Additive Manufacturing in Aerospace and Defence Sector: Strategy of India

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Additive manufacturing (AM), also popularly known as 3-D printing, is revolutionising the global manufacturing landscape. The proliferation of AM technology has had a huge impact on the design and production capability of the manufacturing industry. At the same time, the technology to mimic and print real parts has huge implications for a country's defence capability and security. In order to understand the growing importance of manufacturing technology in the digital age, the article focuses on the fundamental aspects of AM technology and how it is changing the aerospace and defence sector.

Additive manufacturing (AM), otherwise popularly known as 3-D printing, is a revolutionary technology that is emerging as an alternative to traditional manufacturing sector.[1] It was first introduced as a prototyping solution in manufacturing sector. Now, the technology has matured enough for National Aeronautics and Space Administration (NASA) to get closer to building a 3-D printed rocket engine.[2] Major manufacturers are already aware of the technology's competitiveness and are 'actively piloting and using 3-D printed technology today'.[3] According to the *Wohlers Report 2016*,[4] the AM industry has touched the US$5.1 billion

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mark and is estimated to generate US$21 billion revenues worldwide by 2020. The report also claims that the sale of industrial grade 3-D printers went up in 2015 as compared to the previous year, which is evidence of the positive impact of the technology on manufacturing sector. In the long run, many experts believe that metal AM will replace conventional methods of manufacturing. The advantage of AM technology is that it allows the industries to design and produce products on their own, and enhances the idea of the 'prosumer.' At the same time, one cannot neglect the profound effect AM is going to have on the Indian defence manufacturing sector.

Additive manufacturing as a high-tech industry is still evolving though it has already gained importance in the manufacturing sector. The disruptive nature of the technology has generated a lot of interest worldwide. Economists and political scientists are also keenly studying the various aspects of the AM technology which they believe will have a major impact on globalisation and geopolitics, among other things. Experts also believe that the increasing usage of AM will lead to a fundamental shift in the global economy. The production and distribution of material products could become de-globalised as the manufacturing of many goods moves closer to the consumer and on-demand. Since AM enables the designing and building of products from composite, locally available and recycled materials through printing, it could reduce a country's reliance on imported raw materials.

For defence manufacturers, AM offers a variety of advantages in terms of building parts and components in a cost-effective way. The sector is also investing in AM technology to emerge as a competitive player in the field. Given India's inherent problem of adapting to newer technologies, the advent of AM and allied technologies has raised serious concerns about their impact on the country as a whole, and its defence capability in particular. It is, therefore, imperative to understand the digitisation of manufacturing and to this end, this article primarily focuses on important aspects of additive manufacturing and how it is changing the prevailing manufacturing landscape. The article also examines the international approach to AM technology and its impact on the aerospace and defence (A&D) sector. Finally, it highlights the need to usher the technology into India to improve its manufacturing capability both in the commercial and A&D sectors.

What is Additive Manufacturing?

The American Society for Testing and Material (ASTM)[5] defines AM as 'a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.'[6] Additive manufacturing primarily relies upon computer-aided design (CAD) software for designing complex geometries and features such as non-uniform wall thickness and internal channels. Once the design is ready for a build, the CAD files are exported into stereolithography (STL) files for the manufacturing of real parts. It must be noted that all AM processes are not uniform as they vary on the basis of individual processes and in their method of layer manufacturing. Therefore, ASTM has set a 'Standard Terminology for Additive Manufacturing Technology 2012' that classifies AM into seven categories. Of these seven ASTM F42 categories, four pertain to metal AM (see Table 1).

The growth in AM offers new possibilities, not only in design and prototyping but also in the choice of materials. Additive manufacturing uses metals, polymer, ceramics or composite materials in the building process to fulfil user specifications. Metals and composite alloys are gaining prominence, especially in the automobile, aerospace, defence and pharmaceuticals sectors because they enable the production of lighter weight metallic components at competitive pricing. In terms of tensile

Table 1 Category by Technologies

1.	VAT Photopolymerisation
2.	Material Jetting
3.	Material Extrusion
Metal AM	
4.	Binder Jetting • Infiltration • Consolidation
5.	Powder Bed Fusion • Selective laser melting (SLM) • Electron beam melting (EBM)
6.	Sheet Lamination • Ultrasonic additive manufacturing (UAM)
7.	Directed Energy Deposition (DED) • Laser vs e-beam • Wire fed vs powder fed

Source: ASTM.

strength and hardness, researchers have found that AM printed as-fabricated condition parts are proving to be significantly inferior to those made with conventional materials.[7] However, the post-secondary process (heat treatment, electropolishing, etc.) makes for a greater resilience in the printed parts and improvement in the mechanical properties of the material.[8] The technology is still in the development stage and needs to be perfected in crucial areas, such as faster deposition rates, quality control, machine reliability, cost reduction and new capabilities and materials, in order to move on to the next stage.[9] As AM is still evolving, it will be many more years before it completely takes over the global production process. However, major industrial nations have already promulgated policies to keep comfortable pace with AM technology. The policy outlook of select countries clearly shows that the technology is rapidly maturing and will see significant growth in the next few years.

Third Industrial Revolution: International Approach to Additive Manufacturing Technologies

The rise of digitisation has infused a new process in the manufacturing sector, which is often referred to as the 'third industrial revolution'.[10] The convergence of digital applications with manufacturing processes has led to new innovations in software, artificial intelligence, robotics, novel materials, 3-D printing, etc. Like all revolutions, digitisation is also disruptive in nature. The promise that AM technology offers in terms of design and development is limitless and has immense potential to change the present landscape of the manufacturing sector. Additive manufacturing is a new priority in the innovation policies of several leading industrial nations. However, only a few industrial nations have thought of leveraging the links between digitisation and manufacturing, both theoretically and statistically. The United States (US), Germany, the United Kingdom (UK), Japan, China and South Korea are the few emerging players that hold the maximum number of patents relating to this technology.[11] These countries have responded instantaneously and are well placed to take advantage of the market as discussed below.

1. *The US:* America is a dominant player in the field of AM technologies. Former US President Barack Obama, while inaugurating the National Additive Manufacturing Innovation Institute (NAMII) in 2012, clearly enunciated the country's strategy with regard to AM technology. The NAMII was

established by a consortium set up by the National Center for Defense Manufacturing and Machining (NCDMM) with the objective of accelerating the adaptation of AM technologies to increase domestic manufacturing competiveness. As of February 2016, 31 industry projects and a total of 58 research and development (R&D) projects were initiated.[12] These moves have also motivated a significant number of private players to invest in AM R&D centres.

2. *Germany:* The federal government experts committee report, *Gutachten zu Forschung, Innovation und Technologischer Leistungsfähigkeit Deutschlands 2015* (Expert Report on Research, Innovation and Technological Performance in Germany 2015), has dedicated a chapter on AM technologies, thus underlining its importance for the manufacturing sector. Based on the committee's recommendations, the Federal Ministry of Economic Affairs and Energy has been assigned the task of prioritising digitisation in manufacturing sector. The ministry has initiated an action programme termed 'Digital Strategy 2025' to turn the strategy into reality.[13] Until now, German companies have reportedly been using AM technologies for prototyping and for basic technology experiments. The ministry report states that the rapid manufacturing using metal AM is gaining ground among many German manufacturers.
3. *The UK:* The 2012 Special Interest Group (SIG) study report on 'National Competence in AM' provides a definitive view of AM research within the UK. This report was recognised by *Foresight (2013)*, published by the UK Government Office for Science.[14] Based on the both the reports, the UK government doubled its funding for AM research to over approximately US$40 million in 2015. The number of research organisation also doubled during this period. The major funding is directed towards university–industry collaboration and various other organisations involved in AM-related research.
4. *Japan:* Asian economic giants, Japan, China and South Korea, are leapfrogging in AM technology. The IHS Market Insight report states that Asia is investing heavily in AM technology.[15] This regional development is likely to spur stiff competition between Japan, China and South Korea. Japan has allocated 4 billion Yen ($38.6 million) for various national 3-D printing

projects, most of them for R&D.[16] Japan's Ministry of Economy, Trade and Industry's (METI) *Report on Future Monodzukuri and 3D Printer* pointed out that the economic ripple effect of AM is expected to be about 21.8 trillion Yen as of 2020.[17] Japan wants to use this opportunity to increase its technological superiority over the US and Germany.

5. *China:* The Chinese government has unveiled its first national plan for 3-D printing, called 'Additive Manufacturing Industry Promotion Plan 2015–2016'. The purpose is to create a medium to long-term development plan for AM technology. Addressing the State Council in 2015, Chinese Premier Li Keqiang pointed out that the latest 'development in 3D printing technologies must be part of a push to modernise China's economy.'[18] In terms of research, China has over 10 large research groups and companies that undertake extensive research in AM.[19] China is also among the most advanced countries that have the capability to build aerospace components using DED.
6. *South Korea:* South Korea, an export-led economy, rolled out a grand plan in 2014 to assimilate AM technology into its manufacturing sector. In 2014, the Korean government announced the formation of the '3D Printing Industry Development Council' with the aim of putting the country at the forefront of the booming industry. The master plan includes promoting the industry as well as training 10 million professionals and entrepreneurs in 3-D printing. In 2016, South Korea planned to set up a research project for 3-D printed ship development at the cost of US$20 million.[20] The country is home to major shipbuilders who are keenly looking at AM technology as a future for innovation.

The above-mentioned information on the policies of select countries clearly shows that this technology has gained widespread acceptance among both government and business houses. The policy outlook of the selected countries is also undergoing a significant change in order to accommodate AM technology in a major way, to increase production in the manufacturing sector. Moreover, the acceptance of AM technology by global manufacturers is an indication that it has moved beyond being seen as merely an 'emerging technology into fully a transformative technology'. The major breakthrough in metal AM is now allowing the sector to focus on high value-added products. Aerospace and defence manufacturers, in particular, have taken the lead in production via AM as well as in the research process itself. The aircraft industry has already begun production of various parts using AM technology and is setting the stage for industries to invest in AM, to increase productivity. For the armed forces, AM technology offers the easiest solution for printing tools, replacement parts and manufacturing crucial components, close to battlefield, in the near future. The AM technology impact can be multiplied by innovative ways, which will lead to a significant improvement in the major weapon systems.

Additive Manufacturing Impact: Defence and Aerospace Sector

A paradigm shift in engineering design and manufacturing could greatly affect the defence capability of a country. The worldwide spending on the A&D sector shows that the sector is headed for sustainable growth (see Figure 1). According to IHS Jane's *Global Defence Trade Report 2017*, the global defence market rose to US$62.5 billion in 2016.[21] The US, was the largest defence exporter in 2016, followed by Russia. Moreover, the commercial aerospace sector is optimistic about growth over the next five years as the demand for commercial aircraft is expected to increase significantly in the coming years. Boeing's *Current Market Outlook (2016–2035)* has predicted that the world will require 39,600 airplanes over the next 20 years.[22] The competition among major original equipment manufacturers (OEMs) is driving the sector to opt for newer manufacturing technologies, such as AM, in order to be competitive. The investment pattern of major OEMs in AM technology suggests that they are hoping to use printed parts in future commercial aircraft.

Defence industry standards are higher than those set for commercial items. Their requirements include high steel strength, dynamic strength and adequate static, fatigue and vibration capabilities. The AM built

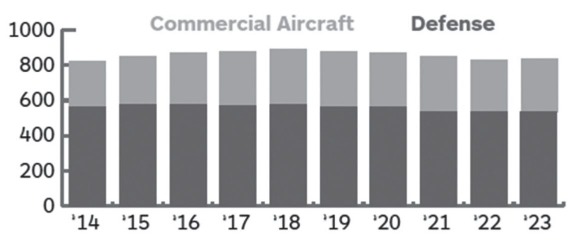

Figure 1 Worldwide Spend on Defence and Commercial Aerospace Equipment (in billions of US$)

Source: IHS.

parts in engines have demonstrated their capacity to withstand the highest temperatures and the compressed pressure ratio of any jet engine in history. The NASA test engine performed with cryogenic liquid hydrogen and liquid oxygen and withstood an extreme environment inside a flight rocket engine where the fuel is burned at higher than 3,315 degrees Celsius to produce thrust.[23] The AM-built turbo pump delivers fuel (liquid hydrogen) below -240 degrees Celsius. This testifies that AM built parts can withstand extreme conditions and drive down the costs and risks associated with the process.[24] The competitive advantage of using AM technology over traditional manufacturing techniques has recently attracted leading OEMs to adopt this technology. For example, General Electronics (GE) made a breakthrough in building sophisticated components for aerospace engines by using ceramic matrix composite (CMC) and the AM processes.[25] This notable achievement in AM technology is driving more companies to opt for the process to enhance their manufacturing capabilities.

At present, AM technology in the A&D sector is broadly used for prototyping, repair of small parts and component manufacturing (Table 2). The US' Defense Advanced Research Projects Agency (DARPA) has launched the 'Open Manufacturing' programme in response to the growing interest in the field of AM technology. The aim of the programme is to understand the physics and process parameters of AM and apply those technologies not just to it but also to a range of potentially new manufacturing methodologies.[26] Multinational companies in the aerospace sector and defence manufacturers have also invested in AM technology to print parts for the commercial/military A&D systems. The industry leaders in aerospace, such as Boeing, Airbus, Lockheed Martin, GE, Honeywell and Rolls Royce, are adapting AM to build parts and components for a large number of aircraft. For example, the 'F/A-18 Super Hornet has approximately 150 printed parts…that have been made by using selective laser sintering.'[27] In 2016, a Lockheed Martin press release confirmed that Trident II D5 missiles with 3-D printed components were test-fired by the US Navy.[28] The US Army and Navy are investing in AM technology for shore activity, R&D, depot repairs, etc.

Although it is a major exporter of arms, the US is also leveraging its AM technology to overcome any procurement obstacles and reshape the supply chain in the A&D sector. During the Ukraine crisis, the Russian government imposed an embargo on the sale of the RD-180

Table 2 AM in Defence and Aerospace: Present and Future Trends

Areas	*Current Application*	*Potential Future Application*
Aerospace and Defence	• Modelling, test units and prototyping. • Fitment parts, visualisation model, tooling, etc. • Building component for defence and aerospace systems. • Replacement parts.	• Embedding additively manufactured electronics directly on parts. • Printing repair parts on the battlefield. • Regenerative medicine to treat severe battlefield injuries. • Printing structures using light-weight, high-strength materials. • Printing parts with minimal waste.

Source: Compiled by the author from various sources.

rocket engines to the US. The latter, which depends upon the RD-180 rocket for its space programme, hired a space company—SpaceX—to build a launch vehicle. To meet NASA's demanding cost and time frame, SpaceX used AM technology to print a key component of the launch vehicle SuperDraco. This was the first time that a printed thrust chamber was used to fire up the rocket. Bolstered by this success, SpaceX is continuing its programme to fine-tune the SuperDraco engine by using AM technology.[29]

Major arms exporting countries like Russia, the UK, China, Israel and South Korea are also investing hugely in AM technology. Eliminating supply chains could be a priority of the arms exporting countries to bring down cost and to increase productivity. The Russian defence manufacturing industry, one of the largest in the world, has rolled out its most advanced tank with AM-built parts. The prototype parts of its T-14 main battle tank and the Armata series of combat vehicles have been built using this technology. According to a news report, the Russian tank manufacturer UralVagonZavod is producing AM-built titanium parts that are several metres in length, for use in armoured vehicles.[30]

China, which has an advanced facility for AM technology, has recently claimed that it has printed the largest titanium component using additive technology. Chinese aerospace companies, which mastered laser additive manufacturing (LAM) by printing titanium, are replicating this success by printing the parts and components of the J-15, J-16, J-20 and J-31 jet fighters and the C919 commercial airliners. The Chinese

People's Liberation Army (PLA) has been granted permission to carry 3-D printers to operate and provide equipment support for the country's armed forces.[31] The PLA Navy destroyer *Harbin* is equipped with a 3-D printer to print parts on board. The Chinese, who have started deploying their navy overseas, view the technology quite helpful while operating far from home shores.

The UK Royal Air Force and Navy use AM for repairing spare parts. The Royal Navy flight tested a 3-D printed unmanned aerial vehicle (UAV) on board *HMS Mersey* in September 2015.[32] The UK's largest defence manufacture, BAE Systems, is using AM-built parts for the maintenance and servicing of Royal Air Force planes. By inducting AM, BAE Systems could reduce the Royal Air Force service and maintenance costs.[33]

More recently, South Korea adopted AM to print parts and components for its armed forces. By effectively employing the AM process, the South Korean Air Force has saved over 90 per cent of the cost of components for jet engines.[34] Warfare is constantly changing and the demand for more advanced technology poses a serious challenge to manufacturers. The defence industry is adapting fast to the changing security situation and is now focused on incorporating new innovations to advance its manufacturing capabilities and develop new weapon systems to fulfil the requirements of the armed forces. In this scenario, AM offers a unique advantage to both manufacturers and the armed forces to enable them to respond effectively to the emerging challenges in manufacture of parts and components. Therefore, AM is not merely a manufacturing technology as it has the potential to dominate the future battlefield.

While the majority of arms exporting countries are rapidly investing in AM technology, their armed forces are, similarly, seeking a newer technologies—AM being a case in point—that offer the great flexibility of printing parts close to the battlefield. The US Army is the first to have an AM facility in Afghanistan to support the troops with the advantage of 3-D printing. This has allowed it to build spare parts in quick time rather than focusing on procuring spare parts, which would take longer.

Where India Stands in Additive Manufacturing

As the above discussion shows, the advancement and adaptation of AM technology varies from country to country and is based on the national agenda. India has been quick to realise the potential of digitisation and has launched several initiatives such as 'Make in India', 'Digital India' and 'Skill India' to improve investment opportunities and to enhance manufacturing capabilities in the country. These initiatives involve an overarching strategy for accelerating economic growth through digitisation. Prime Minister Narendra Modi has also indicated that 'digitisation' should be viewed as an opportunity, not as a threat.[35] Given the government's interest in boosting manufacturing, major manufacturers have established 3-D printing assembly lines and distribution centres in partnership with foreign technological firms. The surge in demand for AM is enticing major global firms to set up their manufacturing units in India. A survey by PricewaterhouseCoopers (PwC) on 'The Global Industry 4.0' in 2016 shows India—at 27 per cent—as being slightly below the global average of 33 per cent, and that of Asia, where nearly 44 per cent of industries have either already invested or will be investing in AM technology within the next five years.[36] Major business houses are showing an interest in AM, but there is a lack of clarity relating to the import of 3-D printers that attract close to 30–40 per cent customs duty, over and above the shipping cost. The huge cost associated with importing industrial grade 3-D printers is too much for the medium and small-scale industries in India.

The lack of AM technology will have a negative impact on India's manufacturing sector in the long term. The defence manufacturing sector, which is gaining prominence under the present government, should take proactive steps to plug this gap in manufacturing technology to achieve indigenisation and self-reliance in weapon manufacturing.

The Indian defence establishment has been using 3-D printers to build components or prototype models for scientific investigations. Hindustan Aeronautics Limited (HAL) and the Gas Turbine Research Establishment (GTRE), which are the two major aeronautic establishments in the country with decades of experience in aerospace technology, are using AM technology for design and development. A brief study of the experience of these two organisations with AM technology clearly shows that the technology is likely to play an important role in the Indian A&D sector. HAL, the only aircraft manufacturer in India, has set its sights on AM technology to build several components for its indigenous engine programme. V. Sridhara, a general manager at HAL, claims that HAL is using direct metal laser sintering (DMLS) technique to print components for the indigenously developed Hindustan Turbofan Engine-25 (HTFE-25).[37] According to Sridhara, AM technology has helped HAL to speedily build a high pressure turbine blade, which generally takes two years to build using of computer numerical control (CNC) machines. In HAL's case, the DMLS process was used by designers to achieve the quick turnaround of intricate parts. HAL is also taking the lead by using the technology for its indigenous aircraft programme because it is sure that it will be able to get DMLS built parts certified in the near future.[38]

Similarly, GTRE, a Defence Research and Development Organisation (DRDO) laboratory entrusted with the responsibility of developing engines for India's aircraft programme, has employed AM technology to build components. For decades, GTRE's biggest challenge was to build prototype engines by using CNC machines. According to U. Chandrasekhar, GTRE Group Director, 'there are approximately 2,500 components that had to be included in the engine assembly line'.[39] With CNC machines, it would have taken 10–12 months to build 2,500 components. With the introduction of fused deposition modelling (FDM) technology, GTRE was able to produce the component much faster and at relatively lower cost. Moreover, this allowed engineers to identify and solve problems which would have been difficult to address with just computer modules. In the case of HAL and GTRE, the DMLS and FDM technologies have been used to build metal parts for prototypes. This has helped HAL and GTRE to validate and built parts in a relatively short period of time. This makes a strong case for AM-related research and technological development in the country.

On the research front, AM technology is presently being used in various Indian institutions but in a fragmented form. The Indian Institute of Technology (IIT) Mumbai, the Central Manufacturing Technology Institute (CMTI), Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), and Council of Scientific and Industrial Research (CSIR)-funded laboratories such as Central Mechanical Engineering Research Institute (CMERI), have established facilities and provide solutions for AM manufacturing. But the lack of a centralised approach to AM is constraining Indian institutions from undertaking intense research on AM-related technologies. The present AM capability available in defence establishments and various other research institutes is inadequate to meet the emerging challenges in the defence and aerospace sector.

On the other hand, foreign OEMs eyeing the Indian defence market have established AM facilities in India. Dassault Systemes has set up a full-fledged R&D centre in Pune.[40] GE has invested over US$200 million to set up an AM plant in Pune, India.[41] Moreover, Stratasys, the world's largest 3-D printing firm that was previously supplying 3-D printer products through distributors in India, has set up shop here after it saw a huge opportunity in the country.[42] Given the growing interest among the major industrial houses in the country, experts believe the AM and its allied technologies can transform the Indian defence ecosystem. Indian companies now have a huge opportunity in defence and aerospace sector as the government has relaxed norms and created a level playing field for the private sector to compete against the defence public sector undertakings (DPSUs). As of December 2016, the Ministry of Defence (MoD) signed 141 contracts worth INR 2,000 crore for capital procurement, out of which 90 contracts were signed with Indian vendors under the 'Make in India' programme. Moreover, the Government of India has also directed DPSUs and ordnance factories to develop short-term and long-term outsourcing plans with Indian private players.

The new Defence Procurement Procedure (DPP-2016) also envisages a bigger role for Indian companies in the A&D sector. Therefore, harnessing the advanced manufacturing technology is vitally important if Indian industry is to compete with DPSUs and foreign OEMs. New foreign direct investment (FDI) norms allow investment up to 49 per cent via the automatic route and 100 per cent after government approval. Thus, it would be greatly beneficial for private companies to acquire advanced 3-D technology from foreign OEMs. Moreover, Indian industries can benefit considerably from defence offsets and acquire niche technological capabilities to build AM in India. Thus, there is a huge opportunity for micro small and medium enterprises (MSMEs) to build their expertise around AM technology and provide AM-built parts for larger companies.

While India has the opportunity to develop competitive strength in AM and its allied technologies, these also pose considerable challenges. Western nations that lead in AM technology have already tightened their export controls. The US has brought AM equipment for manufacturing gas turbine engine blades under the export control regulations monitored by the US Bureau of Industry and Security.[43] International regimes such as the Nuclear Suppliers Group, Missile Technology Control Regime and the Wassenaar Agreement that control technology have been concerned about proliferation of high-performance 3-D printers, which have the capability to print parts for missile or nuclear weapon indigenously before anyone notices.[44] In order to prevent the proliferation of AM technology, the export control regime is developing guidance material for governments and industry on how to apply exisiting control on AM.[45] Such controls over technology will limit India's participation in the technological domain. In the past, the technology denial regimes played a decisive role in India's trajectory as an emerging power. In the nuclear, missile and defence sectors, the control regime still prevents India from acquiring some crucial technologies. Given this scenario, India's underdevelopment in AM technology would have a serious impact on the economic competiveness of domestically manufactured goods in the international market.

At the same time, it is equally important for India to recognise some of the emerging challenges to AM and which require serious consideration. First, since the digitalisation of manufacturing technology is on the rise, the threat factor in cyber domain requires far greater attention. In AM, accuracy of the components manufactured is vital because even a minute change in dimensions can have an adverse impact on the design parameter. A recent study has shown that the 3-D printer connected to online network is vulnerable to cyberattacks. The attackers can re-orient the product during printing and can also create a sub-millimetre defect which is undetectable in the common industrial set-up.[46] The modification of the printer orientation and the introduction of defects are the two major possible attacks which will have serious impact on user's final product.[47] Second, the AM process produces less waste in comparison with other traditional manufacturing techniques. However, greater attention should be paid to the harmful effects of the AM process on both humans and the environment. The researchers have found that the AM process emits hazardous chemicals during printing, including ultrafine particles (UFPs) and volatile organic compounds (VOCs), which are dangerous to the operators.[48] The solvents used in the post-processing phase have also been found to be hazardous to both human health and the environment.[49] As the technology finds widespread acceptance and use, the volatile effect on health and environment has emerged as a major concern among social health activists, environmentalists and industrial ecologists. Third, the ability of AM and its allied technologies to mimic and print any part may create intellectual property (IP) challenges. In 2013, research firm Gartner predicted that 'by 2018, 3D printing will result in the loss of at least US $100 billion per year in intellectual property globally.'[50] The huge economic implications and infringement on IP has created difficulties vis-à-vis AM and a nation's economic security and legal systems. India's advancement in manufacturing sector should build expertise around AM by focusing on some niche areas such as cyber security, industrial ecology and IP-related fields to mitigate problem in the field.

India is warming up to the idea of digitisation, but it has not yet fully understood the changing global manufacturing landscape. If our investments in AM do not match those of the other states, there is a huge possibility that we would fall behind other nations in adapting to AM technology. Given India's manufacturing capability, the country requires structural reforms in both R&D and manufacturing sectors to bring about actual change. The setting up of new facilities and the scaling up of the present facilities into advanced research centres will promote AM-related research and study among scientists and engineers.

A Strategy for India

Given the pace of change in technology, India needs to scale up its digitisation plan and attract investment into a niche area like AM technology in order to achieve economic competitiveness and long-term leadership in it. The three key findings of this article underscore the importance of a comprehensive strategy for AM:

1. Major economies and several Asian countries including Japan, China, South Korea and Singapore are investing in AM and other allied technologies. These countries adopted AM when it was in its nascent stage and strong support from the government and business houses for AM-related studies and R&D spurred growth in this technology.
2. Apart from its commercial and industrial success, AM is rapidly driving changes in the A&D sector. Foreign OEMs are adapting to AM to improve the efficiency and reduce the costs of building weapon systems. Defence manufacturing, which is a capital and technology-intensive sector, perceives AM as a viable option for driving down costs and enabling innovative solutions to many complex problems in modern war fighting. The US and China are researching on AM to bring manufacturing closer to battlefield and improve the battle efficiency of their troops.
3. Research involving AM and its allied technologies in India is inadequate for competing in the global arena. India's research output with regard to AM technology needs to be significantly

> scaled up if it is to emerge as a competitive player in this field. Research in advanced composite materials, powder metallurgy, design and software is equally important to build a complete ecosystem for AM in the country. Given the present scenario in the country, India is likely to persist with traditional means of manufacturing in the near and medium terms, at least in the high-volume production of components.

The above-mentioned points highlight the need for fast-tracking India's approach to digitisation. 'Make in India' and 'Digital India' provide little scope for achieving the larger objective of linking digitisation with the manufacturing sector. The present National Manufacturing Policy (NMP) clearly underlines the importance of technology acquisition, skill development and industry promotion to catapult manufacturing sector growth to 12–14 per cent in the medium to the long run.[51] The NMP plan is to enable manufacturing to contribute at least 25 per cent of the national gross domestic product (GDP) by 2022.[52] However, the emphasis on improving scientific temper in the country with regards to manufacturing technology has not been part of the dominant discourse. The lack of research in high-end manufacturing technology will prevent India from emerging as an industrial nation. Therefore, it is imperative that the government develop mechanisms to capture and analyse the changing nature and role of manufacturing.

This can be achieved by systematically focusing on three areas. First, by encouraging advanced research in AM, material science and technology and university–industry collaborations that will speed up the process to be at par with the rest of the world. Second, by creating an environment that is conducive for industry to form consortiums with foreign OEMs to co-create the technology. Third, training and skilling is another important aspect which requires considerable attention. Only a few national technical institutes are offering MTech courses in AM technology. There is huge scope under the 'Skill India' initiative to reach out to the many technical institutes in the country to sensitise them regarding the opportunities in AM. There is also an urgent need for creating a Centre of Excellence in the country to capture and analyse issues concerning AM and its allied technologies. Moreover, the defence R&D establishment can play a decisive role in developing of indigenous capabilities as well as focus on the standardisation of AM. Additive manufacturing could be a great technological 'game changer' for the Indian armed forces who are operating in tough terrains and facing great difficulties in finding spares for weapon systems. This will allow them to maintain a simpler supply chain rather than maintaining a complex manufacturing logistic chain.

To conclude, Indian institutions like Indian Space Research Organisation (ISRO), DRDO, CSIR laboratories, IITs, Indian Institute of Science and various other scientific institutions can play a significant role in the development of AM technology in the country. Additive manufacturing, which marks a new beginning in the manufacturing technology, can be developed by setting up state-of-the-art facilities with some of these prestigious and already established institutions. The Indian A&D sector is going to be a major beneficiary of this technology and should take the lead in developing this technology as well as handhold Indian industries to enable them to develop this technology indigenously.

Notes

1. The term AM is used in the context of industrial settings, whereas 3-D printing is used with reference to low-cost machines. However, this article uses the term AM as per the ASTM International (2012) standard terminology.
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