

Internal Ballistics Simulation Based on Object Oriented Programming

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Abstract—The knowledge of internal ballistics simulation is quite obscure due to security reason related to rocket implementation for national defense. Internal ballistics simulation involves complex calculation of thrust profile generated by burning solid propellant mass. The design of appropriate solid propellant mass for desired thrust profile requires visualization of propellant mass and overlook how it burns from the start to the end. Object-oriented programming has been used as a tool for simulation of complex mathematic algorithms in many fields. This paper introduced object-oriented programming framework and software architecture for solving complex calculation of thrust profile and visualization of burning solid propellant. JAVA programming language is chosen to implement a test program for proving objected-oriented programming based internal ballistics simulation. The result shows the reasonable trend of thrust profile according to the real behavior of thrust generated by solid propellant. This paper give intuitive idea of implementing simulation tool for designing of solid propellant mass in rocket application.

I. INTRODUCTION

Rocket has been used in defense technology in many countries. However, the art of rocket design has been kept as a classified information. Only a few rocket designing tool has been released to the public, and they are just for educational purpose. Rocket may refer to missile, spacecraft, aircraft, or other vehicle that contains a rocket engine for pushing rocket forward. There are many types of rocket, and they serve different purposes. Due to there are many different types of rockets, each rocket requires different thrust profile for different purposes. A thrust of a rocket engine is entirely formed by exhausive propellants. Designing of rocket propellant is necessary in order to archive suitable thrust profile for each type of rockets. Unlike amateur rockets, military rockets generate high thrust and cause severe damage. This is a complex task and very dangerous to test the real rockets. Therefore, a simulation software is necessary as a tool to design a complex and high-power rocket propellant. In many country, researches have been conducted on developing an internal ballistics simulation software. However, this kind of software affects the national security and cannot be released outside their countries. Thereby research on this topic would be valuable in term of economic and security of country developing its own rocket for national defense.

The paper in [1] presents the use of computer program to design rocket propellant. However the program is limited to design rocket propellant of only 2 layers. In addition it lacks of capability to visualize the rocket propellant design. The geometry of rocket propellant has to be designed in external CAD programs. Object Oriented Programming (OOP) is a programming language model organized around objects rather than actions and data rather than logic. [2] Hence we can model each layer of rocket propellant as object in OOP which make complex calculation of thrust profile easier.

In the next section, we discuss background information and previous studies related to Internal Ballistics simulation. Section II explains the OOP design and implementation of the Internal Ballistics. Section IV presents result of the pilot program to prove our propose concept, and discussed in section V. Section VI concludes and presents future improvements.

II. BACKGROUND AND RELATED WORKS

Inside Rocket Motor stored propellant mass, which drive the rocket forward. The combustion process proceeds throughout the length of the chamber and generate hot gases flow through the nozzle at high speed. Hence, thrust force is produced at the nozzle end.

Solid-propellant rocket is the simplest of all rocket design. Unlike liquid-propellant engines, solid-propellant motors cant be shut down. Once ignited, they burn until all the propellant is exhausted [3], we cant control the thrust force so designing of rocket propellant is necessary in order to archive suitable thrust profiles. Mostly propellants are designed with difference shapes of inner port. Calculating Cross section area is important to design rocket propellant efficiently.

There are two types of solid propellant, Double-Base propellant consist mainly of fibrous nitro-cellulose and a gelatiniser, or plasticiser, such as nitro-glycerine or a similar compound (ethylene glycol dinitrate), each containing oxygen and fuel in the same compound.[4] Composite propellant are solid particles of oxidizer and fuel suspended in a binder. The binder is liquid when cast into the rocket chamber and sets up or cures to form a rubbery compound.[5] The simulation program proposed in this paper only consider Composite propellant.

The principle method of the proposed is to calculate the mass flow rate of the generated gas at the nozzle using iterat

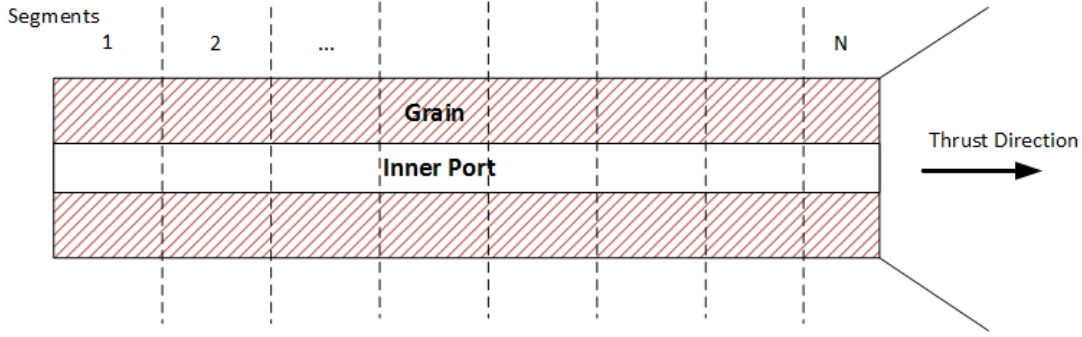


Fig. 1. Burning surface layer at 2 mm distance of solid propellant grain

along with the geometric data of inner port shape of the solid propellant.

The basic principle of mass flow rate calculation can be found in [6] The calculation assume that a rocket is in a steady state that is

$$\dot{m}_{NOZZ} = \dot{m}_p \quad (1)$$

\dot{m}_{NOZZ} = Mass flow rate at the nozzle

\dot{m}_p = Mass flow rate generated from propellant combustion

The relationship between Mass flow rate at the nozzle and Pressure at the nozzle.

$$\dot{m}_{NOZZ} = P A_t / C^* \quad (2)$$

P = Pressure at the nozzle

A_t = Cross section area of the nozzle

C^* = Characteristic Velocity of propellant

Mass Flow Rate generated from propellant combustion is calculated from the following equation.

$$\dot{m}_p = \int \rho r_b dA \quad (3)$$

ρ = Density of propellant

r_b = Burning rate of solid propellant

A = Burning area of solid propellant

For the composite propellant burning rate (r_b) is a function of pressure

$$r_b = a P^n \quad (4)$$

a = Pre-exponential Factor

n = Pressure Exponent

In addition to burning rate given by equation (4) we account for erosive burning component which make the burning rate become

$$r_b = a P^n + \alpha G^{0.8} D^{-0.2} \exp(-c \beta r_b \rho / G) \quad (5)$$

G = Mass Flow Rate per cross section area of Port = \dot{m}_p / A_p

A_p = Cross section area of port

D = Characteristic Dimension of Port = $4 A_p / S$

where S = Port periphery,

α and β are Empirical constant usually $\beta = 53$

III. DESIGN AND IMPLEMENTATION

A. Thrust Calculation

We divide propellant mass into several segments as illustrated in figure . Thrust Profile is calculated from mass flow rate of generated gas at the nozzle.

Mass flow rate at the nozzle is calculated from the mass flow rate from previous segments.

Mass flow rate in each segment is calculated as

$$\dot{m}_i = \dot{m}_{i-1} + m_{gen_i} \quad (6)$$

$$m_{gen_i} = \rho \cdot r_b(P, \dot{m}_i) \cdot A_i \quad (7)$$

m_{gen_i} = Mass flow rate of generated gas in segment i

r_b = Burning rate with erosive burning as a function of pressure and total mass flow rate flowing out from segment i

A_i = Cross section area of throat in segment i

In calculation cross section area and periphery in the segment is a function of burning distance from the previous surface.

To calculate guess pressure and start calculate from the first segment. Assume that mass flow rate into the first segment equal mass flow rate of igniter.

$$\dot{m}_0 = \dot{m}_{igniter}(t) \quad (8)$$

where $t \leq$ burning time of igniter

$$\dot{m}_{igniter} = \dot{m}_{igniter} / (t)$$

where $t >$ burning time of igniter ; $\dot{m}_{igniter} = 0$

Mass flow rate at segment i is calculated by

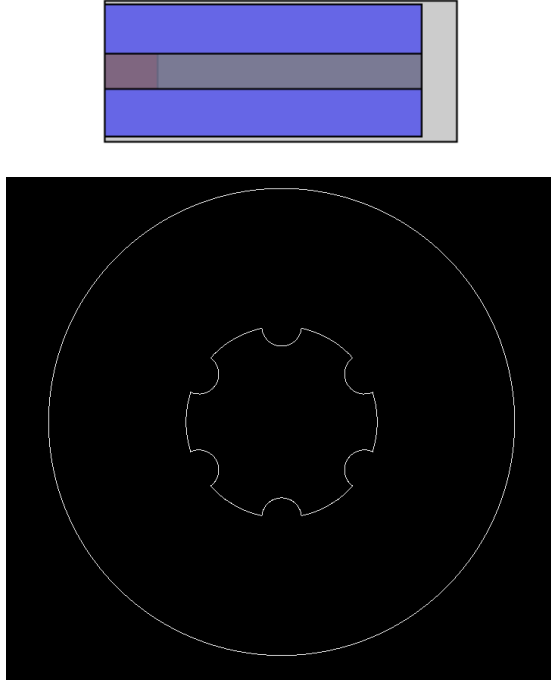


Fig. 2. Cross-section and horizontal cuts of solid propellant's grain

$$\dot{m}_i = \dot{m}_{i-1} + \rho r_{b1}(P, (\dot{m}_i + \dot{m}_{i-1})/2)A(\xi) \quad (9)$$

Mass flow rate at segment N is equal to Mass flow rate at the end of nozzle.

$$\dot{m}_N = \dot{m}_p \quad (10)$$

Verify if P from $\dot{m}_N = \dot{m}_p = \dot{m}_{Nozz} = PA_t C^*$ is equal to guessed P , use P to iterate until guessed P is closed to Convergence Limit.

Use P to calculate thrust at the nozzle[6]

$$F = C_F P A_t \quad (11)$$

where C_F = Thrust coefficient

B. The role of Object-Oriented Programming Architecture

C. Visualization of Solid Propellant Design

The key point of designing solid propellants grain is a visualization of grain. Figure 2 illustrates cross-section cut and horizontal cut of cylindrical grain. The visualization of solid propellant grain illustrates how grain's surface is burnt and generate gas. Computer aided design (CAD) softwares are usually used for designing solid propellant grain. The inner port of the grain is the surface that will burn in the direction perpendicular to previous surface. Figure 3 illustrates burning surface at burnt distance of 2 mm. The offset algorithm is useful to generate such layers of burning as illustrated in

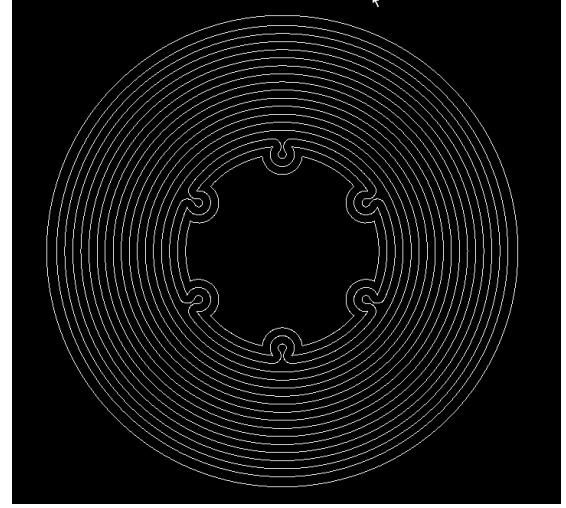


Fig. 3. Burning surface layer at 2 mm distance of solid propellant grain

Figure 3 [6]. In addition, most of CAD softwares have the capability of measuring inner port's periphery and area, which are used in thrust profile calculation.

D. Program Architecture

To illustrate the use of OOP in Internal Ballistics simulation, a test program is written in JAVA to calculate thrust profiles of the . Figure 4 illustrates the high-level system architecture of the software. More than one solid propellants can be contained in a motor case. Each section can be modeled as an object with different propellant properties and geometries. Each section is then subdivided into small segments during calculation process. The program requires user to specify rocket, propellant, and simulation parameters. The process of calculation is already given in Section III. A CAD software is used to design inner port of the propellant grain, and capture inner port's periphery and area at each burning distance. Inner port's periphery and area data is then imported into the test program for calculation of thrust profile. The output of the test program is calculated thrust and pressure as functions of time.

IV. RESULT AND DISCUSSION

The program was simulated with parameters specified in Table I. The simulation assumes two propellant masses placed inside the motor case. Each has the same length and propellant's properties. Each section of propellant mass contains single layer of propellant. During calculation, propellant masses is divided into small segments and mass flow rates of each segment is calculated as mentioned in Section II. The simulation uses 100 segments. More segments would give more precise calculation, but requires longer calculation time. Mass flow rate at the nozzle is the consecutive sum of mass flow rate from each segment. The result of thrust profile is shown in Figure 5.

The peak at the beginning of the plot is the result of mass flow rates of igniter and propellant masses. As the igniter has gone out, thrust starts to drop and only propellant masses are

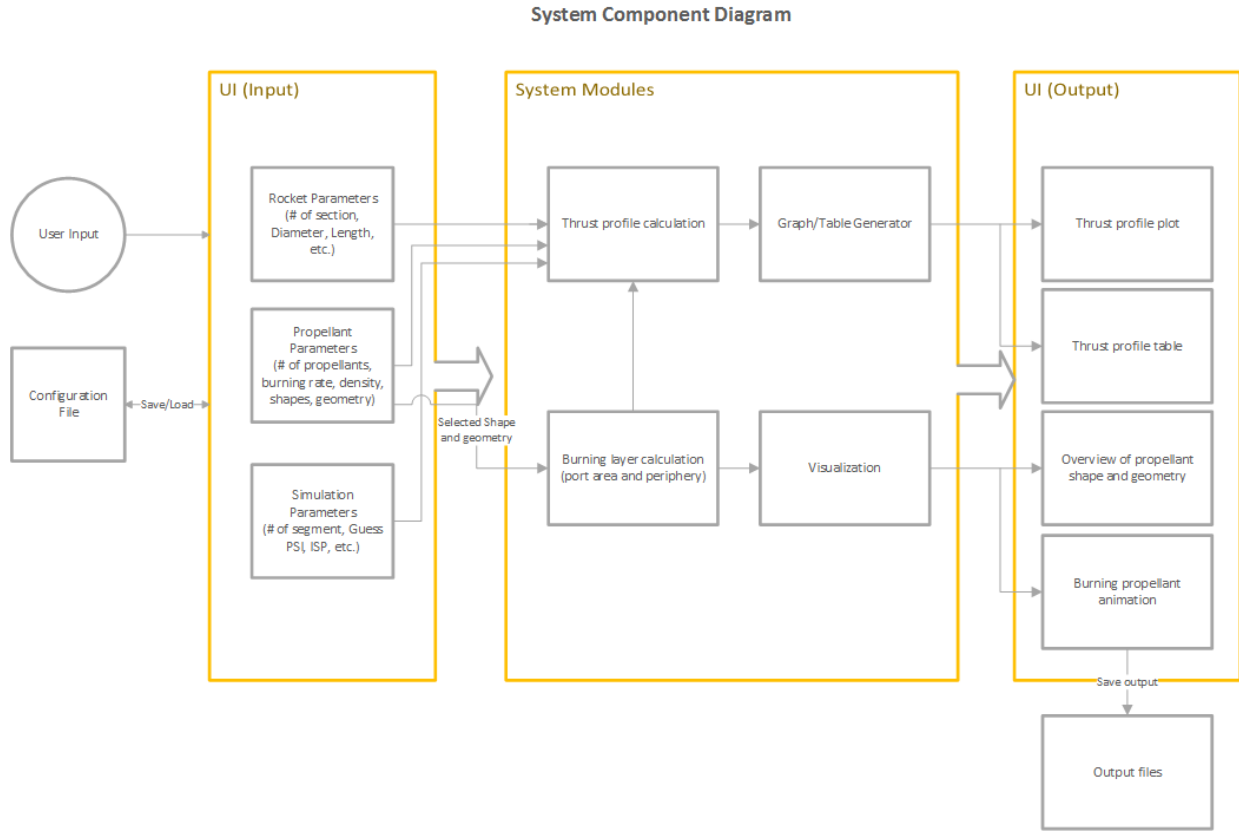


Fig. 4. System Components of the test program

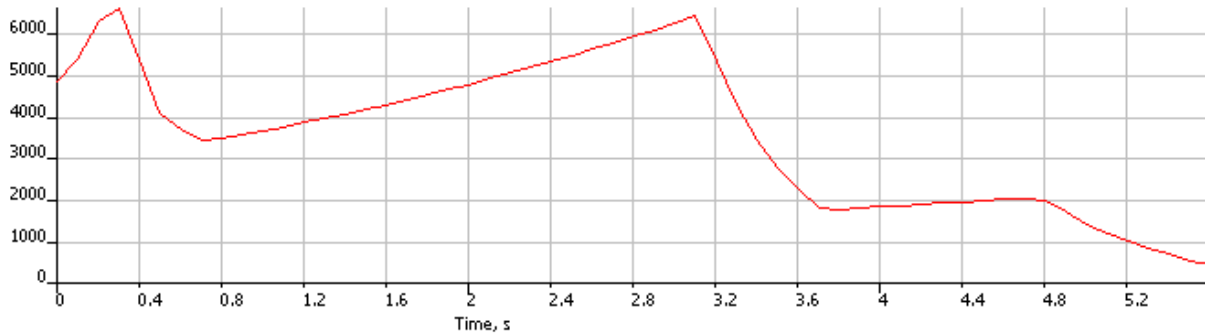


Fig. 5. Thrust profile of simulated propellant grains from the test program

burnt. Thrust starts to go up again as more propellant masses are burnt, and it will drop until pressure is below 50 PSI when all propellant masses are burnt out.

V. CONCLUSION

Simulation of internal ballistics requires complex calculation of thrust profile. The calculation requires many steps of iteration. The use of object-oriented programming helps easy implementation of such complex internal ballistics simulations. The visualization of propellant masses helps designing of solid propellant masses. The designing of propellant grain are usually done in CAD software. CAD software can be

used to extract periphery and area of grain's inner port, which will be in calculation of thrust profile. The test program is implemented to verify the use of object-oriented program to simulate internal ballistics of solid propellant. The test program implement theories and algorithm of thrust profile calculation that was previously conducted by other researches. The result shows that object-oriented program can implement complex calculation of internal ballistics. However, the purpose of this reasearch is to introduce the use of object-oriented programming in internal ballistics simulation. Many further studies should be conducted to obtain effective simulation algorithms.

Parameters	Values
Rocket Length (m)	2.2
Rocket Throat Diameter (mm)	81
Number of propellant mass	2
Number of Segments	100
Shape of inner port	Wheel
Number of propellant layer	1
Burning Rate (kg/s)	0.011
Pressure Exponent	0.48
Density (kg/m^3)	0.001795
Erosive Burning Constant	60×10^{-7}
Gas temperature (K)	3500
Individual Gas Constant	308
Heat Capacity Ratio	1.2
Specific Impulse	265
Guess Pressure (PSI)	1200

TABLE I
SUMMARY OF SIMULATION PARAMETERS

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