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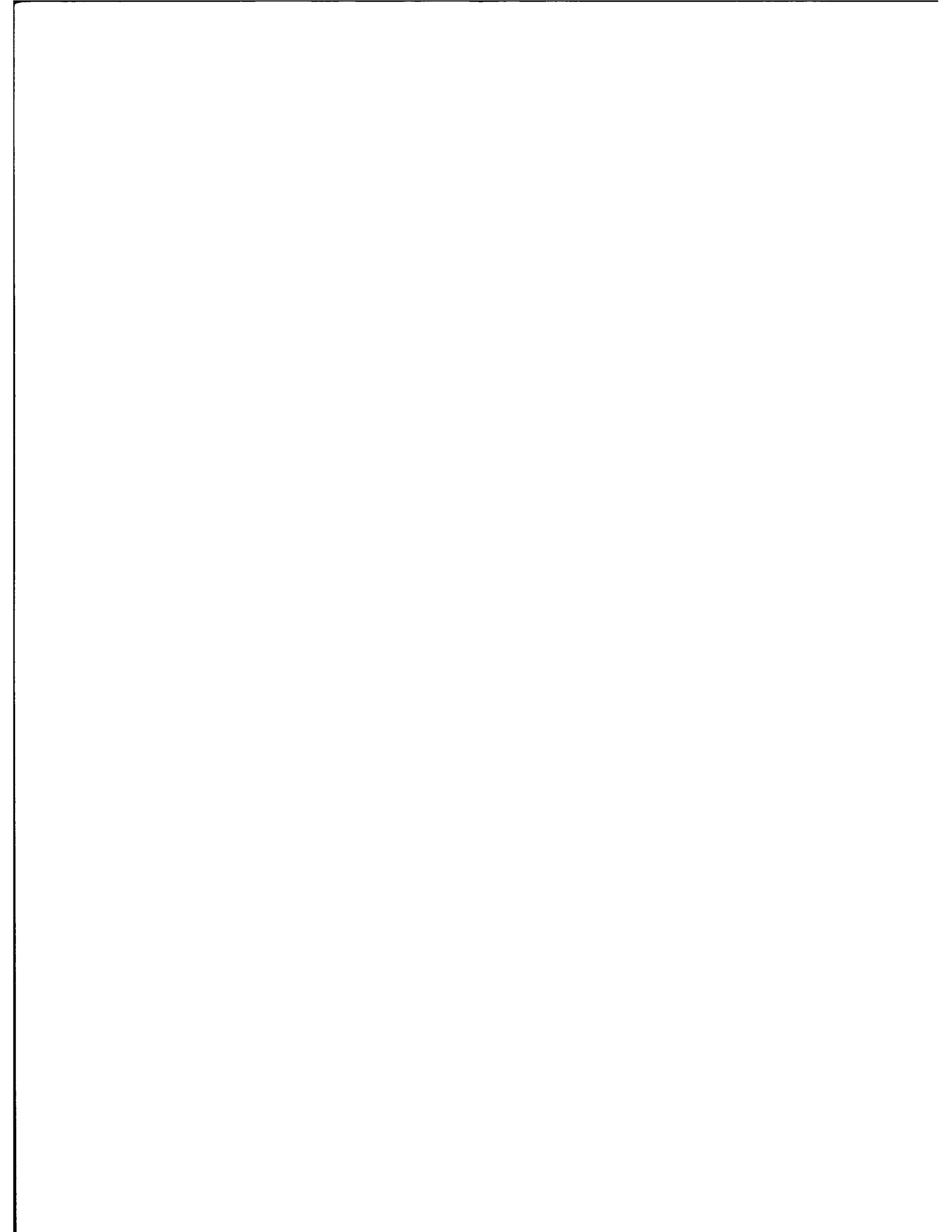
# Materials Research and Technology Initiatives



November 1995

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**MATERIALS RESEARCH  
AND TECHNOLOGY INITIATIVES**

**Final Report  
November 1995**

**Prepared by**

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## ACKNOWLEDGMENTS

The Department of Transportation (DOT) Strategic Plan of January 1994 emphasized the importance of advanced materials applications and related technologies to the transportation enterprise. Goal 3.3 commits the Department to "*Support the use of advanced materials in manufacturing and constructing transportation equipment and facilities.*" The Research and Special Programs Administration (RSPA) assumed the lead role in coordinating and implementing Department-wide research, development, and technology transfer and sharing activities related to advanced materials. RSPA's Volpe National Transportation Systems Center provided technical support to this continuing effort.

RSPA initiated the formation of an Advanced Materials subcommittee of DOT's Research and Technology Coordinating Council (RTCC). This subcommittee is chaired by Tom Pasko Federal Highway Administration (FHWA) with staff support from Dr. Aviva Brecher of the Volpe Center. Its members are RSPA Deputy Administrator Ana Sol Gutierrez, Joseph Soderquist (FAA), Capt. Bob Wenzel (USCG), Tom Hollowell (NHTSA), Don Gray (FRA), Bart Mancini (FTA) and Fred Seibold (MARAD). Norm Paulhus of RSPA's Office of Research Policy and Technology Transfer provides the liaison to the RTCC and facilitates technology transfer activities. The subcommittee reviewed and improved this report as one of its products and activities in support of DOT Strategic Goal 3.3, and is facilitating cooperative R&D efforts and new initiatives.

This report is the first crosscut of DOT's advanced materials and materials-related R&D, including improved modeling and nondestructive testing methods and advanced technology or applications of standard materials. It was prepared by the Volpe Center Transportation Strategic Planning and Analysis Office, which provides technical support on DOT-wide research coordination to RSPA. The report is a Technical Assistance document published by RSPA's Office of Research Policy and Technology Transfer. It is intended to serve DOT's customers and prospective research partners by highlighting some opportunities for joint R&D and for near-term applications of advanced materials and associated technologies to the transportation sector.

Every opportunity for outreach to researchers and industry will be used, to highlight the promise and prospects of advanced materials transportation applications, and to stimulate research and demonstration partnerships. The March 1995 Transportation Research Board "Forum on Future Directions on Transportation R&D" was one such showcase opportunity for the National Science and Technology Council R&D priorities on infrastructure renewal and next generation vehicles.

DOT has been an active participant in the national Advanced Materials and Processing Program: DOT R&D programs are included in the Federal Program FY93 and FY94 White House publications. FHWA has represented DOT's advanced materials research interests since 1992 on interagency committees, and currently serves on materials-related subcommittees of the Civilian Industrial Technology Committee. This committee's Materials Technology subcommittee is preparing a national crosscut of Federal R&D programs for the Fall of 1995, including again DOT contributions.

## EXECUTIVE SUMMARY

This report examines materials research programs across all operating Administrations within the Department of Transportation (DOT). It covers in-house, extramural and cooperative materials research thrusts, as well as technology promotion and outreach activities. This work is part of a concerted effort to implement DOT Secretary Federico Peña's strategic goal to "Support the use of advanced materials in manufacturing and constructing transportation equipment and facilities," as part of a greater goal to "Create a new alliance between the nation's transportation and technology industries, to make them both more efficient and internationally competitive."

The report describes both ongoing (FY94 baseline) and planned (FY95-96) materials-related research and technology efforts within DOT, with special emphasis on the promise and prospects for transportation applications of advanced materials. Cooperative DOT research on materials-related topics, with other federal agencies, State governments, and with university researchers and the private sector entities are also discussed.

Infrastructure renewal is a core element of the Clinton Administration Technology Policy and the DOT Strategic Plan. Chapter 1 provides further policy background, and also establishes the transportation needs context for DOT's materials research programs (such as safety mission-support).

The review found DOT's current research and technology efforts related to materials concentrated in two areas: infrastructure applications and vehicle applications. Regarding infrastructure applications, the review found important activities in RSPA (pipeline safety), FHWA (pavement, road and bridge structures, and seismic research), FRA (equipment and track-related safety research), and FAA (airport pavements and security). Chapter 2 elaborates on these activities, which target both advanced materials and advanced applications of conventional materials. Another major focus of DOT work is on non-destructive evaluation of structures to enable maintenance and risk prioritization, an area offering promising opportunities for collaborative intermodal work.

The R&D programs involving advanced materials applications to transportation vehicles typically focused on safety in design and performance. Activities were proceeding in RSPA (hazardous materials containers); NHTSA, FHWA, and FRA (next generation motor vehicles and railcars), FAA (aging and advanced technology aircraft); and USCG and MARAD (ships and ship structures). Applications of advanced materials to improve fire safety of vehicle interiors, and research to improve the crashworthiness of cars, railcars and freight transportation containers appeared especially important.

DOT has taken a particularly active role as a participant in interagency partnerships to develop and promote applications of advanced materials. Particularly visible coordination and cooperative research activities include the National Science and Technology Council's Transportation R&D Committee, the cost-shared, industry-led Technology Reinvestment Project and Advanced Technology Program, and the University Transportation Centers. These are described further in Chapter 4.

The review highlighted a variety of success stories in the materials research applications area: "smart pigs" for pipeline inspection, use of recycled materials in highway construction, computer based pavement management systems, innovative fire suppression technologies for vehicles, and advanced pavement and structural monitoring techniques, among others. Sidebars in the text provide more specific information on these recent successes, and illustrate their benefits to the nation. An Appendix lists DOT points of contact for further technical information on specific R&D programs.

## ADVANCED MATERIALS RESEARCH AND TECHNOLOGY INITIATIVES

*"One of the greatest challenges we face is to rehabilitate and maintain the huge stock of infrastructure facilities already in place. With this in mind, the Administration will consider establishing an integrated program of research designed to enhance the performance and longevity of existing infrastructure... This program would systematically address issues of assessment technology and renewal engineering. A strategic program to develop new technologies for assessing the physical condition of the nation's infrastructure, together with techniques to repair and rehabilitate those structures could lead to more cost-effective maintenance of the infrastructure necessary to economic growth."*

**Clinton-Gore Technology for America's Economic Growth, A New Direction to Build Economic Strength, February 1993**

### 1.0 BACKGROUND AND INTRODUCTION

The transportation infrastructure of the United States is a vast network of highways, railroads, waterways, transitways, pipelines and supporting infrastructures worth some \$2.4 trillion. These transportation networks are the physical systems that bring people and products together, the foundation on which our economy and society move.

#### **The U.S. Transportation Infrastructure**

- Highways and roads - 4,000,000 miles
- Bridges - 575,000
- Airports - 670 certified, 50 large hubs
- Intercity rail - 240,000 miles
- Urban rapid rail - 11,000 miles
- Petroleum and natural gas pipelines - 190,000 miles
- Navigable waterways - 26,000 miles
- Plus 600 ports, locks; 10,000 waterfront facilities

The well-being and vitality of this infrastructure are essential to the economic prosperity of the nation. In direct expenditures alone, transportation-related activities account for almost 20 percent of the Gross Domestic Product of the U.S., with about 15 percent of that applied to construction, operation and maintenance of transportation systems. Of these expenditures, more than 80 percent is for maintenance of our aging and deteriorating infrastructure.

Transportation infrastructure systems must not only be incrementally restored, renewed, preserved and strengthened, but expanded in capacity if the ever-growing transportation needs of our nation are to be served.

The methods, tools and materials used in vehicles and in transportation infrastructure construction and maintenance change very slowly, limited in part by the desire to avoid the risk of unknown consequences years or decades later, and by the importance in most decision processes of minimizing initial cost. Another constraint is that the supply industries involved may anticipate limited markets and low profits for innovative products and often exhibit little motivation toward performance of advanced R&D.

However, in sectors such as defense and consumer products, various forces have provided a strong incentive for innovation in sophisticated new materials, structural design concepts, and innovative tools and techniques. The inventory of technological advances worthy of infrastructure use grows day by day, awaiting only the effort to develop specific applications, demonstrate their effectiveness and long-term viability, and often, reduce their costs to a competitive level. The reality of this concept is already being demonstrated by results achieved in Europe, where American highway professionals observe a much more vigorous program for incorporating new materials in public works. The degree to which portions of the nation's aging transportation network is nearing or has already exceeded its nominal life, thereby imposing high maintenance costs and periodic service disruptions, warrants aggressive examination of efficient and practical means of improving materials to renew transportation infrastructure of all types. The National Highway System designated by the Department of Transportation (DOT) in 1994, as the foundation for a seamless National Transportation System initiative will benefit from advanced materials and associated process and construction technologies.

Obtaining the best life-cycle performance from the nation's physical infrastructure is important not only to the users but the taxpayers and the government. Materials used construction practices, climate and use of the infrastructure can all vary dramatically, and infrastructure lifetime is normally measured in decades.

Infrastructure renewal is a core element of the Clinton Technology Policy and the **DOT Strategic Plan** (January 1994). A key objective of the Strategic Plan is to "*support the use of advanced materials in manufacturing and constructing transportation facilities and equipment*" (Goal 3.3). In response to the Technology Policy, the National Science and Technology Council (NSTC) Interagency Coordinating Committee on Transportation R&D delegated to its Infrastructure Renewal Subcommittee the task of defining research priorities for the physical infrastructure of our nation's transportation system. Furthermore, the budget guidance for FY96 reflected the NSTC Transportation Committee's report and set requirements for crosscut R&D data collection and review. The White House Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) set eight national priority areas for federal R&D FY96 and again for FY97, including R&D on

transportation physical infrastructure. This encouraged all federal agencies to explore and exploit uses of new materials and associated technologies for infrastructure renewal engineering.

This report reviews current and planned (FY94-96) R&D programs dealing with advanced materials, as well as with advanced applications of common materials used in transportation infrastructure and vehicles, with improved modeling and assessment tools, and with non-destructive sensors and assessment methods.

"This transportation infrastructure strengthens America by bringing people and communities closer together, spurring trade and commerce to meet the new demands of a global economy....Our challenge now is to shift our attention from what we've built to how we can make it work better for our country--through the adaptation and modernization of our existing infrastructure....This reinforcing and rebuilding effort can create jobs, improve our quality of life, spur technological development and fuel long-term economic growth."

"...better quality materials for highways and bridges and other technologies, though available today, have not yet been widely applied in America's transportation system."

"Goal 2: Invest strategically in transportation infrastructure, which will increase productivity, stimulate the economy and create jobs."

Department of Transportation Strategic Plan, January 1994

Specifically, this report provides an overview of DOT's current research and technology efforts, as well as those planned for FY 96, in two major areas:

- 1) Advanced materials research for transportation infrastructure applications:
- 2) Advanced materials research for vehicles and other applications.

This report could also prove valuable to DOT in highlighting common R&D thrusts and technologies will multimodal applications. Certain advanced materials and failure prediction models developed and demonstrated for aircraft structural applied could be applicable to ground vehicles as well.

The report also discusses DOT's role as a partner in national interagency R&D and technology commercialization efforts on advanced materials. DOT is engaged in many other joint R&D and technology demonstration efforts with states (State Planning and Research local governments (Local Technical Assistance Program, and universities (through regional University Transportation Centers and Institutes). More partnerships are possible through the

Intermodal Safety and Efficiency Act (ISTEA) provisions. DOT is currently examining the extent to which R&D on advanced materials for transportation applications is explicitly included in the R&D agenda for existing and prospective partnerships.

Ultimately, DOT's objective is to craft a program plan that integrates crosscutting materials R&D with multimodal applications, examines the completeness and emphasis of modal R&D programs related to advanced materials, and allows modal R&D managers to address perceived redundancies or research gaps, while increasing the efficiency of R&D and partnerships that promise to accelerate technology demonstrations and deployment.

## 2.0 ADVANCED MATERIALS RESEARCH FOR TRANSPORTATION INFRASTRUCTURE APPLICATIONS

"Goal 3: Create a new alliance between the nation's transportation and technology industries to make them both more efficient and internationally competitive."

"Goal 3.3: Support the use of advanced materials in manufacturing and constructing transportation equipment and facilities."

Department of Transportation Strategic Plan, January 1994

In the past decade, a number of influential reports have been published pointing out the economic productivity and quality of life benefits that would result from use of high-performance and high-durability materials for transportation's physical infrastructure. The NAS/NRC published "Infrastructure for the 21st Century: Framework for a Research Agenda" in 1987 and "Towards Infrastructure Improvement: An Agenda for Research" in 1994, while the national Council on Public Works Improvement reported to Congress in 1988 on "Fragile Foundations: A Report on America's Public Works" with key recommendations on enhancing R&D and technology utilization efforts. The NAS/NRC Transportation Research Board (TRB) estimated that even marginal improvements (1 percent) in durability and performance of pavements, asphalts, coatings and structural elements for the nation's highways and bridges would save \$10 to \$30 billion over 20 years. The Civil Engineering Research Foundation (CERF) estimated that life-cycle cost savings gained from using advanced concrete and asphalt in highway pavements would offset the higher front-end costs by more than a factor of six. At the current annual replacement rate of lane-miles, the nation's annual savings on materials alone would come to about half a billion, due to longer service life and lower maintenance and travel delay costs. Specific DOT R&D programs related to applications of advanced materials or technology to transportation infrastructure are described below.

### 2.1 Pipeline Safety Research (RSPA)

Major pipeline incidents, such as the November 1994 rupture during a flood in Houston, have created a significant new focus on the need for enhanced technology related to pipelines. The Research and Special Programs Administration (RSPA) develops reliable technical information and analytical methodologies necessary for planning, evaluation and implementation of pipeline safety regulations. RSPA also conducts studies and collects data in order to develop measures that address the risks inherent in the pipeline transportation of natural gas, including associated liquefied gas facilities, hazardous liquids, and carbon dioxide.

### **2.1.1 Current Research**

RSPA's major infrastructure responsibility relative to pipelines is to ensure the safe operation of the nation's network of oil and gas pipelines and underground storage tanks and caverns. Specific ongoing pipeline safety R&D programs address: corrosion protection of tanks and pipelines; stronger structural materials including steels, composites and high strength plastics; development and testing of nondestructive testing (NDT) and inspection (NDI) methods; and evaluation of new pipeline component technologies, coupled with pipeline safety in design and operation.

#### **RSPA: MATERIALS RESEARCH ON PIPELINES SAFETY AND NONDESTRUCTIVE EVALUATION METHODS**

There are more than 1.5 million miles of pipelines in the United States, delivering petroleum products and natural gas to 55 million commercial and residential customers. RSPA's Office of Pipeline Safety (OPS) has direct regulatory and oversight responsibility for the safe operation of the nation's 190,000 miles of interstate petroleum and natural gas pipelines. Recent major pipeline accidents include the 1993 Colonial Pipeline hazardous liquid spill near Washington, D.C. which affected the water supply; the 1994 Eastern Texas gas pipeline rupture in Houston; and a blowout and fire in Edison, NJ. Materials-related research efforts address corrosion protection of pipelines and tanks, stronger structural materials including steels, composites and high strength plastics, development of effective NDT/NDI inspection methods, stress and corrosion data acquisition systems and failure prediction modeling tools. NDT/NDI technologies for pipeline wall and valves integrity assessment use instrumented, or "smart," pigs based on various techniques: magnetic flux leakage, sonar, ultrasound (see Figure 1). The pig flows with the fluid or is robotically propelled along the pipeline. Data on pipeline mechanical damage (dents, gouges and other flaws), and on corrosion-induced wall thinning are collected onboard the pig and analyzed to identify damaged segments, so that remedial action can be taken before a leak can occur.

Advanced self-propelled, instrumented smart pigs for periodic inspections under cooperative development by the pipeline and pigging industries, research consortia and the Gas Research Institute (GRI) are in the testbed demonstration phase at GRI's new Pipeline Simulation Facility in Ohio. A new smart pig which is in testing on the Trans Alaska crude oil pipeline, detects curvature due to pipe settlement by using space and defense technology--a strapdown inertial system with gyroscopes and accelerometers.

New composite-reinforced pipe wrap material (Clock Spring) has been developed that prevents running fractures on high pressure transmission pipelines. This wrapped-sleeve composite material is an isophthalic polyester resin reinforced with fiberglass, installed in coil form and held in place with a methacrylate adhesive. The adhesive bonds to the pipe surface and to the layers of coil composite reinforcement. OPS accepted this new repair method (under waiver from current pipeline safety regulations) to enable its in-service testing by Panhandle Eastern Corporation in 1993 and by 28 other transmission companies in 1995.



### ***2.1.2 Planned Research in FY96***

New efforts focus on developing analytic tools and advanced automated NDT inspection and diagnostic technology methods (such as self-propelled sensor packages called "smart pigs") for assessing the integrity and predicting failures of pipelines and valves. Emphasis will be placed on evaluating advanced materials that are stronger and more resistant to corrosion and other environmental effects. In addition, several advanced materials R&D initiatives were proposed with multimodal and crosscutting infrastructure applicability.

## **2.2 Highway Infrastructure Research (FHWA)**

The effects of an aging and deteriorating highway system are becoming more visible — increased delays, incidents of bridge catastrophic failure, congestion, and reductions in safety, service and productivity. A significant challenge remains to preserve the existing Figure 1 investment in our infrastructure and improve the strength and life of our pavements and structures to meet the increasing demands for safer and more efficient movement of people and goods. In response to these growing infrastructure needs, the Federal Highway Administration (FHWA) conducts an R&D program designed to preserve and enhance the nation's highway system. Better quality, longer lasting and stronger materials result in fewer repairs, safer highways and longer life cycles. Some of FHWA's research concentrates on identifying new materials technology for 21st century highway applications. FHWA will continue its emphasis on increasing understanding of the properties and performance of these materials, developing standards and enhancing applications of existing materials for use in highway construction.

FHWA has a substantial R&D program focused on infrastructure assessment and renewal, comprising of pavements and structures research (including new and conventional materials), and a Long Term Pavement Performance (LTPP) Program. The following discussion focuses on research aimed specifically at improving highway materials for pavement and structures, ultimately leading to a less expensive and more efficient transportation system.

### ***2.2.1 Pavement Research***

#### ***2.2.1.1 Current Research***

The Pavement Research Program will improve the quality and productivity of pavement construction, rehabilitation and maintenance. Technology demonstration efforts include constructing the test track for the accelerated testing of performance-related specifications for hot-mix asphalt pavements; identifying typical variability for portland cement concrete construction procedures; and evaluating crumb rubber modifier technology as it relates to construction, recycling and pavement performance.

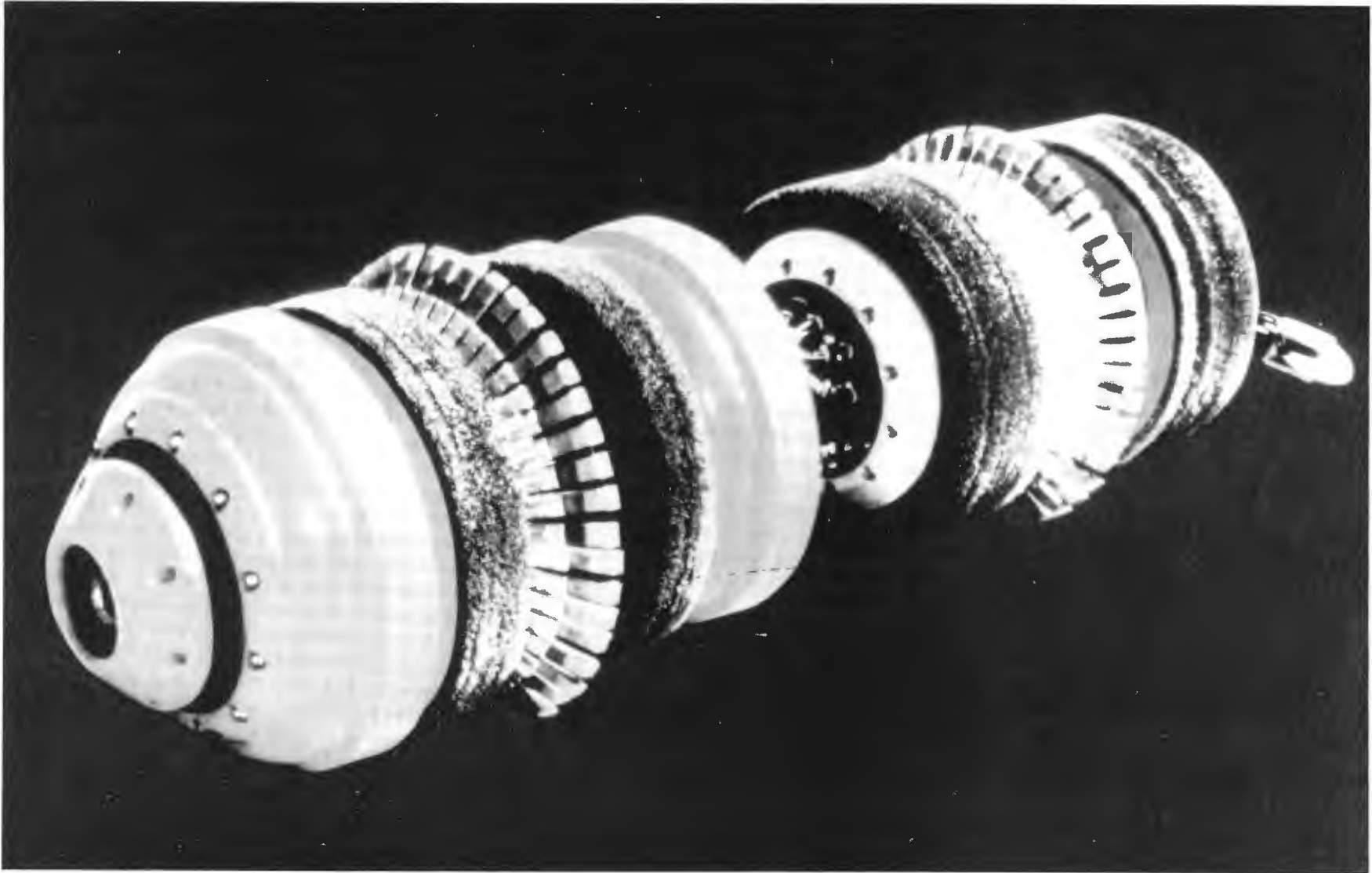


Figure 1 “Smart Pig” for Pipeline Inspection

This Tuboscope integrated system of sensors for nondestructive inspection of pipelines is called a “smart pig.” Such instrumented sensors flow with the liquid or gas inside a pipeline to identify and assess wall thinning due to corrosion and mechanical damage or flaws (dents, gouges) that might lead to pipeline failure and to accidental oil spills or gas explosions.

## **FHWA: NEW MATERIALS APPLICATIONS FOR MULTIMODAL TRANSPORTATION INFRASTRUCTURE RENEWAL**

Transportation infrastructure renewal has been identified as one of eight national R&D priority areas in the Administration's FY96 budget. Structural composites and adhesives materials, innovative structural design concepts, new corrosion protection and control coatings, and new pavement mixtures can improve safety, extend infrastructure service life, and optimize maintenance practices. Illustrative success stories of DOT's R&D efforts include: the Texas High Performance Concrete (HPC) bridge (see Figure 2).

The FHWA is working with the State of Texas on a demonstration of HPC at the Louetta Overpass on State Highway 249. It will utilize advanced materials and advanced concrete casting and processing technology. HPC has higher strength (> 8,000 psi) and durability for the deck and substructure. Innovative U-shaped beams will be used, made of 13,000 psi concrete. HPC is more impermeable to weathering, requiring fewer pillars to support longer spans and a lighter superstructure. Construction and life-cycle cost savings relative to conventional structures, and reductions in erection time, more than offset the material's higher initial cost. This bridge also features advanced nondestructive inspection and testing devices to monitor strain and performance during and after the construction process.

### **2.2.1.2 Research Planned in FY96**

In FY 1996 research efforts will include:

- Evaluate maintenance and repair materials and procedures for rigid pavements.
- Evaluate advanced design and construction features for rigid pavements.
- Conduct research to further develop guidelines for waste materials.
- Expand life-cycle cost methodology.
- Demonstrate and construct new test pavements at FHWA's Turner-Fairbanks pavement testing facility.
- Study the fundamental properties of asphalt and modified asphalt.
- Initiate a new contract to provide research support services for the pavements and materials laboratories.

### **2.2.2 Structures Research**

#### **2.2.2.1 Current Research**

The Structures Research Program is focused on obtaining measurable improvement in the life-cycle costs of U.S. highway structures, and observable inspection and maintenance cost saving or extensions of service life in all common types of existing structures, without degradation of highway safety or the environment. Near-term research efforts include establishing acceptable seismic retrofit performance criteria for increased bridge column strength and ductility;

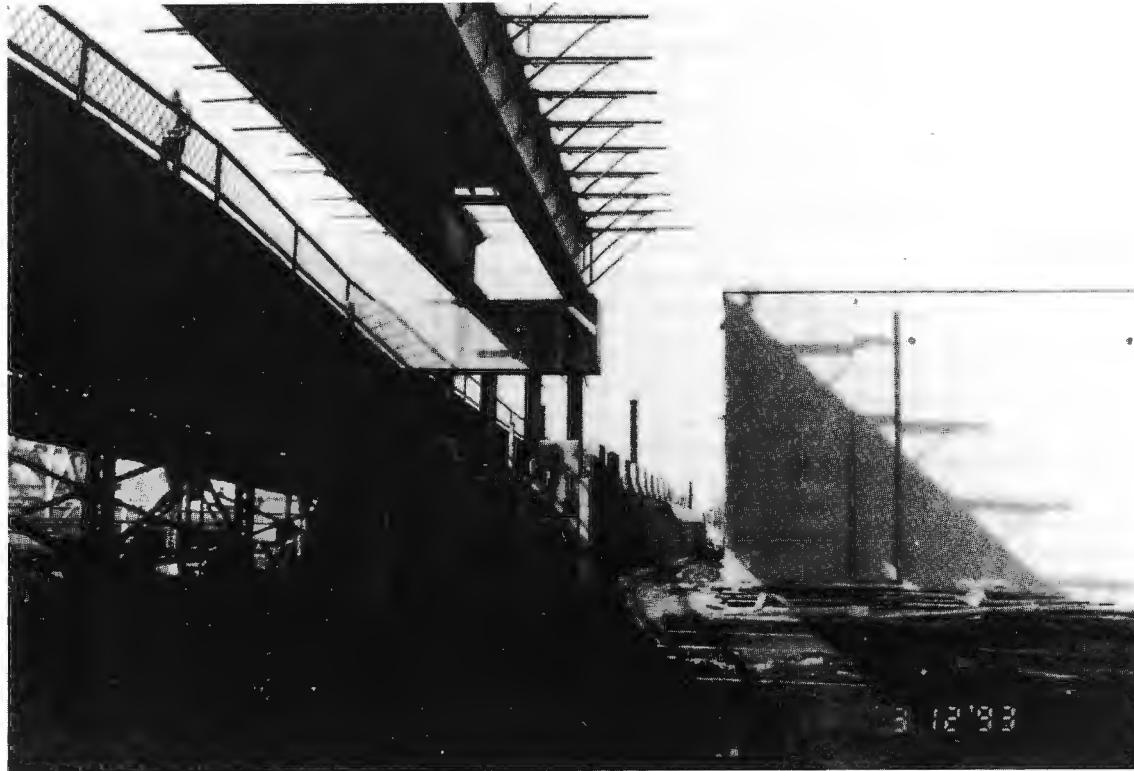


Figure 2: The Texas High Performance Concrete Bridge

The FHWA is working with the State of Texas and ten other participating states on this high performance concrete (HPC) bridge at the Louetta Overpass on State Highway 249. It will utilize advanced materials (>8,000 psi high strength HPC) for deck and substructure), as well as advanced concrete casting and processing technology.

Innovative U-shaped beams will be used, made of 13,000 psi HPC. HPC is stronger and thus requires fewer pillars to support longer spans and a lighter superstructure. It is also more durable, being impermeable to weathering. This bridge also features advanced NDT devices to monitor strain and performance during and after the construction process. Construction and life-cycle cost savings relative to conventional structure more than offset the higher initial materials costs.

identifying engineering characteristics of bedding materials for the design and construction of culverts; developing details for steel and aluminum structures to enhance corrosion resistance and reduce maintenance needs; and publishing reports on the performance of powder coatings and low-volatility organic compound paints in reducing corrosion and environmental damage.

#### **2.2.2.2 *Research Planned in FY96***

Structures research efforts will include:

- Identify engineering characteristics of bedding materials for the design and construction of culverts.
- Develop concrete mix designs to prevent or resist the corrosion of reinforcing steel.
- Release improved specifications for durability of geosynthetic reinforcement elements.
- Publish guides for the design of drilled shafts and spread footings in intermediate quality geomaterials.
- Complete development study for the San Diego advanced composites cable-stayed bridge, which will monitor and demonstrate superior performance.
- Develop scour equations for supporting foundation materials exposed to effects of scour and erosion.
- Quantify the corrosive effects of the environment on bridge steels.
- Develop accelerated test methods to predict the long-term performance of advanced composite materials.

#### **2.2.3 *Long-Term Pavement Performance***

##### **2.2.3.1 *Current Research***

The LTPP is the largest pavement performance research project ever undertaken. It is a national in-service pavement performance monitoring program intended to develop a data base on the effects of pavement design, loading, materials, loading environment and rehabilitation and maintenance on pavement service life. The database, which will eventually include 20 years of performance data, involve periodic data collection and condition monitoring of approximately 2,500 in-service pavement test sections located throughout the United States and Canada. The goal of the program is to increase pavement service life by characterizing the long-term performance of various designs and materials for pavement structures and rehabilitated pavement structures using different materials and under different loads, environments, subgrade soils, and maintenance practices. Efforts are currently under way to develop testing protocols for portland cement concrete bond strength and thermal coefficient of expansion, and creep compliance testing for asphalt mixtures.

## **FHWA: HIGHWAY INNOVATIVE TECHNOLOGY EVALUATION CENTER (HITEC) -- PAVES THE WAY FROM INNOVATIONS TO DEPLOYMENT**

Established by FHWA in 1992 under a 4-years cooperative agreement with CERF, HITEC facilitates the evaluation, demonstration and deployment of innovative materials, products, services and technologies for transportation infrastructure applications. HITEC is a model partnership for successful and timely technology deployment; for each product, an evaluation panel has been created composed of private sector representatives, university researchers, state and local highway officials and highway users. To date, about 20 evaluations of innovative infrastructure technologies are in process, many of which involve advanced materials. For instance, TRANSPRO Industries, Inc. has asked that HITEC evaluate Bondade, a liquid bonding compound for asphaltic materials that can speed up pothole repair and improve patching. Another innovative product is a Sight and Sound Screen, a polystyrene foam panel laminated with DUROCK Cement Board and finished with a decorative coating, made by the US Gypsum Co. Highways and commercial construction sites would benefit from this new, easily deployable barrier system to mitigate noise and other undesirable highway environmental impacts. In collaboration with Washington State DOT, HITEC is evaluating in field and lab tests a new gauge for water/cement ratio in fresh concrete, based on new technology developed by Troxler Electronic Laboratories. This ratio is an important performance indicator and guides acceptance tests for all structural development and rehabilitation projects.

### **2.2.3.2 Research Planned in FY96**

In FY 1996 FHWA LTPP research efforts will include:

- Develop a non-destructive testing procedure to quantify layer thickness.
- Develop a localized expert system for rating preventive maintenance treatments.
- Develop guidelines for preventive maintenance treatments.
- Provide a technically sound assessment of the adequacy of existing procedures for the design of new and rehabilitated pavements.

### **2.2.4 Advanced Research Program**

#### **2.2.4.1 Current Research**

An Advanced Research Program established under ISTEA Section 6001 focuses on innovative, cutting-edge emerging technologies with infrastructure promise, such as robotics for highway state-of-health inspection and pothole filling; self-monitoring systems; high-performance materials for pavements; coatings, adhesives and structures; use of waste and recyclable materials for highway construction; and decision-analysis tools. This program also funds cooperative efforts with other agencies, including the National Institute of Standards and Technology (NIST), the National Science Foundation and DOD's Army Corps of Engineers; and with industry, including the CERF-managed HITEC, designed to enable early application

of novel technologies. Technology transfer activities, both national and international, are included in this initiative.

FHWA is working with NIST to improve understanding of the relationship between acoustic emission (AE) signals and microcracking of structural steel. This effort developed a high-fidelity broad band AE sensor and a high capacity digital waveform recorder. Fracture-surface topography analysis (FRASTA) computer imaging techniques are used to display and study the actual micro-fracture process and reconstruct the bridge steel fracture history. AE records are then correlated with microstructural fracture data to determine characteristic signatures for distinct types of fractures.

#### **2.2.4.2 Research Planned in FY96**

Funded through ISTEA, the FY96 Advanced Research Program will continue to focus primarily on nondestructive evaluation (NDE), materials science and robotics. The program supports the construction and operation of an advanced acoustic emissions test rig at NIST and other NDE methods for detecting fatigue cracks and impending failure in steel strands, as well as neutron scattering methods to characterize novel high performance concretes made with recycled additives (silica fume, fly ash). The robotics program will focus on remote inspection systems and development of automated construction technology.

#### **2.2.5 Applied Research and Technology**

ISTEA Section 6005 also funds an Applied Research and Technology Program, focused on accelerating, testing, evaluating and implementing of technologies designed to improve the durability, efficiency, environmental impact, productivity, and safety of highway transportation systems. There are concentrated efforts on five identified technologies:

- Heated bridge technologies.
- Elastomer modified asphalt.
- High performance blended hydraulic cement.
- Thin bonded overlay and surface lamination of pavements.
- All weather pavement markings.

State and local highway agencies and other users will be exposed to the new technologies through the use of demonstration. In many cases, users are involved in the evaluation process, putting them in the position of change agent and ensuring a much greater probability of adopting the technology.

## **FHWA: "SMART BRIDGES" -- NON-DESTRUCTIVE TEST AND INSPECTION TECHNOLOGIES (NDT/NDI) FOR MONITORING BRIDGE PERFORMANCE**

One third of our nation's bridges are structurally deficient. Public expenditures for construction and maintenance of the highway system are approximately \$80 billion per year, employing about 800,000 workers. Obtaining the best life-cycle performance from aging pavements and bridges that have already exceeded their design life is essential to the nation's productivity and mobility. Novel NDT/NDI sensors, methods and models to monitor the structural integrity of bridges and pillars, and to predict failure are being deployed across the nation to aid in prioritizing maintenance and repair, to save money and to save lives. FHWA maintains a vigorous NDT/NDI research program in partnership with NIST, NASA, the U.S. Navy, and the Department of Energy's National Labs.

"SMART INSPECTOR": The Fatigue Crack Detection System (FCDS) developed by Sierra Matrix of Fremont, California under contract to FHWA is currently undergoing final testing at the Turner-Fairbanks Highway Research Center for a final delivery in the summer of 1995. This unique bridge inspection tool will enable safe and rapid inspection of bridges, using the latest portable computer and voice recording, processing and display technologies. The FCDS combines traditional ultrasonic testing with an AC magnetic field disturbance transducer that discovers cracks in steel members. The FCDS computer is worn by the bridge inspector as a backpack, powered by a belt-worn battery. A visor worn in front of one eye provides a virtual "heads-up display" of magnetic and ultrasonic data, while the inspector maintains contact with the real environment with his other eye. A single hand-held mouse interacts with a virtual keyboard for data entry and I/O operations, and for notes concerning inspection specifics.

"SMART BRIDGES": The 1983 Mianus River bridge collapse on I-95 in Greenwich into the Connecticut River spurred an \$8 billion infrastructure renewal program: to date, nearly 1,800 bridges have been replaced or repaired. The Con-DOT, in cooperation with the FHWA is instrumenting representative bridges with different types of sensors as prototypes for a network of instrumented bridges. FHWA is evaluating innovative applications of sensors that can be embedded in pavements or concrete structures. In partnership with the Naval Research Laboratory (NRL), performance assessment of a fiber-optic strain measurement system is under way in controlled laboratory tests. This system uses electronic measurements of interferometric fringes frequency-shifts due to strain in reinforced concrete structures, as a function of applied stress. Another magnetostriction-based sensor uses the structural steel member in prestressed reinforced concrete to detect in-situ strain. A third type of sensor, intended for weigh-in-motion and vehicle counting intelligent systems applications, uses organic polymer **piezoelectric sensor arrays**.

### ***2.2.6 Strategic Highway Research Program (SHRP) Implementation***

The benefits of the FHWA SHRP, a 5-year research program mandated by Congress, are currently being realized through its systematic implementation. Products of this long-term effort are being developed, modularized and packaged under the guidance of a Coordination Group (which includes FHWA field organizations, industry associations, TRB, and users) and four technical Working Groups (Asphalt, Concrete and Structures, Highway Operations, LTPP). Their work includes the following:



- Publish a SHRP Implementation Plan for fielding more than 130 products and for technical training and technology transfer support.
- Prepare "showcase packages" of technology modules for demonstration and delivery to the states via FHWA's regional offices and through workshops for state planners and industry.

The application of these products by states and local authorities is expected to receive emphasis within the highway community similar to SHRP to ensure that usable and worthwhile products are made available and put into practice by states and local highway agencies. This implementation program will involve the overall highway community--public and private--in the development, evaluation, promotion and adoption of SHRP technology and involve private industry, when possible, in the manufacturing of SHRP products.

**FHWA: RECYCLED SOLID WASTE MATERIALS IN HIGHWAY CONSTRUCTION**

The FHWA's Materials Branch of the Construction and Maintenance Division has been conducting high-priority research on beneficial uses of recycled solid waste materials for infrastructure applications. A recent FHWA report to Congress and a symposium in the spring of 1995 evaluated the potential, progress and prospects for using such solid wastes safely and efficiently in highway materials. Such waste materials include blast furnace and steel slags, fly ash, bottom ash and other coal combustion byproducts, rubber tires, crushed glass, recycled plastics and municipal wastes combustion ash, carpet fibers and roof tiles. These wastes can be recycled as additives in new materials for a wide range of highway applications, such as additives and aggregates for asphalt and concrete pavements, base courses, loose fills and embankments. Other highway uses include fences, guardrails and posts, pothole patching materials, and ice control materials. Active research is continuing in cooperation with the American Association of State Highway and Transportation Officials (AASHTO) and the states to evaluate the environmental compatibility and in-service performance of such new recycled material formulations.

**2.2.7 Seismic Research Program**

**2.2.7.1 Current Research**

The FHWA research program for the seismic protection of bridges consists of two contracts awarded to the National Center for Earthquake Engineering Research headquartered at the State University of New York at Buffalo. Improved seismic guidelines for new highway construction will be developed as well as revised seismic retrofit guidelines to provide cost-effective tools for improved evaluation and seismic upgrading of the existing highway network. Research studies on the seismic vulnerability of major highway system components including bridges, tunnels, retaining structures, slopes and embankments, will be conducted to establish acceptable seismic retrofit performance criteria for increased column strength and ductility.

## **FHWA: ADVANCED COMPOSITES FOR SEISMIC REINFORCEMENT OF BRIDGES AND HIGHWAY PILLARS**

To renew our vital transportation infrastructure rapidly and cost-effectively, we must make greater use of new advanced materials and new construction technologies for seismic reinforcement and for rehabilitation and repair of aging bridges. The damage to highways and bridges from the January 1994 Northridge earthquake in Los Angeles, and the response to and recovery from that disaster, offer valuable lessons on the value of research and technology for seismic reinforcement of aging bridge pillars and decks. New and retrofitted infrastructure performed well in the 1989 Loma Prieta earthquake: Of the approximately 2000 bridges in the epicentral region, only 6 failed and only 4 were severely damaged and require replacement. It is estimated that all could have survived damage had a new renewal engineering technology been used. This advanced composite renewal method, which wraps thin carbon-fiber composite jackets around the support pillars, promises to replace heavy steel jacketing. It is being developed by a consortium led by the University of California at San Diego, and is supported jointly by the Technology Reinvestment Project and FHWA. This retrofitting technology, using light advanced composites for bridge column wrapping and deck repair (300 lbs. of light composite instead of 3,000 lbs. of concrete, with similar strength and more durability), promises to compete in cost-efficiency in terms of its life-cycle (\$10K per column for a half-inch-thick wrapping), speed of repair (10-50 times faster than steel), ease of use and performance under earthquake conditions, especially when allowing for economies of scale in materials costs.

### **2.2.7.2 Research Planned in FY96**

In FY 1996, FHWA's seismic research efforts will include the following:

- Develop a series of seismic design guidelines and implementation aids.
- Produce a workshop to train bridge and highway engineers on the use of these aids.
- Develop a series of tools and technologies that can eventually be implemented in future design codes and standards.
- Hold a workshop on seismic design criteria for long span bridges in order to identify the problems that must be addressed in designing bridges and spans greater than 500 feet to resist earthquake loads.

### **2.3 Materials-Related Rail Safety and Next Generation High Speed Rail R&D (FRA)**

Changes in railroad equipment and operating speeds and procedures must be evaluated to ensure that they do not erode the safety of both freight and passenger equipment operation. The Federal Railroad Administration's (FRA) infrastructure-related R&D programs focus on such safety improvements and on rail development and corridor improvement. Materials-related issues and technologies are an integral part of the programs described below.

### ***2.3.1 Equipment, Operation and Hazardous Materials Research***

#### ***2.3.1.1 Current Research***

The goals of FRA's equipment and components research program are to improve safety and to enhance productivity and effectiveness within the railroad industry by reducing injuries, accidents and their related costs caused by human error, inefficient or ineffective operations; unanticipated and catastrophic equipment or component failures or the inadvertent release of hazardous materials. In the near-term, FRA will continue evaluation of required structural integrity of new materials for tank car construction; continue analysis of parameters for acceptable tank car structural integrity; investigate alternative methods for evaluating continued tank car integrity and update tank car damage assessment; establish minimum performance standards for locomotive fuel tanks; and develop a database for reported locomotive accidents/incidents and model them to correlate personal injury probability with dynamic collision parameters.

Under its Next Generation High Speed Rail Program, the FRA has initiated a Broad Agency Announcement for cost-shared R&D on strong, lightweight advanced materials for rail equipment to improve the financial feasibility of high-speed rail service. Advanced materials that meet crashworthiness standards at lower weight and offer improved energy efficiency will be explored for vehicle structural applications, exploiting aerospace and defense industry experience. High-temperature ceramic brake components and structural components made of fiber-reinforced composites appear especially promising. A cost-shared contract was awarded in 1995 to develop and demonstrate a combination of new friction materials and a lightweight flywheel energy storage system utilizing a composite material rotor. These are applicable to next-generation high-speed trains, and freight and commuter trains engines, as well as to military and electric utility power storage needs. Such advanced materials components and technologies will provide significantly improved braking performance, weight reduction and lower service costs.

#### ***2.3.1.2 Research Planned in FY96***

New materials-related initiatives planned for FY96 include:

- Evaluate impact of advanced lightweight materials on structural integrity of passenger cars.
- Develop and validate NDE methods for inspecting tank car welds.
- Develop an assessment procedure for new tank car designs.

## 2.3.2 Track, Structures and Train Control

### 2.3.2.1 Current Research

The goals of the track, structures, and train control research program are to reduce train accidents due to track and signal defects; develop technology to discover such defects well before failure; develop methodologies for predicting service life of track and signal components and how they behave under dynamic conditions; develop protocols to improve efficiency in inspection, preventive maintenance, repair, and renewal actions; and develop technology to enable safe train operation in heavy tonnage environments.

Research efforts relate to improved materials performance modeling and advanced applications of conventional materials, and partly to utilization of advanced materials. Relevant efforts include: operation and test support for heavy axle load tests; the performance of wood ties with fiber-composite wrap; and determination of conditions under which dynamic interactions between vehicle and track can cause derailment.

#### **FRA: NONDESTRUCTIVE IN-SERVICE TESTING OF RAIL TRACK INTEGRITY**

A unique railroad track inspection device, the Gage Restraint Measurement System (GRMS) was developed by Volpe National Transportation Systems Center's experts for the FRA, with cooperation from the rail industry, to support both rail safety and efficiency goals. The GRMS is an integrated system of sensors mounted on a rail-car platform, which is designed to apply loads to track and automatically measure and record the effectiveness of ties and fasteners while in motion at speeds of 25 mph (see Figure 3).

Over the last five years in the United States, the number one cause of track-related derailments was failure of track to maintain gage caused by missing or defective ties and fasteners. The railroads spend approximately \$1 billion per year on track inspection and tie replacement to combat this problem. Track inspections are currently performed visually, on foot or from highway-rail vehicles, and mechanically, using track geometry-measuring vehicles. Visual inspections of cross ties are largely subjective, and different competent inspectors may reach widely different conclusions concerning the condition of any group of cross ties, depending on their individual training and experiences.

The GRMS is the first continuous tie inspection system that automatically detects locations where rail restraint is inadequate. The system uses objective, performance-based testing to determine track strength, eliminating the subjectivity inherent in visual inspections. The system identifies, marks, and

*(Continued)*

ranks weak or failed fasteners and ties which is used by the railroads for immediate remedial action or long term maintenance planning. Two significant levels of degradation are automatically reported: critical, poses a high risk for derailment and needs immediate repair; maintenance level, that requires attention within 30 days. In addition to the obvious advantages of the GRMS for safety inspections, a railroad can incorporate this information into a maintenance planning program to provide a rational method of allocating cross tie renewal resources to maximize safety and economic benefits. This technology is improving maintenance planning efficiency, preventing derailments due to deteriorating tracks and ties, and thus saving money and lives.

The GRMS technology has been widely accepted by the railroad industry. Many carriers have made substantial commitments to advance the technology by developing their own equipment and by supplying track time and personnel for FRA equipment. The GRMS has surveyed over 22,530 km (14,000 mi.) and is currently being used by several of the largest railroad systems and many regional and short line railroads to evaluate their track's gage strength under a cooperative cost-sharing arrangement with the FRA.

### **2.3.2.2 *Research Planned in FY96***

In FY 1996, FRA research efforts will include:

Quantify and test resistance of concrete-tie track to lateral buckling from heat and load stress.

Heavy axle load tests of track components and improved freight car truck suspensions.

Establish causal factors in long-term processes leading to failure of rail and track components.

Test and evaluation of new NDT and monitoring technology as a means for increasing the sensitivity and quality of ultrasonic measurement of rail internal condition.

## **2.4 *Materials-Related Airport Technology Research (FAA)***

### **2.4.1 *Airport Pavements Research***

The Federal Aviation Administration (FAA) is responsible for encouraging and fostering a safe and efficient national airport system. The airport pavement technology R&D program assists in developing new and improved standards, criteria and guidelines to plan, design, construct, operate and maintain the nation's airports, heliports and vertiports, and to ensure that airport pavement technology will meet the needs of next-generation aircraft (such as the Boeing 777).

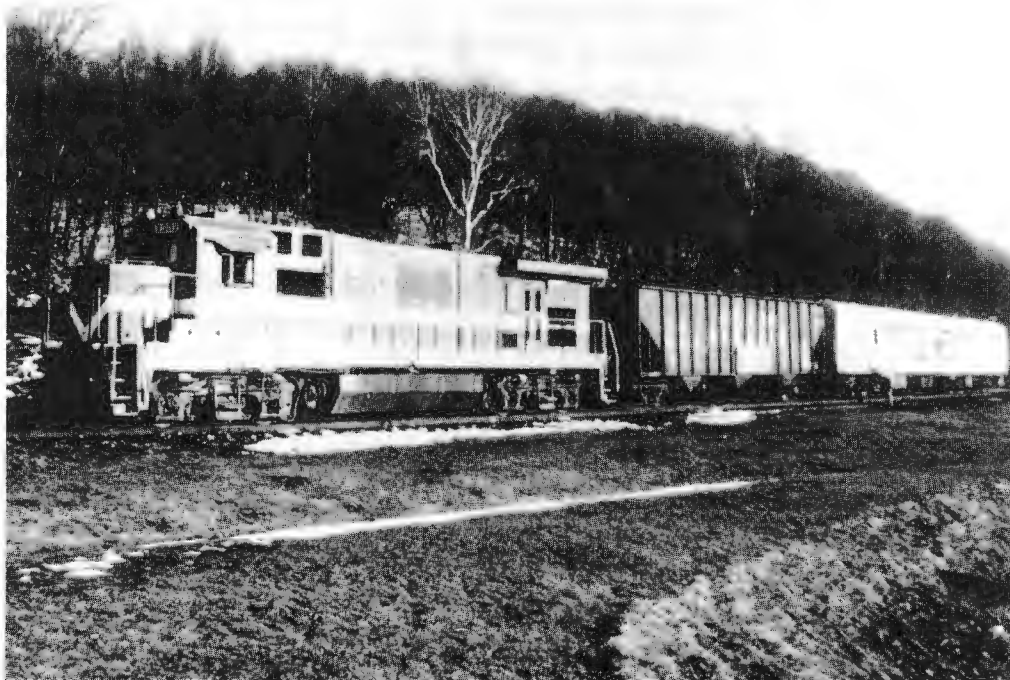
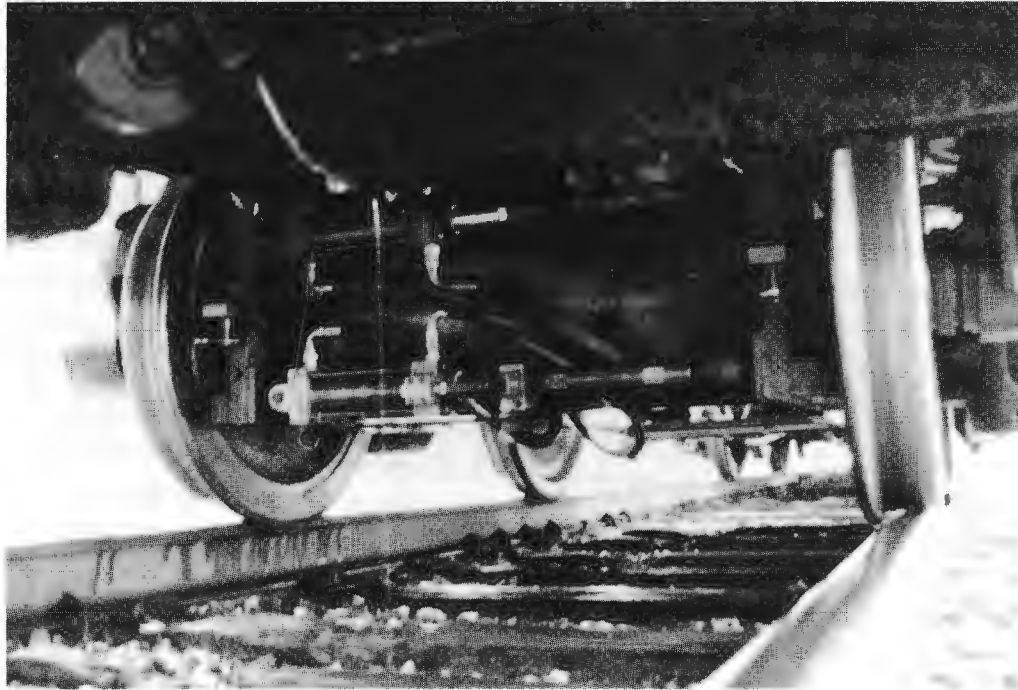


Figure 3: The Gage Restraint Measurement System for Rail Track Inspection  
Top: Unique telescoping axle assembly of the GRMS mounted under a freight hopper car is shown prior to testing rail track for strength capacity.  
Bottom: The GRMS train is shown, which is able to assess in motion the ability of track to support loads applied by freight trains, and mark with paint the locations that have insufficient strength, so as to enable prioritized maintenance.

The FAA's R&D program is focused on ensuring that the nation's over 5500 public use facilities, 670 certified airports, over 400 air traffic control towers and 50 hub airports continue to provide needed capacity and operational safety. In 1994, over 550 million passengers traveled on commercial carriers, and over 50 million General Aviation Aircraft operations, as well as cargo and commuter traffic, were accommodated with high efficiency at the nation's airports, while complying with safety and security standards.

In 1994, the FAA's airport planners approved about 1,500 applications for improvements and expansion under the Airport Improvement Program (AIP) roughly \$ 2 Billion annual grants-in-aid. New airport designs and materials, and new safety certification standards now in R&D phases will be incorporated nationwide in FY97 as capacity and safety enhancements through the AIP.

Key goals of the Airport Pavement Technology Program are to:

develop standards for design, construction and maintenance of airports, that make use of advanced materials and technologies;

enhance the safety of aviation operations and ensure adequacy of airport system designs, construction and maintenance standards;

develop data to support new standards development in order to accommodate a new generation of larger and heavier aircraft and the projected increase in demand for the next century.

reduce the cost of pavement expenditures and eliminate runway accidents due to incursions and slipperiness.

#### **2.4.1.1 Current Research**

Current efforts include the development of layered-elastic based airport pavement design procedure to accommodate new large aircraft, e.g., Boeing B-777 and formulation of design/performance standards for advanced pavements. In 1995, the FAA plans to issue a new design standard based on Layered Elastic Theory named LEDFAA, and design specifications for the National Airport Pavement Test Machine for verification of the new theory..

#### **2.4.1.2 Research Planned in FY96**

FAA plans to start the design and build phase of the test machine. In addition, the agency will:

- Continue to collect and analyze data that relates pavement performance to FAA design and construction standards.

## **FAA: ADVANCED AIRPORT TECHNOLOGY R&D ON MATERIALS, MONITORING AND MODELING**

The nation's 7,800 airports with paved runways are aging, while the pace and cost of their maintenance (approximately \$2 Billion annually) cannot sustain growth in air traffic. New pavement designs, materials and technologies are needed to support the introduction of new, larger and heavier commercial aircraft (e.g., the Boeing 777) designed to accommodate growth in air passenger and cargo traffic. New nondestructive test and evaluation methods to monitor runway integrity and environmental stress are needed, as well as failure models to predict performance and trigger preventive maintenance. These technologies will enable better use of existing airports while lowering maintenance costs, ensuring safety of air and ground operations and extending runways' pavement service life. The new Denver International Airport features instrumented runways, with embedded NDE sensors to measure dynamic in-service pavement response to takeoff and landing stresses and to environmental conditions.

The FAA's Airport Pavements Research Program has scored important recent successes in partnership with industry under the Cooperative Research and Development Agreement's (CRADA) and with the new FAA Air Transportation Center of Excellence on Pavement Research at the University of Illinois Champaign-Urbana. Three recent success stories of materials research for airport pavements are:

Using a new lightweight cellular concrete material, the FAA has developed and tested a soft ground arrestor system under CRADA with ESCO/Datron of Aston, Pennsylvania. This material will enable large aircraft to safely stop over very short distances without overrunning the runways under hazardous takeoff or landing conditions. Current land-use constraints preclude many older airports from extending their runways to meet the FAA-mandated 1,000-foot safety zone between the end of a runway and a highway, water body or other potential safety hazard for aircraft passengers. Many materials, including this cellular concrete, were tested by the FAA since 1987. This soft-ground arrestor material promises short stopping distances with maximum safety, while allowing fire and emergency rescue equipment access to the aircraft.

A Snowfree Heated Pavement System is under development by Superior Graphite Co. of Chicago, IL under CRADA with the FAA. This new technology, currently being demonstrated at Chicago's O'Hare Airport, uses synthetic graphite to conduct electric current through the airport runway pavement to generate heat and prevent icing and accumulating snow. This new cost-effective heated pavement material and technology for large areas will enhance air and ground operations safety, keep the airport open and operating during inclement weather, and save time and cost of snow cleanups by ground crews.

The Virginia Department of Aviation is using a new computer-based Pavement Management System (PMS) to monitor the condition of runways in the 70 public-use airports in Virginia and to prioritize maintenance and rehabilitation. The Pavement Condition Index (PCI) has already improved, while life-cycle and maintenance costs have decreased over the past 4 years. The database on pavement conditions is based on statistical sampling of representative pavement material types that are expected to perform, degrade and fail over time in a similar manner (asphalt, taxiways, aprons and concrete pavements), as well as by traffic wear and climatic conditions. Data are collected and a decision model combined with a predictive failure model is used to rank rehabilitation alternatives and to prioritize and schedule airport pavement repair.



- Issue its annual report on pavement response and performance studies at Denver.
- Develop advanced pavement design tools based on finite element analysis.
- Conduct research on nondestructive pavement test techniques and analytic methods.

#### *2.4.2 Airport Security Technology*

Advanced airport security technologies being evaluated and tested at the nation's busiest airports to protect the public, must enable low rates of false-positive alarms, at high throughput of baggage screening. They are based on state of art knowledge of materials science, and include a wide variety of chemical and physical sensing and identification methods. Current R&D thrusts include explosives detection systems and hardened containers to be developed and deployed worldwide.

Design, development test and evaluation of security systems require application of material science models, integration of diverse sensors, and an exhaustive database of materials properties and their interaction with penetrating electromagnetic radiation, and practical behavior under explosive loading stress. Such tough, fiber-reinforced containers for baggage have multimodal applications in transportation.

### **3.0 ADVANCED MATERIALS RESEARCH FOR VEHICLES AND OTHER APPLICATIONS**

One of the most important functions assigned to DOT at its inception was to ensure the safety of the nation's transportation system. This mandate covers all modes, including road, rail, transit, water, air, pipelines and hazardous materials (hazmat). It also includes physical infrastructure; command, control, communications and navigation systems; and vehicles that operate on this network. Given this basic emphasis, many of the Department's vehicle-related R&D activities are aimed primarily at safety issues. For example, the National Highway Traffic Safety Administration (NHTSA) is responsible for R&D covering highway vehicle passenger safety, a responsibility it shares with FHWA for motor carriers. FRA and the Federal Transit Administration (FTA) also maintain safety responsibilities for rail and transit vehicles, locomotives and passenger buses, as well as related safety research and technology development programs. Other intermodal cooperative programs, such as Intelligent Transportation Systems (ITS) R&D and Operation Lifesaver address prevention and mitigation of grade-crossing hazards to highway vehicles, transit and commuter rail and pedestrians.

The Department's focus for vehicles has been expanded considerably beyond safety assessment and regulations in recent years. The manufacture, sale and maintenance of transportation vehicles, especially automobiles and commercial aircraft, is one of the largest single segments of the U.S. economy, and aircraft exports are a major generator of trade surpluses for the nation. At the same time, the transportation function is increasingly being expected to help meet important energy and environmental goals for our society, including higher fuel efficiency, drastically reduced levels of harmful emissions and a reduction in long-term solid waste disposal requirements. In response to these concerns, the Federal Government and state DOTs are becoming engaged in programs designed to apply state-of-the-art technological advances in transportation in order to meet simultaneously multiple operational, safety and mobility goals, as well as economic efficiency, energy and environmental goals.

#### **3.1 Hazardous Materials Containers (RSPA)**

RSPA's Office of Hazardous Materials Safety (OHMS) is responsible for the development and enforcement of regulations governing the design, construction, testing, certification, inspection and use of containers used for shipping hazardous materials and compressed gases. It works cooperatively with industry to enable and encourage use of advanced materials (carbon fiber composites or titanium alloys) for containers that afford weight savings with improved performance at a comparable or better safety level. The hazardous materials research program is designed to provide a scientific methodology for classifying, routing and tracking transported hazardous materials. This research stresses the use of computers and modern communications to implement the new scientific methodology, coupled with use of new,

stronger and lighter advanced materials for hazmat containers to prevent hazmat releases. Test and certification standards for advanced composite containers will be developed cooperatively with industry.

### **3.1.1 Current Research**

Near-term efforts related to materials aspects include: developing evaluation criteria and classification schemes for dry batteries, thermally unstable substances and radioactive material communication systems; and reporting on identification of factors for selecting modes and routes for shipping high-level radioactive waste and spent nuclear fuel.

#### **RSPA: ADVANCED MATERIALS CONTAINERS FOR HAZARDOUS MATERIALS TRANSPORTATION**

OHMS has the responsibility for developing and implementing the national regulatory program for the transportation of hazardous materials by all modes other than pipelines. The Hazardous Materials Regulations (HMR) contain performance criteria and some specific design requirements for packagings, tanks and containers used for hazmat transportation. OHMS staff evaluate industry applications for variance from the HMR. New packaging designs and the use of advanced materials and design concepts offer benefits for more cost-effective and safer hazmat packagings (see Figure 4).

Advanced composite materials approved by RSPA, such as metal-lined fiberglass and kevlar fiber composite cylinders, have been in use for high-pressure gas cylinders (up to 5,000 psig) for over 15 years, with an excellent safety record. The hazmat applications of these materials (besides pressurized cylinders for breathing apparatus used by firefighters and mine safety and rescue equipment, portable medical oxygen systems, and pressurized inflators for aircraft emergency slides) exceeds \$25 million per year. RSPA monitors industry development of carbon fiber and epoxy composite, filament-wound cylinders for both nonbulk and bulk transportation of compressed gases, including compressed natural gas tanks for automobile applications. This materials technology is a significant improvement over the current technology, because it promises to last longer than fiberglass and kevlar fiber composites. Lightweight, higher volume pressurized cylinders for tube trailers will haul more product per trip at comparable cost. Benefits to the compressed gas industry, the trucking companies and the highway system in terms of maintenance and wear will result. RSPA cooperates with advanced composite cylinder manufacturers and the service industry to assess emerging concepts and regulatory and research issues.

A successful RSPA workshop in 1994 involved over 30 companies evaluating the promise and problems of carbon-fiber composite cylinder technology for hazmat applications. A materials technology challenge is to develop a viable NDT method to evaluate the integrity of such composite cylinders as they age. Carbon fiber strength is sensitive to fiber damage, and a sufficient margin of safety must be provided to ensure structural integrity in service. Sophisticated NDT methods are being developed for composite structures. The R&D challenge is to apply these techniques to various type composites structures, and to integrate them into certification, in-service inspection and failure prediction models.

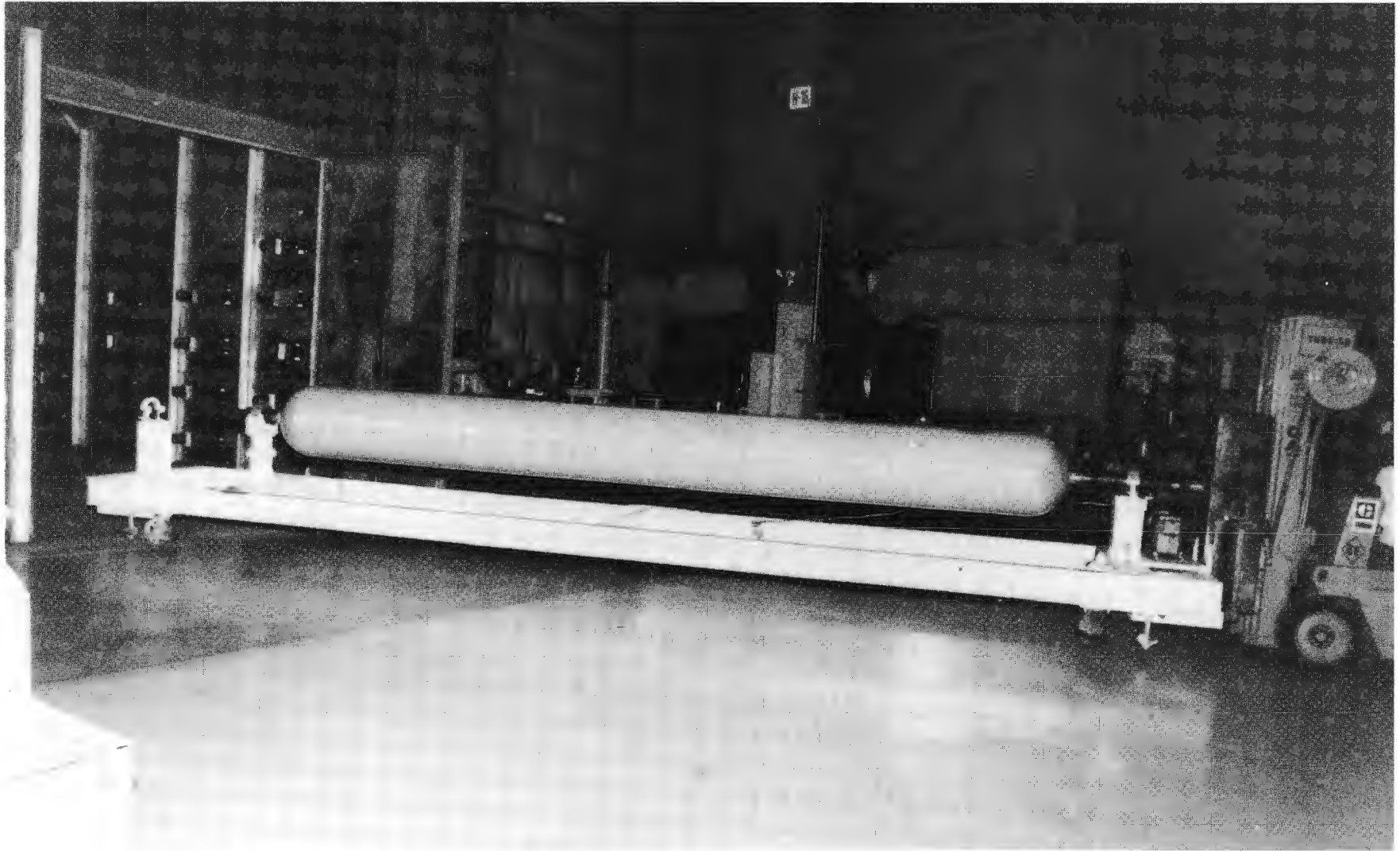


Figure 4 Composite Containers for Hazardous Materials Transportation

This lightweight, high-strength and large capacity composite transportation container was developed by Structural Composites Industries for hazardous materials transportation by rail or truck. Container safety certification standards, as well as non-destructive test and inspection techniques, are being developed to enable industry to replace heavy steel containers with such advanced composites.

### **3.1.2 Research Planned in FY96**

In FY 1996, RSPA will:

- Complete a Molybdenum 99 radiation dose reduction study; an evaluation of radioactive materials (RAM) specification packaging; development of small-scale testing for classification of explosives; and prepare a report to Congress on "Identification of Factors for Selecting Modes and Routes for Shipping High-Level Radioactive Waste and Spent Nuclear Fuel".
- Complete the "Guidelines for Conducting Surveys on the Highway Transportation Patterns of Hazardous Materials".

### **3.2 Partnership for a New Generation of Vehicles (NHTSA, FRA, FTA)**

In September 1993, President Clinton, Vice President Gore and the Chief Executive Officers of Chrysler, Ford and General Motors announced a historic new "Partnership for a New Generation of Vehicles" program, or PNGV, aimed at strengthening U.S. competitiveness and protecting the environment. The overall goals of this effort include developing a range of technologies to yield automobiles with a three-fold improvement in fuel efficiency and reduced emissions, without compromising other features such as performance, safety and utility; and developing and introducing manufacturing technologies and practices that will reduce the time and cost associated with designing and mass-producing this new vehicle.

DOT is an active participant in this program, along with other Federal agencies such as DOC, DOD, DOE, EPA, NSF, and NASA. DOT's role will be to provide technical support to the PNGV initiative, with a focus on safety-in-performance standards for new materials used for components, subsystems and the vehicle shell.

#### **3.2.1 Current Research**

Within the Department, NHTSA is the focal point for PNGV support. Its role is to ensure that the PNGV vehicles will meet existing and anticipated safety standards and that the overall crash and other safety attributes of the PNGV vehicles are not compromised by use of new advanced materials that have not yet been tested in service. Toward this end, the agency is developing advanced computer models (see Figure 5) and acquiring the computing capacity necessary to evaluate the crashworthiness characteristics of alternative vehicle designs and new lightweight materials, such as proposed advanced composites. NHTSA is conducting a Peer Review study of the conceptual designs developed by the program. The Department, primarily RSPA, will also create a comprehensive knowledge base and conduct analyses of the impact of this new vehicle on the U.S. economy, transportation system and motor vehicle industry. DOT participated in the Vice President's symposium February 1995 on "Structural Materials Challenges for the Next Generation Vehicle," where materials-related R&D issues to

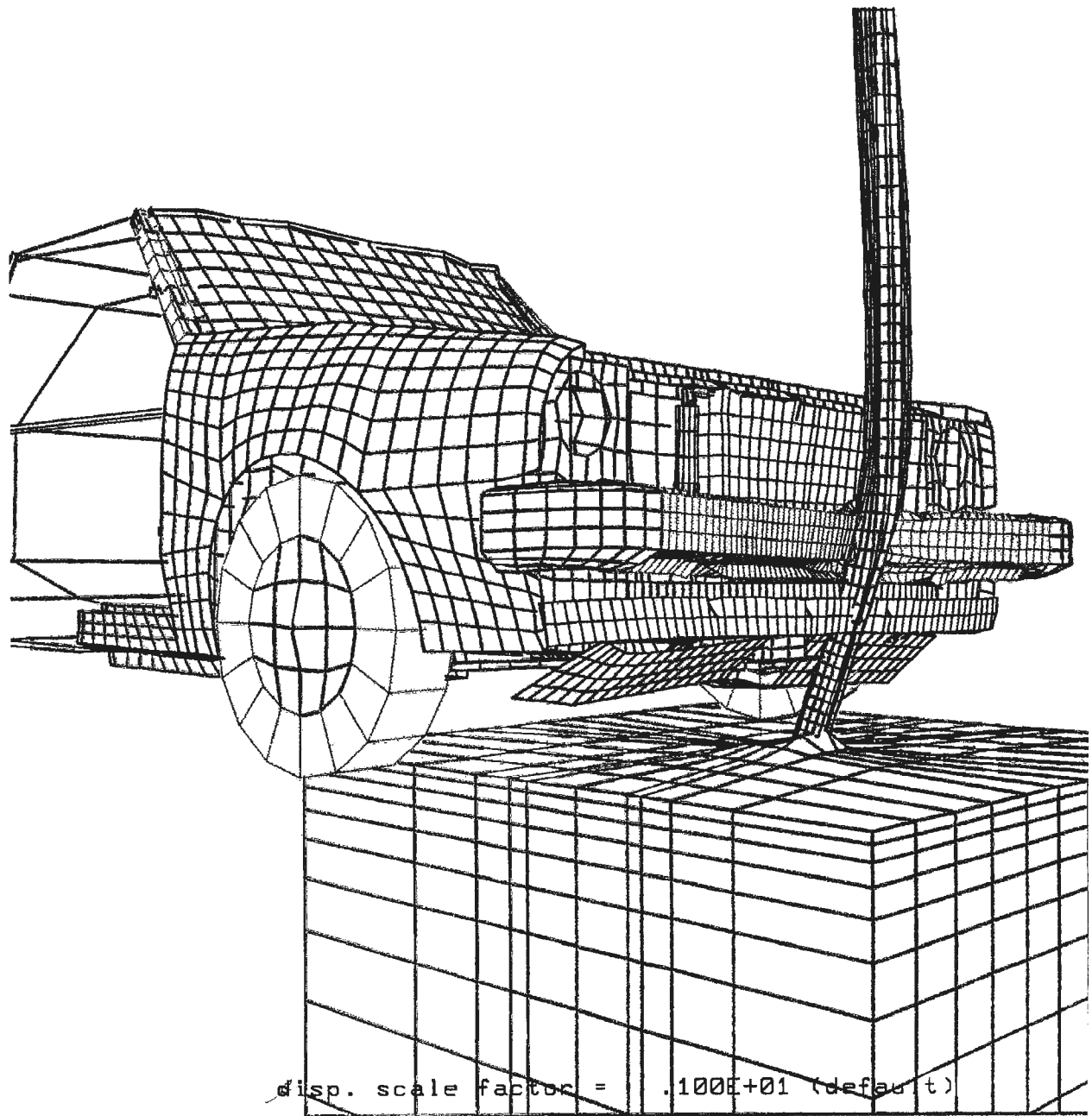


Figure 5 Crash Simulations to Improve Infrastructure and Vehicle Safety

This schematic illustrates the use of three-dimensional finite element analysis models, such as DYNA-3D developed by Livermore National Laboratory, to model vehicle collisions with roadside structures and safety appliances (such as guard rails). This sequence uses real crash test parameters from FHWA's Federal Outdoor Impact Laboratory and actual materials properties to verify design and performance of a sign-post.

be resolved were examined. FRA, FTA and FAA are also concerned with the crash performance of lighter composites and advanced alloys proposed for next-generation vehicle shells and structures.

#### **FTA: ADVANCED MATERIALS FOR TRANSIT VEHICLES**

FTA initiated the Advanced Technology Transit Bus (ATTB) program in 1992 to develop, prototype and demonstrate an advanced space-age bus. Through FTA grants to the Los Angeles County Metropolitan Transportation Authority and the Metropolitan Transit Authority of Harris County, Texas, this 7-year project set out to integrate and demonstrate the following in a single vehicle: advanced lightweight body and frame materials; advanced hybrid-electric propulsion, energy storage, power management and regenerative braking subsystems designed to significantly increase fuel efficiency and meet ultra-low emission air quality standards; and intelligent location, navigation and control combined with public information systems. The first prototype is due in October 1996.

The ATTB makes use of advanced aerospace type materials and manufacturing technology to reduce the bus curb weight by one-third, while maintaining or improving structural strength and crashworthiness. This will result in fuel-efficiency gains, less brake and tire wear and longer service life. The ATTB body shell is made of fiberglass/epoxy skins molded around a foam core, with graphite fiber added to reinforce high stress areas. Northrop-Grumman Corporation is the prime contractor developing the body shell design, materials, tooling, manufacturing and assembly technology. Several dozen other companies are contributing to this cutting-edge bus design.

#### **3.2.2 Research Planned in FY96**

Currently, a list of possible technologies for the national multiagency PNGV has been prepared and a "master schedule" established. The PNGV master plan calls for narrowing the range of candidate technologies between 1995 and 1998 before a concept vehicle is developed. The choices that will be made during this process may have long-term profound impacts on the Department's constituencies (i.e., vehicle users and manufacturers), and on the transportation fuels infrastructure.

This program's purpose is to initiate an activity that will augment the PNGV systems analysis tasks and provide the Department with data for active participation in the PNGV decision-making processes. The multi-year tasks include the following:

- Characterization of vehicle propulsion system components.
- Weight-reduction-potential assessments.
- Assessment of vehicle consumer acceptance attributes.

- Fuel economy and vehicle performance bounds.
- Identification of variables affecting infrastructure requirements and industry cash flows.

Most elements involve advanced materials, but integration of cost and safety performance attributes must be understood in a systems context. Data will be obtained from ongoing research activities or by establishing upper and lower bounds for missing attributes, and system trade-offs will be performed. Opportunities and risks will be assessed, as well as the reliability of available data. The emphasis in FY96 will be on obtaining data on vehicle subsystem performance and component requirements, and on the development of vehicle models for performing the requisite safety analyses.

The most recent projections indicate that a 40 percent reduction of the vehicle mass will be required to meet the fuel economy requirements of the PNGV program. This reduction, coupled with the potential use of materials other than the conventional steels used in automobile construction today and with the possible use of entirely unique power trains, requires that careful attention be given in determining the overall crash safety of the vehicles. Beyond the testing required by the Federal motor vehicle safety standards, the safety analysis must include evaluating the performance of the vehicles in crash modes that are representative of the real world accident environment. When considering the PNGV vehicles interactions with the existing fleet, the mass reduction requires extra attention be given to crash energy absorption characteristics of the vehicle structure and to the performance of the occupant restraint systems. Furthermore, the potential of developing vehicles with mass distributions that vary significantly from today's vehicles may require careful scrutiny regarding how these vehicles will behave in their interactions with roadside safety hardware such as guard rails, breakaway luminaire supports, etc.

Detailed finite element models will be developed for each of the PNGV baseline vehicles and for vehicles representing the fleet (e.g., subcompact, compact, mid-sized, and full-sized cars, small and large pickup trucks, and a minivan). This activity involves the tear down of the PNGV baseline vehicles and selected fleet vehicles for scanning the vehicles to develop geometric data to be used in prescribing the finite element mesh, and for measuring the inertial and other physical properties of the vehicles. Crash testing will be conducted to validate the models as well as provide for audits of simulations undertaken in support of the fleet analysis. Design concepts will be explored and evaluated for the various power trains under consideration for the PNGV vehicles. This includes exploring the use of advanced structural materials such as composites and aluminum. It is anticipated that research into improved material models will be required in the computer software to accommodate these studies. Finally, a system model will be developed for identifying optimal characteristics for the PNGV vehicles.



## **NHTSA, FRA and RSPA: MULTIMODAL CRASHWORTHINESS STANDARDS FOR ADVANCED TRANSPORTATION VEHICLES, CRASH SAFETY AND OCCUPANT SURVIVAL**

Safety is the focus for much of the materials research efforts in various DOT operating administrations: NHTSA is concerned with the crashworthiness of cars and trucks, FAA with aircraft crashworthiness safety, and FRA with rail locomotive cab and passenger car safety in train collisions. The goal of such materials research is to evaluate the crashworthiness and collision performance of transportation vehicles in order to save lives in accidents. DOT sets crashworthiness standards based on predictive modeling using complex 3-dimensional dynamic simulations, combined with realistic testing of vehicle collisions and crashes, equipped with instrumented dummies to monitor biomechanical responses and quantify accelerations and damage sustained under collision impact scenarios.

RSPA's Volpe Center provides engineering support for crashworthiness research to all DOT transportation modes, using sophisticated finite element and biomechanical models, with important crossmodal technology transfer benefits. Models such as DYNA-3D and MADYMO have been successfully applied to predict crash damage profiles and occupant survival probabilities for diverse vehicle structure, cabin interior padding and restraints, occupant body sizes and properties, and crash impact scenarios (frontal, rear and side).

Recently, the FRA has been engaged in R&D to support high speed rail safety standards development in the United States, to ensure crash survivability of passengers. The Volpe Center research adapted school-bus interior padding and restraint specifications, and used NHTSA-validated models to study occupant dynamics and predict fatalities for passengers involved in high-speed train collisions. Volpe evaluated various interior cabin configurations, padding and passenger restraint requirements. The results of this analysis will enable the emerging high-speed rail industry to meet safety performance requirements for the next-generation trainsets. Future railcars will use crashworthy lighter and stronger advanced composites, without constraining cabin seating layouts, interior padding materials and passenger restraints.

### **3.3 Aircraft Safety Research and Security Technology (FAA)**

Materials of particular interest to the aviation community are advanced metals and polymer matrix composites (including high-temperature polymers for applications such as the High-Speed Civil Transport and high-temperature polymeric, intermetallic and ceramic matrix composites for use in subsonic and supersonic gas-turbine engines. Validating the technical feasibility of manufacturing these structures and lowering the cost of engineered materials are challenges that require sustained effort. Traditionally, these areas have been addressed by industry, NASA and the Defense Department. However, materials science and technology is integral to FAA's R&D programs, because issues in aircraft safety, security and airport technology (see 2.4 above) are not adequately addressed by those organizations.

An important element for public confidence in the air transportation system is the aircraft fleet's continued safety. FAA's aircraft safety technology research program consists of several

major thrust areas related to advanced materials: aircraft systems fire safety, long-term fire research, advanced structural materials, structural crashworthiness, aging aircraft, powerplant safety, aircraft catastrophic failure prevention and aircraft hardening. The most important purpose of this FAA R&D effort is to develop technical requirements for aircraft safety improvements in an evolving aviation environment. Examples of this evolution are numerous and include greater composite materials utilization for weight reduction, enhanced fuel efficiency and better performance. Aircraft safety improvements will reduce fatalities and injuries and streamline maintenance and inspection procedures.

The goal of the advanced materials research program is to enable modeling and prediction of the response of a given material system to anticipated in-service chemical, thermal and mechanical environments. Current emphasis is on fiber-reinforced polymer-matrix composites and their derivatives currently in service and in production. Long-term objectives include the safety assessment of new aircraft applications of laboratory advancements, such as metal matrix and ceramic matrix composites for engines.

The purpose of the structural safety research effort is to increase protection for both occupants and crew during an accident. The focus here is on advanced composite materials structured safety. Structural crashworthiness encompasses improvements in passenger restraints and crash energy absorption, as well as facilitating escape by maintaining the integrity of the cabin interior.

One of the main thrusts of FAA's propulsion systems research is powerplant safety. Engine structural safety R&D addresses failure of high-energy or high-temperature engine components that could lead to catastrophic loss of an aircraft. Advanced materials issues relate to the fact that low-wear, high-temperature engine parts are constructed from ceramics, ceramic matrix composites, or high performance alloys. Of prime concern are:

- the structural integrity of blades, spacers, seals and disks during engine operation at high rotational speeds;
- the integrity of the engine case, which contains the high-pressure combustion zone of the engine, in the event of failure of rotating components.

### ***3.3.1 Aging Aircraft Research Program***

The goal of this FAA effort is to develop the theoretical understanding and technologies needed to maintain the structural integrity of older, in-service aircraft through a reassessment of current aircraft design and maintenance and inspection programs. New materials, models and methods will enable extended, safe in-service life; prediction of the effects of aging, and improved ability to reliably detect and then remedy structural fatigue and corrosion.

### **3.3.1.1 *Current Research***

Aging airframe structures have shown increasing susceptibility to widespread fatigue damage and corrosion that could pose a threat to their structural integrity. Instances of structural failures point to the need for increased reliability in inspection methods. Furthermore, the demands on the aviation safety inspectors due to the aging aircraft fleet require automated data-tracking improvements. This research effort will develop the means for evaluating and ensuring safety and reducing the risks associated with aging aircraft structures. The three thrust areas of aging aircraft research are: structural design, maintenance and inspection, and automated methods for surveillance of information relating to the aging aircraft fleet. Research efforts will include developing methods to predict corrosion and corrosion — fatigue interaction in airframe materials; and verifying failure criteria and residual strength predictions.

### **3.3.1.2 *Research Planned in FY96***

In FY96, the aging aircraft research projects will develop inspection and maintenance requirements for nonrotating, safety-critical components of aircraft engines, and an integrated widespread fatigue damage initiation and residual strength risk methodology. Other efforts will evaluate and validate nondestructive inspection equipment and develop an integrated safety network for FAA and industry use in the exchange of maintenance and inspection data.

## **3.3.2 *Advanced Materials and Structural Safety***

### **3.3.2.1 *Current Research***

The advanced materials research is focused on developing data on new materials being introduced into the design of current and future civil aircraft. This data will form the national basis for engineering, manufacturing and maintenance, regulations and associated compliance guidance necessary to ensure the integrity of aircraft structures utilizing these new materials. This research will also foster continued U.S. leadership in commercial aviation, while promoting safety in a demanding and rapidly changing global environment.

The three technology thrusts of this program are: materials, structures and manufacturing and supportability. The goal in the materials thrust is to predict the response of new materials (fiber-reinforced polymer-matrix composites, as well as metallic and ceramic matrix composites) to environmental and operational stresses. The structures thrust requires evaluation of strength, stiffness, durability and damage tolerance of all structural elements, components and full-scale assemblies in an in-service operational environment. The manufacturing and supportability thrust is concerned with research to enable safe operation of the aircraft throughout its life-cycle. This requires development of suitable inspection methods to detect damage or defects in structures, including advanced materials.

Some current research efforts in advanced materials include the following:

- Develop a common standard for materials and processes to repair composite parts.
- Improve mechanical material property test methods and determine load sequencing effects on damage initiation and accumulation.
- Determine response of curved panels to low velocity impacts, such as runway debris or tool drops, by testing and analysis.
- Complete a feasibility assessment of the probabilistic design and failure prediction methodology by surveying U.S. and foreign sources, including a case study on how this approach was used in design of military composite aircraft (see Figure 6).

### ***3.3.2.2 Research Planned in FY96***

In FY96, FAA will conduct the following research efforts:

- Continue research on damage accumulation in composites due to repeated loads to establish test protocols for certification of aircraft.
- Initiate a database on damage tolerance of fuselage structures made of composite materials.
- Develop a computer model for determining the reliability of composite structures.
- Develop a handbook on acceptable composite material mechanical property test methods.
- Fabricate prototype of advanced aircraft energy-absorbing seats.
- Collect data to improve the seat design and analytical model.

### ***3.3.3 Aircraft Catastrophic Failure Prevention Research***

#### ***3.3.3.1 Current Research***

This program focuses on advanced means to predict and prevent catastrophic structural failures on future commercial transport aircraft. A goal of this program is to develop technologies and methods of advancing U.S. expertise in turbine engines, airframe structures and flight control systems. Emphasis will be placed on forming accurate, quantitative definitions of dangerous aircraft loading conditions; structural failure prevention through improved airframe design and maintenance; and structural failure survivability through an improved understanding of failed airframe loading conditions.



Figure 6: Beech Starship Composite Aircraft

To develop new crashworthiness and safety-in-performance standards for advanced materials used for aircraft fuselage, engine and interior applications, the FAA R&D program tests and monitors the behavior of a variety of aircraft types and materials, such as this all-composite Beech Starship aircraft.

In the near term, research will focus on completion of flight testing of a first-generation rotorcraft health and usage monitoring system; continued development of advanced nondestructive inspection concepts for titanium engine rotor alloys; initiation of research in advanced aircraft damage tolerant/smart sensor structures; and completion of a state-of-the-art review of advanced barrier armor materials.

#### **3.3.3.2 Research Planned in FY96**

The aircraft catastrophic failure prevention research program will demonstrate a prototype rotor fragment liberation, barrier penetration and aircraft damage model in FY96. Research will continue on advanced aircraft damage tolerant and smart sensor structures, and on airframe load analysis and testing.

#### **3.3.4 Aircraft Hardening**

The 1990 Aviation Security and Improvement Act prompted modification and expansion of FAA's security R&D program beyond its original focus on weapons detection. FAA's program is concerned not only with structural sabotage from onboard explosive devices but also with spurious electromagnetic security signals that can sabotage or interfere with the flight control of an aircraft. The aircraft hardening portion of this research program will identify methods to increase aircraft survivability by reducing damage caused by small explosive detonation on a commercial airliner.

##### **3.3.4.1 Current Research**

The threat to aircraft survival due to an in-flight detonation of a small explosive device continues to be significant. The aircraft hardening program objectives are to determine the minimum size explosive that must be detected to ensure aircraft survivability, as well as assessing methods of increasing survivability through a reduction in blast effects or an increase in aircraft capability to resist blast through design changes to structures or systems (including hardened luggage containers). Current research efforts include the following: support the testing of alternative containment and blast management designs; validate the analytical vulnerability assessment of wide-body aircraft and determine the minimum amount of explosives that must be detected.

##### **3.3.4.2 Research Planned in FY96**

In coming years, several materials and technologies may be used to harden aircraft and their contents. Advanced fiber-composite materials that are light, tough and can confine explosion damage are of interest. Attention to their initial cost, weight and durability is needed. Of key importance is the promise of aircraft hardening of cargo holds for reducing explosives detection requirements, i.e. the sensitivity of airport screening equipment to amount of explosives. Hardening may also benefit from aging aircraft and catastrophic failure prevention

R&D projects that augment the scientific understanding of aircraft materials. In FY96, FAA will:

- Continue research on the identification and evaluation of potential aircraft hardening techniques.
- Identify, analyze and test mitigation and countermeasure techniques for unique threats.

### **3.3.5 *Advanced Fire-Safe Aircraft Materials***

This effort focuses on preventing fires from occurring, slowing their growth and suppressing them, as well as providing design features that give passengers sufficient time to escape. This program includes advanced materials in a systems approach to improve cabin fire safety, along with fire prevention, detection and control.

#### **3.3.5.1 *Current Research***

Current research focuses on modeling and testing the fire behavior of materials for aircraft cabins, and on devising guidelines and regulations to prevent and mitigate consequences of fires. Thermoset composites (e.g., fiberglass-reinforced phenolic resin composites and sandwiches) are currently used for interior furnishings. These and other materials (foams, insulation, molded plastics) have to meet stringent fire-resistance regulations. Fire safety improvements for both structural and interior materials of future aircraft (such as thermoplastic polymers instead of currently used thermosets) require much more research on flammability, heat of combustion and toxic byproducts, especially if the use of lightweight composites will increase in future fuel-efficient aircraft. Also, in light of the increasing use of advanced electronics in the cabins, more research is needed on fire causes and suppression.

#### **FAA: DEVELOPMENT & DEMONSTRATION OF FIRE-RESISTANT CABIN INTERIORS**

FAA's R&D program on fire research and safety, in cooperation with the Interagency Working Group on Fire and Materials, is conducting materials research to modify advanced polymers for airplane cabin interior applications, with the goal of developing and demonstrating a prototype fire-resistant aircraft cabin interior by 1999. This is a broad program, combining materials fire safety with improved fire management and safety systems (smoke detectors, spray systems). High-temperature thermoplastics, based on tailored polymers with highly cross-linked molecular structure that do not support combustion, and fire-resistant foams that will replace urethane seat cushions are being developed and tested at the FAA Technical Center in Atlantic City, New Jersey, in close cooperation with NIST's Building and Fire Research Laboratory, the US Navy, and the US Navy/Naval Research Lab.

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FAA and industry are developing such materials under CRADA agreements: Dow Corning on siloxane polymers for fire-resistant aircraft interiors; Allied Signal on new fire resistant triazine resins; CIBA-Geigy on advanced cyanate ester resins; and Akzo Chemical on phosphorous-based fire-retardant chemistry. FAA grants to universities support similar efforts: Virginia Polytechnic Institute is working on advanced fire-resistant thermoplastics flame-retardant polymers. Rutgers University is investigating the properties of polysialate resin composites, Case Western Reserve is developing the fundamental molecular understanding of fire-resistant materials behavior, and Penn State is developing flame retardant polymers for various aircraft applications. University of Massachusetts work focuses on high-performance fire-safe polymeric materials.

### **3.3.5.2 Research Planned in FY96**

Although this is a long-range R&D program, FY96 efforts will include research on the synthesis, performance characterization, bench-scale fire testing and modeling of thermo-structural behavior of fire-safe thermoset resins. Cooperative efforts with manufacturers for process control sensors and low-cost processing will be initiated.

#### **FRA: NEW FIRE HAZARD ANALYSIS AND SAFETY REQUIREMENTS FOR PASSENGER TRAIN SYSTEMS HAS MULTIMODAL APPLICATIONS**

Fire safety research on new materials is of particular interest for new lightweight high-speed rail technologies, as well as for conventional intercity and commuter rail and transit vehicles. New guidelines are necessary for passenger train materials selection that consider the considerable advances over the past decade in fire safety engineering, new composite material and modeling.

New composite materials are usually lighter and stronger and less susceptible to corrosion, but their organic resins may increase their flammability. Conventional test methods are not appropriate for predicting the actual fire performance of advanced composites.

A recent FRA effort, performed jointly by system safety experts at the Volpe Center and the NIST Building and Fire Research Laboratory, reviewed current U.S. and international approaches to, and new concepts of, passenger train fire safety (DOT/FRA/ORD-93/23 and NIST Technical Note 1406). New-material flammability and smoke emission test evaluation tools were identified in the initial study. Ongoing work will develop criteria for a new fire test technique applicable to passenger train interior materials, which will validate a mathematical hazard model of full-scale burning behavior of materials and assemblies for passenger trains. This new generation of test methods, based on the heat release rate of interior and exterior vehicle materials combined with the use of fire hazard and fire risk modeling, provides a better and more cost-effective means to predict real-world fire behavior. The new tests will facilitate the use of composite materials for passenger car structural and interior padding applications. In addition to rail and transit modes, air and marine modes will benefit from this materials fire safety study.



### 3.4 Ship Structures and Airframe Research (USCG and MARAD)

To redress the absence from international commercial markets of U.S. commercial shipyards when compared to their foreign counterparts, the Administration has embarked on a program of shipyard revitalization. President Clinton released a report to the Congress, Strengthening America's Shipyards: A Plan for Competing in the International Market in October 1993. Secretary Peña included this issue in DOT's Strategic Plan issued 3 months later. Goal 3.7 of the Strategic Plan commits the Department to "*[I]mplement the President's new shipbuilding initiative to enable American shipbuilding to be more competitive globally.*" Several components of DOT's and DOD's programs have materials R&D and new materials processing technologies components.

#### 3.4.1 Shipyard Revitalization (MARAD)

##### 3.4.1.1 Current Research

The shipyard revitalization program is designed to implement both commercial and national security goals. This program, to be undertaken by the Maritime Administration (MARAD) in close coordination with the Defense Department and the U.S. maritime industry, has five major aspects:

- Identify market niches in which U.S. shipyards can compete in the international arena.
- Construction processes and existing ship standards will be assessed, and problems in the development of new international standards will be addressed.
- Shipyard initiatives to shorten delivery time, lower costs and improve quality will be supported.
- Requirements for a U.S. supply base necessary for shortened delivery times and lower costs will be identified and development of new resources will be promoted.
- The MARAD National Resource and Education Center will assist industry in adopting new standards, applying new technologies and improving business practices and work force training.

The advanced materials and processing technology aspects are primarily related to the second and the last goal.

The MARAD effort will supplement the \$200 million MARITECH shipbuilding technology modernization initiative, managed by the Defense Department's Advanced Research Projects Agency (ARPA) with DOT's active collaboration, which focuses more narrowly on the technological aspects of improved shipbuilding.

### **3.4.1.2 Research Planned in FY96**

Critical areas in support of the U.S. shipbuilding industry, which are not supported by the MARITECH advanced technology approach, have been identified as being important to ensure the survival of the industry. In FY96, MARAD will stress the need for projects that provide immediate benefit, as opposed to those that will not yield results for longer periods of time. MARAD research programs will highlight the following related to infrastructure and materials:

A government—industry cooperative partnership to improve the competitiveness of the U.S. private shipbuilding and ship repair industry through better understanding of the market, improved data availability and education.

Government—industry support and assistance in solving problems related to the development of consensus standards and improved shipyard processes. Possible projects could include conducting tests to determine the acceptability of new materials and associated methods.

### **3.4.2 Ship Structures Research (U.S. Coast Guard and MARAD)**

#### **3.4.2.1 Current Research**

Numerous pressures on maritime operations—cutting crew complements to save money, competitive demands for greater speed and labor productivity, and congestion in harbors and waterways—all tend to increase safety risks. One means of dealing with these concerns is represented by the ship structures research program. This is a cooperative research activity supported by U.S. and Canadian government agencies (U.S. Coast Guard, MARAD, U.S. Navy and its Military Sealift Command, the Canadian Ministry of Transport and the Canadian Defense Research Establishment) as well as the American Bureau of Shipping. Its goal is to facilitate the design and construction of safer and more cost-effective ship structures through the development and sharing of new materials and technologies, lighter, stronger and corrosion-proof ship hull and components and advanced coating materials for corrosion protection.

#### **USCG AND MARAD: R&D ON ADVANCED MATERIALS AND METHODS FOR MARINE VESSELS APPLICATIONS**

The Ship Structures Research Program has been a very successful cooperative effort to explore and develop new technology related to ship structural concepts, materials, reliability and designs. The Ship Structure Committee (SSC), guiding and implementing this program, includes the DOT's US Coast Guard (USCG) and the Maritime Administration (MARAD), with the US Navy, Military

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Sealift Command, American Bureau of Shipping representing industry, and the Canadian Ministries of Defense and Transport. The NAS/NRC Marine Board and Society of Naval Architects are also included in program activities. The SSC makes use of the National Maritime Enhancement Institutes, such as UC-Berkeley and M.I.T., to conduct research and disseminate findings. Each SSC report is distributed for free to over 140 government offices, over 50 universities and over 100 shipyards, to design offices and ship operators, as well as through the NTIS. The benefits to MARAD are more productive shipyards and shipping line operators, and to the USCG--stronger, safer and more spill-resistant ships.

Materials research SSC "success stories" include: stronger ship hull materials and double hull tanker designs to prevent oil spills in case of collisions and grounding accidents; and implementation of new structural materials (high performance and Thermomechanical Controlled Process, TMCP steels for plates and welds, corrosion-proof coatings) residual strength evaluation methods and new designs for weight reduction with improved performance in a corrosive marine environment, a Fracture Symposium, and a design Guide for Composites.

Several research projects were performed by the Maritime Enhancement Institutes, focusing on structural deterioration, damage and failure phenomena data and modeling: UC Berkeley has performed a review of marine structures inspection methods (visual, ultrasonic, magnetic particles and newer experimental methods) by their sensitivity and accuracy in detecting cracks and corrosion, as well as cost. They also developed a standardized industry-wide Structural System Integrity Information System (SSIIS) for data collection, analysis and evaluation; a Repair Management System (RMS), and a fatigue and corrosion damage database. M.I.T. research focused on grounding protection and damage prevention for double hull tankers, and prepared a Design Guide for marine applications of composites, based on evaluation of practical technologies developed for defense and aerospace applications.

#### **3.4.2.2 Research Planned in FY96**

In FY96, emphasis will be placed on improving the safety and integrity of marine structures, reducing marine environmental risks and providing R&D support to the U.S. maritime industry in shipbuilding, maintenance and repair.

#### **3.4.3 Fire Safety Composite Air Frame Research (U.S. Coast Guard)**

##### **3.4.3.1 Fiscal Years 1994-1998**

The material used in the construction of the HH-65 airframe has not been previously tested to determine the characteristics of the materials that make up the composite when exposed to fire. No historical data exists concerning the fire performance of the materials used in the HH-65 helicopter composite airframe. Over 80 percent of this airframe is made from advanced composite material (ACM). Review of ACM thermal decomposition and its potential effects

on Coast Guard personnel raises serious health and safety concerns. Research is necessary to determine what toxic or carcinogenic by-products are generated by ACM in a fire scenario and what actions must be taken to protect personnel from their effects.

The Coast Guard will perform the following research:

- Conduct a background study to identify the materials used in the airframe, any previous studies involving those composites and any existing guidelines issued by other agencies such as the Air Force.
- Determine the fire safety, including both structural and toxicity data, of the materials.
- Conduct laboratory-scale tests on the various component materials of the HH-65 airframe to determine their specific chemical formulas and toxicity.
- Quantify the heats of combustion, rates of heat release, fire spread rates, by-products of combustion and other fire parameters specific to these materials.
- Investigate potential risks added by composites versus risk due to electronics.
- Prepare test site for full-scale tests and conduct tests as necessary.

#### ***3.4.4 Cargo Handling Cooperative Research Program (MARAD)***

The Cargo Handling Cooperative Program is a cost-shared industry research and technology consortium for U.S. flag ocean transportation companies in partnership with MARAD. This R&D consortium has been very effective for the past decade developing innovative maritime cargo handling tools, services and technologies to enhance productivity and improve cargo handling capacity and speed. Several aspects of this program involve applications of advanced materials, such as high-cube multimodal freight containers that make use of advanced composites or light alloys.

#### **4.0 DOT — PARTNER IN NATIONAL INTERAGENCY R&D AND TECHNOLOGY COMMERCIALIZATION EFFORTS ON ADVANCED MATERIALS**

DOT has worked with other Federal agencies the White House OSTP; the Departments of Defense, Energy and Commerce; the National Science Foundation; NASA; and the Environmental Protection Agency — in an aggressive effort to mobilize and coordinate transportation-related R&D activities throughout the government. DOT interagency efforts related to advanced materials are discussed below.

##### **4.1 National Science and Technology Council (NSTC)**

The Clinton-Gore Administration has taken a new approach to R&D, issuing both a Technology Policy and a Science Policy. In an effort to put the policy process in front of the budget process, the President established the NSTC. The principal purposes of the cabinet-level Council are to establish clear national goals for Federal science and technology investments and to ensure that science, space and technology policies are developed and implemented to effectively contribute to those national goals. Through this interagency process, overlapping and duplicative research will be avoided and technology policy will be given a higher profile. President Clinton is chairman of the Council, whose membership includes the Vice-President and the Cabinet.

In order to prepare coordinated and balanced R&D strategies and budget guidance, the NSTC created nine interagency coordinating committees. DOT leads the Committee on Transportation R&D (CTRD) and participates in four other Committees: Civilian Industrial Technologies, which has a Subcommittee on Infrastructure led by DOT/FHWA; International Science, Engineering and Technology; Education and Training; and Environment and Natural Resources. The Deputy Secretary of Transportation, Mortimer Downey, chairs the CTRD.

The Transportation Committee has recently completed a report that was submitted to the NSTC identifying transportation R&D priority areas and providing strategic R&D budget guidance. Transportation R&D priority areas identified by the committee include infrastructure renewal materials, methods and tools and expanded R&D on next-generation vehicles technologies, with particular emphasis on applications of advanced materials. This report has been posted on the OSTP Home Page, accessible to the public via the Internet.

In May 1994, OMB and the President's Science Advisor issued budget guidance to the heads of all Federal agencies. The guidance highlighted important FY96 R&D policies, goals, priorities and evaluation criteria that were developed through the NSTC Interagency Committee process. Six crosscutting areas were identified: a healthy, educated citizenry; job creation and economic growth; world leadership in science, mathematics, and engineering; improved environmental quality; harnessing information technology; and enhanced national security. These six priorities were not intended to be a comprehensive list of all R&D projects

that merit support. Rather, focus on those R&D areas that the NSTC committees identified as needing new or additional emphasis in 1996. The majority of the NSTC Transportation Committee's priorities were included in the goal to promote job creation and economic growth. Those priorities relevant to materials R&D include: the PNGV, materials technology, transportation system assessment; transportation physical infrastructure, and information infrastructure for transportation.

## **4.2 Technology Reinvestment Project**

The Clinton Administration's Defense Reinvestment and Conversion program capitalizes on post-Cold War opportunities by investing in community redevelopment, worker retraining and advanced technology. Secretary Peña decided early on to promote the development of transportation-related technologies. The Department is a full partner in ARPA Technology Reinvestment Project (TRP). The TRP is an effort to stimulate the transition of military dual-use technologies into competitive commercial products that will both boost U.S. productivity and expand the customer base of defense products, thus lowering unit costs to all consumers. A key facet of the TRP is that proposals receiving awards require 50-50 cost-sharing between government and industry. As a partner, the Department joined the Defense Technology Conversion Council, along with representatives from other Federal agencies. DOT also has been active on the Defense Technology Conversion Council Working Group and the Technology Development Activity Area Panel.

The Department of Defense is the largest single customer for commercial transportation in the world, and has substantial needs for modernization of its own transportation facilities and equipment. Dual-use historically, Defense Department R&D has created new opportunities for commercial services and has expanded the market for advanced transportation products and dual-use technologies by lowering unit costs.

Transportation research and DOT have been big winners in the first 2 years of the TRP. By providing proposal evaluators and supplying ARPA with input about transportation-related areas that could benefit from TRP support, DOT has been able to guide TRP funding into key areas that will benefit the nation's transportation system, such as new vehicle technology, advanced materials for infrastructure renewal and advanced battery technology.

In February 1994, the final awards for the FY93 TRP competition were announced. In the Technology Development portion of the program, 69 cost-shared proposals with a total face value of \$800 million were awarded. The Federal share of the \$800 million has yet to be negotiated, but will be a maximum of 50 percent. Twenty-seven proposals with a total face value of \$420 million were directly related to transportation. DOT is the managing agent on nine of these projects, including a \$21 million project for Advanced Composites for Bridge Infrastructure Renewal—a project led by the University of California, San Diego, to demonstrate the use of corrosion-resistant, lightweight composites for repair and replacement of the nation's aging bridges, and for seismic reinforcement of support pillars. As managing

agent, DOT will receive the TRP funds, negotiate the technical/legal issues in the funding agreements, make the awards and conduct follow-up monitoring.

MARAD is the executive agent for the TRP \$13.9 million Commercial Shipbuilding Focused Development Project. Also included in the FY93 TRP awards was a Portable Shipbuilding Robotics project to develop a dual-use, portable robotic welding system that would improve the productivity of the U.S. shipbuilding industry. The effort would integrate technical advances in Personal computers, robotic design, 3-D vision and weld sensors to provide a portable welding system developed especially for the shipbuilding industry. If successful, these robotics would automate up to 75 percent of ship welding, quickly reducing the cost of shipbuilding.

On October 25, 1994, ARPA announced the 39 winners of the 1994 Focused TRP Competition. DOT will have significant technical involvement in five of these projects, which exceed \$69 million in face value. All winning projects demonstrate enhancements to both the military and commercial capabilities of the nation, and further the TRP mission to stimulate integration of the nation's defense and commercial sectors.

TRP also announced a third competition for \$415 million, including 13 Technology Development areas, including affordable matrix composites for airframe structures, low-cost specialty metals processing and ceramic materials applications. Current Congressional action has slowed and might reduce this effort.

In addition to DOT's work on these TRP competitions the Department reviewed 1,200 TRP Small Business Innovation Research (SBIR) proposals and identified those with dual-use transportation promise. In FY95 DOT is managing 22 SBIR TRP awards with a value of \$2.1 million, and will guide research through to commercialization. Several projects deal with development and demonstration of advanced materials technologies. For example, FHWA manages development of a Configurable Automated Pavement Distress Survey system; NHTSA manages advanced processing (Pullform) of titanium and aluminum blades for gas turbine engines; and FAA manages the fabrication of composite turbine powershafts using explosive welding techniques and innovative processing of ceramic core/composite skin structures applicable to commercial aircraft.

### **4.3 Advanced Technology Program**

The Advanced Technology Program (ATP), managed by the Department of Commerce's NIST, is helping U.S. industry to fund the development of high-risk, but powerful, new technologies that underlie a broad spectrum of potential new applications, commercial products and services. The ATP provides support on a cost-sharing basis to industrial R&D projects with a significant potential for stimulating economic growth and improving the competitiveness of U.S. industry. DOT has been working with NIST and with industry to include transportation as a focus area of the ATP.

NIST announced five ATP program competitions in 1994, including one on Manufacturing Composite Structures. This competition will receive \$160 million over 5 years and will highlight transportation applications of composite materials to both vehicles and infrastructure. The three primary areas to be explored through this program competition are the use of composite materials in automobiles, bridges and offshore oil platforms.

In November 1994, the Commerce Department announced the winners of two ATP competitions: the General Competition and the Program on Manufacturing Composite Structures. General competition awards related to advanced materials for transportation applications include the following: film technologies to replace paint on aircraft; low-cost elastomeric composites with application to vehicle tires; engineered surfaces for rolling and sliding contacts; and rapid solidification powder metallurgy for high-nitrogen stainless steels. Transportation-related awards made under the program on Manufacturing Composite Structures include: low-cost automotive manufacturing with injection molding of various composites; automotive composite structures; development of high-volume manufacturing technology; low-cost manufacturing and design/sensor technologies for seismic upgrade of bridge columns; manufacturing composite flywheel structures; high-performance composites for large commercial structures; thermoplastic composites for structural applications; structural composites manufacturing process; innovative manufacturing techniques to produce large phenolic composite shapes; and polymer matrix composite power transmission devices. The ATP awarded \$200 million in FY94 funds. In FY95, \$450 million has been appropriated for the program, which was expected to grow to \$750 million by 1997. The ATP program is also currently facing Congressional opposition and uncertain funding.

#### **4.4 DOT's University and Other Cooperative R&D Programs**

##### **4.4.1 University Transportation Centers**

The DOT established 10 regional University Transportation Centers (UTC) in 1987 to focus on long-term applied research, primarily for the surface transportation modes. The enactment of ISTEA in 1991 led to the establishment of several new university-based National Research Centers and Institutes, with greater research emphasis on regional intermodal linkage and efficiency gains, and on multimodal transportation facilities. DOT currently supports a network of 13 regional University Transportation Centers. This program is managed by RSPA and funded by grants of about \$12 million from FHWA and FTA. These annual grants are matched by state and industry participants in each regional university consortium.

The regional and national research centers established as consortia are led by the following universities:

- Region 1, New England — Massachusetts Institute of Technology
- Region 2, New York/New Jersey — City University of New York
- Region 3, Mid-Atlantic — The Pennsylvania State University



Region 4, Southeast — University of North Carolina  
Region 5, Great Lakes — The University of Michigan  
Region 6, Southwest — The Texas A&M University System  
Region 7, Midwest — Iowa State University  
Region 8, Mountain-Plains — North Dakota State University  
Region 9, California — University of California-Berkeley  
Region 10, Northwest — University of Washington  
National Center for Transportation and Industrial Productivity-  
New Jersey Institute of Technology  
National Center for Transportation Management, Research and Development-Morgan State  
University, Maryland  
Mack-Blackwell National Rural Transportation Study Center — University of Arkansas

ISTEA also established five University Research Institutes (URI) funded on a cost-shared basis by FHWA and FTA (over \$6 million annually) and managed by RSPA. The Infrastructure Technology Institute at Northwestern University, Illinois in particular has materials research thrusts focused on transportation physical infrastructure applications.

Several of the University Transportation Centers perform materials R&D that advances the state of knowledge towards improvements in vehicles and infrastructure. For instance, research highlights from the 1988-1993 UTCP Report for Region 2 include work by Rutgers University on a new spectral analysis of surface waves method for nondestructive testing of pavements, applicable to both roads and airfields. Region 3 reported on research conducted at the Transportation Systems Rehabilitation and Maintenance Institute at West Virginia University, which focuses on conventional and advanced materials and technologies needed for renewal engineering. In UTC-Region 8, Colorado State University researchers from developed and implemented a portable computer tool for inspection of small bridges to facilitate the work of surveying the state and maintenance needs of small bridges in rural locations, while the University of Wyoming focused on improving the rut resistance of rural roads.

#### **4.4.2 University Centers of Excellence**

Several DOT administrations have established University Centers of Excellence (COE):

MARAD and the Coast Guard fund four universities designated as National Maritime Enhancement Institutes (MIT, University of California, Louisiana State University and University of Memphis). Some materials-related maritime research is highlighted in the sidebar on Ship Structures Committee in Section 3.4.2.

The FAA funds an aviation grant program and supports on a cost-shared basis, the FAA/NASA Joint University Program and since 1992, Air Transportation Centers of Excellence. These centers have a strong materials R&D thrust: the Pavement Research

Center at the University of Illinois (Champaign-Urbana) will assist in developing advanced airport pavement designs, materials and modeling tools; and the Center for Computational Modeling of Aircraft, a joint venture of Rutgers, the State University of New Jersey and the Georgia Institute of Technology, is develop the data and models to analyze aging aircraft, life-extension methods and new aircraft designs. Some recent successes in materials-related airport and aircraft performed at these COE's has been highlighted in sidebars in Sections 2.4.1 and 3.3.5, respectively.

#### **4.4.3 Small Business Innovative Program**

Under the SBIR, each Federal agency must set-aside 2.5 percent of its R&D funding for grant to small business. Within DOT, the SBIR is managed by RSPA's Volpe Center. The programs funds innovative small business proposals to solve transportation needs and problems defined by the modal agencies. Most SBIR is applied, and a significant portion deals with improving materials and processing technologies. DOT has consistently exceeded the 2.5 percent statutory setaside, obligating \$4.4 million in FY93, \$7.5 million in FY94 and an estimated \$8 million in FY95. Illustrative materials R&D projects awarded in FY94 include:

FAA-sponsored research on advanced fire suppressants and fire-resistant cabin materials, and on advanced NDT/NDI methods for polymer composites, integrity of aging aircraft, and luggage materials.

An FRA-sponsored project to develop NDE methods to assess weld integrity for tank cars.

Solicited materials-related SBIR topics for FY95 include:

An FHWA call for remote sensing technology to detect structural fatigue cracks, and assess use of recycled materials in concrete.

FAA topics on NDE to monitor composite-bonded aircraft structures, detect widespread fatigue damage in aging aircraft and predict failure of turbine engines.

FRA's improved nondestructive inspection methods for rail. DOT's participation in the TRP SBIR program and its management of transportation related SBIR projects, including several pertaining to advanced materials and technology demonstration, are described in the TRP and ATP sections above.

#### **4.4.4 Other Cooperative R&D and Technology Transfer Programs**

Other cooperative research programs include:

The Long Term Pavement Performance and the National Cooperative Highway Research Program sponsored by the FHWA, and the FTA-sponsored Transit Cooperative Research Program, both managed by the Transportation Research Board (TRB).

Another TRB cooperative R&D program funded by several DOT agencies to identify promising technologies for transportation innovations is the Innovations Deserving Exploratory Analysis (IDEA) program. It includes specific thrusts for advanced materials and composites, repair and rehabilitation methods, pavements and structural use of recycled materials, and nondestructive or noncontact monitoring and assessment tools.

Technology transfer for DOT is also accomplished through full participation of the DOT research centers and experimental facilities listed in Appendix A, which participate in the Federal Laboratory Consortium activities. For instance, the FHWA Highway Research Center in McLean, Virginia and the FAA Technical Center near Atlantic City, New Jersey award contracts for R&D, as well as entering into technology transfer and cooperative research agreements (CRADA) with industry on a broad range of transportation technologies.

## **APPENDIX A: MAJOR DOT RESEARCH CENTERS AND LABORATORIES**

John A. Volpe National Transportation Systems Center (RSPA)  
Cambridge, MA

Turner-Fairbanks Highway Research Center (FHWA)  
McLean, VA

FRA/AAR Transportation Test Center and  
Hazardous Material Training Center  
Pueblo, CO

FAA Technical Center  
Atlantic City, NJ

Mike Moroney Aeronautical Center (FAA)  
Oklahoma City, OK

US Coast Guard Research and Development Center  
Groton, CT

NHTSA Vehicle Research and Test Center (VRTC)  
Liberty, OH

FTA Bus Testing Facility  
Pennsylvania Transportation Institute  
State College , PA

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(609) 485-5777

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**Annual Reports and R&D technical products are available from above contacts.**



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