

Design and Static Stability of a Model Missile Rocket.

Helal Uddin¹, Md. Rasel Ahmed², Eng Touhidur Rahman Sajib³

¹ Department of Mechanical Engineering, Hajee Mohammad Danesh Science and Technology University, Bangladesh.

² Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Bangladesh.

³ PhD in Management, Multimedia University, Malaysia.

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Abstract— This study focuses on ensuring the static stability of model missile rockets, which is crucial for maintaining a zero angle of attack and returning to equilibrium when disturbed by external forces such as wind or model inconsistencies. The objective is to develop and compare methods for determining the center of pressure and assessing static stability to simplify the design process for reliable launches of exhibition and sports model rockets. The methodology includes a simplified method that approximates the center of pressure as the center of the rocket's two-dimensional silhouette, suitable for small angles of attack (15-20°), a graphical method that has been developed and compared to various methods for estimating the center of pressure and assessing static stability and has been validated using SolidWorks Flow simulation. The results show that static stability is achieved by placing the center of gravity in front of the center of pressure. The simplified and practical plane figure method yields an error of 15-28%, which is suitable for demonstration rockets, while the analytical method achieves high accuracy with an error of 0-0.34%, which is ideal for competitive sports models. The graphical method provides moderate accuracy with an error of 3-12%. Validation with SolidWorks confirms the reliability of these techniques. The proposed methods streamline the design process for both demonstration and sports model rockets, ensuring the analytical method recommended for high-performance models in international competitions and the possibility of further refinement in future research. Conclusion. The proposed method for ensuring static stability of a model rocket makes it possible to simplify the design process of both demonstration and sports models of rockets for reliable demonstration launches.

Keywords— SolidWorks, Flow Simulation, Model rocket, Center of pressure, Static stability of the rocket, Rocket design, Stabilizers.

I. Introduction

Without utilizing the aerodynamic lift of the lifting surfaces, a flying model missile rocket, like an airplane, is launched into the air by a model missile rocket engine (MRE). The model missile rocket also features a rescue mechanism to ensure a safe landing. Unguided models of missile rockets that can reach a height of 1.5–2.5 km is used in missile rocket modeling, if the rockets retain static stability while in flight. Conical 1 and transitional 2 components of the fairing, a rocket model body 3, and tail fins stabilizers 5 make up a missile rocket model (Fig.1). The missile rocket equipment includes two guide rings, and a parachute for the rescue system, a Wad 9, and a missile rocket engine10. Whatman paper is used to make the fairing's conical and cylindrical sections. On mandrel 4, the workpiece is coiled and greased with glue. The fairing's conical portion is constructed similarly. It is important to remember that the adapter's diameter should be somewhat less than the body's. so that it can be freely put on and taken off. This ensures free ejection of the rescue system parachutes. The stabilizers of the model rocket, ensuring the displacement of the pressure center closer to the tail of the rocket, are four plates cut from strong cardboard, 1-2 mm thick.

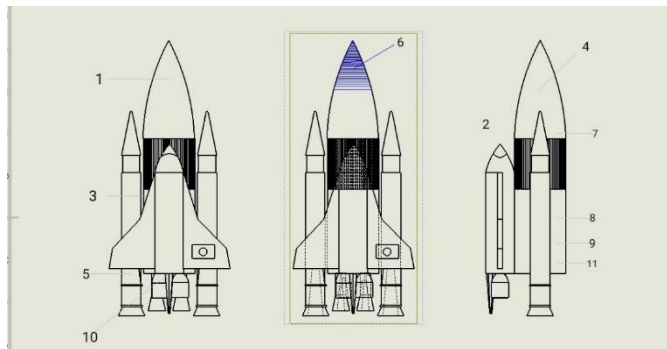


Fig. 1. Model of a missile rocket

1 – conical part of the head fairing; 2 – head fairing adapter; 3 –missile rocket model body; 4 – mandrel; 5 – stabilizer; 6 payload; 7 – parachute lines; 8 – parachute; 9 – wad; 10 – micro-RDIT; 11 – powder checker micro solid propellant.

Paper margins on the US letter size paper are set as follows: top = 0.75 inches, bottom = 1 inch, side = 0.625 inches. Each column measures 3.5 inches wide, with a

During flight, three forces act on the missile rocket: engine thrust (R), aerodynamic drag force (P) and gravity (G) (Fig. 2). The engine thrust force is directed along the longitudinal axis of the model; gravity acts vertically downwards and is applied at the center of gravity ($c. g.$); the aerodynamic force is opposite to the oncoming flow and is applied at the center of pressure ($c. p.$). The center of pressure is the point of application of the resultant of all aerodynamic forces to the body of the missile rocket [1-5]. When designing flying models of missile rockets, one of the complex tasks is to ensure the static stability of the missile rocket in flight along a given trajectory [6-9]. Stability is understood as the ability of the model to return to an equilibrium position disturbed by external forces (wind, model asymmetry, etc.). In this case, the model must be stabilized by the angle between the longitudinal axis of the model and the direction of flight (velocity vector). The condition for ensuring the static stability of the missile rocket model is the location of its center of gravity in front of the center of pressure. In this case, when an angle of attack different from zero appears, the aerodynamic forces will create a stabilizing moment that will return the model to a zero angle of attack [10; 11].

In Fig. 2, we consider two cases of the behavior of a rocket model during its movement along a vertical trajectory. The angle of attack is zero - the axis of the model coincides with the direction of flight. Under ideal conditions (in the absence of external interference), such a trajectory is maintained throughout the entire flight. This almost never happens. External forces (wind, inconstant engine thrust) introduce errors into the flight trajectory due to the appearance of an angle of attack that is not equal to zero. If the model is statically stable (Fig. 2, a), then it will return to a zero angle of attack on its own. An unstable rocket (Fig. 2, b) will increase the angle of attack even more and deviate more from the original vertical trajectory.

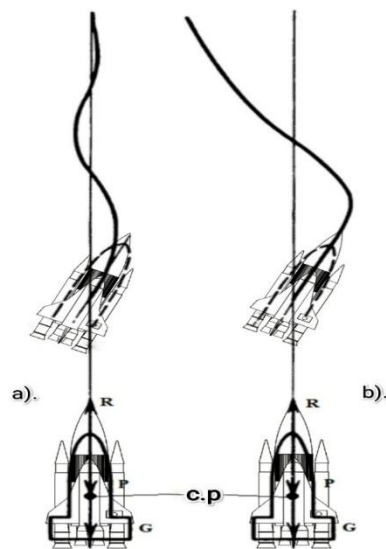


Fig. 2. Flight trajectory of the rocket model a – stable flight and b – unstable flight.

Analysis of existing methods for ensuring static stability of a model missile rocket:

One of the most common methods for ensuring static stability of a model rocket is aerodynamics. It consists of installing special surfaces stabilizers on the rocket body. Let's consider the conditions of aerodynamic stability in more detail. It depends on the relative positions of the center of gravity ($c. g.$) and the center of pressure ($c. p.$) (Fig. 3).

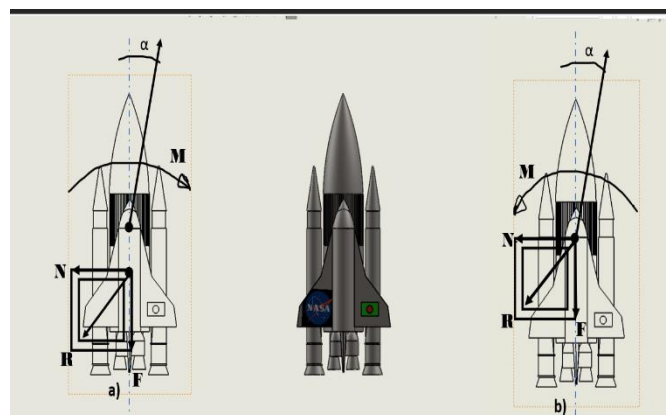


Fig. 3. Influence of the relative position of the center of gravity ($c. g.$) and the center of pressure ($c. p.$) on the stability of the model in flight:

a – the model is stable and b – the model is unstable.

If the c. g. is in front of the c. p. (Fig. 3, a), then when the angle of attack appears, the aerodynamic forces will create a stabilizing moment that will return the model to its original state with a zero angle of attack. This model will be statically stable. And the further the c. p. is shifted relative to the c. g. (counting from the warhead), the greater the margin of static stability the missile rocket model has.

If the model's center of gravity is located behind the center of action (Fig. 3, b), then the aerodynamic forces arising because of the change in the angle of attack under the action of disturbing external forces will create a destabilizing moment that will increase this angle. Such a model will be unstable in flight. The ratio of the distance from the center of gravity to the length of the missile rocket (with the origin at the rocket's nose) is called the static stability margin. For models with stabilizers, it should be 10–20%. In practice, for model missile rockets, the center of pressure is shifted as close as possible to the engine compartment by increasing the total area of the stabilizers and installing them as far away from the nose as possible. In this case, the center of gravity is shifted toward the nose cone by installing an additional payload in the nose cone. As a rule, the calculation of the static stability of a missile rocket is not specially carried out. Either traditional missile rocket models that have already confirmed their static stability are used, or static stability is ensured by test launches during the design of an experimental model.

II. Literature Review

The center of gravity (CG) must be ahead of the center of pressure (CP) for model missile rockets to maintain a zero angle of attack and recover from external disturbances (Barrowman, 1967). This review assesses important static stability research that is pertinent to the current study's goal of creating techniques for CP determination and guaranteeing dependable rocket launches.

A static stability analysis for sounding rockets was presented by Cadamuro et al. (2024), who focused on finding placement and a new stability index. However, its ability to handle flight asymmetries is limited by its reliance on classical methods. Although it provides a potential index to improve future analyses, this is consistent with the current study's use of stabilizers to shift the CP. Bordachev et al. (2023) looked at simplified, graphical, and analytical ways to check the stability of model rockets. They found that the simplified method had a 15% error rate, which is the same as the 15–28% error rate for demonstration rockets in this study. Their work backs up the current study's methods, but it doesn't test them in real-world environments. Riaz et al. (2016) used CFD and Newton's Second Law to look at dynamic stability, but they didn't do much static stability analysis. Their CFD method backs up the SolidWorks Flow Simulation validation in this study, which suggests that dynamic stability should be added in the future.

Liu et al. (2024) made an autopilot for missiles that weren't stable. This isn't very useful for passive model rockets, but it is useful for high-performance designs that need a lot of analysis.

This study fills in the gaps in these works by comparing SolidWorks-validated methods for exhibition and sports rockets that are simplified (15–28% error), graphical (3–12% error), and analytical (0–0.34% error). To make designs more reliable, future research should look into real-world conditions and dynamic stability.

III. Methodology

Methods for calculating the static stability of a model missile rocket:

The condition for ensuring the static stability of a missile rocket model is the location of its center of gravity in front of the center of pressure. As a rule, reference books on the strength of materials or calculation programs (SolidWorks, Ansys) are used to determine the geometric and mass characteristics of the structure [12]. However, the center of gravity of a model missile rocket is easy to determine by balancing it on the edge of a thin ruler. There are several ways to find the center of pressure. As a rule, they are divided into calculated and practical [13–15].

Calculation method for determining the center of pressure

The CP is the point where aerodynamic forces act. For small angles of attack (up to 15–20°), the CP can be approximated by assuming symmetrical flow (angle of attack $\alpha = 0$). The approximate method involves: Approximate Calculation Method for CP.

Step 1: Simplify the Model Geometry Represent the rocket as a flat, two-dimensional figure (a silhouette or side profile).

Break the model into simple geometric shapes (e.g., rectangles, triangles, or trapezoids for the body, fins, and nose cone).

Step 2: Calculate the Centroid of Each Shape For each simple shape, determine its area and the coordinates of its centroid (geometric center). Use standard formulas for centroids of basic shapes (e.g., for a triangle, the centroid is at the average of the vertex coordinates).

Step 3: Compute the Total Static Moment Calculate the static moment for each shape by multiplying its area by the distance from a reference axis (e.g., the nose tip) to its centroid.

Sum the static moments of all shapes:

$$S_{total} = \sum (A_i \cdot x_i) \quad \dots \dots \dots (1)$$

where

A_i is the area of shape (i), and x_i is the distance from the reference axis to the centroid of shape (i).

Step 4: Find the CP

Divide the total static moment by the total area of the flat figure to find the CP's position:

$$x_{cp} = \frac{S_{total}}{\sum A_i} \quad \dots \dots \dots (2)$$

This gives the longitudinal position of the CP along the rocket's axis.

3. Assess Static Stability

- Compare the positions of the CG and CP.
- The rocket is statically stable if the CG is forward of the CP (closer to the nose).
- A common rule of thumb is that the CG should be at least 1–2 body diameters ahead of the CP for sufficient stability.

Approximate determination of the center of pressure from a model drawing (from a flat figure):

The disturbances acting on the missile rocket model during flight are not large. The angle of deflection of the missile rocket changes insignificantly, usually up to 15–20°. At small angles of attack, the position of the c.d. deviates from the calculated one. But when designing, you can use an approximate method for determining the center of pressure in symmetrical flow (at zero angle of attack $\alpha = 0$). The position of the c.d. in this case will correspond to the position of the center of gravity of the flat figure of the model. We will break the model into a few simple figures and find the coordinates of the total static moment (Fig. 4)

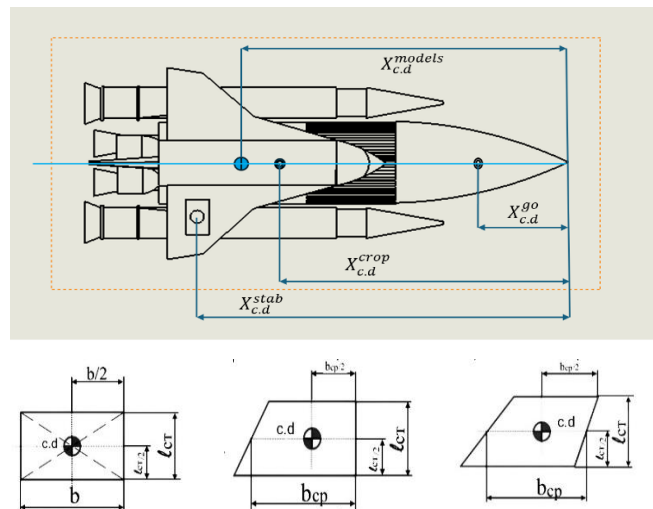


Fig.4. Center of gravity and center of pressure of the model and its parts

The equation,

$$X_{c.d}^{mod} = \frac{S^{go} \cdot X_{c.d}^{go} + S^{crop} \cdot X_{c.d}^{crop} + S^{stab} \cdot X_{c.d}^{stab} + \dots \dots \dots}{S^{mod}} \quad \dots \dots \dots (3)$$

The document's Approximate Calculation Method for CP uses this equation in the simplified (flat figure) method, which finds the center of pressure (CP) by finding the centroid of the rocket's two-dimensional silhouette.

Where,

- S^{mob} = Head fairing projection area.
- S^{crop} = Projection area of the model body.
- S^{stab} = Projection area for all stabilizers.
- S^{mod} = Sum of all areas.
- $X_{c.d}^{go}$ = Ordinate of the head fairing.
- $X_{c.d}^{crop}$ = Ordinate of the model body.

$X_{c.d}^{stab} =$ Ordinate of the stabilizers.

If $X_{c.d}^{mod} - X_{c.m}^{mod} = C$ is a positive number, this means that the model will be stable, where C is the stability margin of the rocket model. The greater C , the more stable the flight will be. To increase the stability margin C , it is necessary to increase the area of the stabilizers or change their location to a more "rear" one (to shift the position of the c.d. closer to the tail section). To ensure a more forward location of the c.g., the mass of the nose cone can be increased.

Graphical method for determining the center of pressure of a missile rocket model:

The position of the center of pressure depends on the relative elongation of the model body,

$\lambda = \frac{L^{crops}}{d_{midship}}$. For a rocket model with a cylindrical body without fins and a conical (or closer to a cone) nose cone, the position of the c.d. of action on the model axis to X_{cd}^k of action can be found from the graph (Fig. 5). Knowing the position c.t and c.d of the unfanned body, we set the stability margin C ($C = 30$, $C = 20$, $C = 10$) and, using the graph, we find the coefficient of influence of the stabilizers K_{CT} proposed by the authors, knowing which we can calculate the area of one stabilizer tail for a 4-stabilizer model (Fig. 6):

$$S_{CT=0,8} K_{CT} \cdot d_{mid}^2 \quad \dots\dots\dots (4)$$

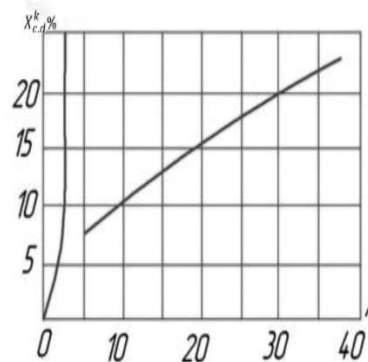


Fig. 5. Graph of the dependence of the position of the center of pressure of the body without stabilizers on its elongation.

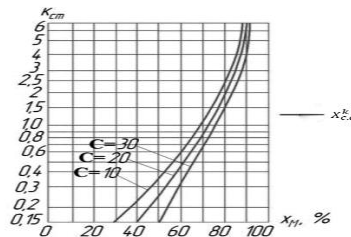


Fig. 6. Graph for determining the stabilizer area of a rocket model with four stabilizers

An analytical method for determining the position of the center of pressure from the model drawing:

A missile rocket model usually consists not only of cylindrical parts, but also of a few conical ones. The graphoanalytical method does not take this into account, and each of these parts is subject to a normal aerodynamic force. Knowing its magnitude and the point of application, it is easy to find the total aerodynamic force R as the sum of individual forces and its coordinate X_{cd} :

$$X_{c.d} = \frac{R_{go} \cdot X_{go} + R_1 \cdot X_1 - R_k \cdot X_k + R_2 \cdot X_2 + R_{CT} \cdot X_{CT}}{R}, \quad \dots\dots\dots (5)$$

Where, R_{go} , R_1 , R_k , R_2 and R_{CT} — aerodynamic forces acting respectively on the head fairing, the first cylindrical part of the model, the conical, the second cylindrical and stabilizers of the model. Since the aerodynamic force depends on the flight speed, it is better to determine not the forces themselves, but their dimensionless coefficients C_R . In this case, the formula can be rewritten as follows:

$$X_{c.d.} = \frac{C_{R_{go}} X_{go} + C_{R_1} X_1 - C_{R_k} X_k + C_{R_2} X_2 + C_{R_{CT}} X_{CT}}{R}, \quad \dots\dots\dots (6)$$

Therefore, $C_R = C_{R_{go}} + C_{R_1} - C_{R_k} + C_{R_2} + C_{R_{CT}}$,

The calculation assumes that a cylindrical body does not create lift at low angles of attack, so the aerodynamic force coefficient of a cylindrical body is close to zero. The calculation determines the aerodynamic parameters for the nose cone, conical transition part and stabilizers. It is necessary to consider that the presence of a cylindrical body affects the air flow near the root chords of the stabilizers. There are two common types of nose cones: conical and ogive. For both types, the aerodynamic force coefficient is the same: $C_{Rgo} = 2$.

For a conical nose cone, the center of pressure is located at a distance $X_{c.d.} = \frac{2}{3}l_{go}$ from its nose point, and for an ogive $X_{c.d.} = \frac{1}{215}l_{go}$.

Where,

l_{go} is the length of the nose cone. The conical transition part can increase or decrease the diameter of the model. The aerodynamic force coefficient for a conical transition part is calculated using the formula:

$$C_{Rk} = 2 \left[\left(\frac{d_1}{d} \right)^2 + \left(\frac{d_2}{d} \right)^2 \right], \quad \dots\dots\dots (7)$$

Where,

d_1 = Lower diameter of the truncated cone.

d_2 = Upper diameter of the truncated cone.

d = Diameter of the nose cone.

For a tapering cone, this coefficient will be negative. This means that the force R_k is directed against other forces and hulls with different aft parts will have different positions of the pressure center. The position of the pressure center of the cone is calculated using the formula:

$$X_k = l_p + \frac{l_k}{3} \left[1 + \frac{1 - \frac{d^2}{d_1^2}}{1 - \left(\frac{d_2}{d_1} \right)^2} \right], \quad \dots\dots\dots (8)$$

Where

l_p = The distance from the nose of the model to the cone.

l_k = The height of the cone.

Complex stabilizers can be represented as the sum of simple stabilizers, and their center of pressure can be determined by the mean aerodynamic chord. stabilizer feather. The aerodynamic force coefficient depends on the number of stabilizing surfaces. For a stabilizer with n surfaces, the aerodynamic force coefficient is calculated using the formula:

$$C_{RCT}^* = \frac{N \cdot \left(\frac{l_{CT}^*}{d} \right)^2}{1 + \sqrt{1 + \left(\frac{2 \cdot l_{cp}}{b_{corn} + b_{conc}} \right)}}, \quad \dots\dots\dots (9)$$

where

l_{CT}^* = stabilizer feather span.

l_{cp} = midline span.

Coefficient N depends on the number of stabilizers. The aerodynamic interaction of the stabilizers and the body of the rocket model is considered by the coefficient

$$k_p = 1 + \frac{r}{(l_{cp} + r)},$$

Where

r = The radius of the aft part of the model.

Then the aerodynamic force coefficient for the entire aft part of the rocket model is

$C_{RCT} = K_p \cdot C_{RCT}^*$. The position of the stabilizer pressure center depends on the stabilizer shape in plan and its location on the rocket body.

The position of the stabilizer's center of pressure depends on the stabilizer's planform and its location on the rocket body:

$$X_k = L + \frac{\nabla l(b_{work} + 2b_{conc})}{b_{work} - b_{conc}} + \frac{1}{6} \left(b_{work} + b_{conc} - \frac{b_{work} \cdot b_{conc}}{b_{work} + b_{conc}} \right), \quad \dots\dots\dots (10)$$

Where

L – is the distance from the nose of the model to the root chord of the stabilizers.

∇l – is the distance between the beginning of the root and end chords of the stabilizer.

Practical method for determining the center of pressure:

The first method:

A figure is cut out of plywood, cardboard or other sheet material according to the contour of the rocket model and the c. g. of this flat figure is found. This point will be the desired c. g. of the model [2] (Fig. 7).

For a real model rocket made according to the contour provided, the true position of the c. g. is determined considering the weight of the warhead, the mass of the engine, the recovery system, etc. The static stability margin of the rocket is also determined by the formula $X_{c.d}^{mod} - X_{c.m}^{mod} = C$.

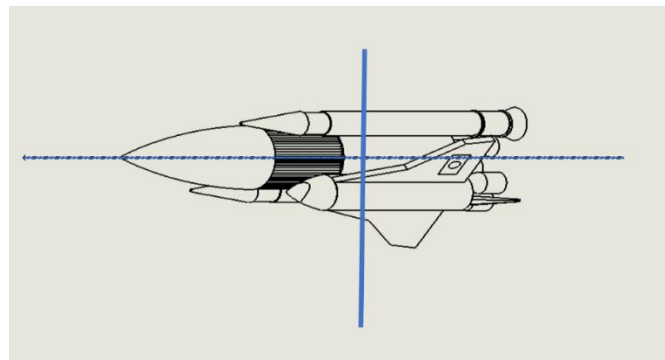


Fig. 7. A useful technique for figuring out c. e. a rocket flat figure model

The second method:

This is a test of the missile rocket for stability using a wind tunnel. To do this, the model is fully equipped: an engine, a rescue system, wads, etc. are installed. Then the rocket is placed in an air flow facing the direction of travel. The most uniform flow is created in a wind tunnel, the speed of which is at least 20-30 km/h. Deflect the rocket with your finger at approximately 10° from the downstream position. If the model returns to its original position, the static stability of the rocket is ensured (Fig. 8).

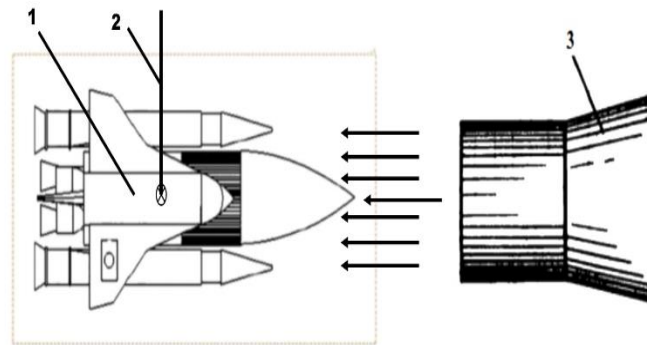


Fig. 8. Tests of a Model Rocket in the Air Flow Out of the Wind Tunnel Nozzle

1. Model rocket 2. Thread 3. Wind tunnel.

During flight, as the fuel in the engine burns out, the position of the model's center of gravity changes. Almost all models have an engine in the tail (stern). As the fuel burns out, the rocket's mass will decrease, and the center of gravity will move closer to the nose, thereby increasing the static stability of the model. There are several known ways to adjust the stability of a model rocket. One of them is to shift the center of gravity toward the stern by increasing the area of the stabilizers and their location. However, this is practically impossible to do on a finished rocket. Therefore, possible options should be considered in advance (during design): expand the stern, choose a lower placement of the stabilizers (behind the engine nozzle), increase the mass of the payload in the nose cone.

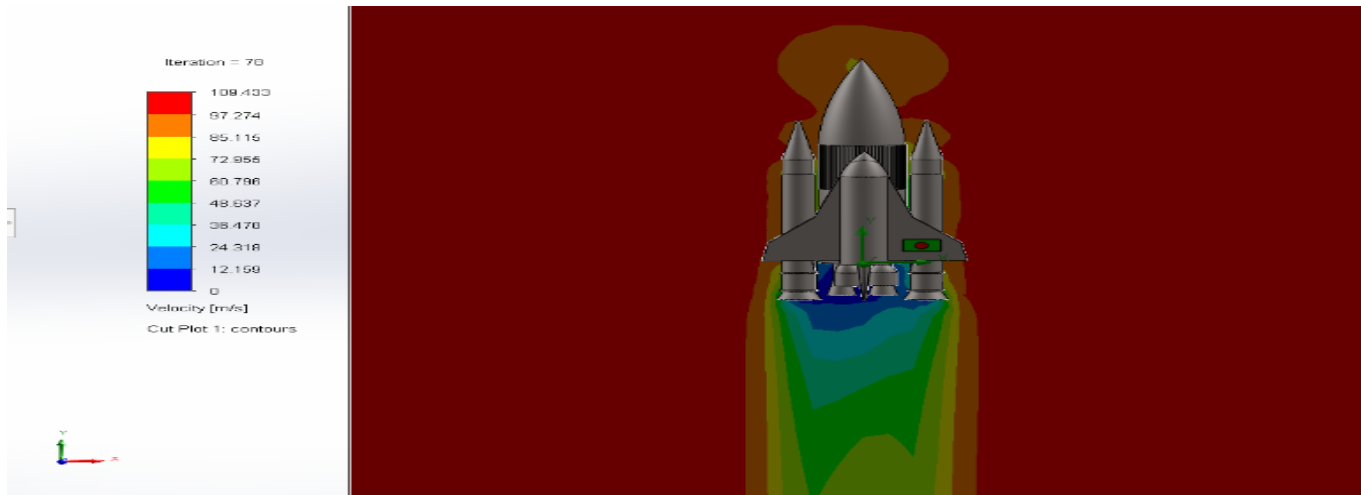
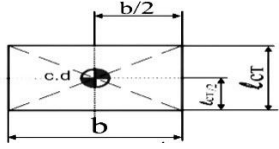
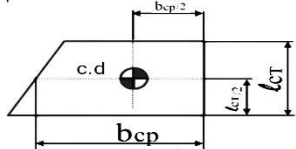
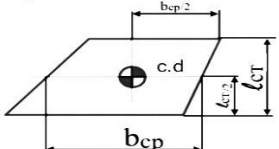


Fig.9. Purge model of a rocket with trapezoidal stabilizers in SolidWorks Flow Simulation

Comparison of methods for determining the center of action of a model rocket and determining the error:

Three single-stage rockets with various stabilizer types are used to calculate the inaccuracy of the methods outlined (Fig. 4).

Keep in mind that the graphical technique uses the model's static stability margin and the rocket's known center of gravity to calculate the size of the stabilizers. As a result, we will take the opposite approach to determine the center of action's location. Specifically, we will determine the stabilizers' coefficient of influence (K_{st}) and the actual location of the model's center of action by knowing the area of the stabilizers and the unfinned body's center of action. We will enter these values into the table. The SolidWorks Flow Simulation software is used to practically determine the c. d. model rocket by blowing (Fig. 9).

	Method of determinimning c.d.	Coordinate c.d., (mm)	Absolute error, (mm)	Relative error, (%)
Estimated	According to the "flat figure"	177	45	15,52
	Graphic	252-258	30-36	10-12
	Analytical	223	1	0,34
Practical	According to the "flat figure"	178	44	15,17
	Blowing	222	---	---
				
Estimated	According to the "flat figure"	173	46	15,86
	Graphic	249-252	30-33	10-11
	Analytical	220	1	0,34
Practical	According to the "flat figure"	173	46	15,86
	Blowing	219	---	---
				

Estimated	According to the “flat figure”	177	82	28,28
	Graphic	243-249	16-10	6-3
	Analytical	259	0	0,00
Practical	According to the “flat figure”	179	80	27,59
	Blowing	259	---	---

IV. Results

The study demonstrated and critically considered various methods of determining the center of pressure (CP) in model rockets using missiles and measuring static stability, the two important considerations when making sure that there is a zero angle of attack and reliable flight against external disturbance. The experiment involved scaling of reduced replica models that was tailored to the replication of both nominal and disturbed flight conditions. The first contribution made by the study was associated with the implementation of the simplified flat figure model, according to which the CP as a point could be approximated by the position of the centroid with respect to the two-dimensional silhouette of the rocket. Once again, though this approach reflected a significant relative error of 1528%, the ease and convenience of calculation evoked this approach to be appropriate to this type of rocket not depriving the approach the ability to show real applicability. A second graphical technique was developed, which involved the introduction of stabilizer influence and body elongation in the estimation of the CP resulting in a more balanced relative error of 3-12% compared to the first one. Such a choice was a tradeoff between computation costs, sturdiness, and design flexibility. The summation of the aerodynamics forces on each of the rocket parts was the most accurate option, with a relative error 0-0.34 % returned. This process is very appropriate in high performance sport models due to its high level of accuracy, especially those that operate on the international platform. Validation was done using SolidWorks Flow Simulation that vindicated the reliability of the methods used and then validated using the wind-tunnels as the experimentation. In sum, the results shorten the development cycle of the model rocket and allow the reliable launches and suggestion of the method under analysis in the high-precision context.

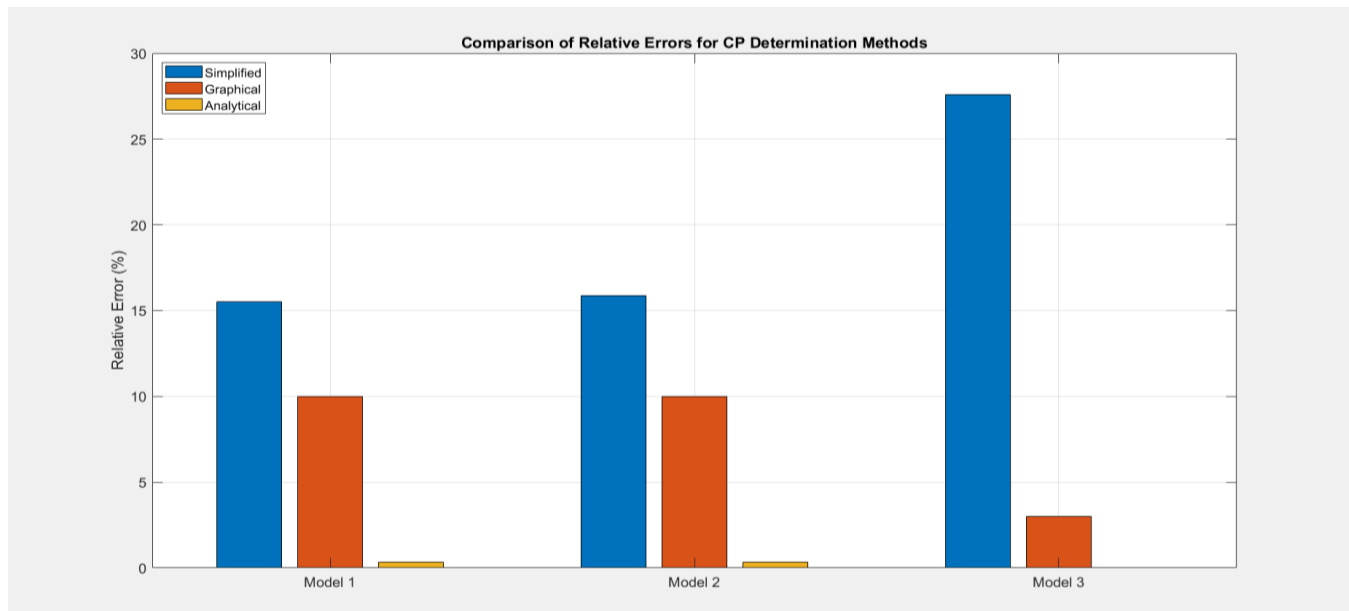


Fig. 8. A bar plot comparing the relative errors for CP (center of pressure) determination methods across three models (Model 1, Model 2, and Model 3).

V. Conclusion

This paper has managed to develop and compare several different techniques of calculating the center of pressure of a model missile rocket and the need to achieve static stability, which is also one of the main aspects of ensuring the zero angle of attack and safe flying during external disturbances like wind or model variance. Applying flat figure method (simplified), graphical method, analytical method, and practical method studied on SolidWorks Flow Simulation, the research demonstrates that location of the center of gravity before the center of pressure is vital in static balance. Easy and applicable in nature, the flat figure method with error range of 15-28% may be used with exhibition rockets, whereas the analytical method may be considered perfect since the error is low (0-0.34% error) and used with high accuracy of competitive sport models involving international competitions. The graphical approach is of medium accuracy (3-12 percent error) and is a balanced approach. The combination of these methods will assist in the designing process of both exhibition and sports model rockets and stable and repeated launches. This analytical method is also advisable in the scenario of high-performance applications, and the answers obtained can be adopted to the future

investigations on enhancement of these techniques in terms of performance in competition-oriented rocket modeling. The conclusion is structured in the standard way, summarizing the study's purposes, procedures, principal findings, and inferences and pointing out potential areas for future development.

VI. Limitation and Future Recommendations

Notwithstanding this study's noteworthy results, a few caveats should be mentioned:

1. **Testing Scope:** Because most of the testing was done in controlled environments, it could not accurately reflect real-world situations where environmental elements like temperature fluctuations and wind variations could affect the stability and performance of model rockets.
2. **Model Variety:** Because the study only looked at rocket models, its findings might not apply to other designs. Further study over a wider range of rocket designs is necessary since different forms, sizes, and materials may provide different stability outcomes.
3. **Error Margins:** Although the techniques used resulted in acceptable misalignment errors of less than 15%, real-world applications may add unanticipated elements that might compromise stability, such as inaccurate design or inconsistent material.
4. **Limited Analytical Depth:** Some approaches may need to be further refined and validated by numerous experimental trials to achieve broader accuracy and dependability, even though they are useful for early assessments of static stability.

Future studies should concentrate on improving the methods for assessing static stability using more sophisticated computational approaches and practical testing in a range of environmental settings. Static stability evaluations will be more robust if the impacts of external disturbances, such as wind shear and engine thrust fluctuations, are investigated. Furthermore, the use of artificial intelligence-powered automated design tools may further expedite the design process and allow for the quick fabrication of high-performance model rockets that are suited for record-breaking efforts and competitive situations.

These constraints should be addressed in future studies, and a few directions for expanding our understanding of model rocket stability should be investigated.

1. **Expanded Testing Environments:** Field testing in a range of weather situations and wind tunnel testing at different speeds and angles of attack can improve comprehension of real-world performance.
2. **Diverse Model Evaluation:** To further generalize results and provide design guidelines that work with a larger range of model rocket types, future research should look at a greater range of rocket designs, such as unusual forms or novel materials.
3. **Advanced Computational Techniques:** Including more complex computational fluid dynamics (CFD) simulations may offer a deeper understanding of aerodynamic interactions and behaviors, which might improve design optimizations.
4. **AI-Driven Design Tools and Automated Tools:** Research into creating AI-driven automated tools for model design optimization might expedite the process and enable rapid prototyping, enabling faster iterations based on performance feedback.
5. **Emphasis on Dynamic Stability:** Researching dynamic stability, particularly the effects of thrust decay and center-of-gravity shifts brought on by fuel use, will yield crucial data for creating rockets that operate dependably over the course of their flights.

Researchers may make a substantial contribution to the development of model rocket stability and design procedures by tackling these constraints and following these potential avenues.

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