INDIA'S BALLISTIC MISSILE DEFENCE

ARJUN SUBRAMANIAN P

According to a DRDO press statement on November 23, 2012, it successfully tested the indigenously developed Ballistic Missile Defence (BMD) system.[1] After the test DRDO officials claimed that the system will be ready for deployment by 2014.[2] Already, India's BMD project has created ripples in Pakistan. In response to India's pursuit of missile defences, Pakistan has expanded its countermeasure efforts, primarily through development of manoeuvring re-entry vehicles.[3] The Pakistan Army Strategic Force Command, which controls Islamabad's ballistic missiles, has since at least 2004 said it wanted to develop such warheads; analysts now believe these are in service.[4] Moreover, Pakistan continues to increase its inventory of nuclear weapons' land vector by citing India's BMD claims as a destabilising factor.[5] In addition to this, China has an advanced nuclear and ballistic missile programme. What is more worrisome is the clandestine nuclear and ballistic missile cooperation between China and Pakistan. Against this backdrop, this paper attempts

Arjun Subramanian P is a Research Associate at the Centre for Air Power Studies, New Delhi.

1. Air Defence Interceptor Missile Successfully Destroys Ballistic Missile, MoD, Press Information Bureau, Govt. of India, November 23, 2013. Available at: http://pib.nic.in/newsite/erelease.aspx?relid=61315
2. Rajat Pandit, "India tests missile shield, DRDO says it will be operational by 2014," *The Times of India*, November 24, 2012.
3. Usman Ansari, "Pakistan Seeks to Counter Indian ABM Defences," *Defence News*, March 21, 2011.
4. Ibid.
5. Pravin Sawhney, "India's Ballistic Missile Defence capability is grossly exaggerated," DNA, April 4, 2011.

to analyse and find out the actual effectiveness of the BMD system based on the parameters of the tests conducted so far. Apart from the main focus area of this paper, which is divided into six parts, it will also briefly look at the nuclear threat scenario, characteristics of Chinese and Pakistani ballistic missiles, challenges in intercepting a ballistic missile, a few recommendations for improving the defence against ballistic missiles followed by a conclusion.

THE NUCLEAR THREAT SCENARIO

In no other part of the world are there three nuclear armed countries sharing land borders with each other.[6] More importantly, India is the only nation to share land borders with two nuclear armed states with which it has serious territorial disputes and other security issues, and one among them (Pakistan) has a First Use policy. Pakistan has never declared a No-First-Use (NFU) and on several occasions threatened to use nuclear weapons (first strike) against India or Indian forces in its territory. Pakistan is using its nuclear weapons capability as a hedge to continue its policy of bleeding India with a thousand cuts through proxy war. In other words, Pakistan is using its nuclear capability as a safeguard against any punitive conventional offensive from India in retaliation to any of its state-sponsored terrorist activities. This nuclear safeguard proved its effectiveness in the 2001–2002 crises which followed the December 2001 terrorist attack on the Indian parliament. Among other reasons, Pakistani threat to go on a nuclear first strike would have been a strong influencing factor on India's decision not to cross the border. This is evident from the fact that India's new war doctrine, termed now as the "proactive strategy," and which was earlier called as the "Cold Start," has been formulated keeping in mind not to cross the Pakistani nuclear threshold.

China which has a stated policy of NFU has very recently created a great deal of ambiguity and concern by not mentioning about a NFU in

6. Pakistan shares a land link with China through the occupied part of Kashmir controlled by it.

its recent defence white paper.[7] However, Colonel Yang Yujun, a spokesman for China's Ministry of Defence, clarified on this question unambiguously during a briefing on April 25, 2013 when he stated: "China repeatedly reaffirms that it has always pursued no-first-use nuclear weapons policy, upholds its nuclear strategy of self-defence, and never takes part in any form of nuclear arms race with any country. The policy has never been changed. The concern about changes of China's nuclear policy is unnecessary."[8] Yet there is a possibility that China is rethinking on its NFU policy largely due to the improving US conventional precision strike capability and BMD efforts. Nevertheless, ambiguity, particularly in nuclear weapons employment doctrine, is more dangerous than a clearly stated First Use policy.

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Pakistan and China have an advanced ballistic missile programme which was developed primarily for delivery of nuclear weapons. China has the longest and the most advanced ballistic missile programme in Asia after Russia. A recent report of the US National Air and Space Intelligence Centre (NASIC) says that "China has the most active and diverse ballistic missile development programme in the world." It further states that, "It (China) is developing and testing offensive missiles, forming additional missile units, qualitatively upgrading missile systems and developing methods to counter ballistic missile defences. The Chinese ballistic missile force is expanding in both size and types of missiles."[9] China has developed and deployed various versions of ballistic missiles like the short range DF-

7. James M. Acton, "Debating China's No-First-Use Commitment: James Acton Responds," *Proliferation Analysis*, Carnegie Endowment, April 22, 2013. Available at: http://carnegieendowment.org/2013/04/22/debating-china-s-no-first-use-commitment-james-acton-responds/g0lx
8. Hui Zhang, "China's No-First-Policy Promotes Disarmament," The *Diplomat*, May 22, 2013.
9. "Ballistic & Cruise Missile Threat," National Air and Space Intelligence Center, 2013. Available at: http://www.fas.org/programs/ssp/nukes/nuclearweapons/NASIC2013_050813.pdf

11, DF-15 and DF-18. Very recently China inducted another Short Range Ballistic Missile (SRBM)–DF-12, which reportedly is a copied version of the Russian Iskander missile. In the Medium Range Ballistic Missile (MRBM) category, China has three to four versions of DF-21s among which the DF-21C has a very high Circular Error Probable (CEP) of around 30m which indicates that it would be largely used for conventional strikes. The DF-21D is an anti-ship version designed to target large ships like aircraft carriers. The rest of the DF-21 versions could be for nuclear strikes.[10]

Pakistan, a recipient of covert nuclear and missile technology transfer and assistance from China also has advanced variants of ballistic missiles in their inventory.[11] Its nuclear doctrine and strategy is *wholly and solely India-centric,* designed to address perceived conventional and nuclear threats from India. Consequently, the nature and function of the Pakistani nuclear deterrent (including delivery mechanisms), as also its rules of employment and deployment, are all tailored to meet this one requirement.[12] Added to this there is also a danger of the Pakistani nuclear weapons falling into the hands of Islamic radicals either within the state institution or outside. The attack on Pakistan Naval Station (PNS) Mehran is an example where the terrorist attack is believed to have taken place with insider help. It is also believed that the base is a storage site for Pakistani nuclear arsenal.[13] Moreover, if Pakistan deploys its tactical battlefield nuclear missile *Nasr*, which by its nature should have a decentralised command and control, then the possibility of radical elements gaining access to the tactical nuclear weapons are high, leading to possible unauthorised use.

CHARACTERISTICS OF PAKISTANI AND CHINESE BALLISTIC MISSILES

All the Pakistani ballistic missiles are solid fuelled except Ghauri 1 & 2

10. The CEP of other DF-21 versions other than DF-21C and DF-21 D are comparatively large and hence could be used for nuclear delivery, while the more accurate ones will be suitable for conventional precision attacks.
11. Duncan Lennox, *Jane's Strategic Weapons Systems* (Surrey, UK, 2011), issue 55.
12. Manpreet Sethi, *Nuclear Strategy: India's March Towards Credible Deterrence* (KW Publishers Pvt. Ltd.), chapter 2, p. 45.
13. Kelsey Davenport, "Militants Attack Pakistani Base," *Arms Control Today*, September 2012.

and the Chinese are rapidly replacing all their liquid fuelled SRBM with solid fuelled missiles and their MRBM, Intermediatory Range Ballistic Missiles (IRBM) and two variants of their Inter Continental Ballistic Missiles (ICBM) (DF-31 and DF-41) are solid fuelled.[14] Solid fuel means—longer storage time, easy maintenance, lesser launch preparation time and better mobility. All these missiles are carried in Transporter Erector Launchers (TELs) and are road mobile, the launch preparation time is shorter from the time of arrival at a pre-surveyed launch site and the accuracy has improved greatly. All these aspects complicate the targeting problem, i.e., targeting the missile before it is launched. Most of these missiles have separating warheads that separate either after burn-out or before re-entry and hence present a more difficult target, i.e., very low Radar Cross Section (RCS). Moreover, in most of their missiles the payload section has either rocket motors or control surfaces for improving accuracy. In addition to that the reaction control motors could also be used to manoeuvre the re-entry vehicle to evade the defences.

The function of a ballistic missile defence system is the same as any other Surface to Air Missile (SAM) system but the characteristics of the function changes because the physical qualities of a ballistic missile target differ from other air vehicles. The primary difference is the velocity and the RCS of the ballistic missile (warhead). The velocity is several times higher (from high supersonic to very high-hypersonic) and the RCS is very small.

CHALLENGES IN INTERCEPTING BALLISTIC MISSILES

The function of a ballistic missile defence system is the same as any other Surface to Air Missile (SAM) system but the characteristics of the function changes because the physical qualities of a ballistic missile target differ from other air vehicles. The primary difference is the velocity and the RCS of the ballistic missile (warhead). The velocity is several times higher

14. Duncan Lennox, *Jane's Strategic Weapons Systems* (Surrey, UK, 2011), issue 55.

(from high supersonic to very high-hypersonic) and the RCS is very small. The velocity of a ballistic missile re-entry vehicle varies depending on the burn-out velocity, range, trajectory, re-entry angle and ballistic coefficient. Normally, a re-entry vehicle of an SRBM with a range of 500 km and an ICBM with a range of 10,000 km has re-entry velocity of Mach 6 and Mach 23 respectively.[15]

The challenge in intercepting a ballistic missile compounds if the attacker employs countermeasures to confuse the defences. A BMD system usually looks for certain characteristics of a ballistic missile to find, track and intercept it and these characteristics are the usual trajectory of the missile, the warhead shape and its radar and optical (infrared and visible region of the spectrum) signature. The first step in the process of intercepting a ballistic missile is to detect it and second is to identify the detected object as a threat and here is where the attacker could use countermeasures by manipulating the signature of the missile to deceive the defence system.

The attacker could manipulate the signature of the re-entering warhead and prevent the defence fire control system from recognising it as a threat. This can be done by deploying decoys that resemble the target (simulation) or the signature of the actual warhead could be manipulated to make it appear and behave like the decoys (anti-simulation).[16] Anti-simulation is an effective technique. One anti-simulation strategy would be to enclose the nuclear warhead in a metallised mylar balloon. This would be released along with a large number of empty balloons. Because the radar waves can pass through the thin metal coating, the radar cannot determine what was inside each balloon. To counter IR sensors the temperature of the balloon could be controlled be employing a small heater.[17] Alternatively the attacker can conceal the nuclear warhead in a shroud made of thermal multi-layer

15. Jurgen Altmann, "Tactical Ballistic Missiles" in *SDI for Europe?: Technical Aspects of Anti-Tactical Ballistic Missile Defences*, RIF Research Report 3/1998, September 1998, p. 32.
16. US Congress, Office of Technology Assessment, Ballistic Missile Defence Technologies, OTA-ISC-254 (Washington DC: US Government Printing Office, September 1985), chapter 7, p. 163.
17. Andrew M. Sessler, "Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defence System," Study group organised by the Union of Concerned Scientists and the Security Studies Programme at the Massachusetts Institute of Technology, p. 44.

insulation and release it along with a large number of empty shrouds.[18]

Apart from these measures, other countermeasures could also be employed where the re-entry vehicle could carry a jammer to jam the tracking radar or release chaffs to create a radar clutter. Chaffs are conducting wires that are cut to a length that maximises its radar reflections, which is one half the radar wavelengths. Hence, chaff cloud could hide the warhead from the radar. Since just one pound of chaff could contain millions of chaff wires, the attacker could deploy numerous chaff dispensers that would create many chaff clouds, only one of which would contain the warhead.[19] Countermeasures could also be employed by changing the trajectory of the missile by either depressing or lofting it, though a significant amount of range and/or payload have to be sacrificed which depends on the apogee selection. For example, the Shaheen II IRBM which has a maximum range of 2,500 km can be launched in a shaped trajectory to hit Delhi from somewhere in Baluchistan, from where the range to New Delhi would be around 1,000 km.[20]

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A BMD Fire Control System (FCS) observes the usual trajectory of a ballistic missile to identify it as a threat. Shaping the trajectory confuses the FCS and the threat might be ignored by it resulting in not firing the interceptors. Besides, a shaped trajectory has other advantages, wherein, a missile fired in a depressed trajectory reduces the reaction time of the

18. Ibid., p. 44.
19. Ibid., pp. 44-45.
20. Range measurement done using the ruler tool in Google earth application. The approximate value was scaled from the eastern region of Baluchistan, Pakistan to Delhi, India.

defences as the flight time is much lesser and the ones whose trajectory has been lofted re-enters with higher velocity and at steeper re-entry angles and hence lesser flight time from re-entry to impact compared to when launched in a minimum energy trajectory. The most likely missile Pakistan could choose for a shaped trajectory launch for a nuclear strike against New Delhi would be the Shaheen II. However, it has to be noted that for achieving extreme shaped trajectories the missile needs some modifications. It is not known if China and Pakistan have prepared their missile for such a role. Nevertheless, it is always better to prepare the defences to counter any type of threat. Other countermeasures include, using a Manoeuvrable Re-Entry Vehicle (MARV), overwhelming the defence by saturating it with multiple warheads either by Multiple Independently Targetable Re-Entry Vehicle (MIRV-ing the missiles), employing cross-targeting, or going for salvo launches.

INDIAN BALLISTIC MISSILE DEFENCE SYSTEM

The trigger for the Indian BMD programme was the Pakistani acquisition of M-11 missiles from China.[21] The Indian BMD programme was initiated in 1995[22] and the first successful test firing was conducted in 2006. There were a total of eight test firings so far and only the fourth test was aborted as the target missile deviated from its path, while the other seven tests were successful.[23] This is a remarkable achievement considering that only five countries have demonstrated successful interception of ballistic missiles. The last test in November 2012 was significant from previous tests as two targets were engaged simultaneously, though one was a simulation. Nevertheless, we have to look at what DRDO has actually demonstrated and what remains to be proved and improved.

ANALYSIS OF THE SYSTEM

In all tests, the Prithvi missile was used as the attacker missile which simulated the trajectory of a 600 km range missile. It was reported that, in

21. Pravin Sawhney, "Games DRDO Plays," *Force*, April 4, 2011.
22. Ibid.
23. http://idp.justthe80.com/missiles/ballistic-missile-defense-bmd-system

the last test, the apogee of the attacker Prithvi was increased to 110 km from its normal apogee of 40 km.[24] This missile has an actual range of 350 km. Despite the fact that the Prithvi's trajectory was altered to simulate a missile with a longer range it does not mimic a longer range missile as claimed for two reasons. Firstly, the re-entry velocity of the attacker Prithvi was very low. Though DRDO claims to have increased the re-entry velocity by adding additional boosters, it is not clear if it attained the required velocity to mimic a longer range missile. However, reports in the media mentioned the interceptor (Advanced Air Defence [AAD]) speed as Mach 4.5 and the closing speed, before interception, as 2 km/sec.[25] The specified interceptor speed should be the average value because observation of the test video shows that the interceptor is at its coast phase at the time of impact during which the speed would be slightly lower than the average speed. So even assuming the interceptor speed to be half of the given closing speed the velocity of the target would be approximately Mach 3 which is still low compared to the re-entry velocity of a 500 km range missile with a ballistic coefficient of 1,000 lbs/ft^2 which would be around Mach 6.[26] Moreover, the ballistic coefficient of the Prithvi could be lower than the above considered value due to the larger surface area of the re-entry body unlike that of a separating warhead.

Secondly, the warhead does not separate from the body of the missile which makes it a large target for both ground-based radar and the radio frequency seeker to acquire and track. In the Pakistani M-9, M-11 and other Chinese missiles with ranges up to 2,000 km the warhead separates from the missile body. According to *Jane's Strategic Weapons System*, the warhead of the M-9 and M-11 separates either after burnout or before re-entry.[27] So in a real scenario the system has to confront a target with much higher re-entry velocity and small radar cross-section. The performance of the BMD system under these conditions has not been proven so far. But the unfortunate fact

24. Ajai Shukla, "Anti-Ballistic Missile Defence: Star Wars Over India," *Business Standard*, December 1, 2012.
25. Ibid.
26. Herbert Lin, "Rationalized Speed/Altitude Thresholds for ABM Testing," *Science and Global Security*, 1990, vol. 2, p. 91, figure 2.
27. Duncan Lennox, *Jane's Strategic Weapons Systems* (Surrey, UK, 2011), issue 55.

Out of the eight tests conducted so far only two were exo-atmospheric, the rest were endo-atmospheric. In none of the first seven tests were both the interceptors fired simultaneously to evaluate the overall system performance. Only in the last test were two attacker missiles simultaneously engaged, though one was an electronic simulation.

is that India, at present, does not have any other missile without these drawbacks in this range that could be used as a target.

A 2,000 km range ballistic missile, launched in the usual minimum energy trajectory, will have a re-entry velocity of around 4 km/sec[28] even at an altitude of 15 km, which means that the velocity is more than Mach 10. As discussed above the system has not been tested against a target with such velocity. Hence the capability of the system to perform under this condition is yet to be proved. Since the AAD missile has the required speed (Mach 4.5) to intercept a re-entry vehicle re-entering at the velocity of a 2,000 km range missile, the primary objective of the test should be to evaluate the performance of the various guidance systems (command guidance, onboard INS and the radio seeker) and the control systems against a ballistic target (separating warheads) re-entering at an actual velocity of missiles with the specified range.

Out of the eight tests conducted so far only two were exo-atmospheric, the rest were endo-atmospheric. In none of the first seven tests were both the interceptors fired simultaneously to evaluate the overall system performance. Only in the last test were two attacker missiles simultaneously engaged, though one was an electronic simulation. The electronically simulated target had a range of 1,500 km and was successfully intercepted by an electronically simulated interceptor at an altitude of 120 km.[29] Dr. Avinash Chander, the then Chief Controller (Missile and Strategic Systems), DRDO cited range limitations and geometry for not using an actual missile

28. N. 26.
29. T. S. Subramanian, "Interceptors' Success—Real and Simulated," *The Hindu*, November 24, 2012.

with a 2,000 km range.[30] This is an acceptable reason, but at the same time, claiming that the last test has fully proved the robustness of the system cannot be accepted, unless tested under a realistic scenario. Moreover, the type of the electronically simulated interceptor is not known. Dr. Ajai Shukla, in his article, had mentioned that the simulated interceptor is an AAD.[31] The AAD is designed only to engage targets at an altitude of 30 km but the reported electronic interception altitude was 120 km, so the electronically simulated interceptor could be the Prithvi Defence Vehicle (PDV), which is said to be the deployment variant of the BMD system. The PDV will be a two stage solid fuelled missile capable of intercepting targets at an altitude of 150 km while the earlier variant, the PAD, can only engage targets at an altitude of 80 km. More exo-atmospheric interception tests should also be done to validate the overall performance of the system, as an effective upper layer defence would reduce the burden for the lower tier. Exo-atmospheric interception is more challenging than endo because the velocity of the re-entry body suffers a sharp decline from an altitude of 20 km[32] due to a denser atmosphere which increases the drag coefficient per unit area, thereby reducing the ballistic coefficient. Additionally the sensors will have to encounter and discriminate decoys (if employed by the attacker) and missile debris at exo- atmospheric altitudes.

The current interceptor uses a radar seeker for terminal guidance. The next test will reportedly include a dual seeker (both radar and an electro-optical seeker) for terminal guidance.[33] An optical seeker will have better target acquisition capability, particularly for low tier defence as the re-entry vehicle will be clearly visible as it would get heated due to friction while travelling down the atmosphere. This would enhance the probability of interception.

The main components of the Indian BMD system are the Long Range Tracking Radar (LRTR), Fire Control Radar (FCR), and the two interceptors—

30. T. S. Subramanian, "Real Time Trial of Interceptors and Simulated Missiles," *The Hindu*, November 22, 2012.
31. N. 24.
32. N. 26.
33. Ajai Shukla, "Prithvi Defence Vehicle test: 'Enemy' ballistic Missile to be downed in space next month," *Business Standard*, December 3, 2013. The test that was planned for January 2013 never happened.

AAD for endo-atmosphere and the PDV for exo-atmospheric interception. Except the interceptors, all the other components are developed with foreign assistance. However, the radar seeker for the interceptors was developed with Russian assistance.[34] The LRTR for example, is a modified version of the Israeli Green Pine radar in which the range has been increased to 600 km. The Green Pine radar can track a target travelling at a maximum speed of 3 km/s[35] (Mach 10), the same data is not known for its modified version (Sword Fish). If the value is the same, the radar cannot track an IRBM with a 2,000 km range which normally has a re-entry velocity of 4 km/sec. The fire control radar which provides command guidance for the interceptor is based on the Thales Multi-function Fire Control radar. DRDO needs to build capability to develop core technologies for these crucial components in the future. Having the capability to build core technologies would enable perfecting, upgrading and enhancing and building future systems.

DRDO has announced major changes to the interceptor and the target missile in the next test.[36] New exo-atmospheric interceptor, as discussed earlier, will have a dual terminal sensor and can climb to an altitude of 150 km. The target missile would also be a new missile—a boosted (to increase terminal velocity) two stage version of the Dhanush missile. It will also feature a new pulse motor, which will provide surges of propulsion during the missile's later stage, increasing its manoeuvrability when very close to the target. This attacker missile would be launched from a ship positioned 300-350 km from the interceptor location reaching an apogee of 150 km. With these improvements, which according to the DRDO chief, the target missile would mimic the *actual* terminal conditions of a 1,500 km class ballistic missile. Along with this, six more electronic interceptions, would also be attempted, both endo- and exo-atmosphere.[37] A test conducted under these conditions would comparatively pose a tough challenge to the BMD system.

34. http://www.globalsecurity.org/wmd/world/india/bmd.htm
35. http://www.radartutorial.eu/19.kartei/karte405.en.html
36. This test was supposed to be conducted in January 2013. However, the test has not been carried out till date.
37. n. 33.

RECOMMENDATIONS

- The Prithvi variants must be replaced with *solid fuelled* SRBMs with separating *warheads with higher re-entry velocity*. This will have two benefits; firstly, it would make it available for testing the real effectiveness of the BMD system. Secondly, it would provide a more reliable and survivable nuclear delivery vehicle that would have shorter launch preparation time and better mobility. Prithvi is reported to have a launch preparation time of two hours and also needs more than ten support vehicles which will make it easy for the enemy to detect and target.[38]
- At present, endo-atmospheric interceptions have taken place within 15 km altitude. The interception altitude should be increased giving the system more time allowing for kill assessment and to fire another round if needed. Faster processors and better algorithm might be needed to perform this in real time. A high altitude interception would also be the best protection if the system is deployed to protect soft targets such as population centres.

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- New long-range wideband X-band radar have to be developed. For terminal ballistic missile defence systems the decoy-warhead discrimination is not needed much as the lightweight decoys would slow down and burn during re-entry. However, in case of SRBMs with a separating warhead and apogee within the atmosphere, the booster after stage separation continues along its trajectory and may come into the radar's Field of View (FOV)[39] which complicates its task in discriminating. It further gets complicated if the stage is exploded to create a chaff effect.[40] Hence, high frequency wideband radar would be more efficient in discriminating the warhead from other objects in its FOV.

38. n. 27.
39. Altmann, n. 15, p. 136.
40. Ibid.

Normally ballistic missile defence radar solid angle is optimised for ballistic missiles launched in minimum energy trajectory. To cater for ballistic missiles launched in lofted and depressed trajectories, multiple radars each with different solid angles should be employed. Handover procedure could be incorporated to keep the data fed to the fire control system within the optimum limit.

- One other use for high frequency radar would be to see through the nuclear cloud created by a masking high altitude atmospheric nuclear explosion the enemy might employ to aid the penetration of the forthcoming strikes, which even S-band radar can perform. However, to increase the probability of intercept, long-range X-band radar netted to the other sensors and systems in the BMD architecture will enable the discrimination of warheads from decoys and other missile debris and track the actual warhead from the mid-course phase itself, providing longer reaction time for the terminal defences, i.e., this would relieve time pressure for the terminal defence systems by allowing it to be prepared to engage the target much earlier. For enhancing the robustness of the system, the mid-course tracking system should be independent of the terminal defence sensor systems. This would also be a stepping stone for building a mid-course interception system for future. An effective mid-course defence system would reduce the burden for the low tier systems providing a better defence.
- Further increase in radar power aperture product would increase the reaction time for the defence system. Along with this the kill probability could be further increased by improving the burn rate performance of the interceptors. Both these improvements would also increase interception altitude resulting in the increase of the defended footprint.
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procedure could be incorporated to keep the data fed to the fire control system within the optimum limit.

- To perfect, improve and fine-tune the system to defend against potential ballistic missile threats, information on the enemy ballistic missile signatures will be enormously helpful. Enemy ballistic missile tests have to be monitored electronically by using long-range wideband high frequency radars and other space based radar and optical sensors which will provide us with a library of signatures of the enemy ballistic missiles. For example the wideband signal returns can be used to obtain a wide variety of target details by using various methods of analysis. Micro-Doppler method can also be employed by using time-frequency analysis to obtain target details like the shape of the target which can also be used for real time Decoy-Warhead discrimination by using the data in the algorithm of the Fire Control System.
- In the present interceptors, fragmentation warhead is employed which is detonated using a Radio Proximity Fuse (RPF). The attacker could harden the re-entry vehicle with additional protective layers to counter this which would ensure that the nuclear warhead inside remains intact. Hence the interceptor should have Hit-to-Kill capability to ensure the complete destruction of the payload.
- Defence against ballistic missile is not only intercepting the missiles after it is launched but the missile also could be destroyed on the ground during launch preparation once it is detected. India has highly accurate supersonic cruise missiles that could be used to destroy the launcher before the hostile missile takes off. India has acquired the Israeli Phalcon Airborne Warning and Control System (AWACS) system and is also in the process of testing the indigenous AWACS system. India also has radar and optical imaging satellites for surveillance. These additional resources should be harnessed to enhance the ability to defend against missiles. These AWACS and satellites can be integrated within a broader missile defence architecture. Defence against ballistic missiles has to be an integrated effort done using multiple methods and at various levels.

- Parallel development of the next phase of the BMD system would help in perfecting the Phase I systems from the experience gained. Once the reliability of the Phase I system is proved after repeated testing under realistic conditions, which should be monitored and certified by an independent and competent body consisting of, but not restricted to personnel in the technical branch of the armed forces and the intended users, it can be put before the government to decide on deploying the system.
- Multiple tests have to be done putting the system under various stressful scenarios, at various weather conditions and operating it for longer duration before deployment. The accuracy of the Patriot system for example was found to be reducing when operated for longer duration. During the first Gulf War, on February 25, 1991, a Patriot battery, charged with protecting Dhahran Air Base, had been running for 100 hours consecutively, and failed to detect the incoming Iraqi Scud.[41] The system should also be tested under a clustered air environment to check its ability to discriminate between the actual target and other objects in its view. There are bitter incidents of friendly fire during the Gulf War where the Patriots shot allied aircraft killing three pilots. The reason was that the Patriot radar was stumped by the cluttered air picture in theatre.[42] The BMD system should not be operated in isolation, it has to be netted with other sensors to have a better situational awareness to avoid friendly fire.
- Looking to the long term, government should initiate policies that would enable the creation of better industrial infrastructure for DRDO enabling it to develop core technologies that could cater for the future technological needs of the country.

41. Victoria Samson, *American Missile Defence: A Guide to the Issue* (California: Praeger, 2010), chapter 6, p. 100.
42. Ibid., p. 105.

CONCLUSION

In view of the various shortcomings in the tests, it would be a wiser choice for the government to decide against deploying this system in the present condition. Instead, DRDO should be directed to improve the system and test it under realistic conditions. What has been demonstrated so far was done in a controlled environment and all the tests were highly scripted. As far as indigenisation is concerned, it is quite evident that there is a huge gap in the capability to develop core technology and complex components, particularly in the design and development of sensors (both radar and optical). To start with, a strong technological foundation and better infrastructure is required to build this capability.

In the race between offence and defence, at present, offence remains at an advantageous position in terms of technological complexity and cost. Penetration aids for ballistic missiles are relatively simpler to develop and employ than countering and shooting down an incoming ballistic missile with penetrating aids. It might take several decades for the defence system to mature technologically. Political will and sustained financial investment are key factors that will speed up the process of technological maturity of the BMD system.