Advanced Crash Analysis Program (ACAP) to Improve Transportation Safety and Security – 2012 Status Report

Background
The Advanced Crash Analysis Program (ACAP) was initiated by the Federal Highway Administration (FHWA) Office of Safety R&D of the Turner Fairbank Highway Research Center (TFHRC) in December 2008. ACAP continues FHWA efforts to promote the application of finite element (FE) models and crash simulations to 1) design and analyze various types of roadside hardware (e.g., sign supports, guardrails, and concrete barriers); 2) assess vehicle-to-vehicle and vehicle-to-barrier impact compatibility; 3) investigate the causes of various types of crashes including rollovers; 4) formulate improved guidelines for the selection and deployment of roadside safety or security hardware; and 5) develop concepts for new roadside treatments. These efforts are expected to result in new treatment options that can be used to mitigate current or emerging safety or security problems; confirm or expand the findings of other analyses and testing; and/or improve hardware application effectiveness.

ACAP will also serve as the platform for FHWA to support a broader spectrum of safety and security research, pioneer the use of new technologies, improve tools and methods, develop new devices, consider the implications of changing conditions, and promote state-of-the-art transfer of findings to public agencies, researchers, and industry. The sharing of models, data, and results that characterized past efforts will continue to support safety and security research and development efforts worldwide.

Objectives
ACAP objectives are to expand detailed knowledge about crashes, promote the application of emerging methods, enhance understanding of crash dynamics, and improve potential effectiveness of designs, materials, or applications for safety and security elements. Under ACAP, FHWA will continue to collaborate with the National Highway Traffic Safety Administration (NHTSA), the Department of State (DOS), and other organizations to continue advanced crash analyses and research.

Achieving these objectives will primarily involve the following efforts:

- Conduct advanced crash research to assist researchers and engineers in resolving safety and security issues in transportation.
- Advance techniques and tools for crash analyses, including FE modeling, simulation, and vehicle design and dynamics analysis tools, and demonstrate their application.
- Maintain a national repository (i.e., knowledge base) of crash videos, films, and documentation.
- Conduct crash and impact testing to provide data for modeling, material characterization, calibration, and validation.
- Disseminate the findings of the research and the applications of the advanced technologies to reap their benefits and accelerate their deployment.
- Support multifaceted outreach and educational opportunities, using state-of-the-art tools, to serve practitioners, decision makers, and students.
- Conduct detailed and clinical analysis of crash data and correlate it to analytical results to expand understanding of crash events.
- Investigate occupant risks in crashes and the effectiveness of mitigation measures.
- Evaluate improved designs and treatments to enhance transportation safety and security.

A key aspect in achieving these objectives is expected to be the continued sharing of resources, findings, data, models, and technologies with others to expedite efforts to address complex safety and security problems. This may involve prospecting in
related fields, forming new partnerships to adapt advanced analysis tools, and considering novel applications to deal with the complexities of safety and security issues and means to mitigate them.

Scope
A task order-based contract has been initiated to support the various activities under ACAP. The George Washington University was selected as the contractor for this program after a rigorous, full, and open competition. The contract provides for research and development efforts to support the missions of the FHWA, NHTSA, DOS, and potentially other government agencies. Task Orders under ACAP may involve considerations of all types of vehicles, different roadway and roadside features, varying impact conditions (e.g., speed and angle of crash), and a range of occupant types and positioning.

Under this program the Federal Outdoor Impact Lab (FOIL) and the Vehicle Modeling Lab (VML) will be operated and maintained to allow full-scale and component level testing to provide essential dynamic response data. Testing and engineering efforts in these facilities will be undertaken in accordance with standard AASHTO, DOS, and ASTM protocols as appropriate. The VML will continue to advance technologies to support reverse engineering and the creation of vehicle and hardware finite element models for the simulation of a broad spectrum of crashes.

Task Areas
The ACAP contract was structured to support research efforts in various subject areas, including:
- Roadside analysis and design
- Impact and material testing
- Development and validation of FE models
- Documentation of research efforts and findings
- Outreach and training
- Infrastructure barrier analysis and testing
- Occupant risk analysis
- Detailed data mining and analysis
- Library maintenance and updates
- Analysis of the feasibility and impacts of new materials
- Technical support

Efforts under one or more of these areas will occur as Task Orders issued by the FHWA defining specific objectives, approaches, timetables, and products. Table 1 lists the Task Orders that have been initiated since the beginning of the contract. The accomplishments associated with each are noted in italics. It is envisioned that ACAP will support efforts to address various future research challenges as they arise.

Products of these efforts will include reports, technical summaries, presentations, FE models, software tools, data sets, and technical assistance. The specific products from any task order effort will be a function of the level of analysis, objectives, audience, and scope defined at the outset.

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| 1          | Project Organization and Kick-Off                                   | Objective: To provide a systematic transition to the new contract and set the basis for management of subsequent Task Order efforts as well as continued maintenance of the FOIL, the NCAC Library, and the finite element models archive.  
Accomplishments: Established contract management system, continued FOIL O&M activities, and provided technical simulation support and problem analyses. [COMPLETED] |
| 2          | Provide Analysis and Evaluation Support for Roadside Safety Team     | Objective: To undertake short-term detailed analyses related to roadside safety issues to develop or improve hardware, enhance deployment, understand the causes of crashes, and/or assist in training agency personnel. These efforts are expected to expand the demonstrated applications of advanced tools and may establish a basis for further analyses.  
Accomplishments: Completed 2010 directives to 1) evaluate performance of raised block-outs for W-beam guardrails, 2) conduct simulation analyses of crash tests of Silverado into common barriers, 3) evaluate the enhanced tractor-trailer model, 4) simulate impacts under MASH criteria, 5) analyze slope testing protocols, 6) analyze barriers on curved roadways, and 7) support TRB and TCRS presentations. Completed 2011 directives to 1) analyze vehicle trajectories for elevated medians, 2) study effects of variations in bridge rail designs, 3) analyze the influence of slope rounding, 4) evaluate options for a TL 2 version of the MGS barrier, 5) generate trace plots for special median configurations, and 6) update past analyses on sign supports. Current efforts are focused on 1) developing improved tire models, 2) analyzing the vehicle dynamics of safety edge treatments, 3) analyzing vehicle compatibility issues, 4) studying crushable nose designs for bogie testing, 5) analyzing barrier terminal anchorage requirements, 6) enhancing guidelines for cable barriers, and 7) assessing the efficacy of the new Yaris model for barrier impacts. |
| 3          | Operation and Maintenance of the FOIL                               | Objective: To provide staff to support the basic efforts to operate and maintain the FOIL facility and the various equipment needed for different testing functions and conduct limited testing in support of research efforts.  
Accomplishments: Since the beginning of the contract more than 100 tests (including 30 full-scale) have been conducted and documented. In addition, new high-speed digital cameras, a new test control computer, various safety devices and tools, and a new storage building have been acquired and put into service. Efforts to secure lab accreditation were completed in September 2011. Ongoing testing efforts involve tests to understand tire and steering/suspension component failures, determination of crushable material requirements for surrogate testing, terrain effects on vehicle trajectories, and tests to capture model for modeling and validation. |
| 4          | Conduct Efforts to Document and Disseminate Research and Support Outreach Efforts | Objective: To assist the research staff in efforts to 1) generate reports, tech summaries, web materials, and other research products, 2) establish standards for documenting the products under ACAP, 3) support various outreach efforts, and 4) implement a process to track the production of research materials and maintain an ongoing catalog of them.  
Accomplishments: The NCAC Website has added 46 new documents related to work from both the previous and current contracts since the contract began. Many additional documents are being prepared for posting. The NCAC staff has organized and conducted various meetings, workshops, and conferences and has participated in various forums to disseminate the findings of the research and keep abreast of advances by others. [COMPLETED] |
| 5          | Update and Maintain Vehicle and Hardware Models and Associated Documentation | Objective: To maintain and upgrade the various vehicle and hardware models (e.g., finite element, rigid body), provide support to users, and manage website.  
Accomplishments: The 2007 Chevy Silverado and Toyota RAV4 vehicle models have been added to the array and numerous updates to hardware models have been made and posted. Documentation and website information have been updated. [COMPLETED] |
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| **Analyze Terrain Effects on the Trajectories of Vehicles that Leave the Road** | **Objectives:** To 1) generate the data necessary to verify or update relationships for terrain effects on vehicle trajectories for the current vehicle fleet, and 2) assess the implications on crashworthiness requirements and/or highway design guidelines to promote enhanced safety.  
**Accomplishments:** Vehicle Dynamics Analyses have been used extensively to understand trajectory effects over a very broad range of road departure conditions. More than 30,000 simulations have been run to capture trajectory data for a range of vehicle types and median configurations. These have been aggregated into proposed guidelines for effective barrier placement. Preparations are underway to conduct trajectory tests at the FOIL during 2012 to provide data to validate the vehicle dynamics analyses results. These efforts are underway to support efforts to formulate testing requirements for barriers on slopes and apply new technologies for tracing vehicle trajectories. |

| **Investigate Causes of Rollover Events for Various Crash Types Using Analytic Methods** | **Objectives:** To 1) undertake detailed analyses of rollover crashes to better understand underlying causes, 2) evaluate the potential effectiveness of new treatments or countermeasures, and 3) investigate whether current design practices can be improved to reduce the contributions to rollovers. It is expected that analytical and simulation methods will be used to assess these effects for various vehicles and impact conditions. The research should focus on rollovers for passenger cars and sport utility vehicles.  
**Accomplishments:** Literature was reviewed, recent empirical data analyzed, new sources of data explored, and a plan generated for Phase 2 efforts to analyze rollover crashes associated with road features. The draft report is being revised and is expected to be available in 2011. Recommendations for further efforts are being considered for Phase 2 efforts.  
[COMPLETED] |

| **Develop Updated Bogie Test Vehicle for the FOIL** | **Objective:** To model, construct, test, calibrate, and document a reusable bogie vehicle to enhance testing capabilities at the FOIL.  
**Accomplishments:** A bogie vehicle has been fabricated from a Silverado pick-up frame. The stability of the bogie has been assessed with tests at the FOIL. Recommendations for improvements to the design and validation have been formulated.  
[COMPLETED] |

| **Analyses and Testing of the Improved Infrastructure Security Barriers (DOS)** | **Objective:** To undertake the testing and analyses efforts needed to improve or enhance infrastructure barrier systems to higher certification levels and to assess barrier performance for combinations or arrays of barriers.  
**Accomplishments:** FOIL testing of a tubular steel fence and a fixed bollard were successfully completed and documented.  
[COMPLETED] |

| **Analysis of Improvements to Infrastructure Barriers to Enhance Performance (DOS)** | **Objective:** To undertake the simulation analyses efforts needed to improve or enhance existing infrastructure barrier systems to achieve higher certification levels, simplify the designs to facilitate construction, and assess the performance of arrays of barriers.  
**Accomplishments:** Crash simulation analyses were completed for the tubular steel fence. Simulations of potential improvements to bollard and knee wall barrier and the effectiveness of various combinations of previously tested barriers have been executed and results provided to the DOS.  
[COMPLETED] |

| **Develop and Validate an FE Model for a Small Car (with NHTSA)** | **Objective:** To develop a detailed vehicle finite element model of an 1100kg small car through reverse engineering and then validate the model in accordance with accepted practices to support future crashworthiness analyses related to vehicle and highway safety research.  
**Accomplishments:** A 2010 Toyota Yaris was procured, subjected to a series of non-destructive tests to capture data for model validation, subjected to reverse engineering, and scanned and meshed to create a finite element model. Teardown and scanning was completed and the initial version of the model developed and validated. This version was released to NHTSA on July 1, 2011. A MASH compatible version and documentation was released in December 2011. The interior elements have been added and additional validations of the model are being conducted for offset, pole, and vehicle-to-vehicle impacts. A second version of the model will be released in Fall 2012.  
[COMPLETED] |
|   | Maintain the Crash Tests Library and Continue Digital Conversion (with NHTSA) | **Objective:** To support basic management of the crash test library with primary emphasis on supporting the FHWA and NHTSA research efforts, cataloging new items, and continuing efforts to convert existing library materials to digital formats.  
**Accomplishments:** Various materials have been cataloged and added to the library. The process of converting films and reports to digital formats continues. Efforts to accelerate the digitization process have been investigated. Contracting issues have delayed the conversion of materials in the library into digital formats. |
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|   | Provide Ongoing Analysis and Evaluation Support for FE Modeling and Simulation (DOS) | **Objective:** To provide ongoing engineering and analytic support, to include finite element analysis to support research and testing activities, related to the evaluation of anti-ram truck barrier systems and assemblies as needed.  
**Accomplishments:** Simulations of various modifications to anti-ram barriers or changes to impact conditions were completed and documented. Undertook assessment of the nature of the world truck fleet to determine candidates for a next generation test vehicle modeling effort. [COMPLETED] |
|   | Assess Effectiveness of Child Safety Devices in Rear Seat Placement (NHTSA) | **Objective:** To use simulation analyses to analyze the risks to child occupants of varying ages in different types of crashes using available restraint devices. The findings will support rulemaking efforts.  
**Accomplishments:** A report summarizing the modeling of three additional child safety seats and the analysis of occupant risks in rear seat placement has been completed. Based upon the results additional simulations of varying crash conditions will be evaluated. [COMPLETED] |
|   | Analyses of New Materials on Vehicle Crash Integrity (NHTSA) | **Objective:** To provide technical support for NHTSA research on potential safety benefits of Plastic and Composite Intensive Vehicles (PCIVs) using current FE models modified to reflect the replacement of components with structural plastics and composites.  
**Accomplishments:** Typical vehicles were assessed to identify the structural components that could be replaced by plastic or composite materials to reduce weight. Working with industry groups, the next generation of materials that could be used in vehicle parts was identified. Some of these materials were fabricated and tested to characterize their fundamental properties. Through selective replacement of components in FE models of vehicles, it was possible to analyze the impact performance of “lightened” vehicles. A major focus was the replacement of the ladder frame of a Silverado pick-up with a composite version. This saved 19% in weight and met the NCAP frontal crash-worthiness requirements. The results suggest that there are potentials for reducing vehicle weight, but it also raised new questions about the effectiveness of the various options. [COMPLETED] |
|   | Occupant Risk Implications of New Vehicle Designs Using Structural Modeling | **Objective:** To investigate measures that will further improve the self and partner protection of occupants of new vehicle designs through structural and restraint system optimization across real world crash scenarios focusing on light-weighting strategies and power train changes. To assess the implications for angle crashes with roadway features.  
**Accomplishments:** Following the approved work plan the contractor has prepared five vehicle models as the basis for the analyses. The baseline simulations of these vehicles for a set of NCAP tests has been completed and documented. Based upon accepted scenarios of future changes to these vehicles, the models have been modified to reflect the various changes (e.g., use of high strength steels to reduce weight). The NCAP tests are being simulated for each variation of the vehicle. Crash impulses from these simulations are then transferred to Madymo models of driver and passenger occupants to determine the likely injuries. The differences between each future variation and the baseline results are then used to project future injuries levels associated with changes to the vehicles. The first round of the analyses will provide a basis for determining the implications of the changes on overall fleet safety. A second phase will focus on the selected types of design changes to determine more specifically how fuel economy can be achieved without compromising safety. |
|   | **Ongoing Analyses and Testing of Improved Infrastructure Barriers (DOS)** | **Objective:** To undertake simulation analyses and testing to improve the design, applicability, constructability, and deployment of previously developed infrastructure barriers for the Department of State (DOS).  
**Accomplishments:** Simulation analyses of combinations of various types of security barriers have been undertaken to determine the combinations and placement requirements for spot hardening of perimeter security. Analyses efforts are underway to develop a secure gate for “picket fence” type perimeter security systems and simulations of security barrier simulations for impacts other than those typically tested. Decisions are pending on FOIL testing of security barriers. |
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| 18 | **Conduct Efforts to Document and Disseminate Research and Support Outreach Efforts (Continuation of Task Order 4)** | **Objective:** To assist the research staff in efforts to 1) generate reports, tech summaries, web materials, and other research products, 2) establish standards for documenting the products under ACAP, 3) support various outreach efforts, and 4) implement a process to track the production of research materials and maintain an ongoing catalog of them.  
**Accomplishments:** Efforts to document NCAC efforts have been intense given the many active task orders. There are now more than 60 documents posted on the NCAC website and more than 20 others nearing completion. A Workshop on Modeling & Simulation of Tire, Suspension, & Steering Components was hosted at TFHRC in Jan 2012 to exchange knowledge on the topic. More than 30 persons participated. |
| 19 | **Update and Maintain Vehicle and Hardware Models and Associated Documentation (Continuation of Task Order 5)** | **Objective:** To maintain and upgrade the various vehicle and hardware models, provide support to users, and manage website.  
**Accomplishments:** Updates to the various NCAC models have been addressed as the need has arisen with some being stimulated by the use of several models in the light weighting projects. The new Yaris FE model has been added to the array and improved documentation for the models have been posted . |
| 20 | **Investigate Causes of Rollover Events for Various Crash Types Using Analytic Methods** | **Objective:** To 1) undertake detailed analyses of rollover crashes to better understand underlying vehicle kinematics associated with causes, 2) evaluate the potential effectiveness of new treatments or countermeasures, and 3) investigate whether current design practices can be improved to reduce the contributions to rollovers. It is expected that analytical and simulation methods will be used to assess these effects for various vehicles and impact conditions. The research will focus on rollovers for passenger cars and sport utility vehicles.  
**Accomplishments:** Efforts to mine the data initiated in the previous effort have continued to capture empirical data for rollover crashes. A work plan has been formulated highlighting the types of rollover crashes that will be analyzed. The intent is to isolate metrics, like roll threshold for highway situations, which will then be related to design and operational parameters to identify disconnects. |
| 21 | **Develop Updated Bogie Test Vehicle for the FOIL** | **Objective:** To model, improve, test, calibrate, and document a reusable bogie vehicle to enhance testing capabilities at the FOIL. The bogie vehicle fabricated under TO 7 will be refined and tested further. Efforts will include development of crushable nose requirements and formulation of testing protocols under MASH. Efforts to model this bogie will be completed to provide a basis for analyses of future bogie tests.  
**Accomplishments:** An FE model of the bogie has been created to identify needed frame reinforcement without changing the inertial character. Efforts to determine the appropriate crushable nose have also been underway with pendulum tests of varying material configurations. Validation testing is planned for the summer 2012. |
| 22 | **Safety Implications of New Vehicle Designs in Roadside Crashes** | **Objective:** The current NHTSA research effort to use FE vehicle models to assess the potential safety implications of emerging changes in vehicle designs in TO 16 will provide a unique opportunity to consider the implications related to roadside hardware. The NHTSA future vehicle models will be used to analyze MASH type angular impacts that will not be looked at under the NHTSA efforts. These simulations will provide an opportunity to consider the implications of changes in the vehicle inertial properties due to alteration of the power plant, the effects of reduced size on occupant risks, and/or the assessment of lateral forces on structural integrity of new materials.  
**Accomplishments:** An analyses matrix has been formulated based upon the various vehicles that were used in the TO 16 efforts to represent future vehicle design configurations. These will be used to simulate MASH impacts into guardrails and concrete barriers in angular crashes. The results will be compared to similar impacts with current vehicles. |
| 23 | Develop and Validate an FE Model for a Mid-Sized Car (with NHTSA) | **Objective:** To develop a detailed vehicle finite element model of a mid-sized car through reverse engineering and then validate the model in accordance with accepted practices to support future crashworthiness analyses related to vehicle and highway safety research.  
**Accomplishments:** A representative mid-sized vehicle has been selected and procured. A series of non-destructive tests on the vehicle have been conducted to capture data for validation purposes and the reverse engineering process has started. Teardown and scanning will take place over the next nine months. It is anticipated that the initial version of the new FE model will be available by September 2013. |
| 24 | Optimization, Documentation, and Demonstration of a Tractor-Trailer FE Model | **Objectives:** The FHWA initiated efforts to develop an FE model of a tractor-trailer vehicle and recently collaborated with NTRCI to enhance and validate the model. The need exists to 1) modify the code for the current tractor-trailer FE model and/or the simulation control parameters to improve the efficiency of simulation runs, 2) develop alternative versions of the tractor-trailer model, 3) document and post the models on the NCAC website, and 4) demonstrate the usefulness of the model for safety studies. The model may also be further validated, if data from tractor-trailer crash tests is discovered or can be obtained from new crash tests.  
**Accomplishments:** Efforts have been undertaken to assess the impact of changing the structural definitions for trailer elements to reduce simulation times. A plan for simulating impacts into various barriers to reflect TL 5/6 tests is being formulated. |
| 25 | Development of an Integrated Structures Model for Occupant Risk Analyses (NHTSA) | **Objectives:** The objectives of this research are to develop and validate an integrated vehicle structure model for occupant risk analysis that is capable of evaluating various interior treatments and restraint systems, and demonstrating the efficacy of the model in representing various crash scenarios and applicability with a range of occupant models. It is expected that a detailed model will be developed to evaluate performance of different occupant models in full frontal, frontal offset, and small overlap impact configurations.  
**Accomplishments:** TO efforts expected to start in October 2012. |