12. MATERIALS CROSSCUTTING RESEARCH AND DEVELOPMENT

A. Technical Cost Modeling

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Contractor: Oak Ridge National Laboratory (ORNL)
Contract No.: DE-AC05-00OR22725

Objectives

- Address the economic viability of new and existing lightweight materials technologies.
- Develop technical cost models to estimate the cost of lightweight materials technologies.

Approach

- Address the economic viability of lightweight materials technologies supported by Lightweighting Materials (LM) technology area development.
- Use cost modeling to estimate specific technology improvements and major cost drivers that are detrimental to the economic viability of these new technologies.
- Derive cost estimates based on a fair representation of the technical and economic parameters of each process step.
- Provide technical cost models and/or evaluations of the "realism" of cost projections of lightweight materials projects under consideration for LM technology area development funding.
- Examine technical cost models of lightweight materials technologies that include (but are not limited to) aluminum (Al) sheet; carbon-fiber (CF) precursor and precursor processing methods; fiber-reinforced polymer-matrix composites (FRPMCs); and methods of producing primary Al, magnesium (Mg), and titanium and Mg alloys with adequate high-temperature properties for powertrain applications.

Accomplishments

- Completed an analysis of the cost-effectiveness of a 25% body and chassis weight reduction LM goal for 2008.
- Completed life-cycle inventory (LCI) data collection for the life-cycle analysis (LCA) of CF-reinforced polymer-matrix composites and initiated the LCA.
- Completed LCI data collection for several Mg manufacturing technologies and completed the first-cut LCA.

- Updated an earlier paper on primary Mg production costs for automotive applications for publication in *Journal of Metals*.

Future Direction

- Perform the joint Ontario-DOE LCA study on natural-fiber-reinforced bioresin-matrix composites for automotive applications.
- Complete the cost-effectiveness assessment of a fiscal year (FY) 2009 40% body and chassis weight reduction goal in light-duty vehicles.
- Continue project-level cost modeling to identify specific technology improvements and major cost drivers that are detrimental to the economic viability of these technologies.

Cost-Effectiveness of a 25% Body and Chassis Weight Reduction Goal in Light-Duty Vehicles

The LM component of the Department of Energy (DOE) Vehicle Technologies Program has a 50% weight reduction goal for passenger vehicle body and chassis systems with safety, performance, and recyclability comparable to 2002 vehicles. To achieve this long-term weight reduction goal, LM has set annual intermediate weight reduction goals, starting with 10% in FY 2007 and finally achieving 50% by FY 2010. The focus of the current work is on the 25% body and chassis weight reduction goal of FY 2008, with emphasis on assessment of the cost-effectiveness of this goal.

Cost-effectiveness of the LM 2008 body and chassis weight reduction goal of 25% in light-duty vehicles was assessed based on the use of lightweight material options for various body and chassis components under two plausible mid-size vehicle scenarios, each scenario focusing on a specific lightweight material option, either Al or glass-FRPMCs. The lightweight material substitution options considered here focused on body systems, but to achieve the desired overall weight reduction goal, additional chassis components were also selected for substitution for the glass-FRPMC scenario. The analysis also considered the effect of primary weight savings of 25% on other vehicle components that can be resized while maintaining the same level of vehicle performance with the reduced vehicle weight. These weight savings are known as secondary weight savings. Estimated secondary weight savings varied between the two scenarios because of the difference in total number and type of components considered for primary weight savings. Due to consideration of secondary weight savings, total body and chassis weight savings is estimated to be in the range of 27–32%, whereas final vehicle weight savings is estimated to be 16–19%. The cost-effectiveness of the 25% body and chassis weight reduction goal is estimated in terms of both vehicle retail price and life-cycle cost using the detailed 35+ component-level automotive-system cost model developed by ORNL and Ibis Associates, Inc. Cost data of components considered for lightweight material substitution are collected from the recently completed major studies, thereby reflecting the latest technology developments and material prices.

Because of the consideration of powertrain resizing and secondary body and chassis mass savings, both lightweight material vehicle options are cost-effective in meeting the LM 25% body and chassis weight reduction goal from the life-cycle cost perspective, as shown in Figure 1. Use of lightweighting materials such as Al and glass-FRPMC would be sufficient to achieve the goal, but cost-effectiveness needs to be considered beyond just the component-to-component material substitution and vehicle retail price bases.

Consideration of secondary weight savings and vehicle life-cycle cost perspectives are important when considering the economic viability of lightweighting vehicles. Among the two lightweight material options considered, glass-FRPMC appears to be more cost-effective because the cost of using Al as a structural material is still high, even with the latest technology

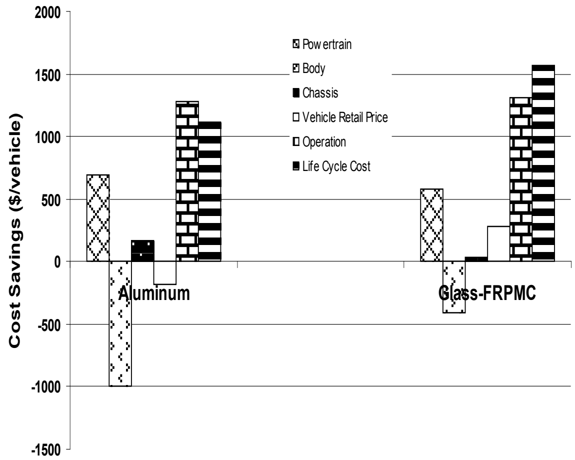

Figure 1. Estimated cost savings of two 25% body and chassis weight reduction vehicle scenarios.

developments and material pricing. In the Al scenario, the vehicle retail price would be about $180 higher; a reduction in Al sheet price to a value of less than $3.00/lb would improve its competiveness at the vehicle retail price level.

Because of consideration of secondary weight savings, the cost penalty due to lightweighting vehicles has been found to be more favorable than previously reported in the literature. As a result of the cost penalty for use of body lightweighting technologies, estimated to be in the range of $400–$1,000/vehicle under the two scenarios when not accounting for secondary weight savings, it is likely that a significantly higher fuel price would be necessary for the cost-effectiveness without secondary weight savings to be achieved on a life-cycle cost perspective, at least for the high-end body structure cost-penalty case.

Life-Cycle Analysis of Mg Front-End Research and Development

This is a Canada-China-U.S. collaborative research and development project which was kicked-off during the second quarter of FY 2007 as one of the 10 enabling technology development tasks to analyze the energy consumption and greenhouse gases effect of Mg production (i.e., CO_2 emissions in primary Mg production via the electrolytic process and traditional and improved Pidgeon processes) and SF_6/SO_2 and other emissions in Mg casting, wrought-alloy processing, and recycling. A total LCA including vehicle use and the end-of-life stages was considered to capture the benefits of lightweighting automobiles such as fuel-economy improvements and associated emission reductions. The functional unit for this study is the service of front-end auto parts (equivalent to 82.2-kilogram [kg] front-end parts made of carbon steel), used in a 1,595 kg, North American (NA)-built, large, luxury, rear-wheel-drive, 4-door 2007 GM-Cadillac CST sedan, driven for 200,000 kilometers (km) in North America, including the end-of-life phase. The baseline steel functional unit includes 79 parts, 90% of stamped hot-dip galvanized coil and 10% of finished cold-rolled coil. The Mg front end for the analysis has a weight of 45.2 kg with only 27 parts (due to consolidation) and a 45% weight reduction compared to conventional stamped steel. Die casting, stamping, and extrusion technologies are used for part manufacturing in weight ratios of 67%, 9%, and 24%, respectively. The corresponding alloys for these technologies are AM60B, AZ31, and AM30, respectively. Part manufacturing, vehicle use, and end-of-life are three major life-cycle stages considered in the analysis. Part manufacturing is based on primary metal production using the LCI data collected directly from existing NA manufacturing facilities. However, Chinese primary Mg production data are used, reflecting recent Mg market trends. Energy-use and emission estimates during the use phase of the life cycle are made separately at the levels of well-to-pump and pump-to-wheel. The consequential allocation approach is considered for end-of-life recycling, providing incentives for recycling at the end of product life, and thereby supports resource conservation. SimaPro, an LCA software package developed by PRé Consultants in the Netherlands and designed for analyzing the environmental potential impact of products and services, was used to perform this life-cycle assessment.

Life-cycle energy estimates, shown in Figure 2, indicate that the Mg front end has about 16.5% lower energy than the conventional stamped steel front end. Estimates for part production and recycling in this figure are based on several pre- and post-processing steps, respectively, considered in the analysis. As one would expect, Mg-part production is more than five times more energy intensive than steel-part production, but substantial energy savings at the vehicle-use and recycling stages cause its overall life-cycle energy to be lower (about 46 gigajoules [GJ]/part versus 56 GJ/part for conventional stamped steel). The use phase dominates the life-cycle energy use, with Mg energy use estimated to be 42% lower than steel after 200,000 km vehicle life-time distance. Mg's higher energy requirements at the part-production stage have been recovered at the vehicle use stage; thus the difference in life-cycle energy is roughly equal to the savings obtained at the vehicle-recycling stage. The negative primary energy at the recycling stage, illustrated in Figure 2, is the net environmental benefit after considering the energy required to recycle Mg and the energy benefits of recycling.

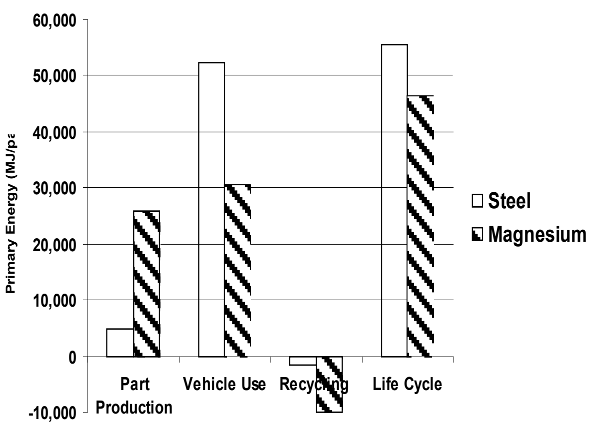

Figure 2. Life-cycle primary energy estimates of an automotive front end.

Life-cycle greenhouse gas (GHG) emissions indicate a trend similar to energy: 3.8 tons (t) CO_2 for the Mg automotive front end compared to 4.5 t CO_2 for baseline steel design. It is likely that a substantial reduction in GHG emissions could be achieved if Mg parts were based on more energy efficient and environmentally friendly primary production or enhanced recycling technologies. Other major pollutant emissions considered in the analysis follow similar trends to GHGs, with the exception of emissions of methane, nitrogen oxides, sulfur oxides, and particulates increasing over the vehicle life cycle. Higher emissions of these pollutants mainly occur at the part-manufacturing step, since most of these criteria pollutants are not as highly regulated at the part-manufacturing stage as at the vehicle-use stage. It is estimated that Mg front-end substitution would achieve life-cycle equivalence in terms of both primary energy and GHG emissions within the life cycle. Primary energy equivalence would be achieved around 116,000 km compared to 148,000 km for GHG emissions.

Life-Cycle Analysis of Carbon-Fiber-Reinforced Polymer-Matrix Composites

An LCA of carbon-FRPMCs has been initiated to compare the potential energy and environmental impacts of alternative carbon-fiber precursor materials and production technologies for manufacturing a representative automotive part, in this case the floor pan of an NA-built, 4-door, large, luxury, rear-wheel-drive vehicle. Although the focus is on the carbon-fiber production step using alternative precursor materials, other life-cycle stages such as part production, vehicle use, and part recycling/disposal are also considered. Conventional polyacrylonitrile and a renewable resource material such as lignin are the two carbon fiber precursor materials considered for the analysis. Lignin is currently isolated from the chemical pulping of wood for paper production, but the byproduct generated during the cellulosic ethanol production provides an alternative, inexpensive resource which has been considered in this analysis. Sheet molding compound and programmable powdered preforming process (P4; see report 8.C) followed by compression molding in each case are the two part manufacturing technologies considered for the floor pan. End-of-life recycling of carbon-FRPMCs will be by the thermal treatment method developed by Argonne National Laboratory. Vinyl ester and polyester are the resin matrix materials considered for P4 and sheet molding compound technologies, respectively. For comparison purpose, hot-dipped mild steel has been considered as the baseline.

LCI data collection for various technologies considered at various life-cycle stages has been completed. Most data collection is by contacting directly the industry personnel involved in the development of such a technology, particularly in the case of lignin-based carbon-fiber production technology. Data collection for conventional carbon-fiber production technology was based on the data available from a commercial production facility. Commercial LCA software such as

SimaPro, containing some of the LCI databases for commercially available processing technologies, will be used for the comparative LCA of alternative carbon-FRPMC floor-pan production technologies. The LCA under investigation would not only provide the positive (lightweighting vehicles for reduced energy and emissions) and negative (energy use and emission during part production) aspects of carbon-FRPMC use in light-duty vehicles but also recommendations for improved environmental impacts when using this material. Sensitivity analysis would be a key element of this assessment, providing information on the robustness of energy and environmental performance of the competing processing technologies.

Conclusions

The specific goal of LM is to develop cost-effective material and manufacturing technologies by 2010 that, if implemented in high volume, could reduce the weight of vehicle body and chassis systems by 50% with safety, performance, and recyclability comparable to 2002 vehicles. The intermediate body and chassis weight reduction goal of 25% in 2008 can be met through either the use of Al or glass-FRPMCs in major body and chassis components. With the consideration of secondary weight savings, a higher body and chassis weight reduction (26–32%) than the 25% weight reduction goal was achieved under two lightweight material scenarios. Powertrain resizing and secondary weight savings can provide cost-effectiveness both at the retail price and life-cycle cost levels for glass-FRPMC vehicles, but in the case of Al vehicles, a vehicle retail price premium of $180/vehicle would be necessary. Consideration of powertrain resizing, secondary weight savings, and life-cycle cost perspectives are therefore important to maximizing the fuel economy gains from a lightweight structure and to eventual successful market penetration of lightweight vehicles in the future.

Life-cycle results here indicate that Mg can have life-cycle advantages over steel, even with the dominance of the energy-intensive and less environmentally friendly primary Mg processes in use today. It is likely that Mg will become increasingly favorable from energy and emissions perspectives with the ongoing improvements being undertaken by Chinese suppliers. It is important that future LCAs capture these ongoing primary metal and part manufacturing technology improvements, including the various end-of-life recycling options, as some of these will become economically viable with increased Mg demand for automotive applications. By analyzing several scenarios, realistic answers to a wide range of major issues such as sustainable material management, product stewardship, energy efficiency, GHG reduction, and the impact of alloy-making and component-production technologies can be obtained from a holistic life-cycle perspective.

Carbon-FRPMCs offer significant potential for reducing vehicle weight while maintaining strength and stiffness. These composites are up to 30% lighter than Al and 50% lighter than steel and can reduce the overall weight of a vehicle up to 10%. Carbon-fiber production is one of the most energy-intensive production steps in the manufacturing of carbon-FRPMCs; its CO_2 emissions are estimated to be 15 times more than conventional steel on a weight basis. Low-cost and renewable precursor materials such as lignin offer significant energy- and emission-reduction potential in the manufacturing of these materials. A life-cycle assessment of this material has been started to compare the potential energy and environmental impacts of manufacturing a representative automotive part, the floor pan, with a focus on comparison of conventional and lignin-based precursor materials technologies for carbon-fiber production. LCA would determine not only the positive (lightweighting vehicles for reduced energy and emissions) and negative (energy use and emissions during part production) aspects of this type of material use in light-duty vehicles, but also recommendations for improved environmental impacts of using this material.

The updated paper on primary Mg production costs for automotive applications indicates that potential for Mg use in automotive applications has been affected during the last 2 years because the prices of competing lightweight materials are trending upward to a lesser extent even with the availability of lower-price Chinese Mg (recent Chinese Mg is priced commensurate with its production cost). Mg will continue to suffer as long as the supply situation does not improve even with the strong demand pressure on other lightweight materials. It is estimated that the Chinese magnesium production cost is around $1.11/lb, but higher raw-material, energy, and labor costs; reduced tax incentives for exports of raw materials; a booming Chinese economy; currency revaluation; and environmental compliance costs may further increase the cost of Chinese-produced Mg even with the continuation of ongoing improvements in its Pidgeon process. A tight supply situation will prevail worldwide with only new plants being built in China in addition to an increase in Chinese domestic consumption and more exports of its final products at the expense of reduced primary Mg. The lack of available financing for the huge capital investment would be the major barrier to expanding existing electrolytic plant capacity or adding new electrolytic capacity in the West, although Mg production costs appear to be economically viable with recent high market prices. New or expanded Western Mg supplies will only occur with continuation of higher prices and assurance of strong market demand in the future (see, for example, Alcoa's consideration of restarting its Addy, Washington, Mg plant). It is unlikely that some of the yet-to-be commercialized technologies considered here will come online, although they do hold significant promise to be competitive with the low-cost Chinese Pidgeon process.

Presentations/Publications/Patents

1. S. Das, "Primary Magnesium Production Cost for Automotive Applications," *Journal of Metals*, **60**(11), pp. 51–57 (2008).

B. Intermediate-Rate Crush Response of Crash-Energy Management Structures

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Contractor: Oak Ridge National Laboratory (ORNL)
Contract No.: DE-AC05-00OR22725

Objective

- Develop unique characterization facilities for controlled progressive-crush experiments, at intermediate rates, of automotive materials (polymer composites, high-strength steels, and aluminum) and structures.
- Study the deformation and failure mechanisms of automotive materials subjected to crush forces as a function of impact velocity.
- Obtain specific-energy-absorption and strain data and correlate with deformation and failure mechanisms to describe the unknown transitional effects from quasi-static to high loading rates for polymer composites.
- Characterize the strain rate effects for metallic materials and components.
- Provide access to the unique test capabilities that are developed to university, industry, and government users for collaborative research.

Approach

- Develop a unique high-force [500 kiloNewton (kN)], high-velocity [8 meters (m)/second], servohydraulic machine to conduct progressive-crush experiments on structural components at intermediate rates.
- Develop a low-force (40 kN), high-velocity (18 m/s), servohydraulic machine for conducting tensile strain rate characterization tests.
- Use high-speed imaging to observe and document deformation and damage mechanisms during the crush event.
- Conduct strain measurements at discrete locations and explore full-field measurement of strains and curvatures.
- Coordinate polymer composite investigations with the Automotive Composites Consortium (ACC) Energy Management Working Group (see the ACC report *Crash Energy Management*).
- Coordinate steel investigations with the Auto/Steel Partnership (A/SP; see the A/SP-ORNL report *Strain Rate Characterization*).

Accomplishments

- Continued diagnostic testing on high-velocity (18 m/s) test machine to better understand inertial effects in the test data.

- Explored electrical-resistance strain gages, extensometers, and optical methods for measuring local and average strains.
- Completed three-point bend tests on the Test Machine for Automotive Crashworthiness (TMAC) second user project with L&L Products.
- Completed tests on high strain rate tensile coupons for the General Motors- (GM-) ACC user project.
- Completed octagonal-tube tests in support of the A/SP Strain Rate Characterization project.
- Completed base-metal tests on dog-bone specimens in support of the A/SP Strain Rate Characterization project.

Future Direction

- Explore techniques for full-field measurement of strains and curvatures.
- Develop real-time data analysis interface.
- Complete a second user project with U. S. Army Corps of Engineers.

Introduction

Progressive crush is an important mechanism by which the kinetic energy of a traveling automobile is dissipated in a collision to protect the safety of occupants. Unfortunately, the mechanisms governing the progressive-crush response of some emerging automotive materials are not well understood. Additionally, many of these materials are known to exhibit responses that are sensitive to rate of loading.

Understanding the influence of impact velocity on the crush response of materials and structures is critically important for crashworthiness modeling inasmuch as collisions occur at a range of velocities. Additionally, from a structural standpoint, the deformation (or strain) rate is generally not unique from either a spatial or temporal standpoint. Consequently, it is important to quantify the behavior of materials at various strain rates.

TMAC

Typically, standard test machines are used for experiments at quasi-static rates, whereas drop towers or impact sleds are the convention for dynamic rates. These two approaches bound a regime within which data for experiments at constant impact velocity are not available by conventional experimental practice. This regime is referred to as the “intermediate strain rate” regime in this report and is defined by impact velocities ranging from 1 m/s to 5 m/s. Investigation of rate effects within this regime requires experimental equipment that can supply a large force with constant velocity within these rates.

Using a drop tower or sled at intermediate strain rates, although technically possible, is problematic due to the prohibitively large mass required to maintain constant velocity during the crush. Consequently, ORNL and ACC collaborated to define specifications for a unique experimental apparatus that mitigates the shortcomings of existing equipment. MTS Systems Corporation designed and built the servohydraulic test machine, TMAC. TMAC is uniquely suited for controlled progressive-crush tests at constant velocity in the intermediate-velocity range (i.e., less than 5 m/s) because of the large energy available at those rates and the sophisticated simulation and control software that permits velocity uniformity to within 10%.

The TMAC experimental facility is used to understand the crush behavior between static and dynamic (8 m/s) conditions. TMAC was originally installed at the National Transportation Research Center (NTRC), Knoxville, Tennessee, as shown in Figure 1. Since then TMAC has been relocated to ORNL.

Figure 1. Installation of TMAC in the NTRC Composite's Laboratory.

Status

Since the last reporting period, activities have focused on completing user projects, developing and promoting new user projects, improving data acquisition, and expanding test capability for higher-rate coupon tests.

Interactions with industry and academia for potential new user projects have taken place with Rutgers, Massachusetts Institute of Technology, SAE High Strain Rate Plastics Consortium, GM, Ford, Imperial College (London, England), Washington University, University of Utah, and L&L Products. Also, discussions continued with the University of South Carolina and Correlated Solutions on developing a full-field, dynamic strain measurement system using digital image-correlation techniques.

In addition to promoting user programs, continued support was provided to the development of a crashworthiness chapter for the military's composite design guide, CMH-17 (formerly MIL-HDBK-17), and the start of a technical division on the Dynamic Response of Materials within the Society for Experimental Mechanics.

Project Support Activities

Tube tests were completed on TMAC in support of the A/SP Strain Rate Characterization project (see report 5.F) These tubes had an octagonal shape with spot welds down the edges of the tube. A base plate having a flange with holes drilled for bolting to existing TMAC fixtures was welded to one end of the tube. The progressive-crush end of the tube was machined at an angle for the triggering mechanism. Three different material systems were tested at three different velocities. In addition to the tube tests, coupon-level strain rate characterization tests were completed on seven different high-strength base metals.

User Programs

A follow-on user project was completed for L&L Products. L&L Products manufactures reinforced composite-steel box-beam structural components that are integrated into key locations in vehicles to improve vehicle crashworthiness. TMAC can conduct tests at rates higher than normally available from other test methods and can supply the needed structure performance data necessary for evaluating L&L's box beams. To help L&L Products define their test plan, 14 exploratory bend-crush tests were conducted in fiscal year (FY) 2007 to explore the suitability of their custom, three-point-bend test fixture and verify the suitability of the test for collecting the desired high strain rate data. Figure 2 shows the test setup, and Figure 3 shows some of the failed specimens.

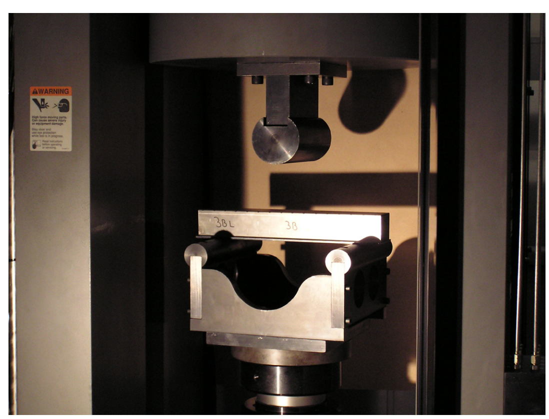

Figure 2. Three-point-bend test setup on TMAC.

Figure 3. Failed L&L Products specimens.

All tests were successful, but minor modifications were needed for the L&L Products test fixture to harden the supports and loading nose. The complete test matrix consisted of more than 100 specimens at various rates up to 8 m/sec. Different specimens were tested to evaluate the role that different beam insert materials had on energy absorption. This was the first non-axial crush testing to be preformed on TMAC and was successful in demonstrating its use for studying side impact crash effects. A follow-on proposal for conducting high strain rate lap-shear tests on coupons is being developed. The prototype specimen is shown in Figure 4.

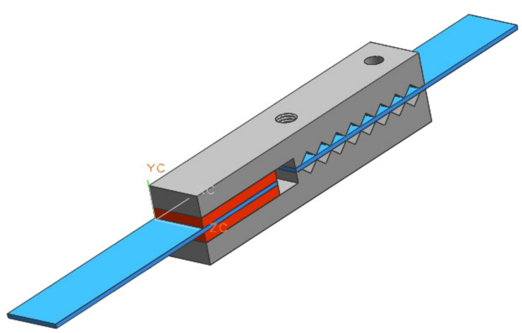

Figure 4. High strain rate lap-shear specimen for L&L Products.

The object of the GM-ACC User Project is to conduct high strain rate coupon tests on carbon-fiber braided material. This same material has been used extensively in other ACC projects for tube-crush studies. The data to be generated from these tests are in support of a rate-sensitive material model developed by Stanford University for predicting the crush behavior of carbon-fiber tubes. These tests were conducted on the high strain rate coupon test machine described in the next section. The coupons used for these tests were machined from unidirectional braided plaques. The test plan consisted of 25°, 45°, and 65° off-axis coupons tested at five different nominal strain rates (0.01, 0.1, 1.0, 10.0, and 100.0/s). The preliminary tests were completed to determine load- and strain-measuring requirements and any corresponding data acquisition modifications. It was determined that updates to the data-acquisition hardware were needed to increase scan rates and that strain gages were the preferred method for measuring strain. The hardware was updated and all specimens were returned to GM to instrument with strain gages. The specimens were returned to ORNL, and all of the planned tests were completed. A typical test setup is shown in Figure 5, and typical failed specimens are shown in Figure 6. The test data were then provided to ACC for analysis.

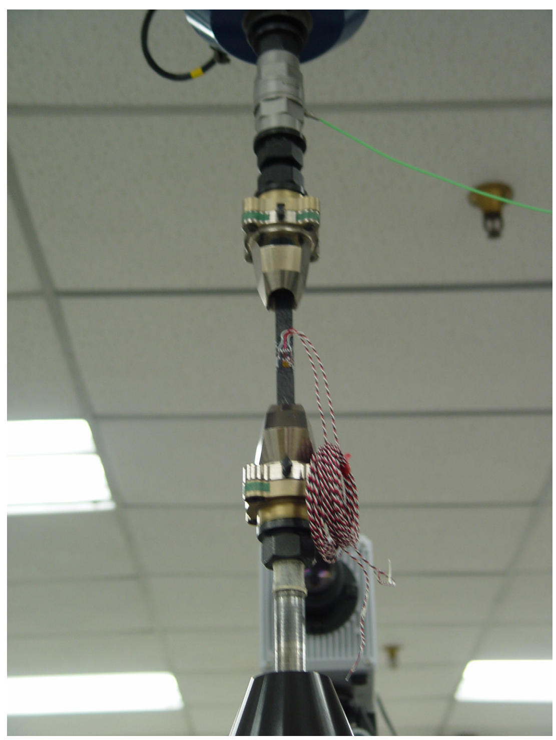

Figure 5. Typical coupon test setup on high strain rate tension machine.

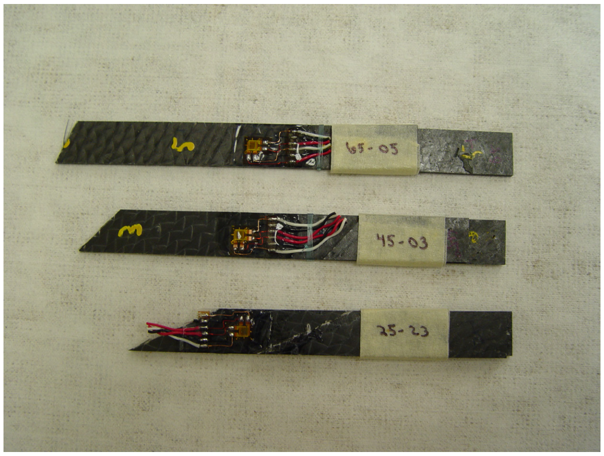

Figure 6. Typical failed off-axis tension specimens.

High Strain Rate Coupon Test Machine

To complement the TMAC capability, a high strain rate coupon test machine was designed, fabricated by MTS, and installed at ORNL (Figure 7). Where TMAC provides the capability for a large-force (500 kN static), structural-level test, this machine was designed to conduct low-force (40 kN static), coupon-sized tests under primarily tensile loads. A typical coupon would be a dog-bone strip where the gage section is 15 mm wide with a thickness of 3 mm. This type of test is ideal for generating rate-sensitive stress-strain curves in development of basic material constitutive laws. The machine has a maximum crosshead speed of 18 m/s with a 400 mm total stroke capacity. The actually working stroke is reduced to 175 mm when installing a slack adapter to allow for the actuator to get up to constant speed before loading the specimen. These specifications were accomplished by a using a 400-gallon-per-minute servovalve and 50-gallon accumulators (see Figure 8). Another feature of the test machine is the use of low mass grips designed to reduce ringing in the system thereby minimizing inertial effects in the load signal. The grips were based on a Colorado School of Mines design and are shown in Figure 9.

Figure 7. High strain rate (18 m/s) coupon test machine.

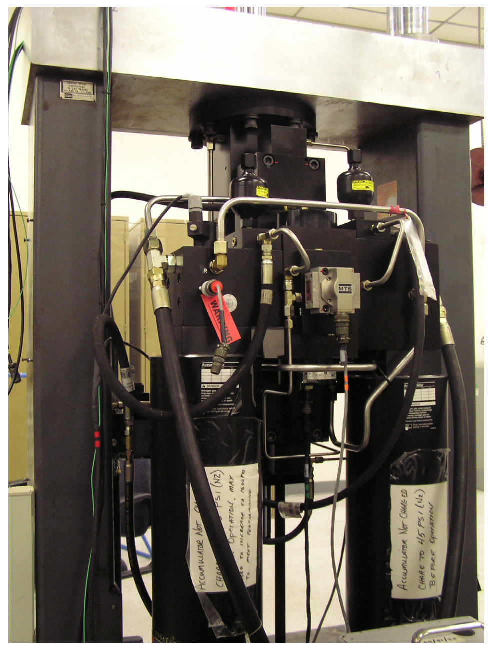

Figure 8. Accumulators and servovalve for high strain rate test machine.

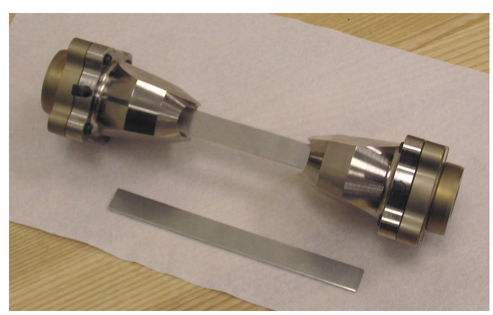

Figure 9. Low-mass grip used in high strain rate test machine.

Conclusions

TMAC provides a unique capability to measure the specific energy absorption on crush tubes and other specimen geometries as a function of (constant) impact velocity within a range from quasi-static to 8 m/s. To complement this capability, a new machine was installed for conducting coupon-level tests up to 18 m/s.

User interest in this equipment remains very high with follow-on projects and new projects being in the draft stage. TMAC was also instrumental in meeting project objectives for the A/SP. In all of these tests, high-speed video was recorded to document the failure mechanisms using a state-of-the-art complementary metal-oxide semiconductor camera that was procured for the TMAC installation.

Presentations/Publications/Patents

None

C. Mission Eggcellence—K–12 Outreach Program

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Contractor: Mississippi State University (MSST)
Contract No.: 4000054701

Objective

The project is designed to develop a commitment from Center for Advanced Vehicular Systems (CAVS) and MSST to the children of the state of Mississippi through curriculum instruction and competitions dealing with the design of a vehicle bumper and/or seatbelt for passenger safety. These instruction and student competitions will create an awareness of the importance of design in safety implications, and the real-world applications of mathematics, science, and engineering problem-solving skills. Mission Eggcellence will also create awareness among the Mississippi school-age population of future job opportunities in the state of Mississippi, as well as college majors associated with these jobs.

Approach

- Create a grade appropriate curriculum, with experiments associated with the physics of car crashes for grades K–2. (Objective 1)
- Create a grade appropriate curriculum, with experiments associated with the physics of car crashes for grades 3–5. (Objective 2)

- Develop a Teacher Workshop for grades K–2 teachers for training in the use of grade appropriate curriculum in the regular classroom. Equipment necessary to conduct the experiments and compete in the competitions would be given to each teacher participant. (Objective 3)
- Develop a Teacher Workshop for grades 3–5 teachers for training in the use of grade appropriate curriculum in the regular classroom. Equipment necessary to conduct the experiments and compete in the competitions would be given to each teacher participant. (Objective 4)
- Design a competition for grades K–2, incorporating bumper design for passenger safety. (Objective 5)
- Design a competition for grades K–2, incorporating car design for passenger safety. (Objective 6)
- Design a competition for grades 3–5, incorporating bumper design for passenger safety. (Objective 7)
- Design a competition for grades 3–5, incorporating car design for passenger safety. (Objective 8)
- Create a grade appropriate curriculum, with experiments associated with the physics of car crashes for grades 6–8. (Objective 9)
- Create a grade appropriate curriculum, with experiments associated with the physics of car crashes for grades 9–12. (Objective 10)
- Develop a Teacher Workshop for grades 6–8 teachers for training in the use of grade appropriate curriculum in the regular classroom. Equipment necessary to conduct the experiments and compete in the competitions will be given to each teacher participant. (Objective 11)
- Develop a Teacher Workshop for grades 9–12 teachers for training in the use of grade appropriate curriculum in the regular classroom. Equipment necessary to conduct the experiments and compete in the competitions will be given to each teacher participant. (Objective 12)
- Design a competition for grades 6–8, incorporating bumper design for passenger safety. (Objective 13)
- Design a competition for grades 6–8, incorporating car design for passenger safety. (Objective 14)
- Design a competition for grades 9–12, incorporating bumper design for passenger safety. (Objective 15)
- Design a competition for grades 9–12, incorporating car design for passenger safety. (Objective 16)
- Expand the Mission Eggcellence Program throughout the state of Mississippi by continuing the teacher workshops and student competitions. (Objective 17)

Accomplishments

- Completed curriculum for grades K–2. (Objective 1)
- Completed curriculum for grades 3–5. (Objective 2)
- Completed Teacher Workshop for teachers of grades K–2. (Objective 3)
- Completed Teacher Workshop for teachers of grades 3–5. (Objective 4)
- Completed Bumper Design Competition for grades K–2. (Objective 5)
- Completed Car Design Competition for grades K–2. (Objective 6)
- Completed Bumper Design Competition for grades 3–5. (Objective 7)
- Completed Car Design Competition for grades 3–5. (Objective 8)
- Completed curriculum for grades 6–8. (Objective 9)
- Completed curriculum for grades 9–12. (Objective 10)
- Completed Teacher Workshop for teachers of grades 6–8. (Objective 11)
- Completed Teacher Workshop for teachers of grades 9–12. (Objective 12)

- Completed Bumper Design Competition for grades 6–8. (Objective 13)
- Completed Car Design Competition for grades 6–8. (Objective 14)
- Completed Bumper Design Competition for grades 9–12. (Objective 15)
- Completed Car Design Competition for grades 9–12. (Objective 16)

Future Direction

The major emphasis for the Mission Eggcellence Program is to expand the range of this program in the state of Mississippi through the teacher workshops (Objective 17). The teacher workshops will provide an avenue for K–12 teacher training in the use of the curriculum in their classrooms. The equipment will be provided to teachers who participate in the teacher workshops. This will give more students the opportunity to learn the physics associated with car crash safety and to incorporate the physics into the design of the car bumper and the car chassis. The student competitions, which are grade appropriate, are held for students of any teacher who has previously attended the teacher workshops. Teachers can enter a team of one to three students in the Mission Eggcellence (bumper) Competition and a team of one to three students in the Automotive (car design) Competition for each of the grade sections (K–2, 3–5, 6–8, and 9–12).

Introduction

MSST CAVS is teaming with the local school districts and the Mississippi Children's Museum (MCM) to develop a sophisticated science and technology curriculum, using teachers and workshops in the museum to inspire young minds to explore the worlds of math, science, and engineering. We will create powerful interactive learning/teaching kits for K–12 students with a program based upon materials design, which will be supported by ASM International, entitled Mission Eggcellence.

Mission Eggcellence provides students with a hands-on introduction into vehicular crashworthiness through applying basic concepts of physics (students are provided with simple definitions from physics such as Mass, Velocity, Momentum, and Energy and how they are used during crash), explanations of what actually happens during a crash (using the physics terms and defining what is necessary to enable passengers to survive a crash), and examples of safety devices (explanations and examples of some devices such as Bumpers, Seatbelts, Airbags, and Safety Cages used in cars and trucks, with simulations to demonstrate how they work). Other explanations provided will include manufacturer goals (creating a vehicle that is lightweight for the lowest price possible, creating a vehicle that demonstrates good fuel efficiency and creating a vehicle that is aesthetically pleasing in appearance) versus consumer goals (a vehicle that is strong enough to protect passengers from impact, a vehicle that is light enough to provide economical fuel consumption, a vehicle that has a pleasing appearance, a vehicle that has a memory of its shape and can be repaired faster, less expensive, and easier) and the difficulties involved in balancing these requirements.

Vehicles, materials, eggs, workbooks/worksheets, and instruction will be provided to the students, with which they must design a safety barrier for each team's vehicle that will prevent the egg from breaking upon impact during an impact competition. The vehicles are released upon a ramp, which is elevated to a higher degree of angle (from 15 to 70 degrees) at each step of the impact competition and the vehicles in which the eggs do not break can win. The winners are determined by the lightweight designs. Competitions are expected to be statewide. Undergraduates and graduate students will play a large role in communicating the principles and overseeing the activities. They will also be used to help monitor the tournaments and mentor some of the K–12 students.

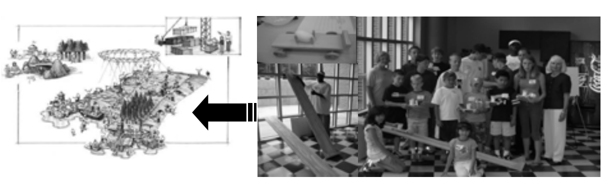
Each curriculum consists of eight grade-appropriate experiments for the physics concepts of velocity, acceleration, Newton's Third Law, momentum, impulse, elastic and inelastic collisions. These experiments will include a bumper design and car design. In the bumper design competitions for grades K–2, 3–5, 6–8, and

9–12, the bumper is tested by rolling a wooden car, with the bumper attached, down a ramp using a raw egg as the passenger. The winner is the car that can make it down the steepest incline with the egg intact. The tie breaker is the car with the lightest mass. In the grades K–2 and 3–5 car design competitions, a car is designed using K'nex pieces from a kit. In the grades 6–8 and 9–12 car design competitions, students will use a car designed from balsa wood. The winner is the car that can make it down the steepest incline with the egg intact. The tie breaker is the car with the lightest mass.

Academic/Research Excellence Basis

An overarching theme of multidisciplinary design integration motivates our research, as well as our multilevel educational activities in K–PhD and continuing education. Our educational approach is structured to overcome the knowledge compartmentalization and overspecialization of traditional technical education that stand as barriers to the implementation and dissemination of science-based engineering. Core university collaboration seeks to empower a broad range of students through a fusion of exciting new science-based tools, with design habits of mind, team creativity, and effective multidisciplinary communication. Our Mission Eggcellence design project work will be enhanced by the emerging technology of a distributed Web-based collaborative environment. We have a clear education accountability structure administered by the CAVS chair professor, Mark Horstemeyer. In addition, MSST CAVS has a strong extension/ outreach center in which quick implementation of research is plausible.

Children's Museum **Student Crash Competition**



Project Objectives and Expected Outcomes/Impacts

In alignment with the objectives and expected outcomes of this task, which is to empower and inspire all our state's children regardless of their social, educational, or economic background and to discover their potential through tapping their curiosity and creativity, through hands-on and engaging exhibits and programs, we will create a dynamic and competitive program that will do the following.

- Provide children the opportunity to perform hands-on experiments; to learn the value of mathematics, physics, and engineering and how their uses in the experiments correlate with "real world" engineering problems; and to create for themselves the experience of mastering tasks they would normally perceive to be difficult, which will increase their self-esteem, demonstrated by increased performance levels in school.
- Address the needs of Mississippi children, especially in the areas of math, science, and engineering.
- Reach children in schools and communities throughout the state through our Outreach Program.
- Complement the mathematics, physics, and science programs being taught in school. Correlated to the math and science standards in the state of Mississippi.
- Promote a desire to learn more about the world in which the children live and how it works.

We need a creative K–Ph.D. program that anticipates the current and future high-tech jobs revolving around the automotive industry in our state. Children need to be excited by math, science, and engineering and the MCM can enkindle that passion. If we can help children develop a passion for learning, they are going to want to understand how things work and how to make things work better. For Mississippi to advance in the science and technology fields, children must become excited about learning, and this is the fundamental mission of a children's museum.

Mission Eggcellence, among other materials design projects, can provide a science/engineering experience that will inspire children to want to return time and time again. Each time that they return, they will learn things about their world that inspire them to want to return and learn more. The imaginative and experimental Mission Eggcellence is relevant to the students' classwork and can be correlated with "real world" safety, reliability, and crashworthiness issues that are faced today within the automotive industries.

Contributions to the Long-Term and Sustainable Engagement of the Team/Unit

MSST is developing an "Automotive Experience" strategic program that includes K–12, undergraduate work, and graduate level work. A new course and certificate are being developed in real time for this endeavor. For MSST to have an excellent Ph.D. pool, we need to have aligned in the pipeline K–12 students. We are viewing these grant funds as start-up funds only, but the program will continue long into the future.

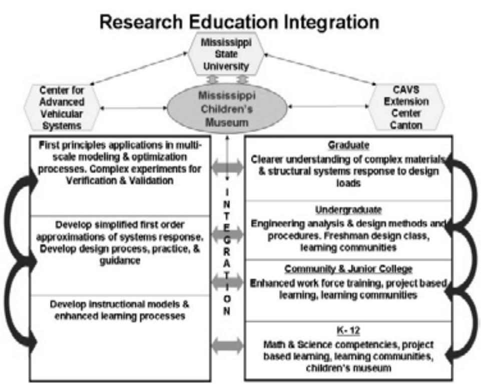
From the Southern Regional Center for Lightweight Innovative Design (SRCLID) Statement of Program Objectives, the transfer of knowledge obtained from leading-edge research to K–12 educational programs is a core requirement: CAVS is required to develop an educational program to integrate lightweighting design concepts with crashworthiness into student curricula. A K–Ph.D. program will be developed that communicates the important issues of crashworthiness and safety. Crash kits will be developed for appropriate educational levels, and state and regional tournaments will be fostered to further interest in the technology and resultant designs.

Specific subtasks include the following.

- **Task 1**—Develop crash kits for K–2, 3–6, 6–8, and 9–12.
- **Task 2**—Develop tournaments with crash kits for Mississippi-wide contests.
- **Task 3**—Assist in the development of modules for MCM.

CAVS will design materials kits and crash kits with their associated documentation (student and instructor) and provide engineering specialists as keynote speakers, trainers, and lecturers. Rosemary Cuicchi (retired teacher—32 years experience) and Dr. Paul Cuicchi (Starkville High Physics teacher and MS Teacher of the Year 2002) are involved in developing the program. ASM will also be involved in helping develop the program. Nissan North America (Canton, Mississippi) and Vista Engineering, Inc. have both donated in-kind contributions to the SRCLID program with specific interest in the educational development aspects of the program.

The MCM administrators and staff will be involved in designing and setting up the exhibits within the museum, as well as establishing agendas for exhibit changes. Dr. Mark Horstemeyer is helping design the regions within the children's museum to help explain the math, science, and engineering aspects.



The graphic above represents the CAVS research resource vision, through which data, research materials, materials design methodologies, and basic science aspects will be made available to students through this task, sponsored by DOE and the MCM.

Evaluation/Assessment

The program will be evaluated internally, by MSST staff, and externally, by partnering organizations, committee members, and visitor surveys. Internal evaluation will take place at monthly meetings, where staff members take the opportunity to debrief with the entire group, provide feedback, and troubleshoot issues.

External evaluations will be completed through a MCM partner survey. During the evaluation of the program, staff will review the types of programs/activities offered to ensure that they accurately represent the culture and decide if an organization's participation in the program helped to provide access to the MCM for members of the community. In addition, staff will track the following:

- number of individuals who participated in the special events, workshops, and programming;
- number of communities served (examples are Latino, Native American, African-American, Asian, and Caucasian);
- number of community-based organizations with which we partner;
- number of opportunities created for cross-cultural programming; and
- number of events we will offer at the museum during the year's Passport programs.

Making a Difference within the Community and the University

University metrics will demonstrate the effectiveness of the program by showing increases in students coming to MSST and other colleges and universities, in the fields of math, science, and engineering. Within the community, we expect to see a higher rate of students becoming involved in math, science, and engineering, and in the long run, expect to see more high-tech companies moving into the state as a result of this program. If we increase the rates of students in math, science, and engineering, indicating a more highly educated future work force, the number of incoming high-tech companies will increase.

Interpreting the Accompanying Logic Model

(refer to p. 12-19)

Situation—The situation, as it applies to this project, is that children in Mississippi do not have access to innovative open-ended educational hands-on programs in which they can be exposed to viable applications of math, science, and engineering. Because the Mississippi public educational system is not considered to be strongly effective in graduating students who are strong in math, science, and engineering, few high-tech companies consider Mississippi to be an economically viable target for relocation or expansion of businesses.

Priorities and Intended Outcomes—The priorities of this project are thoroughly integrated within the mission and vision of CAVS, especially as defined by the DOE-SRCLID Statement of Program Objectives (SOPO). Specifically, the transfer of knowledge obtained from leading-edge research to K–12 educational programs via developing an educational program to integrate lightweighting design concepts with crashworthiness into student curricula, will be accomplished by developing crash kits for appropriate educational levels and by fostering state and regional tournaments to further interest in the technology and resultant designs. The intended outcome will be an increased number of students at all educational levels who will have a deeper understanding of math, science, and engineering and an appreciation of these fields of study in real-world applications.

Inputs—CAVS (MSST), the CAVS Extension (Canton), and the community will integrate into a synergistic teaming effort to provide staff, volunteers, time, money, basic research, materials, equipment, technology, and partners to ensure the success of this program

Outputs—What Will We Do? Personnel from the core facilities mentioned above will conduct workshops and meetings, will deliver services, will develop products, curriculum and provide resources, will provide training, will provide counseling, will assess the program and its effectiveness, will work with the partnering organizations, and will work with media to ensure proper dissemination of information to the public.

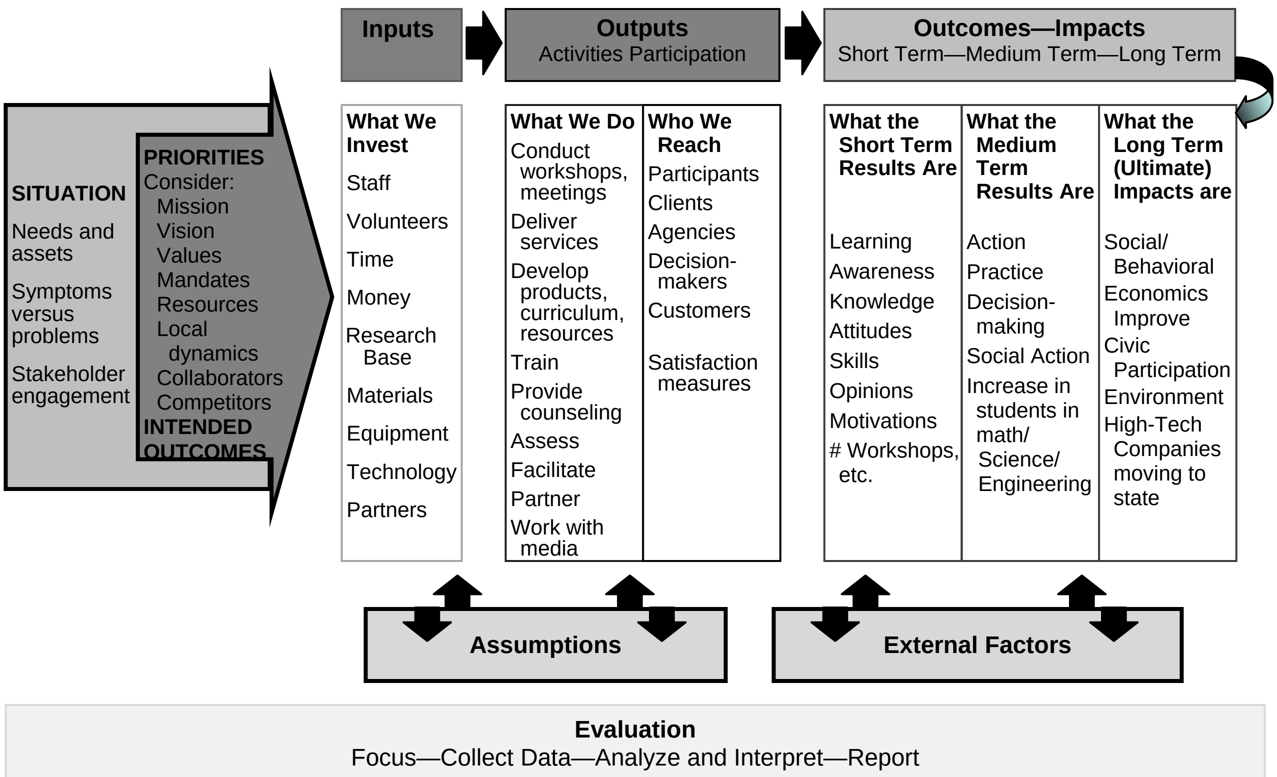
Outputs—Who Will We Reach? We will reach participants (children, parents, and teachers) and provide satisfaction feedback.

Outcomes—Short-Term Impacts. We anticipate an increased interest by students in math, science, and engineering as demonstrated by improved learning, awareness, knowledge, attitudes, skills, opinions and motivations, as a result of student participation in the workshops, et cetera.

Outcomes—Medium-Term Impacts. We anticipate seeing an increase in museum student participation (Actions), an increase in classroom participation (Practice), an increase in understanding and application of lessons-learned by students in their respective schools (Decision-making), an increase in awareness of potential impacts upon society of vehicle lightweighting and crashworthiness (Social Action), and an increase in students interested in math, science, and engineering.

Outcomes—Long-Term Impacts. We anticipate students graduating from their respective schools and entering colleges and universities to pursue degrees in math, science, and engineering, who will have a stronger working knowledge and understanding of math, science, and engineering as they relate to societal/behavioral, economic, civic, and environmental impacts, as well as seeing an increase in the number of high-tech companies moving to Mississippi, as a result of having a more informed and more highly educated student labor base from which future employees can be selected.

Evaluation. The effectiveness of this program will be determined by follow-up investigations, over time, to collect data, analyze and interpret the data, and report on the increase in students who enroll in institutions of higher learning in the fields of math, science, and engineering.



Materials Design Logic Model

Conclusions

The Mission Eggcellence Program has been developed for grades K–2, 3–5, 6–8, and 9–12. The Teacher Workshops for these grades were very successful. Ninety-five teachers have been trained in the Teacher Workshops. Two-hundred forty students have competed in the student competitions. Eighty percent of the teachers who attended the workshop had students compete in both the bumper design and car design competitions. Feedback was excellent.

Acknowledgement

The authors would like to acknowledge funding from the Center for Advanced Vehicular Systems at Mississippi State University and the Department of Energy. We also acknowledge valuable curriculum guidance and ramp construction received from Dr. Paul Cuicchi.