**Physics-Based Model for Rocket Thrust**

This document explains the physics and reasoning behind each constant, equation, and function used in a Python simulation modeling the thrust of a solid rocket motor.

# Constants and Their Physical Meaning

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| Symbol | Description | Explanation |
|  | Atmospheric pressure  (≈ 101,325 Pa at sea level) | The pressure of the surrounding air outside the rocket. The difference between this and internal nozzle pressure drives exhaust flow and thus thrust. |
|  | Specific heat ratio (adiabatic index) | Ratio of specific heats . It affects how gases compress and expand, impacting sound speed and isentropic gas flow equations. |
|  | Specific gas constant | Relates pressure, temperature, and density for the combustion gases: . Different propellant gases have different values. |
|  | Combustion chamber temperature | Temperature inside the combustion chamber. Higher means hotter gases and faster exhaust velocity, increasing thrust. |
|  | Nozzle efficiency coefficient | Dimensionless factor (close to 1) accounting for inefficiencies in gas flow through the nozzle, like friction and turbulence. |
|  | Propellant density | Mass per unit volume of solid fuel. Higher density means more mass burned per unit volume, directly affecting thrust. |
|  | Nozzle throat area | The smallest cross-sectional area of the nozzle where the gas reaches sonic speed (Mach 1). Controls mass flow rate and chamber pressure. |
|  | Nozzle exit area | The area where gases leave the nozzle. Affects expansion and exit velocity but not directly used here for thrust calculation. |
|  | Empirical pressure coupling constant | A tuning parameter used in chamber pressure calculations to model complex effects like nozzle geometry and combustion dynamics. |
|  | Base burn rate constant | The linear burn rate of propellant at reference pressure. It is adjusted by pressure to model real burn rate changes. |
|  | Pressure exponent | Defines how burn rate scales with chamber pressure, typically less than 1. For example, means burn rate scales with the square root of pressure. |
|  | Gaussian shape parameters | Constants that define the time-based shape of the burning surface area via two Gaussian functions modeling thrust profile shape. |
|  | Amplitudes of Gaussian components | Scale the magnitude of each Gaussian in the burn area function, controlling initial thrust spike and plateau magnitude. |
|  | Centers (mean times) of Gaussian pulses | The times at which the initial thrust spike and plateau phase are centered. |
|  | Widths (standard deviations) of Gaussian pulses | Control how sharp or broad each Gaussian pulse is, affecting thrust duration and smoothness. |
|  | Initial total propellant mass | The starting mass of solid fuel. The simulation ends when all fuel is burned. |
|  | Simulation time step | The small increment in time for each calculation step. Smaller values improve accuracy but increase computation. |
|  | Maximum simulation time | Total duration to simulate, long enough to capture full motor burn and thrust decay. |

# Key Equations and Their Meanings

## 1. Burn Area as a Function of Time

The burning surface area is modeled as two overlapping Gaussian pulses:  
  
**first Gaussian** represents the sharp initial spike in burning area (and thrust) just after ignition.  
- The **second Gaussian** models the longer plateau phase of steady burning.

## 2. Burn Rate

The rate at which the propellant surface regresses (burns inward) depends on chamber pressure:  
  
 is the base burn rate.  
- is the pressure exponent (e.g., 0.5 means burn rate scales as the square root of pressure).  
- is the combustion chamber pressure at time .

## 3. Mass Flow Rate

Mass of propellant burned per second, calculated from burn area and regression speed:

## 4. Propellant Mass Update

Remaining unburned propellant mass decreases over time:

## 5. Chamber Pressure

Chamber pressure is determined by the balance between mass flow, throat area, gas properties, and combustion efficiency:  
  
 reduces pressure to account for nozzle inefficiencies.  
- is an empirical tuning constant.

## 6. Exhaust Velocity

Exhaust gas velocity at the nozzle exit:  
  
, and gas properties.

## 7. Thrust

Final thrust produced by the rocket:

# Summary of Relationships

- control the shape and timing of the burning surface area and thus shape the thrust curve.  
- govern how quickly the propellant burns under different pressures.  
- describe physical and chemical properties of the propellant, gas, and nozzle.  
- The model balances **physics-based principles** with **empirical tuning** to reproduce realistic thrust profiles.