CHAPTER IV

MILITARY R&D PROJECTS: FEATURES AND PROGRESS

4.1 INTEGRATED GUIDED MISSILE DEVELOPMENT PROGRAMME

The Integrated Guided Missile Development Programme (IGMDP) was approved during the office of Mr. Venkataraman as Defence Minister and was launched in July 1983. Though the details of the IGMDP were then not available, it was expected that the missiles would enter service commencing 1995.

4.1.1 Preceding Preparation

By 1983, India had developed a very high level of expertise in missile R&D and had perfected sophisticated technologies for their manufacture\(^1\). Research Centre Imarat (RCI) was established near Hyderabad, within the Defence Research and Development Laboratory (DRDL), at an estimated cost of Rs. 110 crore, to conduct research on missiles.\(^2\) The DRDL 'established expertise' in guidance (command, semi-active homing and inertial guidance), 'built competence' in flight control (aerodynamic and thrust velocity control), 'successfully flew' three and four-axis platforms and 'developed' large thrust rocket motors that used solid as well as liquid propellants\(^3\).

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\(^1\) *Asian Recorder* (New Delhi), Vol. 29, no. 22, 28 May-3 June 1983, p. 17195


\(^3\) See the section on "Weapon Systems", in *Towards Self-Reliance in Defence-a silver saga* [n. p., n. d.], with a foreword by the then Director General, V. S. Arunachalam. The document has no page numbers.
4.1.2 Missiles Under Development

**PRITHVI**

**Prithvi** is a tactical, battlefield-support missile. It is planned in three versions—for the army, air force and navy. While the army has opted for the shorter 150 k. m. range version, the air force has gone in for the 250 k. m.—extended range—version. The naval version has a reported range of 350 k. m. **Prithvi** is 8.56 m long and has a thickness of one metre.

**Guidance**

The missile has the latest on-board computers operating with real time software as well as an advanced strap down inertial navigation and guidance system.\(^4\) The inertial guidance system "does not rely on outside reference like heat, light or electromagnetic radiation... [but] measures the distance between two points [launch and impact points] over a period of time"\(^5\).

**Propulsion**

**Prithvi** is a single stage missile that has a two chamber rocket motor with storable liquid propellants\(^6\). **Prithvi** uses fifty per cent xylidene\(^7\)—the fuel—and the remaining

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\(^5\) It is essentially a system of dead reckoning. It can be used against large and fixed targets, but not, by itself, against moving targets. See T. V. Karthikeyan and A. K. Kapoor, *Guided Missiles* [New Delhi, 1991], p. 34.


\(^7\) (CH\(_3\))\(_2\) C\(_2\)H\(_3\)NH\(_2\). An aromatic amine that exists in six isomeric forms, of which five are liquids above 20\(^\circ\)C.; its boiling point is in the range of 216\(^\circ\)C. to 230\(^\circ\)C. Its most common use is in the manufacture of dyes.
fifty per cent triethylamine and nitric acid—the oxidiser—as propellant.\(^8\) The missile has a shelf-life of five years with the propellant loaded and twenty five years without the propellant being loaded.\(^9\) Prithvi-III is a “boosted liquid propellant version, to generate more thrust-to-weight ratio...”\(^10\)

**Range**

The missile has a minimum range of 40 k. m. As stated earlier, Prithvi is planned in three versions. While the army version would have a range of 150 k. m. Prithvi-II would be able to reach targets 250 k. m. away. At the time of one of the flight tests of Prithvi it was revealed that a naval version (Prithvi-III) was also being planned\(^11\), which would have a range of 350 k. m.\(^12\)

**Warhead**

Four variants of the missile’s warhead have been planned. They are: incendiary, fragmentary, unguided munitions and guided sub-munitions. While the first three variants have already been developed, the status of the fourth is uncertain\(^13\). The fifth type of warhead would be a nuclear warhead.

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\(^8\) *Hindustan Times* (New Delhi), 22 May 1993.


\(^10\) Pravin Sawhney, “India’s Missile Policy: Focus Must Shift to Agni”, *Times of India* (New Delhi), 4 March 1997.


\(^12\) Pravin Sawhney, n. 10.

### Table 4.1  Some Land-based Surface-to-Surface Missiles (SSMs)

<table>
<thead>
<tr>
<th>Designation</th>
<th>Warhead (HE/NE)*</th>
<th>Propulsion</th>
<th>Range (k. m.)</th>
<th>Guidance</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frog-7</td>
<td>HE or N</td>
<td>Solid</td>
<td>60</td>
<td>Unguided</td>
<td>Russia</td>
</tr>
<tr>
<td>Exocet MM 40</td>
<td>165 kg HE</td>
<td>2-stage Solid</td>
<td>70</td>
<td>Inertial + Active radar homing</td>
<td>France</td>
</tr>
<tr>
<td>Pluton</td>
<td>N 25 or 15 KT®</td>
<td>Solid</td>
<td>120</td>
<td>Inertial</td>
<td>France</td>
</tr>
<tr>
<td>SS-21</td>
<td>HE or N</td>
<td>Solid</td>
<td>120(e)</td>
<td>-</td>
<td>Russia</td>
</tr>
<tr>
<td>SS-1B (Scud A)</td>
<td>HE or N</td>
<td>Storable liquid</td>
<td>80-150</td>
<td>Radio command</td>
<td>Russia</td>
</tr>
<tr>
<td>Samlet</td>
<td>HE</td>
<td>Turbojet + boosters</td>
<td>200</td>
<td>Command; probably active radar</td>
<td>USA</td>
</tr>
<tr>
<td>SS-1 C</td>
<td>HE or N</td>
<td>Storable liquid</td>
<td>16-270</td>
<td>Simplified inertial</td>
<td>Russia</td>
</tr>
<tr>
<td>(Scud B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-23</td>
<td>HE or N</td>
<td>Solid</td>
<td>500(e)</td>
<td>-</td>
<td>Russia</td>
</tr>
<tr>
<td>Pershing Ia</td>
<td>N 60 to 400 KT</td>
<td>2-stage Solid</td>
<td>740</td>
<td>Inertial</td>
<td>USA</td>
</tr>
<tr>
<td>Pershing II</td>
<td>N 60 to 400 KT</td>
<td>2-stage Solid</td>
<td>740</td>
<td>Terminal</td>
<td>USA</td>
</tr>
<tr>
<td>SS-22</td>
<td>HE or N</td>
<td>Solid</td>
<td>900(e)</td>
<td>-</td>
<td>Russia</td>
</tr>
<tr>
<td>Prithvi</td>
<td>Five versions</td>
<td>Liquid</td>
<td>Minimum 40, Maximum 350</td>
<td>Strapdown Inertial</td>
<td>India</td>
</tr>
</tbody>
</table>

**Notes:** *HE: High Explosive, N: Nuclear, KT: Kilo ton, e= estimated

*Source: Jane's Weapon Systems 1997-98, except for Prithvi*

### AGNI

*Agni* is an intermediate range ballistic missile (IRBM). Classically a ballistic missile is one that travels outside the earth’s atmosphere, during most part of its flight, before re-entering. The missile is set into a ballistic path to prevent deflection. For most part of the missile’s flight, the only external force that acts on it is the gravitational pull of the earth.
Guidance

Like the Prithvi, Agni also relies on strap down inertial navigation.

Propulsion

It is a three stage missile. In the first three tests, the first stage used solid propellant rocket motor and the second stage used liquid propulsion. In the fourth test, the two stages used solid propulsion. In solid propulsion, the propellant grain, the oxidiser and the fuel, whose physical state is solid, is stored in a chamber. When ignited, by means of an electric charge, it burns out completely at a pre-determined rate, and is expelled through a nozzle in the form of gases. The third stage is the missile’s warhead.

Warhead

It can carry a conventional war head and can also carry a nuclear warhead\textsuperscript{14}. The warhead is enclosed in a heat shield to protect it from burning as the missile re-enters the earth’s atmosphere. The four types of conventional warheads are incendiary, fragmentary, unguided munitions and guided sub-munitions. The warhead would have a maximum weight of one ton.

\textsuperscript{14} See interview with Abdul Kalam, “We Can Design Any Missile”, India Today, 15 June 1989, p. 31. In a lighter vein he said, “... It can also carry flowers to offer as a symbol of peace...”
Range

With a warhead of one ton, the missile would be able to reach targets 1,500 k. m. away. With the weight of the reduced, the missile has a maximum range of 2,500 k. m. *Agni* has a CEP of 60 m.

*Agni* Tests

Four tests of the *Agni* missile have been conducted till date. The following table presents the dates of the test and other significant details.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Date</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22 May 1989</td>
<td>Re-entry, heat shield, guidance, stage separation. 1,000 k. m. 'Embarrassingly accurate'.</td>
</tr>
<tr>
<td>2</td>
<td>29 May 1992</td>
<td>Stage separation. Failure of mission goals due to design deficiency in the location of sensors.</td>
</tr>
<tr>
<td>3</td>
<td>19 February 1994</td>
<td>Re-entry, manoeuvre, longer range, control, guidance, 2-stage propulsion, stage separation.</td>
</tr>
<tr>
<td>4</td>
<td>11 April 1998</td>
<td>Version II tested for increased range of 2,000 k.m. plus, from Wheeler Island, Andaman and Nicobar.</td>
</tr>
</tbody>
</table>

Soon after the first was conducted the then Director General of the DRDO stated that technologies such as re-entry and heat shield were proved. Besides, the missile’s accuracy was established. During the second test, the missile did not travel to its full range. The flight duration of the missile should actually have been 56 seconds after launch, but it lasted for fifty seconds, six seconds less than the planned duration.

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The fourth test is unique in that all the stages of the missile use solid propellant. Moreover, for on-board navigation the missile used a 1553 databus, which it is claimed reduces the number of connectivities and makes it more rugged.

**AKASH**

The Akash is a mobile area defence surface-to-air missile (SAM) system being developed for the exclusive purpose of the Indian Air Force (IAF).

**Guidance**

Akash uses both command guidance and active homing—the latter is used in the terminal phase. In active homing, the homing head is switched after which it starts searching for the target. Once the target is located, it is traced and active homing commences.

**Tracking**

The Akash missile system has multiple-target handling capability. The targets are tracked by Indra phased array radar, which can track one hundred targets at a time and is, thus; critical for the missile system.

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18 Karthikeyan and Kapoor, n. 5, pp. 23-34. Active homing is used after the missile gets closer (in distance) to the target. Command guidance is used to bring the missile closer to the target. Active homing could be used with inertial navigation too.


20 Abdul Kalam, DRDO Director General, quoted in *Economic Times* (New Delhi), 23 March 1993.
Propulsion

The missile uses an integrated solid rocket propellant system.

Speed

The missile moves at a speed of 600 metres per second—mach 2, which means that the missile would reach the target at its full range of 30 km in fifty seconds, and in a much lesser duration if the target were located within a distance of 30 km.

TRISHUL

Trishul is a quick-reaction SAM "designed to counter a low level attack." The missile will be used by all the three services. The missile becomes operational at an altitude of 500 metres. It has been described as India’s answer to the U. S. Patriot missiles that have been used to counter the Iraqi Scuds.

Guidance

The missile operates on command-to-line of sight guidance. In this method the guidance signal is transmitted from launch site to the missile, giving the missile its deviation from the pathline pointing from the launcher to the target, also called the

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21 Pratap Narain, Indian Arms Bazar [New Delhi, 1994], p. 133.
24 Asian Age (New Delhi), 30 December 1996.
line of sight (LOS). The missile has a computer on board to actuate its control mechanism to turn it towards the line of sight.  

**Propulsion**

*Trishul* uses a solid dual thrust rocket motor for propulsion.

**Materials**

*Trishul* is made of aluminium alloy structures, fibre glass composites and maraging steel.

**Range and Warhead**

The missile has a minimum range of 500 metres and a maximum range of nine k. m. and can carry a warhead of 15 k. g. weight.

*Trishul* has sea skimming capability when launched from ships. Sea skimming missiles travel at a very low height, just a few metres above the sea level, actually skimming the waves. Hence the name. The utility of such missiles lies in the fact that the low height and high speed of movement render them high single shot kill probability, besides being significantly immune to electronic counter measures (ECMs), given their small radar cross section.

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26 Command guidance is of three types: wire link, radio link and fibre optic link.

27 Narain, n. 21, p. 133. Maraging is heat treatment used to harden alloy steels. Such material is characterised by being tough and resistant to saline corrosion.

28 *Asian Age* 30 December 1996.

While the army version of Trishul has already undergone user trials, the air force version was flight tested, using the Pilotless Target Aircraft (PTA) as the target, and trails of the surveillance radar and fire control system of the naval version have commenced\textsuperscript{30}.

**NAG**

*Nag* is a third generation anti-tank guided missile (ATGM) that possesses an all-weather capability. It has top attack capability. In other words, it targets the turret of the tank, where the armour is the thinnest\textsuperscript{31}. While the first generation ATGMs are wire guided, the second generation is semiautomatic. The third generation is fire and forget type\textsuperscript{32}. *Nag* has been designed to be launched from 'either the *Namica* (BMP-2) vehicle or the Army Aviation version of the Advanced Light Helicopter (ALH)\textsuperscript{33}.

**Propulsion**

*Nag* uses solid propulsion. A smokeless high energy solid propellant is used in *Nag*. The advantage of using such propellant is that it ‘would not leave tell-tale trails behind’, and would, thus, enable the launcher to ‘make good its escape’\textsuperscript{34}.


\textsuperscript{32} For a comprehensive discussion on ATGMs see C. Raja Mohan, “Precision Guided Munitions in Anti tank Warfare”, *Strategic Analysis*, Vol. 7, no. 9, December 1983, pp. 730-50.

\textsuperscript{33} *Strategic Digest* (New Delhi), Vol. 29, no. 4, April 1999, p. 710.

\textsuperscript{34} *Hindustan Times*, 12 September 1997. The launcher would be able to ‘shoot and scoot’.
**Guidance**

*Nag* uses homing guidance. In this type of guidance, a homing head, also called a seeker head, locks on to the target, after receiving the target co-ordinates from the tracking radar, in its infrared or millimetric sights, before being fired. A seeker head is vital to the missile because it enables it to reach the target (home in). The seeker has been successfully tested\(^{35}\).

**Range and Warhead**

*Nag* has a range of four k. m.\(^{36}\). The missile uses a tandem warhead.

*Nag*’s airframe is made of composite materials, which make the missile light, without compromising its strength, while its foldable wings enable it to be launched by a tube, like any other third generation ATGM\(^{37}\). Besides, it has the provision to be launched from a helicopter; however, the exact status of this version is not known. Trial launches of the missile using the *Namaica* have been conducted\(^{38}\).

The following is a table showing some of the important features of High Energy ATGMs.

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\(^{35}\) *The Hindu*, 10 August 1996. Speaking to the media after the test, on 9 August 1996, Dr. Kalam said, "It [the seeker head] is the eye of the missile, the missile to see where it is going". He characterised the successful flight test of *Nag* as the third greatest event in the history of India’s missile development efforts.

\(^{36}\) Though reports prepared by, as well as those tabled in, Parliament, DRDO publications and national English language dailies consistently state that the range is four k. m., the authoritative *Janes Defence Weekly* (London), in its 15 October 1997 edition, writes that *Nag* has a ‘range of up to 6,000 m’, i. e., six k. m.


Table 4.3: Some Anti Tank Guided Missiles

<table>
<thead>
<tr>
<th>Designation</th>
<th>Warhead</th>
<th>Propulsion</th>
<th>Range (m.)</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT</td>
<td>6 kg HEAT</td>
<td>2-stage Solid</td>
<td>4,000</td>
<td>CLOS</td>
</tr>
<tr>
<td>Milan</td>
<td>HEAT</td>
<td>Solid</td>
<td>2,000</td>
<td>Wire-automatic CLOS</td>
</tr>
<tr>
<td>Picket</td>
<td>HEAT</td>
<td>Solid</td>
<td>500</td>
<td>Gyro-stabilised LOS</td>
</tr>
<tr>
<td>AT-2</td>
<td>HEAT</td>
<td>Solid</td>
<td>3,500</td>
<td>Wire CLOS, possibly IR homing</td>
</tr>
<tr>
<td>AT-3</td>
<td>HEAT</td>
<td>Solid</td>
<td>3,000</td>
<td>Wire CLOS</td>
</tr>
<tr>
<td>AT-4</td>
<td>HEAT</td>
<td>Solid</td>
<td>2,000</td>
<td>Semi-automatic CLOS</td>
</tr>
<tr>
<td>AT-5</td>
<td>HEAT</td>
<td>Solid</td>
<td>4,000</td>
<td>CLOS</td>
</tr>
<tr>
<td>AT-6</td>
<td>HEAT</td>
<td>Solid</td>
<td>-</td>
<td>CLOS</td>
</tr>
<tr>
<td>Copperhead</td>
<td>6.4 kg HEAT</td>
<td>Cannon launched</td>
<td>16,000</td>
<td>Laser homing</td>
</tr>
</tbody>
</table>

Source: Jane's Weapon Systems, 1997-98

4.1.3 Progress of the IGMDP

As a first step in the direction of building complex weapon systems, the DRDO commenced the development of technologies relevant to the IGMDP a few years before the programme was actually inaugurated\(^{39}\). Significantly, the DRDO initiated ‘competence building’ in the fields of inertial navigation system and liquid propulsion\(^{40}\). Further, range test facilities were augmented, efforts were initiated for the general development of missiles and rockets and specific hardware projects were undertaken\(^{41}\). Projects were started in the ‘advanced’ areas of lasers and warheads\(^{42}\). By 1984, design of systems for some of the missiles reached an advanced stage, while testing of some of the subsystems had been carried out\(^{43}\).


\(^{40}\) MoD, Annual Report, 1979-80 [New Delhi, 1980], p. 57.

\(^{41}\) Ibid., p. 57.


\(^{43}\) MoD, Annual Report, 1983-84 [New Delhi, 1984], p. 76.
During 1985-86, the preliminary design phase of some of the missile systems was completed and fabrication of sub-systems commenced.\(^{44}\) The first flight test of Prithvi incorporating the twin engine liquid power plant, control, electronics and closed loop strapdown inertial navigation guidance system with onboard software and real time software was conducted successfully on 25 February 1988. "All the sub systems performed to the requirements"\(^{45}\). Simultaneously, several flight trials of Trishul were undertaken "proving propulsion, structures, actuation systems, thermal battery"\(^{46}\). Nag and Akash were in an advanced stage of development tests.

That the Prithvi was successfully tested several times with inertial guidance system, the Annual Report claimed, marked a "significant breakthrough for the missile programme"\(^{47}\). Prithvi was tested for its minimum (40 k. m.) and maximum (250 k. m.) range, "within the stipulated circular error probability [C. E. P.], ensuring design adequacy..."\(^{48}\)

Apart from developing different type of warheads, production of various sub-systems to enable development and user trials of Prithvi was commenced.\(^{49}\) Ground electronics and wide band target gathering system for target acquisition of Trishul

\(^{44}\) MoD, *Annual Report, 1985-86* [New Delhi, 1986], p. 75.
\(^{45}\) MoD, *Annual Report, 1987-88* [New Delhi, 1988], p. 65. The flight test was conducted from India's rocket launch facility—SHAR Centre.
\(^{46}\) Ibid., p. 65.
\(^{48}\) Ibid., *Prithvi* has a C. E. P. of one per cent. C. E. P. is a measure of a missile’s accuracy represented by the radius of a circle around a target point within which there is a 50 per cent probability of the missile landing. See Michael Stephenson and John Weal, *Nuclear Dictionary* [Essex: Longman, 1985], p. 30.
\(^{49}\) Ibid., p. 74. For details on the warhead see preceding pages.
were successfully tested several times, during 1991-92\(^{50}\). Flight tests of the naval version of *Trishul* were also commenced; height-lock loop system and radio altimeter were incorporated into the *Trishul* missile system and successfully tested during flight trials\(^{51}\). Propulsion, control and tube launch system of *Nag* were successfully tested during flight trials; besides, captive tests of the guidance system were held\(^{52}\). *Akash* missile system was tested for evaluating the airframe and propulsion system. Further, the ground systems for the Group Control Centre(C\(^3\)I Centre) and Battery were developed and system integration commenced\(^{53}\). Significant progress was achieved with the integration of the *Rajendra* phased array radar with the missile system, which was sent up for performance and search-phase testing\(^{54}\).

Flight trials of *Trishul* using balloon and Pilotless Target Aircraft (PTA) were conducted; the guidance system of *Trishul* was tested in a separate flight trial\(^{55}\). The mobile launcher—*Trishul* Combat Vehicle(TCV)—was developed and was, in 1992-93, in the final stages of integration\(^{56}\).

During 1992-93, the guidance system for *Nag* was being integrated with the missile for testing the thermal sighting system—for recognising targets five k. m. away—was being set up for field trials, the tandem warhead was being evaluated for

\(^{50}\)Ibid.
\(^{51}\)Ibid.
\(^{52}\)Ibid.
\(^{53}\)Ibid.
\(^{54}\)Ibid.
\(^{56}\)Ibid.
performance and integration of the missile carrier and mobile launchers was just about completed\textsuperscript{57}.

The user trials of \textit{Prithvi} were completed during 1994-95\textsuperscript{58}. Work was commenced on the ground system for the naval and air force versions of \textit{Trishul}\textsuperscript{59}. The integrated functioning of the seeker head and on-board processor of \textit{Akash} was successfully tested, the Annual Report noted\textsuperscript{60}. Captive testing of the \textit{Nag} prototype seeker head was conducted during 1994-95\textsuperscript{61}. Recently the Director General of the DRDO has stated that the \textit{Nag} ATGM was "almost ready for production" and added that "almost all the tests" have been completed\textsuperscript{62}.

\textbf{4.2 \textit{ARJUN} MAIN BATTLE TANK(MBT) PROJECT\textsuperscript{63}}

The project was initiated by the first director of CVRDE, the late Mr. Mukherjee, along with a 'limited team of technicians', who were later 'joined by a large body of technologists, technicians and tradesmen', to design the MBT and most of its sub systems\textsuperscript{64}. The project was started in March 1974 and series production was supposed to have commenced in 1983\textsuperscript{65}. However, the first prototype itself was not ready for

\textsuperscript{57} Ibid., p. 69.
\textsuperscript{58} MoD, \textit{Annual Report, 1994-95} [New Delhi, 1995], p. 39.
\textsuperscript{59} Ibid.
\textsuperscript{60} Ibid.
\textsuperscript{61} Ibid.
\textsuperscript{62} Strategic Digest, Vol. 29, no. 4, April 1999, p. 170. In the first week of September 1999 two tests of \textit{Nag} were conducted successfully. Though the details of the tests are not available, in the light of Kalam's remark that the \textit{Nag} was just about to enter the production phase it could be inferred that these tests are meant to fine-tune the missile before clearing for production.
\textsuperscript{63} The MBT was latter christened \textit{Arjun}.
technical evaluation until 1983, by which time the tank should have been, according to plans, in the final phase of pre-production series tests. Consequently, the year of making the first prototype available for technical evaluation was revised.

4.2.1 FEATURES OF ARJUN MBT

Thirteen labs/establishments, including the CVRDE and academic institutions have been involved in the development of the tank. The General Staff Qualitative Requirements (GSQR) for the tank was revised twice, in 1980—six years after the project was initiated—and in 1985—five years after the first revision.

General features

The tank is 2.3 m high, 3.5 m wide and weighs 58.5 tons. The production tank would weigh 60 tons. It can accelerate to a speed of 30 k. m. p. h., from zero, in eight seconds, 72 k. m. p. h. being its maximum speed. According to an earlier report, the tank achieved an acceleration of 30 k. m. p. h. in ten seconds, while the GSQR was 19 seconds.

It would exert a low ground pressure of 0.84 k. g./c. m.², which would enable easy travel in the Thar desert. The tank has a fuel capacity of 1610 litres; the cross country mileage is eight litres, while it is double on even terrain. The tank would be

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66 Ibid.
67 Ibid., p. 22.
70 Indian Recorder, Vol. 3., no. 15, 8-14 April 1996, p. 1891.
able to cover a distance of 200 k. m. with the fuel tank full to its capacity. In other words, *Arjun*’s cruising range is 200 k. m. The tank is equipped to operate in an environment contaminated by nuclear, chemical and biological agents\(^{71}\).

**Armour**

The tank is fitted with the indigenously developed *Kanchan* armour to protect it from anti-tank ammunition.

At the time of commencing the project, the tank needed to be protected from 105 m. m. guns\(^{72}\). However, a change occurred later in the threat perception—it was anticipated that the tank would have to be protected from 120 m. m. guns—thereby altering armour protection requirements, which pushed up the weight of the tank\(^{73}\).

**Engine**

Due to a change in mobility requirements—with a change in the power-to-weight ratio, from 20 h. p. /ton to nearly 23.6 h. p. /ton—the engine required to be of 1,400 h. p.\(^{74}\)

The tank is powered by a turbo charged diesel engine, a German engine, produced by Motoren-und Turbinen-Union GMBH, designated MTU MB 838 Ka-501 engine\(^{75}\), whose gear box and transmission (supplied by RENK), too, are of German origin. Efforts are being made to develop an indigenous engine for the

\(^{71}\) *Indian Express*, 9 January 1996 and *Financial Express* (New Delhi), 18 February 1996.

\(^{72}\) Subramanian, n. 64, p. 14.

\(^{73}\) Ibid.

\(^{74}\) Ibid., p. 15. Also see the section on ‘import substitution’ below.

\(^{75}\) *Asian Recorder*, Vol. 39, no. 46, 12-18 November 1993, p. 23539
Arjun\textsuperscript{76}. A futuristic engine, for which Rs. 56 crores have been sanctioned as of 1982, is being developed indigenously\textsuperscript{77}. Between 1986 and 1989, 42 engines were imported at a cost of $15 million.

The then COAS, Gen. Rodrigues, said that the tank had been ‘specifically designed to operate in the conditions prevailing in the western sector’\textsuperscript{78}. According to a note submitted by the Department of Defence R&D, Ministry of Defence, the engine has been “specifically designed for Indian desert conditions based on Indian specifications ... to work in the heavy, dust-laden atmosphere of the desert”\textsuperscript{79}. According to the CVRDE director, M. Natarajan, and Maj. Gen. Gurdial Singh, who had conducted several trials of the tank, ‘the engine has an electronically controlled system that adjusts the power delivered, by reducing the quantum of fuel injected into the cylinders’ at temperatures higher than 42°C to 49°C, to its cooling capability, nevertheless enabling the tank to move at a speed of 22 to 25 k. m. p. h. and negotiate sand dunes of about 35° gradient\textsuperscript{80}. As a result, the tank “need not be halted for cooling the engine even in the most adverse weather conditions”\textsuperscript{81}. By implication, the tank would be able to constantly move in the Thar Desert during peak summer too.

\textsuperscript{76} The German engine is planned to be an interim measure. The DRDO is yet to deliver an indigenous engine.

\textsuperscript{77} Asian Recorder, Vol. 28, no. 50, 10-16 December 1982, p. 16930. By 1982, Rs. 18.2 crores were spent.


\textsuperscript{80} Subramanian, n. 64, p. 16, Asian Recorder, Vol. 39, no. 46, 12-18 November 1993, 23539 and Standing Committee on Defence (1995-96), Fifth Report, n. 17, p. 24. “Thus, during higher temperatures and full power requirements, the power output of the engine is reduced to avoid its overheating and consequent seizure”.

\textsuperscript{81} Subramanian, n. 64, p. 16. Army men want the tank’s performance at such temperature to improve.
Fire control system, sight and navigation

The tank uses an independent line-of-sight stabilised, integrated, computerised fire control system that enables the tank to fire while moving both during the day and night; a feature it would not have possessed had it been fitted with a weapon-stabilised system, as originally planned\textsuperscript{82}.

The gunner’s main sight is the thermal imaging system. The demand for an ‘ability’ to shoot at long ranges “necessitated a switch over from an image intensifying system [which had a range of one k. m. at night] to a thermal imaging system”—that provides the means to ‘comfortably engage’ targets, three k. ms. away even in total darkness and in spite of smoke, dust, haze and camouflage\textsuperscript{83}. Besides, the system helps navigation during sand storms\textsuperscript{84}.

Along with the main sight is a laser range finder that helps acquire distant targets accurately. As late as 1996, the possibility of employing a better laser range finder, to pick up ten kilometer-distant targets, was being explored\textsuperscript{85}. The laser warning receiver is being improved, by positioning a combination of several receivers to pick up targeting by the enemy from any angle\textsuperscript{86}. Besides, the commander would be having a panoramic sight, which would enable him to maintain all round surveillance over the

\begin{thebibliography}{9}
\bibitem{82} Ibid., p. 15.
\bibitem{83} Ibid., p. 14.
\bibitem{84} \textit{Indian Recorder}, Vol. 3, no. 15, 8-14 April 1996, p. 1891. Reportedly, the system was used when a sand storm swept while the COAS was on board the tank during trials. An army officer said, “We switched to the thermal imaging mode... There was no problem navigating the tank thereafter”.
\bibitem{85} The choice had to be made between the indigenously developed Bharat Electronic Limited’s (BEL) finder and a Swedish finder. See \textit{The Hindu}, 3 March 1996.
\bibitem{86} \textit{Indian Recorder}, Vol. 3, no. 15, 8-14 April 1996, p. 1891. “The receiver alerts the tank within two seconds after it has been picked up by the adversary, giving it 18 seconds to dodge a strike”.
\end{thebibliography}
battle field, "without removing his eyes from the sight and without being disturbed by the turret motion".  

The tank employs an indigenously developed global positioning system (GPS) receiver that provides the necessary information to precisely define its geographical location on a map and steer its way on the basis of a pre-programmed route.

**Gun and Ammunition**

The DRDO has developed super-velocity fin-stabilised, armour-piercing discarding sabot (FSAPDS) ammunition and a 120 mm calibre gun, and high-explosive squash-head ammunition (HESH) so that the tank has an 'edge' over contemporary tanks and can 'defeat' contemporary armour. The gun has been designed and developed indigenously by the Armament Research and Development Establishment (ARDE), Pune and was extensively tested against moving and static targets at ranges of up to 2.1 km. The tank is endowed with a coaxial 7.62 mm machine gun for anti-personnel rounds and a 12.7 mm machine gun for air and ground targets, as secondary weapons. The anti-helicopter round, which was under development, as of 1993, latter reports suggest, has been developed. It will be fired from the 120 mm main gun.

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88 *Indian Recorder*, Vol. 6, no. 15, 8-14 April 1996, p. 1891. Such a feature, according to army officers, would 'prevent the tank from getting lost' in desert and or hostile terrain.

89 *Economic Times*, 2 March 1993 and Shankar Bhaduri, "The Coming of India's Super Tank", *National Herald*(New Delhi), 8 July 1993. The FSAPDS ammunition can travel at a velocity of 1,600 m. m. per second. 'When hit, an enemy tank, of weight 40 tons, approaching at a speed of 25 k. m. p. h. will momentarily stop in its tracks'. The ammunition would, eventually, be produced at Ordnance Factories and Heavy Alloy Penetrator Factory, Trichur.


92 *Indian Recorder*, Vol. 3, no. 15, 8-14 April 1996, p. 1891. This would be used to strike down tank busting helicopters. A proximity fuse, fixed to the ammunition, triggers off a fragmentation blast, when it gets close to a helicopter.
Fording

The tank can cross 1.4 m high water obstacles. A medium fording capability—"the key to more effective operations in the riverine terrain of Punjab", that would facilitate crossing water obstacles while the tank remained immersed up to the turret level, is being developed93.

Import substitution

Some of the important systems of the tank are now being imported. They are94:

a) engine (from MTU, Germany),
b) transmission (from RENK, Germany),
c) primary sight (from OELDFT, Germany),
d) tracks (from DIEHL, Germany),
e) hydro-pneumatic suspension system (from TCL, USA) and
f) communications equipment

The engine, gun control system and fire control system, now being imported, would gradually be produced in India95.

4.2.2 Features of Some MBTs, A Comparison

Table 4.4 attempts to present a comparison of a few of the features of some of the best known MBTs in service today with those of the Arjun MBT.

93 Ibid.
95 Indian Recorder, Vol. 3, no. 8, 19-25 February 1996, p. 1781. The prototype engine developed by the CVRDE has produce up to 900 h. p. and has been re-configured to give 1400 h. p.
Table 4.4: Features of some MBTs

<table>
<thead>
<tr>
<th>Feature</th>
<th>Arjun</th>
<th>USA</th>
<th>M1A2 Abrams</th>
<th>A2, A4, A4.1</th>
<th>Leopard, A1/A1A1</th>
<th>Challenger 1, UK</th>
<th>Merkava, Mark 1, Israel</th>
<th>T-90, Russia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combat Weight</td>
<td>60</td>
<td>54.5</td>
<td>42.4</td>
<td>54.5</td>
<td>62</td>
<td>60</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Max. Speed on Road (k mph)</td>
<td>72</td>
<td>72.421</td>
<td>65</td>
<td>71</td>
<td>56</td>
<td>46</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Engine h. p.</td>
<td>1400</td>
<td>1500</td>
<td>830</td>
<td>1500</td>
<td>1200</td>
<td>1200</td>
<td>840</td>
<td></td>
</tr>
<tr>
<td>Ground Pressure</td>
<td>0.84</td>
<td>0.96</td>
<td>0.88</td>
<td>0.9</td>
<td>0.97</td>
<td>0.96</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Fuel Capacity (lt.)</td>
<td>1610</td>
<td>1907.6</td>
<td>985</td>
<td>1300</td>
<td>1592</td>
<td>1250</td>
<td>1600</td>
<td></td>
</tr>
<tr>
<td>No. of Rounds</td>
<td>39</td>
<td>55</td>
<td>60</td>
<td>40</td>
<td>64</td>
<td>62</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Crew</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Firing Height</td>
<td>1.849</td>
<td>1.89</td>
<td>1.88</td>
<td>-</td>
<td>n. a.</td>
<td>2.15</td>
<td>n. a.</td>
<td></td>
</tr>
<tr>
<td>NBC System</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>


Source: *Jane's Armour and Artillery*, 1997-98

The *Arjun* MBT exerts the least ground pressure among those of its class. It has comparable speed and its engine horse power is next only to the Abrams. Its fuel storing capacity is impressive, giving it a good range. Like all other modern MBTs, *Arjun* uses laser range finders, NBC system and night vision devices. Thermal imaging devices assist night vision. They are used in a tank’s fire control and surveillance systems in order to display a picture of the target on a television. A laser range finder helps determine the distance between the tank and a target, by measuring the time taken for light pulses to be reflected. It has an accuracy of five metres and a limit of ten kilometres. Modern day tanks use ballistic computers to assist tank gunnery by analysing the temperature, wind speed and range in order to reduce human
error as well as the time that slips from the sighting of a target to hitting it.

4.2.3 PROGRESS

Prototype Testing

The then Defence Minister, R. Venkataraman, announced in Parliament that the first prototype of the MBT was likely to be out in 1983\textsuperscript{96}. True to his announcement, it was ready in 1983. The second prototype was ready by 1984. Based on the technical evaluation of the first prototype, recommendations for improvements were made by the army and were incorporated into the third and fourth prototypes that were nearing completion in 1985\textsuperscript{97}. In its 1985-86 Annual Report, the Defence Ministry announced that the MBT has been formally named \textit{Arjun}\textsuperscript{98}. During this period, the Annual Report mentions, further prototypes were undergoing technical evaluation. During 1991-92, ‘fully integrated prototypes’ were subjected to ‘evaluation trials’. The tanks logged 4,500 k. m. in sandy deserts during summer. Mission reliability of 5,000 k. m. in 40 hours was “achieved without any major problem”, the Annual Report stated\textsuperscript{99}. The rifled gun, electro-hydraulic systems and integrated fire control system were tested, during 1991-92\textsuperscript{100}. The consistency of firing while the tank was stationary was ‘satisfactory’, the Report noted, accepting by implication that it was not ‘excellent’. The Report does not explicitly state if deficiencies in moving mode firing were discovered, but merely notes that the “fire control system was checked thoroughly to

\textsuperscript{96} \textit{Asian Recorder,} Vol. 28, no. 50, 10-16 December 1982, p. 16930.
\textsuperscript{97} MoD, \textit{Annual Report, 1984-85[} New Delhi, 1985], p. 73.
\textsuperscript{98} MoD, \textit{Annual Report, 1985-86, n. 44, p. 72.} \textit{In this Report, a picture of the \textit{Arjun} prototype was released, for the first time, with the caption: \textit{The pride of the Indian Army \textit{\textquoteright Arjun\textquoteright}—the Main Battle Tank (MBT).}}
\textsuperscript{99} MoD, \textit{Annual Report, 1991-92, n. 47, p. 72.}
\textsuperscript{100} \textit{Ibid.}
eliminate any deficiencies...”101. When the prototype trials of the tank were being conducted some of the crucial aspects that remained to be addressed were102:

1. The imported MTU engine encountered seizure above 40°C and had to be therefore improved;
2. The imported RENK transmission and tracks were yet to be proved;
3. The hydraulic suspension was found to be unreliable and it was recommended that it should be replaced by a ‘torsion bar version’;
4. The VHF communication system was not modern, which called for providing the tank with modern communication equipment;
5. The compatibility of the tank with other units of the army was yet to be demonstrated.

_Pre-production series_

By 1992, the project reached a considerably advanced stage. It was also decided by this time that efforts should be initiated to transfer the technology for manufacturing the tank to the production agencies. The user trials of six pre-production series (PPS), whose manufacture was in an advanced stage was planned for in 1992103. The pre-production series tanks were manufactured by Heavy Vehicles Factory (HVF), Bharat Earth Movers Limited (BEML) and Bharat Heavy Electricals Limited (BHEL)104.

During 1992-93, apart the two PPS tanks already handed over for extensive user trials—weapon system and automotive trials—the results of which, the Ministry claimed, were ‘highly satisfactory’,105 an additional four were under fabrication/integration to be sent for trials. That the development of the MBT reached

101 Ibid.


an advanced stage could be gauged from a casual, yet significant, piece of news. The
Chief of Army Staff (COAS), and later, the Defence Minister and the Minister of State
for Defence witnessed the accuracy and consistency of firing, along with Members of
Parliament—probably those on the Standing Committee on Defence.\textsuperscript{106} The designs
of the tank were ‘sealed’ after these trials. Though the Ministry claimed that the trials
were ‘highly successful’, a Report tabled two years later listed ‘ten basic imperatives’
for the tank after the summer trials of 1994\textsuperscript{107}. The extended troop trials of the tank—
with six PPS tanks—commenced in 1993, in the western sector, after the conclusion
of mobility and fire power trials in the Mahajan Ranges, Rajasthan.\textsuperscript{108}

During 1994-95, a total of nine PPS tanks were employed during the summer
trials in the desert, whose over all performance was noted to be satisfactory\textsuperscript{109}. However, further improvements needed to be carried out. Besides, four of the PPS
tanks were subjected to reliability tests in Jammu and Kashmir and the riverine areas
of Punjab.\textsuperscript{110} An additional nine PPS tanks were supposed to have been delivered at
intervals, beginning the first quarter of 1995, for trials\textsuperscript{111}. Most importantly, plans
were being laid for commencing series production.\textsuperscript{112} This leads one to surmise that

\textsuperscript{106} The demonstration conducted on 28 February 1993, which was termed ‘action trials’, included static
to static firing on targets located between 800 metres and 2.1 k. m., mobile to static firing, cross-
country run over an undulating desert terrain of 30° gradient, ditches, bunds, a small concrete
building through which the tank cut through, and a flat service high speed run at a speed of 74 k. m.

\textsuperscript{107} MoD, Annual Report, 1992-93, n. 55, p. 66 a.d Standing Committee on Defence (1995-96), Fifth
Report, n. 17, p. 25.

\textsuperscript{108} Asian Recorder, Vol. 39, no. 28, 9-15 July 1993, p. 23252 and Strategic Digest, Vol. 24, no. 2,
February 1994, p. 325.

\textsuperscript{109} MoD, Annual Report, 1994-95, n. 58, p. 39. As reported in Defense News (Washington), 2 July
1995, the firing rate was two hits for fifteen rounds fired. While the army suspected the accuracy
of the gun, DRDO officials questioned the skills of army gunners.

\textsuperscript{110} Ibid.

\textsuperscript{111} Ibid.

\textsuperscript{112} Ibid.
plans were being initiated in advance to reduce the gestation period between clearance for production and commencement of its production, because the development of the MBT reached a markedly high level; There were no more teething problems; improvements and or modifications remained to be carried out, though.

Amidst doubts expressed in the English language dailies by servicemen and journalists, trials of the pre-production series tanks continued beginning summer through winter, wherein automotive and weapon system tests posted ‘satisfactory’ results during summer, while weapon system trials during winter recorded ‘excellent’ results\(^\text{113}\).

On 9 January 1996, the then Prime Minister, Narasimha Rao, handed over the Arjun tank to the army, at a function in New Delhi, in the presence of the COAS\(^\text{114}\). Besides, plans were being made to induct Arjun into service during the Ninth Plan\(^\text{115}\).

Modifications and or improvements were carried out on the tank, during 1996-97, before limited series production activity would actually begin\(^\text{116}\), as the army was not completely satisfied with the performance of the tank. The then COAS, Gen. Roy Chowdhury, said, “Some weapon parameters needed to be further strengthened”\(^\text{117}\) and the DRDO was working towards that end. As of July 1997, user trials were

\(^{113}\text{MoD, Annual Report, 1995-96 [New Delhi, 1996], p. 54. These were perhaps the last trials of the pre-production series, intended in the main to remove misgivings about the tank’s performance. The trials were witnessed by senior army officers and the COAS.}\)

\(^{114}\text{Ibid. and Subramanian, n. 64, p. 15. Assurances were apparently sought by the DRDO from the COAS that the tank would be inducted, after the necessary fine tuning during the production phase.}\)

\(^{115}\text{MoD, Annual Report, 1995-96, n. 113, p. 54.}\)

\(^{116}\text{MoD, Annual Report, 1996-97 [New Delhi, 1997], p. 15.}\)

\(^{117}\text{Pioneer (New Delhi), 14 January 1996. He did not, however, indicate the systems that required to be further strengthened.}\)
completed, but reports were being prepared. However, improvements were carried out on the tank even after those trials.

Reportedly, plans are afoot to initially manufacture 120 *Arjun* tanks at CVRDE, Avadi. An estimated 40 to 45 tanks are planned to be produced every year. However, it was believed in 1993 that 126 tanks would be produced initially, to replace two armoured regiments. Owing to delays in completing the project, the year of initiation of series production has been revised several times. Induction of the tank should have commenced from late 1996/ early January 1997. A firm date regarding the induction of the *Arjun* MBT is not yet available. Meanwhile, the government has accorded sanction for the production of the tank.

4.3 LIGHT COMBAT AIRCRAFT (LCA)

4.3.1 *Features of the LCA*

The LCA is 13.2 m in length, 4.4 m in height and has a wing span of 8.2 m. It weighs nearly 5,000 k. g., which would enable it to take off from any of the existing runways in the country, including remote ones, thus, extending its effective range. It is a multi-role fighter capable of undertaking defence and strike roles. It is estimated that the LCA would fly at maximum speed of 1.6 mach and would have a service range.

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118 This was stated by Minister of State for Defence N. Somu in a reply to a question raised by Yerra Narayanaswamy. See *RSD*, 30 July 1997, Monsoon Session, Q. No. 821.


120 *Financial Express*, 18 February 1996.

121 *Asian Recorder*, Vol. 39, no. 12, March 19-25 1993, p. 22997. The difference of six tanks may, perhaps, be on account of a change in the number of tanks the army intended to hold as reserves.

122 *Indian Express* (New Delhi), 9 January 1996.


124 See interview with the then Air Chief, D. A. La Fontaine, *Hindustan Times*, 8 October 1986.
ceiling of 15,240 m\(^{125}\). The IAF visualises the LCA as its future workhorse and “would be dependent on [it] quite a bit in its long term requirement plans”\(^{126}\).

**Armaments**

Designed to carry Indian, Russian and Western missiles, the LCA would be able to carry modern, beyond the visible range missiles\(^{127}\). It can carry external weapons of weight equalling more than 4.5 tons\(^{128}\). The LCA would be equipped with two medium range missiles, having a range of at least 60 k. m. The DRDO intends to develop a medium range air-to-air missile Astra, which is now at the drawing board stage, for employing on the LCA\(^{129}\). Cluster bombs are likely to be deployed by the LCA for targeting troop concentrations and mechanised columns\(^{130}\). It is also equipped with the Russian GSH-23 twin-barrel guns, which can carry 220 rounds\(^{131}\).

**Engine**

The first few prototypes would fly with an imported General Electric F404-F2J3 engine. Orders for these were placed after an agreement was signed in Bangalore, between the ADA and General Electric, during the first week of October 1986, for the supply of eleven engines, their servicing, maintenance and spares\(^{132}\). The indigenous engine, Kaveri, is under development. Developing an advanced engine for an advanced aircraft is five to ten times more difficult than developing the airframe\(^{133}\), according to the first director general of Aeronautical Development Agency.

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\(^{126}\) See interview with the then Air Chief, S. K. Mehra, *Times of India*, 8 October 1988.

\(^{127}\) *The Hindu*, 1 November 1995.

\(^{128}\) Ibid.

\(^{129}\) *The Hindu*, 18 November 1995.

\(^{130}\) Ibid.

\(^{131}\) *The Hindu*, 1 November 1995.

\(^{132}\) See Hindustan Times, 10 October 1986.

\(^{133}\) Quoted in *The Hindu*, 1 December 1995.
(ADA)—the nodal agency for the LCA project. In 1995, two engines were being tested at the Gas Turbine Research Establishment (GTRE), Bangalore\textsuperscript{134}.

\textbf{Materials}

The LCA is made of aluminium-lithium alloys (27 per cent), titanium alloys (4.5 per cent), steel (4 per cent), carbon fibre composites (thirty per cent), and other materials (4.5 per cent)\textsuperscript{135}. The LCA incorporates composite wings and fly-by-wire-flight control system\textsuperscript{136}. Composites have several advantages and are widely being used the world over in aerospace industries. They offer a high strength-to-weight ratio, possess better toughness, have functional superiority, are easy to fabricate, have better durability and are less expensive to maintain. Additionally, as in the case of India, where manpower costs are low, they are relatively cheap to fabricate. A fly-by-wire system is a fully automated flight control system.

\textbf{Figure 4.1: Materials used in the LCA}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.1.png}
\caption{Materials used in the LCA}
\end{figure}


\textsuperscript{134} \textit{The Hindu}, 1 December 1995, quoting Dr. Kalam.


\textsuperscript{136} Ibid.
Foreign collaboration

Several foreign companies are providing consultancy to the LCA project\textsuperscript{137}. In the words of a former Air Chief, “It is something which we have designed ourselves, but with the collaboration of others who are already in the field, to fill the knowledge gaps we suffer from”\textsuperscript{138}. In this direction senior Indian officials held discussions with Northrop Corporation\textsuperscript{139}. During the Project Definition Phase ‘general consultancy’ was obtained from Ericsson, Sweden, and Marcel Dassault, France.\textsuperscript{140} The latter was drafted for consultancy in designing the fuselage. The Aeronautical Development Establishment (ADE) and Martin Marietta, USA, collaborated till May 1998 in the development of the flight control computer, air data, rate and acceleration sensors and actuators\textsuperscript{141}. Assistance is being sought from Ericsson Ferranti in the development of the multi-mode pulse doppler radar. Besides, Dowthy and Smith are providing assistance in the development of the Full Authority Digital Control (FADC) computer. The ejection seat has been bought off-the-shelf from Martin Baker of UK, while the ring laser gyro-based inertial navigation system is being imported from the USA\textsuperscript{142}. It is not known whether India followed up an Israeli offer to collaborate in the LCA project. The Israeli’s reportedly offered to assist in light weight weapon

\textsuperscript{137} These include companies from Germany, France, the UK and the USA.

\textsuperscript{138} See interview with the then Air Chief, D. A. La Fontaine, Hindustan Times, 8 October 1986.

\textsuperscript{139} The discussions centred around development work in progress at their plants and its relevance to some of the existing and proposed programmes in India. The officials included Dr. Arunachalm and LCA Project Director Harinarayana. They were scouting for the hardware for computer aided design (CAD) and computer aided management (CAM) systems.

\textsuperscript{140} News Time (Hyderabad), 15 October 1987.

\textsuperscript{141} The collaboration was terminated after the United States imposed sanctions on India in the wake of the latter having conducted nuclear tests.

\textsuperscript{142} The Hindu, 6 April 1995.
delivery system, composite material components, range finder, target designator laser, electronic counter measure (ECM) systems and counter ECM systems\textsuperscript{143}.

4.3.2 PROGRESS OF THE LCA PROJECT

India commenced research in various fields of aeronautics and aero-engines prior to the initiation of the LCA project. Among others, these included transonic compressor, aerodynamic of turbines, combustors, after combustion, blade cooling, cascade flow and catalytic ignition. It was indicated in 1980 that India was planning to indigenously develop an aircraft\textsuperscript{144}. Design and development of advanced technology gas turbine engine and a variant of the same up to demonstrator stage was pursued. The GTX demonstrator engine was run for several hours and further testing was in hand. It was then being considered for the LCA.

Being acutely aware of the challenge that lay ahead in developing an advanced gas turbine engine, a seminar on gas turbine engines was conducted in Bangalore, which was attended by Indian scientists and air force representatives, besides foreign experts, while actively considering the development of such an engine\textsuperscript{145}. The Defence Public Sector Undertaking (DPSU), Mishra Dhatu Nigam (MIDHANI) was brought into picture for the development of several special alloys required components of gas turbine engines\textsuperscript{146}. Pooling of the talent scattered within the country was initiated with the objective of designing, developing and manufacturing

\textsuperscript{143} The offer was reportedly made at the first ever 'Air Show' organised by India, in 1993. See Times of India, 20 December 1993.

\textsuperscript{144} MoD, Annual Report, 1979-80, n. 41, p. 51.

\textsuperscript{145} MoD, Annual Report, 1980-81, n. 42, p. 62.

\textsuperscript{146} MoD, Annual Report, 1981-82 [New Delhi, 1982], p. 62.
"a high performance aircraft to meet the requirements of the Indian Air Force in [the] 1990s". Drawing confidence from the successful experience of developing a 'demonstrator model' of an advanced gas turbine engine, a project was initiated for its 'full development and type certification', besides planning a by-pass variant of the same.

As a beginning, the Aeronautical Development Agency—an autonomous society—was formed for executing the project. During 1984-85, wind tunnel tests of models, whose preliminary configuration was made, were commenced. Important decisions seem to have been made by the first half of 1986. Apart from completing the feasibility study and commencing project definition, the Air Staff Requirement was finalised. Seemingly, several options were weighed regarding the engine, before the choice went in favour of evolving a variant of the GTX engine for the LCA.

During 1987-88, project definition was undertaken by seeking consultancy from Dassault, configuration studies of aerodynamics, structural analysis and design were in progress and a GTX prototype engine was tested for its complete design thrust.

By 1992 work began on design and development of the composite wing, avionics packages, flight-control system, environment-control and the mission computer, besides initiating 'exhaustive plans' to indigenously produce three quarters of the

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148 Ibid., pp. 61-62.
150 MoD, Annual Report, 1985-86, n. 44, p. 71. The decision seems to have been taken after considering modifying the performance of already available engines. Ultimately, it was decided that a variant of the indigenous GTX engine, prototype testing of which was already in progress, would be fitted to the LCA.
materials required for the LCA\textsuperscript{152}. Preliminary work on the indigenous \textit{Kaveri} engine was completed. This included constructing the layout of the core engine \textit{Kabini}, engineering drawings for long cycle components and ‘technical design audit’ of high pressure turbine and rotor dynamics\textsuperscript{153}.

The Annual Report of the Ministry of Defence for the period 1992-93 outlined the progress of the project. This included\textsuperscript{154}

- Aerodynamic configuration of LCA has been frozen;
- Development of flight control laws was in progress;
- Indigenously developed communication equipment and mission computer have been put to ‘rigorous tests’;
- Carbon-fibre-composite (CFC) wing has been designed;
- Development of flight control system was in progress, after finalising the requirements;
- Detailed design of under carriage, wheels and brakes, cold air unit of environment-control system aircraft-mounted gear box and brake management system has been completed, and their fabrication has commenced;
- Advanced computational facilities for design, analysis and optimising studies have been established and the wind tunnel has been upgraded.
- Further progress has been achieved in the development of the indigenous \textit{Kaveri} engine. Detailed production drawings and test specifications of the engine have been finalised, besides having reached the development testing stage of the gear box and made further progress in the development of the (FADC) for the engine.

During 1994-95, the major work of the fuselage has been completed, the structure of flight control laws were evaluated in real time stimulators and the hardware and initial

\textsuperscript{152} MoD, \textit{Annual Report, 1991-92}, n. 47, p.69.

\textsuperscript{153} Ibid, p. 70. It is interesting to note the name given to the engine and the core engine. \textit{Kaveri} is the chief river that flows through Karnataka, while \textit{Kabini} is its tributary. The work on the engine is in progress at GTRE, Bangalore, in the south Indian state of Karnataka.

\textsuperscript{154} MoD, \textit{Annual Report, 1992-93}, n. 55, p. 65.
software for FADC was developed\textsuperscript{155}. A prototype of the *Kaveri* engine and the *Kabini* core engine was assembled and their testing was being planned\textsuperscript{156}.

A significant milestone in the LCA project was reached in late 1995, when the LCA Technology Demonstrator-1 (TD 1) rolled out in Bangalore in the presence of the Prime Minister, the Chief of Air Staff, Dr. Kalam and Dr. Kota Harinarayana, the project Director. The aircraft project reached a stage where it could be put to integration tests on the ground, before being cleared for its first flight trial\textsuperscript{157}. 'Roll out means a completely equipped aircraft, encompassing all the sub-systems, on which integration checks and tests would be conducted. Several technologies/systems were developed indigenously, culminating in the roll out of TD 1. These include design and development of Carbon Fibre Composite (CFC) wings, co-bonded co-fused fins, composite rudder, CFC panels and doors, carbon brake discs, 32 bit computers, micro processor-based electronic controllers for health monitoring, jet fuel starter for starting the engine, FADC computer, flight control laws and avionics software\textsuperscript{158}.

During 1995-96, the *Kaveri* engine was developed and tests commenced. The digital electronic control unit was integrated with the engine and ‘certification of materials’ that are intended to be used for manufacturing the engine was at an advanced stage\textsuperscript{159}.

\textsuperscript{156} Ibid.
\textsuperscript{157} The LCA integration tests include ground resonance test and structural coupling and integrated system checks.
\textsuperscript{159} Ibid., p. 54.
During 1996-97, the flight control laws were 'successfully flown' on an American F-16, in the USA, where they were reportedly acclaimed as being superior to those of the F-16's, while the indigenous development of fly-by-wire flight control system was in progress\textsuperscript{160}. Flight control laws are meant to keep the aircraft on course, in spite of turbulent weather, even as the pilot immerses himself in combat. The \textit{Kaveri} engine and \textit{Kabini} core engine were undergoing development tests. Besides, integration checks were carried out on the LCA. As part of the integration checks ground resonance tests and structural coupling tests were conducted; the integrated testing of the avionics in a dynamic mode with flight-standard software were undertaken during 1996-97\textsuperscript{161}. During the same time, the Project Definition Phase of the naval version of the LCA and the assembling of the LCA Technology Demonstrator-2 (TD-2) was also undertaken. During 1997-98, the LCA was nearing a stage where final systems checks leading to engine ground run could be undertaken\textsuperscript{162}. Recently the LCA completed taxi trials during which airframe, dynamic stability and co-ordination of the engine control system have been tested and would be ready for the first flight test\textsuperscript{163}.

To sum up, all the projects have fallen behind schedule. In the IGMDP, the \textit{Prithvi} missile alone has been produced and delivered to the army. \textit{Agni} version –I has been developed and tested and version–II was test-fired in 1998. The missile is yet to be cleared for production. The \textit{Nag} ATGM has completed most of the tests and

\textsuperscript{160} Annual Report, 1996-97, p. 56 and The Asian Age, 6 September 1996.
\textsuperscript{161} Ibid.
is to be cleared for production shortly. The other two missiles—Akash and Trishul—are in various stages of trials.

The Arjun MBT project was initiated in March 1974. The tank was formally handed over to the army in January 1996. Improvements were carried out on the tank as per the suggestions of the Joint Planning Group and the tank was subjected to trials. Meanwhile, sanction has been accorded for the production of the tank\textsuperscript{164}. However, information is as yet not available if production has actually commenced.

The LCA project is at least six years behind schedule. The first flight test is due, which might be conducted any time now. Table 4.5 tabulates the exiting status of the three projects selected for the study.

### Table 4.5: Project Status

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Project</th>
<th>Year of Initiation</th>
<th>Projected Year of Completion</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Prithvi</td>
<td>1983</td>
<td>1995</td>
<td>Series production</td>
</tr>
<tr>
<td>1c</td>
<td>Akash</td>
<td>1983</td>
<td>1995</td>
<td>Flight Trials</td>
</tr>
<tr>
<td>1d</td>
<td>Trishul</td>
<td>1983</td>
<td>1995</td>
<td>Flight Trials</td>
</tr>
<tr>
<td>1e</td>
<td>Nag</td>
<td>1983</td>
<td>1995</td>
<td>Tests almost complete. About to be cleared for production</td>
</tr>
</tbody>
</table>

\textsuperscript{164} MoD, Annual Report, 1998-99 [New Delhi, 1999], p. 58.