MR & D

Materials Research & Design

m-r-d.com

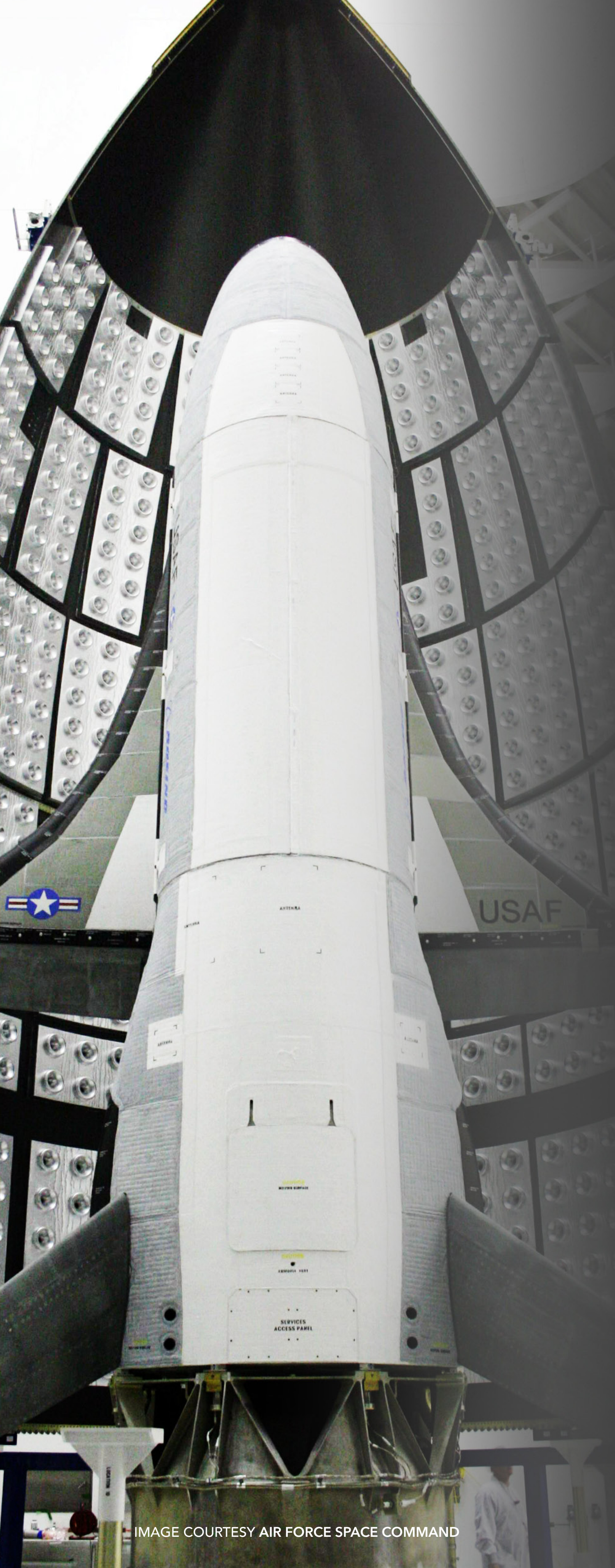
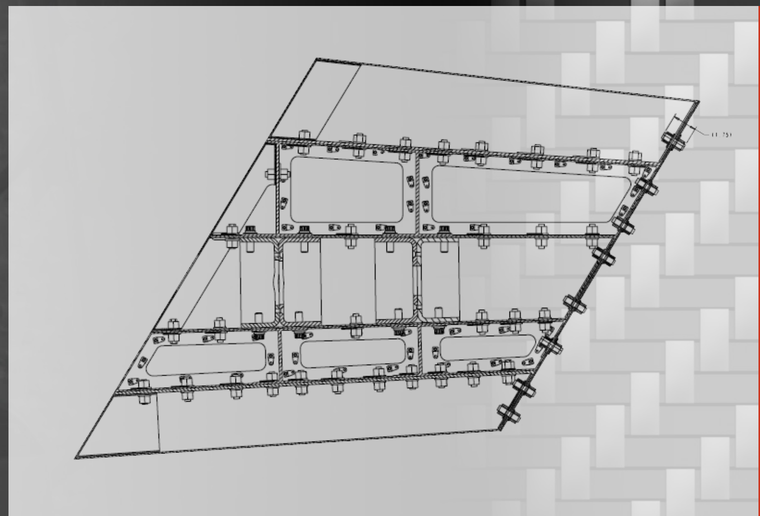
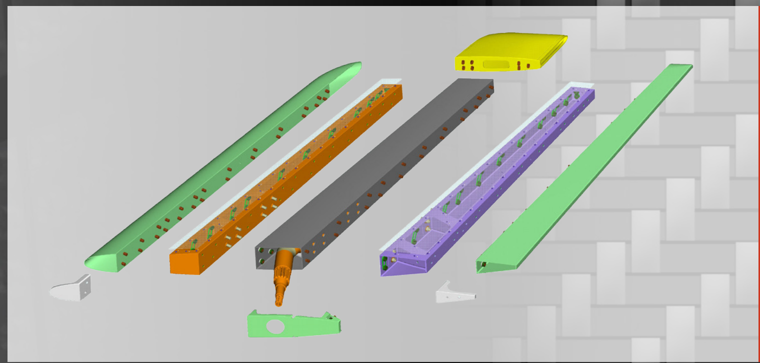


IMAGE COURTESY AIR FORCE SPACE COMMAND





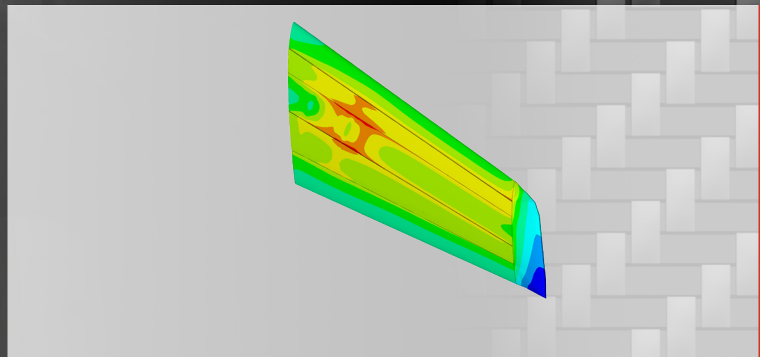
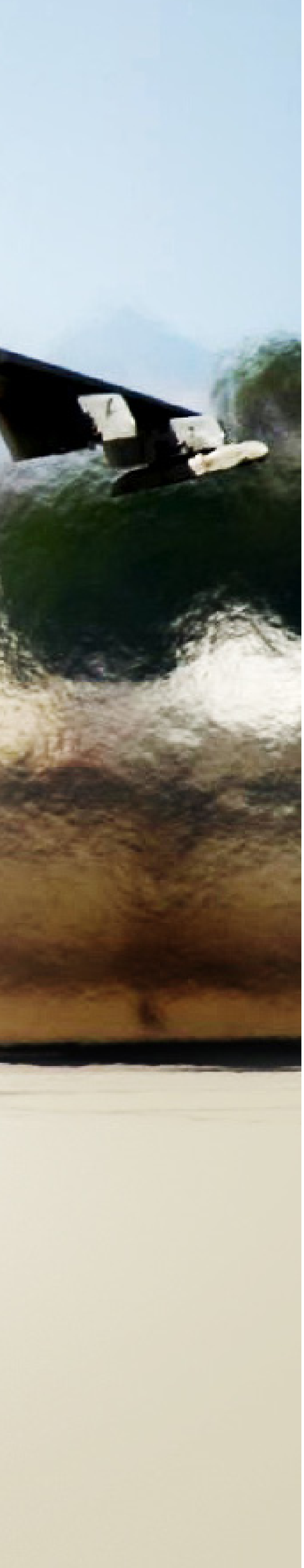


IMAGE COURTESY U.S. NAVY

Materials Research & Design strives to provide excellence in design and analysis services for the advanced materials community.

Leadership Statement

| MISSION | From fundamental research through final, operational hardware, MR&D applies rigorous engineering processes, to develop and advance the next generation of composite material system designs. As a small business with a staff of highly skilled, multi-faceted engineers, MR&D is uniquely positioned for lean, responsive analysis and design work to support your company and your customers' needs. Our extensive experience, in-house material databases and proprietary analysis tools enable accurate, innovative solutions for the advanced material systems of the future. At a time when next-generation materials are ever more costly to manufacture, while lead times and budgets are shrinking, MR&D will ensure your project is completed on time and within budget.



Core Competencies

| TECHNOLOGY | Our expertise lies in the areas of composite micromechanics and simulation technologies. We utilize detailed mathematical models to simulate everything from high-speed impact events lasting only a few micro seconds to full-flight profiles for various aircraft and missile components. Proprietary micromechanical codes deliver accurate material properties when available data is insufficient. Our engineers are also proficient in custom built constitutive models allowing the simulation of virtually any material behavior.

| R&D | The principals at MR&D have worked in the field of composite materials since the early 1980s. Since our founding in 1996, we have primarily focused on the analysis and design of refractory materials for propulsion, thermal protection, and thermal management applications. These refractory materials include both refractory composites and refractory metals. The refractory composites include carbon-carbon, carbon fiber reinforced silicon carbide matrix composites, silicon carbide fiber reinforced silicon carbide matrix composites, and oxide/oxide composites. The refractory metals include rhenium, molybdenum, molybdenum-rhenium, TZM and other high temperature metals.

| SERVICES | Typical programs at MR&D focus on simultaneous design of material and structure to optimize component cost, weight, and/or thermomechanical performance. Additional programs focus on research into behavior of composite materials and constituents and the development of micromechanical models to analyze and understand observed properties. The analytical approach employed by MR&D is based on a practical understanding of engineering issues founded on a strong background of theoretical mechanics.

» Material Modeling: Submicromechanical to Minimechanical Analysis
» Structural Response: Static, Dynamic (Time History, Random, Shock), and Nonlinear (Material and Geometric)
» Heat Transfer: Conduction, Convection, and Radiation
» Fluid Mechanics: Fluid Flow and Conjugate Heat Transfer Problem

Products/Services/ Other Application Areas of Technology

MR&D has capabilities in a wide range of composite design & analysis and component manufacturing projects:

Design of Ceramic Matrix Composites

MR&D specializes in the design of ceramic matrix composites for extreme environment applications. The principals within the firm have been engaged in the design of carbon-carbon and ceramic matrix composites since the early 1980s.

The process begins with the specification of design requirements by the end-item user. These design requirements typically take the form of design loads (static, dynamic, thermal, lifetime requirements, etc.), the geometric envelope of the component, and other goals (e.g., maximum weight, maximum cost) of interest to the user.

Based on these design requirements, the constituents of the design can be selected. For example, for a highly oxidative environment at moderate temperatures, ceramic fibers may be appropriate. Very high temperatures, high strength requirements and/or tight cost constraints may push the design towards the use of carbon fibers.

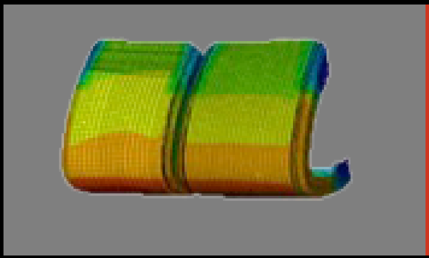
The next step in the design process is the consideration of the most appropriate preform. A cylindrical-shaped item may benefit from a braided architecture. Flat or slightly curved components may be well suited for fabric reinforced preforms. Woven preforms with through thickness reinforcement may be appropriate for parts requiring interlaminar properties beyond those associated with two-directionally reinforced preforms. Non-woven preforms may be best for composites requiring significant interlaminar properties.

In order to have thermo-elastic moduli and/or thermal conductivity properties available for stress analysis and/or heat transfer analyses of the composite design, MR&D makes use of our in-house proprietary micromechanics codes for the calculation of temperature-dependent anisotropic properties. MR&D is in possession of a suite of such codes, which include codes for determining fiber orientations and fiber volume fractions for 2-D and 3-D braided preform composites, 2-D fabric reinforced composites, and 3-D woven preform reinforced composites. Using information generated by these codes, together with fiber and matrix properties baselined from composite data accumulated at MR&D over several decades, MR&D computes all of the temperature-dependent anisotropic thermal conductivity and thermo-elastic properties required for the analyses of our designs. Our in-house data base also includes measured data on composite strengths, from which temperature-dependent strengths are also generated.

At MR&D, thermal and thermostructural analyses are primarily performed using commercially available finite element codes, including ANSYS and ABAQUS. Thermal analyses produce temperature distributions, which are used to calculate thermal stresses in thermostructural analyses. Appropriate methods are used, based on physically reasonable load combination rules, to combine thermal stresses with stresses from static and/or dynamic analyses. Stress and strain results from the combined loads analyses are then used in calculating stress or strain margins of safety by which judgments on the suitability of our designs are based.

Process Modeling

MR&D has experience in developing non-eroding exit cones for solid rocket motors that use carbon-carbon substrates. MR&D has been specifically involved in the analysis of processing stresses to identify potential fabrication modifications that can reduce these stresses. The goal of this work is to recommend material design and processing changes so that the carbonization of a cured carbon/phenolic can be performed without creating delaminations.



Results of these analyses have shown that reductions in cross-ply tensile stresses, which contribute to delaminations, can be achieved by increasing the shingle angle (angle of fabric plies to the axis of symmetry), which decreases pore pressure and reduces the thermal mismatch between the radial and hoop strains. Pore pressures result from the burning of the phenolic into a carbonaceous char, and can be greater than the strength of the material in some cases. The Process Environment Model (PEM) code was used to calculate the effect of various geometries, permeabilities, and boundary conditions on pore pressure. Other ways to reduce cross-ply tensile stress include reinforcement fiber architectures, the use of post-cure temperature cycles to reduce decomposition mass and increase permeability, and tailored carbonization cycles that provide slow heating rates at critical temperatures. Key results of this work have been published in proceedings of International Traffic in Arms Regulation (ITAR) restricted conferences.

Durability modeling of ceramic matrix composite materials

MR&D has had several government contracts for the development and benchmarking of ceramic matrix composite (CMC) life prediction analysis tools. Under a Naval Air Warfare Center (NAWC) Phase II Small Business Innovative Research (SBIR) Contract, MR&D continued the work of a Phase I SBIR contract to predict weight change due to oxidation kinetics and the subsequent modulus and strength degradation of CMC materials. Work continues on this contract to further develop and calibrate the models using measured data on this material system. The focus of this work thus far has been on SiC fiber, SiNC matrix composites for the flaps and seals of jet engines for naval aircraft. Under a NASA Contract awarded in 2007 as part of a NASA Research Announcement, MR&D is developing math model tools to predict the effect of oxygen partial pressures, temperature distributions, and stress state on the oxidation kinetics, mass loss, and stiffness and strength degradation of CMC materials. The primary materials of interest in the NASA contract effort were SiC/SiC and C/SiC materials for airframe and propulsion applications of hypersonic aircraft. The work performed on these contracts has been reported by MR&D engineers at ITAR-restricted conferences, for the peer review provided by forums of this type.

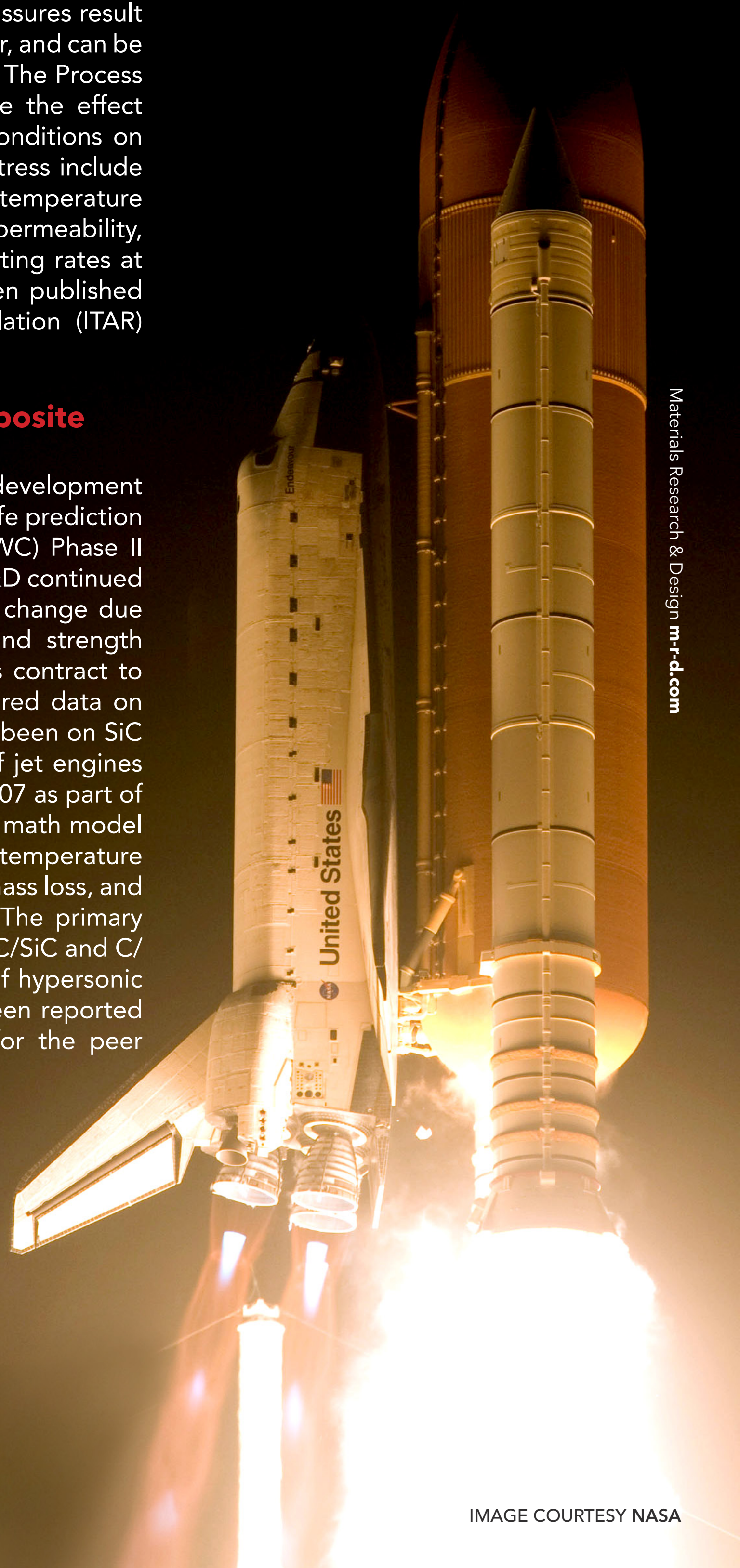


IMAGE COURTESY **NASA**

IMAGE COURTESY NASA

Examples of Application Areas

Flight Hardware

» Nose leading edges for X-43A
» CMC blast heat shield for the "AV-8B" Harrier aircraft
» Design support to ATK for the Chemical Vapor Infiltrated C/SiC Plug Repair for Space Shuttle Reinforced Carbon-Carbon Wing Leading Edges
» Carbon-Carbon radiator panels for NASA Earth Orbiting Satellite (EOS-1)
» Design of organic matrix composite thermal doublers for Lockheed-Martin Traveling Wave Tube Arrays for the Mars Reconnaissance Orbiter
» Design of high thermal conductivity organic matrix composite PCI-format thermal planes for the Lockheed Martin Mars Reconnaissance Orbiter

Impact Simulation

» Design, analysis, fabrication, and testing of advanced armor systems
» Foreign Object Debris Damage of CMCs
» Rain Erosion of Monolithic Ceramics

Thermal Management

» Heat Exchangers
» Heat Pipe Cooled Leading edges for hypersonic cruise vehicles
» Composite spacecraft radiators
» CMC heat exchanger design for V-22 aircraft
» Simulation of Gr/Al composites for thermal management

Thermal Protection for Reentry & Hypersonic Systems

» Space Shuttle Wing Leading Edge TPS Repair
» Hot structure control surfaces

Advanced Missile Components

» Non-eroding nozzle materials
» Nozzle design and analysis
» Radome and antenna window design and analysis
» Missile Control Surfaces

Large scale propulsion systems

» Composite Liquid Engine Nozzle Extensions
» Turbofan Components
» Exhaust Washed Structures
» Metallic & nonmetallic solid rocket nozzles
» Scramjet Components
» Composite-to-metal joints

Markets/Customers

Government

- » Air Force Research Laboratories (Edwards, Eglin, Wright Patterson)
- » Army Research Laboratory
- » Naval Air Warfare Center
- » Jet Propulsion Laboratory
- » Missile Defense Agency
- » NASA (Ames, Dryden, Glenn, Langley, Marshall)
- » Naval Sea Systems Command
- » Naval Surface Warfare Center
- » Navy Sea Logistics Center
- » Office of Naval Research
- » US Air Force Materials Command
- » US Air Force
- » US Department of Justice
- » USAF\AFMC Air Force Research Laboratory

Customer List-Private

- » 3Tex, Inc.
- » Advanced Ceramics Research
- » Advanced Simulation Technology
- » Aerojet
- » Albany Engineered Composites
- » Allcomp Inc.
- » Allison Advanced Development
- » Analytical Services and Mat'ls
- » Aspen Aerogels
- » ATK Composite Optics
- » ATK Launch Systems
- » ATK Thiokol, Inc
- » Cytec Carbon Fibers, LLC
- » Boeing Phantom Works, St. Louis
- » Boeing Research & Technology, Seal Beach, CA
- » B G Smith & Associates
- » Compostite Factory, Inc.
- » Composite Innovations Corp
- » Exothermics, Inc.
- » Fiber Materials, Inc.
- » General Dynamics Information Technology
- » GE Ceramic Composite Products, LLC
- » GE Power Systems Composites, LLC
- » Goodrich, High Temperature Composites
- » Hexcel Carbon Fibers
- » Honeywell Advanced Composite
- » Hyper-Therm High Temp. Co
- » Intermat
- » Jentek Sensors, Inc.
- » Johns Hopkins APL
- » Lockheed Martin Valley Forge
- » Lockheed Martin Palmdale
- » Lockheed Martin Denver
- » Lockheed Martin Houston
- » Lockheed Martin Sunnyvale
- » Material Innovations Inc.
- » Millenium Engineering Co.
- » Materials Resources Int'l
- » Northrop Grumman El Segundo
- » POCO Graphite, Inc.
- » Powdermet, Inc.
- » Plasma Processes, Inc.
- » Pratt & Whitney Rocketdyne, West Palm Beach
- » Pratt & Whitney Rocketdyne, Canoga Park
- » Refractory Composites, Inc.
- » Swales & Associates, Inc.
- » S D Miller & Assocs. Research Foundation (SMARF)
- » SiemensWestinghouse Power
- » SMAHT Ceramics, Inc.
- » SNECMA Propulsion Solide
- » Southern Research Institute
- » Starfire Systems
- » Synterials, Inc.
- » T.E.A.M.
- » Thermacore, Inc.
- » Thor Technologies
- » Touchstone Research Labor
- » Ultramet Corporation
- » United Space Alliance
- » Universal Technology Corp
- » University of Dayton Research Inst.
- » Williams International

Profile

Brief history and Management
Materials Research & Design, Inc. (MR&D) was founded in 1996 by Dr. Brian Sullivan and Kent Buesking to provide research, analysis and design services to the advanced materials community, focusing on composite materials for the aerospace industry. Our work encompasses all types of materials, including carbon-carbon, ceramic matrix composites (CMC), oxides, and refractory metals.

Brian Sullivan (Director, Co-Founder)
Brian Sullivan is a founding member of MR&D and heads the company's team focusing on large scale propulsion systems, reentry vehicles, CMC durability and hot-structure control surfaces. He also oversees the commercialization efforts resulting from SBIR and BAA programs. His 30 years of experience with high temperature composite materials and the community of users ensures technical excellence and customer satisfaction from program definition through final execution.

Kent Buesking (Director, Co-Founder)
Kent Buesking has lead ground breaking research initiatives since he co-founded MR&D in 1996. His team focuses on advanced missile components including CMC nosecones, antenna windows and rocket nozzles. He also lead MR&D's efforts related to the Navy's electromagnetic railgun program. Kent's leadership and 27 years of experience in composite materials research helps ensure a complete engineering solution underlies all projects and moves the company forward.

Core Advantage

As a small business with a staff of highly skilled, multi-faceted engineers, MR&D is uniquely positioned for lean, responsive analysis and design work to support your company and your customers' needs. Our extensive experience, in-house material databases and proprietary analysis tools enable accurate, innovative solutions for the advanced material systems of the future. At a time when next-generation materials are ever more costly to manufacture, while lead times and budgets are shrinking, MR&D will ensure your project is completed on time and within budget.

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