

Jim Dorr
President
Duke Engineering Group Inc

Mr. Dorr retired from McDonnell Douglas Corporation (MDC) in 1995 and formed Duke Engineering Group Inc. Duke Engineering Group Inc has performed a number of Research and Development Programs for the United States Government and provides engineering support to a number of companies and universities, including Boeing, Lockheed, Packer Engineering, Production Products Manufacturing and Sales, Zoltek, Holland Hitch, Touchstone, Blue Road Research, Koppen & Associates, IMPSA, Schwing, Washington University, Northwestern University, Michigan State University, Delaware University, and others. Mr. Dorr's professional career covers 39 years at MDC including work on the F-4, F-15, F-A-18, and AV-8B aircraft, as well as Gemini, Space Shuttle, planetary vehicles, simulators, and advanced missiles. He has a M.S. in Applied Mechanics and a B.S. in Civil Engineering from Washington University. Mr. Dorr was previously Director of Advanced Materials and Structures, responsible for all research and development work on advanced materials and structures at MDC. His areas of expertise include program management, integrated product and process development, design, materials and processes, producibility, structural analysis, structural research, loads, dynamics, weights, planning and administration, advanced manufacturing technology, tooling, quality, information technology, supportability, and testing.

Mr. Dorr has been a pioneer in the application of artificial intelligence and neural networks to advanced materials and structures and advanced manufacturing technology. This included work on intelligent design and manufacturing systems, process simulation and process control, sensor fusion, smart structures, materials database, feature based modeling, and adaptive decision systems. Mr. Dorr was previously the head of the Structural Research Department at MDC. He was instrumental in developing MDC capability in automated fiber placement of thermoset and thermoplastic composites. His development work on advanced metallic structures led to production implementation of the superplastically formed/diffusion bonded titanium aft fuselage on the F-15E and his pioneering work on metal matrix composite structures has been implemented on advanced fighter aircraft and spacecraft. Mr. Dorr was on the board of directors of Zoltek Companies Inc, MidTec, and the Great Lakes Composites Consortium. He has served on the Strategic Advisory Boards of the Air Force Research Laboratory, Naval Research Laboratory, Office of Naval Research, and NASA.

The following is a synopsis of the Research and Development Programs which have been performed by Duke Engineering Group Inc in the ten years since it was founded. The first three programs were Duke Engineering Group Inc prime Small Business Innovation Research Programs performed for the Navy. The other Research and Development programs are Production Products Manufacturing and Sales prime contracts with Duke



Engineering Group Inc providing the engineering support on the programs. Production Products is a Small Disadvantaged Business (SDB) headquartered in St. Louis, Missouri. We jointly perform a wide variety of Research and Development, Prototyping, and Production Programs in composite structures, metal structures, textile products, and electronics.

Development of a Low Cost Process to Provide Improved Carbon Fiber-Vinyl Ester Adhesion – Naval Sea Systems Command – Carderock Division (Dr. Roger Crane, 301-227-5216) – SBIR, Phase I was completed December 1998. In this Phase I SBIR Duke Engineering Group Inc has evaluated sixteen different advanced and currently available sizings and surface treatments for carbon fiber / vinyl ester matrix composite materials to determine which will provide enhanced fiber-matrix adhesion. Carbon / vinyl ester composites are a very important structural material for Navy, DoD, and commercial applications because of their potential for low cost, room temperature processing without the use of autoclaves. These processes include resin transfer molding (RTM) and Vacuum Assisted RTM (VARTM) which can produce high performance composite structures. The program developed several fiber sizings for Zoltek carbon fiber which increased the fiber to matrix bond strength. Dr. Don Ames and Dr. John Kardos were consultants on this program. The Dow Chemical Company, Zoltek, and Virginia Polytechnic Institute provided sizings.

Energy Dissipation Characterization and Design Methodology for Composite Materials - Naval Air Systems Command/Naval Research Laboratory (Carl Matson, 301-342-8084) - SBIR, Phase I was completed November 1996. Duke Engineering Group Inc used strain energy dissipation technology developed by the Naval Research Laboratory (NRL) to develop dissipated energy density (DED) characterization methodology for composite material/laminate characterization and design of aircraft. The Boeing Company (TBC) and Southern Research Institute (SRI) were subcontractors on this program. The advantages of the DED technology over conventional analysis methods were identified. The objective was to develop an approach for certification using DED which will lead to substantial cost and schedule improvements over conventional methods and be acceptable to the design community.

High Speed Research – The Boeing Company (Dave Harmon, 314-233-8625) – Duke Engineering Group Inc provided engineering support to The Boeing Company on the NASA High Speed Research Program. Duke Engineering Group Inc personnel provided expertise in the area of composite materials and accelerated aging of polymer matrix composites. This work centers on elucidating the mechanisms of thermal and thermo-oxidative degradation of the candidate polymer composite material systems for the High Speed Civil Transport.

Intelligent Processing Center – Northwestern University – (Dr. Isaac Daniel, 847-491-5649) – Duke Engineering Group Inc is supporting Northwestern University, Packer Engineering, and Production Products in this Office of Naval Research (ONR) Program to develop intelligent processing tools for resin transfer molding, filament winding, and vacuum

assisted resin transfer molding of composites. A low cost automated resin transfer molding machine has been developed along with new low cost sensors to allow active control of the manufacturing process. The second phase of this program which involved Agile Manufacturing has been completed and the third phase is about to begin.

Affordable Tooling for Composite Structures – This is a Small Business Technology Transfer (STTR) Phase I Program that Production Products was contracted by Wright Patterson Air Force Base (Program Monitor Eric Becker – 937-255-7277). Duke Engineering Group Inc was a subcontractor to Production Products on this program which developed composite processing tools and tooling approaches that offer lower cost and shorter fabrication lead times with adequate durability and thermal performance characteristics. We focused on a novel localized resistive heating concept which applies heat only to the part being processed and does not heat the tool except at the tooling surface. Tooling costs have been identified as a high cost area especially in the prototype environment and as production rates continue to drop. Our composite tooling approach produces dimensionally accurate parts, (match the coefficient of thermal expansion (CET) of the composite part), is affordable to demonstrate the tooling approach in the prototype environment, and is durable enough to meet the requirements of production use. In Phase I we provided a description of the tooling approach, preliminary designs of the tooling system, thermal analysis of predicted thermal performance, and cost analysis of anticipated tooling fabrication costs. We resin transfer molded an F-18 Wing Seal as the demonstration component. In Phase II we developed and demonstrated the new composite processing tool system on a significantly complex tool and verified the phase I thermal and cost analysis predictions and demonstrated the tooling performance.

Elastomeric Composite Bumpers - The Naval Surface Warfare Center - Carderock Division (NSWC Program Manager Dr. Roger Crane 301-227-5126) - Duke Engineering Group Inc was a subcontractor to Production Products on this Phase II SBIR Program to design and develop novel marine impact bumpers for dual use military and commercial markets using highly abrasion resistant and damage tolerant elastomeric matrix composites. These materials have unique properties with significant potential for use in impact applications including bumpers for ships, moorings in shipyards and commercial marinas. Duke Engineering Group Inc developed a unique, low-cost, computer controlled bumper design concept capable of providing an optimum energy dissipation under impact of both large and smaller vessels. Production Products optimized the manufacturing process to produce high quality bumpers at low cost based on previous experience fabricating carbon fiber/polyurethane composites for NSWC and DARPA. In Phase I Production Products fabricated elastomeric matrix composite structural configurations and low cost manufacturing processes and Duke Engineering Group Inc developed innovative bumper designs and characterized mechanical and impact performance properties. These bumper concepts have been patented.

Liquid Molded Composite Armor Smart Structures Using Embedded Sensors - Army Research Lab (Dr. Bruce Fink, 302-831-8645) - Duke Engineering Group Inc assisted

Production Products with data collection and analysis of embedded optical fiber sensors on this Phase I SBIR. As a subcontractor on the Phase II Program, Duke Engineering Group Inc. developed an automated data collection and analysis system which was used throughout the program. Fiber optic Bragg Gratings and Fluorescence Optrode sensors were used to monitor the state of cure along with Smart Weave, conventional thermocouples, and Infrared Sensors. The fiber optic sensors were also used to monitor measure strain versus time during four point bend test, low velocity impact tests, and high speed ballistic impact tests. Micromechanical modeling techniques were used to aid in the interpretation of the sensor output. Both carbon and glass fibers and epoxy and vinyl ester matrix materials were used in this program.

Low Cost Titanium Tow Bar – U.S. Army Tank – Automotive and Armaments Command (Paul Decker, 810-574-5413) - Duke Engineering Group Inc assisted Production Products in Phase I with design, analysis, fabrication, and test of a titanium tow bar for the M1A1 Tank and M-88 Recovery Vehicle. The prototype titanium tow bar was significantly lighter than the current steel tow bar with projections for an improved design tow bar of 140# versus the 360# steel tow bar. The Phase II Program design and analysis of the improved titanium tow bar was completed and all the titanium castings for testing and field evaluation were produced. The tow bar assembly was successfully structurally tested and additional tow bars were provided to the Army for field evaluation.

Alternate Heating and Technology for Thermoplastic Composites and Adhesive Bond Technology - Office of Naval Research (Jim Kelly, 703-696-0688) – Duke Engineering Group Inc was a subcontractor to Production Products on this Phase I and Phase II SBIR Program, providing engineering design and analysis support. The program focused on a novel, low cost process for fabrication of thermoplastic composites and adhesive bonded structures. The applications pursued in the program included the Boeing Joint Strike Fighter wing structure and the Advanced Armored Amphibious Vehicle drive shaft.

Structural Materials – Low Cost Ceramic Matrix Composite Materials for BMDO Program - This was a Ballistic Missile Defense Organization (BMDO) Phase I SBIR. The contracting agency was Code 861 Naval Surface Warfare Center (NSWC) – Carderock Division. Duke Engineering Group Inc provided engineering support to Production Products in this program. In Phase I, Production Products demonstrated the potential low cost fabrication techniques and good mechanical properties of a new glass ceramic composite material made with Applied Poleramics CO-2S ceramic material and conventional 12K carbon fiber. The CO-2S ceramic matrix material was selected for intermediate temperature applications up to 2000°F for missile, airframe, engine, and Ballistic Missile Defense (BMDO) applications. We studied prepreg fabrication techniques utilizing carbon fiber and low cost compression molding methods of fabricating ceramic matrix composite materials and structures. Prepreg was fabricated using a dry winding procedure and the prepreg was cured and post cured using a very low cost tooling technique. This tooling technique allows the use of low cost tooling and minimum energy consumption since it focuses heat

in the part and most of the tooling remains cool. It is compression molding in a ceramic tool using vacuum bag pressure and carbon fiber resistive heating. The resulting coupons had excellent mechanical properties given the need for additional prepreg development techniques.

Affordable High performance Polyurethane Shock and Vibration Mounts – This is a Phase I and Phase II SBIR sponsored by Naval Surface Warfare Center – Carderock Division, Dr. Roger Crane (301-227-5126). The Phase II contract has recently been completed. Duke Engineering Group Inc provided engineering support on this program. The objective of this SBIR was to develop a low cost high performance generic elastomeric machinery mount system which has varying static and dynamic vibration properties to provide vibration and shock isolation over a wide operating load range. These mounts are capable of meeting performance specifications for several mounts / load ranges. A reinforced polyurethane shock and vibration mount system configuration was designed, a prototype fabricated, its shock and vibration performance analytically predicted, and tests performed to demonstrate its ability to meet those analytical predictions. In Phase II we transitioned the analytical and experimental findings of Phase I into a second generation prototype mount concept for a family of mounts. We designed, fabricated, and characterized the static and dynamic properties of these mount concepts. Shock and vibration tests were performed to verify performance predictions. Production Products has manufactured mounts for sea trials by the Navy and for commercial applications. A commercialization plan was developed to allow for manufacture and commercialization of the affordable, high-performance, reinforced polyurethane shock and vibration mounts.

Embedded Sensors in Filament Wound Structures - The U.S. Army Missile Command (MICOM - Program Manager Terry Vandiver 205-876-1683) contracted Production Products in a Phase I SBIR program to develop novel, low cost processing technology to incorporate fiber optic sensors in filament wound composite rocket motor cases, pressure vessels, and other missile components. Duke Engineering Group Inc provided engineering support on this program. The fiber optic sensors were used for cure monitoring, measuring temperature, displacement, strain, and structural health monitoring. In Phase I we developed low cost techniques to place the fiber optic sensors in the filament wound composite structures; fabricated representative Army missile components, Patriot Advanced Capability-3 (PAC-3) rocket motor case, mid-body section, we characterized the strength of the filament wound composite material containing the fiber optic sensors and performed structural tests on missile components to demonstrate the ability of the fiber optic sensors to accurately measure strain, displacement, and temperature; and tracked costs to show the impact on overall system cost of incorporating smart structures in missile components. Loral Vought Systems provided us with Army missile applications and requirements for the PAC-3 missile.

Non-Invasive Communication with Embedded Sensors in Composites - This was a Small Business Innovation Research Phase I and Phase II Program that Production Products was contracted by the Defense Advanced Research Project Agency (DARPA - Dr. Bob

Crowe). Duke Engineering Group Inc provided engineering support on this program. The objective of this program was to investigate the use of fiber optic sensor technology for monitoring composite structures. The program identified low cost, highly reliable sensor systems and manufacturing processes to allow for economic/widespread use in composite DOD application as well as civil structure applications. This system was identified and tested in a composite utility pole demonstration article. In Phase I of the program, the demonstration article was a modular, tapered glass/epoxy utility pole test article that had Bragg Grating Fiber Optic Sensors embedded in it. The joint of the pole was tested in three point bend to verify it's ability to meet the requirements of a 40 foot long pole. The utility pole concept exceeded the requirements of the customer and a Phase II program was awarded.

In Phase II of this SBIR, Production Products Manufacturing & Sales and Blue Road Research completed the development and qualification of a low cost fiber optic Bragg Grating demodulation system and a modular composite utility pole. We have designed and fabricated Education Kits for working with Bragg Gratings and demodulating the signal. We have designed and fabricated Stand Alone Units of the Bragg Grating Demodulator for demodulating high speed changes in longitudinal strain or temperature events. We have also designed, fabricated, and qualified a 65 foot long modular composite utility pole that directly meets the needs of the Utility Industry as well as the DoD, including the Army Corps of Engineers. The poles have undergone environmental qualification tests as well as structural tests and currently are being outfitted for field testing by Union Electric. The pole developed is a unique, modular, filament wound, composite pole design which is very lightweight (10-15% of a comparable size wood pole weight), affordable, durable, environmentally far superior, and offers significant operational advantages because of it's lightweight, modularity and long life. The unique modularity feature allows reduced stockpiles, easy handling with smaller work crews and equipment, and simplified installation and repair. We have demonstrated the ability to install commercially available fiber optic sensors in the composite pole during the filament winding process and have them survive the elevated temperature curing process and subsequent machining and handling. This Phase II SBIR program has resulted in direct commercialization of a broad range of fiber optic sensor products and the modular composite utility pole.