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ARTILLERY ROCKET SYSTEMS

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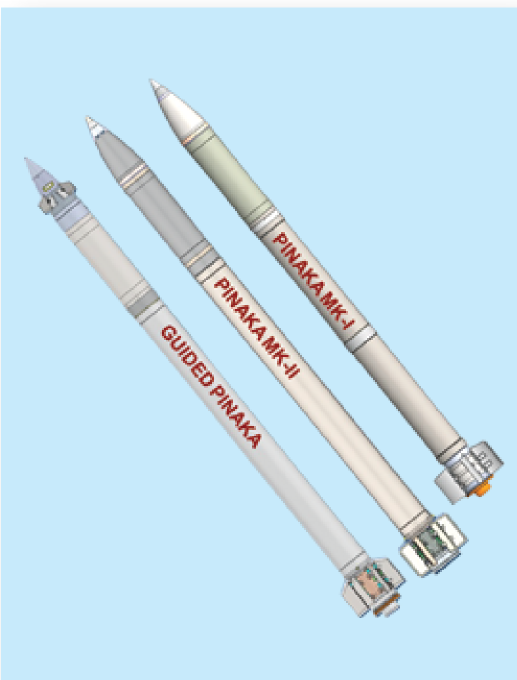

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From the Desk of Guest Editor

Armament Research & Development Establishment (ARDE) is one of the earliest laboratories established under the DRDO umbrella, with mandate to design and develop conventional armaments for the Services and Paramilitary Forces. One of the areas in which ARDE has established core competence is design and development of artillery rockets and associated technologies.

ARDE's emphasis is on finding indigenous solutions for different technologies related to enhanced range, accuracy and lethality of rockets. Various technologies like flow forming of high L/D ratio motor tubes and stabilizer assembly operating at high Mach number have been established. Capabilities of indigenously designed and developed rocket systems such as 122 mm Enhanced Range Rocket (ERR), Remotely Delivered Mine System (RDMS) and Pinaka have been successfully demonstrated. It is worthwhile to mention, Pinaka was put into the service during Indo-Pakistan conflict in Kargil in Op Vijay (June 1999). Presently Pinaka is under production at DGOF. A joint venture project was also undertaken with IMI, Israel for accuracy improvement using Trajectory Correction System (TCS) for Pinaka. CEP of less than 60 m at 30 km range has been successfully demonstrated.

A 60 km range Pinaka Mk-II rocket system has been developed. Various critical technologies, viz., case bonded finocyl grain configuration, PF warhead, WAF stabilizer and nozzle end ignition system have been established. Various problems related to high speed aerodynamics, viz., excessive out-of-plane moment and dynamic instabilities were addressed by innovative design modifications which helped ARDE to foray in cutting-edge technologies for guided Pinaka Rocket System. The main aim of guided Pinaka is to meet the requirement of highly accurate weapons with enhanced lethality and low collateral damage.

ARDE in association with sister DRDO labs, viz., RCI and DRDL, Hyderabad in a very short span of time developed and demonstrated performance of guided Pinaka. Various other technologies related to Launcher Pod, Guidance, Sensors and Ferro-electric Pulse Power Generator (FEPPG) Crystal-based Warhead Initiation are being developed.

This issue of Technology Focus highlights ARDE's contributions towards development of various artillery rocket systems and enabling technologies.

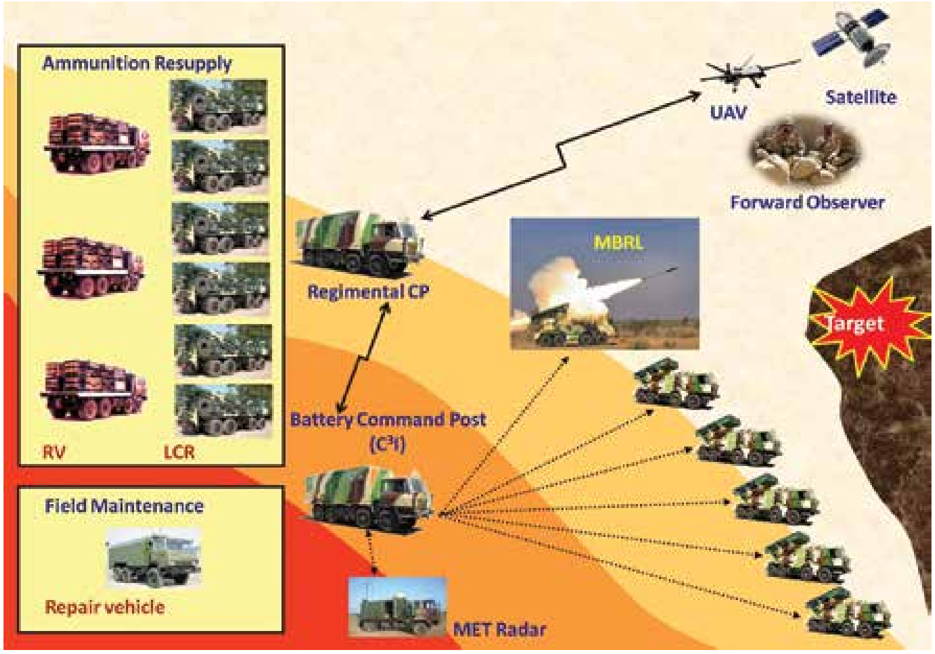
Dr V Venkateswara Rao
Outstanding Scientist & Director, ARDE

Armament Research and Development Establishment

After the Defence Research & Development Organisation (DRDO)was created as an inter-service organisation in 1958, the then existing Technical Development Establishment (Ammunition) and Technical Development Establishment (Weapons) were reorganized into two separate establishments—Armament Research and Development Establishment (ARDE) to carry out R&D functions, and Chief Inspectorate of Armaments (CIA) to look after the production and inspection functions with effect from 1 September 1958. ARDE caters to the need of all the three wings of the Indian Armed Forces - Army, Navy and the Air Force. The maxim of ARDE is to be of "Service to the Services". The endowments of ARDE embraces a whole spectrum of activities related to the complex, multi-disciplinary field of conventional armament technology. These activities comprise basic and applied research and development, prototyping, test and evaluation, modelling, simulation and software development, Transfer of Technology (TOT) and limited scale pilot-plant production of crucial items. A full-fledged Pashan Range for test and evaluation, a prototype manufacturing unit and modern pilot plants for production of air power cartridges and PZT components are some of the unique facilities available at ARDE. ARDE is an ISO 9001:2015 certified laboratory. Over the years, it has contributed several major weapon systems and sub-systems such as Pinaka Multi-barrel Rocket Launcher System, INSAS family of weapons and ammunition, warheads for IGMDP missiles, Arjun armament, Adrushy influence munitions and various categories of aircraft bombs and naval armament. One of the most prestigious programs of DRDO, namely design and development of a 155 mm/52 Cal Advanced Towed Artillery Gun System (ATAGS) jointly with the Indian industries is making rapid strides. ARDE has also taken up several programmes for developing precision guided munitions. Besides other guided munitions programmes at ARDE include: Anti-tank Guided Missile for Arjun, penetration guided bombs, etc.

Pinaka Multi Barrel Rocket Launching System

The Pinaka Multi Barrel Rocket Launching System (MBRLS) designed and developed by ARDE in association with other DRDO labs, is an all-weather indirect fire artillery rocket system. The system is capable of firing free flight as well as guided Pinaka rockets. The free flight rockets can engage targets up to 37.5 km (Pinaka Mk-I) and 60 km (Pinaka Mk-II) range whereas guided Pinaka rocket can engage targets located deep into enemy territory up to a range of 75 km with high precision. The weapon system with Mk-I rockets has been inducted into Services and currently under bulk production. A battery of six launchers can fire a salvo of 72 free flight rockets in 44 seconds. Over 7.2 tons of payload in the form of lethal warheads can be delivered by the system which can effectively neutralize a target area of 1000m x



Pinaka Rocket Battery System

800m. In terms of its characteristics it is comparable to contemporary MBRLs in its performance class.

Role of Pinaka

◊ Neutralization or destruction of exposed troop concentrations, 'B' vehicles and other soft targets.

◊ Engagement of enemy concentration areas, communication centers, air terminal complexes, armour and mechanized concentrations.

◊ Neutralization of enemy guns, rocket and missile launcher locations.

◊ Deny movement of enemy personnel and armoured vehicle columns.

◊ Destruction of FOL and ammunition dumps.

Pinaka Battery Configuration

Pinaka battery comprises of 6 launchers, 6 Loader-cum-Replenishment (LCRs) vehicles, 3 Replenishment Vehicles (RVs), 2 Battery Command Post (BCP) vehicles and 1 DIGICORA MET Radar. Various sub-systems of Pinaka battery are shown in the Figure.

Salient Features of Pinaka Weapon

◊ Free flight rockets have accuracy and consistency of 1.5 % of its range (PE) makes it a good area weapon. Guided Pinaka has accuracy of < 60 m (CEP) makes is suitable for precisely engaging high value targets

◊ High lethality achieved by a family of optimized warheads, viz., Preformed Fragment, Incendiary and sub-munition warheads

◊ Rugged Fire Control Computer (FCC) for comprehensive control of firing mission through secure wireless data link

◊ Automated laying of launchers by powerful microprocessor based servo drive

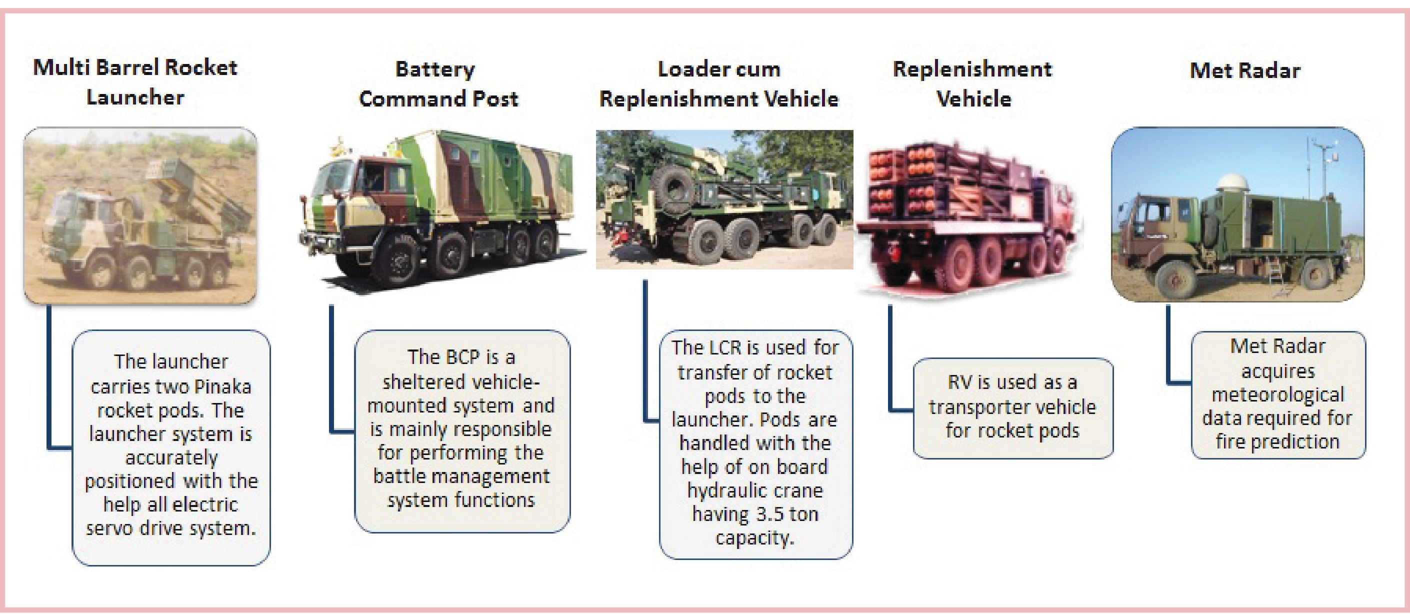
◊ Automatic Gun Alignment and Positioning System (AGAPS) integrated with each launcher for land navigation and launcher orientation

◊ No separate survey team is required for positioning and orientation making the launcher autonomous

◊ Fast coming into action is achieved with the help of automated features enabling fast response to call for fire

◊ Shoot and Scoot capability enables launcher to escape counter battery fire

◊ Matching mobility and logistics commonality by use of a common carrier vehicle (TATRA 8x8) for the entire family of Pinaka vehicles



Components of Pinaka Battery

Artillery Rocket System

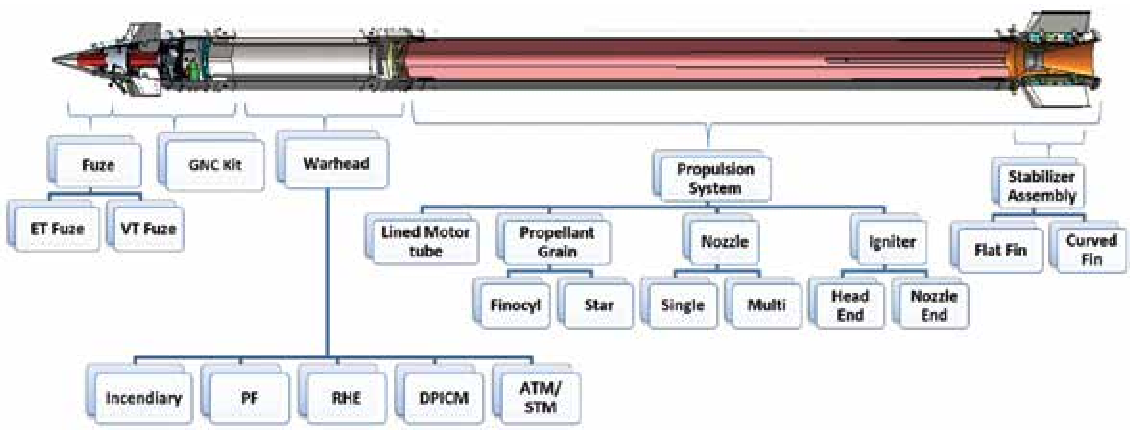
In India during pre-1980s period, development of rockets was done amidst constraints such as limited information in open literature, limited computational and analysis tools, absence of adequate manufacturing technologies, limited choices for materials and propellant. In this background, ARDE started with reverse engineering of in-service GRAD rocket. The impressive field performance of in-service BM-21 system motivated ARDE to design and develop indigenous and state-of-the-art artillery rocket systems.

Since then, emphasis was on development of various technologies related to rocket propulsion, warheads, fuzes, launching system, C4I and ammunition re-supply chain vehicles. ARDE has been involved in development of following artillery rockets. The rocket development is primarily carried out in association with HEMRL and PXE:

- Pinaka Mk-I (37.5 km)
- Pinaka Mk-II (60 km)
- Guided Pinaka (75 km)
- Pinaka Mk-I Enhanced (45 km)
- 122 mm Extended Range (40 km)

Artillery Rocket Sub-Systems

Rocket technology development is a complex and multi-disciplinary field. Demand for high performance rocket systems is on the rise. Rockets with higher accuracy and low collateral damage is the need of the hour. Rocket technology involved amalgamation of technologies related to various sub-systems, which have to work in sync for successful functioning of the rocket. Major sub-systems of a typical artillery rocket are fuze, warhead, propulsion system, GNC kit and stabilizer assembly. Free flight rocket do not have GNC kit.



Components of Typical Artillery Rocket

ET: Electronic Time

VT: Variable Time/ Proximity

GNC: Guidance Navigation and Control

ATM: Anti-tank munition

PF: Preformed Fragment

DPICM: Dual Purpose Improved Conventional Munition

RHE: Reduced/Restricted High Energy

STM: Soft Target Munition

Design Methodology for Artillery Rockets

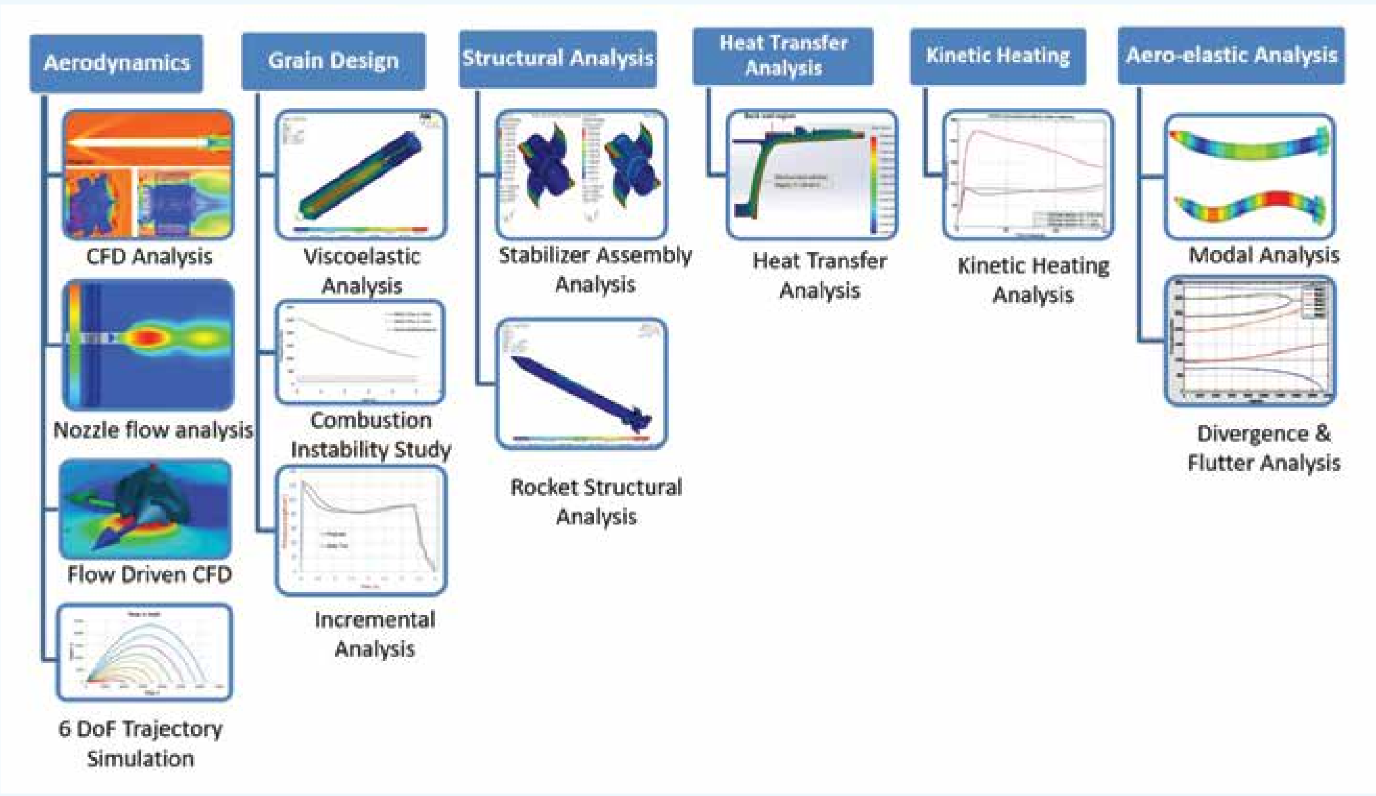
After evaluating User's requirement, a conceptual design of rocket is prepared and system analysis is carried out considering various aspects such as aerodynamics, propulsion, structural integrity and trajectory simulation, etc.

A critical evaluation is required as rocket speed, drag and dispersion increases with higher range requirements.

Longer range requirements ultimately increases the aerodynamic loads, which flight structure has to bear. Flight speed of 3.6 Mach-4 Mach and beyond leads to increase in aerodynamic loads and kinetic heating loads on rocket.

Due to geometrical and mass constraints rockets are designed with high slenderness ratio (L/D ~21) and multiple joints which reduces structural stiffness. Hence, rockets are susceptible to aero elastic problems like body divergence and fin flutter. Apart from aerodynamic loads, rocket structure subjected to internal chamber pressure due to propellant burning and ignition transient.

Thus extensive simulation and numerical techniques are required for rocket design and analysis.



Simulation Techniques used in Design of Artillery Rockets

Fuzes for Artillery Rockets

Fuze is a device with necessary safeties and explosive elements, designed to initiate explosive train when the specified conditions are met. Fuze functions through explosive train which comprises of a detonator/ igniter that generates detonation wave which is further boosted up by a booster that in turn detonates the main explosive filling.

Traditionally, the fuze provides safety by keeping one part of the explosive train in misaligned condition and align the explosive train after launch of the projectile and then detonates the explosive when specified conditions (like time/space) are sensed.

To keep the fuze and ammunition safe, suitable safety interlocks like 'g' sensors, electronic or mechanical timer, pyro delay elements, etc. are used. The explosive train is aligned at appropriate instance during the flight. Fuze is initiated by initiation of first element of explosive train after sensing some input. In a typical mechanical fuze, this is done by force of striker. In an electronic fuze, the initiation is done by an electric pulse generated by a firing circuit. Types of fuzes used for artillery rockets presently are shown in the Table.

Fuzes used in Pinaka Rocket

Type of Fuze	Warhead	Modes of Operation
VT Fuze 10 m Height of Burst (HoB)	a. Pre-formed Fragments (PF) b. Restricted High Explosive (RHE)	RF Proximity/ Point-detonation
ET Fuze (Range: 6s-200s) a. Turbo generator-based b. Thermal battery-based	Incendiary Sub-munition type (DPICM, ATM & STM)	Electronic time

Features of Pinaka VT Fuze

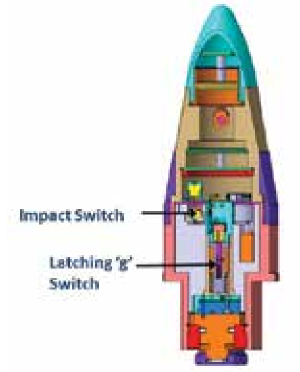
Type	Proximity fuze with impact as secondary mode of functioning
VT (Proximity) mode	Height of Burst 10 m with remaining velocity>180m/s
Impact mode	Approach angle between 22 deg and 90 deg with remaining velocity>160m/s
Primary safety	4 sec (minimum) from launch
Secondary safety	5 sec (minimum) from launch in proximity mode

VT Fuze/ Proximity Fuze

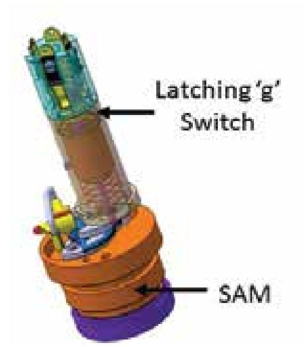
Variable Time (VT) or the proximity fuze is used for PF and RHE warheads which are required to function at nominal height of 10m.

It functions in two different modes as shown in the Table. It also contains impact switch and can work in impact mode when Point Detonation (PD) mode is selected. Configuration of VT fuze with latching 'g' switch and safety and arming mechanism is shown in the Figure.

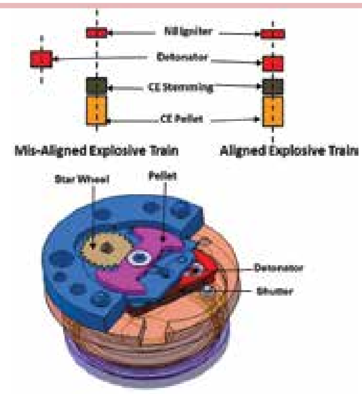
The Safety and Arming Mechanism (SAM) designed for these fuzes consist of two parts. One is latching 'g' switch and the other is Gaine. The latching 'g' switch serves two purposes: The first purpose is to connect the battery to electronic circuit so that the firing circuit starts working. The second function of latching 'g' switch is to remove the obstruction to shutter of gaine so that the explosive train starts its alignment. The latching 'g' functions only when sustained acceleration of 12-18 'g' is imparted by the flight of rocket. Gaine aligns the detonator from 'SAFE Condition' to 'ARMED Condition' after safe separation distance (300 m) of rocket from launch point. This is done by



VT Fuze



Latching 'g' Switch Safety



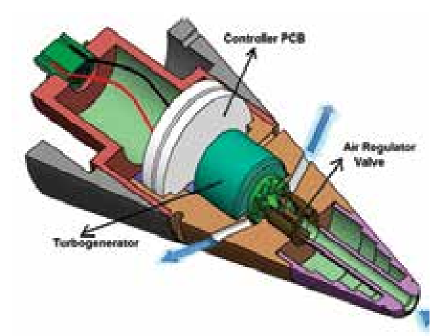
Safety and Arming Mechanism

star wheel, gear, pinion and pallet mechanism. The detonator inside shutter comes to the armed position slowly. The motion of shutter is continuously hindered by the pallet and therefore it takes time (about 900 ms–1 s) for the detonator to come to aligned condition.

ET Fuze

Electronic Time (ET) fuze is required to initiate incendiary and sub-munition warheads. It facilitates the initiation of warhead at a pre-determined time during flight. Pinaka sub-munitions warheads (DPICM, ATM and STM) require multiple electrical pulses to initiate squibs/ detonator from ET fuze. At a pre-determined time in the trajectory, the ET fuze functions and initiates the detonators, which in turn initiates the FLSC and sub-munitions are ejected due to spin and spring force/gas pressure. ET fuzes powered by turbo generator as well as thermal battery have been developed.

ET Fuze with Thermal Battery



ET Fuze with Turbo Generator

DASD Fuze

A miniature Direct Action Self Destruct (DASD) fuze has been developed by ARDE for the sub-munitions of Dual Purpose Improved Conventional Munition (DPICM) warhead. This munition is used for both anti-personnel as well as anti-tank roles. DPICM uses Direct Action Self Destruct (DASD) fuze which functions upon impact with target or after a delay of 20s±2s in SD mode. Each bomblet has a mechanical DASD fuze attached with it. The DASD fuze gets armed only after ejection using aero-dynamic forces during the descending motion. DASD mechanism contains:

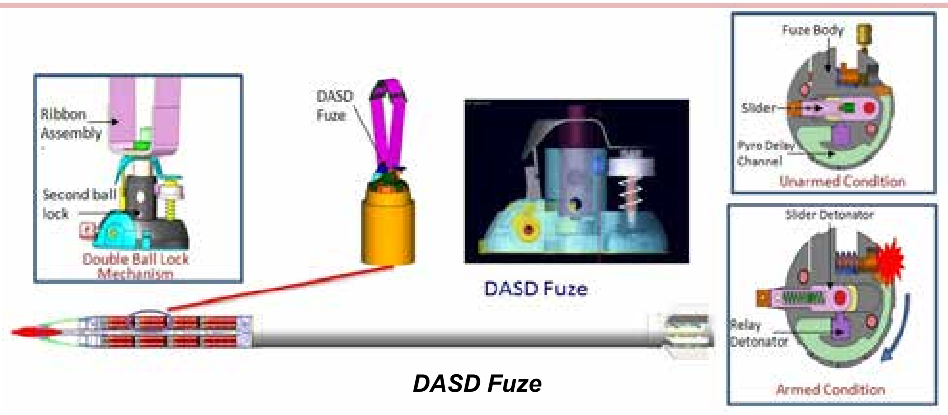
◊ Double ball lock to provide safety and to arm fuze positively

◊ Slider lock mechanism to hold the slider in aligned condition

◊ Self-destruct mechanism for 20s± 2s to clean the battlefield

Features of Pinaka ET Fuze

Parameter	Value
Time programming range	6s-200s
Accuracy	± 50 ms
No. of timed outputs	Four pulses
Overhead safety	No arming till 4s of set time



DASD Fuze

Warheads

A warhead is a part of rocket/ missile that inflicts desired damage to the target and renders it incapable of performing its intended function. In general the damage to a target can be due to physical, thermal and psychological effects. Various warheads developed for Pinaka rocket are:

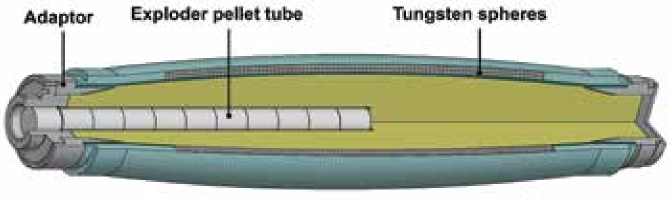
Pre-Formed Fragment (PF) Warheads

These warheads are for anti-personnel and to cause damage to soft skinned vehicles, radar installations and FOL dumps, etc. The warhead is effective up to 60 m radius. The kill mechanism consists of two layers of 6 mm tungsten alloy spheres as pre-formed fragments laid over a filament wound FRP module. Inside portion of the module is filled with high explosive composition, i.e., DENTEX, which on detonation propels the fragments with high velocities. The warhead is detonated at a predetermined height above the target to achieve optimum performance. The warhead is initiated by a proximity fuze (VT).

Incendiary Warheads

This type of warhead is mainly used for setting fire on inflammable targets like FOL dumps and ammunition depots. The incendiary composition is housed inside a container along with a burster charge. These containers are hermitically sealed. Five such incendiary containers are housed inside a steel tube. The steel tube is


Testing Facility for Warhead



Sectional View of PF Warhead Module

provided with notches on outer surface so that secondary fragmentation effect can be achieved. The incendiary rocket is initiated at 300 m HOB. Incendiary composition contains 60:40 ratio of Zr and Red Phosphorous. Warhead is effective up to 75 m radius.

Sub-munition Warheads

The sub-munition warheads are deployed against large area installations. Such warhead comprises a number of sub-munitions/bomblets housed inside a warhead structure. They are dispensed at terminal end with the help of common ejection mechanism. Three such types of warheads, i.e., DPICM, Anti-tank Munition (ATM) and Soft Target Munition (STM) have been developed for Pinaka rockets.

Each sub-munition has its independent kill mechanism, stabilisation and fuzing system. Their lethality is derived from the ability of one or a few bomblets to destroy a major component of the target or to inflict structural damage to the target. They contain a fragment casing or shape charge to achieve desired effect. ARDE has developed sub-munition warheads thus providing a lethal edge to Services.

DPICM Warhead

For proper dispensing of sub-munitions at terminal end, the following two events takes places simultaneously.

- ◊ Ballistic case cutting by FLSC
- ◊ Central buster to generate high gas pressure at center

DPICM is also referred as bomblet. The DPICM warhead is initiated at a HOB of around 750 m above the ground. The case cutting and gas pressure generation are synchronized to dispense the sub-munitions. On ejection, each bomblet gets separated and stabilizes through a ribbon attached to it.

On impact, bomblet fuze functions and destroys the target. In case if it fails, SD mechanism works and demolishes bomblet.

ATM/STM Warheads

These sub-munition warheads are used to stop the advancement of approaching column of enemy personnel (STM) or armoured vehicles (ATM). ATM warhead houses 18 Nos of anti-tank sub munitions, whereas STM warhead houses nearly 48 Nos of sub munitions. These munitions are axi-symmetrically packed and dispensed over the target area by

STM

DPICM

ATM

Sub-munition Warheads

Effect of Incendiary Warhead

cutting the casing into three petals using FLSC. Each ATM is attached with a parachute and gets stabilized. On landing, these parachutes gets detached with the help of a parachute release mechanism. Functioning of a pyro-cutter makes the sub-munitions in up-right position. ATM sense the tank, by change in magnetic field. If no target detected with in set period, munition blows off with SD. In case of STM, it gets activated by pressure. Similar to ATM, after the set period, SD/SDA will ensure the clearing of minefield.

Testing of ATM Warhead

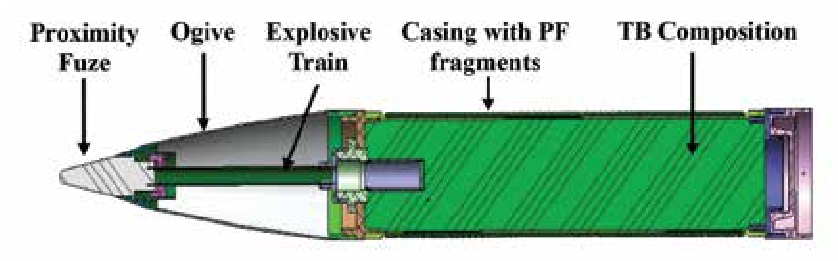
Testing of STM Warhead

Testing of DPICM Warhead

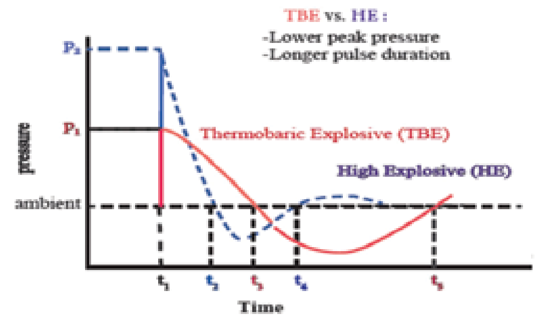
Thermobaric Warheads

Thermobaric warheads contain slow burning explosive compositions that keep their explosive impulse on the target for a longer duration. Thermobaric compositions are essentially metal enriched and oxygen-deficient.

Typical detonation velocities of thermobaric explosives are of 3-4 km/s. Unlike conventional High Explosive (HE) warheads, the thermobaric warheads undergo simultaneous detonation and dispersion. Only a part of the energy is released during the initial detonation phase, which generates active fuel-rich products that undergo after-burning when mixed with the shock-heated air. The energy released through after-burning increases the duration of blast overpressure along with fireball. The burning cloud is capable of penetrating into small gaps, cracks, cleavages, etc. Thermobaric explosives generally contains fuel rich explosives or high TNT equivalence. Their performance is enhanced by addition of excess metals powders of nano and micro fine size. Energy released through aerobic combustion generates high temperatures and lengthens the duration of blast overpressure.



Thermobaric Warhead



Comparison of Thermobaric and High Explosive

Testing of Thermobaric Warheads

Propulsion Systems for Artillery Rockets

Solid Rocket Propellants

Thermodynamic expansion of gas is used in majority of practical rocket propulsion systems. Internal energy of the gases is converted into kinetic energy of the exhaust flow to produce thrust. In artillery rockets, the internal energy required for expansion of gases is obtained through combustion of solid rocket propellant. Initially Double Base Propellants (DBP) were used for artillery rockets. DBP consists of two basic ingredients: Nitrocellulose (NC) and Nitroglycerine (NG). The overall consequence is fuel rich combustion leading to low performance levels in terms of Specific Impulse (Isp) 200 s-220s.

To meet the growing requirement of higher and higher energetics, Composite Propellant (CP) were developed in late 60s. CP is heterogeneous in nature and consists of ammonium perchlorate, aluminium powder and hydroxy terminated polybutadiene as major ingredients in addition to minor ingredients like plasticizer, bonding agent, processing aid-curing agent, etc. These propellants with higher energy in terms of Isp (240s-252s) and higher density (1.76 g/cc) are the most widely used for artillery rockets. Indigenously developed Pinaka Mk-I, Pinaka Mk-II, guided Pinaka and 122 Extended Range rockets use CP to achieve higher ranges. However CPs are inferior in mechanical properties. Recently, attempts are made to overcome the limitations of DB propellants by addition of an oxidizer to DB matrix in order to exploit combustion potential of fuel-rich products.

Thus, attention is centered on systems containing oxygen-rich compounds dispersed in DB matrix, known as Composite Modified Double Base (CMDB) propellants. CMDB propellant have potential to offer marginally higher Isp and better combustion characteristic than CP.

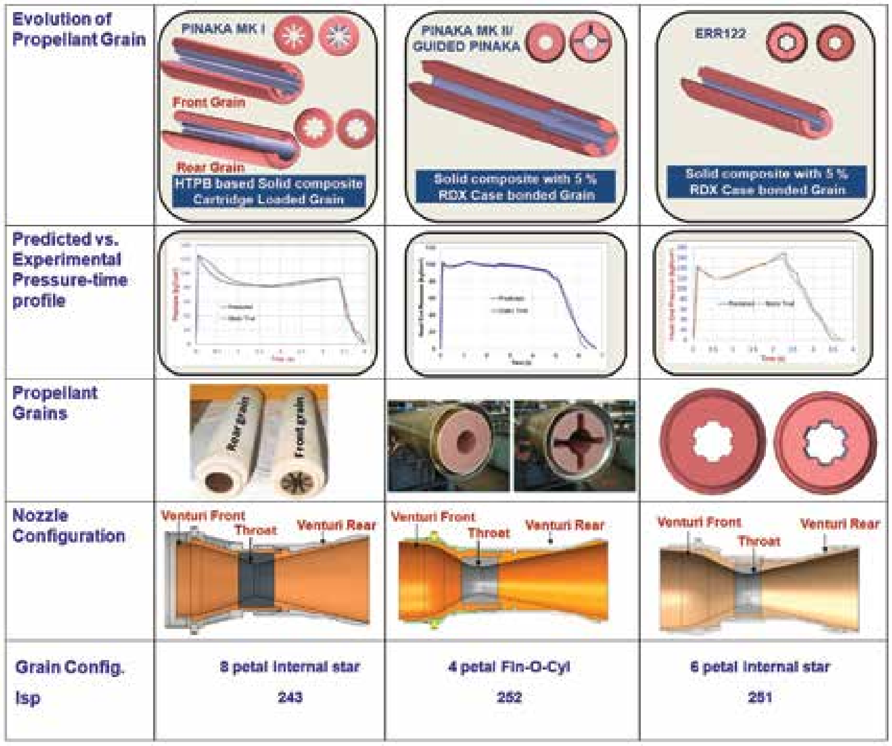
For case bonded rocket motors, a promising Nitrate Ester Plasticized Polyether (NEPE) propellant having high energy, high density and superior low temperature strain capability is being developed. This propellant gives delivered Isp of 250s-255s at 70 kgf/cm^2, density of 1.82-1.83 g/cc and excellent strain capability (% elongation) at temperature as low as -40 °C which is very desirable for artillery rockets.

Propellant Grain

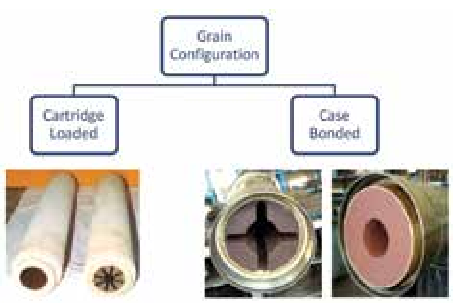
The grain is the shaped mass of processed solid propellant. The composition and geometrical configuration of the grain determines the motor performance. The propellant grain can be a cast, molded, or extruded body and its appearance and feel is similar to that of hard rubber or plastic.

Once ignited, it will burn on all its exposed surfaces to form hot gases that are then exhausted through a nozzle. There are two methods of holding the grain in rocket motor, i.e., Cartridge-loaded or case bonded. Cartridge-loaded or freestanding grains are manufactured separately (by extrusion or by casting) and then loaded into or assembled into the case.

In case-bonded grains, the case is used as a mold and the propellant is cast directly into the case and is bonded to the case resulting in better loading. Free-standing grains can more easily be replaced in case of aged propellants. While Pinaka Mk-I utilizes cartridge loaded grain, Pinaka Mk-II/ERR122 utilizes case bonded grain. A comparison of propulsion system of different artillery rockets using these grains is given in Figure.



Comparison of Propulsion System Performance



Cartridge loaded and case bonded grains

Rocket Motor Tubes

Artillery rockets employ efficient propulsion systems. The rocket motor tube is required to be lighter in weight and at the same time should possess adequate strength to withstand various loads experienced by the rocket during flight. So it becomes important to choose suitable materials and processing techniques for achieving desired mechanical properties for motor tube. One of the most suitable manufacturing technique for motor tube is flow forming.

Flow forming is a chipless, near-to-net shaped metal forming process by which low strength, low cost material can be formed into high strength, and more precise motor tubes with considerably reduced mass. Flow forming is also suitable for mass production of motor tubes. Motor tubes of modern day artillery rockets are generally manufactured by flow forming technique. Reverse flow forming process of motor tube are shown in Figure.

Based on extensive design, analyses and experimental work, ESR grade AISI 4130 steel forging as raw material has proved its suitability for artillery rocket motor application in a cost effective way. Development activities undertaken have successfully established preform dimensions and appropriate heat treatment cycle. The required range of pre-form hardness, grain size and percentage thickness reduction meets the specified strength levels of rocket motor.

Effect of various flow forming parameters like spindle speed, roller feed rate, roller geometric features like approach angle and roller nose radius were also studied and operating parameters for the flow forming of rocket motor were established.

Methodologies for qualification and acceptance of flow formed motor tubes have also been established. Flow formed motor tubes developed for Pinaka Mk-I, Pinaka Mk-II and ERR122 are shown in Figure.

Reverse Flow Forming of Rocket Motors

Pinaka Mk-I
L/D = 6.4

Pinaka Mk II/ Guided Pinaka
L/D = 14

ERR122
L/D = 15.5

Flow Formed Motor Tubes for Artillery Rockets

Nozzle

A solid rocket motor nozzle is a carefully shaped aft portion of the thrust chamber that controls expansion of the exhaust products so that energy produced in the combustion chamber are efficiently converted to kinetic energy, thereby imparting thrust to the vehicle. It generally consists of a converging section, a throat and a diverging section. Approximately, 65-75 per cent of total vehicle thrust is developed by acceleration of the chamber products to sonic velocity at nozzle throat; the remainder is developed in the nozzle expansion cone. The usual objective in nozzle design is to control the expansion in such a manner that range or payload of the total vehicle is maximized within envelope of weight.

The nozzle is thus an integral component of a larger system and cannot be optimized independently of that system. Because of this inter-relationship, nozzle design is an iterative process in which aerodynamic, thermodynamic, structural, and fabrication considerations are manipulated within the constraints to produce a preliminary nozzle configuration.

This configuration is subsequently analyzed in detail, first for thermal and structural loads and second for its contribution to total vehicle performance. This dual iteration process is continued until a thermally and structurally adequate nozzle design is evolved.

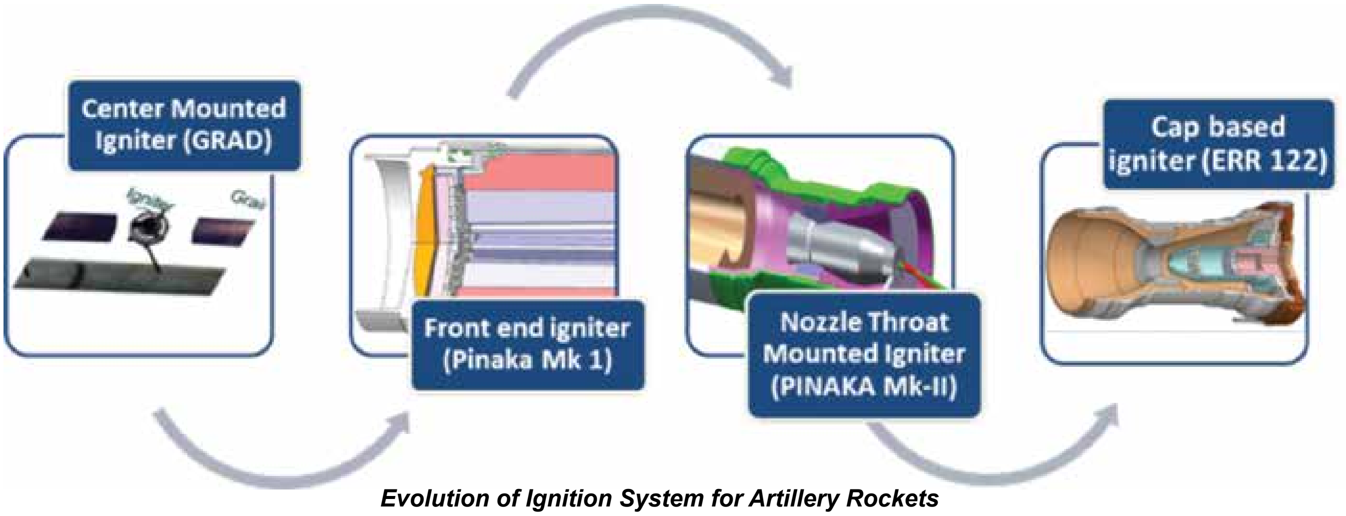
Thermal Protection System

Nozzle and motor tubes have to withstand very high temperatures of around 3000 °C. So they have to be provided with suitable Thermal Protection System (TPS). Glass phenolic (SP-16) material is commonly used for nozzle lining. In cartridge loaded propellant, e.g., Pinaka Mk-I, Si-phenolic cloth is used for lining of motor tubes. In case-bonded rocket motors, (e.g. Pinaka Mk-II and 122 mm ERR) TPS has to meet different requirements as it not only protects motor casing from high temperature combustion gases but it also relieves the stresses arising out of differential expansion between the motor and propellant. EDPM rubber has been found most suitable for case-bonded artillery rocket motor applications.

Thermal Protection System used for Rockets

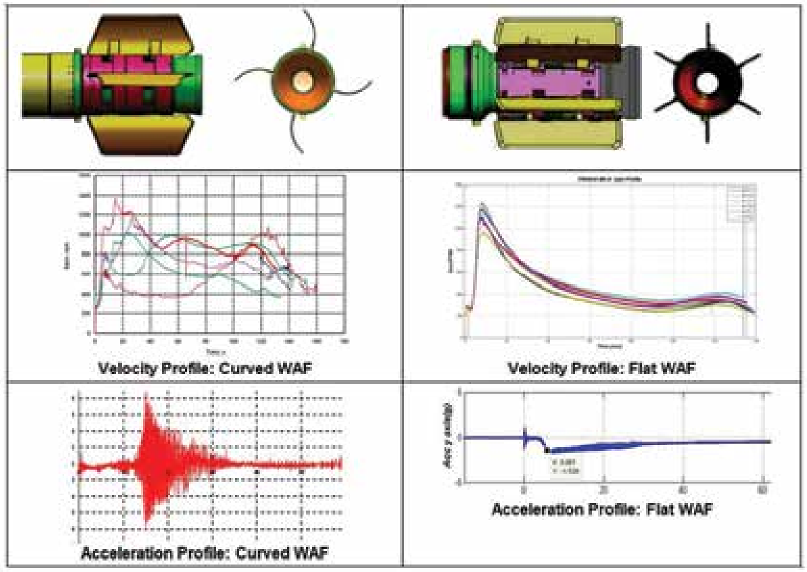
Ignition System

Ignition system (igniter) is required for initiating sustained burning of solid rocket propellant. Igniter comprises of initiation system, charge mass (required for ignition) and igniter hardware. Igniter squib is electrically initiated, which ignites the charge mass and which in turn generates hot gases to achieve a pre-determined pressure and temperature required for sustained burning of propellant followed by ejection of nozzle closure.Traditional ignition systems were 'head-end mounted' or 'centrally mounted' in propulsion unit. Head end igniter is developed for Pinaka Mk-I rocket. These systems suffer from limitation in terms of dead weight penalty as the empty igniter cannot be ejected and has to be carried by rocket throughout the duration of flight. To overcome this limitation nozzle throat mounted ignition system was developed for Pinaka Mk-II. In addition, an ignition system which is mounted on nozzle closing cap of propulsion system is developed for 122 mm ERR and Pinaka Mk-I (Enhanced). Since this system is mounted on nozzle closing cap, it can be easily removed and hence, provides for easy replacement of igniter during life extension of the rocket.



Evolution of Ignition System for Artillery Rockets

Stabilizer System



Stabilizer Redesign to Overcome High Mach Number Dynamic Instabilities
(from curved Wrap Around Fin to Flat Wrap Around Fin stabilizer)

Stabilizer plays a vital role in ensuring flight stability of the rocket. Artillery rocket generally employs Wrap Around Fin (WAF) assembly which offers excellent packaging advantage and helps in carrying more rockets on the launcher in the given space envelope. In case of free flight rockets, fins of a stabilizer assembly are canted to give the required spin to the rocket for minimizing the effect of thrust mis-alignment and dynamic imbalance. It also provides separation between pitch and roll frequencies. In case of guided rockets, which are roll stabilized, the tail fins are without cant. Fins can be flat or curved in shape. Curved WAF, due to flow asymmetry generates side forces and out of plane moment at high Mach numbers and hence, are prone to dynamic instabilities.

A designer has to take care of these aspects before arriving at a preliminary stabilizer configuration. Curved fins have been used for Pinaka Mk-I rocket with careful selection of fin chord, fin span, cant angle and plan-form area. In case of Pinaka Mk-II, the rocket was initially configured with curved fins, however, dynamic instabilities were observed at flight speed of 3.4 Mach.

The major problem of dynamic instability was successfully overcome by switching from curved wrap around fins to flat wrap around fins configuration as shown in Figure. Spin and acceleration profiles, which were erratic in case of curved WAF, became smooth and inline with the prediction in case of flat WAF indicating a stable flight.

Pinaka Mk-I

Pinaka Mk-II

Guided Pinaka

Stabilizers for Pinaka Mk-I, Mk-II and Guided Pinaka Rockets

Rocket Pod

Integrated pod is an assembly of pod frame, launcher tubes, lock assemblies and wire harnessing. The pod frame is an open frame structure manufactured mainly from extruded sections of aluminium alloy. It would act as a transportation, storage container as well as launching platform for rockets. The concept of pod provides flexibility on terms of variety of rockets to be fired from the launcher platform. Launchers with fixed launcher tubes allow only one type/caliber of rocket to be fired. Whereas launcher with pods can be adopted for firing rockets of different caliber and length. The pods developed for Pinaka Mk-I, Mk-II and Mk-I (Enhanced) carry 6 rockets whereas, pod of guided Pinaka carries 4 rockets. All these rockets can be fired from same Pinaka launcher. The launcher tubes developed for these rocket pods are disposable/one time use and are made from E-glass epoxy resin system based composite and manufactured by filament winding process.

Pods Developed for Various Artillery Rockets

Pinaka Ground Systems

Launcher System

Pinaka launcher is a mobile system with a capability of laying and launching twelve rockets individually or in programmed ripple/salvo fire mode. Pinaka launcher has been integrated on a rugged 8x8 TATRA military vehicle.

The launcher also has an on-board Automatic Gun Alignment and Positioning System (AGAPS) to provide land navigation and orientation capability. Pinaka launcher is a world-class system which is highly automatic and incorporates many modern technologies. Important features of launcher are:

◊ 2 axis, position control, all electric

Pinaka Multi-barrel Rocket Launcher

servo drive system for laying of launcher in Azimuth and Elevation

- ◊ RLG based INS used for land navigation as well as feedback element for servo drive system
- ◊ Auto leveling is achieved through four hydraulic outriggers
- ◊ Maintains laying accuracy within 1 milli-radian and prompts operator in case of error in laying
- ◊ System automatically debars firing in case laying gets disturbed during salvo firing. Firing can be restarted after relaying
- ◊ Incorporates software based level correction to ensure accurate laying
- ◊ An on-board generator coupled to the vehicle power take off supplies primary power for launcher operation
- ◊ On board launcher computer for levelling, laying, fuze setting, programming and firing of rockets
- ◊ Capability for comprehensive launcher control from BCP through data or voice link. Communication between the launcher and BCP can be either through radio or line
- ◊ Salvo of 12 rockets fired in short period of time of 44 s
- ◊ Fast coming into action and coming out of action of less than 3 minutes.
- ◊ Crew of four
- ◊ Capacity to store up to five missions
- ◊ Standby modes for launcher levelling and laying in form of manual or battery power assisted modes
- ◊ Standby manual modes for fuze setting, programming rocket data and firing

Battery Command Post

The Pinaka BCP is the command and control center for a battery of six launchers. The BCP is configured around Tatra 8x8 vehicle. The BCP has the following capabilities:

Pinaka Battery Command Post Vehicle

- ◊ Command and control of launchers within the battery through a wireless/line data link or voice communication
- ◊ Collection of information related to positions of launchers and targets
- ◊ Collection of Met data
- ◊ Computation of trajectory
- ◊ Communication with higher echelons – ACCCS SHAKTI

The BCP is an air-conditioned, NBC filtered, EMI/EMC shielded shelterised system. It mainly houses two Enhanced Tactical Computers (ETCs) and various communication equipment. The ETCs are installed with GIS and ACCCS SHAKTI application software which are essential for fire control of launchers. Within the shelter, besides the crew cabin which is ergonomically designed for ease of operations, there are stowage facilities.

Loader-cum-Replenishment (LCR) Vehicle

The LCR is used for transfer of rocket pods to the launcher. Pods are handled with the help of on board hydraulic crane having 3.5 ton capacity. The LCR vehicle is manned by 3 crew members (including driver). The LCR was developed in association with VRDE.

Replenishment Vehicle (RV)

LCR vehicle is used for transporting rocket pods. It carries four rocket pods onboard. RV has locking and lashing provision for securing the pods during transportation and collapsible sidewalk ways for easy crew movement during pod handling. The RV was developed in association with VRDE.

DIGICORA MET Radar

The in-service DIGICORA MET radar has been adoppted for Pinaka weapon system. It is used for obtaining the MET data using a balloon based radio-sonde. The MET data captured is utilised for trajectory computations by the BCP.

Pinaka LCR Vehicle

Pinaka Replenishment Vehicle

DIGICORA MET Radar

TECHNOLOGY AND ROCKET DEVELOPMENT

Pinaka Mk-I

Pinaka is the first indigenous MBRLS designed, developed by ARDE in association with other DRDO labs which has been inducted into the Services. Pinaka was effectively used during Indo-Pakistan conflict in Kargil in June 1999 (Op Vijay). Operation was successfully executed by soldiers of 210 rocket regiment along with DRDO team. The Users trials of Pinaka weapon system with Mk-I rockets were successfully completed in July 2002. Production of Pinaka weapon system commenced in year 2006. Pinaka is the first example of DRDO private industry partnership which culminated into production order to industry which participated in the development. Presently the rockets are being manufactured by OFB. The launchers and BCPs are being manufactured by L&T and Tata, whereas the LCRs and RVs are being manufactured by BEML.

Two regiments of Pinaka have been inducted and became fully operational in 2010. Next two regiments are under induction. Production of Regt No. 5 to 10 is expected to commence shortly after finalisation of contracts. Army has decided to induct total 22 regiments and 1.89 lakhs rockets. With this, anticipated return will be of the order of Rs. 61000 cr against

Pinaka in Operation Vijay (Indo-Pak Conflict 1999)

R&D cost of Rs. 55 cr, leading to an unparalleled return on investment. Now ToT for Pinaka rocket system has been handed over to private industry, and with MoD releasing the RFP on private industry for manufacture and supply of rockets, Pinaka MBRLS is set to scale new heights. Pinaka MBRLS also has very high export potential, with some friendly countries showing keen interest in the weapon systems.

Extended Range Pinaka Rocket

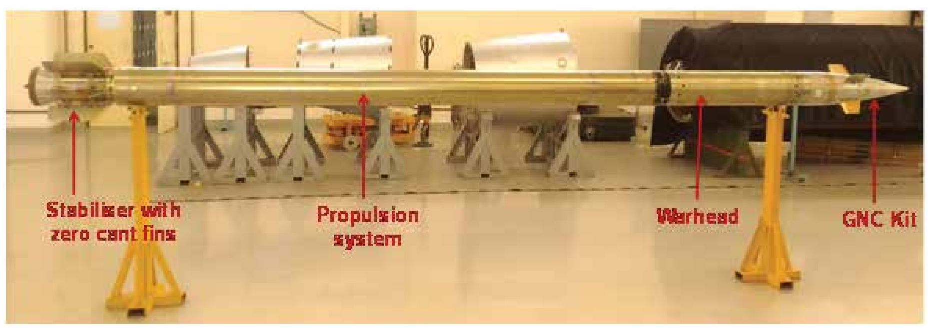
The impressive field performance of Pinaka Mk-I system has led to design and development of state-of-the-art long range artillery rocket systems. In pursuit of this, an enhanced version of Pinaka; a 60 km range Pinaka Mk-II Rocket System has been developed with various contemporary technologies compatible with Pinaka ground system keeping the same payload. Range, accuracy and consistency of Pinaka Mk-II rocket have been successfully demonstrated during series of technical trials carried out at ITR, Balasore and PFFR, Pokran. Propulsion system developed for Pinaka Mk-II has been successfully adopted for Guided Pinaka Rocket. Based on the technologies established for Pinaka Mk-II rocket, development of Pinaka Mk-I (Enhanced) having range of 45+ km is being progressed. Maximum range of 50 km for Pinaka Mk-I (Enhanced) is already demonstrated during design trials carried out at Balasore.

Development of all the Pinaka variants has built technological base for artillery rocket system. Based on these technologies, ARDE and HEMRL have successfully transferred the ToTs of Pinaka Mk-I and Mk-II rockets to OFB as well as to private industries. Some of the critical technologies developed for artillery rockets are as below:

- ◊ High energy composite propellant (cartridge loaded and case bonded grains)
- ◊ Flow Forming Technology for motor tubes
- ◊ Pyro-technique based nozzle end and head end ignition systems
- ◊ Si-phenolic, EPDM and ROCASIN-based thermal protection for motor tubes
- ◊ Wrap around fin stabilizer (curved and flat fins) for providing stability to rocket flying at high Mach No.
- ◊ Family of high lethality warheads
- ◊ Turbo-generator based ET fuzes
- ◊ High reliability miniaturized sub-munition fuzes
- ◊ Light weight pods with disposable FRP launcher tubes
- ◊ Six DoF trajectory model for accurate flight predictions

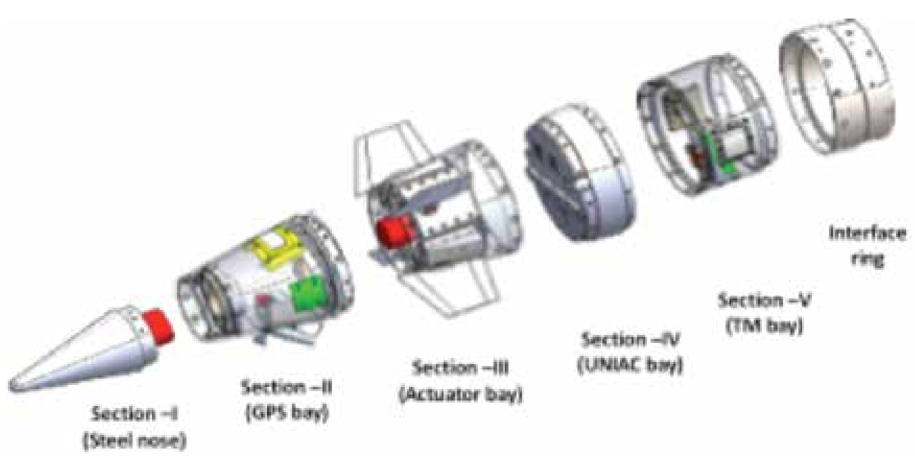
Guided Pinaka

Guided Pinaka rocket being developed by ARDE in association with RCI, DRDL, HEMRL and PXE is a capable of striking targets located deep into enemy territory up to a range of 75 km with precision. It is configured using propulsion system



Guided Pinaka Rocket

Pinaka Mk-II Rocket Trials at Balasore



GNC Kit

developed for Pinaka Mk-II rocket. It makes use of the aerodynamic force for canard control to improve accuracy and increase the range. This is achieved by integrating a Guidance Navigation and Control (GNC) kit with the rocket in its ogive portion. The GNC kit comprises of a UNIfied Avionics Computer (UNIAC), Canards driven by Rotary Electro-Mechanical Actuators, Thermal battery, Fuze, Telemetry and GPS antenna. The configuration of guided Pinaka rocket is shown in the Figure.

A compact UNIAC has been specially developed for guided Pinaka rocket and comprises of On-Board Computer (OBC), MEMS based IMU, G3OM/ IRNSS, SCP+PCM for Telemetry and EIU. UNIAC uses hybrid navigation for guidance purposes (Vector Explicit Guidance) and generates control commands to the canard control surfaces mounted onto the rocket airframe. Guided Pinaka rocket is controlled and guided from lift-off to impact and maneuvered continuously. The features of guided Pinaka rocket are as follows:

- ◊ Deep striking capability up to 75 km range
- ◊ Accuracy of < 30 m at all ranges
- ◊ Improved hit angle at the target
- ◊ Four fixed launch angles to cover entire range spectrum of 20 km to 75 km
- ◊ Wider azimuth coverage: ±30°
- ◊ INS+GPS guidance (MEMS based INS and G3OM/ IRNSS)
- ◊ Canard based aerodynamic control
- ◊ Use of GNC kit components which have already been developed for other missile systems
- ◊ No MET radar required
- ◊ All warheads developed for Pinaka Mk-I rocket to be integrated

Guided Pinaka Rocket Launch at ITR

Accuracy demonstration at PFFR, Pokran

- ◊ Proximity fuze for PF warhead and navigation based altitude sensor for sub-munition and incendiary warheads
- ◊ PZT based warhead initiation mechanism for PF and RHE warheads
- ◊ Only 2-3 missiles are required for achieving a kill probability of 99% against a single target

The range enhancement (75 km) was demonstrated during January 2017 trials at ITR, Balasore.

The accuracy against land targets was demonstrated during Mar 2019 trials at PFFR, Pokran.

ARTILLERY ROCKET SYSTEMS DEVELOPED AT ARDE

Table presents a comparative view of the major artillery rocket systems in terms of technology development.

Parameter	Pinaka Mk-I	Pinaka Mk-II	Pinaka Mk-I (Enhanced)	Guided Pinaka	ERR 122
Range (km)	37.5	60	45	75	40
Calibre (mm)	214	214	214	214	122
Length (mm)	4881	5175	4725	5175	2912
Warhead weight(kg)	100	100	100	100+15 (GNC kit)	21
Accuracy	≤ 1.5% range (PE)	≤ 1.5% range (PE)	≤ 1.5% range (PE)	≤ 60m (CEP)	≤ 1.5% range (PE)
Rocket weight (kg)	277.4	325	280	325	66.5
Propellant weight (kg)	100	131.5	111	131.5	26.8
Fin stabilizer	4 Curved fins (WAF)	Six flat fins (WAF)	Six flat fins (WAF)	Six flat fins (WAF) without cant	4 Curved fins (WAF)
Warhead	PF, RHE, DPICM	PF, RHE, DPICM	PF, RHE, DPICM	PF, RHE, DPICM	HEPF, RHE
Fuze	ET & VT	ET & VT	ET & VT	ET & VT	VT/DA & Delay
Guidance	Free flight	Free flight	Free flight	INS + GPS	Free flight
Launcher	Pinaka MBRL	Pinaka MBRL	Pinaka MBRL	Pinaka MBRL (with ELPC & LRU)	BM-21 Launcher
Pod	2 Detachable Pods each with 6 FRP tubes	2 Detachable Pods each with 6 FRP tubes	2 Detachable Pods each with 6 FRP tubes	2 Detachable Pods each with 4 FRP tubes	No. Fixed cluster of 40 steel launcher tubes
Status	Inducted into Services. Under bulk production.	Development completed	Maximum range demonstration trials completed.	Trials for range & accuracy demonstration conducted.	Under development.

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