IMPACT OF ADDITIVE MANUFACTURING - A DISRUPTIVE TECHNOLOGY FOR JOINT WAR FIGHTING

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"Investing in tomorrow's technology today is more critical than ever…" ***—Bill Gates***

Abstract

Security and sovereignty of a nation is paramount. It is maintained through its military. The war fighting has been ever evolving, and technology has played a determinant role in the outcomes of all the major wars or military operations. Hitherto the technology has been ever evolving and the rate of evolution too has been almost exponential. The ongoing Russia-Ukraine and Israel-Hamas wars have shown to the world that technology will play a dominant role in the maintenance of the aim of the war and determining the outcome. The wars have become very dynamic and, threats keep evolving right through the war to the extent that the cardinal principle of 'surprise' of war has remained sacrosanct.

Additive Manufacturing (AM) or 3D Printing is a niche disruptive technology. It is termed as Digital Manufacturing (DM) as well. This technology has greatly impacted the war zone where the workshops have come right beside the fighting men and machinery. The AM technology has opened up humongous possibilities to keep the machines operational, and tilt the outcome of the operations and the war. The military with an edge of applying AM will have an edge in the outcome too. The Indian military has to examine this technology and apply it in a manner that the

entire military is AM enabled! The paper aims at apprising the military practitioners at home to embrace AM at the right earnest.

Introduction

The present belongs to JW; having its own challenges, i.e., operational, logistical, tactical etc. One major bone of contention is command and control. The thrust today is towards a structured JW, through integrated commands. It is aimed at instilling synergy between the elements of the fighting instruments of the military. Jointness in JW is not limited to the military, but civil as well. The JW, akin to any other fighting doctrine, aims to achieve the objectives, be it operational, tactical or strategic, by integrating the forces for war at land, sea, air, space and cyberspace. It encapsulates that the desired results, be achieved in the shortest time, and with a minimal to optimal use of the limited resources. The ongoing Ukraine-Russia and the Israel-Hamas wars are being studied closely by the strategic military practitioners. JW is going to evolve further drawing lessons from these two wars. A great deal of jointness exists in the Indian military, and more is on the anvil. The second edition of the Joint Doctrine of the Indian Armed Forces 2017 is a comprehensive document on the Indian Military JW.[1] It is a reference document on the Indian Military Jointness.

Discipline & Disruption in the Indian Armed Forces: A Necessity

Discipline is one of the most important attributes of the militaries across the world. Yet, in order for there to be growth, along with discipline; disruption is needed. There is an importance of disruption which should be understood by the military policy making echelons. The discipline is instilled into the soldiers as a part of the evolving training and working culture. Indian military policy makers need to factor instilling disruption along with discipline. The disruption can be in terms of thinking, training, operations, technologies, use of resources, alternative thinking, etc. An example of disruptive thinking is in the story of David and Goliath, quoted from the Bible. When none had the gumption to take on Goliath, a young boy David took the gauntlet. He defeated Goliath by merely slinging a stone which hit Goliath on his forehead. The invincible giant fell flat on his face and was then killed by David.[2] It is a stellar example where a daunting giant, feared by all,

was humbled by an opponent who used his mere presence of mind, using his humble resource, his wit and courage intact, attained victory. This is an epitome of disruption.

Ever Evolving Technology and War Fighting

Disruption in technologies impacts the war and its outcomes. Dropping atomic bombs on Japan by the USA, in World War II, was the use of disruption.[3] It swiftly brought to an end the hostilities and the war. Technology is the backbone of the military, for it to train with and win the operations or wars it undertakes, or is compelled to take. The use of a cheap and an innocuous drone destroying a tank costing millions of dollars, is disruption. The technology has been evolving at a very fast speed.

In order that our ancestors could control and use fire, the time taken was 2.4 million years.[4] An insight into the technological transformation rate over the centuries, one may refer to endnote no.5. Technology changes the way war is fought, and thus the emphasis on JW. Disruptive technologies like CyberSpace, AI, ML, Blockchain, Drones, Generative AI, VR/AR, Space Technology, Additive Manufacturing, Biotechnology, Humanoid Robotic Soldiers etc, are changing the warfighting ways. Several niche technologies were mentioned in the preceding paras. One such disruptive technology is 'Additive Manufacturing' (AM), also known as '3D Printing (3DP)' or 'Digital Manufacturing (DM)'. This has made a significant impact on the JW. When AM is envisaged with COVID-like situation in the background, its significance gains larger proportions.

This paper attempts to highlight the importance of AM/3DP/DM in JW operations. How the military will exploit to apply the technology in peace and war. It is certain that the future wars will be joint. The details of different types of AM processes, input materials for AM, and all kinds of technical information have a passing reference in the paper. This has been done intentionally. There is an amazing amount of information in the open source on these matters. In spite of the mammoth amount of relevant information on AM in the open source, and case studies on its use by the militaries globally, the AM has not found favour with the Indian military practitioners. This paper's focus is to get the Indian military practitioners and the policy makers, to appreciate AM technology. Scepticism about the

functionality of AM is common. The attempt to set aside the scepticism, if not completely, even partially will vindicate its purpose.

History of Additive Manufacturing/3D Printing

Fig-1[5] Below, depicts the historical timeline of AM which had its advent in the 1980s. Initially it faced a great deal of criticism and scepticism. It was labelled as a means of merely prototyping of products or parts.

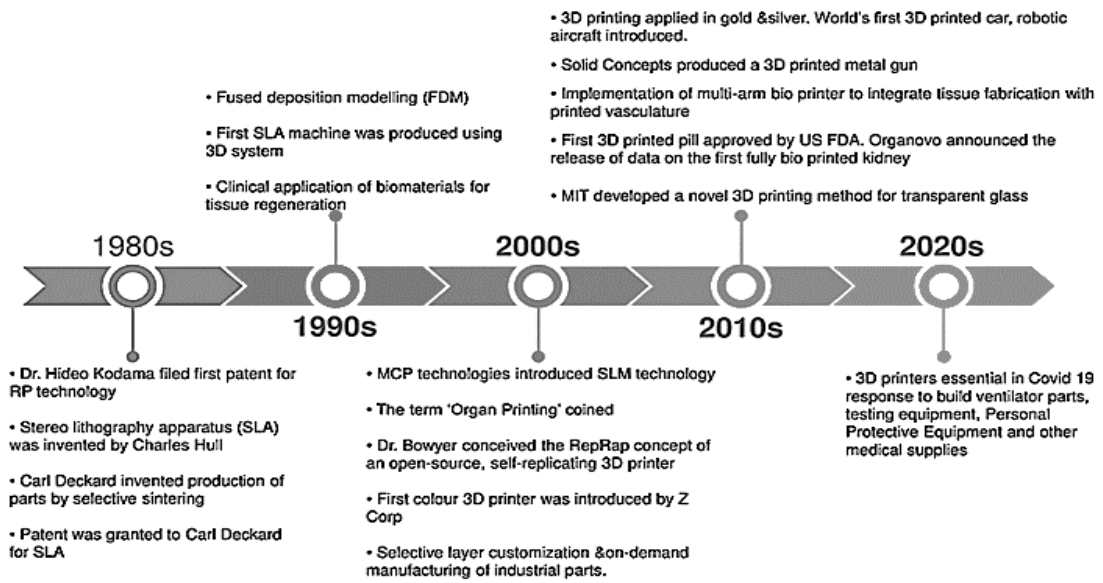

Fig – 1, Historical Timeline of AM, Source: Ministry of Electronics and Information Technology, Government of India, "National Strategy on Additive Manufacturing", https://www.meity.gov.in/writereaddata/files/Additive%20Manufacturing%20Booklet%2014.02.2022.pdf

The AM technology has been in existence for almost five decades now. It has matured along the way. The end-use parts are being 3D printed directly. There is not one industry, or a R&D/training/MRO organisation, not using 3DP. 3DP reached the NASA space station way back in 2014. It is being used for parts manufacturing and has its special applications in spare parts needed for maintenance of the space station.[6]

Fig – 2, The 3D printer at the space station.

On 30 May 2024, an Indian startup company Agnikul Cosmos successfully test-fired its launch vehicle (rocket) with a fully 3D-printed rocket engine, the first of its kind, globally.[7]

An insight to the basics of conventional manufacturing and AM will be useful for anyone who is uninitiated in the nuances of AM. In order to get a finished product, one took a blank and removed material to obtain the end part. On the other hand, AM or 3DP, builds a part, by adding the input material layer by layer. In the case of the AM, the wastage is far reduced when compared to the subtractive manufacturing, refer to Fig - 3.[8] There are several types of 3DP Technologies where input material can be either metal or non-metal (polymer).

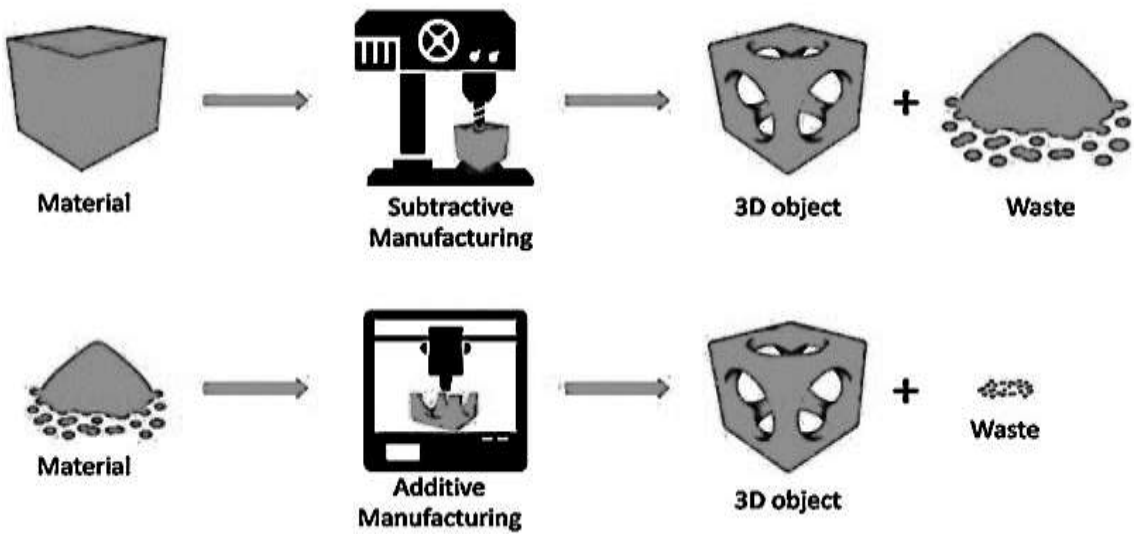

Fig – 3, Difference between additive manufacturing and conventional manufacturing, Source: Stanford Advanced Materials, "Additive Manufacturing vs Traditional Manufacturing 27 Dec 2023 https://www.samaterials.com/additive-manufacturing-vs-traditional-manufacturing.html accessed on 12 Jun 2024.

The types of 3DP for polymers are Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Digital Light Process (DLP), Multi Jet Fusion (MJF) and Poly-Jet Fusion. At the same time, types of metal 3D printing are Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM) and Direct Energy Deposition (DED).[9] Several videos on YouTube, and on the websites of 3DP companies on the differences between conventional manufacturing and AM will be helpful to anyone trying to understand the basic differences. Atmanirbhar Sena (military) is a dire need for the nation's security and sovereignty. The government, having grasped the importance of AM, brought out a national policy on AM.

Indian Government's Initiative in Additive Manufacturing Domain

National Institution of Transforming India (NITI Aayog), in its vision document dated 28 July 2016, has listed out fifteen disruptive technologies in its roadmap for technology advancement and assimilation by the nation; one is 3DP. The Ministry of Electronics and Information Technology (MeitY) published, 'National Strategy for Additive Manufacturing', on 24 Feb 2022.[10] The document is comprehensive and well-written. NITI Aayog has established more than 10000[11] Atal Tinkering Labs (ATL) in schools pan India. Each lab is equipped with a 3D Printer, and impart theoretical and practical training on 3DP. The government rightfully has placed due importance on the 3DP.

A thrust to develop and populate such technologies has been from the National Skill Development Council[12] and National Skill Training Institutes, under the Directorate General of Training, which functions under the Ministry of Skill Development and Entrepreneurship.[13]

The proactive government is setting the right template for the nation to adopt 3DP. 3DP is not replacing conventional manufacturing. It will be complimenting and/or, supplementing it.

AM has been used for military applications by almost all militaries globally, directly or indirectly. It will be worth examining how foreign militaries use the 3DP.

Advantages of Additive Manufacturing or 3D Printing in Military Applications

The advantages are several and significant. Therefore it is pertinent that the military practitioners understand 3DP in order to gainfully apply it.

3DP's great advantage is a fast-paced production of parts involving complex designs. The precision achieved is high and would meet the desired specifications, barring exceptions. On-Demand Production is a key feature. This obviates the long timelines of a typical existing supply chain. AM or 3DP has already proven its battle-worthiness in the ongoing wars. A military can use 3DP to its great advantage in the Tactical Battle Area (TBA), by

on-demand production of the needed part(s), bringing about redundancy in the existing supply chain, and increasing operational efficiency.

In peacetime, 3DP is valuable in speedy customisation of military equipment towards improved performance, functionality and reliability. Reverse engineering and prototyping of any military product is expeditious. It does not the entail tooling needed in conventional methods. The weapon parts can be quickly manufactured to mitigate the evolving threats in operations. 3DP has impacted military logistics in a very big way. It is a precursor to a digital inventory, a part of Industry 4.0, leading to reduced warehousing needs.

It is imperative for the military to harness 3DP's versatility and strength to maintain an edge in any tactical battle scenario.

ADDITIVE MANUFACTURING IN THE FOREIGN MILITARY DOMAINS:

A Look at the US Military Tryst with 3DP

US DoD has constituted a Joint AM Working Group (JAMWG). The JAMWG is a cross-cutting DoD community focused on communication and coordination among the Services and Defence Agencies to maximise AM application in support of the warfighter and sustainers. Formalised in July 2017 and led by the OSD ManTech Program, the team consists of leaders from Military Services, Defence Agencies, other Federal agencies, industry and academia, to reduce barriers to the adoption of innovative AM technologies that benefit DoD and the warfighter.[14]

The US National Strategy for Additive Manufacturing was published in 2022 to address climate change, strengthen supply chains, ensure national security, and improve healthcare.[15]

The US DoD AM Strategy was published in 2021. The US Army, Navy and the Air Force came up with the AM Strategy for their respective services. It was tailored to suit the unique requirements of the respective services for which the US DoD AM Strategy was the guiding document.

Several initiatives of the US DoD and the respective services have been in place. The critical areas being addressed are depicted in the figure below, Fig - 4.

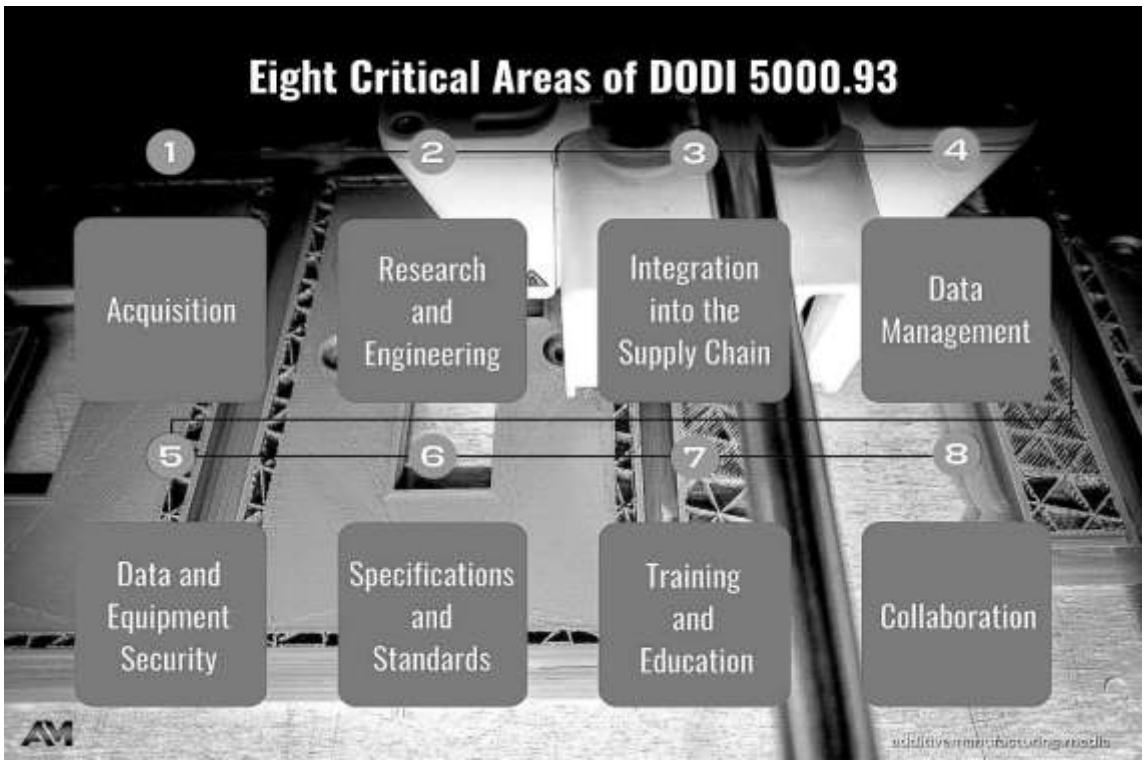

Fig – 4, Areas addressed by additive manufacturing. Source: Brett P Conner, "DOD Drives Transformation of New Additive Manufacturing Policy", Additive Manufacturing, 09 Feb 2022, https://www.additivemanufacturing.media/articles/dod-drives-transformation-with-new-am-policy

The above figure can be adapted by any military and further customised. The US Navy has taken up at-sea production of AM parts and parts of submarines, to enhance the efficiency of the Logistics and Supply Chain. The US Army is using AM for rapid logistics, field level on demand manufacturing, and R&D. US Air Force thrust areas in the field of AM are to manufacture qualified parts for flight critical applications, 3D printed electronics, drones design and manufacture, and its applications for space.[16] The Indian military can take a cue from the above.

UK Military's Foray into Additive Manufacturing or 3D Printing

Project Brokkr is the British Army's enterprise of taking metal manufacturing out of the sheds or shops onto the field. In the Scandinavian mythology, Brokkr & Eitri were legendary dwarf brothers famous for their skills in metal manufacturing of magical objects, leading to the project, named Brokkr.[17]

In 2019, Royal Engineers of the British Army resorted to 3DP for their role in the UN mission in South Sudan to obtain parts at site. It envisaged the production of parts which otherwise could take long to procure. They have now deployable 3DP, called 'Field Army Additive Manufacturing Concentration'.[18] It enhances efficiency and speed of repair, saves on transportation cost, and carbon emission. Fig - 5 depicts the standard ISO container which houses the deployable 3D metal printer and its mobility is also of an ISO container.

Fig – 5, Field Deployable 3D Printing Source: UK MOD Army, "British Army Deploys 3D Printing in the Field", 10 May 2024 https://www.army.mod.uk/news-and-events/news/2024/05/brokkr-pioneering-the-british-army-s-deployable-additive-manufacturing-capability/.

Additive Manufacturing Applications in Russia-Ukraine & Israel-Hamas Wars

The two wars being fought in the present times are unique and unprecedented. The four nations are facing challenges, and sustenance is the key.

Supply Chain Maintenance has been the major concern of all the warring nations. Economic sanctions, diplomatic isolation, rebuilding of critical infrastructure, maintenance of transportation, communication and civil infrastructure while conflict is on, is a great challenge. Healthcare of wounded in the operational zone, and the patients both civil and military in peace locations too, suffer from the scarcity due to choked supply chains resulting from war.

AM obviates supply chain bottlenecks for requirements of end-use spare parts for the war fighting machinery; medical supplies, first aid kits, critical life-saving kits for the wounded etc.

Additive Manufacturing's Stellar Role in Ukraine Military Operations

Project DIAMOND[19] has been a success story of distributed manufacturing, as printers installed across the US and elsewhere in the world, are networked. These can be centrally tasked to produce an item, in the required volumes. More than 300 desktop 3D Printers simultaneously produced tourniquet components needed for Ukrainian wounded soldiers, an excellent example of the agility of the DM process.

Seven massive Speed3D printers have been supplied by the US DoD to Ukraine, to be deployed in the field to help the Ukrainian army rapidly fabricate critical parts for more than forty different armoured platforms. It will serve to overcome the challenges of legacy military platforms' spare parts availability at the war zone.[20]

Ukraine started 3D printing bombs to augment its depleting assets of ammunition. These candy bomb manufactures involved amateur groups who were experienced in AM. One group made 30000 casings in four months for the candy bombs; and the other group working on 800 gas anti-personnel bombs was manufacturing 1000 casings per month. They had demands which were ever increasing. The military did the filling of charge. It is

hitherto an unknown combination of civil military war time cooperation. A possibility unfolded here only due to AM.[21] Several 3D printing companies and service providers volunteered to help the military. 3DP based sustenance here is noteworthy.

Additive Manufacturing's Role in Russian Military Operations

Russia had been using 3D Printers of foreign origins. The indigenous 3D printers don't have the same class. The sanctions impaired the operations. Yet Russia has resorted to the use of home grown Industrial 3D printers, for mass manufacture of drones and UAV components. It's a significant feat in light of the ongoing war.[22]

Additive Manufacturing's Applications of 3DP by the IDF (Israeli Defence Forces) in the ongoing war

AM has proven to be a saviour for the IDF. Israel was caught totally unaware on 07 Oct 2023 when it was attacked by Hamas. Since then the war has been ongoing.

Applications of 3D Printing at the War Zone

Fig – 6

Fig - 7

Fig - 8

Ariel Harush, a material engineering student of Ben Gurion University, started by helping one friend, fighting at the Gaza border, by 3D printing a connector, a small radio part (Fig - 6). Seeing growing demands, he formed a group which has printed more than 43000 parts. Fig - 7 is a 3D printed knee cap, while Fig - 8 shows the kits for the Israeli troops.[23]

Shilo Segev, a 21 year-old soldier was shot in his knee which got shattered. His knee got reconstructed with the aid of 3DP.

Additive Manufacturing in the Indian Armed Forces

The Indian Military has been warming up towards embracing 3D Printing technology. All the three services have used the 3DP for prototyping or for end use parts. AM has been used for reverse engineered spare parts. The details on the AM applications by the three services are scarce in the open domain. The Indian Navy has partnered with a 3D printing service provider company think3D for manufacturing of parts to salvage obsolescence.[24] Military Engineering Services (MES) of the Indian Army used 3DP to construct residential houses.[25] MES 3D printed a runway controller hut at Air Force Station Pune.

The Indian Air Force has set up a metal 3D Printing facility at one of its bases. Any AM facility with the Indian Army & Navy is not publicly known. Ordnance Factory Dehu Road Pune, has set up a 3D Printing facility, recently; the first in any of the ordnance factories.

Hindustan Aeronautics Ltd (HAL) and Wipro3D have collaborated to 3D print aero engine metal parts. They successfully 3D printed a nozzle guide vane with high temperature resistant steel A286 which was certified by CEMILAC (Centre for Military Airworthiness and Certification).[26] A great beginning.

BEML and Wipro Infrastructure Engineering signed a MoU for working together in the domain of AM, AI and the Hydraulic System Engineering.[27] Further there is no information on the association.

The MoD, the Indian Armed Forces, Indian Coast Guard, DPSUs and the DRDO Labs have used AM and also have established AM centres. R&D Engineers Pune has been tasked to develop metal 3D printable bridges and prototypes. Plastic and composite parts of missiles are being developed by Defence Research and Development Lab Hyderabad, and 3D printed metal components are being developed by Defence Metallurgical Research Lab Hyderabad.[28] AM is an Industry 4.0 disruptive technology, and needs to be adapted by all echelons of the MoD.

In the preceding paras, AM technology and its use in ongoing wars, was covered. Briefly, the AM technology and its evolution in the US DoD, Army, Navy and the Air Force has been visualised. The purpose is to intrigue and ignite the military minds. Indian MoD and

the Services Headquarters may consider the use of the information in developing indigenous plans to roll out the AM technology in right earnest at all echelons of the India Armed Forces, and organisations under it. The following will illustrate the impact of AM or 3DP on Joint Warfare.

Impact of Additive Manufacturing on Joint Warfighting

- Impact on Logistics and Supply Chain Management (SCM): Logistics and SCM improves by 'On Demand Manufacturing'. The parts can be manufactured and supplied at the war zone, on board the naval vessels or submarines, and at the air forces operational bases.

- Expeditious and Improved Repair & Maintenance: A weapon platform can be restored to its operational readiness by manufacturing replacement parts on demand on site. This positively impacts the operations and optimal exploitation of the weapons. Spare parts for legacy weapons poses a formidable challenge. AM technology can reverse engineer and 3D print the legacy parts.

- Enhanced Jointness: Land, sea and air forces; operate several platforms which are common. These can be jointly developed using 3DP and maintained digitally. It leads to better interoperability resulting in a more efficient JW. It will foster a collaborative ecosystem where joint forces work together to maintain, innovate and standardise.

- Tactical Advantage : AM can prove vital in manufacturing critical parts whose requirements come from the battle fronts. The 3D printed bombs mentioned in preceding paras for IDF by amateurs is an example. The cycle encompassing design, development, prototyping, testing and obtaining 3D printed end use parts, can be short or swift. The beauty is that a collaborative effort of experts working in displaced and different locations, is possible. The pooled 3D printers in different locations can be used for the simultaneous manufacturing of a common product, known as distributed manufacturing. The Indian military can establish 3DP set-ups in a strategic manner, in different parts of India. These could serve to cater for on demand parts production depending on the proximity of TBA, or for distributed manufacturing. The 3DP set up

can be field deployable or established at the borders, on and off shore, or at any part of the mainland.

- Strategic cum Tactical Advantage: Digital inventory obviates large stores leading to a better economy and efficiency. AM technology is apt for mitigating effects of sanctions and diplomatic isolations. Russia's war waging potential is impaired in the ongoing war.

- Enhanced Agility and Resilience: Situation in a TBA is ever evolving. Mitigating risks on the go is enabled by AM. AM innovations have resulted in lighter end parts. Metal parts have suitably been replaced by carbon-fibre parts with comparable or better mechanical properties but lighter weight. A soldier's mobility gets better if the weight to be carried is lighter.

- Additive Manufacturing Technology Enabled Efficient and Effective Training: AM is being used in more than 10000 schools under ATL, a NITI Aayog's initiative. It simply proves its value in terms of training and development, and can be adapted by the Indian Military.

- Medical & Health Care: In the preceding paragraphs it was seen that AM has come to be a life saving proposition. Doctors and paramedics are able to tend to wounded and injured, close to the TBA aided by AM technology. The real-time examples of IDF, Hamas and Ukrainian military in harnessing AM for life saving propositions and printing of healthcare parts, is phenomenal. This will be of equal value for the Indian Military

- Tapering Down of Costs: AM helps in maintaining the costs, or bringing them down. 3D printed parts produced on demand on site will not carry several other costs of inventory holding, transportation and damages in transit. The wastage is very minimal. These are tangible costs. There could be intangible cost benefits. A life saved due to an on time provisioning of a needed contraption is priceless. An operation won, or weapon platforms saved due to AM of parts on time on site, will empower the operation. A life or a limb saved will boost the morale of both who are fighting and

those for whom they are fighting. AM can be mobile and field deployable, a workshop on the move.

Challenges in the Additive Manufacturing Adoption

AM/3DP is a technology which is evolving and has been able to overcome several shortcomings of conventional manufacturing. Not every manufacturing work will be suitable for the 3DP. Ideally low volume high design complexity manufacturing jobs will be suitable. 3DP will be a good fit for prototyping! It can be applied to replace metal with carbon fibre. The testing and validation procedure for the 3D printed parts for military applications is in the evolving phase, and will take time to mature organically. There are limited materials, and related costs of 3DP could be more than when conventionally manufactured.

The safeguarding of IP, designs and data is paramount, which warrants a robust cybersecurity. The availability of trained resources is a challenge.

A Model Indian MoD Vision for Populating AM in the Three Services, R&D Organisations and Defence Public Sector Undertakings (DPSUs)

Presently AM technology assimilation and its application in the Indian defence construct is sub minimal. Our military environment is discipline heavy and disruption light. Change is resisted vehemently. The Indian military may learn from entities like automotive, IT, infrastructure, agriculture, communication, space etc.; who embraced changes with agility.

Recommendations

National Strategy on Additive Manufacturing, a policy document has been placed by the MeitY in 2022. This can be the guiding document for the MoD.

- At the MoD, a Joint Additive Manufacturing Working Group (JAMWG) will be constituted under IDS HQs. It comprises personnel from the MoD, Department of Defence Production, DRDO, CEMILAC, DGQA, DGAQA, Naval Quality Circle, DPSUs, Indian Army, Indian Navy, IAF, Academia, Ex-Service Men and Industries.

JAMWG in six months time may bring out the National Defence Strategy on Additive Manufacturing (NDSAM).

- JAMWG may join hands with CENJOWS or any other body to create the NDSAM. Simultaneously the quality group will look into formulation of terms of accreditation of quality conformances and approvals.
- At the IDS HQs, an Integrated AM Working Group (IAMWG) will be formed comprising the three services, academia and industry. The group should be a balanced mix of representations from all echelons of the military. This group will create an Integrated AM Force (IAMF), which can take up any AM job from any of the services. Literally a true JW Force.
- AM be the part of curricula of every training institution. 3DP can be used and adapted by anyone irrespective of his education or qualification.
- Creation of five National Defence Additive Manufacturing Growth Centres (NDAMGC): These centres (NDAMGC) could be integrated and be used by all the three services. These centres will be the ones who will develop and groom the IAMF. They will undertake the rapid prototyping, obsolescence management through reverse engineering, R&D and 3D printing.
- Deputing engineers for training on 3DP, as a part of post graduate courses which the services subscribe to. Engineers should be trained at the AM facilities of the overseas defence OEMs like Boeing, Lockheed Martin, Israel Aerospace etc. as part of the discharging offsets, or as a part of the deliverables of the weapon systems contracts.
- Scaling of 3D Printing Labs for the workshops of the Army, dockyards of the Navy and Base Repair Depots of the Indian Air Force would be a prudent step. The assets with the NDAMGC should be of complimentary nature. The assets of 3D printing can be networked and exploited as per need. These will enable distributed digital manufacturing in peace and war.

- j) 3D printing should be placed on every Indian naval vessel for it to serve the emergent spare parts needs.
- k) Weapon platforms green field design mandate to adopt the 3DP and digital inventory from the AON stage itself.

A Fascinating Comparison between Additive Manufacturing & Cellular Phone Technologies

The mobile phones incorporate integrated cutting edge communication and information technologies which are extremely complex. Yet the mobile phones can be used even by an illiterate. AM or 3DP is comparable to mobile phones. They use cutting edge technologies but are simple to use. Any soldier, sailor or an air warrior can use AM technology with ease. This is a potential which could bring about exponential gains in terms of training, operations, MRO and innovation for the services to become Atmanirbhar!

Additive Manufacturing in Military : A Futuristic Perspective

3DP cost will come down. It will enhance the canvas of military rapid prototyping and manufacturing of parts. Printing of complex designs and customised parts will grow. 3DP integrated with Artificial Intelligence (AI) and robotics is the future. The capabilities to handle even far more complex designs will evolve. It will have integrated cybersecurity measures for securing the IP, obviating unauthorised reproduction, maintaining safety and security of critical assets during manufacturing and deployment.

There will be a spur in the innovation in weapon systems design, prototyping, development and manufacturing. 3DP with AI will directly impact the TBA.

It will mark the advent of the digital inventory era in the military.

SCM will get reliable, lead times reduced, bring in tactical gains through distributed manufacturing, and traceability will get robust.

Hybrid 3DP is where a 3D printer and a CNC machine works as an integrated unit. The gain is in enhanced speed, accuracy and economy. The maximum size of the 3D printed

part dimensions are not limited to the bed size and travel, but is the volume the CNC machine can handle. The size limitation of 3D printed parts will cease.

Bio-3DP applications in artificial limbs, regenerative surgeries, 3DP of human organs and tissues etc is shaping up and will prove beneficial in nursing of the wounded soldiers and their healthcare.

The indigenous 3DP/AM hardware is lagging behind the global levels in terms of automation, precision, speed and input materials. The military and the industry-academia combine can work to attain, and surpass global standards. Russia has suffered in the ongoing war by using foreign origin 3D printers from nations imposing sanctions. Indian military drawing lessons from this should act towards indigenous 3D printers and materials.

The following two applications will help in appreciation of 3DP in military applications.

Innovative 3D printed runways, using 3D printed mats for expeditionary military runway laying Fig-8[29] a war fighting enabler. 3D printed propeller for a naval ship by the Naval

Group France, the largest so far, for the French military mine hunter, is a classic example of printing a critical part! Fig - 9.[30] There are thousands of case studies which can be alluded to by our military in the open domain.

Typical 3D Printing Military Applications

Fig - 8

Fig - 9

Conclusion

The 3DP/AM in the military is transformational. It offers immense possibilities in the military manufacturing and MRO. It has found its utility in operations right at the TBA, using deployable 3DP. 3DP has developed technologies where the plastic waste, and 3D printed plastic parts which are discarded, are gathered to be reused as input filaments for 3DP. It is termed as **reclamation** leading towards a safe environment. A military who exploits better 3DP or AM, will always have an edge over its adversary. It is albeit not the weapon, but it is a soldier-weapon duo enabler at war and peace.

AM/3DP will enable, empower and energise the Indian military with tangible and intangible gains in peace and war. A AM/3DP trained military will be a force to reckon with. 3D printing is a medium of infinite possibilities, where the only limit is our own imagination

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NOTES

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