Test Articles For Sounding Rockets

Sourav Chand
Dept of Mechanical Engineering
College of Engineering and Technology, Bhubaneswar, 751029, India

Abstract- *This paper details the designing of an M-class solid rocket engine for testing purposes and a stage separation mechanism for a two-stage sounding rocket.Designing of the motor was completed by hand calculations and analysis was done with the help of various software including Open Motor, RPA, and Burn Sim. For these paration system, one latch made of active and inactive is considered. Final values of the motor components with calculations and CAD models are presented. Various CAD models of the stage separation mechanism as per the design requirements of the rocket are also presented.*

Keywords- Burn rate, Burn rate Coefficient, Burn rate exponent, Total impulse, Burn Time, Nominal Thrust, Specific Impulse, Exhaust Velocity, Acceleration, Propellant Weight, Web Thickness, Casing Thickness, Factor of Safety, Casing Outer Diameter, Casing Inner Diameter, Grain Inner Diameter, Grain Inner Diameter, Yield Strength of Casing Material, Linear Thickness.

I. INTRODUCTION

Sounding rockets are one or two stage solid propellant rockets used for probing the upper atmospheric regions and for space research. They also serve as easily affordable platforms to test or prove prototypes of new components or subsystems intended for use in launch vehicles and satellites. Sounding rockets take their name from the nautical term “to sound” which means “to take measurements”. Sounding rocket experiments are simple, cost-effective and time efficient. The Sounding rockets are divided into two parts: the payload and a solid-fueled rocket motor. After the launch, as the rocket motor uses its fuel, it separates from the payload and falls back to Earth. Meanwhile, the payload continues into space and begins conducting the experiment. In most cases, after the payload has re-entered the atmosphere, it is brought gently down to Earth by way of a parachute and is then retrieved. Scientific payloads are carried to altitudes from 30 miles to more than 800 miles. And although the overall time in space is short (typically 5 to 20 minutes), the experiment is perfectly positioned to carry out its mission successfully.

II. STUDIESANDFINDINGS

Solid rocket engines are used on air-to-air and air-to-ground missiles, on model rockets, and as boosters for satellite launchers. In a solid rocket, the fuel and oxidizer are mixed to form a solid propellant mixture which is tightly packed inside a solid cylinder. A straight hollow opening on the inner side of the cylinder serves as the combustion chamber of the motor. When the propellant mixture is ignited, combustion takes place on the surface of the propellant which is known as the burn area of the propellant grains. Due to this combustion of the fuel, and oxidizer, the resulting flame generated burns into the mixture. This in turn produces great amounts of exhaust gas at high temperature and pressure. The amount of exhaust gas that is produced depends on the burn area of the propellant grains, and engine designers use a variety of hole or grain designs to control the change in thrust for a particular engine. The hot exhaust gas is passed through a nozzle which accelerates the flow by choking the flow at the throat of the nozzle meaning the Mach number at this area is 1. The hot exhaust then exits through the nozzle due to which thrust is then produced according to Newton’s third law of motion.” There are mainly five components of a solid rocket motor and they are bulkhead, casing, liner and insulation, grains, nozzle.

PROPELLANT GRAIN

The grain is the solid body of the hardened propellant. A rocket motor’s operation and its design depend on the propellant’s combustion characteristics such as burning rate, burning surface, and grain geometry.The burning surface of a propellant grain recedes in a direction essentially perpendicular to it. The rate of regression, usually expressed in cm/sec, mm/sec, or in/sec,is the burning rate r.

Two methods of holding the grain in its case:

- Case bonded
- Free standing

Grain configuration:

- The shape or geometry of the initial burning surfaces of a grain as it is intended to operate inside a motor.

Types of propellant burning depending on the burning progression:

- Progressive burning
- Neutral burning
- Regressive burning

PROPELLANT SELECTION

Propep software was used for theoretically analyzing the specific impulse and burn temperatures of different formulations of the propellants I was contemplating. I found out estimates for the combustion temperature, specific heat ratio, exhaust nozzle conditions, and the number of moles of gaseous combustion products in the product mixture. Eventually, I optimized my mixture and decided that I would go with a propellant that is already established to work well, called Cherry Limeade by the Rocketry Club of MIT, Massachusetts. It is a mixture based on ammonium perchlorate. The following are its constituents.

MIT Cherry limeade Formulation

1. 200um ammonium perchlorate (65.5%)
2. 90um ammonium perchlorate (9.5%)
3. Hydroxyl-terminated polybutadiene (HTBP) (10.883%) - Binder
4. Aluminium (7.5%)
5. IsodecylPelargonate (IDP) (4.275%) - Plasticizer
6. Methylene diphenyl isocyanate (MDI) (1.942%) -

Since the latest version of Propep doesn't have MDI plasticizer to input, PAPI was used instead to get a rough estimate of the properties to be analysed. Another plasticizer used is IsodecylPelargonate (IDP) which is also the best plasticizer for HTPB-based binders. The software also didn't have PDMS and Triton X which is why they haven't been included in the calculations below. Both form 0.005 percent of the composition. The options that I enabled were to include Ionic Species, to increase the precision of the ionic species and to show all the combustion species at the end of the burn.
The conclusion from the parameters observed in this file are that for Cherry Limeade, taking into account the 2 ingredients missing

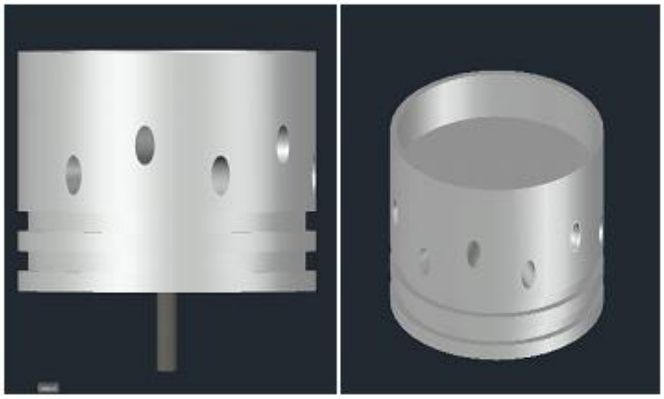
1. Density:0.061lbs/in3
2. Typical ISP: 225s

The reason why I went with cherry limeade was that I had a good amount of data on the propellant formulation. In addition to this, coming with the new propellant formulation takes time and involves lot of resources and time to test, which I didn't have. That is why I went with this formulation.

Density	1680.0041 kg/m3
Specific Heat Ratio	1.21
Combustion Temperature	6300R
ExhaustMolarMass	0.0236 kg/mol
C*	1703.832 m/s
Burn rate coefficient	0.0092 cm/(s*MPan)
Burn rate exponent	0.3273

BULKHEAD

A bulkhead is an upper foreclosure of the solid rocket motor situated at the very front of the casing. It is used to terminate the front opening of the rocket motor casing as well as a structural base for the placement of the recovery system, mating adapter for connecting the second stage, and/or the payload. It is usually in the shape of a circular plate with a hole at the bottom for placement of the propellant ignitor. It is sealed off with an O-ring and fixed in place by snap rings or bolts. In this scenario, we used two alternating rows of bolts to fix the bulkhead in place by drilling holes in the bulkhead, and the casing. The number of holes to be drilled and their placement parameters were determined by calculating the total axial stress on the bulkhead divided by the ultimate tensile strength of the casing, and bulkhead material used. Circumferential shear stress was also calculated to determine the area, or size of the holes to avoid deformation during the flight due to excess load on the holes' boundaries. The diameter is 14.8 cm. The bulkhead here was machined out of the 6061 T651 Aluminum alloy. The material was chosen due to its high ultimate tensile strength 310 MPa, or 45000 PSI, and having a moderate melting point of about 582-651.7 C. Also, this alloy is highly economical and easily available in the market for use.



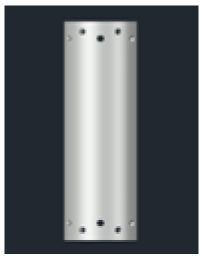
Bulk Head

CASING

The casing of the solid rocket motor is a very essential part that is used to contain the propellant grains, inhibitors, liner, insulation, ignitor, bulkhead, and the upper section of the nozzle inside it. It is a long cylindrical tube usually made up of an alloy designed to fail at the desired pressure, or stress so that in case of a launch failure due to excessive pressure buildup, it does not explode, or create shrapnel but instead tears apart graciously like paper to avoid injury. Here are the various parameters of the casing:-

Material=6061 T651 Aluminum(same as the bulkhead) Length=48.244 cm
Diameter=16.2306 cm Thickness=0.6858 cm Mass=1.3 kg

PARAMETERS	VALUES
Length	48.2cm
Outer diameter	14.8cm
Thickness	0.68cm
Threaded holes	24



Casing

LINER AND INSULATION

Liner is an important aspect of the solid rocket motor as it shields the casing from the high temperature burning propellant, and more importantly doubles up as an insulator to prevent heating, weakening, or melting of the casing, and bulkhead material. Here, I have assumed the thickness of the liner as 0.76 mm. insulation assumed here is based on chopped carbon fiber (CCF)and aramid fiberber in pulp formas reinforcement for ethylene propylene diene monomer (EPDM) along with ammonium polyphosphate (AP) ame retardant agent. Six millimeters long CCFs and/or Kevlar pulp (KP) are dispersed in the EPDM polymeric matrix to obtain a homogenous master batch for curing. The new method involves the development of two types of prepregs and the lamination of these types of prepregs. The first one consists of CCF/EPDM/AP (50phr CCF) and the second type of prepreg KP/EPDM/AP (30phr KP). Laminates composed of six alternative layers of these prepregs have been shown to exhibit better thermal, mechanical, physical, and ablative properties than their non-laminated counterparts.

Summary of mechanical properties for 6061 aluminum alloy

Mechanical Properties	Metric	English
Ultimate Tensile Strength	310 MPa	45000
Tensile Yield Strength	276 MPa	40000
Shear Strength	207 MPa	30000
Fatigue Strength	96.5 MPa	14000
Modulus of Elasticity	68.9 GPa	10000
Shear Modulus	26 GPa	3770 psi

The nominal composition of type 6061 aluminum is 97.9% Al, 0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu.
The density of 6061 aluminum alloy is 2.7 g/cm3 (0.0975 lb/in3).

NOZZLE

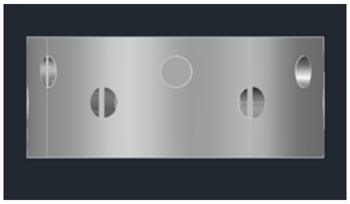
A rocket engine nozzle is a propelling nozzle that is used in a rocket to expand combustion gases to generate thrust. It is fitted right into the end of the motor casing and helps the exhaust gases, that are produced due to the combustion of fuel, escape back into the atmosphere with high velocities. The nozzle used in this sounding rocket consists of a specific type of geometry, (de Laval type) which has several advantages over the other types. The convergent half-angle of the nozzle is 30° and the divergent half-angle is 15°. A glance at various parameters involved is written down in the form of a table below.

PARAMETER	VALUE
Outer Diameter	14.8 cm
Initial Port Diameter	6.3 cm
Throat Diameter	3.21 cm
Convergence Half Angle	30 deg
Convergent Length	2.4 cm
Divergence Half Angle	15 deg
Divergent Length	11.5 cm

Nozzle

RETAINER RING

A retainer ring is used to hold the nozzle in its actual position and cancel out the excess forces of the exhaust gases as a result of combustion inside the casing. The retainer ring is fixed with the help of nuts and bolts which immobilizes the retainer ring and the nozzle so that the latter one remains in its position. The number of bolts and their diameter is calculated by the actual amount of stress acting on it and equating it with the number of bolts under safe operating conditions.



Retainer Ring

Performance of Motor in Burnsim

Burnsim is a solid rocket steady-state internal ballistics simulation software. A solid rocket motor can be evaluated and its characteristics such as Kn, thrust-time curve, specific impulse. With the aid of this software, the values are inserted from our theoretical computations.

Observations

The motor delivered a total impulse of 23658 N-s for a burn time of 9.09 s. The peak thrust is 6227.51 N at 7.3 s. The peak pressure of 9.653 MPa is less than the maximum expected operating pressure of 13.652 MPa.The average pressure of 8.145 MPa is slightly higher than the expected chamber pressure. Port to throat ratio is less than 4, hence erosive burning will be insignificant. The data obtained from the analysis varied from the predicted values by ±0.18.

STAGE SEPARATION MECHANISM

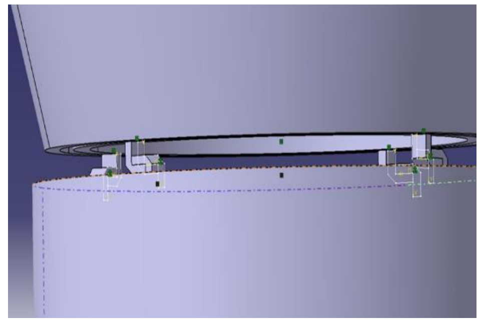
This method is used in every rocket nowadays. The staging allows the thrust of the remaining stages to more easily accelerate the rocket to its final speed and height. The first step was to select the type of staging which will be used for our sounding rocket. I went through two types of staging methods and analyzed their advantages and disadvantages, these two staging methods are- 1. Serial staging 2. Parallel staging. I chose the serial staging method for our rocket as it is a sounding rocket that requires less thrust as compared to other rockets. Parallel staging is used in rockets that travel a larger distance with a larger payload.

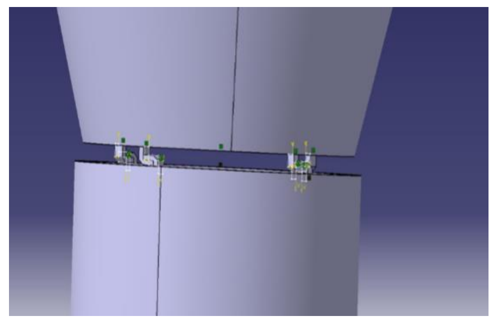
Lock Mechanism

The two arms will be placed in such a way that they will slide over one another and form the locking mechanism. The upper arm will be fixed to the mating adapter called the passive arm and the lower arm will slide over the passive arm with the help of a servo motor which will be attached to the lower stage of the rocket.

Mating Adapters

As the name says these are the devices that are used to connect multistage rockets. Below shown is the CAD model of the mating adapter designed by the team. A circular cut has been made on the upper surface of the mating adapter for the placement of the servo motor. Below shown is the CAD model of the mating adapter and the lock mechanism.





Mating Adapter

Material Selection

Aluminum is chosen because of its wide range of advantages such as:

- It is light in weight
- It is Malleable
- It is Ductile in Nature
- High Strength
- Corrosion Resistance
- Infinitely Recyclable
- Easily Machined and Cost
- Sound and Shock absorber

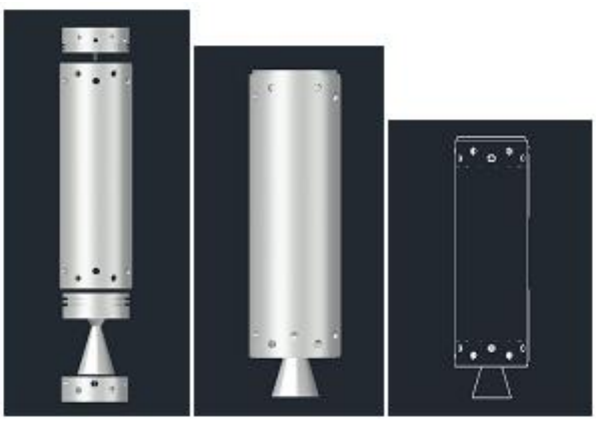
Servo Motor

As Stated above in the locking Mechanism a Servo Motor isused to move the active arm away from the passive arm and thus the 2 stages get separated successfully. A Servo Motor was chosen to separate the passive and active arm because:

- Light Weight
- High Efficiency
- More Constant Torque at higher speed
- Highly Reliable
- Closed-loop Control
- High Acceleration

As the Servo Motors are light in weight, so they do not increase the weight of the rocket. The Servo Motors are usually small in size thus do not increase the size of the mating adapter.

III. CONCLUSION



Final Rocket Assembly

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