

A Laser-Assisted Machining Approach for the High Performance Machining of CMCs

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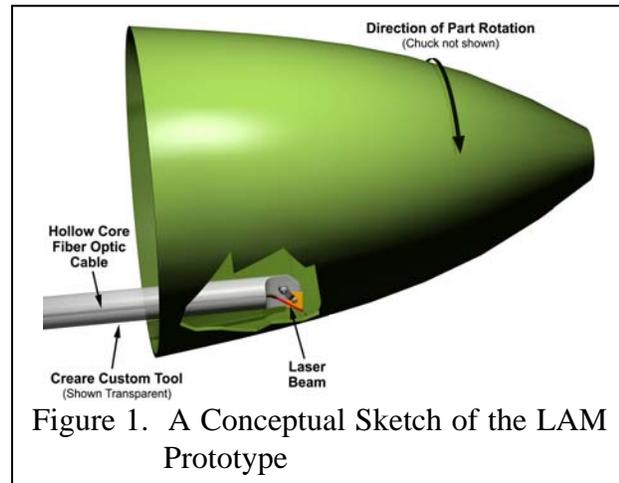
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PROBLEM STATEMENT



Ceramic matrix composites (CMC) are desirable for high performance aerospace and missile components due to their excellent strength-to-weight ratio and their ability to withstand high temperatures. However, CMC components are difficult to machine with conventional single-point tooling, rendering grinding as the only available option. The inaccuracies and sub-surface damage induced render grinding operations less than optimal for manufacturing CMC radomes. As a result, current CMC machining processes are costly and time consuming. New manufacturing technologies are needed to reduce the cost and decrease the cycle time associated with fabricating finished CMC components for key programs, such as the Joint Strike Fighter (JSF) and the Advanced Anti-Radiation Guided Missile (AARGM). The high strength and low density of CMCs are ideal for numerous military applications, including missile radomes and engine and exhaust-washed aircraft structures. The lack of affordable CMC parts available for integration into current military platforms diminishes opportunities to enhance the performance of aerospace systems. Creare's high performance Laser-Assisted Machining (LAM) addresses this problem by enabling the cost-effective, rapid machining of these difficult-to-fabricate materials, with a significant reduction in part rejection/rework, and decreased machine toll maintenance costs.

WHO CAN BENEFIT?

Our manufacturing technology enables the cost-effective production of high-quality, defect-free parts from hard-to-fabricate materials at increased processing speeds. While directly impacting the ability to produce affordable and effective radomes for AARGM, as recognized by PMA 242, Creare's Laser-Assisted Machining System will also enable the increased use of CMCs (and other hard-to-machine advanced materials) on many other aerospace platforms and systems. Consequently, Alliant Techsystems (ATK – AARGM Radome Prime) and key machine tool manufacturers are involved in our commercialization and transition plan. Medium and small-size machine shops which subcontract to Defense primes and other larger firms can also benefit from utilizing our innovation. Additional



applications for Creare's LAM technology can be found in the civilian aerospace, automotive and heavy equipment industries.

BASELINE TECHNOLOGY

The performance of a MilliMeter Wave (MMW) missile such as AARGM is highly dependent on the dimensions of its ceramic radome. Small deviations or variations of extremely tight tolerances on both the inner and outer contours of the ceramic radome impact the RF insertion loss of the radome, which also impacts the radar performance of the MMW missile. The current method for machining radomes utilizes a combination of custom-made and commercial grinding and machining tools on a CNC machine center. The process requires many iterations, with multiple machine setups for both inner and outer contour machining. Furthermore, because of the nature of the base material, repetitive dimensional inspections are required to ensure that the radome wall thickness is tightly controlled. In many instances, it is so difficult to realign the in-process radome properly onto the machine after having been removed for inspection that the radome has to be scrapped as its dimensional deviation makes the radome unusable for radar performance. These limitations in current methods for fabricating radomes also have a dramatic negative impact on costs and production timelines. Thus, there is a critical need to both develop on-machine measurement and tool path control systems, as well as an alternative to current grinding operations.

Creare's technological innovation is a novel Laser-Assisted Machining (LAM) system that enables single-point turning rather than grinding for the fabrication of CMC radomes for AARGM. For LAM, the laser heats, but does not ablate, a very thin layer of material near the surface. By using the laser-assist, the cutting forces during machining are reduced, which enables the production of CMC components at reduced costs and improved surface quality. Carefully controlled laser heating has enabled the single-point turning of other super-hard ceramics like silicon nitride, partially stabilized zirconia, mullite, and polycrystalline alumina (PCA) with no surface or sub-surface damage. Typically, these materials are finished using high speed diamond grinding, which removes material via micro-brittle fracture and grain pullout. While commonly used, grinding also induces significant sub-surface damage due to the material removal mechanism. Past work in laser-assisted machining has consistently produced smooth surfaces with no surface or sub-surface damage at high material removal rate (MRR). At Creare, we have previously demonstrated the two fundamental benefits of LAM for other ceramic materials. We demonstrated the fundamental mechanism of material removal; namely, that the laser facilitates machining of hard ceramics by thermally softening the material and reducing cutting forces. Employing Creare's Laser-Assisted Machining (LAM) system will significantly reduce costs, ease quality assurance challenges, and shorten radome fabrication time from a week to a half-day or less.

TECHNOLOGY DESCRIPTION



Creare's innovation is a novel LAM system for high performance machining of CMC components. For CMC materials, we used a commercial laser to preheat a thin layer of the CMC material prior to its removal using conventional machine tools. As illustrated in Figure 2, the laser heats, but does not ablate, a very thin layer of material near the surface. By using the laser-assist, the cutting forces during machining are reduced, which enables the production of CMC components at reduced costs. Carefully controlled laser heating has enabled the high material removal rate (MRR) single-point turning of other super-hard ceramics with no detectable surface or sub-surface damage when compared to grinding processes. During our testing on CMC materials, we demonstrated that the cutting forces were reduced by as much as 40% using LAM as compared to conventional machining processes. We completed a detailed cost model of our approach compared to the current state-of-the-art and found that our hybrid machining approach reduced the cost of machining CMC materials by as much as 37% compared to current processes. Due to the nature of the LAM process and Creare's unique expertise, an opportunity also exists to combine the LAM and our innovative On-Machine Measurement and Tool Path Control System that is being developed in a parallel Navy Phase II program. Thus, further decreases in cycle time and cost are possible beyond LAM itself. During the current Phase II program, we are integrating the laser with a fiber-optic delivery system and a CNC machine tool for AARGM radome machining.

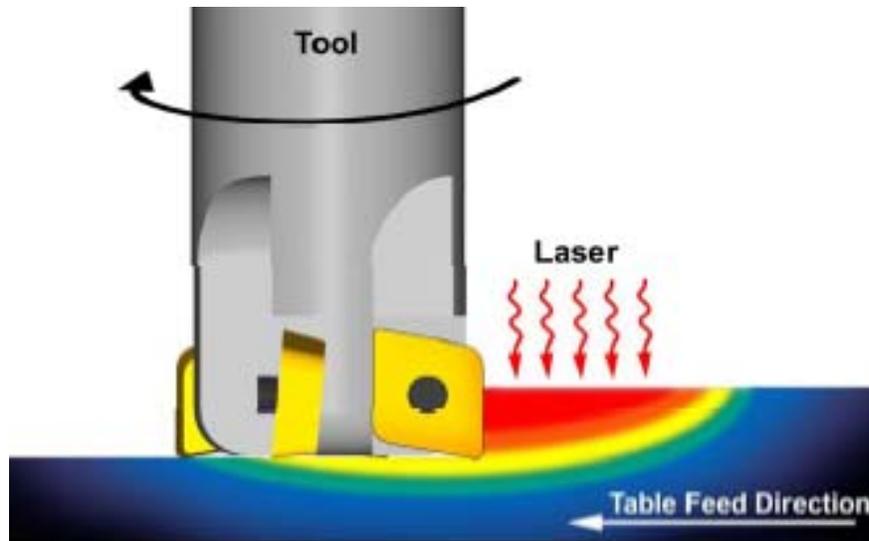


Figure 2. Illustration of Creare's LAM Approach for Machining CMC Materials. During LAM, the laser heats, but does not ablate, a very thin layer of material near the surface. By using the laser-assist, the cutting forces during machining are reduced, which enables the production of CMC components at reduced costs.

CURRENT STATE OF DEVELOPMENT

Table 1 below outlines our milestone schedule for the Phase II project. We are currently working on our first technical milestone, the Prototype Design. We are currently working with NAVSEA and a machine tool manufacturer to determine the funding source



for the integration platform, a commercial Vertical Machining Center (VMC). Our baseline plan is that NAVSEA will purchase the VMC and deliver it to Creare. We will design (Prototype Design), install, integrate, and test (Prototype Fabrication and Integration) a LAM system for the VMC at Creare. Next, the LAM-equipped VMC will be shipped to NAVSEA's Allegheny Ballistics Laboratory (ABL) for the Performance Demonstration. ABL is a NAVSEA-owned facility where ATK plans to complete the manufacturing of AARGM radomes.

Table 1. Phase II Milestone Schedule

Milestone	TRL	Risk-Test	Measure of success	TRL date
Prototype Design	3	Low	Complete Design	3/10
Fabrication and Integration	4	Low	Fabrication and Functional Test Completed	11/10
Performance Testing	5	Low	Demonstrate Reduced Cycle Time	2/11
Performance Demonstration	6	Low	Part machining and Evaluation	5/11

TECHNOLOGY AVAILABILITY

The Navy's need for this technology is near-term. The AARGM radome is currently being produced by an outside contractor, but the volumes are low and the costs are extremely high. Low Rate Initial Production (LRIP) began in 2008 and the full deployment of the technology into the fleet is planned for 2010. We are currently in Year 1 of a Phase II program that ends on 5 May 2011. The project is currently on budget, proceeding on schedule, and our technical results have exceeded our expectations. At the conclusion of the Phase II project, the technology will be at TRL 6. We have formulated a 9 month technology transition plan that will move our technology from TRL 6 to TRL 9 with full program insertion. Currently, funding is not allocated to support the Phase III development schedule we describe below. We envision that the Phase III project will be in parallel with Year 2 of the current Phase II, to accelerate the transition and insertion of the technology to meet the needs of the AARGM deployment.

In parallel with the testing and evaluation work completed during the CPP projects, we will undertake an aggressive Phase III technology development and transition schedule, as shown in Table 2. The focus of the effort is the design, integration, testing, and transition of our technology to the AARGM program. Each of these tasks is reviewed below:

- *Manufacturing Prototype Development.* This prototype will be designed and developed with mass manufacturing in mind, paving the way to commercialization.



We will use the existing prototype from the Phase II project as a baseline, with modifications to improve manufacturability, robustness, and effectiveness.

- *Integration and Testing.* We will integrate and test our modifications in the target manufacturing platform.
- *Process Qualification.* Creare will support the process qualification effort that would lead to program insertion.
- *Technology Insertion.* The technology will be inserted into the AARGM program.

Table 2. Phase III Plan

TRL	Task	Date	Estimated Funding Required	Organizations Involved
6	Manuf. Prototype Dev.	2Q10	\$100K	Creare, PEO, ATK
7	Integration and Test	4Q10	\$200K	Creare, PEO, ATK
8	Process Qualification	2Q11	\$200K	Creare, PEO, ATK
9	Program Insertion	3Q11	\$100K	Creare, PEO, ATK

Creare will also seek T&E support from program offices interested in accelerating the utilization of this Laser-Assisted Machining system for the higher-speed production of high-quality, defect-free parts from CMCs and other hard-to-fabricate materials.

REFERENCES

<p>TPOC: 301-757-7384</p>	<p>ATK Prime Terry Brady CMC Program Manager ATK Tactical Systems MS 16 Allegany Ballistics Laboratory 210 State Route 956 Rocket Center, WV 26726 E-Mail: terry.brady@atk.com</p>
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ABOUT THE COMPANY

Creare was founded as an engineering service company in 1961. Its founding objectives include performing technically excellent work, focusing on results, providing an optimum environment for creative people, and commercializing innovations by the creation of autonomous product companies or licensing technology to existing organizations. We achieve these objectives by utilizing our excellent technical staff and laboratory facilities to address our client's specific technical challenges. In addition, we focus on the commercialization of our technical developments.



Facilities. Creare's offices and laboratory facilities cover over 60,000 sq. ft. and are located in Hanover, New Hampshire. Our office space includes general seating, computer facilities, a dedicated technical library, conference rooms and various community spaces. Over half the facility is dedicated to laboratory space, experimental project rigs, machine shops, and specialized fabrication and test apparatus. These extensive facilities and in-house capabilities have been developed and refined over Creare's 48-year history to serve our broad range of clients. Creare's capabilities enable projects that span development activities in mechanical systems and prototypes, electronics, chemical engineering, nuclear engineering, bioengineering, space-qualified systems, materials development, acoustics, cryogenics, etc. Extensive clean room facilities enable fabrication, assembly, and testing of space-qualified hardware. Our in-house fabrication capabilities are supported by an extensive machine shop and a fully equipped electronics laboratory. To support clients that require qualified and documented hardware, we also maintain a quality assurance program and state-of-the-art inspection facilities. Creare's labs are staffed with approximately 40 highly skilled electrical and mechanical technicians, machinists and support staff who typically support approximately 40 concurrent experimental projects in our laboratories.

Commercialization. Creare has been highly successful in the commercialization of SBIR-developed technology. We commercialize SBIR technology internally via sales of custom or specialized hardware and software and engineering services contracts, as well as externally through creation of spin-off organizations and licensing of technology to third parties. Creare's commitment to commercialization is long-standing and evidenced by the establishment of a number of *independent* product businesses (Figure 3) since Creare's founding which include a leading international supplier of plasma-arc torches founded in 1968; a manufacturer of noninvasive medical instruments; a precision motion controls company; a manufacturer of color ink-jet printers; a geotechnical instruments company; a developer of biotechnologies for continuous production of pharmaceuticals; the world's leading supplier of computational fluid dynamics software, and; a provider of micromachining technology.



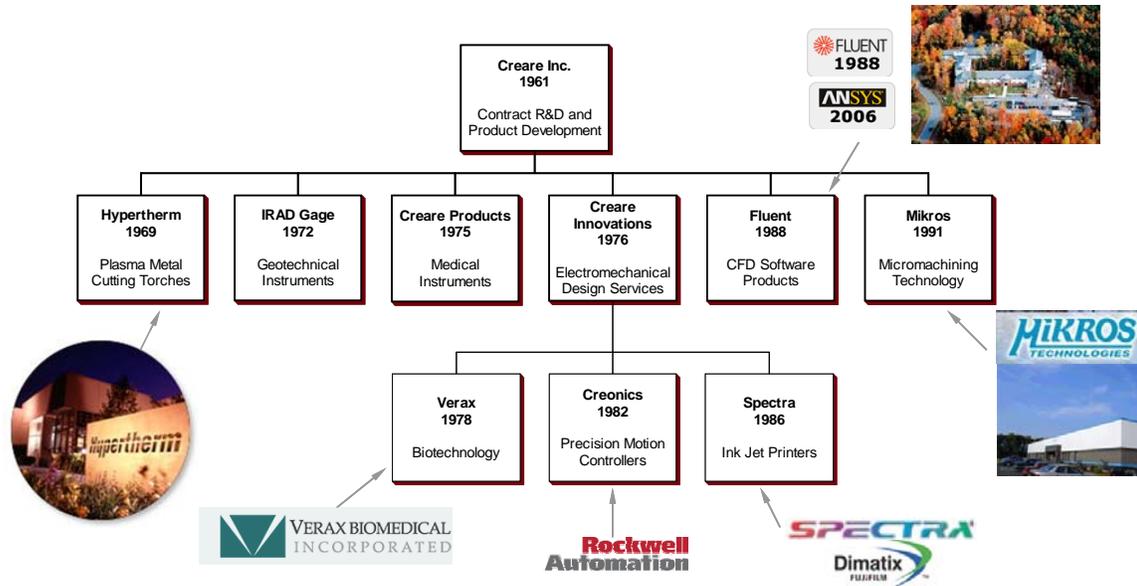


Figure 3. Creare Spin-Offs.

Similarly, new ventures have been established by licensee firms for Creare's corrosion preventative coverings, aerosol vaccine delivery technology, and high performance machining systems. SBIR projects resulted in the creation or direct assistance in the growth of the most recent four of these companies.

Navy Transition and Commercialization. Creare brings an extensive background of highly successful technology development and commercialization for the Navy and DoD. Several of our most successful technology development and commercialization programs have been for the Navy (Figure 3):

Envelop[®] covers are high-tech protective covers for critical topside equipment that dramatically reduce corrosion (<http://www.envelopcovers.com/index.html>). Envelop[®] technology was developed at Creare under SBIR funding and subsequently licensed to Shield Technologies Corporation, which currently manufactures and markets Envelop[®]. Envelop covers have been successfully tested on the weather decks of FFG, DDG, and LHD class ships. Maintenance savings from the use of Envelop on a 0.50-caliber machine gun on a DDG is estimated to be nearly 20 times the cost of the covering. Shield Technologies total commercial and government product sales thus far exceed \$15 million. Five patents have been awarded for this technology, and the estimated, ultimate market for these coverings is in excess of \$100 million.

Aircraft catapult cylinder slot gap measurement: Creare developed and supports a small product line of robotic instruments used on aircraft carriers to inspect and measure the width of the slot gap in catapult cylinders. These instruments are now routinely used on every U.S. aircraft carrier to monitor the status of the catapults and guide maintenance procedures.



Innovative hearing protection for carrier deck flight crews: For NAVAIR, Creare conducted extensive R&D into bone-conducted sound and developed new technology for flight-deck cranials that offers unparalleled hearing protection. This program has entered the system development and demonstration phase aiming for acquisition in 2010.

In addition to these Navy technologies, Creare has successfully developed and commercialized cryogenic coolers for spacecraft, vacuum pumps for spacecraft scientific instruments, high-torque threaded fasteners, and CFD software.



25 mm gun on a US Navy ship –
Protected by an Envelop cover



Creare's robotic inspection
instruments are used to measure
catapult slot gaps on every US carrier



Creare's Flight Deck Cranial helmet
undergoing evaluation testing by a
U.S. Navy aircraft maintainer

Figure 3. Examples of Successful Transition of Creare Technology to the Navy

Creare recently completed a licensing agreement with MAG IAS for technology related to the high performance machining of titanium. This project is currently in a Phase II.5 and a Phase III for the JSF program, where we have partnered with Lockheed Martin Aeronautics Company in Fort Worth, Texas.