

# Analyzing a Rocket movement Using Empirical Modelling Principles in 2D Space

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## Abstract

Rocket science is usually used to teach Math and Physics to students. But Analyzing Rocket Movement is a very hard task taking in account all the forces that will affect the rocket during its flight. And trying to model this movement in traditional or object-oriented programming languages will force a limitation on how we interact and learn from this model especially when trying to change or extend the parameters affecting the movement of the rocket in an easy and obvious way. Empirical Modelling principals introduced new concepts that will allow the building of robust models that can be manipulated and extended at runtime, which introduce more interactive models for learning and interaction. Eden and Cadence are used to build this Model using EM principles. This project will be focusing on building a model for studying rocket movement for educational proposes, and analyzing forces which are involved.

## 1 Introduction

It is difficult to describe what is the best approach to use when teaching students new concepts. This is obvious especially in math, engineering teaching and computer science. M. Klawe (1995) has proposed that interaction is an invaluable method for improving understanding. And because of this many organizations and schools are trying to find out what is the best way to merge software into education. And Empirical Modeling (EM) concepts can achieve this goal, by constructing software components that are easy to use, and which are also flexible to modify easily based on changing definition and dependencies between different observables.

Math and Physics are very hard to study when not combined by practical examples. This is why most schools currently teach Rocket science to know how forces can interact to produce movement when the rocket is launched. NASA<sup>1</sup> is considered one of the big contributors in this field. But most students could not afford to have a real model rocket. In this case we must provide some kind of good interactions mechanism which is proposed by this project.

This work will be focusing on building a model for studying rocket movement and the forces that can be used to explore EM principles, also give students, who are interested in the field of Rockets and Aerodynamics, a grasp on math and physics principles, through interactions with a lively model demonstration.

Rocket movement is influenced by several forces and is the focus of several fields of study like Aerodynamics and Gravitational forces. And there is a strong relation with thermodynamics and gas dynamics to study the effect of how other factors can affect the movement of the rocket. I will be focusing on the most important forces that will affect the movement in 2D space, trying to build an Interactive model which will allow manipulation of Parameters (Like : weight, Dimension, Fuel amount and Type, Gravity ...) and will show the rocket movement in 2D graphics.

This model allows students to modify most parameters that affect the rocket movement. Also there are a lot of interactive observables like: time, forces, parameters, distance. There are also a lot of dependencies between these observables which are expressed as mathematical formulas. This makes EM the best approach to construct such a model.

The rocket Simulator which is built using EM model is proposed to be used as an interactive learning tool for both Engineering and Computer Science student. It is proposed for engineers because it can show how math is used to solve the problems of analysing

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<sup>1</sup> Beginner's Guide to Rockets

<http://exploration.grc.nasa.gov/education/rocket/bgmr.html>

forces that affects a model rocket when launched. Also computer science student can benefit from this model to understand how EM is used to construct such software. Especially to see a scenario on how to connect Cadence and Eden together to build such a construal based on EM concepts. Cadence was used as the rocket engine. Eden is used as an interactive interface linking the user interaction with the Cadence engine. It uses the DoNaLD extension for drawing graphs, and SCOUT for creating windows and buttons.

## 2 Rocket Science

There are a lot of forces which affects the movement of a rocket Figure.1:

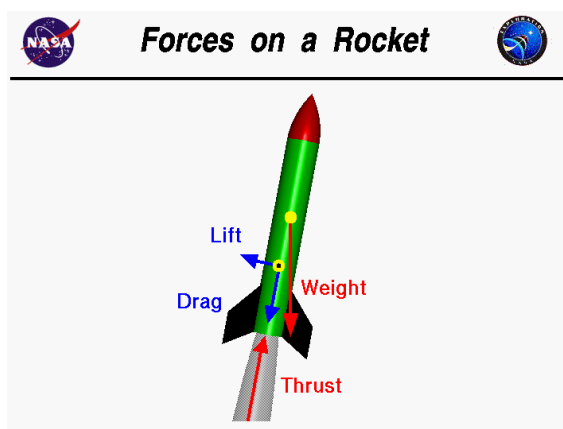


Figure.1 Forces affecting Rocket (NASA)

There are mainly two sets of forces:

- Forces affecting the Centre of Gravity, like Weight and Thrust.
- Forces of Aerodynamic which affects the Centre of Pressure, like Lift and Drag.

We didn't implement the Lift affect on the rocket.

By using Newton's Laws it is known that the total Force which affects the rocket can be calculated as (all are vector values):

$$\text{Total} = \text{Thrust} + \text{Weight} + \text{Drag}$$

Many inputs affect the calculation of each force; these inputs are presented for the user so that he can interact through the model and ana-

lyze the rocket movements. These parameters are:

### 1. Thrust Related Parameters:

- Fuel Mass
- Fuel Burning Rate
- Fuel Exhaust Speed

### 2. Weight Related Parameters:

- Fuel Mass
- Rocket Mass
- Gravitational Acceleration

### 3. Drag related Parameters:

- Air density
- Rocket velocity
- Rocket Reference Area
- Drag coefficient

Some parameters affect multiple forces which creates an interdependency relation. Also all these forces are dependent on time. Most of these forces can be solved as differential equation to time. But to keep matters simple Ordinary Differential Equations (ODE) are introduced on Unified Engineering<sup>2</sup> site. These equations tries to calculate next step values based on the previous step values.

$t$	time	$\rho$	air density
$h$	altitude	$g$	gravitational acceleration
$V$	velocity, positive upwards	$m$	mass
$F$	total force, positive upwards	$C_D$	drag coefficient
$D$	aerodynamic drag	$A$	drag reference area
$T$	propulsive thrust	$\dot{m}_{\text{fuel}}$	fuel mass flow rate
$\Delta t$	time step	$u_e$	exhaust velocity
$\dot{(\ )}$	time derivative ( $= d(\ )/dt$ )	$i$	time index

<sup>2</sup> Unified Engineering  
<http://web.mit.edu/16.unified/www/FALL/systems/>

$$\begin{aligned}
h_{i+1} &= h_i + (V_i)(t_{i+1} - t_i) \\
V_{i+1} &= V_i + \left( -g - \frac{1}{2} \rho V_i |V_i| \frac{C_D A}{m_i} + \frac{V_i}{|V_i|} \frac{\dot{m}_{\text{fuel}} u_{e_i}}{m_i} \right) (t_{i+1} - t_i) \\
m_{i+1} &= m_i + (-\dot{m}_{\text{fuel}})(t_{i+1} - t_i)
\end{aligned}$$

These formulas only deal with the rocket moving vertically, launched in  $90^\circ$  angels. These formulas were extended to deal with movement on the horizontal axis also. These formulas were implemented using Cadence and it will be mentioned in later section.

## 3 Related Work

### 3.1 Education

Electronic devices are heavily used now in the Education process. Many software were developed to aid teacher in introducing the information for their students. Usually students are used the features that are only present in that software. This makes the learning experience limited, especially when trying to have new questions that need to be modified in the system. Beynon (1997) comments "To the imaginative pupil, IT products for educational use often appear too limited in scope". This means that any software needs to be flexible enough to be opened for change. EM approaches this by constructing software using observables and dependencies.

Beynon (1997) goes further in explaining why EM is appropriate in the learning process "because the principles of model construction are bound up with the learning process", which means that it will make the student not only to receive information, but also be part of educational process. Also Beynon mention that EM "can be the basis of a successful approach to computer-based model construction precisely because it established a direct link between the conception of the model and its construction", which means that the student will be also responsible of building the learning experience.

So it is better to have software that can be flexible to any input and only be limited by the user imagination.

### 3.2 Software for Rocket Simulation

A lot of example can be found on this topic. NASA provided a Rocket Simulator <sup>3</sup> using Java applet Figure.2.

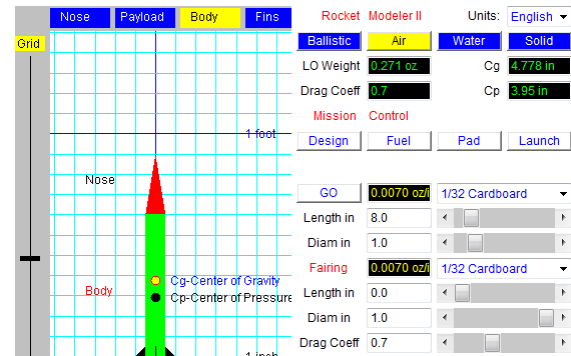


Figure.2 Rocket Simulator

Although this simulator is so powerful, but it lacks the flexibility factor. That means that this system is only designed as a static perception of what the programmer thought as a good learning example. It can't be extended or manipulated by students to enrich the learning experience. While this project didn't tackle each parameter that can affect the rocket, but it showed a good flexibility in development, which means it can be extended to have new features easily.

### 3.3 Models

A lot of pre-existing models were studied to construct this model. These models can be found in the EM project archive<sup>4</sup>. Yung's 'Room Viewer' was inspected to study how observables and dependencies can be defined. Especially using multiple notations like Eden, Scout and Donald.

Traffic lights by James McHugh also was inspected to see how Eden and Cadence can be used in a single model. Other models will be mentioned at the end of this project.

## 4 EM model

Eden and Cadence were used because Sharing of observables has a number of advantages. Cadence supplies mechanisms that address deficiencies of EDEN where large families of similar definitions have to be created. It also affords more elegant and expressive ways to organise contexts and to introduce process-like observables. EDEN provides a way to handle input and output and to inject agency into Cadence models without having to use the more sophisticated techniques.

The main Idea is to split the domain of concerns into two areas Figure.3:

- Cadence will be used as the rocket engine.
- Eden will be used as an interactive interface with the learner.

<sup>3</sup> Rocket Simulator

<http://exploration.grc.nasa.gov/education/rocket/rktsim.html>

<sup>4</sup> EM projects archive,

<http://www2.warwick.ac.uk/fac/sci/dcs/research/em/projects/>

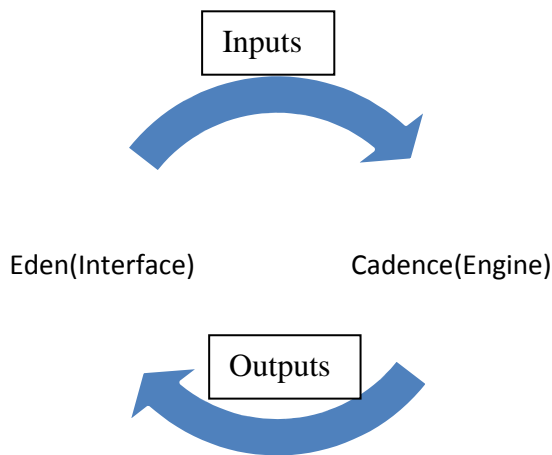


Figure.3 Overview Model

#### 4.1 Cadence

“rocket\_cadence.dasm” file contains all observables which relates to the rocket movement and forces. Also this file creates the Handle and Oracles which will be used to Interact with Eden environment Figure.4.

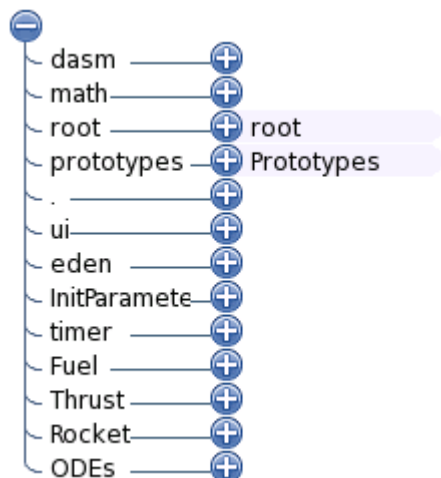


Figure.4 Cadence Observables

There is a timer observable which is responsible of starting the clock of the simulation. The main observable is “ODEs” which contains the Ordinary Differential Equations for both horizontal and vertical forces analysis.

“edenParams” are created as a Handler, and “cadenceParams” are created as an Oracle.

#### 4.2 Eden

“rocket.s” contains all notations related to UI interactions. Scout and Donald are used to construct the User Interface Figure.5:

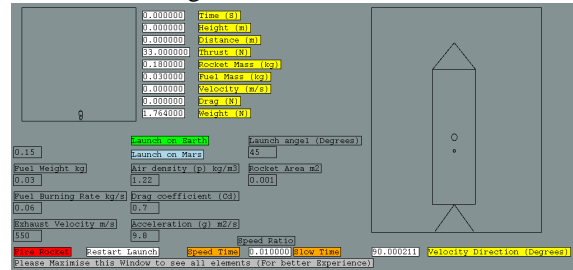


Figure.5 Eden Rich UI

In the user interface there is a main view which shows the rocket movement with another window which shows a zoom-in feature. There is a main part to input and change parameter. Also there is a main part which shows how values and forces change in time when the rocket is launched.

#### 4.3 Possible Interactions

A learner can interact with this model in different ways:

- Engineers can use the Eden UI to learn and experiment different values for parameters. As an example try to make the rocket reach the Limit Velocity based on some inputs. Also trying to change the Launch Angel to see how far the rocket will travel.
- Computers science student can Learn EM concepts by interacting with both Eden and Cadence. They can see how clicking the “Fire” in Eden starts the engine in Cadence. And they can bypass the UI to change and extend this model if they like.

#### 4.4 Running the Model

First “rocket\_cadence.dasm” file must be executed in Cadence environment. This will launch Eden tool. Then “rocket.s” must be included in Eden and then Executed. This will launch the UI and link Cadence and Eden.

#### 4.5 Model Evaluation

This model is entirely new, and it was constructed to aid in the Educational process to both Engineers and EM Computer Science learner. It showed a retch interaction between Eden and Cadence. Also the UI is easy to understand. And most observables are defined using clear meanings. Also feedback was positive from EM class colleges who tested the model.

## 4.6 Future Enhancements

A lot of enhancement can be introduced to the model:

- Enhancing Rocket look and feel with Forces vectors showing on the rocket.
- Adding extra parameter to change Rocket dimensions, which will change the Gravity Centre accordingly.
- Lift force can be introduced with the Wind factor.

## Acknowledgements

I want to thank all the EM team members in helping us to understand EM concepts. Also want to thank all who contributed to the EM project archive to make the learning process much easier.

## Eden and Cadence models

Traffic lights, by James McHugh  
racingGardner1999 (Racing Cars)  
roomYung1989 (room viewer)  
oxoGardner1999 (O's and X's game)

## References

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