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The Rocket Artillery Reference Book

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English Summary

This report contains a general overview of the current state of rocket artillery. Its aim is to give a complete picture of the technology, capacity and distribution of these types of weapon.

Although the principles of rocket propulsion have been known for centuries, the concept of rocket artillery, as it is known today, was introduced during The Second World War. Since then its popularity and distribution has steadily increased, and it is currently a part of the inventory of more than one hundred national armies. In addition, non-state armed units have also acquired this capacity, and have used it on several occasions during the last decade. This use has also included the application of improvised rockets based on readily available components, and used in a mode where the precision and the accuracy of the delivery have been compromised. This development is a result of the increasing tendency towards asymmetric warfare, where direct exchange of fire in a regular battle is of secondary importance.

Herein, rocket artillery is defined as rockets fired in an indirect mode and with a capability to engage targets at less than 100 km range, but not excluding systems capable of reaching several hundred kilometres However, the class commonly known as *short range ballistic missiles* is not included here. With these limitations, rocket artillery includes systems of around 50 mm calibre with a range of a few kilometres and a load of a few hundred grams of explosives up to large systems that may contain more than 100 kg of explosives.

The report discusses several technological aspects including construction, ballistics, accuracy of delivery, use, and the effect of the warhead. Some examples of use and its effect on a given target are presented. This target is chosen to represent a typical target in the context of defence of camps against such ordnance.

Serving the purpose of a reference document, a high number of rocket artillery systems are briefly described. Systems that are obsolete or that never have matured beyond the prototype level have not been included.

Norwegian summary

Denne rapporten gir en generell oversikt over rakettartilleriet slik det er i dag. Formålet er å gi et fullstendig bilde av teknologi, kapasitet og utbredelse av denne typen våpen.

Selv om prinsippene for rakettdrift har vært kjent i århundrer, ble rakettartilleri først introdusert under andre verdenskrig. Siden den gang har dets popularitet og utbredelse stadig øket, og det er pr i dag en del av inventaret til mer en ett hundre nasjonale hærer. I tillegg har ikke-statlige aktører også skaffet seg denne kapasiteten, og tatt den i bruk flere anledninger i det siste tiåret. Denne bruken har også omfattet bruk av såkalte improviserte raketter som er basert på bruk av allment tilgjengelige komponenter, og brukt i en sammenheng hvor presisjon og nøyaktighet av ildgivninger er av underordnet betydning. Denne utviklingen er et resultat av den økende tendensen til asymmetrisk krigføring, hvor direkte utveksling av ild i regulære slag ikke er vanlig.

I denne rapporten er rakettartilleri definert som raketter som fyres i en indirekte modus og som er i stand til nå mål som ligger på mindre enn 100 km avstand, men uten å ekskludere systemer med lenger rekkevidde. Den klassen som omtales som ballistiske kortdistansemissiler (*short range ballistic missiles*) er ikke tatt med her. Med disse begrensningene, vil rakettartilleri omfatte systemer fra ca 50 mm kaliber med noen hundre gram sprengstoff og med noen få kilometers rekkevidde opp til store systemer som er i stand til å nå flere hundre kilometer med en sprengladning på over 100 kg.

Rapporten diskuterer flere teknologiske aspekter inkludert konstruksjon, ballistikk, leverings-nøyaktighet, bruk, og virkningen i målet. Eksempler på bruk mot et gitt mål er vist. Målet er valgt som en representant for et typisk mål i sammenheng med beskyttelse av leire (camper) mot slik våpen.

Ettersom denne rapporten skal være et referanseskrift, så er et større antall systemer gitt en kort beskrivelse. Systemer som er avleggs, eller som aldri har kommet forbi prototyp-stadiet, er ikke tatt med.

Contents

Preface

The present report is written for the NATO Defence Against Mortar Attacks (DAMA) project, the ninth initiative under the Defence Against Terrorism Programme of Work. The decision to make a reference report on rocket artillery was taken at the joint meeting of the DAMA Working Group and CRAM Team of Experts in Copenhagen, Denmark in September 2008.

A similar work on mortars[1] was presented to the DAMA WG in 2007. For ease of comparison between the two weapons systems, The Mortar Reference Book has been used as a template for this report when appropriate. However, rocket artillery is a more versatile and complex weapon system than mortars. This fact is reflected in the description of the systems and in the scope of the themes that are discussed. Rocket artillery is easier to improvise than conventional gun artillery and even mortars. Improvised rockets are also a reality in some war affected areas. Thus, aspects concerning the possibility of using primitive components, and the limitations of such technology are also discussed.

The report starts with a general historical overview of the theme and a classification of the different types of systems in chapters 2 and 3. The technology of the different parts and payloads are discussed in chapters 4, 5 and 6. Performance aspects as accuracy and lethality are the theme of chapters 7 and 9. The important aspect of making improvised systems is discussed in chapter 9. The final three chapters are committed to organizational aspects, some examples of the effects to be expected in attack of a typical camp, and finally some speculations on the future of these kinds of weapons.

The author would like to thank Thor Engøy, who has managed this project and who is also chairing the DAMA WG. The author also would like to extend his gratitude to several other colleagues at FFI for their contribution and useful discussions.

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1 Introduction

In many armies, field artillery is considered as the most precious of weapons, superior to both infantry and cavalry. During the twentieth century, no other weapon contributed to the enemy casualty rate as the artillery. Therefore, in most nations, artillery has been a major component of the army, and the supreme fire support weapon at short and medium ranges. This status has been most prominent in the Soviet and Russian armies where artillery often is referred to as the "God of War".

There are several types of artillery; coastal artillery, air-defence artillery, ship artillery, and - field artillery. The concept of field artillery usually is understood as two types of weapons – gun artillery, usually howitzers, and rocket artillery.

Although rocket artillery is not as common as the tube artillery, delivery of fire by rockets provides several advantages over guns

- the launching unit can be made light and simple
- the launching does not put heavy strain on neither platform nor projectile
- very high calibre charges can be fired by relatively primitive launchers
- the payload does not have to be as rugged and robust as that of gun artillery projectiles because the acceleration of a rocket may typically be just a percent of that experienced in gun artillery
- a high volume of fire can be delivered within a very short period

Of course, there are also some disadvantages like:

- accuracy
- ammunition weight
- ammunition cost
- not suited for direct fire mode
- more pronounced signature
- limited ability to deliver sustained fire

This report will focus on the different aspect of rocket artillery. Hopefully this will make the reader more able to understand these kinds of weapon, and to find ways to counter the threat they constitute.

1.1 Defining rocket artillery

There are certain challenges in delimiting the extent of the definition of rocket artillery, both at the low end and at the high end.

The main characteristics of field artillery is that it fires in an indirect mode, i.e. the target can not be seen from the launcher unit, and the attitude of the launcher is set upon information from forward observers, or intelligence information, on where a valid target is located. So far, such a definition may seem clear-cut. However at the low end there may be cases where a weapon designed for direct fire is used in an indirect mode. These weapons will in general not be considered here. There are, however, some interesting examples on how direct fire weapons have been reconfigured to an indirect mode. Some of these will be mentioned.

Some indirect systems can also be used in a direct mode. The effect of such use will not be included in this report.

At the high end, the limitations may be more difficult to set. The requirement of *multiple* rocket launchers will be too strict as some very common rocket systems are also found in a single tube configuration. The most reasonable criterion may be that of firing range. In this report, systems being able to deliver its payload at ranges of less than 100 km are included, while systems exceeding around 200 km will generally not be considered. The latter systems are usually theatre level, or strategic, weapons that are only supposed to be used in a conflict of continental extent. However, it has recently been observed that such systems are used in conflicts of limited size and at relatively short ranges, which justifies their inclusion.

More specifically, we will include systems with singular vehicle-mounted rockets that have a maximum range not exceeding 500 km and a minimum range of less than 80 km. Thus they will have an operational range that is overlapped by MRL. This class will not cover the so-called SRBM class (Short Range Ballistic Missile), which by definition has a range exceeding 500 km.

Many of the weapons mentioned in this report have the capacity to carry nuclear warheads, but this aspect is not considered here.

Some “lateral” limitations also have to be drawn. The following rockets or rocket-like projectiles are not considered

- gun artillery projectiles with rocket-like auxiliary propulsion. Hence, projectiles with rocket propellant assistance (RAP or BB) are not included.
- surface-to-air rockets
- air-to-surface rocket, unless they have been reconfigured to surface-to-surface mode
- rockets intended for maritime warfare, including sea-to-land systems
- types that have not been deployed in regular armies or never seen in use by non-state parties
- systems with rockets exclusively intended for mine-laying or mine-clearance

1.2 Legal aspects

There are no international convention regulating the use of rocket artillery as such, but the type of payload may be affected by several conventions. Among these are

- Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects (Geneva 1980)
- Chemical Weapons Convention (1993)
- Protocol on Prohibitions or Restrictions of Mines, Booby-Traps and Other Devices (Ottawa 1996)
- Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons (1980)
- Convention on Cluster Munitions (Oslo 2008)

However, the validity of some of these conventions is still limited as many nations, and especially the most belligerent nations, have not signed some of the conventions.

2 Historical overview

2.1 Pre WWII

There seems to be consensus among historians that rockets were first used in China in 1232 AD during the Mongol siege of the city Kai Fung Fu. It is not known what kind of rockets was used, and it may even be doubted whether they can be classified as artillery.

Figure 2.1 William Congreve – the father of rocket artillery

In Europe rockets were not used in earnest until early 19th century. This development was due to the pioneering work by Sir General William Congreve in Britain. He is considered as *The Father of Modern Rocket Artillery*. His proposed designs, which were like today’s fireworks rockets, were promoted to British authorities and were used by for the first time by the British Navy in the attack against the French city of Boulogne in 1806. The first massive use of these rockets was made by Lord Admiral Horatio Nelson’s fleet attacking Copenhagen in 1807. 25000 rockets were fired at this event, resulting in a total burn-down of the city. Congreve’s rocket design was used during the British attack on United States in 1813 (see box)

The rockets' red glare

On September 13 and 14, 1814 a 25-hour barrage of Congreve rockets was fired from the British ship Erebus against Fort McHenry in Baltimore. The Erebus carried about 20 Congreve rocket batteries consisting of a box housing multiple metal firing tubes. Each of the rockets fired against Fort McHenry weighed about 30 pounds, and carried an incendiary charge. Although a number of American ships were destroyed by Congreve rockets during the War of 1812, just four deaths and minimal damage was reported at Fort McHenry during the siege. However, the battle was witnessed by a young lawyer named Francis Scott Key, who mentioned the Congreve "rockets' red glare" in his song "The Star Spangled Banner". The song later became the U.S. National Anthem, paying tribute to the tenacity of the American forces under siege. [2]

Congreve's rocket fired from a boat

In the mid 1800s, Congreve's concepts were modified and improved by his countryman William Hale leading to the development of a spinning rocket which dramatically improved the accuracy of the vehicle. He was also the first to use rails or grids to support the rocket in the first phase of acceleration, which also improved the precision. Although Hale was an Englishman, his rockets were used by the U S Army in the American – Mexican war during the 1840s.[3]

Over the next decades the rockets were discarded in favour of gun artillery, which made great progress during the American Civil War. The other main wars; the Crimean War, the Franco-Prussian War, the Boer War, the Balkan Wars, the First World War, did not include any significant use of rocketry.

2.2 WWII developments

During WWII rocket artillery was developed by all main fighting parties – US, UK, Germany, USSR and Japan. However, for the latter the development and use were very modest.

Germany had their Wurfgranate or Nebelwerfer in various configurations with calibres from 150 mm to 300 mm. US had their M8 rocket in the Calliope system with a 60-tube rack at the top of a Sherman tank. Britain did not have any working system before the last year of the war. Most notable was the Land Mattress which was a towed 12-tube rack able to fire 127 mm rocket out to almost 8 km.[4]. UK and US made an exchange of data on their development before US entered the war.

The first 20 months of WWII went by without any use of rocket artillery. However, in the USSR the military rocket development started in the early 1930s. By 1939 the first prototypes were ready. The order to produce these weapons issued on 21 June 1941, the day before the German invasion started. Rocket artillery was used for the first time in WWII during the Soviet defence of Orsha, a city on the Minsk – Moscow line, on 14 July 1941, just 23 days after the order was issued. The system used was the BM-13-16 with a rack of rails on the back of ZIS-6 truck. [5;6] The rack consisted of 8 rails on which there were two M13 132 mm rockets on each – one at the upper side and one at the lower side of the rail. The M13 rocket was a fin-stabilized device, 1.4 m long and with a weight of 42.5 kg. It could reach a velocity of 355 m/s and had a firing range of about 8.5 km [7]. The M13 rocket was the most proliferated rocket during WWII and was produced at the number of almost 7 millions.

Although the official name of the system was as mentioned above, the soldiers soon gave it the name of Katyusha, a name that is now used for artillery rockets in general. The reason was no other than that the carrier trucks had the letter “K” painted on the doors. Katyusha is a diminutive of the common Russian female name Yekaterina.

BM-13 stayed in service in the Soviet Army until 1960 and is in fact still in service in PR China in a modified form as a mine laying rocket.

The table below shows some characteristics of the systems used by the Soviets during WWII. These systems were to become the basis of the systems to come.

	M-8	M-13	M-13-UK	M-31	M-31-UK
Calibre (mm)	82	132	132	300	300
Rocket weight (kg)	8.0	42.0	42.5	95.5	94.8
Warhead weight (kg)	3.2	21.6	21.6	51.6	51.6
Weight of high explosive (kg)	0.6	4.9	4.9	28.9	28.9
Weight of propulsive fuel (kg)	1.2	7.2	7.2	11.2	11.2
Maximum velocity (m/s)	315	355	335	255	245
Launch velocity (m/s)	70	70	85	55	50
Maximum range (m)	5515	8470	7900	4325	4000
Longitudinal dispersion (%)*	1.9	1.3	1.0	2.4	1.4
Transversal dispersion (%)*	4.0	2.4	1.2	5.9	1.9
Radius of total defeat (m)*	3 - 4	8 - 10	8 – 10	(15 – 18)	(15 – 18)
Radius of effective defeat (m)*	10 - 12	25 - 30	25 - 30	(45 – 50)	(45 – 50)

Table 2.1 Some characteristics of WWII Soviet artillery rockets [5]
**) The exact definition of this term is not known*
Numbers in parentheses are assumptive

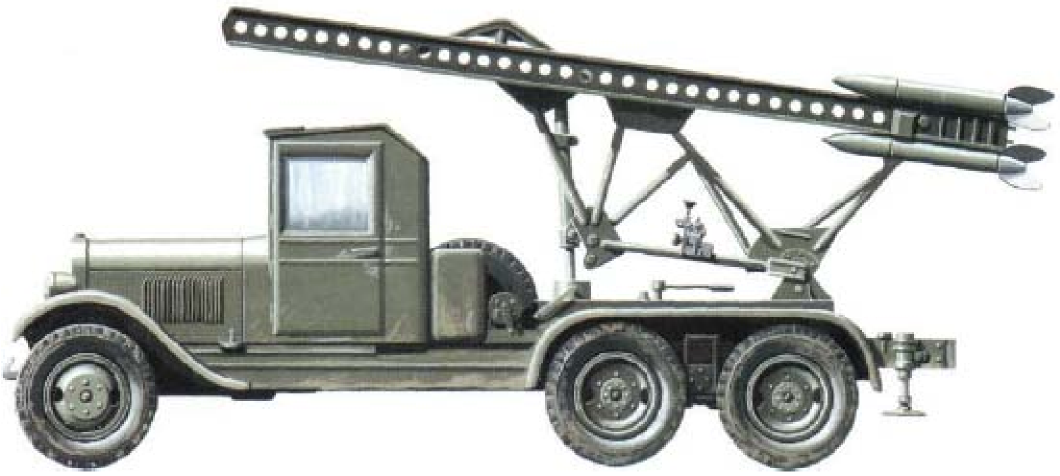


Figure 2.2 The original BM-13-16

2.3 Cold War developments

After WWII, the development in the Western countries was either progressing at low pace or more or less discontinued. U S developed their towed 24 tubes M21 which was used until the late 1980s. The truck mounted 45 tubes M91 (115 mm) was declared obsolete in the mid 1990s. The most significant development was the development of MLRS (Multiple Launch Rocket System) which had its first test firing in 1980 and which had its first wartime use in Operation Desert Storm in 1991. [8]

For the long ranges, U S started off designing the rockets Lance and Honest John. However, theses systems were relatively short lived. The ATACMS (Army Tactical Missile System) was developed as follow-up to MLRS, using the same launching platform. This system was also used during the Gulf War in 1991.

Some other Western countries also had their development. The most prominent was the German LARS (Leichte Artillerie Raket Systeme), which was in service in the German Army from 1969 until quite recently. Also France, Italy and Spain each developed their systems.

Israel deployed their first system, a 290 mm calibre long range mounted on a tank, in the mid 1960s. Following the Yom Kippur war in 1973, IDF (Israel Defense Forces) issued a requirement for a lighter system, which matured into the 160 mm LAR. This was used in combat for the first time in 1982 in Lebanon.

USSR, however, continued their development at very high pace throughout the period. The types used during WWII, were kept and additional type based on new principles were developed and deployed in massive numbers. Designs based on spin stabilization, liquid propellants or tubular launchers replacing the rails were all deployed. Range, calibre and accuracy were also steadily improved or increased. A wide variety of payloads like smoke, illumination, mines, bomblets and ECM were also developed.

2.4 Distribution

By the end of the Cold War the former Warsaw Pact nations had around 7000 MRL systems deployed, while NATO had less than 1000. A limited number of other nations had systems of Soviet origin, of which many were of WWII designs or other more or less obsolete kinds.

Today, Russia and other former Soviet nations have sold or phased out a substantial part of their rocket artillery systems. NATO has slightly increased their inventory, which is focused on the MLRS system in addition to some systems inherited from former Warsaw Pact states. Since the end of the Cold War, there has been a proliferation to many nations. Currently more than 100 nations have rocket artillery units deployed, although some nations may just have a handful of units. The most disturbing fact is that these weapons have proliferated into a number of non-state parties. It seems that these units often are of Iranian origin, but nations like China, North Korea and some former Soviet states have contributed in this respect.

3 Types of rocket artillery

3.1 Portable systems

This is the most primitive of all artillery and can be made out of a single tube attached to a tripod along with aiming devices and an umbilical system for remote triggering or ignition. (see figure 3.1 below). The tube and tripod may have a mass of some 20 kg. Rockets up to 122 mm calibre and 45 kg rocket mass can be fired in this way. A squad of 4 – 5 men can carry the launcher and three rockets. However, the mass of the different units prevents long tactical movements without access to a vehicle of some kind. Twin tubular launchers on a tripod have also been seen. Such systems are particularly favoured by guerrilla and insurgency forces.

Figure 3.1 A portable single tube launcher

Portable systems can also be designed in a mortar-like way, with a bipod and a baseplate. The Yugoslavian system called M-71 Partizan (see figure below) with a 128 mm calibre is an example. This is for a spin stabilized rocket. There is also a parallel design for the fin stabilized M-77 Oganj system.

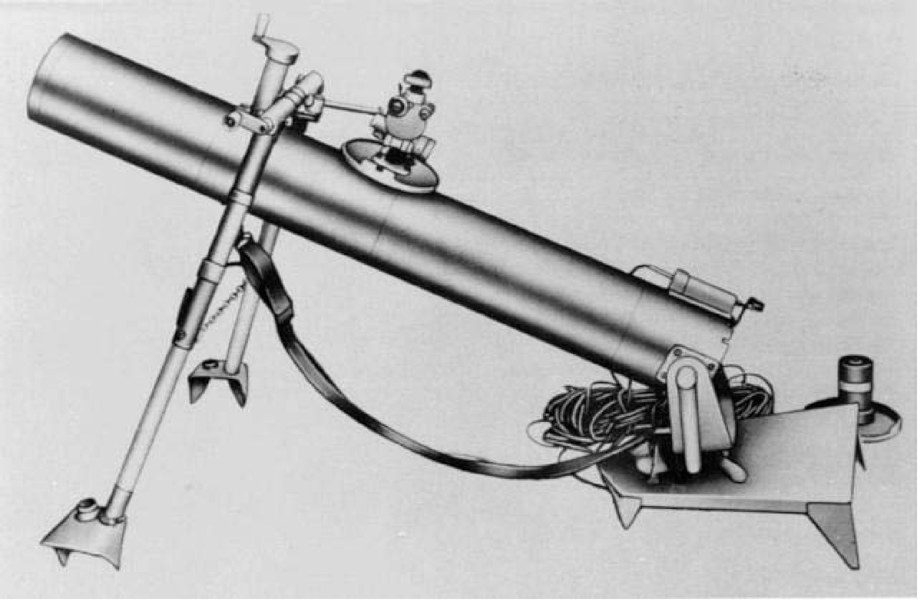


Figure 3.2 The M-71 Partizan system with a mortar-like configuration.

The advantage of having a mortar configuration is obviously the stability. It is probably possible to fire several rockets without readjustment of the sight. However, such a system may be far heavier than tripod systems.

3.2 Towed systems

The first systems developed by Germany, UK and US during WWII were multiple tube racks placed on top of a two-wheeled boggy and with an arm to facilitate towing behind a vehicle. Systems of that type are still in use today in many countries, and are popular among non-state armies due to their size, lightness, simplicity, cost and low maintenance requirements. The number of tubes attached can vary from a handful to dozens.

The limitations on size and on the total weight of a loaded system prevent any use of high calibre rockets or rockets with an elongated motor section. Short spin stabilized rockets are consequently usually chosen as ammunition for such systems. Thus the possible maximum firing range will usually be limited to 8 – 10 km.

Figure 3.3 A 12-tubed towed system behind a light vehicle with the same system mounted on the vehicle

3.3 Vehicle mounted systems

When a tube rack is mounted on the back of a truck or on a specially designed vehicle, we have a fully fledged multiple rocket launcher (MRL). Most MRL-types belong to this type. However, this class covers a wide spectrum in vehicle size, rocket calibre and number of tubes/rails. Smaller systems may be placed on an ordinary truck. Larger systems may require a specially designed carrier vehicle.

With some few exceptions, an MRL system carry only the ammunition that is ready to fire and loaded in the tubes or at the rails. Additional rockets have to be carried by support vehicles.

Vehicle mounted systems requires a crew consisting of 3 – 8 soldiers. Highly automated systems, like the MLRS, have the lowest crew requirement. Systems based on manual loading, like the BM-21, have a crew of 7 soldiers.

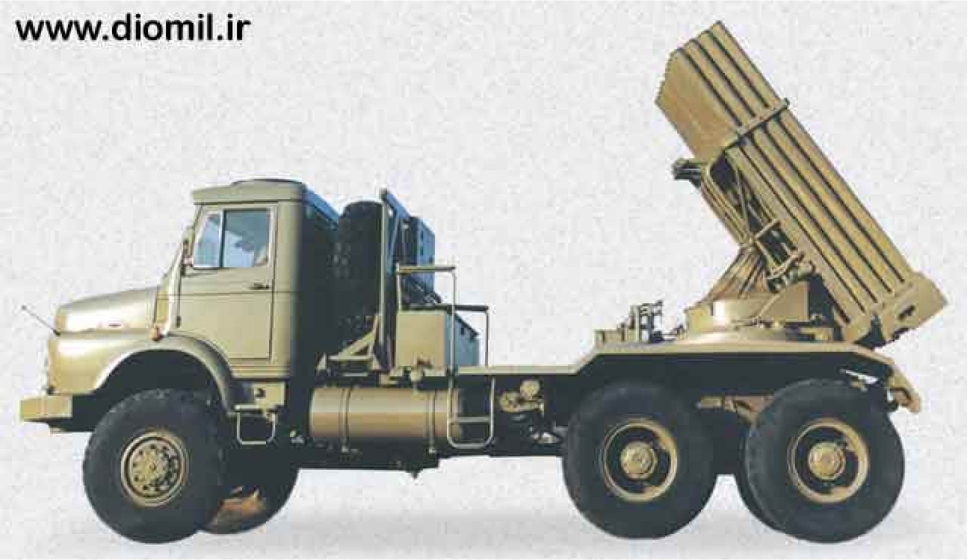


Figure 3.4 Truck-mounted multiple rocket launcher

3.4 Artillery missiles / tactical missiles

This class consists of systems with singular vehicle-mounted rockets, as to distinguish them from multiple rocket systems. Herein, we will consider those systems that have a maximum range not exceeding 500 km and a minimum range of less than 80 km. Such rockets are carried by specially designed vehicles with just one rocket on board. The mass of these rockets exceeds 1 ton, their calibre may be 500 mm or more and they may be more than 10 m in length. Obsolete systems like the American Honest John and the Soviet made FROG fall into this category. Although these rockets originally were intended for grand scale warfare, they were seen in use in the Russian-Georgian conflict in 2008.

The current systems of this type are the American ATACMS, the Russian FROG, Tochka and Iskander, and some Chinese and Iranian systems.

All systems in this class must have some kind of guidance in order to effectively hit a target at long range.

Figure 3.5 Iraqi FROG-7 rocket encountered during OIF

3.5 Guidance systems

The majority of artillery rockets are unguided (free rockets). However, guided rockets are becoming more common. The guidance systems are usually based on either inertial navigation (INS) or GPS.

3.5.1 Inertial Navigations Systems (INS)

Inertial navigation is a well proven principle. The system is based on accelerometers and gyros that register the linear and angular movements in each direction. The inputs are then integrated to find to position relative the initial position of the unit. INS thus requires the initial position and orientation as input.

All inertial navigation systems suffer from integration drift. Small errors in the measurement of acceleration and angular velocity are integrated into progressively larger errors in velocity, which result in still greater errors in position. This is a problem that is inherent in every system. The inaccuracy of a good-quality navigational system is normally less than 1 km per hour in position and on the order of tenths of a degree per hour in orientation.

3.5.2 Global Positioning System (GPS)

A GPS receiver calculates its position by carefully timing the signals sent by the GPS satellites high above the Earth. Each satellite continually transmits messages containing the time the message was sent, precise orbital information, and the general system health and rough orbits of all GPS satellites (the almanac). The receiver measures the transit time of each message and computes the distance to each satellite. Geometric triangulation is used to combine these distances with the location of the satellites to determine the receiver's location. The position is displayed, perhaps with a moving map display of latitude and longitude; elevation information may also be included. Many GPS units also show derived information such as direction and speed, calculated from position changes.

Opposite to INS, GPS does not suffer from any drift over time. However, disturbances and other technical limitations limit the accuracy to a few meters horizontally. Differential GPS, where the position is measured relative to an accurately known reference point, has an accuracy of a few centimetres. GPS is becoming the most used navigational system for guidance of artillery rockets.

GPS is an external system not controlled by the user. It is currently operated by U S Air Force. Other nations, or group of nations, have or are in the process of establishing alternative systems based on the same principles

4 Components of rocket artillery

The concept of rocket artillery is comparatively simple, both with respect to the projectile, the rocket, and the launcher platform, whether the system is a self propelled vehicle or a tubular device put on a simple tripod.

The basic components are shown in the table below

Rocket components	Launcher components
Fuze	Rail or tube
Warhead	Aiming devices
Motor incl. fuel and nozzle	Fire control system
Igniter	Carrier
Fins	

Table 4.1 Basic rocket components

The rocket components, i.e. the ammunition will be covered the succeeding chapter.

4.1 Rail or tube systems

There are basically three ways of launching a rocket – by a rail, by a tube, or by the so-called *zero length launch*. In the latter mode the rocket is just held stable during the initial launch, but has no devices that keep the direction once it is free. Well known examples of such are NASA’s space rockets. Firing in this mode requires that the rocket is fully guided and steerable in every phase. Most artillery rockets are exclusively based on rail of tube launchers, but some tactical rockets use zero length launchers. All unguided systems have to use rails or tubes as they initially have to obtain the predefined flight direction.

The first rocket artillery systems, like BM-13, were true rail launchers. The rockets started their flight sliding along a straight rail of a few meters length. This way of launching is not very accurate, as the rocket continues to accelerate for a long distance after leaving the rail. Such a non-spinning rocket is very prone to disturbances during this phase. Manufacture flaws and other disturbances will seriously affect the accuracy.

A tube basically has the same function as a rail. The only difference is that the rocket may be free to rotate, or it may have a device inducing spin to it. A common solution is a tube-rail combination, a tube with helical rails on which the rocket rides. The rail system can be inside the tube, which requires a tube that is wider than the rocket diameter. Alternatively, the tube fits the rocket calibre, while the rails protrude from the tubes, making them clearly visible.

A disadvantage of a tube is that it may be difficult to adapt to rockets with fixed fins. This can be solved by using a kind of cage construction, but this will require more space on the launcher. A majority of the modern multiple rocket systems have solved this problem by using so-called wrap-around fins (WAF). They fit the curvature of the rocket hull, and flip out into a locked state after leaving the launcher. Wrap-around fins give a somewhat higher drag than fixed fins, but when all factors are considered, it is a good solution.

4.2 Aiming devices

There is no principal difference between gun artillery and rocket artillery with respect to aiming. Both artilleries are indirect fire in the sense that the target or aim point cannot be seen from the firing post. The launching platform must therefore point its rockets in a direction determined by ballistic calculations. The aiming devices are indicators displaying the orientation relative to the vehicle, and a compass and other navigational instruments for determining the orientation and position.

4.3 Fire control systems

Like howitzers, rocket artillery systems require a Fire Control System (FCS) capable of handling a comprehensive amount of input – the Fire Control Input (FCI). The output of the fire control system will be the parameters needed to complete the fire mission, i.e.

- launcher elevation
- launcher azimuth angle (horizontal orientation)
- use of any braking device if applicable
- fuze setting (timing) if a time fuze is applied
- the types and amount of rockets to be fired

If the mission involves multiple launchers, possibly an entire battalion, each launcher or each battery has to be given individual firing data.

The FCI may consist of the following groups of input, but the amount depends on the complexity of the system.

- launcher geographical position
- target geographical position
- meteorological data (temperature, air pressure and wind velocity at different altitudes)
- ammunition data (aerodynamic data, motor data, physical data, expected precision data)

Modern systems have a ballistic computer that makes use of all the data mentioned above. Older systems may still be based on ballistic tables and slide rulers and will not be able to fully make use of all the data above.

4.4 Carrier

Most rocket artillery systems are carried on the back of a 4-wheeled of 6-wheeled truck. These trucks are usually multirole vehicles that have been specially adapted to carry the rocket launching units. These truck mounted launchers will require a crew of 4 to 7 men in addition to one or more supply vehicles.

The largest rocket type, like the tactical missiles, may use a specially designed vehicle, mostly 8 x 8 wheeled, as the carrier.

Some systems with calibres not exceeding 122 mm may be man portable, but the distance to be covered or the load to be carried will be severely limited by the size and weight of the rockets.

4.5 Rate of fire

Many rocket artillery systems have a rate of fire far exceeding both conventional artillery and mortars. While manually loaded conventional artillery may reach 5 shells per minute in short salvos, and hardly more that 3 per minute in sustained fire, multiple rockets systems may fire the whole load of 40 rockets in as little as 20 seconds. Consequently a battery of MRLs can fire hundreds of rockets onto a limited area within a short interval.

A high rate of fire requires that the launcher platform is very stable. For some systems, like MLRS, each rocket in the launcher may be designated to an individual aim point. Thus the system has to re-aim for each shot, and the rate of fire may be as low as 10 – 15 rockets per minute.

A major drawback with rocket systems is their inability to deliver sustained fire. When the whole load has been fired, it may take many minutes, even as long as 20 minutes to reload the system.

The table below gives some values for the firing rate and the reload time

System	No. of rockets	Firing time	Reload time
BM-21Grad	40	20 s	10 min
BM-22 Uragan	16	20 s	25 min
BM-27 Smerch	12	38 s	20 min+
M26 MLRS	12	60 s	10 min
LAR-160	26	60 s	5 min
Filin (FROG)	1	n/a	20 min

Table 4.2 Duration of full salvo firing and reloading

It appears that most rocket artillery systems are able to fire their load in one batch. There is usually possible also to deliver smaller salvos, even a single rocket. For systems with a high rate of fire, like the BM-21, there is usually no readjustment of the launcher during the salvo. This implies that all rockets in a salvo are aimed at the same target, and that the lack of readjustment results in a wide dispersion of the salvo.

5 Basic rocket design

5.1 General design

The figure below show the typical rocket design with the following components:

- warhead
- fuze
- motor casing with propellant grain
- nozzle
- fins (if not spin stabilized)
- igniter (in the front or back end of the motor)
- umbilical(s)

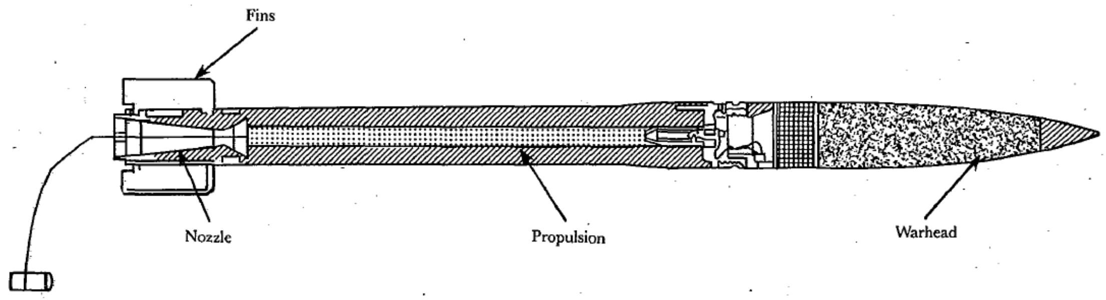


Figure 5.1 Typical rocket design

5.2 Warhead

The warhead may account for 25 – 50% of the rocket mass. It is almost exclusively placed in the front part of the rocket. The payload has to be encapsulated in a casing which is rigid enough to withstand the firing loads and normal handling. For fragmenting warhead, this encapsulation is may be designed in order to generate an optimal fragment pattern.

The different payloads are treated in more detail in the successive chapter.

5.3 Motor

The motor consist of a shell encapsulating a propellant grain or several grains. The design of the grains is described in the interior ballistics section in the next chapter.

It should, however, be pointed out that most rocket artillery motor have a quit short burn time – usually less than 3 seconds. This is contrary to the impression one might get when observing rocket artillery. After this short time, the rocket may still burn and eject smoke, but just slivers of propellant are burning and the acceleration is very weak or completely absent.

The smoke gives a quite high visual signature. The use of smokeless propellants has obviously not been a serious issue in rocket artillery, but smokeless seems to be in use for some newly developed spin stabilized systems. The rocket will in any case will give a quite high launch signature in terms of dust and flash. Besides, a rocket may be readily detected by artillery locating radars.

5.4 Nozzle

The primary function of the nozzle is to expand the hot propellant gases from the high pressure in the combustion chamber to the external ambient pressure, thereby converting thermal energy into directed kinetic energy or thrust. The theoretical thermodynamic relations provide methods for the calculations of rocket motor performance and nozzle design parameters. The flow of combustion gases, as they are expanded through the nozzle, is assumed to be an isentropic flow (adiabatic and reversible).

The maximum thrust from a motor is obtained when the combustion gases are expanded to the ambient atmospheric pressure. Since rockets usually operate at varying altitudes and the atmospheric pressure varies with altitude, the selected design expansion ratio of the nozzle is usually a compromise between the thrust and the nozzle expansion ratio, length, and weight.

An ideal nozzle profile should obey the following requirements:

- There should be no heat transfer across the rocket walls; therefore, the flow is adiabatic.
- There should be no appreciable friction and all boundary layer effects are neglected.
- There should be no shock waves or discontinuities in the nozzle flow.

- The flow of the combustion products should be steady and constant. The expansion of the working fluid should be uniform and steady, without vibration.
- All exhaust gases leaving the rocket should have an axially directed velocity.
- The gas velocity, pressure, temperature, and density should all be uniform across any section normal to the nozzle axis.

In reality, these, and even more requirements, can not all be fulfilled. A nozzle design is a compromise that gives an acceptable performance at different environmental condition and during the entire burning phase. There will also be a substantial heat transfer in the nozzle material and some erosion of the nozzle material.

The most common nozzle materials are:

- tungsten (alloyed with molybdenum)
- graphite
- glass phenolics
- ceramics
- steel

The latter is of course the most inexpensive choice. Steel may be the natural material if the burn time is short, like a couple of seconds. A material that has better erosion properties is advantageous from the accuracy point of view.

5.5 Fins and stabilizers

The purpose of stabilizers is to ensure that the rocket becomes aerodynamically stable. More specifically, the stabilizer moves the aerodynamic centre of pressure backwards. Usually, the centre of pressure should be put behind the centre of gravity and thus ensuring a statically stable rocket.

5.5.1 Fixed fins

Fixed fins are the most obvious choice and the conventional kind of fins. Unguided rockets, however, require some kind of restrained movement until a certain velocity has been achieved, which is realized by rails of tubes. Fixed fins are quite cumbersome in this respect. Rail launchers may handle fixed wings – tubular launcher usually will not. Rail launcher imposing initial spin is technically rather complicated, but has been solved for some large calibre systems.

Fixed fins were the only configuration when the concept of rocket artillery was introduced during WWII, but today they are used very rarely.

5.5.2 Wrap around fins

There are two types of Wrap-Around Fins (WAF). The original and genuine type is the one where the fin is a flexible blade, made of spring steel, that wrapped around the rocket body, usually in a half circle. When leaving the launch tube, the fins open up and stay in a position that is tangential to the body. This type is also known as tangential tri-form, or tangential six-form, etc., according to the number of fins.

The other type has rigid fins shaped like a quarter cylinder attached to the body with a spring-loaded hinge. In the launcher tube the fins are wrapped around the rocket body and locked by a strap around them. This strap is broken at or immediately after leaving the launch tube. After release the fins are locked in a fixed position, usually almost perpendicular to the body.

The first type, with spring steel fins, is usually not used in rocket artillery, as they tend to flex and vibrate at high speed. Rigidity of fins is paramount for the performance of high velocity rockets.

Wrap-around fins may be opened either way, with or against the spin direction. It does not seem to be any regular policy here. Left-spinning MLRS rocket fins open up to the right, i.e. against the spin. Most Russian systems, which are right-spinning, also open to the right.

Wrap-around fins are not suited as a steering device. For that purpose canard fins at the fuze section must be applied.

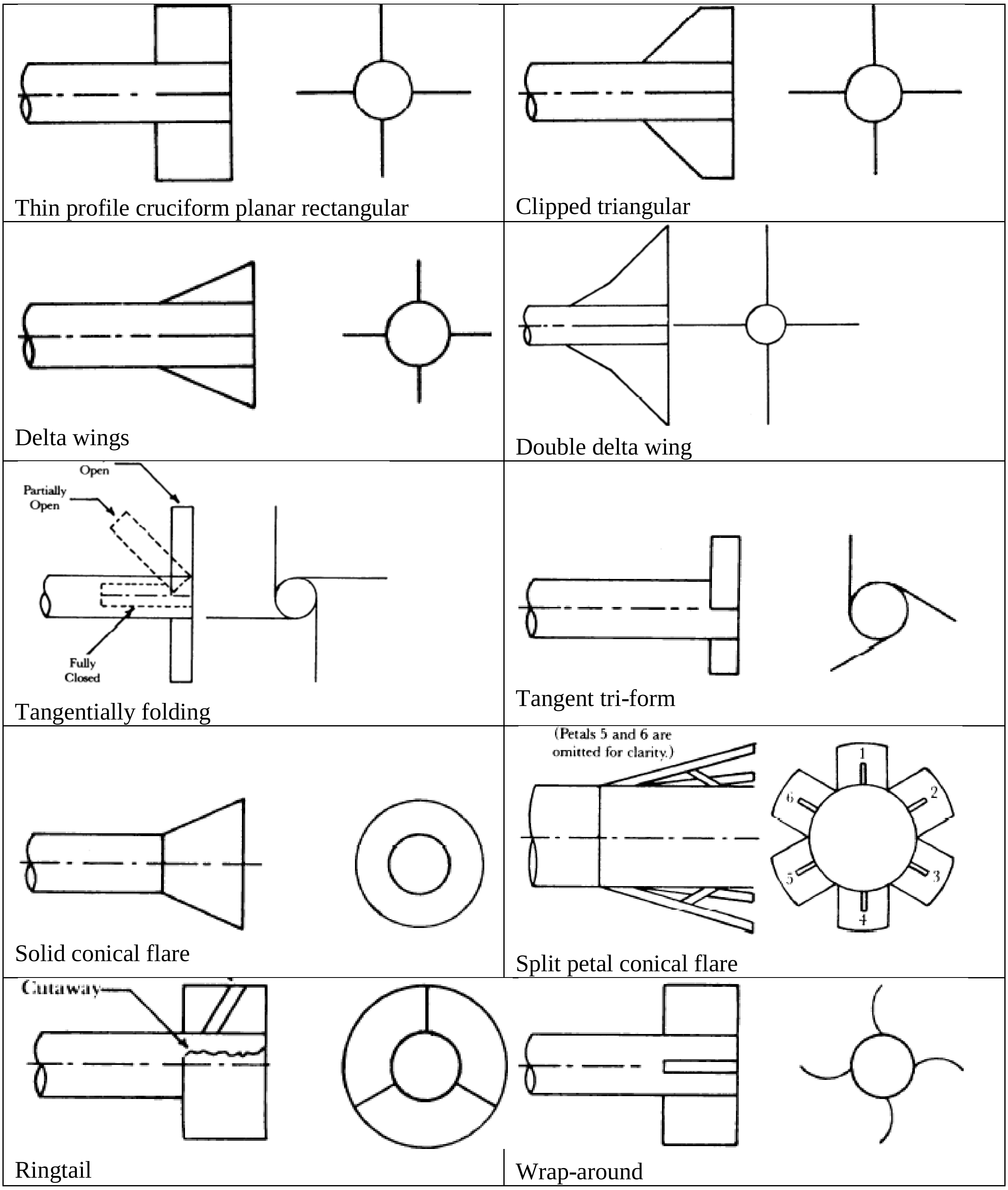
5.5.3 Grid fins

Grid fins are planar grids that are placed parallel to the body during launch. After launch they are locked into a position perpendicular to the body. This type was first used by Soviet Union in the 1970s on their tactical missiles like SS-21. Such fins are very well suited for guided rockets. Guidance is achieved by tilting the fins around an axis transverse to the body axis.

Figure 5.2 Grid fins at an the back American bomb[9]

5.5.4 Other fins or stabilizers

An overview of several kinds of aerodynamic stabilizers is shown in the table below. The table also includes some of the types mentioned above.



Thin profile cruciform planar rectangular

Clipped triangular

Delta wings

Double delta wing

Tangentially folding

Tangent tri-form

Solid conical flare

Split petal conical flare

Ringtail

Wrap-around

Figure 5.3 Different types of stabilizer devices[10]

5.6 Fuzes

The role of the fuze is threefold

- to ensure that the rocket can be handled safely during storage, loading, transport and launch
- to arm the ignition train prior to the time of function
- to function by detonating or ejecting the payload

Basically, rocket artillery fuzes have the same set of functions as gun artillery fuzes. For gun artillery, the high acceleration is usually exploited to arm the fuze in combination with spin. However, a gun artillery fuze can not be used as on a rocket because rockets have far less acceleration, and often far less spin, than gun artillery projectiles. While a gun artillery fuze may be subject to an acceleration exceeding 20000 G, the acceleration for a rocket may typically be around 200 G. The latter is a level of acceleration that can be experienced during handling of the munition. Thus the design of a rocket fuze may be more challenging than a gun fuze. However, the need to make the fuze rugged and robust can be somewhat relaxed for rocket artillery.

5.6.1 Impact fuzes

This is, without comparison, the most common type of fuze. Impact fuzes can be made simple, inexpensive and with adequate reliability. The more sophisticated versions contain features that arm the fuze by acceleration or spin or both. If safety can be compromised, the ignition may take place by a firing pin that is strikes an igniter by inertia alone.

Figure 5.4 Some impact fuzes (left to right) MRV for 122 mm Grad, M20-C1 for Astros II, V-24 and V-25 both for 240 mm spin stabilized rockets

5.6.2 Time fuzes

Time fuzes are required for kinds of rockets carrying submunition payload. A representative type is the M445 for MLRS. It is described in [11] and in the following factbox illustrates the complexity of such a fuze.

The M445 fuze

The fuze is composed of a fluidic (ram air) generator power source, an electronic module with telemeter umbilical and setter cables, an S & A mechanism, and an explosive lead charge

Fuze safety is achieved by restraining a rotor by an acceleration-time sensor and a piston actuator initiated by the fluidic generator operated from sustained airflow.

Upon firing, a spring-based setback weight moves rearward, oscillating in a zigzag path. If a proper rocket motor boost is obtained, this partially releases the rotor and closes a switch to an electronic timer. In flight, ram air passes through an annular orifice into a resonating cavity and the acoustic vibrations oscillate a diaphragm connected to a reed in a magnetic field and thus generate an electromagnetic field. After 1024 cycles of the diaphragm, a capacitor is charged, and after 1536 cycles, it is discharged into the piston actuator. The piston actuator removes the second lock to release the rotor completely. Sustained acceleration rotates the unbalanced rotor against a bias spring to the armed position; this rotation unshorts the detonator and closes the firing circuit. The rotor is then I s then locked in the armed position by a lock pin. Timing is accomplished with a twin oscillator, a divider circuit, and a counter. To enhance overhead safety, at 3.4 s before set time the firing capacitor is charged and, at set time, functions the Mk84 detonator, which initiates the lead.

Before flight the fuze is set by the MLRS FCS. A status switch, which is closed when the rotor is unarmed and open if the rotor moves, assures that the fuze can be set only if it is unarmed prior to launch. The S & A assembly is designed so that it cannot be installed in the fuze if the rotor is armed.

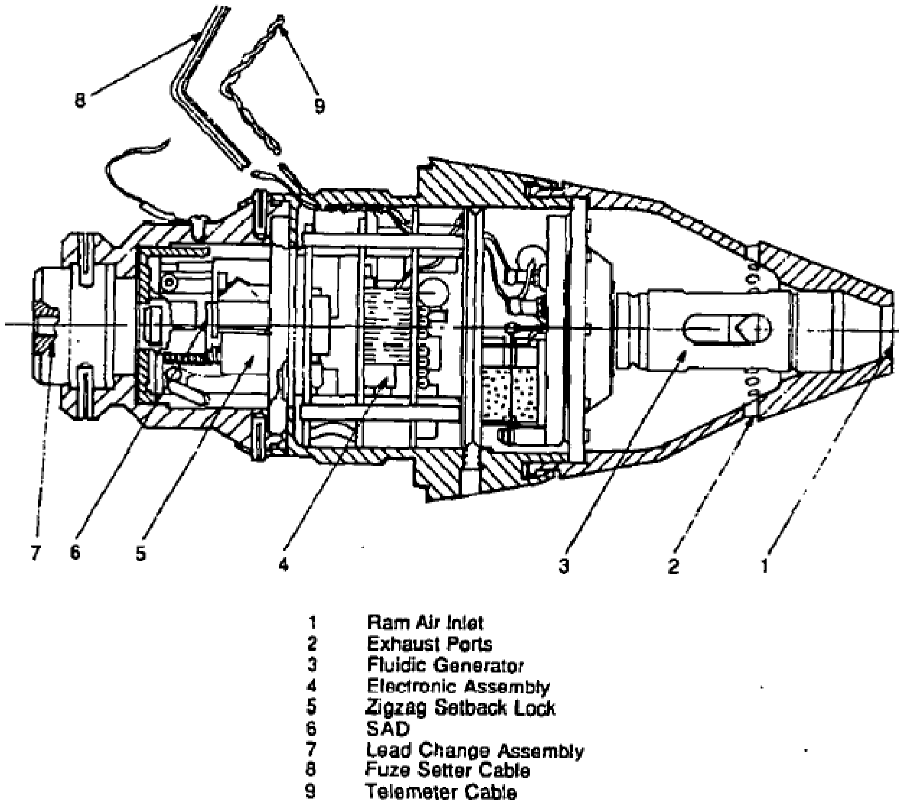


Figure 5.5 The M445 for MLRS (see description above)

5.6.3 Proximity fuzes

Warheads of the unitary high-explosive and fragmentation type (not bomblets) may be set off by a proximity fuze. Such fuzes respond to the echo of a radio wave emitted from the fuze itself and are designed to function at an altitude of 5 – 15 m above ground. Small calibre rocket will benefit from a lower height than large calibre rockets. Proximity fuzes may be subject to jamming. To minimize this threat, they may be set to arm and emit signals just a couple of seconds before the intended target encounter.

5.6.4 Multi-function fuzes

Multi-function fuzes contain a suite of functions like impact, proximity, time and even delay. For obvious reasons, the time function must override the proximity function, which again must override the impact function. The latter will be the last resort function if the others should fail.

5.7 Igniters

The igniter's mission is to initiate the burning of the fuel. This is made possible by injecting a flame into the empty cavity in the interior of the propellant grain. Ideally the whole surface of the grain should start burning simultaneously.

The igniter may be placed in the forward end, in the middle of the motor cavity or in the nozzle opening. In the latter case the igniter is spit out as the pressure inside the rocket builds up. In spin stabilized rocket the igniter is placed in the centre of the rocker rear end, surrounded by the suite of nozzles.

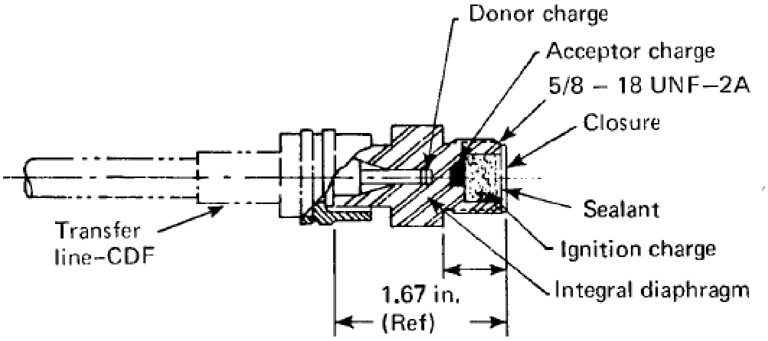


Figure 5.6   A squib type igniter

Small and medium rockets often have a squib placed in the nozzle. For the sake of redundancy, 2 squibs may be used. MLRS uses this method.

Larger rockets may need a larger igniter like the pyrodyne, which is a rod with perforations at the sides that eject burning particles. This principle is also used to ignite other charges like those of large calibre tank ammunition.

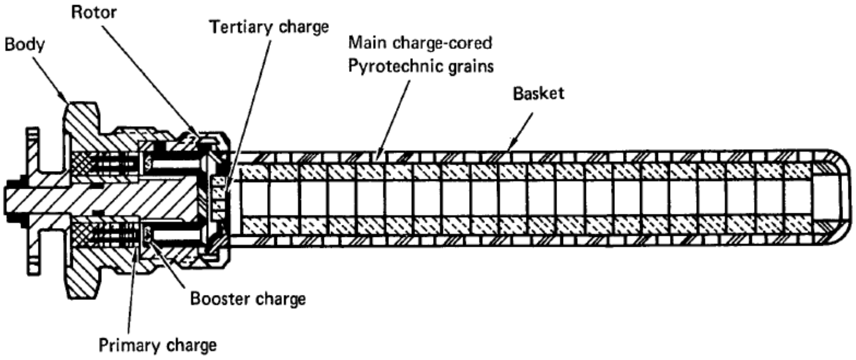


Figure 5.7   A pyrodyne igniter

A smaller variant of this principle is the pelleted pyrotechnics that ejects burning powder pellets. BM-21 rockets apply this principle with the additional feature that the ignition unit is placed half-way inside the motor, ejecting the propellant grains in both directions.

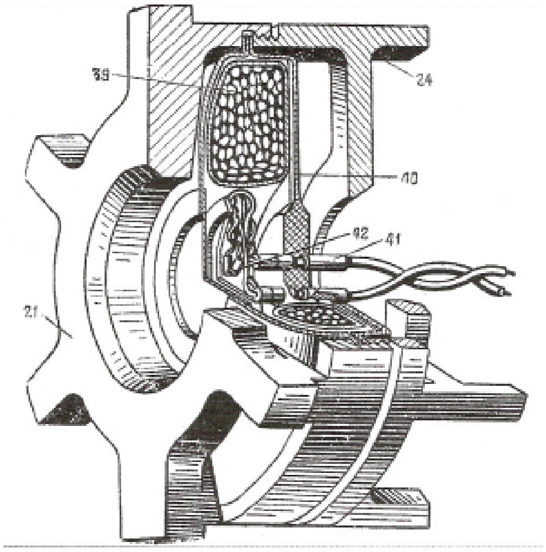


Figure 5.8 The BM-21 igniter ejecting burning pellets in both direction

The largest rockets may have a so-called pyrogen igniter. This device is like a rocket motor itself, initiated by a squib. The exhaust gases from this device ignite the propellant grain of the main rocket.

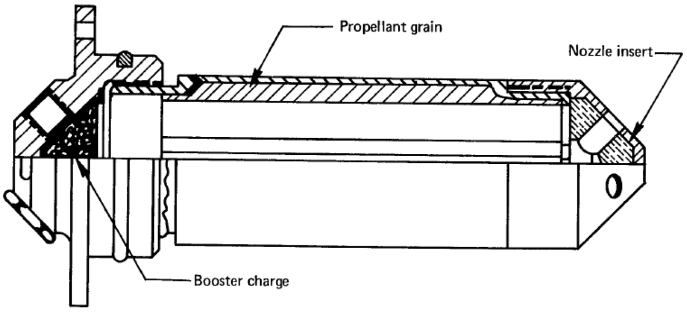


Figure 5.9 A Pyrogen igniter

The igniter is triggered by an electric current (of the order of 1 Ampere) supplied by the fire control system. The current is transmitted though the umbilical chord. The attachment to the rocket is cut as the igniter is spit out or as the chord is broken by the tension caused by the rocket movement.

5.8 Guidance devices

Steering or trajectory correction can be achieved in two ways – aerodynamically, by fins, or reactionary, by thrust vector control.

When the rocket is spinning, it is very difficult to use the fins at the back end of the rocket as steering devices. One way is to let the body spin while the fin assembly does not. However, it may be difficult to achieve this mechanically as the spin of the body will always induce some spin on the fins. The most used way is to use canard fins – 4 small fins extending from the front part of the body, usually integrated with the fuze. On a spinning rocket, this part should be despun in order to ease the control. This system in used at the guided version of MLRS.

6 Rocket artillery ballistics

6.1 Interior ballistics / propulsion

The interior ballistics of rockets is different from that of guns and rifles. In most rockets only a fraction of the fuel has been consumed when the rocket leaves the launcher. Thus the exterior ballistics phase starts before the interior ballistics phase is over. This phase will therefore have aspects of both interior and exterior ballistics.

6.1.1 Fuel burning

From a purely dynamical point of view, the best way to propel a rocket is to consume all the fuel in the shortest time possible. However, such an approach will converge into a conventional gun barrelled system. That would, however, require equipments that is as heavy and rugged as those of guns. The main advantages of rockets over guns could then not be exploited. They are

- relatively low and smooth acceleration
- lighter and less robust constructions for both the launcher and the warheads
- possibilities to reach longer ranges
- less mechanical stress on the crew in terms of blast waves

Artillery rockets have almost exclusively used solid fuel propulsion. Although liquid fuel has been uses in the past, such propellants are now only used for tactical and strategic rockets.

As opposed to guns, where the fuel is found as a granulate of rather small and fast burning powder grains giving a very large surface, the rocket fuel usually has the shape of a unitary grain, or a very small number of grains. The burning rates are also slow compared to gunpowder – a few centimetres per second.

The larger rockets will usually have its fuel as one unitary grain that is cast inside the motor tube. Such grains are usually star shaped in the sense that they have an internal cavity, with a star shaped cross section. The star shape provides a reasonable burning surface and also ensures that the surface area is close to constant throughout most of the burning phase.

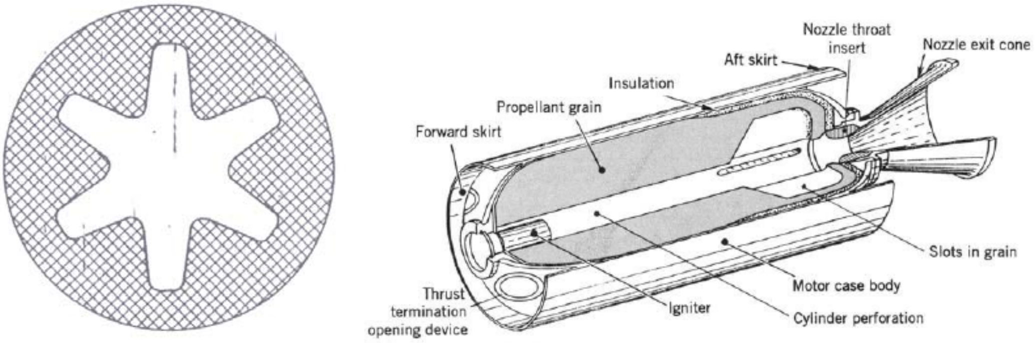


Figure 6.1 A modern grain configuration

The alternative to one star shaped grain is to have a small number (e.g. seven) of tubular grains placed inside the motor chamber. Here the tube shape ensures that the burning takes place both on the inside and the outside face of the grain which gives a quite stable surface area. Older Soviet rockets usually had this configuration. (see figure above [7]). This alternative is somewhat simpler as the casting inside the chamber is avoided. (figure 7.1-right).[12]

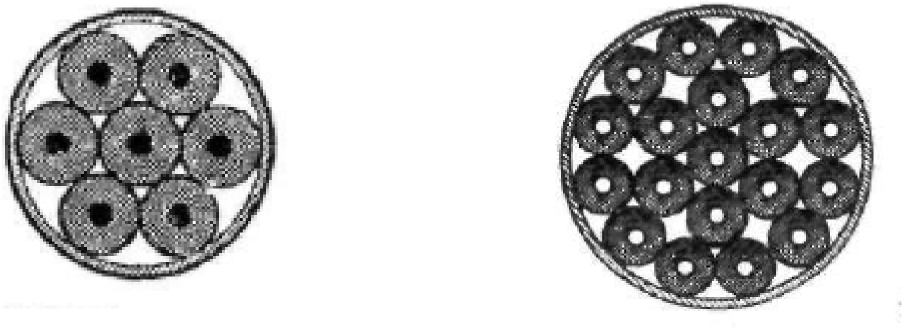


Figure 6.2 Cross sections of old propellant grain configurations (left - 140 mm; right – 240 mm)

The guiding factor for construction of a rocket motor chamber is to let the combustion gases exit through the nozzle with as high velocity as possible while maintaining an internal chamber pressure not exceeding the level where the chamber will be blown apart.

The burn time for the motor is typically a few seconds. In the example below, showing thrust as a function of time is a result of the grain shape. At a certain time (in the figure below at 1.6 s at 25ºC ambient temperature), the grain is burnt through (web burn-through) at which the thrust falls abruptly. However, the motor may continue to burn for another few seconds until the grain slivers are completely consumed. The burn time is very dependent on the initial temperature of the fuel. In extreme low temperatures the burn time may be twice as long as in hot conditions. However, the total impulse, quantified as the area under the thrust curve is less affected. The impulse is just a couple of percent higher at the high temperature compared to the low one. In terms of rocket velocity at burn-out, the effect is somewhat larger than that.

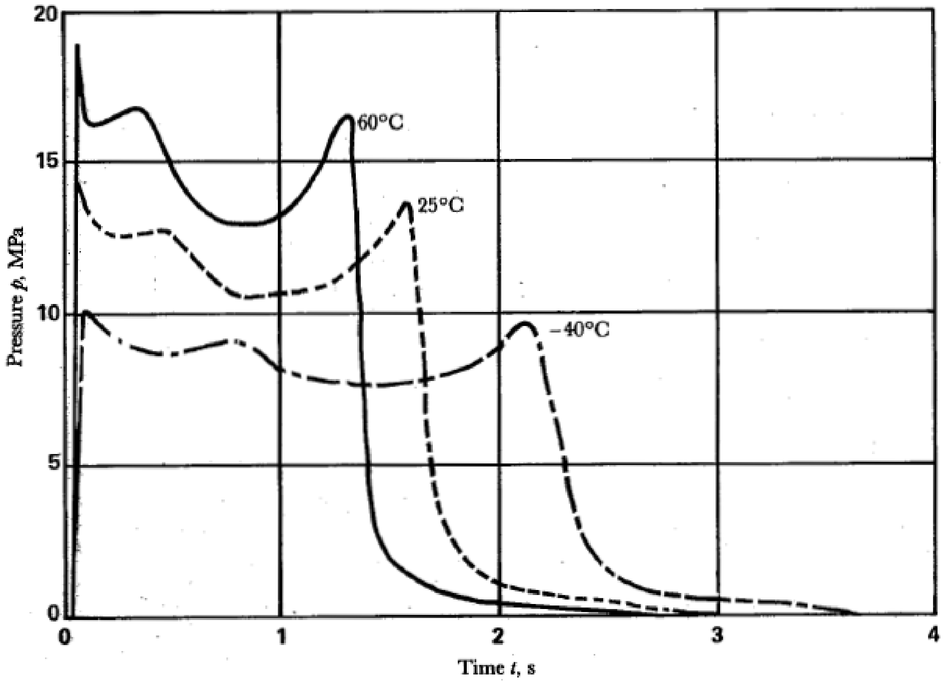


Figure 6.3 A typical thrust profile at three different ambient temperatures [14]

Specific impulse

The term specific impulse expresses the propulsive quality of the rocket propellant. The purpose of the propellant is to increase the momentum of the vehicle. That again is depending of speed which the exhaust gases from propellant can gain.

The Specific Impulse, I_{sp}, is expressed in two ways – as speed or as time. When given as speed it is simply the exhaust velocity – as time it can be considered as the time at which one kilogramme of the propellant can maintain a force of 1 Newton.

Modern solid rocket propellants have an I_{sp} in the range of 210 – 250 s. Liquid propellant fuel can reach an I_{sp} of around 450 s.

An example: The M26 rocket has a fuel content of 98.4 kg with an I_{sp} of 239 s. Assuming that the force is constant for 1.8 s, this force becomes

$$F = \frac{I_{sp} m_p g_0}{t} = \frac{239s \cdot 98.4kg \cdot 9.82ms^{-2}}{1.8s} = 128.3kN$$

6.1.2 The rocket equations

The basic equation relating the velocity of the rocket to the payload and the amount of propellant is the so-called Tsoikovskiy's equation[1] giving the final velocity of the rocket at burnout as

$$v = v_e \log\left(\frac{m_t}{m_p}\right)$$

where v_e is the exhaust velocity, m_t is the total mass of the rocket at ignition and m_p is the payload[2]. The exhaust velocity is of historical reasons mostly written as $v_e = I_{sp} g_0$ where I_{sp} is called the specific impulse and g_0 is the standard acceleration of gravity. (see box above)

Having found the exhaust velocity, the thrust of the rocket motor is simply given as

$$T = \left(\rho_f v_e^2 + p_e - p_0\right) A_e$$

where A_e is the nozzle area, ρ_f is the gas density at the nozzle, p_e is the pressure at the nozzle and p_0 is the ambient pressure. The shape of the nozzle is the determining factor for p_e and thus the efficiency of the rocket. This equation also tells us that the performance increases with lowering ambient pressure reaching its optimal performance in vacuum.

6.1.3 Rail phase movement

Before and during firing the rocket is usually not free to move along the rail. The rocket is generally held at the back end of the rail by some retaining device. Apart from avoiding unintended movement while under transport and loading, this device also have the purpose of letting the thrust build up until it has reached a certain level before the rocket is released. This ensures better control of the launch velocity and better consistency of the impact point. The retaining device may be a set of bolts that breaks at a certain force (shear bolt). The strength of the shear bolts is for MLRS around 5 kN. The negative aspect of a retaining device is that it may generate a vibrational movement in the launcher that negatively affects the accuracy.

As will be explained later, most systems induce a moderate spin on the rocket during launch. This is not for stabilizing the rocket, but to even out asymmetries in the thrust and the drag and thereby improving the accuracy. Many tubular launchers have helical rails on the inside of the tubes in order to induce spin on the rocket. The rocket has to be fitted with knobs or lugs that follow the helical rails during launch and thus induce spin to the rocket. These lugs are usually located at the hinge of the wrap-around fins in order to minimize the drag they may cause during the flight of the rocket. Most systems seem to induce a right turned (clockwise) spin – the same direction as with most guns and rifles. The MLRS induces a left turn for whatever reason.

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[1] Named after the renowned Russian rocket designer Konstantin E Tsoikovskiy (1867 – 1935)

[2] In this context, the payload is the rocket mass excluding the fuel

Spin stabilized rockets, i.e. rapidly spinning, also seem to rotate to the right as a general rule. However, it is known than the original Russian 240 mm M-24 rocket was left spinning. It is not known whether later foreign version of this projectile was made the same way. A subtle advantage of left spin is that it results in a drift that is opposed to the Coriolis force – as long as the rocket is used on the northern hemisphere.

6.2 Launch dynamics

6.2.1 Windage jump

The rocket leaves the launcher at a relatively low speed (40 – 80 m/s). At this stage, any wind across the tube axis will affect the flight of the rocket. The part of the rocket that has passed the tube opening will be subject to the wind force while the rear end of the rocket is attached to the rails. This may make the axis of the rocket to deviate slightly in the direction of the wind. In MLRS this effect is minimized as the rails only occupy the rear half of the tube and the rocket then moves freely through the forward half of the tube. In Russian systems the rail extends along the whole length of the launch tube.

6.2.2 Launcher movement

As mentioned above, in order to increase the launch velocity, the rocket movement may be obstructed until a certain thrust has built up. During this phase, the launcher is subject to a recoil that may result in a slight movement or shaking of the launcher. This may result in a deviation of the direction of the rail and even a pitching or yawing motion at launch with a certain inaccuracy as a result.

After the release of the rocket, friction between the rocket and the launch tube will inflict some recoil, but this is quite small. If spin is induced by the launch tube, the rotational momentum must be counter-balanced by an equal momentum to the launcher. Usually the inertial moment of the launcher by far exceeds the axial inertial moment of the rocket. The turning of the launcher will thus be minimal. However, for light launchers this effect may be significant.

Rockets with self induced spin, or no spin at all, have the most benign effect on the launchers. Consequently, such rockets may be launched from very primitive launchers like a simple rack, a tripod or a light towed multiple launcher.

6.3 Exterior ballistics

Fin stabilized projectiles, like a mortar bomb, have a high degree of stability. In order to do ballistic calculation, the so-called point mass model (PMM) is sufficient. This kind of ballistics is characterized by having the air drag coefficient as the only aeroballistic coefficient needed in the model. The axis of the projectile is always assumed to be aligned the trajectory or its velocity. Thus there is no need to calculate the attitude of the projectile.

For spin stabilized projectiles, like those fired by tube artillery, the so-called modified point mass model (MPMM) is applied for ballistic calculations. Here a number of aeroballistic coefficients is applied, like drag, lift, spin damping, overturning moment etc. Both the trajectory and the attitude of the projectile axis are calculated through two coupled differential equations. The method is not able to represent the swirling motion taking place during one revolution of the projectile, but have expressions determining the average attitude during one revolution.

The ballistics for rockets, and indeed for spinning rockets, should be described by using the so-called six degrees of freedom model (6DOF). This may be characterized as a physically complete solution of the ballistic equation. Apart from keeping track of the position of the projectile, the attitude of the projectile during a revolution is solved along with the phase of the revolution. The method requires access to a high number of aeroballistic (aerodynamic) coefficients, some of which may be very difficult to obtain. In some instances, even second or third order coefficients are required. The accuracy of and availability to these coefficients is the main limitation of the method. One should, however, bear in mind that the ballistic equations will not exactly represent nature. The basic limitation is that the aerodynamic coefficients are represented as linear functions of the angle of attack of the projectile.

The quaternions

Rocket exterior ballistics is usually solved by 6DOF-models. Some of these models, like one of those applied to MLRS [13], make use of quaternions. Hidden behind this name is a type of algebraic entities, discovered and developed by the Irish mathematician William Rowan Hamilton (1805-1865) in the mid 19th century. Quaternions constitute an extension of the well-known complex numbers. While complex numbers have a real part and an imaginary part, quaternions consist of one real part and three imaginary parts and can be generally written as

$$Q = q_0 + q_1 i + q_2 j + q_3 k$$

where $q_0 \ldots q_3$ are scalar magnitudes and i, j and k are the imaginary units. An important point here is that the product between these units is non-commutative giving $ij = k$, $ji = -k$, $jk = i$, $kj = -i$, $ki = j$, $ik = -j$ and $i^2 = j^2 = k^2 = -1$ from which it follows that $ijk = -1$, $jik = 1$, etc.

The quaternions are well suited to describe the orientation or attitude of an object in space. A change in orientation is represented as a multiplication of the current quaternion with another quaternion describing the change. The use of quaternions makes the ballistic equations more compact, but also more abstract, which may be the reason for their limited use. The theory of quaternions was a breakthrough in multidimensional algebra, but it was soon overshadowed by more general theories. More recently quaternions have found their renaissance in the description of movable bodies in computer games.

The exterior ballistic phase of most rockets has two distinct phases:

- the boost phase in which the motor burns and the rocket is accelerating
- the coast phase in which the motor has completely burnt out giving no contribution to any forward force
- there is also an intermediate phase in which the motor force is too weak to generate acceleration, but the motor still gives some forward force or contributes by reducing the base drag of the rocket

The most critical parameter for the exterior ballistics is the aerodynamic drag coefficient. This parameter has several components:

Wave drag

The wave drag is the component of the drag caused by the parts of the rocket facing the airstream, in particular the nose part. Nose wave-drag is influenced by the fineness ratio, nose shape, and Mach number. For preliminary design estimates, the nose shapes are mainly cones and ogives.

Skin friction drag

Friction drag results from the boundary layer airflow over the rocket surface. Shear stress is imposed on the external surface of the rocket due to the velocity gradient in the boundary layer. The magnitude of this shear stress is a function of the position of transition from laminar to turbulent flow, and therefore of the air velocity. Skin structure caused by surface treatment or painting affects the skin-friction contribution.

Drag due to fins

The fins contribute to wave drag, friction drag and base drag. The critical parameters determining the fin drag are their length, width and thickness, and the shapes of the front and rear edges. Whether they are of the fixed type or they are wrap-around fins is of less importance.

Base drag

The base drag is caused by the pressure forces resulting from airflow separation at rearward facing steps, especially the body base and the nozzle section. The low pressure behind the base works as a suction force that slows the rocket. As long as the motor burns the rear pressure is high and the base drag is absent.

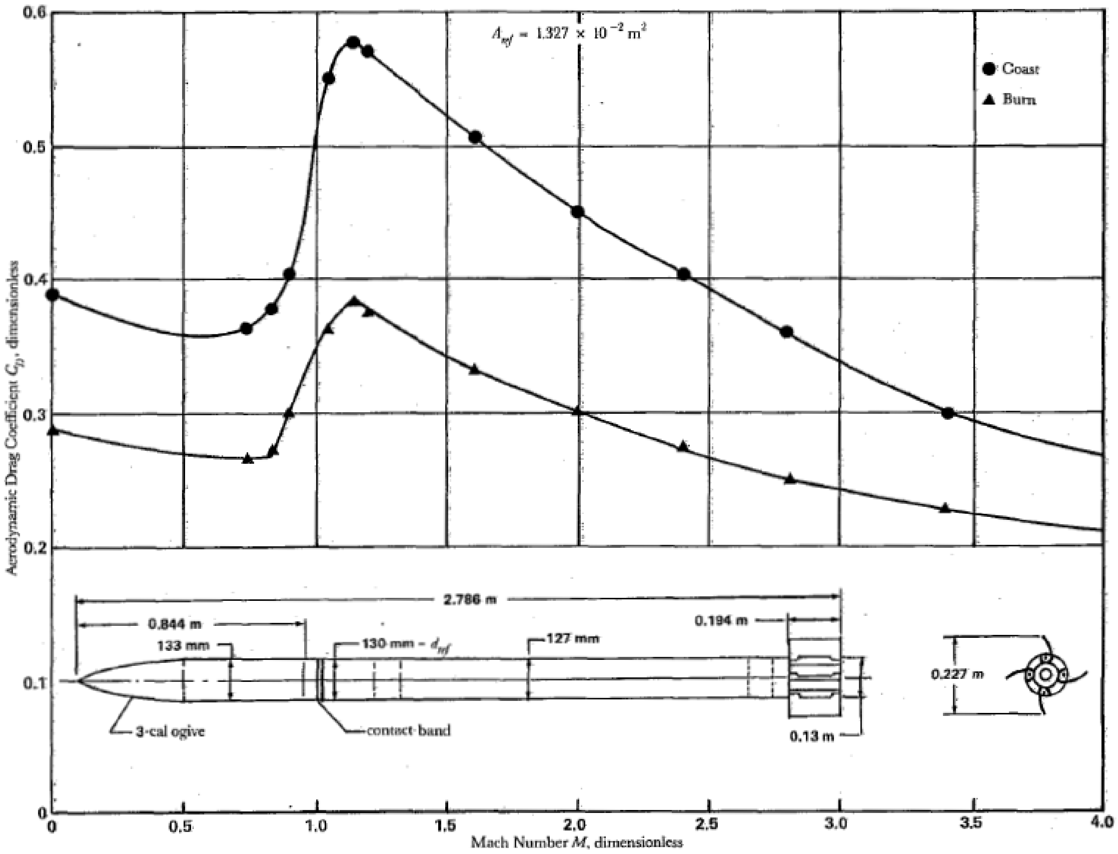

Figure 6.4 Air drag coefficient (CD) for a 130 mm rocket showing the difference in drag during boost phase and coast phase. The figure is taken from MIL-HDBK-762 [14].

Other aerodynamic coefficients that are accounted for are:

The lift coefficient (C_L).

This is the force acting perpendicular to the velocity vector and caused by the angle of attack between the rocket axis and the trajectory tangent.

The Magnus[3] force coefficient (C_{Npa}) (spin stabilized rockets only).

This force, which is caused by any difference in the surface stream velocity on one side of the projectile compared to the other, works perpendicular to the angle attack. Its contribution is mainly small and is present only when the rocket has a pitching/yawing motion. Wind from the side will also result in Magnus forces.

The overturning moment coefficient (C_{Ma}).

This term quantifies the tendency of the rocket to overturn. A slow spinning or non spinning rocket will have a positive coefficient as long as the fins are closed. A positive coefficient means that an overturning disturbance will increase with time. As the fins open, the coefficient becomes negative contributing to the stabilization of the rocket.

The pitch damping moment coefficient (C_{Nq}).

This is mostly used together with the previous coefficient, but this coefficient is not affected by the fins. A rocket body will usually have a negative damping coefficient which means that a rotation around an axis perpendicular to the rocket axis will be dampened.

*The spin damping (and driving) coefficient (C_{lp})***.**

A spinning object will tend to slow its spin due to the air streaming along the body surface. A rocket with fins may also have a spin driving moment that is realized by canting the fins, asymmetric fin edges, or flaps at the nozzle exit diverting the exhaust gases. For spin stabilized rockets the spin driving moment is extremely high during the boost phase.

The Magnus moment coefficient (C_{Mpa}) (spin stabilized rockets only).

This momentum, which is caused by any non-zero Magnus force, works perpendicular to the plane spanned out by the rocket axis and the Magnus force. Like the Magnus force, it is usually small, but it may affect the stability of the spinning rocket.

6.3.1 Stabilization

In general, there are two main type of stabilization – by spin (gyroscopic stabilization) and by fins (aerodynamic stabilization)

The first artillery rockets had fixed fins for stabilization. Being launched from a straight rail, there were no possibilities to obtain spin during launch. A non-spinning fin stabilized rocket is a quite simple and safe design. The prime drawback is its lack of accuracy. Any asymmetry in design or propulsion may seriously affect the accuracy. Likewise, the disturbances caused by wind will do the same.

Gun artillery shells are spin-stabilized induced by the gun rifling. Likewise, rockets can also get their spin by helical rails on which they ride during launch. However, as rockets have a rather moderate launch velocity, this spin will be much lower than for gun artillery and insufficient to

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[3] Named after the German physicist Heinrich Gustav Magnus (1802- 1870)

fully stabilize the rocket. A better solution is to have a rocket motor with a multiple nozzle arrangement where each nozzle is mounted eccentrically and inclined to the rocket axis so that the motor both gives forward thrust and angular momentum inducing spin. In this way, a spin rate exceeding 300 rps (revolution per second) is possible which is sufficient for stability. Spin driving motors will to some extent decrease the range of the rocket, but at an acceptable rate.

Spin-stabilized rockets are known to have better accuracy than rockets that only have fins for stabilization.[14]

The ballistic aspects of spin-stabilized rocket are addressed in [15]

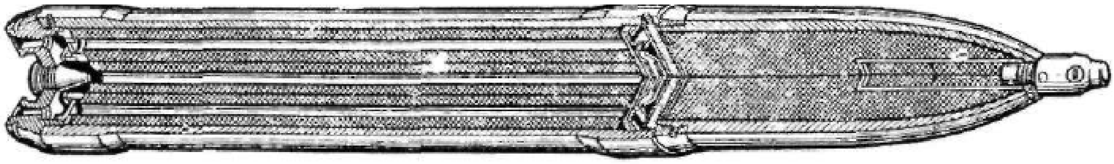

Figure 6.5 The spin stabilized rocket for RPU-14 towed system.

Figure 6.6 Test firing of a 107 mm spin stabilized rocket (MKEK)

It is not possible to spin-stabilize a rocket for which the length to diameter ratio is 7 or more. This is the reason why such rockets have a more stubby shape than modern rockets like, MLRS, or Uragan. The limitation in length also has the consequence that the effective range of such rockets is limited to hardly more than 10 km. The limitation in length limits the amount of fuel to weight ratio.

Fins are incompatible with fully spin-stabilized rockets, as the fins themselves tend to dampen a high spin. However, as fin-stabilized rockets will benefit from some degree of spin, some fin configurations have a spin driving moment that is obtained by having a slightly inclined mounting or by having an asymmetric profile.

An advantage with spin stabilized rocket is that they, just like a gun artillery projectile, may have a smooth surface which diminishes the radar cross section. Finned rockets, even those with wrap-around fins have a far larger radar cross section and may be easily detectable by an artillery locating radar.

Spin stabilization (elementary theory)

Spin stabilization is obtained by having multiple nozzles that are inclined with respect to the rocket axis and situated eccentrically to induce spin moment.

The number of nozzles may be between 6 and 16. Irrespective of the number of nozzles a simple theory for the boost phase can be outlined as follows.

Consider a rocket with mass m and with a motor that yields a thrust T. The rocket has an axial momentum of inertia I_x. The nozzles are inclined an angle θ with the axis and their opening are situated at a distance r from the rocket axis.
The axial acceleration then becomes

$$\ddot{x} = \frac{T}{m}\cos\theta ,$$

while the rotational acceleration becomes

$$\ddot{\varphi} = \frac{Tr}{I_x}\sin\theta .$$

Thus, disregarding the aerodynamic drag, the ratio between the rotational and axial acceleration, is found by

$$\frac{\dot{\varphi}}{\dot{x}} = \frac{mr}{I_x}\tan\theta$$

As an example, consider a rocket with 240 mm calibre with 200 kg mass. Assume that the momentum of inertia is 1 kgm^2, the nozzles are 0.1 m from the axis and $\tan\theta$ is 0.2. The ratio between the rotational and axial velocity then becomes 4 rad/m. The implication of this value is that if the rocket leaves the launch tube at a velocity of 30 m/s, the spin is 120 rad/s. This rate is sufficient to make the rocket aerodynamically stable.

Calibre	Country of origin	Length (m)	Mass (kg)	Range (km)	Explosive mass (kg)	Spin or velocity
107 mm	TUR	0.84	14	8.5	2.5	370 m/s
128 mm	SER	0.81	23	8.5	4.0	444 m/s
140 mm	RUS	1.08	40	9.8	4.2	370 rps
240 mm	PRC	1.12	112	10	27	250 rps
333 mm	IRN	1.82	255	13	60	

Table 6.1 Some examples of spin stabilized rockets. These are the standard configurations. Some calibres have rockets with enhanced range, but with smaller payloads.

6.3.2 Braking devices

A drawback with many artillery rocket systems is the relatively large minimum range. A long minimum range is not just a problem when faced with short range targets, but also when targets are found behind high crests. It is also problematic to obtain the sufficient accuracy at short ranges as the angle of fall will be very shallow and small inaccuracies up or down will result in a substantial error in impact point.

Gun artillery can circumvent such problems by selecting at smaller propellant charge, but rockets have just one charge. The problem may be partially solved by giving the rocket a higher air drag, making the trajectory shorter and more curved.

Some systems, of which the most pronounced is the 122 mm BM-21 and its derivates, have a braking device implemented and rings, a narrow ring (around 80 mm diameter) for moderate reduction and a wider ring (122 mm diameter) for a more drastic velocity reduction. The ring is put over the fuze part, and serves as a kind of spoiler, For BM-21 the ring reduces the minimum range from 5 km to 1600 m. Such a ring is inserted at the interface between the fuze and the warhead, at which the BM-21 rocket has a diameter of 64 mm.

The ring will increase the air drag and make the trajectory more curved. The air drag curve will approximately be multiplied by a certain factor depending on the diameter of the brake ring.

This kind of device was originally used on the now obsolete Soviet system 140 mm M-14. It is not known for certain whether it is used on other systems than 122 mm.

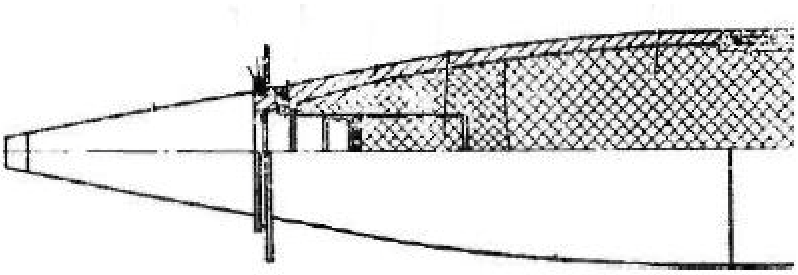

Figure 6.7 Braking system / spoiler on BM-21 (both small and large ring fitted)

6.3.3 Coriolis' force

The Coriolis'[4] force is not a real force, but virtual force due to the rotational movement of the reference system. If induces a drift to the right on the northern hemisphere and to the left on the southern one. It also depends on the compass direction of the fire.

When firing at distances beyond 10 km the Coriolis' force must be included as its contribution may exceed more than one per cent of the range of the rocket. However, there are no principal difficulties with the inclusion of this force in the equations. The trajectory calculation will consequently depend on the latitude of the firing post and the azimuthal direction of fire. In order to include this force a three-dimensional model must be applied.[5]

6.4 Trajectories

Appendix D contains a collection of trajectories and other characteristics for some of the most common rocket artillery systems.

6.5 Accuracy of delivery

There are many factors affecting the accuracy of rocket fire. Statistically they are of two different kinds:

Systematic error

- those errors that repeat themselves from rocket to rocket resulting in a bias in the impact pattern of the fire

Random errors

- those that are completely random from rocket to rocket resulting in a dispersion within a salvo of rockets

In general, every error component has a vector character. If every component is independent of each other, they should be summarized as vector and not as scalars. Some error components, however, may not be completely independent. If these are summed vectorially, a covariant component should be subtracted from the sum.

Assuming that there n error components with variances σ^2_i, $i = 1, \ldots n$ and with correlation coefficients ρ_{ij}, $i,j = 1, \ldots n$, the total error can be written as

$$\sigma^2_{total} = \sum_{i=1}^{n} \sigma_i^2 - 2\sum_{i=1}^{n}\sum_{j=1}^{n} \rho_{ij}\sigma_i\sigma_j$$

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[4] Named after the French mathematician Gaspard-Gustave Coriolis (1792 – 1843)

[5] The Coriolis force may be felt if sitting in a merry-go-round. Try throwing a ball to a friend sitting in a distant seat. The ball follows an oddly curved path as seen from both you and your friend. However, from an observer standing on the ground the curve looks normal.

Often the correlations coefficients are zero, indication the actual error sources are independent.

6.5.1 Random errors

Random errors are mostly connected to the rockets. Examples are

- variations in mass
- variation in fuel mass
- variations in surface finish affecting the skin friction drag
- variations in the shape of fins
- variations in fuze timing (if applicable)
- variations in centre of gravity and moments of inertia
- thrust misalignment
- unpredicted launcher movement and vibrations
- short term meteorological variations

6.5.2 Systematic errors

The systematic errors are more of operational inaccuracies and environmental variations like:

- difference between the actual and measured or predicted meteorological state
- deviations of the ammunition lot properties compared to the standard properties
- aiming errors
- errors in target acquisition data
- error in launcher position and orientation
- incomplete ballistic models
- deviations between actual and anticipated ammunition temperature

6.5.3 Wind induced errors

Rocket artillery projectiles have two distinct phases:

- the boost phase, in which the fuel burns and the rocket accelerates
- the coast phase, in which there is no propulsion and the projectile flies like any other projectile

The effect of wind is opposite in the two phases. In the latter phase, the projectile is affected in a “normal” way and it diverts in the direction or the wind. In the boost phase however, there is a net acceleration of the rocket and the fins will align the rocket with the airstream felt by the rocket. If the wind comes from the right, the net airstream will divert to the right and consequently the rocket will also divert to the right. The rocket will thus, somewhat counter-intuitively, move against the wind. The tendency to move against the wind will be in proportion to the net acceleration, i.e. the higher the acceleration, the more it will divert.

The boost phase will take place in the lower few hundred meters of the atmosphere. Although the wind speed is low near ground and has a steady increase with altitude, the variability of the wind is most pronounced in the lowest atmosphere. At hundred meters altitude wind variations take place at a time scale of a few minutes. This effect is especially pronounced when in broken terrain. This implies that it is almost impossible to forecast the boost phase wind and that any measurement of this wind will be valid for just a few minutes.

When firing at ranges beyond 20 km, this factor is the most serious contribution to inaccuracy of the rocket. Compared with tube artillery fired at the same range, rockets tend to have an average error in the hit point that is twice as high. A typical error produced by tube artillery is 0.9% of its range, while rockets typically may have 2% error.

6.6 Reported accuracy

The value of the accuracy is known for the most prominent rocket systems. However, for many of these reports the concept of accuracy is not well defined. The numbers are not defined according to random or systematic error contributions. Often it is not even specified whether the numbers refer to the probable error or the standard deviation with respect to the aim-point.

There are no standards on how to define average conditions for the state of the troposphere. As an example, the term average wind may be defined as

- the time average
- the median value of a regularly sampled set of values
- the surface wind average value
- the ballistic (see box) wind average value

Ballistic wind

The term ballistic wind is a term used in gun artillery ballistics for calculating the effect of the wind. It is based a vertical sampling of the meteorological state of the atmosphere. The sampling is made at specified layers (zones) of the atmosphere and the ballistic wind is weighted average of the wind measurements for the part of the atmosphere through which the projectile moves. The weighting is done according to how much the wind in certain zone potentially may affect the total accuracy. In addition to ballistic wind, term like ballistic air density and ballistic temperature can be defined in the same way. However, while temperature and density are scalar values, the wind is defined as a 2-dimensional (horizontal) vector.

The definition of ballistic wind can be found in [16]

The table below shows some values for accuracy of some common rocket systems. The values given are for the maximum firing range. At shorter range, the values can be assumed as being proportional to the range raised to 3/2.

System	Max. range (km)	Random errors (m)	Systematic errors (m)	Total error for single fire (m)
107 mm	8	70 x 100	45 x 90	80 x 130
122 mm (portable)	11	100 x 150	90 x 180	130 x 230
122 mm	20	110 x 180	120 x 240	160 x 300
227 mm	32	160 x 360	120 x 240	200 x 430
240 mm	11	180 x 400	110 x 220	210 x 460
300 mm (guided)	70	-	-	150 x 150

Table 6.2 Some assumptive values for accuracy of some selected systems at maximum firing range. For the two first systems, the error will vary according to the quality of the launcher.

6.7 Direct fire

Direct fire by artillery is normally not used. The need to use rockets in direct mode may be as a last resort in a defensive operation, when no other means are available. The firing range in direct fire may be limited to 1000 m.

Many of the vehicle borne rocket systems have a minimum and maximum angle of elevation. The maximum value may be like 50 - 55° and the minimum value may be around 10°. Such systems cannot be used in a direct mode as the required elevation will just be a few degrees. It can however be circumvented by using a braking devices like rings at the front tip of the rocket, or by placing the vehicle in downhill slope facing the target.

Most portable or towed systems can easily be used in direct mode provided that a simple aiming device is adapted to the launcher. On improvised systems, any restriction on elevation can also easily be circumvented.

6.8 Submunition ballistics

Submunition payload is quite common for rocket artillery munitions. As mentioned elsewhere in this report, there is a wide variety of submunitions.

The main reason for using submunitions is to spread the effect of the payload over an area. If the submunition is inadequately spread, there will be an oversaturation of effect inside the area, and much of the effect will be spilled. The size of the area should be so large that oversaturation is avoided against any kind of target. On the other hand, the area can not be so large that it exceeds the size of a typical target, thereby spilling some of the effect outside the target and increasing the possibility of collateral damage.

6.8.1 Ejection

One way to spread out the payload would be to split the casing covering the payload in two pieces, exposing the payload to the air-stream. The possible disadvantages are that the spread could be small, the submunitions could be damaged by interference with the motor shell and the process could have limited repeatability. Consequently, most payloads contain a centre charge that blows the submunitions away from the canister. Such a charge can eject the submunitions with a speed exceeding 100 m/s. The charge itself can be a high explosive charge or a powder charge.

The splitting of the casing can be due to the inside pressure caused by the centre core burster (CCB). Alternatively can be a separate process as the casing is split by the detonation of an explosive cord stretched along the inside of the casing. (see figure 7.8)

The timing of the centre charge and also of the detonating cord is governed by the main fuze of the rocket warhead.

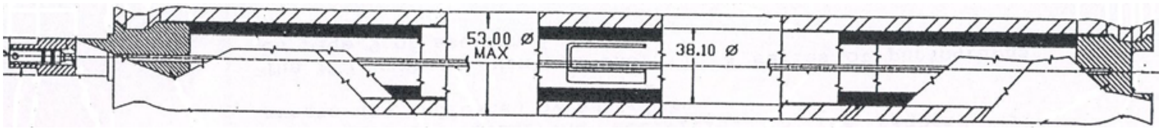

Figure 6.8 The expulsion charge of the MLRS M26 rocket

The next two figures show an example of the trajectory of the bomblets expelled from a MLRS rocket and the impact pattern on the ground.

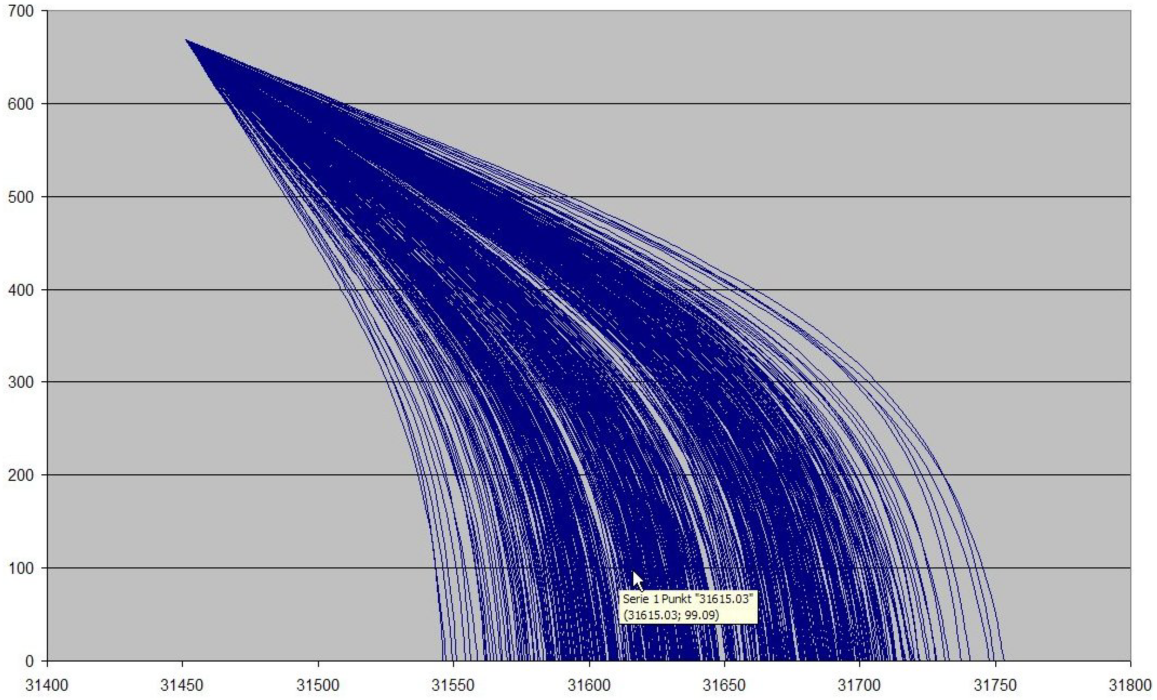

Figure 6.9 Bomblet trajectories for M26 cluster rocket. The ejection takes place at a height of 760 m.

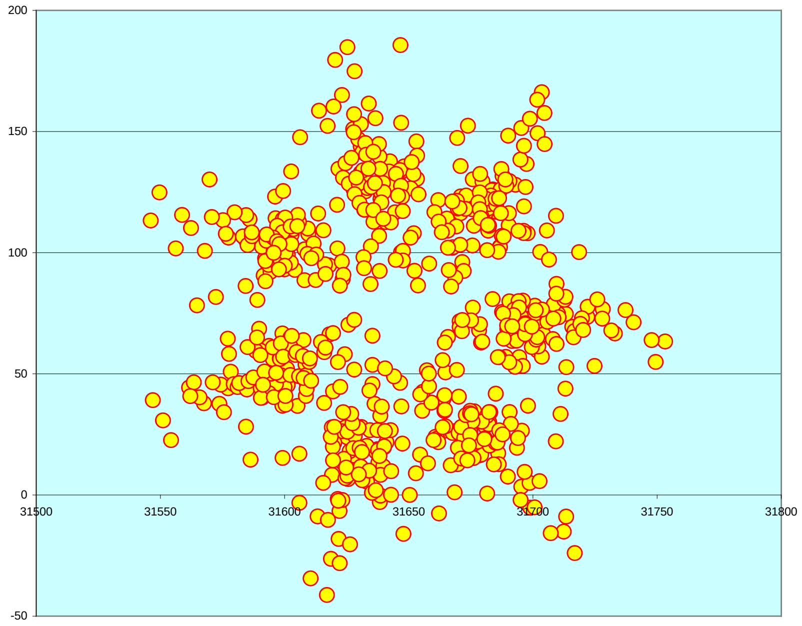

Figure 6.10 Dispersion pattern of M26 cluster munition rocket

6.8.2 Descent phase

The ballistics of the submunition is usually a quite simple process that can be modelled by 2-dimensional ballistic models. Most of the submunition has some kind a stabilizer, like a ribbon or streamer, or flaps or fins avoiding any chaotic rotation of the munition.

There are also some examples of a two stage descent phase, where initially a number of packages containing several submunitions (literally sub-submunitions) are thrown out. The packages are then set to open after a certain time at which the true submunitions are released.

7 Rocket payloads

7.1 Fragmentation high explosive charges

This is the classical and simplest kind of warhead. The payload is just a batch of high explosive intend to detonate at impact with the ground, or in some cases a few meters above ground. Apart from the explosive charge, the warhead contains a fuze with a detonator to initiate the high explosive charge. Before 1970, almost all rocket artillery warheads were of this kind.

Explosives like TNT or RDX confined in a metallic container have their primary effect by ejecting fragments and, to less extent, by emitting a pressure wave in order to destroy structures and incapacitate humans.

7.2 Enhanced effect warheads

Some explosives or explosive mixtures have a blast pressure character different from that of a conventional explosive.

In some cases, it may be desirable to have warheads with an enhanced pressure wave. Actual targets could be urban areas, people in shelters with strong overhead protection. There are basically two ways to achieve this – by thermobarics or by fuel-air explosives.

7.2.1 Fuel-air explosives (FAE)

Fuel-Air Explosives (FAE) in military munitions are based on the same principles that cause many accidental explosions in buildings, silos and industries – deflagration or detonation reactions of highly combustible materials in mixture with air. Military FAE however use these principles intentionally for generating intensive air blast and heat impulses for destruction of ground forces (personnel and vehicles), infrastructure, and to set off mines in a mine field.

The main advantage of FAE systems in general is the fact that only a part of the explosive energy has to be delivered at the target. Additional energy is extracted from the oxygen in the air. The combustible part are usually dispersed and mixed with the air by a smaller explosive charge and ignited at a stage when the mixture with air is supposed to be optimal.

The combustible part is often one of the following compounds:

- ethylene oxide (C_2H_4O)
- propylene oxide (C_3H_6O)
- decane ($C_{10}H_{22}$)
- kerosene (C_nH_{2n+2})
- mixture of 51% methyl acetylene (C_3H_4), 26% propane (C_3H_8) and 23% propadiene (C_3H_4)

The blast effect of a FAE charge may be 2 – 3 times greater than the same amount of TNT.

U S Army implemented FAE in a rocket system called SLUFAE (Surface Launched Unit, Fuel Air Explosive) using the rocket M130 carrying 45 kg FAE. The rocket had a calibre of 345 mm and a weight of 85 kg. Its range was quite short as it was primarily intended for clearing minefields. The development started in the 1970s, but the system never entered production.[17]

FAE warheads are not yet very widespread, but it is known that the Russian Uragan and Smerch systems have FAE-ammunition. It is not known whether these munitions have been exported. Also the Russian TOS-1 Buratino[6] 220 mm system, fired from a modified main battle tank, has FAE payloads.

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[6] Buratino is a Russian fairy-tale figure whose parallel is the American Pinocchio

Figure 7.1 220 mm TOS-1 systems firing FAE rockets

7.2.2 Thermobaric explosives

FAE may be called a two stage explosive, involving dispersion and detonation. Its relative, the thermobaric explosive (TBX) is more of a one stage explosive like conventional ones. Thermobaric explosions involve a conventional detonation followed by rapid burning of detonation products with the surrounding air a in deflagration regime close to the detonation. The initial detonation disperses detonations products and unreacted fuel into the air where detonation products, the fuel and the ambient oxygen continue to burn. The reactions of detonation products reinforce the pressure wave from the initial detonation and create a long-lasting moderate wave that will travel down streets and corridors and around corners.

This technology has been implemented in Russian munitions for around two decades. Some Western countries are also in the process of acquiring this technology.

The original TBX was a mixture of magnesium powder and isopropyl nitrate (IPN) surrounding a conventional explosive charge. Later aluminium powder has replaced the magnesium and liquids like nitramine, ammonium nitrate, ammonium chlorate or ethyl nitrate have been applied.

The effect TBX may give a pressure pulse which is twice as high and with a longer duration than that of TNT. In addition, an extensive flame zone with around 0.7 s duration is also created.

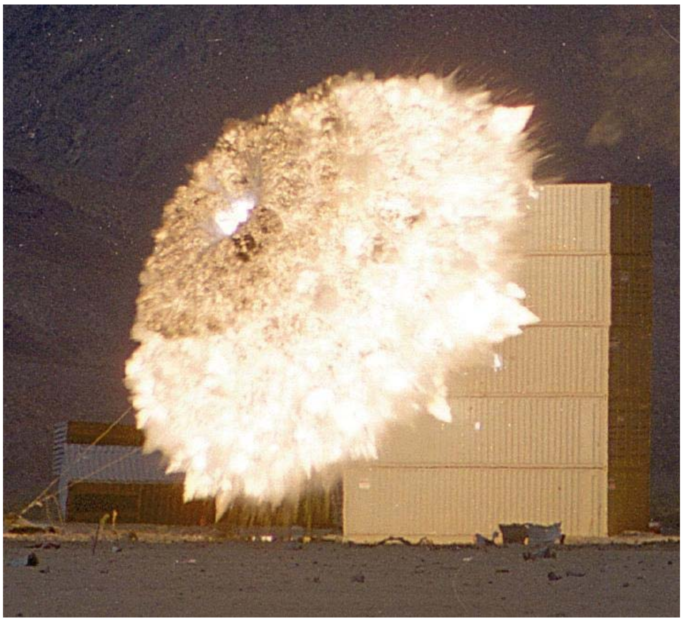

Figure 7.2 Explosion of a thermobaric charge [18]

7.3 Submunition payload

Submunition payloads are also known as cargo payload and even as cluster warhead. The first type of submunition was probably mines, either of the anti-personnel or the anti-tank type. Later many other type have been deployed including

- explosive and fragmenting bomblets (ICM – Improved Conventional Munition)
- explosive and fragmenting bomblets with a shaped charge (DPICM – Dual Purpose Improved Conventional Munition)
- incendiary bomblets
- subunits generating electromagnetic noise (ECM – Electronic Countermeasure)
- anti-tank mines
- anti-personnel mines
- advanced anti-armour submunitions

Submunitions are normally ejected from the carrier at a certain altitude, ensuring an adequate dispersion of the bomblets without compromising the precision of the delivery. In some systems, the time of ejection is controlled by the fire control system specifying or actively setting the timing of the fuze. In some occasions it may be useful to override this setting in order to minimize the dispersion or to reach targets situated behind high crests. An automated fuze setting set by the fire control system can easily be circumvented by specifying a false target altitude.

The maximum spread of the submunition is mainly determined by the mass and, to some extent, the size of the submunition units. If the expulsion takes place at an altitude that ensures that the submunition reaches the natural free fall velocity, the impact velocity will also be determined by the mass and size of the submunition. Expulsion at an altitude exceeding the optimum height is pointless as it will just marginally increase the dispersion of the submunition, but decrease the accuracy of the bombardment.

The table below shows some examples of typical ballistic properties of common submunition units.

Sub-munition	**Carrier**	**Type**	**Mass (kg)**	**Cross-section (cm^2)**	**Expulsion height (m)**	**Free-fall velocity (m/s)**
M77	MLRS/M26	DPICM	0.23	14	~500	40
KB-1	M67 Orkan	DPICM	0.25	14	~500	(40)
9N235	Smerch	AP	1.9	33	n/a	(70)
SPBE	Smerch	SFW	15.6			30
M74	ATACMS	AP	0.59	270	~1000	50
PTM-3	Uragan	AT	4.9	1750		70

Table 7.1 Ballistic properties of some typical submunition rocket systems

The Russian SPBE submunition is a Sensor Fuzed Warhead that is designed to engage targets that have characteristics associated with armoured vehicles. The sensors are a suite of radiometry, radar, infrared at different wave-lengths, and laser. Usually two or three of these are found in a warhead. The submunition are expelled at high altitude, say 1000 m, and is decelerated by different devices before it enters the search phase 200 – 300 meters above ground. Its shape ensures that the movement of the warhead is nutative[7] so that it scans the ground along an inward spiralling track. When a possible target is found the warheads ejects at solid projectile weighing around 1 kg and with a speed of around 2000 m/s against the top of the target. Against an armoured vehicle a hit should implicate 20 – 50% probability of a kill.

This kind of submunitions is in development for different types of ammunition for artillery and bombs. However, Russia is so far the only nation that has applied this technology in rocket artillery munition. There were plans to develop a MLRS projectile with this submunition, but these plans seems to have been put aside.

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[7] A *nutation* is a movement where the axis of rotation deviates from the natural axis of the object. In the present case this deviation is around 30º.

Figure 7.3 The search mode of a Sensor Fuzed Warhead

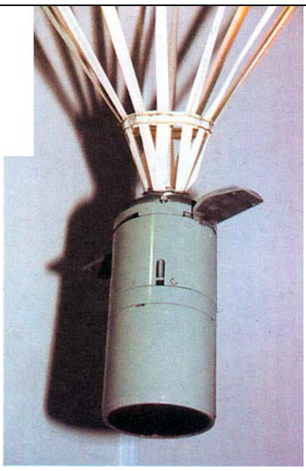
 M77	 KB-1	 SFW
 M74	 PTM-3	 9N235

Figure 7.4 Some submunitions in rocket artillery payloads

The performance for submunitions are described in [19].

7.4 Incendiary payload

Some warheads may have the ability to burn and to create fire as its primary effect. It is well known that white phosphorus (WP) has this ability in addition to creating smoke screens. Other materials with incendiary effect are thermite (aluminium power mixed with iron oxide), and magnesium powder. Liquid hydrocarbons can also be used.

FAE and TBX warhead are sometimes called incendiary warheads, which may be somewhat inaccurate. As indicated above, those warheads should rather be called explosive.

Incendiary warheads are not very widespread as rocket artillery ammunition, but incendiary bomblets have been used in cluster munitions in combination with explosive bomblets.

7.5 Chemical payloads

It is well known that U S Army acquired large amounts of chemical rockets for their 115 mm M91 towed launcher in the 1950s and 1960s. It is probable that such developments also took place in other nations. The rocket was called M55. It was never used in combat and was declared obsolete in 1981. It could carry 4 – 5 kg of either GB (Sarin) or VX agent. Both are nerve gases. [20]

In 1998, U N inspectors found 122 mm rockets with nerve gas in Iraq. It is probable that such ammunition was used during the attack on the Kurdish village of Halabja in 1988 killing more than 5000 civilians. [21]

8 Lethal effects

8.1 Lethal area

Quantifying the effect of warhead is quite complicated. Apart from the effect of being directly hit by the warhead, the effects at distance are the following three:

- *Blast effects* may be the easiest effect to quantify, as the pressure and impulse from an explosion is a function of the charge size and distance. Other factors are of secondary importance.
- *Fragment effects* are more complicated. Firstly it is a problem to assess the initial state of the fragments, i.e. their initial velocity, their weight distribution and their shape. Secondly, the aerodynamic performance is not known with certainty. Thirdly, there is some uncertainty about the effect fragments have when entering a human body. Finally, the exposed area and the posture of the human body are to some extent random.
- *Incendiary effects* are also complicated to describe. They will depend on environment, the victim’s clothing, and incendiary components. The short term effect may be benign and vague, while the long term effect could be fatal. Compared to the previous effects, this is of lesser importance and will not be discussed further herein.

Whatever the effect is, it can be quantified by a two-dimensional function *p(x,y)* which is the probability of being affected by the weapon when the position of the target is given by the ground coordinates *(x,y)*. The position of the bomblet can be set as origin *(0,0)*, although it is not a necessary premise.

When this injury probability function has been established, the effect of the munition can be stated as a single quantity called lethal area. However, the term *lethal* may sound more dramatic than it is. In military context this means *incapacitation* which may not necessarily imply lethality. This term is defined as

$$A_L = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p(x,y)dx,dy$$

The interpretation of the lethal area in practical terms is the size of the area that is completely affected by the warhead. In military terms, if the number of targets per area is known to be σ, then the number of targets destroyed by the warhead is found as:

$$N = A_L \sigma$$

Example: A 155 mm artillery shell is known to have a lethal area of around 800 m^2 against unprotected soldiers in an upright posture. The density of such soldiers in a target area is assumed to be 20 soldiers per hectare, or 0.002 soldiers per square meter. The number of soldiers incapacitated by this warhead will then be 800 m2 x 0.002 soldiers/m^2 = 1.6 soldiers.

When trying to estimate the probability of being incapacitated when being a distance *x* from the detonation, then the following expression can be used when the lethal area A_L is known.

$$P(x) = \exp\left(-\frac{\pi x^2}{A_L}\right)$$

Example: Returning to the previous example with a lethal area of 800 m$^{2;\ t}$he probability of being incapacitated at 3 m distance will be 97%, at 10 m it will be 68%, at 20 m 21%, and at 40 m 0.01%.

When multiple warheads are spread out over a footprint area A_F, there will be more or less overlap between lethal areas originating from different warheads or bomblets. As there is no need to kill a target more than once, the total lethal area will become less than the sum over individual areas. The expression for the cumulative lethal area of a cluster bomb containing *N* bomblets with individual lethal areas A_L each then becomes:

$$A_{L,total} = A_F\left[1-\exp\left(-\frac{NA_L}{A_F}\right)\right]$$

This formula presupposes that the bomblets are uniformly distributed over the footprint; if not the total lethal area will be even more diminished.

Of course, these approaches can be applied for any warhead against any target, also for quantifying the humanitarian effect of a cluster munition.

8.2 Fragmentation

Fragments usually originate from the casing surrounding the explosive charge of a bomb or a shell. Fragments may come in all sizes and shapes. When the casing has a smooth and even surface, both at the inside and outside, the casing will splinter by so-called natural fragmentation. The fragments will then usually get quite irregular shapes, and cover a wide variety of sizes. A typical shape is the elongated one as in the left figure below, but any shape is possible. Prefragmented ones have a more regular shape as shown in the right picture

Figure 8.1 Examples of fragments. Left – a natural fragment, right – prefragmented fragments[17]

Prefragmentation is made by having grooves or scores on the inside or outside of the shells. The casing is split up preferably along these grooves. Alternatively, spherical particles of a hard or heavy metal can be embedded in a matrix of a softer or lighter material. The spheres will then be the main injuring mechanism. Heavy spherical fragments will also have a far longer range than light or irregularly shaped fragments.

The effect of fragments on humans is determined by their mass and velocity and to a lesser extent by their size and shape.

The initial velocity of the fragments is given by the so called Gurney’s equation

$$v_0 = \frac{\sqrt{2E}}{\sqrt{\frac{M}{C}+k}},$$

where v_0 is the initial velocity. M is the mass of the fragmenting material. C is the mass of the explosive. E is the energy content per mass of the explosive. k is a shape factor of the charge. Its value is 0.5 for a cylindrical charge and 0.6 for a spherical charge. The numerator, $\sqrt{2E}$, the Gurney velocity, is found in table 6.1. These values are valid for ideal charges (i.e. perfectly spherical or cylindrical). In reality there will be deviations from these values due to variations in the casing thickness and radius, and due to other non-ideal shapes. However the Gurney equation may serve as a good estimate of the maximum speed of the fragments. Initial fragment velocities are usually between 800 and 2000 m/s.

All fragments, ejected from a certain part of the warhead, get the same initial velocity, independent of the size. The velocity of small fragments will subsequently decrease far more rapidly than larger fragments. This fact can most easily be illustrated by the so called *half-distance* defined as the distance over which the velocity of the fragment will be halved. As an example, consider a fragment with initial velocity of 1200 m/s and a half-distance of 30 m. After a travel of 30 m the velocity will be 600 m/s, after 60 m it will be 300 m/s, after 90 m it will be 150 m/s and so on. Actual values of the half-distances are shown in the Table 8.1 below. As most shells eject either natural shaped fragments or spherical fragments, and accounting for the difference in air drag for these two shapes, the table below addresses both these shapes.

Fragment mass	**Natural shape (steel)**	**Spherical shape (steel)**	**Spherical shape (tungsten)**
10 mg	4 m	8 m	14 m
100 mg	8 m	17 m	30 m
1g	20 m	40 m	70 m
10 g	40 m	80 m	150 m
100 g	**80 m**	**170 m**	**320 m**

Table 8.1 Performance of fragments in air in terms in distances travelled to reach 50% of their initial velocity

The direction of the ejected fragments is exclusively determined by the geometry of the charge. In most cases the direction of the fragments will be close to the normal[8] to the surface of the fragmenting body. When the detonation wave sweeps along the inner surface of the body, the direction will be slightly diverted along the direction of propagation. This deviation is, however, usually less than 10°[22].

Many warheads have a predefined fragment mass of 0.1 to 0.2 grams. This is considered the optimum fragment size if the main purpose is to defeat unprotected soft targets [23]. The optimum size is a compromise between having a few massive, long ranging fragments, or a high number of small and short-ranged ones.

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[8] At right angle to the surface.

The effective direction of ejection is of course also dependent upon the velocity of descent which is added vectorially to the ordinary ejection velocity. A fall velocity of several hundred meters per second will divert the fragments into a more forward facing trajectory that may affect the performance of the ammunition.

Another factor that is very dependent on distance is the hit probability. Let us consider a case where a shell detonates ejecting N fragments. Disregarding the velocity loss and the curved trajectory of fragments, the probability that a person will be hit by any of these fragments can be found by the following formula

$$P = 1 - \exp\left(-\frac{NA}{4\pi r^2}\right)$$

where A is the body area exposed to the charge and r is the distance from the shell. The formula presupposes that N is a large number. Figure 8.2 shows how the hit probability decreases with distance for a typical case of a shell ejecting 1000 fragments. The exposed area of the person is set to 0.5 m^2, which is a typical value for an adult person. The figure also shows that at 200 m distance the probability of being hit is quite marginal.

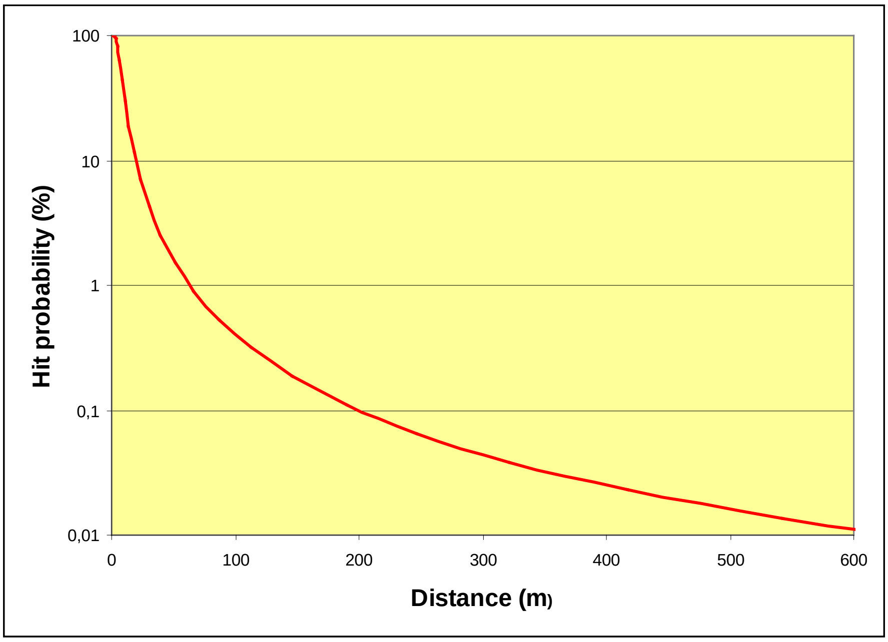

Figure 8.2. Hit probability as a function of distance to a shell ejecting 1000 fragments.

The fragment's capacity for perforation of armour plates is shown in the following Figure 8.3. It shows the velocity required to perforate armour steel plates of 1 mm and 3 mm thicknesses. When these data are combined with the deceleration of fragments in air it can be shown that the ability of fragments to perforate armour is very limited.

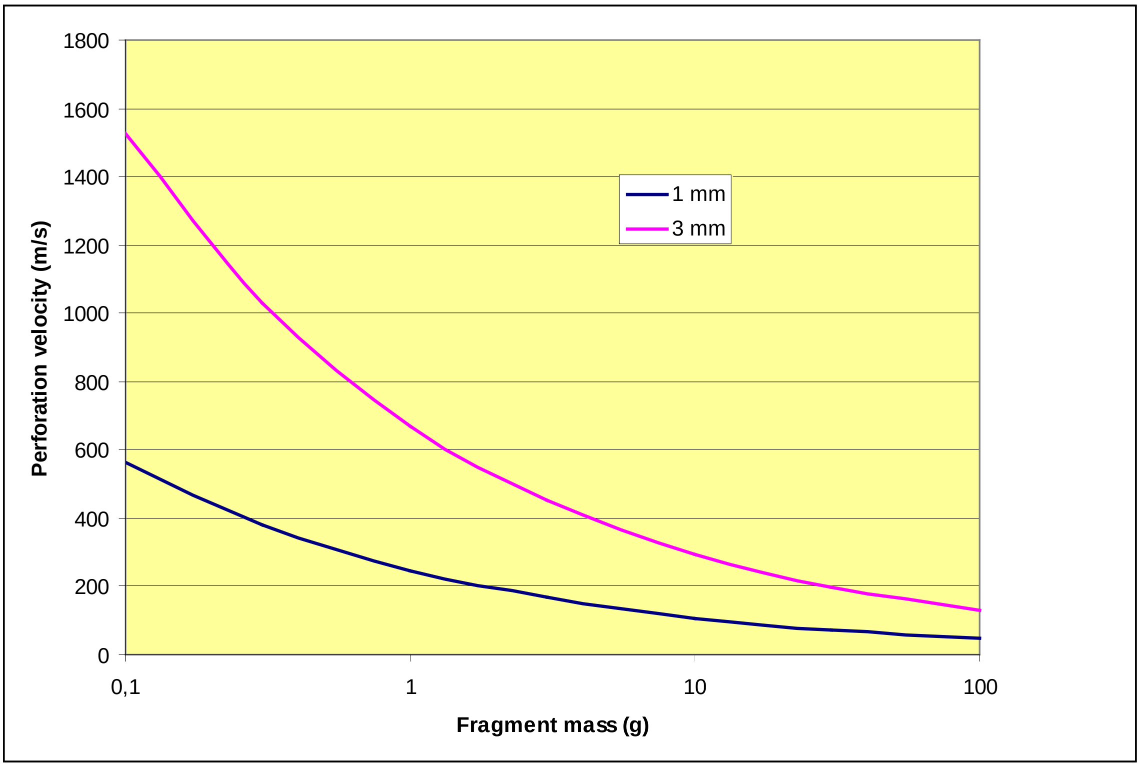

Figure 8.3 Armour perforation capacity of naturally shaped fragments

8.3 Blast

The blast effect of warheads is believed to be the most important effect when suppression of enemy fire is the purpose of the fire mission.

Table 8.2 below shows the basic characteristics of the most common military explosives.

	Density (kg/m^3)	Detonation velocity (m/s)	Detonation pressure (MPa)	Gurney velocity* (m/s)	TNT equivalent factor
Comp B	1742	7920	29.5	2350	1.15
HMX	1903	9110	39.0	2970	1.26
Octol	1843	8480	34.2	2830	1.23
RDX	1806	8700	33.8	2451	1.19
TNT	1654	6930	21.0	2097	1.00

Table 8.2 Properties of some common explosives
** see section 8.2*

The blast effect from an explosive detonation is characterized by a shock wave that propagates outwards from the detonation point. The speed of propagation is initially very high and supersonic (several km/s). Depending on the size of the charge, the speed eventually drops to the sonic level, and the wave becomes an ordinary pressure wave.

The quantitative characteristics of a shock wave are its *peak pressure* and its *duration*. The general shape of the shock wave is shown in Figure 8.4 below. Here the duration is the length of the initial positive part of the pressure.

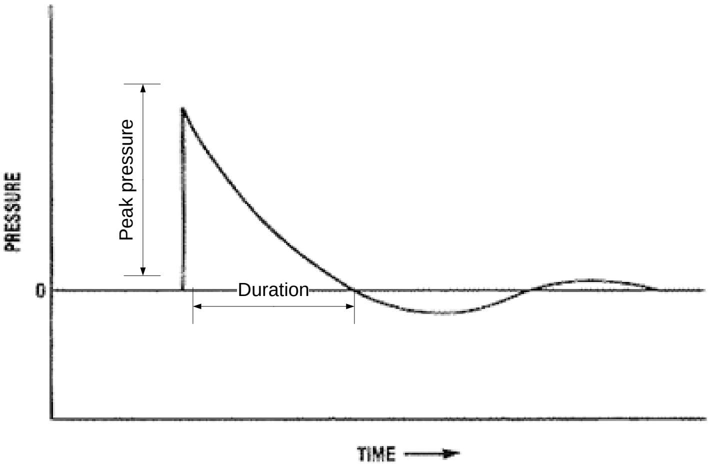

Figure 8.4 A shock wave profile showing peak pressure and duration.

The peak pressure is the height of the discontinuous front, while the duration is the time length of the positive phase. These two parameters, which we may call p and t respectively, are both scaled according to the size of the charge. The principle behind scaling is shown in Figure 8.5 below where κ is the geometric one-dimensional scaling factor of the charge.

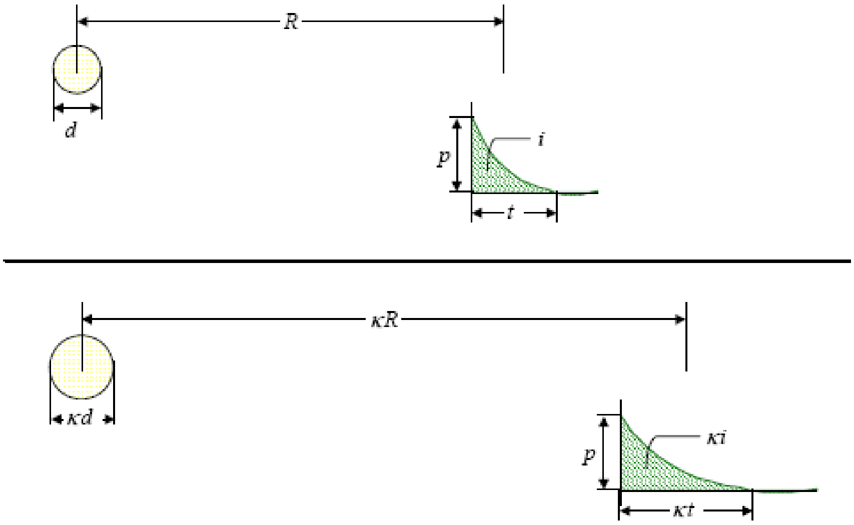

Figure 8.5 Scaling of blast wave effects

The essence of the scaling is that the distance and duration both scale with the charge size, while the peak pressure remains constant at scaled distances. This also implies that the impulse in the shock wave scales with the charge size.

An encased charge will have a somewhat reduced pressure compared to a bare charge. If the casing has a weight twice the weight of the explosive, the pressure will be reduced by more than 50%. We can define an effective explosive mass C' which is less than the actual mass explosive C. The formula to be used here is

$$C' = \left(0.2 + \frac{0.8}{1 + M / C}\right) C$$

where *M* is the mass of the casing.[9] *C'* is then the effective explosive mass generating the blast wave.

8.4 Examples of performance

Some of the effects described above may be hard to compare, especially against complex or composite targets. In order to exemplify the performance the human body may be easiest one to use.

As explained in section 8.1, ordinary warheads have a combination of fragment effects and blast effects. The concept of lethal area is the common way to quantify the effect. In an open environment the fragments dominate the damage inflicted on the target. Blast effects are of secondary importance. In closed space environment, the blast effect may be the most effective one. However, as rocket artillery is designed for area targets, which for obvious reasons have to be open space targets, fragments will be the most important effect for most targets. For guided systems, which may have a point target role, blast warheads may be viable. The following tables give typical values for lethal areas for some typical systems.

System	Explosive mass (kg)	Lethal area (m^2) (point fuze)	Lethal area (m^2) (proximity fuze)
107 mm spun	1.3	450	550
122 mm finned	6.4	700	850
160 mm finned	9	1050	1200
220 mm finned	52	1700	1950
240 mm spun	42	1500	1700
300 mm finned	75	2400	2600
333 mm spun	60	2400	2700
610 mm finned	~200	5300	5600

Table 8.3 Typical performance data for some high explosive rocket warheads

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[9] Putting a casing around the explosive will have the same effect as downscaling the dimensions of the explosive by a factor equal to the third root of the expression inside the parentheses.

System	**Number of bomblets**	**Dispersion area (ha)**	**Bomblet type**	**Bomblet lethal area (m^2)**	**Total lethal area (m^2)**
122 mm	39	(1.5)	MZD-2	17	650
160 mm	104	3.1	M85	41	3500
227 mm	644	4.0	M77	19	10200
300 mm	646	(2.5)	KOBE	20	10500
610 mm	980	(4.0)	M74	30	25000

Table 8.4 Typical performance data for rocket delivered cluster munition warhead. Numbers in parentheses are assumptive.

8.5 Comparisons between conventional artillery, rocket artillery and mortars

The following graphs briefly show some comparisons in terms of ammunition weight, range and accuracy for some selected but typical systems. For the purpose of comparison, mortars and conventional howitzers are also included. Furthermore, we have also distinguished between fin stabilized and spin stabilized systems, as the latter category has used in light rocket systems, but is also inferior in terms of range.

Figure 8.6 shows the relations between calibre and range of the systems. The most noticeable feature is that guns, mortars and spin stabilized rockets all have limited range. Especially for guns and mortars, it may be claimed that they have reached their limit in terms of range. This limit is determined mechanical and propulsive constraints. For rockets, and especially for fin stabilized rockets, such a limit hardly exists, as the graph could have extended to include strategic and intercontinental systems.

Guns and fin stabilized rockets roughly increase their range in proportion to the calibre. Spin stabilized have, as mentioned earlier, an aerodynamic limitation as it is very difficult to spin-stabilize long slender bodies. Thus spin stabilized rocket have to keep a rather small length to diameter ratio. This factor subsequently limits the payload to fuel ratio.

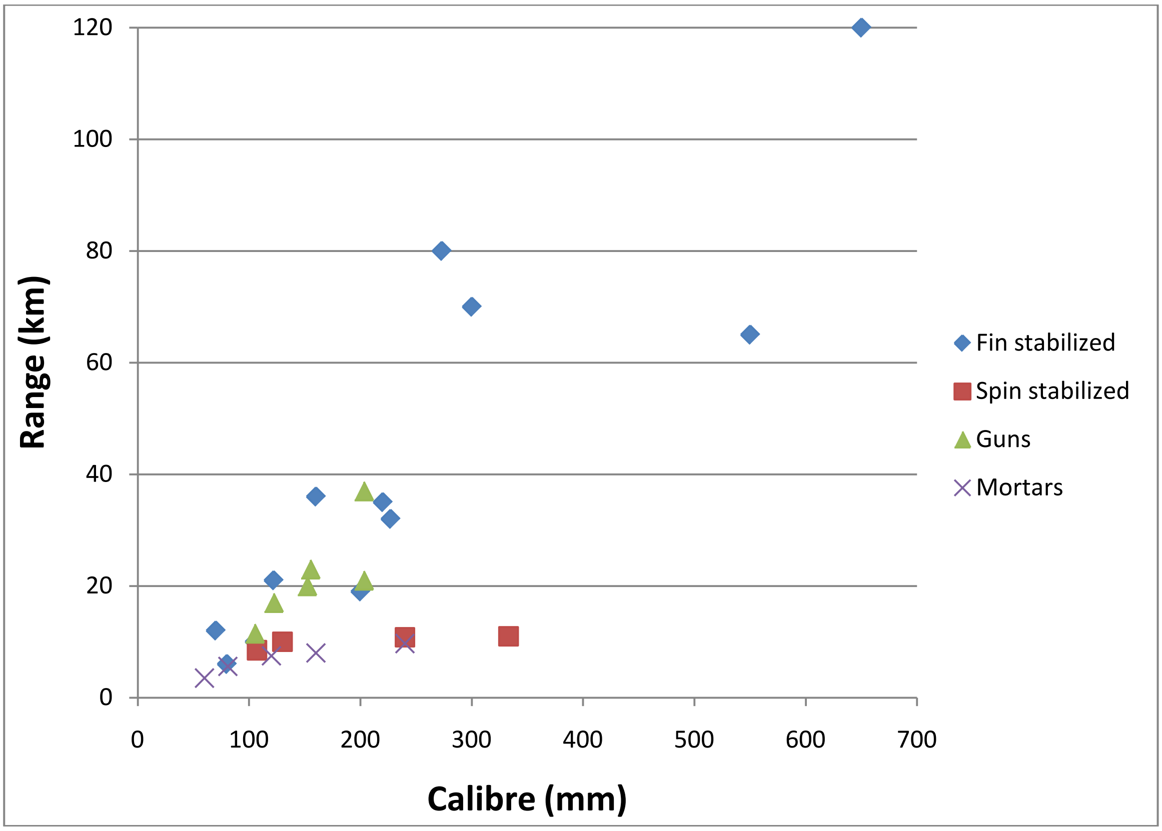

Figure 8.6 Maximum range as a function of the calibre. A few extremely long range systems are not included here.

Figure 8.7 shows the same systems as shown in figure 8.6, but here the system weight as a function of calibre is plotted. The categorization of systems is the same as in figure 8.6. As the figure shows, there is no strong correlation between calibre and system weight for rocket systems. For guns and mortars, this correlation is quite strong, but rocket system may have very different weights due to the number of rockets carried by the vehicle. Some systems have a single rocket, while others may have 40 rockets ready to fire.

No rockets system seems to have a system weight exceeding 45 tons. This limit is due to mobility. A heavier system put a heavy load on roads and bridges and on the strategic mobility by rail.

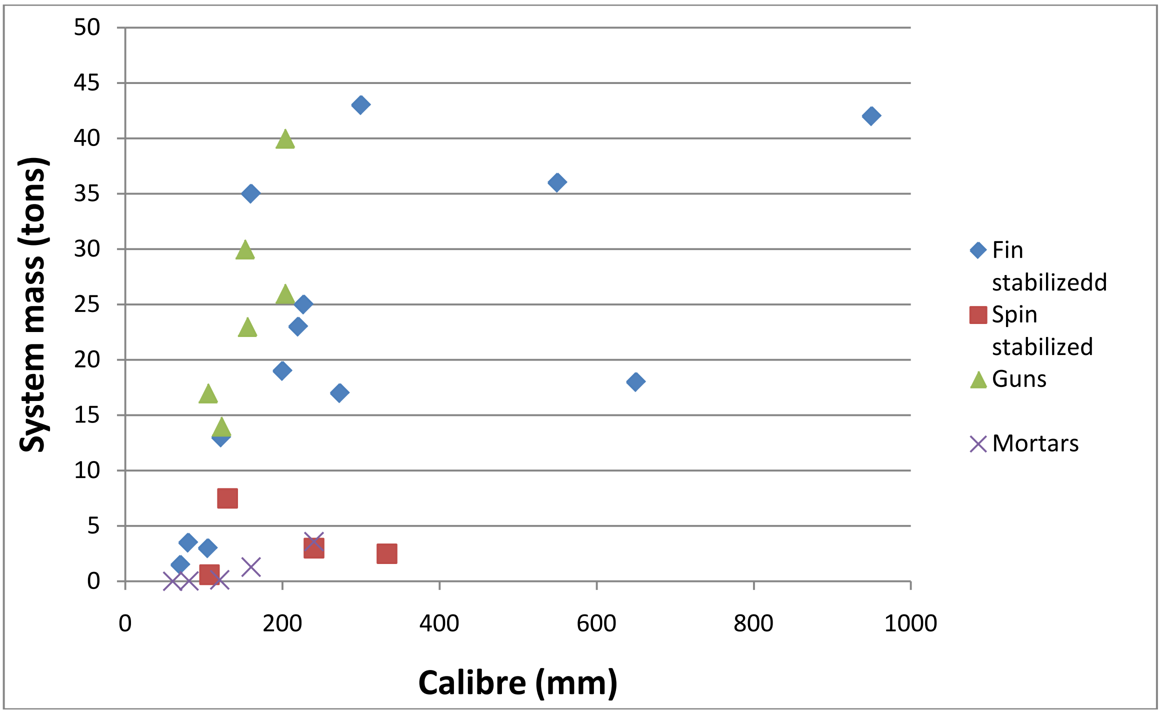

Figure 8.7 System mass as a function of calibre

9 Improvised systems

As mentioned before, rocket artillery is a relatively simple system. Compared to cannons or howitzers, a workable rocket launcher can be made without any strict requirements on strengths or tolerances in the construction. Even the rockets themselves can be made in moderately advanced workshops provided that the requirements for firing accuracy are relaxed.

Building and firing rockets is an acknowledged and fully legal hobby in many countries. Consequently there is an abundance of literature available on subjects like ignition, propulsion, stabilization and aerodynamic design.

9.1 Explosives

The explosive may be the easiest component to get. In war-ridden areas there is abundant access to Explosive Remnants of War (ERW) from abandoned ammunitions stores, unexploded ordnance (UXOs) and booty. The high explosive content can with acceptable risk be melted and recasted into new charges and warheads.

Secondary explosives can also be home made based on components that may be readily available. Recipes of explosive are available from a wide variety of sources – anarchists, terrorists, hobbyists etc. However, the most authoritative, as well as safest, source may be the technical manual [23] on improvised explosives that was issued by the U S Department of the Army during the Vietnam war. Although dated, it is still an invaluable source on how to make your own explosive out of simple ingredients, and in a relatively safe manner.

One of the most popular high explosives is ANFO which is an abbreviation for the mixture of ammonium nitrate and fuel oil. Ammonium nitrate is an ordinary fertilizer which is available in most countries while the oil can be regular diesel fuel. However, ANFO may be hard to bring to detonation and requires a small lump of TNT or another high explosive to react with high order.

Primary explosives are in general more difficult and risky to make, but the technical manual mentioned above also provides recipes for that. Primary explosives are only needed in small quantities, and they can also be acquired by disassembling left-behind fuzes.

9.2 Propellants

Unlike most high explosives, rocket propellants contain curing compounds and can not be melted out of abandoned ammunition and reused in other systems.

The Qassam rockets manufactured by the Hamas at the Gaza strip are made with TNT high explosive warheads and a propellant made of fertilizer, potassium nitrate (KNO_3) and cane sugar. Depending on the quality of ingredients and of the mixing and curing process, such propellants can reach a specific impulse (see chapter 6.1) of 90 – 120 s. This is approximately half of what is achieved by ordinary propellant. Still it is adequate for producing workable rockets.

Sugar syrup propellant

100g KNO_3, finely powdered
40g cane sugar
30g corn syrup

The KNO_3 is placed in a pan and heated to 200 degrees in a conventional oven. This is to keep it from cooling down the sugar syrup too much when it is added.
Warm KNO_3 mixes in easier and allows a longer working time.

Sugar and corn syrup are placed in a 1-quart Pyrex measuring pitcher, mixed together, and heated in a microwave oven on "high" until the liquid is perfectly clear.

Heavy shirt, face mask, and gloves are used to make the body more flame-resistant, just in case.

Sugar syrup is stirred to eliminate any "hot spots." Then the KNO_3 added, and everything is stirred vigorously with a wooden spoon. Whilst stirring, mouth of glass container is pointed away from face and other things of importance, just in case.

Upon cooling, this propellant tends to be somewhat crumbly and more brittle than recrystallized propellant. Heating to 200 degrees F does not soften it like recrystallized. But heating to 250 to 270 degrees brings it to a near-liquid state, at which point it can be stirred and then kneaded as it cools a bit.

Figure 9.1 One of many recipes found on the Internet on how to make your own rocket propellant. (Plain copy of the text) [24]

It should also be noticed that if potassium nitrate is in scarcity, it can be made by heat treating wood ash with alcohol. This recipe, and other recipes are documented in the U S Army Technical Manual on improvised munition.[25]

Figure 9.2 Improvised rocket fuel being poured into a plastic casting container to cool and cure. The container is then cut away and the casting is placed inside the rocket. [26]

9.3 Fuzes

The fuzes of an improvised rocket do not have to be very sophisticated. A simple device consisting of a firing pin aligned with a detonator can be made quite easily. The firing pin is forced into the detonator at impact and the only safety precaution could consist of a safety pin (e.g. like that on a hand grenade) that is withdrawn just before launch. The firing pin can be merely restrained by a helical spring that resists the acceleration during launch and boost, but not the forces imparted at impact with the ground.

9.4 Rocket bodies

The main challenge of making a rocket may be the strength of the motor casing including the nozzle and the nozzle-tube interface.

While the grain is burning the pressure inside the motor may be as high as 10 MPa (100 atm.). To make a 120 mm tube able to withstand this pressure, a wall thickness of 6 mm is adequate if aluminium is used and 4 mm if steel is used. If high strength alloys are used the thickness can be reduced further

9.5 Launchers

An improvised launcher does not have to be very sophisticated. A simple gutter or tube supported by a bipod or tripod will be sufficient provided that it is heavy and rigid enough to be stable during launch. The rigidity or stability is crucial for the accuracy of the firing. However, for systems not intended for precision firing, this is not an issue.

9.6 Fire control system

In order to obtain a reasonable accuracy of an improvised system, some kind of fire control input data (FCI) has to be in place. However, such a system requires extensive testing and monitoring of a high number of rockets to give reliable data. Such data will mainly consist of aerodynamic data and motor performance data at different ambient temperature. The absence of such data will seriously affect the accuracy of the weapon. In addition, geographical and meteorological inputs are also a requirement for an FCI.

However, when firing small or medium sized rockets onto an extended area in a terror mode, a rigid FCI may not be required. When firing a rocket at some kilometres distance into a large urban area, the probability that the rocket will hit something, or at least create the desired havoc, will be quite large.

9.7 The Qassam rockets

The Hamas organization, which currently governs the Gaza strip, has an inventory of rocket artillery that partially belongs to the term *improvised*. Hamas has some rockets produced in China (PRC), but they also produce a suite of home made rockets called Qassam (or Kassam) which has been in service since 2001 and which are frequently launched into Israel.

The first version of Qassam was rather primitive, reaching approximately just 3 km. By 2007 the range of the same size rocket had increased to 10 km. Due to the improvised nature of the production, it is hard to exactly quantify the parameters of the rockets. Current sources mostly operate with three sizes (classes) of Qassam rockets as given in the table below. [27]

	Qassam I	**Qassam II**	**Qassam III**
Diameter	60 mm	150 mm	170 mm
Weight	5.5 kg	32 kg	90 kg
Length	79 cm	180 cm	> 200 cm
Range	3 km	8 -10 km	10 km
Explosive payload	0.5 kg	5 - 7 kg	10 kg

Table 9.1 Basic properties of Qassam rockets

There is also supposed to be a recently developed Qassam IV rocket capable of reaching 15 – 17 km.

Figure 9.3 Preparations for firing Qassam II rockets

Some of the warheads on the Qassam rockets seem to be mortar bombs that are fixed to the extension

9.8 IRAM

IRAM has become the acronym for Improvised Rocket Assisted Munition. As the name indicates the clue is here to adapt any ammunition for which the proper launching platform is unavailable onto the front of a rocket. Thereby the original potential of the munition is regained although not with the same precision of delivery. The warhead will then be of high standard while the rocket may be of inferior quality. This method became popular with IRA in Northern Ireland in the 1980. In 2008 it was also seen among the Mahdi Army in Iraq. [28]

The munition that is most easily adapted to this kind of improvisation is, above all, mortar munitions, but small calibre artillery, rocket propelled grenades and hand grenades could also be candidates. The rocket propelled grenades RPG-7 is very widespread, but this warhead will not function in this role unless its self-destruct function is disabled. Otherwise, the warhead will self-destruct after 3 – 4 seconds of flight..

Vehicle Overview

WIRES RUN FROM THE IRAM ROCKET MOTOR SECTION TO A INITIATION PACKAGE NEXT TO THE DRIVERS' SEAT

NUMBERED "1" THROUGH "7"

7 Dual Rocket Arrays Numbered Launchers; Total of 14 Launchers

Team concluded that Special Group criminals utilized 14 IRAMs, fired from a cargo truck, with 14 improvised rocket tubes setup in the bed with remote initiation to attack FOB Loyalty on April 28.

Figure 9.4 Wreckage from Iraq containing launchers for IRAM

An IRAM can also be made with improvised warhead. In Iraq big propane tanks have been used for this purpose. These are heavy warheads for which the range with rockets will be limited. They can be characterized more like remotely launched IEDs.

9.9 Other examples

Only fantasy may limit the possibility of making improvised rocket artillery, as the following two pictures show

Figure 9.5 Young Hezbollah soldiers manning an improvised vehicle intended for both indirect and direct rocket fire. The type of indirect rocket is not identified. http://community.livejournal.com/shushpanzer_ru/?skip=20&tag=2007

Figure 9.6 A small truck discovered in the Basrah area in Iraq displaying built-in rocket launching tubes in the floor of the platform. It is supposed that this unit is able to fire 122 mm BM-21 rockets. [29]

Another special example is shown below where a primitive rack, a piece of sheet metal and a car jack are put together to make a launcher for a 107 mm spin stabilized rocket.

Figure 9.7 Improvised launcher for 107 mm rocket [Colin King]

Launchers can be made with even less sophistication than this. The next picture shows a “battery” of 107 mm launcher pads that is simply dug out in the soil. The accuracy of such a system will, of course, be terrible, but the method may be satisfactory if the target is a larger area a few kilometres away. In this particular case, the target was a US regional depot south of Mosul, Iraq.

107 mm spin stabilized rockets are, despite their limited range, very popular for improvised systems. The rocket is light (less than 20 kg), but with a powerful warhead. It is very robust, as it can be handled very roughly without losing performance. It can easily be carried by one man and is easy to hide. Moreover, spin stabilized rockets are less in need of accurate and sophisticated launchers than fin stabilized rockets. As we have seen, finned rockets also have to spin, although slowly, in order to compensate for some inherent inaccuracies. They have to draw their spin from the launcher, which put certain requirements on the launcher. Spin stabilized rockets draw their spin from themselves and are thus in less need for launcher quality.

Figure 9.8   107 mm rocket with extremely simple launch pads[20]

The picture below shows a rocket with an apparently 122 mm nozzle section with quite large fins. It is claimed to be a Qassam rocket found in Israel [30]. As this is originally made with wrap-around fins, the picture indicates that this is a incomplete replica of the 122 mm, or a reused motor section on which the original fins have been missing or damaged.

Figure 9.9   Finned and spin stabilized rocket wreck found in Israel.

10 Organization

Rocket artillery is not just the rockets, the launchers, the carrying vehicles and the crewmen. Without a supporting organization the rocket artillery may be of feeble use. The need for ammunition supply is obvious, so is also the supply of fuel, lubricant, water, food and spare parts. However, the most important component may be the collection information on where any potential targets are located. Without such information, artillery will just become a logistic burden without ability to exploit its truly tremendous potential. This fact was bitterly experienced by the Iraqi Army in 2003. The Iraqi inventory of rocket artillery was very impressive, but they were quite unable to locate targets and were just serving as tempting targets for the coalition forces. [31]

Like conventional gun artillery, rocket artillery has both an offensive and defensive role. The ability to engage in counter-battery fire may not be as good as for gun artillery, due to the lack of precision. On the other hand its ability to inflict damage on an extensive target area with a short time is surely impressive. As a consequence of this, multiple rocket forces are considered as a vital part to be organized at a high level, usually at divisional level or higher.

According to OPFOR FM 100-60 [32] the artillery group of the mechanized divisions (DAG – Divisional Artillery Group) has three battalions of 152 mm howitzer and one battalion of 122 mm MRL. The latter has 18 launchers organized in three batteries. In a battery, in addition to the 6 launchers, there are 2 command vehicles, 6 trucks, 5 officers and 56 enlisted men[33].

A battalion of light artillery rockets has the following requirement on manpower and vehicles according [34]:

- 18 launcher vehicles
- 8 command and control vehicles
- 24 close-in defence units
- 41 support trucks
- 8 vans
- 36 trailers
- 16 rangefinders
- 32 GPS receivers
- 28 radios
- 23 officers
- 234 enlisted men [32;33]

The number of men directly dedicated to a launcher is mostly between 3 and 8. The most automated systems require less crew, while towed systems require a lot of manpower.

On the corps or army level there is one artillery brigade of howitzers only and an artillery regiment with either 122 mm or 220 mm organized in three battalions.

300 mm MRL is considered a national asset and will be organized on an army group level in the event of a war. The army group will then contain an artillery division in which there will be an MRL brigade with 4 MRL battalions of either 220 mm or 300 mm. An artillery division may be designated to a particular army as the Army Artillery group (AAG). Each battalion has 3 batteries. The 220 mm has 6 launchers in each battery while 300 mm units have just 4 launchers.

At each level the howitzer seem to outnumber the MRL by 3 to 1.

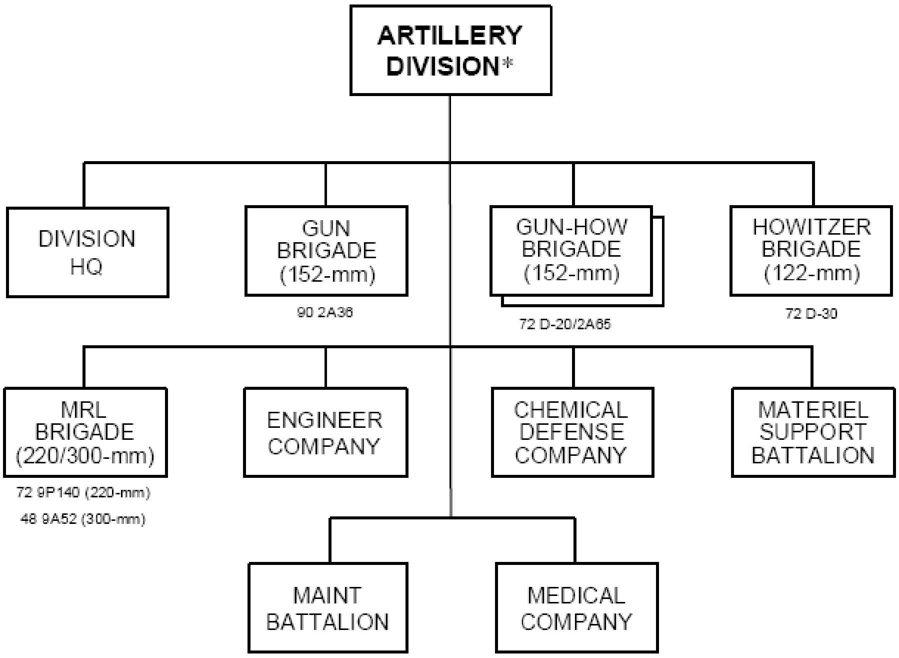

Figure 10.1 Organization of an artillery division [25]

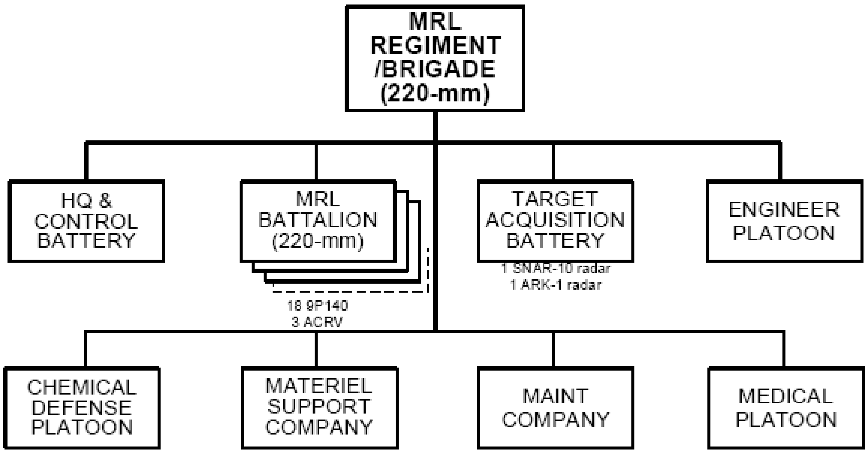

Figure 10.2 Organization of rocket brigade [25]

Rocket battalions have the same manpower requirement as battalions with self-propelled howitzer. As comparison, a towed artillery battalion has around 10% higher manpower demand.

Traditionally, on the battlefield, the launchers were deployed with 15 – 20 m between each in a battery. However, improved FCS and communications leaves an opportunity to extend the separation. Within a battalion, the spacing between the batteries is 1 – 2 km.

The DAG may be located 3 – 6 km behind the forward edge of battle area (FEBA). For the AAG this distance may be increased to 8 km. It is of course paramount to keep this distance as small as possible in order to exploit the range of the systems. [35].

Tactical missiles may be organized on army level as separate SSM brigades with 12 – 24 launchers and a manpower of 1000 – 1500 men.

Considering insurgency forces, and referring to OPFOR 7-100.4 [34], 122 mm MRL may be organized with one battery subordinated to a brigade tactical group and as a part of a composite artillery battalion.

In a smaller insurgent group the single tube launchers may be found in so-called direct action cells together with light mortars and grenade launchers. Such a cell may consist of 13 men with 6 men assigned to the mortar and 6 men assigned to the rocket launcher. The single tube may be either 9P132 122 mm or 107 mm Type 63 or Type 85.

11 Some scenarios

This chapter describes some generic scenarios involving rockets and adapted to the question of defence of military camps. The camp chosen for these scenarios is a camp used in a previous Norwegian study [36]. The camp is dimensioned for a single company and has an internal perimeter of 130 x 170 m^2. It is outlined in the figure below. The blue dotted line is the external perimeter which has a size of around 250 x 210 m^2. The camp is intended to accommodate 154 officers and soldiers plus 14 visitors, interpreters and other external personnel.

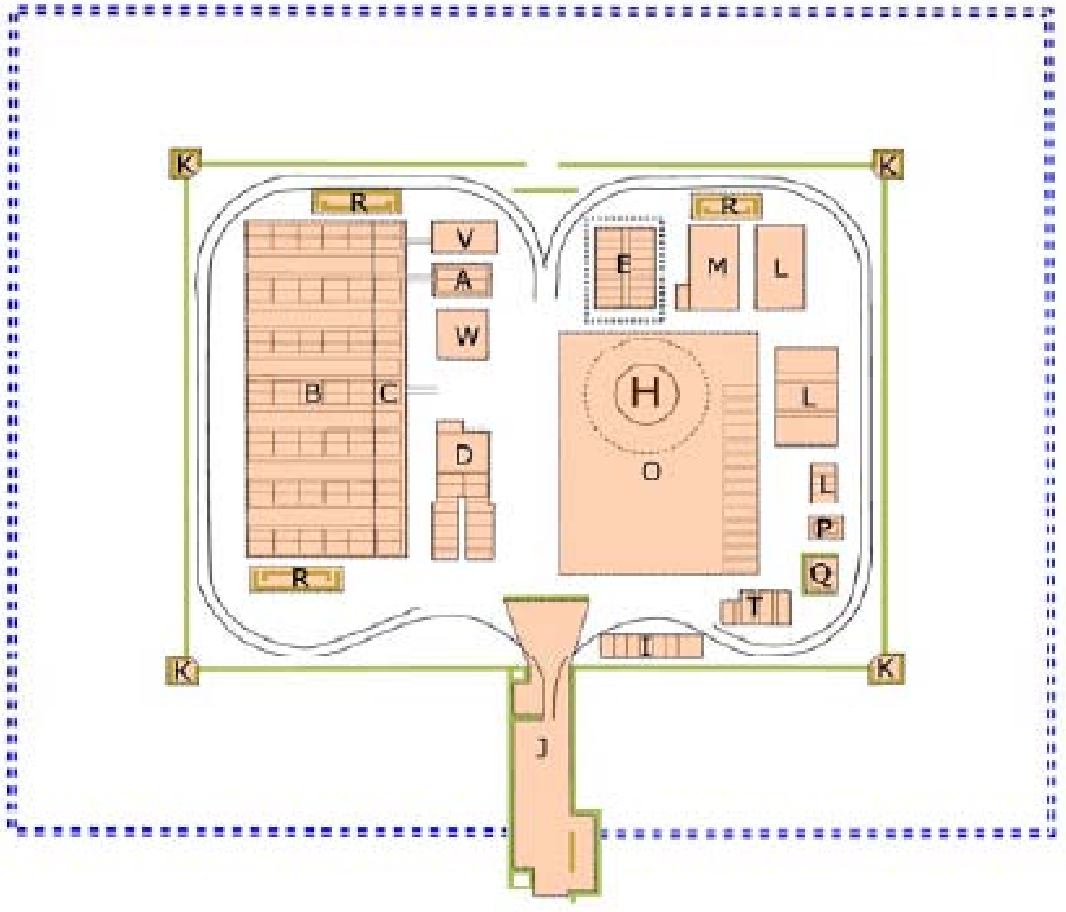

Figure 11.1 Possible layout of a company camp

The following table shows a breakdown of the area used in the camp.

Code	Type	Container area (m^2)	Outdoor area (m^2)
A	VIP accommodation	60	
B	Common accommodation	1125	2000
C	Laundries and wet rooms	310	
D	Kitchen and Cantina	300	
E	Offices	215	
I	Guard	70	
J	Entrance control		600
K	Observation towers	60	
L	Storages	120	500
M	Vehicle maintenance	10	300
O	Outdoor activities / cleaning	210	2400
P	POL site	15	
Q	Weapons and ammo depot	40	
R	Shelter area	150	
T	Power station	75	
V	Sports and fitness area		100
W	Welfare	140	

Table 11.1 Space distributions of the different functions in the camp

The total used area sums up 2900 m^2 of indoor area and 5900 m^2 of dedicated outdoor area out of a total area of 22900 m^2 inside the inner perimeter including the entrance control area

Scenario 1 Light fire – one BM-21 launcher stationed at a distance of 15 km from the camp and firing HE munition.	The launcher contains 40 rockets each having a fragmenting warhead of 18 kg. Anticipated lethal area is 400 m^2 against unprotected standing personal. All 40 rockets are fired within a period of just 20 seconds. The flight time is 39 s. The firing is supposed to take place during calm and stable weather conditions. The mean point of impact deviates just 50 m from the target centre. The salvo dispersion has a standard deviation of 90 m both along and across the line of fire. The rockets impact at a speed of around 300 m/s and at an angle with the ground close to 35 deg.
Scenario 2 Cluster fire – a group of 6 9P132 single tube launchers at 6 km range firing ammunition each containing 39 MZD-2 DPICM munition. Each launcher will fire three rockets each.	Due to reloading the fire will be distributed over 2 – 3 minutes, with a steadily decreasing intensity. However the first volley of 6 rockets may come quite simultaneously. The rockets will eject in total 702 bomblets. Of these around 300 will hit inside the outer perimeter and will be quite evenly distributed inside this area. The rockets eject their cargo at an altitude of 500 m. The bomblets hit the ground after 8 – 10 seconds. Around 40 bomblets are expected to remain on the ground as UXOs.
Scenario 3 Heavy fire – a battery of 6 Falaq-1 launcher units firing at 5 km range with HE munition.	Each launcher vehicle has 6 rockets ready to fire. All 36 rockets are fired within a period of 15 seconds. All rockets will probably hit inside the perimeter, around 10 rockets will fall inside the inner perimeter. They arrive with a speed of 250 m/s and at an angle of fall of 15°. Each rocket carries around 20 kg of high explosives and has a lethal area of around 1400 m^2.
Scenario 4 Close fire – a group with 2 12-tube 107 mm launchers firing at 1.5 km range using HE munition.	The 24 rockets arrive with a speed of 350 m/s and with a low trajectory attitude of 8 – 10°. The salvo arrives within a period of 15 seconds. Almost all rockets will fall inside the perimeter.

12 The future of rocket artillery

The intention of this report has been to describe all aspects of rocket artillery technology and especially those related to their use against permanent camps in order to understand the problems of defending the camps against this threat.

The advantage of rocket artillery is its ability to deliver a massive firepower at long range with a relatively simple technology, as long as no guidance devices are applied. Its main drawbacks are, however, its lack of precision, and its inability to engage close-in targets by direct fire. The ideal target for this weapon is large areas of unprotected or lightly protected infantry units.

Contemporary rocket artillery is a product of WWII when Soviet forces, after a very hasty development, used this weapon en masse and successfully against large opposing infantry units.

During the Cold War, the concept was retained in the Eastern Bloc which contined to improve its rocket inventory with increasing range. In the west, the development was slow, but made a boost by the development of MLRS during the last two decades of the Cold War. However, the objective was still to defeat large targets at long distance.

Lack of precision made the weapon attractive for deployment of wide-area indiscriminate payloads like cluster munitions. Such munition was also adapted to the role of defeating armoured units. However, the success of this approach was limited as the armour protection of such units improved.

In the post Cold War era, the role of Rocket Artillery has been maintained. In terms of numbers deployed, there is less rocket artillery now than 15 years ago, but this can be seen to follow a general decrease in armed forces worldwide.

Mortars have been considered as the “poor man’s artillery”, albeit with limited firing ranges. Rocket artillery may equally deserve the characterisation of “the poor man’s artillery”. It is a comparatively simple system, has longer ranges and may cover an area exceeding any other system having a comparative degree of sophistication. This assessment is supported by the fact that ever more nations, and mostly third world nations, acquire rocket artillery.

In the recent decade we have seen the use of rocket artillery by non-state parties, especially in the Middle-East and adjacent areas. The target is not primarily large infantry units, but infrastructural node point or simply urban areas. For the latter, the goal is apparently not to hit a specific target but just to hit something in order to inflict havoc and fear. In this role, medium sized, improvised, inaccurate rockets serve the purpose. Unfortunately, rocket artillery is an almost ideal weapon for this purpose and there is reason to believe that the gap between improvised systems and regular systems will close as the skill and experience of the manufacturers and operators improve.

Unguided rocket artillery is probably at the end of its development potential. The main limiting factors of progress are not in technology, but environment. The lack of precision is mainly due to wind and especially the rather unpredictable wind during the boost phase.

Guided artillery rockets should be expected to fill in at ranges where the lack of precision for unguided rockets is a problem. The accuracy of today’s guided rockets is in the area of 10 – 30 m or better. The ability to defeat buildings is probable on the verge of becoming realistic. The ability to gain direct hits at parked vehicles may also soon be available. However, the ability of hitting moving vehicles is not that easy to achieve because of the long and curved trajectory. For that purpose the rockets must carry advanced seeking and guiding devices. In this role, advanced jet-fuelled cruise missiles may be an alternative.

We have during the last 5 years seen large scale use of rocket artillery at least four times

- the Hezbollah – Israeli conflict in Southern Lebanon in 2006
- the Russian – Georgian conflict in 2008
- the continuous use of rockets by Hamas onto Israel, especially until the beginning of 2009
- on the eve of the Sri Lankan civil war in 2009

This relative frequent use demonstrates that rocket artillery is still a capability to be taken seriously. However, rocket artillery was initially designed for large scale conventional war, where the target areas are large and densely populated with individual targets are abundant. After the end of the Cold War such targets have become a rarity.

On the other hand rocket artillery have several properties that are attractive to non-state party forces and insurgency groups:

- the technology is simple, robust, inexpensive and can be made without strict tolerances
- it can be made in primitive workshop
- it can be handled by a poorly educated crew
- it is light and mobile
- there is an easy access to launchers and ammunition in many areas

As long as the requirement on accuracy, consistency and reliability are relaxed, rocket artillery may be the ideal kind of weapon. Such improvised are not the tool for winning a battle, but it well suited to in the role of creating havoc, imposing fear, and thereby terrorizing large areas.

Defence against rocket artillery is a challenge. Locating the launch site and attacking the launch crew have to be made before any rockets are fired. This is a fire-and-forget weapon and the launch site may be abandoned before the rocket hits the target. The only realistic alternative is then to destroy or neutralize the rocket before impact. Although this aspect is beyond the scope of this report, but the aspects of simplicity and robustness, as mentioned above, adds to that problem.

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Appendix A Abbreviations

AAG	Army Artillery Group
AP	Anti-Personnel
AT	Anti-Tank
ATACMS	Army Tactical Missile System
BB	Base-burn (or base-bleed)
BM	Boyevaya Mashina (War Machine)
CBRN	Chemical Biological Radiological Nuclear
CCB	Centre Core Burster
DAG	Divisional Artillery Group
DOF	Degrees Of Freedom
DPICM	Dual Purpose Improved Conventional Munition
ECM	Electromagnetic Countermeasure
EFP	Explosively Formed Projectile
ERW	Explosive Remnants of War
FAE	Fuel-Air Explosive
FEBA	Forward Edge of Battle Area
FCI	Fire Control Input
FCS	Fire Control System
FIROS	Field Rocket System
FROG	Free Rocket Over Ground
HE	High Explosive
HMX	High Melting Explosive
ICM	Improved Conventional Munition
IDF	Israel Defence Force
IED	Improvised Explosive Device
ILL	Illumination
IPN	Isopropyl Nitrate
IRA	Irish Republican Army
IRAM	Improvised Rocket Assisted Munition/Mortars
LAR	Light Artillery Rocket
LARS	Light Artillery Rocket Systems
MPMM	Modified Point Mass Model
MRL	Multiple Rocket Launcher
MLRS	Multiple Launch Rocket System
NASA	National Air and Space Administration
OEF	Operation Enduring Freedom (2001 -)
OIF	Operation Iraqi Freedom (2003 -)
OPFOR	Opposing Force
PMM	Point Mass Model

RAP	Rocket Assisted Projectile (or Propulsion)
RDX	Research Department Explosive
SFW	Sensor Fuzed Warhead
SLUFAE	Surface Launched Unit, Fuel Air Explosive
SRBM	Short Range Ballistic Missile
SSM	Surface-to-Surface Missile
TBX	Thermobaric explosive
TCS	Trajectory Correction System
TGW	Terminally Guided Warhead
TNT	Trinitrotoluene
UXO	UneXploded Ordnance
WAF	Wrap-Around Fins
WHE	WarHead Event

Appendix B Accuracy of long range artillery

B.1 Sources of inaccuracy

- Launcher position
- Target position
- Launcher alignment
- Launch release force
- Launch velocity variation
- Launch tip-off
- Temperature and air pressure
- Aerodynamic errors
- Boost phase wind
- Ballistic phase wind
- Fuze error

B.2 Meteorological models

The most critical meteorological parameter for is the wind. For any system firing at distances beyond 10 – 15 km the wind is the most contributing factor to the overall lack of accuracy. The simplest approach to wind is the so-called Didion's[10] equation then says that

> *the deviation due to sideway wind is equal of the sidewind velocity multiplied with the time loss caused by axial air drag*

Most artillery systems have a meteorological unit allocated to the parent battalion. This unit will monitor the wind, temperature and air pressure up to a required altitude. However, these meteorological data may have been sampled several kilometres from the actual trajectory, and several hours before the firing took place. Consequently, it is not the wind speed itself that determine the accuracy, but the change in wind from the time and position of the sampling to those of the firing. The variability, i.e. expected change of the wind, is strongly dependent of the following three parameters

- *altitude* – The wind tends to become increasing stable with altitude. At low altitude, e.g. below 500 m, the wind is very unstable and may change dramatically in a matter of 5 – 15 minutes. It is also heavily influenced by the terrain structure and even the vegetation. At high altitudes, like in the stratosphere, the stability is very good and the wind may be very stable on a time scale of many hours, even days. It is assumed that the altitude variability increases as the inverse cubic root of the altitude.
- *wind speed* – The variability increases with the average wind speed. The variability during a gentle breeze is far less than during a gale. When spectral models of the wind is

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[10] Named after the French artillery general Isidore Didion (1798 – 1878)

considered, it can be shown that the variability increases with the wind speed raised to 4/3.

- *time and distance* - There is an equivalence between time and space variability. It is usually assumed that one hour time variability is equivalent to the 30 km space variability. The variability will increase as the cubic root of time (or space)

The following table shows the expected variability after 2 hours (or 60 km) and different altitudes and different wind speeds. Please note that the variabilities may be come larger than the average wind velocities as the velocity here must be considered as a vector.

Altitude	**Gentle breeze (5 m/s)**	**Moderate gale (18 m/s)**	**Strong gale (25 m/s)**
100 m	3.3	10.2	28.3
500 m	1.9	5.9	16.5
1000 m	1.5	4.7	13.1
2000 m	1.2	3.7	10.4
5000 m	0.9	2.8	7.7
10000 m	0.7	2.2	6.1
20000 m	0.6	1.7	4.8

For rockets, the wind induced deviation is most pronounced during the boost phase due to the high rate of acceleration. After the boost phase is over the wind influence is more moderate. However the wind near the top of the trajectory becomes quite important as the rocket spends more time near the top due to the shape of the trajectory and because the velocity is at a minimum in that region. The wind influence during the descending part of the trajectory is even more moderate than the ascending part because the remaining trajectory is short and any wind deviation will have a short time to work.

Appendix C Lethality models

Fragments are the dominating effect of artillery warheads, including those of rocket artillery. hence, lethality models will focus on that effect.

There are several ways to quantify the effects of fragments on the human body. Such a model requires the following components

- criteria for a fragment to be able to penetrate the human skin
- the probability of an incapacitating injury if the body is penetrated
- injury criteria have to depend on which part of the body is hit

C.1 Sperrazza's model

This is quite detailed vulnerability model based on the U S Army experiences during the Vietnam War and probably also the Korean War. The model is documented in a paper by Kokinakis and Sperrazza[11] [37]. In mathematical terms the model is based on the following expression of probability

$$P_{kill}(m,v) = 1 - \exp\left[-a\left(mv^{3/2} - b\right)^n\right]$$

The expression gives the probability of kill (inability to serve as a soldier) when hit by a fragment with velocity v and mass m. The parameters a, b and n are adapted to experimental and empirical data obtain through firing made on goats and, to some extent, on human cadavers. The values of the parameters may be given for body as a whole or for any major body part. Separate sets of a, b and n are also made for different clothing, for different fragment shapes and for different tactical roles. As an example, the table below shows the set for a fully clothed soldier with helmet, in a defensive role and exposed to randomly shaped steel fragments

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[11] This work was originally classified as *Secret*, but it is now downgraded to *Unclassified*

Body part	**a**	**b**	**n**	**r***
Head & Neck	0,19866	0,21808	0,57884	0,0651
Thorax	0,43317	0,49068	0,27859	0,1304
Abdomen	0,13200	0,47433	0,48523	0,1065
Pelvis	0,02766	0,39800	0,77314	0,1156
Arms	0,15519	0,33258	0,45662	0,2045
Legs	0,12437	0,34239	0,47749	0,3778
Entire body	0,15368	0,34239	0,45106	1,0000

Table C.1 Set of parameters for a soldier in winter uniform exposed to random fragment and in a defensive role. SI-units are used. The number of digits in the numbers does not reflect the accuracy of the model.
** r is a relative exposed area of the respective body part.*

As another example consider the following graph showing a soldier with practically no clothes, and in an assault role. In this role the locomotive body parts is given more emphasize. The model uses two separate assault modes – assault < 30 seconds, and assault < 5 minutes – were the time gives time maximum time between the hit and the moment at which the incapacitation takes place.

In order not to be considered incapacitated, the soldier must be able to run, to use his weapon, to see, to hear and to communicate with his fellows.

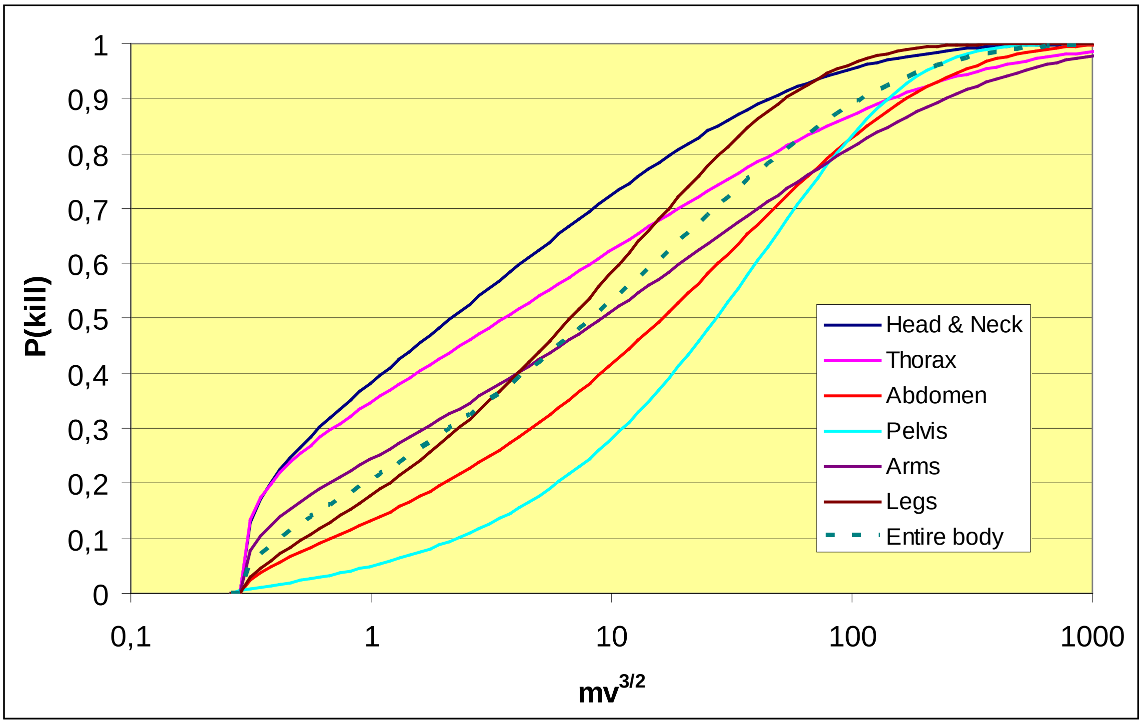


Figure C.1 Sperrazza/Kokinakis criteria for nude soldier in assault mode (< 30 seconds) exposed to random steel fragments. Head & Neck is shown as the most vulnerable body part.

C.2 Feinstein's model

Starting with the first criterion, according to Lewis[38], the probability of skin penetration for a fragment with kinetic energy *K* and cross section area *A*. The empirical formula for this probability is

$$P(SkinPenetration) = \left[1 + \exp\left(34.19 - \ln\left(\frac{2K}{A}\right)\right)\right]^{-1},$$

where SI-units are strictly applied.

A criterion according to Feinstein is used herein[39]. The probability of injury when being hit by a fragment with kinetic energy *K* is given by the following, quite complex expression containing a log-normal distribution

$$P(injury \mid K) = \int_0^K \frac{1}{x\beta\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \ln\alpha)^2}{2\beta^2}\right] dx$$

When the probability of being injured by a given fragment is known, the total probability of injury when hit by several, say *n*, fragments is

$$P = 1 - \prod_{i=1}^{n}(1 - p_i),$$

where the index *i* designates the individual fragments.

The vulnerability model according to Feinstein divides the human body into three parts: the head, the thorax, and the rest of the body (abdomen, arms, legs). The reason for this rather rough division is believed to be that each of the parts has a quite uniform vulnerability.

There are other criteria for vulnerability of warfighters which use the term incapacitation. This implies that the soldier has received an injury that makes him unable to perform his duties. These criteria, however, are not dramatically different from Feinstein's criteria.

The parameters for each body part are given in the table below

Part	**α (J)**	**β**	**Area (%)**
Head	75	1.32	9
Thorax	60	1.45	23
Abdomen & limbs	130	1.54	68

Table C.2 The parameters of Feinstein's model

The parameter α indicates the energy level where the probability of kill is 50%, while β is a measure for the width of the region where the probability goes from close to zero to almost 100%.

The actual kill probabilities are plotted below

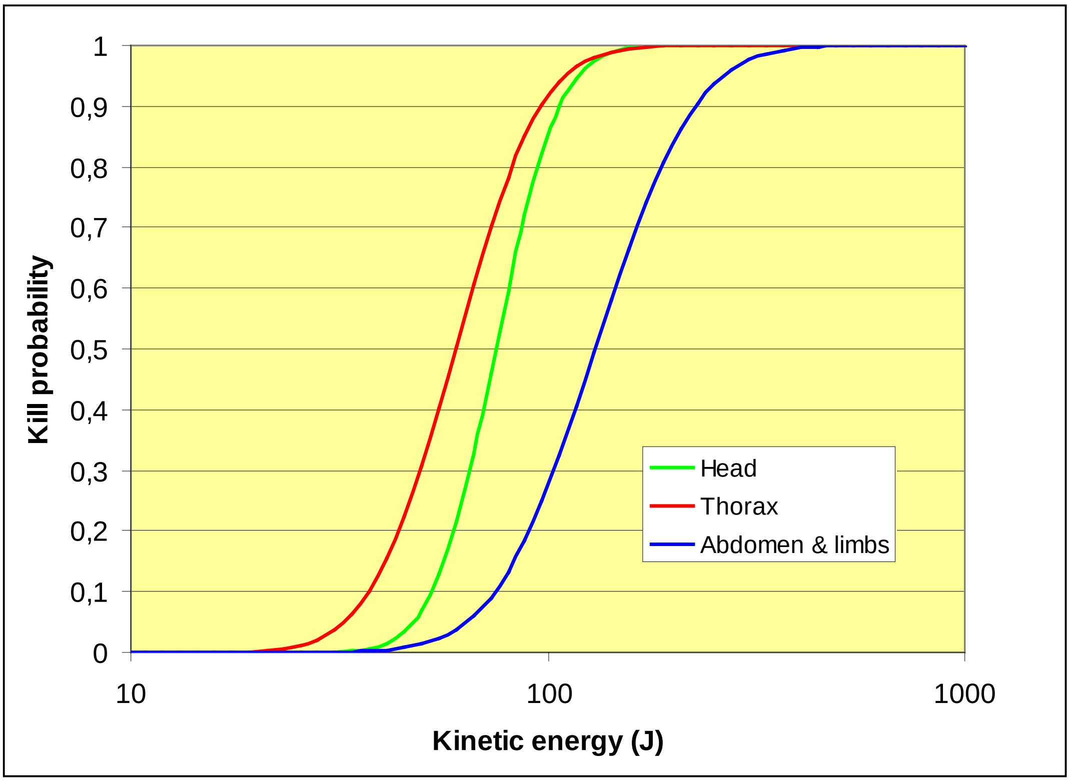


Fig C.2 Graphical presentation of the Feinstein model

Appendix D Details on some typical systems

	Qassam-1	9K132	Grad 9M22	LAR-160	Uragan 9M27F	MRLS M26	Smerch 9M55K
Diameter of fuselage (mm)	60	122	122	160	220	227	300
Rocket length (m)	0.79	1.905	2.87	3.31	4.83	3.94	7.6
Mass at launch (kg)	5.5	45.8	66.35	110.0	280.4	306.2	800
Fuel mass		(10.7)	20.45	(34.4)		98.4	(227)
Max. range at std. cond. (km)	3	10.8	20.4	34	34	32	70
Muzzle velocity (m/s)			50			60	(50)
Max velocity (m/s)	(200)	450	715	1022		818	(1030)
Motor thrust (kN)						125	(220)
Burn time (s)				(1.5)		1.5	(2.0)
Specific impulse (s)	(140)	(240)	(240)	(240)	(240)	239	(240)
Axial mom. of inertia (kgm^2)		(0.105)	(0.152)	(0.434)	(2.09)	2.43	(11.1)
Transv. mom. of inertia (kgm^2)		(11.1)	(36.8)	(80.8)	(440.6)	320.1	(3112)
Spin rate at launch (rps)						10.76	
Final spin rate (rps)						6 - 7	

Table D.1 Basic data for some selected types of rocket artillery. Numbers in parentheses are assumptive.

D.1 Aerodynamic data

Most current artillery rockets belongs either to one of the following two types

- long rockets with a length to diameter aspect ration in the order of 20 with wrap-around fins near the rear end and with moderate spin
- spin stabilized rockets without fins and with a length to diameter aspect ratio in the range of 5 to 7

As an indication of the value aerodynamic coefficients consider the following table.

Aerodynamic coefficient	**140 mm spin stab.**	**227 mm fin stab.**
Drag coefficient at 0.9 Mach	0.31	0.15
Drag coefficient at 1.1 Mach	0.57	0.39
Drag coefficient at maximum velocity	0.56	0.34
Lift coefficient at 0.9 Mach	2.3	3.6
Lift coefficient at 1.1 Mach	2.5	4.5
Lift coefficient maximum velocity	2.7	2.2
Overturning moment at 0.9 Mach	0.74	2.1
Overturning moment at 1.1 Mach	1.92	2.7
Overturning moment at maximum velocity	1.8	1.2
Pitch damping moment at 0.9 Mach	-15.7	-12
Pitch damping moment at 1.1 Mach	-96.7	-16
Pitch damping moment at max. velocity	-116	-9.5
Spin damping moment at 0.9 Mach	-0.04	-0.14
Spin damping moment at 1.1 Mach	-0.04	-0.16
Spin damping moment at maximum velocity	-0.04	-0.08

Table D.2 Typical values for the most important aerodynamic coefficients

D.2 Error budget

Most sources that give the accuracy of rocket systems present the round-to-round accuracy or random error contribution. The accuracy turns out be around 1 – 2% of the firing range. Such a value is actually quite good, but is somewhat removed from reality as the systematic error contribution may exceed the random errors to become the dominating errors. Systematic errors can be minimized by accurate launcher and target positioning and, above all, advanced wind monitoring systems especially in the vicinity of the launcher and the boost trajectory of the rocket.

D.2.1 Systematic errors

Using MLRS as an illustration of systematic errors, consider the table below. It is believed that these numbers are representative for any un-guided system fired at the same ranges.

Error source	12 km	20 km	30 km
Temperature deviation	8/0	10/0	14/0
Manufacturing inaccuracies	18/10	28/14	45/26
Aiming errors	0/17	0/28	4/14
Fuze timing errors	9/0	9/0	6/0
Wind induced errors	40/65	48/122	83230
Atmospheric temperature and pressure	20/0	32/0	58/0
Total systematic error	50/68	66/126	112/235

Table D.3 Error budget for the M26 systematic errors (in meters). Numbers show probable error in meter along (before the slash) and across (after the slash) the line of fire[31]

D.2.2 Random errors

.Error budget requires detailed information of a specific system, which in general is not available. The following table is taken from [40] describing the values for the M26 rocket of MLRS. It shows the random error along and across the line fire when firing at normal condition at three different ranges.

Error source	12 km	20 km	30 km
Shear bolt strength	2/0	3/0	7/0
Motor impulse	35/0	55/0	89/1
Grain temperature	15/0	18/0	27/0
Rocket mass	8/0	20/0	37/0
Nozzle inclination	0/20	1/27	6/52
Transversal centre of gravity	0/0	0/9	2/18
Longitudinal centre of gravity	0/0	0/0	0/0
Time fusing	9/0	15/0	20/0
Fin angle	0/0	0/0	0/2
Fin release	0/0	0/2	5/4
Air drag	20/0	45/0	95/0
Tip-off	3/83	4/160	44/314
Aiming	0/23	1/38	14/57
Boost wind	10/70	6/76	6/143
Coast wind	14/14	17/17	24/24
TOTAL ERROR	**48/114**	**80/184**	**149/355**

Table D.4 Error budget for M26 random errors (in meters). Numbers show probable error in meter along (before the slash) and across (after the slash) the line of fire[31]

D.3 Trajectories and firing tables

In order to illustrate the ballistics of rocket artillery, we have worked through the ballistics for some of the most common rocket artillery systems. The calculations are based upon the TRANSM model developed by LTV for simulating the MLRS rocket [13]. This model requires a high number of input parameters, of which many are not known. However, many of these parameters have a minute effect on the trajectory. The most critical input parameters are:

- size and mass of rocket
- fuel mass
- specific impulse
- burn characteristic
- air drag coefficients

Even some of these parameters may be unknown, but based or design and other constraints, assumptive values can be used and adjusted to give the expected values for known performances like the maximum range and others.

Six different systems have been simulated. These are

- a 60 mm Qassam rocket
- a 107 spin stabilized rocket
- a 122 mm short rocket
- the 122 mm 9M22U as used in BM-21
- the 160 mm rocket as used in LAR-160
- the 220 mm 9M27F as used in Uragan
- the 227 mm MLRS M26 rocket
- the 240 mm Falaq-1 rocket
- the 300 mm 9M55K rocket used in Smerch

D.3.1 60 mm Qassam fin stabilized

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
1.0	8.5	5.4	32	187	7.4
1.5	12.6	8.4	78	170	12.7
2.0	17.6	11.8	159	156	19.7
2.5	23.6	15.8	291	146	28.6
3.0	34.3	22.2	579	141	43.3
3.1	44.8	28.2	945	145	56.4

Table D.5 Suggestive firing table for a 60 mm Qassam rocket

D.3.2 107 mm spin stabilized rocket

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
2	8.0	6.6	41	318	4.9
2.5	9.3	8.2	66	303	6.5
3	10.7	9.9	101	291	8.4
3.5	12.2	11.7	147	279	10.6
4	13.7	13.6	199	269	12.8
4.5	15.4	15.6	259	259	15.4
5	17.3	17.8	353	250	18.2
5.5	19.3	20.0	454	242	21.3
6	21.6	22.6	582	235	24.8
6.5	24.1	25.3	735	230	28.7
7	27.0	28.3	929	226	33.0
7.5	30.5	31.8	1185	224	38.1
8	35.0	36.2	1541	224	44.0
8.5	46.0	45.9	2500	233	56.2

Table D.6 Suggestive firing table for 107 mm spin stabilized rocket

D.3.3 122 mm short (6 feet)

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
2	4.6	5.3	26	405	3.1
3	6.3	8.0	64	358	5.3
4	8.3	11.1	129	314	8.5
5	10.6	14.5	227	288	12.3
6	13.3	18.1	371	277	16.7
7	16.5	22.3	574	262	22.0
8	20.3	27.0	856	251	28.2
9	24.9	32.4	1249	244	35.3
10	31.2	39.4	1861	244	43.9
10.8	46.0	54.1	3515	260	59.5

Table D.7 Suggestive firing table for 122 mm short rocket

D.3.4 122 mm 9M22U for BM-21 Grad (9 feet)

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
5	3.5	8.5	69	540.9	3.7
6	4.3	10.5	110	490.6	5.0
7	5.2	12.6	165	442.6	6.7
8	6.3	15.2	245	403.1	8.9
9	7.5	17.8	345	368.2	11.6
10	8.8	20.6	469	339.8	14.5
11	10.4	23.8	640	318.4	18.2
12	12.2	27.2	853	306.5	22.2
13	14.2	30.8	1114	299.3	26.4
14	16.5	34.7	1442	294.7	30.8
15	19.0	38.8	1833	292.9	35.2
16	21.9	43.3	2312	293.8	39.7
17	25.1	48.1	2886	297.4	44.2
18	28.7	53.4	3573	303.7	48.5
19	33.3	60.1	4515	311.6	53.3
20	39.2	68.3	5803	318.0	58.6
20.47	47.0	78.8	7600	324.1	63.6

Table D.8 Suggestive firing table for 122 mm 9M22U rocket

D.3.5 160 mm LAR

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
12	5.6	17.4	323	444	9.0
13	6.3	19.7	423	403	11.2
14	7.3	22.3	550	369	13.9
15	8.3	25.2	711	339	17.2
16	9.5	28.3	912	320	20.9
17	10.8	31.4	1148	310	24.7
18	12.2	34.6	1421	305	28.4
19	13.8	38.1	1754	303	32.3
20	15.5	41.7	2132	303	36.1
21	17.3	45.4	2558	304	39.7
22	19.2	49.2	3034	307	43.1
23	21.2	53.2	3565	309	46.5
24	23.3	57.3	4153	312	49.6
25	25.6	61.8	4834	314	52.8
26	27.9	66.4	5552	316	55.8
27	30.3	71.2	6341	318	58.6
28	32.9	76.4	7242	320	61.4
29	35.6	82.0	8227	322	64,0
30	38.6	88.2	9379	324	66.6
31	41.5	94.1	10552	326	68.3
32	44.6	100.2	11863	330	69.7
33	47.9	106.5	13324	335	70.8
34.2	55.6	120.7	16916	353	73.0

Table D.9 Suggestive firing table for 160 mm LAR rocket

D.3.6 220 mm 9M27F for BM-27 Uragan

Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
9	5.1	13.0	177	588	5.4
10	5.7	14.8	231	553	6.5
11	6.3	16.5	291	523	7.6
12	7.0	18.4	368	492	9.0
13	7.8	20.6	465	463	10.7
14	8.7	22.9	584	436	12.7
15	9.6	25.2	714	414	14.7
16	10.6	27.7	870	394	17.0
17	11.7	30.4	1054	376	19.6
18	12.9	33.2	1270	362	22.3
19	14.2	36.2	1520	349	25.3
20	15.6	39.3	1806	340	28.4
21	17.1	42.6	2132	334	31.6
22	18.7	46.0	2501	330	34.8
23	20.4	49.5	2915	329	37.9
24	22.1	53.0	3351	329	40.8
25	24.0	56.8	3864	330	43.8
26	25.9	60.6	4403	332	46.6
27	28.0	64.7	5027	335	49.4
28	30.1	68.8	5681	338	51.8
29	32.4	73.2	6429	344	54.2
30	34.9	77.9	7279	352	56.4
31	37.5	82.8	8201	360	58.5
32	40.5	88.3	9309	369	60.6
33	44.3	95.1	10772	381	62.8
34	52.2	108.6	18825	407	66.7

D.3.7 227 mm M26

Range (km)	Elevation (°)	Fuze time (s)	Apogee (m)	HOB (m)	Velocity (m/s)	AOF (°)
7	9.6	9.25	646	640	650	-2.2
8	9.6	10.84	669	668	614	-0.8
9	9.6	12.53	672	669	580	0.8
10	9.6	14.33	672	641	548	2.6
11	9.6	16.24	672	579	517	4.6
12	9.6	18.28	672	480	488	6.8
13	10.2	20.44	758	470	461	8.7
14	11.0	22.73	884	489	438	10.7

Range (km)	Elevation (°)	Fuze time (s)	Apogee (m)	HOB (m)	Velocity (m/s)	AOF (°)
15	11.9	25.16	1033	510	416	12.9
16	13.0	27.73	1207	530	397	15.2
17	14.1	30.44	1409	551	380	17.8
18	15.3	33.30	1642	572	366	20.6
19	16.6	36.31	1909	592	355	23.6
20	18.1	39.48	2215	613	346	26.7
21	19.6	42.79	2561	633	340	29.9
22	21.2	46.46	2952	654	336	33.2
23	23.0	49.89	3392	674	334	36.5
24	24.9	53.68	3886	695	334	39.7
25	26.9	57.66	4441	716	336	42.8
26	29.1	61.83	5061	736	339	45.8
27	31.4	66.25	5763	761	344	48.7
28	34.0	70.99	6568	795	351	51.4
29	36.9	76.16	7507	829	360	54.2
30	40.2	82.17	8657	863	370	57.0
31	44.8	90.06	10287	896	386	60.3
31.5	50.9	99.98	12526	930	406	64.0

Table D.10 Firing table for M26 MLRS rocket

The M26 MLRS rocket may serve as typical example of a large calibre medium range rocket with a high number of submunitions.

D.3.8 240 mm Falaq-1 spin stabilized rocket

Range (km)	**Elevation (°)**	**TOF (s)**	**Apogee (m)**	**Velocity (m/s)**	**AOF (°)**
3	8.8	8.9	79	321	6.7
3.5	9.9	10.5	114	308	8.4
4	11.2	12.2	158	298	10.2
4.5	12.6	13.9	212	290	12.2
5	14.0	15.8	277	280	14.4
5.5	15.6	17.8	357	272	16.9
6	17.2	19.8	446	265	19.3
6.5	19.0	21.9	555	259	22.1
7	21.0	24.3	685	254	25.1
7.5	23.1	26.7	834	249	28.3
8	25.6	29.5	1026	246	32.0
8.5	28.3	32.5	1248	244	35.8

9	31.5	35.9	1531	243	40.1
9.5	35.7	40.2	1928	245	45.4
10	45.5	49.5	2936	254	55.8

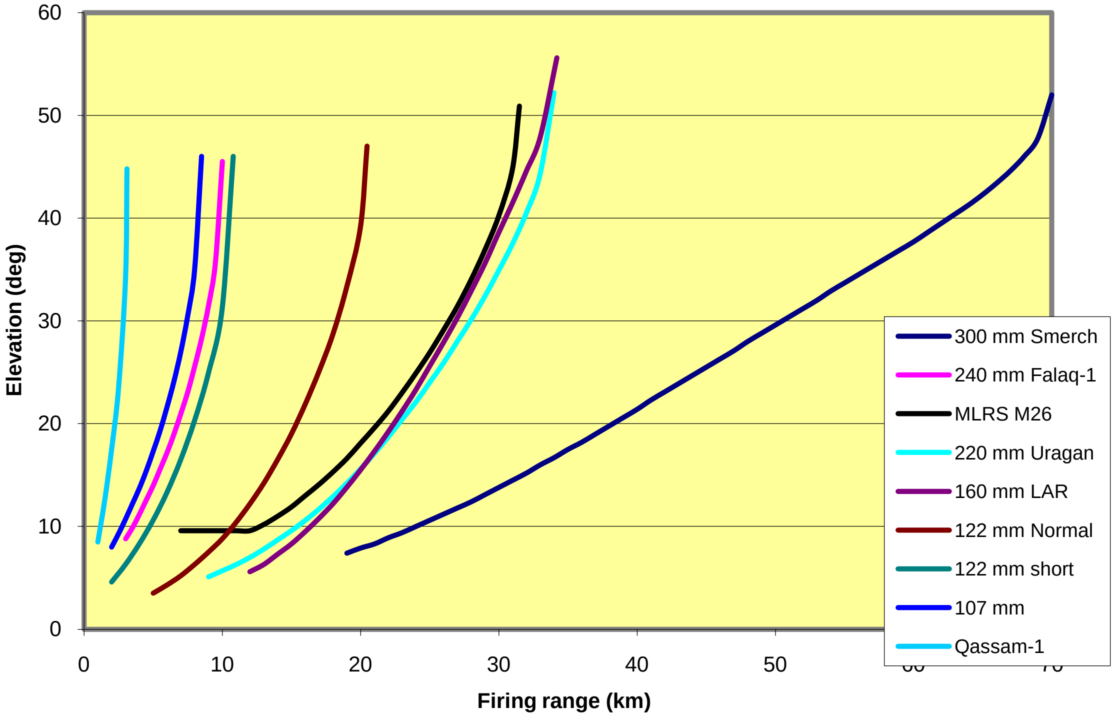
D.3.9 300 mm 9M55K for BM-30 Smerch

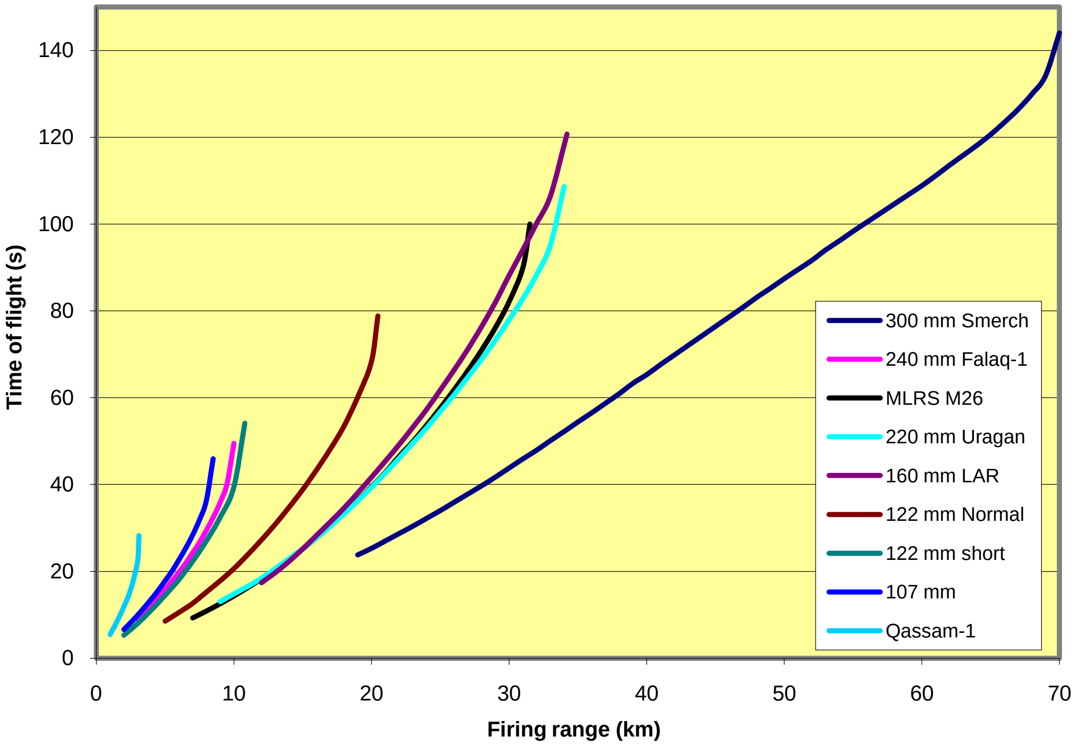
Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
19	7.4	23.8	607	642	9.1
20	7.9	25.3	695	622	10.0
21	8.3	27.0	793	604	11.0
22	8.9	28.7	901	586	12.0
23	9.4	30.4	1018	570	13.1
24	10.0	32.2	1146	554	14.2
25	10.6	34.0	1288	540	15.4
26	11.2	35.9	1438	527	16.6
27	11.8	37.8	1604	515	17.9
28	12.4	39.7	1779	504	19.2
29	13.1	41.7	1971	494	20.6
30	13.8	43.8	2176	486	22.0
31	14.5	45.9	2392	478	23.4
32	15.2	47.9	2633	472	24.8
33	16.0	50.1	2869	466	26.2
34	16.7	52.2	3128	462	27.2
35	17.5	54.4	3403	458	29.1
36	18.2	56.5	3683	455	30.4
37	19.0	58.7	3988	453	31.8
38	19.8	60.9	4299	452	33.1
39	20.6	63.3	4623	452	34.4
40	21.4	65.3	4958	452	35.6
41	22.3	67.6	5311	452	36.8
42	23.1	69.8	5669	454	38.0
43	23.9	72.0	6042	455	39.1
44	24.7	74.2	6425	458	40.1
45	25.5	76.4	6814	460	41.1
46	26.3	78.6	7218	463	42.0
47	27.1	80.8	7627	466	42.9
48	28.0	83.1	8072	470	43.8
49	28.8	85.2	8494	474	44.6
50	29.6	87.4	8929	478	45.3
51	30.4	89.5	9372	482	46.0
52	31.2	91.6	9824	486	46.7

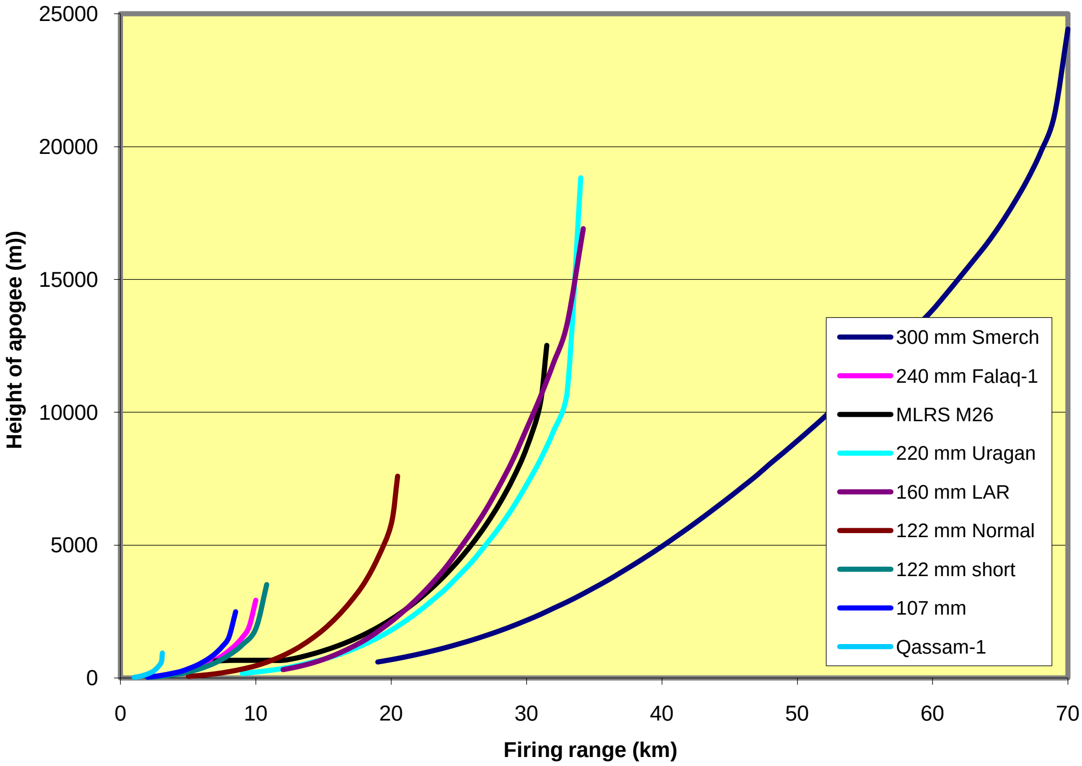
Range (km)	Elevation (°)	TOF (s)	Apogee (m)	Velocity (m/s)	AOF (°)
53	32.0	94.0	10319	491	47.4
54	32.9	96.1	10818	497	48.0
55	33.7	98.3	11301	502	48.5
56	34.5	100.4	11793	507	49.0
57	35.3	102.5	12294	513	49.5
58	36.1	104.6	12805	518	50.0
59	36.9	106.7	13325	524	50.4
60	37.7	108.8	13855	530	50.8
61	38.6	111.1	14457	537	51.3
62	39.5	113.5	15078	543	51.7
63	40.4	115.8	15705	550	52.2
64	41.3	118.1	16343	557	52.6
65	42.3	120.6	17062	565	53.1
66	43.4	123.4	17865	573	53.6
67	44.6	126.4	18753	582	54.2
68	46.0	129.9	19806	592	55.0
69	47.8	134.2	21179	605	56.0
70	52.0	144.0	24427	632	58.5

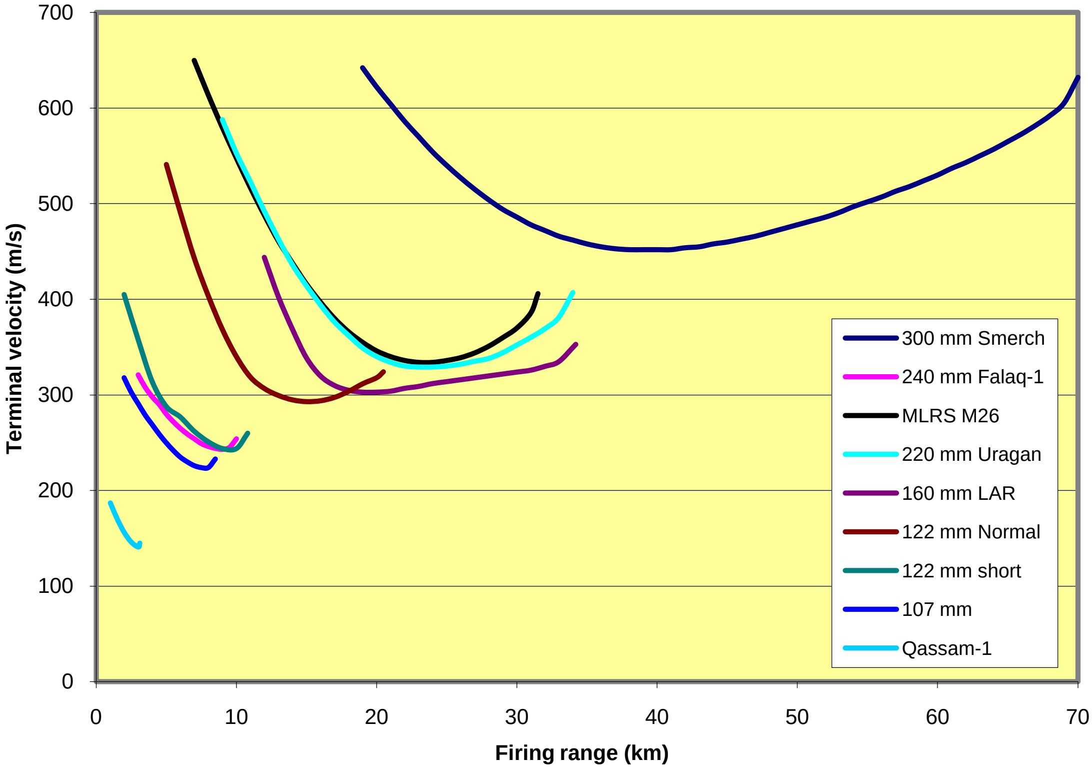
Table D.11 Suggestive firing table for 300 mm Smerch rocket

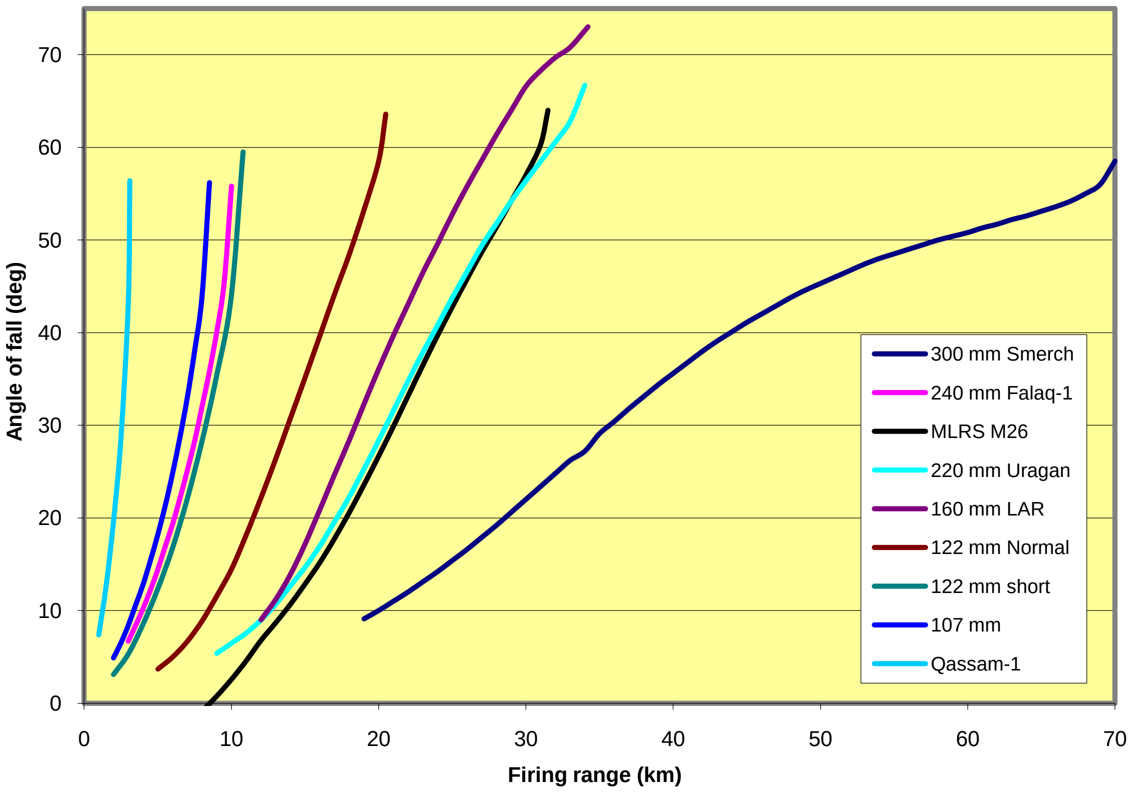
D.4 Graphical displays of ballistic tables




Time of flight (s)
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
Firing range (km)
300 mm Smerch
240 mm Falaq-1
MLRS M26
220 mm Uragan
160 mm LAR
122 mm Normal
122 mm short
107 mm
Qassam-1


Height of apogee (m))
0
5000
10000
15000
20000
25000
0
10
20
30
40
50
60
70
Firing range (km)
300 mm Smerch
240 mm Falaq-1
MLRS M26
220 mm Uragan
160 mm LAR
122 mm Normal
122 mm short
107 mm
Qassam-1


Terminal velocity (m/s)
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
Firing range (km)
300 mm Smerch
240 mm Falaq-1
MLRS M26
220 mm Uragan
160 mm LAR
122 mm Normal
122 mm short
107 mm
Qassam-1


Angle of fall (deg)
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Firing range (km)
300 mm Smerch
240 mm Falaq-1
MLRS M26
220 mm Uragan
160 mm LAR
122 mm Normal
122 mm short
107 mm
Qassam-1

Appendix E Russian ammunition nomenclature

Russian nomenclature for munitions can be quite confusing especially when it comes to such complex systems as rocket artillery. Basically the GRAU index (see below) is used, but other and less strict systems are also used. In addition, the Russians tend to give their most popular ordnance nicknames that eventually may become an official part of the name

The GRAU index (Главное ракетно-артиллерийское управление – Main Agency of Missiles and Artillery) has names that consist of three parts:

- a number from 1 to 17 indicating the category of equipment (e.g. artillery, air-defence, missiles)
- a letter signifying the class of equipment with the category (e.g. launcher, missile, warhead)
- a number with up to 3 digit signifying a particular model

In addition variants of the model may be differentiated by adding an additional letter and digit at the end.

As an example, consider the BM-21. The system has GRAU-number 9K51; the vehicle is 2B5; the launcher is 9P132, the main ammunition is 9M22; the ammunition transport vehicle is 9T530; the warhead itself could have a 9N number and so would also any submunitions have. However, the latter two items do not have a number that is known.

- Equipment for rocket artillery mainly belongs to category 9.
- The system including vehicle and launcher usually have class P or sometimes A.
- The launching unit usually has class K. However is the vehicle is inseparable from the launching unit (i.e. special built vehicle) the whole system has class K
- The rocket itself has class M.
- If the warhead is a separate unit (i.e. interchangeable warhead) is has class N
- Any submunition in a warhead may also have class N

A list of GRAU indexed equipment for rocket artillery in the following pages.

2Б2 - vehicle BM-14M 140 mm MRL
2Б2Р - vehicle BM-14MM 140 mm MRL
2Б5 - vehicle BM-21 122 mm MRL Grad
2Б7 - vehicle BM-13HM 132 mm MRL
2Б7Р - vehicle BM-13HMM 132mm MRL
2Б17 - vehicle BM-21-1 122 mm MRL Grad

2П13 - СПУ Br-230 tactical rocket complex Luna
2П16 - СПУ S-123A tactical rocket complex Luna
2П17 - ТЗМ S-124A tactical rocket complex Luna
2П21 - СПУ Br-226-II tactical rocket complex Luna

3M16 (9M16) - 122-mm rocket projectile MRL Grad with cluster warhead (5 POM-2 mines)

3Ф1 - 240-mm explosive charge MD-24F с blast warhead for MRL M-24

3Х1 - 240-mm explosive charge MS-24 for chemical warhead for MRL M-24

8Т137Л – modification of tactical rocket system Luna

8У012 – Cable for remote firing of MRL BMD-20, BM-24, BM-14
8У017 – Pneumatic starter ПЩС for MRL
8У31 - vehicle BM-24
8У32 - vehicle BM-14
8У33 - vehicle BMD-20
8У34 - vehicle BM-24T
8У36 - vehicle BM-14-17
8У36М - vehicle BM-14-17M

9А51 - MRL vehicle Prima
9А52 - MRL vehicle Smerch
9А52-2 - MRL vehicle Smerch (M)
9А52-2Т - MRL vehicle Smerch (M), Tatra chassis
9А349 – self-aiming anti-tank munition Motiv-3M

9Б63 – automativ inertial system for guided rocket 9M79 Tochka
9Б64 – command gyroskopic device for rocket 9M79 Tochka
9Б65 – diskette analog computer for rocket 9M79 Tochka
9Б66 – circuit board rocket 9M79 Tochka
9Б67 – hydraulic feeding station rocket 9M79 Tochka
9Б68 – lower steering unit – 2 ea. rocket 9M79 Tochka
9Б69 – upper steering unit – 2 ea. rocket 9M79 Tochka
9Б149 – turbo charger power supply for rocket 9M79 Tochka
9Б150 – guidance unit for rockets 9M79 Tochka
9Б151 – resistance unit in 9B149 for rocket 9M79 Tochka
9Б152 – gas turbine unit in 9B149 rocket 9M79 Tochka
9Б171 - onboard system management for 300 mm for rocket projectile system Smerch
9Б172 –electroninc timer for 9B171
9Б174 – apparatus for electronic measurement 9B171
9Б191 - onborad system managment 300 mm for rocket projectile systems Smerch
9Б217 – apparatus unit TZM 9T29M2
9Б232 – apparatus unit TZM 9T29M2
9Б242 – regulatory unit in 9B149 rocket 9M79 Tochka
9Б616 – hydraulic drive for rockets 9M79 Tochka
9Б877-1Б – angular speed gauges for tactical rocket 9M723

9В57М-1 - computeR КР 9S445M
9В69 – test unit for rocket complex 9К714
9В120 – impulse meter
9В370М – firing monitor for BM-21
9В391 – operator’s console for launcher 9P129 complex 9К79
9В394 – remote console for launcher 9P129 complex 9К79
9В396 – ground based monitor for launcher 9P129 complexa 9К79
9В818-820 – automatic control and montoric unit for tactical rocket complex Tochka
9В818-820-1 - automatic control and montoric unit for a tactical rocket complex Tochka-U
9В844 – service vehicle for tactical rocket complex Tochka
9В844М – service vehicle tactical rocket complex Tochka-U
9В932-1 – test and control unit for. 9B172

9Д12 - solid fuel rocket engine OTR 9M71, 9M72
9Д19 - solid fuel rocket engine TR type 9M21
9Д140 - solid fuel rocket engine
9Д158 - solid fuel rocket engine 122 mm for rocket projectile type 9M28
9Д159 - solid fuel rocket engine 220 mm for rocket projectile type 9M27

9K51 - MRL Grad
9K52 - tactical rocket complex Luna-M
9K52M - tactical rocket complex Luna-Z
9K52M2 - tactical rocket complex Luna-M2
9K54 - rocket complex Grad-B
9K55 - MRL Grad-1
9K57 - MRL Uragan
9K58 - MRL Smerch
9K59 - MRL Prima
9K79 - tactical rocket complex Tochka
9K79-1 - tactical rocket complex Tochka-U
9K510 – illumination rocket "Illyuminatsiya"
9K711 - operational-tactical rocket complex Uran
9K714 - operational-tactical rocket complex Oka
9K720 - operational-tactical rocket complex Tender (Iskander)

9M16 (3M16) - 122-мм rocket projectile MRL "Grad" with cluster warhead (5 POM-2 mines)
9M21 (3P11) - tactical rocket Luna-M complex 9K52
9M21A (9M21Д) - TP 9M21 with propaganda warhead 9N18A
9M21Б - TP 9M21 with nuclear warhead AA-52
9M21Б1 - TP 9M21 with nuclear warhead AA-38
9M21Г (9M21X) - TP 9M21 with chemical warhead 9N18Г
9M21E (9M21У) - TP 9M21 with practice warhead 9N32E
9M21E1 - TP 9M21M1 with practice warhead 9N36E
9M21E3 – TP 9M21 with practice warhead 9N32E
9M21E4 – TP 9M21 with practice warhead 9N36E
9M21K (9M21-OF) - TP 9M21 with cluster warhead 9N18-OF
9M21M - tactical rocket Luna-3 complexa 9K52M
9M21M1 - tactical rocket Luna-M1 complex 9K52
9M21M2 - tactical rocket Luna-M2 complex 9K52M2
9M21TФ - TP 9M21 with heavy explosive warhead
9M21Ф - TP 9M21 with explosive warhead 9H18F
9M21Ф2 - TP 9M21M1 with explosive warhead 9H18F2
9M22 - 122 mm rocket projectile M-21-OF MRL type Grad with HE/frag warhead
9M22Д - 122 mm rocket projectile MRL type Grad with propaganda warhead
9M22K2 - 122 mm rocket projectile MRL type Grad with cluster warhead (3 PTM-3 mines)
9M22M - 122 mm rocket projectile for unit Grad-P
9M22C - 122 mm rocket projectile M3-21 MRL type Grad with incendiary warhead
9M22У - 122 mm rocket projectile M-21-OF MRL type Grad with HE/frag warhead
9M22У2 - 122 mm rocket projectile MRL type Grad with HE/frag warhead
9M23 - 122 mm rocket projectile Leyka MRL type Grad with chemical warhead
9M23M - 122 mm rocket projectile MRL type Grad with chemical warhead
9M24 - tactical rocket complex Reseda
9M25 - tactical rocket Luna-3M complex 9K52M
9M27 - 220 mm rocket projectile MRL 9K57
9M27Д - rocket projectile Absats - 9M27 with propaganda warhead
9M27K - rocket projectile 9M27 with cluster warhead (30 fragmenting submunition)
9M27K1 - contains incendiary submunition
9M27K2 - rocket projectile Inkubator - 9M27 with cluster warhead (24 mines PTM-1)
9M27K3 - rocket projectile 9M27 with cluster warhead (312 mines PFM-1S)
9M27C - rocket projectile Abrikos - 9M27 with incendiary warhead
9M27Ф - rocket projectile 9M27 with explosive warhead
9M28Д - 122 mm rocket projectile MRL type Grad with propaganda warhead
9M28K - 122 mm rocket projectile MRL type Grad with cluster warhead (3 mines PTM-3)
9M28C - 122 mm rocket projectile MRL type Grad with incendiary warhead
9M28Ф - 122 mm rocket projectile MRL type Grad with separate explosive warhead
9M42 - 122 mm rocket projectile system 9K510
9M43 - 122 mm rocket projectile MRL type Grad with smoke warhead
9M51 - 220 mm rocket projectile MRL 9K57 with fuel air warhead

9M52 - TP 9M21M2 with HE/frag warhead
9M53Ф - 122 mm rocket projectile MRL type Grad with HE/frag warhead
9M55K - 300 mm rocket projectile MRL 9K58 with cluster warhead (72 fragmenting submunition)
9M55K1 - 300 mm rocket projectile MRL 9K58 with cluster warhead (5 self-aiming submunition 9A349 Motiv-3M)
9M55K4 - 300 mm rocket projectile MRL 9K58 with cluster warhead (25 PTM-3 mines)
9M55K5 - 300 mm rocket projectile MRL 9K58 with cluster warhead (646 shaped charge submunition)
9M55C - 300 mm rocket projectile MRL 9K58 with termobaric warhead
9M55Ф - 300 mm rocket projectile MRL 9K58 with HE/frag warhead
9M59 - 220 mm rocket projectile MRL 9K57 with cluster warhead (9 PTM-3 mines)
9M61 – remotely piloted flying devicefor T90-11 for 300 mm for rocket projectile 9M534
9M79 - tactical rocket complex Tochka
9M79-1 - tactical rocket complex Tochka-U
9M79-1Б - TP 9M79-1 with special warhead
9M79-1K - TP 9M79-1 with cluster warhead
9M79-1Ф - TP 9M79-1 with explosive warhead
9M79K - variant with cluster warhead 9N123K
9M79M - tactical rocket complex Tochka-M
9M79P - tactical rocket complex Tochka-P
9M79Ф - TR 9M79 with explosive warhead
9M79ФP - TR 9M79P with explosive warhead
9M217 - 122 mm rocket projectile MRL type Grad with cluster warhead (2 self-aiming submunitions)
9M218 - 122 mm rocket projectile MRL type Grad with cluster warhead (45 dual-purpose submunition)
9M334 – four-rocket module complex 9K331
9M519-1...7 - complex 122 mm rocket projectile Liliya-2 MRL type Grad for постановки радиопомех
9M521 - 122 mm rocket projectile MRL type Grad with HE/frag warhead
9M522 - 122 mm rocket projectile MRL type Grad with отделяемой HE/frag warhead
9M525 - 300 mm rocket projectile MRL 9K58 with cluster warhead (72 fragmenting submunition)
9M526 – 300 rocket projectile MRL 9K58 with cluster warhead (5 self-aiming submunitions)
9M527 - 300 mm rocket projectile MRL 9K58 with cluster warhead (25 PTM-3 mines)
9M528 - 300 mm rocket projectile MRL 9K58 with separate HE/frag warhead
9M529 - 300 mm rocket projectile MRL 9K58 with fuel air warhead
9M530 - 300 mm rocket projectile MRL 9K58 with explosive warhead
9M531 - 300 mm rocket projectile MRL 9K58 with cluster warhead (646 shaped charge submunitions)
9M533 - 300 mm rocket projectile MRL 9K58 with cluster warhead (5 self-aiming submunitions)
9M534 - 300 mm rocket projectile MRL 9K58 with remotely piloted flying device
9M714 - OTR system Oka
9M714Б - OTR 9M714 with special warhead
9M714K - OTR 9M714 with cluster warhead
9M714F – fragmenting-explosive warhead for 9M714
9M723K1 - OTR complex Tender (Iskander)

9H16 - warhead
9H18A (9H18Д) - propaganda warhead TP 9M21A (9M21D)
9H18Г - chemical warhead TR 9M21G (9M21Kh)
9H18K (9H18-OФ) - cluster warhead TP 9M21K (9M21-OF) with 42 fragmenting-explosive submunition
9H21Ф - explosive warhead TP 9M21Ф
9H21Ф2 - explosive warhead TP 9M21F2
9H24 - fragmenting submunition for cluster warhead
9H32 - nuclear warhead TP 9M21B with charge AA-21
9H32E - practice warhead for 9M21E
9H32M - nuclear warhead with charge AA-52 for TR 9M21
9H36 - nuclear warhead with charge AA-38 for TR 9M21
9H36E - practice warhead for 9M21E1
9H38M - nuclear warhead TP 9M21M with charge AA-38
9H39 - nuclear warhead TP 9M21 with charge AA-60
9H39 - nuclear warhead TP 9M79Б with charge AA-60
9H56 - chemical warhead for rocket projectile
9H57 - chemical warhead for rocket projectile
9H58 - chemical warhead for rocket projectile

9Н65 - nuclear warhead TR 9M79B with charge AA-80
9Н65 - nuclear warhead TR 9M79B1 with charge AA-86
9Н123Г - chemical warhead TR 9M79
9Н123Г2-1 - chemical warhead TR 9M79
9Н123К - cluster warhead TR 9M79К, 9M79-1К with 50 submunition 9N24
9Н123Ф - fragmenting-explosive warhead TR 9M79F, 9M79-1F
9Н123Ф-1 - fragmenting-explosive warhead TR 9M79FR with passive radar homing warhead
9Н128Д - propaganda warhead for rocket projectile 9М27Д
9Н128К - cluster warhead for rocket projectile 9М27К with 30 fragmenting submunition 9N210
9Н128К2 - cluster warhead for rocket projectile 9М27К2 with 24 mines 9N211
9Н128К3 - cluster warhead for rocket projectile 9М27К3 with 312 mines 9N212
9Н128С - incendiary warhead for rocket projectile 9M27S
9Н128Ф - explosive warhead for rocket projectile 9M27F
9Н138 - warhead for rocket projectile 9М55К with fragmenting submunition
9Н139 - cluster warhead for rocket projectile 9М55К with 72 fragmenting submunition 9Н235
9Н150 - separate fragmenting-explosive warhead for rocket projectile type 9М55
9Н152 - cluster warhead for rocket projectile 9М55К1 with 5 self-aiming submunition Motiv-3M
9Н174 - thermobaric warhead for rocket projectile type 9М55
9Н176 - cluster warhead for rocket projectile 9М55К5 with 646 dual-purpose submunition
9Н210 - fragmenting submunition for cluster warhead
9Н211 - anti-tank mine ПТМ-1 for cluster warhead
9Н212 – anti-personell mine ПФМ-1С for cluster warhead
9Н215 – passive radar homing warhead for TR 9M79R
9Н230 - chemical submunition
9Н235 - rebounding fragmenting submunition Poprygunya for cluster warhead
9Н310 – warhead hull 9Н123F rocket 9M79F Tochka
9Н311 – hull for cluster fragmenting warhead 9N123К rocketы 9M79К Tochka
9Н516 - cluster warhead for rocket projectile 9М27К1 with осколочными submunition 9N235
9Н519 - chemical warhead for rocket projectile
9Н524 - cluster warhead for rocket projectile 9М59 with 9 PTM-3 mines
9Н528К3 - cluster warhead for rocket projectile
9Н539 - cluster warhead for rocket projectile 9М55К4 with 25 PTM-3 anti-tank mines

9П112 – Self-propelled launcher Bp-237 complex 9К52 (tracked)
9П113 – Self-propelled launcher Bp-231 complex 9К52 (wheeled)
9П113М - Self-propelled launcher complex 9К52М
9П113М2 - Self-propelled launcher complex 9К52М2
9П114 - Self-propelled launcher Бр-257 complex 9К53
9П125 – military vehicle BM-21B MRL "Град-В"
9П129 - Self-propelled launcher complex 9К79
9П129М-1 - Self-propelled launcher complex 9К79-1
9П132 – portable launcher ПУ ТКВ-042 Grad-P (Partizan) for 122 mm for rocket projectile 9M22M
9П138 – combat vehicle MRL Grad-1
9П139 – combat vehicle MRL Grad-1 (tracked)
9П140 – combat vehicle MRL Uragan
9П612 – device for remote installation of initiators 9Eh260-1
9П618-1М - аппаратура дистанционного ввода данных в БСУ 9В191
9П71 - Self-propelled launcher complex 9К714
9П78 - Self-propelled launcher Astrolog complex 9К720
9П78-1 - Self-propelled launcher complex 9К720
9П81 - Self-propelled launcher complex 9К720

9С83 – metorological station
9С445 – reference point
9С445М – command node complex 9К52
9С473 – staff command vehicle
9С482 – navigational vehicles ПУ-12 (with variants)
9С522 – staff command vehicle system 9К720
9С619 – data transmission unit for radar data processor
9С738 – staff command vehicle Pled

9С766М1 – rear units maintainance vehicle
9С910 – automatic guidance unit
9С920 – information distribution unit complex 9К720

9Т114 – airport storage handler for container 9Ya236
9Т127 - airport storage handler complex 9К79
9Т133 - airport storage handler for containerов 9Ya234
9Т29 – auxiliary transport vehilce complex 9К52
9Т29-1 - auxiliary transport vehilce complex 9К52
9Т29М - auxiliary transport vehilce complex 9К52М
9Т29М2 - auxiliary transport vehilce complex 9К52М2
9Т215 - transport vehicle for rocketных частей ОТР 9М76
9Т218 - auxiliary transport vehilce complex 9К79
9Т218-1 - auxiliary transport vehilce complex 9К79-1
9Т218-1М - auxiliary transport vehilce complex 9К79-1
9Т219 - transport vehicle for warhead ОТР 9М76
9Т222 - transport vehicle complex 9К79 и 9К79-1
9Т230 - auxiliary transport vehilce complex 9К714
9Т232М - auxiliary transport vehilce MRL Prima
9Т234 - auxiliary transport vehilce MRL Smerch
9Т234-2 - auxiliary transport vehilce MRL Smerch
9Т234-2Т - auxiliary transport vehilce MRL Smerch (Tatra chassis)
9Т238 - transport vehicle for rocket complex 9К79 (with variants)
9Т239 - transport vehicle
9Т240 - transport vehicle complex 9К714
9Т250 - auxiliary transport vehilce complex 9К720
9Т254 - transport vehicle MRL Grad
9Т33 - transport vehicle complex 9К33
9Т35 – crane for complex 9К76
9Т315 –overload support arm for rocket, warhead complex 9К79
9Т316 – overload support arm rocket, warhead complex 9К79
9Т325 - complex такелажного оборудования
9Т450 - auxiliary transport vehilce MRL Grad-1
9Т452 - auxiliary transport vehilce MRL Uragan
9Т460 - rack for MRL
9Т52 – rocket complex rig
9Т53 – crane for auxiliary transport vehilce 9Т29М2
9Т55 – overload support contruction for rocket and warhead complex 9К79
9Т55А - rocket complex rig
9Т57 - rocket complex rig
9Т62 – isothermal vehicle for rocket and warhead complexa 9К79
9Т63 – isothermal vehicle for rocket and warhead complexa 9К79
9Т64 – support beam for rocket and warhead complex 9К79
9Т66 – support beam for rocket and warhead complex 9К79
9Т610 – isothermal vehicle for rocket and warhead complexa 9К79

9Ф19 – mobile technical repair base MRL
9Ф25 – computer simulator for rocket complexes Tochka, Tochka-U
9Ф110 - mobile technical repair base
9Ф117 - process equipment unit
9Ф222 – machine storage
9Ф223 - transport vehicle warhead complex 9К52
9Ф32 - transport vehicle
9Ф37 – rack system MRL Grad
9Ф37Б - rack system MRL Grad
9Ф37В - rack system MRL Grad-B
9Ф37М – unified rack complex for MRL Grad, Grad-1, Prima, Damba
9Ф342-344 - rig
9Ф370 - special arsenal complex for equipment and tools for Tochka
9Ф370-1 - special arsenal complex for equipment and tools for Tochka-U

9Ф374 – welding equipment at auxiliary transport vehicle for 9T29M2
9Ф381 – special arsenal complex for equipment and tools MRL Uragan
9Ф625 – computer simulation complex self-propelled launcher complex Tochka
9Ф625-1 - computer simulation complex self-propelled launcher complex Tochka-U
9Ф647 – education and training unit Sizyak in complex Smelchak
9Ф689 – target arrangement Bobr for MRL Grad
9Ф817 – training and practice complex MRL Uragan
9Ф819 - complex special arsenal complex for equipment and tool MRL Smerch
9Ф827 – education and training unit MRL Smerch
9Ф839 - 122 mm rocket projectile – air target imitator complex 9F689
9Ф839-1 - 122 mm rocket projectile - air target imitator complex 9F689
9Ф839-2 - 122 mm rocket projectile - air target imitator complex 9F689
9Ф840 – education and training arrangement MRL Smerch

9X11 - charge solid fuel rocket engine 9D12
9X15 - powder charge solid fuel rocket engine
9X18 - charge solid fuel rocket engine 9D19
9X37 - explosive charge submunition 9H210
9X111 - charge solid fuel rocket engine for rocket projectile 9M22
9X111M2 - charge solid fuel rocket engine for rocket projectile 9M22U
9X111M3 - charge solid fuel rocket engine for rocket projectile 9M22U2
9X151 – fuel charge DAP-15V impeller unit rocket 9M79 Tochka
9X164 - charge solid fuel rocket engine for rocket projectile 9M27
9X226 – ignitor safety unit (for incendiary 9Kh249)
9X249 – fuel ignitor charge 9Kh151 rocket 9M79 Tochka

9Э92 - safety and arming unit
9Э96 - safety and arming unit
9Э117 – safety and arming mechanism for warhead 9N123F(K) rocket 9M79F(K) Tochka
9Э118 –no contact fuze for warhead 9N123F rocket 9M79F Tochka
9Э128 – contact fuze for warhead 9N123F rocket 9M79F Tochka
9Э132 - safety and arming unit
9Э136 - fuze Prosvetitel' for OFS 3OF30, 152 mm and 122 mm OFS
9Э29 - fuze warhead 9N18F
9Э210 - mechanical fuze MRV for for rocket projectile 9M22, 9M23
9Э231 - fuze for rocket projectile 9M22M
9Э234M - safety and arming unit
9Э236 - fuzing device
9Э244 - mechanical fuze for rocket projectile 9M27F
9Э245 – 120 seconds remote tube for rocket projectile 9M27K
9Э246 - fuze for submunition 9N210
9Э246M - fuze for submunition 9N210
9Э260 - electro-mechanical head proximity-contact fuze 122 mm for rocket projectile
9Э260-1 - electro-mechanical head PD - proximity fuze 122 mm for rocket projectile 9M53F
9Э265 – fuzing device
9Э268 - safety and arming unit 300 mm for rocket projectile
9Э269 - safety and arming unit 300 mm for rocket projectile
9Э271 - fuze
9Э272 - fuze for fragmenting submunition
9Э273 – fuzing device
9Э285 - electro-mechanical head PD - proximity fuze 301B 122 mm for rocket projectile
9Э310 – proximity (radio-localizing) fuze 122 mm for rocket projectile 9M23
9Э326 – radio warhead 9N123K rockets 9M79K Tochka
9Э328 - proximity fuze Gibrid
9Э343 - proximity fuze Polufinal
9Э428 – guidance head self-aiming submunition
9Э436 – guidance head OTR 9M722

9Я26M – transport container warhead AA-52 for TR 9M21
9Я224M – transport container warhead AA-38 for TR 9M21

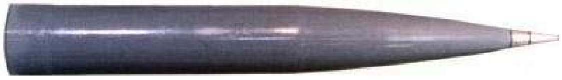
9Я230 – transport container OTR 9M76
9Я234 - transport container rocket motor part of complex Tochka
9Я236 - transport container warhead complex Tochka
9Я248M - container for for rocket projectile MRL Uragan
9Я281 - transport container for rocket module 9M334
9Я43 - transport container
9Я616 - transport container for rocket motor part of complex Luna-M2
9Я634 - transport container for warhead 9N18F, 9N32E and 9N36E
9Я665 - transport container for warhead 9N18E

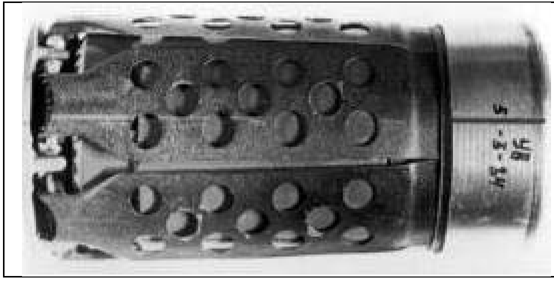
Appendix F Rocket artillery in Iraq and Afghanistan

The following data is taken from the EOD guides that U S Navy have issued for the forces in Afghanistan [41] and Iraq [42].

The pictures are not to scale.

F.1 Afghanistan

	Type 63. Chinese 107 mm HE for MD-21
	R107 North Korean
	9M28F
	9M22U. Standard rocket for BM-21 Grad
	9M22M Standard rocket for portable system Grad-P
	9N128K2 AT mine dispensing warhead on 9M27K2 for Uragan
	9N128F HE/Fragmenting warhead on 9M27F for Uragan
	9M27K1
	9M27K3 AP mine dispensing rocket
	KB-1 submunition from 262 mm rocket
	PTM-1 scatterable AT mine delivered by BM22 Uragan

	POM-2S AP mine delivered with 9M18 122 mm rocket

F.2 Iraq

	Type 63 . Chinese 107 mm HE for MD-21
	Type 63-1 Chinese 107 mm Incendiary for MD-21 and MJ-1
	Type 63-2, Chinese 107 mm HE for MJ-1
	Type 81, Chinese 122 mm HE for MJ-4 and MJ-4A
	Firos, Italian 122 mm HE
	9M22U, Russian 122 mm HE for BM-21 Grad
	M77 DPICM bomblet delivered with M26 MLRS

Appendix G Rockets and rocket launchers operated by non-state parties

G.1 Hezbollah

The Hezbollah organization, representing the Shia muslims in Southern Lebanon, made use of their stock of rocket artillery most recently during the war in Lebanon in 2006. Hezbollah is supposed to have received most of its inventory of ordnance from Iran through Syria, as a major part of their inventory is of Iranian origin. However, some quite modern Russian or Chinese systems are also found probably received directly from Syria. The whole arsenal is supposed to constitute around 13000 rockets.

The table below shows the types that a believed to be in stock. The number of each type is too uncertain to be given here.

Type	Calibre (mm)	Range (km)	Warhead (kg)
Haseb*	107	9	8
BM-21	122	20	21
Type 90	122	30	
BM-27	220	40	100
Fadjr-3	240	45	45
Shahin I (Ra’ad I)	333	13	190
Shahin 2	333	29	190
Fadjr-5 (Khaibar-1)	333	75	90
Falaq-1	240	11	50
WS-1	302	80	150
Fateh-110	170	>200	500
Arash	122	20	18
Oghab	230	45	70
Zelzal-2	610	400	600

Table G.1 Rockets in the inventory of Hezbollah
**) Haseb is an Iranian version of the Chinese Type 63, which again was a copy of the Russian BM-12*

During the war in 2006 close to 4000 rocket were fired into Israel. Hezbollah itself claims that twice that number was fired. According to Human Rights Watch [43] the following six types were used:

- 1111 of 122 mm rockets of unspecified types
- 246 of 122 mm enhanced range rocket, probably Type 90
- 86 of 220 mm Uragan
- 6 of 240 mm Falaq-1 spin stabilized rockets
- 6 of 240 mm long range Fadjr-3 rockets
- 31 of 302 mm rockets probably WS-1

In addition 107 mm Haseb rockets were probably also used. The list above is not complete since it does not sum up to 4000 rockets. It contains only examined sites of strike.

Figure G.1   Hezbollah preparing the launch of a rocket – probably the Shahin-1

G.2 Hamas

The Hamas organization in the Gaza strip is known to have a wide variety of rockets, both for direct fire and indirect fire. The Qassam rockets are the most renown. They are described in chapter x.x as improvised systems.

The Gaza conflict that started in late December 2008, proved that Hamas was in possession of 122 mm Grad rockets reaching beyond 20 km range, even as far as 40 km. It is not known what kind of launcher has been used. The length and size of these rockets would make them hard to smuggle. However, it may be possible to divide the long range motor of Grad into three parts. The fourth part would then be the warhead, which is rather small on that rocket.[44]

The Hamas is also claimed to have other rockets as well. The data about these are scarce and hard to verify. However according to an Israeli source [45], Hamas or other Palestinian organizations like Islamist Jihad, Jenin Martyr's Brigade and Fatah, are in possession of rockets as shown in the table below. It should be emphasized that this source may not have total credibility.

It has been claimed that Hamas is in possession of 70 km range Fadjr rockets. These rockets are 10 m long and it would be very challenging to smuggle and conceal such ordnance. This claim has not been confirmed.[44]

Name	Weight (kg)	Length (cm)	Calibre (mm)	Range (km)	Warhead (kg)
Haseb	19	84	107	9	8
Nasser 3 (long)	30	160	90	9	9 – 10
Nasser 3 (short)	25	125	90	6	9 – 10
Nasser 4	40	180	115	9	9 – 10
Quds 2A	23.5	150	90	6	8
Quds 2B	33.5	110	115	7	8
Quds 3A	35	130	102	8.5	6 – 7
Quds 3B	42	200	127.5	9	8
Hawkeye				55	15 – 20
Kafah				17	
Arafat				8	

Table G.2 Rockets in the inventory of Hamas

Recognizing that quite unsophisticated rockets with obviously low accuracy are quite effective as weapons of terror, Palestinian organizations seems to be very active in developing new versions of their rockets with ever increasing range.

G.3 Taliban

Before Operation Enduring Freedom starting late 2001 which toppled the Taliban regime in Afghanistan, it was known that Taliban had a considerable inventory of rocket artillery. It consisted primarily of the old Soviet Russian systems 122 mm BM-21, the old 132 mm BM-13-16, the spin stabilized BM-14 and 220 mm BM-14-17. [46;47] The number is uncertain, but possibly in the range of 50 – 80 units.

It is not known for certain how many of these unit still are in Taliban service, but the majority of inventory was obviously lost or destroyed during Operation Enduring Freedom. However, there have been reports indicating that some units of BM-21 have been used in the aftermath of that operation. Among those was a claim that BM-21 was applied in an air defence role. However, BM-21 or any other rocket artillery is very ill-suited for such a role. [48]

Appendix H Current launcher systems

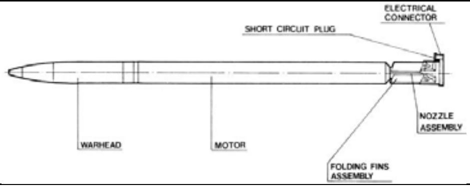
This appendix describes, in some detail, the current rocket system that is believed to be in operation. For many systems, the operational status is not known with certainly. However, the possibility that some of these systems can be revived should not be excluded.

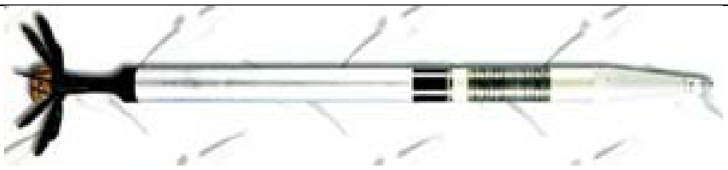
The list is not complete. Especially, several North Korean and Iranian systems are excluded due to lack of available information.

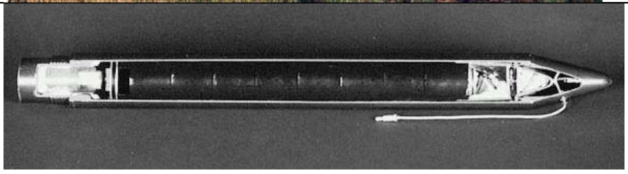
The systems are ordered according to the calibre of the system.

For country abbreviations, see appendix J.

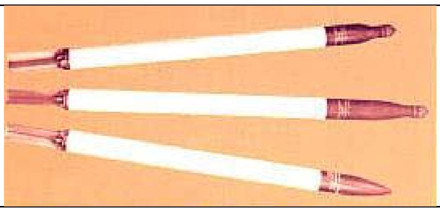
The main sources for this section are Jane's Armour and Artillery (JAA) [49] and Jane's Ammunition Handbook (JAH) [50]. Some information are also taken from World Equipment Guide 2001 [51], and the book by Hull et al [52]

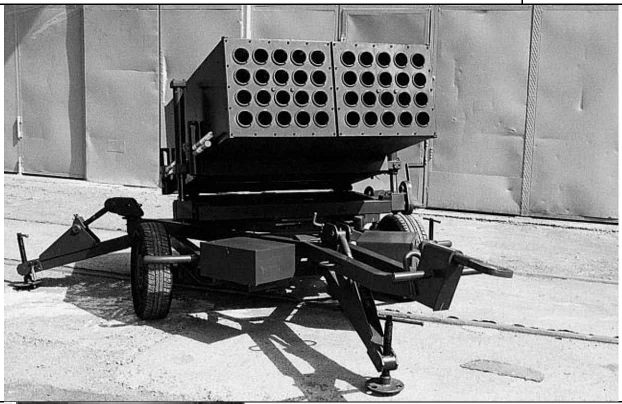
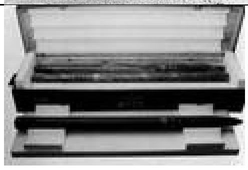
Firos	BPD Difesa e Spezio	Italy
Calibre 51 mm		
Carrier: ACMAT Jeep		
No. of tubes/rails: 48		
Range 6.5 km		
Ammunition types		
HE		
HE – preformed fragments		
AT/AP – shaped charge		
Smoke		
Spotting		
Training smoke		
Used by: MEX	Rocket mass 4.8 kg; warhead 2.2 kg Velocity 515 m/s at burnout at 1.1 s Firing rate 10 rockets/s	

S-5		Soviet Union
Calibre 57mm		
Carrier: Light truck		
No. of tubes/rails:20		
Range - 4.5 km		
Ammunition types:		
HE		
		
Used by: UKR, BIH	To large extent an improvised system The pod is an original direct fire rocket pod for the Mi-24 Hind helicopter	

LAU97	Forges de Zeebrugge	Belgium
Calibre 70 mm		
Carrier: VLRS 4.15 LRM		
No. of tubes/rails: 40		
Range 0.7 - 9 km		
Ammunition types		
FZ-100 Cargo		
FZ-49 Anti-Armor		
FZ-71 Anti-personnel		
M257 ILL		
		
Used by: UAE, INA	A ground launched version of the air-launched HYDRA system. Cargo warhead contains 9 DPICM 0.48 kg each. The rocket weighs about 6.2 kg	

Source: JAA

SBAT-70		Brazil
Calibre : 70 mm		
Carrier: Towed		
No. of tubes/rails:36 or 42		
Range - 7.5 / 12 km		
Ammunition types		
HE		
		
Used by: BRA	Rocket mass 14.6 kg; warhead 3.2 kg Velocity 700 m/s Developed in U SA as Slammer-6	

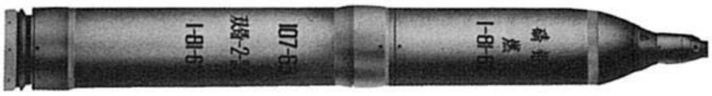
TF M95 Heron		Croatia
Calibre:70 mm		
Carrier: Towed		
No. of tubes/rails: 40		
Range -8 km		
Ammunition types		
HE		
ILL		
Smoke		
Incendiary		
Training		
Used by: CRO	Rocket mass 10 kg; warhead 3.7 kg Velocity 400 m/s (enhanced version 550m/s) A modified version has a range of 10 km	

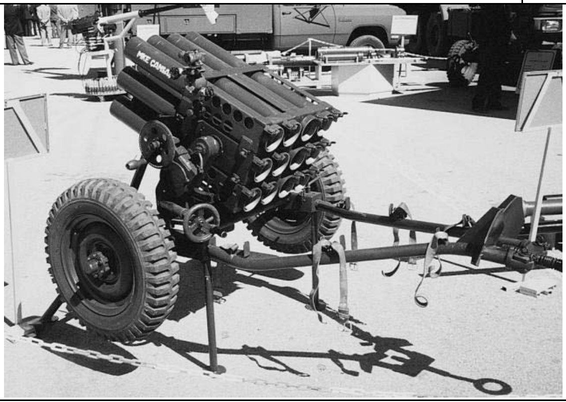
JAH

S-8		Soviet Union
Calibre: 80 mm		
Carrier: Light/medium truck		
No. of tubes/rails: 20		
Range - 6 km		
Ammunition types		
HE		
		
Used by: UKR, ABK	An half-improvised system applying the rocket pod of the S-8 system used av Russian helicopters. Rocket vel. 450 m/s. Rocket mass 15.2 kg; warhead 7.4 kg.	

PAMPERO	Fabrica Militar Fray Luis Beltran	Argentina
Calibre: 105 mm		
Carrier: MB unimog 4 x 4		
No. of tubes/rails:16		
Range - 10.1 km		
Ammunition types		
HE		
		
Used by: ARG	Rocket weight 28.5 kg, length 1,467 m; burn-out velocity 530 m/s	

JAA; JAH

Type 63	NORINCO	DR Korea
Calibre:107 mm		
Carrier: Towed or jeep mounted		
No. of tubes/rails: 12		
Range - 8.5 km		
Ammunition types		
HE		
Incendiary		
ECM		
		
Used by: ALB, BUF, CMB, DRC, JOR, LIB, MYA, NIC, PAK, SUD, SYR, UGA	Spin stabilized (6 nozzles). Launch velocity 34 m/s Rocket mass 14 kg Previously known as H-12 Variants made in IRN, NKO, RSA	

T-107	MKEK / Roketsan	Turkey
Calibre: 107 mm		
Carrier:Towed		
No. of tubes/rails:12		
Range - 8.5 km		
Ammunition types		
HE (TR-107)		
HE (TRB-107 – prefragm.)		
Used by: TUR The launcher may also be placed on a light vehicle	Spin stabilized rocket, mass 19.5 kg, length 0.84 m Warhead 8.5 kg, 1.25 kg TNT Max. velocity 370 m/s	

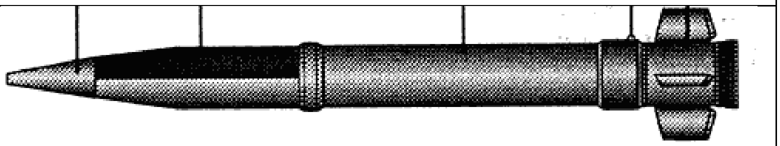
108-R	Avibras,	Brazil
Calibre: 108 mm		
Carrier: Towed		
No. of tubes/rails: 16		
Range - 9.1 km		
Ammunition types		
HE		
Used by: BRA (may be phased out)	Rocket mass 16.8 kg, warhead 7.8 kg, explosive 2.5 kg Rocket length 0.97 m. Max.velocity 440 m/s	

JAA

Kung-Feng VI		Rep China
Calibre: 117 mm		
Carrier: M52A1 (6 x 6)		
No. of tubes/rails:45		
Range: - 14.9 km		
Ammunition types		
HE		
Used by: ROC	Rocket mass 59.8 kg To be replaced by RT2000 Mk15	

RT2000 Mk15		Rep China
Calibre: 117 mm		
Carrier: M977 HEMTT		
No. of tubes/rails: 60		
Range -15 km		
Ammunition types		
HE		
Used by: ROC	Rocket mass 59.8 kg (same rocket as for Kung Feng IV A)	

http://www.military-today.com/artillery/rt2000.htm
http://wiki.livedoor.jp/namacha2/d/117mm45%cf%a2%c1%f5%bc%ab%c1%f6%a5%ed%a5%b1%a5%c3%a5%c8%cb%a4%a1%d6%b9%a9%cb%aa6%b7%bf%a1%d7

9K132 Grad-P	Kovrovsk Mech. Plant	Soviet Union
Calibre: 122 mm		
Carrier: Portable		
No. of tubes/rails: !		
Range 0.8 – 10.0 km		
Ammunition types		
HE		
Smoke		
		
Used by: RUS, EGY, HIZ Egyptian version is called PR-113	Rocket mass 91 kg, warhead 46 kg	

Sakr-30/36/40		Egypt
Calibre: 122 mm		
Carrier:Towed or truck		
No. of tubes/rails:6 /21/30/40		
Range - 20/36 km		
Ammunition types		
Sakr 10 (HE)		
Sakr 18 (HE)		
Sakr 30 (HE)		
D-4000 (smoke)		
D-6000 (smoke)		
Cargo (98 DPICM)		
Mines (5 AT mines)		
Used by: EGY	Rocket mass: Sakr-30 56.5 kg; Sakr-18 – 67 kg Rocket length:Sakr-30 2.58 m. Sakr-18 3.25 m Velocity Sakr-30 – 1090 m/s, Sakr-18 - 1290 m/s	

SAKR Series 122 and 325 mm Multiple Launch Rocket Systems - Archived 8/2003; Forecast International, August 2002

BM-21 Grad		Soviet Union
Calibre: 122 mm		
Carrier:		
No. of tubes/rails:40		
Range 1.6/5 – 20.75		
Ammunition types		
HE		
DPICM		
AT mines		
AP mines		
		
Used by: Numerous (see section H-1 and I)	This system and its variants are described further in section H-1	

Equiv PRC Type 81

Firos-25/30	Snia Viscosa	Italy
Calibre: 122 mm		
Carrier:		
No. of tubes/rails: 40		
Range: 8 – 25/34		
Ammunition types		
HE		
HE-prefragmented		
WP smoke		
AT-mines (6)		
AP-mines (22)		
DPICM (77)		
Used by: ITA	Rocket mass 58 / 65 (Firos-30)	

FIROS 51 and 122 mm Multiple Launch Rocket Systems - Archived 8/2003

Type 90 / KRL 122	Norinco	PR China
Calibre: 122 mm		
Carrier: XC2000 6 x 6		
No. of tubes/rails: 40		
Range: 12.7 – 32.7 km		
Ammunition types		
HE		
Used by: ARM, BAN, PRC	Another 40 rockets is transported on the vehicle. Rocket length 2.75 m. Long range version 40 km range	

T-122 Sakarya	Roketsan	Turkey
Calibre: 122 mm		
Carrier: XC2000 6 x 6		
No. of tubes/rails: 40		
Range: 3 – 40 km		
Ammunition types		
HE		
HE/Frag		
Used by: TUR, UAE	See table x.x	

JAH

Type 89	Norinco	PR China
Calibre: 122 mm		
Carrier: 12150L.		
No. of tubes/rails: 40		
Range: 15 - 40 km		
Ammunition types		
HE/Frag		
prefragmented		
DPICM		
AT mines		
AP mines		
Used by: PRC,	Another 40 rockets is transported on the vehicle. Rocket length 2.75 m.	

BM-11		Soviet Union
Calibre: 122 mm		
Carrier: Various		
No. of tubes/rails: 30		
Range: 5 – 20.75		
Ammunition types		
HE		
		
Used by: NKO	North Korean version of BM-21 with same rocket	

RM-70 /RM-75		Czech Rep
Calibre : 122 mm		
Carrier: Tatra 813 8 x 8		
No. of tubes/rails: 40		
Range: 1.6 - 20		
Ammunition types		
HE/Frag		
DPICM (56 AGAT)		
AT mines		
Ap mines		
		
Used by: ANG, CZE, FIN, GEO, GRE, LIB, MYA, PER, POL, ROM, RWA, SLK, SRI, UGA, YEM	See own 122 mm /BM-21section below HE-version has 6.4 kg explosives	

Romanian version is called APR-40 and APR-21

LAROM BM-21		Romania
Calibre: 122 mm		
Carrier:SR-114		
No. of tubes/rails:		
Range - 20.75 mm		
Ammunition types		
HE		
Used by: ROM	Same rockets as BM-21 Grad	

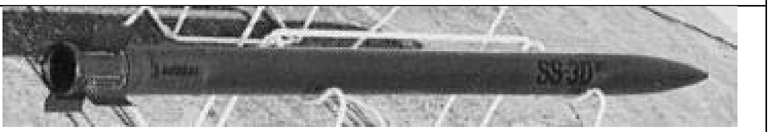
Lynx	IMI	Israel
Calibre: 122 / 160 / 300 mm		
Carrier:KamAZ-740		
No. of tubes/rails: 40 / 26 / 8		
Range - 21 / 45 / 150 km		
Ammunition types		
HE Frag		
Smoke		
Prefrag		
Incendiary		
AT mines		
Cluster		
Illumination		
Used by: AZB	122 mm uses same rockets as BM-21 Grad 160 mm uses same rockets as for LAR-160 300 mm rocket weighs 450 kg; warhead 150 kg; Length 3970 mm; guided	

http://www.military-today.com/artillery/azerbaijan_lynx.htm

Valkiri Mk I 22	Armscor	South Africa
Calibre 127 mm		
Carrier: Samil 20		
No. of tubes/rails: 24		
Range 8 – 22.7 km		
Ammunition types		
HE - 53.5 kg		
		
Used by: RSA	Remarks: Firing on less than 15 km requires drag rings	

http://www.army-technology.com/projects/astros/specs.html

Kung-Feng III/IV		Rep China
Calibre: 126 mm	No picture available	
Carrier: Tracked		
No. of tubes/rails:40		
Range: - 9 km		
Ammunition types		
HE		
Used by: ROC	Limited information. Some sources claim that the calibre is 117 mm	

Astros II (SS-30)	Avibrás	Brazil
Calibre 127 mm		
Carrier: Tectran 6x6 AV-LMU		
No. of tubes/rails: 32		
Range 9 – 30 km		
Ammunition types		
HE		
		
Used by: BAH, BRA, IRQ, MLA, QAT, KSA	Previously built in Iraq under licence as Sajil-30 Rocket length 3.9 m Weight 68 kg	

JAA/ JAH

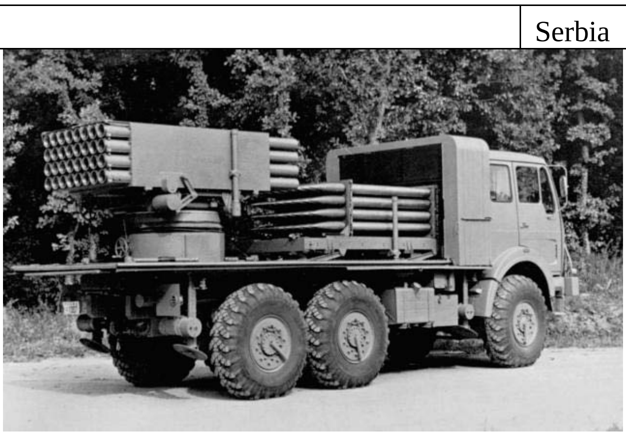
http://www.army-technology.com/projects/astros/specs.html

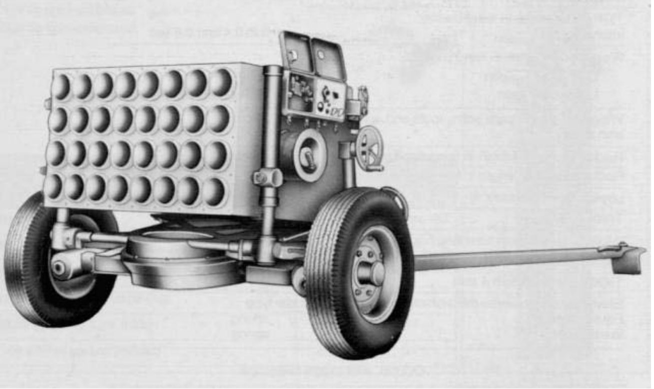
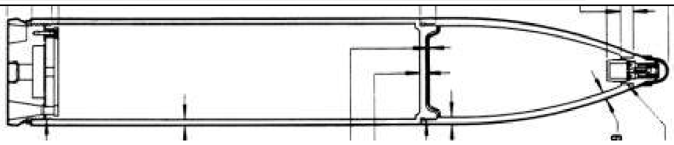
Valkiri Mk I 5	Armscor	South Africa
Calibre 127 mm	No picture available	
Carrier: Towed		
No. of tubes/rails: 12		
Range 5.5 km		
Ammunition types		
HE - 18 kg - prefragmented		
Used by: RSA	Remarks: Burnout velocity 250 m/s at 0.8 s Rocket mass 30 kg; length 1.4 m,	

Valkiri I	Armscor	South Africa
Calibre 127 mm		
Carrier: Samil 20 4 x 4		
No. of tubes/rails: 24		
Range 8 - 22 km		
Ammunition types		
HE - 18 kg - prefragmented		
Used by: RSA	Rocket length 2.68 m; weight 53 kg Production has ceased for the benefit of Bateleur	

http://www.military-today.com/artillery/valkiri.htm

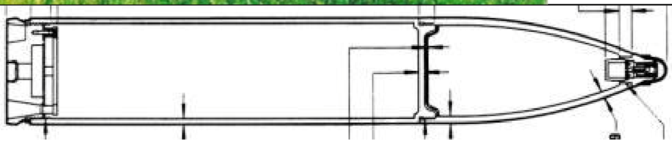
Bateleur	Armscor	South Africa
Calibre 127 mm		
Carrier: Samil 100		
No. of tubes/rails: 40		
Range 8 - 36 km		
Ammunition types		
HE - 18 kg - prefragmented		
Used by: RSA	Rocket mass 62 kg; length 2.95 m	

M77 Oganj		Serbia
Calibre 128 mm		
Carrier: FAP-2026		
No. of tubes/rails: 32		
Range 1.5 – 20.6 km		
Ammunition types		
HE		
DPICM		
Used by: BIH, CRO, SER A portable system is also available	Rocket length 2.6 m, Mass 66.8 m, warhead 19.5 m Max velocity 750 m/s	

M63 Plamen	SDPR, Belgrade	Yugoslavia
Calibre: 128 mm		
Carrier: Towed		
No. of tubes/rails: 32		
Range 3 – 8.5 km		
Ammunition types		
HE M85		
HE M87		
		
Used by: BIH, SER, CRO, MAC, SLV, CYP Portable variant: M71 Partizan	M63: length 0.814 m, rocket mass 23 kg, warhead 8 kg M87: length 0.96 m; rocket mass 25.5 kg, warhead 9.4 kg Max velocity 444 m/s, Spin stabilized system	

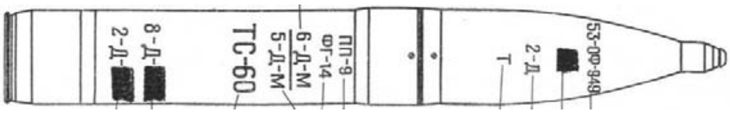
Type 82		PR China
Calibre: 130 mm		
Carrier: 6 x 6 truck		
No. of tubes/rails: 30		
Range - 10.1 km		
Ammunition types		
HE		
Enh. frag (2600 frags.)		
		
Used by: PRC, BAN	Spin stabilized rocket Rocket mass 32 kg; warhead 3 kg, length ~1 m Improved Type 63 system	

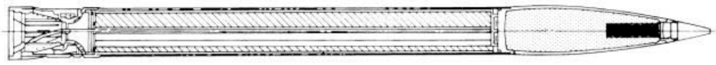
sinodefence

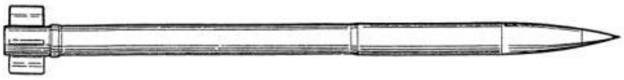
LOV RAK 24/128	RH ALAN	Croatia
Calibre: 130 mm (128 mm)	 Source: Croatian Min. of Defense	
Carrier: LOV APC		
No. of tubes/rails:24		
Range: - 8.55 km		
Ammunition types		
HE M91		
HE M93		
		
	Same rocket as for M85 Plamen	
Used by: CRO	M91 mass 23.2 kg, warhead 8.5 kg, fuel 4.5 kg M93 mass 26.0 kg, warhead 9.0 kg, fuel 7.5 kg M93 has 13 km range. Spin stabilized	

Kooyong	Daewoo Heavy Ind	Rep. Korea
Calibre 130 mm		
Carrier: KM809A1		
No. of tubes/rails: 36		
Range 10 – 32 km		
Ammunition types		
Mk 1 – 54 kg		
Mk 2 – 64 kg		
Used by: SKO	Remarks: Warhead weight 21 kg with 6.5 kg HE	

BM-13-16		SOV
Calibre: 132 mm		
Carrier: ZIL-151		
No. of tubes/rails: 16		
Range - 9.0 km		
Ammunition types		
HE		
		
Used by: CMB, EGY, SML, TLB, VIE	Rocket mass 93 kg; warhead 43 kg	

BM-14-16/17		Soviet Union
Calibre: 140 mm		
Carrier:GAZ-63		
No. of tubes/rails:16/17		
Range - 10.6 km		
Ammunition types		
HE (FG-14)		
Smoke		
Incendary		
		
Used by: ALG, CMB, CON, CUB, INA, KAZ, SML, TLB, VIE, YEM	Rocket length 1051 mm; mass 40.3 kg Warhead 7.65 kg, explosive 4.2 kg Velocity at launch 27 – 40 m/s; at burnout 400 m/s	

Teruel	Santa Barbara	Spain
Calibre 140 mm		
Carrier: Pegaso 3055 6x6		
No. of tubes/rails: 40		
Range 6 – 18/28 km		
Ammunition types		
HE		
Cargo – 42 ESPIN bomblets		
Cargo – 24 DPICM		
Cargo – 6 AT mines		
Smoke – 14 grenades		
Used by: SPA, GAB (Spain to replace by HIMARS)	Remarks: Two rocket versions – a standard 18 km range and an extended range 28 km	

<table>
<tr><td>VCLC-CAL</td><td>Thyssen-Henschel / IMI</td><td>Argentina</td></tr>
<tr><td>Calibre: 160 mm</td><td colspan="2" rowspan="9"></td></tr>
<tr><td>Carrier:</td></tr>
<tr><td>No. of tubes/rails: 36</td></tr>
<tr><td>Range 12 – 35 km</td></tr>
<tr><td>Ammunition types</td></tr>
<tr><td>HE</td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td><td colspan="2" rowspan="4"></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>Used by: ARG</td><td colspan="2">No concrete information on the rocket, but probably the same as the Israeli 160 mm</td></tr>
</table>

<table>
<tr><td>LAR-160</td><td>IMI</td><td>Israel</td></tr>
<tr><td>Calibre 160 mm</td><td colspan="2" rowspan="9"></td></tr>
<tr><td>Carrier:Various</td></tr>
<tr><td>No. of tubes/rails: 36</td></tr>
<tr><td>Range 12 – 34 km</td></tr>
<tr><td>Ammunition types</td></tr>
<tr><td>LAR Mk 1</td></tr>
<tr><td>LAR Mk II</td></tr>
<tr><td>LAR Cargo</td></tr>
<tr><td>ACCULAR Mk I</td></tr>
<tr><td>ACCULAR Mk II</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>ACCULAR Mk IV</td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>Used by: ISL, GEO, VEN</td><td colspan="2">Remarks: LAR Mk II weighs 110 kg with 46 kg WH, length 3.31 m, burnout velocity is 1022 m/s. Cargo WH carries 104 M85
ACCULAR has a TCS in nose.</td></tr>
</table>

LAROM LAR-160	Aerostar	Israel
Calibre: 160 mm		
Carrier:		
No. of tubes/rails: 28		
Range - 45km		
Ammunition types		
HE/Frag		
DPICM		
Used by: ROM	Joint development with IMI, Israel Rocket length 3.3 m, Weight 110 kg Warhead 46 kg (MKII)	

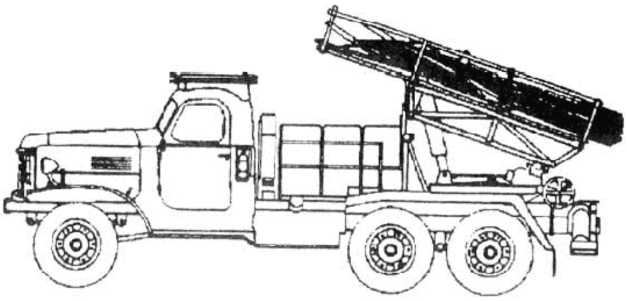
Rayo	FAMAE,	Chile
Calibre 160 mm		
Carrier: MAN SX2000		
No. of tubes/rails: 24		
Range – 45 km.		
Ammunition types		
HE 11 kg		
		
Used by: CHL	Remarks: Rockets weigh 122.5 kg, length 3.5 m and reaches 1240 m/s after 2 seconds..	

http://www.acapomil.cl/investigacion/boletines/boletin_2000/03_Articulos_Gestion_de_Calidad/03_Art%EDculos_Gesti%F3n_de_calidad_por_medio_de_la_administraci%F3n_de_proyectos_e_ingenier%EDa_de_sist emas.htm

Astros II (SS-40)	Avibrás	Brazil
Calibre 180 mm		
Carrier: Tectran 6x6 AV-LMU		
No. of tubes/rails: 16		
Range 15 – 35 km		
Ammunition types		
HE-1		
DPICM (20 bomblets)		
Mines (AP or AT)		
Anti-tunway		
		
Used by: BAH, BRA, IRQ, MAY, KSA	Rocket length 4.2 m Weight 152 kg Built in Iraq under licence as Sajil-40 Bomblet are probably 72 mm in diameter	

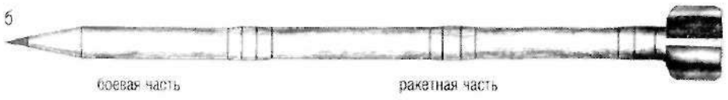
RT2000 Mk30		Rep. China
Calibre: 180 mm		
Carrier:M977 HEMTT		
No. of tubes/rails: 27		
Range - 30 km		
Ammunition types		
HE		
Cluster		
Used by: ROC	The vehicle can fire while moving.	

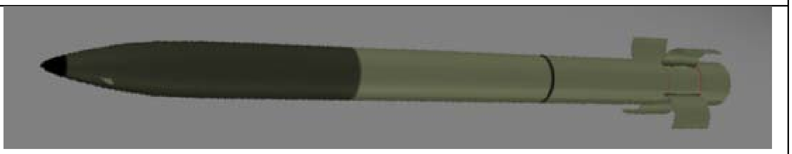
http://www.military-today.com/artillery/rt2000.htm

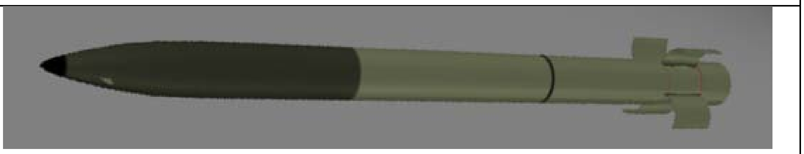
BMD-20 (8U33)		Soviet Union
Calibre: 200 mm		
Carrier:ZIS-151		
No. of tubes/rails: 4		
Range - 18.75 km		
Ammunition types		
HE (MD-20F)		
HE (MD-24F)		
		
Used by: ETI, PRK	Rocket weight 194 kg Burn-out velocity 535 – 590 m/s	

Pinaka	Larsen & Toubro / Tata group	India
Calibre 214 mm		
Carrier: Tatra T-815		
No. of tubes/rails: 12		
Range 7 –45 km		
Ammunition types		
HE		
Incendiary		
Cargo - AT mines		
Cargo - AP mines		
Cargo – DPICM bomblets		
Used by: IND	Rocket weighs 276 kg with around 100 kg explosive. Full load salvo takes 44 s. Rocket length 4.9 m	

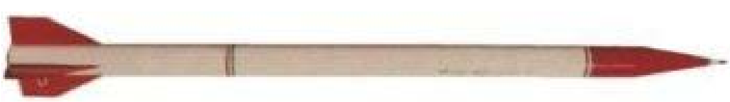
TOS-1		Ryssia
Calibre: 220 mm		
Carrier: Tank chassis (T-72)		
No. of tubes/rails: 30 km		
Range: 0.4 – 3.5		
Ammunition types		
FAE (tetranite fuel)		
Used by: RUS	Incendiary warhead with FAE or Thermobaric content	

BM-27 Uragan	Splav	Soviet Union
Calibre: 220 mm		
Carrier:		
No. of tubes/rails:		
Range		
Ammunition types		
Varied ammo available		
See section H.x		
		
Used by: AFG, BLR, GUI, KAZ, MOL, RUS, TLB, TRM, UKR, UZB, YEM	Se special section H-2	

MLRS	Vought Corp.	USA
Calibre: 227 mm	 © 2001 Danish Army Vehicles Homepage	
Carrier: M270 tracked veh.		
No. of tubes/rails: 12		
Range 7 - 32/40 km		
Ammunition types		
M26 (644 M77 DPICM)		
M26A1 (518 M77 DPICM)		
M26A2 (518 M85 DPICM)		
M30 (404 M101 DPICM)		
AT2 (28 AT2 mines)		
Used by: BAH, DEN, EGY, FRA, GER, ISL, ITA, JAP, NOR, ROK, TUR, UAE, UK, US	See appendix H-3 Tubes have 240 mm inner diameter	

MLRS		USA
Calibre: 227 mm		
Carrier: HIMARS		
No. of tubes/rails:6		
Range - 32 – 60 km		
Ammunition types		
M26 (644 M77 DPICM)		
M26A1 (518 M77 DPICM)		
M26A2 (518 M85 DPICM)		
M30 (404 M101 DPICM)		
AT2 (28 AT2 mines)		
M26 (644 M77 DPICM)		
Used by: SIN, UAE, US	Tubes have 240 mm inner diameter Further described in section H-3	

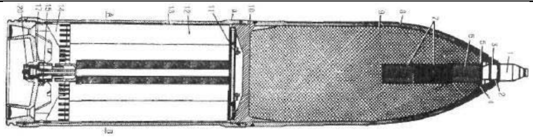
TOROS 230A	MKEK / SAGE	Turkey
Calibre: 230 mm		
Carrier: Various trucks		
No. of tubes/rails: 6		
Range 10 - 65 km		
Ammunition types		
HE/Frag		
		
Used by: TUR	Rocket mass 326 kg, warhead 120 kg Rocker length 4.1 m 4 WAFs	

Oghab	Parchin Missile Ind./AOI	Iran
Calibre: 230 mm		
Carrier: 6 x 6 truck		
No. of tubes/rails: 4		
Range - 34 km		
Ammunition types		
HE/Frag		
Long range version 45 km		
		
Used by: IRN	Max. velocity 750 m/s. Rocket length 4.82 m. Rocket mass 360 kg, 70 kg warhead, 128 kg propellant	

JAH

RT2000 Mk45		Rep. China
Calibre: 230 mm	 Military-Today.com	
Carrier:M977 HEMTT		
No. of tubes/rails:12		
Range - 45 km		
Ammunition types		
HE		
Cluster		
Used by: ROC (status uncertain)	The vehicle can fire while moving	

http://www.military-today.com/artillery/rt2000.htm

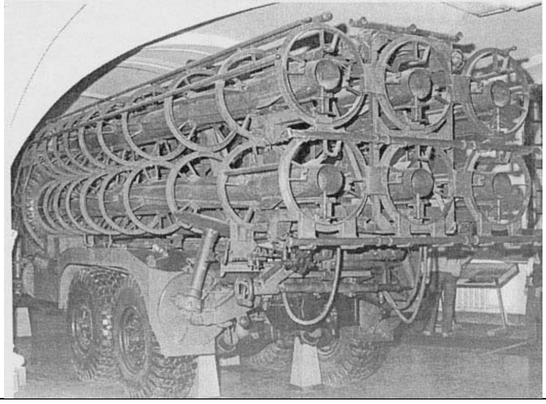
BM-24		Soviet Union
Calibre: 240 mm		
Carrier: ZIL-151/157		
No. of tubes/rails:12		
Range - 10.2		
Ammunition types		
HE		
Smoke		
Chemical		
		
Used by: AFG, ALG, EGY, HEZ, ISL, SML, YEM	Warhead weight 60.8 kg; explosive 27.4 kg Rocket length 1124 mm; mass 112 kg	

Fadjr-3	Parchin Missile Ind./AOI	Iran
Calibre: 240 mm		
Carrier: MB 6 x 6		
No. of tubes/rails:12		
Range: 17 - 43 km		
Ammunition types		
HE/Frag		
Smoke		
Inc		
Chemical		
		
Used by: IRN, HEZ Believed to be equiv to north Koren M1985 and M1991	Rockat mass 407 kg; warhead 90 kg, explosive 42 kg Rocket length 5.2 nm. 3 WAFs	

JAH, JAA, Shapir

Falaq-1	Aerospace Industries Organization	Iran
Calibre: 240 mm		
Carrier:4 x 4 light jeep		
No. of tubes/rails: 4		
Range - 10.8 km		
Ammunition types		
		
Used by: IRN	Rocket length 1,32 m. Rocket mass 111 kg Warhead mass 50 kg The rocket is right spin stabilized with 16 nozzles A single launch tube be mounted on a tripod	

JAH, Cordesman[53]

Korshun 3P7 / BM-25		Soviet Union
Calibre:250 mm		
Carrier: KrAZ-214 6x6		
No. of tubes/rails: 6		
Range - 55 km		
Ammunition types		
HE		
Used by: YEM (may now be phased out)	The motor is supposed to be liquid based Rocket mass 375 kg, wahead 100 kg. Rocket length 5535 mm Burn time 7,8 s. Max. velocity 1002 m/s	

Öst

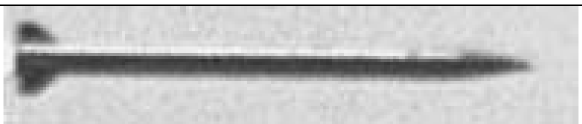
The term BM-25 is also a tactical rocket system (North Korean), but is not related to 3P7

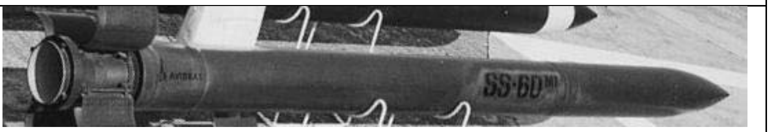
TOROS 260A	MKEK / SAGE	Turkey
Calibre: 260 mm		
Carrier: Various trucks		
No. of tubes/rails: 4		
Range 15 - 100 km		
Ammunition types		
HE/Frag		
Used by: TUR	Rocket mass 410 kg, warhead 145 kg Rocker length 4.8 m 4 WAFs	

M87 Orkan (R-262)		Serbia
Calibre 262 mm		
Carrier: FAP 2832 and others		
No. of tubes/rails: 12		
Range: 5 - 50 km		
Ammunition types		
Cargo – 288 DPICM bomblets		
Mines – 24 AT mines		
Used by: SER; BIH, CRO. System was developed jointly with Iraq, where it was known as Ababil-50	Remarks: Bomblet contain 420 spherical fragments. Rocket mass 390 kg, (mine-rocket 382 kg) Booster 10 kg, sustainer 130 kg (burns for 5 s) Burnout velocity 1200 m/s 3-step aerodynamic brake	

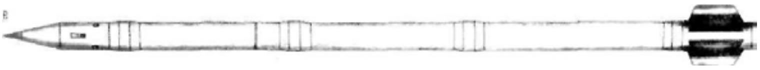
Type 83	Norinco	PR China
Calibre: 273 mm		
Carrier: Type 60-1 tracked		
No. of tubes/rails: 4		
Range 23 - 40 km		
Ammunition types		
HE/Frag		
80 km version available		
	 Source: U.S. Naval EOD Technology Division	
Used by: PRC, Iran produces its own variant called Oghab	Rocket length 4.753 m Lauch velocity 39 m/s; burnout velocity 810.5 m/s Rocket mass 484 kg	

WM-80	Norinco	PR China
Calibre: 273 mm		
Carrier: TA-580 8 x 8 truck		
No. of tubes/rails:8		
Range 34 - 80 km		
Ammunition types		
HE/Frag		
Cargo (380 DPICM)		
Used by: PRC	Launch velocity 40 m/s, burnout velocity 1140 m/s, apogee 31 km. Rocket length 4.582 m Rocket mass 505 kg, propellant 205.5 kg, warhead 150 kg, explosibe 34 kg	

MAR-290	IMI	Israel
Calibre 290 mm		
Carrier: Centurion/Sherman		
No. of tubes/rails: 4		
Range - 40 km		
Ammunition types		
		
Used by: ISL Status uncertain)	Remarks: The rocket is launched from a rail with both rail and rocket inside a tube due to the fixed fins arrangement.	

Astros II (SS-60/SS-80)	Avibrás	Brazil
Calibre 300 mm		
Carrier: Tectran 6x6 AV-LMU		
No. of tubes/rails: 4		
Range 20 – 80 km		
Ammunition types		
DPICM (65) 212 kg		
Mines (AP or AT)		
HE-I		
Anti-runway		
	 	
Used by: BAH, BRA, IRQ, MAY, QAT, KSA	.Built in Iraq under licence as Sajil-60 SS-80 has a range of 22 – 90 km Rocket length 5.6 m Weight 595 kg Bomblet is 390 mm long 130 mm in diameter	

JAH/JAA
http://www.army-technology.com/projects/astros/specs.html

BM-30 Smerch	Splav	Soviet Union
Calibre: 300 mm		
Carrier:		
No. of tubes/rails: 12		
Range 20 – 70 km		
Ammunition types		
Various		
See section H.x		
		
Used by: ALG, AZB, BLR, IND, KUW, RUS, TRM, UAE, UKR	See special section H-4	

A-100	Norinco	PR China
Calibre: 300 mm		
Carrier: WS-2400		
No. of tubes/rails:10		
Range: 20 – (50-100)		
Ammunition types		
Frag-bomblets		
Mines		
HE/frag		
FAE		
DPICM		
Used by: PRC, PAK		

sinodefemce

http://trishulgroup.blogspot.com/2008/09/pakistan-army-upgrades-its-field.html

T-300 Kasirga	Roketsan	Turkey
Calibre: 302 mm		
Carrier: MAN 6 x 6		
No. of tubes/rails: 4		
Range 20 - 100 km		
Ammunition types		
HE/Prefrag		
Cluster		
Used by: TUR Turkish version the Chinese WS-1	Rocket length 4.7 m; weigth 524 kg Warhead 150 kg	

Asian Defence

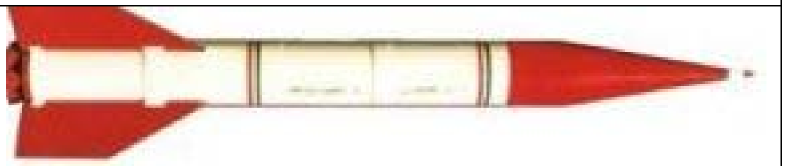
WS-1		PR China
Calibre: 302 mm		
Carrier: 6 x 6 or 8 x 8 truck		
No. of tubes/rails: 4		
Range: 40 -100 km		
Ammunition types		
Various		
Used by: PRC	Rocket length 4.737 m; mass 524 kg; warhead150 kg Burnout velocity: 1250 m/s Accuracy 1 – 1.25%	

Sinodefence, Shapir

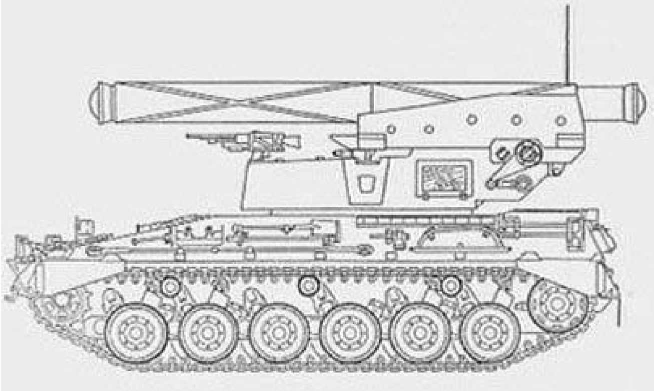
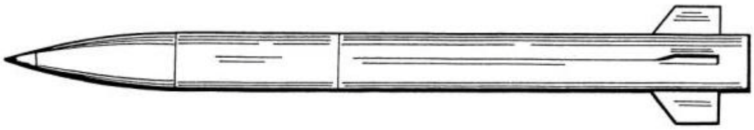
WS-1B		PR China
Calibre: 302 mm		
Carrier: Various trucks		
No. of tubes/rails:4 - 8		
Range: 60 -180 km		
Ammunition types		
Various		
Used by:	Rocket length 6.376 m; mass 725 kg; warhead150 kg Burnout velocity: 1750 m/s Accuracy 1 – 1.25%	

Sinodefence

Falaq-2	Shahid Bagheri Ind /AOI	Iran
Calibre: 333 mm		
Carrier: 4 x 4 jeep		
No. of tubes/rails:1		
Range - 11 km		
Ammunition types		
HE		
		
Used by: IRN, HEZ	Rocket mass 255 kg; warhead 120 kg, explosive 60 kg Rocket length 1.82 m. Max altitude 3200 m Right spin-stabilized with 8 nozzles	

Shahin II	AOI	Iran
Calibre: 333 mm		
Carrier:		
No. of tubes/rails:		
Range - 20 km		
Ammunition types		
HE		
		
Used by: IRN, HEZ Also called Fadjr-4	Rocket mass 384/530 kg, Warhead mass 190 kg, length 2.90 (Shahin I), 3.90 m (Shahin II) Picture above is Shahin II, Shahin I is shorter with 13 km range	

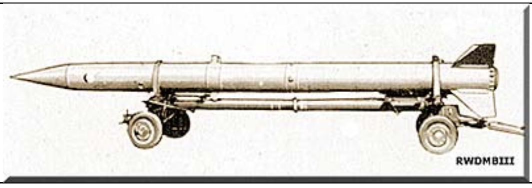
Fadjr-5	Aerospace Industries Organization	Iran
Calibre: 333 mm		
Carrier: 6 x 6 truck		
No. of tubes/rails: 4		
Range: - 75 km		
Ammunition types		
HE/Frag		
		
Used by: IRN, HEZ	Rocket length 6.485 m Rocket mass 915 kg Propellant 175 kg, warhead 90 kg	

MAR-350	IMI	Israel
Calibre: 350 mm		
Carrier: Tank chassis		
No. of tubes/rails: 2		
Range 40 - 80 km		
Ammunition types		
HE/Frag		
Cargo (770 Bantam bomblets)		
TCS rocket available		
		
Used by: ROM, ISL (status is uncertain)	Rocket mass 835 kg, propellant 320 kg, warhead 334 kg Rocket length 5 m Launch velocity 40 m/s; burnout velocity 1200 m/s; burn time 3.3 s; apogee 28 km; thrust 235 kN	

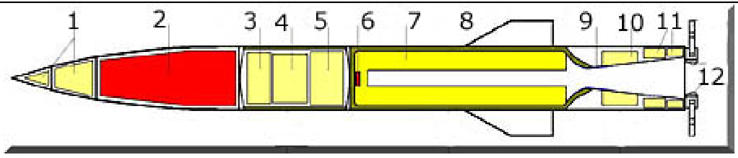
Nazeat	AIO	Iran
Calibre 356 mm		
Carrier: MB 2624 6 x 6		
No. of tubes/rails:		
Range - 120 km		
Ammunition types		
Used by: IRN	Different version N4, N5, N6 Max velocity 1800 m/s	

WS-2		PR China
Calibre: 400 mm		
Carrier:		
No. of tubes/rails: 6		
Range 70 – 200 km		
Ammunition types		
Used by: PRC	Rocket length 7.3 m; mass 1285 kg, warhead 200 kg Primitive INS guidance with accuracy 0.17%	

Sinodefence

Luna-M (NATO:FROG-7B)	BAZ	Soviet Union
Calibre: 544 mm		
Carrier:ZIL-135 LM		
No. of tubes/rails:1		
Range: 15 – 65 km		
Ammunition types		
9M21B (nuc)		
9M21F (HE)		
9M21E (42 9N18 bomblets)		
9M21Kh (chem. bomblets)		
		
Used by: BLR, BIH, CUB, EGY, HUN, NKO, LEB, ROM, RUS, SLV, SYR, UKR, YEM	Warhead weight 420 – 57 kg, Rocket length 8.95 – 9.4 m Rocket weight 2.5 tons	

http://www.rwd-mb3.de/pages/9m21.htm

9P129 Tochka OTR-21, (NATO: SS-21 Scarab)	KBM, Kolomna	Russia
Calibre: 650 mm		
Carrier: BAZ-5921		
No. of tubes/rails:		
Range: 20 – 120 km		
Ammunition types		
9M79F (HE)		
9M79K (50 9N123K bomblets)		
9M79B (Nuc.)		
		
Used by: AZE, BLR, BUL, POL, RUS, UKR, SYR, YEM	Rocket length 6.4m, weight 2.0 tons, warhead 482 kg Max. velocity 1800 m/s INS guidance	

http://www.rwd-mb3.de/pages/9m79.htm

MGM-140 ATACMS	Northrop - Grumman	USA
Calibre : 607 mm		
Carrier: M270		
No. of tubes/rails:2		
Range - 140+ km		
Ammunition types		
M39 (950 M74 bomblets)		
Used by: BAH, GRE, ROK, UAE, US,	Rocket length 3.978 m; mass 1495 kg Warhead 500 kg;	

Zelzal-2	AIO	Iran
Calibre : 610 mm		
Carrier: MB truck		
No. of tubes/rails:1		
Range - 210 km		
Ammunition types		
HE		
Used by: IRN	Rocket length 8.325 m; mass 3400 kg Warhead 600 kg; propellant 1840 kg Isp 235 s PPG fuel Accuracy 5%	

Iskander (NATO: SS-26 Stone)	KBM, Kolomna	Russia
Calibre 950 mm		
Carrier: MAZ-79306 8 x 8		
No. of tubes/rails:2		
Range. 50 – 500 km*		
Ammunition types		
HE		
Cluster (54 bomblets)		
Others		
		
Used by: RUS	Rocket weight 3800 kg, length 7.2 m Burnout velocity 2100 m/s, warhead 480 kg Guided – accuracy < 10 m	

Range is 280 km for Iskander-E (export version)

H.1 122 mm systems

H.1.1 BM-21

122 mm constitute are by far the most proliferated systems of rocket artillery. The classical type is the Russian (Soviet) BM-21 Grad which was developed in the mid 1950s. This system has been exported into many countries of which several have modified and improved the system into their own independent product.

BM-21 was used for the first time in combat during the brief Soviet-Chinese conflict on the Damanskiy Island on the Ussuri river in March 1969.

This BM-21 system has been developed along several avenues and is currently in used in dozens of countries. A somewhat obsolete feature of the system is that it has to be reloaded manually and with one rocket at a time. A process that with a well trained crew takes 10 – 15 seconds per tube.

When fired at a range of around 14 km, BM-21 rockets are supposed to have an accuracy (probable error) of 100 m in range and 80 m in deflection [33]. It is believed that only random errors are included in this budget.

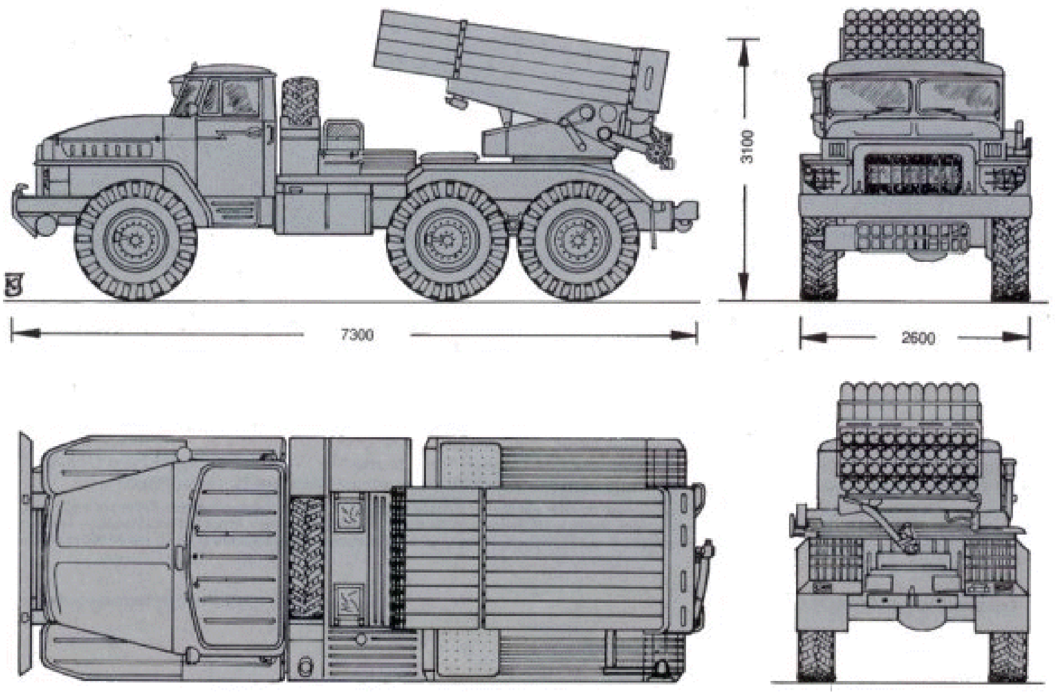


Figure H.1 BM-21 – the most proliferated artillery rocket system

The most known types are

- BM-21 – the original type – had 40 launch tubes (4 rows with 10 each) and was carried by an Ural-375D 6 wheeled truck. As with other truck carried version the rockets could be fired selectively or by a complete salvo.
- BM-21V (Grad-V) has 12 tubes (2 rows with 6 each) carried by a Gaz-66B 4 wheeled light truck providing better terrain mobility than the original one. It was intended to be used by air deployed units.
- BM-21B (Grad-1/9P138) has 36 tubes arranged in the same way as on the original one but two tubes in the middle of the two lower rows has been removed. It is carried by a Zil-131 6 wheeled truck. Only rockets with high explosive warhead and with reduced range can be used.
- BM-21-1 is similar to the original version but is mounted on a more modern Ural 4320 truck. It was developed in the late 1980s
- BM-21 P (Partizan) was originally developed for Speznaz or special forces. It is a single tube system consisting of a bipod, a tube and a shortened version of the rocket weighing 46 kg. The total weight of the system including one rocket is around 75 kg. The rocket can be disassembled into two parts for the purpose of portability. This system has become popular in some non-state forces like Hezbollah. This system can not fire the standard 3 meter long BM-21 rockets.
- Prima (9A51) is the latest development taking place in the early 1990s. It uses the same vehicle as BM-21-1. The launcher has 50 tubes. The complete system also includes at reloading vehicle.

- Romania once showed a single tube version consisting of a tube, an aiming device and a tripod. Including one rocket the weight was supposed to be 105 kg. The range of the rocket was limited to 13.4 km probably due to the limited elevation at launch.
- RM-70 is a modernized version of the original system made in the early 1970 by Czechoslovakia. It is carried by a Tatra 813 8-wheeled vehicle. The improvement consisted of crew fragment protection a devices to speed up the reloading process
- RM70/85 was also developed in Czechoslovakia. It is quite similar to the previous version but uses a Tatra T815 vehicle. The emphasize to put more on CBRN-protection than on fragment protection

Ammunition for BM-21

Type	**Length (m)**	**Weight (kg)**	**Min range (km)**	**Max. range (km)**	**Content**	**Remarks**
9M22	2.87	66		20.75	HE/Frag	700 m/s
9M22U	3.226	66.35	1.5	20.38	HE/Frag	18.4 kg WH
9M22M	1.913	45.7	3	10.8	HE/Frag	Portable
9M22S					Incendiary	
9M23					Frag/Chem	2.3 kg agent
9M28D					Leaflets	
9M28F	1.93	56.5	1.4	13.4	HE/Frag	450/585 m/s 21 kg WH
9M53F	3.037	70	5	33	HE/Frag/p	
9M43	2.949	66	5	20.2	Smoke	5 elements w/0.8 kg RP
9M42	~1.5	27	1	5	Illumination	1.5 min
9M28K	3.019	57.7	4	13.4	AT mines	3 PTM-3
3M16	3.019	56.4	4	13.4	AP mines	5 POM-2
9M21	2.87	66	5	20.4	Chemical	
9M519	3.025	66	4.5	18.5	Jammer (9 types)	18.5 kg
9M521	2.84	66		40	HE/Frag	
9M522	3.037	70		37.5	HE/Frag	Parachute descent
9M217	3.037	70		33	2 SFW	
9M218	3.037	70		30	DPICM	45 KOBE
9M22S		66.6				9N510

Table H.1 Russian 122 mm ammunition

The BM-21 was produced by the Russian company NII-147 in Tula. This company was later renamed Splav.

H.1.2 Chinese variants

People’s Republic of China has several quite modern versions of 122 mm systems. Beside the classical Soviet made BM-21 they also have the track vehicle carried Type-89, the wheeled carried Type 90 which both are from the 1980. An even newer version of the WS-6, as new 40 barrel on a truck is produced by The Sichuan Aerospace Industry Corporation (SCAIC) and has recently gone into production. (JAH). It is not what the difference between WS-6 and WS-1E is.

Warhead	Length (m)	Total weight (kg)	Warhead weight (kg)	Max. range (km)	Min. range (km)
He/Frag	2.87	67	18.3	20	9.6
Enhanced fragmentation	2.87	67	18.3	20	9.6
Enhanced fragmentation	2.87	67	18.3	20	12
Cluster (39 bomblets)	3.037	66	18.3	20	9.6
Cluster (74 bomblets)	2.87	68	28	26	13
He/Frag	2.757	61	18.3	33	12.7
Enhanced fragmentation	2.757	61	18.3	33	12.4
Cluster (13 bomblets)	2.927	61	18.3	32	15
Enhanced fragmentation	2.9	67	22	40	20
Cluster (44 bomblets)	3.008	67	22	40	20
Cluster (6 AT mines)	2.95	58	26	15	6
Cluster (8AT mines)	2.83	63	33	7	-
Cluster (128 AP mines)	2.83	63	33	7	-

http://rbase.new-factoria.ru/search/index7.htm and JAH

Table H.2 Chinese types of ammunition for 122 mm rockets (The cluster warhead with 39 or 44 bomblets probably contain MZD-2 bomblets; the 74 bomblets warhead must have smaller bomblets). The enhanced fragmentation warheads have metal spheres in the casing

H.1.3 Turkish variants

The Turkish variant of 122 mm is produced by the company Roketsan. It seems likely that Turkey has got a lot of their MRL technology from PR China. Many similarities are found for 122 mm systems and for higher calibre types.

Warhead	Length (m)	Total weight (kg)	Warhead weight (kg)	Max. range (km)	Min. range (km)	Fuze
TR-122 HE	2.93	65.9	18.4	40	10	PDet
TRB-122 HE/Frag	2.93	65.9	18.4	40	10	Prox
TRK-122 Cluster (see text below)	3.24	71.6	22.9	30	16	Time
SR-122 HE	2.9	66.6	18.4	20	3	PDet
SRB-122 HE/Frag	2.9	67.1	18.4	20	3	Pros
Cluster (128 AP mines)	-	-	-	-	-	

http://www.new-factoria.ru/missile/wobb/t122/t122.shtml

Table H.3 Turkish variant of 122 mm ammunition. The cluster warhead contains 50 DPICM and 6 incendiary bomblets each weighing 280 g with hexogene content

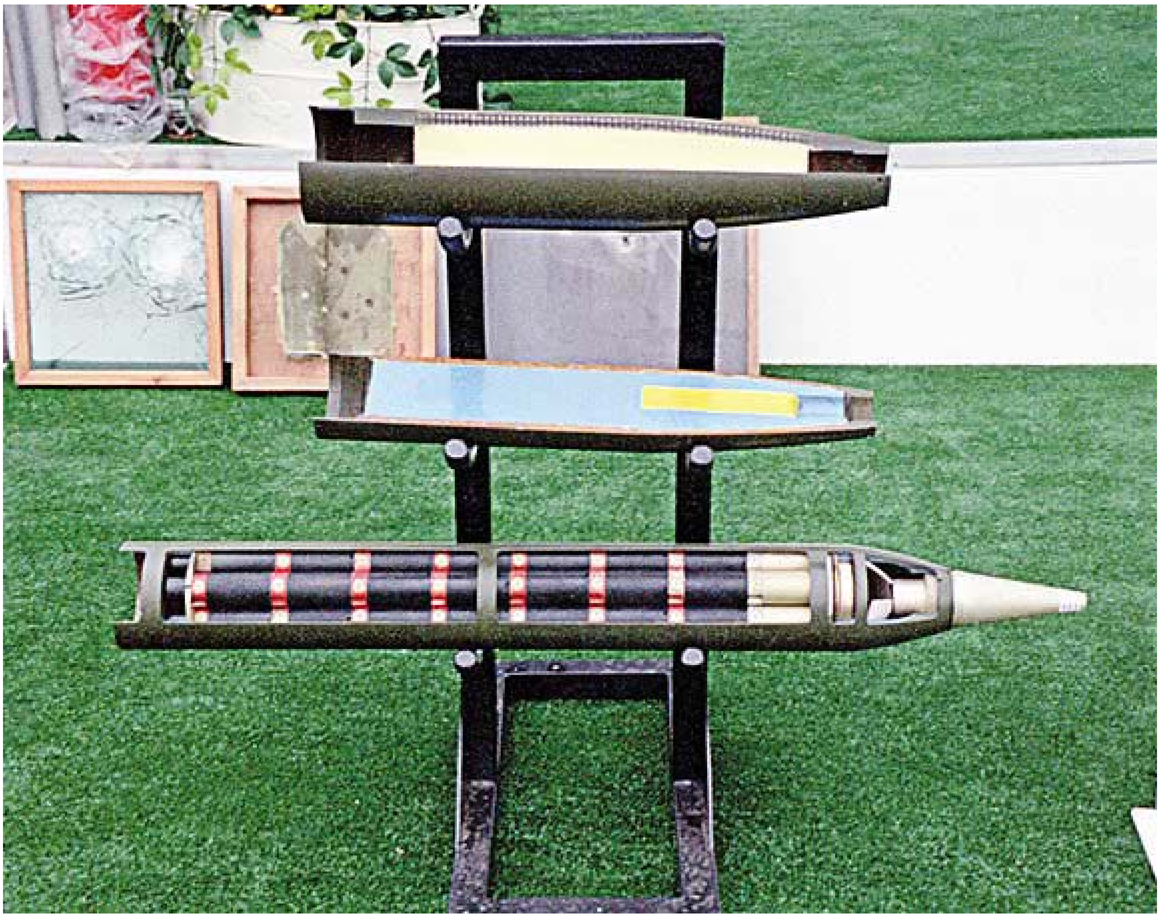


Figure H.2 Chinese warheads for 122 mm. From above: HE with enhanced fragmentation effect (metal spheres); ordinary HE, and DPICM warhead. (http://rbase.new-factoria.ru/search/index7.htm)

Other countries producing equivalent ammunition for 122 mm rockets are shown in the table below.

Country	Manufacturer	Rocket/system name	Note
Belarus		BelGrad	
Bulgaria	Vazov Eng.	M-21 OF	
China	Norinco	Type 81	4 types of ammo
		Type 83 (tracked)	
		Type 83 (wheeled)	
		Type 89	
		Type 90A	
	Sichuan AIC	WS-6	
Croatia	R H ALAN	M93	M-21 OF copy
Czech Republic		RM-70	
		RM-70/85	
Egypt	Heliopolis	Saqr copies	
	Helwan	Saqr-10 (short 46 kg)	Cargo WH
		Saqr-18	
		Saqr-36	Smoke D-6000
		PR-111	
		PR-113	
India	ARDE, Pune	LRAR	9M22 copy
Iran	AMIG	Arash	9M22 copy
		Noor	Single tube version
		Arash (long range)	Enlarges motor
		Fadjr 6	Mines payload
Italy	Simmel	Firos 25 Firos 30	7 types for each (HE, TP, WP, prefragmentes, AT mines, AP mines and DPICM)
North Korea	State factories	BM-11	9M22 copy
Pakistan	Pak. Ord. Factories	Yarmuk	9M22 derivate
	A Q Khan Res. Lab.	-	HE/Frag rocket
Poland	Tlocznia MPSA	Grad	9M22 derivate
		Spall	Airburst
		Platan	AT mines
	Presta		M21 HE/Frag
			M21-OF HE/FRag
			AT mines
Romania		APR-21	
Serbia	Yugoimport-SDPR	M88	9M22 derivate
Slovakia	Technopol	AGAT/JRKK-G	DPICM bomblets
		LR (long range)	Aircraft mounted
		Trnovik	DPICM bomblets

Country	Manufacturer	Rocket/system name	Note
	Synthesia ZVS Holding	EXP-122 JROF JROF-K	9M22 derivate 9M22 derivate Shortened rocket
South Africa	Mechem	RO 122 68 mm subcalibre	Prefragmented Training
Turkey	Roketsan	T-122	Long range version
Ukraine		BM-21/KraZ chassis	

H.1.4 Other variants

It is known that North-Korea, Belarus, former Yugoslavia, Czech Republic, Iran, Egypt have produced their own variants of BM-21

H.2 220 mm systems (BM-27 Uragan)

The 9P140 Uragan (previously referred to incorrectly as BM-22 or BM-27) is the world’s first modern fin and spin-stabilized heavy rocket system. Essentially a scaled-up version of the BM-21, the 9P140 use many of the same design features. The launcher, the 9T452 transloader, the rockets, and support equipment constitute the 9K57 complex.

The 9P140 and its transloader are both based on variants of the gasoline-powered ZIL-135LM 8-ton 8x8 chassis. The truck is unusual in that it uses two engines, each driving the wheels on one side of the truck, and only the front and rear axles steer. The 9P140 cab has a blast shield that is raised during firing, and the vehicle is stabilized during firing by two manually emplaced hydraulic jacks at the rear of the chassis.

The launcher has electrically powered traversing and elevating mechanisms. During travel, the launcher assembly is oriented rearward and a light sheet metal cover over the muzzle end of the tubes prevents foreign material from entering the tube. This is a safety feature that is designed for travel when loaded. There is no such cover for the muzzle end of an unloaded launcher.

The rockets have a maximum velocity of 700 – 800 m/s. The motor is said to burn for 3.18 s, but the maximum thrust of 58 kN is probably reached at 15 – 2.0 seconds after start.

The ammunition used for Uragan is shown in the table below. Less is known about Uragan than the other Russian systems

Type	Length (m)	Weight (kg)	Min range (km)	Max. range (km)	Content	Warhead
9M27F	4.832	280.4	10	35	99 kg HE	9N128 F
9M27K	5.178	271	8.5	34	30 ICM	9N210
9M27K1		270			Cargo	9N128K1
9M27K2		270			AT mines	9N128K2
9M27K3		270			AP mines	9N128K3
9M51		256			FAE	9N515
9M59	5.178	270	10	35	AT mines	9 POM-2
9M27S					Incendiary	9N128S
9M27?					Chemical	
9M27D					Leaflets	
9F839					Air target	
9F689					n/a	
unknown				35	SFW	

H.3 The MLRS system

In the West, rocket artillery systems were never given a major role in the armies until the mid 1980s. NATO armies shortly tried systems like Honest John in the 50s and 60s, but their role was quite short-lived. One of the main drawbacks of the Honest John system was its lack of accuracy. It simply could not be used if the wind in the launch area exceeded a certain level, as a strong wind during the boost phase would result in a very unpredictable hit point.

This situation changed in the 1980, when the defensive NATO doctrine shifted towards increased emphasize on the defeat of second echelon forces. This strategy was especially expressed by the SACEUR, general Bernhard Rogers. The MLRS (Multiple Launch Rocket System), which had been planned since the early 1970[51] got a pivot role in this strategy.

The MLRS was, with the possible exception of the German LARS (Light Army Rocket System) the first NATO MRL in earnest and with a capacity to deliver a wide variety of warheads.

The first combat test of MLRS took place during the Gulf War (Operation Desert Storm) in Kuwait in 1991. There is hardly any doubt that MLRS made a devastating effect on enemy forces, but the conflict lasted to short to be called a comprehensive test of the systems. In the aftermath the problems of the dud from the ammunition left in Kuwait was said to create more casualties among EOD forces than among enemy soldiers.

After the Gulf War there were many plans to develop a number of alternative warheads for MLRS in addition to the cluster warhead and the anti-tank mine warheads developed so far. The development plans included

- Sensor Fuzed Warheads (SFW)
- Terminally Guided Warheads (TGW)
- BAT (Brilliant Anti-Tank submunitions)
- cluster warheads with improved bomblets
- Unitary warheads
- Guided rockets

Programs for guided versions of MLRS have been conducted in Israel, USA, Switzerland, Germany and Taiwan. Only Israel and USA are known to have a guided system in operation. That system in base on radio frequency ground tracking and is supposed to have an accuracy of 70 – 120 m. The other programs were supposed to give an accuracy of 50 m based in GPS and INS technology. [54]

The first three of these programs were terminated in the late 1990 with reaching the beyond the prototype level. However, the last three have been completed.

The current MLRS ammunition currently includes the following rockets

Rocket	**Warhead**	**Submunition**	**Calibre**	**Range**
M26	Cargo	644 M77	227 mm	31.5 km
M26A1	Cargo	518 M77	227 mm	45 km
M26A2	Cargo	518 M85	227 mm	45 km
AT-2	AT mines	28 AT-2	237 mm	37.5 km
M28A1	Training		227 mm	14.3 km
FZ204	Training	-	70 mm	9.05 km
M30 (guided)	DPICM	404 M101	227 mm	70 km
M31 (guided)	Unitary	82 kg warhead	227 mm	85 km

Source [55]

As an example, the following table shows the sequence of events for the M26 MLRS rocket from ignition to ground impact

Time	Event
-17 ms	Igniter squib fired by FCS
0	Shear bolts break (first motion)
12 ms	Forward tube cover impact
13 ms	Fin restraint delay device initiated (500 ms delay)
25 ms	External umbilical connector separation
85 ms	Sabot separation (free flight)
130 ms	Nozzle exits tube
250 ms	Fuze timer active
513 ms	Fin restraint device release
535	Fins deployed and locked
1000 ms	Fuze mechanical arming
1500 ms	Motor web burn-out
7300 ms	Complete burn-out
WHE - 3400 ms	Fuze electrical arming
WHE	Warhead event – payload ejection
WHE + ~15 s	Payload ground impact

H.3.1 610 mm ATACMS

ATACMS (Army Tactical Missile System) is the American the counterpart to the Russian FROG and other tactical missiles. It uses the same M270 launcher as MLRS and can be considered as a MLRS-munition. The rockets have a calibre of 610 mm and are fired from a pod that externally is the same as the ordinary MLRS pod. Instead of 6 rockets, the ATACMS pod contains a single rocket. The rocket is guided.

Currently, three different types of rockets are on the market as shown below

Rocket	Warhead	Submunition	Calibre	Range
Block I	Cargo	970 M73	610 mm	
Block IA	Cargo	M73	610 mm	
Unitary	HE	-	610 mm	

H.4 300 mm systems (Smerch)

This is the largest and most complex of the Russian systems, and is superior to the other systems in terms of range, size and accuracy.

The system, called 9A52 or 9A52-2, is placed on an MAZ 8 x 8 wheeled special vehicle weighing 44 tons. There are two sets of ammunition available. The original set had a range of 70 km, while the new set has a range of 90 km. The minimum range is 20 – 25 km. The vehicle has 12 tubes that can be elevated up to 55°. The rockets have a weight of 800 – 815 kg, of which 240 kg constitutes the warhead. The rocket is believed to reach a velocity of 1030 m/s after around 3 seconds of flight.

At 90 km, a guided rocket is a prerequisite. At the Smerch this is implemented as small nozzles at each side of the tip of the rocket. The principle for guidance is not known, but it is probably an inertial systems. The accuracy is claimed to be 0.21%, which translates to 190 m at 90 km range. This is considerably better than unguided systems.

The Chinese A-100 systems are probably built with Smerch as a model.
The table below shows the ammunitions available for this system

Type	**Weight(kg)**	**Content**	
9M55F	820	He/Frag	1100 frags 50 g ea
9M55K	800	ICM	72 9N235
9M55K1	800	SFW	5 Motiv-3M
9M55K3	800	AP mines	64 POM-2
9M55K4	800	AT mines	24 PTM-3
9M55K5	800	DPICM	646 or 588 (2 var)
9M55K6	800	SFW	5 9N268
9M55K7	800	SFW	20 SPBE
9M55S	800	TBX	100 kg HE
9M525	815	ICM	72 9N235 (8 9N139 subcontainers)
9M526	815	SFW	5 Motiv-3M
9M527	815	AT mines	25 PTM-3
9M528	815	HE/Frag	800 frags 5 g ea
9M529	815	TBX	100 kg HE
9M530	815	AS*	75 kg HE
9M531	815	DPICM	646 or 588 (2 var)
9M532	815	SFW	20 9N282
9M533	815	SFW	5 9N268
9M534	815	Drone	“Kipchak”
9M536	815	ICM	20 POBE
9M537	815	ICM	32 OBE NP

AS – anti structural (penetrator)

Submunition used in Smerch

Type	Name	Mass (kg)	Length (mm)	Diam.(mm)	HE mass (kg)	SD* time	Remarks
ICM	9N235	1.75	263	69	0.32	110 s	
ICM	POBE	2	800	40	0.6		70 mm steel pen.
ICM	OBE NP	4.5	215	114	0.9		
DPICM	KOBE	0.24	118/128	43	0.35/0.46	130 – 260 s	120 mm steel pen.
SFW	Motiv-3M	15		185	4.5		70 mm steel pen.
SFW	9N282 Gnom	6.7	307.5	114		110 s	70 mm steel pen.
SFW	9N268	17.3	384	185	5.8		70 mm steel pen.
AP mine	POM-2		180	63	0.13	4 – 100 h	
AT mine	PTM-3	4.85	330	84	1.85	16 – 24 h	

*) SD = Self-Destruct device

Cluster munition delivered with Smerch is dispersed over an area of 40 hectares.

Appendix I Distribution of rocket artillery

This list is based on different sources, but mostly on Jane's. However, even different sources from Jane's do not always match. Other sources may deviate substantially. The list below or what seems to be the most probable one. Apart from Jane's, it is mainly based on Wikipedia pages and the home pages of the respective armies.

Country	Systems
Abkhazia	7 BM-21; S-8
Afghanistan	BM-21; 18 BM-27; BM-24
Albania	Type 63
Algeria	50 BM-21; 50 BM-14; 30 BM-24[12]; 18 BM-30
Angola	50 BM-21; 40 RM-70
Argentina	Pampero; VCLC-CAL
Armenia	50 BM-21; 4 WM-80; KRL-122
Azerbaijan	63 BM-21; 3 LAR-160; 2 TR-107; 3 MAR-350; 12 BM-30; 3 OTR-21; Lynx
Bahrain	Astros II; 9 MLRS (incl ATACMS)
Bangladesh	KRL 122 / Type 90B; Type 82
Belarus	208 BM-21; 84 BM-27; 48 BM-30; 36 OTR-21; FROG
Bosnia- Herzegovina	2 BM-21; S-5; M94 Plamen-S; 7 M-77 Oganj; 1 M-87 Orkan; FROG;
Brazil	20 Astros II; SBAT-70; 108-R
Bulgaria	350 BM-21; 18 OTR-21
Burkina Faso	4-6 Type 63
Burundi	10 BM-21
Cambodia	8 BM-21; 10 BM-14; BM-13; Type 63
Central African Rep.	5 BM-21
Chad	5 BM-21
Chile	8 Famae Rayo (LAR-160)
China	WS-1B; Type 63; Type 81; Type 70; Type 90; WS-1A; A-100; Type-82; Type-83/WN-40; Type 85/YW 306; WS-2; (WM-80); 3500 in total
Congo DR	30 Type 63
Congo Rep	6 BM-21; BM-14
Croatia	36 BM-21; 8 M-91 Vulkan; 2 M-95 Tajfun; 68 RAK-12; 4 M87 Orkan; 4 M63 Plamen; M77 Oganj; LOV RAK 24/128
Cuba	250 BM-21; BM-14; FROG
Cyprus	18 BM-21; 24 M63 Plamen

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[12] http://www.country-data.com/frd/cs/algeria/dz_appen.html

Country	Systems
Czech Rep	60 RM-70
Denmark	12 MLRS (out of service)
Djibouti	BM-21
Ecuador	6 RM-75; BM-21
Egypt	96 BM-11; 24 BM-13; 215 BM-21; 48 BM-24; PR-113: 120 Saqr-4; 48 Saqr-8; 50 Saqr-10; 72 Sakr-18; 130 Saqr-30; 50 Sakr-36; 48 FROG; 46 MLRS; 60 Saqr-80
Eritrea	25 BM-21
Ethiopia	10 BM-21; BMD-20
Finland	36 Rakh 89 (RM-70/85); Rakh 91; Rakh 07; 22 MLRS
France	55 MLRS
Gabon	8 Teruel, 16 Type 63
Georgia	150 BM-21; 135 RM-70; 15 GRADLAR-160; 12 M63 Plamen
Germany	72 MLRS (MARS)
Greece	116 RM-70; 36 MLRS, ATACMS
Guinea	2 BM-27
Hamas/Fatah	Qassam 1; Qassam-2; Qassam-3; al-Quds; al-Nasser; Saria-2; Kafah; BM-21;
Hizbollah	BM-21; Grad-P; BM-24; Zelzal (B302); Fajr-3; Fajr-5; Thunder 1
Hungary	56 BM-21; FROG (uncertain)
India	150+ BM-21; 38 BM-30; 80 Pinaka
Indonesia	24 BM-14; 9 RM-70; FZ Lau-97
Iran	64 BM-21, Haseb, Arash; Noor; Fajr-2/3/5, Shahin II, Fajr-5/6/7; Hwasong-5; Shahab-1/2/3/4/5/6; Ml 2; ML 4; Zelzal-2; WS-1; OSS-8; Nazeat; 20 BM-11; 50 Hadid/Azrash/Nur; 100 Type-63, Type-81; Falaq-1/2; Samid, Oghab, Tondar-69
Iraq	Had a very rich and varied inventory prior to 2003. None seems to be kept in the current forces.
Israel	50 LAR-160; 20 Mar-290; 86 MLRS; 36 BM-24; 58 BM-21
Italy	22 MLRS; Firos 30
Japan	90 MLRS
Jordan	Type 63
Kazakhstan	190 BM-21; 130 BM-27; 220 Type 63; 13 M1985 (BM-21 variant); 80 BM-14
Kenya	35 BM-21
Kuwait	27 BM-30
Kyrgyzistan	21 BM-21
Lebanon	25 BM-21; 5 BM-11; FROG
Libya	400 BM-21; 200 RM-70; 300 Type-63
Macedonia	6 BM-21; 15 M63 Plamen

Country	Systems
Malaysia	36 Astros II
Mali	2 BM-21
Mexico	Firos 6
Moldova	15 BM-27
Morocco	36 BM-21
Mozambique	5 BM-21
Myanmar	30 Type 63; RM-70
Namibia	5 BM-21
Nicaragua	30 BM-21, 33 Type-63 (JAA)
Nigeria	11 BM-21
North Korea	BM-21; BM-11; BMD-20; FROG; Hwasong-5/6, Rodong-1; 2000 in total
Norway	12 MLRS (out of service)
Oman	27 BM-30 (uncertain)
Pakistan	Type 81; 36 A-100; 45 Type 83 (Azer)
Peru	14 BM-21
Poland	219 BM-21; 30 RM-70/85; 4 OTR-21; 6 WR-40
Qatar	4 Astros II
Romania	128 APR-40; 24 LAROM; FROG
Russia	1750 BM-21; 106 BM-30; 675 BM-27; TOS-1; 140 OTR-21; Iskander
Rwanda	5 RM-70 (uncertain)
Saudi Arabia	60 Astros II
Serbia	100 M-63 Plamen; M-77 Oganj; 1 M-87 Orkan; M71; Kosava; 18 M94 Plamen-S (modified M77)
Singapore	18 HIMARS
Slovakia	87 RM-70/85; FROG
Somalia	Light systems (up to 122 mm) are believed to be possessed by non-state-parties
Somaliland (northern Somalia)	74 BM-21; BM-13; BM-14; BM-24
South-Africa	60 Valkiri; Bateleur; RO 68
South Korea	156 Kooryong (K136); 96 MLRS, 29 ATACMS
South Ossetia	BM-21
Spain	14 Teruel
Sri Lanka	BM-21; 24 RM-70
Sudan	22 BM-21; 400 Type 63; WS-2
Syria	280 BM-21; 200 Type 63; 18 OTR-21; FROG
Tadjikistan	10 BM-21
Taiwan	RT-2000; 117 mm KF-VI; 126 mm KF-IV

Country	Systems
Taliban	BM-13; BM-14; BM-21; BM-22[13]
Tanzania	50 BM-21
Thailand	60 130 mm Type 82
Turkmenistan	86 BM-21; 54 BM-27; 6 BM-30
Turkey	TOROS-230A; TOROS 260A; 24 MLRS (incl 72 ATACMS); 100+ TR-107; 100+ T-122; 100+ T-300Kasirga (WS1A/B)
UAE	6 MLRS (incl ATACMS); 73 Firos 25; 6 BM-30; 48 BM-21; 20 HIMARS; 18 LAU-97
Uganda	6 RM-70; Type 63
UK	36 MLRS
Ukraine	450 BM-21; 76 BM-27; 100 BM-30; S-5M1; S-8M; 50 Frog; 90 OTR-21
Uruguay	5 RM-70
US	857 MLRS; ATACMS; 60 HIMARS;
Uzbekistan	49 BM-27; 60 BM-21
Venezuela	20 LAR-160
Vietnam	800 BM-21; 500 BM-13; 700 BM-14
Yemen	280 BM-21; 14 BM-14; 35 BM-24; 13 BM-27; 30 BM-13; RM-70; 12 FROG-7; 10 OTR-21
Zambia	30 BM-21
Zimbabwe	60 RM-70/85, 18 Type 63; 25 BM-21

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[13] http://www.fas.org/terrorism/str/index.html

Appendix J Country abbreviations

AFG	Afghanistan	GEO	Georgia	POL	Poland
ALB	Albania	GER	Germany	PRC	China
ALG	Algeria	GRE	Greece	PRK	North Korea
ANG	Angola	GUI	Guinea (Conakry)	QAT	Qatar
ARG	Argentina	INA	Indonesia	ROC	Taiwan
ARM	Armenia	IND	India	ROK	South Korea
AUT	Austria	IRN	Iran	ROM	Romania
AZB	Azerbaijan	IRQ	Iraq	RSA	South Africa
BAH	Bahrain	ISL	Israel	RUS	Russia
BDE	Bangladesh	ITA	Italy	RWA	Rwanda
BEL	Belgium	JAP	Japan	SER	Serbia
BIH	Bosnia – Herzegov.	JOR	Jordan	SIN	Singapore
BLR	Belarus	KAZ	Kazakhstan	SLK	Slovakia
BRA	Brazil	KEN	Kenya	SOM	Somalia
BUF	Burkina Faso	KSA	Saudi-Arabia	SOV	Soviet Union
BUL	Bulgaria	KUW	Kuwait	SPA	Spain
BUR	Burundi	KYR	Kyrgizia	SRI	Sri Lanka
CAR	Central African Rep.	LEB	Lebanon	SUD	Sudan
CHA	Chad	LIB	Libya	SYR	Syria
CHL	Chile	MAC	Macedonia	TAD	Tadzhikistan
CMB	Cambodia	MEX	Mexico	TAN	Tanzania
CON	Congo (Brazzaville)	MLA	Malaysia	THA	Thailand
CRO	Croatia	MLI	Mali	TRM	Turkmenistan
CUB	Cuba	MNG	Montenegro	TUR	Turkey
CYP	Cyprus	MOL	Moldova	UAE	United Arab Emirates
CZE	Czech Rep.	MOR	Morocco	UGA	Uganda
DEN	Denmark	MOZ	Mozambique	UK	United Kingdom
DJI	Djibouti	MYA	Burma	UKR	Ukraine
DRC	Congo (Kinshasa)	NAM	Namibia	URU	Uruguay
ECU	Ecuador	NED	Netherlands	US	United States
EGY	Egypt	NIC	Nicaragua	UZB	Uzbekistan
ERI	Eritrea	NIG	Nigeria	VEN	Venezuela
ETI	Ethiopia	NOR	Norway	VIE	Vietnam
FIN	Finland	OMA	Oman	YEM	Yemen
FRA	France	PAK	Pakistan	ZAM	Zambia
GAB	Gabon	PER	Peru	ZIM	Zimbabwe
None-state parties and areas that are not generally acknowledged as states					
ABK	Abkhazia (GEO)	HEZ	Hezbollah (LEB)	SOS	South Ossetia (GEO)
HAM	Hamas (Palestine)	SML	Somaliland (Somalia)	TLB	Taliban (AFG, PAK)