CHAPTER III

INDIA'S BALLISTIC MISSILE PROGRAMME: HISTORY AND CURRENT STATUS

Barely five years after the Integrated Guided Missile Development Programme (IGMDP) was set up, India successfully test fired its first ballistic missile Prithvi in February, 1988. A year after, it became the second country outside the club of declared nuclear powers to demonstrate an intermediate range ballistic missile (IRBM) capability. Today India is one of the most successful missile powers having the capability to design, build and test any kind of ballistic missiles. But India has not attained this capability in just one day or a month. India's progress in the missile field has become possible by the dedication and hard-work of the scientists, technicians and defence personnel engaged in the programme over the years.

This chapter is divided into three parts. While the first part gives a brief account about the ballistic missiles, the second part deals with the pattern of India's ballistic missile programme. The third part traces the history and current capability of India in the missile field.

I

WHAT IS A BALLISTIC MISSILE?

The term ballistic missile refers to "a missile which is self-propelled and guided, with a range of many kilometers." Ballistic missiles carry their own fuel and oxidizer propellants (as opposed to aircraft and cruise missiles which must stay in the atmosphere and get their oxidizer-oxygen from it). Ballistic missiles also do not generally need aerodynamic control surfaces.

CHARACTERISTICS

The most important characteristic of ballistic missiles is that "they are unmanned, guided weapons-delivery platforms having one or more rocket stages that typically provide propulsion over a small portion of the flight path." During most of their flight path, missile warheads traverse a free-
flight ballistic trajectory which, for larger range missiles, is partly or totally above the atmosphere. Flight times to targets range from a few minutes for short-range tactical systems to about thirty minutes for the ICBM.

Ballistic missiles typically incorporate inertial navigation systems that sense the instantaneous acceleration and orientation of the missile. Prior to launch, the co-ordinates of the target and launch point are entered into the missile computer; the guidance and control system using navigation information, steers the missile so that at thrust termination the warhead has the proper velocity vector to reach the target. Unlike aircraft, ballistic missiles are one-shot systems and once launched, can not be recalled or refused. It is generally perceived that ballistic missiles but not necessarily aircraft has a “free ride” to their targets.

Ballistic missiles can be semi-mobile, fully mobile or non-mobile and typically deploy from a main operating base or garrison. Mobile missile garrisons have missile garages, maintenance and training and warhead handling facilities. The missiles are transported on vehicles (i.e. mobile launchers) that provide environmental control and system power prior to launch. Other vehicles such as those for command and control and security usually accompany the dispersed mobile launchers. Although a mobile system is inherently more complex than a fixed-base system, mobility can assure high survivability under attack, assuming that the mobile launchers are disposed from their garrisons and that the dispersed launchers are not easily locatable. The “infrastructure for ballistic missiles consists of personnel and facilities for missile storage and handling, maintenance, flight tests, even training and warhead handling and deployment.” As such, it is not an extra ordinary complex or expensive activity nor is it dependent on acquiring personnel with the highest levels of technical skill or training. This is in marked contrast to the deployment of infrastructure required for maintaining and fielding advanced aircraft systems.
**TYPES**

Ballistic missiles can be of four types: Short Range Ballistic Missile (SRBM), Inter-Mediate Range Ballistic Missile (IRBM), Long Range Ballistic Missile (LRBM) and Inter-Continental Ballistic Missile (ICBM). But the range do not necessarily correspond the typology. In fact, there is no unanimity among the countries which type should be of what range. For instance, under traditional definitions, short-range systems are defined as having ranges of less than 1,000 km, intermediate range less than 5,500 km and long range as exceeding 5,500 kms. The INF Treaty has classified SRBMs with a range below 500 km, those with a range of 500 to 5,500 km are called IRBMs and missiles with ranges over 5,500 km are termed as ICBMs. As per China, range nomenclature equations are short range (1,000 km), medium range (1,000 to 3,000 km), long range (3,000 to 8,000 km) and ICBM (beyond 8,000 km). As far as India is concerned, missiles upto 1000 km are called short range, from 1000 to 5000 km are called intermediate range and above 5000 km are called long range missiles.

**KEY COMPONENTS AND TECHNOLOGIES**

Four components are vital to the success of a ballistic missile development programme. In descending order of their degree of technical complexity, they are the guidance system, the re-entry vehicle, the propulsion system and the warhead. The missiles that result can be single or multistaged and can vary widely in performance, depending on the synergism among such variables as range, accuracy, type and size of payload and reliability.

**GUIDANCE SYSTEMS**

Guidance technology, the most vital and most complex aspect of ballistic missile design and production has been described by one analyst as the "brain and central nervous system" of a missile, without which it could not be targeted or controlled in flight. Guidance capabilities determine a missile's accuracy, the key measurement of its ability to reach and destroy a
target. Because ballistic missiles are powered through only the earliest stages of their flight (usually 10 to 20 per cent of total flight time), they must be guided toward their targets at exactly the right velocity well before reaching a destination: "this requires a sophisticated, computer driven guidance and central system adequate to position the missile as desired, exact knowledge of the co-ordinates of the launch site and target and the ability to programme a computer to achieve the desired flight path."

Of the three kinds of guidance used in missiles, external command systems, flight programmes and inertial guidance — the inertial system accords the greatest accuracy and reliability but is the most challenging to produce. Manufacturing advanced inertial guidance systems require precision machining, the ability to fabricate advance materials and access to computers used by the accelerometers, gyroscopes and associated sub-components needed for accurate warhead delivery. "The complexity of materials development and the precision of design, fabrication and assembly required for even modest accuracy makes the manufacture of actual systems as much an art as a science." Sophisticated guidance systems designed specifically for advanced ballistic missiles are extremely complex and must be able to withstand high acceleration and a wide range of temperatures. These systems of which there are relatively few, are subject to strict export controls.

RE-ENTRY VEHICLES

The second most technologically challenging element of missile development is the re-entry vehicle, "the container that helps a ballistic missile warhead withstand physical stress and heat when it re-enters the earth's atmosphere." This means that technologies for designing, producing and testing re-entry vehicles must ensure they have "a structure and materials that will survive the physical stresses of re-entry, minimise weight, accommodate the size and shape of the payload and not appreciably degrade accuracy." For missiles upto medium range, developing the systems for a
durable re-entry vehicle is not as challenging as it is for larger range systems because shorter-range missiles are subject to less re-entry, stress and heat and their briefer flight times distort accuracy less (some short range missiles, of course, do not leave the atmosphere during flight and thus do not need re-entry vehicles).

Two basic considerations such as the aerodynamic and thermal loads are placed on the re-entry vehicle. The aerodynamic loads require a structural design which will survive the stresses of re-entry and at the same time will minimise weight, accommodate the size and shape of the payload and not appreciably degrade accuracy. The thermal loads require an ablative material which will carry away the heat generated as the re-entry vehicle encounters the friction of atmospheric re-entry. Neither technology is especially sophisticated especially for short range missiles without demanding accuracy requirements. ICBMs experience higher loading during re-entry and their accuracy requirements are often such that sophisticated modelling of the shape changes due to ablation during re-entry are needed.

PROPULSION SYSTEMS

Gaining expertise in propulsion techniques is less difficult than acquiring guidance systems or designing re-entry vehicles. Ballistic missiles can use either liquid or solid propellants. Liquid-propellant missiles carry fuel and oxidizers separately in the missile airframe, then pump them into the engine to burn and create thrust. In solid-propellant missiles, the fuel and oxidizer are pre-mixed. Solid propellants are easier to store and handle than liquid propellants and require engines with fewer moving parts. Liquid propulsion systems are less simple to operate but can deliver greater payloads to longer distances and are easier to control in-flight. However, liquid systems may require an hour or more to launch. Solid propulsion systems allow a missile to be fired more rapidly. The trade-off, then the solid-fuel system’s operational simplicity for the liquid-fuel system’s superior performance.
An important means of acquiring expertise in propulsion techniques has been to import solid-fuel systems associated with space research especially the sounding rockets. Although sounding rockets are too small to carry military payloads, their propulsion technologies can be converted for use in ballistic missiles. In principle, any solid-propellant rocket can be turned into a two-stage ballistic missile. Stacking additional stages poses significant technological challenges and degrades performance, but some countries have overcome these problems.

**WARHEADS**

Depending on its type, designing and manufacturing, a warhead arguably involves the least complicated of the processes required to produce a missile. Generally, there can be three types of warheads for a ballistic missile-chemical weapons, biological weapons and nuclear weapons. Chemical weapons have been used in war since ancient times but they have never been delivered by modern ballistic missiles. The most deadly use of chemical weapons since World War I, for instance, occurred during the Iran-Iraq war and although both nations were armed with ballistic missiles, they used aircraft and artillery, not ballistic missiles, to deliver chemical agents. Most analysts believe that neither country had the technical capability to mount chemical weapons on ballistic missiles during the war. It is unclear, however, why nations that could manufacture chemical artillery shells would find it especially difficult to arm missiles with chemical warheads. However, the fear of chemical weapons has prompted international community to reach agreement (Chemical Weapons Convention) on the ban of the production, storing and use of chemical weapons.

Biological weapons can be divided into two distinct categories: (toxic chemicals produced by living organisms) and pathogens (living organisms that produce disease). No nation is known to possess biological weapons today but the United States, the UK and Japan are known to have developed several types of biological weapons in the past and Iraq and Syria are strongly suspected of stockpiling such weapons today.
Developing nuclear weapons is an aspiration of some of the more successful missile producing states. Although Israel, India and Pakistan possess nuclear warheads for their missile force, this prospect is still fairly distant for other states. Even those who have tested a nuclear device, the move from testing a device to producing reliable warheads that are light enough to be carried by missiles is not easy. In the future, however, countries may acquire or produce advanced conventional munitions, which married to missile systems of sufficient accuracy, could enable them to destroy adversaries military strength without resorting to nuclear or chemical warheads.20

II

PATTERN OF MISSILE DEVELOPMENT

Developing countries have used three major patterns for missile development programmes “(a) producing missile prototypes and systems in national defence industries as has been done by South Korea, (b) acquiring foreign components, expertise and resources to modify imported missile systems as have been done by Iran, Iraq and Pakistan, and (c) modifying space-launch vehicles to create ballistic missiles as has been done by India.”21 These strategies may overlap and countries such as India have both space programme and defence industries. Countries also vary in the relative emphasis they give to alternative technology sources and technologies for missile development.

ADAPTATION OF SPACE LAUNCH VEHICLES: THE CASE OF INDIA

Ballistic missiles are closely related to space launch vehicles in design and performance. The two differ in the payloads they can carry, their trajectories, and, to a lesser degree, the kinds of guidance and control they require. According to the Arms Control and Disarmament Agency, however, “the only major difference between the space and missile variants is that the final boost stage of the ICBM is terminated earlier, before the payload has achieved enough velocity to enter orbit, resulting in its return to earth.”22 In principle, space-launch vehicles may require less accuracy than missiles,
but their guidance systems are similar and thus potentially convertible for use in missiles.

Along with Israel, India leads the industrialising world in manufacturing space launch vehicles and components. This situation is the result of three decades of investment in infrastructure facilitated by extensive assistance from West Germany, France, the United States and the Soviet Union. Although the United States has been increasing its involvement in India’s space and defence industrial programmes recently, its role as a supplier has been relatively modest since the mid 1960s.

**India’s Launch Vehicle Technology: History and Current Capability**

To accommodate its co-operative space ventures with advanced countries, India established the National Committee for Space Research as part of its Department of Atomic Energy in 1962. The space sector extended steadily. The Indian Space Research Organisation (ISRO), in-charge of sounding rocket experiments, was established in 1969 and in 1972 the Cabinet level Department of Space, which was heralded as highlighting, "the transition of the space effort from a scientific undertaking of limited magnitude to a co-ordinated programme with specific goals and time-bound projects in space applications and technology," was set up. India’s Defence Research & Development Organisation (DRDO) established in 1958 to oversee defence industrial investment, was explicitly linked with the space sector when missile production efforts became part of the space enterprise in 1983.

Indian began working with the Soviet Union on experiments with sending rockets in the 1960s, and on satellite launch vehicles a few years later. In 1971, the Soviet Union and India signed an agreement for joint development of a satellite that culminated in the first successful launch by the Soviets of the Indian satellite Aryabhata in 1975. Most of the sub-systems in the Aryabhata were manufactured in India, although the Soviets provided some key elements. The Soviet launch of the follow-on Bhaskara in 1979
established the foundations for more independent Indian efforts the following year.

Both the Aryabhata and the Bhaskara launches experienced major technical difficulties. The Aryabhat's power supply systems failed and the Bhaskara lost a crucial monitoring capability. Both required Soviet booster rockets to achieve orbits. Still, the joint equipments conducted as part of these ventures, including systems manufacturing and satellite tracking and monitoring, gave Indian scientists sufficient expertise to design and build their own solid fuel rocket by late 1979.25

India's capability in the launch vehicle technology was first demonstrated through the successful launch of SLV-3 (Satellite Launch Vehicle) in July 1980, which placed a 40 kg Rohini satellite into a near-earth orbit. The 22.7 metre tall SLV-3 was an all-solid four stage vehicle with a lift-off weight of 17 tonnes. Two more launches of SLV-3 were conducted in May 1981 and April 1983 with the Rohini satellites on board incorporating application oriented solid state imaging sensors.

The second was the Augmented Satellite Launch Vehicle (ASLV) which was successfully launched twice from Sriharikota Range (SHAR) on May 20, 1992 and May 4, 1994, respectively.27 These were the third and fourth developmental launches (ASLV-D3 and ASLV-D4). They injected the SROSS-C and SROSS-C2 (Stretched Rohini Satellite Series) satellite, respectively into a near-earth orbit. ASLV is a five stage, solid-propellant launch vehicle capable of putting 150 kg class payload in near-earth orbit, intended for proving several technologies required for PSLV and GSLV missions.28 All the objectives of ASLV Programme have been realised.

However, the most significant achievement of India in the launch vehicle area so far is the completion of the development of the Polar Satellite Launch Vehicle (PSLV). The 283 tonne, 44 metre tall PSLV employing
solid and liquid propellant is capable of putting 1,000-1,200 kg IRS class of satellites in 800-900 km polar sun synchronous orbits. The first developmental flight of PSLV took place on September 20, 1993. Though it could not place the IRS-1E satellite, on board, into the intended polar orbit, the flight proved almost all the sub-systems.

The second developmental launch, PSLV-D2 on October 15, 1994 was a total success and it placed the IRS-P2 satellite in the desired polar sun-synchronous orbit. PSLV-D3 was launched from Sriharikota on 21 March 1996 with IRS-P3 on board, reinforcing the success of PSLV-D2 on October 15, 1995. The fourth launch (operational) of PSLV-C1 took place on September 29, 1997 which placed IRS-1D into the Polar Sun-Synchronous Orbit. The fifth and the final launch of the PSLV C2 was held on May 26, 1999. The significance of this launch is that it not only put the IRS P-4 into the orbit but also took India into the commercial launch vehicles market. This success also ended ISRO’s dependence on Russian vehicles to launch IRS space craft. The technology demonstrated in this flight will feed directly into the GSLV.

The next step is to achieve the capability to launch 2,500 kg class communication satellites into the Geo-Synchronous Satellite Launch Vehicle (GSLV) which is now under development. As per the 1996-97 Annual Report of the Department of Space (DoS), substantial progress has been made in the development of the GSLV project. Successful completion of the one tonne cryogenic engine development programme during the 1996-97 has given further fillip towards developing indigenously the cryogenic upper stage of the GSLV. Several hardwares for the infrastructure for ground test and launches are getting ready. The first developmental launch of the GSLV is planned during the year 2000-2001. The government has already sanctioned Rs.735 crore for this purpose. A chronology of India’s launch vehicle technology is given in the under-mentioned table:
## India's Launch Vehicle Technology: A Chronology

<table>
<thead>
<tr>
<th>Launcher</th>
<th>Date</th>
<th>Satellite Payload</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLV-3</td>
<td>10 August 1979</td>
<td>Rohini</td>
<td>Failure</td>
</tr>
<tr>
<td>SLV-3</td>
<td>18 July 1980</td>
<td>Rohini</td>
<td>Success</td>
</tr>
<tr>
<td>SLV-3</td>
<td>31 May 1981</td>
<td>Rohini</td>
<td>Failure</td>
</tr>
<tr>
<td>SLV-3</td>
<td>17 April 1983</td>
<td>Rohini</td>
<td>Success</td>
</tr>
<tr>
<td>ASLV</td>
<td>24 March 1987</td>
<td>SROSS</td>
<td>Failure</td>
</tr>
<tr>
<td>ALSV</td>
<td>13 July 1988</td>
<td>SROSS</td>
<td>Failure</td>
</tr>
<tr>
<td>ALSV-D3</td>
<td>19 May 1992</td>
<td>SROSS</td>
<td>Success</td>
</tr>
<tr>
<td>ALSV-D4</td>
<td>4 May 1994</td>
<td>SROSS</td>
<td>Success</td>
</tr>
<tr>
<td>PSLV-D1</td>
<td>20 September 1993</td>
<td>IRS-IE</td>
<td>Failure</td>
</tr>
<tr>
<td>PSLV-D2</td>
<td>15 October 1994</td>
<td>IRS-P2</td>
<td>Success</td>
</tr>
<tr>
<td>PSLV-D3</td>
<td>21 March 1996</td>
<td>IRS-P3</td>
<td>Success</td>
</tr>
<tr>
<td>PSLV-C1</td>
<td>29 September 1997</td>
<td>IRS-ID</td>
<td>Success</td>
</tr>
<tr>
<td>PSLV-C2</td>
<td>26 May 1999</td>
<td>IRS-P4</td>
<td>Success</td>
</tr>
<tr>
<td>GSLV-D1</td>
<td>2000-2001</td>
<td>GSAT-1</td>
<td>-</td>
</tr>
</tbody>
</table>

Sources:  
- The Indian Express (New Delhi) 21 September, 1993.  
- The Times of India, 27 May 1999.  
- The Hindustan Times, 19 April 1999.

In early 1980s, space related achievements (achievements in the area of launch vehicle technology) were formally integrated into India's national defence planning when the Government established the IGMDP in 1983 with a mandate to develop a series of missile systems and to be run under the auspices of the DRDO. According to one estimate, the DRDO operates more than forty-five defence-related plants and research facilities, of which nineteen are engaged specially in various aspects of missile design. India's investment in space programmes has thus proved useful in helping it acquire expertise in techniques pertinent to missile development and in building the modern scientific and industrial infrastructure needed for more ambitious military endeavours. This is clearly evident especially when "some of the systems and components which were earlier developed for the space programme like the
heat shield, guidance system, maraging steel and launch vehicle modules are used in the missile programme."

This does not, however, mean that the missile and civilian space programme are sister organisations. India’s missile programme has only benefited from the expertise achieved in the space programme. A US government analyst has rightly indicated that “there is unlikely a very close relationship between ISRO and DRDO: they are separate empires although their technological base overlaps.” Indeed, they compete for resources. The IGMDP is clearly taking money that otherwise would be used in the civilian programme. Meanwhile, it appears that defence has taken precedence over the civilian use of rocket technology. DRDO is recruiting young talented and “visionary scientists” such as Dr. Kalam, formerly head of ISRO’s SLV-3 programme, away from the ISRO. According to one VSSC employee, ISRO is left with scientists and engineers that are “burnt-out and aging.” According to a 1988 US Embassy assessment.

“We believe that most ISRO scientists agree with the official (Government of India) policy of keeping separate India’s military and civilian rocket programmes. They argue that ISRO is not developing military missile technologies in its civilian space programme even though certain technologies can be shared by both. They are supported by defence scientists who maintain that using the ISRO rockets would involve major modifications (and) that they would rather design and are designing military missiles from scratch.”

The cable also states that some ISRO scientists believe that “without explicit military backing, ISRO’s rocket programme will not gain sufficient momentum to achieve its aims.” In this view, India’s relative weakness in rocket technology is due to its civilian rather than military focus. The US assessment concludes that development of military missiles is not “antagonistic” to a peaceful space programme and that it is “natural for scientists and engineers, working on similar problems … to discuss problems and successes (and to share) information about their projects.”
INDIA’S BALLISTIC MISSILE PROGRAMME: TRACING THE HISTORY

No other mythology deals with missiles as extensively as the India one. *Astra* was the ultimate weapon of only the outstanding warriors. Even in those days it was not within the reach of every body. Arjuna did penance to obtain the *Divya Astras* but newer had to use them in the Mahabharata war. In the medieval India, Hyder Ali of Mysore was one of the first leaders to harness missiles for war. In the late 18th century, he introduced the Rockets in his war arsenal and his son Tipu Sultan used metal clad rockets with telling impact against the British in the battles at Sirangapatnam in the 1790’s. Thus, India had the “rocket sense.”

But modern Indian efforts to design and build surface-to-surface (SSMs) missiles span nearly three decades. Lacking resources (and in many cases an established military requirement from the armed forces), India’s military R & D establishment first sought basic knowledge in rocketry and to increase awareness among service personnel of missilery and its military applications. With these very basic first steps, “each successive phase of New Delhi’s missile development effort has involved greater resources, more specific system development goals and closer co-operation with service end users.” Today, all five Indian missiles developed under the IGMDP—the short-range surface-to-air missile Trishul, the surface-to-air missile Akash, the smokeless high-energy anti-tank guided missile Nag, the short-range surface-to-surface missile *Prithvi* and the intermediate range ballistic missile *Agni*—have been test fired. One(*Prithvi*) has entered service, two(Trishul and *Prithvi-II*) are in series-production, in the case of one(*Agni*) the technology has been ‘demonstrated’ and the two others(Aakash and Nag) are almost at the end of their development cycle. India has also the technological infrastructure to undertake development of intercontinental ballistic missiles (ICBMS) and cruise missiles.
Indian SSM research began in the early 1960s under the direction of the Defence Research and Development Organisation (DRDO), which has established on January 1, 1958. A department of the Ministry of Defence, DRDO is the primary source for all Indian military R & D, with a mandate to "enable the nation (to) become self-reliant in weapons, weapon systems and equipment through research in wide ranging areas of modern technology." Maj. Gen. B.D. Kapur, DRDO's first Chief Controller, played an integral role in India's initial missile efforts. Kapur helped establish both a foreign training programme for Indian scientists (which included the study of space and rockets) and a curriculum of basic rocketry science for service personnel at the Institute of Armament Studies.

Following on "information gathering" trip to the United States in early 1962, where he toured R & D centres, SAC bases, missile training sites and NASA facilities, Kapur stopped in Switzerland to meet with representatives from the Zurich-based firm Contraves. The meeting produced an Indo-Swiss agreement to design and manufacture an intermediate range surface-to-air missile (SAM) known as "Project Indigo." However, at the time Kapur was meeting with the Swiss, New Delhi was also negotiating with the Soviet Union for purchase of SA-2 SAMs. India opted for the Soviet system and "Project Indigo" which would have been a first attempt to actually build a missile system was cancelled.

Although it never came to fruition, "Project Indigo" did provide impetus for a more broad-based Indian missile research programme. That effort was institutionalised in a Kapur-drafted plan approved by the Defence Committee of the Cabinet sometime in mid-1962, to create a "missile establishment" in India. Located at the "Special Weapons Establishment" in Hyderabad, the plan called for a group of scientists "to study missilery so that they could advise the services at the appropriate time." There is no evidence that developing a deployable SSM was one of the goals of the project. Initially directed by Air Commodore V. Ganeshan, the project began by launching experimental rockets to study their ballistic behaviour. In 1963, "a number
of two-stage rockets" were fired from Hyderabad and "work on the development of rocket propellant was carried out at the (DRDO) explosives laboratory."\textsuperscript{48}

In 1965, the \textit{ad hoc} Electronics Committee provided the impetus for sustaining these early developments. Headed by Dr. Vikram Sarabhai, then Chairman of the Atomic Energy Commission and later the first head of the Indian Space Research Organisation (ISRO), the Committee concluded that India should move forward with a missile production programme\textsuperscript{49}. The Committee noted that since a base for rocket manufacture had already been established with licensed production of the French Centaure Sounding Rocket, work should proceed in developing propellants and guidance systems.\textsuperscript{50}

The "Devil Programme"\textsuperscript{51} can be considered the next significant milestone in India's missile programme. The project which involved a greater concentration of manpower and financial resources than previous research efforts, began in the early 1970s and involved Indian attempts to convert SA-2s into SSMs. Reportedly involving over 880 experts, the project developed two liquid propulsion rocket motors by 1974.\textsuperscript{52} However, following the failure of several prototype systems, the project was cancelled in 1978.\textsuperscript{53} The liquid fuel motors developed under the "Devil Programme" later became the basis for the propulsion systems on India's first operational SSM, the \textit{Prithvi}.

Failure of the "Devil Programme" was based on several factors. The project was "ill-conceived", according to one official as it was headed by an Air Force officer with "good political connections" but who did not have the support of the military bureaucracy.\textsuperscript{54} No General Staff Qualitative Requirements or GSQRs, were issued for the project, meaning that the armed services did not envision a specific need for the system and, therefore, did not advocate its development. Moreover, the Rs.2.3 crore per year devoted
to the project (though greater in relative terms than earlier projects) was not enough to create the critical mass of a technical and manufacturing infrastructure to develop a deployable missile.55

In July, 1983, New Delhi authorised a Rs.380 crore ($133 million) Integrated Missile Development Programme (IGMDP) to make India independent in missile design and production.56 The plan, which has now received a total of over Rs.788 crore ($275 million) involved the development of four missile systems: Trishul, a short-range SAM; Akash, a medium range SAM, Nag, a “fire and forget” anti-tank guided missile; and Prithvi, a battle-field support SSM. Development of Agni, an IRBM is being undertaken “concurrently with the other IGMDP systems.57

Although the IGMDP draws upon the knowledge gained and technologies developed under India’s earlier missile efforts, it represents a clear departure from those undertakings in several respects. The project signals a dramatic change in the way missile research is done in India for it is a well-funded, broad-based effort, involving not only the defence laboratories but also technical institutions, Universities, Defence Ministry ordnance factories and public and private sector firms.58 The IGDMP also represents the first Indian attempt to develop several missile systems simultaneously. Moreover, the closer co-operation between the services (especially the Army) and the R&D institutions created specific system development goals at the onset of the project. Therefore, apart from the missiles that are developed within the programme, the IGMDP’s enduring legacy may well be its creation of a vast missile design and production establishment within India that is more integrated with and responsive to the needs of the armed forces.59

THE MISSILE ESTABLISHMENT

The IGMDP is a DRDO effort, with substantive research and design work being carried out by the Defence Research & Development Laboratory
(DRDL). Dr. Abdul Kalam, DRDO's Director, heads the missile development programme, replacing Dr. V.S. Arunachalam, who held the DRDO directorship for over a decade. A Rs 100 crore ($35 million) Research Centre, Immarat (RCI) was built 6 km from DRDL for developing advanced missile technologies in co-operation with University scientists. Reportedly, RCI will also incorporate missile production facilities. There are now over a thousand scientists and engineers working on missile related projects at the two facilities.

For developing missile technologies, a total of 19 other defence research laboratories, seven Universities and seven other institutions like the ISRO, Tata Institute of Fundamental Research (TOFR) and Shar (Sriharikota) have been involved. Similarly, the setting up of production facilities has brought together 19 public sector units, 11 ordnance factories, 9 private sector corporations and two other organisations. Today, this conglomerate supplies virtually every need of the missile programme - computers, guidance software, aero-space quality aluminium, precision gyroscopes, rocket propellant, warheads, special radars and ground vehicles.

Missile test takes place at several sites: six of the first eight Prithvi tests took place at the Shriharikota (SHAR) test range, which is under the control of ISRO's Vikram Sarabhai Space Centre (VSSC). Four Agni tests were conducted at the Interim Test Range (ITR) facility located at Baliapal in Orissa which has built up an impressive array of tracking equipment and a telemetry station that can track and receive information from missiles launched thousands of kilometres into the Indian Ocean. Several of the facilities which form the ISRO Telemetry, Tracking and Command Network (ISTRAC) such as those at SHAR and Car Nicobar Island, were used to monitor Agni's maiden launch. The INSAT communication satellites, which fall under ISRO's control, were used to transmit Agni's launch data.
INDIAN BALLISTIC MISSILES

*Prithvi* and *Agni* are the two ballistic missiles developed under the IGMDP. A detailed discussion about each of them follows as under:

PRITHVI (Earth)

The *Prithvi* is a single stage, short-range battlefield support missile. According to Dr. Kalam, thirty-four R & D organisations designed and developed the missile and 22 PSUs, ten ordnance factories and nine private sector industries are involved in system or sub-system production. Described by the scientists as having the "best warhead to weight ratio" of any missile in its class", the *Prithvi* has an impact point accuracy of 0.1 per cent. This accuracy is much greater than the Scud missiles which were successfully used in the Gulf War and the Chinese M-11 missiles, the supply of which to Pakistan has created a major controversy.

India authorised *Prithvi* development in July 1983 but actual work began in October 1984 under the direction of Major General V.J. Sundaram, who previously worked on solid fuel propulsion technologies. The system's first flight test was from SHAR on February 25, 1988; at this writing sixteen tests have been conducted so far. The missiles minimum range is reportedly 40 km and the cost of each missile is Rs.5 crore.

Powered by liquid propellant, the state-of-the art 'Prithvi' has the latest on board computers as well as an advanced inertial navigation system. It uses two radars: one for guidance and the other for targetting. *Prithvi* has a unique three-stage trajectory - the initial powered phase, the plain cruise and the steep descent phase of nearly 80 degree that makes it almost impossible for the radars to get time to pick up a signal and counter it. Missile's two liquid propellant rocket engines are gimballed to operate independently which makes it easier to steer the missile on all three axis using thrust vector control during the first 60 seconds of its flight. Thereafter the missile switches axis to closed loop guidance and aerodynamic control
exercised by its four wings. The missile follows a tailored trajectory rather than a purely ballistic one. 69

During war, the missile will be transported to the launch site on an all-terrain eight wheeled Kolos Tatra truck and each battery of four Prithvi carrier vehicles will be accompanied by a missile resupply and load vehicles, a propellant tanker and a command post to provide target information. 70 However, using the missiles on mobile, beyond visual range, targets like a moving armoured column would prove to be a problem mainly because it would be impossible to get a near real time intelligence output on such targets. For instance, Iraq had fired 81 missiles in 42 days during the Gulf war without any substantial gain.

Prithvi’s short reaction time, supersonic speed and raggedness could be more effective than manned air strifes. The 8.5 metre missile with a 1000 kg payload Prithvi can carry several types of warheads, including unitary high explosive, prefragmented, minelets and cluster munitions. 71 The first static warhead test, probably of the unitary HE type was conducted at Pokharan, Rajasthan in March 1990. Reportedly, DRDL is studying fuel-air explosive (FAE) warhead feasibility for Prithvi and it is, therefore, possible that Prithvi will deploy the FAEs. Given the missiles throw weight, particularly at shorter ranges, Prithvi may also be nuclear capable.

Approximately, five to ten per cent of Prithvi’s components are imported. 72 DRDO currently has enough of these goods in stock to complete initial production runs. These imports, according to one analyst, consist primarily of precision sensors, a few special alloys and materials and microprocessors. Given the history of progress in the Indian missile programme, it is safe to assume that way of these components will eventually be produced within the country. Indigenous production of these goods would, at least initially, increase the costs of Prithvi and the other IGMDP systems.

Mainly developed as a weapon against Pakistan, Prithvi could be employed against static targets such as the large maintenance areas required
by Pakistani Army Reserves, command centres, Pakistani airfields and fixed air defence sites. Such targets could include Pakistan's Kamra and Chalala air bases, the Lahore airfield and the command headquarters at Bahawalpur. Close collaboration between Army and Air Force strike would be required for such missions, Prithvi also might be used as a "close support" weapon against reserve formations moving up after armed penetrations. Even in this mode, the effective use of Prithvi would prove difficult unless India strengthened its reconnaissance capabilities. Nonetheless, given a nominal 60-minute reaction time and a 60 minute reload time, a Prithvi regiment would theoretically be able to deliver 12 to 18 tons of HE to targets at 150 km range within two hours upon arrival at a pre-surveyed launch site. Prithvi will, therefore, provide the Indian Army with a needed boost in operational firepower, particularly when operating without strike aircraft.

**Prithvi** is available in three versions: Prithvi-I, Prithvi-II and Prithvi-III. Prithvi-I or the Army version has a maximum range of 150 km and a capacity of 1000 kg payload. Being manufactured at Bharat Dynamics Ltd. (BDL). Prithvi-I has been produced and inducted into the Army. There were reports in the US media about its possible deployment near the Indo-Pak border which is not correct. However, in view of the new threat from Pakistan, these missiles need to be kept in a state of combat readiness, particularly in the border areas.

Prithvi-II or the Air Force version has a range of 250 km and a 500 kg payload capacity. It is likely to be used by the IAF for specific purposes and its function for the force would be a little different from that for the Army. The IAF had earlier wanted specific modifications for the ground support systems. Apparently, there were too many ground support vehicles along with the missile which IAF officials wanted to cut down upon. As per the modifications, the DRDO would now have provided some of those support systems in the missile launcher itself to facilitate the IAF. The IAF is likely to use Prithvi-II as a surface-to-surface missile for the destruction of anti-
aircraft guns, fuel dumps and the airfields. The developmental work on *Prithvi*-II for the IAF has already been completed.75

The *Prithvi*-III or the Naval version of the indigenous medium range missile has a maximum range of 350 km. So far, no developmental flight of this missile has taken place. When test-fired, the *Prithvi*-III will have the distinction of being capable of launch from both a ship or a submarine. While initially the ship launch version would be developed, it would subsequently be upgraded to a submarine launch variant.76 The Naval *Prithvi* is understood to be a more complex system to develop as its guidance system would be capable of operating in two mediums - sea and air. Although it is difficult to say at this time the exact time-frame for testing and trials of the Naval *Prithvi*, it is clear that the ultimate induction of this missile is expected to lend a lot of punch to the Indian Navy as it is expected to enhance its reach.

**Prithvi at a Glance**

<table>
<thead>
<tr>
<th>Type</th>
<th>Surface-to-surface battlefield support missile.</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Test Flight (Year)</td>
<td>1988</td>
</tr>
<tr>
<td>Launch weight (kg)</td>
<td>4,000</td>
</tr>
<tr>
<td>Payload (kg)</td>
<td>500 to 1,000</td>
</tr>
<tr>
<td>Accuracy (CEP in metres):</td>
<td>250</td>
</tr>
<tr>
<td>Range (km)</td>
<td>40 to 350</td>
</tr>
<tr>
<td>Length (metre)</td>
<td>10</td>
</tr>
<tr>
<td>Cost (Rs.)</td>
<td>5 crores</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Twin-gimballed engine using liquid propellant</td>
</tr>
<tr>
<td>Guidance</td>
<td>Strap down inertial navigation</td>
</tr>
<tr>
<td>Other features</td>
<td>Controlled and guided all the way</td>
</tr>
</tbody>
</table>

AGNI (Fire)

Like the Prithvi, the Agni relies on propulsion and motor case technologies developed under previous missile and space programmes. However, some new technologies developed for Agni (such as an indigenously designed heat shield) as well as the systems intermediate range capability, are indicative of India's success in its drive towards an increasingly sophisticated missile design infrastructure. Agni's development may also be indicative of a change in what New Delhi views as the appropriate military response to its nuclear and missile-armed neighbour China (PRC).

Agni has two versions: Agni-I and Agni-II. Each of the two versions are discussed below:

Agni-I

Agni-I is a two-stage IRBM with a length of 18.4 metres and a body diameter of 1.3 metres at its widest point. It has a range of 1000 km and a payload capacity of 1000 kg. It is based on first stage solid and second stage liquid fuel configuration. As an IRBM, Agni-I provides many battlefield advantages such as better interception rate, speed, night operation capability, pre-launch survival ratio etc. It has a remarkable Circular Error Probability (CEP) figures (which determine a missiles strike accuracy). It excels in crucial operational areas like re-entry, long range manoeuvering and two-staged propulsion and stage separation.

Agni-I was first test-fired from the ITR in Orissa on May 22, 1989. The missile travelled 1000 km during its first flight, which was designed to test heat shield, inertial guidance and stage separation technologies. Following two flight postponements in 1990, the missile was tested for the second time on May 29, 1992. Although the officials first claimed the test was a success and that the missile followed its projected course exactly, DRDO later acknowledged that the "mission objective of the final manoeuvering could not be fulfilled due to the premature ignition and
separation of the second stage." The third and the last test of Agni-I was carried out on February 19, 1994. The three tests of Agni-I was done at a cost of about Rs.55 crore.

Agni-II

Agni-II is the extended version of Agni-I. First test fired on April 11, 1999, this intermediate range ballistic missile has a range "in excess of 2000 km" which it can cover only in 11 minutes. Other features of the 20 metres long and 16 tonnes weighs Agni-II include: mobile launch capability, solid-solid propulsion system, features designed to carry special payload, state-of-the-art navigation, guidance and control systems and sophisticated on-board packages including advanced communication interface.

The most significant aspect of Agni-II is the usage of solid fuel as a propellant. Solid fuel is non-corrosive and easy to handle. Its user-friendly characteristics cut the down pre-launch preparation time and enable faster sequential firings. Besides, solid fuel is compact and easy to store. The resulting storage advantages can help in beefing up the size of ready-for-battle missile stocks and thus increase the overall missile punch.

Salient features of Agni-II in brief

- The successful test-launch signified that India has reached the point of operationalising Agni-II as a weapon system.
- It demonstrated the mobile launch capability signifying that the missiles can be moved anywhere, including rugged areas, by a very compact system and launched.
- Agni-II, the 20-metre long missile with a weight of 16 tonnes, has a solid propulsion system, meaning the solid-solid operational configuration.
- It is mounted on re-entry vehicle.
- It can cover a range of over 2,000 km in only 11 minutes.
- Its features designed to carry special weapon payload of over 1,000 kg.
- It has sophisticated on-board packages and advanced communication interface.
- Makes India part of the exclusive global missile club of very few countries.

The Times of India, 12.4.99
According to specialists, solid-fuelled motors can be transported and stored with the propellant intact and can be readied quickly for launch.

The significance of Agni-II lies in its linkage with the Pokhran blasts. While the Shakti series of nuclear tests had given India the capability to design all kinds of atomic warheads, it did not address the question of delivering them. India, for instance, lacked a missile - the preferred means of nuclear delivery - which could take warheads to a range beyond 2,000 km. The test of the Agni-II frontally addresses this problem. Analysts point out that India would ideally require a good solid fuel missile with a range of around 3,000 km to complete the acquisition of its nuclear deterrent.

According to George Fernandes, India’s Defence Minister, Agni-II was launched from a mobile platform. The mounting of the weapon on a rail or road mobile launcher is vital for enhancing its deterrence value. Easy movement can result in flexible deployment of the weapon system. Besides, unlike fixed silos, mobile launched missiles have a better chance to evade air raids or other forms of destruction. These advantages were evident during the Gulf War when US forces, despite their overwhelming technological domination, found it hard to target Iraq’s mobile-launched Scuds.

Agni-II is equipped with global positioning system (GPS) in order to improve its accuracy or reduce the circular error of probability in military parlance. This means that the missile’s on-board computer during its flight gets inputs from the satellites to home in on the designated target.

India has been under considerable pressure from the US and China to cap the Agni project. Agni-II’s test-firing which came after a gap of five years, is being widely seen as a forceful assertion of India’s right to safeguard its national security interests. However, a day before the Agni-II test, the Indian Government informed the five permanent members of the United Nations Security Council and the Governments of Germany, Japan and Pakistan, of its intention to conduct the test. Under the Lahore Agreement
signed by India and Pakistan in February, the two countries had pledged to
give advance notice of tests of ballistic missiles.  

Comparison between Agni-I and Agni-II

There are two striking features of Agni-II which make it different from
Agni-I. The first feature is that it is propelled in two stages by solid fuel.
Agni-I was fuelled by solid as well as liquid propellants: the latter gives the
missile some uncertainty due to its unstable nature affecting its circular error
of probability, in simpler terms its accuracy.

The second feature is the ability to launch the Rs. 10 crore missile from
an easily assembled mobile launcher. In strategic terms, it is giant leap
from the static launchers. A mobile launched Agni gives India an enormous
flexibility in deploying it literally anywhere even on the Andaman Islands.
In times of war, the missile can be transported by rail or road to a destination
where the launcher can be assembled for use.

The Agni Series

<table>
<thead>
<tr>
<th>Agni Flight</th>
<th>Launch Date</th>
<th>Technology</th>
<th>Length/ Diameter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-01</td>
<td>May 22, 1989</td>
<td>S1: Solid</td>
<td>Approximately 19 m/1 m</td>
<td>Technology demonstrator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2: Liquid (SLV-3+Prithvi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1-02</td>
<td>May 29, 1992</td>
<td>S1: Solid</td>
<td>Approximately 21 m/1m</td>
<td>Failure of mission goals caused by design deficiency in the location of sensors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2: Liquid (SLV-3+Prithvi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1-03</td>
<td>Feb. 19, 1994</td>
<td>S1: Solid</td>
<td>Approximately 21 m/1 m</td>
<td>Increased range* and manoeuvring re-entry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2: Liquid (SLV-3+Prithvi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2-01</td>
<td>April 11, 1999</td>
<td>S1: Solid</td>
<td>Approximately 19 m/1 m</td>
<td>Increased range*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2: Solid (SLV-3+New Stage)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The exact range of Agni-I and Agni-II has never been officially released. Agni-I's range is believed to be in access of 1,000 km and Agni-II's range is believed to be in excess of 2,000 km.

Source: R. Ramachandran, Frontline, May 7, 1999
Agni-III?

_Agni-II_ is certainly a step towards achieving minimum credible deterrent but it still does not give India cent per cent credibility. So, India needs to develop still longer range versions to be fully secure. According to the Jane's Defence Weekly, Indian scientists are reportedly developing a longer version of the intermediate range ballistic missile _Agni-III_ with 3,500-km reach capable of engaging targets deep inside China. In a country defence profile on India, the Weekly points out that "together with the just test-fired two stage solid fuel, 2,000 km range _Agni-II_, designed to carry nuclear warhead, _Agni-I_, already test-fired three times and short-range surface-to-surface missile _Prithvi I_ and II, surface-to-air Akash and Trishul missiles and to-be-acquired Russian 300V anti-tactical ballistic missile, the under-development _Agni-III_ will form India's Minimum Nuclear Deterrent (MND)."

Taken together, the _Agnis_ have a number of beneficial effects. First, _Agni_’s guidance system and vehicle structure form an excellent configuration for the missile’s modification as the inter-continental ballistic missile (ICBM), _Surya_, which is already in the pipeline and which would be able to reach targets in other continents. Second, _Agni_ ends the strategic imbalance in the region _vis a vis_ China and even U.S.A. While Beijing can strike India’s Gangatic heartland from occupied Tibet with short-range ballistic missiles of the kind with which it terrorised Taiwan three and a half years ago, India would need deep penetration IRBMS to strike key Chinese strategic targets. With a range of 2,000, the _Agni-II_ will be an important stepping stone to an upper range IRBM that could reach several Chinese targets even if fired from secure bases in central Southern India. This also applies to US air and naval base at Diego Garcia for it tends to reduce the efficiency of the U.S. Rapid Deployment Force (RDF) or other U.S. pressure tactics as the sending of the Enterprise in 1971 to press a point against India.

Third, a credible missile based deterrence with China or for that matter
U.S., will not only make India militarily secure but also enable it to focus its attention on economic and social progress by diverting its resources, which it has been spending so far on improving its conventional weapon systems, to developmental activities. According to a U.N. report, India has spent US $12.4 billion during 1988-92 for importing conventional weapons. Fourth, *Agni* would make India a significant actor in international power politics. If it is followed by the successful ICBM (*Surya*) tests, then there can be no future international arms control negotiations without India's voice being heard with much greater attention than has been the case till now. Finally, *Agni* 's role as a weapon is less important. It is a confidence builder and a symbol of India's assertion of self-reliance not merely in the field of defence but in the broader international political arena as well.

However, there are attempts by an insignificant minority to discredit India's successful missile programme, particularly the *Agni* by implying that it owes its origin to NASA's Soviet rocket. In a recent publication, the Indian Institute for Defence Studies and Analysis reiterated that both the *Prithvi* and the *Agni* are based on components produced by Indian engineers. According to the Institute's Director, the *Prithvi* has a propellant tank and missile frame made of aluminium alloys developed locally and "virtually none of the components for the engine or other parts were imported." Similarly, the *Agni* is portrayed as representing a significant advancement in Indian guidance technology and re-entry and heat-shielding capabilities. The carbon heat shield is reported to be "completely indigenous." Even the Arms Control and Disarmament Agency (ACDA) and the Central Intelligence Agency (CIA) have opined that the Indian missile development programme is rooted in indigenous technology. The CIA ex-Director, William Webster, is on record saying, "Little could be done to stop Indian (and Israeli) ballistic missile programmes because they largely use technology developed indigenously."
There is very little public or official information available regarding a potential Indian ICBM. On the same day as Agni's first launch, press reports did claim that defence scientists "would begin work on an ICBM named Surya, with a range exceeding 5,000 km."\textsuperscript{102} While there is no clear evidence that this is the case, Dr. Kalam has said that "if given the resources and the okay, it is possible for India to build on ICBM" and that India would develop the missile "when required."\textsuperscript{103} According to R.N. Agarwal, Agni's guidance system and vehicle structure would be roughly the same for an ICBM although the 'stage structure and configuration would have to be changed.'\textsuperscript{104} Missile analyst Seth Carus suggests that the powerful solid fuel motors developed by ISRO for the PSLV's first stage may be used in an Indian ICBM design.

Whatever the case, it can not be denied that today India is a world leader in both solid and liquid propellants and has the most broad based missile capabilities after the P-5 states.\textsuperscript{105} As the Donald Rumsfeld-led Congressional Commission has concluded, "India has already arrived as a missile power and its capabilities are now "sufficiently advanced."\textsuperscript{106}
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