Review of Ford Motor Company's Test of FIRE Panel™ in a Simulated Rear Collision Scenario

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Prepared for:

FIRE Panel™ Vehicular Fire Protection Systems

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1.0 EXECUTIVE SUMMARY

Ford Motor Company conducted a single test of the FIRE Panel™ technology to evaluate its performance in suppressing fires in police vehicles resulting from rear end collisions. The flawed test design and execution was not a reasonable evaluation of the technology. This report describes many of the problems and limitations of the testing.

The FIRE Panel™ system consists of ABC dry chemical fire suppression powder encased inside of a custom-molded plastic assembly. The powder is contained within cavities located inside the molded plastic panel. The plastic panel is adhered to the outside surface of the fuel tank and is designed to fracture and release the dry chemical when the fuel tank is impacted during a rear-end collision. When the fuel tank is pushed forward into the axle and other structures, the impact between the fire panel mounted on the front face of the fuel tank and the axle/differential assembly causes a release of dry chemical.

The single test conducted by Ford Motor Company on the FIRE Panel™ product imposed an unrealistic and invalid set of test conditions. The test conditions were arbitrary in many respects and there were numerous problems in test design, arrangement and execution as described in the report. While many potential problems with the test are identified and discussed in this report, three critical and obvious testing errors dominate the results. The arrangement of the simulated fuel tank and axle assembly, and the towing of this assembly at 30 mph prior to the simulated impact in order to simulate post-crash displacement of the target vehicle, was unrealistic and had a substantial negative effect on the test results. The induced 30 mph airflow at the time of panel actuation artificially reduced the suppressant cloud concentration at the ignition location. This effect does not occur to this extent in actual crashes since, in most cases, the target vehicle is at rest at the moment of impact and during the release of the suppressant powder. The impact of this effect was exaggerated by the delay in actuating the ignition source. A second major problem lies in the simulation of the fuel tank/axle assembly impact. The test simulated this impact by accelerating the simulated axle assembly into a stationary fuel tank as opposed to the expected scenario of the FIRE Panel™/fuel tank assembly being pushed into the differential/axle assembly. Since the FIRE Panel™/fuel tank assembly was not moving forward during impact, as it would be in a rear end collision scenario the test did not realistically reproduce the discharge and dispersion of dry chemical from the FIRE Panel™. Finally, the use of a model rocket motor as an ignition source is obviously unrealistic, and especially critical in the evaluation of a local application aerosol fire-extinguishing agent. The effect of the model rocket motor in diluting and displacing the suppressant cloud at precisely the location where ignition is expected was critical to the outcome of the test and the effect obviously does not occur in any real crash scenario.

Given the list of problems encountered with this test it is not clear why only one test was conducted. In general, it is not possible to evaluate a product against a realistic set of scenarios and conditions with a single test. This fundamentally flawed single test was not a reasonable evaluation of the FIRE Panel™ technology.

2.0 INTRODUCTION

Hughes Associates, Inc. was requested by FIRE Panel™ to review a test of the FIRE Panel™ conducted by Ford Motor Company in November 2002. Hughes was requested to review the test arrangement and protocol with respect to its validity in terms of evaluating the performance of the FIRE Panel™ technology.

There was no formal report of the test available for review. Details of the test arrangement and protocol were established from the videotape record of the tests, from correspondence of both Ford and FIRE Panel staff related to the test plan and conversations with FIRE Panel™ staff that witnessed the test.

Initially a series of tests were planned to evaluate the technology; however only a single test of the product was conducted. The scenario for the test conducted by Ford is that of a vehicle at rest struck in the rear by another vehicle. The collision results in pushing the fuel tank into the differential and rear axle assembly and other structural elements. This impact may result in the release of liquid gasoline; gasoline vapor may then be ignited by ignition sources occurring as a result of the collision. These ignition sources include metal heated by rapid deformation & tearing or friction sparks caused by metal parts, heated exhaust system components and electrical sparks or heating. In a real scenario, the vehicle is struck, is accelerated from rest to a speed of approximately 30 mph and displaced a distance of approximately 100-150 feet forward. This was not simulated directly in the Ford test reviewed.

The FIRE Panel™ system consists of ABC dry chemical fire suppression powder encased inside a custom-molded plastic assembly. The powder is contained within cavities located inside the molded plastic panel. The plastic panel is adhered to the outside surface of the fuel tank and is designed to fracture and release the dry chemical when the fuel tank is impacted during a rear-end collision. In this case, where the fuel tank is pushed forward into the axle and other structures, the impact between the fire panel mounted on the front face of the fuel tank and the axle/differential assembly causes a release of dry chemical.

The FIRE Panel assembly is designed to release an adequate concentration of dry chemical to prevent flame propagation through the gasoline vapor/air mixture, which develops as the gasoline leaks or is ejected from the fuel tank. The ability to suppress the development of a flame front in the pre-mixed gasoline vapor and air mixture is often called inerting.

The FIRE Panel™ takes advantage of the extremely efficient flame suppression and extinguishing properties of dry chemical powders, which are well known. See for example:

> Lake, James, "Chemical Extinguishing Agents & Application Systems," Fire Protection Handbook, Cote, A., *et al* eds, 19th edition, NFPA, Quincy, 2003, (pp 11-77, 11-89).

Additional references may be found in the Bibliography section of this report.

The important design requirements of an effective dry chemical fire suppression, inerting or extinguishing system are as follows:

1) Generate a cloud or suppression volume with a sufficient concentration of dry chemical to inert an environment or extinguish a flame;
2) Generate a cloud or suppression volume of sufficient size or volume to inert the flammable region of a flammable gasoline/air mixture; and
3) Maintain this suppression volume for sufficient time to preclude ignition of the gasoline, consistent with the scenario. In this case, ignition sources arise near the

front of the tank during and immediately after impact of the tank with the differential/axle assembly.

Any test of the technology should be performed in a way that ensures the important physical aspects of the powder release and dispersion, powder cloud dissipation, fuel quantity, fuel vapor/air mixture cloud formation and ignition source are representative of the scenario being evaluated.

3.0 FORD TEST ARRANGEMENT

The arrangement and test sequence of the FIRE Panel™ test conducted by Ford in November 2002 is based on a review of the videotapes of the test, notes and conversations held with FIRE Panel™ representatives present at the tests, and a review of the transcript of a deposition taken on February 6, 2003, of Joseph Dierker, a Ford employee, which in part, described the test.

The test arrangement consisted of a simulated target vehicle equipped with a fuel tank and a mechanism designed to simulate the impact of a differential housing assembly into the fuel tank, primarily for the purpose of activating the FIRE Panel™. This assembly was placed into the target vehicle as shown in Figure 1. According to Ford, the impact choice was intended to replicate the kinetic energy of a 108 lb projectile impacting at a speed of 30 mph into the fuel tank. The actual speed at impact with the FIRE Panel™/fuel tank was expected by Ford to be a minimum of 15-25 meters per second. The alignment of the impact device with the FIRE Panel™ /fuel tank assembly was incorrect relative to the expected impact geometry of a fuel tank into a differential housing/axle assembly. In the Ford test, the impact device aligned with an opening cut out of the FIRE Panel™. In addition, the area of impact in the test was small with respect to a real-world expected case, resulting in less powder being released on impact.

Gasoline was spilled from a separate fuel storage tank across the top and protected face of the fuel tank to simulate leakage and dispersal of fuel during a crash. The fuel storage canister was pressurized to approximately 40 psi. According to Ford, this over-pressurization was done to simulate the ejection of fuel from the fuel tank impacted by the differential/axle assembly during a rear collision. The basis of this over-pressurization, the fuel spill rate and the spilled fuel quantity (1.5 gal) is unknown. Note that the simulated fuel tank did not leak or dispense fuel following the impact of the simulated differential housing, but was dispersed from a separate fuel container as described above.

The ignition source used for this test was an Estes model B 6-6 model rocket motor, which had a burning duration of approximately .8 seconds.

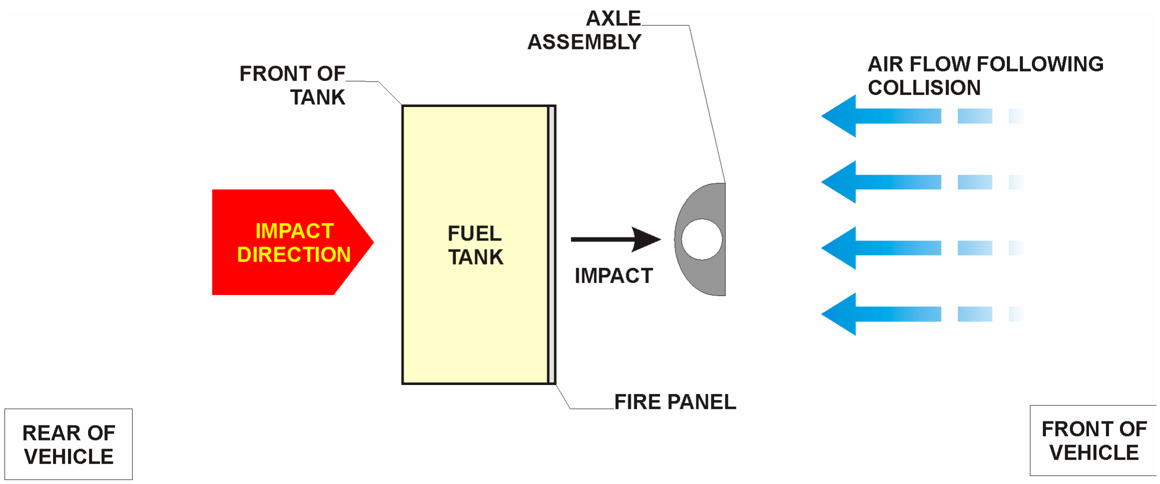

Fig. 1 - Normal Impact Schematic (Side View)

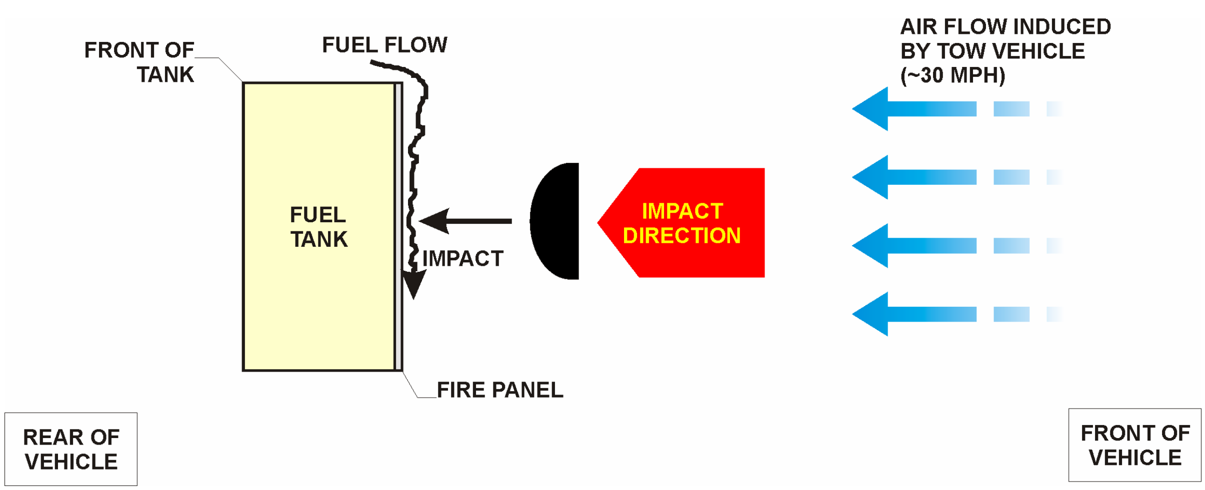

Fig. 1 - Ford Test Schematic (Side View)

4.0 TEST SEQUENCE

4.1 Planned Test Sequence

The planned test sequence was as follows:

1. Begin towing test vehicle
2. Achieve steady towing speed of 30 mph
3. Activate impacting device into fire panel
4. Begin decelerating target vehicle
5. Begin fuel flow simultaneous with panel activation; with a fuel flow duration of 3 seconds
6. Simultaneously ignite rocket motor ignition source (<1 second duration), Estes model B 6-6
7. Stop tow vehicle approximately 3 seconds after impact device initiation

4.2 Actual Test Sequence

The actual test sequence as determined from videotapes and witnesses as follows:

1. Vehicle towed to a speed of approximately 30 mph
2. T = 0 FIRE Panel™ activated
3. T = 1 second; begin fuel spill
4. T = 3-4 seconds; ignition of rocket motor, Estes model B 6-6
5. Fuel flow continued for approximately 1 minute (estimate)
6. Vehicle stopped

In addition, just prior to the test, a quantity of gasoline was inadvertently spilled into the passenger compartment of the test vehicle and onto the fuel tank. The spill was wiped down with rags.

5.0 ANALYSIS

5.1 Fuel Tank Arrangement

In the typical accident scenario, the target vehicle is struck from the rear. The collision forces the fuel tank into the differential housing and axle assembly. This basic geometry was preserved in the Ford test except that the simulated axle/differential housing was forced into the fuel tank from the front of the vehicle.

In the Ford test scenario, the panel faces the airflow induced by the towing of the test vehicle; hence the dry chemical cloud is subjected to the induced flow pattern on the windward side. In a normal collision scenario the target vehicle is at rest, not moving at 30 mph. This artificial induced airflow at the time of panel actuation greatly increases, in an unrealistic way, the rate of dissipation of the dry chemical cloud, since normally the agent cloud in the immediate vicinity of the fuel tank is subjected to zero airflow at the time of actuation. This direct immediate exposure to a 30 mph air stream as the agent is released significantly negatively affects the dispersion of the powder. The vehicle being towed with its front wheels off the ground aggravates the negative and artificial effect of the 30 mph airflow.

A more important deficiency of the test arrangement lies in the post-impact release and dispersal of the dry chemical from the ruptured FIRE Panel™. In an actual rear-end collision scenario, the fuel tank and FIRE Panel™ are accelerated toward the front of the vehicle. The fuel tank/FIRE Panel™ assembly is moving forward as it strikes the differential/axle assembly and other vehicle structures. As the FIRE Panel™ strikes these structures and ruptures, the dry chemical is discharged in a cloud moving forward. This is shown in Figure 2 as the "Normal Impact Schematic". In the Ford test scenario, the fuel tank/FIRE Panel™ assembly is stationary with respect to the impact device and the impact device is accelerated rearward into the fuel tank. In this case the powder is not being accelerated forward but is at rest, hence the dispersal of the powder is not nearly as great and relatively less powder is dispersed toward the front of the vehicle (an exaggerated Schematic view of this behavior is shown in Figure 2). This results in a smaller volume and lower concentration of dry chemical in a real rear-end collision scenario. This is not only important immediately after impact, but during the time the target vehicle is accelerated forward following impact, since the target vehicle is being moved in the direction of the more extensive dry chemical cloud. In summary, in a rear-end collision scenario, the powder, when released, has significant forward momentum resulting in larger quantities of dry chemicals being released and being dispersed forward into the ignition zone and the direction of target vehicle motion. In the Ford test scenario, the panel/powder had no forward momentum resulting in less powder being released over a smaller volume. These two behaviors are illustrated schematically and in an exaggerated fashion in Figure 2.

In addition to the artificial airflow pattern, it appears that the geometry in and around the front of the fuel tank is not representative of the open volume expected in a crash scenario. This may have negatively impacted the concentration of dry chemical powder in the vicinity of the fuel leak and ignition source.

It is difficult to ascertain from the video primarily because the tests were conducted at night without lighting, but it appears there is an opening directly above the front face of the fuel tank; if such an opening were present in the test article this would also unrealistically impact the dilution and dispersion of the suppression agent.

The geometry of the impact device with respect to the impact location and the size of the impact area on the fuel tank/FIRE Panel™ assembly are incorrect.

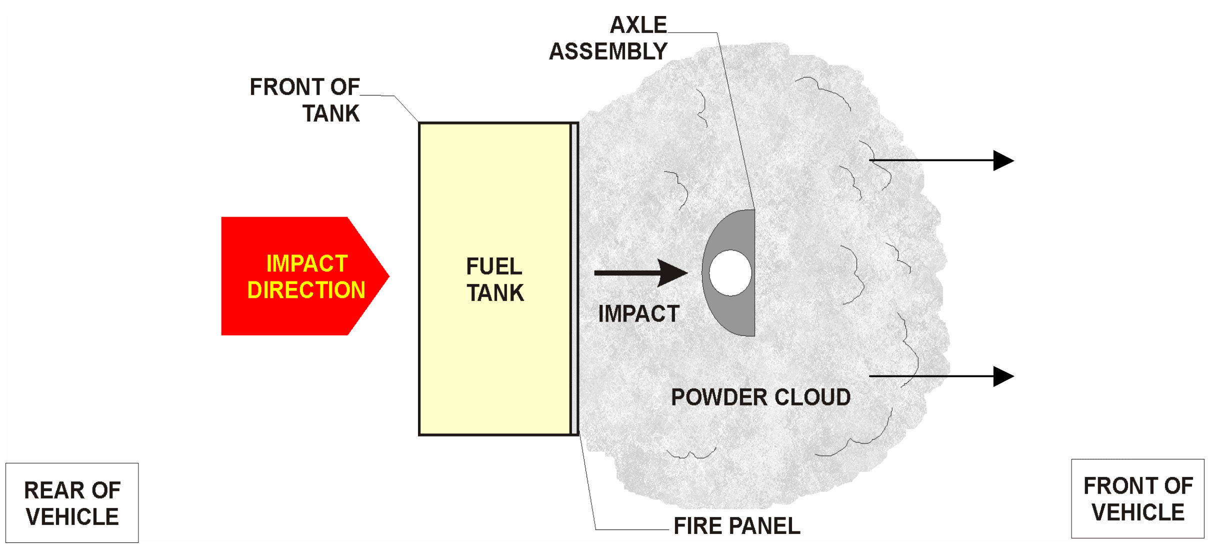

Fig. 2 - Normal Impact Schematic (Side View)

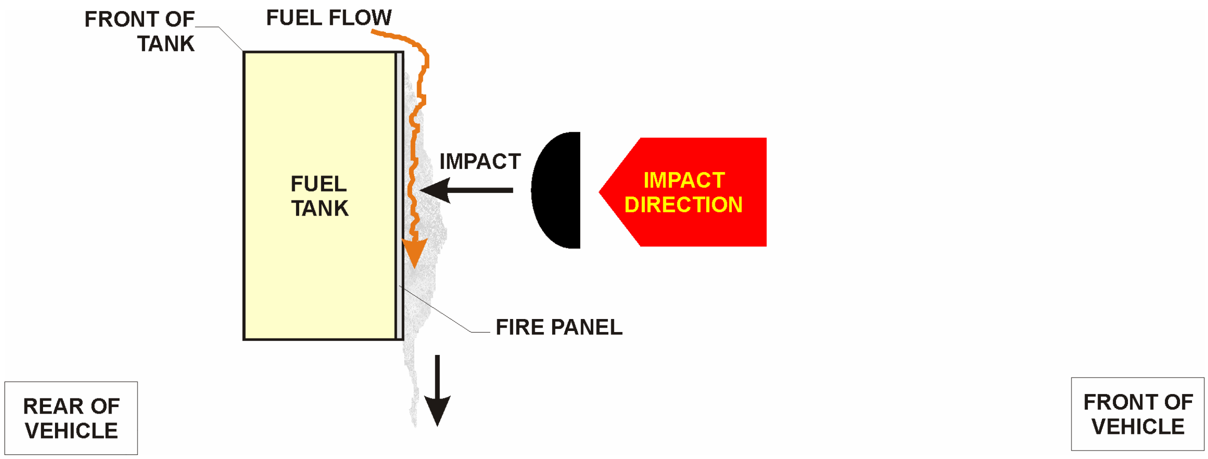

Fig. 2 - Ford Test Schematic (Side View)

5.2 Fuel Dispersal and Spillage

In the subject test, fuel was not ejected or spilled from the impacted fuel tank. Gasoline was sprayed and spilled from a container located above the fuel tank. The container was pressurized to increase the fuel flow rate. There are two potential problems with this arrangement as it relates to the performance of the FIRE Panel™ product in the rear collision scenario.

A. Fuel Dispersal Method

There appears to be no scientific basis for the selection of the fuel dispersal method. Spraying liquid gasoline across the front face of the fuel tank results in a challenging, but not necessarily realistic, initial condition for evaluating fire suppressant performance. It is important to simulate the approximate size and extent of the post collision fuel leak as a function of time. It also appears from the videotape that fuel leakage occurs for approximately one minute after the test vehicle was stopped.

B. Fuel Quantity

The initial test plan called for dispersal of 40 ounces of fuel in 3 seconds. The test was conducted using 192 ounces of fuel, which appeared to continually spill for at least one minute after the target vehicle came to rest. It is not clear whether or not this inconsistency resulted in an unrealistic or invalid test condition. Again, the basis for selection of the fuel quantity is unclear and appears arbitrary.

5.3 Ignition Source

The ignition was planned to be an Estes B-6 rocket motor, mounted in the top of the car rear-axle cavity region, in front of the fuel tank, aimed at the frontal fuel tank area. According to one witness the rocket motor was located approximately one inch from the tank with its exhaust pointed at the tank/FIRE Panel™ surface.

There are several serious problems with the use of this ignition source. The most important issue is the ignition source strength. The total thermal energy of the rocket motor is in the range of 10,000 Joules as compared to a typical wooden match in the range of 200 J. The energy release rate of the model rocket motor is approximately 10,000 Watts, well in excess of any ignition source resulting from mechanical heating or sparking or expected electrical sources. It is also well known that the critical inerting concentration for any gaseous or particulate suppression or inerting agent is a function of the ignition energy. For this reason, inerting concentrations are established based on standardized electrical spark energy sources. These ignition sources are in the range of 30 W versus the 10,000 W estimated power of the rocket motor. Inerting concentrations based on these spark energies have been found to be effective across a wide range of applications and ignition sources including mechanical sparks and electrical arcs. The use of an excessively energetic source such as a solid rocket motor may have imposed an unrealistic, invalid and unfair condition during the test.

The second problem with the use of the model solid rocket motor is in its potential to substantially perturb the flow field into and around the suppressant cloud. Rocket motors, by design, create large volumes of hot exhaust gas. In the test condition this hot exhaust gas displaces the suppressant and the momentum of the rocket exhaust plume prevents the dry chemical suppressant cloud from dispersing into the ignition region. The rocket motor exhaust physically displaces the dry chemical suppressant cloud at precisely the location it needs to be - at the point of ignition. This poses a critical and very substantial unrealistic condition on the effectiveness of any gaseous or aerosol suppressant.

A third problem is related to the physical size of the ignition region. In an actual crash scenario the ignition sources are high temperature but physically small ignition points, such as sparks or electrical arcs. The energy output and size of the rocket motor and its high temperature exhaust plume discussed above, used during the test, may have resulted in a much larger ignition source then would occur during a real crash scenario. The size of the initial unsuppressed ignition kernel is key to the effectiveness of any gas phase fire suppressant. Reasonable evaluation of gas phase suppressants should include realistic and reasonable ignition sources. This is done in standard practice for explosion inerting using high-energy electrical arcs.

A fourth problem is that temperatures in the rocket motor exhaust are substantially higher than gasoline-fueled diffusion flames. This may have resulted in decomposition of the dry chemical in the region of the rocket exhaust. It is not clear whether this had any effect on the results of the test but it is clear that expected real-world ignition sources are not at a high enough temperature to result in decomposition of the suppressant.

The most significant problems with the ignition source are the extremely unrealistic energy release rate and the influence of the rocket motor exhaust flow in diluting or eliminating the suppressant in precisely the location that ignition would occur. None of these effects are expected in any real crash scenario.

5.4 Pre-Test Conditions

It was reported that gasoline spilled into the passenger compartment immediately prior to running the test. The size of the spill is unknown. The quantity of residual gasoline or gasoline vapor is also unknown. To the extent that any fuel liquid or vapor remained at the time of the test, the results of the test should be considered suspect. The longer time available for any liquid fuel or fuel film to vaporize, the higher the probability that it had a negative and unintentional effect on the test results.

6.0 SUMMARY

The test conducted by Ford Motor Company on the FIRE Panel™ product imposed an unrealistic and invalid set of test conditions. While many potential problems with the test have been identified, three issues dominate the results. The induced 30 mph airflow at the time of panel actuation artificially reduced the suppressant cloud concentration, which was exaggerated by the delay in actuating the ignition source. The stationary (with respect to the impact device)

FIRE Panel™/fuel tank assembly did not realistically reproduce the discharge and dispersion of dry chemical from the FIRE Panel™. The ignition source type and strength are completely unrealistic. The use of the rocket motor igniter is especially critical for a local application aerosol or gaseous fire-extinguishing agent, especially with respect to the motor exhaust diluting or displacing the suppressant cloud at precisely the location where ignition is expected. There is no analog of this effect expected in any real crash scenario.

Given the list of problems encountered with this test it is not clear why only one test was conducted. In general it is not possible to evaluate a product against a realistic set of scenarios and conditions with a single test. Only conducting a single test compounds the lack of technical or scientific basis for the selection of many of the test variables. Clearly this single test was not a reasonable evaluation of the FIRE Panel™ technology.

There will always be some debate relative to the relevance or realism of any test protocol but this test involved such basic flaws in its design and execution that it should not be considered a reasonable evaluation of the performance of the FIRE Panel™ product.

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About Hughes Associates Inc.

Hughes Associates, Inc. (HAI) is a fire protection engineering, research and development company founded in 1980. Our technical staff of over 130 engineers and scientists has broad expertise in fire science and fire protection technology. Our focus has been and remains the development and application of new technology to fire protection problems. Our clients include Federal government agencies including DOD, DOT, EPA, NIST, and NASA, among many others, as well as state and local governments. Our private sector clients include architects, attorneys, engineers, developers, process industries, and all sectors of manufacturing, as well as telecommunications, financial and insurance services companies.

For the past 24 years, we have been actively engaged in research, development and engineering on a wide range of fire suppression technologies. These include:

- Advanced firefighting foam technologies
- Gaseous fire extinguishants
- Fine water mist fire suppression systems
- Advanced fire detection technologies
- Dry chemical agents
- Delivery systems and particulate aerosol technology

We have conducted thousands of full-scale tests of fire suppression technologies for the military, government and commercial sectors. Applications of these technologies have included aircraft, ships, rail and ground transportation systems, as well as buildings across a wide range of specialized applications. In addition to fire suppression and detection technology, we are recognized experts in the application of mathematical modeling technologies, material flammability and fire resistance, and fire hazard assessment and risk analysis.

Additional information about HAI can be found at www.haifire.com.