven in previous studies, has been corrected with flight and ground test data based on errors.

Figure 3-9 Mau-12 Ejector Release Unit

For this study, its use, reliability and performance have been demonstrated with many documents, MAU-12 ejector release unit has been preferred, which is still in use by many NATO countries. This was developed with the aim of carrying and ejecting weapon up to 5000lb. This ERU, known in operational terms, has been used directly in many combat environments. It is known to be used in fighter aircraft such as F-4, F-15 and F-16. In this suspension and release equipment, the electrically triggered cartridge explodes and the mechanism is operated with hot gas pressure, i.e. it is pyrotechnic. This ERU, which is about 70 pounds, has a length of 32 inches, a height of 6.25 inches and a thickness of 3 inches.

If we had to drop the weapon from the MAU-12 ERU, it seems that it would be easier to calculate what the force is required on normal flights. The force-time plot of the MAU-12 field with varying weights was shared in the study [6]. This graphic includes the initial firing, releasing and calming process.

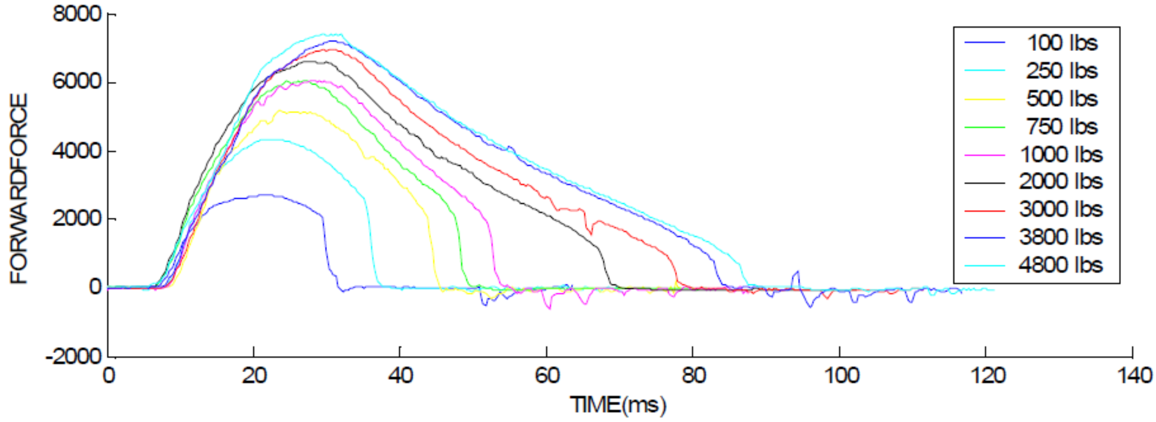


Figure 3-10 Force Time Plot of Mau-12

Kozak et al. [38] studied the effect of aeroelastic behaviour of the aircraft on separation of weawpon in their study. In this context, a simulink mathematical model has been prepared in order to reach the results of the previous study. The pressurized gas in the combustion chamber was modelled in MATLAB simulink by converting the accelerated weapon with the surface area of the piston and the piston, which was pushed with this gas, into equations.

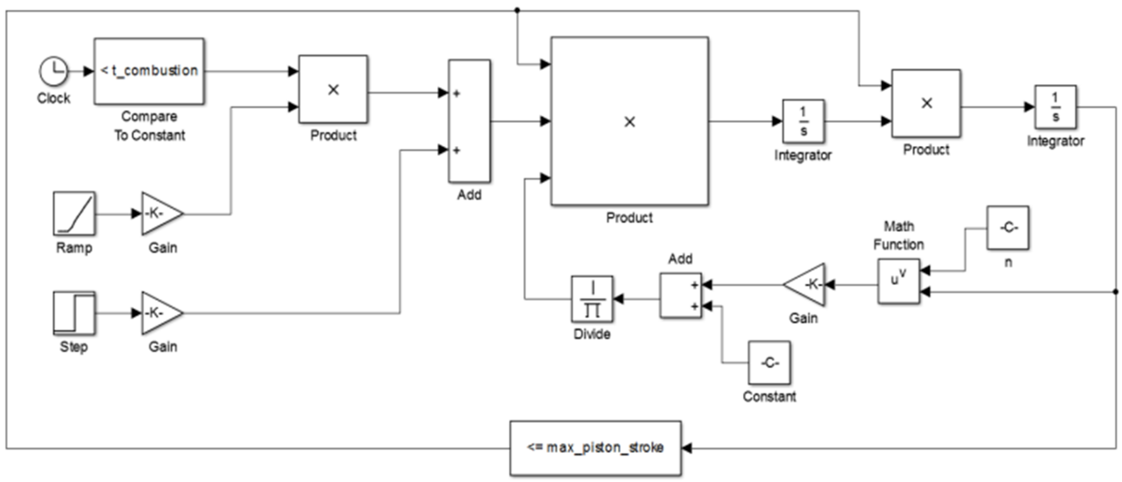


Figure 3-11 Ejector Simulink Model

As shown in Figure 4-12, when the model was run, the impact forces were similar to Carter's. As a result of these studies, double check was performed on the performance data of the MAU-12 field. The MAU-12 area, which has both 14 and 30 in suspension hooks, performs proportional forces to weapon in various weights and performs separations in accordance with the separation speed.

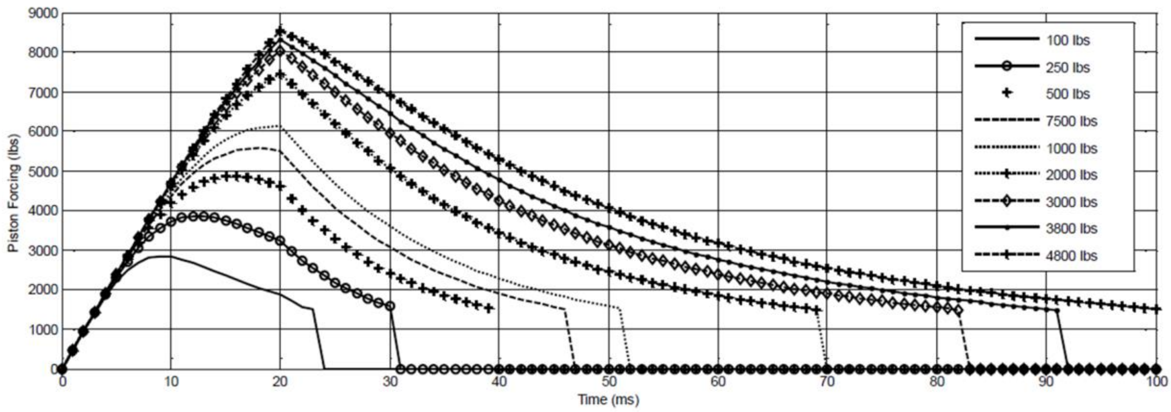


Figure 3-12 Ejector Simulink Model Results

Studies for MAU-12 have not only been limited to these but many data have been collected due to their frequent use in our country. For this purpose, in order to enrich our defence industry in terms of knowledge and gain the development capability that emits similar features, static ejection measurements of the MK-82 bomb were carried out. These tests were completed by performing many operations such as the change of thrust force over time, the velocity values at the end of the stroke, the tension on the launcher and the weapon, force, temperature values, and the processing of time measurements. In these tests carried out in TUBITAK SAGE facilities in May 2014 within the scope of our country's facilities and technology, force time graph has emerged. Because of classification just maximum forces will be given as, in the range of 30-35kN force per piston for 500lb bomb ejection.

When the results were compared, it was understood that all tests showed great similarity, minor changes occurred due to the explosive cartridges used, but the overall slope and maximum values were consistent. Within the scope of these studies, the questions of how much thrust force it takes the weapon of the MAU-12 ERU throws are answered. It has been understood which forces should be created under the same requirements for those who are to be designed to weapons with similar weight. The data set that can be used during the preliminary design has been brought together and the logic of this method has been confirmed.

The table below lists the weapon weight and maximum force generated during its release from all sources as a summary.

Table 5 Weapon Weights and Necessary Piston Forces

Weapon Weight (kg)	Maximum Forces per Piston (kN)
46	12.5
114	17.5
227	22.5
454	27.5
908	32.5

As stated in the MIL-STD-2088B standard, a 1000lb class store has been accepted to be maximum 1450lb in the light duty ERU where it can be carried. For this purpose, the force required to be ejected was chosen as the midpoint of 1000lb-2000lb in the graph.

Table 6 Maximum Carriage Capacity of ERUs from STD 2088B

Type	Vertical support spacing	Maximum carriage mass
I	14-inch	1450 lbs
II	14/30-inch	1450 lbs for 14-inch 5000 lbs for 30-inch

When the air-air missiles in the literature were examined, it was observed that they had a maximum weight of 450 lb and a launch force of 500 lb was selected in the table.

3.3 Final Design Structural Optimization

In the defence industry, where cost and competition increase, the main purpose of companies is to produce their products with as few materials as possible. A more detailed study was needed during the attempts to produce the product that was suppressed with the high raw material expenses that were attempted to be produced, with the least possible material. These detailed studies have a serious impact on both the cost of production and the usability of the product.

Structural optimization is trying to find the appropriate size, shape or material distribution of a structure while satisfying different structural behaviour constraints to perform its task in the best way [39]. Structural optimization techniques are generally developed to be used towards the end of the design and there are many examples in the market that have become widespread for this purpose. It is considered that more cost and time loss can be prevented by using it in earlier stages to increase performance. Optimization can be summarized as the fastest and most efficient solution to a problem in certain situations. It is generally divided into three main sections. In the initial structural optimization studies, firstly size, then shape and finally topology optimization was used [40].

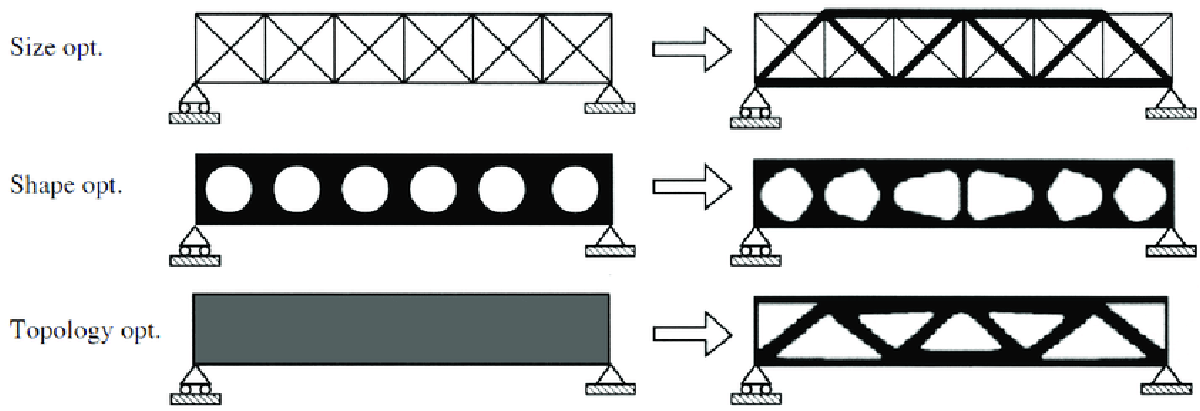


Figure 3-13 Structural Optimization Methods [41]

3.3.1 Size Optimization

Size Optimization is the simplest form among structural optimization techniques. The aim is to dimensionally optimize the parts of the structure with known shape [42]. It is the aim to reach the most efficient structure in size optimization without making any change in shape and topology. Shape and material distribution are not affected.

Design variables width, height, length and thickness are handled iteratively within the scope of this optimization technique. It is also preferred in studies to find the most efficient cross-sectional area. As a result, it can be applied to 2D and 3D designs without effecting fasteners.

3.3.2 Shape Optimization

Shape optimization is called to try minimizing and optimizing the high stress that occurs in the boundary of the structure [40].

With this technique, changes in the geometry of the structure are made without touching the topology. Shape optimization does not change the total number of holes and the corner curved surfaces in the design while handling with various iterations. It is emphasized that a particular topology can be modified by studying with its geometry to suit the desired goal.

The difference of the topology optimization, which will be described later, will be clearer on this issue. Just like size optimization, it can be used to find the optimum shape in 2 and 3 dimensional parts. The aim is to make holes and corner curves, which are more efficient, in terms of vibration, durability, tension, or frequency by paying attention to the constraint functions.

3.3.3 Topology Optimization

The evacuation of unnecessary areas without destroying the integrity of the structure is the basis of topology optimization. In this method, unlike shape optimization, the optimum model is achieved by losing volume without targeting a change in the outer dimensions of the structure. It determines the locations, shapes and numbers of holes, space or connection surfaces in the structure [43].

In topology optimization, the design is improved in order to reach the most appropriate material distribution, i.e. the structural variables. The aim may be to reducing weight or stress, changing frequency.

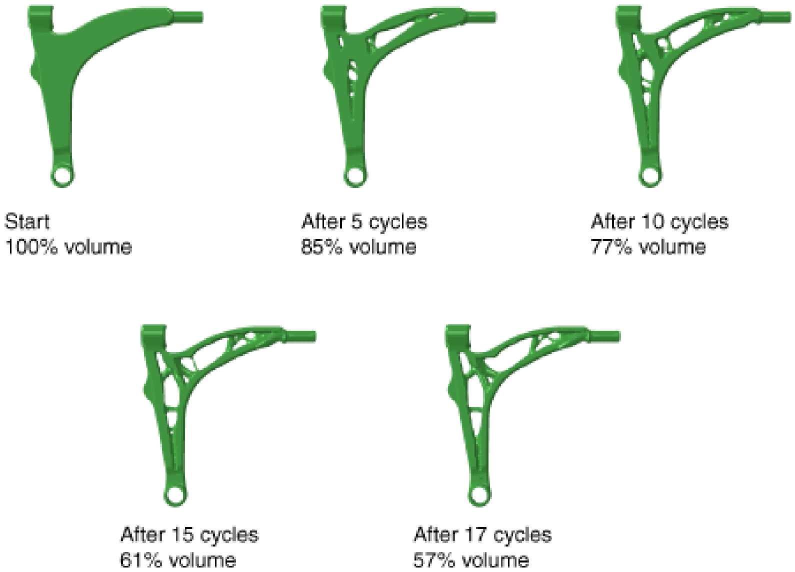


Figure 3-14 Topology Optimization from ABAQUS User Guide

We can divide the topology optimization into two different areas, continuum and discrete structures. Structures such as large buildings and lattices are considered discrete, while smaller ones are within the continuum structure. In this study, since topology optimization in continuum structures will be discussed, different types in that area will be summarized.

3.3.3.1 Homogenization Method

In the homogenization method, it is aimed to reach the optimum target by changing the dimensions of the spaces within the material of a certain design area. Distribution is controlled by this method. Bendsøe and Kikuchin's work is an important milestone about the use of this method in topology optimization. It is important that the method accept the material property homogeneous for each element. The disadvantage is that the required design variables are higher in number than other methods [44].

The aim of the homogenization method is to determine the possible association of microstructure variables that minimize their functions. Global Stiffness, which is maximized in order to minimize strain energy within a specified volume, can be expressed as follows [45];

$$S.E = \frac{1}{2} U^T K U \tag{3.31}$$

$$\sum_{k=1}^{k=n} (1 - \mu_1 \mu_2) v_k \leq V^* \tag{3.32}$$

S.E is the strain energy, U is the global displacement vector, K is the global stiffness matrix and N is the number of finite elements.

3.3.3.2 Material Distribution Method (SIMP)

It is a method developed on the constant properties of the material in the elements. Physical properties, element thickness or porosity are among the important parameters. By creating a finite element model, it is aimed to reach the optimum element thickness. Meanwhile, Von Misses stresses are taken into consideration. The model creation process continues after each stress calculation. The regions that do not undergo stress are removed slowly and the most robust structure is tried to be reached [46].

It can be seen as an advantage of this method to use the optimum design in terms of manufacturability. In current applications, it can be said that this method was used in inplane force situations, where it created an additional study requirement for three-dimensional load cases after the study. This also appears as a disadvantage.

After a certain period, it was started to be called the punishment of solid isotropic materials (SIMP). The density of each element, expressed as pseudo, takes a value between 0 and 1. This value depends on the stiffness of the material. It can be expressed as follows.

$$x_i = \frac{\rho_i}{\rho_o} \tag{3.33}$$

ρ_i is the density of Ith element, ρ_o is the density of the base material, x_i is the pseudo-density of the Ith element.

$$K_i = {x_i}^p K_o \tag{3.34}$$

K_o is the stiffness of the base material, P is the penalization power and should be more than 1 . If x_i and K_o are 0 means no material exists, but the meaning of 1 is existing of material.

In solid isotropic materials punishment method , for optimal design middle densities cause to inefficiency in case of selecting value P higher than 1.

3.3.3.3 Level Set Approach

It is a method based on boundary conditions between structural topology optimizations. The basics are based on the work prepared by Osher and Sethian for monitoring free boundaries with the average curvature [47]. Levet set movements from the current state of optimization are changed along with boundary conditions.

The advantage of this method over SIMP is that the densities of middle value are not used. Although it improves with the developing methods, it can be stated that it contains high adherence to the structure in the initial design as a disadvantage [45].

$$S(t) = \{x(t) : \Phi(x(t), t) = c\} \tag{3.35}$$

C is the arbitrary constant, x is a point on boundary, level set vary with time. With this equation and chain rule, application ensures the Hamilton-Jacobi equation.

$$\frac{\partial\Phi(x,t)}{\partial t} + \nabla\Phi(x,t)\frac{dx}{dt} = 0, \Phi(x,0) = \Phi_0(x) \tag{3.36}$$

$\frac{dx}{dt}$ is the movement of a point and expressed as position x. The optimum boundary can find with the partial differential equation. X is a point in space on the izo-surface.

3.3.3.4 Evolutionary Structural Optimization

The method of adding or removing a certain number of elements in the design area is called Evolutionary Structural Optimization. This material mobility is random. A criterion value is calculated for each element named as sensivity number. Then, the lower value is deleted. Numerical imbalances such as mesh dependencies can be shown as a disadvantage of this method [45].

Within the scope of the evolutionary optimization method, the structure is first subjected to topology optimization and then size optimization unlike other methods. If enough attention is not paid to some design criteria within the scope of topology optimization, optimization in the second stage may result in failure [48].

Maximizing stiffness under fixed volume constraint;

$$C(p) = F^T U \tag{3.37}$$

$$V^* - \sum_{e=1}^{N} (V_e p_e) = 0 \tag{3.38}$$

$$KU = F \tag{3.39}$$

$$p = p_{min} \; or \; 1 \tag{3.40}$$

3.3.3.5 Topology Optimization with ABAQUS and TOSCA

TOSCA is a program that cooperates with various finite element solvers (Abaqus, Ansys and Nastran), optimizes size, shape and topology and offers economical, safe and efficient solutions. Their solutions are flexible and non-parametric. In addition, there is a customized 'Tosca for Abaqus' plugin for Abaqus used in this study. Studies can be started directly under the optimization title on 3D Abaqus models. This application is user-friendly as it can use the post-process part of the Abaqus environment and control errors [49].

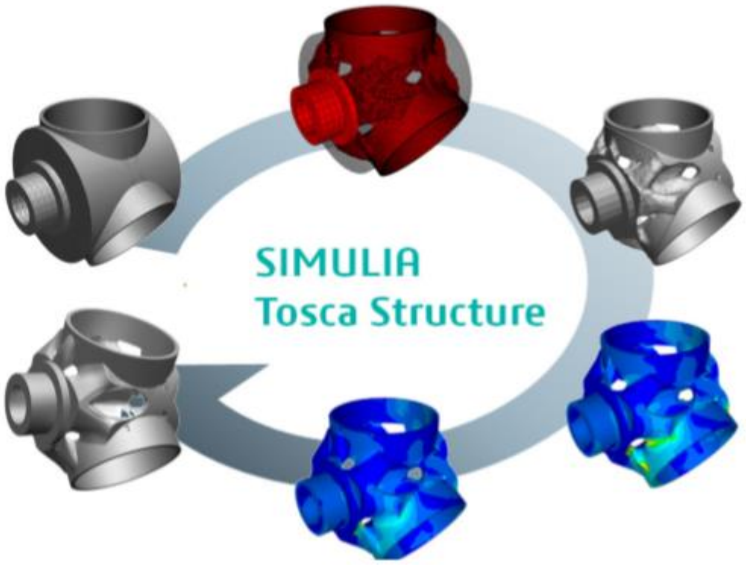


Figure 3-15 ABAQUS –TOSCA cycle

4 METHODOLOGY FOR YOKE STRUCTURE AS A CASE STUDY

4.1 Combining Total Forces for Universal Yoke Structure

In the studies described so far, the effect of the aircraft on the center of that weapon due to the inertial or aerodynamic forces during the carriage of weapon was examined. Reaction force is distributed to sway braces; Afterwards, studies on the MAU-12 ERU found that how much reaction force emerged when ejecting weapon. Thus, the maximum conditions under which the structure used to fix the weapon and the structure used during the releasing of the weapon were exposed separately were learned. In this common structure design, which keeps the weapon stable and leaves it when necessary, these inputs combined and contributed to the formation of design boundaries. It is aimed to find out what kind of reaction they will give in a common structure against these high forces that are exposed to two different situations.

Figure 4-1 F-35 Fighter Aircraft with Weapons

Firstly, using the data obtained from the open source of the f-16 aircraft of the calculated values, then the working area was narrowed by using the distances between the suspension hook and the sway braces of the MAU-12 ERU and its compatibility with the studies for calculating the forces exposed during the release with the MAU-12. If desired, different releases for different airs can be tested and loads of sway brace or suspension hooks during transportation can be found.

Written code output screen for air to surface bomb according to the maximum conditions given in table 7;

Table 7 Load Factors, Accelerations and Result Forces for Bomb

n_x	n_y	n_z	$\ddot{\Phi}$	$\ddot{\Theta}$	$\ddot{\Psi}$	$S_{z\,(lbs)}$	$S_{y(lbs)}$	$S_{total(lbs)}$	$MAX_{(lbs)}$
-1.50	-1.00	7.00	-0.25	0.50	0.00	3085.82	1123.15	3283.86	3283.86
-1.50	-1.00	8.50	-0.50	0.50	0.00	3462.67	1260.31	3684.90	3684.90
-1.50	-1.00	10.00	-0.50	0.50	0.00	3837.67	1396.80	4083.96	4083.96
-1.50	-0.50	7.00	-11.00	3.00	2.00	3171.71	1154.41	3375.26	4083.96
-1.50	-0.25	6.50	-13.00	1.00	1.00	2547.20	927.11	2710.68	4083.96
-1.50	-0.25	6.00	-17.00	1.00	1.00	2451.77	892.37	2609.12	4083.96
-4.00	-1.00	2.00	0.00	6.00	4.00	3415.16	1243.02	3634.33	4083.96
-1.00	-1.00	4.00	0.00	4.00	2.00	2744.22	998.81	2920.34	4083.96
-1.50	-1.00	6.00	-13.00	0.50	1.00	3124.23	1137.13	3324.73	4083.96
-1.50	-1.50	1.00	-1.00	0.00	1.50	2343.99	853.14	2494.42	4083.96
-1.50	-1.00	1.00	0.00	0.00	0.00	1564.10	569.29	1664.48	4083.96
-1.50	-1.00	3.00	0.00	0.00	0.00	2064.10	751.27	2196.57	4083.96
-1.50	-1.00	6.00	-0.50	0.00	0.00	2817.80	1025.59	2998.64	4083.96

In the case where the maximum value for the bomb was found, the air air missile was also examined. The resulting maximum loads is shown in the table below.

Table 8 All Loads to Combined Total Forces

	Missile	Bomb
Releasing	22500 N	30000 N
Exposing with Maneuvers	28950 N	35657 N

4.2 Design Space of the Base Universal Structure

Within the scope of this thesis, it is aimed to design and optimize a sway brace-yoke design structural part that can be used with an air-to-air missile or air-surface weapon, which is included in a new suspension and release equipment design.

In this context, the missile, which is planned to be used jointly, is required to have a 7-inch body diameter. When examining missiles with this diameter, open source valuable data of the AIM-120 missile mentioned earlier can be used for this purpose. This missile is used with the LAU-142 and LAU-147 launchers on 5th generation fighter jets when it is aimed to launch vertically.

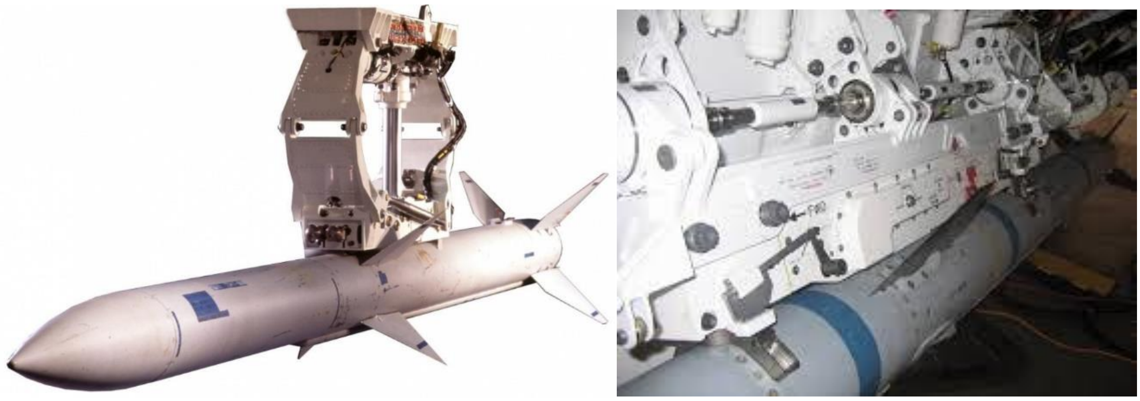


Figure 4-2 Missile And Different Vertical Eject Launchers

Another weapon intended for common use is a 1000lb class surface bomb. The dumb bomb can be used because the exterior surfaces are important in terms of design. For this purpose, MK-83 weapon, which we frequently encounter in open source, was preferred. It is assumed that the points where this weapon is fixed with sway braces have a diameter of approximately 14 inch. Although this weapon can be ejected with many products, examples of BRU-46 and BRU-67/68 are given here, as the method of suspension on 5th generation aircraft will be mentioned.

Figure 4-3 Recent Ejector Release Units

It should be noted that with the progress of the design, it is necessary to try to carry 11-inch diameter 500 lb class weapon in the future. It is known that Mk-82-like smart weapon is frequently used in airborne missions in operation.

When this subject is taken into consideration with this information, it is seen that the design of a common releasing that pushes 7-inch missiles by wrapping, and 14 inches weapon by pushing them from the hard point areas is required.

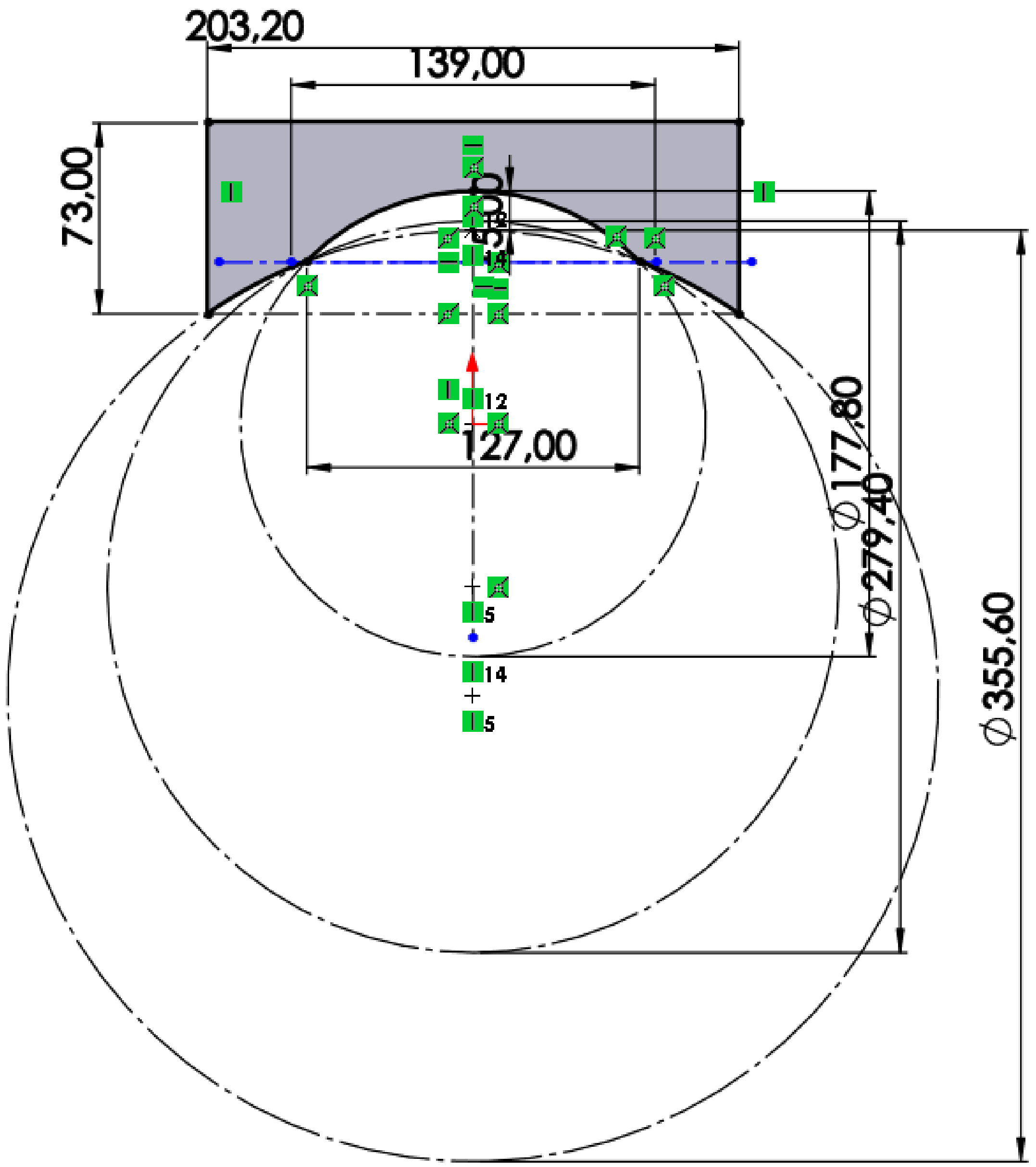


Figure 4-4 Solidworks Drawing of Design Space with Different Weapons

As can be seen above, when two weapon and a missile are placed on top of each other and examined by considering the suspension interfaces, an image like the above appears. Thus, the shape of the surfaces that contact the weapon will be determined. Since the top-level will start with a wide design, it is compared with the competitors to be mentioned in the future and the amount of safe thickness is given in other axes. 11-inch weapon was added to the drawing and its possible compatibility was examined for just future works.

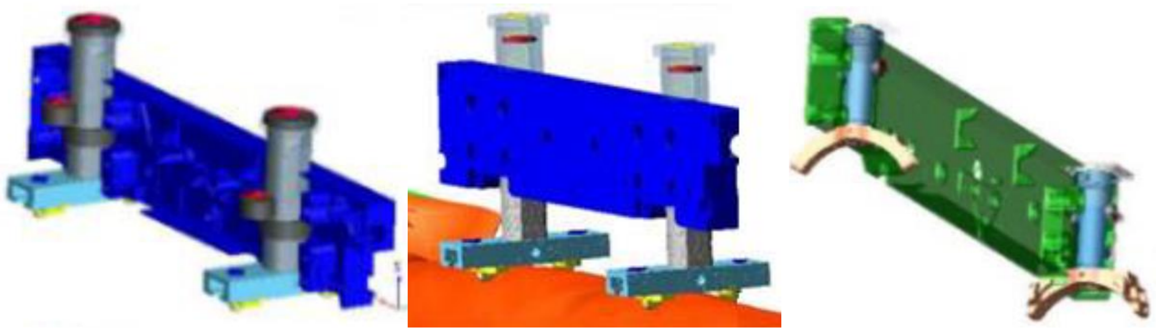


Figure 4-5 Sway Brace and Yoke Examples

The thickness of the structure that will push the weapon should be expanded in all directions so that topology optimization can be done according to the weapon. For this purpose, the widest design space should be created and optimization should be performed over this volume. The part of the structure that will connect with the piston should be fixed. The study has been carried out considering that the small missile is certified for pushing from the middle part and it will be pushed from the hard point areas where large diameter weapon is fixed. This work was carried out in Solidworks 2019. The design space created by paying attention to the other connected surfaces of the sway braces and launchers shown below.

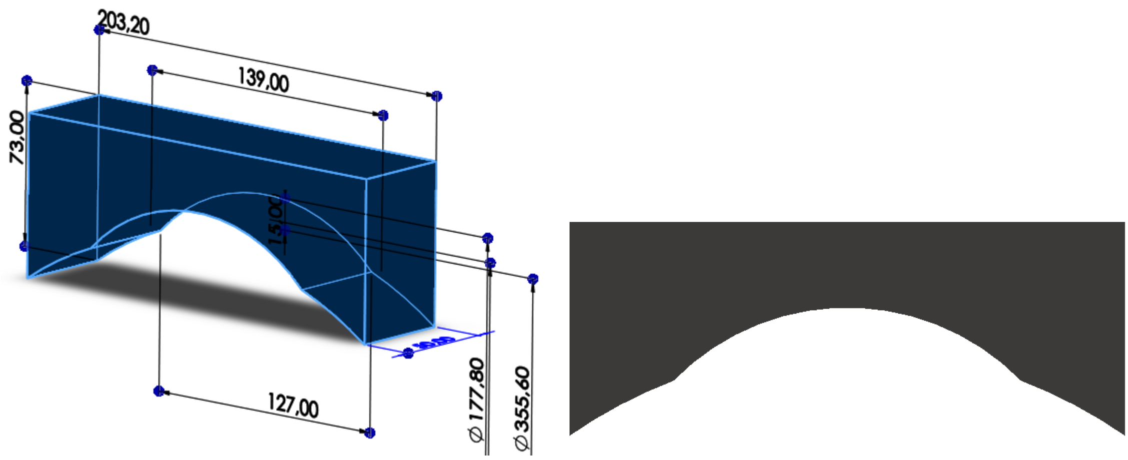


Figure 4-6 Solidworks Drawing of Design Space

4.3 FE Model Creation

While modelling the structure, it is evaluated according to the speed and importance of the analysis and divided into elements accordingly. Second order (C3D10) was used for important critical regions to minimize problems. The regions that will carry the loads distributed to the weapon and missile are handled with precision. Stress analysis was carried out with this precision. Finite element analysis was performed with 643k, 784k and 944k element number and stress results appeared with a difference of less than 1 percent. For this reason, optimizations with 50 cycles have continued with 643k in order not to take long time. A total of 899166 nodes and 643348 elements were used.

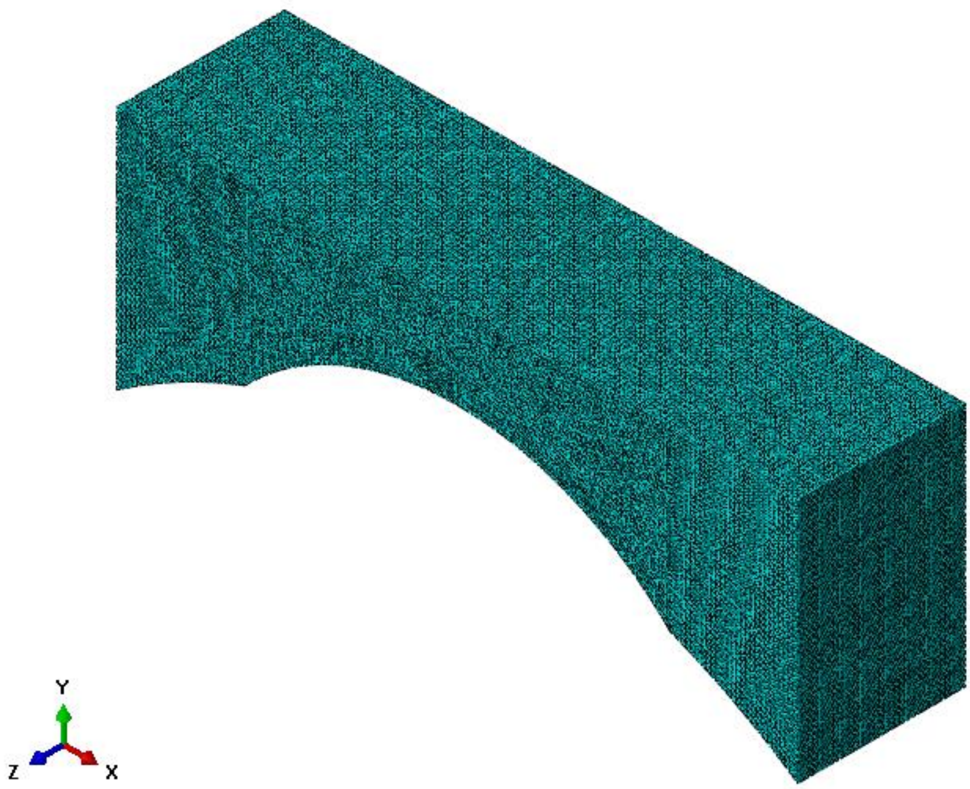


Figure 4-7 Finite Element Model of Structure

4.4 Material Property

Three materials used in similar transportation systems were investigated as candidates. 17-4PH H1025 steel is preferred because the structure to be designed will have an impact force both for fixing the structure and for safe separation when desired. While the Yield strength value was enough value among the candidates, having an average elastic modulus value was preferred. According to the results in the future, Grade 250 maraging steel or AISI 4340M Steel will also be kept in the evaluation list. The properties of all selected and candidate materials are given in the table below.

Table 9 Mechanical Properties of Candidates

Mechanical Properties	Grade 250 maraging steel	AISI 4340M Steel	17-4PH H1025
Tensile strength	1758 MPa	1930 MPa	1276 Mpa
Yield strength	1724 MPa	1585 MPa	1170 Mpa
Density	8.2 g/cm3	7.75 g/cm3	7.75 g/cm3
Elastic modulus	190 GPa	210 GPa	196 GPa

(a) (b) (c)

Figure 4-8 a) Grade 250 maraging steel (b) AISI 4340M Steel (c) 17-4PH H1025

4.5 Multiple Load Condition Definition

Within the calculated worst cases, 22500N was applied to the lower inner surface of the structure for the purpose of ejecting for the missile, 28950N for fixing while exposing to maneuvers; 30000N was applied to the lower end surfaces of the structure for the purpose of releasing for bomb, 35657N was used to fixing while exposing to maneuvers. As a result, a maximum of 4 forces to be applied for both weapons are selected, and according to these cases, all load cases are applied separately and common structure optimization is provided in ABAQUS. The 1st position refers to the loading cases applied to the side areas for air to surface weapon and the 2nd position to the middle zone for the missiles. Situations 3 and 4 are the loading cases applied by these weapons to the structures while attached to the aircraft.

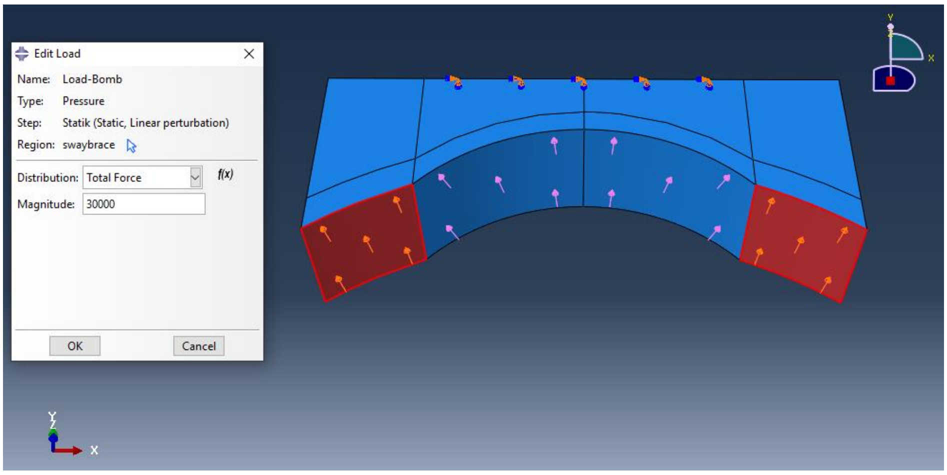


Figure 4-9 Ejection Force to Sway brace

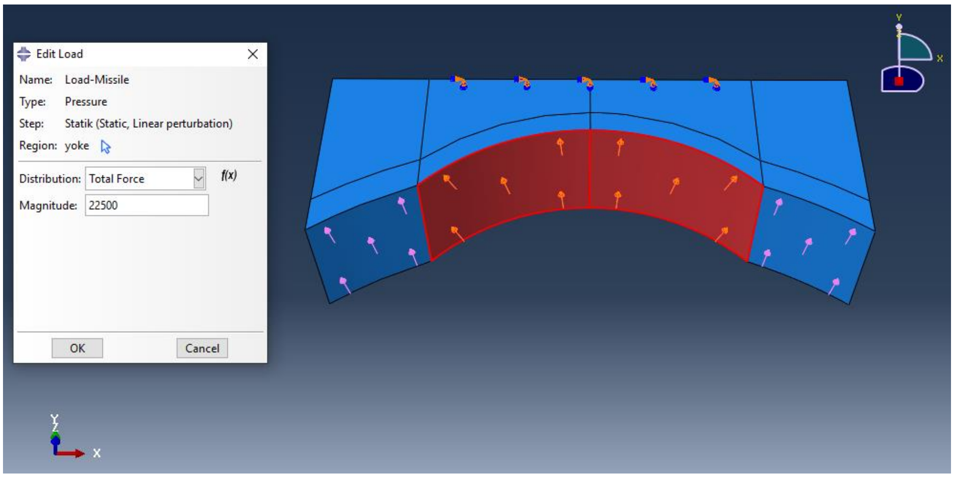


Figure 4-10 Ejection Force to Yoke

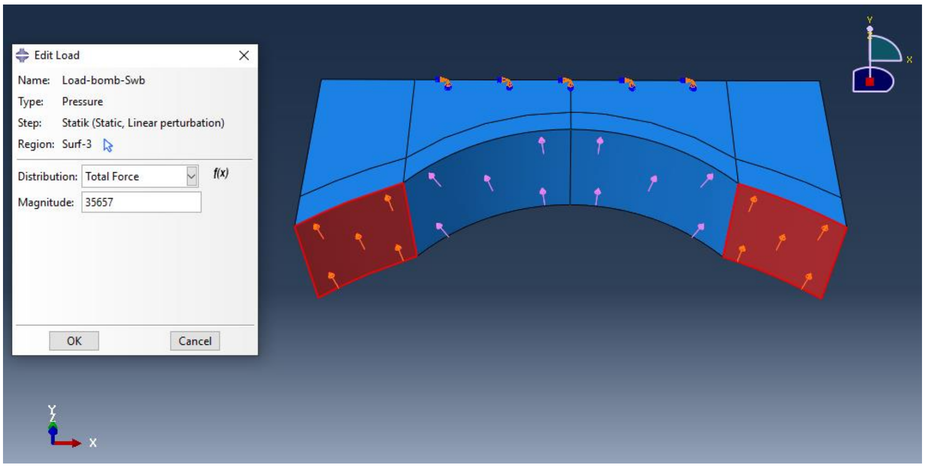


Figure 4-11 Fixing Reaction Force to Sway brace

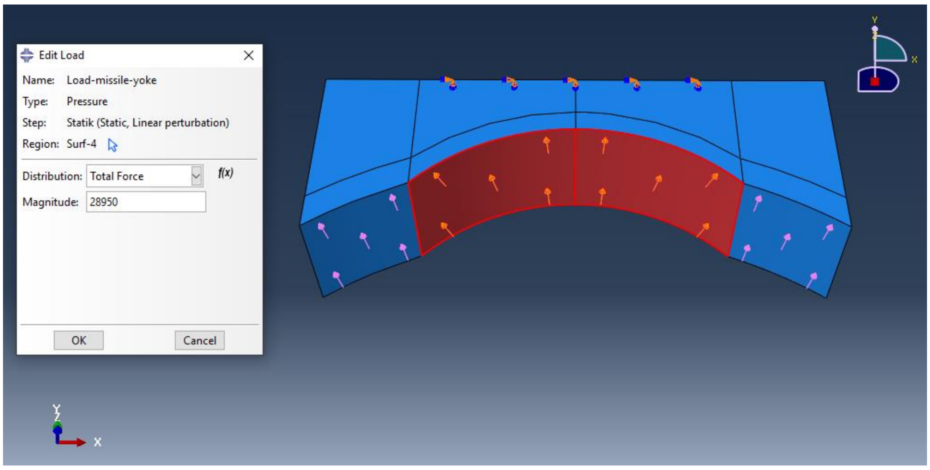


Figure 4-12 Fixing Reaction Force to Yoke

4.6 Stress Analysis

After selecting a large volume without detail, analysis should be performed to evaluate whether it is suitable for emptying. The effect of stress analysis is shown below. Analysis was performed by applying 4 different forces for 4 different load cases. The maximum stress values formed in both analyses were changed to gray, and the highest level of red color was taken close to half of the maximum stress value in order to make the results appear clearer. In order to make clear the boundary conditions and the surfaces where the force acts, visuals were taken from 2 different angles. It is seen that the maximum forces formed in the analysis do not cause any danger to the structure.

In the first case, the light and small diameter missile compatible part was handled. Maximum stress occurs around the boundary conditions to be connected to the piston at the top of this structure. It is seen that the maximum pressure that may occur during the launch of the missile is 65.05 MPa, and during extreme maneuvers, the pressure loaded on the structure reaches 83.7 MPa.

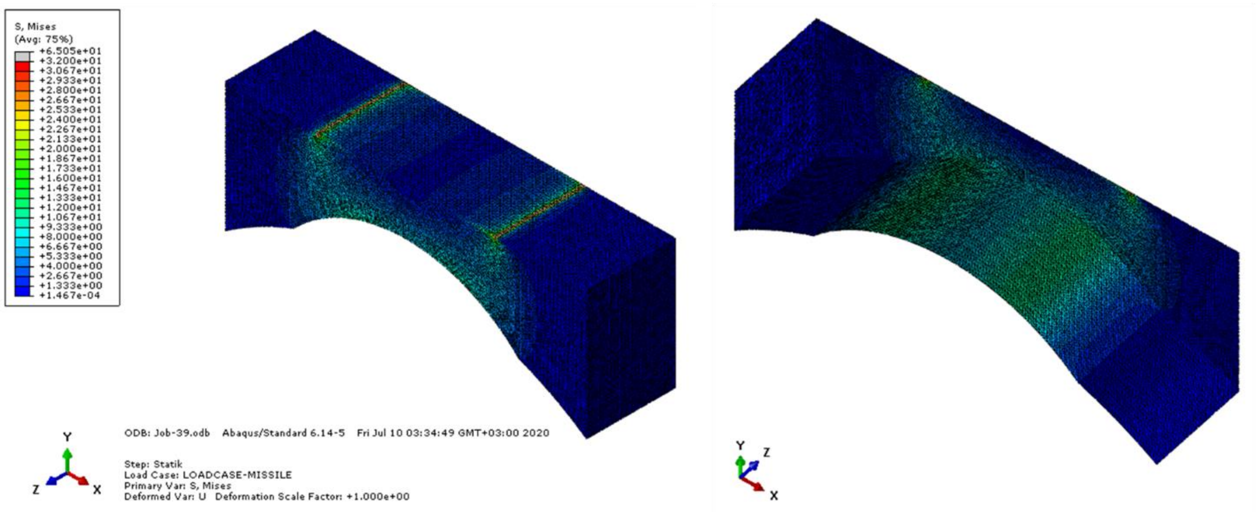


Figure 4-13 Stress analysis result of Ejecting Load Case of Missile

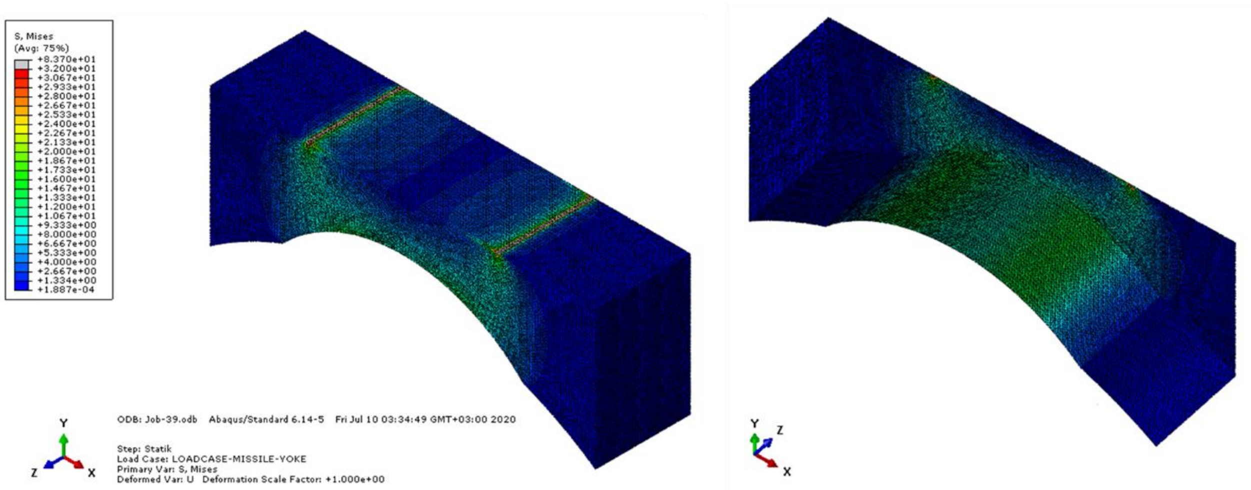


Figure 4-14 Stress analysis result of Fixing Load Case of Missile

Then, a relatively heavy and larger diameter bomb-compatible part was discussed. Again, as expected, the region where the maximum stress occurs is the same. It is seen that the maximum pressure that may occur during the bombing is 435,2 Mpa with a few fold increase compared to the first situation, and during extreme maneuvers, the pressure loaded on the structure reaches 517,2 Mpa.

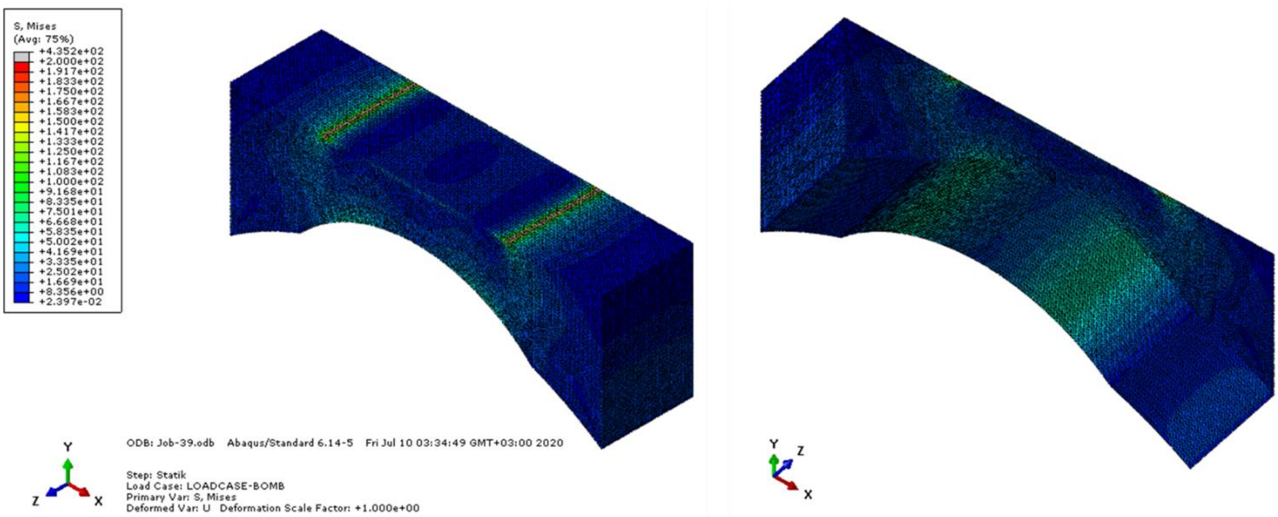


Figure 4-15 Stress analysis result of Ejecting Load Case of Bomb

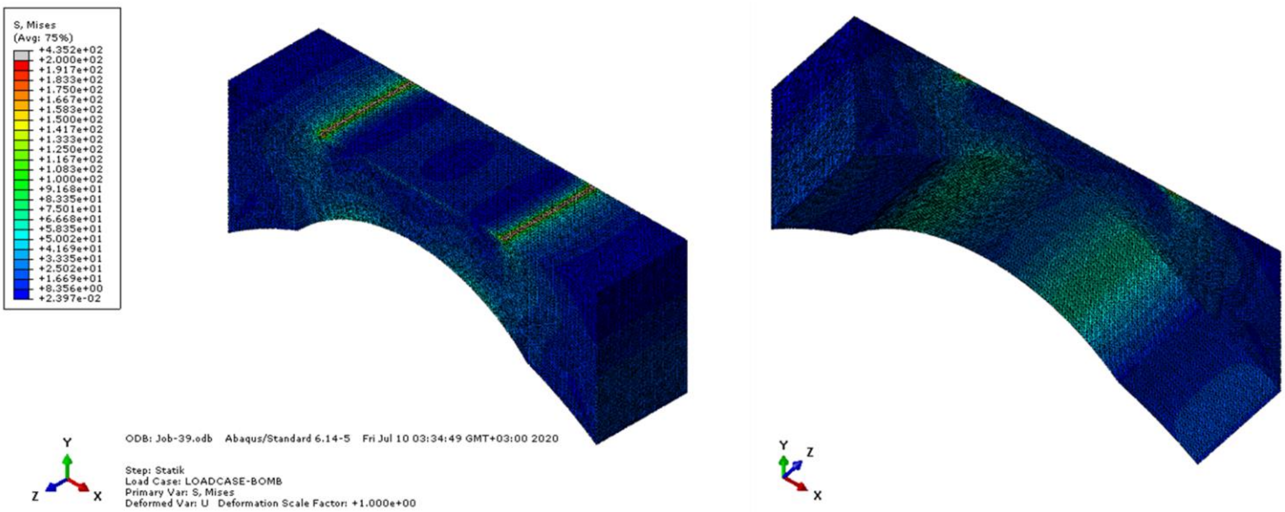


Figure 4-16 Stress analysis result of Fixing Load Case of Bomb

4.7 Design and Non-Design Space Definitions and Design Variables

Within the optimization, the boundary areas and the parts that should remain constant should be taken into account when evacuating the building. While performing topology optimization, some regions should be taken out of the design area without thinking of the main purpose. The fixed parts are marked below. The upper part of the structure was taken as 50 mm width as preferred in missile yokes. The parts that touch the missile and weapon are frozen in the scope of optimization because they are critical regions.

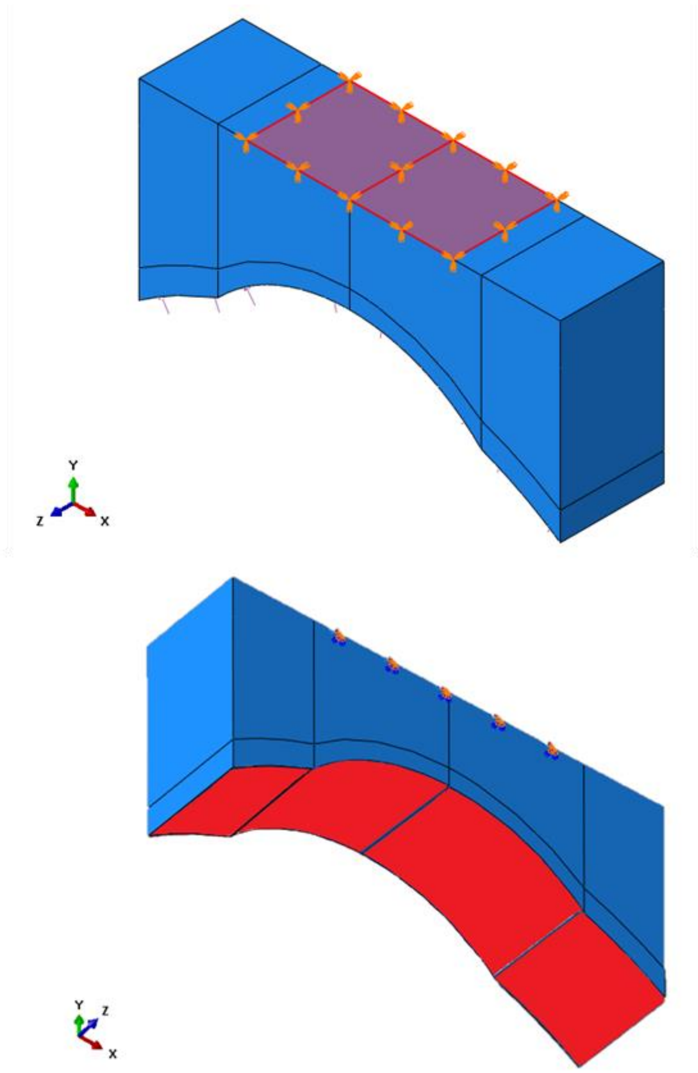


Figure 4-17 Design and non-design features

4.8 Response, Objective and Constraint Function

In order to prepare topology optimization, design responses should be defined first. Strain energy and volume values were used together as a design response for 4 different load cases. While trying to decrease the compliance of a particular structure as an objective function, the volume decrease was limited and added to the constraint function. While trying to reach the targeted high stiffness value, it is aimed that the volume will be discharged not to exceed 20% at the end of this study. The reason for the serious reduction of the volume is that it is desired to catch 700-800 grams within the scope of the design goal. Base design comes around 3.5 kg as a result of the material used. In the design, it is aimed to reduce the weight to the desired values with the volume decrease.

Design Response functions can be seen below.

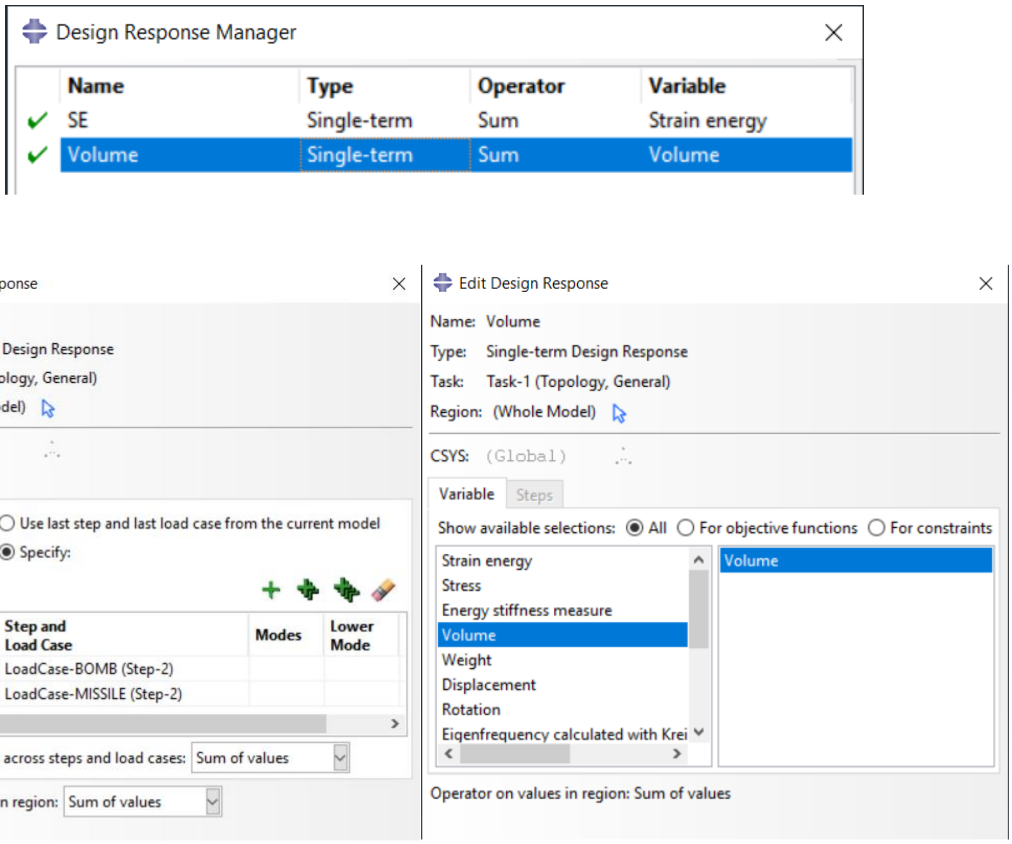


Figure 4-18 Abaqus Screenshots to Edit Design Response

Objective functions can be seen below.

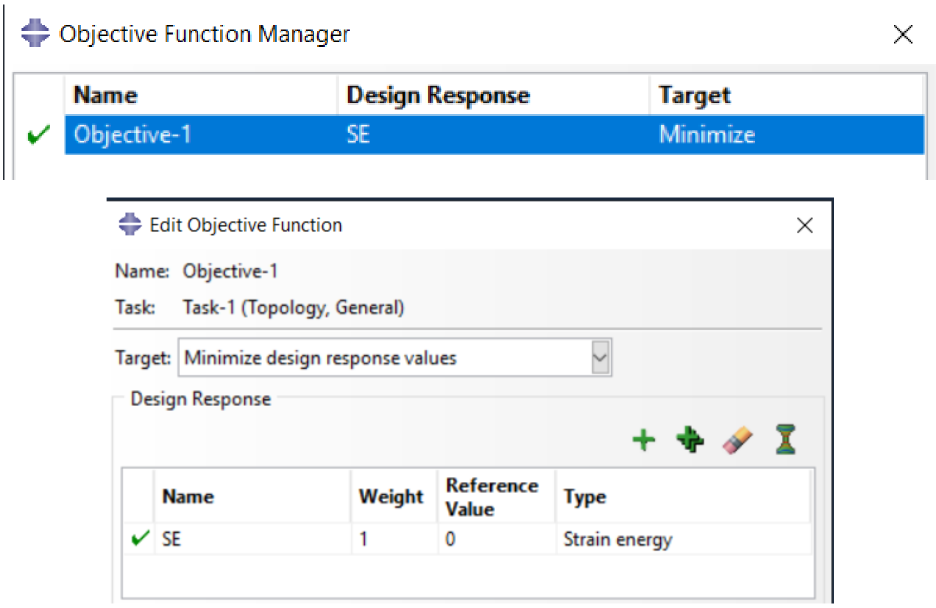


Figure 4-19 Abaqus Screenshots to Edit Objective Function

This main optimization constraint can be seen below.

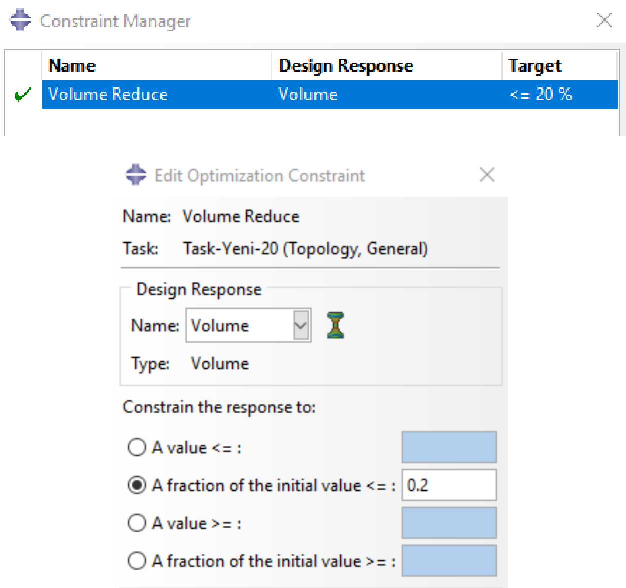


Figure 4-20 Abaqus Screenshots to Edit Constraint

4.9 Geometric Restrictions

Various geometric constraint criteria such as freezing certain areas, member size, demold control and symmetry limitations can be resolved thanks to this Tosca optimization tool. Especially in this study, demold control was taken into consideration and for this purpose, demolding on the central plane was found appropriate. This restriction can be seen below.

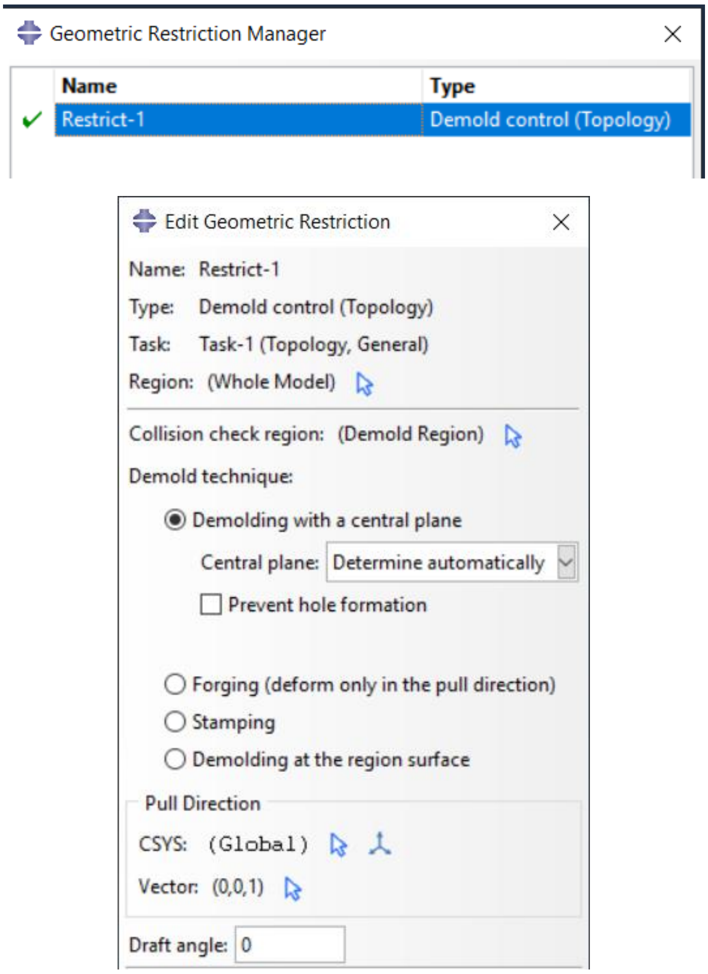


Figure 4-21 Abaqus Screenshots to Edit Geometric Restriction

4.10 Results Monitoring of Topology Optimization

As a result of the study, it is seen that stiffness is maximized while reducing the volume with iterations. Although 50 iteration optimization was initiated by default, it ended in 38. cycle.

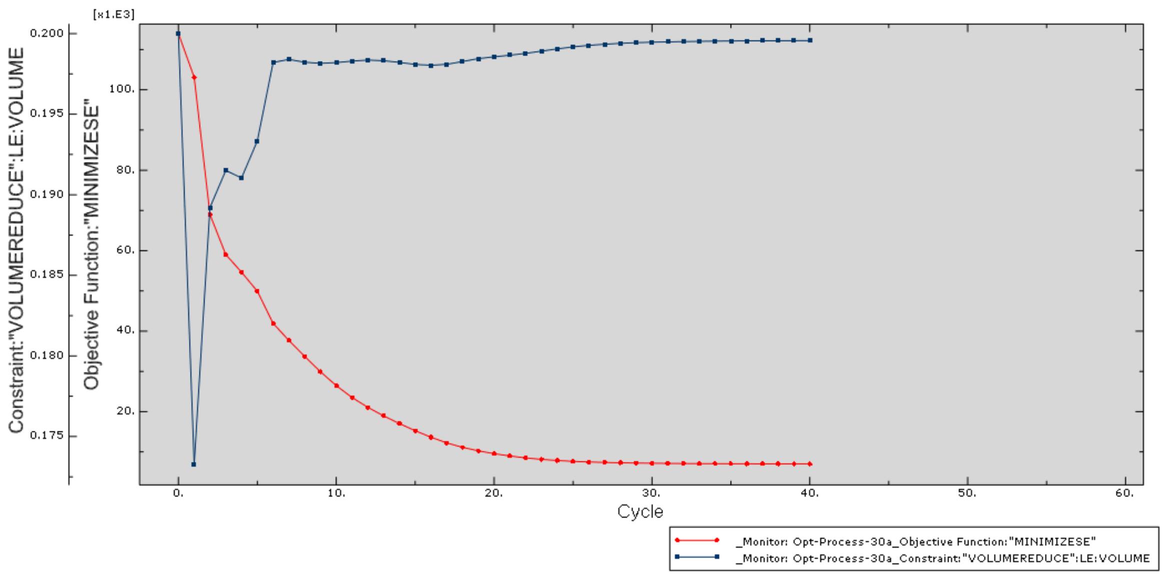


Figure 4-22 Stiffness Maximization and Volume Reducing Monitoring for the Structure

Displacement reached maximum 0.09 mm as a result of the iteration, the volume decreased to 20%. The weight of the structure was finally measured as 705 gr.

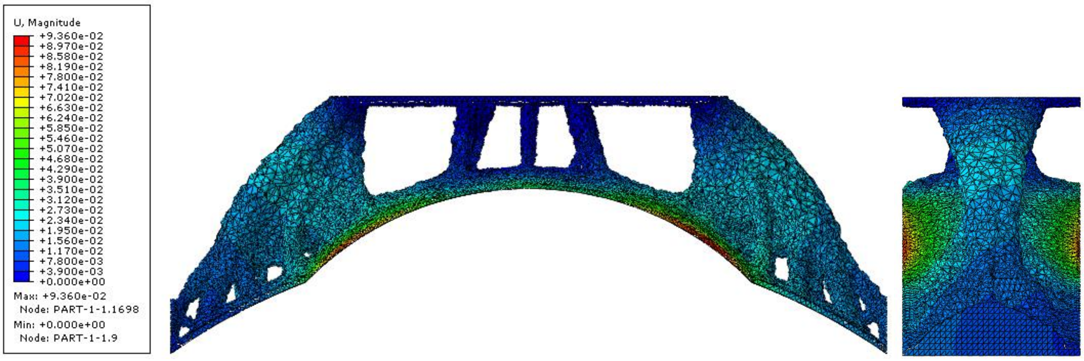


Figure 4-23 Displacements of Optimized Geometry

When we look at the result geometry, we see that the elements shown in red have the required density for the design. It can also be said that the blue parts are open to further optimizations. As seen below, the gaps formed on the right and left sides of the structure provide clues for possible weight reduction studies.

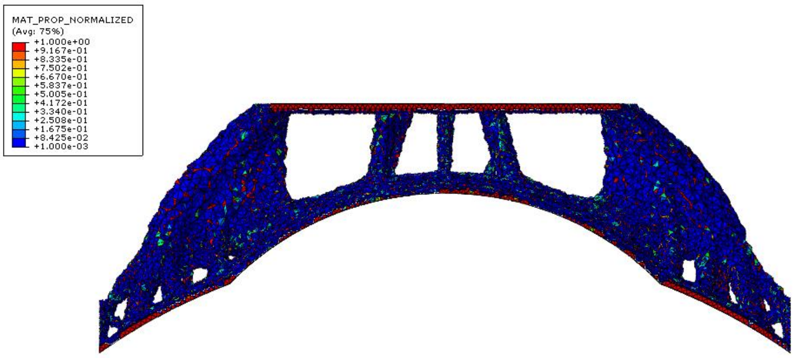


Figure 4-24 Density of Optimized Geometry

4.11 Optimization Results Smoothing

Surface smoothing is made in order to be able to use the part resulting from topology optimization. For this purpose, the drawing exported from the ABAQUS program is brought to 10 cycle from the smoothing settings and extracted in stl format. For this purpose, corners and shapeless surfaces are combined. These light touches should be done within a certain scope in order not to affect the optimization result.

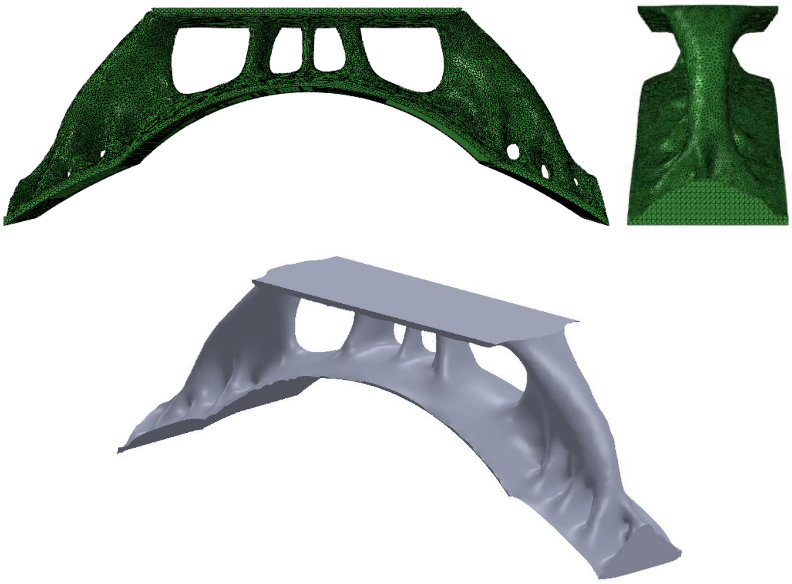


Figure 4-25 Smoothing After Optimization

4.12 Latest Design and Analysis of Universal Yoke Structure

Since the region where the optimized structure will be used is on the aircraft, it will be taken as a factor of safety between 1.5-2.5. Based on this, safety factor 2 was taken. It is seen that the yield value of 17-4PH H1025 steel selected under 4 different load conditions is also limited to half of the yield limit and it is desired to be a maximum 585 Mpa.

According to the results of the analysis, it is understood that the highest value formed in the structure is 521 and this value is below the maximum desired value.

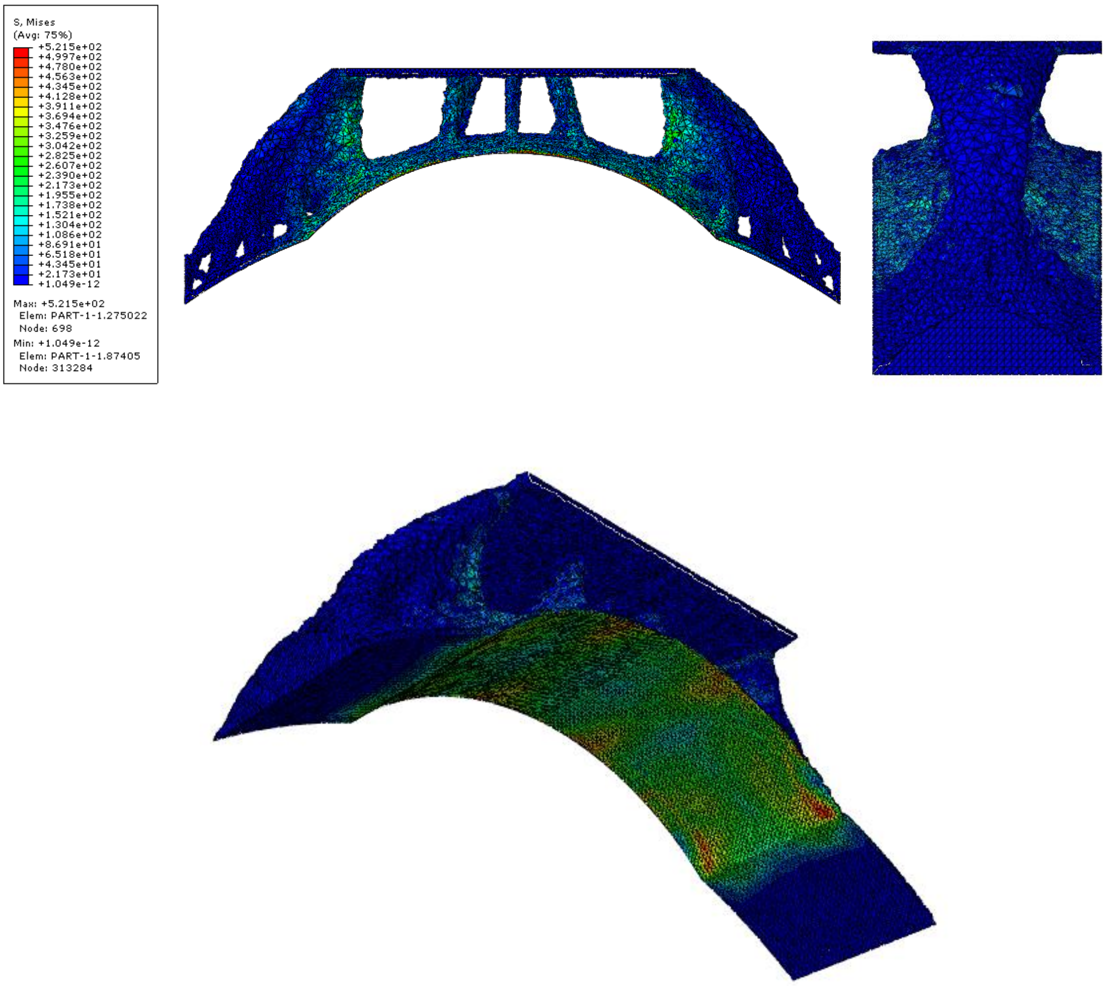


Figure 4-26 Stress Values of Optimized Geometry

4.13 Comparison with Alternative Geometries

Many generic models have been created except for the products mentioned in the literature. These product types are geometries in military aviation that have the chance to be used separately for carrying, stabilizing and releasing missiles and bomb. These parts are yoke and sway brace sections used in ejector release units and vertical eject launchers. These models, whose drawings were made with SOLIDWORKS, were subjected to the impact of the striking or fixing forces they were exposed to, depending on the weapon they were used, and stress analysis was performed. The preparation and test results of the samples used below are available.

4.13.1 Alternative Geometries

Example 1 Missile Yoke:

This structure, which may belong to a generic launcher, enables the 7-inch diameter air-to-air missile to be ejected from the fighter aircraft with vertical launch. The same diameters of the products used are incompatible in terms of different missiles and bombs. The need for adjustability was not considered. The bottom surface of this structure is designed to cover the missile as much as possible.

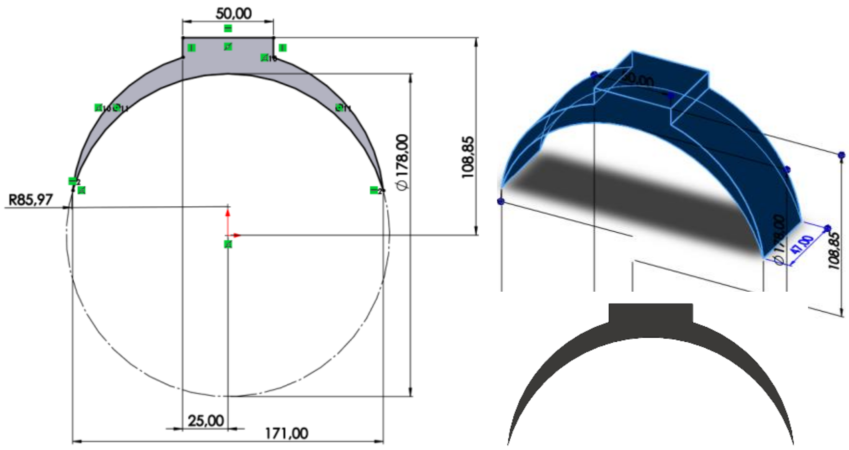


Figure 4-27 Solidworks Drawing of Alternative Design 1

Example 2 Missile Yoke:

This structure, which may belong to another generic launcher, is again removed with a 7-inch diameter air missile vertically. Other bombs incompatibility exists in this structure as well. There is no chance to be adjusted for missiles of various diameters. The lower surface of this structure is less in contact with the missile compared to its counterpart, but the upper part of the structure seems to be thicker.

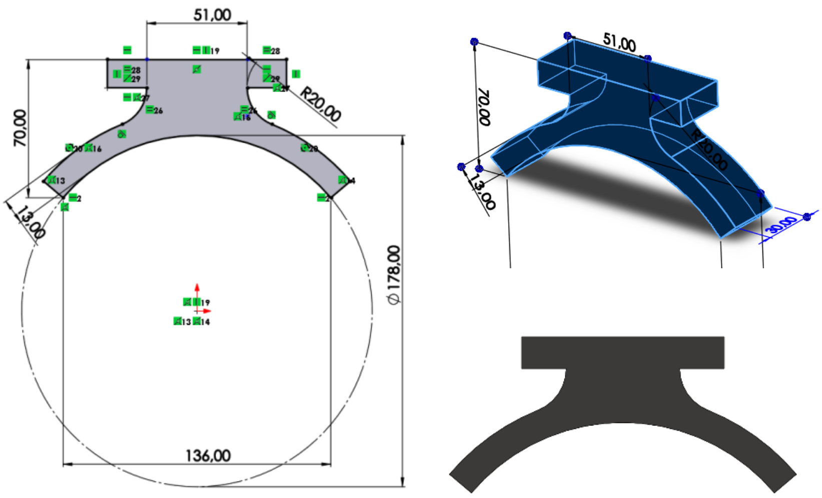


Figure 4-28 Solidworks Drawing of Alternative Design 2

Example 3 Bomb Sway brace:

This structure, which may belong to a generic ejector release unit, can be used with many different diameter bombs. In this study, an example was taken to fix the 14-inch diameter bomb. It can be seen that the structure was designed to cover as much as possible the hard areas on the upper side surfaces of the air-surface weapon.

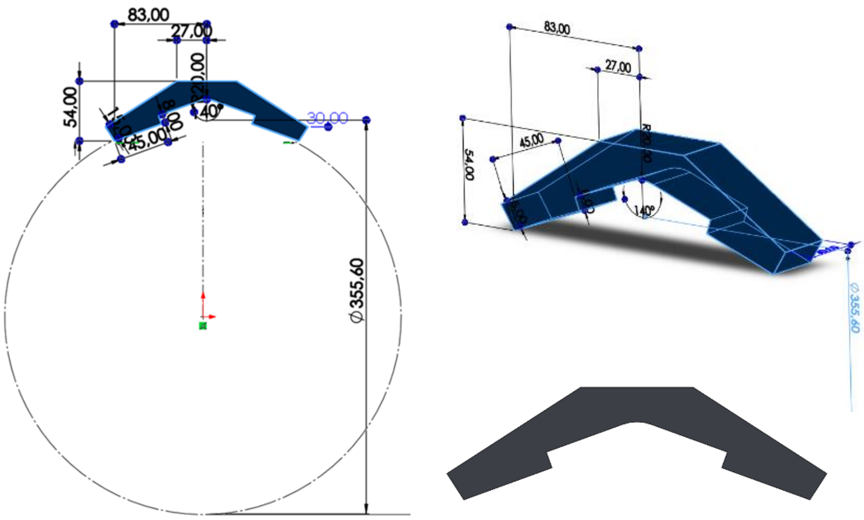


Figure 4-29 Solidworks Drawing of Alternative Design 3

Example 4 Bomb Sway brace:

This rare structure, which may belong to another generic ejector release unit, can generally be used with bombs of close diameter. It is seen that the structure that fixes the 14-inch diameter bomb touches the hard areas on the upper side surfaces of the air surface weapon.

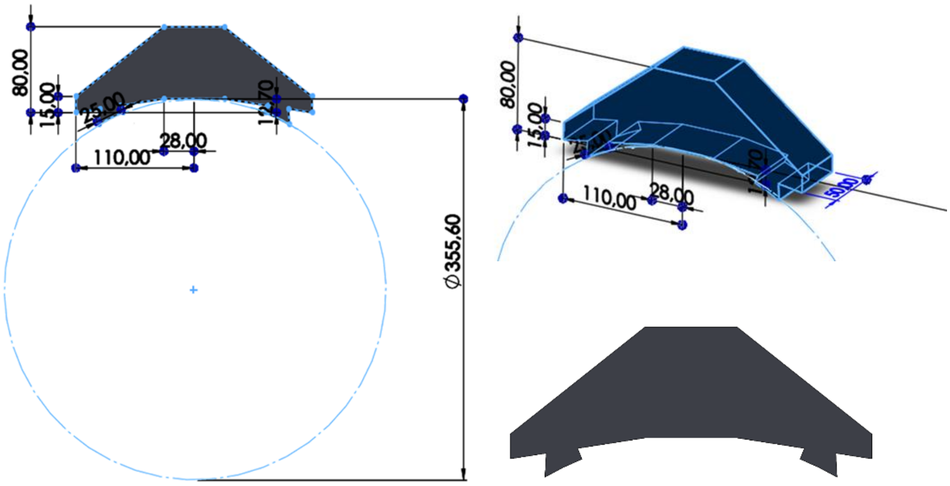


Figure 4-30 Solidworks Drawing of Alternative Design 4

Example 5 Bomb Sway brace:

This generic product structure, which is most likely to be encountered in military aviation, can be used with many different bombs. The process is completed by pressing the structure known as the fixing pad on the weapon. It is distributed over the load to the sway brace structure.

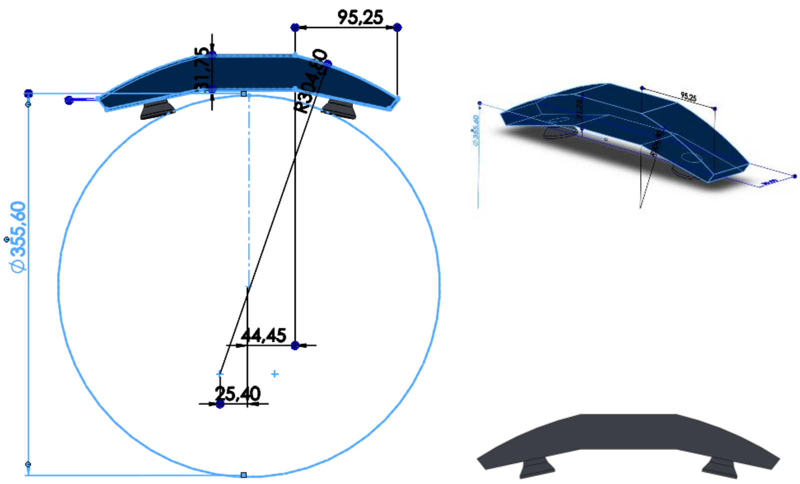
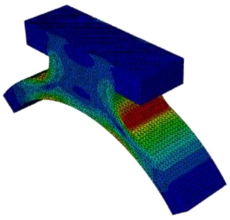
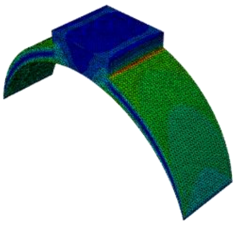
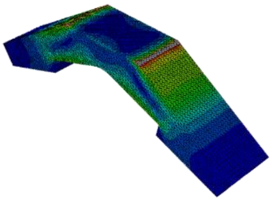
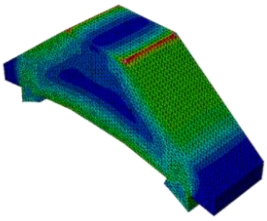
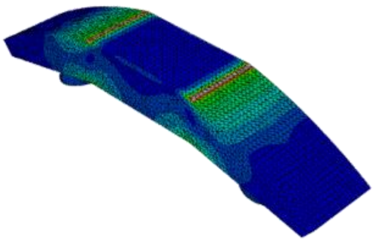


Figure 4-31 Solidworks Drawing of Alternative Design 5

4.13.2 Stress Analyses and Comparison

After all alternative structures are drawn in SOLIDWORKS, they are exposed to different load cases, optimized within the scope of the thesis, and their behaviours are examined by giving the same material as the structure to be designed. Opinions were formed about the structure to be designed with the maximum stress values that occur.

Table 10 Alternative Design Geometries and Evaluations

No	Alternative Designs	Mass (kg)	Max Stress (Mpa)	Active Load Case
1		0.965	273.1	Missile Eject Case Missile Yoke Case
2		0.870	1297	Missile Eject Case Missile Yoke Case
3		0.898	1151	Bomb Sway Brace Case
4		4.24	107.9	Bomb Sway Brace Case
5		3.07	324.8	Bomb Eject Case Bomb Sway Brace Case

It is seen that the 4th and 5th weight of alternative designs considered for bombs are higher. For this reason, it can be seen that aluminium can be used instead of steel in the design.

The number of designs considered for the bomb has given the number 3 weight, and the maximum stress value remains below the yield. In terms of bomb fixing, it is seen that larger surfaces can be used instead of small ones.

Alternative geometries intended only for missile are numbered 1 and 2. Both designs are at the desired level in weight. The question of whether a thin structure or a thick structure would make more sense when carrying the missile was tried to be solved. As seen above, the stress values that will occur with a thin structure are really high and create a risky situation. For this reason, it seems that it is reasonable to wrap the missile with a thicker structure.

Based on these results, it is understood that the structure designed with optimization would be similar to the preferred designs numbered 1 and 3. Designed for common use, the structure has taken good sides of these two alternative designs as a result.

5 CONCLUSION & FUTURE WORKS

The structure desired to be designed with topology optimization has been transformed from design space into a unique design that can withstand the evacuated loads. The change from base design to optimized design is shown below. Alternative designs were also considered for bombs or missiles only. Base design was continued by using alternatives' positive sides. The stress values formed in this structure, which was reduced in volume to reach the desired weight levels, provided the desired safety factor level.

Table 11 Design Comparisons

Design	Base Design Space	Alt Design 1	Alt Design 3	Latest Design
Weight (gr)	3520	965	898	705
Compatibility	Missile and Bomb	Missile	Bomb	Missile and Bomb

The base design is shown in blue and the new design is shown in red, with front and side visuals.

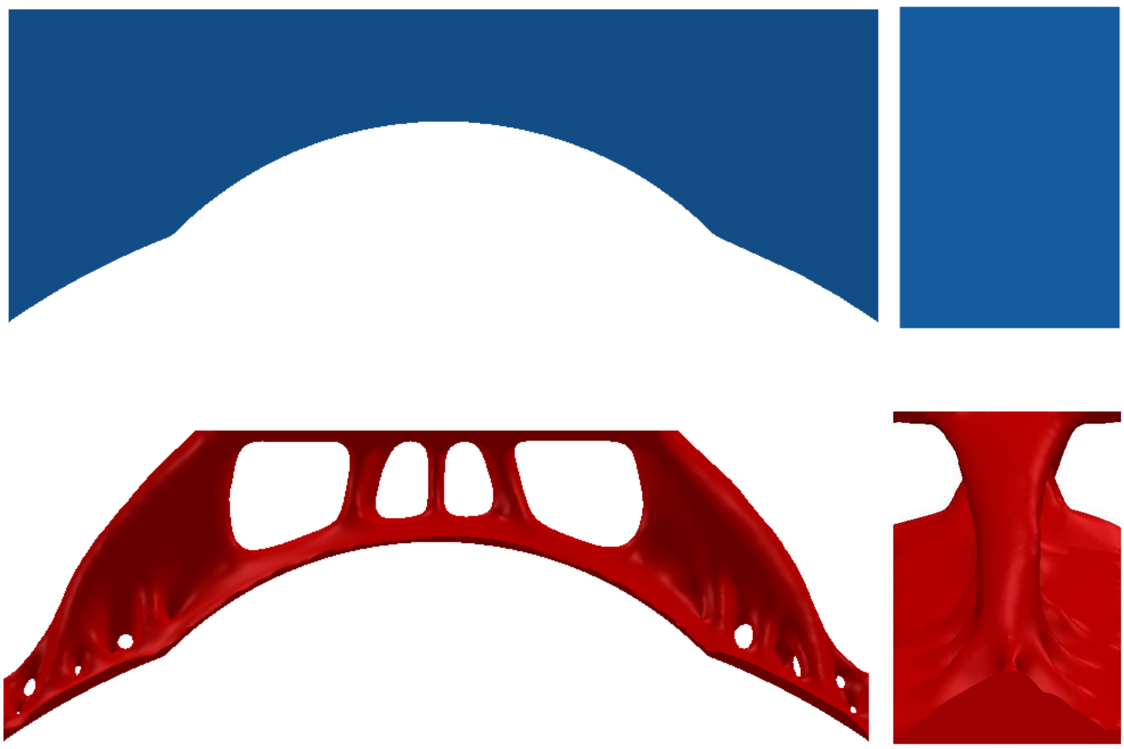


Figure 5-1 Front and Side Views of Base and. Final Optimized Design

The structure, whose surfaces were cleaned as a result of the study, was visualized in Solidworks with the generic air air missile and 1000 lb air surface weapon that obtained from the open source. Two structures are placed on weapons from the same positions, with a distance of 25 inches between them.

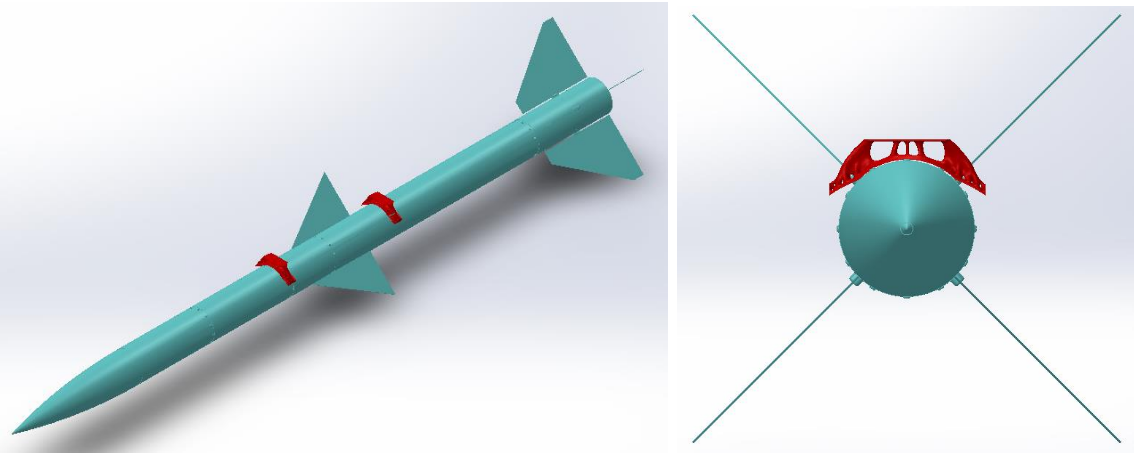


Figure 5-2 Designed Structures with Air-Air Missile

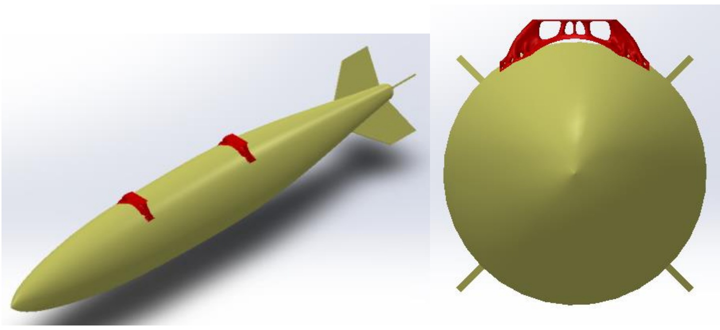


Figure 5-3 Designed Structures with Air-Surface 1000lb Bomb

The main goal of this shudy is to create a basic guideway for aircraft application that can be assist to anyone who wants to develop a part on the fighter aircraft. Calculation of the forces and moments on this related product, aim to gain literature for our country. This goal was accomplished on important interfaces for mentioned hard maneuvers. When it comes to designing a part on the fighter aircraft, it is critical to determine extreme conditions. Weapon systems have chosen as an example these parts. The relevant part of suspension and release system designed with optimization to reduce the weight. While designing this product, it is aimed to be universal for both air-air missiles and air-surface bombs. As a result of this study shows us a couple of maneuvers which push to aircraft its limits can be used calculation of maximum forces which occurs at interface areas between store and aircraft. It is understood that inertial loads are more determinant than aerodynamic loads at carriage phase. It has been observed that the forces resulting from fixing the weapon are as important as the forces required to eject it. It was emphasized that this study was carried out to guide the preliminary design process, maximum forces would be sufficient and the design process should be matured with feedback from flight and ground tests.

In this study, inertial and basic aerodynamic factors have been used to calculate the loads to be caused by maneuver, but in future studies aerodynamic calculations can be detailed on carrying on the wing. These studies may include the flutter effect. With the data taken with flight tests, error reduction can be made on the results of the study. Different combinations of suspension and release equipment and weapon can be studied. Considering that there are 7 and 14 inch diameter weapons within the scope of the study, compatibility studies can be performed for 500lb weapon with a diameter of 11 inch as mentioned before. Ejecting tests are required even if this study has been carried out by paying attention to the hard point of the weapon. Ejecting bomb with two structures in 25 inch spacing can be observed in test setups. Additive manufacturing or composite content is seen as an opportunity in material selection and production. Material selection can be further elaborated to work on different combinations. Each work mentioned within the scope of future work will help guide the methods that can be used in the preliminary design of future projects and provide more accurate results.

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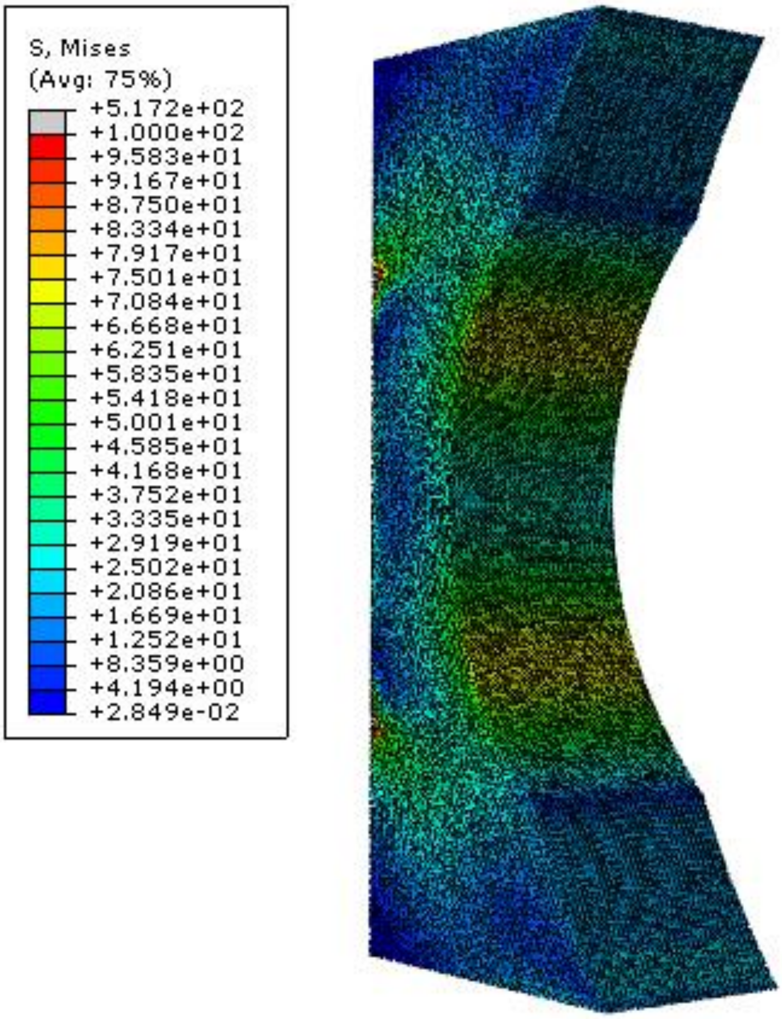
APPENDICES

APPENDIX A: Model Figures

APPENDIX B: Optimization Cycles *.log file

APPENDIX A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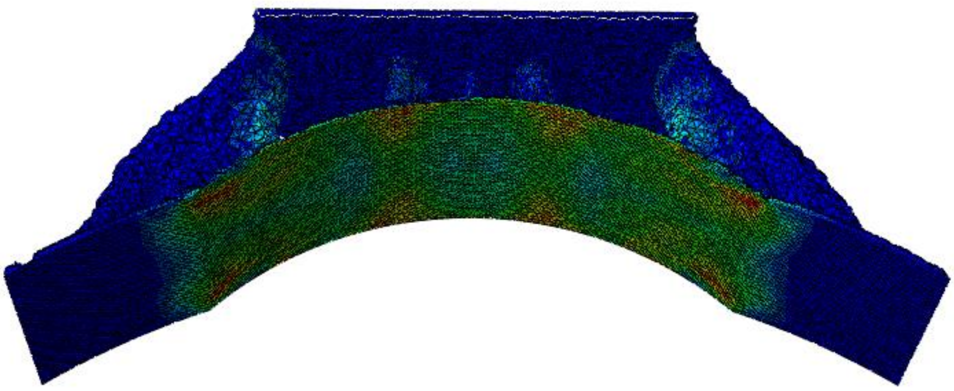
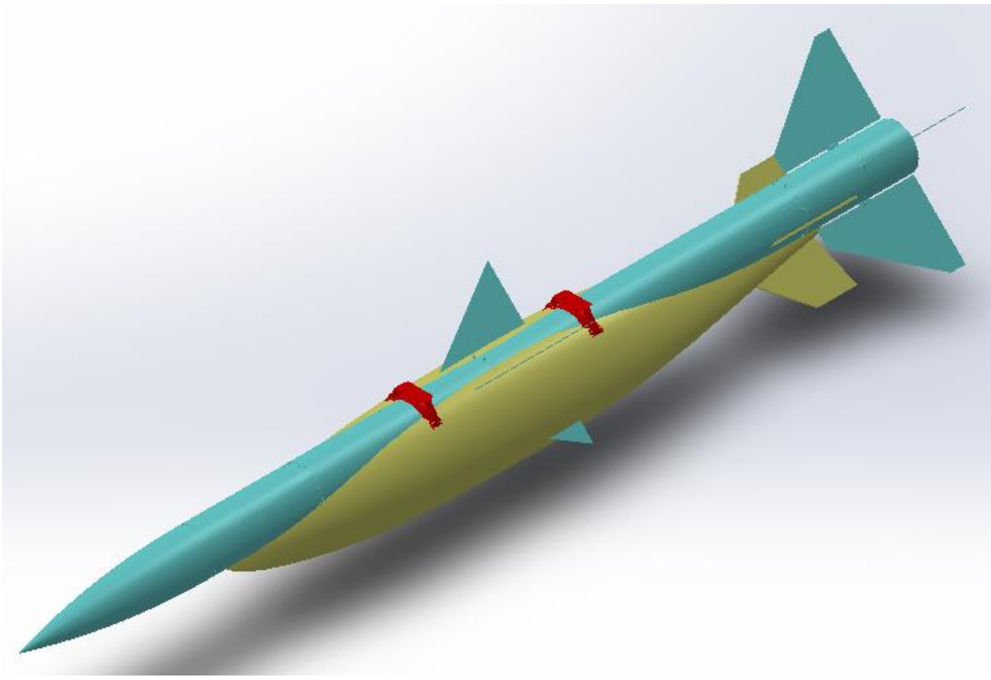
+5.418e+01
+5.001e+01
+4.585e+01
+4.168e+01
+3.752e+01
+3.335e+01
+2.919e+01
+2.502e+01
+2.086e+01
+1.669e+01
+1.252e+01
+8.359e+00
+4.194e+00
+2.849e-02





APPENDIX B

<u>Abaqus Tosca input (par) file</u>

! Optimization Process name: Opt-Process-30a

! Model name: Yoke

! Task name: Task-Yeni-20

! Generated by: Abaqus/CAE 6.14-5

```
FEM_INPUT
  ID_NAME = Opt-Process-30a-Job_INP_
  FILE = Opt-Process-30a-Job.inp
END_
! ------------------------------------------------------------
!
! Design Response: Strain Enegy
!
DRESP
  ID_NAME = "Strain Enegy"
  LIST = NO_LIST
  DEF_TYPE = SYSTEM
  TYPE = STRAIN_ENERGY
  EL_GROUP = ALL_ELEMENTS
  GROUP_OPER = SUM
  LC_SET = ALL, 1, ALL, MAX
  LC_SET = ALL, 3, ALL, MAX
  LC_SET = ALL, 2, ALL, MAX
  LC_SET = ALL, 4, ALL, MAX
  LC_SEL = SUM
END_
```

```
! ---------------------------------------------------------------
!
! Design Response: Volume
!
DRESP
  ID_NAME = Volume
  LIST = NO_LIST
  DEF_TYPE = SYSTEM
  TYPE = VOLUME
  EL_GROUP = ALL_ELEMENTS
  GROUP_OPER = SUM
END_
! ---------------------------------------------------------------
!
! Design area for task: Task-Yeni-20
!
DV_TOPO
  ID_NAME = Task-Yeni-20_DESIGN_AREA_
  EL_GROUP = _PickedSet47_ELEM
END_
! ---------------------------------------------------------------
```

```
!
! Objective Function: Minimize SE
!
OBJ_FUNC
  ID_NAME = "Minimize SE"
  DRESP = "Strain Enegy", 1.
  TARGET = MIN
END_
! ---------------------------------------------------------------
!
! Constraint: Volume Reduce
!
CONSTRAINT
  ID_NAME = "Volume Reduce"
  DRESP = Volume
  MAGNITUDE = REL
  LE_VALUE = 0.2
END_
! ---------------------------------------------------------------
!
! Geometric Restriction: Manufacturability
!
```

```
DVCON_TOPO
  ID_NAME = Manufacturability
  EL_GROUP = _PickedSet44_ELEM
  CHECK_TYPE = CAST
  PULL_DIR = 0., 0. , 1.
  ANGLE = 0.
  CHECK_GROUP = _PickedSet44_ELEM
  MID_PLANE = AUTO
  PULL_CS = CS_0
  CREATE_PULL_GROUP = NO
END_
! ---------------------------------------------------------------
!
! Task: Task-Yeni-20
!
OPTIMIZE
  ID_NAME = Task-Yeni-20
  DV = Task-Yeni-20_DESIGN_AREA_
  OBJ_FUNC = "Minimize SE"
  DVCON = Manufacturability
  CONSTRAINT = "Volume Reduce"
```

```
  STRATEGY = TOPO_SENSITIVITY
END_
OPT_PARAM
  ID_NAME = Task-Yeni-20_OPT_PARAM_
  OPTIMIZE = Task-Yeni-20
  AUTO_FROZEN = BOTH
  DENSITY_UPDATE = NORMAL
  DENSITY_LOWER = 0.001
  DENSITY_UPPER = 1.
  DENSITY_MOVE = 0.25
  MAT_PENALTY = 3.
  STOP_CRITERION_LEVEL = BOTH
  STOP_CRITERION_OBJ = 0.001
  STOP_CRITERION_DENSITY = 0.005
  STOP_CRITERION_ITER = 4
  SUM_Q_FACTOR = 6.
END_
STOP
  ID_NAME = Task-Yeni-20_GLOBAL_STOP_CONDITION_
  ITER_MAX = 50
END_
```

CONFIG

${fe_solver_add_call} = "message messaging_mechanism=DIRECT listener_name=DESKTOP-QKSN7OI listener_resource=13996 direct_port=52020 memory=90% cpus=8";

add_move_per_iter_list("ever", "SAVE.odb", "*.odb");

add_move_per_iter_list("ever", "SAVE.msg", "*.msg");

add_move_per_iter_list("ever", "SAVE.dat", "*.dat");

add_move_per_iter_list("ever", "SAVE.sta", "*.sta");

END_

EXIT