Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Research and comparative analysis of rockets external ballistic characteristics by constant thrust and different time impulses

Master's Final Degree Project

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Kaunas, 2019

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Aeronautical Engineering (6211EX024)

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Declaration of Academic Integrity

I confirm that the final project of mine, Hari prasanna Manimaran, on the topic „Research and comparative analysis of rockets external ballistic characteristics by constant thrust and different time impulses“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Study Programme – Aeronautical Engineering 6211EX024

Task Assignment for Final Degree Project of Master Studies

Student: Hari Prasanna, Manimaran

1. Title of the Final Project:

Title: Research and comparative analysis of rockets external ballistic characteristics by constant thrust and different time impulses

Raketų su pastovios traukos ir skirtingos trukmės impulsais išorinės balistikos tyrimas ir palyginamoji analizė;

2. Aim of the Final Project:

Research and comparative analysis of rocket external ballistic characteristics by constant thrust and different time impulses to implement this data for modernisation of RT-400 for middle range air defence system

3. Tasks of the Final Project:

1. Engineering conception of aerial target for middle range air defence system;
2. create a methodology of investigation;
3. analysing rocket motor with constant thrust and different time impulses;
4. research of external ballistics of each model;
5. comparative analysis of external ballistics characteristics.

4. Requirements to be fulfilled.

Maximum flight range (km)	20
Maximum flight altitude (km)	10
Total rocket mass with 4 motor (kg)	185

5. Initial data

Total impulse (Ns)	32000
Average thrust (N)	10000
Burn time (s)	3.2
Specific impulse (s)	182

Motor length (m)	1.15
Motor diameter (m)	0.16
Motor mass without propellant (kg)	17
Propellant mass (kg)	18
Total motor mass (kg)	35

6. Structure of the text Part:

- Study of different aerial targets;
- detailed investigation of ballistics characteristics of RT-400;
- research on different possible configuration to fulfil requirement;
- design of computational model and and numerical model;
- analyse for external ballistic characteristics of siutable configurations;
- comparision of the obtained results;
- concluding the best design for middle range rocket target.

7. Consultants of the Final Project:

Author of the Final Project ________________________________
(Name, Surname, Signature, date)

Supervisor of the Final Project ________________________________
(Name, Surname, Signature, date)

Head of Study Programme Janina Jablonskytė
(Name, Surname, Signature, date)

Manimaran, Hari prasanna. Research and comparative analysis of rockets external ballistic characteristics by constant thrust and different time impulses. Master's Final Degree Project supervisor Prof. habil. dr. Algimantas FEDARAVICIUS; Faculty of Mechanical Engineering, Kaunas University of Technology.

Study field and area (study field group): Aeronautical Engineering (E14), Engineering sciences.

Keywords: solid propellant rocket motor, external ballistics, flight range, velocity, acceleration, thrust impulse, rocket target.

Kaunas, 2019. 64 pages.

Summary

The objective of the research is to analysis the external ballistic characteristics of middle range rocket target with constant thrust and varying rocket motor operating time.

The main requirement is to achieve the rocket target with horizontal distance (range) of 20 km and vertical distance (altitude) of 10 km. The rocket motor to be used should be RM-12K designed and built by Kaunas University of technology, Institute of Defence technology. This motor can produce up to 12 kN thrust for 3.2 seconds.

To achieve the goal, computational model is designed using SOLID WORKS student edition and numerical modelling for ballistic analysis is carried out in MATLAB Simulink. In this research three different configuration is used to achieve the requirement. First, one motor is ignited for 3.2 seconds to produce 12 kN thrust. In second test all four motors are ignited together for 3.2 seconds which produce 48 kN thrust force. In third configuration two motor is used for 3.2 seconds to produce 24 kN and after the burnout, second two motor is ignited for 3.2 seconds. Comparative analysis of three different configuration shows that the requirement of 20 km range and 10 km altitude was realised by using two plus two motors for 6.4 seconds of operational time.

Manimaran, Hari Prasanna. Raketų su pastovios traukos ir skirtingos trukmės impulsais išorinės balistikos tyrimas ir palyginamoji analizė; baigiamasis projektas; vadovas prof. habil. dr. Algimantas Fedaravicius; Kauno technologijos universitetas, Mechanikos Inžinerijos ir Dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): aeronautikos inžinerija (E14) Inžinerijos mokslai.

Reikšminiai žodžiai: kietojo kuro raketinis variklis, išorinė balistika, skrydžio nuotolis, greitis, pagreitis, traukos impulsas, raketinis taikinys.

Kaunas, 2019. 61 puslapis.

Santrauka

Tyrimo tikslas – išanalizuoti vidutinio nuotolio raketinio taikinio su pastoviu traukos ir skirtingos trukmės impulsais išorinės balistikos charakteristikas.

Pagrindinis tikslas buvo pasiekti, kad raketinioio taikinio horizontalusis skrydžio nuotolis būtų 20 km, o vertikalusis nuotolis (aukštis) 10 km. Tam panaudotas raketinis motoras RM-12K, kuris buvo sukurtas Kauno technologijos universiteto Gynybos technologijų institute. Šis motoras išvysto 12 kN trauką, o jo darbo trukmė yra 3,2 s.

Šiam tikslui, panaudojant mokomąją programinę įrangą Solid Works, buvo sukurtas kompiuterinis modelis, o balistikos analizė atlikta MATLAB Simulink aplinkoje. Buvo ištirti trys skirtingi atvejai. Pirmuoju atveju buvo įjungtas vienas 12 kN traukos motoras, kuris veikė 3,2 s. Antruoju atveju 3,2 s buvo paleisti vienu metu visi keturi motorai, kurių traukos jėga buvo 48 kN. Trečiuoju atveju 32 s buvo įjungti du motorai, o po to kiti du motorai su 24 kN trauka buvo įjungti 3,2 s. Palyginamoji šių trijų atvejų analizė analizė parodė, kad 20 km nuotolio ir 10 km aukščio reikalavimas buvo pasiektas panaudojus du plius du motorus, kurių veikimo laikas buvo 6,4 s.

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Nomenclatures:

k = specific heat ratio
R = universal gas constant (8314 Nm/ kmol-K)
M = molar weight
T_o = combustion temperature
P_e = exit pressure
P_o = chambre pressure
A^* = nozzle downstream area
A_e = area of the exit of the nozzle
α = nozzle divergence half angle
F = thrust force
I_{sp} = specific Impulse
g_0 = standard gravity
v_e = exit or exhaust velocity of the nozzle
m_0 = initial mass
m_f = final mass
A_c = area of the converging nozzle
β = nozzle converging half angle
$\dot{m}$ = mass flow rate
V_x = horizontal velocity
V_0 = velocity at burnout
Θ = flight angle
kN =kilo Newton
m = meters
kg = kilogram

Introduction

As the defence technology is rapidly growing, it requires effective training to operate the defence hardware. Live firing exercise are mostly conducted to test the specific military equipment such as weapon systems. During the practice, personnel requires target that imitates real incoming enemy military hardware is required. It demonstrates the realistic scenario for the trainee to acquaint with the battle situation. More precise practise making the personnel a skilful operator. For this purpose, targets that resemble enemy aircraft or rocket are used. Initially, the practice is limited to virtual and dummy targets. Targets are of different types based on the requirements. The main objective of targets is to be used as a bullseye target for practice. Most of the targets are designed to be destroyed during the exercise. Targets may be used in land, sea and air defence.

Most of the developed countries have designed their own targets for their personnel. Targets are three types as stationary, UAV, rocket target. Some targets are turbojet engine powered drones and missile targets. These are mostly made from the missile parts without warheads. Other designs are particularly designed to meet the demand. As the drone targets are used to resemble as low-speed vehicles like spy planes, unmanned aerial vehicle and subsonic missiles. These drones cannot simulate the situation for fast moving missile and fighter aircraft. To fulfil this requirement rocket target are used. These target use rocket motor, mostly solid propellant.

Rocket target usually slower than the real missile or aerial vehicle which is used to shoot the target. This is because, the trainee personnel requires training to acquire, lock and terminate target. In the early stage of the training, identifying the fast-moving object is difficult. To match the trainee reaction time, the speed of the target is decided. Rocket target is used once and mostly destroyed during the exercise unlike drones can be reused. In drones, the rocket is kept as secondary target and ejected to resemble the missile. Some drone use rocket for the first stage as rocket assisted take off (RATO). Drone targets are difficult to maintain and cannot be operated in all-weather condition. But solid propellant rocket target can be fuelled and stored for a longer period. And require less maintenance. In considering all the benefit of using rocket target for a military exercise, it is necessary to design and test the hardware.

In rocket target design internal and external ballistics are mainly analysed. Internal ballistics deals with the propulsion system characteristics whereas the external ballistics study about the flight of the projectile. The external ballistics of the target gives the basic parameters such as thrust, velocity, acceleration, altitude flight angles and range. With the help of this parameter, the target can be optimised for particular requirements. Design can be altered to meet the required specification. In this research rocket target to be used for the air defence system is analysed. RT-400 is designed and developed by Institute of defence technology, Kaunas University of technology with a range of 5km. The range can be increased by the optimising the propulsion system. By making the alteration in any system, it is required to analyse for the performance. External ballistics is the performance of the rocket target.

Based on RT-400 with single motor data, multiple motor grid can be studied. As per the requirement, the range of the missile varies. To increase the range from short to the medium additional motor is added. In this research, the middle range rocket target with four motors will be used to achieve 15-20 km range.

Aim

Research and comparative analysis of rocket external ballistic characteristics by constant thrust and different time impulses to implement this data for the modernisation of RT-400 for middle range air defence systems.

Objectives

- to analyse the external ballistics of the middle range rocket target to increase the operating range by using existing technology;
- design of rocket target with a range of 20 km;
- the target can reach up to the altitude of 10 km;
- the total mass of the target is between 160-250 kg;
- external ballistic parameters such as thrust, velocity of flight, acceleration of flight; maximum altitude of flight, maximum range of light is to be defined;
- comparing the different possible solution to match the requirement.

Tasks

- engineering conception of an aerial target for middle range air defence system;
- create a methodology of investigation;
- analysing rocket motor with a constant thrust and different time impulses;
- research of external ballistics of each model;
- comparative analysis of external ballistics characteristics.

1. Literature study

1.1. Battle Air Defence Systems

Missile defence systems are a system of technology or weapon that identify, track and destroy the incoming or attacking missile. It can be classified as strategic (long range), theatre (medium range) and tactical (short range) missile defence systems [1].

Long range missile defence system: This system defend against intercontinental ballistic missile and missile which travel above 7 km/s velocity. The range of this category is above 800 km [2].

Medium range missile defence system: defence against missile travels about 3 km/s or less in velocity and also called as theatre missile defence system. Middle range rockets can travel up to 800 km [3].

Short range missile defence system: this missile defence system defence against 1.5 km/s velocity missile and also called tactical missile defence system and can have range from 20 to 80 km [3].

The research is about analysing the external ballistic characteristics of rocket target for tactical missile defence system range. Few missile defence systems are explained.

Stringer missile system

Stringer is a man-portable air-defence system manufactured by Raytheon missile system of United States and operated by US and 29 other county militaries [4]. The missile system is developed by US army missile command from Redeye weapon system. It is a short-range missile defence system to protect military bases, military weapon and high-value targets from airborne threats. Stinger is a fire and forgets system, it employs a passive infrared seeker to home in on its airborne target [5]. The man-pad system contain rocket launcher and the rocket. The projectile is launched after acquisition of target. Based on the infrared seeker the missile travels towards the high temperature signature and terminate the target,

Table 1. Specification of stringer missile defence system [6].

Propulsion	Dual thrust solid fuel rocket motor
Length	1.5 m
Width	13.96 cm
Total weight	15.66 kg
Range	1-8 km
Speed	Supersonic in flight

Fig. 1. Stringer missile defence system [6].

Grom

Grom is man-portable shoulder launch surface to air missile. Grom is designed and manufactured by Poland military institute of armament and Mesko. The missile has the mass of 16.5 kg with 1.27 kg warhead. It uses solid propellant rocket motor with an operational range of 5.5 km and can travel up to 3.5 km altitude. It is a single stage rocket which can travel up to the speed of 650 m/s. Passive infrared homing is used as the guidance system. Grom is being operated in Poland, Lithuania, Georgia, Indonesia and Donetsk people's republic [7].

Fig. 2. Grom man-pad missile launcher [7].

RBS-70

ROBOSYSTEM-70 is a man-portable short-range air defence system missile developed by BOFORS defence (now SAAB BOFORS dynamics) in Sweden. This missile uses smokeless solid propellant and mass of 87 kg in total including the stand and sight. 1.32 m long missile with a diameter of 106 mm and carries a warhead of 1.1kg. the operational range of 8 km and a maximum altitude of 5 km. it is a supersonic missile and can reach flight velocity of Mach 2.0. laser beam riding is used for guidance. Currently twenty-one country operate RBS-70 including Lithuania [8].

NASAMS: (Norwegian/National advanced surface to air missile system)

NASAMS is a highly adaptable mid-range air defence system to protect the military assets from ariel threats. It is equipped with three multi-missile launchers each carrying up to six ready to fire AIM-120 AMRAAM missiles inside the protective canisters. This missile unit has a modular design comprising a command post-fire distribution centre, an active 3D radar AN/MPQ64F1 sentinel, a passive electro-optic and infra-red sensor. NASAMS is operated by 9 countries as of 2018. Lithuania has ordered 2 batteries (4 launchers) of NASAMS [9]. This research thesis mainly focused to provide the design and ballistic analysis of target missile for NASAMS missile defence systems.

Table 2. Specifications of NASAMS [10].

Propulsion	Solid fuel rocket motor
Length	3.7 m
Width	0.18 m
Total weight	152 kg
Speed	Mach 2.7
Range	50 km

Fig. 3. NASAMS systems with AIM 120 AMRAAM [9].

1.2. Training equipment for air-defence system

Training is important for the personnel to nurture his/her skill in operation of the weapon system on the real battlefield. Good training provide the air defence system crew to understand the challenges of modern missions [11]. Military personnel spends time undergoing training during the non-combat time. The military's ability to train and rehearse with tremendous efficiency and effectiveness make the difference between success and failure in conflicts. The effective and safe operation of high technologies require trained people [12].

To perform training many methods are used. Basically virtual (computational) training equipment and live firing exercise with aerial targets.

1.2.1. Virtual (computational) training equipment

It is a type of training method includes interactive 3D simulation using computer software and hardware to provide real-time battle situation. It provides safe training for the personnel. The equipment is not damaged or destroyed during the training. So, it is cost-effective and reliable for longer usage. Simulated or virtual training best suits for the beginner in training of the military hardware. Use of this kind of platform reduces the loss of human life as well as the hardware. As it is a simulated environment which pre-programmed and recorded scenario, it cannot provide real-time battle situation. So aerial target is used for real-time live fire exercise [13].

Fig. 4. Virtual man-pad missile launch [14].

1.2.2. Aerial targets for air defence systems

The initial stage of the training, the personnel are trained with a stationary target. As the training progress and with experience in the usage of a weapon system such as target acquisition, target locking and termination the more advanced and complex moving targets are used. Today the aerial target used is slow and imitate low velocity moving targets like drones, low-speed aircraft. This kind of targets is ineffective to train the personnel for the real battle scenario for high-speed vehicles because of its design constrains. The operation and maintenance of the training drones need skilful pilots and most of the drones are not capable withstanding the adverse weather conditions.

To obtain high-speed targets with low cost of manufacturing are to use the rocket-powered aerial targets. The use of rocket motors in aerial target systems can fulfil and simplify various demands based on target dimensions and shapes intended to mimic specific aircraft models or even to fly at similar cruising speeds for some period of time [15].

Other operating rocket and drone targets

DRDO Lakshya: The Lakshya is high-speed target drone controlled by ground control station (GCS) is developed by aeronautical development establishment (ADE) of defence research and development organisation (DRDO), India as the aerial target for live firing exercise. It carries a payload of tow target used for training personnel using a surface to air missile and air to air missile. Tow target can travel at speed of Mach 0.7 for the range of 5 km. It also carries air target imitator which is used for an infrared homing surface to air missile's aerial target. It has a range of 4.8 km [16].

DRDO Abhyas: It is a high-speed aerial target developed by ADE of DRDO. Abhyas uses rocket booster during the launch and uses a gas turbine engine for flight phase. It is used to simulate aircraft and missile for air defence training [17].

Fig. 5. DRDO Abhyas [17].

Northrop BQM-74 chukar: The BQM-74 is high-performance aerial target power by a turbojet engine. It simulates the anti-ship cruise missile and aircraft in the air- to air combat. It is developed by Northrop and used for United States of America's military personnel training. It has a maximum speed of 972 km/h and flies at an altitude of 12 km [18].

Nord CT-41: Designed and built by Nord aviation and used as an aerial target by France military. It is ramjet power and launched using the elevating ramp. Initial boost is provided by two solid rocket motor after reaching Mach 1.7 ramjet provide the thrust. It can be used for both high and low altitude by having two variants and can be recoverable. It can fly up to a maximum speed of Mach 3.1 up to 20 km altitude [19].

HESA karrar: Karrar is manufactured by Iranian aircraft manufacturing industry company. It is a jet-powered aerial target. It has cylindrical blunt nose fuselage with a clipped delta wing. It is powered by a turbojet engine and for initial take-off uses rocket propulsion and can be recovered by parachute. Karrar can travel up to 900 km/h speed with a range of 500 km [20].

Fig. 6. Hesa Karrar target drone of Iran [20].

Beechcraft MQM-107 Streaker: This aircraft is designed and developed by Beech Aircraft of United States. It is a high subsonic aerial target used by U.S military. It is powered by a turbojet engine and for take-off, uses solid propellant rocket booster. It can travel up to 926 km/h speed with the altitude of 12 km. Mostly used as an aerial target for the surface to air missiles such as Stringer patriot, AIM-9 sidewinder and AIM-120 AMRAAM [21].

Denel Dynamics Skua: Skua is South African turbojet powered target drone used as target to simulate the high-speed SAM and air-to-air missile. It has a maximum speed of Mach 0.86. skua can fly up to 200 km range and altitude up to 10 km. A two-stage parachute is used to recover the drone. It can carry 130 kg of tow target and signature augmentation equipment [22].

Fig. 7. Denel Dynamics Skua Target drone [22].

RT-400

An RT-400 is rocket target designed and tested by the Kaunas University of Technology, Institute of defence technology, Lithuania by a research team of Prof. Algimantas fedaravicius, Arvidas Survila, and Saulius Rackauckas and used as an aerial target in various military exercise for the stringer missile system. RT-400 aerial target is mostly used for the practice of air defence or anti-missile defence system in Lithuania for practice in the land as well as the navy ship. Advancement of this type is being researched.

RT-400 is simple design with low manufacturing cost. It can be transported and need less area for launch. It is very cost effective and reliable rocket target. RT-400 is towed and can be transported to any location and has specially designed mobility vehicle for transportation. It can be launched at any angle as the vehicle can be lifted. Launch rod provides support to rocket body during transportation as well as during the launch. For transporting to any place, the tow vehicle is attached to an automobile [15].

Fig. 8. Rocket Target-400 [15].

RT-400 is designed for short-range rocket target. Increasing military strength and addition to new military hardware in military force demands the longer-range rocket target for practice. But designing a new motor takes more time for research and development and requires the additional cost of testing. The advantage of RT-400 is cheap, ease of testing. In order to fulfil the requirement of increasing the range and reachable altitude without changing the construction of rocket motor requires research towards alternate possibilities. These possibilities are analysed in this research.

2. Engineering conception of the aerial target for middle range air defence systems.

To design the rocket target, different types of previous design are required to be analysed. As this research is based on the RT-400, most of the data's can be adopted from the existing design. The material to be used in rocket, nozzle, motor casing, ignition methods, etc., as the outer dimension is also similar to RT-400, aerodynamic characteristics will match the new design. The selection of nose cone, the body, arrangement and dimensions of fins, propulsion system characteristics are adopted from the previous design. Only the external ballistics of the rocket is analysed in this research. RT-400 has the range 0f 4.5-5 km with a single motor of rocket total mass 104 kg. It is necessary to use the same motor, but the range has to be increased. This restriction can to be rectified by using multiple motors in a gridded configuration. Grid configuration is defined as the arrangement of multiple motors in the parallel attachment as it is in the large space launch vehicle with boosters. The only difference in space rocket is that it will eject its empty weight after the different stage and gain the advantage of the reduction in mass and gaining the delta-v of the previous stage. But in the rocket target case, all the casings are being attached. So cannot obtain the advantage over the mass variation. The only gain is by the expel of propellant mass. There are different possibilities are considered before selecting the final designs.

2.1. Modification of the short-range rocket target RT-400

To increase the range, it is required to increase thrust and velocity. The number of the motor to be used is increased to four, arranged in a gridded configuration.

2.1.1. Rocket motor RM-12K

RT-400 is aerial target uses a single rocket motor which produces 12 kN thrust is represented as RM-12K. Properties are given in the table below.

Table 3. Properties of RM-12K motor

No	Property	Values	No	Property	Values
1.	Length of the target (m)	5.2	9.	Rocket motor mass with propellant (kg)	35
2.	Length of the rocket motor, (m)	1.06	10.	Rocket mass (kg)	104
3.	Diameter of the target (m)	0.4	11.	Burn time of the rocket motor (s)	3.25
4.	Diameter of the rocket motor (m)	0.16	12.	Maximum flight time of the rocket (s)	44.92
5.	Nominal thrust of the rocket motor (kN)	10	13.	Maximum flight range (km)	4.5
6.	Impulse of the rocket motor (s)	32	14.	Maximum flight height (km)	2.2
7.	Specific impulse of the rocket motor (s)	182	15.	Velocity range of the rocket (m/s)	30-282
8.	Propellant mass (kg)	18	16.	Drag coefficient	0.486

The external ballistics of RT-400 has been already studied and different graph of thrust, velocity, acceleration, gravity versus time and angles of flight, altitude versus range is obtained. Thrust, velocity vs time, acceleration vs time, range vs altitude, drag vs time, g loads against time are calculated and analysed. These data are essential for the external ballistics to optimise rocket target to extend the range and altitude.

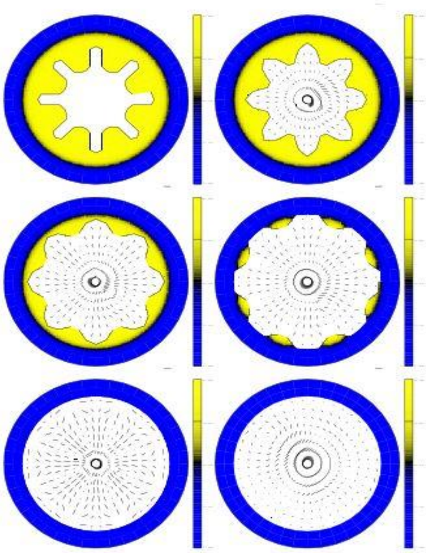

Fig. 9. Combustion evolution of star grain in RM-12K [23]

Combustion evolution over time in typical star geometry grain is shown in the figure-9 simulation image. This change in the area of burn affects the internal ballistic characteristics of the motor. star grain is chosen for the neutral thrust [23].

Propellant grain is the basic geometric form of any processed propellant. All grains are considered as cylindrical in shape to fit into the case of the rocket to obtain maximum volumetric efficiency. The central core that extends the full length of the grain to increase the surface area exposed to the combustion [23].

There are different shapes of the core to obtain various thrust-time curve. Most of the amateur rocket prefer the tubular core and for good performance, star grain is chosen [24].

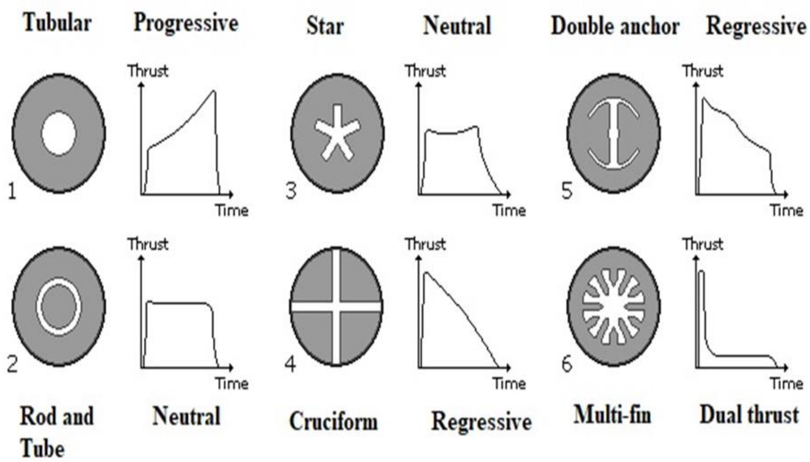

Fig. 10. Different grain geometry and performance

Thrust is directly proportional to the burning area at that instance of time is an instantaneous burning area. The receding of the burning surface is perpendicular to the surface of the grain measured in inches per second or mm per second [25].

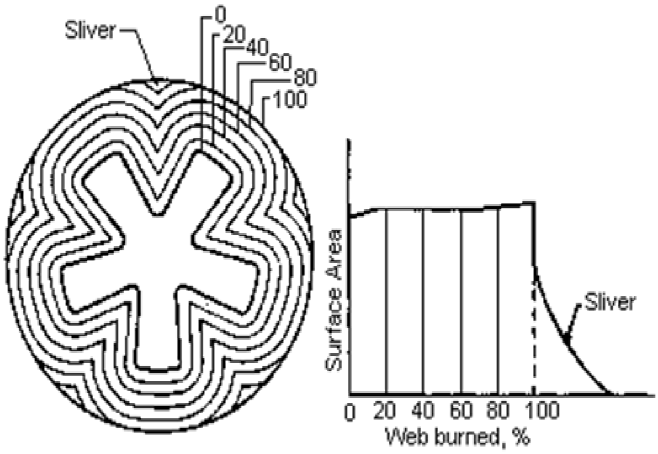

Fig. 11. Typical star grain and its thrust graph

Thrust vs time graph gives the variation of thrust for the entire duration of burn. RM 12-k burns for 3.2 seconds and produce total impulse of 180 s. on average it produces 12 kN thrust [23].

From star grain image, the contour lines represent the core shape at successive moments in time during the burn. Notice that the shape of the thrust-time curve changes, with the vertical lines corresponding the same successive moments during the burn. The star grain provides an approximately neutral burn, as the surface area remains constant throughout the burn duration. A neutral burn is usually desirable because it provides for greater efficiency in the delivery of total impulse, as a nozzle operates most efficiently at a constant chamber pressure [26].

Nozzle design parameter:

High-energy combustion products are diverted towards the convergent-divergent nozzle (CD nozzle or con-di nozzle or de-Laval nozzle) to produce thrust. Mostly heat resistant material such as carbon-based amorphous graphite or carbon-carbon material to withstand combustion flow. This nozzle is tube-shaped which is pinched in middle as throat area and shaped asymmetrically to form hourglass shape to make divergent exhaust. Due to its shape, it converts the high-energy heat flow into kinetic energy [27].

The assumption for analysis of C-D nozzle [28].

- The gas is considered an ideal gas;
- flow is assumed as isentropic. (constant entropy);
- the gas is steady, constant during the entire duration;
- the combustion is projected at the centre or along the axis of inlet to exhaust;
- the gas is considered as compressible.

The fluid properties of the compressible fluid are affected by the friction of the fluid, change of cross-sectional area and heat loss. To study about compressible fluid the four-equation to be studied are

- Energy equation;
- continuity equation;
- momentum equation;
- the equation of state.

The nozzle exit velocity can be calculated by

$$v_e = \sqrt{2T_o\,(\frac{R}{M})\,(\frac{k}{k-1})[1-(\frac{P_e}{P_o})^{\frac{k-1}{k}}} \quad (1)$$

To find the nozzle exit area ratio

$$\frac{A^*}{A_e} = (\frac{k+1}{2})^{\frac{1}{k-1}}\;(\frac{P_e}{P_0})^{\frac{1}{k}}\;\sqrt{\frac{k+1}{k-1}\;[1-(\frac{P_e}{P_o})^{\frac{k-1}{k}}} \quad (2)$$

Area of the throat can three times smaller than the area of the converging nozzle. Ac ≥ At. Based on this assumption the area throat can be designed and efficiency can be increased after the trade-offs iterative process. Length of each chamber is calculated using the convergent and divergent angels. In solid rocket motor, the combustion chamber is where all the combustion process is carried out and the place for storage of fuel. For the design of the C-D nozzle, the length of each section is required to calculate. The converging section of the nozzle is given by [27],

$$L_{CN} = \sqrt{\frac{A_C}{\pi}}\;\frac{1}{tan(\beta)} \quad (3)$$

Length of the divergent nozzle is given by

$$L_{DN} = \sqrt{\frac{A_e}{\pi}}\;\frac{1}{tan(\alpha)} \quad (4)$$

Mass-flow rate: It is defined as the quantity of mass exits through the nozzle denoted by m-dot ($\dot{m}$). Thrust can be increased by increasing the amount of mass flows out of the engine [29].

$$\dot{m} = \frac{F}{I_{sp}\cdot g_0} \quad (5)$$

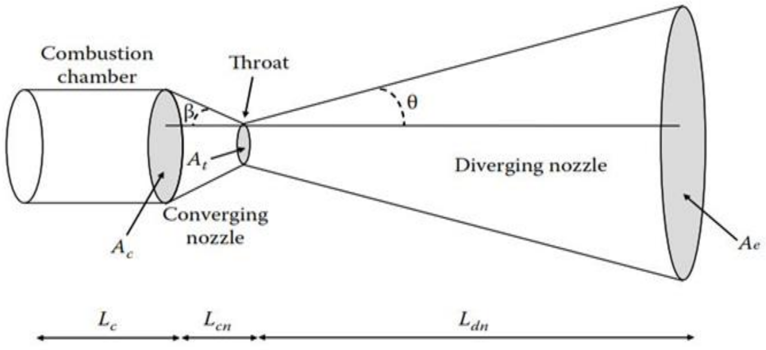

Fig. 12. C-D nozzle

Based on the equations the basic internal ballistic characteristics are determined and analysed. Due to the grain geometry, the RM-12K obtain the neutral thrust and specific impulse of 182 seconds. Each motor produces 12-kilo newtons of thrust for 3.2 seconds of burn time. The nozzle design is major concern towards obtaining thrust. The shape and geometry decide the amount of thrust produced. The convergent section increases the pressure and reduces the velocity to form choked at the throat. The velocity at the throat is of Mach 01 and the pressurised combustion gases are released towards the divergent nozzle. The high-pressure products are released and expanded in the divergent section of the nozzle to produce high-velocity mass ejection. This high amount of mass and velocity coupled to produce thrust. Due to Newton's third law, the rocket is pulled forward.

Thrust is given by the equation of force

$$F = \dot{m}\, v_e + (P_e - P_0)A_e \tag{6}$$

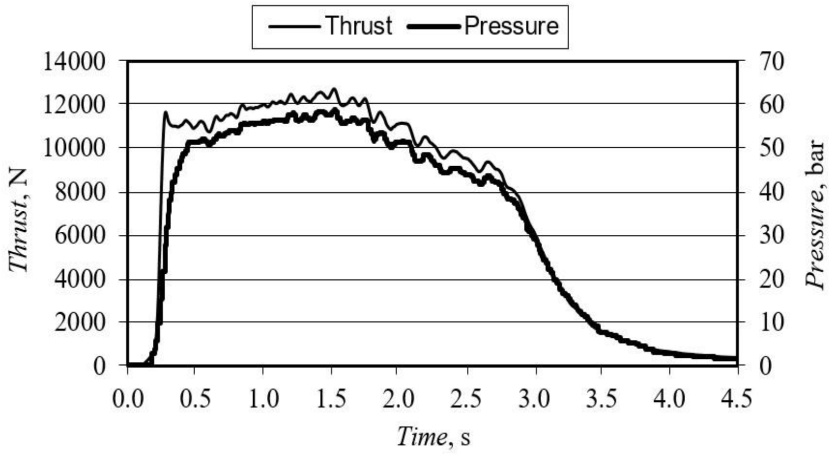

Fig. 13. Thrust vs time graph of RM-12K

Velocity vs time graph

The velocity of the flight is the outcome of the thrust produced. Velocity changes with increment in the thrust. As the star grain of neutral thrust produced the uniform increase in velocity also seen. RT-400 obtain maximum velocity of 270 m/s before the burnout. This gives longer flight duration. The velocity of flight is given by the delta-v produced [15].

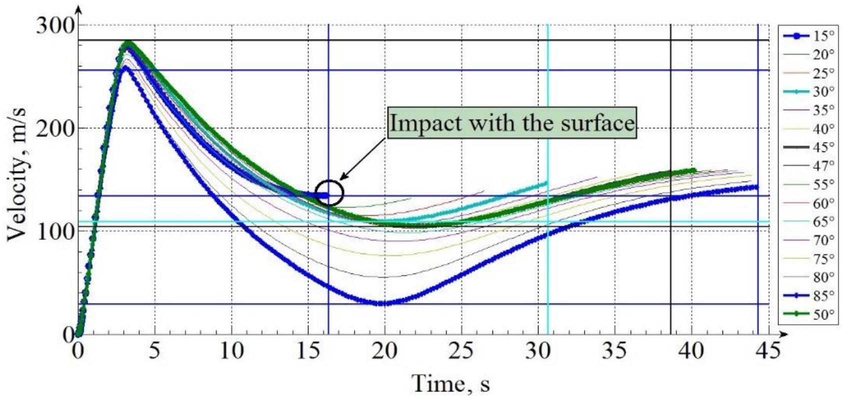

Fig. 14. Velocity vs time graph of RM-12K

Delta-v: Δv is the incremental velocity produced by the rocket by burning the fuel mass. Delta-v is directly proportional to the exhaust velocity of the rocket.

The horizontal velocity is given by

$$V_x = v_0 * \cos\theta \tag{7}$$

The vertical velocity is given by

$$V_y = v_0 * \sin\theta - gt \tag{8}$$

Acceleration vs time

Acceleration is the integral of velocity. It is measured based on the increment of velocity for each second. Acceleration vs time graph of RT-400 Is given. Using the Tsiolkovsky equation delta-v can be found with the initial and final mass.

$$\Delta v = I_{sp}.g_0\ \ln\frac{m_o}{m_f} \tag{9}$$

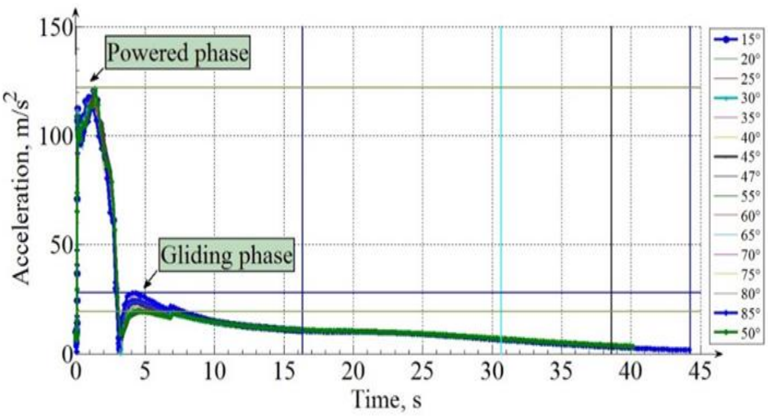

Fig. 15. Acceleration vs time graph

RM-12k can make RT-400 accelerate up to 120 m/s for a period of 3.2 seconds and after burning out the acceleration reduces to a minimum and increase during the gliding stage.

Flight angles vs time

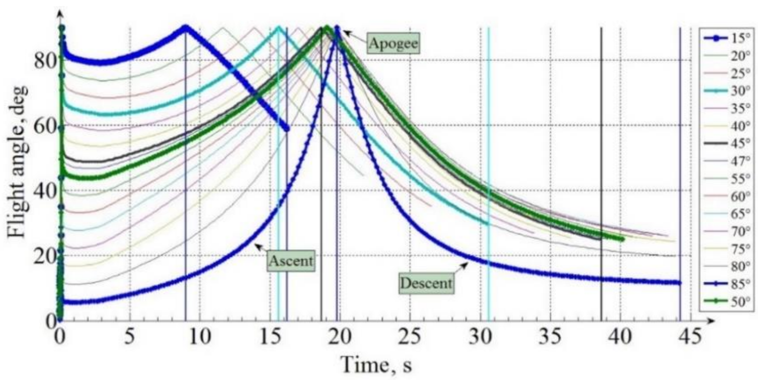

Fig. 16. Flight angles vs time

Rocket target is launched at a different angle. This does not contain the trajectory correction system or guidance system. Based on the projectile motion, the path of flight is parabolic and undergoes different angle over the complete duration of the flight. This is shown in the above graph.

Range vs altitude

Distance reached by rocket is given by the equation

$$r = 2 * V_x * \frac{V_y}{g} \tag{10}$$

Altitude of the rocket trajectory is given the equation

$$h = \frac{V_y^2}{2*g} \tag{11}$$

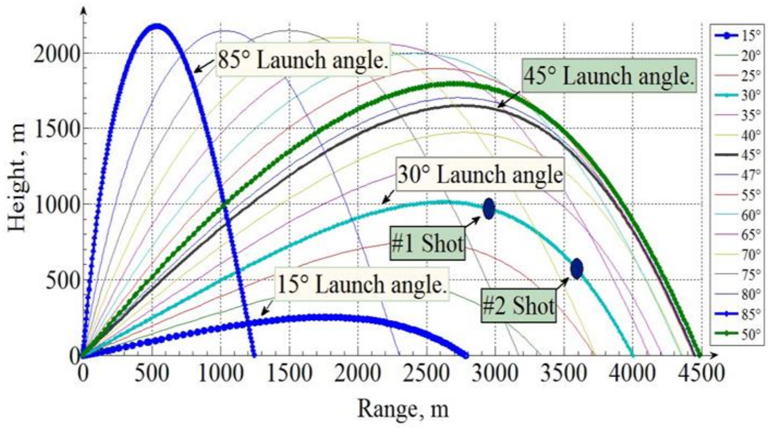

Fig. 17. Altitude vs range graph

The important parameter of external ballistic is the range and altitude. RT-400 can travel up to an altitude of 2.5 km and reach a range of 4.5 km. The longest range can be obtained by launching at 45 degrees from the ground and the highest point in altitude can be reached by launching at 80-degree angle.

Drag force vs time

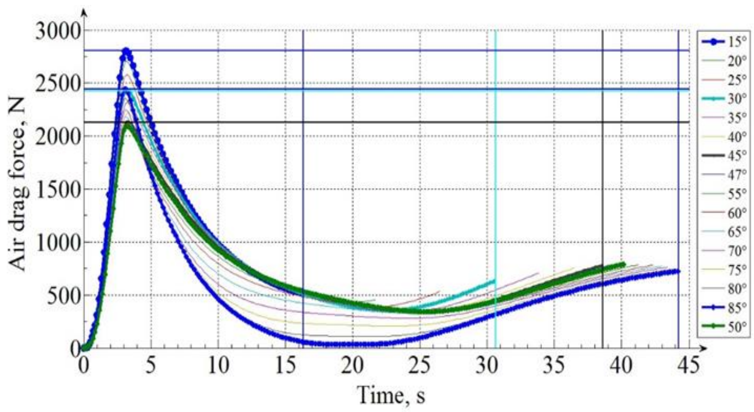

Fig. 18. Drag vs time graph

Drag force varies proportionally to the velocity over time is shown in the above graph.

2.1.2. Construction of middle range aerial target

Construction of rocket target is done computationally for analysis. Based on RT-400 data new middle range rocket target can be designed.

Table 4. Requirements for middle range rocket target

Total rocket length (m)	5.4
Rocket diameter (m)	0.4
Maximum flight range (km)	20
Maximum flight altitude (km)	10
Total rocket mass with 4 motor (kg)	185

Basic parameters to be considered for the design of motor grain geometry and nozzle.

Table 5. General condition for the flight

Ambient pressure (pa)	101325
Ambient temperature (K)	288
Combustion Chamber pressure (pa)	5339000
Chamber temperature (K)	2322
Fuel density (kg/m^3)	1623.4
Molecular weight (mol/g)	23.896
Gas specific heat J/kg/K	2102
Burning coefficient	0.039
Burning exponent	0.27

The nozzle is designed with convergent and divergent section. The efficiency of the nozzle is taken as 85%. With reference to given specific impulse and the motor data thrust is calculated.

Table 6. Nozzle data

Nozzle section	Diameter (m)	Radius (m)	Area (m^2)	Length (m)
convergent	0.16	0.08	0.020	0.05
throat	0.053	0.027	0.0022	-
divergent	0.15	0.075	0.0177	0.316

The propellant is chosen as ammonium nitrate composite-based propellant (ANCP). A composite propellant is a solid propellant in the form of heterogeneous propellant grains composed of oxidizer crystals held together in a matrix of a synthetic or plastic binder. In this design, RM-12k is used without any major change in design. The grain geometry is same as for RT-400. Mass and another parameter remain the same. So, the internal ballistics is not required to be analysed for the configuration. The mixer of different components is required to obtain maximum efficiency. The ratio of different chemicals is shown for the 100 g of propellant. This component includes fuel, oxidiser and binder.

Table 7. Propellant mixers

Chemical	Weight (g)	Density (g/m^3)	Composition
Ammonium nitrate	55	0.06230	4H-2N-3O
Potassium perchlorate	8	0.09100	K-Cl-4O
Aluminium	14	0.09760	1Al
Carbon	2	0.06370	1C
Silicon	20	0.03610	6H-2C-1O-1Si
Iron oxide	1	0.184	3O-2Fe

Computational modelling:

Designing in Solid Works® student edition allows to visualise and analyse the target. This can be done using part design. Every part like nozzle, grain, bottom and top rings, ignitor, grain cylinder, rocket frame body are modelled separately and assembled. This model can be exported as initial graphics exchange specification (IGS) to open in any other CAD software for further analysis.

Modelling begins by designing the grain of the propellant. The propellant mass is 18 kg and it has a star-shaped design. It is tubular cylindrical arrangement extruded by the star geometry.

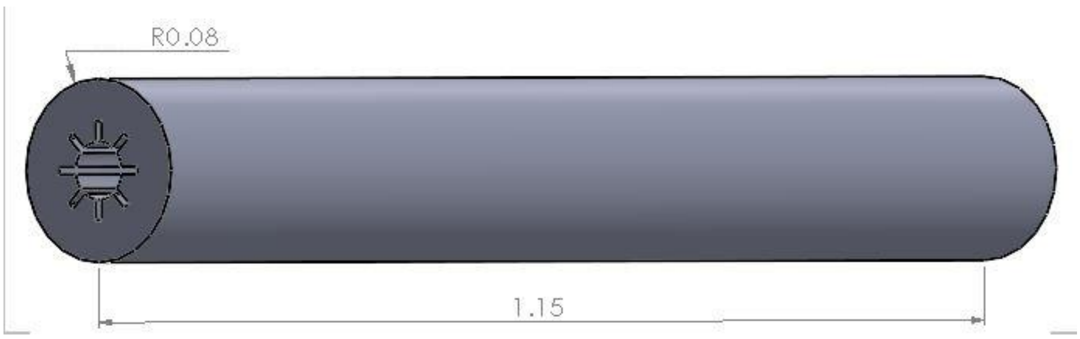

Fig. 19. Star grain to be used in Rocket target

The metal casing is designed to protect from the thermal fluxes and keep the grain in fixed with the outer structure. Stainless steel is chosen for its properties against temperature and pressure to withstand the combustion. The thermal protection layer is applied inside the case. The total mass of 12 kg for each propellant case is used.

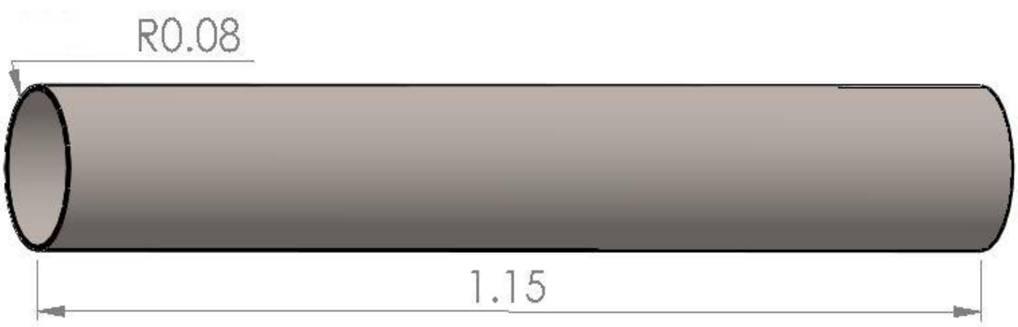

Fig. 20. Metal casing

The nozzle is constructed based on the calculated data. The C-D nozzle is attached to grain and casing and form a single body.

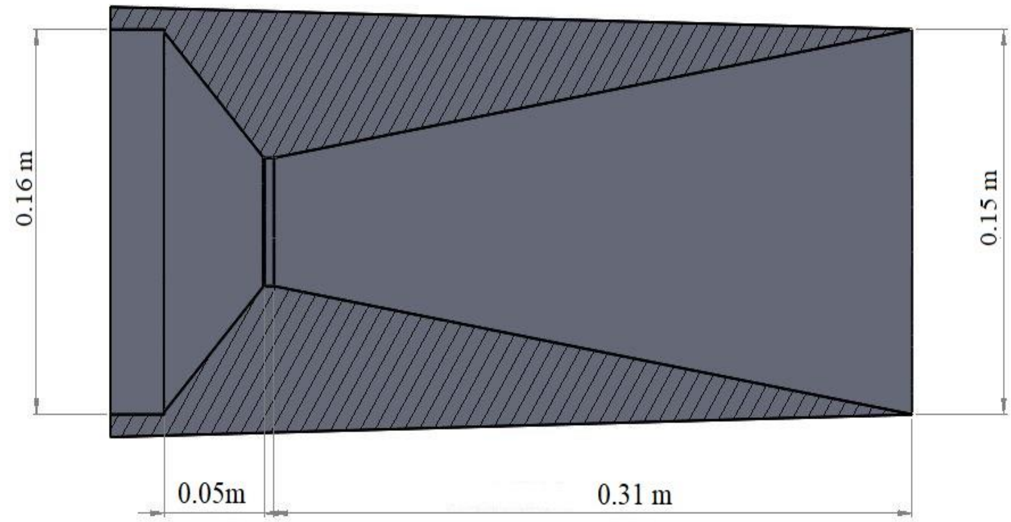

Fig. 21. Nozzle

The bottom ring is used to keep all the designed parts to remain attached. The diameter of the ring 0.4 meters same as of the rocket diameter to fit the body. Each grain attached to the grid holes. With this, the grid configuration is completed and to give arrangement for the propulsion system.

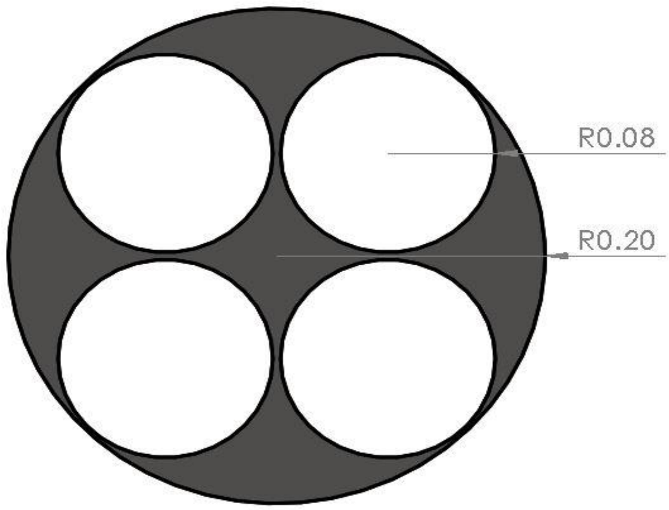

Fig. 22. Bottom ring for grain support

The subassembly of grain, nozzle, casing and central ring is made grid configuration for the propulsion system of middle range rocket target.

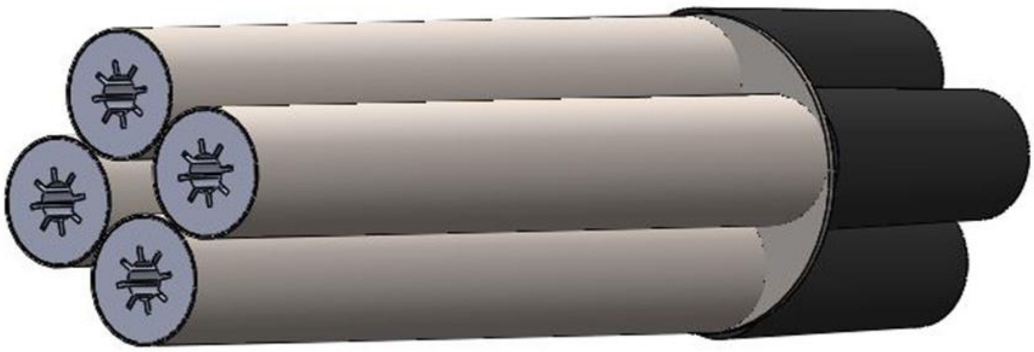

Fig. 23. Propulsion system of rocket target

After the grid arrangement, the outer body is designed and fitted with a propulsion system. The aerodynamic shape reduces the drag and protects the inner motor.

Then the four fins are arranged perpendicular to each other. Fins are used for increasing the surface area. For stability, it is required to keep the centre of pressure (CP) lower to the centre of gravity (CG) as possible. The more projected area at the lower part produces the increment of CP location. The stability of the rocket target being minimum is satisfactory. As most of the mass is concentrated at a lower part of the rocket arrangement of four fins is required. This forms the complete rocket body.

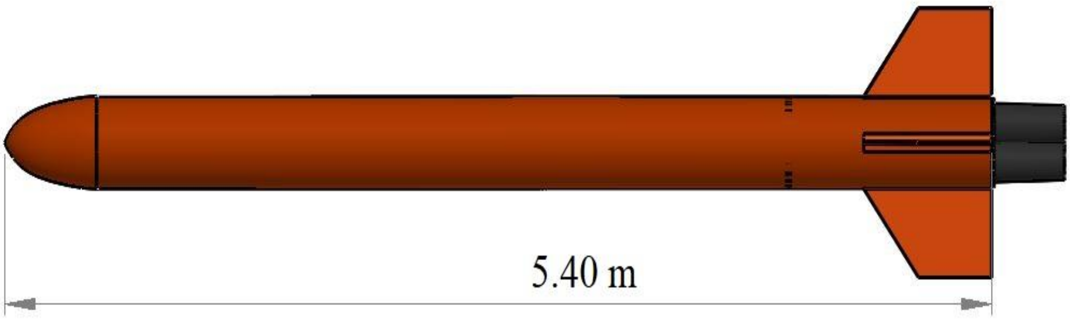

Fig. 24. Completed assembly of rocket target

Front and back view

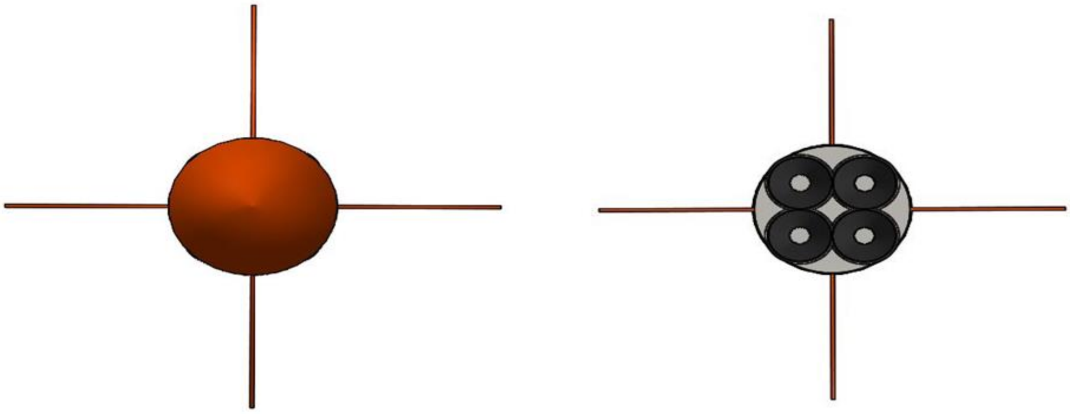

Fig. 25. Front and back view of the assembly

2.2. Middle range aerial target external ballistic by constant thrust and different time impulse

External ballistics is the study on the behaviour of the projectile during the flight that is influenced by gravity. It can either be atmospheric flight or outer space flight, powered or unpowered, stabilised or rotating, guided or unguided. External ballistics deal with the trajectories of the rocket and other projectiles.

During the flight, the projectile experiences several forces. Gravity tends to pull the projectile downwards. Mostly the ballistic missile uses the gravitational pull as means of acceleration during the re-entry. Then during the atmospheric flight, air resistance produces drag and decelerates the projectile. The crosswinds deviate the projectile from its initial trajectory this can be countered by control surfaces [29].

Stability is a major concern in external ballistics as the projectile travel in trajectory. Centre of pressure (CP) usually kept lower to the centre of gravity (CG). This CP is the point where all the aerodynamic force acts and produce stabilising force. In large projectile, CP is kept behind CG to obtain stable flight. But the smaller projectile like a bullet is allowed to spin around its longitudinal axis to produce gyroscopic force to keep the axis resistance to destabilising forces. So, fins are not required, and the CP is kept in front of CG. In a rocket target, minimal stability can be satisfactory [29].

The atmospheric projectile should be kept in an angle to reach a higher distance mostly 45-50-degree angle is preferred. Due to the gravitational forces the line of travel of the projectile to forced downward and away from the line to departure. So, the optimum angle is set to reach longer range and higher altitude [30].

Forces affecting the ballistics of the projectile

- wind pushes sideways and makes projectile deviate from trajectory;
- vertical angle: launching angle will affect the range and altitude to reach due to gravity;
- air density: lower humidity increases the density of air and increase the drag;
- gyroscopic drift: due to rotation the projectile tends to deviate to the direction of rotation;
- horizontal effect;
- vertical (Eotvos) effect;
- Magnus effect;
- Poisson effect;
- Coriolis drift.

Design requirement for rocket motor

As the rocket target mass is mainly concentrated on the grain and nozzle. Rocket targets do not have any kind of guidance system or electronics and warhead so, there is no possibility of mass distribution towards the nose. Stability parameters are to be considered low due to the low flight duration and the target is designed to be destroyed. Mostly 1 to 1.5 calibre stability is maintained. Burning regression of propellant is from bottom to top of the motor causes the change in mass distribution inside the chamber and push the centre of gravity towards the nose and retain more stability in the course of the trajectory.

3. Research of the rockets external ballistic characteristics by constant thrust and different time impulses

3.1. Research methodology

Middle range rocket targets external ballistic characteristics are analysed by considering different possibilities. The various configuration is discussed, and the most technologically suitable design is chosen to be analysed.

Different types of design is considered to increase the range.

Use of a single motor for each stage one after the another: As this rocket is not designed to eject the previous stage burnt motor. So, the combustion products of the second stage cannot be ejected. And this design required high technology for the sequential ignition system.

Use of multiple motors in the parallel configuration: use of more than four motor increase the diameter of the body and the body need to be tested for aerodynamics and structural strength.

Addition of small rocket booster: Again, in this case, the aerodynamics need to be tested and the structural material used for the outer body is glass fibre, so this structure will not withstand the loads and moments created by boosters.

Use of single motor one after another in grid configuration: This design overcomes the constraint of the former design, but the asymmetrical thrust force produced will make the rocket to wobble in a circular manner and make the rocket unstable.

Use of four motors and ignite all at the same time: This will increase the range and produce symmetrical thrust force, but the total burn time will be less. The velocity gain will much higher than the other possibilities.

Use of two motors for the first stage and use another two motor for the second stage: Igniting the alternate motor gives symmetrical burn and increasing the total burning time give the advantage of thrust for more time. This configuration may increase the range.

The last three design is researched in detail and the different external ballistics characteristics are also analysed and discussed to find a better option for middle range rocket target design.

RT-400 dimensions remain the same so the dimension of the motor will be modified according to the requirements. Numerical simulation of ballistics will be done in MATLAB® Simulink® for one motor, 4 motors and 2+2 motors. The thrust produced by the motor remains constant.

During the analysis thrust, velocity, acceleration vs time is noted and repeated for various launch angle to determine the range at each angle. Comparison of results for performance analysis is to determine the efficient configuration for middle range rocket target.

The assumption to be considered during the analysis

- the rotation of the earth is not considered as the range of the rocket is small;
- atmospheric changes are not considered in the first two cases;
- the angle of attack of the rocket is considered as zero during the entire flight;

- the curvature of the earth is not considered;
- acceleration due to gravity is considered constant for the first two case only.

The ballistic analysis is based on the motion of the projectile, that influenced by the thrust characteristics. it is necessary to find the required thrust of each motor and the possible delta-v.

Table 8. Motor data

Total impulse (Ns)	32000
Average thrust (N)	12000
Burn time (s)	3.2
Specific impulse (s)	182
Motor length (m)	1.15
Motor diameter (m)	0.16
Motor mass without propellant (kg)	17
Propellant mass (kg)	18
Total motor mass (kg)	35

From the motor parameter, specific impulse and the mass variation before and after burn will give the incremental velocity delta-v and exhaust velocity of the nozzle. Taken the initial mass rocket as 185 kg and Isp of 182 s, acceleration due to gravity is 9.81 m/s, and exhaust velocity of 1785 m/s

Table 9. Delta-V for different motor combination

Number of motor	Rocket Final mass (kg)	Delta-v (m/s)	Delta-v (km/s)
1 motor of propellant mass 18 kg	167	182.7	655
2 motor of propellant mass 36 kg	149	386	1389
3 motor of propellant mass 54 kg	131	616	2217
4 motor of propellant mass 72 kg	113	879	3164

Drag produced due to the rocket body is taken into the account for calculation. The drag force will oppose the motion further and reduce the velocity. So, the two-motor configuration velocity can be reduced to transonic speed. From the data of delta v, it is clear that the usage of more than two motors will result in supersonic flight. Supersonic flight requires the consideration of the compressibility effect. The structural strength due to the high pressure and temperature variation also need to be reconsidered. So, avoiding such situation is beneficial.

From the values of mass flow rate, exhaust velocity, area of nozzle exit, and pressure difference, thrust force can be calculated. Thrust values of a different combination of the motor are given. The values of mass flow rate as 5.6 kg/s.

The motor is tested for other ballistic characteristics

Thrust data for a number of motors shows that one motor of total mass 35 with a propellant mass of 18kg can produce 12 kN of average thrust for 3.2 seconds and total burn time 6.8 seconds. The additional motor ignited simultaneously will produce an approximately same amount of thrust equal to the value of summation of two motor thrust. This result can be shown in MATLAB graph.

3.2. Problem-1 external ballistics of single motor:

Rocket target with RM-12K is tested with a single motor analyse the external ballistics of the single motor. The thrust produced is 12 kN for 3.2 seconds. The thrust generated by a single motor in the grid configuration of four motors. Thrust generation will not be influenced by the addition of mass.

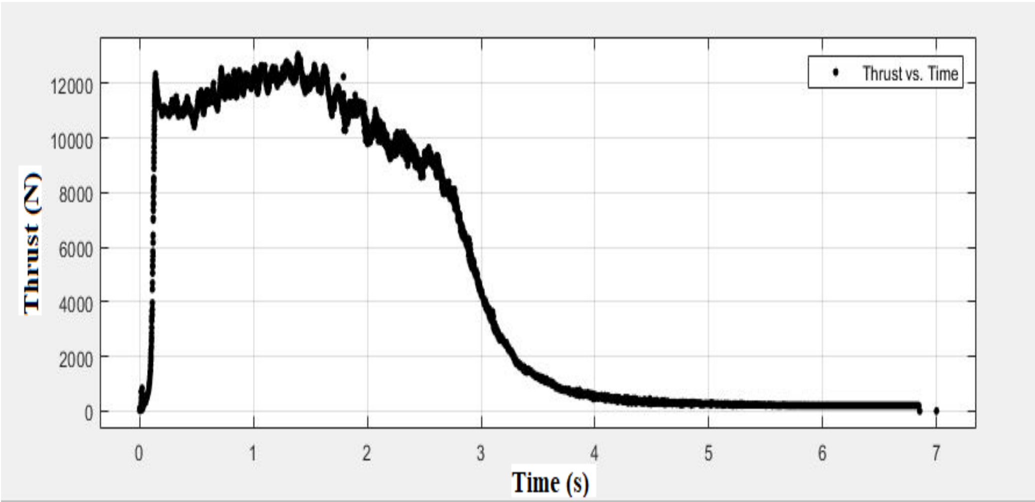

Fig. 26. Thrust vs time graph of single motor configuration

From the MATLAB analysis and the analytical method, the amount of thrust produced is 12 kN for 3.2 seconds with an average thrust of 10 kN. From the data, velocity and duration of thrust production, the trajectory is calculated.

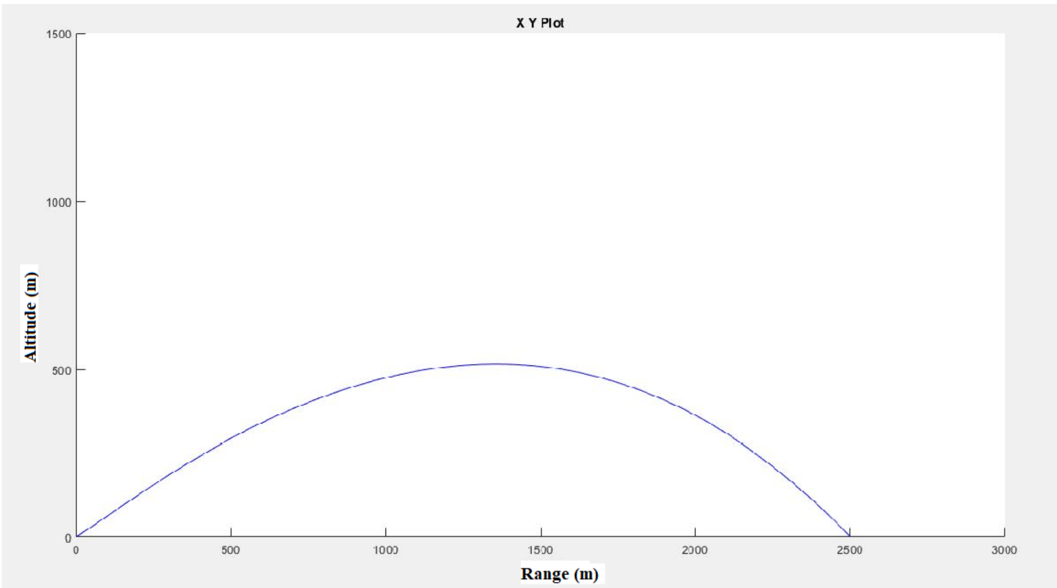

Fig. 27. Trajectory of rocket at 45-degree angle of launch

A single motor can reach up to 2.5 km of range at 45-degree launch angle and the altitude of 1.1 kmat 80-degree launch. At the 45-degree angle of launch, the horizontal and vertical forces are equally balanced. So, the possible higher range is obtained. Due to its lower thrust, the mass of 185 kg cannot reach the required range. So, in addition to single motor multiple motors are required to be used.

Altitude vs time graph

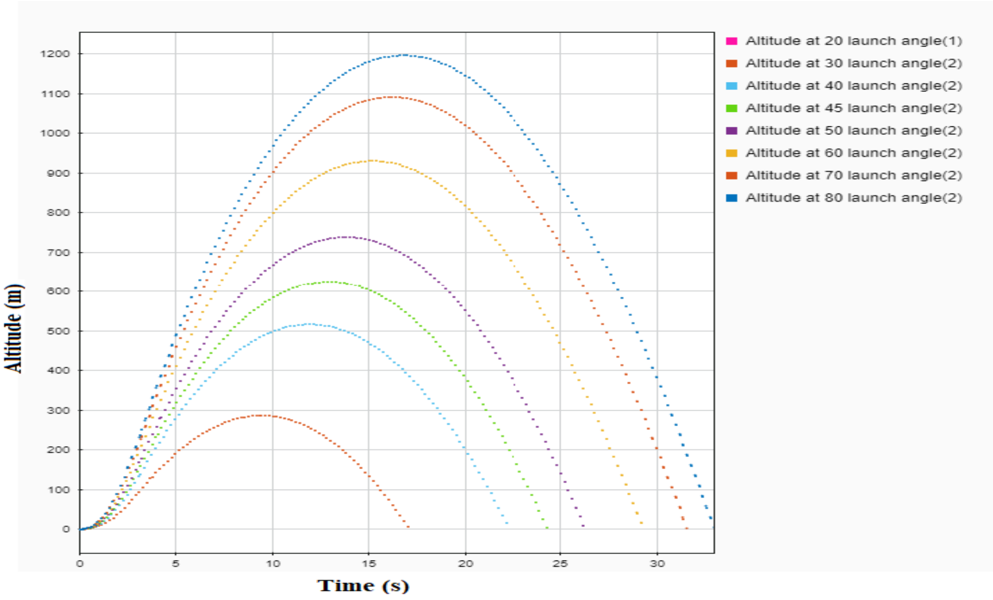

Fig. 28. Altitude vs time graph of single motor

At various launch angle, the single rocket motor of 18 kg propellant mass can reach a maximum altitude of 1196 m at 80-degree launch angle. At a higher angle, the vertical force will be higher so the rocket can reach the highest possible altitude. 90-degree launch angle is not analysed because mostly this angle is preferred for space launch vehicles. As this experiment is for rocket target where the trajectory is required to be parabolic as possible.

Velocity vs time graph

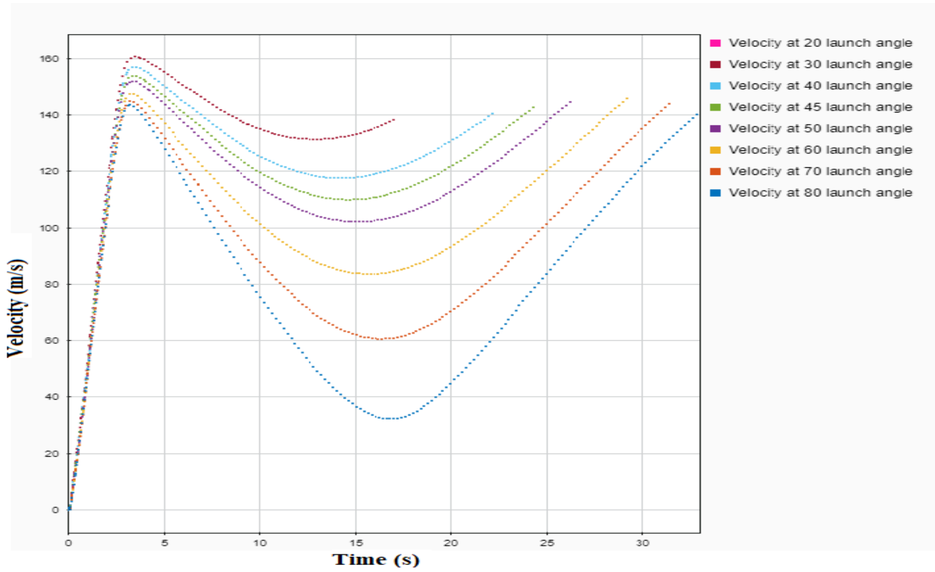

Fig. 29. Velocity vs time

From the graph, the average velocity of the flight is noted as 150 m/s and maximum velocity is achieved about 157 m/s. Velocity slightly varies with launch angle due to the downward force of gravity. As the launch angle increases the gravitational vector is higher and reduces the total velocity.

Acceleration vs time graph

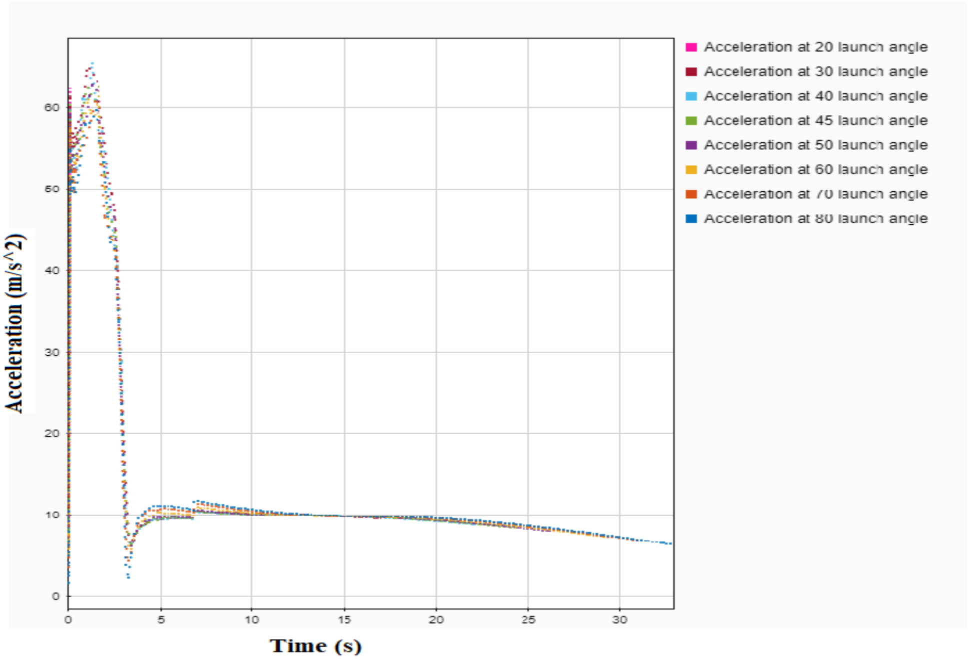

Fig. 30. Acceleration vs time graph of single motor

Motor acceleration increases to the maximum during the initial powered flight and decelerates on the glided phase and the increase in acceleration towards the ground as the missile approach towards the ground in its unpowered ballistic phase.

Drag vs time

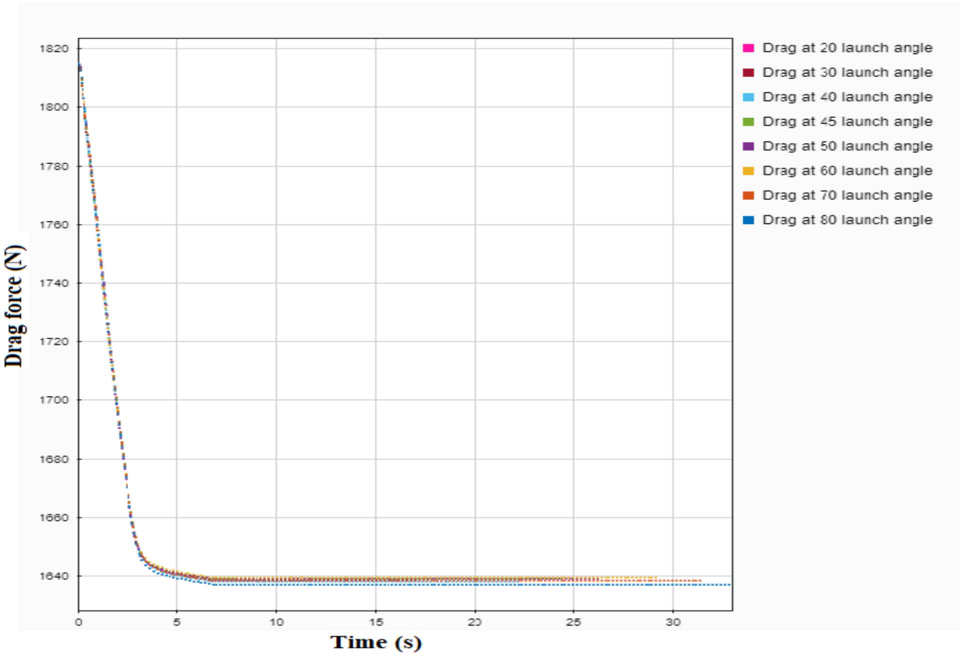

Fig. 31. Drag force vs time graph

As the projectile researches its maximum velocity the drag force also reaches its highest value and decreases along with its unpowered flight due to the reduction in acceleration and reaches its lower values. The maximum drag force of 1810 Newton at maximum velocity obtained. Drag is calculated with the help of a drag coefficient of 0.29, the air density of 1.22 kg/m^3 and surface area of 7.5 m^2.

g-loads vs time graph.

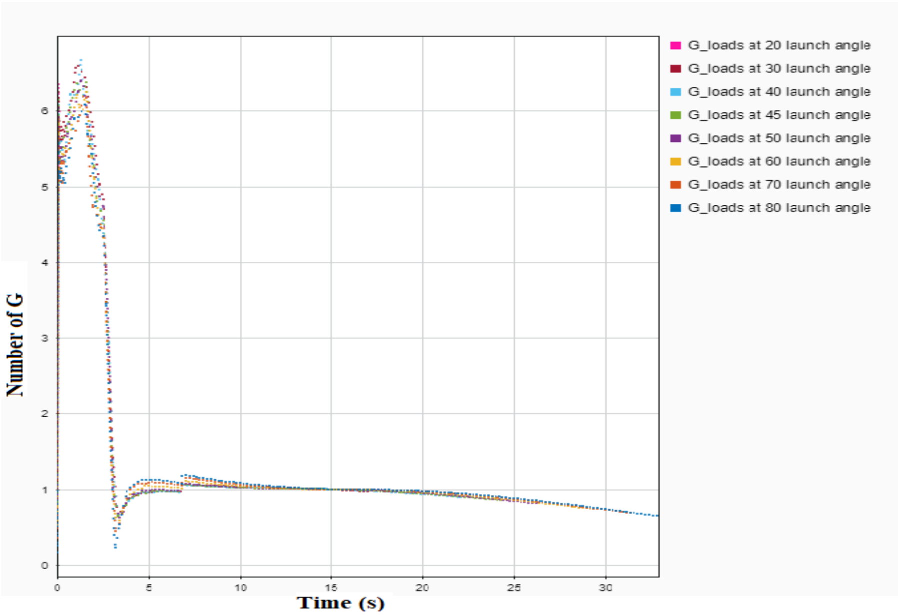

Fig. 32. g-loads vs time graph

While the projectile moves in ballistic trajectory it undergoes the influence of gravity. the g-force act upon the mass of the body. As this graph resembles the acceleration graph and increases proportional to the acceleration of the flight and decrease during the unpowered flight. Maximum of 6-g is experienced on the body.

Results of single motor

A single motor is tested on rocket target with a total mass of 185 kg with propellant mass 18 kg in each and case mass of 17 kg. Four casing is used. Each filled with propellant. And the frame mass of 45 kg produces constant thrust 12 kN. Density of air is taken from sea level as 1.22 kg/m2, the temperature of 288 K. The acceleration due to gravity is 9.81 m/s^2. The coefficient is taken from the reference for the low-speed vehicle with bullet shaped object as 0.29 and from the computational data.

Table 10. Results of single motor launched at different angles

Angle of launch (degrees)	Velocity (m/s)	Acceleration (m/s^2)	Altitude (m)	Range (m)
30	160	64.7	286	2132
40	157	65.4	516	2501
45	153	62.5	624	2548
50	152	62.8	738	2552
60	147	61.4	930	2320
70	145	60.7	1019	1816
80	143	59.7	1196	1012

From the result of a testing a single motor, the maximum range can obtain is 2552 m with a maximum altitude of 1196 m. At 45-degree launch flight can go to 153 m/s velocity.

Thrust required to reach a distance of 20 km cannot obtain by a single motor. A single motor cannot be ignited one by one of four times, and it is not possible due to the stability constraint. The control surface used is not movable because the rocket target is not designed to do the manoeuvre. It is not possible to obtain a stable condition. So, the configuration is necessary to use the alternate motor to produce more thrust or all the motor can be ignited at the same time. Both the case will be discussed. Multiple engines ignited in sequence and the combination of half number of the motor for a particular time and after the burnout, remaining motors will be ignited. Thus, by increasing the total number of burning time and extending the operational range.

Case-2 all four motor are ignited

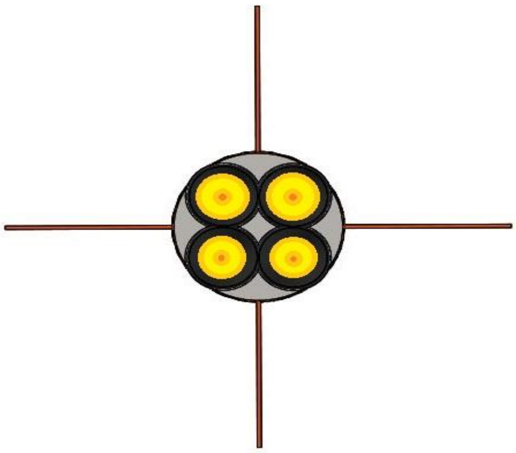

Fig. 33. Back view of rocket with all four-motor burning

Case-3 two out of four motors are ignited in first stage and later remaining two motor are ignited.

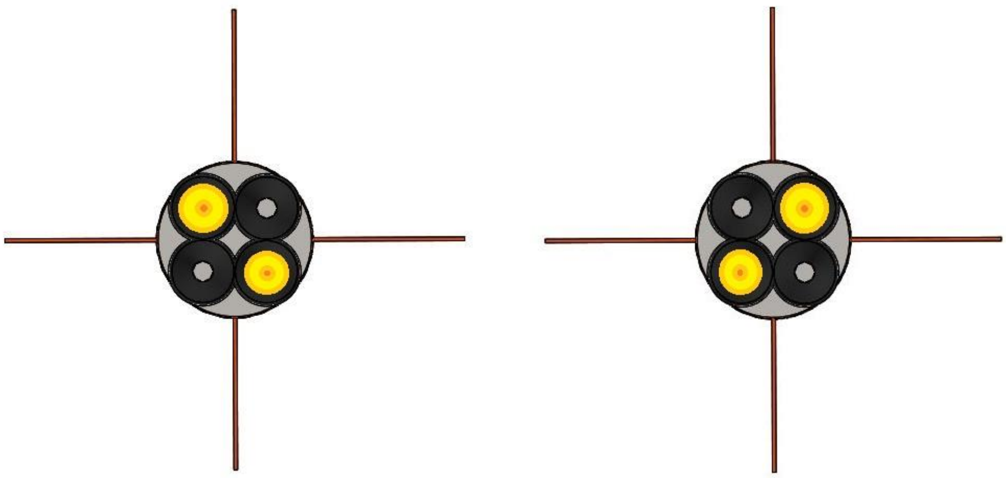

Fig. 34. Ignition of 1,3 motor and 2,4 motor

Alternate motors are ignited due to stability requirements. After the burnout of 1, 3 motor, 2 and 4 motor are ignited. Thrust, acceleration vs time is measured. This two cases will be discussed in detail.

3.3. Problem-2 external ballistic numerical modelling by 4T*1t

In this configuration, all four motors are burned to produced maximum possible thrust and analyse the external ballistics to obtain maximum range and altitude.

Initial condition.

- Total mass :185 kg;
- fuel mass: 18 x 4 = 72 kg;
- case mass 17 x 4 = 68;
- density of air =1.22 kg/m^3;
- temperature = 288.15 K;
- gravitational constant = 9.81 m/s^2;
- coefficient of drag = 0.29;
- four motors will be ignited all at once for the period of 3.2 seconds.

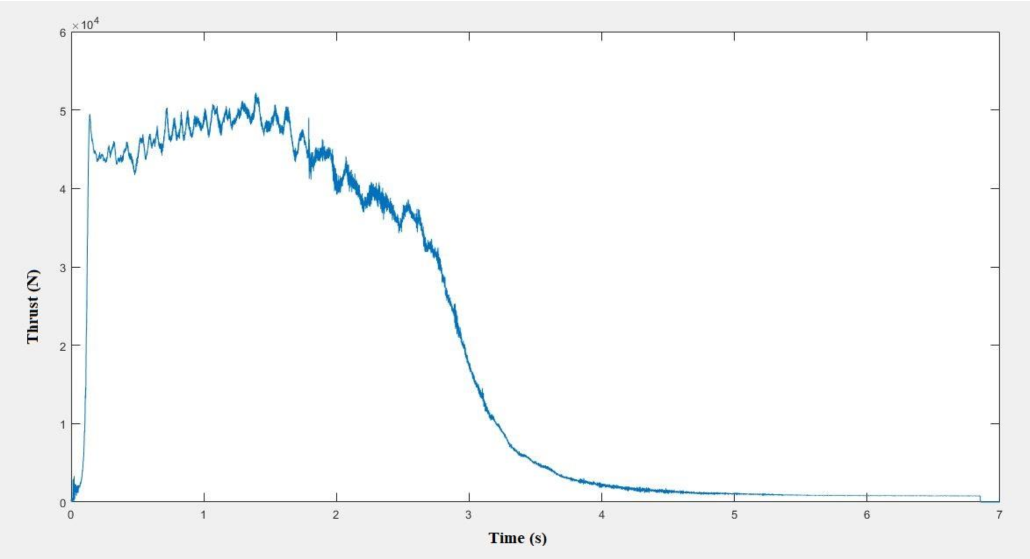

Fig. 35. Thrust vs time of four motor

The initial condition is taken as a ground condition. Temperature and gravitational values are taken at mean sea level. Air density is considered constant throughout the flight as the duration and the possible range remains lower. The total thrust of 48 kN is produced for the 3.2 seconds and starts reducing after 3.2 s due to the unavailability to propellant until the grain reaches the silver. The total amount of thrust produced by the four-motor grid is a total summation of thrust produced by the four-individual motor. As there is no variation in thrust and it remains constant.

Velocity vs time graph

As the thrust is being constant the rapid increase in the flight velocity and it continues to increase throughout the burn time. velocity reaches the maximum at burnout and after the burnout, the flight remains travelling in the trajectory due to the inertial forces. As the boost given by the motor burning reduces, the magnitude of drag force increases and velocity of the flight steeply reduce. After this phase, the rocket became an unpowered projectile and starts to travel in the ballistic phase. During the ballistic phase the projectile fall towards the ground, the velocity increases rapidly due to acceleration due to gravity. In this phase the velocity magnitude increases and due to air resistance, the velocity reduced again to a minimum and hit the ground at the end of the final phase. These different phases are shown in the graph. Velocity change due to the angle of launch remains lower in this case as compared to the single motor due to the high amount thrust. The maximum velocity of 720 m/s is reached. the flight reaches the supersonic regime at its maximum thrust.

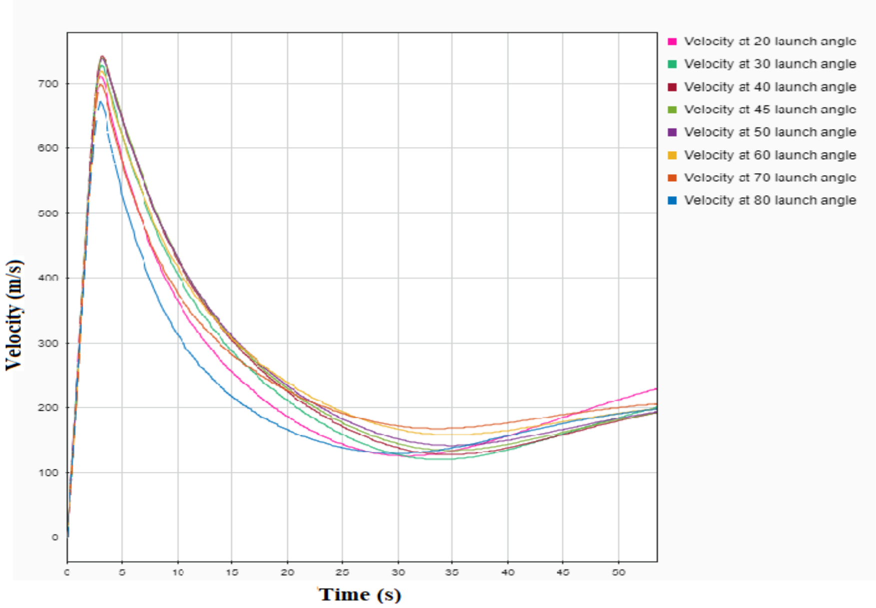

Fig. 36. Velocity vs time graph

Acceleration vs time graph

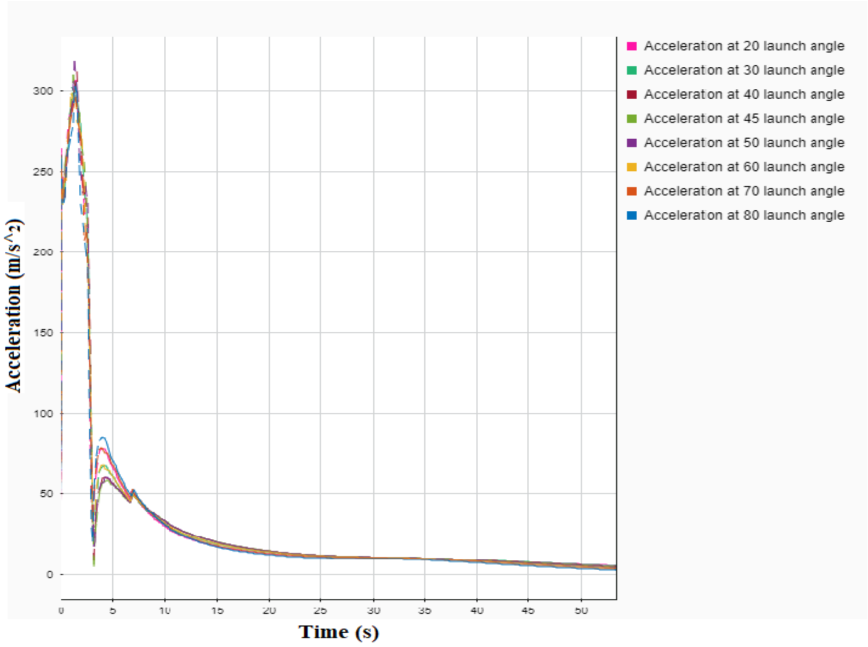

Fig. 37. Acceleration vs time of four motor

Acceleration increases proportionally with the thrust increment. At maximum thrust, acceleration can reach up to 320 m/s^2. And after the burnout, acceleration reaches towards zero and in ballistic stage a slight increase in magnitude due to the free fall towards the ground.

Altitude vs time graph

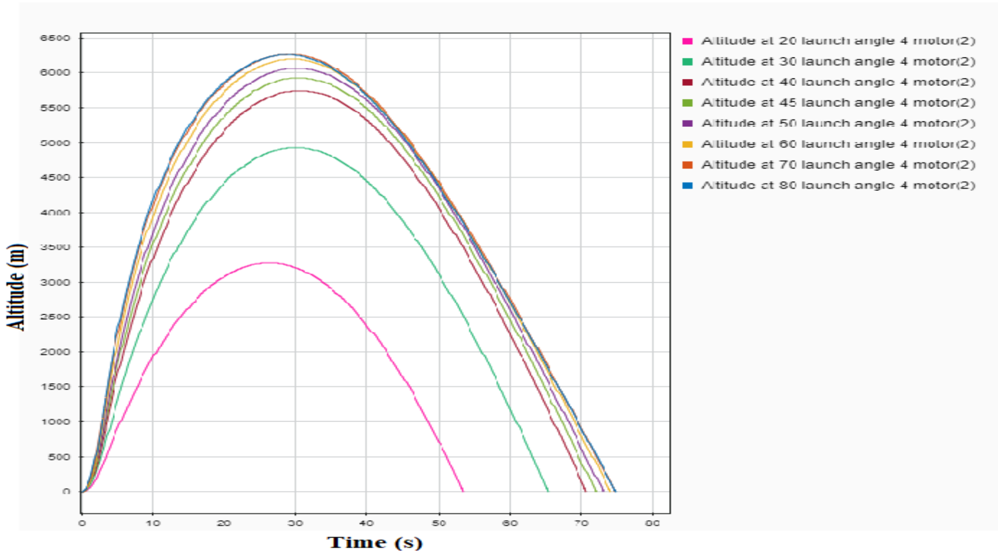

Fig. 38. Altitude vs time graph

The altitude varies based on the angle of launch. Velocity and acceleration decide the highest reachable height of the rocket. The four-motor configuration has higher velocity compared to the single motor and reaches three times more vertical distance. At a maximum angle of 70-degrees, the vertical forces overcome the horizontal forces and gravity to reach a maximum altitude of 6265 m. the rocket reaches its maximum altitude at 30 seconds of flight time.

Flight angle vs time graph

Flight angles of this configuration vary with the trajectory. During the powered phase, the angles increase above the launch angle and after reaching the apogee, rocket starts reducing to the lower angle during the ballistic phase. The pattern in a change of flight angle is similar to other cases only the time of change varies.

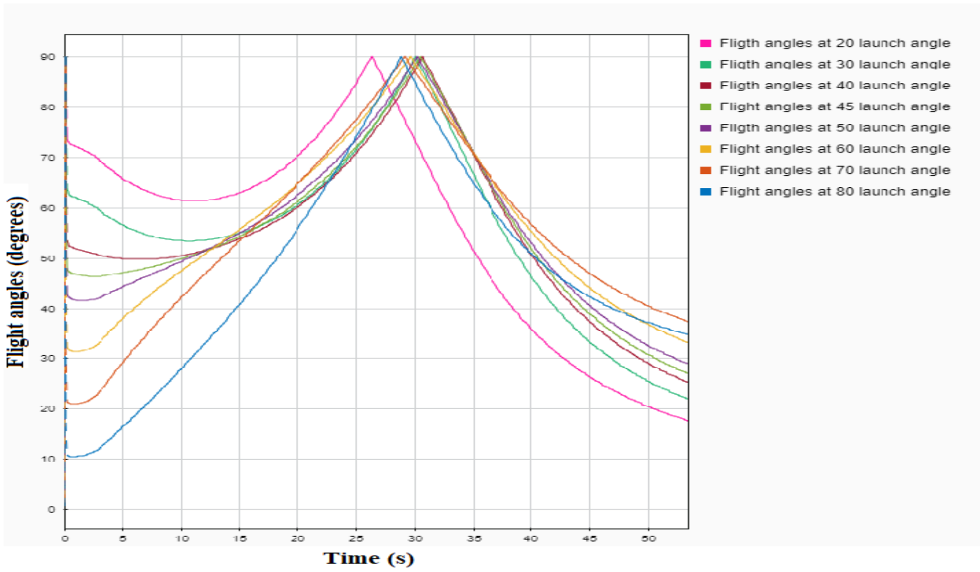

Fig. 39. Flight angle vs time

Range vs altitude graph

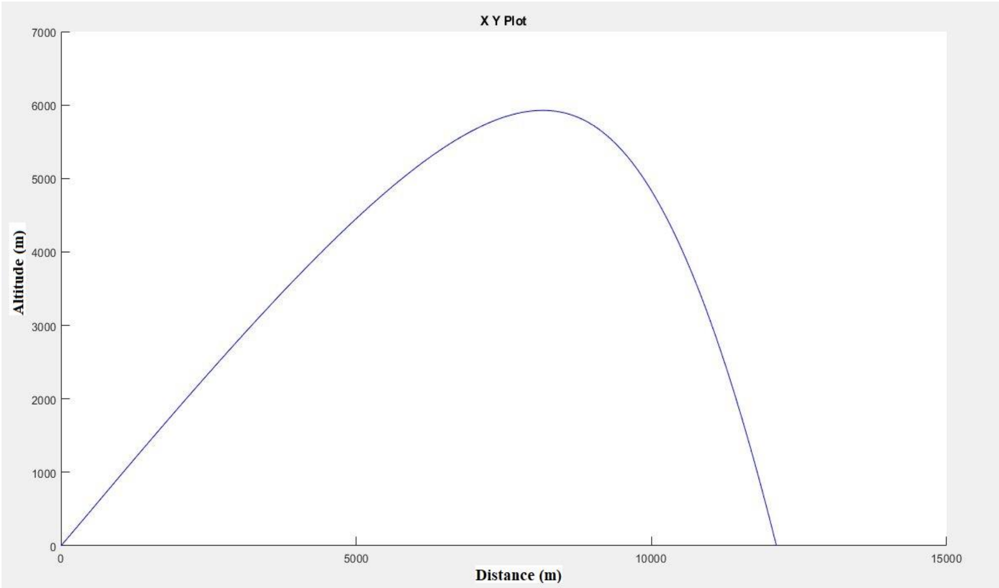

Fig. 40. Trajectory of four motor at 45-degree launch angle

The maximum range is obtained at 50-degree launch is 12,660 m with an altitude of 6065 m. The range obtained is more than 5 times the range obtained in the single motor case. This is due to the increment in the thrust and velocity.

Table 11. Ballistics data for four motor configuration

Launch angle (degrees)	Velocity (m/s)	Acceleration (m/s^2)	Altitude (m)	Range (m)
20	712	302	3275	10,280
30	728	305	4928	11240
40	742	312	5743	11870
45	739	310	5927	12120
50	738	318	6065	12660
60	719	298	6195	12434
70	699	296	6265	12280
80	672	307	6257	9137

A total number of motors being used are the same from the single motor case, only the ignition sequence varies. So, the structural mass and motor dry mass remains unchanged. When four motors are ignited simultaneously the amount of thrust reaches the maximum possible and the velocity of light reaches the maximum. As a result, the total flight time of 75 seconds is achieved, and the rocket target can travel to 12 km.

Since the required range of 20 km and the altitude of 10 km is not reached, another configuration also needs to be analysed.

3.4. Problem-3 External ballistic numerical modelling by 2T*1t + 2T*1t

Case-3 has two subdivision the ignition of 2 motors for the first 3.2 seconds and remaining two more motors are ignited for another 3.2 seconds. Thus, by increasing the burn time, the longer duration flight is possible and can increase the range and the altitude. But the thrust produced will be half of the thrust produced by the four-motor case.

Initial condition.

- Total mass :185 kg;
- fuel mass: 18 x 4 = 72 kg;
- case mass: 17 x 4 = 68;
- two motor fuel mass of 36 kg is used;
- density of air: 1.22 kg/m^3;
- temperature: 288.15 K;
- gravitational constant: 9.81 m/s^2;
- coefficient of drag: 0.29;
- two motors will be ignited for the period of 3.2 seconds.

Thrust vs time graph of two motor for 3.2 seconds

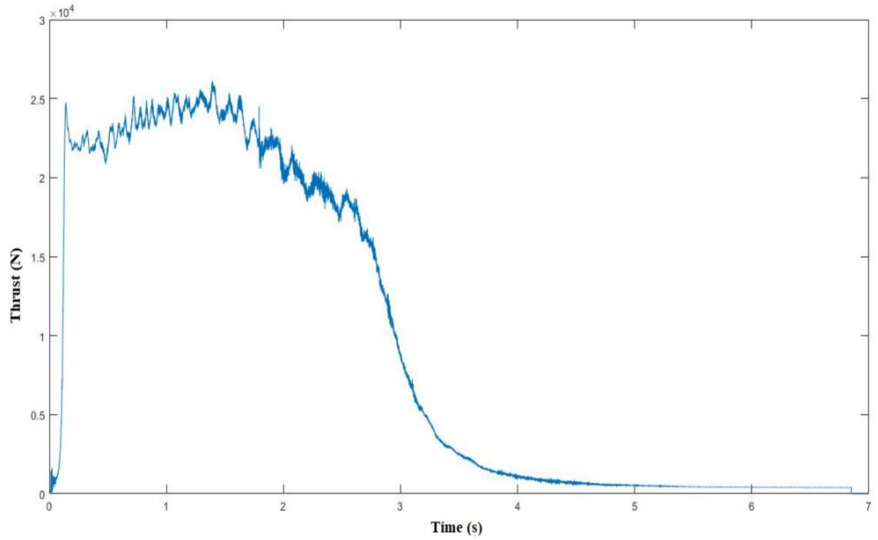

Fig. 41. Thrust vs time graph of two motor

Thrust vs time graph shows the increment of thrust to 24 kN at the beginning of the burn when there is the large area of propellant is exposed to the hot gas the neutral burn progress for the period of 2.4 seconds and the total surface area exposed becomes circular, the thrust force starts falling until the burnout at 3.2 second. The initial mass of 185 kg and the final mass this stage is 149 kg, the velocity is affected by this factor of change in mass. As only two motors are ignited remaining two remains intact with propellant being filled. The burning motor has to produce the thrust to push the entire weight of the rocket body. It is obvious that the 24 kN force generate higher velocity increment than the single motor and can reach longer distance and altitude but the comparably lower than the four motors.

Velocity vs time

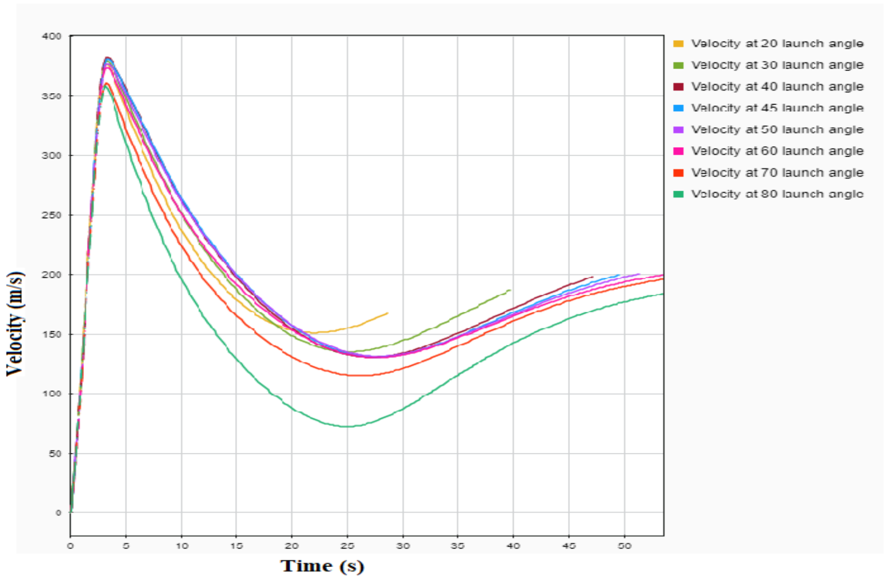

Fig. 42. Velocity vs time graph of two motor

The velocity of flight for two motor reaches a maximum of 382 m/s at 40 degrees of launch angle and the average velocity of different angle is 355 m/s. During the powered flight of 0 to 3.2 second the velocity increase to maximum and after the thrust cut-off and the velocity reduces to 100 m/s until 20 second of flight and after the loss of all the horizontal velocity provided by the thrust, the projectile starts falling, from 20-50 second of flight the ballistic phase velocity increases on free fall. Then the projectile touches down to the ground.

Acceleration vs time

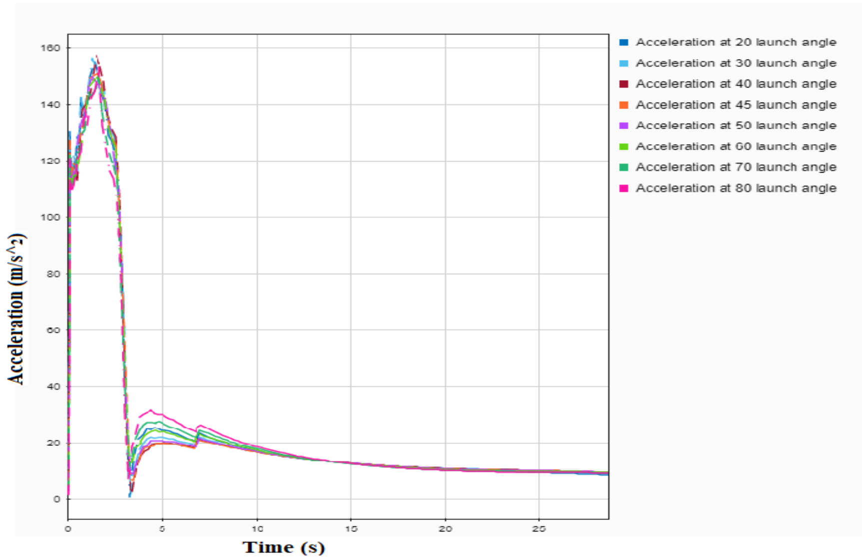

Fig. 43. Acceleration vs time for two motor

In this case, the acceleration is similar to that of other cases and proportional to the variation in thrust. g-loads variation also vary based on the acceleration and varies from 12-18g during its peak acceleration.

Altitude vs time graph

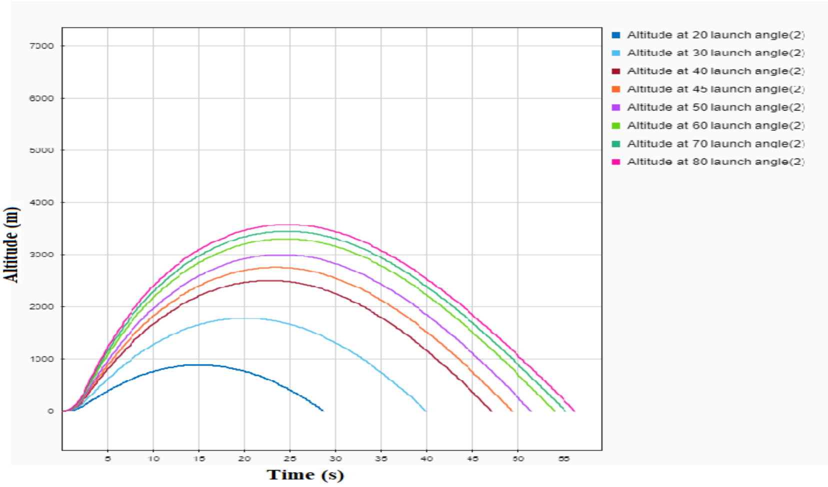

Fig. 44. Altitude vs time for two motor

With two motor power, the rocket can travel up to the maximum of 3401 m at 80-degree launch angle.

Range vs altitude

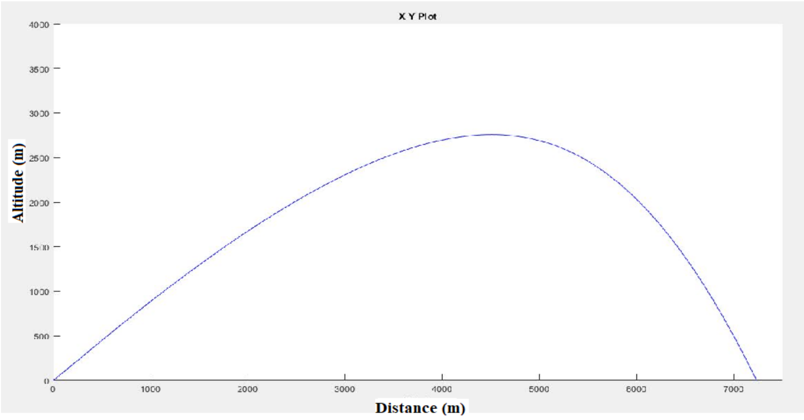

Fig. 45. Trajectory of four motor at 45-degree launch angle

With the power of two motors the rocket can reach 7105m of range.

Table 12. Ballistics data of two motors

Angle of launch (degrees)	Velocity (m/s)	Acceleration (m/s^2)	Altitude (m)	Range (m)
20	339	149	679	5132
30	341	144	1458	6325
40	340	136	2172	6920
45	337	136	2439	7013
50	338	142	2714	7105
60	328	135	3031	6701
70	324	136	3286	5691
80	318	133	3401	3429

3.4.1. Ballistic characteristics of 2T *1t +2T*1t

In this case, the remaining two motors are ignited for 3.2 seconds. The second stage uses the final velocity of the first stage as the initial velocity and accelerates further. As the object is already in motion, adding additional thrust will increase the total velocity. In this case, the mass is reduced due to the combustion of two first stage motor propellant.

Initial condition.

- Total mass :149 kg;
- fuel mass: 18 x 2 = 36 kg;
- case mass: 17 x 4 = 68 kg;
- two motor fuel mass of 36 kg is used.

Atmospheric condition at 3000 m altitude,

- Density of air: 0.909 kg/m^3;
- temperature: 268 K;
- gravitational constant: 9.79 m/s^2;
- coefficient of drag: 0.3;
- two motors will be ignited for the period of 3.2 seconds.

Initial velocity is considered as 350 m/s which is added from the first stage. The second stage motor also burns for 3.2 seconds and produce a total thrust of 24 kN, but the average velocity is increased comparatively from the first stage. This cause the total flight duration and range to increase.

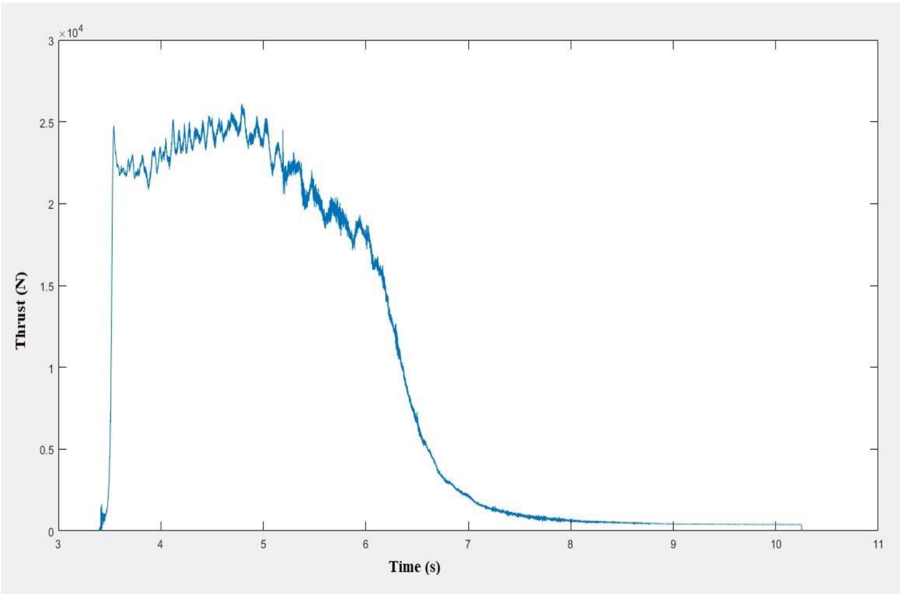

Fig. 46. Thrust vs time of two motor after 3.2 seconds

Velocity vs time graph

Velocity at this stage display the variation in the curve as the velocity of flight starts with incremental momentum of the first stage the steep change is observed. The speed starts falling at this stage and after the ignition of second stage two motor, the momentum gained and the velocity increases to a maximum of 635 m/s. This stage reaches the Mach 1.7 until 7 seconds. Later due to thrust cut-off, the speed falls to lower at the inertial flight regime for a short period. Then the ballistic stage starts at 32 seconds and the velocity increase. Here only the magnitude of the velocity is mention in the graph so the velocity change towards the ground in considered increment. velocity curve stops at touch down.

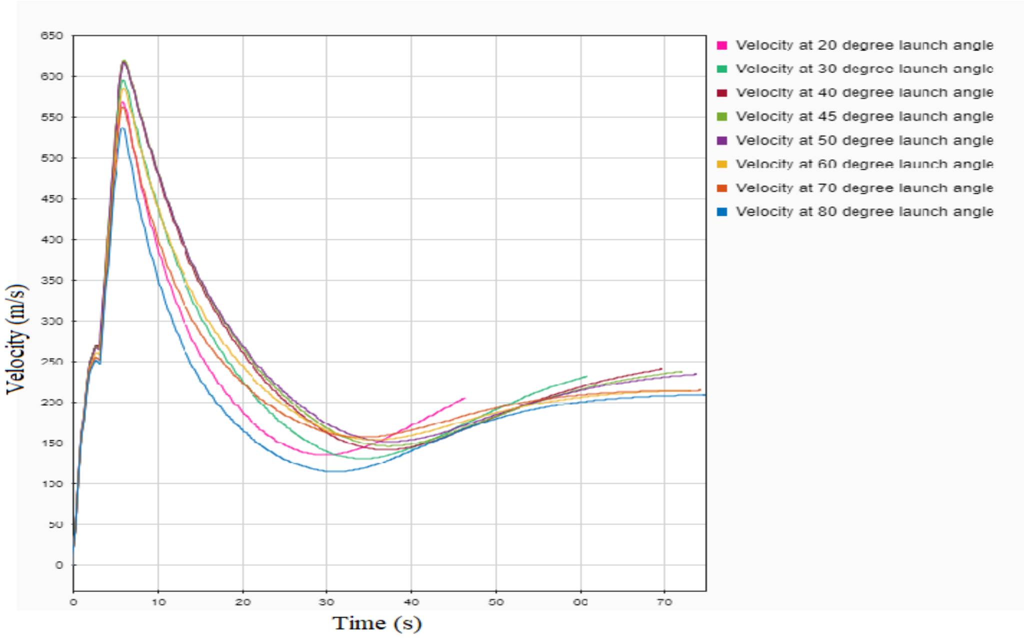

Fig. 47. Velocity vs time for two motor

Acceleration vs time

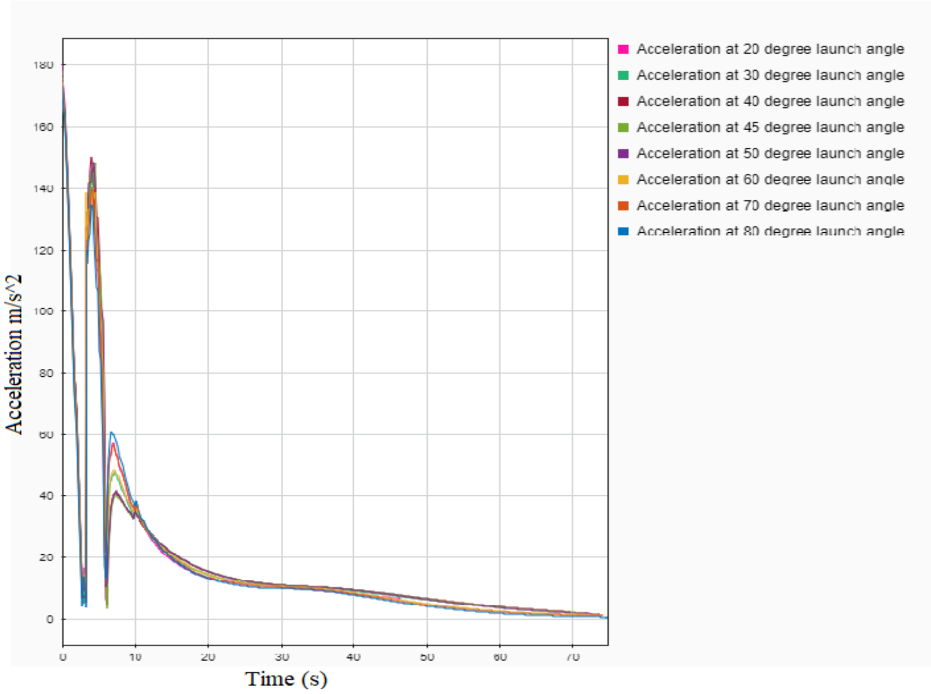

Fig. 48. Acceleration vs time for second two motors

Acceleration graph is different from the other corresponding graph. The variation is due to the two stages. At burnout of the first stage, the acceleration drops to zero as there is no thrust to produce an acceleration, after the ignition of the second stage the acceleration increases to the maximum for this stage of 150 m/s^2 addition to the first stage velocity variation. Then after the ignition cut-off of the second stage it falls again to zero at the end of the ballistic stage and touches down to zero.

Altitude vs time

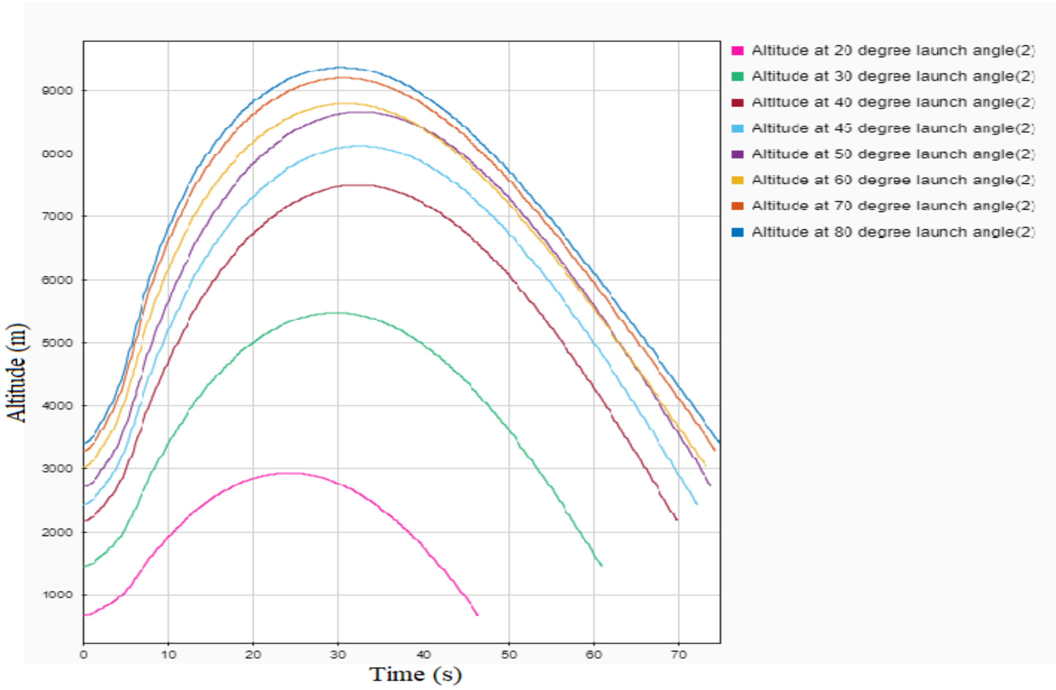

Fig. 49. Altitude vs time for second two motor

The graph shows that the altitude varies for each angle of launch. This angle are corresponding angle of first stage at burnout. At these heights atmospheric condition is different from the ground. The density of air, temperature, gravity changes. All these factors contribute to the increase in altitude. At the highest thrust and velocity, the rocket reaches the maximum altitude. The variation in total mass due to the 36 kg propellant burn at first stage, contribute more for the increase in the second stage.

Distance vs altitude graph

From 3000 m attitude and 7200 m distance travelled from point zero, the power from the second stage boost the rocket to the further distance of 12 kilometres. At the end of the flight, the rocket reaches 19.9 km distance and total altitude of 9360 m.

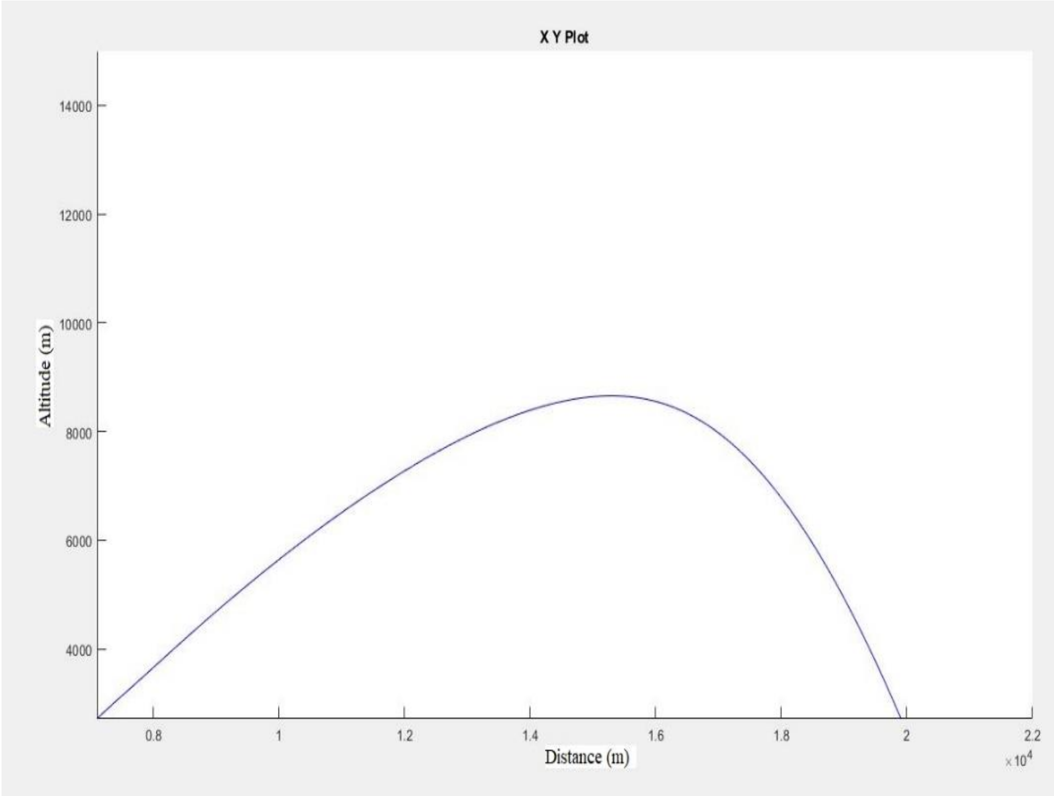

Fig. 50. Trajectory of second two motor at 50-degree launch angle

Table 13. Ballistic data of second stage

Launch angle (degrees)	Velocity (m/s)	Acceleration (m/s^2)	Altitude (m)	Range (m)
20	568	179	2,932	14,334
30	595	178	5,473	17,215
40	619	176	7,496	19,284
45	621	177	8,116	19,628
50	616	175	8,656	19,916
60	585	174	8,787	18,445
70	562	173	9,192	16,805
80	537	173	9,360	11,489

3.5. Comparative analysis of the rocket external ballistics characteristics

Three suitable configurations are being tested and two feasible design are detailed. The comparison of these configuration gives the variation in ballistics. The total of four motors is used. The total output thrust is the same, only the time impulse change. The thrust vs time graph shown below gives a clear representation of thrust output for the given time. Four and two motor characteristics are compared in this graph.

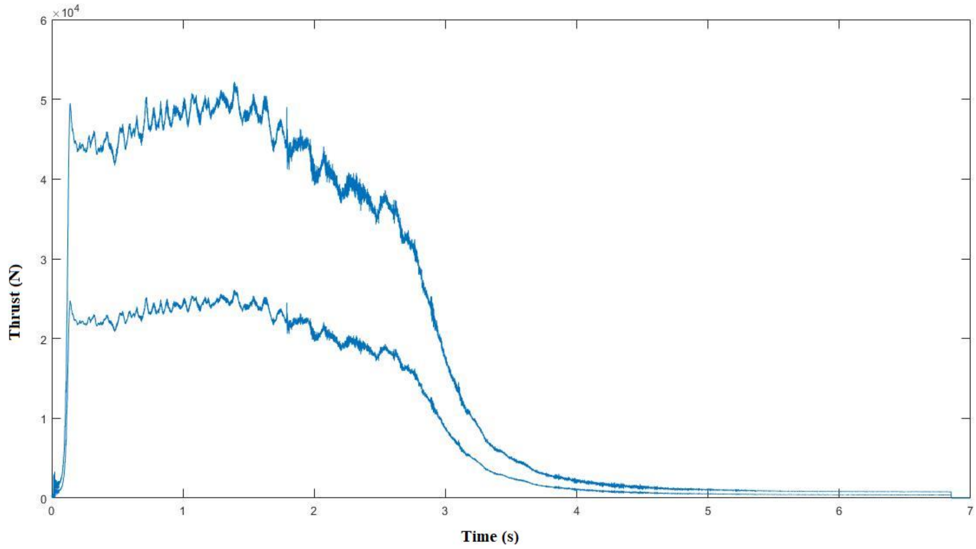

Fig. 51. Thrust vs time for second two motors

The similar burning pattern is observed in both the configuration only the amount of thrust varies with the number of motors. As the mass of the body casing and nozzle remains attached until the touch down only variation in propellant mass cause the change in velocity of flight.

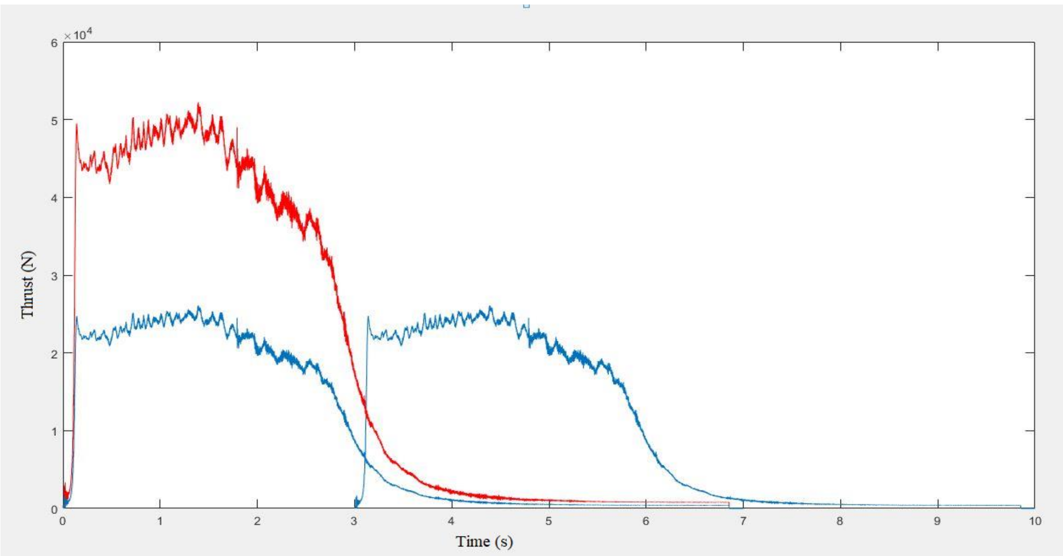

Fig. 52. Thrust vs time comparison of two cases

In the figure-52 thrust of the two cases is compared. Brown coloured curve shows the four-motor thrust and blue represents the two plus two motor thrust. In the first case the total burn time of 3.2 seconds and the second case the total of 6.4 seconds of burning is observed.

Comparison of velocity vs time graphs

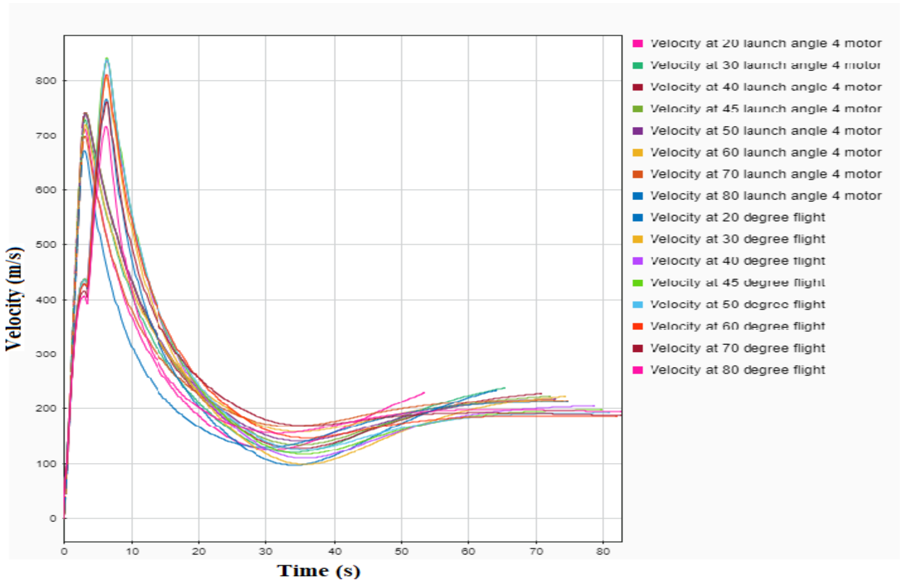

Fig. 53. Velocity vs time of two cases

Two sets of graphs from two case is compared in figure-53. As the four-motor produce nearly a similar amount of velocity but for lesser time, whereas the second case total amount of velocity is higher, but the duration of velocity change is more comparing the first two cases. Thus, the flight time increases, and the rocket can reach farther range. As it can be noticed that the touchdown time varies due to the flight time but the velocity during the ballistic stage is similar and same for both the cases. During this unpowered ballistic phase, the mass is the same in both cases.

Comparison of acceleration.

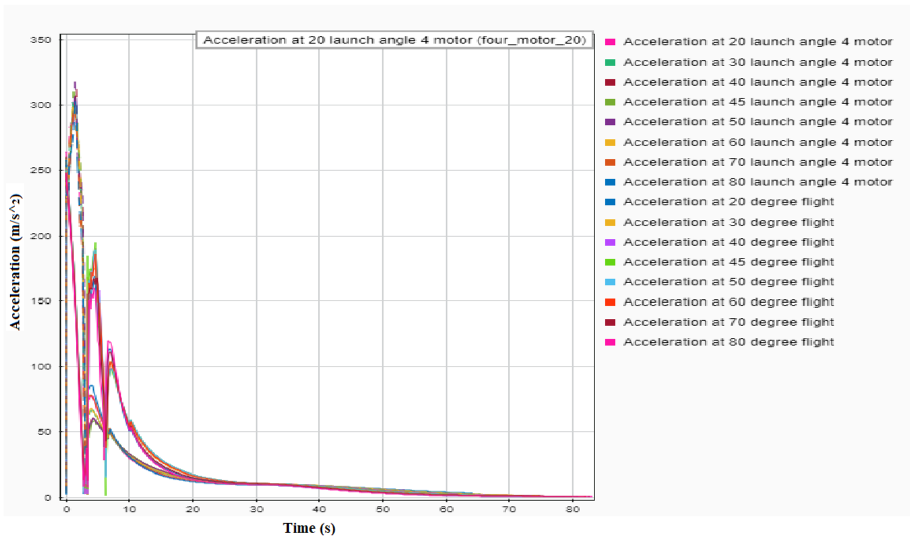

Fig. 54. Acceleration vs time for two cases

The four-motor configuration gives the maximum acceleration due to the continuous supply of the high amount of thrust for a short time. It can be observed that the acceleration is given only for the period of 3.2 seconds. But the second case has lesser acceleration but given for a longer duration. Double variation is seen in the second case as the motors are burnt twice.

Comparison of altitude graphs

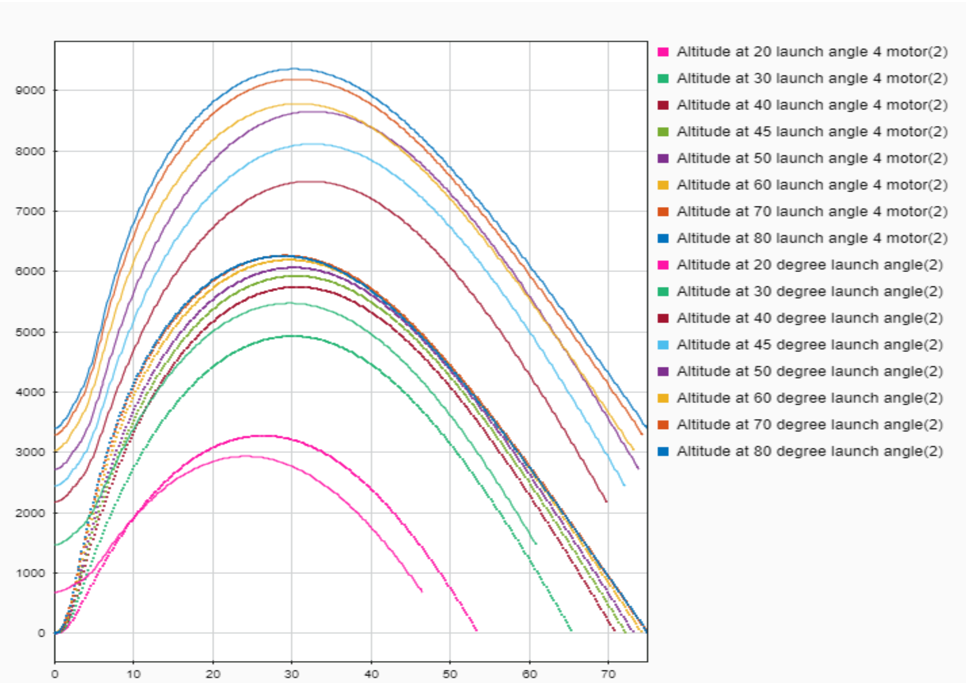

Fig. 55. Altitude vs time for two cases

The comparison of altitude shows that the two plus two motor configuration reaches the highest altitude possible. It reaches above 9 km height.

Comparison of range vs altitude graph.

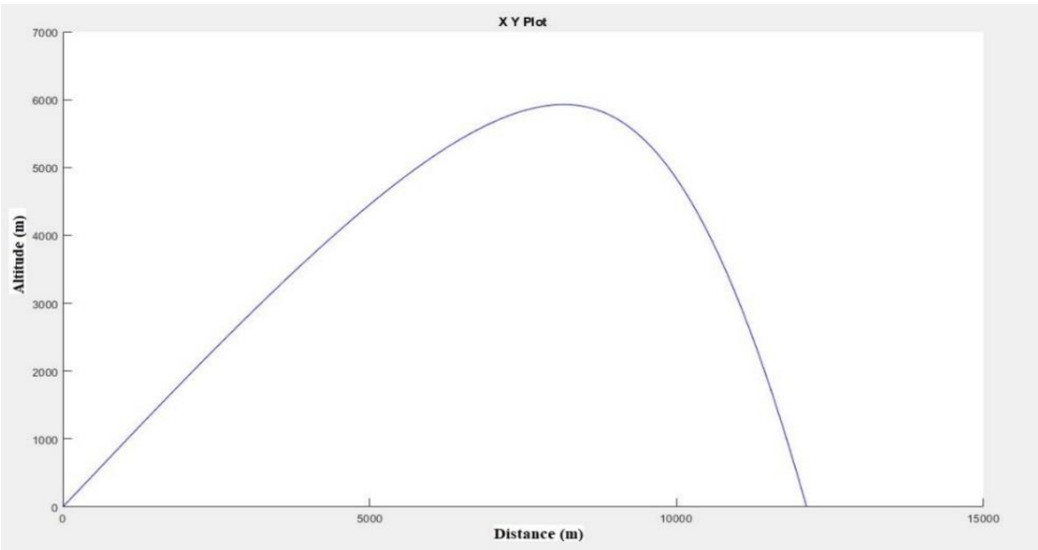

Fig. 56. Range of four motor for comparison

In a comparison of two configurations for the range, the third case gives a maximum range. Although the total amount of thrust given is constant of 48 kN, the variation in time impulse increases the range and altitude. Comparatively the magnitude of thrust lower in this case of two motors. The drag force is reduced and the number of g-forces acting on the body is lower due to the lower acceleration than four motor grid.

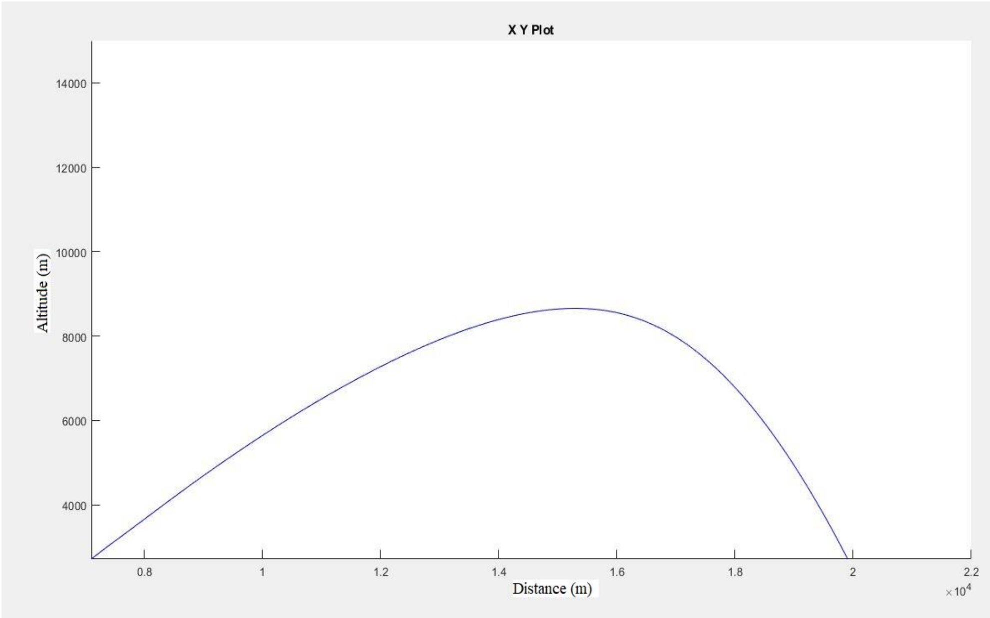

Fig. 57. Range for comparison of two cases

Maximum range can be reached by igniting the second set of two motors at 50-degree angle this gives a parabolic path and can reach more distance than the 45-degree angle.

Discussion:

The table discus the results of comparison between the configurations.

Table 14. Comparison of results for range and altitude

Launch angle (degrees)	Altitude of single motor (m)	Altitude of four motor (m)	Altitude of 2+2 motor (m)	Range of single motor (m)	Range of four motor (m)	Range of 2+2 motor (m)
20	180	3275	2932	1890	10,280	14,334
30	286	4928	5473	2132	11,240	17,215
40	516	5743	7496	2548	11,870	18,284
45	624	5927	8116	2501	12,120	19,628
50	738	6065	8656	2552	12,360	19,916
60	930	6195	8787	2320	12,660	18,445
70	1019	6265	9192	1816	12,280	16,805
80	1196	6257	9360	1012	9137	11,489

Comparsion of all cases

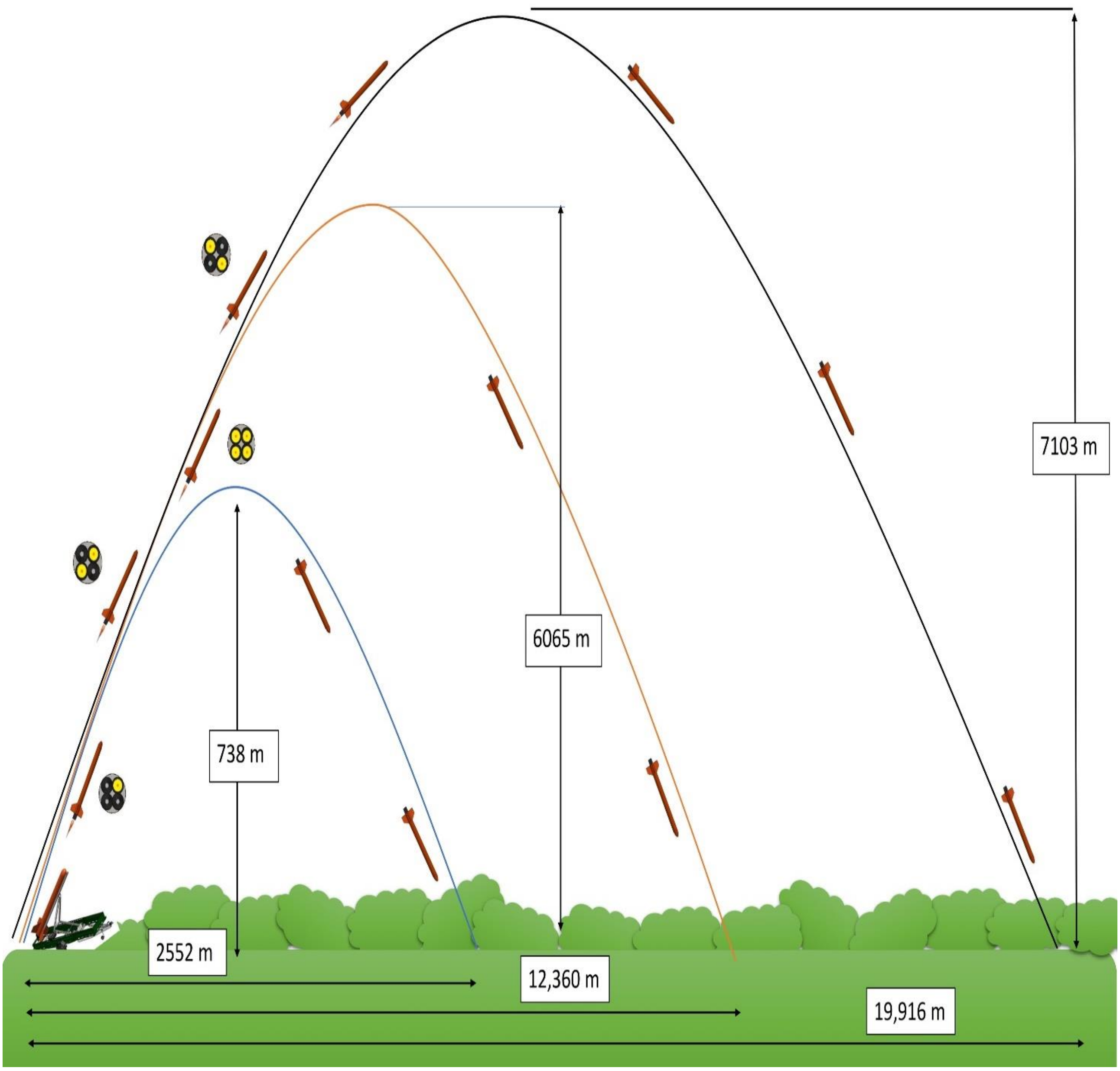

Fig. 58. Schematic of all three cases.

Use of one motor to carry a mass of 185 kg and launched at 45 to 50-degree launch can provide a thrust to reach the rocket target the distance of 2552 m with 738 m of altitude. Highest altitude in this configuration can be reach by launching at 80-degree.

In case-2 the ignition of four motor together will pull the rocket to 12,360 m of distance and height of 6065 m at 45-50-degree launch angle. Highest possible altitude is 6265 m.

In third case of burning two plus two motor make the rocket to reach the distance of 19,916 m close to 20 km range with altitude of 7103 m at 48-degree launch. At 80 degree launch the rocket can reach 9360 m.

Conclusions

- Engineering conception of the computational model using SolidWorks® and numerical modelling in MATLAB® is carried out;
- creation of methodology of investigation to analyse the three design possibilities is chosen;
- analysing rocket target of four motor configuration with sequential burning of two plus two motor is discussed;
- external ballistic parameters such as thrust, velocity, acceleration, altitude (height), range (distance), drag force, g-loads, flight angles are detailed;
- from the research of different model following results are obtained;
  1. rocket burning one motor can travel up to range of 2552 m with altitude of 1196 m
  2. four motor burning together reaches range of 12360 m and altitude of 6257 m
  3. igniting two motor in first stage and burning two more motor after burnout of first two motor can make the rocket to travel 19916 m with altitude of 9360 m;
- even though the magnitude of thrust output from the third configuration is lower compared to the four-motor grid of 48 kN, the advantage of continuous supply of thrust boost the second stage to maximum distance;
- from the comparative analysis, it is concluded that the rocket target with four motor grid using sequential ignition, first stage of two motors for 3.2 seconds produce 24 kN and igniting another two motor for 3.2 seconds with 24 kN after the burnout of the first stage is preferred;
- Four motors are arranged in a parallel configuration. Alternate motors are ignited to produce symmetrical thrust which gives stable rocket flight;
- The reduction in second stage mass and initial velocity of 350 m/s from the first stage coupled to produce a higher range for the rocket target;
- The flight velocity reaches supersonic during the flight of both four and two plus two motor configurations;
- Research and comparative analysis of rocket external ballistic characteristics by constant thrust and different time impulses is completed to use the data in modernisation of rocket target for middle range air defence systems.

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Appendices

Appendix 1. MATLAB program

```
% Author: Saulius Rackauskas
% Edited by; Hari prasanna Manimaran
% engine RT-160
% 12kN 3,5s 32k Ns 182 Ns
% case 1 and 2, 2 and 4 times thrust


Time= [0.000460938, 0.000949219, 0.0014375, 0.001925781, 0.002414063, ...

0.002902344, 0.003390625, ……….6.852511719, 7];

% engine running time [s]

Thrust= [30.439, 27.690, 98.888, 36.556, 67.415, ...

………………72.978, 16.380,  195.45, 195.96, 196.34, ...

196.39, 196.82, 195.94, 0, 0];

% Motor thrust [N]

Max_Thrust=max (Thrust); % maximum Motor thrust [N]

Avg_Thrust=mean (Thrust); % Average Motor thrust [N]

Burn_Time=max (Time); % Motor burn time [s]

Propellant_mass=72 ; % Propellant mass [kg]-----------++++++++++++++++++++++++

Total_impulse=abs (trapz (Thrust, Time)); % Total impulse [N*s] -----

 Empty_Motor_mass=68-Propellant_mass; %motor mass after combustion [kg]+++++++++

 Total_Motor_mass=Propellant_mass+Empty_Motor_mass; % Total motor mass [kg]------

Rocket_diameter=400/1000; % Diameter in meter +++++++++++

Air_Density=1.22; % Air density at sea level ++++++++++++++

Cd=0.29; % Drag Coefficient +++++++++++++

%Cd=0.3; % Data taken from book Cd

 Rocket_frame_Mass=185-Total_Motor_mass; % Rocket body mass without motor [kg] ++++++++

g=9.81; % m/s^2 gravitational constant

Launch_angle_in_degrees=20; % Rocket launch angle (sliding angle from horizontal axis)

Launch_angle=(Launch_angle_in_degrees*pi)/180; % launch angle in radians
```

Appendix 2. Conference and Research journal publication related to this research.

Transport means 2018.

Certificate of Participation

This is to certify that

Hari Prasanna Manimaran

has presented a paper titled

RESEARCH AND DESIGN OF MIDDLE RANGE ROCKET TARGET

at the 22nd International Scientific Conference „**Transport Means 2018**“

held on 3–5 October, 2018 in Trakai (Lithuania)

Chairman of the Conference

Prof. Dr. Zilvinas Bazaras

Conference on challenges to national defense in contemproary geopolitical situation.

THE GENERAL JONAS ŽEMAITIS MILITARY ACADEMY OF LITHUANIA

COGITA UNIVERSALITER - AGE REGIONALITER
NATIONAL DEFENCE FOUNDATION

ktu kaunas university of technology 1922

International Conference and Live Firing Show' 2018
CHALLENGES TO NATIONAL DEFENCE IN CONTEMPORARY GEOPOLITICAL SITUATION

Certificate
OF ACHIEVEMENT

This is to certify that

Hari Prasanna MANIMARAN

has successfully participated and made the presentation "DESIGN OF ELECTROMAGNETIC RAIL POWERED MISSILE FOR PENETRATING MISSILE DEFENCE SYSTEM" in the International Scientific Conference *Challenges to National Defence in Contemporary Geopolitical Situation*, dedicated to the 100th Anniversary of the Restoration of Lithuania's Independence held at the Pabrade Training Area, 25-27 April 2018, Lithuania.

Chairman Dr. Svajonė Bekešienė

2018
Vilnius

Young scientist conference 2018 Kaunas.

Jaunųjų mokslininkų konferencija

pažymėjimas

PRAMONĖS inžinerija 2018

Nr. V24-11-57

pažymime, kad 2018 m. gegužės 10 d.

Hari Prasanna Manimaran, Mastan Raja Papanaboina, Naga Manikanta Kommanaboina

dalyvavo KTU Jaunųjų mokslininkų konferencijoje „Pramonės inžinerija-2018“ ir pristatė pranešimą

CONCEPTUAL DESIGN OF FULLY REUSABLE SPACE LAUNCH SYSTEM

MIDF Dekanas dr. Andrius Vilkauskas

„Santakos“ slėnis, Kaunas

organizatorius

ktu 1922 mechanikos inžinerijos ir dizaino fakultetas

partneris

PTO PAKUOČIŲ TVARKYMO ORGANIZACIJA