# Parametric Comparison of Four Different Missile System

Mehmet TOPALÖMER[1], Çiğdem GÜNDOĞAN TÜRKER[2]

[1]Department of Defence Technologies, Istanbul Gedik University, İstanbul, Türkiye
mehmettopalomer34@gmail.com

[2]Department of Mechatronics Engineering, Istanbul Gedik University, İstanbul, Türkiye
cigdem.gundogan@gedik.edu.tr

**Abstract:** In the design of a missile, the rocket engine, aerodynamics, structural warhead, fuse, launcher and control unit are important with the guidance system. Four different missiles named as Atgm_1, Low Drag_8, Patriot_TR, and New Missile are designed. The structure and working principle of the missiles are analized. The designed missiles were simulated at a platform with shooter and target values determined by the Rocket Simulator Program. Speed, distance, altitude, mach number and maneuverability number which are important criteria during the cruise, test flight or when the missiles take action to hit the target were evaluated by test flights in the simulation.

**Keywords:** Defence Technologies, Defence Industry, Missile Design, Test Flight

## 1. INTRODUCTION

Missiles and rockets have been very active and effective military weapons due to the ongoing cold wars, technological competitions and military strategies of the countries. So, they have an important place in terms of defense industry. Missiles are military vehicles that investigate the target in the direction of the target point. Missiles are mechanisms that can be adapted for different functions and tasks, can be controlled and have the ability to observe. These highly equipped mechanisms with high communication systems, electronic sensors and smart software can also hit their targets at very close range if decision making systems are added to the design. Missiles can be classified according to their dropout conditions, whether they are long or short range, control system or monitoring systems and guidance methods [1, 2].

The current development technologies of the defense industry sector accelerate the reliability and accuracy of the missile mechanism. Missiles with guided system are attracted more attention because of their success in military operations. Moving or directing of a physical object from one place to another can be achieved by many methods. If an object that changes its position is expected to reach its certain target or to aim an active object, a guidance mechanism must be designed for this object. Some reasons like unexpected displacement of the target, deviation from the target due to wrong aim, changing of the trajectory due to weather conditions causes the failure performance of missiles. If a warhead is used in larger areas, but size of missile also get increased. Another method is to use the closed loop system in guided systems. Thus, the rate of deviation from the target decreases and the probability of destruction increases in one shot [3-6].

Missile is the mechanism driven by the thrust created by burning of a flammable object. Unlike rockets that are directed to a specific target by unguided, missiles can be moved in the target direction using the guidance method [7]. A missile includes some units as below;

- The seeker to find the target,
- Fins that allow the missile to focus on the target and an engine system that performs its movement,
- Guidance and control units that resolve all errors detected in the missile and decide the orientation.

Moreover, the missile systems consist of a heat with heat (IR) guidance or radar-guided seeker, sensors, tracking and control antennas, optical systems for infrared waves, electronic and flight tracking systems, warhead and propulsion systems [8].

An aerodynamic model of a guided missile includes all control and thrust variables covering kinematic values, geometric characteristics and aerodynamic interactions. Also force components in a set of axes specified with respect to the direction of flight as bearing force, drag force, lateral force and torque components as pitching torque, yaw torque are mentioned.

Aerodynamic designs and analysis of four different missiles named as Atgm_1, Low Drag_8, Patriot_TR, and New Missile are given in this paper. Test flights of the missiles are simulated in the Rocket Simulator Design. In next section, the structure and working principle of the missiles are introduced. In the third part, the design of the missiles is presented for rocket engine and guided algorithms. The Analysis of the aerodynamic configuration values and static parameters are evaluated by Rocket Simulator Program. The results and conclusion in the simulation of flights are introduced in the last section.

## 2. THE WORKING PRINCIPLE OF THE MISSILE

The working of a missile is based on the response principle. Missiles which use liquid fuel, liquid oxygen or nitric acid operate at high speed in the space and atmosphere. These fuels are sprayed inside the combustion chamber and a reaction is composed by ignition. Oxygen causing the combustion of the fuel in the missiles is saved inside the missile. Thus, the missiles also can be operated in space [9].

While the missile follows a predefined trajectory after the firing phase, the seeker tries to find the target. Following the locking system, the seeker transfers the target information to the command computer. So, the guidance computer performs the necessary operations and sends the necessary commands to autopilot. The autopilot sends control surface commands to the propulsion control system using information transmitted from navigation and sensors. The propulsion control system performs these commands within its dynamics and changes the direction of the forces falling on the missile. Thus, the missile is located in a new position.

Guidance unit in missiles includes trajectory control system and position control system. The function of the trajectory control system sends necessary commands for tracking the trajectory to the position control system. The function of the position control system is to control the wobble, pitching and turning angles. As a result of the calculations by these systems, the control surface commands are created to stay on the appropriate orbit and transmitted to the actuators in the control section [10].

The trajectory of the guided missiles from the firing point to the target may be in different ways according to the control and guidance methods. The most widely used orbital systems are; Straight Line Orbit, Navigation Orbit, Line of Sight Orbit, Proportional Navigation Orbit, Ballistic or Free Fall Orbit.

## 3. THE DESIGN ANALYSIS OF THE MISSILES

Four types of guided missiles are designed in this work, and these missiles are; Atgm_1, Low Drag_8, Patriot_TR, and New Missile. These missiles were designed by Rocket Simulator program. Rocket engine, aerodynamic design, warhead, missile, guidance system, launcher, control unit of missiles are analyzed comparatively for all design process of the missiles.

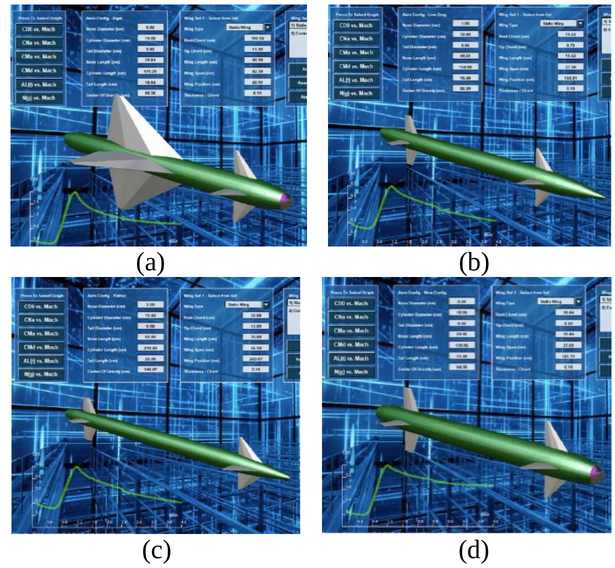


**Figure 1.** Aerodynamic design of the missiles a) Atgm_1 , b) Low Drag_8, c) Patriot_TR, d) New Missile

### 3.1. Design of Rocket Engines

Firstly, static tests are performed of the missiles calculated with some specific values of rocket engines. So, the main parameters of the thrust, chamber pressure, exit pressure, mass of propellant and impulse coefficient of nozzle are calculated mathematically. In the table 1, the static test parameter measurements of the rocket engines for all missiles are shown.

**Table 1.** Static Test Parameter Values of Missile Rocket Engines

| Static Test Parameters of Rocket Motors | Atgm_1 | LowDrag_8 | Patriot_TR | NewMissile |
|---|---|---|---|---|
| Thrust | 312.7 kgf | 228.9 kgf | 378 kgf | 168.1kgf |
| Chamber Pressure | 29.8 atm | 31.3 atm | 35.5 atm | 35.5 atm |
| Exit Pressure | 1.2 atm | 0.7 atm | 1.4 atm | 0.7 atm |
| Mass of Propellant | 0 | 0 | 0 | 0 |
| Impulse Coefficient of Nozzle | 1.46 | 1.46 | 1.48 | 1.48 |
| Time | 17.4 sec | 13.3 sec | 15.8 sec | 9 sec |

Thrust which is required for the missiles to move platform is realized by the propulsion systems. Thrust is generated through some application of Newton's third law of motion. For every action there is an equal and opposite reaction. Propulsion systems are the mechanisms that enable the generation of a force in the opposite direction as a result of the acceleration of the high pressure gas generated by the reaction of the fuel with the oxidizer in the combustion chamber. Hence, the missile travels to the target by this thrust force of the propulsion system. The rocket engine of the missiles performs sufficient thrust to exceed of both the weight and dragging of the missile. The missile can rise through the highest altitude, when the fuel runs out. Accordingly, static firing test is performed in order to calculate the performance of the rocket engine. In this test, the engine is ignited by connecting to a special platform and parameters of the engine such as thrust, temperature and pressure are calculated based on time.

Particularly, the total impact of the engine is calculated using thrust-time data and this measurement value is compared with theoretical calculations to verify the rocket engine. The thrust of the rocket engine is used to accelerate the missile and fight the missile's friction force in the air. A well-designed engine maintains the high speed obtained from the bust stage and enables the missile to reach long distances and to use the maneuverability ideally.

Patriot_TR has the highest thrust value according to data shown in the table 1. Atgm_1 has the longest burning time of rocket engine.

Rocket engines operating according to the action-reaction principle use the impulse that occurs during the extraction of high-energy combustion products. The biggest segment of the impulse is formed by the acceleration and removal of gases with high temperature and pressure inside the combustion chamber with the help of a small hole nozzle [10]. Under normal conditions, the combustion chambers in the rocket engine are between 10 and 200 atm and operated at an extremely high pressure value. According to the data in the table 1, two missiles with the highest combustion chamber pressure are Patriot_TR and New Missile. Then, Low Drag_8 and Atgm_1 follow them. The exit pressure of the rocket engine is one of the most important factors that affect the performance of the engine. Patriot_TR has the highest exit pressure in the table After, Atgm_1 has the second highest exit pressure [11, 12].

The propellant powder can be defined as the chemical or explosive substance that provides energy for dispatching the missile. The mass of all propellant in the table is 0 kilograms.

The thrust coefficient of nozzle which is the ratio of the thrust force to the combustion chamber presuure and the cross-sectional area is a dimensionless parameter that characterizes the amount of exhaust gas from the nozzle. Patriot_TR and New Missile have the highest thrust coefficients of nozzle in the table.

### 3.2. Analysis of Aerodynamic Configuration Values

Basically, Aerodinamic coefficients as drag coefficient, normal force coefficient, control torque coefficient, pitching torque coefficient, attack of angle coefficient, and maneuverability coefficient are calculated according to the mach number. The aerodynamic coefficient values of the missiles are compared in the Table 2 below.

**Table 2.** Aerodynamic Coefficient Values of Missiles

| Aerodynamic Coefficient Values | Atgm_1 | Low Drag_8 | Patriot_TR | New Missile |
|---|---|---|---|---|
| Drag Coefficient | 1 | 0.3 | 0.3 | 0.7 |
| Normal Force Coeffient | 26 | 8.9 | 9 | 8 |
| Pitching Torque Coefficient | 36.6 | 6 | 3.3 | 4.3 |
| Control Torque Coefficient | 6.4 | 6 | 13.5 | 5.7 |
| Angle of Attack Coefficient | 1.6 | 12 | 28.6 | 17.7 |
| Manueverability Coefficient | 22.3 | 40 | 40 | 40 |

Drag coefficient in the air can be defined as a number used to model the complex dependencies of the drag force according to the shape slope and a number of flow conditions. The rocket gains speed as it descends, so the drag increases. The rocket is arrived at the destination when the drag is equal to the weight but in the opposite direction. For a normal missile, the drag coefficient has an average value of 0.75. As shown in the Table 2, Atgm_1 has the highest drag coefficient value. After that New Missile has the second one for the drag coefficient value.

The aerodynamic system in a missile has two important force components which are drag force and normal force [13]. According to the data in the table, Atgm_1 has the highest normal force coefficient and it is about three times greater than other three missiles. After, Low Drag_8 and Patriot_TR have the second highest value and they are equal. New Missile missile has the lowest normal force coefficient.

Pitching torque coefficient which is defined as the torque around the lateral force axis is another significant criteria of aerodynamic configurations [14]. The pitching torque occurs in the interval between the center of mass and the center of pressure in the missile by the wind force. In other words, the pitching torque is the movement of the missile’s nose in the up and down directions during the orbital movement [15]. In the table 2, Atgm_1 has the highest pitching torque coefficient and this missile is significantly higher than the other three missiles.

Control torque coefficient refers to the angle of deflection of the missile from the control. This aerodynamic coefficient depends on wing angles, mach number, angle of attack, and angle of slip. In the Table 2, Patriot_TR has the highest control moment coefficient. After, Atgm_1, Low Drag_8 and New Missile follow it. Moreover, control torque coefficients of these three missiles are close to each other.

The angle of attack is defined as the angle realized by the plane in the missile movement axis set and the missile speed vector. Also, in the missile axis set, the angle between the components on the x-axis and z-axis of the velocity vector is expressed as the angle of attack**.** Patriot_TR has the highest angle of attack coefficient. Atgm_1 missile has the lowest angle of attack coefficient value in the data.

Maneuverability is an important criteria for missiles to reach the desired target correctly and to hit the systems in motion. It is achieved by controlling the wings and small ailerons in the tail and wing sections of the missile. Furthermore, the guidance systems determine the missile's maneuverability. The maneuverability of missiles varies according to the target type and the purpose of the operation. Low Drag_8, Patriot_TR and New Missile have the highest maneuverability coefficients. Atgm_1 has the lowest value.

### 3.3. Design and Analysis of Guidance Systems

Basically, fin lock time, detection range, heatseeker diameter, flight path following guidance system and terminal guidance were given in the Table 3.

In the guidance systems of missiles, the aileron lock mechanism is adjusted to increase the performance of the missile by minimizing the drag [16]. The fins are important for the missile to stay in the motion stability. The pressure center should be located behind the center of gravity for a stable flight. The fins do not need to be active, because stability can be achieved with fixed wings that are simple and costly compared with wings in active control surface in the unguided rockets**.** Locking of the fins occurs at the bust stage of the system. The missile travels in a ballistic orbit and locks the fins and also the guidance system cannot be worked in the bust stage. So, it is allowed the missile to accelerate its maneuver without losing stability and speed. The fin lock time is designed to adjust the maneuvering speed of the missiles in the simulation program. In the Table 3, the fin lock times of all missiles are the same.

**Table 3.** Guidance System Parameters of Missiles

| Guidance System Parameters | Atgm_1 | LowDrag _8 | Patriot_ TR | NewMissil e |
|---|---|---|---|---|
| Fin Lock Time | 1 sec | 1 sec | 1 sec | 1 sec |
| Detection Range | 1000 m | 1000 m | 1850 m | 1000 m |
| Seeker Diameter | 15 cm | 10 cm | 14 cm | 10 cm |
| Midcours e Guidance | Remote Command-Intercept Line | Remote Command-Intercept Line | Remote Comman d-Line of Sight | Remote Command-Line of Sight |
| Terminal Guidance | Self Homing-Proportion al | Self Homing-Proportion al | Self Homing-Dog Chase | Self Homing-Dog Chase |

The size of the seeker determines the target's detection distance at the terminal stage of the system. It is expected to catch the target by following different energy types such as radio wave, laser reflection, infrared, visible light or sound. According to the data in the Table 3, Patriot_TR has the longest detection range. The detection ranges of all other missiles are the same.

The seeker is a system that allows missiles to track and follow until that they hit the target**.** Atgm_1 has the largest seeker diameter. New Missile and Low Drag_8 missiles have shorter seeker diameter than other two missies and they have same seeker diameter values.

The flight path following guidance system is involved in the process from the end of the missile launching phase to the beginning of the terminal guidance system phase. One of the main purpose of the guidance system is to direct the missile to the most appropriate position. So, attacking to the target becomes more effective in the terminal phase [17, 18].

In the guidance system phase, the missile is normally too far to detect the target itself. Therefore, it uses a commanded guidance system from the launcher or control unit. There are generally two types of methods which are the line of sight method and the intersection point method. The line of sight method is used in many anti-tank missiles. In the intersection point method, the launcher part of the missile calculates a predicted or planned intersection point and directs the missile towards that point. The line of sight guidance system is a line between the place in which the missile was launched and the target. A different number of lines of vision are composed of different times along the path of the target**.** Shown in the Table 3, Atgm_1 and Low Drag_8 missiles use the intersection point guidance system in the flight path following guidance phase. On the other hand, Patriot_TR and New Missile missiles use the line-of-sight guidance system.

In the terminal guidance system phase, the target detection distance of the missile is determined. This system, which is the last stage of the guidance system, is the most critical phase. The guidance system in the terminal phase must be highly accurate and react quickly to signals. At this stage, the missile's maneuverability is crucial to catch and hit the target. For this reason, the performance capabilities of the missile should be compatible with the terminal guidance system. The greater the target acceleration, the more critical the terminal guidance system is**.**

The change of the missile velocity vector angle is proportional to the change of the line of sight in the proportional navigation guidance system. One of its important advantages is that it does not need much information about the characteristics of the target. The movement of the target relative to its follower constitutes the basis of proportional navigational guidance**.** Moreover, proportional navigational guidance is used to verify missile route in high speed missiles. The missile aims to reset the angle of the sight line to the target**.** The simplicity of this system is the most marked feature**.** Atgm_1 and Low Drag_8 missiles use proportional navigation guidance system in the terminal phase. However, Patriot_TR and New Missile missiles use the tracking guidance system at this stage.

### 3.4. Comparative Analysis of Static Tests

After the design analyzes for all missiles, speed, range, mach, and maneuver parameters were evaluated in the static test. It is analyzed that how fast the missile was, how fast it would gain speed after the engine was fired, how long it would fly, and how far it would reach in this test.

**Table 4.** Static Test Parameters of Missiles.

| Static Test Parameters | Atgm_ 1 | Low Drag_8 | Patriot_ TR | New Missile |
|---|---|---|---|---|
| **Speed** | 150 m/s | 145 m/s | 160 m/s | 170 m/s |
| **Range** | 16000 m | 19961 m | 24815 m | 10710 m |
| **Mach** | 0.4 M | 0.5 M | 0.6 M | 0.5 M |
| **Maneuver** | 7 g | 7.5 g | 7.3 g | 4.4 g |

At the static test simulation with the rocket simulator program, the missiles are assumed to fly as straight flight at the sea level. The engine's thrust is used to accelerate the missile and fight the missile's friction force in the air. A well-designed engine maintains the high speed obtained from the bust stage enabling the missile to reach long distances and making the most of maneuverability. At the end of the static test, the engine and aerodynamic values of the missile can be improved. As shown in the Table 3, New Missile has the highest speed. Later, Patriot_TR, Atgm_1 and Low Drag_8 follow it.

The range of the missile is as important as its speed in the operations. Because, the range is determined by the location of the target and it can be changed during the mission. Also, the missile must reach long ranges after being thrown from the launcher in order to hit the target. In the Table 3, Patriot_TR is the missile that reaches the longest range. After, Low Drag_8, Atgm_1 and New Missile missiles follow it.

When the missile reaches a certain speed, the air cannot catch the missile's speed. When the missile reaches the speed of sound, it cannot find the air to pass through. At this point, shock waves are formed. Variable air pressure in the shock wave causes modification in the forces acting on the missile. In this case, the current passing through the wings changes, the friction and pressure on the tail increase. Shock waves have a great effect on an object that reaches the speed of sound. To measure this effect, missile speed and sound speed are compared. This ratio is called Mach number.

For example; if a missile flies at twice the speed of sound, than mach number is 2. If the sound speed is flying at half speed, than mach number is 0,5. According to the data in the table, the missile with the highest Mach number is Patriot_TR missile. Later, New Missile and Low Drag_8 missiles follow it, and they have same mach number. Atgm_1 has the minimum mach number.

The most important feature of the missile expected during the mission is that it hits the target with high maneuverability in a short time. Therefore, the maneuverability of the missile is very important. Maneuvering performance also affects the command signals, the performance of high acceleration and attack angles in the missile**.** The maneuver values of Atgm_1, Low Drag_8 and Patriot_TR missiles are close to each other. However, the missile with the highest maneuverability is the Low Drag_8. Later, Patriot_TR and Atgm_1 missiles follow it. New Missile has the lowest maneuver value.

## 4. RESULTS AND CONCLUSION

In the design of a missile, the rocket engine, aerodynamics, structural warhead, fuse, launcher and control unit are also important with the guidance system. The designed missiles were simulated at a platform with shooter and target values determined by the Rocket Simulator Program. Speed, distance, altitude, mach number and maneuverability number which are important criteria during the cruise, test flight or when the missiles take action to hit the target were evaluated by test flights in the simulation. The results are given at the Table 5 for the test flights.

The missiles require high speed in order to be effective against high-speed ones, to move faster than them, to make sudden maneuvers, to resist high accelerations and to eliminate any deception by other aircraft. According to the data in the table 5, the missile with the highest speed for the test flight is the Patriot_TR missile.

**Tablo 5.** The simulation results of the test flights

| Simulation Values | Atgm_1 | Low Drag | Patriot_ TR | New Missile |
|---|---|---|---|---|
| **Speed** | 350.3 m/s | 560.9 m/s | 689.8 m/s | 386.3 m/s |
| **Range** | 1990 m | 1875.9 m | 1967.6 m | 1650.7 m |
| **Altitude** | 667.5 m | 650.5 m | 871.3 m | 627.1 m |
| **Mach** | 1 M | 1.7 M | 2 M | 1.1 M |
| **Manuaver** | 5 g | 0.5 g | 5.4 g | 0.3 g |

The speed of the missile is important as well as the distance it travels. The distance is varied depending on the location of the target. Also, the missile had to reach long distances after throwing off the the launcher to hit the target. According to the data in the table above, the missile that reached the longest distance in the simulation test flight is the Atgm_1 missile.

Altitude is the vertical distance of any object or point calculated on the basis of average sea level. In other words, this parameter can be defined as the total rise and advance of the missile received during the flight. The altitude parameter varies according to the intended use of the missiles. Generally, it appears as low altitude, medium altitude and high altitude. High-altitude missiles are used for long-range targets. However, at higher altitudes the air density decreases, so the aerodynamic and engine performance of the missile changes. Medium altitude is generally used in field or point defense to eliminate the target at medium altitude. Low altitude is preferred against threats located close to the ground. According to the data in the table above, the missile that reached the longest altitude in the simulation test flight is the Patriot_TR missile.

The most important feature of the missile expected during its duty is to hit the target in a short time with high maneuverability at a specified distance. The maneuver performance of the missiles following the targets should be extremely effective. It also affects the command signals in the missile, the performance of high acceleration and angles of attack. The missile which has the best manueverability is the Patriot_TR.

According to the five criteria given in the table 5, the missile with the lowest performance in the simulation test flight is the New Missile missile. Low Drag_8 missile ranks second in speed and mach number tests. Atgm_1 missile is the second according to altitude and manuevaribility tests. In the distance test, Atgm_1 missile as a guided tank destroyer missile takes first place, Also it is used in medium missile and long range to destroy armored vehicles. The Low Drag_8 missile is designed as a low air friction missile. According to the five criteria in the table above, the lowest performance of the missiles is deternmined as the New Missile.

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