MVFRI RESEARCH SUMMARY
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Analysis of Vehicle Fire Tests – GM/DoT and Others

Based on contracts with
FM Global
Southwest Research Institute

TESTS UNDER THE GM/DOT SETTLEMENT AGREEMENT

Under a contract with MVFRI, the GM/DOT Settlement research program in motor vehicle fire safety was reviewed by a team of fire experts led by FM Global. Of particular interest was the analysis of eleven, highly instrumented burn tests using crashed vehicles. These tests included underhood ignition scenarios and spilled fuel fires of an intensity that could be possible after a crash. Eight of the tests explored the fire growth and spread under a variety of baseline conditions. Three tests were primarily for the purpose of evaluating countermeasures to increase the time for fire to penetrate the occupant compartment. Among the baseline tests there were four vehicles that had been subjected to rear crash tests. One was a passenger car, one was a minivan, and the other an SUV. The fourth type of test was of an intumescent coating that was intended to expand upon exposure to heat and reduce the size of openings into the occupant compartment. The four vehicles from the rear crash tests were subjected to pool fires under the rear of the vehicle. The other four baseline tests were vehicles that had been subjected to frontal crash tests. One of these was a passenger car subjected to a pool fire under the vehicle in the rear. The others were subjected to underhood fires with ignition sources either at the battery location or by the ignition of sprays and pools of mixtures of hot engine compartment fluids. The heat of ignition was from a propane flame located in and below the engine compartment.

Three additional tests were conducted to evaluate countermeasures. The effectiveness of a fire retardant treatment of the HVAC unit was evaluated by tests of engine compartment fires in 2 vehicles with frontal damage. One of the vehicles was tested with the treatment and the other without. The other countermeasure was an intumescent coating on the underbody of the vehicle. The SUV pool fire baseline test was replicated to evaluate this countermeasure.

A list of the tests and vehicles is as follows:

1. 1996 Dodge Caravan-front crash and fire started in the engine compartment;
2. 1996 Plymouth Voyager-rear crash and fire started by igniting a gasoline pool under the vehicle;
3. 1997Chevrolet Camaro-rear crash and fire started by igniting a gasoline pool under the vehicle;
4. 1997Chevrolet Camaro-front crash and fire started in the engine compartment;
5. 1997 Ford Explorer-rear crash and fire started by igniting a gasoline pool under the vehicle;
6. 1997 Ford Explorer- front crash and fire started by igniting a gasoline pool under the vehicle;
7. 1998 Honda Accord-rear crash and fire started by igniting a gasoline pool under the vehicle;
8. 1998 Honda Accord-front crash and fire started in the engine compartment;
9. 1999 Chevrolet Camaro- FR HVAC- front crash and fire started in the engine compartment;

10. 1999 Chevrolet Camaro-non-FR HVAC control-front crash and fire started in the engine compartment;
11. 1999 Ford Explorer undercarriage coated with intumescent paint–rear crash and fire started by igniting a gasoline pool under the vehicle.

An in-depth analysis of these tests was published [Tewarson, October, 2005 Vol I; Tewarson, SAE 1555, April 2005]. The objectives of the subsequent review were to investigate the ignition and flame spread behaviors of engine compartment fluids and plastic components, to assess time to flame penetration into the passenger compartment and to assess the creation of untenable conditions in the passenger compartment.

The analysis found significant differences in the time required for fire to penetrate into the passenger compartment in the front and rear crashed vehicle tests. In the rear crashed vehicle burn tests with ignition of gasoline pools under the vehicle, flame penetration time into the passenger compartment varied between 30 seconds to 3 minutes. For the front crashed vehicle burn tests with ignition in and under the engine compartment, flame penetration time into the passenger compartment varied between 10 to 24 minutes.

Once the flame penetrated the passenger compartment, the environment rapidly became untenable. In some tests, the passenger compartment became untenable before flame penetration. The untenable conditions were due to heat exposure (burns) and exposure to fire products (toxicity and lethality). The time between flame penetration and untenability of the passenger compartment varied from minus 2.5 to plus 3.2 minutes.

The windshield and the bulkhead were the principal ports of entry for the flame spread into the occupant compartment. If the hood remained relatively intact, the fire tended to enter through openings in the bulkhead. The windshield was the principal flame entry port when it was directly exposed to flame as a consequence of openings in the hood near the base of the windshield. Whether the windshield is intact or broken as a result of the crash will also influence the rate of flame spread into the passenger compartment.

The review also showed that some of the plastic or polymeric components in the engine compartment can burn as molten pool fires with high heat release rates and produce CO, smoke, and other toxic compounds - typical of ordinary polymers. Pool fires of the molten plastics are major contributors to the intensity of the fire and contribute to the penetration of fire into the passenger compartment. The fire retardant treatments of the plastics that were tested in the program proved ineffective in delaying fire penetration into the passenger compartment.

After the completion of the FM Global three volume report, a peer review panel was established to review the reports and to briefly summarize the most significant findings [Digges 2007]. These findings include but are not limited to:

1. The heat release rate (HRR) of a material in flaming combustion is a good predictor of its fire hazard but HRR in combination with ignition properties gives a fire propagation index that is the speed at which the material burns in a vehicle fire. Calculations by Quintiere suggest that 10 additional minutes of escape time in a post crash fire could be obtained by reducing the HRR of automotive plastics by a factor of 2 to 4, making them comparable in fire performance to plastics used in electronics and aircraft cabins, respectively.

2. Fire penetration from the engine compartment to the passenger compartment could be delayed by fire-hardening bulkheads, openings, and conduits between the engine and

passenger compartments. Strategies include using fire resistant materials or fire initiated seals around firewall penetrations, less flammable underhood liners, fire suppression and fire containment systems.

3. Fire penetration from a fuel fire under the vehicle into the passenger compartment could be delayed using crash hardening technology, fire blocking fabrics, fire/crash hardening of the fuel tank, fire suppression systems, etc.

The references listed below include the related reports dealing with the fire properties of underhood materials and fire testing methods [Tewarson, October 2005, Vol II and Vol. III; Tewarson, SAE 1560, April 2005].

DATABASE OF FULL-SCALE CALORIMETER TESTS OF MOTOR VEHICLE BURNS

The objective of the research was to examine the worldwide publications of motor vehicle fire tests and document the results, particularly the heat release rate. Eleven series of tests were examined and documented in a database. The test series and publications were as follows:

Series 1 Mangs, J. and O. Keski-Rahkonen, "Characterization of the Fire Behavior of a Burning Passenger Car. Part I: Car Fire Experiments." *Fire Safety Journal*, Vol. 23, 1994, pp. 17-35.

Series 2 Steinert, C., "Smoke and Heat Production in Tunnel Fires." in *International Conference on Fires in Tunnels,* Swedish National Testing and Research Institute, Borås, Sweden, 1994, pp.123-137.

Series 3 Shipp, M. and M. Spearpoint, "Measurements of the Severity of Fires Involving Private Motor Vehicles." *Fire and Materials, Vol. 19*, 1995, pp. 143-151.

Series 4 Joyeux, D., "Natural Fires in Closed Car Parks - Car Fire Tests." CTICM Report No. INC-96/294d-DJ/NB, CTICM, Metz , France , 1997.

Series 5 Van Oerle, N., A. Lemaire, and P. van de Leur, "Effectiveness of Forced Ventilation in Closed Car Parks (in Dutch)." TNO Report No. 1999-CVB-RR1442, TNO, Delft , the Netherlands , 1999.

Series 6 Steinert, C., "Experimental Investigation of Burning and Fire Jumping Behavior of Automobiles (in German)." *VFDB,* Vol. 49, pp. 163-172, 2000.

Series 7 Stroup, D., L. DeLauter, J. Lee, and G. Roadermel, "Passenger Minivan Fire Tests," FR 4011, National Institute of Standards and Technology, Gaithersburg, MD, 2001.

Series 8 Santrock, J., "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 3: Propagation in an Engine Compartment Fire in a 1996 Passenger Van."NHTSA-998-3588-119, General Motors Corporation, Warren , MI , 2001.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 4: Propagation of an Underbody Gasoline Pool Fire in a 1996 Passenger Van.”

NHTSA-1998-3588-143, General Motors Corporation, Warren , MI 2002.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 6: Propagation of an Underbody Gasoline Pool Fire in a 1997 Rear Wheel Drive Passenger Car.” NHTSA-1998-3588-158, General Motors Corporation, Warren , MI , 2002.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 7: Propagation of an Engine Compartment Fire in a 1997 Rear Wheel Drive Passenger Car.”

NHTSA-1998-3588-178, General Motors Corporation, Warren , MI , 2002.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 9: Propagation of a Rear-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle.”

NHTSA-1998-3588-188, General Motors Corporation, Warren, MI , 2002.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 10: Propagation of a Mid-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle.”

NHTSA-98-3588-189, General Motors Corporation, Warren, MI , 2002.

Santrock, J., “Demonstration of Enhanced Fire Safety Technology-Fire Retardant Materials-Part 1: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing an HVAC Module Made from Polymers Containing Flame Retardant Chemicals.” NHTSA-1998-3588-190, General Motors Corporation, Warren , MI , 2002.

Santrock, I. , “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 12: Propagation of an Underbody Gasoline Pool Fire in a 1998 Front-wheel Drive Passenger Vehicle.” NHTSA-98-3588-201, General Motors Corporation, Warren, Ml, 2003.

Santrock, J., “Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 13: Propagation of an Engine Compartment Fire in a 1998 Front-Wheel Drive Passenger Vehicle.” NHTSA-98-3588-203, General Motors Corporation, Warren , MI , 2003.

Santrock, J. and D. LaDue, “Demonstration of Enhanced Fire Safety Technology - Part 3: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing an Intumescent Paint on its Underbody.” NHTSA-98-3588-204, General Motors Corporation, Warren , MI , 2003.

Series 9 Joyeux, D., J. Kruppa, L. Cajot, J. Schleich, P. Van de Leur, and L. Twilt, "Demonstration of Real Fire Tests in Car Parks and High Buildings," Final Report. Contract No. 7215 PP 025, CTICM, Metz , France , 2002.

Series 10 Shintani, Y., N. Kakae, K. Harada, H. Masuda, W. Takahashi, "Experimental Investigation of Burning Behavior of Automobiles." 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629, 2004.

Series 11 "CTICM Fire Tests on Cars." Personal communication from J. Kruppa, CITCM, Metz , France , 2004.

Only four of the eleven test series provided all the information that was needed for the analysis. The purpose of the proposed work was to re-examine the results of the eleven test series, and to request needed data from the authors and perform an analysis based on the complete data sets.

The heat of combustion (MJ/kg) for 11 tests with adequate data ranged from 15.2 to 31.0. The author noted that there was a general rise in the heat of combustion with the year of publication. However, there was insufficient data to confirm this trend.

The burn period was defined as the time duration for the heat release rate to be greater than 10% of the peak value. The burn duration varied from less than 20 minutes to more than 70 minutes.

The database is available at www.mvfri.org.

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Tewarson , A., "Thermophysical and Fire Properties of Engine Compartment Fluids", SAE paper 2005-01-1560, April 2005. Available at www.sae.org