INDIA'S MISSILE PROGRAMME: A HISTORICAL ANALYSIS

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CERTIFICATE

Certified that the dissertation entitled, **India's Missile Programme: A Historical Analysis** submitted by **D. Ashok Maharaj** is in partial fulfilment for the award of the degree of **Master of Philosophy** of this University. This dissertation has not been previously submitted for any other degree of this or any other university. This is a bonafide work to the best of our knowledge.

It is recommended that this dissertation be placed before the examiners for evaluation.

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For Dada, Mom, Anna and Thambis

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D. Ashok Maharaj

CHAPTER I

MISSILES: THE NUTS AND BOLTS

The rocket as a battlefield weapon was, in fact, first used by the Chinese to defend themselves against the Mongols in the 13th century. In the same century, this technology made its appearance amongst European countries. The Arabs are reported to have used rockets on the Iberian Peninsula around the same time. The immediate precursor to the modern day missiles owes its credit to Konstantin E Tsiolkovsky, Robert H Goddard and Hermann Oberth. Their efforts significantly influenced the development of rocket propulsion. The VTR-- Verien Fur Raumschiffhart --the German rocket society was the brainchild of Hermann Oberth, who was responsible for placing Germany in the forefront of all other nations. The society was responsible for the design and construction of the V1 and V2, ballistic missiles in Tauren and Peenemunde. It was the technical wonder of the V2 that heralded post World War II missile development and missile technologies. Later, the missile arms race during the Cold War between the US and the Soviet Union saw a growing sophistication of missiles in terms of range, guidance and payload.

Ballistic missiles are large, complex systems. There is no simple roadmap to successful development of short-range and long-range missiles. There are rules, which most programmes must respect if they are to have any chance of success. This dissertation is about India's missile programme. It traces the history of missiles in India from 1950 to 1989. As rockets and missiles share the same technology, with minor differences, a comprehensive look at the growth of rocket technology that assisted in missile development has been undertaken.

Any country trying to evolve immensely complex ballistic missiles has to provide, conceptual, organisational, and financial factors. The challenge of missile development is getting these factors right at the same time and place. The soft technology creates the environment in which scientists and engineers apply their basic labours.[1] The value of sound organisation in providing effective defence was realised in India soon after independence[2] Some of the organisational factors listed here help us to understand the complexities involved in the construction of missiles (large technological systems). The factors are not rigid in the sense that they form an inalienable part of rocket development but a country which wants to sustain a large technological system has to obey these factors for success.

Organisational factors are central for assembling the physical hardware. They help in marshalling goals, money and people essential for military innovation. Agencies who do the organising part guide the overall programme. The most successful rocket projects have enjoyed continuous leadership from one agency and often one individual manager. With continuity come experience and skill, but also authority.

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[1] Factors such as personnel, organisation and finance are the 'software', the 'invisible technology', of innovation in some respects they are more important than the hardware or physical equipment usually associated with weapon development. See Aaron Karp, *Ballistic Missile Proliferation: Politics and Techniques* (Oxford: SIPRI, 1996), p. 4.

To build a missile it requires qualified technicians, designers and research. It takes a lot of time to accumulate a skilled work force. A labour force proficient in the skills of fuel mixing, chemical milling, beryllium fabrication and the thousands of other exotic skills of missile making cannot be cobbled together merely by raiding existing companies or through advertising in newspapers. A labour force is a delicate resource that must be cultivated like any other. It requires years of deliberate effort including arduous planning and training and careful co-ordination with other projects to ensure its survival and maintain its competence.[3] To design a successful missile requires a large number of designers. They are required to take into consideration the components that go into a system. They have to overcome problems associated with it. And lastly, research helps in bringing about the improvement of military equipment. What is needed is the co-ordination of defence research with scientific research. A thorough study of weapon systems and its accessories is required. To sustain defence research what is needed is general scientific and industrial development as well. The breakthrough in defence research occurred in India only with the report of Wansborough Jones in November 1946. On the basis of this report, a scientific advisor was appointed and later the Defence Science Organisation was established.[4]

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[2] *Lok Sabha Debates 1952*, 10 June, Col.1149. Cited in Sunil Sondhi, *Science Technology and India's Foreign Policy* (New Delhi: Anamika Prakashan,1994), p. 36.
[3] Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 82.
[4] Chris Smith, *India's Ad Hoc Arsenal: Direction or Drift in Defence Policy* (Oxford: SIPRI, 1994), p. 49.

Viewed as a currency of military and political power, missiles become a much-coveted weapon system that almost all states yearn to possess in their military inventories. Missiles can provide deterrence, an effective means of self-defence, and greater freedom of military and diplomatic manoeuvre. Missiles also present the means of achieving the maximum degree of surprise since they have a low readiness time. They also have very high flight speeds, giving less warning time in comparison to aircraft. Yet another element of surprise represented by missiles is that of the type of warhead that can be fitted on them. Defence against missile is costly and resource intensive. Missiles and nuclear warheads became ideal "partners". Spectacular developments in the realm of computers and propulsion made missiles fast, agile, accurate and survivable. Missiles became attractive as a replacement for, and as a complement to, manned aircraft for offensive roles.

Prestige, deterrence, defence, war fighting capability, power projection, the low vulnerability of mobile launchers and the non-effectiveness of available defences against missiles may be considered as the prime motivators for missile acquisition. Today ballistic missiles are the most prominent delivery system for nuclear weapons. Missiles have immense political value, and they carry a big image on account of the nuclear linkage. Moreover, missiles have their own dynamics in the context of deterrence. National security as well as, technical and economic motives drive the developing world's appetite for missiles. [5] As political weapons, missiles

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[5] Andrew Hull, "Motivations for Producing Ballistic Missiles and Satellite Launch Vehicles", *Jane's Intelligence Review* (February 1993), pp. 86-9.

count for a great deal. In conjunction with a nuclear warhead, missiles represent deterrence. Missiles also play a crucial role in the nuclear context.

Missiles: The Hardware

This section deals with the technological dimensions of missiles. It gives an overview of the basic technical parts that are needed to engineer a missile. Missiles belong to the class called rockets. A rocket is a general term used broadly to describe a variety of jet-propelled missiles in which forward motion results from reaction to the rearward ejection of matter at high velocity. This propulsive jet of gases usually consists of the combustion products of solid or liquid propulsion. Theoretically, a rocket, obeying Newton's third law of motion, is a simple machine, but structurally what makes the rocket obey this simple law is the harmonious interaction of complex components. The complexity calls us for defining a ballistic missile.

Defining a ballistic missile is very difficult. The *Cambridge Dictionary of English* defines a ballistic missile as one that is powered as it rises but then falls freely. Owing to a great many advances in missiles, the basic Newtonian definition may not be sufficient. In this dissertation I stick to the definition given by Aaron Karp: "A missile is an unmanned, aerodynamic actively guided rocket propelled vehicle that can be fired ground to ground along a ballistic or parabolic trajectory".[6] A guided missile is broadly any military

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[6] Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 4.

missile that is capable of being guided or directed to a target after having been launched.

Missiles are divided into two: strategic and tactical. Tactical guided missiles are shorter-ranged weapons designed for use in the immediate combat area. Long-range or strategic-guided missiles are of two types: cruise and ballistic cruise missiles are powered by air-breathing engines that provide almost continuous propulsion along a low-level flight path. A ballistic missile is propelled by a rocket engine for only the first part of its flight; for the rest of the flight, the unpowered missile follows an arcing trajectory small adjustments being made by its guidance mechanism. Strategic missiles usually carry nuclear warheads, while tactical missiles usually carry high explosives.

Strategic missiles are developed to attack the enemy at a distance. They can be divided into two categories: those that are launched from land and those that are launched from the sea. They can also be divided according to their range into intermediate range ballistic missiles (IRBMs) and intercontinental ballistic missiles (ICBMs). IRBMs have ranges of about 600-3500 miles, while ICBMs have ranges exceeding 3500 miles. A ballistic missile is usually a multistage one; it increases the range and throw-weight. By shedding weight as the flight progresses, each successive stage has less mass to accelerate. This permits a missile to fly farther and carry a larger payload.

The flight path of a ballistic missile has three successive phases. In the first part called boost phase, the rocket engine or engines provide the precise amount of propulsion required to place the missile on a specific ballistic trajectory. Then the engine quits and the second stage of the missile coasts usually beyond the earth's atmosphere. This is called the midcourse phase. The payload containing the warhead, the guidance systems and such penetration aids, as decoys, electronic jammers and chaff to help elude enemy defences, re-enters the atmosphere. This phase is called as the terminal phase. The terminal phase of the flight occurs when gravity pulls the warheads back into the atmosphere and down to the target area.

A missile's potential can be understood by assessing the quality of the parts that go into it. The following section is about the key parts of a missile. The hierarchy chosen shows a descending order of complexity.

MISSILE GUIDANCE

Guidance is the most essential and most intricate portion of a ballistic missile.[7] Accuracy of a missile is achieved only through the guidance system. Scientists often call the guidance package the brain or the central nervous system of a missile. Guidance helps to target, control and monitor the orientation of a missile. Guidance technology, based on Newtonian physics, involves, the measuring of missiles disturbances in three axes, x, y and z.

[7] Not all rockets need guidance. Clean aerodynamics and high acceleration can provide acceptable accuracy up to 90 kms. Beyond this you need active guidance to ensure acceptable accuracy.

Owing to its complexity the guidance hardware is called the Achilles heel of any incipient missile development programme.[8]

Guidance relies on advanced pieces of equipment such as high performance sensors-gyros and accelerometers that give the details about the missiles attitude and acceleration. The three gyroscopically stabilized accelerometers mounted at right angles to one another are used to measure the disturbance that accrues to a missile.[9] The data collected is then passed on to the navigation, guidance and control system (NGC). The NGC decides whether any correction or changes are needed. Since an inertial navigation system is very complex, budding missile-makers stick to strapped-down guidance. India's 240 km range Prithvi, first tested in February 1988, uses a strap-down system, probably derived from the Soviet SA2 surface-to-surface missile. Here, instead of having all the gyros and accelerometers housed in a stabilised platform, strapped-downs are directly attached (strapped-down) to the missile's airframe. Unlike a true inertial system which measures motion from its own independent frame of reference, a strapped-down gyro can only detect a change in the motion of the rocket itself, which is then compared to a pre-set trajectory stored in a mechanical can or on a computer.[10]

The technology for gyros and accelerometers is among a country's most closely guarded secrets. S.C. Gupta, who developed the inertial sensors and the guidance system for India, points out that

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[8] Janne E. Nolan, *Trappings of Power: Ballistic Missiles in the Third World* (Washington D.C.: Brookings Institution, 1991), p. 34.
[9] Gyros give the information regarding the missiles attitude and accelerometers give information on the missiles acceleration.
[10] See Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 120.

> The governing theory of operational gyroscopes and accelerometers [is] well known and well documented...However, the technological information about their construction features and the exotic materials used, which make them capable of measurement with the accuracies required during the flight is highly classified....As these devices form the critical subsystem of guided missiles, of both tactical and strategic calibre, they are classified under weapon systems of the most sophisticated type. As such, these devices are not generally available for even the peaceful uses of outer space.[11]

PROPULSION

Propellants account for three quarters of any rocket's weight. To accelerate a vehicle to overcome the drag and to affect a change in its velocity and to provide sufficient lifting, one needs a propulsive force. Missiles are either propelled by solid motors or by liquid motors. In both cases, the chemicals for rocket propulsion involve combining an oxidiser and a fuel for burning in the combustion chamber with a resultant forward motion. The power that can be produced by a typical propellant combination varies.[12] The propulsive force that forms the key for all missile systems comes under the family called jet propulsion that include turbo-jet, pulse-jet and ram-jet. Jet propulsion is either provided by a rocket motor or by an air-breathing engine.[13]

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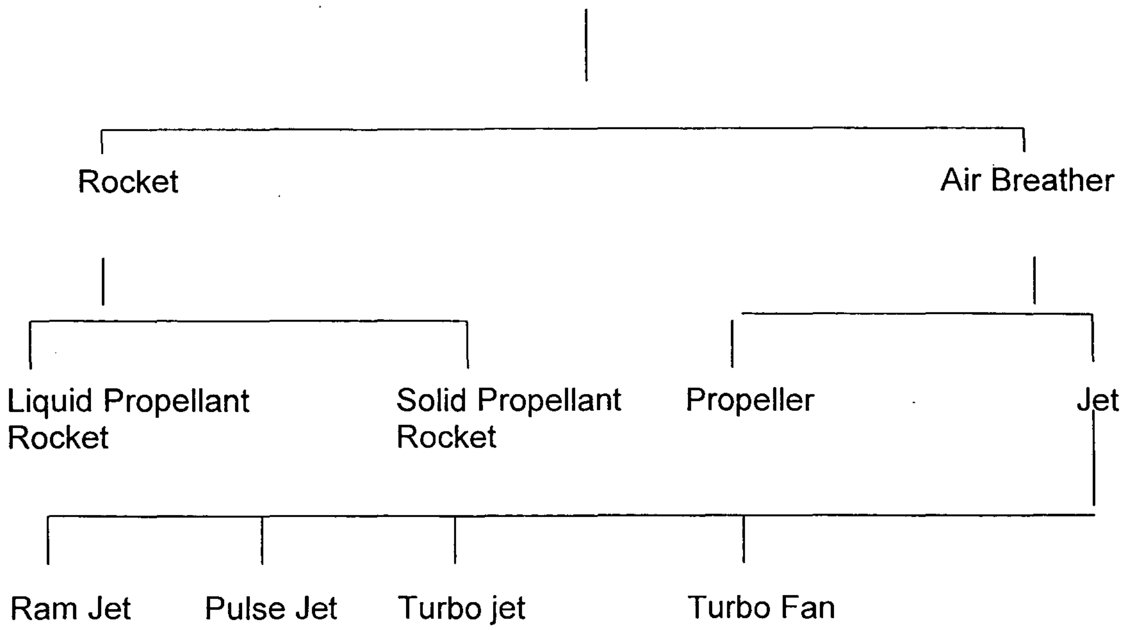
[11] Gopal Raj, *Reach for the Stars: Evolution of India's Rocket Programme* (New Delhi: Viking, 2000), pp. 145-6.

[12] See Appendix 1.

[13] Air-breathing engines; turbo-jet, pulse-jet and ram-jet, carry their fuel and depend on the oxygen content of the air for burning. Since they need continuous supply of oxygen for it's functioning they are limited to operation within the Earth's atmosphere. Rocket motor on the other hand is a non air breathing and has the completely self-contained propulsive elements. The fuel is supplied with an independent oxidiser within the vehicle, which supplies the necessary oxygen. The thrust thus generated is independent of the medium through which the vehicle travels, making the rocket engine

The following chart shows the principal types available.

Propulsion Systems[14]



Liquid Propellants

Liquid propellants help the missile to generate the required thrust for easy lift to the desired range. It differs from solid motors with respect to construction and operation. The mechanical and metallurgical demands of liquid fuel engines raise serious obstacles. Missiles based on liquid propellants are dangerous and volatile, and their use requires complicated tanks, high-speed pumps, fuel injection systems, combustion chambers, regulators and ignition systems.[15] It requires delicate arrangement of parts and chemicals. Owing to their immense complexity, liquid propellants are

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capable of flight beyond the atmosphere or propulsion underwater. See R.G. Lee, et al., *Guided Weapons*, Vol. I (London: Brasseys, 1988), p. 26.

[14] Ibid. p. 9.

[15] Aaron Karp, *Ballistic Missile Proliferation*, p. 102.

usually regarded as poor choices for ballistic missiles.[16] The common understanding is that the solid propellants are for missiles and liquid for launch vehicles. Nevertheless, liquid motors have greater efficiency and other advantages, which make it the preferred option for most rockets in the initial stages of their development.

A liquid engine and its stages require far more high-precision mechanical fabrication and assembly than a solid stage. Unlike the solid propellant motor, the liquid propellants are stored outside the combustion chamber in a separate tank from the engine. The propellant is directed to the engine through special plumbing mechanism. Valves and regulators control the proportion of the fuel to reach the engine. A special kind of material is needed for chamber and other parts of the engine to protect it from the hot gases generated during combustion. When the question of high specific impulse (*Isp*) arises, the best type of fuel complex would be a bipropellant type in which the fuel and oxidant are tanked separately. [17]

Liquid motors come with another advantage. Fuel flow can be regulated in flight or shut off altogether, making control of the rocket much easier. They burn at low pressures, permitting simpler construction of the rocket airframe and combustion chamber. Liquid motors have the inbuilt ability to vary the thrust, and it can be stopped and restarted if necessary.

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[16] Balaschak, M. et al., *Assessing the Comparability of Dual Use Technologies for Ballistic Missile Development* (Cambrdge: Massachusetts Institute of Technology, 1981), pp. 45.
[17] Specific impulse (*Isp*) is a rocket motor performance parameter. It is defined as fuel flow rate divided by the propellant mass flow rate. Liquids can produce 15-40 % more thrust (*Isp*) than solids. See R.G. Lee, et al., op. cit., p. 276.

Owing to this benefit, launchers all over the world have liquid engines for their core propulsion with solids providing extra thrust for lift off.[18]

The high corrosive factor of fuels and oxidants in liquid fuel engines raises more imposing barriers. Because of the corrosive nature, it doesn't allow pre-packing of the fuels due to storage problems. Some challenges come from the demands on high-performance pumps that inject huge volumes of propellant in precise quantities into the combustion chamber. Other problems come from the problems of cooling the combustion chamber and exhaust nozzle. Notwithstanding the problems in handling liquid propellants, one cannot dismiss the utility of liquid propellants for military applications because of their easy availability as they can be produced by established chemical industries.[19]

Solid Propellants

Solid motors are very simple and easy to construct. What they need is an igniter and a mass of fuel in a casing that ends with a nozzle. The propellant charge for the solid motor is divided in to homogenous and heterogeneous. A typical homogeneous propellant consists of nitro-glycerine and nitro-cellulose. They are also referred to as double-based propellants. When the propellant consists of a suitable mixture of fuel and oxidant, it is described as heterogeneous. The best-known type of heterogeneous propellant consists of crystalline ammonium per-cholorate which acts as the

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[18] Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 103.
[18] Ibid., p. 104-105.

oxidiser, one of a range of poly-merisable binders, and possibly, powdered aluminium as the fuel. This type is often referred to a composite propellant and is of a rubbery nature.[20] There is also a third type based on a combination of the double base and composite types. This consists of ammonium per-chlorate and powdered aluminium in a matrix of nitricellulose/nitroglycerine.[21]

The major advantage of solid propellant, compared with a liquid propellant, is its high density. This is an asset in volume-limited designs. Another advantage is its instant readiness and stability. Finally, the basic materials that are needed for a solid motor are readily available. To the user, the chief advantages of the solid rocket in missiles is the avoidance of field servicing equipment, the straightforward handling and easy firing, usually with simple electrical circuits. The solid fuels are highly advantageous because they are much easier to handle and operate. Solid propellants are typically assumed to be the best choice for ballistic missiles. Once deployed, most solid fuel engines can be left for years with only minimal maintenance.[22]

Although solid motors appear simple, devoid of moving parts and the complex plumbing of liquid engines, they are also extremely difficult to handle. A small flaw can destroy the motor and the missile with it. Handling

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[20] Composite materials are composed of a mixture of combination of two or more constituents wich differ in form and material composition and which are essentially insoluble in one another. The materials which combine may be metallic, organic or inorganic. While other material combinations possible are virtually unlimited, the most typical composites in launch vehicles are made of structural constituents, embedded in a matrix. Large variety of glass fibre reinforced plastic composites and opened avenures for the entry of Kevlar, polyamides and carbom-carbon composites, ceramics are special types of baked clay used for microwave transparent enclosures.

[21] This combination is very energetic but suffers from the production of dense white smoke, as do most of the composite propellants.

[22] Aaron Karp, *Ballistic Missile Proliferation*, op. cit., p. 104.

and operation of solid propellants is very cumbersome and they accumulate stresses, which result in cracks and voids, leading to larger burning area when the motor is fired. This unexpected rise in temperature can cause the motor to blow apart. Unlike liquid motors the propellant flow cannot be regulated or cut off, so a rocket's trajectory is more difficult, so designers focus on an aerodynamic breaking system for control. Moreover, solid propellants are very sensitive to temperature changes, humidity, aging, as well as shocks and vibrations. Without careful treatment, the propellant will decompose. Solids produce lower thrust, pound for pound, than liquids. Solid motors also raises the serious problem of engine cooling. Solid fuels burn at higher temperatures than most liquids. Unlike liquids, solid propellants cannot be circulated around the combustion chamber for cooling purposes. Instead, designers must rely on highly advanced materials and the use of complicated aerodynamic cooling techniques.

RE-ENTRY VEHICLE

The re-entry vehicles are the nose cones that protect the missile armament during its return into the atmosphere. As the re-entry vehicle comes down, it is subjected to a searing temperature of 3000 degree centigrade. To withstand this immense temperature and to protect the delicate payload from desiccation, the temperature inside the payload should be maintained below 50 degrees centigrade. For this reason the design of the re-entry vehicle is very critical. Moreover, the re-entry vehicle should be precise; otherwise, it would keep skimming the atmosphere like a flat stone thrown across the surface of a lake or pond. The re-entry vehicle, while entering the atmosphere, undergoes a process of ablation like a snake sloughing off its skin. The carbon composite material covering the payload is sloughed off or is removed leaving the payload untouched. Building the structural elements inside the payload is a challenge. India took a long time to develop this technology.

Conclusion

The creation of missiles results from bringing together heterogeneous elements. The components of a technological system like a missile include physical artifacts, organisations, and components, such as books, articles and University teaching and research programmes, which are the intellectual basis for the system. The design, development, and employment of the missiles involve tremendous efforts. A multidisciplinary team effort is required. It engages expertise in such diverse areas as aerodynamics, structures materials, electronics, chemicals, computers and software development, pyrotechnic devices, and so on.[23]

[23] Gopal Raj, *Reach for the Stars*, op. cit., p. 51.

CHAPTER II

DEVELOPING THE TECHNOLOGICAL BASE FOR ROCKETS: 1950-1972

This chapter will focus on the efforts made by Indian scientists and engineers with the backing of the political establishment to build a base for rockets in India. The chapter is divided in to three sections followed by a conclusion. The first section deals with the origins of the technological base for research on rocketry in India. The second deals with India's space programme. The last section deals with the dichotomy in space and missile research in India. The period covered here is the roughly two decades beginning in 1950 and extending up to the establishment of the Vikram Sarabhai Space Centre in 1972.

Initial Origins

Rockets as a battlefield weapon are not something new to India; its use has been well documented. Rockets surfaced in the later half of the 19^{th} century when Haider Ali and his son Tipu Sultan used them against the British in India in the 1780s. Its use in India is well documented at the battles of Panipat (1526, 1576) Samugharh (1758), Carnal (1739), and by Hyder Ali (1768, 1790) and Tipu Sultan (1783, 1784)[1].

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[1] Denys Forrest, *Tiger of Mysore: The Life and Death of Tipu Sultan* (Edinburg: Orville, 1970), p. 140. It was the rocket used by Tipu Sultan at the siege of Seringapatanam in 1799 which attracted the

Technology emerged as the *sine qua non* of great power status soon after World War II. The war had three major military technological breakthroughs: the atom bomb, the jet engine, and the missile. The jet engine increased the might of the bomber and the potent technologies inherent in the atomic bomb and the VI and V2 rockets led to the development of missiles in a big way. Missiles today represent the ability to alter the concept of strategic bombing by their ability to strike directly at an enemy's military machinery. Although missiles had been under development for long (United States Air force ballistic missile division was established in 1954), the missile race between the US and USSR began in earnest only in 1957 with the launching of the Sputnik by the latter.

An intensive effort to develop and eventually marry both technologies was mounted in the late 1940s and early 1950s. Soviet progress in the direction of long-range missiles was much more intense than in the US. Thus, between the end of the World War II and launching of the Sputnik, Soviet and US strategic thought on missiles diverged on the issue of the long-range missile while being similar on the synergistic import of the missile platform-nuclear warhead combine.

Missiles and nuclear warheads became ideal partners and they added a new dimension to the realm of strategy. Spectacular developments in the realm of computers and propulsion made missiles fast, agile, accurate,

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attention of the British gunnery expert Colonel Sir William Congreve, who took it as a model and improved upon it to bombard Boulogne in 1806 and Copenhagen in 1807.

survivable and space worthy; missiles became most attractive as a replacement for, and as a complement to, manned aircraft for offensive roles.

India's efforts to acquire autonomous technological potential were affiliated with its pursuit of major world power status. The emergence of nuclear and space sciences were seen as technological marvels that promised modernity and international prestige. Jawaharlal Nehru, the chairman of the National Planning Committee set up by the Indian National Congress, in a report, observed:

> It is not only the needs of modern industrialisation that necessitate the immediate establishment and rapid development of such heavy or engineering industries within the country on a large scale. The demands of our national security also require that such industries be set up as early a date as possible. Modern war is won more and more with machines.[2]

Sardar Patel, Home Minister in Nehru's cabinet, maintained that India must be industrialised quickly and efficiently in certain directions or else be left behind in the modern world because a modern army requires many things which only machines can produce. Vikram Sarabhai while delivering a speech at the Aeronautical Society observed:

> The progress of science and technology is transforming society in peace and in war. The release of energy of the atom and the conquest of outer space are two most significant landmarks in this progress. Largely due to the consistent national support which the programmes of the atomic energy commission has received since independence, India is amongst the nations of the world advanced in atomic energy and is striving for a similar position in space technology and research. There are those who preach that developing nations must proceed step-by-step following the same process by which the advanced nations themselves progressed. One is often told that such and such a thing is too sophisticated to be applied. This approach disregards what should perhaps be obvious that when a problem is great one requires the most effective means available to deal with it. The seeming advantage of

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[2] *National Planning Committee Series* (Bombay: Indian National Congress, 1948), p. 17. Cited in Sunil Sondhi, *Science Technology and India's Foreign Policy*, op. cit., pp. 55-56.

> a developing nation such as India, which has only a limited existing technological infrastructure to build on, can be an asset rather than a liability. I suggest that it is necessary for us to develop competence in all advanced technologies useful for our development and for defence, and to deploy them for the solution of our own particular problems, not for prestige but based on sound technical and economic evaluation as well as political decision making for a commitment of real resources.[3]

The early planners in India believed that space technology would provide significant contributions to the solution of problems such as overpopulation, mass illiteracy, frequent natural disasters and poor exploitation of resources. Sarabhai envisaged space activities and space research as an engine for the process of industrial and technological development. According to him, an annual investment of 40 million U.S. dollars in a five-year period, for the provision of community television to all the villages in India, would generate a strong industrial base in electronics, providing employment to about 120,000 qualified scientists and engineers, technicians and managers and other administrative personnel. [4]

Before independence, the scientific services of India had little to do with the war machine. They limited themselves only to testing. The initial factor that catalysed the course of space and missile research was the war of 1962, when the Indian armed forces were defeated by Chinese troops in a war on the northern frontier. Even after the 1962 war, the Indian armed forces remained rather unscientific in the matter of equipment. Consequent on the reported use of proximity fuses by Pakistani troops in the 1965 war, Indian

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[3] Government of India, Atomic Energy and Space Research: *A Profile for the Decade 1970-80* (New Delhi: Government of India Publications, 1980), p. 34.

[4] Kamala Choudhry ed., *Vikram Sarabhai: Science Policy and National Development*, (New Delhi: Macmillan, 1974), p. 35.

scientists and soldiers began to co-operate in the matter of defence research.[5] Operational research and system analysis gradually came to be adopted in the Indian armed forces. A political consensus evolved regarding high military spending for national defence. Arms production was greatly expanded and new items were introduced into the armed forces. The existence of threats and bureaucratic pressures created demands for new weapons and for shifts in the doctrines of the three armed services.

Launch vehicles for civilian applications and missiles are technologically one and the same. The two differ in their payloads, their trajectories and to a lesser degree, guidance and control. The only major difference between the space and missile variants is that the final boost stage of the missile is terminated before the payload has achieved enough velocity to enter orbit, resulting in its return to earth. In principle, space-launch vehicles may require less accuracy than missiles, but their guidance systems are similar, and this is potentially convertible for use in missiles. With the arguable exception of Japan, no country has invested in the production of space-launch vehicles solely for non-military objectives. Converting a rocket from one role to another has never been an insurmountable one. Large rockets have been used interchangeably for civilian and military missions. [6]

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[5] It has been said that the most remarkable scientific development of the war, save for the atom bomb, was the proximity fuse. This was a small radar set—power plant, transmitter and receiver--which was built in to an explosive shell. It activated the detonator of the shell when it was properly located with respect to the target. Among other things, it did away with the necessity of computing the correct time of flight and setting the fuse before firing the projectile. See Bernard and Fawn Brodie, *From Crossbow to H-Bomb* (New York: Dell Publishing Company, 1962), p. 213 and Nair A Balakrishnan, *Facets of Indian Defence* (New Delhi: S.Chand & Company, 1983), p. 123.

[6] When pressed to comment on the difference between ballistic missiles and space launchers, president John Kennedy allegedly responded 'attitude'. Apocryphal or not, the comment sums up the matter up neatly. See Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 55.

The characteristics of long-range missiles are high-accuracy guidance, control, and re-entry technologies. Such components do not have to be designed for a rocket at the start. In most cases they can be developed and fitted later, long after a rocket has been introduced for civilian use. The differences are not in the rocket so much as in the minds of policy makers.[7]

In India, we see a synergy between satellite launch vehicles and defence programmes. In the next chapter, the translation of the SLV3s into a defence-capable space weapon capability will be illustrated. American security expert John Pike is convinced that the only difference between the satellite launch vehicle and ballistic missile is a 'coat of paint'.[8] Unlike the West, where the origin of high technology is generally strategic and is later adapted to civilian use, in India the reverse is the case. The American and Soviet space programmes developed out of explicitly military programmes, designed to create ballistic missiles for the delivery of nuclear weapons.[9] Even the Chinese are adapting ICBM technology for a very ambitious space programme that aims at manned space mission. Though the concept of conversion looks easy, it is much more difficult to adapt civilian technology to military purposes. Although New Delhi continues to portray the space programme as a peaceful scientific venture, Indian officials have referred to its military potential since at least the early 1970s.[10]

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[7] Ibid., p. 56.
[8] John Pike is the policy analyst at the Federation of American Scientists. He currently serves on the board of the FAS, and is a member of the council on foreign Relations. Available at, http:/www.fas.org/bio-pike.htm.
[9] William Shauer, *The Politics of Space: A Comparison of the Soviet and American Space Programmes* (New York: Praeger, 1976), p. 41.
[10] Janne E. Nolan., *Trappings of Power,* op. cit., p. 43.

Both launch vehicles and missiles come under the same genus called rocketry, with minor technical difference with respect to payload and accuracy. This technological 'synonymy' forces one to study India's missile programme by looking at India's space programme, which was shaped when research on rocketry was first attempted by young scientists and engineers in the early 1960s. The rest of this chapter looks at the independent research on rocketry by the space group and by the missile team. An important fact to note is that, though both took different routes, they were partly united when the Indian missile programme went ahead at full pace in 1983 with the creation of the Integrated Guided Missile Development Programme (IGMDP). The period chosen focuses on a number of facilities that were established to create a technical base for rocketry. Efforts were also made during this phase to build up a cadre of scientific and technical personnel who were to be engaged in research on space sciences. In dealing with the space programme not much importance has been given to satellites and other space applications. The stress instead has been on efforts to build a base for making rockets capable of carrying both a civilian payload and a warhead.

India's Space Programme: A Technological Base for Missiles

This section will deal with the genesis of India's space programme. The time period chosen is from 1950 until 1972, when the Vikram Sarabhai Space Centre (VSSC) was established in Thumba by amalgamating various ISRO units which later became a major research and development establishment working on the development of sounding rockets, satellite launch vehicles, and ground and vehicle-borne instrumentation.

From a humble beginning in the early 1960s, the Indian space programme grew to a giant monolith capable of launching satellites for other countries. The basic goal envisaged by the Indian leadership for the space programme was the utilisation of space technology for national development. With the primary objective to make India self-reliant in space technology and to achieve competence in developing the appropriate technology systems, the Indian Space Research Organisation (ISRO) was established in 1969 as India's primary space R&D organisation, responsible for both space launch and space applications and its mandate included developing launcher and propulsion systems, launch sites, satellites and their tracking networks.[11] The major thrust areas were identified later. The immediate objectives were in the realm of satellite communication for domestic uses, remote sensing for satellite survey and management, environmental monitoring and meteorological services and development, and operationalisation of indigenous satellites and launch vehicles. The Government of India established most of the infrastructure for supporting the space programme during the initial phase of the space programme.

India's space programme is very unique in comparison to others. Most of the countries including China developed their space programmes from their missiles. India's launch vehicles on the other hand were built from scratch.

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[11] The organisation grew to include twelve distinctive centres. See Appendix I

India's space programme owes much of its present status to the pioneering work of Dr. Vikram Sarabhai. Sarabhai along with Dr. Homi Bhabha, the pioneer of India's atomic energy programme, was the most important policy entrepreneur of the programme. Born in Ahmedabad on 12 August 1919, to a wealthy family of industrialists, Vikram Ambala Sarabhai laid the foundation for the genesis of India's space programme. He graduated in the study of natural sciences at Cambridge University. In 1947, he received his doctorate for his thesis on 'Cosmic Ray Investigation in Tropical Latitudes'. During his brief stay (before his doctorate) at the Indian Institute of Science in Bangalore, which was then headed by CV Raman, he had a chance meeting with Bhabha, who shared a serious interest in science as well as the desire to ensure its growth in India. Soon after his doctorate in 1947, Sarabhai returned to India to hold a multitude of portfolios, which trained him enough in all spheres to take up the giant task of building India's space programme. [12]

A cosmic ray physicist by training, he saw the geographic positioning of the Indian subcontinent, which was in the equatorial region, ideal for meteorology and aeronomy. It was the launch of Sputnik in 1957 that triggered research into space applications of rocketry in key countries,

[12] He established the Ahemadabad textile Industry's Research Association (ATIRA), started the Physical Research Laboratory (PRL) at Ahemadabad, took over the management of Sarabhai Chemicals in 1950, established Suhrid Geigy Limited in 1955, assumed the management of Swastik Oil Mills Limited, founded the Ahemadabad Management Association in 1957, and set up Sarabhai Merck Limited in 1958, also took over Standard Pharmaceuticals in Calcutta, established Sarabhai Research Centre in Baroda and the operations Research Group (ORG) in 1960, was also the prime mover behind establishing the Indian Institute of Management (IIM) at Ahemadabad. See Gopal Raj, *Reach for the Stars: The Evolution of India's Rocket Programme* (New Delhi: Viking, 2000), pp. 6-7.

including India. Sarabhai gave vivid expression to the importance of modern technology for the developing countries. He declared "if we are to play a meaningful role nationally in the community of nations, we must be second to none in the application of advanced technologies to the problems of man and society which we find in our country and we should note that the applications of sophisticated technologies and methods of analysis to our problems is not to be confused with embarking on grandiose schemes"[13]

Under the chair of Vikram Sarabhai, the Indian National Committee for Space Research (INCOSPAR) was created by the Department of Atomic Energy (DAE) in 1962. Soon after its establishment the United Nations formed a Committee on Space Research (COSPAR) which pointed to the importance of the magnetic equator for meteorology. India, being close to the magnetic equator, was fortunate enough to be sponsored by the United Nations for a sounding rocket launching facility. Having identified a place for launching sounding rockets, Sarabhai used the opportunity to gear up the technological base for space research. INCOSPAR, set up in August 1962, and later ISRO, set up in 1969, both under DAE, were responsible for carrying out the programmes related to space research.

The Government of India entrusted the responsibility for space research to the Department of Atomic Energy in 1961. In 1972, the Government carried out a major administrative restructuring by setting up a separate space commission and a Department of Space (DOS) under the

[13] Baldev Nayar, *India's Quest for Technological Independence*, Vol. II (New Delhi: Lancers, 1983), p. 433.

direct jurisdiction of the Prime Minister. At the same time, ISRO was reconstituted as a research and development organisation under DOS. In 1972, the whole complex, comprising the Thumba Equatorial Rocket Launching Station (TERLS), the Space Science and Technology Centre (SSTC), the Rocket Propellant Plant, Rocket Fabrication Facility (RFF) and Propellant Fuel Complex (RFC), was designated as the Vikram Sarabhai Space Centre (VSSC). VSSC, located at Trivandrum, is the largest of the ISRO centres and is the lead institution for launch vehicle development (SLV3s, ASLV, PSLV, and GSLV), and it pioneers in rocket research and planning and execution of launch vehicle development projects.

The Department of Space is the executive agency of the space programme. Its activities cover three broad areas: space sciences, which involve research in agronomy, cosmic rays, and plasma physics; space technology, which includes the development of launch vehicles satellites; and space applications, which represent the applications of space technology in the fields of telecommunications remote sensing. [14] ISRO is the major research and development agency of DOS. It is responsible for carrying out the programmes of DOS, areas of space technology and space applications, which it does through its centres located around the country. The Government of India resolution of June 1972, which established the space commission, assigned to it responsibility in the entire field of science and technology in outer space and their applications.

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[14] Government of India, Department of Space, *Annual Report* 1972-73 (New Delhi: Government of India Publications, 1974), p. 14.

The Indian space programme began with the setting up of a station to launch sounding rockets.[15] These rockets do not carry a payload but they do carry instruments, and they fall back to the earth once when their fuel is exhausted. Experimentation with sounding rocket is an excellent point of departure for space research because of the relatively simple techniques and range facilities required. A sounding rocket programme effectively stimulates technological interest, study and co-operation.[16] Sounding rockets were used in the 1950s to study the equatorial electro-jet phenomena.[17] A sounding rocket facility on the magnetic equator enabled the early scientists to do a detailed analysis of the elector-jets vertical structure and fluctuations. The sounding rocket facility created a base for Sarabhai to recruit a small group of young men to visit the U.S's National Aeronautics and Space Administration (NASA) for training at the Goddard Space Flight Centre and at the Wallops Island facility used for sounding rocket launches. The training was only in assembling imported sounding rockets and their scientific payloads, procedures for the safe launch of these rockets, tracking the flight of the rockets, receiving data radioed down during flight and collecting other scientific information required. On their return, these persons, with help from the United States, USSR and France, set up the Thumba Equatorial Launching Station (TERLS), which became operational on 21 November 1963.

[15] Sounding rockets are so called because they sound the atmosphere that is it measures various parameters during their flight.
[16] K.P Prakasam, *Space Horizons* (New Delhi: Chand &Company, 1981), p. 13.
[17] They are a stream of electric current flowing in a narrow band of about three degrees on wither side of the magnetic equator at a height of some 100kms.

TERLS was established for the purpose of "supporting scientific instruments with necessary launch instrumentation and other back up facilities for carrying out investigations in the equatorial upper atmosphere".[18] Though Thumba was not directly below the magnetic equator, sounding rockets launched from Thumba would be able to probe phenomena associated with it. The earlier facilities at Thumba consisted of one launcher, a church and some old fishermen's dwellings. TERLS later became an international range under UN sponsorship, with the capability to launch different types of rockets- Nike Apaches, Centaures, M 100s, Skua Patrols, Boosted Arcas, Dragons and Judi Darts. The launching of Indian sounding rockets was and is carried out under the Rohini sounding rocket programme which co-ordinates the development, production, and launch of the Rohini series of sounding rockets and the Centaure rockets for research of the upper atmosphere and for meteorological purposes.[19]

Initially, NASA helped India in assembling and launching imported sounding rockets. Later, the Centre National d'Etudes Spatiales (CNES) of France supplied radars and sounding rockets. Later still, the British and Soviets launched their own sounding rockets from India. On 21 November 1963, India assembled and launched the Nike Apache rocket supplied by NASA with a sodium vapour experiment provided by CNES of France. This marked the beginning of India's space programme. During 1964-65, an

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[18] Government of India, Department of Space, *Annual Report 1978-79* (New Delhi: Government of India Publications, 1980), p. 27.
[19] Government of India, Department of Space, *Annual Report 1980-81* (New Delhi: Government of India Publications), 1982, p. 13

agreement was signed with Sud Aviation of France to build their two-stage Centaure rocket under licence in India. An indigenous attempt led to the Rohini sounding rocket programme. The successful launch saw the creation of the Space Science and Technology Centre (SSTC) by the government. The objectives of the Centre were to design, develop, and construct rocket and satellite payloads and instrumentation and to promote research in space sciences and technology.[20] Sarabhai recruited several young Indians who were abroad, almost all of them from the United States, who would later determine the course of the space programme. [21] Several of the agencies that were set up in the early years of the space programme were established on the personal initiative of either Bhabha or Sarabhai, the first being the Physical Research Laboratory (PRL) for cosmic ray studies set up by Sarabhai in 1948. It was largely at Bhabha's insistence that the Tata Institute of Fundamental Research (TIFR), which trains scientific cadres in various advanced disciplines, was established.

The first indigenous sounding rocket was the RH 75, which was launched on 20 November 1967. This was flown using cordite as fuel.[22] Cordite is used as a double base propellant in which the same chemical acts as a fuel and oxidiser. Later, the RH 100 and RH 125 were tested. The RH 125 rockets were used for testing and perfecting techniques like stage separation, destruct systems, clustering of boosters to serve a single large

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[20] Government of India, Department of Atomic Energy, *Annual Report,* 1966-67 (New Delhi: Government of India Publications, 1968), p. 23.
[21] Gopal Raj, *Reaching for the Stars* op. Cit., p. 24.
[22] Cordite is a mixture of nitro-glycerine and nitrocellulose.

booster, payload recovery systems and ejection of nose cones. The need for research on propellants led to the development of the Liquid Propulsion Systems Centre. Simultaneously, two people were involved in the research on propellants. These were A.E. Muthunayagam and Vasant Gowarikar, a chemical engineer, who was working on tactical missiles in the Summer Field Research Station in Britain, when Sarabhai recruited him. Initial research on propellants was solid based. This may have been due to its prevalence in the other launch vehicle programmes in the rest of the world or due to the initial experience with cordite as a propellant. Muthunayagam was working with natural rubber resin, which was commercially available, and Gowarikar was working on a polyester-based propellant by the name of Mirnal. Later, a two-stage sounding rocket with an RH 75 on top of an RH 125 was successfully flight tested on 30 August 1968.[23]

Training in France led to the production of the Centaure sounding rockets in India. The scientists were trained in PVC composite propellant design, where the fuel and oxidisers are separate. A number of ingredients go into making these propellants. Polymers, such as those used to make plastics, act as binders, holding the other constituents in place and setting them into solid blocks. These polymeric binders also act as fuel. Ammonium per-chlorate is usually the oxidiser. A metal powder, such as aluminium powder, provides further fuel and, by raising the combustion temperature, also increases the thrust generated. Early experiments on crude propellants led to the establishment of a Rocket Propellant Plant (RPP) next

[23] Gopal Raj, *Reach for the Stars*, op. cit., p.37.

to the Thumba launching site with the French providing the necessary infrastructure. The rocket motor casing for the Centaure rocket were fabricated at the central workshop of the Bhabha Atomic Research Centre in Trombay. Three Centaure rockets were flown using imported propellants and the first indigenous Centaure Rocket using the indigenous propellant made at RPP flew on 7 December 1969. The success led to the starting of the Rocket Fabrication Facility in Thumba.

The successful indigenisation of the Centaure technology was a major landmark in establishing rocket capability. The Centaure technology provided a vital understanding of equipment, facilities, procedures and safety precautions needed to make large solid motors. The RPP is still used to produce solid motors. The Centaure technology brought with it the use of 16 CD V6 steel.[24] The experience from the Centaure provided India with self-sustaining technological growth in solid propulsion. Establishment of the RPP led to a whole family of sounding rockets being designed and built in rapid succession including Menaka I and II, RH 300, RH 300 MK II and RH 560. The Balasore test range became operational with the launching of the RH 200, which used a 10 kg payload to a height of 65 km for monsoon experiments. The effort, begun in the mid 1960s, to build sounding rockets within the country had reached a reasonable degree of maturity by the early 1970s. This created a base from which the more difficult challenge of building a launch vehicle could be attempted. These sounding rockets also became a

[24] This is a special type of steel used for rocket casings. It is known for its high strength and fracture toughness.

test bed to try out key technologies required for launchers. An RH 560, for instance, was used to test the guidance and control system for the SLV 3, India's first launch vehicle.[25]

The development of systems as complex as a satellite launch vehicle and the satellites themselves needs understanding in depth and a complete, mastery of the technology of each subsystem that is involved. The thrust of the programme at the Space Science and Technology Centre over the years has been to grow the capability through a number of individual projects, each by itself modest in character, but progressively involving increasing technological complexity and sophistication.[26] Janne E. Nolan in his book *Trappings of Power* sees sounding rockets as an excellent departure for establishing a cadre of rocket personnel, through which further rocket or missile activity can be carried out. Apart from this, training in sounding rocket technology led to development and training experience with respect to launch site and test procedures.[27]

The sounding rocket programme gave the newly-recruited scientists hands-on experience and created basic competence in some important technologies It gave the aspiring scientists and engineers confidence in conceiving projects and in executing them with a multi-disciplinary team. In a paper published by the American Aeronautical Society in 1966, Sarabhai pointed out that when a nation succeeds in setting up a scientific programme

[25] Gopal Raj, *Reach for the Stars*, op. cit., p. 43.
[26] Government of India, *Atomic Energy and Space Research Profile for the Decade 1970-80* (New Delhi: Government of India Publications, 1981), p. 45.
[27] Janne E. Nolan, *Trappings of Power*, op. cit., p. 42.

with sounding rockets, it develops the nucleus of a new culture in which a large group of persons in diverse activities learn to work together for the accomplishment of a single objective.[28]

Missile Efforts

By the late 1950s, missiles, along with aircraft were beginning to be considered as delivery systems. The space programme was possibly the earliest pointer that the search for a reliable vehicle to deliver nuclear weapon had begun. India dedicated its space programme in the early 1960s and 1970s to peaceful applications, relegating missile research and development to a largely ineffectual effort under the auspices of the DRDO[29]. This section focuses on the early efforts by the defence scientists and engineers to create a technological base for missiles.

Soon after independence there was a rapid demobilisation of the army and the defence budget was very modest. The importance of defence had to wait till the coming of Krishna Menon as Defence Minister. His stress on self-reliance was popular with Nehru and other political leaders as well as some in the defence forces. To rapidly build India's technological competence, he sanctioned numerous research projects. It was under his initiative that a big plan was launched to construct roads in India's remote borders, a factory set up to manufacture heavy-duty trucks and another to manufacture rifles. But

[28] Gopal Raj, *Reach for the Stars*, op. cit., p. 31.
[29] George Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation* (California: University of California Press, 1999), p. 244.

perhaps his most ambitious project was a proposal to build guided missiles.[30] Major General Brahm Dev Kapur, DRDOs first Chief Controller, played an integral role in India's initial missile efforts. Kapur, through his experience with Project Indigo, was instrumental in establishing 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.[31] After being briefed by B.D.Kapur, Menon clearly understood the potential of missiles in determining the future of wars. His foresight led to the establishment of a missile research centre at the Special Weapons Establishment in Hyderabad. A team was set up to study missilery so that it could advise the services[32] Initial attempts to build missiles were directed by Air Commodore V. Ganesan. The effort was to launch 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 propellants was carried out at the DRDO explosives laboratory.[33] In 1965, under the head of Sarabhai, the Ad-Hoc Electronics Committee was

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[30] Raj Chengappa, *Weapons of Peace: The Secret Quest of India's Quest to be a Nuclear Power* (New Delhi: Harper Collins, 2000), p. 135.

[31] This is an Indo-Swiss agreement to design and manufacture an intermediate range surface-to- air missile. It was bought about solely through the efforts of B.D.Kapur. The project, which would have been a first attempt to actually build a missile system, was cancelled due to India's preference for the Soviet built SA2 SAMs[31]. Although the programme never saw the light of the day it provided the impetus for a more broad based Indian Missile research programme and for the establishment of key research centres like Missile Establishment Centre located in Hyderabad and the Ad-Hoc Electronics Committee headed by Vikram Sarabhai.

[32] B.D. Kapur, *Building a Defence Technological Base* (New Delhi: Lancer International, 1990), pp. 98-99.

[33] William C. Potter, and Harlan W. Jencks, *The International Missile Bazaar, The New Suppliers Network* (Boulder: Westview Press, 1994), p. 202.

formed to sustain early developments in rocketry. The committee concluded that India should move forward with a missile production programme.[34]

DEFENCE SCIENCE ORGANISATION

As India chose to remain non-aligned, early attempts were made to develop an indigenous military capability to withstand external pressures. To do this, Nehru and Krishna Menon sought to create a domestic arms industry that would eventually satisfy all the requirements of the armed forces. It was with this in mind that the Indian government, in the late 1940s, contacted the British scientist P.M.S.Blackett to suggest how to develop a "defence base" in India.[35] With a handful of scientists recruited from the universities, D.S Kothari formed the Defence Science Organisation (DSO), in May 1948. Unlike their Western or Soviet counterparts, the early defence scientists were not familiar with defence problems and defence equipment characteristics and requirements. Hence it needed time for the defence scientists to understand the problems of the armed forces and to develop the skills to design and develop equipment asked for by them. Among the pioneers were R.S. Thakur, a chemist, Atma Ram, a mathematician, W.T. Adesheshiah, an applied psychologist, B.N Singh and S.S Srivastava, both physicists with a specialisation in electronics.

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[34] Ibid.

[35] P.M.S. Blackett, The Scientific Problem of Defence in Relation to the Needs of the Indian Armed Forces, Report to the Honourable Defence Minister of India, 10 September 1948, Cited in Amit Gupta , *Building the Arsenal*, op. cit., p 30.

Atma Ram became the first director of the Defence Science Laboratory. Sampuran Singh, an explosive chemist, joined the laboratory, and together they established the Ballistic Research Laboratory in Chandigarh with 300 acres of land. The Defence Science Laboratory operated as a separate entity directed by Kothari. This group of about 150 scientists formed the nucleus for future expansion. Some of the research centers that mushroomed during this time were the Armament R&D at Pashan, the Institute of Armament Technology, Pune, the Metallurgical Research Laboratory at Hyderabad, and Ballistic Research Laboratory at Chandigarh. The Defence Science Organization, though formed in 1948, achieved partial maturity in the early 1960s. Initially, the much-desired self-reliance was not achieved, due to poor allocation of funds for research. There were too few people who looked at science and technology as a catalyst for growth and so finding was patchy and inadequate.

DEFENCE RESEARCH AND DEVELOPMENT ORGANISATION

The expansion and reorganisation of the DSO, by merging a number of service and technical institutions, was followed by its renaming as the Defence Research and Development Organisation (DRDO) in 1958 with a network of nine laboratories. DRDO formulates and executes programmes of scientific research, design and development in the fields of relevance to national security leading to the induction of new weapons, platforms and other equipment required by the Armed Forces. It also functions as the nodal agency for the execution of major development programmes of relevance to defence through the integration of research, development, testing and production facilities with the national scientific institutions, public sector undertakings and other agencies. The Research and development activities of DRDO cover important demarcated disciplines like aeronautics, rockets and missiles, electronics and instrumentation, combat vehicles, engineering systems, naval systems, armament technology including explosive research, terrain research, advanced computing, artificial intelligence, robotics, systems analysis and life sciences including high-altitude agriculture, physiology, food technology and nuclear medicine.[36]

Due to the absence of a strong industrial base, DRDO could not get the necessary industrial support. Until the late 1960s, the industrial sector in the country, which was growing, though not very rapidly, was not making a significant contribution to the country's defence production. This was partly because national policy had been to produce defence items only from ordnance factories and defence public sector units. The early defence scientists failed to recognise the potential in the private sector companies, which had the capacity and potential to innovate and produce defence requirements. Moreover "India's defence R&D budget has historically not matched the DRDO's vast organisational structure. In the 1960s, it hovered around one percent of the defence budget".[37] Nevertheless, DRDO took up a number of projects in the areas of inertial guidance, lasers, infrared sensors and ramjet and dual thrust propulsion, all of which are of direct relevance to

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[36] See Appendix II.
[37] Ron Matthews, *Defence Production in India* (New Delhi: ABC Publishing House, 1989), p. 96.

missile development. In later years, with the growth of industries in the private sector and public sectors, DRDO became a giant monolith that was able to make rapid progress towards self-reliance in defence production.[38]

The history of the Indian space programme shows India, right from the start, publicly disavowing the use of space research for military purposes. Early research in rocketry and nuclear reactors in India were supported by broad national themes like nation building, self-reliance and international prestige and the goal of creating and sustaining a strong scientific and technical capability. The space department under Sarabhai was able to form stable alliances through the projection of economic benefits that could accrue out of satellites. [39] However, fear of embargoes that might thwart the growing space programme led to the dichotomy in space and missile research in India. The personal view of Bhabha and Sarabhai might provide a partial answer for the dichotomy. Sarabhai's personal animosity towards weaponisation led to the avoidance of rocket research for military purposes. Though his opposition was not unequivocal, he did not want the Indian space organisation to be preoccupied with missiles.

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[38] Today the Department functions in close partnership with 70 academic institutions, 50 national science and technology centres, 150 public & private industries who have supported the efforts of the Department in meeting the stringent needs of the services.

[39] The space programme is supported by a stable national consensus based on broad themes that are found through out Indian politics. The missile programme is less stable; an historically contingent alliance of particular interests an alliance that could shift substantially in the future. See Steven M Flank, *Reconstructing Rockets: The Politics of Developing Military Technology in Brazil, India and Israel* (Cambridge: Massachusetts Institute of Technology, Ph.D Thesis, 1993), p. 133.

Conclusion

Technologically, research on space and nuclear systems is a leading-edge activity requiring techniques and skills equivalent to those employed in the advanced engineering areas of civil industrial enterprise. Constructing rockets is a multifaceted effort, which involves the network of different industries, scientific laboratories and personnel, and huge amounts of money. The sophistication the Indian space and missile organisation has achieved in building Agni and Prithvi owe a lot to the early stages of research. This technology-gathering phase can be thought of as a *System Building Stage* through which a platform was created for actualising future launch vehicles and missiles. [40] The early stages were the difficult days for India's fledgling space programme as the space scientists were grappling with the new technology. There were just three stars in their eyes: the three space applications of remote sensing, communications, and meteorology, identified by Sarabhai.

This phase also clearly brings out the early quest for self-reliance and indigenisation of various systems. For the early scientists, indigenisation was a very difficult process; it involved the overcoming of numerous development and technological obstacles. Owing to handicaps in infrastructure, the industrial base grew slowly but steadily. The 1960s marked the Government

[40] This term has been borrowed from Social Construction of Technology (SCOT) theory. According to this theory, the components of technological systems are socially constructed. Before the components become socially determined, a system is built for its creation. A missile becomes a reality only when diverse communities like the security elite, scientific enclave and commercial subcontractors agree to come together with the weapon advocates who feel the need for the new technology. The conclusion of this dissertation analyses India's missile programme according to this theory.

of India's attempt to build a cadre of scientific and technical personnel in all fields of science and technology, including space science and technology. This led to an almost twenty-fold increase in the number of scientific and technical personnel involved in space research within the country. Between 1965 and 1969, there were only 110 scientific and technical personnel involved in space research. In 1975, this number went up to 2000. [41]

Unlike the atomic establishment, where the military aspect of the programme was an adjunct to the larger and comprehensive civil programme, the military missile programme was deliberately separated from the civilian space programme right from its inception. The poor performance in the missile effort has been due to the much lower amount of support for ballistic missiles than for space vehicles. In fact, if one regards the creation of DRDO in 1958 as the beginning of the missile programme at the Defence Research Laboratory (DRDL) in Hyderabad, then the Indian missile programme actually predates the civil space programme by at least four years. According to one assessment, the two programmes "competed for resources".[42] Though the two programmes saw a dichotomy, there was co-operation at times. This co-operation is best illustrated by Dr. Abdul Kalam, who began his career as a scientist in DRDL, was moved to ISRO in the 1970s to head up the Satellite Launch Vehicle (SLV) programme, and then returned to DRDL in the early

[41] Government of India, Department of Atomic Energy, *Atomic Energy and Space Research: A Profile for the Decade,* 1970-80 (New Delhi: Government of India Publications, 1970), p. 31.
[42] W.P.S. Sidhu and Chris Smith, *Indian Defence and Security: Industry Forces and Future Trends* (Surrey: Jane's Information Group, 2000), p. 96.

1980s to lead the ambitious Integrated Guided Missile Development Programme (IGMDP).

Many have viewed the space programme as being "directly linked to the destructive system of reliance on force and violence in the international arena."[43] However "in India, the space programme has been deliberately linked to the productive rather than destructive system...." [44] There is little evidence to suggest that India's space programme started exclusively with missiles in mind. It is almost certain that it was directed towards acquiring complete technological capability, which included the capability to produce missiles. India has utilised her experience in launching satellites in designing and developing missiles for defence purposes. The space programme has served a dual purpose. It has not only supported the socio-economic development of the country but has also contributed towards the country's security needs.

[43] Baldev Raj Nayar, *India's Quest for Technological Independence,* op. cit., p. 391.
[44] Ibid.

CHAPTER III

ABORTED ARTIFACTS: THE TECHNOLOGY-GATHERING PHASE, 1973-83

This chapter is an overview of the early attempts by the newly formed DRDO to indigenise missiles. The purpose of this chapter is to look at the efforts made by the defence establishment to indigenise an anti-tank missile, to innovate an ICBM, and finally to reverse engineer a surface-to-air missile. All these artifacts never saw the light of day, but experimenting on them gave the missile team excellent training in gathering the required technology, which came in handy when the country's missile programme went ahead full steam in 1983 with the start of the Integrated Guided Missile Development Programme (IGMDP). As seen in the last chapter, space research and defence research took parallel courses to recruit people who were trained in rocketry and other related technologies. The Indian Space Programme has yielded a useful spin-off in sophisticated conventional surface-to-surface, surface-to-air and anti-tank missile systems. Though much of this effort came from the DRDO, it had extensive coordination with ISRO. The use of ISRO's test and tracking facilities reflects the close, though not integral, relationship between the missile programme, its related defence production agencies, and the civilian space programme.[1] This chapter also

[1] Potter and Jencks, *The International Missile Bazaar*, op. cit., p. 204.

looks at ISRO's success with SLV3, which later formed the platform for future missiles like Agni I and Agni II.

Vikram Sarabhai, though not very cooperative in defence efforts, did help DRDO by sending key people and giving key technologies. But the division between the two organizations came when Homi Bhabha chose INCOSPAR to build huge rockets and missiles at a time when Sarabhai was building a nation-wide consensus regarding the use of space technology for civilian use. During this networking stage, Sarabhai did not want the space programme to be an easy target for embargoes from the US. He wanted to remain above the atomic debate and promote the advancement of the civilian use of space. The relationship between ISRO and DRDO became bitter when Satish Dhawan took over as the chairman. By that time the space department had achieved success in all spheres and was not willing to ally with the ineffectual DRDO and its laboratories. Though both organizations practiced autonomy, space research was built on a larger consensus that had the backing of the whole nation. The research team on missiles was, however, not able to form stable alliances, which led to the abortion of all the artifacts attempted by DRDO.

Project Indigo

Project Indigo was an Indo-Swiss agreement to design and manufacture an intermediate range surface-to-air missile. The project, which would have been a first attempt to actually build a missile system, was cancelled due to India's preference for the Soviet built SA2 SAMs[2]. Although the programme never came to fruition, it provided the impetus for a more broad-based Indian missile research programme and for the establishment of key research centres like the Missile Establishment located in Hyderabad and the Ad-hoc Electronics Committee headed by Sarabhai.

Anti-Tank Missile

The anti-tank, or anti-armour missile, was one of the most important categories of guided missiles to emerge after World War II.[3] The first anti-tank missiles were controlled by electronic commands transmitted along extremely thin wires played out from a spool on the rear of the missile. The rockets were propelled by solid fuel and the missiles used aerodynamic fins for lift and control. The guidance was by means of a joystick and controlled by visually seeing the flares in the tail region of the missile.

Once it was realized that tanks were there to stay, a reliable and cost effective method of countering them was attempted. The first dedicated anti-tank weapon to be tried were large caliber rifles, such as the 13 mm, like over-sized bolt action rifles weighing more than 15 kg.[4] These weapons were heavy and were not easy for the infantry to handle within the confines of trench systems. Furthermore, the fierce recoil did not make them popular.

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[2] India ordered its first SA2 battalions in 1962, with deliveries beginning in 1965-66. See Steven J. Zaloga, *Soviet Air Defence Missiles* (Surrey: Jane's Information Group, 1989), p. 55. Cited in Potter and Jencks, et al., *The International Missile Bazaar*, op. cit., p. 202.

[3] The precursors of the modern day anti-tank missiles date back to the First World War when the Germans used field guns to fire directly at tanks. See John Norris, *Anti-Tank Weapons* (London: Brasseys, 1984), pp. 7-8.

[4] Ibid.

Finally, just penetrating the armour itself did not stop the tank. It was imperative to disable it.

The next phase was the introduction of specialized anti-tank guns, which the Germans developed in the form of the Rheinmetall 3.7cm gun.[5] Weighing some 160kg, this weapon could destroy a tank in the way we know today. The Second World War was to see a great change in the way in which tanks were attacked. As tanks became more complex, so did anti-tank weapons. The Germans developed a range of disposable infantry weapons called Panzer Faust, which became more powerful as the range developed. The Americans built the M1 2.36 inch anti-tank weapon and for some years this was the model on which other recoilless (RCL) anti-tank weapons were based.[6] The new generation of anti-tank weapons was based on guided missile systems, because it was realized that they offered better accuracy over free-flight projectiles. The first guided anti-tank missiles were large cumbersome affairs, but technological advances brought their overall size and weight down, while at the same time increasing their lethality. Indeed, guided missiles emerged as the preferred and most effective method of dealing with MBTs, especially at long ranges. Only their high cost prevents some of the smaller countries from acquiring such weapons.

With a firm belief in self-reliance, and ambitions to build guided missiles, Krishna Menon, the controversial yet dynamic Defence Minister who set up DRDO, took the early initiative to build an anti-tank missile. The anti-

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[5] Ibid.
[6] Ibid.

tank missile was chosen not out of strategic compulsion but due to the poor state of India's industrial infrastructure and the low level of scientific competence. Ignorant of the delicate hard-ware of rocketry, the new missile team found it difficult to configure and build the missile: "everyone in the team was foxed because frankly none of them had even seen an anti-tank missile."[7]

After the establishment of DRDO, Krishna Menon and Kothari, through the Defence Science Laboratory, started the guided missile team led by B.N.Singh.[8] The team was very unique, as it did not have people who were well-trained in rocketry. The task of building an anti-tank missile seemed a mammoth one for the new team, which had never seen an anti-tank missile. The artifact that was to be copied and produced indigenously was supposed to be based on the French model but by the time the new team started to work with it and the requirements were specified it ceased to be anything like the original.[9]

Every subsystem of the French anti-tank missile proved tough to duplicate. The complexity of the French missile and the requirements of the army led B.N. Singh, a physicist by profession, to send Sunder Lal Bansal and two others to the College of Aeronautics in Cranfield, U.K, to attend what was then called the NATO Guided Missile Course.[10] Within three years after its establishment, the Defence Science Laboratory in 1961 was able to put

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[7] Raj Chengappa, *Weapons of Peace*, op. cit., p. 137.
[8] The name was later changed to Special Weapons Development team.
[9] Raj Chengappa, *Weapons of Peace*, p. 138.
[10] Ibid., p. 137.

together the gamut of hardware for testing the missile. Seeing the first successful anti-tank missile, the Army, in February 1962, developed its General Qualitative Staff Requirements (GSQR) for anti-tank missiles, for which V.Ganesan obtained six lakhs of rupees as a grant.[11] The missiles developed by the DRDL were of 1.6 km range and were wire guided. The missile path was controlled using Roll Control. In 1969, the Army unilaterally wanted to revise its GSQR and wanted the missile to have a range of 3kms instead of 1.6 kms, this change in the range demanded many operational changes which the team found it very difficult to make.

The success of the missile did not guarantee further innovation; it failed miserably owing to the sickness that plagued DRDL: "the team was handicapped by the lack of proper equipment, for the flight trials instead of theodilites that accurately tracked its flight path they had to adopt the cumbersome process of filming its flight and then analyzing it frame by frame."[12] N.R. Iyer, a young physics graduate with specialization in missilery, while doing the systems evaluation for these missiles, recalls that "there are plenty of glitches still to be ironed out, ...out of a hundred missiles about sixty percent would hit the target." [13]

This frustration was surmounted when the French prepared to sell India their latest anti-tank missile with a licence to produce 1000 anti-tank missiles every year for a period of 10 years. This led to the creation of Bharat

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[11] Ibid., p. 139.
[12] Ibid., p. 141.
[13] He later became the project director of Nag, India's state of the art anti-tank missile.

Dynamics Limited. (BDL) which was established in 1970 for the purpose of manufacturing anti-tank missiles. The main aim and motive behind establishing BDL was to create a technological base, which could in the future undertake, manufacture and develop missile weapon systems, sub systems and accessories. The establishment of BDL saw the influx of many key scientists from DRDL. BDL grew by building missiles under license, and slowly increasing the indigenous components. BDL formed an efficient platform for research on guided missiles and other accessories. Today it is the indigenous source of supply for components and materials for India's missiles.

The Devil and The Valiant

In late 1969, Sarabhai had Vettakkorumakankav Sivarama Narayanan and Avulpaniker Jalaubdeen Abdul Kalam inducted into the Missile Panel, formed newly by the Ministry of Defence. Among the proposals that the Panel discussed was to have a long-range missile.[14] Soon after the Indo-Pakistani war of 1965, Sarabhai introduced Narayanan to Basanti Dulal Nagachaudhuri, scientific adviser to the Defence Minister and DRDO chief. Narayanan became the Director of the Defence Research Development Laboratory (DRDL), with a twin mandate: he was to reverse engineer the SA2 missiles indigenously within 7 years under a project code named 'Devil' and

[14] Raj Chengappa, *Weapons of Peace,* p. 149.

set up the technological infrastructure to build a range of missiles.[15] No overt declaration was made regarding the Valiant project, as India wanted to develop the missile unobtrusively lest the US try to block its progress. Gopalsami who was back from the UK was set to join DRDL to design rocket engines for the Valiant and Project Devil.

Sarabhai's demise on December 30, 1971 brought in Satish Dhawan to lead the space effort. Born on 25 September 1920 in Srinagar, Dhawan soon after his graduation at the University of Punjab went on to do his Masters in Aeronautical Engineering from the University of Minnesota and later a doctorate from Caltech. On 1 June 1972, the government established a Space Commission modeled on the Atomic Energy Commission and also a separate Department of Space. The Indian Space Research Organisation was brought under these. In September 1972, Satish Dhawan became the Chairman of the newly established Space Commission, Secretary for the Department of Space and Chairman of ISRO.

From the day Dhawan took over, he ran into conflict with DRDL's ambitious plans to build long-range missiles. DRDO scientists felt that Dhawan had begun asserting a subtle influence over the plan to build long-range missiles. Dhawan says he never ever wanted to work with missiles. The reason: "I guess I am a peaceful person".[16] Yet when SLV3 was launched in 1980, among the statements Dhawan made was that India had to

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[15] Ibid., p. 152.
[16] Ibid., p. 157.

have the capability to make ballistic missiles.[17] Bhabha, when he geared up INCOSPAR to attain mastery in rocketry, had the dual nature of rocketry in mind. Narayanan visualized the SLV, which was based on the Scout missile, in his paper on missiles. [18]

Like the atomic energy programme, a peaceful space programme gave India a legitimate reason to set up the infrastructure for rocket building without risking the ire of the West. There would be no bar on purchasing advanced technology from the West. MGK Menon, who had guided the space effort from its inception and was briefly ISRO chairman in the transition period from Sarabhai to Dhawan, admitted that "for us peaceful uses of space was legitimate for both our public image as well as to tap the benefits of such research for communications, remote sensing and weather prediction. But it also helped us develop all the capability needed for rocketry and therefore the option to make powerful missiles. Like nuclear energy we could cross the divide whenever needed. The solid propellant was a clear indication of our intentions".[19] Yet a separate missile establishment was needed to absorb the technology and go ahead with India's plans to defend itself. DRDL fitted the bill flawlessly. In June 1972, Nagchaudhuri submitted a paper asking for sixteen crore rupees to begin work on Valiant. Though, the Union Cabinet turned it down. Indira Gandhi sanctioned a partial amount using her discretionary powers.[20] Nagchaudhuri realized the need for proper allocation

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[17] Ibid.
[18] Ibid., p. 158.
[19] Ibid.
[20] Ibid., p. 159.

of funds because, unlike atomic energy, DRDL had not built up any infrastructure. It would require an overt commitment to massive amounts of money and manpower needed to build such a long-range missile. The following sub sections deals with the Devil and Valiant.

THE DEVIL

The Devil Programme can be considered a significant landmark for India's missile programme. The programme was ambitious given the lack of technological know-how needed to produce this missile. The idea of reverse engineering was not as easy as it was thought. Although scientists had built the SA2 in the 1950s, every major subsection had proved tough to duplicate. The construction of the present-day Prithvi owes a lot to the expertise gained by reverse engineering the SA2. The liquid fuel motors that this project bequeathed in 1974 later became the propulsion system for India's first operational SSM, the Prithvi. However, "following the failure of several prototype systems the Devil project was cancelled in 1978".[21]

The Devil project was sanctioned by the Indian government in February 1972. This was an attempt to convert the Soviet SA2 surface-to-air missiles into surface-to-surface missiles.[22] The project involved a greater

[21] Potter and Jencks, *International Missile Bazaar*, op. cit., p. 203.

[22]The role of battlefield surface-to-air guided weapons is to prevent an enemy from interfering with the conduct of ground operations from the air. This involves detection and destruction of an incoming aircraft or a helicopter at supersonic speeds at heights of well over 15000 metres. Guided surface-to-air missiles or SAM, was under development when World War II ended, notably by the Germans, but were not sufficiently perfected to be used in combat. This changed in the 1950s and 1960s with the rapid development of sophisticated SAM systems in the Soviet Union, the United States, Great Britain and France, with other industrial nations following suit. Surface-to-air missiles of indigenous design, particularly in the smaller categories, were fielded by many armies and navies. The Soviet Union committed more

concentration of manpower and financial resources than previous research efforts and it was the first attempt to develop an operational surface-to-surface missile.[23]

The SA 2 is a very complex system and all the materials were produced abroad.[24] The acute problem of expensive spares was the main reason for reverse engineering the SA2. After the Indo-Pakistani war of 1965, India began negotiating with the British for a surface-to-air missile. Meanwhile the Soviets, as a last minute offer, sold India three squadrons of SA2s. V.S.Narayanan was then sent to the USSR to evaluate it. As the spares proved very expensive and maintenance problematic, in 1968 he prepared a project to reverse engineer the SA2 and develop it in India within a span of five years at a cost of 16.5 crore rupees.[25] The SA2 was chosen because it was a proven missile.

The Configuration of SA2

In the realm of missiles, especially the surface-to-air and surface-to-surface variety, the Soviet Union committed more technical and fiscal resources than any other nation. Beginning with the SA1 Guild, developed in the immediate post war period, the Soviets steadily fielded SAMs of growing

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technical and fiscal resources than any other nation. The need for surface to air missile was felt during the Indo-Pakistani war of 1965. In 1965 India negotiated with Britain for surface-to-air missiles. At this point of time the Soviets came with an offer to sell India 3 squadrons of SA2 missiles. India ordered its first SA2 battalions in 1962, with deliveries beginning in 1965-66.

[23] Potter and Jencks, *The International Missile Bazaar*, op. cit., p. 203. This project employed between 700 to 800 technical personnel and had a budget of about US$700 million. See W.P.S. Sidhu and Chris Smith, *India's Ad-hoc Arsenal*, op. cit., p. 84.

[24] See Appendix 3.

[25] Raj Chengappa, *Weapons of Peace*, op. cit., p. 148.

sophistication. These fell into two categories: systems such as the Guild, the SA3 Goa, the SA5 Gammon, and the SA 10 Grumble, which were deployed in defence of fixed installations; and mobile tactical systems capable of accompanying land forces.[26]

The SA2 Guideline introduced in 1958 was the most widely deployed of the early SAMs and was the first surface-to-surface guided missile system used in combat. This two stage missile, with a solid booster and a liquid propellant (kerosene and nitric acid) sustainer, could hit targets at ranges of 28 miles and as high as 60,000 feet. It was equipped with an array of van-mounted radars for target acquisition and tracking and for missile tracking and command guidance. The sophistication increased considerably, and later versions of the SA2 were equipped with optical tracking to counter the effects of ECM (electronic countermeasures); this became the standard feature on SAM systems. SA2 is a 2-stage missile with a kill range of 26 kilometers and with a speed of 2 to 3 mach.[27] The body was made out of magnesium alloy of 350 kgs. Red fuming nitric acid and Xylidine formed the fuel complex that gave the rocket a sustained thrust of 3 tonnes.

The Making of Devil

Initiating the Devil project led to a massive drive to recruit scientists and set up the infrastructure needed.[28] DRDL had sixteen crore rupees to reverse engineer SA2 and to build the infrastructure for long-range missiles.

[26] David Baker, *The Rocket: The History and Development of Rocket and Missile Technology* (London: New Cavendish Books, 1978), pp. 199-200.
[27] Raj Chengappa, *Weapons of Peace*, op. cit., p. 148.

B.D.Nagchaudhuri wanted to build the key technologies so as to indigenise the SA2. Many were recruited from the aeronautic department at the Indian Institute of Science (IISC). Vijay Kumar Saraswat was chosen to design the liquid propellants for the two missiles. The experience gained through building the liquid propulsion for the two made him a key a key player later in Prithvi. V.Prahalda, another product of IISC, was appointed by Air Commodore V.S. Narayanan. V.S.Narayanan, a physicist by training, chose to design and work on the guidance control of the Devil. Ram Narain Agarwal, who had joined DRDL in 1963, spent most of his initial years testing missiles traveling at supersonic speeds. In 1968, he went to IISC to finish his masters degree in rocketry. On his return in 1970, he was assigned to configure the Valiant----an experience he put to use when he became project director of Agni.[29] There were others who would join this growing band of home-grown engineers and scientists that powered Indian technology in the 1970s and 1980s. From the armed forces came Valecheri Jagadesan Sundaram, who later became Prithvi's project director in 1982. Before joining DRDL he was in the army, where he was sent for a year's course in guided missiles. He did so well that he was sent on a deputation to DRDL. In 1972 he joined DRDL and entered the BACA workshop where the Soviet SA2 missiles lay.[30] In 1972, Anand Kumar Kapur, an IIT graduate, was chosen to cast the motor of the solid booster rocket. Bharat Heavy Plates and Vessels Limited (BHPV) was

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[28] DRDL started with only 400 employees with a budget of forty lakh rupees. By 1974 it had 2,500 employees with an annual budget of sixteen crores of rupees.

[29] Raj Chengappa, *Weapons of Peace,* op. cit., p. 162.

[30] BACA is the acronym of the unpronounceable Soviet name for the missile.

approached.[31] They had never cast anything that required such precision or handled metals that needed to withstand enormous pressure.

To understand SA2's innards they had to cut open the Soviet missile and study each component. Saraswat, who studied electronics, was struck by the fact that the missile still used giant valves instead of the more miniaturized and reliable transistors.[32] The launch pad for testing the missile proved really difficult. There was no expertise in the country to build them. It was done in Imarat Kancha where the anti-tank missiles were tested earlier. They built a test bed by digging a hole twelve feet deep and dumping loads of cement to hold up the steel braces. They then put structures sixteen metres high and welded giant metal clasps that would restrain the engines from flying off when it was being tested.

The primary achievement of Project Devil was a three-ton regeneratively cooled engine, which was the progenitor of the Prithvi engine. The Prithvi uses liquid fuel, which is a combination of self-igniting red fuming nitric acid and Xylidine. This fuel, particularly Xylidine, is common to the SA2 which is what DRDL was trying to reverse engineer under Project Devil. Apart form the specific success of the Devil engine, DRDL had in the two decades leading up to the early 1980s established the basic technology required for missile systems in solid and liquid propulsion, control and guidance, and precision fabrication. In sum, an indigenous capability came to exist for developing almost all missile subsystems, but in isolated pockets.

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[31] Ibid., p. 165.
[32] Ibid., p. 162.

PROJECT VALIANT

Valiant was an ambitious project for a team which could not get a small anti-tank missile to fly 1.6 kms. The Valiant was configured to be an ICBM. The compulsion for an ICBM during the 1970s was very minimal. The period in which the project came up was during the low-threat period. With Pakistan dismembered, India was the predominant power in South Asia. Good relations with China and with the superpowers shifting their focus to other crisis areas, there was no incentive to go in for an ICBM. Economically, the 1970s was the period when India was facing shortages of hard currency. The period also saw defence technologists failing to provide indigenous systems for the use of the services. In spite of these handicaps, a full go was given to indigenously produce an ICBM under the project named Valiant with Indira Gandhi sanctioning the required money from her discretionary powers[33]. As no major capital expenditure could be made for the project, everything had to be broken up in to smaller amounts so that Cabinet sanction was not required.

Nuclear physicist, Basanti Dulal Nagchaudhuri, scientific adviser to the defence minister and DRDO chief conceived of Valiant in January 1971. He asked Sunderlal Bansal, head of DRDLs rocketry division, to put together a small group and prepare a proposal for building long-range missiles within four years that could traverse a distance of over eight thousand kilometers with a payload of five hundred kilograms. Bansal outlined the possibilities and

[33] The amount estiamated was 18 crores. The group could get only a paltry amount to kick start the project. Raj Chengappa, *Weapons of Peace*, op. cit., 131.

preferred a small project for a missile that could travel 1500 kms.[34] Bansal's team believed that even this was overoptimistic as they had not even built a short-range missile by then. But Nagchaudhuri was obstinate and demanded a feasibility study done right away and wanted charts to be made detailing each milestone needed to build the missile. The desire for a ballistic missile was partly initiated by Indira Gandhi. In conversation with Nagachadhuri, she said "if we are going to have a nuclear explosion we should prepare for it in such a way that all pieces fell in line. But we couldn't say it at that time".[35]

Missile Configuration

The architecture of the missile is that it was designed to have a cluster of four, thirty-tonne liquid fuel engines lashed together in the first stage to give it a giant boost, two in the second stage for the coasting phases, and one in the final stage which would push the missile to the 8000 km trajectory. When the Valiant was conceived, Bansal and his team focused on two vital technologies: one was building the thirty tonne thrust engine, and the other was the inertial guidance system linked to the onboard computers that would navigate the missile. Raghavan Gopalsami was involved in designing the liquid rocket engine, which he modelled from the Blue Streak rocket developed by the UK. He later used it for the Valiant. The vital instrument system for testing the inertial guidance systems was imported from France.[36]

[34] Ibid.
[35] Ibid., p. 132.
[36] Ibid., p. 170. The vital instruments for testing the inertial guidance systems was imported from France under the guise that it was needed for the National Physical Laboratory. DRDL funded the project and secretly used the facilities set up for the Valiant.

Paritosh Banerjee headed the inertial navigation system. At Hydrabad, a test bed facility was set up and fabrication of the engine began. There were three major subsystems: the combustion chamber, injector, and the nozzle. By the mid 1970s, the inertial navigation system was tested on a Canberra aircraft.

DRDL was also making use of fibre-reinforced plastics for the nose cone. Initially, Bansal looked at ISRO where Kalam was making it for the SLV3, but found that its capacity was not sufficient for Valiant's needs. The nosecones for the missiles re-entry vehicle were produced by importing an expensive winding machine from the US. A special vacuum-bracing furnace was established for manufacturing the re-entry vehicle. The facility was later used for making the nose cone of the Agni. [37]

Success of SLV3

Amidst the failures experienced by DRDO, the civilian space sector was successful in launching the SLV3. SLV3 gave ISRO the capability to develop more powerful launch vehicles needed to put operational satellites into orbit. India's SLV project success joins with it a militarily applicable missile programme. SLV3 formed a platform on which future missiles like Agni could be fabricated.[38]

By launch vehicle standards, the SLV3 is a simple launcher. Yet an enormous technological gulf separates it from sounding rockets. SLV3 is

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[37] Ibid. p. 171.

[38] Agni's first stage solid propellant motor is a direct copy of the SLV motor. See Indranil Banerjie, "The Integrated Guided Missile Development Programme", *Indian Defence Review*, Vol.12, No.7 (July 1990), p. 106.

closely modeled on the SCOUT (Solid Controlled Orbital Utility) system of the US. It was an all-solid four-stage vehicle. The SLV3 design had to be based on materials, propellants and systems that the Indians could develop or get hold of. Technology had to be developed to meet those design specifications. Every single technology element, from propellants to the electronics, had to be developed, tested and proven to be reliable enough to be used in a launch vehicle. Just how difficult the task turned out is shown by the fact that the entire 1970s went in developing SLV3. The number of scientific and technical personnel involved quadrupled during the SLV3 period. Equipment was made or imported, existing facilities were improved and new ones, including solid propellant casting and testing facilities, were augmented.

The SLV3 first stage was made up of three segments instead of the single monolithic motor used in the SCOUT. A launch vehicle requires the activities of multidisciplinary teams to be coordinated and focused. Project management for the development of a launch vehicle from conception to execution is, therefore, a complicated exercise in itself. Different members handled the detailed design and development of each of the four stages of the launch vehicle as a separate sub-project. The propulsion technique was solid based and no comparable capability existed on the liquid side.

Kalam was appointed the project leader of the SLV3. Some forty-six industries and institutions outside ISRO contributed to the building of SLV3, e.g., Larsen and Toubro and Walchandnagar made motor cases, while

Hindustan Aeronautics Limited (HAL) carried out some of the fabrication needed. A number of small industries were used. [39]

Conclusion

The three artifacts were ridden with "reverse salients". Reverse salients are components in the system that have fallen behind or are out of phase with the others. Because it suggests uneven and complex change, this metaphor is more appropriate for systems than the rigid visual concept of a bottleneck. Reverse salients are comparable to other concepts used in describing those components in an expanding system in need of attention, such as drag, limits to potential, emergent friction, and system inefficiency. In a manufacturing system, one productive unit may have had its output increased, resulting in all other components of the system having to be modified to contribute efficiently to overall system output. Until the lagging component can be altered often by invention, they are reverse salients. [40] This became the main reason for its abortion. SCOT sees reverse salients as not only applying to physical artifacts but also to organizations as well. DRDO was ridden with reverse salients--scarcity of resources, bureaucratic mismanagement, poor allocation of funds and ineffectual work force. With overwhelming reverse salients, the organisation could only innovate a limited amount of hardware; some bought from other countries, some poorly

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[39] Gopal Raj, *Reach for the Stars*, op. cit., p. 68.
[40] See Weibe, Bijker, *Social Construction of Technology, New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 1987), p. 74.

produced, some parts which were tough to duplicate were fixed using alternate parts developed indigenously which did not undergo rigorous testing. The result was artifacts that had to be aborted.

All the missiles that DRDO chose to indigenise involved “leading edge” technologies, which a developing country like India was not able to handle. The team that built the anti-tank missile project was handicapped by the lack of proper equipment. For example, the flight trials, instead of theodilites that accurately tracked its flight path, they had to adopt the cumbersome process of filming its flight and then analyzing it frame by frame. The missile was wire guided. This essentially means that a tiny wire is attached to the body of the missile and the spool is part of the missile operators trigger equipment. When he fires it the spool unwinds, and he can shift the missiles course with the help of a joystick that sends the commands through the wire.

The anti-tank missile did not fulfil the criteria of the Army. The Army increasingly became doubtful of the laboratories ability to deliver. By 1969, the army brass began preparing for another war with Pakistan and decided to unilaterally revise its range. Instead of 1.6 km they now required a 3km range for the missile. They also wanted the missile to be mounted on a mobile launcher rather than being hand-held. The modification in the GSQR was like changing the rules of the game when you are almost half way through.

The efforts to build an ATM indigenously led the scientists for the first time to pry open the black box called missiles. This underlines the fact that a large technological system evolves by experimenting with small systems and increasing their complexity. The limitation of resources and the paucity of technical persons led the defence research team to experiment on something that would be feasible instead of researching complex machines[41]. This experimentation with anti-tank missiles sufficiently helped in shaping future projects on guided missiles. The limitations were overcome by sending people abroad to do a course in the relevant field. The experiment in small missiles showed the new research organisation where the weak areas were and how to rectify the reverse salients. Several methods were adopted to improve the functioning of the teams. One was by employing people who had been trained abroad and had sufficient knowledge in the related field of the research areas. Secondly, the scientific establishment set up exclusive research centers. Finally, industries to fabricate the raw materials were also set up anew.

The Devil project involved some seven to eight hundred technical personnel with expenditures on the order of $ 700 million, a large programme especially by Indian standards. Devil did not involve a sector-wide approach. Reverse engineering the missile was a nightmare: everything had to be built from scratch, including instrumentation, and there was not enough experience in the country. Even making the metallic alloys needed for the rocket frame proved to be a major hurdle. To cast the liquid fuel engine, they needed magnesium alloys of around 350 kgs. HAL, Koraput, had a foundry and

[41] As starters Menon asked the new team to build anti tank missiles and sanctioned two lakh rupees.

casting capacity that could handle only up to three hundred kilograms of magnesium. Finally, The military was not cooperative with the scientists and they always sought other alternatives when things were not going their way. [42]

The reason for Devil's failure can be sourced to various factors. Apart from the project being ill-conceived, it was led by an air force officer, who had good political connections but did not have the support of the military bureaucracy. Secondly, there was no GSQR for the missile, which meant that the armed forces did not foresee its use. Lastly, the budgetary support for the project was not enough to create the technical base to develop a deployable missile. Even though Project Devil failed to create a complete system, it led to the development of several critical technologies, which contributed to the subsequent success of the Prithvi and Agni missiles under the IGMDP.

Attempts to develop an ICBM at a stage when DRDO was struggling with the basics of rocketry proved highly difficult. Valiant was beyond the technological feasibility of the defence scientists, and there was not sufficient consensus amongst defence technicians to build an ICBM. Unable to form a consensus, the organisation could not mobilize enough funds to support it. Lastly, more scientists were interested in Devil than Valiant.

The aborted artifacts nevertheless were the platforms on which future missiles could be erected. For example, the experience gained out of the anti-tank missile project was a precursor for producing the Akash. The efforts to master the technology to reverse engineer the SA2 led to the creation of the

[42] Failure to deliver Devil made the military to consider the purchase of Pechora missiles which assured greater flexibility.

Prithvi. Finally, the efforts to innovate an ICBM led to the creation of a workforce which was used to create the PSLV and GSLV which has ICBM capacity.

CHAPTER IV

INTEGRATED GUIDED MISSILE DEVELOPMENT PROGRAMME (IGMDP): 1983-1989

The accumulation of technological capability, the need for advanced strategic tactical and strategic delivery systems and international prestige brought about a shift in strategic thinking which ultimately led to the dedication of a missile programme in 1983. This chapter is an overview of the IGMDP. IGMDP represents the first Indian attempt to develop a series of missiles simultaneously. The aims of the programme and organisational systems and the infrastructure created for it constitute a major breakthrough in the development of indigenous weapon systems. The most important achievement of the programme is that it is the first successful endeavour in the country to harness indigenous talent to design and develop state-of-the-art tactical and strategic missiles. The chapter is divided in to five sections. The first section deals with the making of IGMDP and the second with Abdul Kalam, the chief architect of the missile programme. The third and fourth sections deal with the Agni and Prithvi respectively and the last section dealing with the other three minor missiles, namely, Akash, Trishul and Nag. The time period chosen is till 1984 -1989 which marked the completion of five years of IGMDP and the completion of the second test of the Agni which demonstrated the competence in the crucial area of re-entry technology. The same year also saw the maturation of technology in India to undertake and build a variety of missiles.

The Making Of IGMDP

The Failure of Devil and Valiant threw the scientists into a state of despair. During the quiescent years, before the inception of IGMDP, DRDL was itself gearing up for the missile programme that was in the making. The scientists in DRDO were working on five staff projects and sixteen competence build-up projects. They were also involved in several technology-oriented activities with a view to gain lead-time for the development of indigenous missile systems. Very good work on a surface-to-surface missile with a vertical rise–turn straight-line climb ballistic path had been done by that time.[1]

The IGMDP was approved by the Government of India in the fiscal year 1983-84 with the aim of designing and building a wide range of guided missiles. The motivations for starting a programme of that nature stemmed from the fact that throughout the 1970s the development of indigenous missiles was not accorded primary importance because the armed forces did not give much importance and attention to them in their strategic calculations. It was evident from the total disregard shown by them towards modernising the existing missile systems. The Falklands war and the Iran Iraq war radically changed their perceptions of the role missiles played in the conduct of warfare. The motivations behind this decision were significant. The

Government of India felt that foreign arms suppliers were often reluctant to sell the kinds of missiles demanded by the Indian Armed Forces. Moreover, the cost of imported missiles was often prohibitive and missiles themselves were invariably not of the current generation. Moreover, India having successfully tested a nuclear device in 1974, none of the manufacturers of large missile systems was willing to sell their hardware, so the Government decided not to be dependent on the import of critical parts. In addition, scientists wanted to free India from dependence on Soviet for missile technology.

By the late 1970s, the Indian arms industry was in a slump, as its indigenous production projects were not getting off the ground. What changed the state of affairs was the availability of financial resources and key changes in the decision making structure. In the late 1970s, Dr.Raja Ramanna was appointed Scientific Adviser to the Government. He had headed the team that constructed the 1974 nuclear device and therefore wielded considerable influence in political circles. Ramana recognised that if the arms industry was to survive it had to develop systems that could meet the challenges of the modern day battlefront. This meant producing high technology weapons systems. Ramanna's successor was Dr.V.Arunachalam who, in 1983, was able to convince the political leadership and the armed forces of the need for an entire range of missiles including ballistic ones. Another crucial figure was the Army Chief K.Sundarji's personal interest in IGMDP.

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[1] A.P.J. Abdul Kalam with Arun Tiwari, *Wings Of Fire: An Autobiography* (Hyderabad: University Press, 2000), pp. 110-112.

Abdul Kalam: Father of India's Missile Programme

Like Sarabhai for the Space Programme, the genesis of India's missile programme owes a lot to Dr. Abdul Kalam--he became the chief architect of India's Integrated Guided Missile Development Programme. Dr Kalam, an aeronautical engineer by profession, started his career with Hindustan Aeronautics Limited at Kanpur. He then joined ISRO to lead the team that made Rohini and Menaka, and later led the team that built the SLV 3. The two tiny rockets and the SLV3 instilled pride and passion in him. Its success convinced him that with will and even without money, Indian science and technology could attain heights.

His major achievement in Indian rocketry was to create an environment for teams of young people to put their heart and soul into their missions. He offered room for innovation and risk taking among the young scientists and orchestrated the group to enable constant communication with key people. Kalam's concept of management is very different. He saw every employee as a technology person. He valued them for their interdependence and he mooted interdependent joint ventures by getting the forces together, networking people, resources, time schedules, costs, and so on. He evoked the concept of management by participation. He involved middle level scientists and engineers in the management of activities of the laboratory. In IGMDP, Kalam tried to integrate the vision of his earlier counter parts in space field especially the ideas from Vikram Sarabhai, Dhawan and Bhram Prakash.[2]

The coming of Kalam initiated the flux of scientists from other organisations into DRDO. He started inviting people from the Indian Institute of Science, Indian Institutes of Technology, Council for Scientific and Industrial Research, Tata Institute of Fundamental Research, and many other educational institutions where related experts could be found.[3]

Kalam joined DRDL on 1 June 1982. When he joined DRDL, he saw that the senior scientists were dispirited: "There was a widespread feeling that the scientists of this laboratory had been cheated by senior officials in the Ministry of Defence."[4] Kalam constantly brought out the fact that missile development is a multi-dimensional point business. He found the laboratory playing a truncated role that did not reflect its existing or potential capabilities or even fulfil the expectations of South Block. As a collective endeavour, he created a forum of senior scientists where important matters could be discussed and debated. This slowly led to the formation of a high level body called the Missile Technology Committee within DRDL, which ultimately conceived the Guided Missile Development Programme. With Kalam's chairmanship, a committee was constituted to conceive of a missile development programme for the production of indigenous missiles.[5]

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[2] Abdul Kalam, *Wings of Fire,* op. cit., p. 173.
[3] Ibid., p. 112.
[4] Ibid., p. 111.
[5] The members were Z.P.Marshall, then chief of Bharat Dynamics Limited, Hyderabad, NR Iyer, AK.Kapoor and KS Venkataraman.

For the first time a paper envisaging the development of missiles was discussed with the armed forces, and after this consultation the paper was given final shape. Initially, the group that was constituted by Kalam sought the funds to develop and produce two missiles: a low-level, quick-reaction, Tactical Core Vehicle (TCV) and a medium range surface-to-surface weapon system. The team also proposed to develop a third generation anti-tank missile having "fire and forget" capabilities.[6] During this time, Kalam wanted to revive his re-entry Vehicle Launch Experiment.

Kalam viewed technology to be synonymous with huge amounts of money and massive infrastructure. Neither of these was available, unfortunately, in adequate measure. For the management technique of IGMDP, he chose pro-active follow up which consisted of analysing the technical as well as procedural applicability of a possible solution, testing it with work centres, discussing it with the general body of associates and implementing it after enlisting everybody's support. Through follow up on the work done at different laboratories on design, planning, support services, and by inspection agencies and academic institutions, rapid progress was achieved.[7]

Through his efforts, IGMDP acquired the status of a colossal scientific industrial edifice of a kind that has never before existed in the country. To develop the missile technologies, a total of 19 other defence research laboratories, seven universities and seven other institutions, like the Indian

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[6] Abdul Kalam, *Wings of Fire*, op. cit., p. 111.
[7] Ibid., p. 130.

Space Research Organisation (ISRO), Tata Institute of Fundamental Research (TIFR), and SHAR (Shriharikota) 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, aerospace quality aluminium, precision gyroscopes, rocket propellant, warheads, special radars and ground vehicles The missile programme had been pursued together and had partners in design, development and production from 12 academic institutions and 30 laboratories from DRDO, the Council of Scientific and Industrial Research (CSIR), ISRO, and industry. In fact more than 50 professors and 100 research scholars worked on missile related problems in the laboratories of their respective institutes.[8] From a single laboratory project, it webbed out to multi-laboratory programmes to laboratory-industry exercises. Taking a step further, academic institutions were asked to initiate programmes related to the essentials of rocketry. Joint Advanced Technology Programmes were started at the Indian Institute of Science (IISC), and Jadavpur University.

THE TEAM

In early 1983, DRDL constituted a study team consisting of development, production and user agencies to recommend the specifications and technologies needed for the indigenous development of different missiles

[8] Ibid. p. 132.

systems.[9] A feasibility report on the missile programme was prepared and presented at a meeting presided over by the Defence Minister in early 1983. This meeting was itself unusual in that it brought together for the first time the three services chiefs: General Krishna Rao, Air Chief Marshall Dilbagh Singh, Admiral D.Dawson, the Cabinet Secretary, Krishna Rao Sahib, Defence Secretary S.M. Ghosh, the Deputy Minister for Defence, Singh Dev, the principal secretary, Dr.P.C.Alexander, two Ministry of Finance Officials, and other defence secretaries.[10] Defence Minister R.Venkataraman told V.S. Arunachalam and A.P.J. Abdul Kalam that instead of developing the five missiles *adseriatim*, DRDO should work on them all at once as a part of an Integrated Guided Missile Development Programme. With a budget of 338 crore rupees India's prestigious missile programme was launched.

The proposed projects were christened in accordance with the spirit of India's self-reliance.[11] Thus the surface-to-surface weapon system was named Prithvi (the earth) and the tactical core vehicle was called Trishul (the trident of Lord Shiva). The surface-to-air area defence system was named Akash (sky) and the anti-tank missile project called Nag (Cobra). Kalam gave the name Agni to the long cherished dream of Re-entry Experiment (REX).[12] IGMDP was formally launched on 27 July 1983. DRDL was soon to witness a matrix type of structure for the execution of various activities needed for the

[9] Angathevar Bhaskaran, *Technology Development in India's Space Programme 1965-1995: The Impact of Missile Technology Control Regime* (Sussex: University of Sussex, Ph.D. Thesis, 1996), p. 76.
[10] Abdul Kalam, *Wings of Fire*, op. cit., p. 114.
[11] Ibid., p. 117.
[12] Ibid.

projects. In less than four months four hundred scientists began to work on the missile programme.[13]

Once IGMDP came into being, a bigger place was chosen to facilitate integration and check out facilities needed for missile projects. Research Centre Immarat (RCI) was chosen to establish a model high technology research centre with very advanced technical facilities like an inertial instrumentation laboratory. Full scale environmental and electronic warfare (ERMI/EMC) test facilities, a composites production centre, high enthalpy facility and state-of-the art missile integration and checkout centre.[14] Unlike the space launch vehicles, a missile launch involves wide ranging safety hazards. Two radars, three telemetry stations, one tele-command station and four electro-optical tracking instruments to monitor the missile trajectory had been deployed. In addition, the telemetry station at Car Nicobar (ISTRAC) and the SHAR radars were also commissioned to track the vehicle. Dynamic surveillance was employed to cover the electrical power. That flows from the missile batteries within the vehicle and to control system pressure.

The task of building a sophisticated test range fell into the hands of the physicist, Suryakantha Rao. An interim infrastructure adjacent to the Proof Experimental Establishment (PXE) at Chandipur in Balasore District of Orissa was chosen and the interim test range came into being. The first instrument to be tested was an attitude control system. An onboard computer developed by Paritosh Banerjee, K.V. Ramana Sai and their team. The instruments were

[13] Ibid., p. 121
[14] Ibid., p. 117

tested on a Devil missile, which was fired on 26 June 1984. In Kalam's words, "the experiment was the first and very significant step in the history of Indian missile development which had so far been restricted to reverse engineering, towards engineering our own systems".[15]

The leaders Kalam chose for different missiles were pretty interesting. His search for someone to lead Prithvi ended with Col. Valecheri Jagadisan Sundaram who belonged to the EME Corps of the Indian Army. With a postgraduate in electronic engineering and expertise in mechanical vibrations he was an experimenter and an innovator in teamwork. He had an extraordinary capability for evaluating alternative ways of operating. To lead the Trishul project, Kalam chose a man who not only had a sound knowledge of electronics and missile warfare, but who could also communicate the complexities to his team in order to promote understanding and to earn his team's support. For Agni, he chose R.N. Agarwall who had been managing the Aeronautical Test Facilities at DRDL with keen professional acumen. For Akash and Nag, he chose Prahlada, and N.R. Iyer. Once the team was formed, he set up a forum to discuss and debate decisions, which are of general importance. To give focus the Scientific Council was created--a sort of *Panchayat* - where the community would sit together and take common decisions. Every three months, all scientists – juniors and seniors, veterans and freshers-would sit together and let off steam.[16]

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[15] Ibid., p. 129.
[16] Ibid., p. 124.

NETWORKING

IGMDP was sanctioned at a time when India did not have enough of a technological base to cater to the various demands on it. The expertise was scattered, and it was very difficult therefore to utilise it. The task was big and it demanded wise sharing of resources and the induction of manpower. This led to the borrowing of ideas that had been developed elsewhere and by suitably adapting them. In the management of the programme as much as in technology development attempts were made to develop a model that was appropriate, even tailor-made for specific needs and capabilities. This orchestration led to the IGMDP having as many as 78 partners, including 36 technology centres and 41 production centres spread over public sector undertakings, ordnance factories, private industries and professional societies, besides a well knit bureaucratic structure in the Government.[17]

Nag, Akash and Trishul

Nag Akash and Trishul were the minor missiles which IGMDP envisaged. For Trishul, Kalam chose Cmde. S.R. Mohan from Defence R&D, who had a sound knowledge of electronics and missile warfare. Due to technological complexities, Akash and Nag were then considered missiles of the future; their activities were expected to peak in about half a decade later. Therefore Kalam selected the relatively young Prahladaand N.R. Iyer for Akash and Nag.[18]

[17] Ibid., p. 174.
[18] Ibid., p. 123.

NAG

The Nag is a third generation, all weather, top-attack, fire-and-forget anti-tank missile. The Nag was first tested in November 1990. There are two versions of Nag - the land version has been tested from a tracked vehicle known as MICA (Missile Carrier), carries four missiles in a ready-to-fire mode on the turret and more missiles can be reloaded without exposing the crew on the battlefield.

Nag was also configured to be used on the indigenous Advanced Light Helicopter (ALH). Launchers mounted on either side will have nose-mounted stabilized thermal sight and a laser range finder package. It employs a high-energy warhead to destroy any future armour including reactive armour of ranges up to 4 km. It also employs high-energy smokeless propellants using Nitramine with an *Isp* of 230 seconds. The target acquisition systems includes Thermal sight operating in the 8-12 km region with 4 km recognition range, Carbondioxide Laser Range Finder (LRF) with 5 m range accuracy, day sight (CCD camera), and other vision aids for the crew.[19]

TRISHUL

Trishul is a quick reaction, battlefield air defence weapon with multiple roles. It also can be used as an anti-ship missile. The solid fuel powered Trishul can carry 15-kilo warheads up to a range of 9.89 kms. It has all-weather, low-level attack capability in quick reaction time. The Trishul also has the distinction of

[19] Ibid., p. 174.

possessing triple battlefield competency. It will find its place in the armouries of the Army, Air Force, and Navy.

AKASH

The Akash is a medium-range, theatre defence, surface-to-air missile. It is comparable to the Patriot Missile of the US. It employs the integrated two-stage ramjet rocket propulsion system. The solid-propellant booster accelerates the missile in 4.5 seconds to Mach 1.5, which is then jettisoned and the ramjet motor is then ignited for 30 seconds to Mach 2.8 - 3.5 at 20g. India will be only the fourth country apart from the US, Russia and France to possess such a technology.[20] It is provided with a highly software intensive ground system with phased array radar Rajendra for multiple target handling capability.

In appearance, the Akash is very similar to the SA-6, with four long tube ramjet inlet ducts mounted mid-body between wings. Guidance system is inertial with mid-course command updates from Rajendra and semi-active radar seeker for terminal phase. Warhead has lethal radius of 20 metres, weighs 60 kg and has Doppler radar proximity/contact fusing.[21]

Agni

Agni marked the first time that India had used directly a component of its civilian space research program for military purposes.[22] Agni is the coming

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[20] Ibid.
[21] Ibid.
[22] Gary Milhollin, "India's Missiles with a Little Help from our Friends," *Bulletin of the Atomic Scientists* (November 89), pp. 31-35.

together of several ripe technologies, the outcome of technical progress. It appeared ready made in response to a national call to arms. The missile is capable of reaching parts of China, and it can clearly reach all parts of Pakistan. Agni is a two-stage rocket system and employs re-entry technology developed in the country for the first time. It is boosted by a first stage solid rocket motor derived from the SLV3 and further accelerated at the second stage with the liquid rocket engines of the Prithvi. Agni was the first technology demonstrator for India's long-range missile programme.[23] The Agni team comprised more than 500 scientists. Many organisations were networked to undertake this huge effort. To develop multi-institutional participation, the consortium approach and empowering technology was adopted.

Agni is a fusion. It is both a liquid and solid fuel missile It is constructed out of both the missile and space programmes. It depends on development from both military and civilian organizations. It is both a technology demonstrator and an IRBM. The success of the Prithvi and SLV3 played a crucial part in building Agni. The Agni missile is a hybrid and unique missile since no outer country had experimented a missile with one liquid and one solid stage.

The successful launch of SLV3 did prove a potential IRBM capability at a later stage. However, some of the gains came also from years of work

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[23] Technology demonstration research aims to verify not only the effectiveness of advanced technology that has high technology risks, but also feasibility of such technology as a weapon system. Consequently, prototype products are developed using such technology but not on the assumption that specific equipment will be developed for actual use. See *Defence of Japan 1996* (Japan Defence Agency: Tokyo, July 1996), p. 113.

done by DRDL on the Devil programme that resulted in the fabrication of a three ton, liquid fuelled rocket engine which became the progenitor of the Prithvi engine. This later formed one of the stages of the Agni. According to one report, IGMDP, funded at around Rs 780 crores for a 10 year period in 1983 was not specifically set up to build Agni. In fact, Agni is a by product of the programme with a Rs 37 crore appropriation for three test launches.[24]. Agni and SLV3, though seemingly similar, are in fact different from each other. The SLV 3 has a high L/D (length diametre ratio) and it was configured to go high into space. On the other hand, defence missiles have to hit a target point and thus have to be configured for high manoeuvrability. The only thing which these vehicles share is the first stage solid fuel rocket engine. Engineering of the Agni can be best understood by looking at the SLV3. The SLV3 formed the platform on which the Agni was successfully fabricated.

PROPELLANT

Agni is a two-stage missile with the first stage using the solid-fuel booster motor of the SLV-3 satellite launch vehicle. This marked the first time that India had used directly a component of its civilian space research program for military purposes. The second stage is possibly a shortened version of the Prithvi missile. It was not the best option because a decade later a decision would be taken to make all future Agni missiles powered by solid motors.

India could have saved at least six years time in terms of the missile development and possibly several hundred crores of rupees had it decided to

[24] Manoj Joshi, "Agni Importance", *Frontline* (June 1989), p. 5

go for solid fuel motors in the first place. In the Agni missile, the chamber that houses the rocket motors are indigenously made. The fabrication of these rocket chambers is a demanding task because they should have very high strength. They are made of low carbon and high alloy steel. This high-strength steel is produced at Mishra Dhatu Nigam Ltd., (MIDHANI) in Hyderabad and Walchandnagar Industries Ltd., Maharashtra. The missile technologists said fabrication technology for making these high-pressure motor chambers was available since the SLV3 days. The country also had a hold on liquid propellant technology that was demonstrated in the liquid stages of ISRO's PSLVs and Agni I.

GUIDANCE

The guidance package for Agni was produced by A.V. Ranga Rao and Col R. Swaminathan. The young scientists took up the challenge of building the strap down inertial guidance system, an onboard computer and a ram-rocket in the propulsion system. These were attempted for the first time in the country. The young scientists not only designed these systems but also developed them into operational equipment. The effort of these young teams made the country self-reliant in the area of protected technologies.[25]

Agni's long range and reentry manoeuvres introduced its own complications. A team headed by Paritosh Banerjee and later by Avinash Chander developed an entirely new system. Software too had to be developed to take care of flight errors peculiar to ballistic flights. Over a larger

[25] Abdul Kalam, *Wings of Fire*, op. cit., p. 143.

distance, missiles tend to drift from their set course. DRDL veteran, J.C.Bhattacharya and later Ramana Sai, perfected the onboard computation system and ran it by lashing together two relatively common 16 bit Intel 8086 microprocessors.[26]

Although accuracy is reduced with increased range, the Agni is believed to be fairly accurate, employing strapped down inertial navigation in a closed-loop guidance system that use accelerometers and gyroscopes which feed the onboard computer. The onboard computer steers the vehicle along its charted path by correcting any abnormalities enroute. Instead of only correcting the vehicle's attitude, the onboard autonomous systems are able to calculate the vehicles exact position throughout its flight. The strap-down inertial navigation system that DRDO has adopted is cheaper than the platform inertial navigation system in which gimbaled gyroscopes are used, requiring complex precision engineering, but has succeeded in achieving very impressive circular error probability. During the first test, Agni proved "embarrassingly accurate", landing just one meter from its target.[27] The success is mainly due to the possession of the sensitive position correcting reaction control system employing velocity-trimming modules.

Germany gave India help in three indispensable missile technologies: guidance, rocket testing and the use of composite materials. All were supposed to be for the space programme, but all were usually used for military missiles. The German Space Agency, the then DFVLR, helped Indian

[26] Raj Chengappa, *Weapons of Peace*, op. cit., p. 348.
[27] Indranil Banerjie, op. cit., p. 106.

scientists with the computers and algorithms in the guidance systems for the SLV-3, Agni and Prithvi.[28] According to one report, the closed-loop inertial guidance system is said to have been developed with a great deal of West German assistance.[29]

RE-ENTRY TECHNOLOGY

Key difference between missile and satellite launch vehicle technologies pertained to re-entry dynamics. For a missile, a heat shield is very necessary. The payload with guidance electronics is housed in the reentry vehicle structure. The payload, namely, the warhead, inside the re-entry vehicle is firmly seated on the nose cone of the second stage. As Agni would re-enter the atmosphere at twelve times the speed of sound, the re-entry vehicle is subjected to a searing temperature of 3000 degree centigrade. It had to be ensured that the temperature inside the payload was below 50 degree centigrade; hence the design of the re-entry vehicle is very critical. The re-entry should be exact or else the friction while entering the atmosphere will annihilate the payload. The re-entry vehicle then undergoes a process called ablation through which the carbon composite material covering the payload is sloughed off.

Agni's stated objective was to master the sophisticated reentry technology. For this difficult segment, Abdul Kalam chose Ram Narain Agarwal to head the project because of his involvement in Valiant. He wanted

[28] Aaron Karp, *Ballistic Missile Proliferation,* op. cit., p. 119.
[29] Gary Milhollin, "India's Missiles with a Little Help From our Friends," *Bulletin of the Atomic Scientists* (November 1989), pp. 31-35.

to concentrate on developing the reentry technology. The first flight would have had only a 150 kilogram payload instead of one tonne. Agarwal then got down to mastering the technology that prevents the missile from going up in flames when it reenters the atmosphere. The composite produced as a result is carbon-carbon. It was Kalam's classmate and physicist Rama Rao who was entrusted with the task of developing the composite along with two other technologists. Doing the carbon-carbon nose cones was not easy.

Building the structural elements inside the payload is a great challenge. Sufficient sophistication is needed to see to that the warhead inside bay should withstand the acceleration and deceleration temperatures. For a heat shield the common technique is to swathe the missiles nose cone which house the warhead with layers of slow burning ablative components usually made of carbon. When the missile reenters the earth's atmosphere, these layers get charred and peel off leaving the interior cool. The process of making the composite is called fibre architecture. Machines similar to those used by textile manufacturers weave strands of carbon tightly together. Then molten graphite is impregnated into a matrix to plug the microscopic gaps.

To carry out the test, the team that built Agni did not have a wind tunnel to generate that kind of speed. Through the help of SM. Desphande of the IISC, Kalam found four young scientists working in the field of fluid dynamics. Within a span of six months, the team developed the software for Computational Fluid Dynamics for Hypersonic Regimes, which is one of a kind in the world. Another achievement was the development of missile trajectory simulation software, ANUKALPANA by I.G Sharma of IISC to evaluate multi-target acquisition capabilities of an Akash type weapon system. Bharati Bhatt of IIT Delhi, working with the Solid Physics Laboratory (SPL) and Central Electronics Limited (CEL), broke the monopoly of the Western countries by developing ferrite Phase shifters for use in the multi-function, multi tasking 3 D Phased Array Radar for Surveillance, tracking and guidance of Akash. A.H. Saraf of IIT, Kharagpur, working with BK Mukhopadhyay, made a milli metric wave (MMW) antenna for the Nag Seeker Head in two years, a record even by international standards. The Central Electrical and Electronics Research Institute (CEERI), Pilani, developed an Impact Diode in consortium with the SPL and RCI to overcome technological foreign dependence in creating these components which are the heart of any MMW device.[30]

The Prithvi Missile

The metallic grey stubby tactical missile, rose from the ashes of the Devil project. Prithvi is a surface-to-surface missile code named SS 150. The missile is capable of carrying a warhead weighing half a tonne to one tonne to a distance of 150-250kms With a length of 9 metres and diameter of 1.1 metres, the Prithvi is powered by a duet of two liquid propellant regeneratively cooled rocket engines designed and developed at the DRDL.[31] The single stage missile uses liquid fuel produced at the ordnance factory Kirkee. Bharat Dynamics Limited (BDL) builds the missile structure from indigenously

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[30] Abdul Kalam, *Wings of Fire*, op. cit., p. 139.
[31] See Appendix IV for other specifications.

developed light aluminium alloys. The fins are manufactured using magnesium alloys.

Prithvi was launched at 11:23 hrs on 25 February 1988. It was an epoch making event in the history of rocketry in India. Prithvi was not merely a surface-to-surface missile with a capability of delivering a 1000 kg conventional warhead to a distance of 150km with an accuracy of 50 meter CEP. It was in fact the basic module for all future guided missiles in the country.

PROPELLANT FOR PRITHVI

The benefits of solid propellants for short-range missiles like Prithvi need not be overstressed. Missiles that are solid propelled are ready to fire and can be stored for seven years. Solid engines are less complicated and do not involve pumps and valves that are characteristics of liquid propulsion. In contrast missiles powered by liquid fuel has disadvantages interms of its retinue of fifteen support vehicles including special ones to carry the fuel which make it more detectable by the enemy.[32] Also, while transporting the toxic fuels, extreme care had to be taken that those do not leak. The process of loading the missile with fuel itself takes a good twelve hours making it vulnerable to enemy strikes. At the launch pad, the liquid engines take much time to generate thrust, making it susceptible to the new range of ABMs that are

[32] Prithvi is fuelled by a liquid propellant, which is highly volatile, corrosive and toxic; thus, it has to be loaded just prior to launch, dangerous to crew in case of spillage or leaks, and cannot be used for practice exercises. Prithvi is deployed in missile regiments along with several other vehicles. The launch procedure is said to take about two to three hours. See Z. Mian, A. H. Nayyar, M. V. Ramana, "Bringing Prithvi Down to Earth The Capabilities and Potential Effectiveness of India's Prithvi Missile", *Science and Global Security*, 1998, Available at http://www.fas.org/nuke/guide/india/prithvi.htm

being developed by other countries. The use of liquid propellant made the missile very fat.

DRDL, because of the Devil and Valiant projects, concentrated on making liquid fuel engines. Kalam was keen that Prithvi should be powered by solid propellants for their engines. Unfortunately, technological considerations were not the prime reasons for the choice of the propellant for Prithvi. Kalam, having spent more than two decades designing and building solid motors, pushed hard for solid motors. But most of the DRDL scientists did not like the idea of asking ISRO for the solid motors. Gopalsami, in many ways father of DRDL's liquid fuel complex, was loathe to let so many years of work go waste. By then he had been chosen by Arunachalam to be his staff officer in Delhi and was in position to influence the decision. He says "There was a feeling then that what could be DRDL's contribution if we used solid motors. ISRO could as well have taken over the entire project management".[33]

As the battle raged, Arunachalam stepped in and decided in favour of the liquid lobby, because DRDL would get demoralised if they went in for the solid propellant. Another reason for choosing a liquid motor was that the Army's request for a variable range which only a liquid fuel engine could provide. But the decision to go ahead with a liquid fuel engine was primarily DRDL driven, and it was a costly mistake. Kalam, though disappointed, points out that the use of a liquid engine for Prithvi has saved India a lot of money and brought down the time schedules considerably.

[33] Raj Chengappa, *Weapons of Peace*, op. cit., p. 311.

Prithvi is fuelled with a hypergolic combination of RFNA and Xylidine. RFNA is a trusted standby for the Indian missile programme and is in common use throughout the world. Xylidine, on the other hand, is something of an odd choice. After some research in the 1950s, the United States never used Xylidine even in developmental systems. Nor do any currently operational systems in the former Soviet Union use Xylidine. In India, as well, some have expressed puzzlement at the archaic Xylidine propellant when India also has the technology for much more powerful propellants.[34]

The choice of Xylidine for Prithvi can be best understood if you happen to have a rocket engine specifically engineered for it. Xylidine use in the Prithvi SA2 and Devil led to the engineering of a rocket motor similar to them that used Xylidine. Changing the configuration at a later stage would have involved great modifications in the injector and nozzle materials. The Indian development teams thus seem to have adopted the Devil's engine wholesale, not even performing the modifications that would be needed to use a different fuel.

The Prithvi's fuel is interesting for what it is not. Notice that while the Prithvi incorporated the foreign technology the Soviet SA2 missile, ISRO's much more advanced technology is nowhere to be seen. ISRO's new liquid fuels could only be used in the Prithvi by a substantial engine redesign, an effort that the Prithvi team was not strong enough to carry out alone and an

[34] Hormuz Mama, "Improved Prithvi Missile Launched," *International Defence Review*, Vol. 25, No. 8 (August 1992), p. 784.

effort in which the space agency had no interest. Xylidine was imported till 1981. It is now being produced at EDRL at Pune. By contrast, ISRO has developed more advanced fuels and subsequently transferred their production to industry. Prithvi's success can be attributed to the renaissance of liquid fuel technology in India and the vastly strengthened position of DRDO and the support of the other missiles in the IGMDP alliance.[35]

GUIDANCE

A team of young engineering graduates at Jadavpur University under the guidance of G.B.Ghoshal developed the required robust guidance algorithm. At IISC, postgraduate students under the leadership of I.G. Sharma developed air defence software for multi-target acquisition by Akash. The re-entry vehicle system design methodology for Agni was developed by a young team at IIT Madras and DRDO scientists. Osmania University's Navigational Electronics Research and Training Unit developed state-of-the-art signal processing algorithms for Nag[36]

The engines are gimballed to operate independently making it possible to steer the missile in all three axes using thrust vector control during flight. The project team also had to build a new onboard navigation system not only to improve accuracy but also to ensure that the missile had a manoeuvrability

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[35] Steven Flank, *Reconstructing Rockets and Missiles,* op. cit., p 131.
[36] Abdul Kalam, Wings *of Fire*, op cit., p. 137-138.

trajectory to avoid detection. The guidance system was a strapped down guidance.[37]

Apart from the main guidance package, there were other items such as valves, chips, microprocessors, and even gyros that DRDL engineers and scientists realised would require time to make in India. So they were given a carte blanche to import them, and they did it in their own unique way. They formed a special purchase team headed by Bhattacharya from DRDL. The missile team stocked up components for as many as fifty missiles including those for Prithvi, Agni and Trishul. They picked up the gyros from Swedish and French companies, hydraulic actuators from France, computers and motion simulators from the US, and three axis measuring machines from West Germany. In all, the bill came to around 50 crore rupees.[38]

THE PAYLOAD

The Prithvi development programme has a strong emphasis on accurate delivery of a variety of advanced conventional warheads. Pre-fragmented warheads, cluster munitions, fuel air explosives, and quite possibly terminally guided RVs have all been proposed and to some extent tested. The Army version has a payload of 1000 kg for its range of 150 km, while the Air Force

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[37] Strapped down guidance is a simple and accessible alternative to inertial navigation system, but it is very inferior to the inertial guidance system. Here the gyros and accelerometers are fixed directly to the missile frame so that the actual accelerations measured are those along the axis of the missile and along the pitch and yaw axes attached to the missile airframe. The information gathered is fed into a microprocessor, which continuously computes the value of the acceleration along the three space axes. X,Y,Z. The strap-down inertial guidance system has a twin microprocessor-based computer integrated with interrupt-driven, real-time software. Its navigation system guides it to the target within a CEP (Circular Error Probable) equal to .01% of its range. See R.G.Lee, et al., *Guided weapons*, op. cit., p. 112.

[38] Potter and Jencks, *International Missile Bazaar,* op. cit., p. 206.

version has a payload of 500 - 750 kg for its range of 250 km. DRDO has decided to increase the payload of the IAF version to 1000 kg, by using boosted liquid propellant to generate more thrust-to-weight ratio.[39] The Prithvi reportedly has the highest warhead-weight to overall-weight of any missile in its class. The missile can carry a variety of warheads, though not simultaneously, such as bomblets, sub-munitions, cluster munitions, pre-fragmented explosives, fuel-air explosives and high-explosives.[40] In terms of defence, the Prithvi has a special type of radar absorbing paint to reduce the radar signature

FIELD OPERATIONS

For field operations, Prithvi will be transported on an all-terrain, eight wheel, Kolos Tatra 8x8 Transporter Erector Launcher (TEL).[41] The missile is deployed from the vehicle and fired from a simple launcher. Each battery of four Prithvi carrier vehicles will be accompanied by a missile re-supply and loading vehicle, a propellant tanker and also a command post to provide target data to the missile's guidance system before launch. It also has an integrated surveillance and mission support capability and other support vehicles and equipment.

The second successful flight of Prithvi was conducted on September 1988. In the words of Abdul Kalam, "Prithvi has proved to be the best surface-to-surface missile in the world today. It can carry 1000 kg of warhead to a

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[39] Ibid.
[40] Indranil Banerjie, op. cit., p. 104.
[41] Ibid.

distance of 250 km and deliver it within a radius of 50 metres. It is hundred percent indigenous in all respects-design, operations, deployment. "[42]

Conclusion

By the time IGMDP came in to being, India had achieved sufficient expertise to build missiles. The organisational approach adopted for IGMDP is the major reason for its success. With bureaucracy taking a back seat, a collaborative venture of the DRDO scientists as well as ISRO and the 60 other work centers including laboratories, universities and production centers, both in the private and public sectors, was the major reason for its success. The integrated development helped in tackling issues simultaneously, thereby minimising time and cost. The consortium approach adopted to develop a series of missiles led to the construction of durable networks and linkages. Unlike other indigenous programmes, the IGMDP was able to obtain the technology for the missiles from other countries, and lastly, the scientists had the full backing for the IGMDP.

As a project leader, Kalam was able to identify quickly the key person or people with whom he conducted negotiations of the success criteria. As a team leader, he was able to influence and negotiate with key people for their requirements and to ensure that the dialogue continued on a regular basis as the situation developed or changed. Kalam's concept of management is woven around an employee who is a technology person. He values them for

[42] Ibid., p. 155.

their interdependence. He mooted interdependent joint ventures by getting the armed forces together, and by networking people, resources, time schedules and costs. Earlier attempts on different missiles led to a strong technological build up in the country. By now, advances in both solid and liquid propellant technology showed promising potential. The scientific enclave was increasingly convinced of the technical feasibility to go in for a range of missiles. A dedicated missile programme was conceived when the scientists were satisfied that the technology would reasonably support all the missiles integrated into one project.

The IGMDP is the first attempt to indigenise a major class of frontline state-of –the-art weapon systems. Indian defence planners have for the first time succeeded in harnessing indigenous talent to design and produce missile systems. IGMDP's success was the decision to design the Indian missiles on the basis of materials and technology available in the country. Dozens of public and private firms were approached for the manufacture of items. these included things as diverse as thermal batteries, titanium alloy, air bottles, launchers, radars, propellant engine nozzles, hydraulic motors, actuators and a mind boggling range of testing and telemetry equipment. The companies that took up the challenge and persevered, today find that they not only have a permanent client in the military sector but also new-found technological capabilities that can be used in numerous areas entirely unrelated to missiles. Moreover, the closer co-operation between the services (especially the Army) and R&D institutions created specific system development goals at the onset of the project.[43]

The successful launch of SLV3 increased the confidence that an independent missile programme could be maintained by the industry without much dependence on foreign assistance. The entire project shows a significant change in the way missile research is done in India. Today IGMDP is a highly critical component of the India's security package.

[43] Potter and Jencks, *International Missile Bazaar,* op. cit., p. 204.

CHAPTER V

CONCLUSION

SCOT ANALYSIS OF INDIA'S MISSILE PROGRAMME

Ballistic missiles are large complex systems that are equipped with speed, precision, and the ability to penetrate defences with conventional and nuclear charges. Design, development, and employment of these artifacts involve tremendous efforts by both human and non-human actors[1]. To critically view the development of these technological systems one should go beyond theories focusing on security threats, nationalism and bureaucratic politics.[2] A quick look at the motivations to develop strategic missiles leads one to concentrate on India's often-hostile relations with its nuclear-armed neighbours, China and Pakistan, or to the domestic compulsions, or even to international prestige. All three factors may have played a part in the development of India's missile programme. However, the story of India's missiles unfolds rather differently when we look at the whole of the programme in a technological systems perspective. [3]

[1] Actors include everything from animate to inanimate and individuals and organisations. Actor networks composed of a series of heterogeneous elements that have been linked to one another for a certain period of time. An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of. See Michel Callon, *Society in the Making: The Study of Technology as a Tool for Sociological Analysis*, in W.Bijker, T.P.Hughes, T. Pinch eds., *The Social Construction of Technological Systems,* op. cit., p. 93.

[2] Greenwood amongst others has pointed out that single factor explanations are not very successful in accounting for the complexity of weapons development. See Ted Greenwood, *Making the MIRV: A Study of Defence Decision Making* (Cambridge, MA: Ballinger, 1975), pp. 141-43. Cited in Graham Spinardi, *From Polaris to Trident: The Development of US Fleet Ballistic Missile Technology* (Cambridge: Cambridge University Press, 1994), p. 14.

[3] This approach or perspective has many names: History and sociology of Technology, Historical sociology and technology, social study of technology, large technological sysstems theory, network theory, and the social construction of technology (SCOT). All flavors rely heavily on historical and narrative methods, deriving understanding more from experience than theory. See Donald Mackenzie, *Inventing Accuracy: A historical Sociology of Nuclear Missile Guidance,* Cambridge: MIT Press, 1990, pp. 6-12. Cited in Steven Flank, " Exploding the Black Box", op. cit., p. 284.

In social science research, case studies have always been the most important one for studying weapons technology. Case studies involve detailed investigation of the decisions surrounding the development and deployment of a particular aircraft or a missile. With no alternative methodology around, work on weapons technology have always retained the case study tint. The Social Construction of Technology or SCOT does what a case study does not do: it brings to attention phenomena that escaped individual case studies and simultaneously looks at economic, political, organizational, cultural and legal aspects. [4]

SCOT does not identify a factor (say, technology or the military industrial complex) as being the key determinant. Rather, it suggests how technology and society interact. The theory focuses on processes and treats technology as a political subject worthy of detailed scrutiny. [5] By looking at the technical build up necessary for the development of missiles, it sees a seamless web of different factors that contribute to the evolution of India's missiles. It does not ignore the non-technical and non-scientific factors but believes that technology is shaped by its social, political, and economic context. A fundamental principle of SCOT is that:

> Our technologies mirror our societies. They reproduce and embody the complex interplay of professional, technical, economic, and political

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[4] Changes in technology go hand in hand with changes, small and large, in the preconditions of their use, in the ways they are used, in who uses them, and in the reasons for their use. For the way technology changes cannot be explained in isolation from the economic, political and other social circumstances of that change. See Donald Mackenzie and Judy Wajcman, eds., *The Social Shaping of Technology* (London: Open University Press, 1985), p. 112.

[5] Technology consists not only of artefacts but also a network of social interests some are of course embedded in the design of the artefact. See Langdon Winner "Do Artefacts Have Politics?" *Daedalus*, Vol 109 (1980), pp. 121-136.

> factors...All technologies are shaped by and mirror the complex tradeoffs that make up our societies...The idea of pure technology is nonsense.[6]

Thus, SCOT insists on opening up the black boxes of technological systems to inspect, deconstruct and challenge their contents.[7]

To understand the evolution of missiles in a country, the SCOT approach takes the Large Technological Systems (LTS) as the basic unit of study.[8] The reason for taking missiles as an LTS is due to the coming together of diverse resources to construct missiles. Large Technological Systems by definition include both social and technical aspects. A technological system becomes large when its components include not only physical artifacts -- guidance packages, sensitive computer parts, onboard navigation and power systems--but also organisations that are far removed from the actual system, such as manufacturing firms, utility companies, investment banks, books, articles, and university teaching and research programmes. A successful LTS recruits allies to add new capabilities which, transform existing components to support the future growth of the system. An LTS like a ballistic missile evolves by combining organisations, interests, existing artefacts and other heterogeneous elements. All this makes a technological system like the missile very complex and big, and hence the term Large Technological System. In India, the missile LTS includes

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[6] Wiebe Bijker and John Law, "General Introduction" in Bijker and Law, *Shaping Technology / Building Society: Studies in Sociotechnical Change,* Cambridge: MIT Press, 1992, 1-14, 3. Cited in Steven Flank, Exploding the Black Box, op. cit., p. 263.

[7] The term is used by cyberneticians whenever a piece of machinery or a set of commands are too complex. In its place they draw a little box about which they need to know nothing but its input and out put. Prying open a black box is profound. What is needed is an understanding of technology from inside both as a body of knowledge and as a social system. See Bruno Latour, *Science in Action*, Milton Keynes: Open University Press, 1987, pp. 108-32.

[8] Ibid.

everything from university lecturers handling a course on windtunnels, to scientists at the command and control centers.

Technology comprises not only artifacts but also networks of social interests (some of which are of course embedded in the design of the artifact). For a technology to succeed, networks must be put in place and, for them to remain successful, networks must be sustained. To build complex strategic and tactical missiles, missile advocates had to recruit an array of allies: the security elite, the military R&D establishment, commercial subcontractors and others in the private and public sectors. These diverse communities and interests would never monolithically decide to construct missiles. Instead, complex systems start small and build painstakingly on existing resources. If successful, a growing missile LTS recruits both social and technical allies along the way.

As seen in this study, missiles, coming as they do under the family of rockets, are the most complex area of space technology. Developing a missile is a slow, evolutionary process requiring a significant investment of technological resources and expertise. Even rudimentary production requires some experience in missile design, manufacturing, testing and systems integration. Missile system builders face limits on all resources--money, political authority and consensus, laboratory quality reagents, access to imports and so on. The missiles are actualised when these scarce resources are recruited and fixed in stable networks capable of producing the artifacts called missiles.

Assembling a missile requires personnel skilled in advanced materials development, microelectronics, computer engineering, software design and rocket design. India had a rationale behind its space programme with respect to satellite applications. During this period, India did not have access to the manufacturing technology and assistance needed to develop a sophisticated defence industry, and, moreover, ballistic missile programmes require considerable domestic investment and relatively high technical sophistication to elude restrictions on such activities by advanced powers. It is very clear that there is no simple roadmap to the successful building of long-range rockets; instead, there are rules, which most programmes must respect if they are to have any chance of success. While all countries and programmes may have their unique characteristics, all are constrained by various limitations inherent in the very nature of technology itself. For example, any development programme must deal with the inherent problems of organisation personnel and finance as well as the physics, chemistry and engineering of rocket flight.[9] The difficult task of assembling missiles requires constructing large stable networks. To build missiles, a large number of allies from different arenas need to be recruited. These allies do not merely provide specific components needed for a workable weapon but also broader social support needed to sustain the overall effort. The SCOT approach spans the panoply of human motivations, greed, self-sacrifice, organisational interests, national prestige or aesthetic pleasure.[10] The processes, at the heart of the matter, are the associations by which these heterogeneous elements are built into more or less durable networks through the help of heterogeneous engineers. Heterogeneous engineers are system builders who by

[9] Aaron Karp, *Ballistic Missile Proliferation: The Politics and Techniques*, op. cit., p. 6.
[10] Steven Flank, Exploding the Black Box", op. cit., pp. 279-80.

their creative activity do not abide by traditional distinctions such as technology versus society. One of the primary characteristics of a system builder is the ability to construct or to force unity from diversity, centralisation in the face of pluralism and coherence from chaos. [11]

Throughout the rocket programme, Abdul Kalam and Vikram Sarabhai stand apart. In SCOT parlance, both of them approximate to the ideal heterogeneous engineers. Dr. Kalam led the SLV3 project and he forged alliances with many research centres spread throughout the country and developed a strong personal relationship with the political establishment. Heterogeneous engineering provided the continuity and stability that India's missile programme needed to construct a successful technology. The research at DRDO in time became a mythic ideal for Indian scientists, especially in the realm of generous funding, a powerful leader, and freedom in pursuing research. Kalam established an organisationally insulated missile enclave. Kalam was only responsible to the Defence Minister and could overrule the other members of the commission, except for an certain financial matters.

The three decades, starting from the inception of DRDO in 1958 to the successful test of Agni in 1989, shows a clear pattern of how technology developed in India in the area of missiles. Analysing the three decades of missile

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[11] See Thomas P Hughes, *Evolution of Large Technological Systems,* in Bijker, et al., op. cit., p113, Law has coined the phrase heterogeneous engineer to describe what effective system builders need to be when attempting to build a world where bits and pieces, social, natural, physical or economic, are interrelated and keep each other in place in a hostile and dissociating world. See John Law, 'On the Social Explanation of Technical Change: The Case of the Portuguese Maritime Expansion', *Technology and Culture,* Vol28, No.2 (1987), pp. 227-52. According to Bruno Latour, the task facing the heterogeneous engineer is to make your environment such that whatever other human or non human actors think or do, they are either kept at bay or else they help strengthen your position, making the world safer, more predictable and more enjoyable for you. To do this, the heterogeneous engineer must translate the interest of disparate actors in order to build

development we see three phases. First there was the evolution of a Large Technological System by which the resources to build rockets were actualised. In this *system building stage* (from 1950 through the 1970 creation of VSSC), it saw the construction of the core organisations and norms within the missile establishment occured. Secondly, there was the *technology gathering phase* (from the early 1970s to 1983) or the experimental stage, in which sufficient expertise was brought together. The technology gathering phase saw the failure of several prototypes. Though all the artifacts which the establishment built were aborted, nevertheless, they formed a platform for the later strategic and tactical missiles. Lastly there was the phase of *heterogeneous engineering* in which stable alliances were formed to bequeath a series of missiles under IGMDP.

In India, space research and defence research took parallel courses to recruit people who were trained in rocketry and other related technologies. Rivalry between the space and missile teams brought about a dichotomy, and independent research was carried out right from start in both teams. Defence research in India has the support of a very small section of the Indian political establishment. The space programme obtained a broad consensus. The advantage of launch vehicles for a space programme were more obvious, especially from a development point of view in the 1950s and 1960s. This led to discrepancies in the way the technologies were chosen; a good example is the propulsion techniques that DRDO and ISRO chose for their rockets[12]. Though

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the desired technological network. See Bruno Latour, The Price for Machines as well as Machinations' in Brian Elliot ed., *Technology and Social Process* (Edinburgh: Edinburgh University Press, 1988), pp. 20-43.

[12] ISRO had a team working on solid propulsion and DRDO on liquid propulsion. Researches on the propellants were carried out independently.

Vikram Sarabhai was not very cooperative in defence efforts, he did help DRDO by sending key people and key technologies to them. The division between the two programmes came when Bhabha chose INCOSPAR to build huge rockets and missiles. At that time, Sarabhai was building a nation-wide consensus regarding the use of space technology and the benefits that could accrue by exploiting space for civilian use. During this networking stage, he did not want the space programme to be an easy target for embargoes from the US. He wanted to remain outside of the bomb programme and promote the advancement of the civilian use of space. The relationship between ISRO and DRDO became bitter when Dhawan took over. By that time the space department had achieved success in all spheres and was not willing to ally with the ineffectual DRDO.

The three key artifacts that DRDO tried to develop, (the anti tank missile, the ICBM and the short range surface-to-surface missile) never saw the light of day, but experimenting on them gave the missile team excellent training which came in handy when the country went to a dedicated missile programme in 1983 under IGMDP. The failures of DRDO were due the presence of numerous "reverse salients" within the organisation -- scarcity of resources, bureaucratic mismanagement, poor allocation of funds, ineffectual work force, and the absence of heterogeneous engineers. With overwhelming reverse salients, the organisation could only produce limited hardware: some bought from other countries, some poorly produced, and some parts, which were tough to duplicate, were produced using alternate parts developed indigenously which did not undergo rigorous testing.

IGMDP set up a monolithic scientific industrial edifice of a kind that has never before existed in the country. A traditional analysis, based on the security model when examining IGMDP in 1983 may point to the security rationale for missile development. Such an analysis would gloss over the critical links between ISRO and DRDO, success of SLV3 and the experience gained in indigenising anti-tank missiles and reverse engineering the SA2.

The IGMDP is a set of relatively independent missile programmes, bound together it seems only because they could not receive sufficient support as isolated programmes. Any one of the programmes could probably be cancelled with only the most minimal effects on the others. Yet the IGMDP is sold as a package deal, with the programme as a whole providing protection against too close an inspection of any single element therein. The IGMDP is also trying to tie its capabilities and facilities to broader defence and high-tech sectors, making itself (in Bruno Latour's phrase) an "obligatory point of passage" for other technological development projects. [13]

A system according to SCOT evolves by slowly adding and adapting existing resources and components. IGMDP saw the cobbling together of components and systems. IGMDP came out when the technology was mature enough to support all the missiles integrated into one project. The idea of dedicating a separate missile programme arose from several ripe technologies, the inevitable outcome of technical progress during the years. The scientific enclave became increasingly convinced of the technical feasibility of going in for

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[13] Steven M Flank, *Reconstructing Rockets: The Politics of Developing Military Technology in Brazil,* op. cit., p. 133.

a series of missiles. Earlier attempts on different missiles led to a strong technological build up in the country. Advances in both solid and liquid propellant technology made much of the difference.

Technical potential alone did not bring new technology into being, nor defined its workability. The most important factor was selling the technological projections to the government and to the armed forces. The scientists were able to use IGMDP to convince the government to provide funding for an expensive project based on an extrapolation of what had been achieved so far. Large Technological Systems succeed and structures endure because the networks in which they are embedded become more obdurate.[14] IGMDPs success can be attributed to the networks, which it was able to establish.

Today, close to two decades after the launch of IGMDP, India's missile armory includes a range of tactical and strategic missiles. Successful testing of Agni II in April 1999 and in January 2001 and the recent testing of BrahMos-a supersonic cruise missile, will help India to bridge a key gap in its evolving nuclear force structure. Success in the space realms with respect to launch vehicle design and technology have helped the development of missiles tremendously. The recent success of the Geostationary Satellite Launch Vehicle (GSLV) by ISRO has brought forth the technological know how to construct missiles of intercontinental range. Recent developments in the defence and space sector augurs well for a credible missile based defence systems in the coming years. The limited opening up of private enterprises into the defence

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[14] Thomas P Hughes, *Evolution of Large Technological Systems,* in W.Bijker, op. cit., p. 113.

realm will eventually help the defence establishment in developing key components and subsystems. An Indian alternative for private corporations like Raytheon or Lockheed Martin is not too far.

Appendix I

Performance of Major Rocket Propellants

Type	Oxidiser	Fuel	Storable?	Tc	Isp
Liquid	Oxygen	Hydrogen	No	4 180	366
	Nitric Acid (HNO3 NO2)	Hydrazine	No	5 100	277
	Oxygen	UDMH (CH3) NNH2	Partially	5 450	276
	Oxygen	RP-1 (Kerosene)	Partially	5 650	266
	Nitrogen tetroxide (N2O4)	Hydrazine	Partially	4 990	265
	Nitrogen Tetroxide	UDMH	Yes	5 390	256
	Inhibited Nitric Acid	UDMH	Yes	4 990	250
Solid (Double based)	Nitro-cellulose and Nitro glycerine		Yes	1 400	220
Solid (Composite)	KCLO4	C2H4O	Yes	1 200	210
	NHRNO3	C2H4O	Yes	1 200	200
	AP+KNO3	C2H4O	Yes	1 140	195

Tc= Combustion Temperature in degrees F
Isp= Specific Impulse in kilograms of thrust, per kilogram of propellant consumed per second, at sea level conditions.

Sources: Constant, N.J., *Fundamentals of Strategic Weapons: Offence and Defence Systems*, Vol 1 (Martinus Nijhoff: The Hague, 1981); and Sutton, G.P., Rocket Propulsion Elements, 6th edn (John Wiley: New York. 1992).

Appendix II

ISRO grew to include twelve distinct centres, these include
1 Vikram Sarabhai Space Centre VSSC
2 ISRO Satellite Centre ISAC
3 Liquid Propulsion Systems Centre LPSC
4 SHAR Centre
5 Space Application Centre SAC
6 Development and Educational Communication Unit DECU
7 ISRO Telemetry, Tracking and Command Network ISTRAC
8 INSAT master Control Facility MCF
9 ISRO Inertial Systems Unit IISU
10 National Remote Sensing Agency NRSA
11 Physical Research Laboratory PRL
12 National Mesosphere/ Stratosphere Troposphere Radar Facility NMRF

ISRO's Strategic Programmes

Organisations	Research Area	Location
Vikram Sarabhai Space Centre VSSC	It is ISRO's single largest facility providing the technology base for launcher and propulsion development.	Trivandrum
The Liquid Propulsion Systems Centre LPSC	It is the key centre for development of liquid propulsion system with its facilities. It is supported by major test facilities at Mahendragiri for a wide spectrum of liquid motors, from reaction control system thrusters to the 720 kN Vikas and Cryogenic engines	Bangalore and Trivandrum
Physical Research Laboratory PRL	It is a premier centre under DOS and carries out research in space and allied sciences.	Ahemadabad
ISRO Inertial Systems Unit IISU	It carries out development of inertial systems for both satellites and launch vehicles such as reaction wheel, gyros, solar array drive assembly etc.	Trivandrum
SHAR Centre	It is the main launch centre of ISRO. This centre also undertakes large-scale production of solid rocket propellant and ground testing of solid fuelled rocket stages of Indian Launch Vehicles. The Centre also has ISROS largest static test and Evaluation Complex (STEX) and Solid Space Booster Plant (SPROB)	Shriharikota
Space Science and Technology Centre SSTC	It was established in 1965 as a research and development unit. Its main area of research in propellants, propulsion systems, rocket hardware, design, onboard and ground electronics and control systems for application in launch vehicles, payloads and space craft systems for their test and qualification.	Veli Hill - Trivandrum

Appendix III

Establishments/Laboratories of DRDO [1]

•Defence Laboratory • DRDO Computer Centre • Defence Science Centre • Scientific Analysis Group • Field Research Laboratory • Defence Food Research Laboratories • Microwave Tube R&D Centre • Solidstate Physics Laboratory • Defence Research Laboratory • Centre For Artificial Intelligence • Defence Institute Of Work Study • Defence Electronics Research Laboratory• Institute Of Armament Technology • Defence Institute of Fire Research • Proof & Experimental Establishment • Range Centre & Interim Test Range • Defence Metallurgical Research Laboratory • Defence Electronics Application Lab • Gas Turbine Research Establishment • Defence Terrain Research Laboratory • Snow Avalanche Study Establishment • Defence Research & Development Lab • Defence Research & Development Unit • Terminal Ballistics Research Laboratory • Research & Development Establishment • Institute Of Systems Studies & Analysis • Aeronautical Development Establishment • Defence Agricultural Research Laboratory • Naval Chemical & Metallurgical Laboratory • Naval Science & Technological Laboratory • Naval Physical & Oceanographic Laboratory • Defence Institute of Psychological Research • Institute Of Nuclear Medicine & Allied Science • Explosive Research & Development Laboratory • Vehcile Research & Development Establishment • Electronics & Radar Development Establishment • Defence Research & Development Establishment • Defence Institute Of Physiology & Allied Sciences • Armament Research & Development Establishment • Centre For Aeronautical System Studies & Analysis • Instruments Research & Development Establishment • Advance Systems Integratum Evaluation Organisation • Defence Bio-Engineering & Electro-Medical Laboratory • Aerial Delivery Research & Development Establishment • Defence Scientific Information & Documentations Centre • Combat Vehicles

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[1]Rakesh Koshy, Indian Missiles: Defence Research Development Organisation, available at http:// www.bharatrakshak.com. Downloaded in October 2000.

Research & Development Establishment • Defence Materials and Stores Research & Development Establishment

Key Defence Establishments that Formed the Foundation for Rocket Research.

• Hindustan Aeronautics Ltd. (HAL): Set up in 1964, it has 12 divisions located in six states with its corporate office in Bangalore, Karnataka. The principal function of HAL is to design, manufacture, repair and overhaul various types of aircraft, helicopters and related aero-engines, avionics, instruments and accessories. HAL has manufactured, under license, the Jaguar IS/IB, the Do-228 and MiG-27ML jet fighters, Cheetah and Chetak helicopters and various types of aero-engines. HAL is also engaged in the design and development of the Light Combat Aircraft and the Advanced Light Helicopter. The first ALH prototype flew on 30 August 1992 and the LCA is set to fly in 1999. Also under development is the Medium Combat Aircraft (MCA) which is set to have its first flight in 2008.

• Bharat Electronics Ltd. (BEL): Established in 1954. Presently, it is the country's premier electronics organisation, having nine manufacturing units all over India with its corporate office is in Bangalore. BEL is engaged in the design, development and manufacture of sophisticated, state-of-the art electronic equipment for the use of Indian Defence Services, and para military organisations.

Other users are All India Radio, Doordarshan, Department of Telecommunications, the police, and the Meteorological Department. It has a very wide product range, which consists of over 350 different products, comprising communications equipment, radars for military and civil use, optical and opto-electronic equipment, sound & vision broadcasting equipment and electronic components.

• Bharat Earth Movers Ltd. (BEML): Commenced its operations in January 1965. It has three modern production units at Bangalore, Kolar Gold Fields and Mysore a subsidiary foundry unit in Tarikere, Karnataka and a nation-wide network of sales offices, spare parts depots and service centres. Its corporate office is at Bangalore.

The company is presently engaged in the design, development and manufacture of a wide range of sophisticated equipment and systems, particularly earth-moving machines, rail coaches, track-laying equipment, heavy-duty trucks and trailers, diesel engines etc. BEML is a leader in earth-moving industry with over 70% market share. Over 30,000 of its equipment and systems are productively deployed in India and over 30 other countries across the globe.

• Mazagon Dock Ltd. (MDL): It is the country's leading ship-building dockyard and can build warships upto 6000T displacement and merchant ships upto 2700 DWT. It has units at Bombay, Nhava and Mangalore and headquarters at Bombay.

At present, its major activities include construction of submarines, missile boats and destroyers for the Indian Navy and offshore supply vessels and well-head platforms for the Oil and Natural Gas Commission (ONGC). The company also provides diving services as well as services for coating/laying sub-sea pipes.

• Garden Reach Shipbuilders and Engineers Ltd. (GRSE): It is a multi-unit shipyard and general engineering company. It has six units in and around Calcutta and a Diesel Engine Plant at Ranchi (Bihar). Its corporate office is at Calcutta. It is presently engaged in the construction of corvettes, frigates and fleet tankers for the Indian Navy.

It also manufactures survey vessels for the Naval Physical Oceanographic Laboratory (NPOL). Also refits Indian Navy and Coast Guard Vessels. The company is also manufacturing portable bridges, marine sewage treatment plants, deck-machinery items, agricultural pumps and diesel engines.

• Goa Shipyard Ltd. (GSL): Located at Vasco-da-Gama. Primarily comprises construction and repair of vessels. It has undertaken the construction and refit of variety of vessels for the Indian Navy and the Coast Guard as well as for the non-Defence sector. It is currently building advanced offshore patrol vessels of inhouse design.

• Bharat Dynamics Ltd. (BDL): Established in 1970. Primarily engaged in the manufacture of guided missiles and other equipment. It corporate office is at Hyderabad, with production facilities at Hyderabad and Bhanur. It is the prime production agency for the Prithvi, Trishul, Akash and Nag being developed indigenously. BDL, which had earlier diversified its activities in a number of Naval projects, now proposes to take up manufacture of 7.62mm self-loading rifles (SLRs) and 9mm pistols.

• Mishra Dhatu Nigam Ltd. (MIDHANI): Established in 1973. MIDHANI's product range includes super alloys, titanium alloys, maraging steels, heat resistance alloys, controlled expansion alloys, tungsten, molebdenum, etc. Most of the products of MIDHANI are import substitution items. They also supply armaments-grade steel for the T-72 tank. The maraging steel production is used for the missile program, nuclear program and powder metallurgy products.

Appendix IV

PRITHVI SPECIFICATIONS

Range km	Prithvi-1 = 150 Prithvi-2 = 250
Length meters	8.5
Width meters	1
Payload kg	Prithvi-1 = 1,000 Prithvi-2 = 500-650
Weight kg.	4,500
Guidance	Inertial+terminal
Propulsion	Liquid

Bibliography

Primary Materials

India Government of, *A Profile for the Decade 1970-80*, Atomic Energy and Space Research: Atomic Energy Commission, (1970).

______________, Department of Space, *Annual Report*, 1972 –73, p. 11

______________, Department of Atomic Energy, No.31, P. 27.

______________, Department of Space, *Annual Report*, 1976-77, p. 56.

______________, Department of Space, No.11, p. 35.

Secondary Sources

Articles

Abraham, Itty, "India's Strategic Enclave: Civilian Scientists and Military Technologists", *Armed Forces and Society*, Vol.18, No.2, Winter 1992, pp. 231- 52.

"Agni II", *The Hindu,* Tuesday, April 13, 1999.

Agarwall, R.N., "Emphasis was on Re-entry Technology, *Frontline,* June 10-23, 1989, p. 14.

Banerjee, Indranil, "India Enters the Missile Age", *Sunday*, Vol.15, No.16, March 13-19, 1988, pp. 35-37.

Bary, A.L., "National Approach to Missiles", *Tribune*, November 22, 1978.

Bhatia, Anita, "India's Space Program: Cause for Concern", *Asian Survey*, Vol.25, No.10, October 1985, pp. 1013-30.

Bingaman, Jeff, et al., "Missile Control Act of 1989", *Congressional Records*, 22 June 1989.

Bobb, Dilip, "Agni: Chariot of Fire," *India Today,* 15 June 1989, pp. 28-32.

Cariappa, A.C., "Missiles in Conventional Warfare", *The Hindu,* November 25, 1973.

Carus, Seth W., "Ballistic Missiles in the Third World: Threat and Response", *The Washington papers*, No.146, New York, 1990.

Chengappa, Raj, "Boosting the Arsenal", *India Today*, February 29, 1996.

Congressional Research Service, "Ballistic Missile Proliferation of Non Major Military Powers- An Update", *Strategic Digest*, Vol.18, No.5, May 1988, pp. 612-642.

Dantes, Edmond, "Missiles in Gulf Buoy: India's Defence Drive", *Defence News*, February 2, 1991, p. 3.

"Devil Program", *The Hindu,* July 14, 1988.

Flank, M Steven, "Exploding the Black Box: The Historical Sociology of Nuclear Proliferation", *Security Studies*, Vol 3, No.2, Winter 1993-94, p.261.

Milhollin, Gary, "India's Missiles With a Little Help From our Friends," *Bulletin of the Atomic Scientists,* Vol.45, No.9, Nov 89, pp. 31-35.

Gopal, Raj N., "From Sounding Rockets to Satellites", *Frontline,* Vol.3, No.21, 31 October1986, pp. 76-85.

Gole, C.V., "The Prithvi-Facts and Fancies", *Vayu,* Vol. IV, 1994, pp. 23-30.

Gupta, Shekar, "Missile Shooting Ahead: Prithvi's Flight Trial is Successful", *India Today,* Vol. 13, No.6, March 16-31, 1988, pp. 70-71.

Hull Andrew, " Role of Ballistic Missile in the Third World Defence Strategies", *Jane's Intelligence Review*, Vol.3, No.10, October 1991, pp. 464-70.

"India Puts Agni IRBM Program on Ice", *Jane's International Defense Review,* Jan 96, p. 26.

"India Tests Variety of Anti-armor, Ballistic Missiles", *Defense News*, 25 Feb 91, p. 44.

"India Models SLBM After Prithvi Missile", *Defence News*, 25-31 July 94.

"Indian's Place Cloak Over Missile Plans", *Defense News*, 11-17 Dec 95, p. 5.

Iqbal, Mohammed, "Missile Proliferation in South Asia", *Regional Studies*, Vol.8, Spring 1990, p. 15.

Jacobs, Gordon, "Third World Ballistic Missiles: A Cause for Concern", *Jane's Defence Weekly*, Vol.6, No. 19, November 15, 1986.

Joshi, Manoj, "The Indigenous Effort", *Frontline*, April 13-26, 1992, p. 51.

__________, "Prithvi Missile Edge", *Frontline*, Vol. 5, No.7, April 2-15, 1988, pp. 35-39.

__________, "Agni: Importance, Implications," *Frontline*, Vol. 6, No.12, June 1989, pp. 4 -9.

__________, "Space Technology in the Third World: Commercialization and the Spread of Ballistic Missiles", *Space Policy*, Vol. 2, No.1, March 1986, pp. 157-68.

__________, "Controlling Ballistic Missile Proliferation", *Survival*, Vol. 33, No. 6, November-December, 1991, pp. 517-30.

__________, "Ballistic Missiles in the Third World", *International Security*, Vol. 9, No. 3, Winter 1984-85, pp.166-195.

Kaul, Kapil, "India in Space", *Strategic Analysis*, Vol.10, No. 7, October 1986, p. 855.

Keith, Payne, "Ballistic Missile Proliferation: A Quick-Look Summary," *The World In Conflict 1994-955, Jane's Intelligence Review,* January 1995, pp. 20-24.

Kumar, Nanda, P., "Space Research in India," *India and Foreign Review*, Vol.15, No.2, November, 1977, p.15.

Navias, M., "Ballistic Missile Proliferation In The Third World", *Adelphi Papers* 252, London: Brassey's For IISS, Summer, 1990.

Mahapatra, Chintamani, "Cryogenic Technology Deal: American Pressure Tactics", *Strategic Analysis,* Vol. 15, No.4, July 1992, pp. 313-24.

Marwah, Onkar "India's Nuclear and Space Programs: Intent and Policy," *International Security*, Vol.2, No.2, Fall 77, pp. 102-103.

Matthews, R.G., "The Development of India's Defence Industrial Base, *Journal of Strategic Studies*, June 1989, p. 423.

Menon, Amarnath K., "We can Design any Missile," *India Today*, June 15 1989, p.12.

Morrison, David C., "Asia's Missile Powers", *South*, Vol. 40, October 1984, pp. 13-16.

Mukherjee, Sadananda, "India has ICBM Ability," *Jane's Defence weekly*, February 3, 1990, p. 191.

Panwar, Sango, "India's Missiles: A New Dimension in South Asia", *Vayu Aerospace Review*, No. 6, 1999.

Parthasarathy, Anand, "For a Weapons Delivery System", *Frontline,* Volume 15 - Issue 12, June 06 - 19, 1998.

Perkovich, George, "A Nuclear Third Way in South Asia", *Foreign policy*, No.91, Summer 1993.

Prabhu, Rajendra, "Space Programme: Defence Aspects cannot be Ignored," *Hindustan Times*, 8 May 1992.

Rahul Bedi, "India Ignores West and Test Fires Prithvi II," *Jane's Defence Weekly*, 7 February,1996.

Raj, Gopal, "French Firm Willing to Supply ISRO Parts", *The Hindu*, 8 July, 1992.

________, "Corporate Front for Dept of Space", *The Hindu*, 28 May 1992, p.16.

Rajan, Y.S., "Benefits From Space Technology: A Review From Developing Country," *Space Policy*, Vol.14, No.3, August 1988, p.221.

Ramachandran, R., " Cooperation in Space Technology: Indo-Soviet Experience, *The Hindu*, 19 November 1988.

Ravi, K., "The Military Implications of India's Space Programme: Some Observations," *Defence Analysis,* Vol. 5, No. 3, 1989, pp. 267-70.

Richardson, Doug, "Missiles for the Modern Battlefield," *Asian Defence Journal*, 1996, pp. 48-59.

Sashtri, Ravi, "Spread of Ballistic Missiles and its Implications", *Strategic Analysis,* Vol. 12, No.2, May 1988, pp. 157-68.

Siddhu, W.P.S., "Tactical Gap", *India Today*, September 15, 1992.

Singh, Jasjit, "The Strategic Deterrent Option", *Strategic Analysis*, Vol. 12, No. 6, September 1989, pp. 585-604.

Singh, Pushpinder, "India's Agni Success Poses New Problems," *Jane's Defence Weekly*, June 3, 1989, p.1052.

Singh, Ravinder Pal, "Indian Ballistic Missile Development: Possibilities and Potentialities", *Strategic Analysis*, Vol.13, No. 10, January 1991, pp. 1147- 162.

Stephen F. Von Welck, "India's Space Policy: A Developing Country in the Space Club", *Space Policy Kent,* Vol. 3, No. 4, 1987, p. 326.

Thomas, Raju, G.C., "India's Nuclear and Space Programmes: Defence or Development?" *World Politics*, Vol.38, No.2, January 1986, pp 315-42.

"World Missiles", Special Supplement, *Defence and Foreign Affairs*, Vol. 16, No. 3, March 1988, pp.17-31.

Winner, Langdon, "Do Artefacts Have Politics?" *Daedalus*, Vol 109, 1980, pp. 121-136.

Books

Abraham, Itty, *The Making of the Indian Atomic Bomb: Science, Secrecy and the Postcolonial State,* Hyderabad: Orient Longman, 1998.

Baker, David, *The Rocket: The History and Development of Rocket and Missile Technology*, London: New Cavendish Books, 1978.

Batra, Madan Mohan, *Planning in India: Development perspective Towards the 21st Century,* Bareilly: V.K. Publishing House, 1987.

Bijker, Weibe, T.P.Hughes, and T. Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* Cambridge, MA: MIT Press, 1987.

Birla Institute of Science Research, *Self-Reliance and Security: Role of Defence Production,* New Delhi: Radiant Publishers, 1984.

Birla, N.C., and B.S., Murthy, *Indian Defence Technology, Missile Systems*, DRDO 1998.

Bracken, Paul, *Fire in The East: The Rise of Asian Military Power and The Second Nuclear Age*, New Delhi: Harper Collins, 1999.

Brian Elliot, ed., *Technology and Social Process* Edinburgh: Edinburgh University Press, 1988.

Brozoska, Michael and Ohlson Thomas, *Arms Transfers to the Third World 1971-85*, New York: Oxford University Press, 1987.

Chari, P.R., et al., *Nuclear Non Proliferation in India and Pakistan: South Asian Perspectives*, Colombo: Manohar, 1996.

Chengappa, Raj, *Weapons of Peace: The Secret Story of India's Quest to be a Nuclear Power,* New Delhi: Harper Collins, 2000.

Cotright, David and Amitabh Mattoo, *India and the Bomb*, New Delhi: Bahiri, 1996.

Gsponer, Andre and Jean Pierre Humi, *The Physical Principles of Thermonuclear Explosives, Internal Confinement Fusion, and the Quest for Fourth Generation Nuclear Weapons*, Technical Report, INESAP, September 1997.

Kalam, A.P.J., Abdul and Arun Tiwari, *Wings of Fire*, Hyderabad: Universities Press, 1999.
_______________and Y.S., Rajan, *Vision 2000*, New Delhi: Penguin, 1998.

Kapur, B.D., *Building A Defence Technology Base,* New Delhi: Lancer, 1990.

Karnad, Bharat, ed., *Future Imperilled: India's security in the 1990s and Beyond,* New Delhi: Viking Penguin India, 1994.

Karp, Aaron, *Ballistic Missile proliferation: Politics and Techniques*, Oxford: SIPRI, 1996.

Katz, James, E., ed., *Arms Production in Developing Countries*, Lexington, Mass: Lexington Books, 1984.

Kavic, J Lorne, *India's Quest for Security: Defence Policies, 1947-1965*, Berkeley: University of California Press, 1967.

Kaldor, Mary, *The Baroque Arsenal*, London: Andre Deutsch, 1982.

Krause, Keith, *Arms and State: Patterns of Military Production and Trade,* Cambridge: Cambridge University Press, 1992.

Latour, Bruno, *Science in Action*, Milton Keynes: Open University Press, 1987.

Lee, R.G., et al., *Guided Weapons*, London: Brassey's Defence Publishers, 1988.

Menon, Raja, *A Nuclear Strategy for India*, New Delhi: Sage, 2000.

Mackenzie, Donald., *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, Cambridge: The MIT Press, 1990.

_____________, and Judy Wajcman, eds., *The Social Shaping of Technology,* Milton Keynes: Open University Press, 1985.

Mirchandani, G.G and P.K.S., Namboodri, *Nuclear India: A Technological Assessment*, New Delhi: Vision Books, 1981, pp. 58-69.

Moshaver, Ziba, *Nuclear Weapons Proliferation in the Indian Subcontinent*, New Delhi: Macmillian, 1991.

Munson, Kenneth, *World Unmanned Aircraft,* London: Jane's Publishing Company, 1988.

Nayar, Baldev Raj, *India's Quest for Technological Independence*, Vol. I & II, New Delhi: Lancers, 1983.

Neufeld, Michael J., *The Rocket and the Third Reich: Peenemunde and the Coming of the Ballistic Missile Era,* Cambridge: Harvard University Press, 1995.

Nolan, Janne E., *Trapping's of Power: Ballistic Missile Proliferation in the Third World,* Washington D.C.: The Brookings Institution, 1991.

Parson, Nels A., *Missiles and The Revolution in Warfare*, Cambridge: Harvard University Press, 1962.

Perkovich, George, *India's Nuclear Bomb: The Impact on Global Proliferation,* Berkeley: University of California Press, 1999.

Potter, William C., and Harlan W. Jencks, *The International Missile Bazaar, The New Suppliers Network,* Boulder: Westview Press, 1994.

Poulose, T.T., *Nuclear Proliferation in The Third World,* Delhi: ABC Publishing House, 1982.

Raj, Gopal, *Reach for the Stars: The Evolution of India's Rocket Programme*, New Delhi: Viking, 2000.

Raju, J.K., *Security in The Missile Age*, Calcutta: Allied Publishers, 1967.

Rao, P.V.R., *Defence Without Drift,* Bombay: Popular Prakashan, 1970

Rao, U.R., *The Next 40 Years in Space: A View Point of Developing Countries,* Bangalore: ISRO, 1989.

Rikhye, Ravi, *The Militarisation of Mother India*, New Delhi: Chanakya, 1990.

Sharma, Dhirendra, *India's Nuclear Estate,* New Delhi: Lancers, 1983.

Singh Jasjit, ed., *Nuclear India*, New Delhi: Knowledge World, 1998.

Sondhi, Sunil, *Science Technology and India's Foreign Policy*, New Delhi: Anamika Prakashan, 1994.

Spinardi, Graham, *From Polaris to Trident: The Development of US Fleet Ballistic Missile Technology*, Cambridge: Cambridge University Press, 1994, p.14.

______________,*India, Pakistan and China: Defence and Nuclear Tangle in South Asia,* New Delhi: ABC Publishing House,1995.

Sutton, George P., *Rocket Propulsion Elements*, 5th ed., New York: John Wiley and Sons 1986.

Thomas, Raju G.C., *Indian Security Policy*, Princeton: Princeton University Press, 1990.

______________, *The Defence of India: A budgetary Perspective of Strategy and Politics*, New Delhi: Macmillan, 1978.

Udgaonkar, B.M., et al., *Homi Jehangir Bhabha: Collected Scientific Papers*, Bombay: TIFR, 1985.

Victor, Cecil, *India: The Security Dilemma*, New Delhi: Patriot Publishers, 1990.

Zaloga, Steven, J., *Soviet Air Defence Missiles,* Alexandria, VA: Jane's Information Group, 1989.