



Investigation Of Rocket And Control Systems And Flight Equations Of Rocket Motion And The Amount Of Fixed Wing In Low Range Rocket

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Abstract

A rocket is an internal combustion engine (that is, it produces its propulsion power by burning fuel inside the engine) which operates according to Newton's third law (action and reaction). A missile is a device that has a body, a propellant, a warhead, a seeker and a control system. It is a very practical device and produced in high variations. The missiles have three control systems. These systems include wing control, tail control and canard control. Choosing the right arrangement of fixed and moving blocks in a system will create a suitable control command. Combining each of the blocks with another for a missile is also normal and has its own advantages and disadvantages. The missile in question in this article was small and short range. The missile has a control system of canard and tail-stabilizing beam, and in this article, the type analysis including the analysis of the number and angle of the tail-stabilizing blade has been investigated. At first, explanations about the rocket, flight equations and then simulations have been made. And finally, a detailed analysis of the layout is provided.

Keywords: Control system, control beam, stabilizer beam, missile, flight equations.



Introduction

The main difference between a missile and a rocket is guidance and control. Without accurate guidance, missiles become a weapon of little value. There are different ways to control the missile, from which we can refer to control by aerodynamic surfaces and thrust vector control. Design engineers have designed several types of aerodynamic surfaces to control the trajectory for these flying devices. In rockets, these surfaces are mobile and execute the control operator, but in rockets, these surfaces are fixed and they are used only for the stability and control of flight variables, so that the rocket is kept on track. Special names have been considered for these levels, which include three main categories: canard, wing and tail. Most of the time, the words "wing", "canard" and "bulk" are used interchangeably, which can be misleading. Because these surfaces work in completely different ways depending on where they are located relative to the center of gravity of the missile. In general, a wing is a relatively large surface that is located near the center of gravity of the missile, while the canard is a surface near the nose of the missile and the wing is a surface near the end of the missile body. Most missiles are equipped with at least one set of these aerodynamic surfaces, especially the fuselage, which provides flight stability.

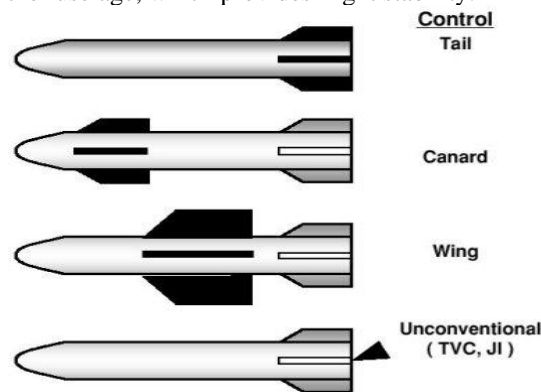


Figure 1: Aerodynamic surfaces

A) Tail control: The tail control method is probably the most used in missile control. The first and main reason for using this method for such missiles is the excellent maneuverability of these types of warheads at high angles of attack, which makes it possible to intercept aircraft with high maneuverability. Missiles that use tail control mostly use fixed wings to improve the missile's range by creating lift.

b) Canard control: Canard control is also commonly used. The most important advantage of this type of control is better maneuverability at low angles of attack, but canard becomes useless and ineffective at high angles of attack due to the flow separation that causes Levels remain. Since the canard is in front of the center of gravity, it has left instability effects and therefore requires large fixed blocks to stabilize the missile. These two sets of wings produce enough force to eliminate the need for wings. It should be noted that the double canard is also considered a new type of aerodynamic control surfaces. The first canard is fixed and the second canard is movable. The advantage of this method is that the first set of canards creates high-energy vortices, which increases the speed of the current passing over the second canard and, as a result, makes it more effective. Additionally, vortices delay flow separation and allow canards to reach high angles of attack without stalling. Reaching high angles of attack gives the missile more maneuverability than a single canard missile.

c) Wing control: Wing control is one of the first methods of missile control. But this method is less used in today's designs. The main advantage of wing control is that the wing deviation causes the body to move and change its direction suddenly. This feature is useful in the case of small tracking errors and makes the missile remain locked on the target even during large maneuvers. The most important drawback of this type of control is that the wings must be large enough to create both thrust and thrust. The control of the missile should be effective, which will cause the missile to be too large. In addition, the wings produce strong vortices, which may have a negative effect on the wing and tail, and lead to the rotation of the missile. This behavior is known as induced rotation, which if it is large enough, the control system may not be able to neutralize it. According to the explanations made, the chosen missile of this article was of the type of small missiles, short range, and canard control system. Stabilization means that sometimes the designer needs to keep the roll angle at zero or small due to the simplicity of the equations and the control system used. Also, he can improve the yaw and twist angles under the control command.

Equations of motion

At the beginning of this section, it is necessary to mention the basic point, the equations are mentioned only for familiarity and better understanding of the movement. Any flying device will require equations of flight to describe. The way of deriving these equations is available to the public, so here only the definition of these equations will be discussed. Rocket motion in the air is expressed by non-linear differential equations that express the motion of six degrees of freedom. For a rigid body with six degrees of freedom, there are six equations of motion, which are three force equations and three torque equations. . The body device is also a device that is hypothetically installed on the



missile, and its axis x is in the direction of the longitudinal axis of the missile towards the nose and its axis y is in the direction perpendicular to the body and in the direction of the right wing, and finally the axis perpendicular to the body is downward and law The right hand means page xOy . It should be noted that these equations are the same in rockets and rockets for the general state, so both words can be used to describe

horizontal plane of \mathcal{F}_E .

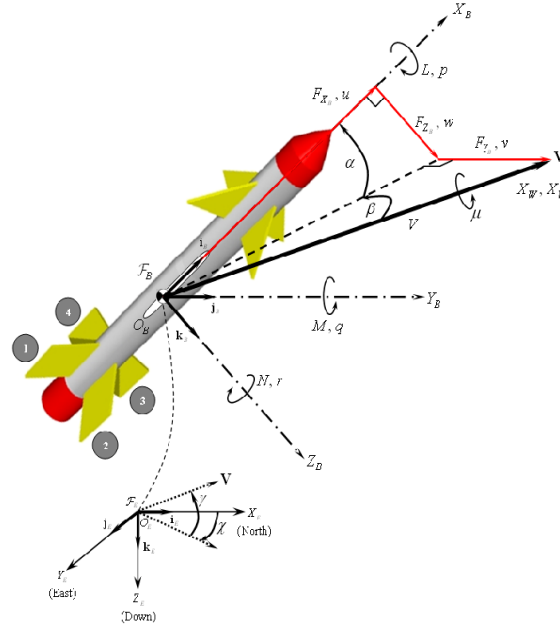


Figure 2: Rocket body system

We will have linear velocity and angular velocity respectively as follows:

$$V = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad \omega = \begin{bmatrix} p \\ q \\ r \end{bmatrix} \quad (1)$$

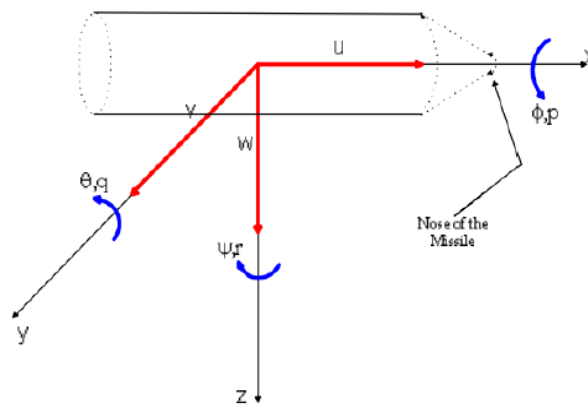


Figure 3: Rocket body device with linear and angular velocity

Moments of inertia are also defined as follows:

$$I_x = \int (y^2 + z^2) dm$$

$$I_y = \int (x^2 + z^2) dm$$



$$I_z = \int (y^2 + x^2) dm \quad (۲)$$

$$I_{xy} = \int xy dm$$

$$I_{xz} = \int xz dm$$

$$I_{yz} = \int yz dm$$

External forces and torques on the rocket or rocket as well.

$$F = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$$

$$M = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix}$$

$$\begin{bmatrix} F_{ax} \\ F_{ay} \\ F_{az} \end{bmatrix} = Q_d A \begin{bmatrix} C_x \\ C_y \\ C_z \end{bmatrix}$$

(۳)

$$\begin{bmatrix} L \\ M \\ N \end{bmatrix} = Q_d A d \begin{bmatrix} C_l \\ C_m \\ C_n \end{bmatrix}$$

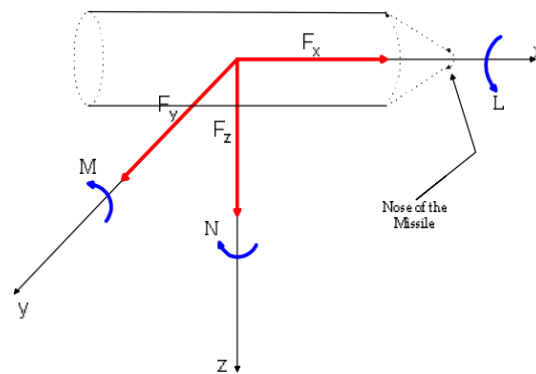


Figure 4: Rocket body plane with forces and torques

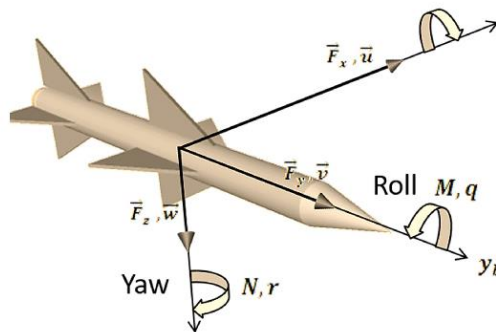


Figure 5: Rocket body device with Euler angles

The equations of translational and rotational motion are derived:

$$\begin{aligned} F_x &= m(u' + qw - rv) \\ F_y &= m(v' + ru - pw) \\ F_z &= m(w' - qu + pv) \end{aligned} \quad (۴)$$

$$\begin{aligned} M_x &= p'I_{xx} + rq(I_{zz} - I_{yy}) - I_{xz}(pq + r') = l \\ M_y &= q'I_{yy} + rp(I_{xx} - I_{zz}) + I_{xz}(p^2 - r^2) = m \\ M_z &= r'I_{zz} - pq(I_{yy} - I_{xx}) + I_{xz}(qr - p') = n \end{aligned} \quad (۵)$$

which are actually the first three equations for linear motion and the second three equations for rotational motion of the plane. Since the rocket has two planes of symmetry (up and down planes), it should be noted that the values of moments I_y and I_z will be removed and Euler's equations will be as follows:

$$\begin{aligned} M_x &= p'I_{xx} + rq(I_{zz} - I_{yy}) = l \\ M_y &= q'I_{yy} + rp(I_{xx} - I_{zz}) = m \\ M_z &= r'I_{zz} - pq(I_{yy} - I_{xx}) = n \end{aligned} \quad (۶)$$

If we assume that the angles of the inertial device are defined as $[\theta \quad \varphi \quad \psi]$, the relationship between the angular velocity vectors in the two devices is as follows:

$$\begin{aligned} p &= \varphi' - \psi' \sin(\theta) \\ q &= \theta' \cos(\varphi) + \psi' \cos(\theta) \sin(\varphi) \\ r &= -\theta' \sin(\varphi) + \psi' \cos(\theta) \cos(\varphi) \end{aligned} \quad (۷)$$

The weight force is a non-linear function of the racket's position, which is defined as follows:

$$G = \begin{bmatrix} -9.81 \sin(\theta) \\ -9.81 \cos(\theta) \sin(\varphi) \\ -9.81 \cos(\theta) \cos(\varphi) \end{bmatrix} \quad (۸)$$

The reason for mentioning the flight equations in this section is just to get familiar with the dynamics of the bird and is not used for simulation. Since it is also stated in the purpose of the article. The rocket must navigate a straight path to the target, therefore, with this assumption, the equations are very simple and many parameters are removed. As mentioned, for direct movement with the assumption of a wind device matching the rocket, the horizontal and vertical velocities must be ignored, that is, their values are be zero or very small so that they can be ignored so that the racket is aligned ($v = w \approx 0$). The pitch and yaw angular velocities must also be small or zero so that the racket remains stable. ($q = r \approx 0$) from the two Euler angles of the pitch and Yaw must also be zero to satisfy the desired condition. ($\theta = \Psi \approx 0$) As it is known, therefore, there is a longitudinal speed and there will be a roll angle for stability. The equations are defined as follows for the transitional motion state:

$$\begin{aligned} F_x &= m(u') \\ F_y &= 0 \\ F_z &= 0 \end{aligned} \quad (۹)$$

The above equations show that there must be movement in the longitudinal direction, but it is important to mention that, for example, the force in the vertical direction is zero, that is, the weight force must be equal to the lift force to be in a straight position. The rotational motion equations will be defined as follows:

$$\begin{aligned} M_x &= p'I_{xx} = l \\ M_y &= m \\ M_z &= n \end{aligned} \quad (۱۰)$$

The above equations also indicate that the torque exists only in the direction of the longitudinal axis caused by the movement of the roll, and it must be zero in the other two axes so that the necessary condition is met. Euler's angle equations are also defined as follows:

$$\begin{aligned} p &= \varphi' \\ q &= 0 \\ r &= 0 \end{aligned} \quad (۱۱)$$

The weight force equations will be converted as follows according to the mentioned assumptions:

$$G = \begin{bmatrix} 0 \\ -9.81 \sin(\varphi) \\ -9.81 \cos(\varphi) \end{bmatrix} \quad (12)$$

So far, after mentioning the flight equations and the objective condition of this article, i.e. the straight line motion of the rocket in the air, the flight equations were extracted. As it was said, the aim was to familiarize with the dynamics of the bird and describe its movement for a better understanding of the continuation of the research.

Modeling

In this section, modeling has been done for several different modes. At first, the geometry of a model rocket is stated, all dimensions are in centimeters. One of the reasons for choosing the length of the nose of the body is the same as the diameter of the body, the condition of moment symmetry is considered, which was discussed in the flight equations and confirmed here.

Table 1: Specifications of the missile body

Row	nose length	10 cm
۱	tail length	5 cm
۲	body diameter	10 cm
۳	Center of mass distance	30 cm
۴	The total length of the racket	100 cm

Table 2: Specifications of the control block

Row	Balk width	3 cm
۱	Balk height	8 cm
۲	The mounting angle of the winder	90 degrees
۳	Distance from Balk nose	30 cm

Table 3: Specifications of the tail stabilizer beam

Row	Balk width	3 cm
۱	Balk height	8 cm
۲	The mounting angle of the winder	90 degrees

۳	Distance from Balk nose	92 cm
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Modeling for alpha angles was from negative ten to positive ten degrees and Mach number was from 0.1 to 0.5. But in the results, Mach number 0.3 was desired, which was a reasonable speed and closer to reality. The length of control and fixed beams is considered to be 80% of the body diameter, and also the width of the beams is considered to be 30% of the body diameter. The topic of flight path stability and its control with fixed blocks installed on it is intended and important parameters have been used for performance comparison, which are torque coefficient, lift coefficient, drag coefficient, lift-to-drag ratio (aerodynamic efficiency), respectively, which are very It is important in the intended target of the missile that four important static parameters and three important dynamic coefficients, namely the screw torque coefficient due to the angular speed of the screw, the roll torque coefficient due to the angular roll speed and the yaw torque coefficient due to Yaw speed is checked. . It should also be noted that due to the symmetry in negative and positive angles, the measured values are recorded and compared in the tables related to aerodynamic control parameters for positive angles.

Table 4: The studied aerodynamic parameters

Row	parameter	Parameter definition
۱	C_d	Drag coefficient
۲	C_L	lift coefficient
۳	$C_{m\alpha}$	Torque coefficient
۴	$\frac{C_L}{C_d}$	Aerodynamic efficiency
۵	C_{mq}	Screw torque coefficient, screw angular speed
۶	C_{lp}	Roll torque coefficient, roll angular speed
۷	C_{nr}	Yaw torque coefficient, yaw angular velocity

To check these parameters, a lower drag coefficient, a higher lift coefficient, a lower or more negative torque coefficient, a higher aerodynamic efficiency, a more negative twist and roll torque coefficient and a more positive yaw torque coefficient should be desired.

Standard mode:

In this case, there is a front control beam or a canard control system, and there are four fixed stabilizer or tail beams with an installation angle completely similar to the canards and along them.

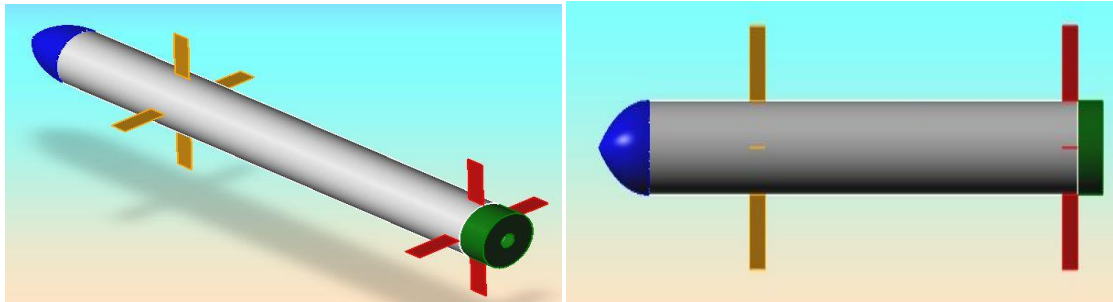


Figure 6: Standard mode rocket

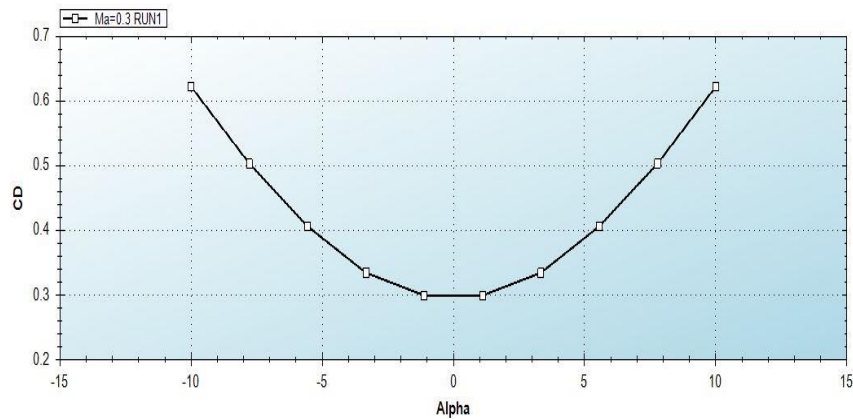


Figure 7: Drag coefficient diagram

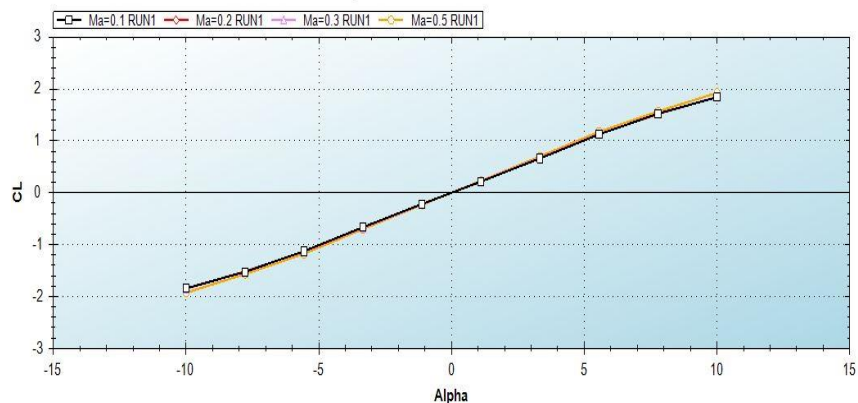


Figure 8: Lift coefficient diagram

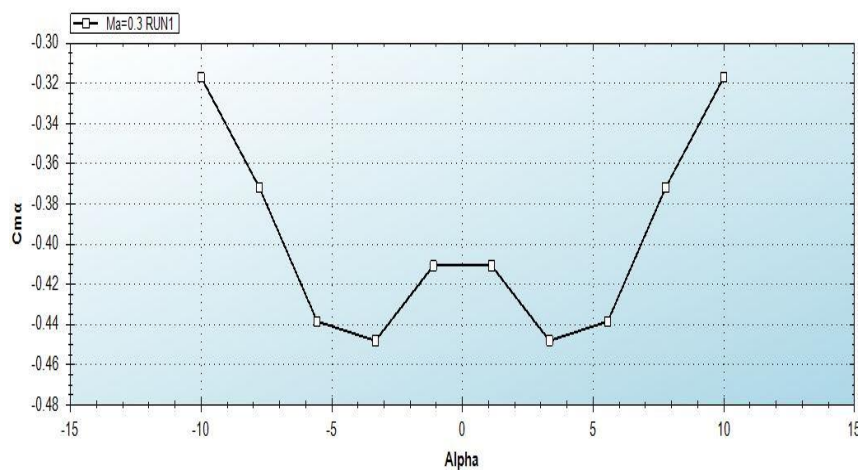


Figure 9: Torque coefficient diagram

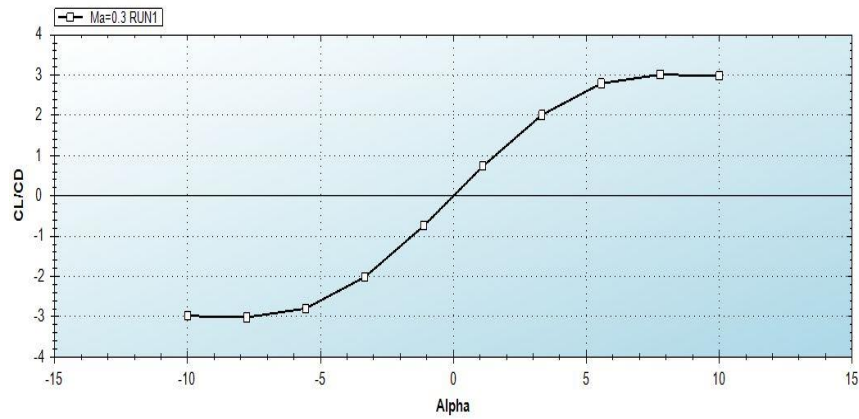


Figure 10: Aerodynamic efficiency diagram

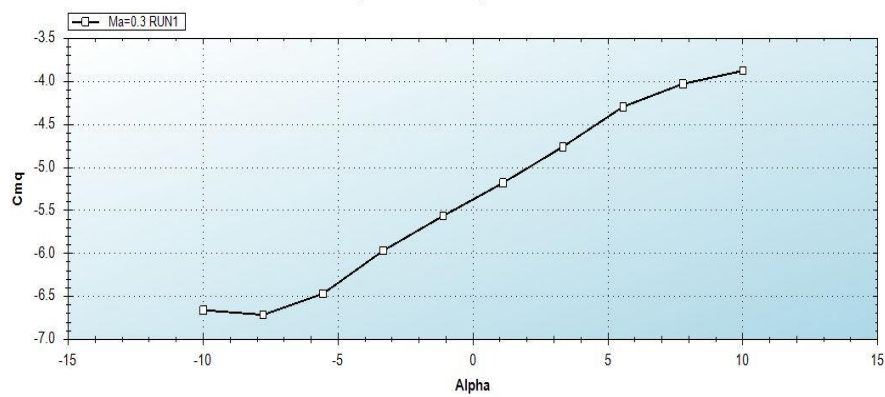


Figure 11: The diagram of the screw coefficient of the screw angular speed

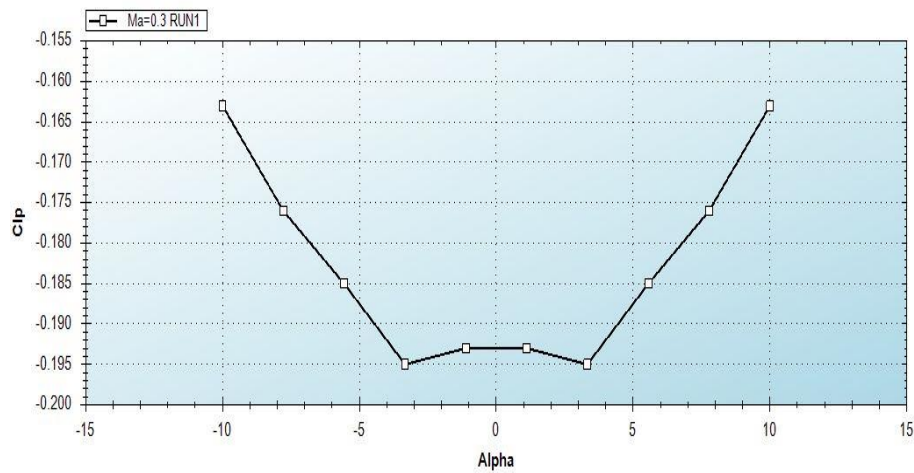


Figure 12: Roll coefficient chart of roll angular velocity

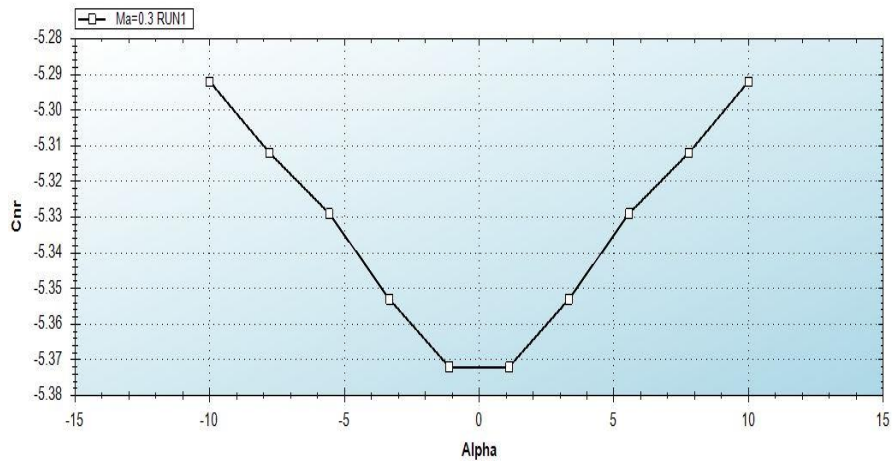


Figure 13: Diagram of yaw coefficient and yaw angular velocity

Table 5: Aerodynamic parameters of standard mode

Row	the amount of	parameter
1	[0.3 , 0.63]	C_d
2	[0 , 1.9]	C_L
3	[- 0.41, - 0.32]	$C_{m\alpha}$
4	[0 , 3]	$\frac{C_L}{C_d}$
5	[- 5.4, - 3.8]	C_{mq}
6	[- 0.193 , - 0.163]	C_{lp}
7	[- 5.37, - 5.29]	C_{nr}

The second mode:

Since the control system is a canard, the front blades remain unchanged with the standard or first mode, and the topic of stabilizer blades is changed. This change is due to the reasons related to the launch and the cost of the same dimensions as the standard mode, and in this case only They have a 45-degree predominance angle when installed around the missile axis, so the control and stabilizer beams are not aligned.

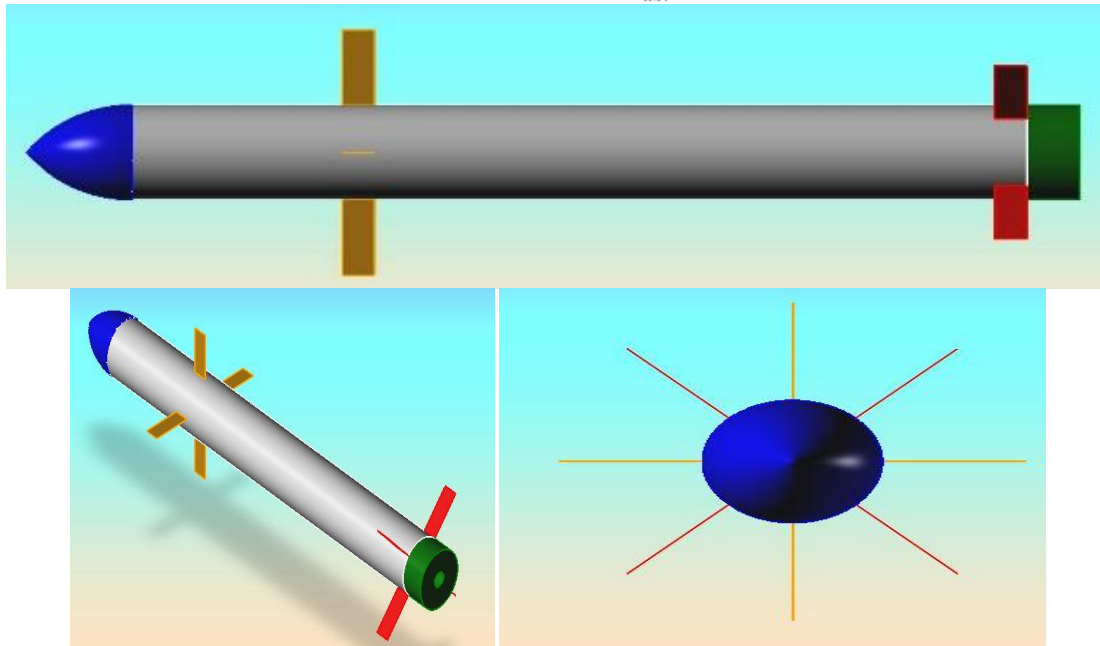


Figure 14: Missile body in the second state

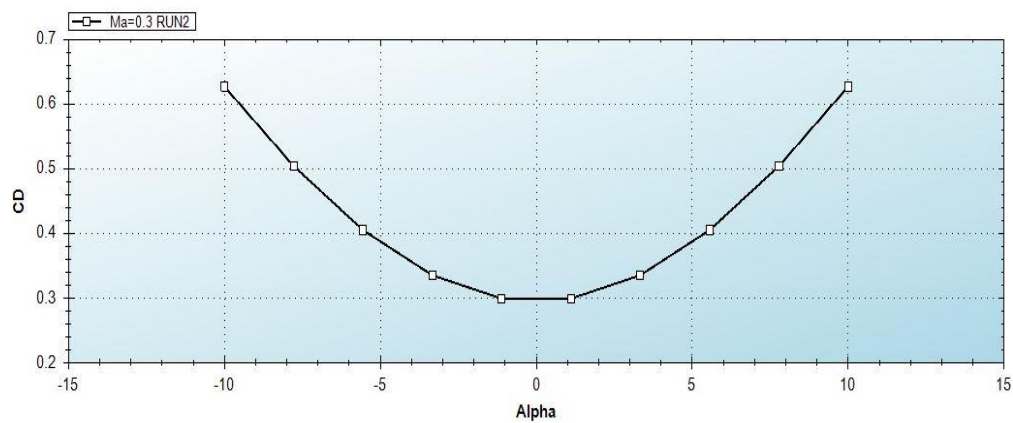


Figure 15: Drag coefficient diagram

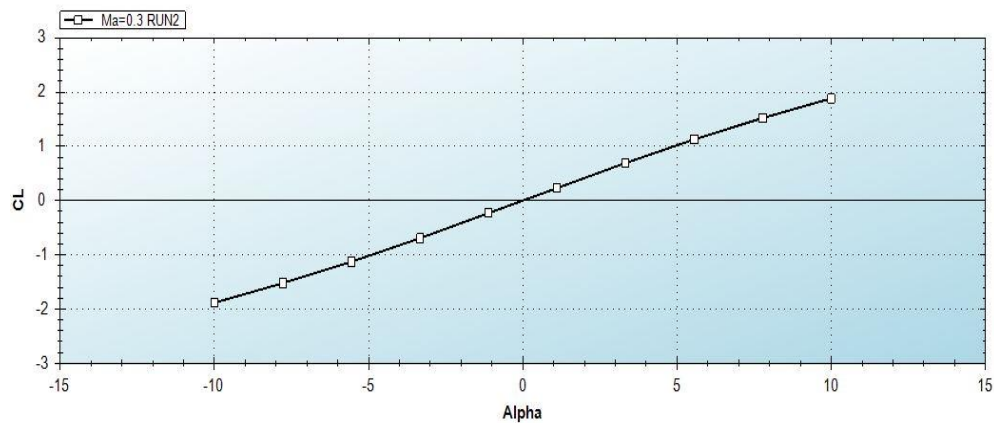


Figure 16: Lift coefficient diagram

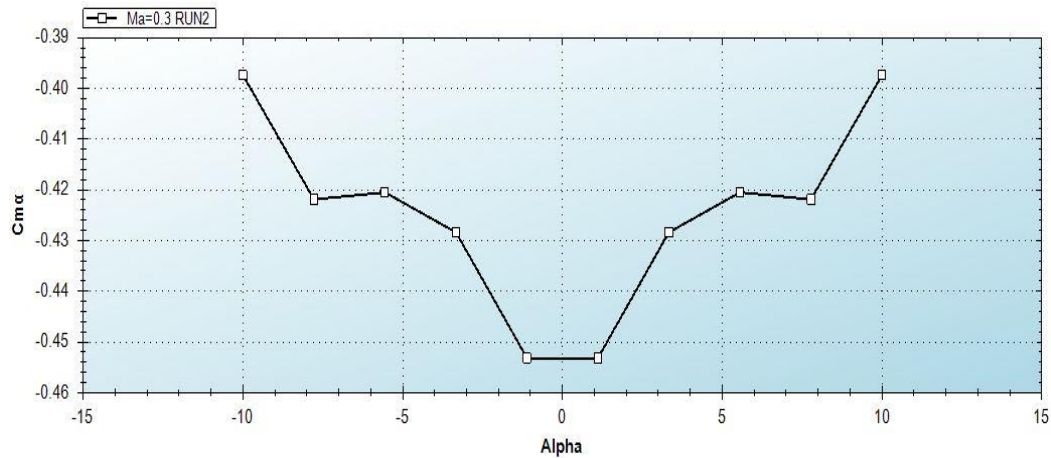


Figure 17: Torque coefficient diagram

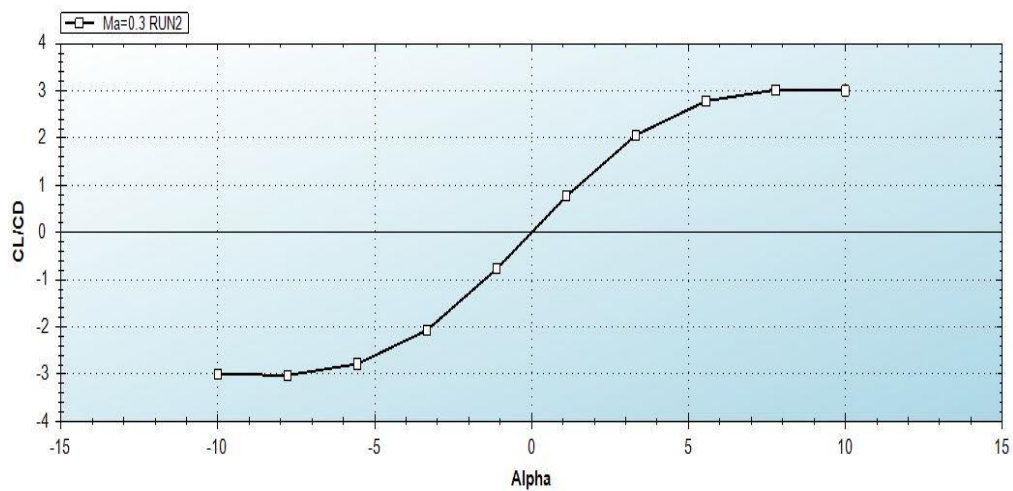


Figure 18: Aerodynamic efficiency diagram

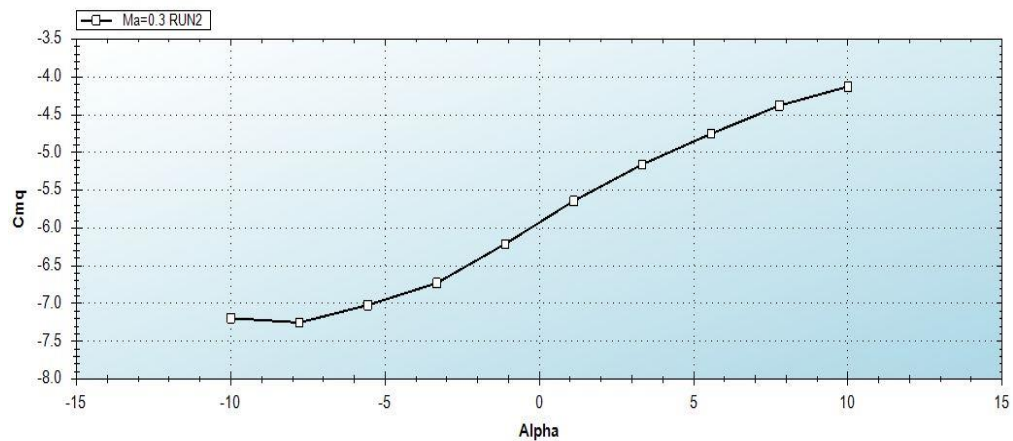


Figure 19: The diagram of the torque coefficient of the torque angular velocity

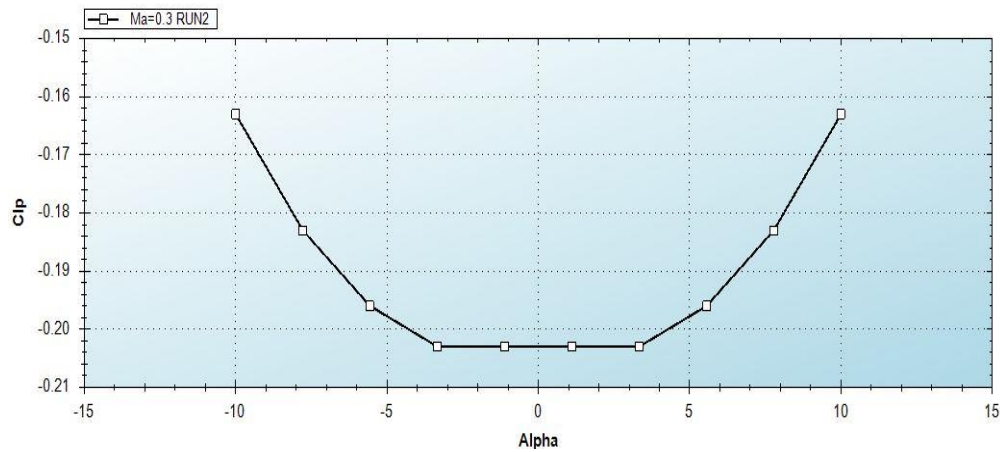


Figure 20: Chart of roll coefficient of roll angular velocity

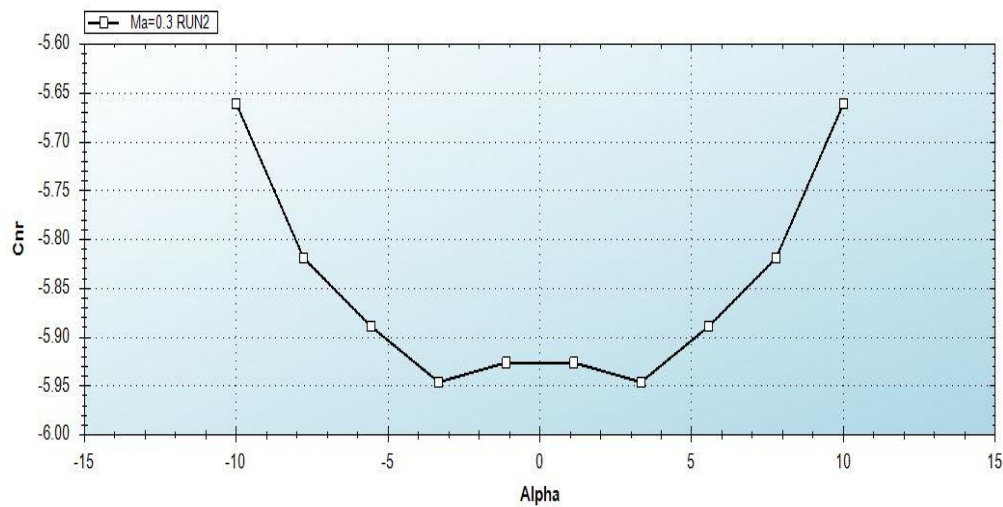


Figure 21: Diagram of yaw coefficient and yaw angular velocity

Table 6: Aerodynamic strings of the second mode

Row	the amount of	parameter
1	[0.3 , 0.65]	C_d
2	[0 , 1.9]	C_L
3	[- 0.455, - 0.41]	$C_{m\alpha}$
4	[0 , 3]	$\frac{C_L}{C_d}$
5	[- 6 , - 4.1]	C_{mq}
6	[- 0.20 , - 0.163]	C_{lp}
7	[- 5.93, - 5.66]	C_{nr}

Third mode:



In this case, the dimensions are exactly the same as the previous two cases, but the combination of the previous two cases, i.e. the standard mounting angle and the phase lead, which results in double the number of blades, means that we will have the number of stabilizing blades in the tail.

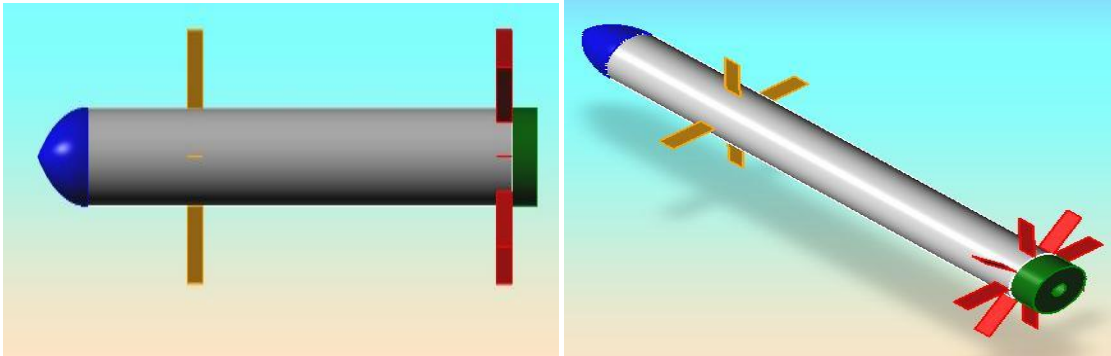


Figure 22: Missile body in the third state

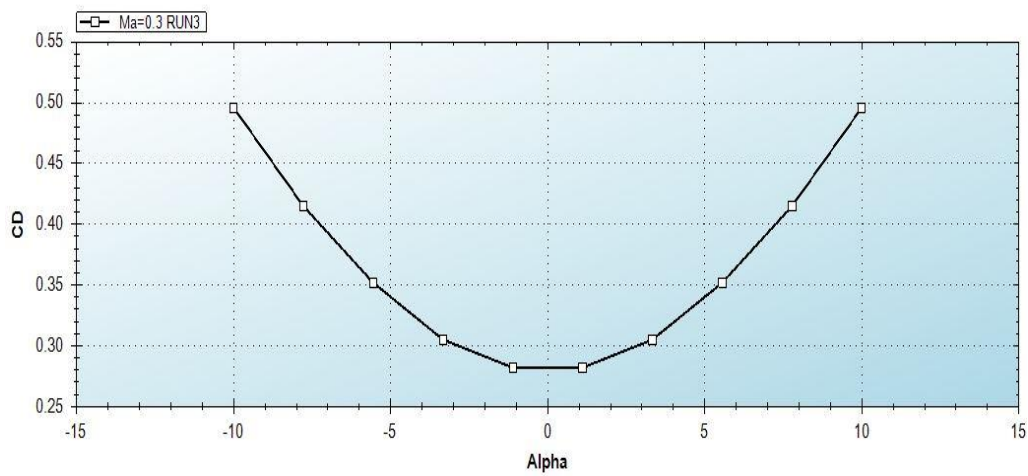


Figure 23: Drag coefficient diagram

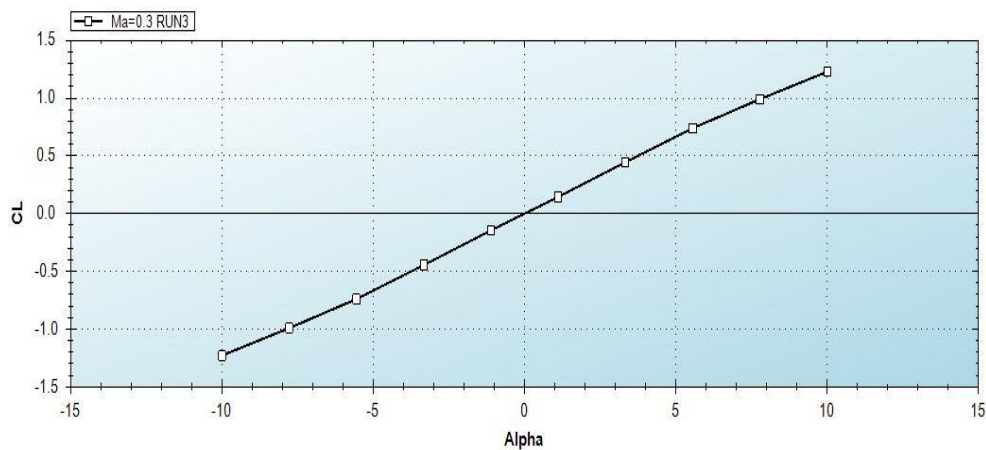


Figure 24: Lift coefficient diagram

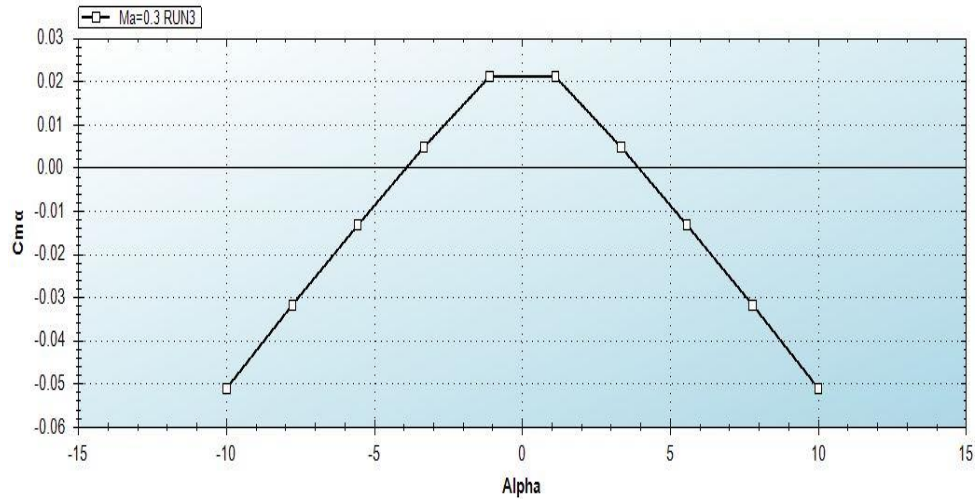


Figure 25: Torque coefficient diagram

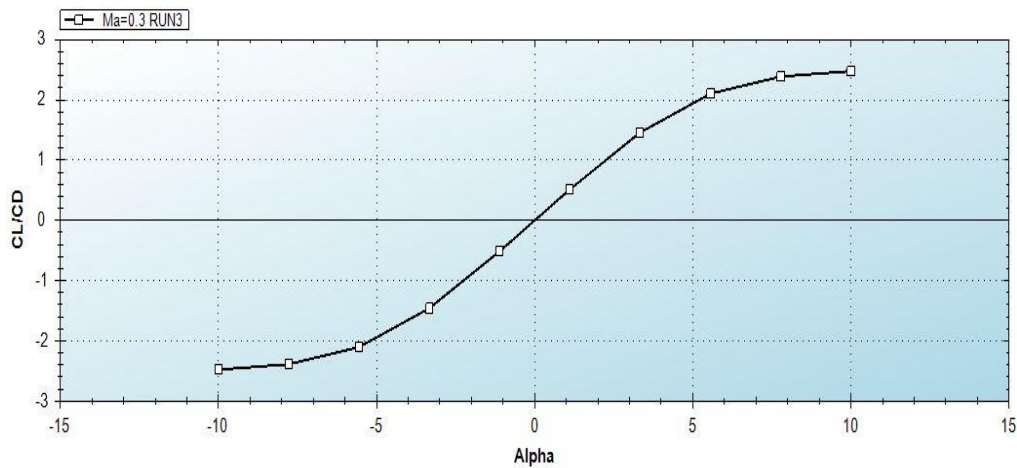


Figure 26: Aerodynamic efficiency diagram

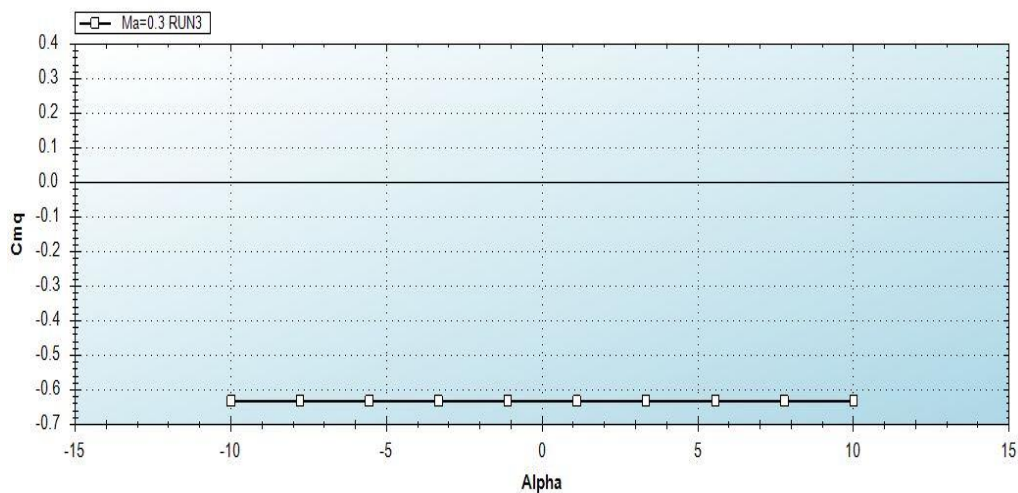


Figure 27: The graph of the twist coefficient of the twist angular velocity

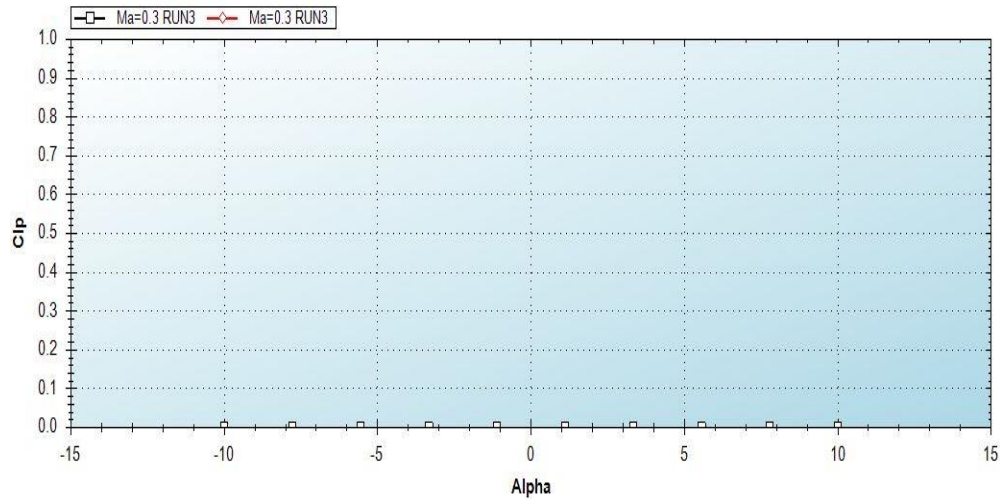


Figure 28: Roll coefficient diagram of roll angular velocity

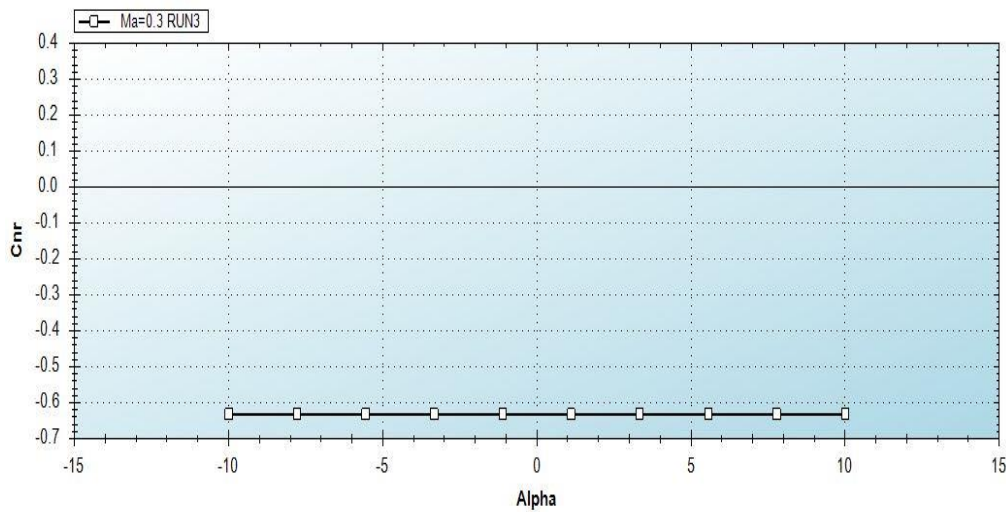


Figure 29: Diagram of yaw coefficient and yaw angular velocity

Table 7: Aerodynamic parameters of the third mode

Row	the amount of	parameter
1	[0.27 , 0.5]	C_d
2	[0 , 1.3]	C_L
3	[0.02, - 0.05]	$C_{m\alpha}$
4	[0 , 2.5]	$\frac{C_L}{C_d}$
5	[-0.6]	C_{mq}
6	[0]	C_{lp}
7	[-0.6]	C_{nr}



Conclusion number one:

Since the following conditions should be considered to check the static and dynamic parameters. To check these parameters, a lower drag coefficient, a higher lift coefficient, a lower or more negative torque coefficient, a higher aerodynamic efficiency, and a more negative twist and roll torque coefficient and a more positive yaw torque coefficient should be desired. (The meaning of negative or positive sign is the same as being up and down in that interval.)

The result of the second number:

The comparison table is as follows:

The third mode	The second mode	The first mode	parameter	No
[0.27 , 0.5]	[0.3 , 0.65]	[0.3 , 0.63]	C_d	۱
[0 , 1.3]	[0 , 1.9]	[0 , 1.9]	C_L	۲
[0.02, - 0.05]	[- 0.455, - 0.41]	[- 0.41, - 0.32]	$C_{m\alpha}$	۳
[0 , 2.5]	[0 , 3]	[0 , 3]	$\frac{C_L}{C_d}$	۴
[-0.6]	[- 6 , - 4.1]	[- 5.4, - 3.8]	C_{mq}	۵
[0]	[- 0.20 , - 0.163]	- 0.193 , - 0.163]	C_{lp}	۶
[-0.6]	[- 5.93, - 5.66]	[- 5.37, - 5.29]	C_{nr}	۷

The following results are extracted from the above table:

- 1) For the drag coefficient that is lower, the third mode is preferred.
- 2) For higher lift coefficient, the first and second mode are better.
- 3) For the negative torque coefficient (in fact, it means a downward trend), the third mode will be considered.
- 4) More aerodynamic efficiency is desired in the first and second state.
- 5) Negative screw torque coefficient (the same as the descending course) of the third mode is the best mode due to the fact that it is a constant negative value.
- 6) The negative roll torque coefficient of the first state is more negative, but the important thing that designers pay much attention to is that sometimes the role of the stabilizing beam should be kept at zero, that is, the roll must remain unchanged, which creates this condition in the third state.
- 7) The positive yaw torque coefficient of the third mode is the best.

Conclusion



In this article, which aims to investigate and analyze the installation angle around the axis in the missile and the number of stabilizer blocks in a short and small range model missile. First, the missile and control systems are defined, and in the second part, the flight equations are mentioned to know the movement and dynamics of the missile. In the next part, the simulation for the model rocket is carried out in three modes and the results are mentioned. With the result obtained from this article, it is possible for the designers to choose any of the parameters they have in mind for their design by comparing with these results, which indicates the choice of the designer. However, this article has proven the best and most optimal mode according to its investigation, the third mode. One of the innovations of this article is the detailed, simple and understandable analysis that has been completely performed for seven important static and dynamic parameters. This type of research that has been done in this article has been almost a new thing in recent years. With this review, a correct understanding of the stabilizer beam can be reached. It should also be mentioned that if the dimensions of the beams are considered and the angle of vertical installation and variation in the geometry of the beams, you can refer to the published article by the authors of the same article, which is also mentioned in the references.

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