Additive manufacturing (AM) (also referred to here as 3D printing) offers the ability to build lightweight components that are optimally suited for use in aerospace applications. AM can also support sustainable exploration of the surfaces of the Moon and Mars by enabling needed components to be fabricated onsite. Significant strides have been made in the development of AM, with 3D-printed components now being part of active aircraft and spacecraft. While the use of AM has enabled nontraditional designs and decreased part counts, full inspection of each component is typically required postbuild to determine fitness for the final application. Complex geometries, rough as-built surface finishes, and porosity can hinder inspection. If 100% inspection is not possible, proof test logic or some other method of proving fitness for use must be applied. Defects that occur can force a complete reprint. The ultimate promise of AM is to enable on-demand production of customized unique components. For utility in space applications, printed parts have to be fully functional, with zero to minimal postprocessing. Ideally, parts need to be built with acceptable form, fit, and function the first time, with sufficient documentation to allow direct entry into service. To enable the full realization of the potential of 3D printing, a capability for closed-loop control of the process that integrates in situ monitoring, real-time defect detection and identification, and print parameter modification is required.

Wire-feed or extrusion-type AM, with its relative simplicity, wide range of feedstocks, and build volume flexibility, is a popular 3D-printing technique that is well suited to space applications. Fused filament fabrication (FFF) of thermoplastics and electron beam free-form fabrication (EBF3) of metals are useful examples of wire-feed processes to
illustrate the limitations placed on AM by presently available design and process control tools. After designing an object using 3D modeling software, the geometry is passed to a slicing and tool path planning code, which generates the list of instructions needed by the printing hardware. Once received by the printer, no further modifications or corrections can be made, and the process continues to completion.

Proposals are invited to advance the manufacturing technology by incorporating an in situ defect detection and correction capability into wire-feed processing of metallic parts and FFF or related extrusion processing of thermoplastic, thermoset, or composite components.

In Phase I, contractors should prove the feasibility of integrating sensor feedback with appropriate software tools and computation resources to be able to detect defects during fabrication of parts with complex geometries, evaluating the potential impact of the defects to the part performance and the correction of those defects. Solutions sought include software that can be integrated into the 3D-printing workflow, hardware requirements to run that software for real-time data processing, and sensors capable of operating in the build environment to provide data, also in real time. The proposed approach should be demonstrable at least on the coupon scale for shapes such as circles or boxes.

The proposed solution must include all of the following: (1) defect sensing and detection, (2) assessment of the impact of the defect on part performance, and (3) corrective actions other than scrapping of the build. Proposals that do not clearly include these three elements will be considered out of scope.

Phase II should demonstrate the feasibility of Phase I concepts to arrive at closed-loop solutions to build parts in which information on the processing generated from gathering and analyzing sensor data is used for the prediction of part performance, unique to each individual part, as it is being built. Incorporation of defect correction during fabrication, rather than requiring a print to be scrapped and restarted, should be demonstrated on sample parts.

**Expected TRL or TRL Range at completion of the Project:** 2 to 3

**Primary Technology Taxonomy:**
Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
Level 2: TX 12.4 Manufacturing

**Desired Deliverables of Phase I and Phase II:**

- Hardware
- Software
- Prototype
- Research
- Analysis
Desired Deliverables Description:

Phase I: Concept studies documenting the feasibility of incorporating sensor data feedback and appropriate software tools and computation resources to be used to detect defects during fabrication of parts with complex geometries, evaluating the potential impact of the defects on the performance of the parts and the correction of those defects.

The proposed solution must include all of the following: (1) defect sensing and detection, (2) assessment of the impact of the defect on part performance, and (3) corrective actions other than scrapping of the build. Proposals that do not clearly include these three elements will be considered out of scope.

Phase II: Scale demonstration of a printer with closed-loop control that incorporates defect detection, identification, and correction during fabrication. The complexity of defects that are detected and corrected, as well as the size of the parts, should demonstrate the challenges that would come up in full-scale use of the control processes. Printed part sizes should be at least 10 cm per side for cubes, with detectable defects down to the mm scale or smaller. The defects should have a demonstrable effect on the part performance, such as a decrease in mechanical properties, that is then corrected for by the process.

State of the Art and Critical Gaps:

AM is seeing rapidly expanding applications in many areas, including in aerospace. Despite this growth in AM, filling its full potential has always been limited by quality-control issues and certification of the manufactured parts, as each component that is built is unique. Some work has begun to add defect detection and correction to powder-based manufacturing processes, such as direct metal laser sintering (DMLS) and wire-feed AM. There has, however, not been the requisite advance in ensuring that defect detection and identification is coupled with the real-time correction of those defects and ensuring final performance of the manufactured part in a particular application.

Gap: Real-time defect detection, identification, and correction in AM processes that would ensure the performance of the as-printed parts without relying on postproduction inspection processes, with parts built with acceptable form, fit, and function the first time, with sufficient documentation to allow direct entry into service, has not been demonstrated.

Relevance / Science Traceability:

This topic fits under STMD (Space Technology Mission Directorate). It supports Advanced Manufacturing of Lightweight Structures. Enhancing quality control in AM opens up its use in many industrial applications as well as its use by NASA. In particular, in-space use of AM in future Gateway, lunar, and Mars exploration missions will require that parts that are produced are ready for use as-produced, because there will be limitations in availability of material for reprinting as well as limitations on crew time and equipment for postprinting inspection.

References:

Rutherford Engine Build"] (last visited on 09/28/2020)


6. [IBM Internet of Things blog: “Why quality is the obstacle to mass adoption of 3D printing"] (last visited on 09/28/2020)
