IMPROVEMENTS IN FIRE PROTECTION FOR ARMORED AND TACTICAL VEHICLES

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INTRODUCTION

The ongoing military activities in Iraq and Afghanistan have led the military to the conclusion that the Army was not ideally structured, prepared, or conditioned for the challenges posed by enemies employing irregular warfare tactics which included: Improvised Explosive Devices (IED), Molotov cocktails and other ways to ignite fuel fires, incendiary hand-grenade charges, and concealed explosive/incendiary packages.

New generations of significantly improved RPG's and Anti-tank missiles with enhanced penetration capability and extended firing range are operated by infantry or small groups of soldiers from concealed shelters, or remotely by radio communications. Sophisticated explosives and sticky incendiary materials coupled with conventional propellant and explosives mixtures, create more hazardous and lethal weapons that not only penetrate the armored vehicle causing havoc and secondary fires in the crew or engine compartments, but also stick to its surface igniting the vehicle's external equipment and wheel bay and preventing the rescue of the trapped soldiers from the vehicle.

A reexamination of US strategy has yielded a myriad of changes aimed at developing the capabilities required to succeed in small wars or wars fought in the midst of civilian population. The Army is in the midst of its most radical reorganization since World War II. By converting from a division-based structure to one centered on a brigade-sized unit of action that possesses organic combat, combat support, and sustaining capabilities, thus being able to deploy more rapidly and fight upon arrival. Light tactical and fast-deployed vehicles, special trucks and tractors, logistics and engineering vehicles are part of the modern units arsenal engaging the enemy in its territory.

The enemy's use of guerrilla warfare tactics coupled with the heavy traffic of large numbers of tactical wheeled vehicles that provide logistics, security, and command and control in danger areas, led the Army to recognize the importance of forces protection, and to establish the MRAP programs to introduce new highly surviving vehicles on the battlefield.

The Mine Resistant Ambush Protected (MRAP) vehicles include the RG 33L and CAIMAN which are based on the well proven reliable Family of Medium Tactical Vehicles (FMTV) platform and the combat-proven Low Signature Armored Cab (LSAC) and provide an enhanced degree of mission flexibility offering both improved

Figure 1. *Typical Crew and Engine Compartments AFES*

survivability and more volume under armor than any other mine protected vehicle, incorporating the latest designs in protecting against improvised explosive devices.

Lessons learned in the battlefield theater had generated major efforts to enhance the physical vehicle protection and the fire detection and extinguishing systems upgrading. The effort to provide fire survivability addressed several areas including:

- Soldier Survivability
- Vehicle Survivability
- Safety
- AFE System Survivability

The effort was to improve current performance and to introduce Automatic Fire Extinguishing System (AFES) to the different types of vehicles, tailored to their structure and needs. These systems are designed to provide suitable detection and extinguishing capabilities that address the individual threats and the extinguishing challenges to save human life, prevent skin burns, enable soldiers to save themselves or be rescued from disabled vehicle, and enhance vehicle survivability and continued operation on the battlefield.

SOLDIER SURVIVABILITY

In a combat or hazard zone, the vehicle and its system design should enable the troops to stay in the vehicle and to be better protected from enemy fire than the threats that may result in unwanted egress that will expose the troops to enemy fire (life threatening).

For troops to stay inside a vehicle hit by IED, RPG, or when fire may occur, they must be confident that the protection they are being provided with is safer than it is outside of the vehicle.

A fuel fire can rapidly grow to engulf areas that are covered with fuel and can then produce a high intensity of heat radiation, smoke, and the risk of becoming a catastrophe.

Automatic Fire Extinguishing System (AFES) cannot protect the troops if it does not detect a fuel fire at all or detects it very late when it engulfs large portions of the vehicle.

The extinguishing process can produce very irritant decomposition products (mainly HF) proportional to the speed and efficiency of extinguishment that may affect the soldiers in the vehicle.

For troops to stay inside a vehicle hit by an IED or RPG resulting in fires, the fires must be rapidly and efficiently extinguished by the Automatic Fire Extinguishing System (AFES). If not:

- Troops who are able to egress will do it however they can and as fast as they can.
- Troops who are wounded or cannot egress may be injured or even die from exposure to toxic gases or flames.

Troops need to be protected against both explosive and slow growth type fires.

Most MRAP combat fires are as a result of an IED causing slow growth type fires.

- Slow growth, secondary fires are usually a result of burning fuel, engine transmission hydraulic fluids, steering fluids and tires.
- A slow growth fuel fire that develops in a few seconds after an IED event can be uncontrollable if not extinguished quickly.

The multiple threats posed by fires developing on and under the external surface of military vehicles require special fire detection and suppression measures. In many cases, fuel tanks sustain direct hits from missiles, RPG's or hidden explosives, spraying fuel all over the vehicle's surface engulfing it in flames. The fuel spill under the vehicle may further ignite and spread to the wheel bay and tire area causing a major fire and potentially, even an explosion. Even if the fuel tank remains intact, the impact of the modern and improvised incendiary weapons and missiles on the vehicle external surface may ignite flammable equipment stored on the vehicle's outer compartments causing a major fire that if not detected and suppressed in time, could destroy the entire vehicle.

SOLDIER SAFETY

All types of fuel fires must be rapidly addressed to provide conditions that will not result in any risk to the troops or loss of confidence that may later result in unwanted egress from the vehicle.

Fires must be suppressed fast and efficiently to prevent skin burns and formation of high concentration of poisonous irritant decomposition products like HF, CO, HCN etc.

No physical impact (pressure or blow) on the crew during extinguishing agent discharge (particularly for personnel sitting next to or in front of the discharge nozzle).

The US Army has reviewed and refined its requirements for fire detection and suppression systems for the Up-Armored HMMWV (M1114), the MRAP, and the JLTV vehicle according to the present battlefield threats.

AFES SURVIVABILITY

In some cases, the combat vehicles AFES are being rendered inoperative by the explosion, penetration, or fire.

Harnesses, connectors, control box, etc could be damaged by fragments or fire before they manage to activate the cylinders.

This may be the result of excessive time lag between the hit or initiation of fire and the time it takes for the system to provide an activation signal to the cylinder.

In the HMMWV and the MRAP, the PM 3 detectors are connected to the control box and to one another in serial connection. In the event of a hit, fire, or explosion, the fragmentation and blast can cause a short or open circuit that will result in incapacitation of the detectors thus rendering the system inoperative.

Until the Iraq war, these vehicles were not protected by any AFES system. They are currently being upgraded with an automatic engine and crew and cargo compartment AFES systems to protect them from intentionally caused and rapidly developing fuel fires.

Future combat vehicles are being considered in order to address the identified vulnerabilities of the modern battlefield. The JLTV family of vehicles draws special attention from both the military, and vehicle and survivability systems developers.

The future family of vehicles will comprise five armored versions, ranging from infantry combat vehicles, command vehicles, reconnaissance, and armored utility vehicles.

Specifications defined by the services for the JLTV family of vehicles address current capabilities gaps, to increase force protection, survivability, fuel-efficiency, capacity, maneuverability and automotive safety balanced with the total cost of ownership. Vehicles also must meet current weight and dimension requirements for transportability aboard ships and aircraft. In general, JLTV is expected to provide the U.S. Army and Marine Corps with a family of more survivable vehicles and greater payload than the current HMWWV.

The future family of vehicles will comprise five "Mission Role" variants: the Combat Tactical Variant, the Command and Control Variant, the Utility Variant, the Light Infantry Squad Carrier Variant, and the Reconnaissance Variant. The vehicle family will also include compatible trailers.

JLTV design will include a basic armor protection package as well as provisions to accommodate an additional add-on armor kit. The vehicle's power plant will supply power for all on-board electronic components to enable continuous network-enabled operation. The engine will provide the primary source of electrical power. The power plant will also be required to provide external power for dismounted users, during extended silent watch. Satisfying these design issues, meeting transportability and mobility requirements, and making this an affordable family of vehicles, will require the use of innovative technologies and design strategies.

In the past year, several variants of new Mine Resistant Ambush Protected (MRAP) vehicles were supplied to the US Marine Corps, incorporating the latest safety and survivability systems to ensure troop welfare on the battlefield.

The Mine Resistant Ambush Protected (MRAP) vehicles include the RG 33L and CAIMAN, which are based on the well-proven reliable Family of Medium Tactical Vehicles (FMTV)

platform and the combat-proven Low Signature Armored Cab (LSAC). These provide an enhanced degree of mission flexibility offering both improved survivability and more volume under armor than any other mine protected vehicle, incorporating the latest designs in protecting against improvised explosive devices.

MRAP II AFES PERFORMANCE SPECIFICATION

The MRAP vehicle shall be equipped with Automatic Fire Extinguishing Systems (AFES) for the crew area, engine compartments, fuel tanks (passive extinguishment), and cargo compartment if not isolated from the crew area. The systems shall address slow growth and rapidly developing fuel fires generated by any of the explosive effects.

The systems shall be able to extinguish Petroleum, Oil, and Lubricant (POL) fires before crewmembers are incapacitated or significant vehicle damage occurs.

Removal of any individual fire sensor shall not render the remaining of the system inoperative.

In these modern armored vehicles, the advanced troops survivability is obtained through blast-resistant seating technology, transparent armor, and specially designed Automatic Fire Suppression Systems (AFSS) protecting both engine and troop compartments. The crew compartment system is capable of detecting and suppressing all possible types of fires, i.e., small or large, slow or rapidly growing, limited in area or widely spread, as well as fuel explosions which are likely to occur during combat or training service of these military vehicles. The system protects against combat-initiated and slow-growth fires, featuring high-speed optical detection in less than 3 milliseconds, explosion suppression within 150 milliseconds, multiple ultra fast extinguishing agent discharge and dispersion. Control electronics provide system activation, self and built-in test capabilities, and system monitoring. System components are robust, comply with the latest Mil-Specs and provide for a highly reliable free of false alarm system. In the engine compartment, the system has the capability of detecting fire and overheat, and of successfully extinguishing fuel fires.

SURVIVABILITY ON THE MODERN BATTLEFIELD

When a kinetic or a chemical energy (HEAT) ammunition round penetrates a vehicle, a fuel oil or other hydrocarbon spray in the vehicle will be ignited by the high intensity of heat and will cause the creation of an inferno inside the crew or engine compartments. It is the uncontrolled growth of explosion and resulting fire that causes the most damage, injury, and death in combat vehicles, often resulting in catastrophic destruction.

Today's weapons used against military vehicles are not limited to traditional missiles like guided missiles (ATGM), shoulder fired anti-tank rockets, recoilless rifles, mortars, and artillery, since the recent world conflicts- terrorist activities have created new threats and challenges that need to be addressed.

The guerilla-type of war has added to their tool bag fire threats of a rapidly approaching fire that hits the vehicle and fuel tank causing a pool fire. Some of the weapons used by the enemy are Improvised Explosive Devices (IED), Molotov cocktails, incendiary hand-grenade charges, and concealed explosive/incendiary packages.

These threats may ignite a fire or fuel explosion in or on one or more of the vehicle's areas:

- Crew compartment - generated internally from a hit, or penetration through open windows
- Engine or fuel tank - direct hit
- Air-intake ports
- External walls (body) of the vehicle
- Under the Vehicle - pool fire (fuel; hydraulic, engine, steering and braking lubricants)
- Wheel bay area (Tire Fires)

Detecting the approaching fire or penetration by optical means, detecting the pool or flash fire in the engine and crew compartments, tire wheel bay, or on the vehicle surface by optical, heat, or hybrid detectors, are just some of the fast detection capabilities available.

However, detecting the fire before it becomes a major threat to the vehicle and its occupants is just one facet of the solution – suppressing

TABLE 1. CREW SURVIVABILITY CRITERIA	
PARAMETER	**REQUIREMENT**
Fire Suppression	Extinguish all flames without re-flash
Skin Burns	Less than second degree burns (<2400°F-sec over 10 seconds or heat flux < 3.9 cal/cm^2)
Overpressure	Less than 11.6 psi
Agent Concentration	Not to exceed NOAEL*
Acid Gasses	Less than 1,000 ppm peak
Oxygen Levels	Not below 16%

**NOAEL - No Observed Adverse Effects Level*

NOTE: Often the Skin Burns Requirement is converted to a fire out time of 250 milliseconds or less. (250/1000th of a second)

the fire in time to prevent skin burns to the personnel and at the same time save the vehicle and allow its continued operation, is the KEY to survivability on the battlefield.

To research and development engineers, survivability means providing special design and hardware that addresses these performance requirements as well as many other vehicle and operational considerations. To the logistician, it means reducing the loss of equipment. To the user, the soldier on the battlefield, it means life or death.

MILITARY FIRE EXTINGUISHING SYSTEMS

The US Army Tank Automotive Command worked with the US Army Surgeon General to establish the guidelines shown in Table 1, as the minimum acceptable requirements of Automatic Fire Extinguishing Systems (AFES) for occupied vehicle compartments. These parameters have been set at levels that do not result in incapacitation of the crewmen from the fire and its extinguishing process, and allow them to take corrective action and to potentially continue their mission.

The standards established by the Army Surgeon General clearly state that time is the enemy of a fire extinguishing system. Once a fireball begins to grow inside of the crew compartment, if not extinguished fast (<250 ms), it takes more extinguishing agent to suppress the fire; there is greater potential for the production of toxic gasses; there is less oxygen; exposed skin can be injured; and higher overpressures. In simple terms, the faster the AFES extinguishes the fire, the higher the probability that the crew will not be injured.

A typical fire and explosion detection and suppression system is comprised of modular components designed to fit into any type of armored vehicle. The AFES incorporates explosion/fire detection and fast suppression technologies. Special systems are designed for the crew compartments (where several soldiers occupy the area) and different systems for the engine compartment (which is usually much smaller in volume).

Crew compartment systems are based on High Speed Optical UV/IR or IR/IR Flame Detectors, free of false alarms that respond to fire in under 5 milliseconds, communicating with a reliable control system with normal and combat modes and activating extinguishing cylinders with high speed valves opening within 5 milliseconds and rapidly-dispersing the extinguishing agent and allowing for a second shot capability.

Engine compartment systems are based on optical, linear, or spot heat detection and fast suppression technologies. The fast and reliable system is designed to fit the unique engine compartment configuration for both air and water-cooled engines.

An important factor to be considered in the detection system integration in the vehicle is the connection mode of the detectors.

All combat vehicles, AFES and other types of life supporting system detectors are being, for reliability reasons, connected in parallel. A serial

connection of detectors or other components increase the likelihood of malfunction.

In a serial connection, damage to any detector or formation of an open or short circuit in the plugs or harnesses will result in rendering all the detectors from that point inoperative and in the case of short circuit the entire detection system will be inoperative.

For that reason, in all the combat vehicle systems (Abrams, Stryker, BFV, LAV, FASSV, AAV, etc.) all fire detectors are connected to the control box in parallel.

Another major consideration of combat vehicle AFES and key element in the system design is the false alarm rate. Automatic fire extinguishing system should have minimal or no false alarms. If a soldier loses confidence in an AFES because its detectors are providing false alarms resulting in activation and release of agent, the soldier will soon find a way to circumvent the system.

If the AFES is unreliable, breaks down often, is difficult to diagnose and repair, the logistics burden becomes an enemy of the AFES. Yet another challenge is finding an extinguishing agent that will efficiently fill all space, effectively extinguish fires, and be friendly to both humans and the environment.

CONVENTIONAL AFES SYSTEMS

The Detection Subsystem in laymen terms either sees or feels the fire event. If it is in an occupied compartment such as the crew compartment, an electro-optical sensor is the quickest mean to identify a fire. It acts like an eye. Since the eye can see light at the speed of light, it is almost instantaneous. A special UV/IR, dual IR or triple IR combination provides greater sensitivity and higher speed of response while providing a high immunity to false alarms.

Engine Compartment System provides the following performance:

- Complete detection coverage by means of overheat wire detector
- Two levels of operation: Overheating will activate an alarm, Fire will automatically activate the extinguishing subsystem
- Extinguishing within 15 seconds
- Double-shot operation
- Built-in-Test and monitoring
- Operational under all possible vehicular working conditions
- Uniquely designed nozzles for extremely effective extinguishing

The sensors in the engine compartment act like our skin in that a wire sensor (thermistor) senses the changes in temperature and at predesignated temperature points, gives an alarm or activates the extinguisher.

The wire detectors are not as fast, but are preferred because they are very reliable in dirty and hard to get to areas such as under the engine, under batteries, under the auxiliary power unit, under turret floor areas, etc. Only the optical detector can meet the speed requirement for occupied spaces. The optical detector can certainly identify slow growth accidental fires effectively, but if in areas that make it difficult to clean the windows of the optical detector, it is not practical.

The Controls Subsystem acts like a brain. It receives input from sensors, verifies if it's a real fire, and then sends a signal to the extinguishers to release the agent. Just like our brain, it constantly monitors the health of the whole system. In other words, it has a Built-in-Test (BIT) that monitors the whole system to determine if all components are operational. For example, if a detector is inoperable, the control will identify that there is a problem with the detection and automatically look for information from the other detectors as back-up; or if a cylinder malfunctioned and did not release agent, the control, in less than four milliseconds, will tell another cylinder to release the agent. The controls provide redundancy and backup to components that malfunction or are damaged. The control subsystem can be easily adjusted to provide additional functions that the customer desires, such as audible alarms, continuing to monitor for fire after the master switch is turned off, or shutting down exhaust fans or engines if a fire is detected.

The Fire Extinguishing Subsystem consists of an agent, shatterproof pressurized cylinder or by a gas generator, high speed valve, wiring harnesses, nozzles, and piping. For decades, Halon 1301 was the agent of choice for military applications, but with the approval of the Montreal Protocol, Halons were banned from production and the military community worldwide conducted a wide search to find the "silver bullet" that would be a “drop-in” replacement of Halon 1301. After an exhaustive search, they did not find the "silver bullet" but they did find several acceptable replacements.

A published report written by Mr. Steve McCormick, Fire Research Team Leader, US Army TARDEC and Mr. David Koehler, Manager, Army ODC Elimination Program, state the following, concerning their search for a Halon replacement:

Performance equivalent to Halon 1301 can be achieved with available agents and delivery system technologies. Crew survivability criteria have been satisfied against ballistic fires with HFC-227ea concentrations well below accepted exposure limits. Adding small amounts of sodium bicarbonate powder to the HFC reduces acid gas formation by half. Water mist with potassium acetate salt also proved to be very effective with no concern of hazardous byproducts and simple cleanup. Hybrid gas generators offer a smaller overall envelope for the same agent weight, pressure on demand, and a more consistent agent discharge. Wet mains allow the agent to be prepositioned for very rapid agent dispersion and offer the flexibility of nozzle locations.

Other agents can be used in the engine compartment such as Sodium bicarbonate based dry powder such as the Abrams M-1 Series Tank. HFC-227ea will be used in vehicles that shut the engine off prior to agent discharge (including the M2/M3 Bradley Fighting Vehicle) because of its ease of retrofit.

The AFES for combat vehicles certainly works well. However, there is always room for improvement. The US Air Force Research Laboratory in co-operation with the US Army, has developed an Ultra High Speed Water Deluge System that is able to extinguish fires in less than 30 ms. Water is the agent and this system protects individuals working next to explosive materials as they are being manufactured.

Future combat systems will definitely have need of an AFES; however, weight and space are critical design parameters. Therefore, FCS will be used to drive AFES to smaller and lighter packages. The challenges for the AFES are changing as technology looks at using hybrid electric propulsion, electro-magnetic or electro-thermal guns, capacitors, and fuel cells. These power and propulsion systems offer new types of threats that the AFES of the future

System Considerations

Crew System Considerations:

Vehicle operational requirements
- Access to ammo storage and other stored items
- No interference with weapon systems and other vehicle systems
- No interference when entering/exiting vehicle
- Withstand vehicle operating environment – vibration, shock
- Vehicle maintenance routine

Agent discharge and dispersion
- Discharge will not cause threat to crew – design appropriate valve outlet
- Secure homogenous and effective dispersion throughout the protected volume

Crew safety
- Appropriate anti-recoil device
- Divert discharge from direct impact on crew

Engine System Considerations:
- Protect dispersion nozzles from dirt
- Locate extinguisher beyond engine compartment bulkhead
- Consider airflow, sources of fire hazards
- Consider airflow and need for engine shut down before agent discharge

will need to address. Mr. Steve McCormick stated, "These fire threats may require completely new survivability strategies with respect to detection, suppression/mitigation, and/or post event safety."

The next generation system will be governed by an integrated microprocessor based Control Electronics Unit (CEU).

The CEU will acquire analog and digital signals from the system detectors, manual activation devices and external status switches; process the inputs; activate the fire extinguishers according to the system logic including selection of properly charged and connected cylinders and enabling back-up extinguisher activation; control indication and annunciation devices (audio-visual); and enable performance of system maintenance and trouble shooting according to diagnostic information continuously gathered from the system components.

The CEU will provide all system component status, faults, alarms and extinguishing signals to the vehicle electronics by means of RS-485 or Ethernet serial data communication. The CEU will have dedicated independent software that governs all operational, maintenance and diagnostics tasks. The CEU will have a built-in maintenance program that issues recommended corrective actions.

The CEU can be either an independent stand-alone box or be integrated into a vehicle common interface electronic box that will govern several vehicle subsystems.

In either case, the system will provide all information to a control and display panel or to designated crewmember panel/s. Such panel/s will include operation capability switches and enable the operator to perform troubleshooting, receive diagnostics and prognostics information.

KEY FEATURES OF MODERN AFES SYSTEMS

Various technologies are currently evaluated for external vehicle fire protection, whether it's for protecting the vehicle's surface or its "soft belly" before they are engulfed in flames that may cause irreparable damage. Improvements to conventional crew and engine compartments have been introduced to meet the new critical design parameters for the Future Combat Vehicle (FCS) and other new armored and tactical vehicles.

Key features of these modern AFES systems include:

1. Valve and dispersion special design that provide for:

- *a.* Rapid efficient and homogenous dispersion of the extinguishing agent throughout the protected volume (ensuring suppression in less than 250 milliseconds)
- *b.* Dispersion mechanism (deflector) that ensures rapid drop in pressure at a short distance from the valve outlet and substantially increased safety to personnel during cylinder discharge, compared to the previously used high pressure pointed discharge nozzle

2. Sensitivity of the optical detectors that ensures optimal detection

System Technologies

Optical Flame Detection: Spectral analysis of fire phenomena discriminates between slow-growth fuel fires, ammunition fires and high-energy penetration (HEAT and Kinetic charges). The spectral analysis is performed in the UV and IR spectral bands that are emitted by the various combustion processes. Optical detectors based on this technology include the well-known UV/IR – featuring fast response, high reliability, enhanced immunity to false alarms, and dual IR and the Triple IR (IR3) – featuring increased sensitivity to small fires, highest reliability and best immunity to false alarms.

Logic and Control: Microprocessor based electronics, enables flexibility to fit specific system configurations and operating logic. Control panel includes mode selector, indication and warning signals, and Built-In-Test capabilities. Modern RS-485 serial communication port enables connection to a main control system and can be used for maintenance and trouble-shooting. The control unit can also interface with a Local Area Network (LAN) via TCP/IP Ethernet port, enabling integration of the system into an existing vehicle communication infrastructure.

Extinguishing Technologies: Chemical and physical-acting fire suppression agents featuring clean gaseous agents (Halon Alternatives) such as HFC-227ea combined with scrubbing agents such as BS (Sodium Bicarbonate) for reduced toxic by-products and increased extinguishing efficiency. These agents are rapidly and effectively discharged from pressurized cylinders that feature squib activated valves and dispersion nozzles that provide homogeneous total flooding of the protected volume. Novel concepts in fire suppression employing propellant-extinguishing technologies either as stand-alone systems or as propelling means for conventional extinguishing agents. These novel concepts are provided in cooperation with leading propellant industries.

Armored Personnel Wheeled Vehicles Programs

- The **LAV** and the **Stryker** are being equipped with a single shot crew compartment system (3 cylinders 6lb HFC-227 - BL) and a double shot engine system (1 cylinder 7 lb HFC-125). System also includes 7 Optical Fire Sensors (4 in crew and 3 in engine) and a control electronics panel.
- The **M1114 HMMWV** up-armored vehicles are being equipped with a system that protects both crew and cargo areas. System comprises 3 optical detectors, 2 cylinders HFC-227 and a controller.

coverage of the protected volume including detection of penetration in less than 3 milliseconds as well as detection of small and slow growth fires (size of 8 in. pan fire located anywhere in the crew compartment), all combined with increased detector immunity to false alarm

3. Preferably a double shot system providing a second shot suppression to address the high likelihood of a vehicle being hit twice once acquired as a target by the enemy in the battle field

4. Embedded diagnostics that detect and isolate all essential system critical performance functions of each one of the optical flame detectors, extinguisher valves and the system control unit

5. Embedded prognostics that enhances the availability of the system and its components and reduces support costs by predicting critical performance failures in advance of their occurrence

6. Microprocessor based control units providing for:

a. Visual alarm, fault, status indications and operational switches on panel or detailed indication by LCD display (as an option)

b. RS-485/422 serial communication port connects to external control system for test, maintenance, diagnostics and troubleshooting

c. TCP/IP Ethernet port interfaces with LAN for integration into vehicle communication infrastructure (option)

d. Built-in event recorder (option)

Novel environment friendly fire extinguishing agents and new methods of dispersion are considered for the modern AFES. Fire suppression solutions may include:

- Small particles or dry powder "shot" directly at the incoming fire threat to counter/diminish the fire ball that may hit the vehicle's surface
- Dry powder in direct stream or through piping and nozzles discharge. The powder dispersion in cloud form or surface area coverage to protect the vehicle surface
- Surface-acting wetting agents (chemical agents) such as foam or fuel and rubber decomposing material by itself or in combination with dry powder for the wheels compartment
- Total flooding and streaming agents discharged from hybrid systems

The mechanisms by which these fire suppression agents extinguish the fire are complicated and usually more than one mechanism applies for fast and successful fire suppression. Some of the most effective fire extinguishing mechanisms identified so far include:

- Dry powders (various particles sizes) that act chemically and physically on the fire propagating species in the gaseous phase, disrupting the flame front and causing fire suppression
- Wetting agents/foams that act chemically on the burning surface to prevent further burning
- Water-based agents with additives (loaded streaming agents) that act chemically and physically to suppress the fire and cool-down the fuel surface

As technology changes, leading companies with their aggressive research and development programs are up to the challenge that will provide innovative fire protection strategies and products for the modern battlefield.

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