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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Additive Manufacturing Methods, Techniques, Procedures, & Applications - Enabling Technologies for Military Applications

- Additive Manufacturing gives capability to print parts at point of use in theatre
- In order to print parts, 3-D model data and machine manufacturing instructions are required (CAD + CAM)
- Pedigree of part is conditional upon certified model and manufacturing data
- DoD wants soldiers to have capability to make parts in theatre using additive manufacturing

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Armament Research, Development and Engineering Center

Research

Development

Production

Field Support

Demilitarization

Vision:

Innovative Armaments Solutions for Today and Tomorrow

Mission:

To develop and maintain a customer focused, world-class workforce that will execute, manage and continuously improve integrated life cycle engineering processes required for the research, development, production, field support and demilitarization of munitions, weapons, fire control and associated items.

Advanced Weapons – line of sight/beyond line of sight fire, non line of sight fire, scalable effects, non-lethal, directed energy, autonomous weapons

Ammunition – small, medium, large caliber, propellants, explosives, pyrotechnics, warheads, insensitive munitions, logistics, packaging; fuzes, environmental technologies and explosive ordnance disposal

Fire Control – battlefield digitization, embedded system software, aero ballistics and telemetry

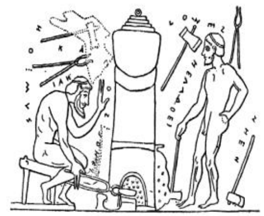
ARDEC Provides the Technology for Over 90% of the Army's Lethality and Provides Significant Support to other Services' Lethality

What is Additive Manufacturing?

Additive Manufacturing (AM) is the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. (ASTM F2792-12a)

Stone Age

Early subtractive processes



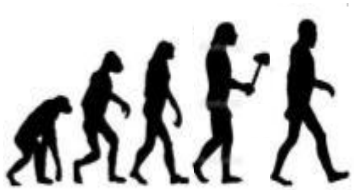
Bronze Age

Early additive processes

Iron Age

Consolidation of subtractive processes

To add or subtract…



that is the question

20th Century Processes

Subtractive	Additive

Machining   Forging   Sintering   Direct digital (additive) manufacturing

Materials for AM: Powder to Product

Expertise in each aspect of the manufacturing process for transition to the industrial base

Characterization → Consolidation → Confirmation

Fundamental understanding of the impact of all processing parameters is essential at each step

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Army Opportunities

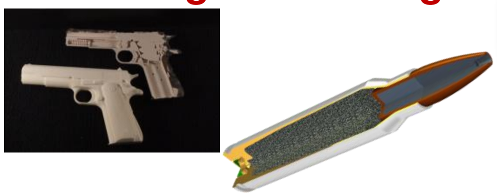
There are opportunities for AM to impact all Army systems

Remote Weapon Systems, UGVs, UAVs

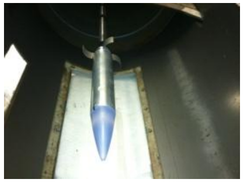
Aviation Systems

Weapon Systems/Subsystems:

Training & Planning



Test & Analysis: Models, Test Platforms, BITs, Prognostics& Diagnostics



Soldier Systems

Munitions & Missiles: Metal Parts, Fuzes, Energetics, Warheads

Life Cycle Optimization: Parts Replacement & Improvement, Embedded Tracking & Monitoring

To be successful, the Army needs a strategy make AM available to users

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Why Are We Interested?

- **Reduced manufacturing costs**
  - Rapid Prototyping
- **Systems Resilient Engineering / Reduced reliance of proprietary system**
  - IP Protection, Data Rights, Database Access, TDP ownership(s)
- **Conformal designs & better interior volume utilization**
  - Reduced size & weight
  - Electronics/mechanics applied to interior surface of the munitions and/or onto Warfighters
  - More room for added components
- **Affordable components for smaller munitions items**
  - Sensors, antennas, Fuzes, etc.
- **Mission tailored**
  - Direct from CAD to prototype
  - Performance tailored to the materials employed
- **Versatile**
  - Can include, electronics, MEMS, electromechanical, optoelectronics and power sources
- **Easier transition from single prototype to large scale manufacturing**
- **Faster material release**
  - Factory in a truck, Fabrication in theatre, Just in time
- **More immune to obsolescence**
- **Potential for less reliance on off-shore sourcing**
- **New Techniques / Methodologies for Munitions Design / Integration / Fabrication**

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Current RDECOM AM Capability

TARDEC

Ground and Support Systems Technology Prototyping & Integration

Processes **Total # of machines**	• Direct Metal Deposition • Fused Deposition Modeling • Selectively depositing liquid binding material • 4 machines in total
Materials **Applications**	• Fe, Co, Ni, Ti, and Cermets • Coating / part repair, 3D printing, & Multi-material joining

ARDEC

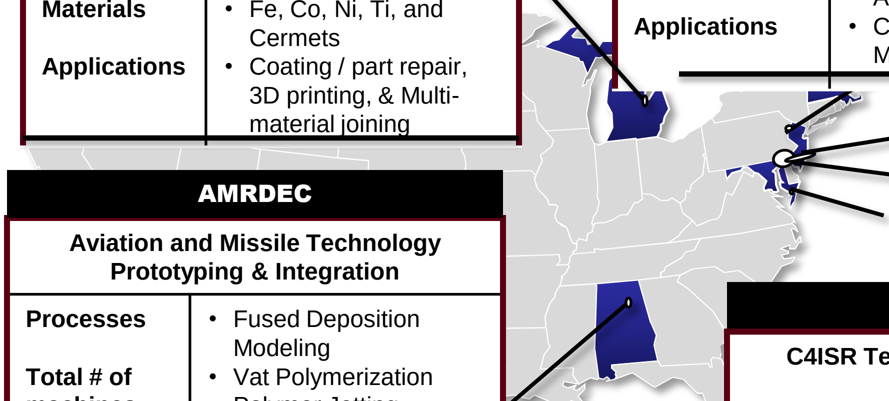
Armaments Technology Prototyping & Integration

Processes **Total # of machines**	• Printed Electronics, Polymer Extrusion, Vat Polymerization, Powder Bed Polymer and Metal Fusion • 46 different machines / capabilities
Materials **Applications**	• Epoxy, ABS, PLA, Wax, 17-4 SS, 300 Maraging Steel, Nylon, Alumide, PE Materials, etc • Casting molds, Prototypes, Munitions' Components

ARL

Army Research Lab

Processes **Total # of machines**	• Polymer extrusion • Vat Polymerization • Powder Bed Metal • InkJet • Aerosol Jet • Micro Pump Deposition • Non-Commercial Systems • 13 machines in total
Materials **Applications**	• Polymers, Metals, Ceramics & materials for printed electronics • 6.1-6.2 materials and tech development



AMRDEC

Aviation and Missile Technology Prototyping & Integration

Processes **Total # of machines**	• Fused Deposition Modeling • Vat Polymerization • Polymer Jetting • Dimatix • 10 machines in total
Materials **Applications**	• ULTEM*, ABS (Acrylonitrile Butadiene Styrene), PLA (polylactide) • Prototypes, electronics

CERDEC

C4ISR Technology Prototyping & Integration

Processes **Total # of machines**	• Polymer jet printing • 1 machine
Materials **Applications**	• photopolymer • Engineering development prototyping

ECBC

Chemical and Biological Technology Prototyping and Integration

Processes **Total # of machines**	• Polymer extrusion • Vat Polymerization • Powder Bed Polymer and Metal • Polymer Jetting • Binder Jetting • 13 machines in total
Materials **Applications**	• ABS, ULTEM*, PC, PPSF (polyphenylsulfone), Nylon 11, Nylon 12, Steels, Cobalt Chrome, plus more. • Prototypes, unique fixtures, end-use items, Tooling and tooling inserts

*** ULTEM -** Resin family of amorphous thermoplastic polyetherimide (PEI) resins offers outstanding elevated thermal resistance, high strength

Additive Manufacturing – Applications Roadmap

2012 | 2014 | 2016 | 2018 | 2020

Sustainment-Centric:
Tooling and Repair

Substitute/Replace

Process Centric

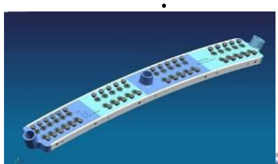
Process drives design and performance

Rapid Tooling/Fielding

Novel Designs

Process Substitution:
Alternative manufacturing for conventional manufacturing processes





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The Additive Manufacturing Challenge

New additive manufacturing processes bring the promise of enhanced performance with the flexibility of historical additive processes like casting and welding

- Current additive processes can produce
  - Tailored material combinations
  - Functionally gradient materials
  - Opportunity for material customization
  - Ability to produce unique geometries
- Each part is unique, therefore certification of the material, process, and qualification are paramount
- A roadmap must recognize both the opportunity and the challenges presented by the uniqueness of the process

Welding, sintering, and casting provide excellent benchmarks for additive manufacturing, since they have similar requirements for process qualification and part uniqueness for part acceptance

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Summary of Major Technology Challenges

- **Each part is unique, therefore certification/qualification of the material and process are paramount**
  - Part quality is tied closely to process parameters, therefore processing conditions must be defined to ensure a quality part
  - Because industry views AM process data as proprietary, the process data needed to guarantee part performance is not available and is held as IP
- **AM standards are not available – much of work is still in progress**
  - The relationships between materials, process and performance have not been established, so standards development is slow
  - In specific cases, companies have established their own standards, which they retain as proprietary
- **There are a limited number of machines, additive processes and materials available from the equipment manufacturers**
  - Material performance is not always "as advertised" on the equipment mfr. Data sheets and not fully characterized for all use cases
- ***No full materiel release – no systems in the field using additive parts***
  - The few cases where additive has been used to produce a part are on an exception basis: SOCOM, REF for spares, repairs and/or tooling

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Army AM Investment Strategy

The RDECOM Community has developed a plan for five year progressive stages of adoption, supported by four pillars of investment:

FY15-19	FY20-24	FY25-29+
Part Alternative	**Process Alternative**	**Product Alternative**
Rapid Fielding – Point of Use manufacturing	**Process Substitution**	**Novel Designs**
Tooling and Repair	**Primary manufacturing**	**Novel Materials**
Part Substitution		

Pillar 1: Material and process certification and qualification

Pillar 2: Army Additive Manufacturing Knowledge-base

Pillar 3: Machine Technology and Material Improvements

Pillar 4: Transfer technology to the industrial base and field

Level of complexity from low to high, evolving from part to system, and from early adopters to traditional acquisition

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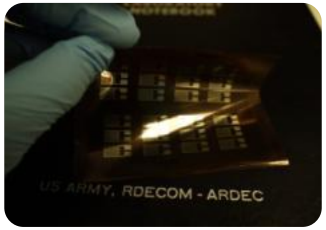
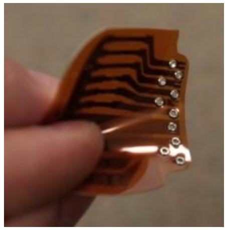
Military Considerations

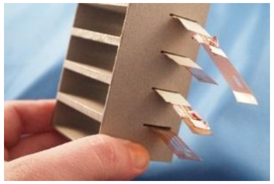
- DOD heavily investigating the utilization of Additive Manufacturing for weapon systems.
- Transportation, storage, and operational environments must be considered.
- DOD represents unique environment for printed electronics utilization.
  - High G loads
  - Extreme Temperature and Humidity ranges
  - High shock and vibration loads
  - Extended Periods of dormancy (+20 Years)
- Limited data for failure mechanisms, failure rates, reliability, survivability.
- Need for high reliability devices in DOD applications.

Systems / Sub-System Efforts

- Munitions & Warheads
- Printed Super-capacitors
- Flexible Power Sources
- Detonation Sensors
- Armaments/Munitions Prognostics & Diagnostics
- HERO Safe RFID Tags
- Instrumentation for Training & Simulation (MILES, TAGS, P&D, etc.)
- Fuze Systems / Components
- Printed PROX / Fuze Antennas
- Remote Weapon and Unmanned Systems Integration





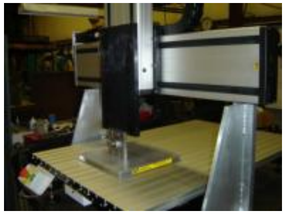


Process Development Efforts

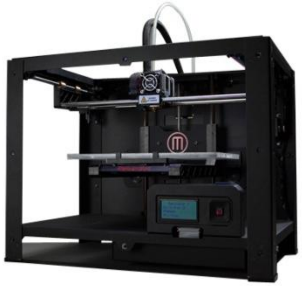
- Materials Development (Inks, Powders, Binders, etc.)
- Ink Formulations
- Recycling / material Re-use
- Additive Manufacturing Techniques
- Integration of 2D & 3D Printing
- Integration with Munitions, Warheads & Energetics
- Equipment modification / Development (i.e. multi-head /material capabilities)
- Deposition Techniques
- Testing and Evaluation
  - Qualification
  - High –G survivability
  - Reliability
  - Long-term Survivability
- Interconnects / Solderability

ARDEC 3D Printing Capabilities

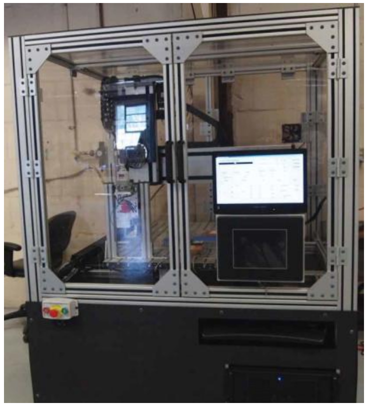
- Material Printers / 3D Printers
  - Plastics (PLA, ABS, other)
  - Inks
  - Powder-Binder
  - FDM
  - LOM (Laminates)
  - Direct Laser Sintering (Metals & Plastics)
  - Several Custom & Multi-material systems



- 3D Scanners
  - Photo, Digital, Laser, etc.

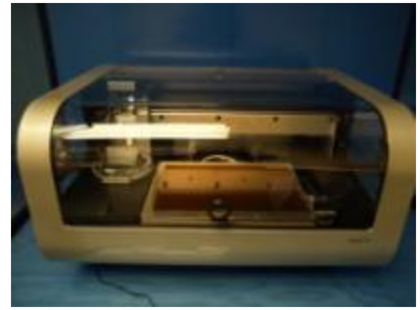


- 3D CAD / Modeling
  - NetFab
  - MasterCam
  - Pro-E
  - Maya
  - Solid Works
  - Sketch-Up
  - Adobe Design Suite
  - 3D Studio Max
  - Z-Edit
  - Others



PEEMS Capabilities

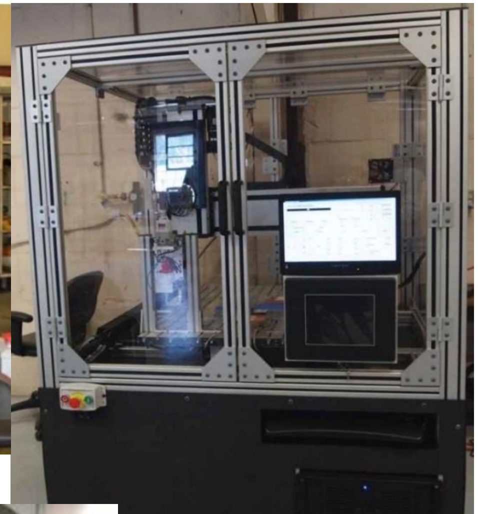
- **Ink Jet**
  - Dimatix, Epson, PixDro

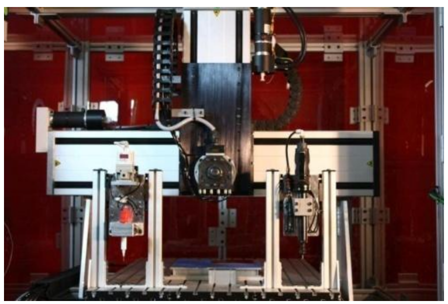


- **Aerosol Jet**
  - Optomec
- **Micropen / Direct Write / DipPen**
  - Sonoplot, EFD, M3P, NanoInk, Controlled Syringe, nFD
- **MicroPump**
  - nScrypt

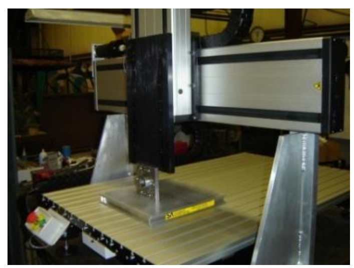
- **Screening & Stenciling**
- **Etching & Routing**
- **Transfer & Plating**
- **Multi-Axis Module Manufacturing Platform (M3P)**
- **Numerous 3D Capabilities**

Multi-Axis Multifunctional Manufacturing Platform M^3P





ABS extruder tool module



Camera/inspection tool module

Syringe deposition tool module

Spray/encapsulant tool module

4-point robe/inspection tool module

Router tool module

The M^3Platform is a part of the concepts being developed at ARDEC looking at new and innovative production methods to better meet future Army needs. By combining multiple manufacturing techniques with direct write and additive manufacturing capabilities, ARDEC's goal is to have flexible and low cost capabilities for prototyping and production. Just-in-Time Manufacturing and Fab-in-the-Field concepts are being explored.

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Unique AM Technology - SuperScrypt

SuperScrypt

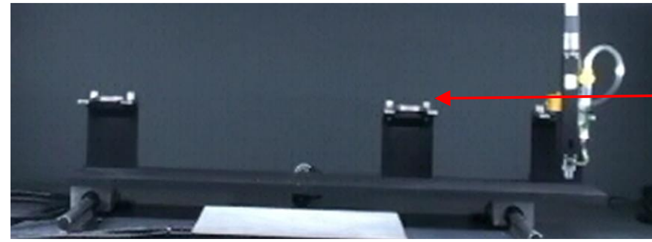
Dubbed the SuperScrypt, this multi-technology printing system is the only one of its kind. The systems is based on nScrypt processing controls and software, which are fully open for manipulation (variation of processing parameters). This system includes:

- Line Scanning
- Thermoplastic Extrusion (up to 400°)
- Thermoset Deposition
- Ink Deposition
- 6-Axis Motion Control
- Tool Switching
- Pick-n-Place

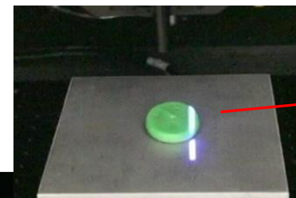
(0 to 2,000,000cP, with pico-liter control)

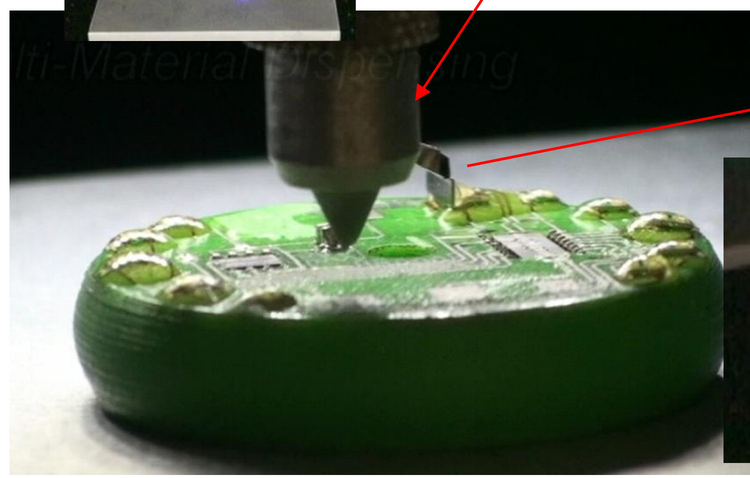
To be added in FY15:

- Micro-Sprayer
- Micro-Milling
- Laser Sintering
- Aerosol Jet Deposition
- Micro Cold Spray Deposition
- Materials Hopper
- Auger

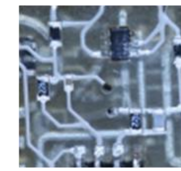


Tools can be added as needed

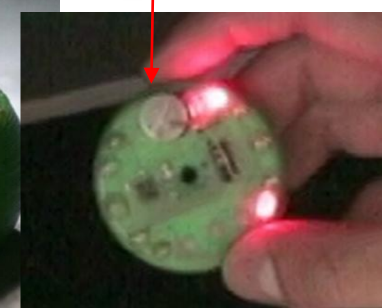




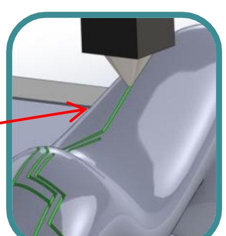
Scan-to-Print



Fabricate a functioning device



Conformal Printing



With Scan-to-print capability, the SuperScrypt can deposit on complex curves, or build 3D shapes from scan data.
Inverse kinematics enabled 6-axis motion control allows for true 3D printing instead of stacking 2D layers. Robust hardware allows for +/- 200nm precision.

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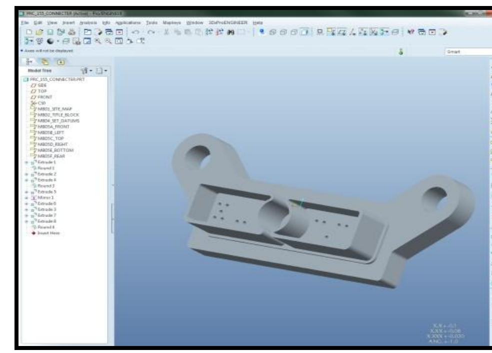
Additive Manufacturing Success Story

PROBLEM:

- ARDEC engineers received the new GD—PRC155 Radio to integrate into our fire control systems.
- The radio had a special connector and when ARDEC engineers tried to order it…
- The connector was on 3-4 month back ordered and at a cost ~$300 each, with a min purchase of 50 ($15,000).



SOLUTION:

- ARDEC engineers modeled and then printed the connector on an in expensive in-house 3D printer.

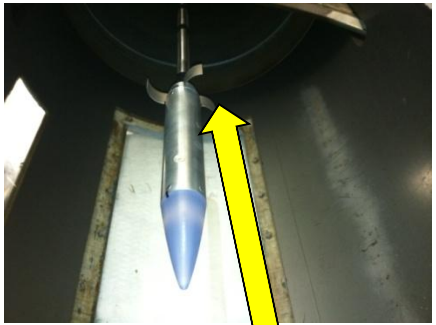
PAYOFF:

- Cable fabricated & tested with-in 1 day!
- Avoided 3-4 Month program slip
- ~$14,500 savings in program cost
- 3D Printed Part: ~$0.25, 2 hr modeling time & 1 hr print time

Additive Manufacturing Success Story

PROBLEM:

- Novel design of Wrap Fins on Next Generation PGM required custom fixtures, required wall thickness makes casting very difficult and costly, and different variants are required for wind tunnel testing.
- Geometries of Wrap Fins lead to cracking with conventional manufacturing methods (EDM).



AM SOLUTION:

- ARDEC Engineers were able to use Additive Manufacturing via metals selective laser sintering to fabricate Wrap Fins for wind tunnel testing.
- Alternative designs and variants were fabricated with limited turn-around time that would be almost impossible with conventional metals manufacturing processes.

BENEFIT / SAVINGS

- Devices fabricated and tested in days vs. months using conventional procedures
- Enhanced design capabilities that could only be fabricated via 3D printing (unique geometries).
- Cost Savings

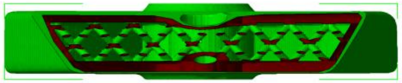
Additive Manufacturing Success Story

PROBLEM:

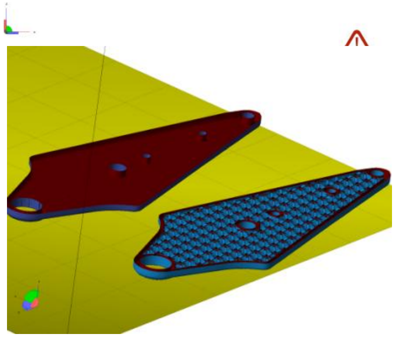
- Warfighter need to reduce weight of PackBot to meet weight requirements for man portable system.
- iRobot proprietary models and design files.
- Original Flippers are cast metal and machines holes with plastic coatings for environmental protection.

AM SOLUTION:

- Used 3D scanning capabilities to rapidly create 3D models of best candidate parts for weight reduction.
- Used CAD software to redesign with reduced weight and material alternative designs (flipper & support arms) that could not be fabricated cost effectively with traditional processing (casting, machining).



BENEFIT / SAVINGS



- Devices fabricated and tested in days vs. months
- Enhanced design capabilities that could only be fabricated via 3D printing (unique geometries).
- 45% Volume/Weight reduction (242.30 cm^3 reduced to 134.84 cm^3)

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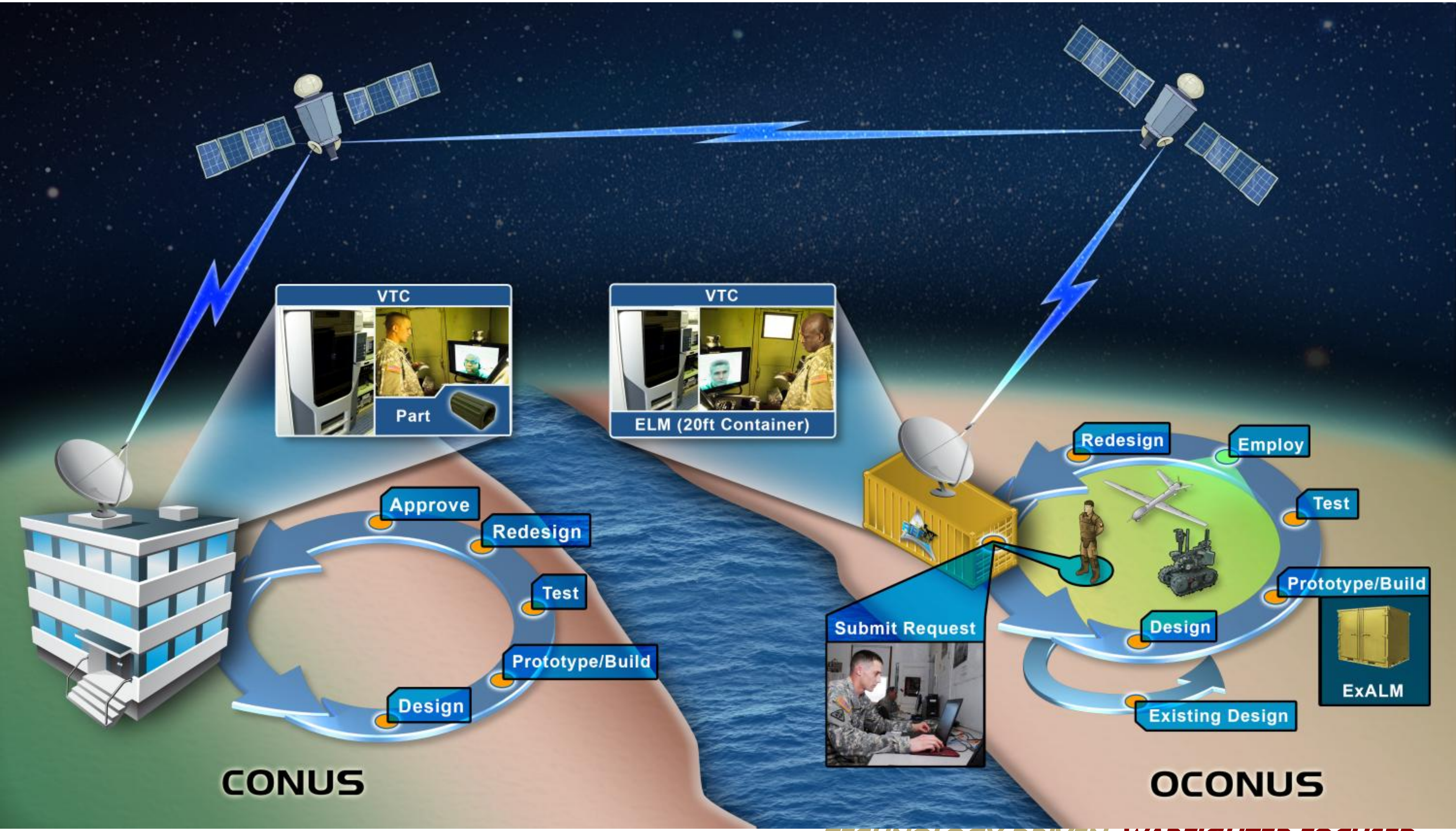
"Soldier to Solution"



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http://www.additivelib.co
www.additivelib.com
Additive Manufacturing Library
A Digital Repository of Robotic Concepts and Designs for Use by the Warfighter
REF
U.S.ARMY
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Mini Track Bot
Designed as an ultra portable bot for camera surveillance in any terrain. Operated by a small touch screen controller with adequate range for the soldier to standoff at a safe distance.
Weight: 2 pounds
Dimensions: 8” x 7” x 5”
Status: Approved for printing
Order
More Info
Log Interest
Concept
Approved
Conditionally Approved
Under Review
Approved
Approved
Search:
Category
Ground System
Air System
Component
Other
All
Filter
Approved
Conditionally Approved
Under Review
Concept
All
Key Word
Sort By
Newest
Author
Class
State
Rapid Equipping Force | 10236 Burbeck Road, Ft Belvoir, VA 22060
10:30 AM
4/7/2014

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Warfighter Benefits

- Provide the Army with state-of-the-art technologies
- Weight / Volume savings
- Cost effective prototyping & fabrication techniques
- Increased force effectiveness and reduce operations, support, maintenance, and liability costs
- Transition from scheduled to condition based maintenance
- Increase Army readiness by reducing equipment downtime
- Increase safety by providing ammunition assurance
- Reduce reliance on proprietary systems
- Systems Resilient Engineering (IP Protection, Data Rights, Database Access)
- Improved asset protection
- Paradigm Shift in Energetics Development, Production & Testing
- Improved Testing Capabilities
- Improved Training & Planning Operations
- Optimized R&D / Systems Engineering

The Future !?!

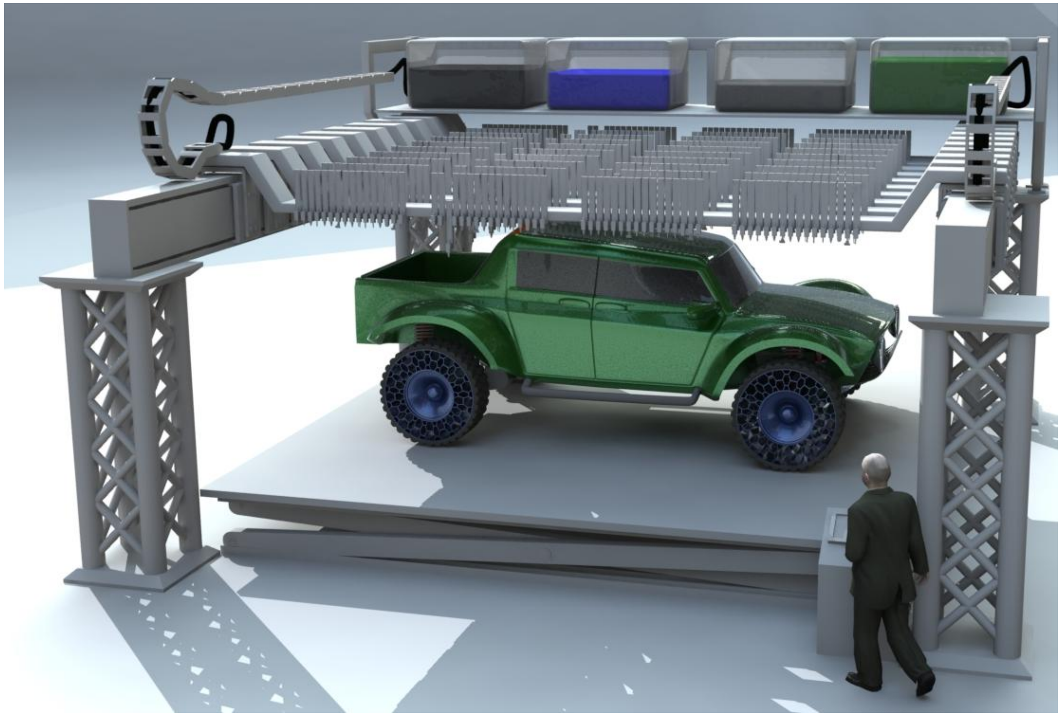
Reference: Ken Church - UTEP

3D Printing (Additive Manufacturing) has had an impressive record.

Combining 3D Printing with Printed Electronics will create a disruptive approach with the Cyberfacturing of **ANY** electronic device.

The biggest benefit will be seen by the DoD and consumers.

When entrepreneurs can begin to inexpensively produce the dreams of their imaginations, the manufacturing revolution will begin.



Imagine a day when large automobile factories are replaced by Dealer Cyber Factories.

Thoughts ?

Ralph Tillinghast
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