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International Journal of Aeronautical Science & Aerospace Research (IJASAR)
ISSN 2470-4415

Analytical Calculation On Rocket Stability

Research Article

Gedlu Solomon[1*], Yisehak Abreham[2]

[1] Associate Researcher, Space Engineering Research and Development, Ethiopia Space Science and Technology Institution, Addis Ababa, Ethiopia.
[2] Assistant Researcher, Ethiopia Space Science and Technology Institution, Addis Ababa, Ethiopia.

Abstract

In this paper, we describe the method of analytical calculation on rocket stability by adjusting fin dimension. To reach on that the center of gravity and center of pressure are calculated and by introducing clipped delta fin Static Margin are checked.

Keywords: Center or Mass, Center-of-Pressure, Static Margin, Fins.

Introduction

The definition for model rocket stability is when the Center-of-Gravity (CG) is in front of the Center-of-Pressure (CP). The further distance the CG is in front of the CP, the more stable the rocket will be [1].

Metrology

Center or mass (CM) is the average location of all the mass of an object. For fully symmetrical objects the CG will be at the geometric center.

Ways to locate the CG

• List the mass of each component,

Mass of rocket body or chamber plus propellant = 981 kg
Mass of nosecone with payload = 34.69326615 kg
Mass of nozzle = 1.4 kg, since nozzle is not exposed component we can ignore for CP and for CG value it is relatively very small let's compensate its effect on stability by further analysis.

• Calculate the "CG station" of every component.

$\bar{X}_{CGi}$ is its CG location with respect to a fixed origin

Equations for solid or hollow cylinders

$$X_{CGcylinder} = \frac{1}{2} * L$$

$$X_{CGcylinder} = 0.972393937m$$

$$\bar{X}_{CG\ cylinder} = 4.002162248m$$

Equations for tangent ogive nosecone

$$X_{CG\ Nosecone} = 0.685 * L2$$

$$X_{CG\ Nosecone} = 2.075391292m$$

$$\bar{X}_{CG\ nosecone} = 2.075391292m$$

• Calculate a sum of the masses

$$M_{total} = \Sigma M_i = M_{cylinder} + M_{nosecone} 3$$

M_{total} = 1,015.693266 kg

• Calculate a sum of CG stations * masses

***Corresponding Author**:
Gedlu Solomon,
Associate Researcher, Space Engineering Research and Development, Ethiopia Space Science and Technology Institution, Addis Ababa, Ethiopia.
Tel: +251973342296
Email: gedlusolomon076504@gmail.com

Received: July 23, 2020
Accepted: October 06, 2020
Published: November 30, 2020

Citation: Gedlu Solomon, Yisehak Abreham. Analytical Calculation On Rocket Stability. *Int J Aeronautics Aerospace Res.* 2020;7(4):244-248.
doi: http://dx.doi.org/10.19070/2470-4415-2000030

$$\Sigma M_i \bar{X}_{CGi} = M_{cylinder} \bar{X}_{cylinder} + M_{nosecone} \bar{X}_{CGnosecone} \quad 4$$

$$M_{tot} \bar{X}_{CGtotal} = 3{,}998.123268$$

• Find $\bar{X}_{CGtotal}$ by dividing to M_{tot}

$$\bar{X}_{CG\ total} = \frac{M_{tot} \bar{X}_{CG\ total}}{M_{tot}} \quad 5$$

$$\bar{X}_{CG\ total} = 3.936349094$$

Center of pressure (CP) is the average location of all the aerodynamic forces acting on an object as it travels through the air. we will focus just on components of aerodynamic forces that are "normal" to the body as opposed to the drag forces which point backward, parallel to the rocket body [2].

Ways to locate the CP

• List the normal force coefficient of every exposed component

$C_{n\ cylinder} = 0$

$C_{n\ nosecone} = 2$

• Calculate the "CP station" of every component.

Its CP location with respect to a fixed origin

$$X_{CPcylinder} = \frac{1}{2} * L \quad 6$$

$X_{CP\ cylinder} = 0.972393937$ m

$X_{CP\ cylinder} = 0.972393937$ m

$X_{CP\ Nosecone} = 0.466 * L$ 7

$X_{CP\ Nosecone} = 1.411872032$ m

$X^{-}_{CP\ nosecone} = 1.411872032$ m

• Calculate a sum of the normal force coefficients.

$N_{total} = \Sigma Nc = C_{n\ cylinder} + C_{n\ nosecone}$ 8

$N_{total} = 2$

• Calculate a sum of CP stations * coefficients

$$N_i \bar{X}_{cpi} = N_{cylinder} \bar{X}_{cylinder} + N_{nosecone} \bar{X}_{CPcylinder} \quad 9$$

$$N_{total} \bar{X}_{cptotal} = 2.823744064$$

• Find $\bar{X}_{cptotal}$ by dividing to N_{total}

$$\bar{X}_{CP\ total} = \frac{Ntot\ \bar{X}_{CP\ total}}{Ntot} \quad 10$$

$$\bar{X}_{CP\ total} = 1.411872032$$

Static Margin (SM) is characterizes the tendency of a rocket to self-correct its direction of travel back towards nose, first if it is disturbed for any reason while in flight.It is a dimensionless number found by dividing the distance between the Center of Gravity (CG) and the Center of Pressure (CP) by the body tube diameter, the worst-case scenario is to use the largest diameter of the rocket [3].

Here are those conditions that can cause uncontrolled pitch in a model rocket [4].

✓ Basic instability in the design
✓ Imperfection in construction
✓ Fly in the excessive wind

Fins

Fins should be constructed so that they can withstand the forces expected during flight. The materials and methods of construction determine how much force they can withstand. Very small models do not need very strong fins, and simple cardboard or balsa fins will suffice. Large models and those intended to fly at extremely high velocities will need more strength.

The following list gives several materials and construction methods, in order of increasing strength [1]:

• Thick cardboard (not corrugated)
• Balsa wood fins
• Plastic fins
• Balsa wood with paper reinforcing
• Balsa with spruce wood reinforcing
• Built-up fins
• Foam core fins
• Fiberglass reinforced fins
• Plywood

Balsa wood is a very good material for fins as its strong and light, and perfect for rockets up to around D impulse. Balsa has a tendency to dent or split if it's handled roughly, and some rocket fliers use basswood as a stronger alternative. Some model shops stock thin plywood, which makes excellent fin material for rockets in the E to H impulse range. Sheet plastic can also be useful as a fin material in low power rockets, though it can be quite flexible which precludes its use for large fins. Fibre glass is very common for F motors and above as it is light, stiff and strong. Glueing plastic and fibre glass to cardboard tubes can be quite difficult, so most low and medium power rockets use wooden fins [5].

let take U type or 1,310,000 to 2,620,000 total impulse classifieds is fiber glass.

Various alternative fin shapes can be used during the rocket design process considering the mission requirements. The most commonly used fin types are clipped delta, swept, trapezoidal and triangular. Each of them can be sized using different number of geometric sizing parameters such as: span length, root chord length, tip chord length, sweep angle, and thickness. Within the content of this research the four fin shapes illustrated in figure 1 are examined.

Each fin shape is sized using different number of parameters. Clipped delta fin and trapezoidal fin have 4 different sizing parameters that are root chord, span, tip chord, and thickness. Swept fin has 5 different sizing parameters that are sweep angle, root chord, span, tip chord, and thickness. Triangular fin has only 3 different sizing parameters that are root chord, span, and thickness [6].

Fins thickness

$$d = \frac{pLD}{4E\Delta L}(1-2v) \quad 11$$

d= 0.0054485011 mm let say d≅1 mm

D = (1/2*(0.949)+(1.14))=1.6145 m

D = diagonal length

Maximum force experience in hazard condition on fin flat position and C_{fin} =1.28 [7].

$$\mathbf{F_{fin}} = \mathbf{C_{fin}} * \frac{\rho \mathbf{V}^2}{2} * \mathbf{A} \quad 12$$

A= 0.765 m^2

F_{fin} = 459,358.8996 newton

$$\mathbf{p_{fin}} = \frac{\mathbf{F_{fin}}}{\mathbf{A}} \quad 13$$

p_{fin} = 600,469.1499 pascal

Equations for a "clipped delta" fins.
Ways to locate the CG

• List the mass of each component

$$m_{fin} = 2,495\frac{\text{kg}}{\text{m3}} * (0.001m * 0.765m^2) = 1.908675$$

• Calculate the "CG station" of every

$$X_{CG\ fin} = \frac{b^2 + \frac{2}{3} * m^2 + 2 * m * b}{2b + m} \quad 14$$

Where from figure 2

b = 0.7 m

Figure 1. Frequently Used Fin Shapes and Geometric Sizing Parameters.

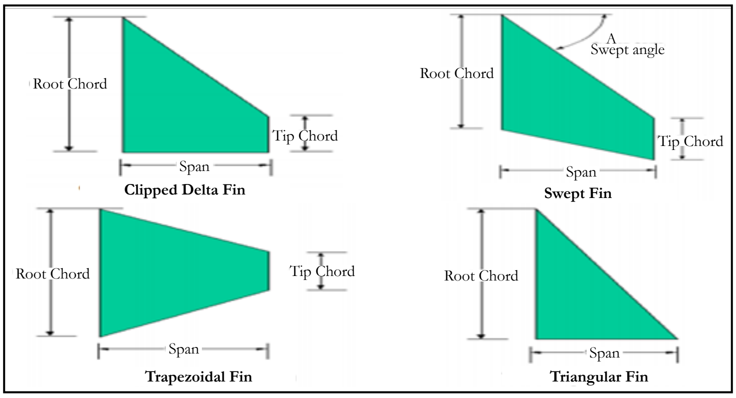
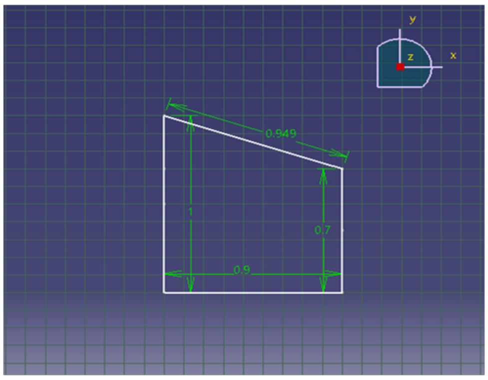


Figure 2. fins dimension.



m = 0.3 m
s = 0.9 m
L = 0.912 m
a = 1

$\mathbf{X_{CG\ fin}} = 0.570588235\mathbf{m}$

$\bar{\mathbf{X}}_{\mathbf{CG\ fin}} = 4.84514442\ m$

• Calculate a sum of the masses

$M_{total} = \Sigma M_i = m_{fins} = 4 * 1.908675$ kg = 7.6347 kg

• Calculate a sum of CG stations * masses

$$\Sigma M_i \bar{X}_{CG\ i} = M_{fin} \bar{X}_{fin} \quad 15$$

$$M_{fin} \bar{X}_{fin} = 4*[1.908675 * 4.84514442] = 36.9912241$$

Ways to locate the CP

• Normal coefficients for n "clipped delta" fins where N = 4 fins.

$$C_{n\ fin} = (4N(s/d)^2)/(1+\sqrt{(1+((2*l)/(a+b))^2)}) \quad 16$$

$C_{n\ fin} = 14.3090304$

Taking the body interference factor into account

$$K_{fb} = 1 + \frac{r}{s+r} \quad 17$$

$K_{fb} = 1.251855915$

$$C_{nb\ fin} = C_{n\ fin} * K_{fb} \quad 18$$

$C_{nb\ fin} = 17.91284435$

• Calculate the "CP station"

$$\mathbf{X_{CP\ fin}} = \frac{\mathbf{m(a+2b)}}{\mathbf{3(a+b)}} + \frac{1}{6}(\mathbf{a+b} - \left(\frac{\mathbf{ab}}{\mathbf{a+b}}\right)) \quad 19$$

$X_{CP\ fin} = 0.355882342$

$\bar{\mathbf{X}}_{\mathbf{CP\ fin}} = 4.630438527$

• Calculate a sum of the normal force coefficients

$N_{total} = 17.91284435$

• Calculate a sum of CP stations * coefficients

$$N_i \bar{X}_{CP\ i} = N_{fin} \bar{X}_{fin} \quad 20$$

$N_{fin} \bar{X}_{fin} = 82.94432461$

Fin correction and stabilizations

CG.

mass

Mass of rocket body or chamber plus propellant = 981 kg
Mass of nosecone with payload = 34.69326615 kg
Mass of nozzle = 1.4 kg
Mass of fin =7.6347 kg

CG stations

$\bar{X}_{CG\ cylinder} = 4.002162248$ m
$\bar{X}_{CG\ nosecone} = 2.075391292$ m
$\bar{X}_{CG\ fin} = 4.84514442$ m

Sum of mass

$M_{total} = 1{,}024.727966$ kg

Sum of CG stations * masses

$$\Sigma M_i \bar{X}_{CG\ i} = M_{cylinder} \bar{X}_{cylinder} + M_{nosecone} \bar{X}_{CG\ nosecone} + M_{fin} \bar{X}_{fin}$$

$$M_{tot} \bar{X}_{CG\ total} = 4035.114492$$

$$\bar{X}_{CG\ total} = \frac{\text{Mtot}\, \bar{X}_{CG\ total}}{\text{Mtot}} = 3.937742138$$

CP.

Normal force coefficient of every exposed component.

$C_{n\ cylinder} = 0$
$C_{n\ nosecone} = 2$
$C_{n\ fin} = 17.91284435$

"CP station" of every component

$\bar{X}_{CP\ cylinder} = 4.002162248$ m
$X_{CP\ nosecone} = 1.411872032$ m

$\bar{X}_{CP\ fin} = 4.630438527$

Sum of the normal force coefficients

$N_{total} = \Sigma Nc = C_{n\ cylinder} + C_{n\ nosecone} + C_{n\ fin}$

$N_{total} = 19.91284435$

Sum of CP stations * coefficients

$$N_i \bar{X}_{CP\ i} = N_{cylinder} \bar{X}_{cylinder} + N_{nosecone} \bar{X}_{nosecone} + N_{fin} \bar{X}_{GPfin}$$

$$N_{total} \bar{X}_{CP\ total} = 85.76806867$$

$$\bar{X}_{CP\ total} = \frac{\text{Ntot}\,\bar{X}_{CP\ total}}{\text{Ntot}} = 4.307173158$$

Acknowledgement

They author of this paper appreciate Space Engineering Research and Development Department, Ethiopia Space Science and Technology institution, Addis Ababa, Ethiopia for their valuable advice.

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