3D Printing: Opportunities for the Indian Armed Forces

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Abstract

3D printing or Additive Manufacturing (AM) technology has grown by leaps and bounds in recent years; however, we have witnessed negligible use in our armed forces. As per past precedent we have assimilated technologies once they are well into circulation thereby losing out on time - technology curve. It is about time that we not only absorb this technology current levels but invest in further R&D to exploit it fully. We should appreciate its advantages and employ the technology suitably to improve our efficiency and economy.

Introduction

Additive Manufacturing (AM) can produce an array of parts/objects spanning complex engineering components and assemblies to the medical accessories like dentures etc. From 3D printed door handles of vehicles and rifle grips to fighter jet engine parts and custom prosthetics, AM has tremendous utility in the military. There is no doubt that it is the technology of tomorrow and the sooner our armed forces adopt it the better it is. 3D printing at a production scale can transform the way military hardware is built while reducing supply chain fragility. However, not all parts can be printed cost effectively by AM such as high tensile materials like gun barrels etc. The precision and tolerances of 3D printers also needs consideration, normal grade printers may not be able to print with tight tolerances and precision. However, with growing technology, each day ushers in new possibilities and opportunities. It is such a versatile technology that it can be employed in almost every field and branch of military.

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It can shorten the supply chains immensely specially during operations or even through unprecedented times such as the ongoing pandemic. This technology simplifies sourcing of materials, reduces lead time, and simplifies logistical and supply issues. Once we get to the more complicated parts, the result could be a 60-to-70-day reduction in flow time for aircraft for maintenance.[1]

AM has proven itself in many industry segments, the technology is unbeatable when rapid design innovations and part iterations are involved. 3D printed objects have amazing strength and suited for all applications. AM brilliance in creating honeycomb-style parts goes a long way toward making assemblies lighter and, therefore, more energy efficient. The strength and accuracy of the objects is also remarkable. Automobile industry is one of the major users of AM and is far ahead when it comes to adopting and deploying this technology. This industry is a very capital-intensive business with massive outlay each year on design and development. 3D printing has proven it can improve the overall speed and agility of design and manufacturing. It shortens development time and iteration steps leading to faster delivery. AM is an epitome to customisation; vehicles can be customised to the extent that seating options can be designed to passengers' orthopaedic needs. Special-fitting headrests and seats can be produced using 3D-printed foams. AM excels in providing intricate, customised structures that optimally address applications for heating and cooling as well as lumbar support. While the concept of 3D printing an entire vehicle/assembly may sound improbable, it may materialise in near future.

Increasing reliance on AM for production of parts helps manufacturers improve their materials usage while reducing scrap and wasted parts. AM also reduces carbon footprint considerably. 3D-printed objects made of thermoplastic urethane (TPU) that become surplus can be recycled and reground for use elsewhere.

Manufacturers and their parts/assemblies manufacturing partners maintain gigantic, multi-location warehouses to store a seemingly endless supply of parts and accessories. AM lessens this burden with its ability to significantly reduce warehousing space. When a part is needed, instead of searching the stores and racks, a digital file is called up and the request is printed on demand. Thus, 3D printing optimises supply chain while eliminating expensive tooling costs. Not only does AM reduce the physical need for costly and vast warehousing, but the process can also be set up virtually anywhere, putting parts acquisition much closer to the end-customer, reducing time-to-delivery. AM is thus poised to be the major change in manufacturing.

Basic Process and Current Technology

3D printing appears to be a highly complex process for many, however, its simplicity and economy relative to the current technology environment is remarkable. One does not have to be a technical graduate to tinker with this technology. With locally available materials and electronics it is possible to build a basic Fused Deposition Modelling (FDM) printer at home. With open-source literature and software[2], it is possible to construct a 3D Printer using commonly available components and materials. Though the simpler ones can print only plastic objects, the complexity, accuracy and strength of the objects churned out by the home-made printer is surprising. The fact is that 3D printing is not rocket science and can be easily inducted into our processes like a normal ink printer. Further, with minor modifications it can do laser engraving or even light CNC machining.

3D Printing essentially involves three stages and utilises complex but user-friendly software. The object to be printed must be conceptualised, then modelled on a CAD Software like AutoCAD, SolidWorks etc. There is a plethora of open source online and offline software available for this purpose. The 3D model so prepared is then “sliced” using a “slicer” software. The slicer produces a Tool Path File (normally g-code file) of the object which is loaded on the 3D printer to physically print the object. Most of the required software is available in the open-source domain. Most objects may require finishing to improve its surface or finish. Scanning of 3D objects has also evolved to a high level. Objects can be scanned by photogrammetry using a high-resolution camera or laser triangulation. 3D scanning yields a digital file which can be processed further to print the final object. The stages for printing a 3D object from conceptual stage to production are depicted in the following figure.

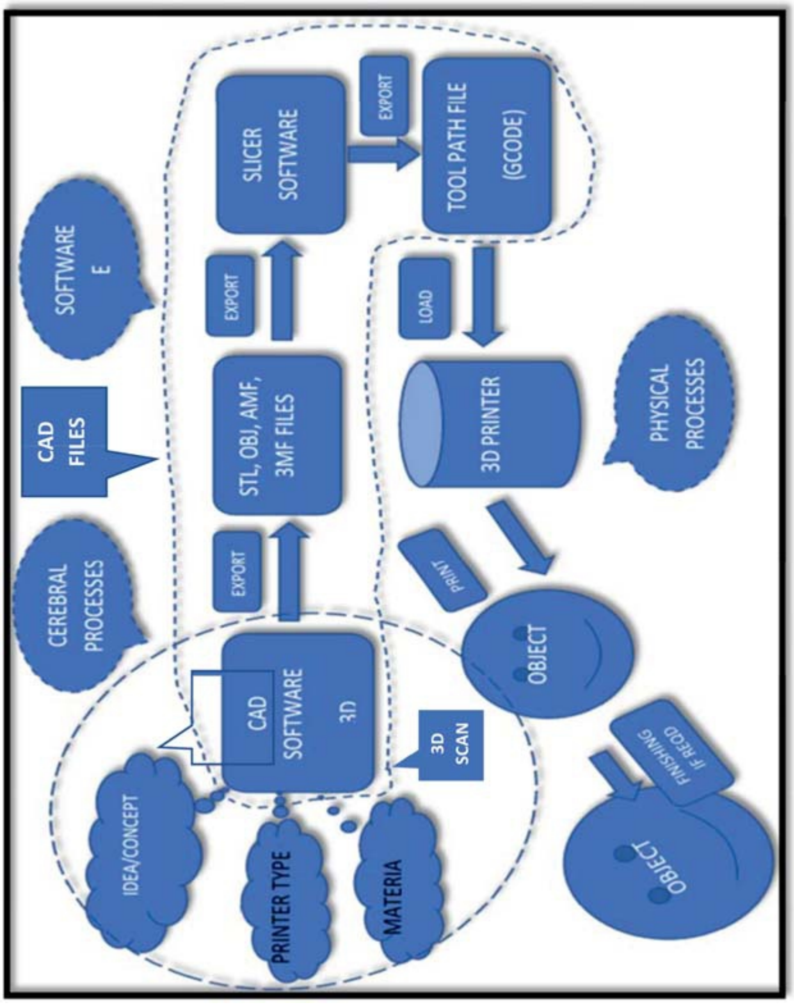

Fig. 1 : Stages for Printing a 3D Object

SLA (Stereolithography) is amongst the first 3D printing innovations and can print resin objects. Fused Deposition Modelling (FDM) / Fused Filament Fabrication (FFF) printer works by extruding a thermoplastic plastic layer-by-layer onto a "bed". A plastic "filament" is pushed through a heated nozzle, where it liquefies. The nozzle moves along programmed directions, where the printer fibre cools and solidifies thus creating the object. Multi Jet Fusion (MJF) printers create objects from nylon powder. Laminated Object Manufacturing involves layers of paper, plastic, or metal laminates coated with adhesive fused together with heat and pressure and then cut into required shape.

Most metal 3D printing technologies utilise metal powder — the variations lie in the method of fusing the powder into objects. Lasers may be used to fuse loose powder, or a metal powder filament may be extruded and deposited in shape of an object. Powder bed melting is the most common type of metal 3D printing wherein a fine layer of powder is distributed over a build plate and the powder is selectively melted to form a cross section (layer) of the part. Specific Laser Sintering (SLS)[3] is similar in principle to SLA; however, it makes use of powdered material placed in a container. A roller deposits a layer of powdered material on the previous layer which is sintered by a laser beam according to a programmed pattern. Selective Laser Melting (SLM) and Electronic Beam Melting (EBM) is very similar to the SLS process, however, it fully melts the powdered material. Direct Energy Deposition method uses powder or wire feed and a laser to fabricate parts. A powerful laser beam fuses the dispensed metal powder or wire layer by layer till the object is formed. In Binder Jetting process metal powder is evenly distributed over a print bed after which a jetting head distributes binding polymer conforming to the shape of the object which is later sintered. Bound Powder Extrusion utilises metal powder bound in a polymer which is extruded like FFF. Cold Spray technique uses a stream of supersonic gas to accelerate metal powder particles at a surface, building up a dense deposit.

Employment of AM in the Military

Combat Vehicles Hulls. Monolithic hulls of combat vehicles are more survivable and lighter. Such hulls are superior; however, they are not cost-effective nor suited to large-scale conventional production. Hulls of combat vehicles can now be printed in one piece using 3D Printing. This will enable production of vehicles which are lighter and cheaper, however, with greater impact resistance.

Construction of Field Shelters. 3D printers can construct entire buildings with quick-drying concrete. In just 36 hours, a 3D printer manufactured by Icon[4], and operated by US Marines, whipped up a concrete structure bunker big enough to hide a truck-mounted multiple rocket launcher system.[5] This technology can thus create quick and effective field shelters. We can train our combat engineers to operate the equipment and use it effectively in field. It will be possible to create durable structures virtually anywhere for personnel, equipment, and supplies.

Fabrication of Essential Components. At times, the original manufacturer discontinues manufacture of a certain part and may charge exorbitantly for the part. 3D printing can be effectively used in such situations. A case in point is the vehicle hatch plug which is an essential component mounted on combat vehicles for missions conducted in low-light conditions. The OEM discontinued the part, which meant that the replacement would cost about $10,000 with lead time of months. With metal 3D printer from Markforged[6], the US Army was able to fabricate hatch plugs that were not only significantly cheaper, but sleeker and more efficiently designed. Further the engineers simplified the design of the hatch plug down to four parts from ten. In this case 3D Printing saved them more than $244,000 in costs for low-volume production, as well as streamlined the design of the crucial part.[7] The AFLMC too has found numerous uses of AM. The Black Hawk helicopter (41 years old), B-2 Spirit (Stealth Bomber), Super Galaxy[8] to the B-52 Stratofortress add to some of the examples. There are only twenty aircraft in the B-2 fleet due to which its replacement costs are enormous with long lead period. However, with AM it is possible to design and print a printable part within a week with fraction of cost of conventional processes.

Manufacture of Equipment Parts. Research is underway to create lightweight vehicle parts, such as brackets, turret components, propulsion systems, and weapons, using AM. The use of lightweight metals, such as titanium, titanium alloys, and hybrid ceramic tile composites are being explored in conjunction with 3D printing for the US Army's Next-Generation Combat Vehicles (NGCV) program.[9] The F-22 Raptor, the US Airforce's most expensive fighter jet is flying with 3D printed parts since 2019.The 3D printed part is used in the cockpit that was made originally of aluminium and was replaced repeatedly during maintenance. Its replacement, the 3D printed titanium part does not corrode and could last the lifetime of the stealth fighter. At least five more metallic 3D printed parts are planned for the F-22.[10] There are many other 3D printed parts approved for use on military aircraft around the world, including the aging E-3 Airborne Warning and Control System and the B-52 Stratofortress.[11] 3D printed propellers provide ships with greater efficacy at sea, including increased thrust efficiency, stealth and is lighter. French have developed the largest 3D printed metal ship propeller for a warship. It has a 2.5-meter span supported by five 200-kg blades. This new technology will considerably reduce technical constraints and allow for manufacturing with complex geometrical shapes which cannot be produced through conventional processes with significantly reduced construction periods.

Submarine Manufacture and Repair. The Australian Submarine Corporation (ASC) is trying to explore the potential of using cold spray technology at sea for submarine repairs.[12] This technology will be employed to repair naturally occurring faults in the pressure hulls of submarines. A cold spray printer that can fit within a submarine and carry out repairs at sea will increase the deployment periods of submarines. This will also reduce the docked periods for conventional repairs. The USA has constructed small 3D printed submersible hulls in four weeks and cut production costs by 90 per cent. The hull is 30 feet long and made of six carbon fibre composite sections. A similar submarine built by conventional means would have taken about 5 months. A traditional SEAL Delivery Vehicle costs between $600,000 and $800,000, however, this submarine took costed as low as $60,000 and it took only a few days of printing effort.[13]

US Army Research Laboratory have recycled PET (Polyethylene Terephthalate) from bottles and plastics without any chemical modifications or additives and used it as the material in AM in form of FFF.[14] This will enable printing of replacement parts on demand in field and will increase the readiness of their equipment and print mission-specific devices.

Design with 3D Models. 3D Models are proving to be very effective in construction process, for instance the United States Coast Guard is constructing a new vessel that was designed, built, and verified using an end-to-end 3D design process. This implies that it used only 3D models — no paper — in design and construction for all structures. This process reduces costs and time investment and ensures interaction between all stakeholders throughout all the phases. It ensures that the designer, engineer, production manager, fitter, welder, and surveyor all work from the same complete model. Everyone has access to both the micro (component) and macro (complete assembly) with which they are working to better understand the bracket, frame, or bulkhead as it relates to the module, section, and ship.[15]

3D Explosives. 3D printing of explosives reduces storage and transport costs and provides enhanced performance with duplicability. The explosives can be printed to custom shapes for specific missions providing greater effect with lesser material. The British Armed Forces have created a technique which could offer on-demand, 3D-printed explosives. The explosive charges can be fabricated with hitherto-impossible intricacy, on-demand, and fully tailored to specifications.[16] AM can also be used to produce gun propellants with greater efficacy than traditional methods. A 3D printed gun propellant based on SLA was developed to overcome the limitation of traditional extrusion technologies.[17]

Medical Applications. AM can be employed to produce custom prothesis, dental tools, and medical models and hearing aids. The USA Veteran Affairs uses 3D printing technologies for pre-surgical planning, which has been reported to save doctors as much as two hours per surgery, or up to $9,600 in cost.[18] It also reduces the time patients are under anaesthesia and thus increases availability of operating rooms. The Army Medical Research and Development Command (USA) has been 3D printing more than 12,000 nasal swabs per day to conduct Coronavirus testing as well as prototyping and testing N95 respirator masks.[19]

Reduction of Supply Chains. It is obvious that bringing the factory to TBA can shorten the military supply chains. A company ExOne[20] has been awarded contract by US Department of Defence to create a special military-edition 3D printer capable of binder jet 3D printing more than 20 metal, ceramic and other powder materials into direct final products or tooling. This will be a 12 m long military grade portable AM unit capable of being deployed on land and sea housed in a container.[21] Australian Military has also developed a similar system. It's use of cold spray technology as an alternative to gasses or lasers makes it ideal for military applications.

Reduction of Static Inventory. 'Produce on Demand' 3D printing offers enormous scope to reduce inventory of spares. The entire printable inventory can be held in digital form and printed on demand on a printer held in a unit or subunit or higher levels. For one all plastic parts of a rifle can be held in a pen drive or a computer as a 3D object. It will even be possible to hold Tool Path Code (g-code) files for specific printers and conditions. All then what is required is to load the file onto a 3D printer and the part will be printed and used. Complex printers printing metal parts can be held at the level of a brigade or a division. An officer (not necessarily a 'techie') who can use a CAD software can design custom made parts for custom objects/innovations. It thus reveals incredible opportunities at all levels. Using an CAD software is a matter of interest and can be as simple as handling a word processor depending on one's aptitude. Units carry a stockpile of replacement parts to field, which is an expensive affair both in terms of money and manpower. Furthermore, a large proportion of spares remain unused. Having the ability to 3D print on demand reduces costs and frees up space.

Reduced Lead Times. AM can provide capability to design and produce parts with lead times in terms of days rather than months. It can thus respond faster to combat equipment needs at all locations. It can produce parts of aging but still serviceable equipment for which commercially available replacement parts are not available.

Minimum Order Quantities. This technology enables the repair and maintenance echelons to acquire the replacement parts on short notice without concern over the minimum order quantities. This issue is particularly challenging for some types of equipment which have a small inventory or fleet sizes but are still in service.

Formal Structures for AM in other Militaries

AM is already being used in many major militaries particularly USA. In USA, the Joint Defence Manufacturing Council is trying to synergise AM under a unified strategy to employ it to promote military readiness, cut costs, shorten supply chains, and accelerate innovation. The Pentagon has enunciated an AM strategy which calls for 3D printing to be integrated into the defence industrial base and promoted for use within all the branches. Further, US Marine Corps have established Advanced Manufacturing Operations Cell (AMOC). The AMOC issues policy, certifies and store digital files of 3D-printed parts, and has established a 24/7 help desk to assist the field forces. It captures several technologies and processes, including directed energy deposition and cold spray.[22] The USA Marine Corps Systems Command (MCSC) is providing instructional courses on basic computer-aided design, 3D printing and other technical skills to Marines. The aim is to enable them to produce custom parts on-demand. Yet another USA entity, the Air Force Lifecycle Management Centre (AFLMC)[23] has also found numerous uses of AM for extending life of older aircraft.

The Way Ahead

The Indian Armed Forces should plan induction of AM at all levels down to subunit level. The inexpensive and simpler versions could be issued at the Brigade, unit, and subunit levels which could be FDM, SLA or FFF types. The metal printing SLM types could be procured at the levels of Divisional and Corps Workshops. The Base Workshops should be equipped with heavy duty versions of metal printers. The quantity of these printers should be worked out in due course depending upon the workload. The Technical Group at the Service HQ should monitor the utilisation of these printers and provide technical inputs and designs. These printers are so versatile that the designing of parts can be accomplished at any level other than those which are very complex and require professionals. The 3D printers for field formations (Corps and below) should be field transportable. The larger ones can be vehicle mounted or carried in field containers. DRDO should undertake research on the AM to develop fresh technologies and processes and feed the services.

It would be worthwhile to introduce AM in military education to make all ranks aware of its potential. This education is more important at impressionable stages at pre commissioning levels. The deployment of AM could take the following format in the Army:

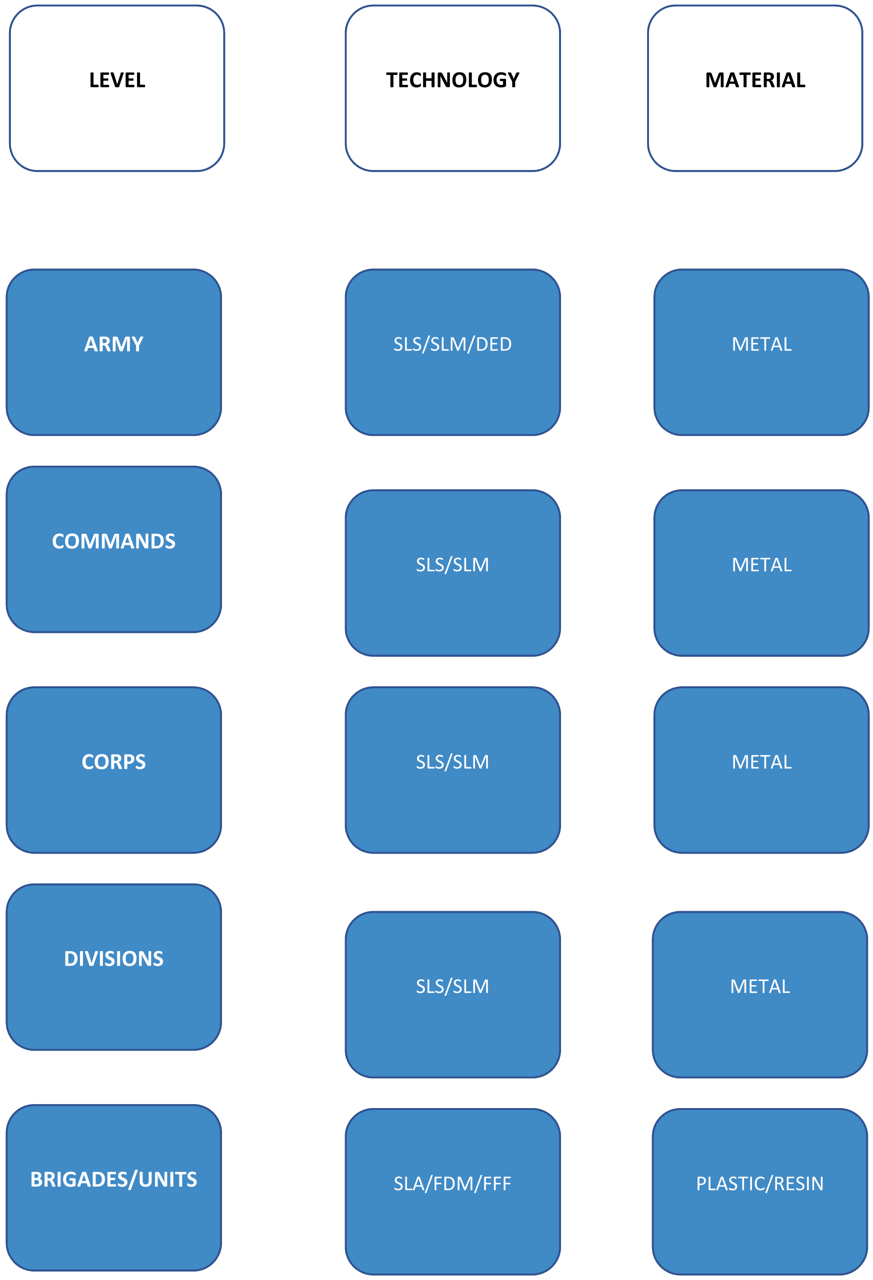

Fig. 2 : Format for Deployment of AM in the Army

All technologies have lead time, it is about time that we take 3D printing seriously and deploy these systems in near future. In fact, the cost of these systems has reduced drastically it can be inducted at local levels within an overall policy framework. It may not require long, and lengthy bureaucratic process mired in red tape. The onus thus rest upon the armed forces themselves.

Endnotes

[1] https://www.arpc.afrc.af.mil/News/Article-Display/Article/1734558/first-metallic-3d-printed-part-installed-on-f-22/

[2] example at https://www.prusa3d.com/

[3] Sintering is a process of converting loose fine particles into a solid object by heat and or pressure without fully melting the particles to melting point.

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[5] https://www.popularmechanics.com/military/a33500541/marines-3d-print-rocket-launch-shelter/

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[20] https://www.exone.com

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