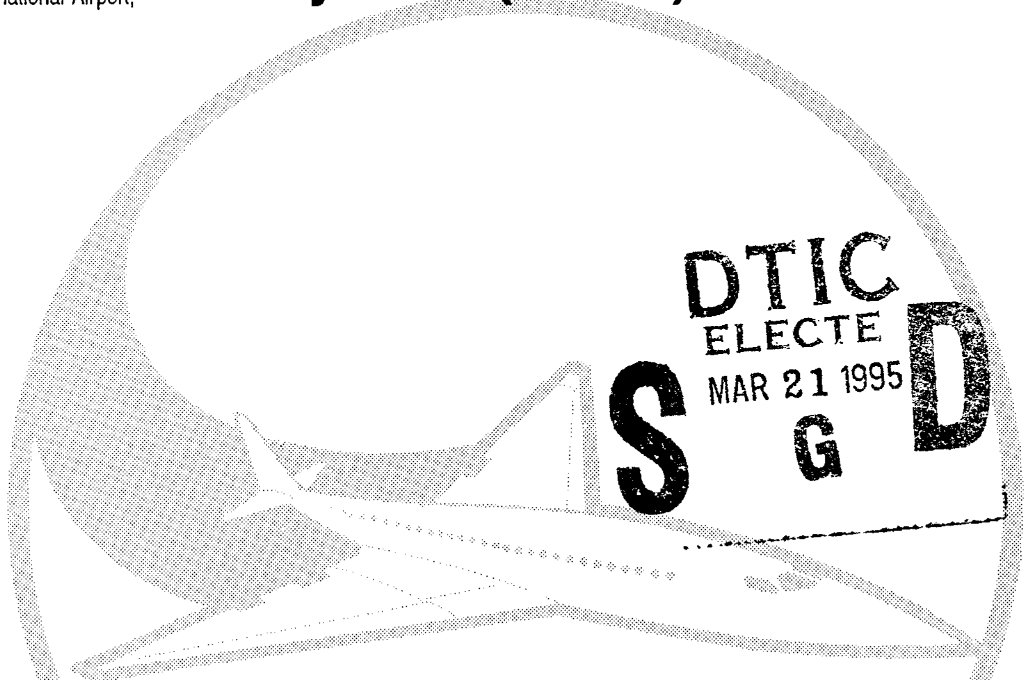
DOT/FAA/CT-94/99

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Driver's Enhanced Vision System (DEVS)



January 1995

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.
DOT/FAA/CT-94/99

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
DRIVER'S ENHANCED VISION SYSTEM (DEVS)

5. Report Date
January 1995

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTFA03-89-C-00043

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
ACD-240

15. Supplementary Notes
FAA Technical Center Project Manager Joseph A. Wright

16. Abstract

A study was conducted to determine the feasibility of using advanced technologies to enhance the response capability of Aircraft Rescue and Fire Fighting crews in extremely low visibility conditions. This study has identified technology, evaluated systems, and defined requirements for equipment necessary to meet this need, the Driver's Enhanced Vision System (DEVS).

DEVS is composed of three subsystems: Night Vision, an infrared camera and monitor which enhances vision in smoke, fog, adverse weather, and darkness; navigation, a Differential GPS receiver and moving map display inside the cab; and Tracking, a digital radio datalink between the command center and the vehicles over which accident information, vehicle position reports, and other messages are sent.

This document describes the constituent technologies and evaluations that were performed and defines preliminary specifications for the DEVS system.

17. Key Words
Driver's Enhanced Vision
Aircraft Rescue and Fire Fighting
Forward Looking Infrared
Global Positioning System
Night Vision
Vehicle Navigation
Vehicle Tracking
Reduced Visibility

18. Distribution Statement
This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	106	

ACKNOWLEDGMENTS

The Fire Safety Branch of the FAATC would like to thank the following organizations for their participation in the DEVS research effort:

Air Line Pilots Association
Astronautics Corporation of America
Atlanta Fire Department
Atlanta Hartsfield International Airport
Atlantic City International Airport Fire Department
Cairnscomm
Delta Data Systems
Federal Aviation Administration Southern Region
FAATC Visuals and Exhibits Branch (ACM-410)
FLIR Systems Incorporated
Galaxy Scientific Corporation
GEC Marconi Avionics
Inframetrics Incorporated
Insight Vision Systems Incorporated
Interstate Electronics Corporation
Lucas Deeco Corporation
Massachusetts Port Authority
New Jersey Air National Guard
Opto Mechanik Inc.
Port Authority of New York and New Jersey
Port of Seattle
Rockwell International
Sharp Electronics Corporation
Westinghouse Electro Optical Systems
Wilray Audio-Visual

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LIST OF ABBREVIATIONS AND SYMBOLS

ac	Alternating Current
AC	Advisory Circular
ADS	Automatic Dependent Surveillance
AOA	Airport Operational Area
ARFF	Aircraft Rescue and Fire Fighting
ASDE-3	Airport Surface Detection Equipment
CAD	Computer Aided Design
CIP	Capital Investment Plan
COTS	Commercially available Off The Shelf
CRT	Cathode-Ray Tube
DC	Direct Current
DEVS	Driver's Enhanced Vision System
DGPS	Differential Global Positioning System
DR	Dead Reckoning
DVE	Driver's Vision Enhancer
ECC	Emergency Command Center
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
FAR	Federal Aviation Regulation
FLIR	Forward Looking InfraRed
FM	Frequency Modulated
FOV	Field Of View
FSI	FLIR Systems Incorporated
GPS	Global Positioning System
HFOV	Horizontal Field Of View
HPRV	High Performance Research Vehicle
HUD	Head Up Display
IBM PC	International Business Machine Personal Computer
INS	Inertial Navigation System
IR	Infared
LCD	Liquid Crystal Display
MB	Megabytes
MFD	Multi Functional Display
MHz	Megahertz
MLS	Microwave Landing System

MTTR	Mean Time To Repair
PEV	Pyro Electric Vidicon
PPS	Precise Positioning Service
R&D	Research and Development
RAM	Random Access Memory
RF	Radio Frequency
RIV	Rapid Intervention Vehicle
RTCM	Radio Technical Commission for Maritime Services
RVR.	Runway Visual Range
SMGCS	Surface Movement Guidance and Control System
SPS	Standard Positioning Service
TBD	To Be Determined
TTFF	Time To First Fix
TTS	Transponder Tracking System
TWDS	Transparent Window Display System
UPS	Uninterruptable Power Supplies
USGS	United States Geological Survey
VAC	Volts Alternating Current
VDC	Volts Direct Current
VFOV	Vertical Field Of View
VGA	Video Graphics Array

EXECUTIVE SUMMARY

Sophisticated avionics systems now allow routine aircraft operations in extremely low visiblity conditions; Aircraft Rescue and Fire Fighting (ARFF) services must be able to respond if accidents should occur in such conditions. The Driver's Enhanced Vision System (DEVS) program, performed by the Aircraft Rescue and Fire Fighting Research Group at the Federal Aviation Administration's Technical Center, has identified technology, evaluated systems, and defined requirements for equipment necessary to meet this need.

For maximum cost effectiveness, DEVS is foreseen to primarily consist of the integration of commercial off-the-shelf equipment. As such, related technology developments, such as the Army's Driver's Vision Enhancer program, Global Positioning System (GPS) enhancements, and digital wireless communications are constantly investigated and tracked for appropriate inclusion in the program.

DEVS is composed of three subsystems: night vision, navigation, and tracking. The purpose of the night vision subsystem is to improve the ARFF vehicle driver's ability to see at night and through smoke, fog, and adverse weather; it consists of a Forward Looking InfraRed (FLIR) camera and a monitor in the cab. The navigation subsystem shows ARFF vehicle drivers their location, the accident site, and the path between to ensure rapid advance toward the site; a Differential GPS and moving map display inside the cab is used. The vehicle tracking subsystem allows an overview of all vehicles at the command center and provides reliable digital communications with vehicles; it is comprised of a display at the command center and a digital radio datalink between the command center and the vehicles.

Prototype DEVS components supplied by vendors were evaluated and used as proof of concept test beds. Evaluations conducted at the FAA Technical Center and other airports around the country demonstrated that DEVS technology can improve a driver's ability to locate fires, aircraft, and people at night in rain, snow, and heavy fog. Fires, aircraft, and people that were not visible under these conditions with the naked eye were detectable with the night vision subsystem. The ability to locate and navigate to accident sites using the navigation and tracking subsystems was also demonstrated.

Additional research should be conducted by ARFF research group to further refine DEVS requirements and to develop a prototype DEVS that can be used to measure improvements in operational response times during poor visibility conditions. These topics are described in Section 5.4 of the report.

To fully realize benefits of the system, implementation of DEVS technology must proceed cautiously. The following issues must be addressed in the implementation and acquisition of DEVS technology:

- Initial DEVS installations should be done as pilot programs in close cooperation with FAA headquarters and the FAA Technical Center's ARFF research group, to gain operational experience. Pilot programs will minimize risk in implementing the complex and rapidly developing technologies which comprise DEVS.
- DEVS installations must be implemented as integrated, coherent systems with all three subsystems. Piecemeal acquisition of partial systems is unlikely to result in significant performance improvement.
- Each site implementation should be researched and customized according to the specific operational environment.

The DEVS program has successfully demonstrated that appropriate technology can significantly enhance the response of ARFF services in poor visibility conditions.

1. INTRODUCTION.

The Driver's Enhanced Vision System (DEVS) program is a Research and Development (R&D) effort being performed by the ARFF research group, Aircraft Rescue and Fire Fighting Research Group at the Federal Aviation Administration (FAA) Technical Center (FAATC). The program grew out of a need to improve the response times of Aircraft Rescue and Fire Fighting (ARFF) services during periods of poor visibility. ARFF research group performed research between November 1992 and May 1994 that identified the necessary requirements. These requirements were further defined through vendor supplied demonstration systems that were installed on the ARFF research group High Performance Research Vehicle (HPRV) and twin agent Rapid Intervention Vehicle (RIV). These research vehicles provided a means for ARFF crews to interact with the demonstration systems under simulated operational conditions. The ARFF crews who participated in DEVS demonstrations provided valuable information, which had a direct impact on DEVS requirements development. This final report will summarize the research findings and specify DEVS requirements to date. Section 1 provides DEVS introductory and background information. Section 2 summarizes operational requirements. Section 3 provides an upper level functional description of the system. Section 4 specifies DEVS performance characteristics. Section 5 presents research which supports the findings presented in the other sections.

1.1 BACKGROUND.

Between January 1990 and February 1991, three major accidents occurred involving collisions between two airplanes on active runways [reference 1]. All three of these accidents occurred at night and involved fatalities. The response by ARFF services to two of these accidents was impeded by poor visibility conditions. ARFF vehicle operators were forced to drive slower than usual to avoid becoming lost or colliding with obstacles in the fog. The fog also made locating the accident sites difficult.

The FAA Capital Investment Plan (CIP) makes provisions for conducting flight operations safely during periods of poor visibility. Improved landing aids such as the Microwave Landing System (MLS) and ground surveillance radars such as the Airport Surface Detection Equipment (ASDE-3) are being developed. More requirements for fire fighting in low visibility conditions can be expected as these systems are deployed around the country.

ARFF services are required to demonstrate an ability to respond to a simulated aircraft emergency on the airport operational runway area in under 3 minutes for certification purposes. This certification response time was used as a bench mark when setting requirements for DEVS. The response time goal when responding to an actual emergency is to get to the accident scene in as little time as possible. During periods of poor visibility, ARFF response times are longer because vehicle drivers must proceed with caution. DEVS is a program designed to improve ARFF service response capability during periods of poor visibility. The need to equip ARFF vehicles with a DEVS capability has become urgent with the recent proposal to permit Category III operations with a Runway Visual Range (RVR) of only 300 feet.

1.2 PURPOSE.

The purpose of this final report is to summarize the findings of DEVS research and prototype system demonstrations. The findings of this research will be expressed as a set of minimum operational requirements and specifications which can provide guidance to airports interested in acquiring DEVS equipment. Details regarding the research activities on which the DEVS requirements are based are also presented.

1.3 RELATED EFFORTS.

For maximum cost effectiveness, the DEVS system is foreseen to primarily consist of the adaptation and integration of commercial off the shelf (COTS) equipment. As such, related technology developments that may contribute to achieving the FAA's objective are constantly investigated and tracked for appropriate inclusion in the program.

In the poor visibility arena, the Army's Driver's Vision Enhancer (DVE) program is focused on the development of low-cost, uncooled Forward Looking Infrared (FLIR) sensors to assist truck drivers during night operations. The DVE program is forecasted to dramatically reduce infrared system cost, while providing the additional benefit of "instant-on" viewing, since no cool-down time is required. The FAATC program manager has conferred with the Army program manager regarding the DVE program, and observed prototype sensors from both contractors in action.

2. OPERATIONAL REQUIREMENTS SUMMARY.

The goal of DEVS is to improve the response times of ARFF services to emergencies during periods of poor visibility. The FAA has not defined an operational response time requirement in poor visibility for ARFF services. An operational response capability test is specified in Federal Aviation Regulation (FAR) Part 139. ARFF services are required to demonstrate an ability to meet this response test time in their annual airport certification. FAR Part 139, paragraph 319 states that "within 3 minutes from the time of the alarm, at least one required airport rescue and fire fighting vehicle shall reach the midpoint of the farthest runway serving air carrier aircraft from its assigned post, or reach any other specified point of comparable distance on the movement area which is available to air carriers . . ." [reference 2]. All other required vehicles must be able to reach this point within 4 minutes from the time of the alarm.

This regulation's test times are the yardstick against which ARFF response capabilities are measured. However, ARFF crews structure their operations to minimize response time under all circumstances. Some airports take special precautions during periods of poor visibility to improve response time. For example, at Atlanta's Hartsfield International Airport, a crash truck is positioned near the operational runway when visibility is low. Precautions such as these are aimed at improving the three difficult aspects of a poor visibility response: locating the accident, navigating to the accident site, and avoiding obstacles and locating people on the way to the accident site. DEVS is being designed to improve ARFF crew response times during periods of poor visibility without adversely impacting current ARFF vehicle operation. The following sections describe the required operational capabilities and training/ maintenance philosophies for DEVS.

2.1 OPERATIONAL ENVIRONMENT.

The goal of this effort is to improve Aircraft Rescue and Fire Fighting (ARFF) service responses to emergencies at airports. To do this requires an examination of the environment in which the improvement will operate. The operational environment consists of: aircraft operations in various visibility conditions, the airports at which they are likely to be conducted, and the ways the airports practice operations and offer their services. Each of these elements need to be examined in more detail to identify the operational requirements for the ARFF response improvement(s).

In conducting the examination, groupings are used. This approach was selected because commonalities and differences become more evident when groups within each of the environment's elements are examined. What follows are the results of the application of groupings to the environment described above.

2.1.1 Visibilities.

Recent improvements in avionics and pilot training are permitting aircraft operations in lower than ever visibility conditions. By January 1, 1995, all airports desiring to service aircraft operations (landings and take offs) below 1200 feet Runway Visual Range (RVR) are expected to have certain standards in place. These are addressed in Advisory Circular (AC) No. 120-57, Surface Movement Guidance and Control System (SMGCS).

When SMGCS becomes operational, the stated visibilities defining it are predicted or exist. In addition to the airport visual cue standards such as pavement markings and lighting, the AC addresses other airport ancillary services such as ARFF. This verifies that ARFF services are a necessary element in airport visibility conditions below 1200 feet RVR. This provision of ARFF services under these conditions is of central importance to the response improvement's operation. The services must function effectively in visibility conditions below 1200 feet RVR.

It is expected that these low minimum operations will be limited to airports, pilots, and aircraft which serve the larger passenger markets. This means that SMGCS is not desired at all airports and the provision for ARFF service responses is subject to different visibility conditions. At these airports ARFF services are provided in visibilities which range from a clear day with unlimited visibility through the existing approach minimums categories down to the visibility addressed by SMGCS.

The visibility requirement for the ARFF response improvement(s) to function in is not common throughout the airport population and the associated visibility improvements should reflect the various approach categories for airports.

2.1.2 Airports.

As mentioned, passenger markets are most likely to be the greater influence on implementing aircraft operations at lower minimums. Generally, the airports which service these markets are airports certificated under Federal Aviation Regulation (FAR) Part 139.

The owners of these airports hold certificates indicating they meet and maintain the minimum requirements of that regulation. It is also at these airports where most of the air carrier passenger service is conducted. Other airports in the overall inventory of airports are grouped under the heading of General Aviation Airports. Owners of airports in either group may be private individuals or public bodies.

While airport owners in the first group (certificated airports) must offer ARFF services, the others may consider ARFF service optional. Because of the density of flights and that regulatory requirement for

ARFF services, the group of airports with certificates will be examined in more detail to identify other operational requirements for the ARFF response improvement.

The numbers of airports with certificates and the kinds of certificates gives us some logic for grouping limits important to this effort. There are 674 airports whose owners hold certificates attesting that they meet the requirements of FAR Part 139. Seventy one percent of these airports hold a full certificate and the remaining 29 percent hold limited certificates, as shown figures 1 and 2.

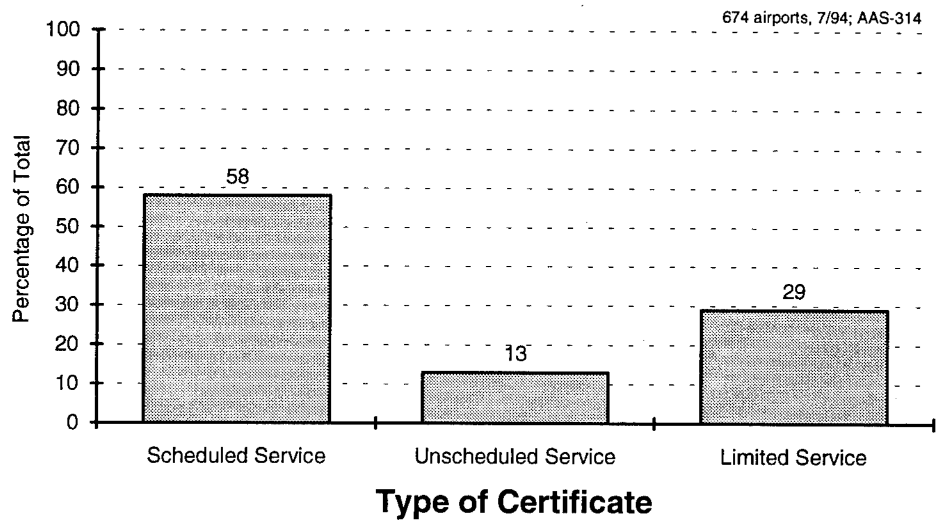


FIGURE 1. FAR PART 139 AIRPORTS BY TYPE OF CERTIFICATE

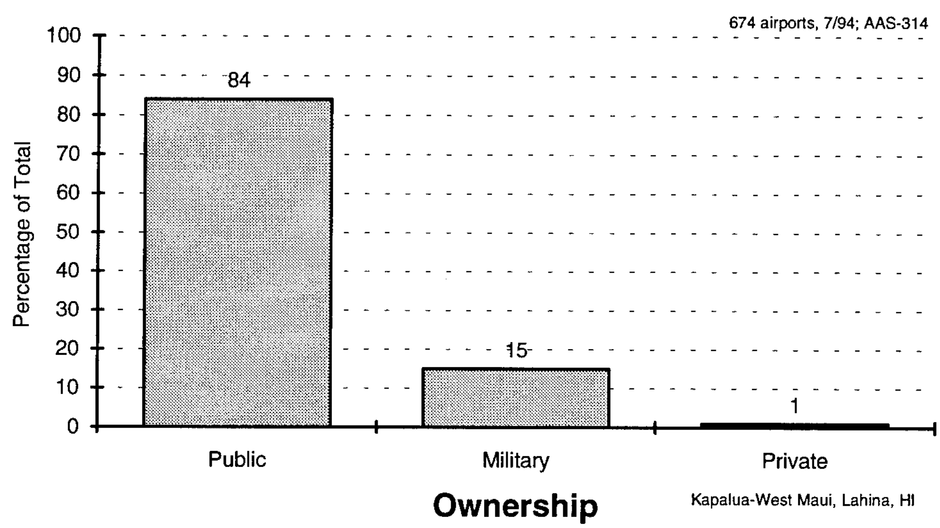


FIGURE 2. FAR PART 139 AIRPORTS BY OWNERSHIP

While airport operations may be common to both groups, the airport services in each of these airport certificate groups have some slight but important differences. For an airport in-either of those certificate groups, a key minimum requirement that owners must have and maintain to hold their certificate status is the provision of an ARFF capability.

2.1.3 ARFF Operations, Capabilities and Tests.

The key task in any response action is ARFF vehicle operations. The task includes and is dependent on the operator's ability to see and observe events. As visibility in the environment changes from unlimited to rain, fog, snow, night conditions or any combination of these, the cues the vehicle operator can observe is restricted and the expected speed at which this task is accomplished is reduced.

In addition, vehicle operators are primarily interested in other accomplishments, such as: locating the incident or wreckage scene, navigating to the incident or the wreckage scene, avoiding obstacles in getting there, and avoiding people enroute. From the vehicle operator's perspective, the ARFF response improvement must operate in a range of restricted visibility environments in the same way as if the operator were making a response on a clear day with unlimited visibility.

To assure that the ARFF service is maintained, the certificate holders airports are inspected by the Federal Aviation Administration (FAA) periodically. The importance of this inspection service is that during it the airport owners demonstrate their required ARFF capability.

To assure readiness of the ARFF capability a test is made. Specifically the ARFF vehicles must reach the midpoint of the farthest runway from the fire station and begin applying fire suppression agent within three minutes from time of alarm. This test applies to holders of full certificate and limited certificate airports. At some airports the required capability is met with more than one ARFF vehicle. These latter vehicles must be at the scene within four minutes from the alarm. Any proposed improvement in ARFF response would have to be one which is operational within these test times.

The required ARFF capabilities at certificate holder's airports also vary. The requirements differ according to the frequency of air carrier operations, size of the air carrier aircraft that the airports service, and in the numbers of vehicles the ARFF services uses. The ARFF servicing capabilities are indexed according to minimum requirements prescribed by the regulation.

Five indexes prescribe the different ARFF capabilities. The minimum capability is Index A. The requirements gradually increase in fire suppression agents and numbers of vehicles to Index E.
For the airports with full certificates, the required indexes are diverse. For airports with limited certificates, the minimum capability recommended is Index A, however at some of these airports this requirement is exceeded.

For any response improvement these indexes serve two purposes. First, they support the earlier indication that more than a single style of improvement is required. Second, they serve as logical break points where add-ons can be made or taken away if a modular style of improvement is adopted.

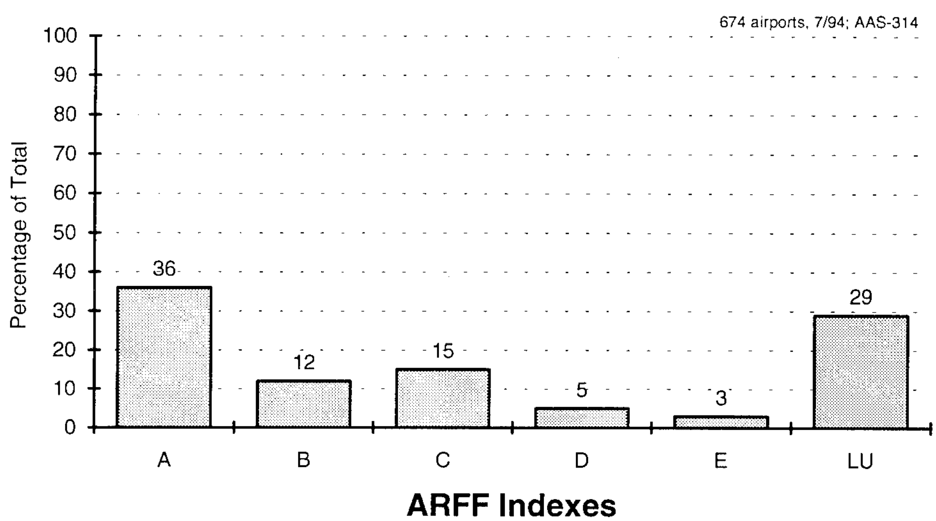
2.1.4 Responses.

In actual response situations ARFF crews try to arrange their operations to minimize the response time under all circumstances. At some airports this is achieved by moving ARFF vehicles outside of the ARFF vehicle shelter or station nearer the runway(s) during air carrier operations at that airport. Due to this practice any improvement proposed must be operational from these positions as well as when the vehicles exit the ARFF vehicle stations where supporting utilities are readily available.

Furthermore, the manning of ARFF vehicles is an important element and it varies. Whereas the top 20 of the 54 (rounded) airports with Index E and D ARFF capabilities have crews solely dedicated to providing ARFF services, it does not follow that this is the normal practice at all airports. At some airports the ARFF service is provided by units of the military, or the Air National Guard. At others it may be provided by contract with private companies.

At the Index A and B and some Index C airports, the airport manager or the duty airport operations or maintenance person(s) may well be the first responder(s) to emergency events. Back-up services at these airports for the emergencies can come from airport tenants or from mutual aid responders. This broadens the group of persons expected to use a proposed response improvement and adds to the operational-requirement that it must be "friendly" to a diverse group of users

The distribution of ARFF capability indexes by percent for airports with certificates is shown in figure 3. From that figure the majority of certificated airports (36%) have the minimum required Index A capability: 12 % have Index B; 15 % have Index C; 5 %. have Index D; and 3 % have Index E. The distribution presents some grouping alternatives which are helpful for setting operational requirements for ARFF response improvements.



Notes

ARFF Indexes	Serves Aircraft Of Lengths (ref: FAR Part 139, Sec.. 139.315)
A	90 ft. Or less
B	90 ft. To less than 126 ft.
C	126 ft. To less than 159 ft.
D	159 ft. To less than 200 ft.
E	at least 200 ft.

LU is a limited Certificate Airport serving unscheduled air carrier operations (see FAR Part 139, Sec. 139.3)

FIGURE 3. FAR PART 139 CERTIFICATED AIRPORTS BY PERCENT ARFF INDEX

2.1.5 Finances.

All airports with certificates do not enjoy the same financial well being. Experience within FAA's Airport Certification Program indicates that initial and operational costs for services provided are critical and are often cited as the bottom line cause for surrendering the certificate. Costs considerations are a prime factor in the decision on whether to add a response improvement to an existing ARFF capability. It is therefore essential that these costs for response improvement be minimized for the greater majority of airports. It is estimated that only 20 of the 54 (rounded) full certificate airports, that is those with ARFF Index D and Index E ARFF capabilities, will have limited difficulty funding operational and maintenance costs for a response improvement.

If all airports with certificates are expected to use a single improvement product, then the levels of technological sophistication and complexity will have to be adjusted to produce results to meet ARFF response improvement goal.

2.2 REQUIRED CAPABILITIES.

DEVS should improve the capability of ARFF crews to perform the following three emergency operations during periods of poor visibility:

a. Locating accident sites,
b. Navigating ARFF vehicles to crash sites, and
c. Recognizing obstacles and locating people.

Navigating ARFF vehicles to crash sites is also a task complicated by poor visibility conditions. ARFF vehicle drivers know that seconds lost can mean lives lost during an aircraft emergency response. Consequently, they drive as quickly as possible to the accident location. Drivers must balance the need to get to the accident quickly with the need to operate their vehicles safely under all circumstances. When visibility is poor, this balancing act becomes more difficult because the envelope of safe vehicle operation is reduced by an unknown amount. Poor visibility also increases the chances that ARFF vehicle drivers will become lost or disoriented on the way to the accident site. DEVS should provide ARFF vehicle drivers with the capability to drive their vehicles faster and more safely during periods of poor visibility and reduce the chances of becoming lost or disoriented.

Recognizing obstacles and locating people is especially difficult in low visibility conditions. The only visual aids that rescue services currently have for seeing in dark, snowy, foggy, icy, and rainy conditions are windshield wipers and headlights. These devices often do not improve visibility enough to allow rescue teams to drive safely at high speeds due to the increased chances of driving into obstacles on the way to the accident site. Responding fire fighters must be able to recognize an impact threat to the vehicle early enough to respond effectively. As ARFF crews get closer to the accident scene, the chances of encountering plane wreckage, other emergency vehicles, and people increases. Aircraft accident survivors instinctively try to get away from an accident site as quickly as possible. DEVS should provide ARFF vehicle drivers with an ability to more easily recognize obstacles and people during a response to an aircraft accident when visibility is poor.

Besides these fundamental required capabilities, DEVS should be fully functional when the fire equipment departs the fire station facility. This exit time is typically under 30 seconds. Bringing the equipment on line and operational can in no way impede the ARFF service's ability to respond. Equipment must be automated and require little attention by the vehicle operator.

2.3 TRAINING AND MAINTENANCE.

The training required for DEVS should be similar in scope to the training required for a new fire vehicle. Manufacturers should design their systems so that no more than several hours of indoctrination are required to learn proper operation. One of the requirements for DEVS is that it be designed in such a way as to not increase the work load of the ARFF vehicle driver during a response. To meet this requirement, DEVS should require little or no operator intervention for operational use. Integration of DEVS technology into ARFF vehicles will not require firefighters to develop additional computer skills. ARFF services should continually train vehicle drivers to improve proficiency using DEVS after system operation is understood. Each airport should develop a training routine that allows drivers to exercise the required capabilities of DEVS. This means getting ARFF crews into their trucks during periods of poor visibility and using the system to locate simulated aircraft accidents, navigating to the accidents, and avoiding obstacles and people on the way to the accidents. Appendix A contains suggestions for DEVS training exercises.

DEVS components should be modular in design for easy field maintenance. If a system component should fail, it should be easily replaceable. The specifics of maintenance arrangements for DEVS equipment will ultimately depend on the individual suppliers since it will be supplied as Commercially available Off The Shelf (COTS) equipment. Ideally, troubleshooting of hardware problems should not be required in the field. Equipment should be sent back to the supplier for repair or replacement according to the terms of the warranty. ARFF services should take responsibility for ensuring a 24-hour Mean Time To Repair (MTTR) for DEVS equipment through negotiated vendor maintenance agreements or by keeping spare components readily available.

2.4 METHODOLOGY FOR MEETING REQUIREMENTS.

Deployment of ARFF response improvement systems will be phased into the operational environment according to the levels contained in the ARFF index. ARFF response improvement prototype(s) will be installed and tested under actual conditions at these airports. The results of these early installations will feed subsequent development and rule-making. This phased approach will help define the different cost and operational requirements for the improvement at other airports.

The airport choice for early DEVS deployment will be on the following criteria:

a. As restricted visibility weather is difficult to predict, proximity to the investigators.
b. The availability, sizes, and numbers of ARFF vehicles and crews.
c. Implementation of a Surface Movement Guidance and Control System Plan.

3. TOP-LEVEL SYSTEM DESCRIPTION.

The required operational capabilities of DEVS are the basis for the functional system design. Three functional subsystems were identified that will address the required capabilities of locating aircraft accidents, navigating to the accident sites and locating obstacles and people. These subsystems are the night vision, navigation and vehicle tracking subsystems. The purpose of the night vision subsystem is to improve the ARFF vehicle driver's ability to see at night and during periods of reduced visibility due to smoke, fog, or adverse weather. The purpose of the navigation subsystem is to help the ARFF vehicle driver arrive at the accident site in the most efficient manner possible while reducing the probability of becoming lost. The purpose of the vehicle tracking subsystem is to reduce the ARFF vehicle driver's communications workload and to improve situational awareness in the vehicles and the central dispatch or command center. Table 1 summarizes how the DEVS subsystems meet the required capabilities.

TABLE 1. REQUIRED CAPABILITIES

	Locating Accidents	Navigating	Obstacle/People Location
Night Vision	x	x	x
Navigation	x	x	
Tracking	x		x

The night vision subsystem satisfies all three required capabilities by improving the driver's ability to see at night and during periods of low visibility due to smoke, fog and other adverse weather. The navigation subsystem helps a driver locate and navigate to accidents by providing a digital map of the area with the position of the vehicle displayed in real time. The tracking subsystem helps locate accidents, obstacles and people by allowing drivers to communicate precisely the position of the vehicle and objects encountered to the ARFF dispatch or Emergency Command Center (ECC). From the ECC, the position of objects can be transmitted to ARFF vehicles.

Research was conducted to identify currently available technology and equipment that would satisfy DEVS subsystem functionality. The identified technologies require additional equipment in the ECC as well as in the vehicles. Figure 4 demonstrates how the subsystem functionality will be distributed between the vehicles and the ECC. The night vision subsystem will require additional equipment in the vehicles. The navigation and tracking subsystems will require additional equipment in the vehicles and the ECC. The following sections describe the equipment required for each subsystem.

3.1 NIGHT VISION SUBSYSTEM.

Early DEVS research identified the Forward Looking InfraRed (FLIR) device as the primary night vision subsystem sensor. Additional research and FLIR camera evaluations helped to identify important characteristics for the DEVS FLIR. For example, the FLIR should operate in the long wave (8-12 μm) portion of the electromagnetic spectrum, should be internally cooled, and should be equipped with a "standby" mode of operation, which allows a thermal image to be generated in 30 seconds or less. There must also be a way to remove rain from the outer lens surface such as a windshield wiper or pressurized air.

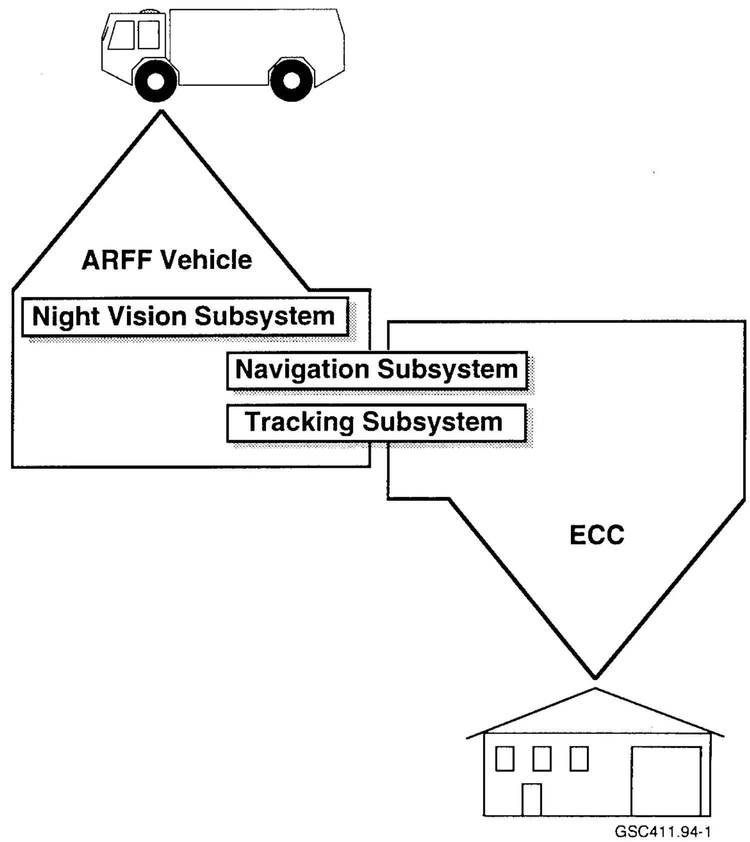


FIGURE 4. DEVS SUBSYSTEM DISTRIBUTION

A FLIR can sense the energy of objects that is radiated in the infrared portion of the electromagnetic spectrum. FLIRs can be used to improve visual awareness in smoky, foggy or dark environments. For simplicity, a FLIR can be thought of as a video camera that sees heat instead of light. FLIR cameras have a lens, electronics and controls like video cameras that are used to produce a thermal image. They also require an electronic display or monitor to view the thermal image. Figure 5 shows the primary components of the night vision subsystem.

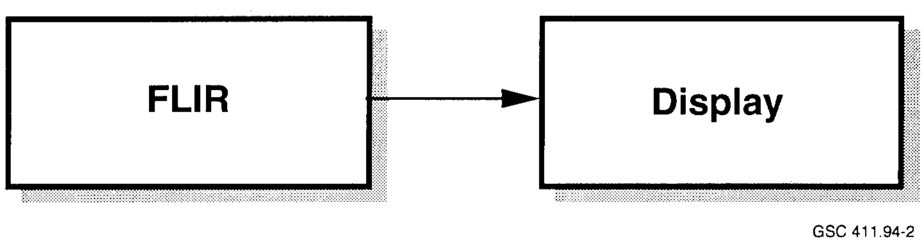


FIGURE 5. NIGHT VISION SUBSYSTEM

FLIR cameras cannot see through glass. This restriction limits the positioning of the FLIR to the outside of the ARFF vehicle. Research has shown that the line of sight of the FLIR should be aligned as closely as possible with the line of sight of the vehicle driver. The best place to mount the FLIR on most vehicles is on top of the cab, directly above the driver. The display used with the FLIR should be mounted near the inside roof of the cab and be as close to the driver's line of sight as possible.

The night vision subsystem should require no intervention by the ARFF vehicle driver for proper operation as a driver's aid. The FLIR should have automatic gain and level controls to ensure optimal performance. The display controls should be optimized at installation and should not require further adjustments. The orientation of the FLIR should be constant during driving operations but the capability to change the orientation from inside the vehicle cab should exist for search operations. This capability can be satisfied by mounting the FLIR on a pan and tilt platform with a remote control.

3.2 NAVIGATION SUBSYSTEM.

The purpose of the navigation subsystem is to make the ARFF vehicle driver aware of the vehicle's location, and to serve as an aid in locating the accident site. Early DEVS research determined that the best way to convey the vehicle position to the driver is by way of an electronic map display in the cab. Other research indicated that the Global Positioning System (GPS) provides a readily available source of vehicle position data but the accuracy (300 feet) is not sufficient to support DEVS. A Differential Global Positioning System (DGPS) is accurate enough to support DEVS (10 to 15 feet) and is the preferred navigation sensor. Other sensors that measure heading and distance traveled are recommended for dead reckoning when DGPS position solutions are not available.

DGPS works on the principle that position errors will be about the same for GPS receivers operating in the same general area. If one of these receivers has an antenna positioned at a precisely known location, the error in that receiver's determined position can be computed. This computed position error can then be broadcast to other GPS receivers in the area and used to improve the accuracy of their position solutions.

Dead reckoning is a navigation method which uses distance traveled and heading information to extrapolate a vehicle's position from the last known point. A flux gate compass and digital odometer are two possible sensors for dead reckoning. The dead reckoning capability would be very useful when the vehicle first leaves the fire house and at other times when GPS signals are unavailable.

The navigation subsystem based on DGPS requires hardware and software to be installed in ARFF vehicles and the ECC. Figure 3 shows what hardware is required and where it resides for a representative DGPS based navigation subsystem. There is more than one correct way to implement a DGPS navigation capability. For the implementation shown in figure 6, the ARFF vehicles are equipped with a GPS receiver, a computer, a display, a Radio Frequency (RF) transceiver and a radio modem. The RF transceiver and radio modem are used to receive differential correction messages from the DGPS base station at the ECC. The DGPS base station at the ECC consists of a computer, a display, a GPS receiver, an RF transceiver and a radio modem.

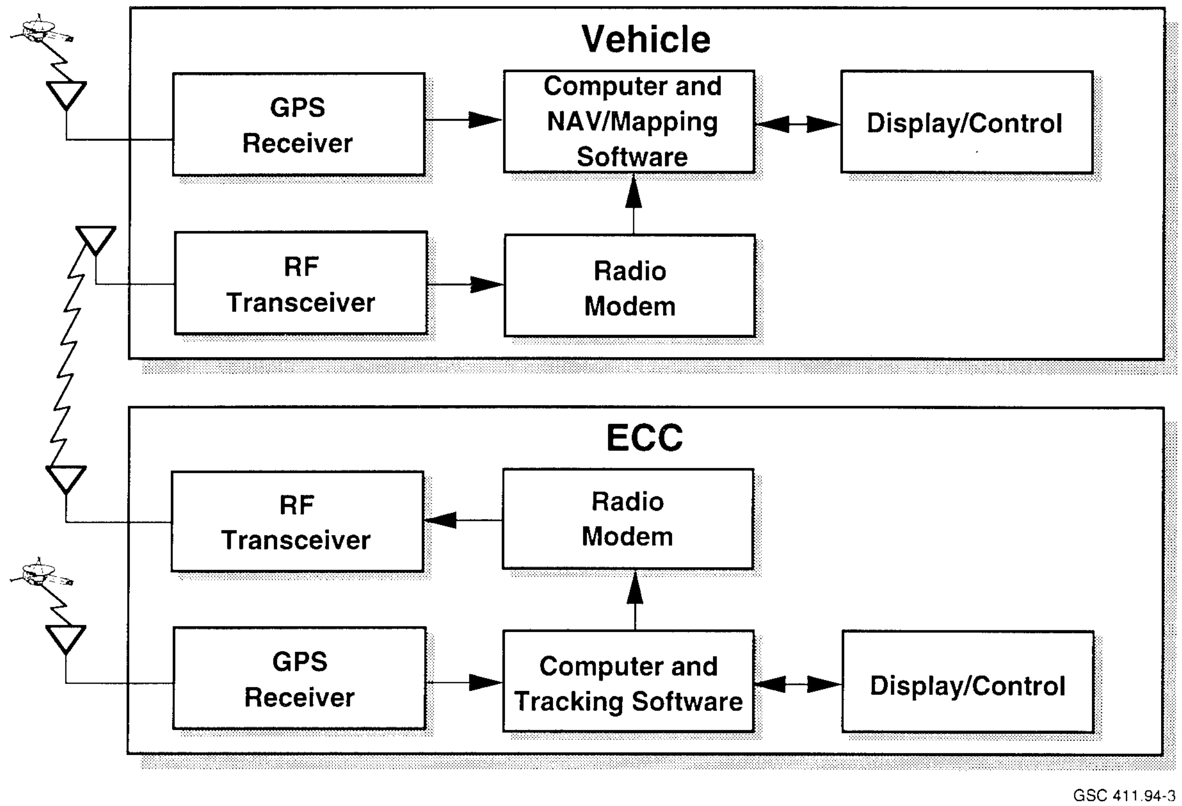


FIGURE 6. NAVIGATION SUBSYSTEM

Software on the vehicle computer processes differential correction messages received from the DGPS base station to improve the GPS derived position solution. The improved ARFF vehicle position solution is then displayed on the electronic map display as an icon.

The electronic map in the vehicle should operate in at least two modes: (1) fixed map, moving vehicle mode, and (2) moving map, fixed vehicle mode. Fixed map mode would be in effect when the entire airport surface is being displayed. In this mode the vehicle icon would move about on the map image and the map would be fixed in a "North Up" orientation. Moving map mode would be in effect when a small section of the map is being displayed in detail. In this mode, the vehicle would remain at a fixed location on the display while the map moves underneath it. The preferred frame of reference in this mode is called a "heading up" orientation. It prevents drivers from becoming disoriented. If the map suggests the driver should make a right hand turn, the driver should make a right hand turn. An alternate approach to this moving map, fixed vehicle mode of operation is to use a fixed north up map with driving cues such as directional arrows or lines that convey the vehicle orientation.

The navigation subsystem software on the vehicle computer also controls operation of the map display and all features of the operator interface. For example, there should be an ability to "zoom" in and out on the map display to show different percentages of the area of interest. The map should include at least the following four levels of detail:

a. Level 1 — The "driving area", 1/2 mile in front of the vehicle, in a heading-up orientation.

b. Level 2 — The Airport Operational Area (AOA);

c. Level 3 — The area out to the airport property boundary including dirt access roadways; and

d. Level 4 — The area surrounding the airport, minimum of 5 miles from the airport center in all directions.

The software should also allow the operator to pan left, right, up or down to look at different areas on the map.

Software on the DGPS base station computer formats DGPS correction messages and controls the transmission of these messages to the vehicles. This software would also control other aspects of the DGPS base station such as reference antenna position surveying.

3.3 TRACKING SUBSYSTEM.

Research indicates that adding an ARFF vehicle tracking capability to DEVS will reduce driver communications work load and improve the situational awareness of the driver and command or dispatch personnel. The main function of the tracking subsystem is to transmit the vehicle position to the ECC. This function improves the situational awareness of dispatch personnel. Another function is to allow the vehicle operator to transmit messages associated with the vehicle location to the ECC. For example, the vehicle operator could request an ambulance, police backup or other assets at his current location by pressing a button. This feature reduces driver work load.

The vehicle tracking capability can be tightly integrated with the navigation subsystem so little additional hardware is required in the vehicles. The tracking subsystem can be implemented by adding an RF transceiver and radio modem for the data link to the ECC. Vehicle tracking functionality can be added to the software that runs on the navigation subsystem vehicle computer. The equipment required at the ECC consists of an RF transceiver and modem, a computer and display screen. It is also possible to integrate tracking subsystem functionality in the ECC with DGPS base station hardware and software. Figure 7 shows the equipment required for the DEVS tracking subsystem.

The tracking subsystem software that runs on the vehicle computer is primarily responsible for formatting and transmitting vehicle position report messages to the ECC. This software also prepares and transmits other messages such as the asset request messages described above. Besides message transmission, this software also receives and interprets messages from the ECC. For example, the tracking subsystem data link could be used to transmit the location of an accident site from the ECC to a vehicle. The tracking subsystem vehicle software would receive the accident position location message and display an icon at the correct location on the vehicle electronic map.

The tracking subsystem software that runs at the ECC computer is primarily responsible for receiving vehicle position reports and displaying vehicle icons at the correct locations on a map display similar to the one in the vehicle. The ECC tracking subsystem hardware and software should be set up to display the position of many vehicles simultaneously. Preliminary estimates indicate that it may be desirable to track as many as 100 vehicles. Other functions of the tracking subsystem software on the ECC computer include formatting and transmitting messages to the vehicles and receiving and processing messages from the vehicles.

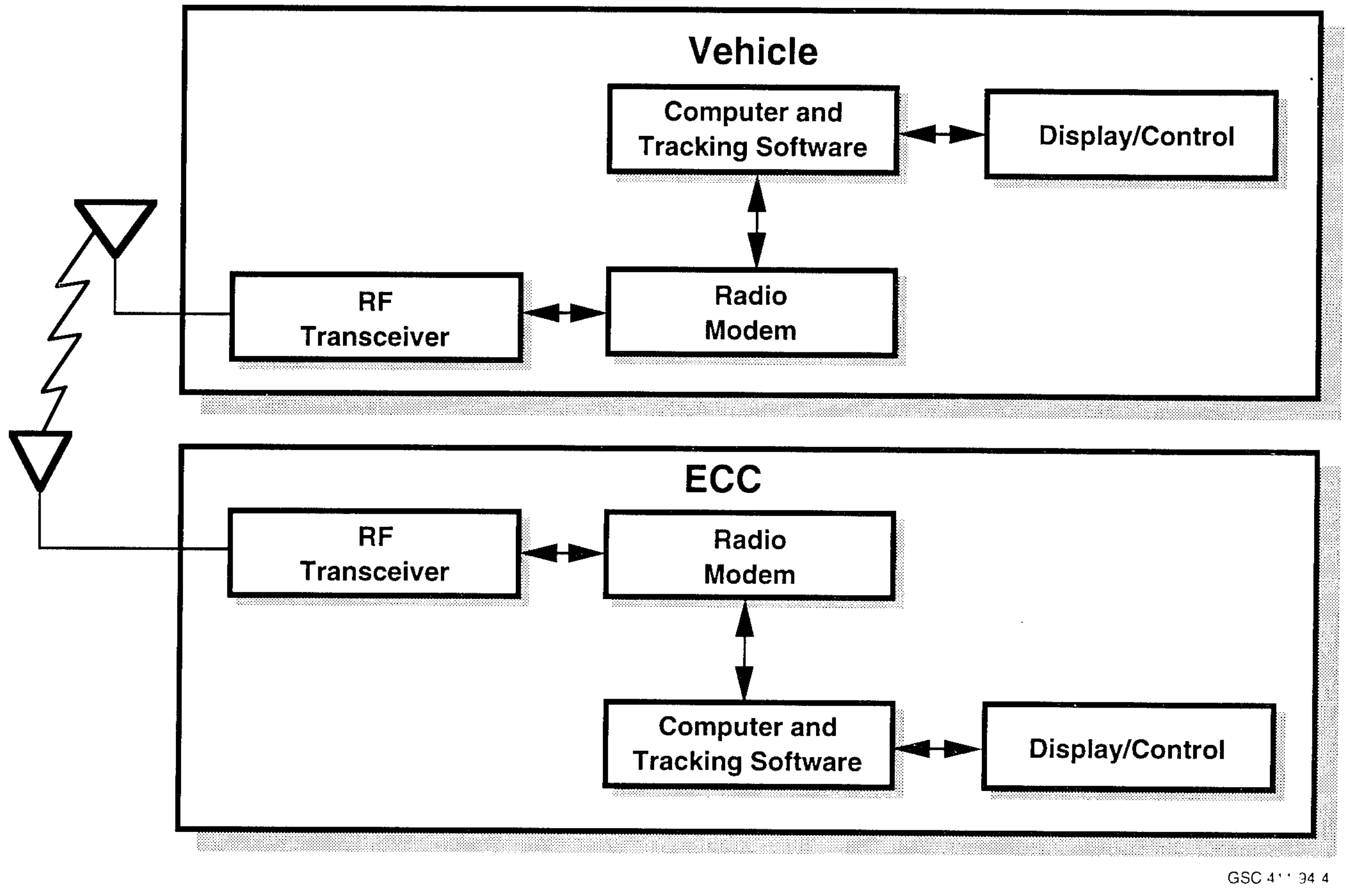


FIGURE 7. TRACKING SUBSYSTEM

3.4 OPERATIONAL SCENARIO.

The following scenario describes how DEVS would be used in an emergency.

On a dark, foggy night, airport operations are restricted by Category II visibility conditions. Because of this restriction, airport operations are slowed but not stopped. The ARFF crew stationed at the airport takes the usual low visibility precautions. Communications channels are checked every 30 minutes and the DEVS is put in standby mode by plugging the auxiliary power unit into a 115-Volts Alternating Current (VAC) wall socket, and setting the mode switch to "standby." In standby mode, the DEVS night vision subsystem is capable of producing an image that is useful for driving within 30 seconds.

The DEVS navigation subsystem is automatically initialized for the location of the firehouse and the current date and time.

Later that evening, two commuter jets collide at the intersection of runway 13 and taxiway C. Air traffic controllers activate the emergency alarm and then phone the airport operation duty officer and ARFF dispatcher to describe the approximate location of the accident. The ARFF dispatcher enters the accident location at the DEVS vehicle tracking subsystem base station by pointing to the intersection of runway 13 and taxiway C on the airport map display with the mouse and clicking. This location is then transmitted to the ARFF vehicles by pressing the transmit key.

When the alarm sounds at the firehouse, ARFF crew members climb into their vehicles. DEVS continues to operate in standby mode until the vehicle engines are started. When the engines are started, DEVS automatically transitions to its operational state and "pop out plugs" use compressed air or electric solenoids to disconnect the truck from 115 VAC. Before the ARFF vehicles leave the firehouse ramp area (about 30 seconds), the night vision subsystem is completely operational and the navigation subsystem is computing the vehicle's position to within 10 feet.

The DEVS map display comes up in the "airfield view" mode which shows the runways and taxiways. Depending on the location of the accident, the driver may choose to select the "airport view" which shows the area inside the airport boundary or the "airport plus view" which shows the area within a 3-mile radius of the airport. The driver proceeds to the accident site and monitors his progress on the DEVS map display. The driver negotiates the terrain and locates the accident site with the aid of the image generated by the night vision subsystem.

When the first ARFF vehicle appears at the accident scene, it relays its position back to the ARFF dispatcher at the DEVS vehicle tracking subsystem base station. The dispatcher then uses the vehicle tracking subsystem base station to broadcast the updated accident location to all ARFF vehicles equipped with DEVS.

4. DEVS PERFORMANCE CHARACTERISTICS.

Desirable subsystem characteristics have been identified through research conducted during the course of this project. The characteristics outlined in the following sections are meant to serve as a set of minimal performance requirements that DEVS equipment should meet for use at airports. General specifications that apply to the entire DEVS system are presented first, followed by specifications for the night vision, navigation and tracking subsystems. The navigation and tracking functions are presented as individual subsystems to maintain consistency with the functional description presented in section 3. ARFF research group recommends that developers who offer both of these functions provide only one operator interface that appears to be one integrated navigation/tracking subsystem.

4.1 GENERAL.

The following performance requirements apply to all DEVS subsystems.

4.1.1 Driver Work Load.

Operation of DEVS must not increase ARFF vehicle driver work load during a response to an aircraft emergency.

4.1.2 Modifications to Existing Vehicles.

Installation of DEVS equipment in existing ARFF vehicles should not require extensive modifications to the vehicles.

4.1.3 Obstruction of Driver's View.

DEVS equipment installed in ARFF vehicles should not obstruct the driver's view out of the ARFF vehicle windshield.

4.1.4 Power Characteristics.

A source of "clean" power should be available for all DEVS hardware. This includes equipment installed in ARFF vehicles and equipment installed in buildings. The power required to operate DEVS equipment must be free from voltage spikes and current surges.

4.1.5 Vehicle Power Isolation.

The DEVS hardware installed in ARFF vehicles must be electrically isolated from the noisy vehicle electrical system. If power is drawn from the vehicle, it must be sufficiently filtered to prevent vehicle electrical system noise and voltage variations from entering the sensitive electronics of the DEVS system. It is up to individual ARFF departments to determine whether sufficient capacity exists in the vehicle to power DEVS, or if a physically isolated power system should be provided with the DEVS system.

4.1.6 Estimated Power Loading.

The power source used to operate DEVS equipment installed in ARFF vehicles should be able to power the maximum load of the system for a minimum of 4 hours. The power source used to operate DEVS equipment installed in buildings should also be able to power the maximum load of the system for a minimum of 4 hours.

4.1.7 Recommended Voltage Levels.

The recommended operating voltage range for DEVS equipment installed in ARFF vehicles is 10- to 15-VDC. The recommended operating voltage range for DEVS equipment located at the ECC is 110- to 120-VAC.

4.2 NIGHT VISION SUBSYSTEM.

The following performance requirements describe desirable characteristics of the night vision subsystem. The night vision subsystem is composed of a FLIR camera and a display monitor.

4.2.1 General.

The following performance requirements pertain to the night vision subsystem.

4.2.1.1 Time to Become Operational.

The night vision subsystem must be able to transition from an off or standby mode to an operational mode within 30 seconds.

4.2.1.2 Operator Workload.

The night vision subsystem must not increase the ARFF vehicle driver work load. The subsystem must be capable of operating with little or no operator intervention.

4.2.1.3 Expected Worst Case Visibility.

The night vision subsystem must provide an image which can be used to drive the crash/fire rescue vehicle under 0/0 visibility conditions.

4.2.1.4 Detection of Objects Close to Fires.

The night vision subsystem must be able to detect people, debris, wreckage, and equipment near a fire. For example, the night vision subsystem must be able to detect people, debris, wreckage, and equipment within 20 feet of a six-foot diameter Jet A fuel fire from a range of 1000 feet.

4.2.1.5 Detection of Humans.

The night vision subsystem must be able to detect people under the following conditions:

TABLE 2. HUMAN DETECTION DISTANCES

Distance	Ambient Temperature	Humidity (%)	Camera Dynamics	Weather
500 ft.	-20 to 115°F	0 to 100	Moving 55 mph	Clear
500 ft.	-20 to 115°F	0 to 100	Moving 50 mph	Light Fog
400 ft.	-20 to 115°F	0 to 100	Moving 40 mph	Heavy Fog
400 ft.	-20 to 115°F	0 to 100	Moving 40 mph	Smoke
300 ft.	-20 to 115°F	0 to 100	Moving 35 mph	Rain/Snow

4.2.1.6 Detection of Aircraft.

The night vision subsystem must be able to detect a typical General Aviation aircraft under the following conditions:

4.2.2 FLIR.

The following performance requirements pertain to the night vision subsystem FLIR.

TABLE 3. AIRCRAFT DETECTION DISTANCES

Distance	Ambient Temperature	Humidity (%)	Camera Dynamics	Weather
2500 ft.	-20 to 115°F	0 to 100	Moving 55 mph	Clear
1000 ft.	-20 to 115°F	0 to 100	Moving 50 mph	Light Fog
500 ft.	-20 to 115°F	0 to 100	Moving 40 mph	Heavy Fog
500 ft.	-20 to 115°F	0 to 100	Moving 40 mph	Smoke
500 ft.	-20 to 115°F	0 to 100	Moving 35 mph	Rain/Snow

4.2.2.1 IR Waveband.

The FLIR must be able to detect long wave (8-12 μm) IR energy.

4.2.2.2 Video Output.

The FLIR must have an industry standard video output such as RS-170.

4.2.2.3 Mounting.

The FLIR should be mounted outside, on top of the vehicle on a pan and tilt platform. The line of sight of the FLIR should be aligned with the line of sight of the vehicle driver.

4.2.2.4 Mounting Platform Remote Control.

A remote control unit for the pan and tilt platform should be installed inside the ARFF vehicle. The ability to determine the direction of the FLIR's line of sight.

4.2.2.5 Weatherproofing.

The FLIR must be weatherproof. It must produce a thermal image that can be used to drive by in rain, sleet, hail, snow, and fog.

4.2.2.6 Lens Clearing.

The FLIR should have a means of keeping rain, sleet, and snow from the lens. Two acceptable methods for achieving this are a windshield wiper that can be activated during periods of rain, sleet, and snow or by directing high pressure air across the lens surface.

4.2.2.7 Temperature and Humidity Changes.

The FLIR should be able to withstand the temperature and humidity changes that occur when ARFF vehicles go from inside to outside of the firehouse. For example, repeatedly going from a warm, heated fire house to a cool, humid outside environment should not cause condensation inside the FLIR housing.

4.2.2.8 Automatic Controls.

The FLIR should have automatic controls for performance parameters such as gain and level to ensure hand-free optimal performance.

4.2.2.9 Field of View.

The FLIR must have a Horizontal Field Of View (HFOV) of at least 28°, and a Vertical Field Of View (VFOV) of at least 20°. Wider HFOV and VFOV are preferred.

4.2.3 Display.

The following performance requirements pertain to the night vision system display.

4.2.3.1 Video Input.

The display should use an industry standard video format such as RS-170.

4.2.3.2 Controls.

The display should have brightness and contrast controls that are accessible to the vehicle operator. Ideally, the display brightness would adjust to ambient light conditions.

4.2.3.3 Color.

The display may be monochromatic.

4.2.3.4 Screen Size.

The display should have an eight to ten-inch diagonal screen.

4.3 NAVIGATION SUBSYSTEM.

The following performance requirements describe desirable characteristics of the navigation subsystem. The navigation subsystem requires installation of hardware and software in ARFF vehicles and the ECC. The vehicle hardware and software consists of a GPS receiver, a computer with navigation/mapping software, data link hardware, and display/control hardware. The ECC hardware and software consists of a GPS receiver, a computer with DGPS correction software, data link hardware, and display/control hardware.

4.3.1 General.

The following performance requirements pertain to the navigation subsystem.

4.3.1.1 Time to Become Operational.

The navigation subsystem equipment in the ARFF vehicle must be able to compute a vehicle position solution within 30 seconds from the time the ARFF vehicle leaves the fire house. The navigation subsystem equipment in the ECC must be able to generate differential GPS correction messages continuously (24 hours/day, 7 days/week).

4.3.1.2 Accuracy.

The navigation subsystem should be able to compute the two-dimensional position of the ARFF vehicle antenna to be within a circle with a radius of 15 feet centered on the actual antenna position.

4.3.1.3 Dead Reckoning.

The navigation subsystem should provide a dead reckoning capability for use when satellite track is lost. The dead reckoning position solution should be based on heading and distance sensors other than GPS.

4.3.1.4 Position Update Rate.

The navigation subsystem must provide a vehicle position update at least once every second.

4.3.1.5 Automatic Initialization and Operation.

The navigation subsystem equipment in the ARFF vehicle should be automatically initialized with the position of the vehicle and the correct date and time when the subsystem starts up. No actions will be required by the vehicle operator to initialize and operate the navigation subsystem.

4.3.1.6 Shock and Vibration.

The navigation subsystem equipment in the ARFF vehicle should be able to withstand the shock and vibration of the ARFF vehicle environment.

4.3.2 Vehicle GPS Receiver.

The following performance requirements pertain to the navigation subsystem GPS receiver in the ARFF vehicle.

4.3.2.1 DGPS Capability.

The vehicle GPS receiver should be able to accept differential correction messages in the Radio Technical Commission for Maritime Services (RTCM) SC-104 standard format. The receiver should be able to use these messages to compute a differentially corrected GPS position solution once a second.

4.3.2.2 Time to First Fix.

The vehicle GPS receiver should be able to achieve Time To First Fix (TTFF) of 30 seconds.

4.3.2.3 Antenna Mounting.

The vehicle GPS antenna should have a magnetic mount capability. The antenna should be mounted on top of the ARFF vehicle at the highest possible location with a clear view of the sky. It is best to have the antenna close to the center of the vehicle because the GPS receiver computes the position of the antenna.

4.3.2.4 Weatherproofing.

The vehicle GPS antenna or receiver/antenna should be weather resistant because it must be mounted on the vehicle exterior. GPS receiver performance should not be affected by rain, sleet, snow or other severe weather.

4.3.2.5 Interfaces.

The vehicle GPS receiver should interface with the vehicle computer.

4.3.3 Vehicle Computer.

The following performance requirements pertain to the navigation subsystem computer in the ARFF vehicle.

4.3.3.1 Processing Speed.

The vehicle navigation subsystem computer should provide the required processing power and speed to support DEVS navigation and mapping software and still have a 50 percent throughput capacity in reserve.

4.3.3.2 Memory.

The computer should provide enough volatile and non-volatile memory to support DEVS navigation and mapping software and associated data files. The memory capacity should be upgradable for future expansion of capabilities.

4.3.3.3 Hard Drive.

The computer should not use a hard drive. Solid state memory boards that simulate a hard drive are preferred.

4.3.3.4 Size and Weight.

The computer should be small and weigh as little as possible. Ideally, the computer should be about the same size as a standard laptop PC, or smaller.

4.3.3.5 Interfaces.

The vehicle computer should interface with the vehicle display/control, data link, and GPS receiver equipment.

4.3.4 Vehicle Navigation/Mapping Software.

The following performance requirements pertain to the navigation/mapping software that runs on the computer located in the ARFF vehicle.

4.3.4.1 Levels of Map Detail.

The map displayed in the ARFF vehicle should offer at least four levels of detail:

a. Level 1 — The “driving area,” 1/2 mile in front of the vehicle, in a heading-up orientation.

b. Level 2 — The Airport Operational Area (AOA);

c. Level 3 — The area out to the airport property boundary including dirt access roadways; and

d. Level 4 — The area surrounding the airport, minimum of 5 miles from the airport center in all directions.

It would also be useful to be able to zoom in on the AOA for greater detail.

4.3.4.2 Map Operation at Full Scale (Level 4).

When the digital map is "zoomed out" to full scale (Level 3), an icon showing the ARFF vehicle position should move on the map display to indicate the location of the moving ARFF vehicle. If the ARFF vehicle goes outside of the map boundary, an indicator should show the last known position and direction of the ARFF vehicle. The map should always remain in a "North Up" orientation.

4.3.4.3 Map Operation at Reduced Scales (Levels 2 and 3).

When the map is at the airport boundary level or the airport movement area level (Level 3 or Level 2), the map should be stationary on the display and the ARFF vehicle position icon should move. If the ARFF vehicle goes outside of the displayed map area, the map should "slide" or pan to recenter the ARFF vehicle icon. The map should always remain in a "North Up" orientation.

4.3.4.4 Map Operation at Reduced Scale (Level 1)

If the map is "zoomed in" beyond the airport movement area level (Level 1), the location of the ARFF vehicle icon should remain fixed near the bottom of the screen, and the map should translate and rotate to maintain this position with a "Heading up" orientation.

4.3.4.5 Vehicle Orientation and FLIR Visual Cues.

At scales where the map does not display in a "Heading up" orientation, visual cues describing the vehicle orientation should be displayed on the map. One suggested visual cue is a wedge attached to the vehicle icon that corresponds to the driver's FOV. One side of the wedge should be blue and one yellow representing the left and right edges of the FOV respectively. A third black line that bisects the wedge should be used to indicate the vehicle's heading. In addition, an indicator of the direction in which the FLIR is pointed is recommended.

4.3.4.6 Information Displayed on Map.

The information displayed on the map should include primary and secondary roadways, all surfaces of the airport movement area, and significant buildings and landmarks.

4.3.4.7 Other Map Control Features.

Besides displaying different levels of map detail by zooming in and out, the mapping software should allow the vehicle operator to pan to areas on the map other than the area occupied by the vehicle. The operator should also be able to select a variable sized area of the map to display on the entire map screen.

4.3.5 Vehicle Data Link.

The following performance requirements pertain to the data link equipment in the ARFF vehicle that is used to receive DGPS correction messages.

4.3.5.1 Messages Received.

The vehicle navigation data link equipment must be capable of receiving DGPS correction messages. The source of the correction messages can be a locally installed DGPS base station, a United States Coast Guard DGPS base station, or a commercially available subscription service. A locally installed DGPS base station is the preferred source of correction messages.

4.3.5.2 Messages Transmitted.

The vehicle navigation data link does not require messages to be transmitted from the vehicle.

4.3.5.3 Error Checking.

The vehicle navigation data link should employ standard error checking algorithms, such as check sums and parity checks, to ensure correct receipt of messages. If possible, a handshake mechanism should be built into the data link to confirm receipt of messages from the DGPS base station.

4.3.5.4 Frequency Selection.

The ECC navigation data link should use currently allocated ARFF communications frequencies whenever possible.

4.3.5.5 Interfaces.

The vehicle navigation data link should interface with the vehicle computer.

4.3.6 Vehicle Display/Control.

The following performance requirements pertain to the display/control equipment for the navigation/ mapping subsystem in the ARFF vehicle.

4.3.6.1 Display Color.

The map display should provide at least 16 colors. Monochromatic displays are acceptable but not preferred.

4.3.6.2 Display Type.

The map display can be a Transparent Window Display System (TWDS) or a Head Up Display (HUD). Standard head down displays are also acceptable if positioned near "natural" line-of-sight.

4.3.6.3 Display Brightness.

Map display brightness should be adjustable for ambient lighting conditions using a control that is accessible to the vehicle driver. The display should be bright enough to be seen in daylight and must not be too bright at night.

4.3.6.4 Contrast Ratio.

The map display should be capable of achieving a contrast ratio of at least 3:1. The contrast ratio is defined as follows:

$$\text{Contrast} = \frac{\text{Luminance emitted by screen area of greatest intensity}}{\text{Luminance emitted by screen area of least intensity}}$$

The contrast ratio should be adjustable using a control. Once the desired contrast ratio has been achieved, it should remain constant as overall screen brightness is adjusted.

4.3.6.5 Mounting.

The map display should be mounted so it is easily seen by the vehicle driver but does not obstruct the view out of the windshield.

4.3.6.6 Navigation/Mapping System Control.

The navigation/mapping system should require little operator intervention to control. Therefore, only a simple operator control mechanism is required. A display with programmable buttons is the preferred control device. A touch screen, or programmable keypad tailored for DEVS are also acceptable control devices. Standard computer control devices, such as a keyboard and mouse, should not be required to use DEVS under operational conditions. These devices are acceptable, however, for use during non-operational functions such as database and software updating.

4.3.6.7 Digital Format.

The navigation/mapping system display should use an industry standard digital format that meets or exceeds the VGA standard.

4.3.6.8 Screen Size.

The navigation/mapping system display should have an eight to ten-inch diagonal screen size.

4.3.6.9 Interfaces.

The navigation/mapping system display and control equipment should interface with the vehicle computer and the firefighter operating the vehicle.

4.3.7 DGPS Base Station GPS Receiver.

The following performance requirements pertain to the GPS receiver that is used for a DGPS base station. Alternative means for supplying DGPS corrections may be used, provided that accuracy exceeds 5 m and availability and reliability are assured. Alternative sources of DGPS corrections are outlined in Section 5.1.2.2.

4.3.7.1 Satellite Tracking.

The DGPS base station GPS receiver should be able to track the same satellites that are tracked by the GPS receiver in the ARFF vehicles. To assure that the same satellites are tracked, an "all in view" DGPS base station receiver should be used. This receiver should have a minimum of eight channels but a twelve-channel receiver is preferred.

4.3.7.2 DGPS Correction Messages.

The DGPS base station receiver should be able to generate differential correction messages in RTCM SC-104 standard format.

4.3.7.3 Position Update Rate.

The DGPS base station receiver must be capable of computing a position solution at least once every second.

4.3.7.4 Continuous Operation.

The DGPS base station receiver must be capable of operating 24 hours a day, 7 days a week.

4.3.7.5 Antenna Mounting.

The DGPS base station receiver antenna should be mounted at a location with a clear view of the sky. The exact location of this antenna must be known with a high degree of accuracy. Ideally, the antenna should be on a survey monument. If an existing survey monument is not available, the position of the DGPS receiver antenna should be surveyed and accurately determined to within 3 feet.

4.3.7.6 Interfaces.

The DGPS base station receiver should interface with the ECC navigation computer.

4.3.8 ECC Computer.

The ECC computer is the navigation subsystem computer which controls the DGPS base station. The anticipated location of this computer is at the ECC. This computer can be an integral part of the DGPS base station GPS receiver. If not, the following performance requirements apply. The following performance requirements pertain to the GPS receiver that is used for a DGPS base station. As noted in section 4.3.7, alternative means for supplying DGPS corrections may be used, obviating the need for the base station and interfaces to it.

4.3.8.1 Processing Speed.

The ECC computer should provide the required processing power and speed to support DEVS navigation software and still have a 50 percent throughput capacity in reserve.

4.3.8.2 Memory.

The computer should provide enough volatile and non-volatile memory to support DEVS navigation software and associated data files. The memory capacity should be upgradable for future expansion of capabilities.

4.3.8.3 Hard Drive.

The computer should use a hard drive that provides enough capacity to support DEVS navigation software.

4.3.8.4 Size and Weight.

The computer should be small and weigh as little as possible. Ideally, the computer should not be much bigger than a standard desk top PC.

4.3.8.5 Interfaces.

The computer should interface with the DGPS base station receiver, the ECC data link equipment, and the computer display/control equipment.

4.3.9 ECC DGPS Software.

The following performance requirements pertain to the ECC DGPS software that runs on the ECC computer. As noted in section 4.3.7, alternative means for supplying DGPS corrections may be used, obviating the need for DGPS software in the ECC.

4.3.9.1 DGPS Message Formatting.

The ECC DGPS software performs any additional formatting to the RTCM SC-104 standard format DGPS correction messages generated by the DGPS base station receiver.

4.3.9.2 Message Flow Control.

The ECC DGPS software controls the flow and timing of DGPS correction messages from the DGPS base station receiver to the data link equipment.

4.3.10 ECC Data Link.

The following performance requirements pertain to the ECC data link equipment used to transmit DGPS correction messages to ARFF vehicles.

4.3.10.1 Messages Received.

The ECC navigation data link does not require messages to be received at the ECC.

4.3.10.2 Messages Transmitted.

The ECC navigation data link equipment must be capable of transmitting DGPS correction messages. The transmitted messages must have built-in error checking or correcting codes such as check sums and parity.

4.3.10.3 Transmission Power.

The ECC navigation data link should transmit with sufficient power to facilitate broadcast of DGPS correction messages to all areas where the ARFF vehicles would be expected to respond.

4.3.10.4 Frequency Selection.

The ECC navigation data link should use currently allocated ARFF communications frequencies whenever possible.

4.3.10.5 Interfaces.

The ECC navigation data link should interface with the ECC computer.

4.3.11 ECC Display/Control.

The ECC display and control equipment is used to provide the operator interface with the ECC Computer. If the ECC computer is not an integral part of the DGPS base station GPS receiver, the following requirements pertain to the display and control equipment.

4.3.11.1 Display Color.

The ECC display should provide at least 16 colors. Monochromatic displays are acceptable but not preferred.

4.3.11.2 Display Type.

The ECC display should be a standard CRT or LCD type of display.

4.3.11.3 Display Brightness.

Map display brightness should be adjustable for ambient lighting conditions using a control knob that is accessible to the operator.

4.3.11.4 Contrast Ratio.

The map display should be capable of achieving a contrast ratio of at least 3:1. The contrast ratio is defined as follows:

$$\text{Contrast} = \frac{\text{Luminance emitted by screen area of greatest intensity}}{\text{Luminance emitted by screen area of least intensity}}$$

The contrast ratio should be adjustable using a control knob. Once the desired contrast ratio has been achieved, it should remain constant as overall screen brightness is adjusted.

4.3.11.5 ECC Navigation Control.

Standard computer control devices, such as a keyboard and mouse, are acceptable control devices for the ECC navigation subsystem. Touch screens and key pads are also acceptable.

4.3.11.6 Digital Format.

The navigation/mapping system display should use an industry standard digital format that meets or exceeds the VGA standard.

4.3.11.7 Screen Size.

The navigation/mapping system display should have a fourteen-inch or larger diagonal screen size.

4.3.11.8 Interfaces.

The ECC navigation subsystem display and control equipment should interface with the ECC computer and the computer operator.

4.4 TRACKING SUBSYSTEM.

The following performance requirements describe desirable characteristics of the tracking subsystem. It is assumed that a tracking subsystem will derive vehicle position data from the navigation subsystem. The tracking subsystem requires installation of hardware and software in ARFF vehicles and the ECC. The vehicle hardware and software consists of a computer with tracking/communications software, data link hardware, and display/control hardware. The ECC hardware and software consists of a computer with tracking/communications software, data link hardware and display/control hardware. The navigation subsystem hardware should support the tracking subsystem function.

4.4.1 General.

The following performance requirements pertain to the tracking subsystem.

4.4.1.1 Time to Become Operational.

The tracking subsystem equipment in the ARFF vehicle must be able to report the vehicle position to and exchange messages with the ECC within 30 seconds from the time the ARFF vehicle leaves the fire house. The tacking subsystem equipment in the ECC must be able to display vehicle locations and exchange messages with vehicles continuously (24 hours/day, 7 days/week).

4.4.1.2 Capacity.

The tracking subsystem should be able to initially track at least forty vehicles simultaneously and be upgradable to track one hundred vehicles.

4.4.1.3 Position Update Rate.

The tracking subsystem must provide updated vehicle positions at the ECC at least once every second.

4.4.1.4 Automatic Initialization.

The tracking subsystem equipment in the ARFF vehicle should be automatically initialized when the subsystem starts up.

4.4.1.5 Minimal Operator Intervention.

The actions required by the vehicle driver to operate the tracking subsystem will be minimal. For example, the operator should be able to transmit pre-defined messages by selecting no more than three menu choices.

4.4.1.6 Shock and Vibration.

The tracking subsystem equipment in the ARFF vehicle should be able to withstand the shock and vibration of the ARFF vehicle environment.

4.4.2 Vehicle Computer.

The following performance requirements pertain to the tracking subsystem computer located in the ARFF vehicle. If possible, the tracking subsystem should use the same computer hardware as the navigation subsystem.

4.4.2.1 Processing Speed.

The vehicle tracking subsystem computer should provide the required processing power and speed to support DEVS tracking software and still have a 50 percent throughput capacity in reserve.

4.4.2.2 Memory.

The computer should provide enough volatile and non-volatile memory to support DEVS tracking software and associated data files. The memory capacity should be upgradable for future expansion of capabilities.

4.4.2.3 Hard Drive.

The computer should not use a hard drive. Solid state memory boards that simulate a hard drive are preferred.

4.4.2.4 Interfaces.

The vehicle computer should interface with the vehicle display/control and data link equipment.

4.4.3 Vehicle Tracking Software.

The following performance requirements pertain to the tracking subsystem software that runs on the computer located in the ARFF vehicle.

4.4.3.1 Vehicle Position Reports.

The vehicle tracking software should format and transmit vehicle position reports to the ECC once a second.

4.4.3.2 Asset Request Messages.

The vehicle tracking software should be able to transmit asset request messages to the ECC by touching a single button. Assets include police, fire, or ambulance services. These messages request the asset be sent to the current vehicle location. An icon indicating the vehicle position when the asset request message was sent should be displayed on the map display in the vehicle.

4.4.3.3 Vehicle Position Mark.

The vehicle tracking software should be able to mark the current vehicle position, display an icon at that location on the map display in the vehicle and transmit a message to the ECC that reports that marked location.

4.4.3.4 ECC Message Processing.

The following messages transmitted from the ECC will be processed as described:

a. Accident Site Location — An icon indicating the accident site will be displayed on the vehicle map display. If the accident site is off the map, an icon indicating the direction of the accident site should be displayed.

b. Text Message — Informational Text messages transmitted from the ECC should "pop up" automatically on the map display screen. The message display should be cleared with the touch of one button. Clearing the display should also send an acknowledgment message to the ECC.

4.4.4 Vehicle Data Link.

The following performance requirements pertain to the vehicle tracking subsystem data link equipment located in the ARFF vehicle.

4.4.4.1 Messages Received.

The vehicle tracking data link equipment must be capable of receiving accident location and text messages from the ECC.

4.4.4.2 Messages Transmitted.

The vehicle tracking data link equipment must be capable of transmitting vehicle position report, vehicle mark report and asset request messages to the ECC.

4.4.4.3 Error Checking.

The vehicle tracking data link should employ standard error checking algorithms such as check sums and parity checks to ensure correct receipt of messages. The same convention should apply to messages transmitted to the ECC.

4.4.4.4 Message Transmission Handshake.

A message transmission handshake should be established between the vehicle and the ECC. A message should be transmitted from the vehicle to the ECC each time a message is received from the ECC.

4.4.4.5 Frequency Selection.

The ECC navigation data link should use currently allocated ARFF communications frequencies whenever possible.

4.4.4.6 Transmission Power.

The ECC tracking data link equipment in the ARFF vehicles should be able to transmit messages from the ARFF vehicles to the ECC from any location within the area where ARFF vehicles are expected to respond.

4.4.4.7 Interfaces.

The vehicle tracking data link should interface with the vehicle computer.

4.4.5 Vehicle Display/Control.

The following performance requirements pertain to the display/control equipment for the tracking subsystem that is located in the ARFF vehicle. If possible, the tracking subsystem should use the same display/control hardware as the navigation subsystem.

4.4.5.1 Display Color.

The tracking display should provide at least 16 colors. Monochromatic displays are acceptable but not preferred.

4.4.5.2 Display Type.

The tracking display can be any type of display capable of providing required brightness and contrast for viewing. The two most likely candidates are flat LCD displays and standard CRT monitors. LCDs have the advantage of easier mounting within the cab confines. More exotic displays, like Heads Up Displays (HUDs) are also acceptable.

4.4.5.3 Display Brightness.

Tracking display brightness should be adjustable for ambient lighting conditions using a control knob that is accessible to the vehicle driver. The display should be bright enough to be seen during the daylight and must not be too bright at night.

4.4.5.4 Contrast Ratio.

The tracking display should be capable of achieving a contrast ratio of at least 3:1. The contrast ratio is defined as follows:

$$\text{Contrast} = \frac{\text{Luminance emitted by screen area of greatest intensity}}{\text{Luminance emitted by screen area of least intensity}}$$

The contrast ratio should be adjustable using a control knob. Once the desired contrast ratio has been achieved, it should remain constant as overall screen brightness is adjusted.

4.4.5.5 Mounting.

The tracking display should be mounted such that it is easily seen by the vehicle driver but does not obstruct the view out of the windshield.

4.4.5.6 Tracking Subsystem Control.

The tracking subsystem should require little operator intervention to control. For this reason, a very simple operator control mechanism is required. A display with programmable buttons is the preferred control device. A touch screen, or programmable keypad tailored for DEVS are also acceptable. Standard computer control devices such as a keyboard and mouse should not be required to use DEVS under operational conditions. These devices are acceptable, however, for use during non-operational functions such as database and software updating.

4.4.5.7 Digital Format.

The tracking subsystem display should use an industry standard digital format that meets or exceeds the VGA standard.

4.4.5.8 Screen Size.

The tracking subsystem display should have an eight to ten-inch diagonal screen size.

4.4.5.9 Interfaces.

The tracking subsystem display and control equipment should interface with the vehicle computer and the firefighter operating the vehicle.

4.4.6 ECC Computer.

The following performance requirements apply to the ECC tracking subsystem computer. If possible, the tracking subsystem should use the same computer hardware as the navigation subsystem.

4.4.6.1 Processing Speed.

The ECC computer should provide the required processing power and speed to support DEVS tracking software and still have a 50 percent throughput capacity in reserve.

4.4.6.2 Memory.

The computer should provide enough volatile and non-volatile memory to support DEVS tracking software and associated data files. The memory capacity should be upgradable for future expansion of capabilities.

4.4.6.3 Hard Drive.

The computer should use a hard drive that provides enough capacity to support DEVS tracking software.

4.4.6.4 Size and Weight.

The computer should be as small and weigh as little as possible. Ideally, the computer should not be much bigger than a standard desk top PC.

4.4.6.5 Interfaces.

The computer should interface with the ECC data link and control/display equipment.

4.4.7 ECC Tracking Software.

The following performance requirements pertain to the tracking software that runs on the computer located at the ECC.

4.4.7.1 Digital Map.

The ECC tracking software should display the locations of DEVS equipped ARFF vehicles on a digital map of the airport and surrounding area.

4.4.7.2 Levels of Map Detail.

The map displayed at the ECC should offer at least three levels of detail:

a. Level 1—The AOA;

b. Level 2—The area within the airport property boundary including dirt access roadways; and

c. Level 3—The area within a 3- to 4-mile radius of the airport center.

It would also be useful to be able to zoom in on the AOA for greater detail.

4.4.7.3 Map Operation at All Scales.

Icons showing ARFF vehicle positions should move on the map display to indicate the locations of the moving ARFF vehicles. If an ARFF vehicle goes outside of the map boundary, an indicator should show the last known position and direction of the vehicle. The map should always remain in a "North Up" orientation.

4.4.7.4 Information Displayed on Map.

The information displayed on the map should include primary and secondary roadways, all surfaces of the airport movement area, and significant buildings and landmarks.

4.4.7.5 Other Map Control Features.

In addition be being able to display different levels of map detail by zooming in and out, the mapping software should allow the operator to change the area of the map displayed by panning in any desired direction. The operator should also be able to select a variable sized area of the map to display on the entire display screen.

4.4.7.6 Vehicle Icons.

Icons indicating ARFF vehicle positions should have an identification tag associated with them. The ability to display or not display these identification tags should be provided.

4.4.8 ECC Data Link.

The following performance requirements pertain to the ECC data link equipment used to track ARFF vehicles.

4.4.8.1 Messages Received.

The ECC tracking data link receives position report, position mark, and asset request messages from ARFF vehicles.

4.4.8.2 Messages Transmitted.

The ECC tracking data link transmits accident location and text messages to ARFF vehicles.

4.4.8.3 Transmission Power.

The ECC tracking data link should transmit with sufficient power to facilitate transmission of messages to all areas where ARFF vehicles would be expected to respond.

4.4.8.4 Frequency Selection.

The ECC navigation data link should use currently allocated ARFF communications frequencies whenever possible.

4.4.8.5 Interfaces.

The ECC tracking data link should interface with the ECC computer.

4.4.8.6 Error Checking.

The ECC tracking data link should employ standard error checking algorithms such as check sums and parity checks to ensure correct receipt of messages. The same convention should apply to messages transmitted to ARFF vehicles.

4.4.8.7 Message Transmission Handshake.

A message transmission handshake should be established between the ECC and ARFF vehicles. A message should be transmitted from the ECC to the vehicle each time a message is received from a vehicle.

4.4.9 ECC Display/Control.

The ECC display and control equipment is used to provide the operator interface with the ECC Computer. If possible, the tracking subsystem should use the same display/control hardware as the navigation subsystem.

4.4.9.1 Display Color.

The ECC display should provide at least 256 colors. Monochromatic displays are acceptable but not preferred.

4.4.9.2 Display Type.

The ECC display should be a standard CRT or LCD type of display.

4.4.9.3 Display Brightness.

Display brightness should be adjustable for ambient lighting conditions using a control knob that is accessible to the operator.

4.4.9.4 Contrast Ratio.

The display should be capable of achieving a contrast ratio of at least 3:1. The contrast ratio is defined as follows:

$$\text{Contrast} = \frac{\text{Luminance emitted by screen area of greatest intensity}}{\text{Luminance emitted by screen area of least intensity}}$$

The contrast ratio should be adjustable using a control knob. Once the desired contrast ratio has been achieved, it should remain constant as overall screen brightness is adjusted.

4.4.9.5 ECC Tracking Control.

Standard computer control devices such as a keyboard and mouse are acceptable control devices for the ECC tracking subsystem. Touch screens and key pads are also acceptable.

4.4.9.6 Digital Format.

The tracking subsystem display should use an industry standard digital format that meets or exceeds the VGA standard.

4.4.9.7 Screen Size.

The tracking subsystem display should have a fourteen-inch or larger diagonal screen size.

4.4.9.8 Interfaces.

The ECC tracking subsystem display and control equipment should interface with the ECC computer and the computer operator.

5. SUPPORTING RESEARCH.

DEVS program activities included research, vendor prototype system evaluations, and operational demonstrations conducted at FAATC and other airports around the country. The research consisted of ARFF crew surveys, literature searches, and analysis. System evaluations provided a way to learn the capabilities of available commercial equipment. The operational demonstrations showed the feasibility of using DEVS technology to improve ARFF response time during low visibility conditions.

5.1 RESEARCH.

ARFF research group conducted research to determine the desirable characteristics of a DEVS. This research focused on interviews or surveys with ARFF crew members, literature searches, and analysis.

5.1.1 ARFF Crew Surveys.

Interviews with ARFF, and airport operations and air traffic control personnel, were conducted to gain an understanding of the operational requirements of DEVS. The interviews focused on three questions:

a. How do ARFF crews currently respond to emergencies involving aircraft?
b. How are airport operations affected when visibility is low?
c. How does low visibility impede emergency response capability?

The following paragraphs provide answers to these questions based on the information gathered through the interviews.

Many airports have a multiple stage process for dealing with aircraft emergencies. The process varies between airports but a representative system uses the following three levels of alerts:

Alert Level 1—A standby situation has been identified. A standby situation usually involves an aircraft on approach to the airport which is experiencing some sort of mechanical problem. The pilot typically notifies the local controller of the problem. The local controller then notifies the airport operator and fire chief. One common example of a mechanical problem that causes a standby situation to occur is failure of an aircraft's landing gear indicator to light. Many times this failure is due to a problem with the indicator but ARFF crews are put on standby in case the problem is with the landing gear. The airport remains open while the ARFF crews position their vehicles on the ramp nearest the firehouse.

Alert Level 2—A standby situation has been identified in which there is a strong possibility that the distressed aircraft will crash. In this scenario, the airport is closed and ARFF crews position their vehicles at predetermined locations along the runway.

Alert Level 3—An emergency has occurred. In this scenario, controllers close the airport, call the fire station and direct ARFF crews to the accident location if they can. ARFF crews respond immediately to the emergency.

Many airports take special precautionary measures during periods of poor visibility. Air traffic controllers typically slow operations and increase communications with pilots. Depending on the severity of the conditions, operations may be restricted to Category II or III equipped aircraft and runways. If conditions exceed Category IIIC restrictions, airports are closed even though the air traffic control system and many aircraft can still operate safely. Airports are sometimes closed during Category IIIC conditions because ARFF crews can no longer respond effectively to an emergency.

Some airport fire companies position ARFF vehicles at strategic locations near the runways during periods of low visibility. ARFF services at the Atlanta Hartsfield International Airport have implemented this strategy because it may allow ARFF crews to respond quickly to accidents with a known location. However, this strategy will not necessarily improve the response time to an unknown accident location.

Low visibility due to darkness, fog, rain, snow, sleet, dust, etc., impedes the ability of ARFF crews to respond to emergencies in three ways:

a. Accident locations are hard to find. As described above, air traffic controllers are usually the first to know about an aircraft accident. When visibility is clear, tower controllers can usually tell ARFF personnel the location of an accident at or near the airport because they can see it. When visibility is low, tower controllers may not be able to see where an aircraft accident occurred. Under these circumstances, ARFF crews search for the accident on the ground.

b. Traveling to the accident is difficult. Anybody who has driven a car in heavy fog knows how difficult it is to get from point A to point B when visibility is low—even when traveling a well known route. Low visibility forces drivers to slow down to stay on the desired route. In the case of an emergency response to an aircraft accident, these problems are exacerbated. If the vehicle driver deviates from the most direct route, the response time will be greater. With the arrival of all terrain ARFF vehicles, the most direct route may be over open ground. If the ARFF vehicle driver is forced to take an indirect route to an accident location because visibility is low, valuable time will be lost. If an ARFF vehicle driver becomes lost due to low visibility conditions, even more time will be lost.

c. Locating people and obstacles on the way to and near the accident location is difficult. A major concern of ARFF crews (especially those who had participated in an aircraft rescue situation) is avoiding people and debris on the way to an accident location. As ARFF crews are trying to get to a wrecked aircraft as fast as possible, accident victims are trying to get away from the aircraft as fast as possible. This situation forces ARFF vehicle drivers to approach an accident site very cautiously when visibility is low to avoid creating more casualties. ARFF vehicle drivers must also be careful to avoid driving into aircraft debris that would turn them into casualties.

5.1.2 Literature Searches.

The ARFF crew surveys produced a general idea of what DEVS should do to improve response times during low visibility conditions. DEVS should improve the ARFF crew's ability to locate accident sites, navigate to the accident sites, and locate people and obstacles around the accident sites. Literature searches were performed to define operational requirements and to identify candidate technologies.

FAR Part 139, paragraph 319 defines aircraft rescue and fire fighting operational requirements. This document specifies that "within 3 minutes from the time of the alarm, at least one required airport rescue and fire fighting vehicle shall reach the midpoint of the farthest runway serving air carrier aircraft from its assigned post, or reach any other specified point of comparable distance on the movement area which is available to air carriers . . ." [reference 2]. This regulation is generally not interpreted as an operational requirement. ARFF services respond to aircraft emergencies as quickly as possible despite visibility or operational conditions. The 3-minute demonstration response time was used in the DEVS program as a reference point against which system performance parameters were compared. For example, assuming a theoretical response in which it takes 20 seconds to get the vehicle started and out of the firehouse and 25 seconds to accelerate from 0 to 50 miles per hour (mph), 135 seconds would be left (from 3 minutes) to travel to the accident scene at 50 mph. Assuming constant acceleration from 0 to 50 mph and maintaining a constant 50 mph for the rest of the 3 minutes, a vehicle could travel over 2 miles (10767 feet) in this time. The first ¼ mile of this response would take a little over 30.6 seconds. Because ARFF vehicle drivers will be in familiar territory for the first ¼ mile of any response, ARFF research group has determined that all DEVS equipment must be operational within 30 seconds of when the vehicle leaves the fire house.

Further literature searches were conducted to identify technologies that could be applied to DEVS. Three main technology areas were identified: Night vision technology, navigation technology, and vehicle tracking technology. Night vision technology was selected because it had the potential to improve ARFF crews' ability to locate accidents, navigate to the accidents and locate people and obstacles in poor visibility. Navigation technology was selected because it had the potential to improve ARFF crews' ability to navigate to accidents. Vehicle tracking technology was selected because it had the potential to help ARFF crews locate accidents, people, and obstacles.

5.1.2.1 Night Vision Technology.

Literature searches of alternate night vision technologies indicated that FLIR devices would improve visibility during poor visibility conditions. FLIRs detect the heat energy radiated by objects to produce a "thermal image." This thermal image is converted by electronics and signal processing into a visual image that sometimes is comparable in crispness and clarity to a black and white television picture. The main advantages of this technology are that it can be used in daylight and in total darkness and can penetrate mist and smoke.

The use of a FLIR is analogous with the use of a camcorder with the important distinction that the FLIR detects energy in the infrared region of the electro magnetic spectrum while the camcorder detects energy in the visible region. There are two regions of high energy transmittance in the infrared portion of the spectrum. These regions are known as the long wave (8-12 μm) and medium wave (3-5 μm) regions. Most FLIR devices operate in one of these two regions. High wave, cooled cameras are the preferred devices for the DEVS application. The long wave FLIRs have the following inherent advantages over the medium wave devices:

a. Medium wave sensors are subject to an effect known as blooming when exposed to the heat energy of a fire.

b. All objects emit more long wave energy than medium wave (approximately 3.7 times more);

c. Many medium wave sensors operate poorly in low ambient temperatures (below 0°C); and

d. Medium wave sensors cannot penetrate common smokes such as diesel fuel fires [reference 3].

FLIRs were developed by the military and are used for such applications as surveillance, gun sights, and missile guidance. The army is currently sponsoring a program called Driver's Vision Enhancer (DVE), which investigates the use of FLIRs as a vehicle navigation aid. A survey of the FLIR industry indicated that there were different types of FLIR sensors. The most sophisticated FLIR technology is not available for sale to nonmilitary customers due to national security concerns. The FLIR technologies that were identified for further evaluation are cooled FLIR cameras, uncooled FLIR cameras and cameras based on the Vidicon tube. Table 4 summarizes the advantages and disadvantages of the different types of thermal imagers studied and lists their approximate costs.

TABLE 4. NIGHT VISION TECHNOLOGY

Technology	Approximate Cost	Advantages	Disadvantages
1st generation Cooled IR Camera	$40,000	Good image quality Autonomous system	Low MTBF Medium life cycle cost
2nd generation Cooled IR Camera	$30,000	Good image quality Autonomous system Small, light, low power	Medium wave IR band
Uncooled IR Camera	$18,000	Low maintenance High MTBF	Immature technology
Vidicon Tube	$15,000	Low cost Low maintenance High MTBF	Short visual range

There are currently two "generations" of cooled FLIR cameras available today. First generation FLIR cameras must cool their IR detector element to approximately -200°C. This cooling is accomplished with either a Joule Thompson or Sterling Cycle cooling system. The Joule Thompson coolers rely on high pressure gas to cool the detector element. This type of cooler was eliminated from consideration for DEVS based on field logistic support difficulties and limited running time. The Sterling Cycle Cooling Engine is a self-contained autonomous cooling system which is like having a little refrigerator inside the camera. The second generation of cooled FLIR cameras available require a constant temperature to maintain performance levels. They incorporate cooling and heating elements to achieve this constant temperature. One advantage of this type of system is that it is generally smaller, lighter, and requires less power that the first generation FLIRs. The main disadvantage is that this technology is limited to operation in the medium wave IR band. Cameras that operate in the medium wave IR band are subject to blooming when directed at a high energy heat source such as a fire. Blooming is an effect where "The radiation is strong enough to significantly heat the propagation medium . . ." to the point where ". . the resulting white spot in the reproduced image often appears many times larger than the radiation image should." [reference 4].

Uncooled IR detectors are the next generation thermal image device. This technology takes advantage of new techniques in detector element manufacturing that allow the FLIR to operate at ambient temperature. This type of system offers many advantages over cooled cameras including a lower initial cost, lower life cycle costs, lower power consumption, higher reliability, and smaller size. Several companies have developed breadboard prototypes but none of these cameras are currently in production. It is estimated that production units will be available in three to five years.

FLIRs based on vidicon tubes are a proven technology that has been in existence for over twenty-five years. The U.S. Navy currently uses hand held vidicon tube systems for fire fighting on board ships.

These systems use the pyroelectric effect in a thin slice of polar crystal. "Variations in the electrical polarization of the target resulting from temperature changes produce a distribution of surface charges corresponding to the pattern of heat absorbed. The signal current is the result of neutralization of the charges by the scanning beam." [reference 5]. After talking to two vendors that sell vidicon tube systems, it was discovered that the visual range of these units is only about one hundred feet. This range was considered too short to be useful for finding accidents at an airport and vidicon tube technology was considered no further.

5.1.2.2 Vehicle Navigation Technology.

Literature searches of alternate vehicle navigation sensors indicated that DGPS is the most attractive choice available today. It provides a way to determine the position and velocity of ARFF vehicles accurately. Other navigation sensors considered include Loran C, inertial navigation systems, and dead reckoning systems. Table 5 summarizes the advantages and disadvantages of the different types of navigation sensors studied and lists their approximate costs.

GPS is a satellite navigation system developed by the U.S. military. The system was declared operational in December 1993 when twenty-four GPS satellites were available for navigation use. GPS provides worldwide, around-the-clock position, velocity, and time information for military and civilian users. Two levels of GPS service are available: Precise Positioning Service (PPS) and Standard Positioning Service (SPS). The PPS is available to US military and other authorized users. The SPS was made available to civilian users with the following announcement at the Tenth Air Navigation Conference in September 1991: "GPS-SPS is planned to be available beginning in 1993 on a continuous, worldwide basis with no direct user charges for a minimum of ten years. Beyond the original offer of GPS-SPS for a minimum of ten years, the U.S. intends to continue operation of GPS and to offer GPS-SPS for the foreseeable future free of direct user fees." [reference 6]. Position and velocity errors for the PPS and SPS services are typically less than, or equal to the values shown in table 6, 95 percent of the time [reference 7].

TABLE 5. NAVIGATION SUBSYSTEM TECHNOLOGIES

Technology	Accuracy (ft)	Approximate Cost	Advantages	Disadvantages
DGPS	15	\$1500/vehicle \$20,000/airport	High Accuracy	Signal easily shaded Requires Data Link
GPS	300	\$500/vehicle	Autonomous, Worldwide, Accurate No user fee	Signal easily shaded
Dead Reckoning	2 to 5%	\$300/vehicle	Low Cost	Not very accurate May require mods to vehicles
Loran	540	\$300/vehicle	Low cost Autonomous	Poor accuracy Coverage gaps
Inertial	error grows with time < 450 after 1 hour	\$10,000 to \$65,000/vehicle	Independent	Expensive Error growth with time Calibration required

TABLE 6. GPS POSITION AND VELOCITY ERRORS

	Horizontal Position (ft)	Vertical Position (ft)	Velocity (ft/sec)
SPS	300	470	1
PPS	60	90	0.3
DGPS	12	18	0.3

DGPS improves accuracy by eliminating bias type errors from the GPS navigation solution. A GPS receiver at a surveyed location computes the difference from its actual location and broadcasts GPS errors to other users. These users apply the differential corrections to improve their navigation solution. This technique can reduce errors to the 10 to 15 foot range. For DEVS to use DGPS, a source of DGPS correction messages must be provided.

There are currently at least three potential sources of DGPS correction messages: Local differential base stations, coast guard radio beacons, and commercially available subscription services. Setting up a local differential base station requires locating or determining an accurately surveyed site for the base station antenna. After the antenna is set up, the base station receiver computes DGPS correction messages for broadcast to DGPS capable receivers. The local DGPS base station is the currently preferred source of correction messages. If a local DGPS base station does not already exist at an airport installing DEVS, one can be installed at an estimated one time cost of about $15,000 to $25,000. A local station has the advantages of higher accuracy (the closer the base station, the higher the accuracy) and independence from outside agencies. Coast guard radio beacons located along the coast of the coterminous United States are beginning to broadcast DGPS correction messages. The Coast Guard is providing this service primarily for maritime use, but airports near the coast may eventually be able to use it. The Coast Guard beacons are not currently being considered for DEVS because their signals will not reach many U.S. airports. Commercially available DGPS subscription services are currently becoming available. These services broadcast DGPS correction messages on the sub-carriers of Frequency Modulated (FM) radio broadcasts. DGPS subscription services are currently not desirable because they are not yet widely available and sometimes broadcast correction messages in proprietary formats. The use of proprietary formats limits the choices of available DGPS receivers.

There are at least two other reasons to use DGPS instead of regular GPS in the DEVS. First, DGPS may allow the GPS receivers in the fire trucks to lock on and track satellites sooner. The DGPS base station will always have up to date information about the location of the GPS satellites because it will always be tracking them. If this data is broadcast to the fire trucks along with the differential corrections, the GPS receivers on the trucks will be able to acquire satellites quicker. Second, there is a trend in the FAA to make differential corrections available at most major airports. Tests have been conducted at the FAATC which explore the use of DGPS as a precision approach and landing aid. If this capability is built into the airport infrastructure, equipping ARFF vehicles to take advantage of it will not add significantly to the cost.

Dead Reckoning (DR) is an inexpensive navigation aid that should be included in DEVS. DR is a navigation method which uses distance traveled and heading information to extrapolate a vehicle's position from the last accurately known point. Many GPS based vehicle navigation systems being developed for the commercial markets today use DR to maintain vehicle position accuracy during periods when the GPS signals are blocked by trees and buildings. Most of these systems use a reading from the vehicle's odometer for distance and get heading information from an angular sensor on the steering wheel or a gyrocompass. An airfield is a good environment for receiving GPS signals because there are not too many obstructions for the signals. The addition of a DR system to a DGPS system is recommended for DEVS due to the possibility of responses outside of the airport boundary.

Long Range Navigation system (Loran C) is a radio navigation system operated in the U.S. by the Coast Guard that is not accurate enough to support DEVS. The Loran C was developed at MIT's Radiation Laboratory during World War II to support ship convoys in the Atlantic Ocean. The system operates based on the principle that two radio transmitters at precisely surveyed positions transmit a pulse simultaneously. A ship receives these pulses and measures the time difference between them to determine a line of position. When two or more lines of position are determined, the ship's position is known. Several upgrades have been made to the system since the 1940s. The currently available system, Loran C, operates at 100 kHz and provides accuracies of approximately 540 feet. This level of accuracy is not sufficient to support DEVS since it is several times larger than the average airport surface width (100 to 150 feet). Another drawback of Loran is that it may not be available to all airports. Because it was originally a maritime system, Loran chains provide better coverage of coastal areas than areas that are far inland.

Inertial Navigation Systems (INS) are autonomous navigation devices but were considered too expensive for use in DEVS. INS use accelerometers and gyros to measure vehicle movements. Given an accurate initial position an INS can compute its current position based on the measured vehicle movements. Inertial navigation systems provide an autonomous source of position, orientation, and velocity. They have been used since World War II for military applications such as submarine and ship navigation. With the arrival of fiber optic strap down gyros and solid state accelerometers the price of INS has dropped. However, these systems are still much more expensive than radio navigation systems. Another big disadvantage of these systems is that their error grows with time and distance traveled. To ensure accuracy, these systems require a position fix before movement begins. Because of the cost and operator workload aspects of these systems, they were not evaluated for use in DEVS.

5.1.2.3 Vehicle Tracking Technology.

Vehicle tracking systems add a command and control aspect to DEVS which will be very helpful for locating fires, reducing the driver's work load and improving the situational awareness of the emergency commander. The only type of tracking technology considered for DEVS was Automatic Dependent Surveillance (ADS). An ADS system relies on the vehicle being tracked to determine its own position and relay that information back to a command center using datalink. Other possible tracking technologies include primary radar such as the ASDE-3 and secondary radar such as the Transponder Tracking System (TTS).

ASDE-3 is currently being installed at forty of the nation's busiest airports. It is a primary radar that detects aircraft and vehicles in the Airport Movement Area. This radar is being installed in air traffic control towers at airports and will be used by ground controllers when visibility is low. One advantage to this type of tracking system is that it imposes no requirements on the vehicles being tracked. The disadvantages are that the system is expensive (over one million dollars), and it does not positively identify the targets being tracked.

The TTS is another type of tracking system that is currently under development. This system multilaterates aircraft transponder returns to determine position. Transponders could be attached to vehicles to provide a tracking system that tracks aircraft and vehicles. The main advantage of this system is that it will positively identify the aircraft and vehicles being tracked based on the unique transponder codes. The main disadvantage is that the system is still being developed.

An ADS system based on a vehicle navigation system and a data link is the preferred type of vehicle tracking system for DEVS. Because the DEVS concept includes a navigation system in the rescue vehicles, the vehicle tracking capability can be added by including a data link between the vehicles and an ECC. The ECC will be the destination for position reports from all DEVS equipped vehicles. The ECC will include a digital map of the airport that will show the positions and identifications of all emergency vehicles equipped with DEVS. The ECC will also provide the capability to send messages to DEVS equipped vehicles over the data link.

Several alternate data link technologies were considered before deciding on RF modems. Cellular phones and modems were considered and hold several advantages. First, no special Federal Communications Commission (FCC) licensing is required. Second, many fire departments already own cellular phones. The main disadvantages of this option, however, are the dependence on an outside service and ongoing service fees, and the possibility of data loss due to noisy cellular channels. Satellite communications links were considered but this approach also introduces a dependence on an outside service and service fees. The main advantage of a satellite link is that it can be used to transmit data between points that are separated by large distances. In DEVS, this advantage is lost because the coverage area will probably be a 5-mile radius or less. RF modems provide a way to introduce a dedicated, independent data channel between the ECC and DEVS vehicles that can be optimized for the RF environment of the airport.

5.1.2.4 DEVS Equipment Power Considerations.

Research into the power requirements of DEVS equipment indicates that the source of DEVS power should be separate and isolated from the ARFF vehicle power system. The two most promising sources of DEVS power are battery systems and gasoline powered generators. It was also determined that DEVS equipment in ARFF vehicles should all use the same type of power (12-VDC) to simplify the system and reduce the need for power conversion devices. The following paragraphs provide more detail about DEVS power considerations.

The electrical system on most ARFF vehicles is not meant to support sensitive electronic equipment such as computers, FLIRs, and GPS receivers. It is designed to support fire fighting equipment such as pumps, hose reels, and lights. This type of equipment is not severely affected by the frequent voltage and current surges, spikes, and deficits characteristic of the ARFF vehicle electrical environment. Two approaches were taken to integrate DEVS equipment into the ARFF vehicle environment. The first approach was to condition ARFF vehicle power to be acceptable for DEVS use. The second approach was to install an independent source of power for DEVS equipment on ARFF vehicles.

Devices such as inverters, power conditioners, and power supplies can be used to make vehicle power more acceptable for DEVS use. DC to AC inverters generate AC power from DC power. Inverters could be used in ARFF vehicles to produce 115 VAC power from the vehicle's 12-VDC electrical system. Power conditioners filter, limit, and generally "clean up" DC power sources. They allow sensitive electrical equipment to run on the noisy vehicle electrical system. Uninterruptable Power Supplies (UPS) provide battery backed up and conditioned DC voltages from AC voltages. The main disadvantages of using inverters, power conditioners, and power supplies is that they add to the total electrical load of the system and do not guarantee that sensitive electronics will be protected.

Generators and battery systems were explored as sources of power that were isolated from the ARFF vehicle power system. Generators are an autonomous source of AC power. The main advantage of generators is that they are independent of the vehicle electrical system. The main disadvantages are that they require scheduled maintenance and may not operate reliably if used infrequently. Batteries provide a clean source of DC power that is independent of the vehicle electrical system. Commercially available deep-cycle batteries are relatively inexpensive. The main disadvantage is that they require recharging after use. Recharging should not be a problem for ARFF vehicles, however, because they spend a lot of time at the fire house where AC power is readily available and battery charging equipment could be located.

Battery systems are the most attractive potential power source for DEVS. A typical deep-cycle battery that is quick to recharge and supplies 175 amp/hr costs about $82.00. Three of these batteries would be required to supply the estimated 1200-Watt DEVS power load for 4 hours assuming a 12-VDC operating voltage for the equipment. With dimensions of 12"L by 7"W by 9"H, these batteries could easily fit onto an ARFF vehicle.

5.1.3 Analysis.

Further research and analysis was performed to determine such parameters as the visual distance and Field of View (FOV) required for the night vision subsystem, the range of preferred brightness for the night vision and navigation subsystem displays, the navigation system accuracy, and digital map orientation.

5.1.3.1 FLIR Visual Distance.

The visual distance of the night vision system is the distance from the front of the vehicle to the point where obstacles and terrain are no longer distinguishable enough to provide useful visual cues for driving. This distance was based on the stopping distances of ARFF vehicles and the reaction times of the drivers. The National Fire Prevention Association (NFPA) recommends the following stopping distances, as shown in table 7, for ARFF vehicles [reference 8].

TABLE 7. ARFF VEHICLE STOPPING DISTANCES

Speed (mph)	Class 1, 2, 3 Vehicles	Class 4 Vehicles
20 mph	35 ft	40 ft
40 mph	131 ft	160 ft

Class 1, 2, 3 and 4 vehicles have water capacities of 1000, 1500, 2500 and 3000 gallons respectively. With a typical driver response time of 2.5 seconds [reference 9], a vehicle moving at 40 mph will travel approximately 148 feet between the time that the driver realizes there is a need to stop and the time that the foot is applied to the brake. A class 4 vehicle would require 308 feet to stop under these circumstances. The required visual distance would also be at least 308 feet. Of course, ARFF vehicles are capable of traveling faster than 40 mph. As additional research is being done to determine ARFF vehicle braking distances at greater speeds, a conservative estimate of acceptable visual distance can be based on the current ARFF vehicle night vision subsystem—high beam headlights. Normal high beam headlights are effective to a distance of about 500 feet. This figure can be used as an acceptable minimum visual distance for the DEVS night vision subsystem.

5.1.3.2 FLIR Field of View.

Acceptable ranges for FLIR camera field of view are 20° to 30° for the VFOV and 28° to 40° for the HFOV. These ranges are based on target values developed from ARFF vehicle driver visibility requirements, limits of currently available FLIR devices, and constraints imposed by tracking and navigation tasks.

The NFPA standard for ARFF vehicles states that "The vehicle shall be constructed such that a seated driver, having an eye reference point of 31 3/4 inches (805 mm) above the seat cushion and 12 inches (30.5 cm) forward from the seat back, shall be able to see the ground 20 feet (6 m) ahead of the vehicle and have vision of at least 5° above the horizontal plane. The vision in the horizontal plane shall be at least 90° on each side from the straight ahead position." [reference 8]. The VFOV for the FLIR can be based almost entirely on this requirement. The HFOV of 180° cannot be met by commercially available FLIRs or humans without having the ability to pan from side to side.

The ability to meet the VFOV requirement stated above will depend on the location of the FLIR. Consider a FLIR camera mounted on top of an ARFF vehicle cab, at the front of the truck, a distance of 10 feet above the ground. The angle between the FLIR and a spot 20 feet in front of the vehicle on the ground is 26.5°. If another 5° is required above the horizontal plane, (applying this constraint to the plane at 10 feet will satisfy the constraint for the driver at 8 feet) the VFOV required would be 31.5°. For a FLIR mounted at 8 feet from the ground, the angle required to satisfy the NFPA requirement is 26.5°. These values of 31.5° and 26.5° can be considered a theoretical target range for FLIR VFOV. Most commercially available FLIRs, however, have VFOV values closer to 20°. For this reason, we recommend that VFOV be in the 20° to 30° range.

The theoretical target HFOV for the FLIR cannot be based on the NFPA ARFF vehicle standard due to limitations in commercially available FLIRs. Instead, the theoretical foundation for the HFOV is based on human factors studies regarding human vision and the tasks of searching for objects and driving a vehicle. For searching, the FOV should be small. For driving, the FOV should be large. A compromise must be reached that accommodates these conflicting needs.

When searching for objects with their eyes, people only use a very narrow view cone that they sweep over the area being searched. This narrow view cone has been termed the "useful field of view" (UFOV) and is defined as "a circular area around the fixation point from which search information is extracted." [reference 10]. The UFOV varies from 1 to 4° depending on the search task being performed. As mentioned before, the time to recognize an object increases as the size of the area being searched increases. The FOV should be small to minimize this search area but should be wide enough to be able to recognize obstacles in front of the vehicle. If the vehicle is 10 feet wide, the FOV must be only 1.1° at a distance of 500 feet from the vehicle. At 20 feet from the vehicle, the FOV must be 28°. The HFOV should be at least 28° to be able to recognize obstacles in front of the vehicle.

Another task the driver performs using vision is navigation by landmarks. Navigation by landmarks is another search task where the UFOV is used. To navigate by landmarks, the driver must be able to see areas on either side of the surface being traveled. To cover an area twice as wide as a typical runway (150 feet) at the maximum stopping distance (500 feet), a HFOV of 34° is required.

The UFOV is not the only visual area used while driving a vehicle. Peripheral vision is also important. A driver gains information about the direction and speed of travel from peripheral vision. To take advantage of this information, the HFOV should be as wide as possible. This requirement conflicts with the statement above that the HFOV should be narrow to limit the search area for avoiding obstacles and navigating by landmarks. Research performed on the Army DVE Program determined that the minimum HFOV for navigation should be 40° [reference 11].

In summary, the HFOV should be small to limit search times, but no smaller than 28°. The HFOV should be wide to improve navigation by landmarks and make use of peripheral vision. The upper limit for the HFOV should be about 40°.

5.1.3.3 Display Brightness.

The appropriate brightness of any display is dependent on the ambient lighting. What is bright enough on a gray overcast day may be totally washed out on a bright sunny day. The most common "guideline" for determining brightness is two-fold. First, make it adjustable. Second, maintain an appropriate contrast between objects (i.e., symbols, text, etc.) and the background. Adjustable brightness permits the operator to change the display brightness to work within not only the ambient light conditions, but his/her own visual sensitivity. When the overall brightness is adjusted the contrast ratio established should be maintained.

The following formula [reference 12] is used to calculate the appropriate contrast:

$$\text{Contrast} = \frac{\text{Luminance emitted by screen area of greatest intensity}}{\text{Luminance emitted by screen area of least intensity}}$$

5.1.3.4 Navigation Sensor Accuracy.

The required DEVS navigation subsystem accuracy is based on the size of typical airport surfaces. Taxiways are generally about 100 feet wide and runways are typically 150 feet wide at many airports. Many of these airport surfaces intersect each other or run parallel to each other. For safety reasons, it is important to know which surface a vehicle is on. An accuracy of 50 feet would be required to show a vehicle located on the center of a 100-foot taxiway.

5.1.3.5 Digital Map Orientation.

Research was conducted to determine if the digital map used with the DEVS navigation subsystem should maintain a fixed North Up orientation or provide a variable heading up orientation. Current findings suggest that a North Up map display with visual cues which help the driver correlate the scene on the map with the view out the window is a good approach.

Paper maps traditionally represent areas in a North Up orientation in which the top of the page is North, the bottom is South, the right edge is East and the left edge is West. When traveling North and looking at a North Up map, landmarks and roads shown on the map are spatially correlated with the driver's view out of the window. A road that intersects the traveled road from the right on the map appears on the driver's right hand side when looking out the windshield. When driving South, East or West, the North Up map is not spatially correlated with the driver's view out of the window. For example, a road that intersects the traveled road from the right on the map appears on the driver's left hand side when traveling South. Many people rotate paper maps to correlate the map with their forward view. The question asked for DEVS is: Should the electronic map also provide an ability to rotate?

Studies have shown that when a fixed, North Up map is out of alignment with a driver's view out the windshield, the driver will mentally rotate the map. The cost of this mental rotation has been documented in studies which involved "reading topographic maps (Eley, 1988), studying buildings (Warren, Rossano, & Wear, 1990), flying helicopter simulations (Aretx, 1991; Harwood & Wickens, 1991), or studying 'you are here' (YAH) maps such as those in shopping malls . . ." [reference 10].

Reducing the driver's mental workload is one reason to adopt a rotating electronic map. There are, however, at least two reasons why a rotating electronic map is not always the best solution. First, a rotating electronic map requires more frequent display updates than a fixed map. This need to update the display more frequently adds to software development costs and requires more computer processor time. Second, "comparative evaluations of the two map types have revealed that the advantages for one over the other are not consistent and appear to be task-dependent." [reference 10]. For tasks requiring a high degree of spatial awareness, rotating maps are best. For tasks that depend on the location of landmarks on the map or learning the relative location of features in the environment, a fixed North up map works best. A North up map display may also be advantageous for applications like DEVS where many vehicles who have to communicate with each other and a dispatcher would all have the same map orientation.

The concept of visual momentum can be exploited to add visual cues to a North up map that will reduce the mental workload associated with map rotations. Visual momentum describes "the characteristics of a system design that influence an operator's ability to extract and integrate information across several displays. A high degree of visual momentum aids the operator in maintaining a cognitive representation of the system by presenting one display's information in the context of the other." [reference 13].

Figure 8 is an example of a visual cue that has been shown to reduce the cognitive processing required to mentally rotate a North up map [reference 13]. The wedge in this figure corresponds to the driver's FOV. In the case of DEVS, this could correspond to the FOV available from the night vision subsystem. One line is blue and one is yellow representing the left and right edges of the FOV respectively. The third line is black and bisects the wedge to indicate the vehicle's heading. A textual representation of the heading may also be helpful.

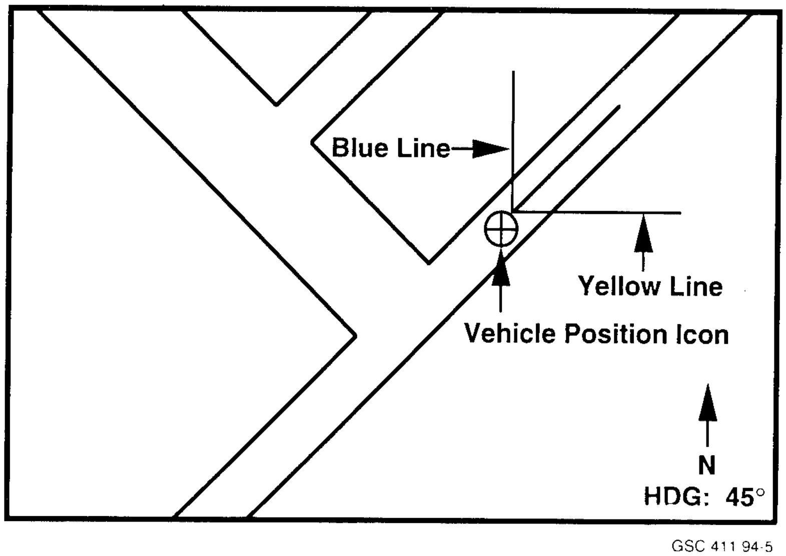


FIGURE 8. VISUAL CUE WHICH INDICATES VEHICLE ORIENTATION

5.2 SUBSYSTEM AND COMPONENT EVALUATIONS.

Evaluations of candidate subsystems and components were conducted during this research project. Most of the evaluations focused on FLIR devices but, navigation and tracking subsystems were also evaluated. Computer and video displays and different types of computers were also evaluated.

5.2.1 FLIRs.

FLIR cameras were evaluated to determine their effectiveness for navigation purposes and as an aid in locating fires and aircraft. These FLIR cameras were not scientifically tested. They were demonstrated in the field under simulated operational conditions which varied from evaluation to evaluation and from FLIR to FLIR. The purpose of the evaluations was to determine which types of IR technology were best suited for DEVS and which FLIR camera features were important. Table 8 provides a brief summary of the FLIRs evaluated and lists their major strengths and weaknesses.

The Westinghouse MicroFLIR was the thermal imager evaluated most often. Westinghouse loaned a MicroFLIR to ARFF research group for over a year. ARFF research group installed this FLIR on research vehicles and considered it a baseline against which other FLIRs were measured. The MicroFLIR provides a clear thermal image. During ideal conditions (sunlight, low humidity) this FLIR's thermal image is close in quality to that of a black and white video image. During worst case conditions (high humidity, and rain) the thermal image quality degrades and becomes less usable as a navigation aid. The image is still very useful for locating fires during worst case conditions. According to Westinghouse, the shortcomings of the MicroFLIR for the DEVS application are being addressed. A standby mode of operation is being offered which will allow the unit to cool down and become operational within 30 seconds. A windshield wiper and heated germanium window are also being added to improve operation during rain, sleet, ice, and snow. Finally, the contents of the separate electronics box are being incorporated into the FLIR housing.

TABLE 8. SUMMARY OF EVALUATED FLIRs

Manufacturer	Model	IR Band	Strengths	Weaknesses
Westinghouse	Micro FLIR	Long Wave	Good image quality Requires little tuning once set	Cool down > 2 minutes Must install Electronics box
FSI	SA FLIR	Long Wave	Good image quality Requires little tuning once set	Cool down > 2 minutes Chops picture at top and bottom
FSI	Prism	Medium Wave	Good image quality Small, light Moderate power consumption	Severe blooming when tracking fires Cool down > 2 minutes
OMI	LITE	Long Wave	Small Fast Cool Down < 30 sec Good image quality	Chops picture at top and bottom
Inframetrics	IRIS	Long Wave	Good image quality	Required frequent adjustments Cool down > 2 minutes
Inframetrics	Infracam	Medium Wave	Good image quality Small, light Low power consumption	Severe blooming when tracking fires Cool down > 2 minutes
GEC Marconi	PYRO-2000	Long Wave	Uncooled (FPA) Small, light	Poor image quality
Rockwell	Infravision	Medium Wave		Poor image quality in high humidity Severe blooming when tracking fires
Insight	SCOUTsight	Long Wave	Uncooled Pyro Electric Vidicon (PEV) Light, small	Poor thermal image quality Required superimposed video image

The FLIR Systems Incorporated (FSI) SA FLIR also provided a clear thermal image that was at least as good in quality as the Westinghouse MicroFLIR image. This FLIR performed well under all atmospheric conditions it was evaluated in. The only real drawbacks of this FLIR are the long cool down time and the cropped picture. The thermal image does not fill the entire vertical area on the display screen. Another drawback of this FLIR is the narrow vertical field of view (16°). This narrow field of view introduced problems in tracking a fire over soft airfield terrain. When the vehicle went up or down bumps or hills, the fire often went outside the field of view. This product is currently installed on ARFF vehicles at the Atlanta Hartsfield International Airport.

The FSI PRISM is a hand held thermal imager that operates in the medium wave IR band. This FLIR provided an exceptionally clear thermal image until it was used to track a fire. The heat energy of the test fires overwhelmed the PRISM and caused an effect known as blooming. This blooming caused the displayed thermal image to "white out" and become useless.

The Opto Mechanik Inc. LITE FLIR is a long wave FLIR that provides a clear thermal image. This was the only cooled FLIR evaluated that demonstrated the fast cool down with a "stand by" mode of operation. This FLIR was able to display a usable thermal image less than 30 seconds when operated in stand by mode. This FLIR was also the only one evaluated with a 40° horizontal FOV. All other FLIRs had a narrower FOV. The only real drawback of this FLIR was the vertical picture cropping.

The Inframetrics IRIS is a long wave FLIR that provides a clear thermal image. The first time this FLIR was evaluated the field of view was too narrow (less than 4°) to use it as a driving aid. The second time this FLIR was evaluated, the field of view was much wider but the picture quality suffered. According to the manufacturer, the telescopic lens used for the first evaluation was replaced with a prototype lens that had a wider field of view. This prototype lens, however, was not coated with a substance that improves IR transmittance.

The Inframetrics Infracam is a medium wave hand held IR camera similar to the FLIR PRISM. This camera also produced a clear thermal image but took a very long time to cool down and experienced severe blooming when tracking fires.

The GEC Marconi PYRO-2000 is a long wave, small, light weight, uncooled thermal imager. It produces a thermal image that is not quite clear enough to support ARFF vehicle navigation. This imager uses a 100 by 100 pixel detector array to produce an image. At the time of the evaluations of this camera, the manufacturer was working on a 200 by 200 pixel array that would improve resolution. The quality of the thermal image of this camera was expected to be competitive with cooled FLIRs in another one or two years.

The Rockwell Infravision is a medium wave FLIR that was evaluated under worst case atmospheric conditions and produced a poor quality thermal image. Besides poor image quality, this camera also experienced blooming when tracking a fire.

The Insight FIREsight-F is a hand held, uncooled FLIR which used a Pyro Electric Vidicon (PEV) tube as the IR sensor. This device also demonstrated the unique feature of superimposing a video image over the thermal image. When the thermal image was demonstrated without a superimposed video image, it was not of sufficient quality to support DEVS.

Table 9 compares performance parameters of the different FLIRs.

In summary, evaluation of these products leads to the following conclusions regarding IR technology. First, cooled, long wave FLIR cameras are the best technology currently suited for DEVS. These FLIRs produce a high quality thermal image that can be used for navigating and locating fires. Enhancements required for most commercially available cooled, long wave FLIRs include a 30-second standby mode of operation, a windshield wiper and a heated lens surface. Second, medium wave FLIRs are not usable for the DEVS application because they experience blooming when tracking fires. Third, uncooled FLIRs such as the PYRO-2000 do not currently produce a thermal image with sufficient quality to support DEVS. Other manufacturers such as Texas Instruments, Loral and OMI are developing variations of solid state, uncooled technology; demonstrable prototypes are appearing. Recent progress has been impressive, and it is expected that low-cost, instant-on FLIRs with image quality rivaling today's cooled FLIRs will soon be available. As such, ARFF research group believes these FLIRs to be the future sensor of choice. Finally, FLIRs based on PEV technology are not suitable for DEVS because they do not have sufficient visual range. PEV FLIRs are used by the Navy and some municipal fire companies for fighting fires on ships and in buildings where a limited visual range of 100 feet or less is acceptable. A longer visual range is required for DEVS.

5.2.2 Navigation.

Two GPS based navigation subsystems were evaluated. One navigation subsystem is manufactured by Astronautics Corporation of America, the other by Rockwell Collins. Both systems were loaned to ARFF research group for extended periods of time and were evaluated at FAATC and other airports around the country. The following paragraphs describe these systems in greater detail.

The Astronautics navigation subsystem uses GPS based vehicle position reports to display the location of the vehicle on a digital map inside the vehicle cab. The prototype subsystem lent to ARFF research group is composed of a GPS receiver, a computer, a keypad and two displays.

The GPS receiver is a Trimble Placer 300 which is capable of determining the vehicle position within a spherical area having a diameter of approximately 300 feet. This receiver has a battery backed up memory that stores the last known vehicle position and satellite almanac data to allow it to reacquire satellites after being turned on. Typical TTFF with this type of receiver is 30 seconds or less. The computer used by Astronautics is a ruggedized International Business Machines Personal Computer (IBM PC) compatible which they manufacture. The computer loaned to ARFF research group had 8 MB of RAM and a solid state flash memory "hard drive" which provided storage for map files, the DEVS executable and other utility programs. No major problems were experienced with the computers loaned to ARFF research group during the evaluation period which lasted over a year.

The keypad provided with the Astronautics navigation subsystem is a reconfigurable membrane type of keypad that allows the operator to control certain aspects of the subsystem configuration and control. For example, the operator can use the keypad to "zoom" the map display in or out around the current vehicle location, pan the map left, right, up or down, or access administrative functions.

The Astronautics navigation subsystem used two different types of displays in the ARFF research group research vehicles. One is a TWDS, the other is a Multi Function Display (MFD). More detail about these types of displays will be presented in a later section about displays.

The Astronautics navigation subsystem provides a clear, easy-to-use map display and generally displays the vehicle position at the correct location on the map. It does not always put the vehicle on the correct surface due to the inherent inaccuracies of the GPS sensor. Astronautics produce their digital raster maps by scanning a paper map and using a Computer Aided Design (CAD) software package to tailor it for the DEVS application. The Astronautics maps were generally line drawings. They did not provide much detail, like street names, contour lines etc. After comparing this type of map to other types of digital map displays, it was determined that most ARFF crews prefer minimal detail for the in vehicle maps.

TABLE 9. FLIR PERFORMANCE PARAMETERS

	MicroFLIR	SA FLIR	PRISM	LITE	IRIS-T	Infracam	PYRO	Infravision	FIREsight-F
FOV	30°X22.5°	28°X15°	17°X13°	40°X20°	30°X20°	8°X7°	11°X11°	40X40	33°X33°
Magni-fication	1X	1.9X	1X	1X1.45	1X	1X	1X	1X	1X
Scanner Type	Serial/parallel CVROS	Serial/parallel	None	Serial/Parallel	Serial	None	None	None	None
Detector Type	8 Bar SPRITE	2X4 TDI array	FPA 244X320 Pixels	16 discrete elements	2 element TDI	FPA 256X256 Pixels	FPA 100X100 Pixels	FPA 256X256 Pixels	FPA
Detector Material	HgCdTe	HgCdTe	PtSi	HgCdTe	HgCdTe	PtSi	PbScTa	HgCdTe	DTGS
Spectral Range	8-12 µm	8-12 µm	3-5 µm	8-12 µm	8-12 µm	3-5 µm	7.5-14 µm	3.8-4.8 µm	8-14 µm
Input Power	55-65 W	130 W	22 W	21 W	10 W	4 W	12 W	55 W	3.6 W
Input Voltage	12-VDC or 24-VDC	28-VDC	12-VDC	12-24-VDC	11-32-VDC	6-VDC	6-VDC	28-VDC	12-VDC
Output Format	RS-170	RS-170	RS-170	RS-170 or CCIR	RS-170	RS-170	CCIR or RS-170	RS-170	RS-170
Cooler Type	Integral Stirling	Split Stirling	Split Stirling	Integral Stirling	Integral Stirling	Integral Stirling	None	Closed Cycle	None
Size	20"X9.25"X6.25"	8.6"X8.7"X12.1"	9.25"X5.9"X5.0"	12.5"X6.3"X4.5"	7.35"X5.5"X10"	5.3"X9.7"X2.5"	10"X3"X5.5"	10"X7"X6"	3.2"X4.8"X7.6"
Weight	11 lbs	21 lbs	8 lbs	6.6 lbs	15 lbs	2.93 lbs	5 lbs	15 lbs	6.5 lbs

HgCdTe - Mercury Cadmium Telluride
PtSi - Platinum Silicate
PbScTa - Lead Scandium Tantalum
DTGS - Devterated Triglycerine Sulfide
TDI - Time Delay and Integration

This subsystem requires a calibration process to geo-reference a map when used for the first time. Calibration involves driving the vehicle to a location that is displayed on the map, manually positioning the vehicle cursor at that location, and collecting GPS position data for several minutes. The averaged GPS position is correlated to the corresponding X,Y position of the cursor on the display and stored for future coordinate conversions. This process is then repeated at a second location to complete the two-position calibration process. ARFF research group found that this calibration process did not always work on the first try.

The Rockwell Collins navigation subsystem uses DGPS based vehicle position reports to display the location of the vehicle on a digital map inside the vehicle cab. The prototype subsystem loaned to ARFF research group is composed of a GPS receiver, a computer, and an RF data link in the vehicle. The RF data link is used to receiver differential correction messages transmitted by a DGPS base station from a surveyed position at the airport.

Rockwell uses a Loral GPS receiver which is based on the five-channel Rockwell NavCore V GPS receiver engine. This receiver, like the trimble receiver used by Astronautics, is also capable of locating its current position within 300 feet. This receiver also has a battery back up capability to allow for short TTFF times.

The computer used by Rockwell is a commercially available Toshiba 486 33 Megahertz (MHz) IBM PC compatible laptop. The laptop demonstrated to ARFF research group had 8 MB of RAM, a 200 MB hard drive and a color LCD screen. Three of the main software functions that run on this computer are to show the vehicle position on a digital map displayed on the LCD screen, to allow the operator to control and configure the subsystem using the keyboard and mouse, and to process differential correction messages which allow the vehicle position to be refined to an accuracy of 10 to 15 feet.

Rockwell demonstrated two types of maps for in-vehicle display: a digitally scanned raster map and a database generated vector map. The raster maps were generally digitized images of United States Geological Survey (USGS) Quad maps. These maps provide too much detail for use in the vehicles. The vector map looked like a simple line drawing and was better suited for in-vehicle use. Unfortunately, the database from which the sample vector map was drawn was also too detailed. There were too many vectors for the computer to draw when it was time to update the map display.

The Rockwell navigation subsystem requires no calibration process to geo-reference maps. Using the positions of surveyed bench marks shown on the maps, the Rockwell maps are accurately geo-referenced when they are installed.

The Rockwell display control software is written in MicroSoft™ Windows compatible format and runs under Windows. The use of this system is intuitive for people familiar with the Windows environment and easy to learn for those who are not. By using the mouse and keyboard, the user can zoom in and out, pan in any direction, or select a particular section of the map to view. The user also has access to GPS availability and status information. ARFF research group found this system to be somewhat complicated. The Windows interface is visually pleasing but a simpler "bare bones" interface would be better. Also, the mouse or trackball is very difficult to operate in a vehicle moving at 50 mph. A touch screen interface would make this system easy to use.

The differential correction message processing software is currently configured to generate a DGPS vehicle position solution once every 4 seconds. This processing is necessary to compute sufficiently accurate position reports but occurs at too slow a frequency for fast-moving ARFF vehicles. ARFF research group recommends that a 1 second DGPS position update rate would be ideal for DEVS. Rockwell originally developed their navigation subsystem for use on slow-moving canal barges and is aware of the need to generate more frequent DGPS position reports for DEVS.

Rockwell uses a commercially available Kenwood radio transceiver and a radio modem for the DGPS message data link in the vehicle. This transceiver operates at approximately 152 MHz and can support voice and data transmission. An identical transceiver and modem are at the DGPS base station.

The Rockwell DGPS base station uses a NavCore V receiver engine, and a 66-MHz 486 computer to generate differential correction messages for transmission to the ARFF vehicle. When the antenna for the DGPS base station is first installed, a survey of the antenna position is performed. This survey requires special software on the base station computer to run for about 24 hours to determine the antenna position with less than one meter accuracy. After the precise location of the base station antenna is known, it is entered into the base station on-line software and used as the basis for computing differential GPS correction messages. The base station software compares the measured GPS antenna position with the surveyed position, computes the differences and formats a message for transmission to the vehicle over the RF data link. As mentioned before, this message is broadcast once every 4 seconds.

5.2.3 Tracking.

Only one vehicle tracking system was evaluated during this project. This tracking system was developed by Rockwell and is tightly integrated with their differential base station.

As explained above, Rockwell uses an RF data link and a differential base station to achieve 10 to 15 feet accuracy for their ARFF vehicle position solutions. Rockwell uses this data link and DGPS base station computer to add a vehicle tracking capability to their system. Software on the laptop computer in the ARFF vehicle formats the highly accurate DGPS vehicle position estimates into messages that are transmitted to the base station once every 4 seconds. The base station computer software displays the position of the vehicle on a digital map of the area. As the vehicle drives around the area, the location of the vehicle can always be determined at the base station by simply looking at the computer screen.

Rockwell has demonstrated four types of maps for the tracking system computer screen. They have shown the same raster USGS quad maps and vector maps used in the vehicles. Besides these maps, they have also demonstrated the ability to superimpose an aerial photograph of the airport on the USGS map and the ability to superimpose a vector map on an aerial photograph. The map display at the tracking subsystem base station can be more detailed than the map displayed to ARFF vehicle drivers. The color USGS Quad maps worked very well on the base station display. All the maps displayed on the tracking system base station would be adequate for DEVS. Individual airports could possibly choose which type of map display they like best. To date, the display preferred by ARFF research group is the aerial photograph with the superimposed vector map.

The display and controls of the Rockwell vehicle tracking subsystem are the same at the base station as they are in the vehicle. The base station software can display maps, zoom, pan, select windows and display DGPS status information. The map manipulation features meet DEVS requirements to show at least three levels of map detail: (1) the airport movement area (runways and taxiways), (2) the area inside the airport boundary, and (3) an area within a 3-mile radius of the airport. The tracking subsystem also allows for informational messages to be transmitted between the base station operator and the ARFF vehicle driver. For example, the base station can transmit the approximate location of a crash site to the ARFF vehicle. The crash site shows up on the base station and vehicle map display as a red icon on the map at the selected location. The vehicle can send requests for police, fire and rescue backup to the base station through a similar process. The ability to transmit text messages also exists. For example, the base station operator can send a text message such as "Return to Station" to the ARFF vehicle. This message will appear on the computer display in the vehicle.

The message transmitting feature of the vehicle tracking subsystem is an added feature not required to track vehicles. ARFF research group believes this feature is worth getting because it is a low risk, low cost addition to the tracking subsystem that can significantly reduce ARFF vehicle operator communications work load. This feature is low cost, low risk because it takes advantage of the tracking subsystem data link and computer infrastructure. Implementation of this feature requires software enhancements.

5.2.4 Displays.

All three DEVS subsystems require an electronic display. The night vision subsystem should have a dedicated display and the navigation and tracking subsystems should share a display. The following paragraphs describe some displays evaluated during this project.

The night vision subsystem consists of a FLIR camera and a display. Most FLIR cameras provide an RS-170 standard video output. Table 10 summarizes the advantages and disadvantages of the displays evaluated for the night vision subsystem.

TABLE 10. SUMMARY OF EVALUATED DISPLAYS

Manufacturer	Type/Model	Advantages	Disadvantages
Panasonic	Color CRT/BTS700	110-VDC operation Clear picture 7-Inch Screen	Large, heavy
RCA	Black & White CRT/TC1910A	12-VDC operation Clear picture 9-Inch Screen	Large, heavy
Samsung	Black & White CRT/DSG0992EL	9-Inch Screen Low cost ($300)	Large, heavy Poor picture quality Adjustments on back
Interstate Electronics	Black & White Flat Panel LCD/1000-9.5	Thin, Light Sunlight readable Ruggedized 9.5-Inch Screen	Only shows 16 shades of gray Poor black & white image quality High cost ($2,000)
Sharp Electronics	Color flat panel LCD / QD100MM	Thin, Light High quality picture Accepts RS-170 and VGA inputs 10.5-Inch Screen	High cost ($7,000)

The CRT displays that were evaluated had similar strengths and weaknesses. They were all large, heavy and difficult to mount. The picture quality was usually adequate for DEVS. However, the Samsung displays had a poorer than average picture quality and were not adjustable because the controls were located on the back of the display.

The LCD displays offered advantages over the CRT's in terms of size, weight and ease of installation. The Interstate Electronics is a black and white flat panel LCD being considered for use by the Army for the DVE program. The main advantages that this display has over all others is that it is sunlight readable and ruggedized. Sunlight readability is not a major factor in the night vision subsystem since it will mostly be used during periods of poor visibility. The Sharp Electronics color, active matrix flat panel LCD provides an excellent picture. This active matrix LCD does not suffer from the viewing angle limitations of passive LCD displays. Its performance is comparable to a color VGA display terminal. Because the LCD is essentially a digital display, it can accept both VGA and RS-170 inputs. This means that the same display could be used for the night vision and navigation subsystems. The QD-100MM can switch between the VGA and RS-170 inputs with the press of a button. Active matrix flat panel displays could represent the future of video display systems if they become price competitive in the commercial market.

5.3 DEMONSTRATIONS.

The night vision, navigation and tracking subsystems described in the previous sections were evaluated and demonstrated at the FAATC and other airports around the country. These demonstrations focused on determining functional performance parameters and identifying desirable characteristics of DEVS. Table 11 summarizes the demonstrations and evaluations performed during this project and lists the major lessons learned for each.

Operational demonstrations usually involved a simulated response to a small test fire. These demonstrations occurred at night and under a variety of weather conditions including clear and cold, hot and humid, rain, snow, and fog. The ARFF research group HPRV and twin agent RIV were equipped with up to four FLIR camera systems and two navigation and tracking subsystems in support of these demonstrations. The following sequence of events was typical of these demonstrations.

a. The ARFF vehicle driver positioned the vehicle at a point approximately 1 mile from the test fire site. At operational airports such as Atlanta and Boston, the vehicle was usually positioned at a fire house. When the vehicle was in position, fire department personnel at the test fire site and the DGPS base station were notified.

b. Fire department personnel at the test fire site started a test fire. The test fires were made by lighting jet A fuel poured over water in metal pans. Usually 40 to 50 gallons of jet fuel were distributed over 2 to 4 pans that covered an area that was 15 to 20 feet in radius. A gallon of gasoline was often used to start the fires. Once the fire was lit, fire department personnel in the vehicle and contractor personnel at the DGPS base station were notified.

TABLE 11. SUMMARY OF DEVS DEMONSTRATIONS

Location	Date	Purpose	Lessons Learned
FAATC	07/28/93	FLIR/GPS	Medium wave FLIR exhibits blooming when aimed at small test fire
FAATC	08/04/93	FLIR/GPS	Uncooled FLIR does not have good image quality
FAATC	08/16/93	FLIR/GPS	(1) TWDS is too bright at night — high glare (2) Driving application requires wide FOV
FAATC	09/08/93	FLIR/GPS	(1) Stand alone GPS sometimes puts vehicle on wrong surface (2) Uncooled FLIR technology too immature for DEVS (3) Nav system Computer Human Interface needs to be very simple
FAATC	10/20/93	FLIR/DGPS /Tracking	(1) Medium wave FLIR exhibits blooming when aimed at small test fire (2) DGPS accuracy always puts vehicle on correct surface but is not good enough to drive by (3) Tracking system display in vehicle should be color (4) Touch screen interface is desirable for nav/tracking system control (5) Tracking system should have 1 second update rate (6) USGS Quad map is too busy (7) Aerial photograph needs highlighting
FAATC	10/27/93	FLIR	PEV thermal sensor does not provide sufficient resolution on thermal image
Atlanta	01/15/94	FLIR/DGPS /Tracking	(1) FLIR displays should be mounted as close to driver's line of sight as possible. (2) FLIR cameras should be mounted as close to driver's line of sight as possible. Ideally, they would be on roof above driver. (3) There should be some way to tell which direction FLIR is pointed from inside truck.
Seattle	02/17/94	FLIR	(1) Need to keep rain/moisture off lens (2) Could track aircraft from behind that were not visible to naked eye in fog. Visibility was ½ mile. (3) Training would be needed to identify aircraft in poor visibility. Could only see heat from engines at ½ mile. (4) FLIR image not very useful for navigation under worst case conditions (rain and little temp. difference for three days in a row). It was hard to distinguish edge of roadway. (5) FLIR should have automatic gain and level control to provide hands free optimal performance
New York	03/03/94	FLIR	(1) FLIR could track aircraft not visible to eye due to poor visibility in heavy snow (2) Need to keep snow/ice off lens
Boston	04/14/94	FLIR/GPS /Tracking	(1) FLIR could track fires and aircraft in heavy fog (RVR < 500 feet) (2) FLIR could locate person in water (3) DEVS should not be affected by sudden temperature and humidity changes (4) The FLIR image should use the entire display screen (5) Navigation map displays in vehicles should only display planimetric data (6) Messages exchanged over tracking system should be time stamped and logged.

c. Contractor personnel at the DGPS base station transmitted the position of the test fire to the vehicle. The location of the test fire appeared on the map display in the vehicle cab as a red icon. A text message which read "PROCEED TO CRASH SITE" also appeared on the vehicle map display.

d. The vehicle proceeded to the test fire as soon as the heat from the fire was detected by the FLIR. The FLIR could usually detect the fires before they were visible to the naked eye. The FLIR image was evaluated during this trip by the vehicle occupants and was also recorded for later review. At the FAATC, the response followed a straight and direct path to the fire. This allowed the fire to be in the FLIR image most of the time. At operational airports, the responses were limited to service roads and usually did not take a direct path to the fire. The fire often went out of view of the FLIR during the response. The vehicle navigation subsystem display was also evaluated by vehicle occupants during these responses and was sometimes recorded for later review. The DGPS base station and tracking display was also evaluated and sometimes recorded. Text messages such as "B-767, 143 passengers" were transmitted from the base station to the vehicle during the response.

e. The vehicle usually stopped about 200 yards from the fire site. People were asked to walk around the fire when the vehicle was in this position to simulate accident victims. The FLIR images of the people and the fire were evaluated and recorded for later review. The tracking subsystem was used to send messages from the truck at its position near the fire to the base station. Messages typically included crash site location updates, requests for additional police, fire or ambulance assistance, and text messages typed in at the laptop keyboard.

f. After the fire was extinguished, the simulation was usually repeated one or two times.

For further information about specific demonstrations, see the demonstration summaries and trip reports in Attachment B.

5.4 RECOMMENDED FURTHER RESEARCH.

Much has been learned about ARFF response during low visibility and the impact DEVS can have on the ability to respond. The results of this study are the recommended requirements for ARFF vehicle and command center equipment included in section 4 of this document. Additional research will help to refine DEVS requirements. The following topics should be investigated while refining ARFF research group's prototype DEVS.

5.4.1 Operational Performance Trials.

Operational performance trials to measure the effectiveness of DEVS should be conducted with the ARFF research group prototype DEVS. Simulated responses should be conducted in low visibility conditions with and without DEVS to determine the impact of DEVS on ARFF response time.

5.4.2 Map Orientation.

The requirement for heading-up vs. north-up map displays should be explored. Heading-up maps show features directly ahead of the vehicle at the top of the map display, while north-up displays always show north at the top. In-vehicle moving map systems generally use heading-up maps for real-time navigation, as they show a natural left-right orientation of landmarks and necessary navigation, while north-up maps are usually used for static situation displays and route planning. All of the experimental systems evaluated in this program used north-up maps. A rotating heading-up map should be developed and operationally evaluated against north-up maps, with and without visual cues that help the driver mentally rotate the map.

5.4.3 Driving Cues.

Vehicle navigation cues should be studied. Such cues include overlay of FLIR images, vehicle and FLIR pointing indicators, display of range/bearing indicators, and computer graphic information. Use of these cues should be studied with relation to heading-up and north-up map displays to determine the best combination for enhancing the drivers' situational awareness of where they are and how to proceed to the emergency site.

5.4.4 Displays.

In the course of this program, several displays for maps and FLIR images were evaluated, including monochrome and color CRTs, LCDs, and a transparent window display. HUDs and alternate display systems should be examined. All displays should be examined in a more formal manner for operational suitability and emergency crew performance.

5.4.5 Ergonomics.

A structured analysis of ergonomics and human factors of the "automated" truck cab should be systematically examined, including link analyses and body-posture tradeoffs. The cabs of modern ARFF vehicles are becoming complex, with multiple systems and controls. The ergonomics analysis should be done to ensure a manageable cab environment for drivers.

5.4.6 Map Sources.

One of the lessons learned while developing digital maps of different airports is that there is no readily available, inexpensive source of map data for airports that is perfectly suited for use in DEVS. Additional research should be performed to determine what the sources of mapping data are, and how each source of data must be customized for use in DEVS. A generic operator interface should be developed for the vehicle and ECC computer displays and controls which can accommodate mapping data from different sources.

5.4.7 Job Aids.

An on-board computer system with digital data link provides an opportunity to install real-time job aids in the vehicle. For instance, aircraft plans information includes door locations and penetration points, as well as flight specific information, such as the number of souls on board, fuel quantity, and the presence of hazardous material. The benefits and means of providing such job aids should be investigated.

5.4.8 Power System Requirements.

An integrated means for powering DEVS should be explored. The DEVS electronics require several different voltages, and are generally less resistant to surges, spikes, and voltage variations than existing truck equipment. Methods for delivering appropriate power to these electronics should be explored.

5.5 IMPLEMENTATION RECOMMENDATIONS.

The DEVS R&D program has demonstrated technological capabilities with prototype systems. Due to the exploratory nature of the program, as well as the rapid developments in relevant technology, it is not possible to fully define DEVS requirements at this time. For full benefits of the system to be realized, implementation of DEVS technology must proceed cautiously to ensure proper configuration of equipment for maximum performance enhancement.

5.5.1 Pilot Programs.

Initial DEVS installations should be done as pilot programs, in close cooperation with FAA headquarters and the FAA Technical Center's ARFF research group. DEVS technology is complex and rapidly advancing. The purpose of this cooperation is twofold. First, airports acquiring DEVS should receive the benefit of experience in obtaining the best technology cost-effectively. Second, by feeding back the results of operational experience gained to the research group, the specifications and requirements for DEVS equipment can be refined to benefit all ARFF departments and potential future users of DEVS equipment.

5.5.2 Integration.

Proper integration of all distinct DEVS components (Night Vision, Navigation, Tracking, and digital communications with the Command Center) into a coherent system is necessary to realize the full potential of the system. Piecemeal acquisition of partial systems is unlikely to result in significant performance improvement. Only complete, integrated DEVS systems should be acquired.

5.5.3 Retro-fit Ergonomics.

Retro-fit installation of DEVS into existing vehicles, some of which already have multiple systems and controls, must be systematically examined for proper ergonomics. While haphazard addition of complex controls could overwhelm operators, proper ergonomics analysis and design for retro-fit installations will ensure a coherent system which will enhance ARFF response. In acquiring DEVS, airports must ensure that sufficient ergonomics analysis and design efforts are included to ensure the effectiveness of retro-fit installations.

5.5.4 Site Customization.

Each site implementation should be researched and customized according to the specific operational environment. Some airports will require mobile command centers, while others will prefer fixed bases. Frequencies for the digital radio communications link must be compatible with other radio use in the area, and the number of vehicles to be equipped will depend on the operational environment.

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APPENDIX A
SUGGESTED TRAINING EXERCISES

ARFF research group recommends that ARFF services conduct DEVS proficiency training after personnel have completed DEVS operation indoctrination. The following suggested training exercises should help ARFF crews learn how to use DEVS during low visibility responses.

a. Aircraft and vehicle location using FLIR—Locate the ARFF vehicle at a position with a good view of an active runway at night. Aim the FLIR camera at aircraft on the runway. Observe the difference between the FLIR generated image of the aircraft and the view out of the windshield. Conduct this exercise during all weather and visibility conditions.

b. Fire location using FLIR—Light small test fires at night and observe from different distances with the FLIR. Conduct a response drill to the test fire to practice sighting the fire while driving fast. Conduct this exercise during all weather and visibility conditions.

c. Navigating to accident site using FLIR—Drive around the airport at night and observe the image generated by the FLIR camera. Notice and be able to recognize the FLIR generated image of familiar landmarks such as buildings and other airport installations. Conduct this exercise during all weather and visibility conditions.

d. Negotiating terrain and locating people using FLIR—Drive the R&D vehicle in a dark area of the airport at night. Observe the FLIR generated images of the terrain and roadway. Turn out the lights of the vehicle and slowly drive by the FLIR image alone. Identify test participants located along the way of the test route. Experiment with detecting different type of obstacles placed along the route such as other vehicles and other objects which simulate accident debris. Conduct this exercise during all weather and visibility conditions.

e. Aircraft and vehicle location using tracking subsystem—Down link the location of a simulated aircraft accident from the ECC to the ARFF vehicle. Observe how the location of the accident automatically appears on the airport map in the vehicle.

f. Navigating to accident site using navigation subsystem—Use the displayed digital map of the airport and the DGPS derived position of the R&D vehicle to determine the best route to a simulated accident site. Respond to areas outside of the airport property boundary.

APPENDIX B
DEMONSTRATION SUMMARIES

The following pages contain trip reports, notes, attendee lists, and tape logs from demonstrations and evaluations conducted at the FAATC and airports in Boston, Seattle and Atlanta. They are presented in reverse chronological order with the most recent demonstration notes presented first. Many of these summaries are actual trip reports presented in their original format.

TRIP REPORT
DEVS - 1014.2.12.1

Location:	Boston, MA
Dates:	April 11-14, 1994
Purpose:	DEVS Technology Demo
Travelers:	R. Lewis, Galaxy Scientific

Summary

The purpose of this trip was to demonstrate Driver's Enhanced Vision System (DEVS) technology to Massachusetts Port Authority (Massport) personnel, and to collect DEVS performance data during water rescue operations and foggy conditions.

Five Forward Looking InfraRed (FLIR) systems, one GPS vehicle navigation system and one GPS vehicle navigation and tracking system were successfully demonstrated. All FLIR units were internally cooled and all but one were designed for the 8-12 μm range.

FLIR Systems	FOV (H by V)
Westinghouse Micro-FLIR	30° by 22°
FLIR Systems Inc. Situation Awareness (SA) FLIR	28° by 16°
Thorn EMI LITE	40° by 20°
Inframetrics IRIS	30° by 20°
Inframetrics Infracam (3-5 μm)	8° by 7°

Navigation and Nav/Tracking Systems
Astronautics (navigation only)
Rockwell (navigation and tracking)

The ability of a FLIR camera to help locate accident victims in water was successfully demonstrated. Assistant chief Bob Donahue donned a wet suit and jumped into the harbor (water temperature was approximately 43°F). Even with the well insulated wet suit, Chief Donahue was easily detectable by the FLIR cameras at a distance of about 150 yards.

The ability to locate fires with the FLIR during periods of low visibility was demonstrated. With visibility only 1000 ft due to fog, the FLIR cameras were able to detect a small test fire at a distance of about 1 mile. The fire was not visible to the naked eye at this distance. People and aircraft were also visible with the FLIRs before they could be seen with the naked eye.

The 3-5 μm camera demonstrated severe blooming when pointed at a fire. While this camera provided an excellent thermal image of normal airport operations, its picture rapidly deteriorated when aimed at a fire or source of high heat such as a jet engine.

The Rockwell mapping system demonstrated the technique of overlaying a digitized photograph of Logan airport (raster image) with a vector map. This multi-layered approach provided the best airport map display seen to date. The digital photograph provided a believable base map which was greatly enhanced by the vector image.

The vector map generated by Rockwell for the remote unit display (laptop LCD) was more effective than previously scanned paper maps and photographs. The white line vector image on a dark background provided a clear, uncluttered map of the airport that was easily visible. While the combined raster/vector map seemed to work best for the base station, the vector only approach worked best for the remote unit. One disadvantage of the vector display on the remote computer, however, was a slow update rate. The laptop computer could not erase and redraw the vectors fast enough to update the screen in a reasonable amount of time when the remote unit exceeded the boundary of the displayed map.

The following people supported this demonstration:

Name	Agency/Company
Joseph Wright	FAA Technical Center
Larry Hampton	FAA Technical Center
Bob Donahue	Massport
Paul Moore	Massport
Rick Lewis	Galaxy Scientific
Rich Winnie	Westinghouse
Franz Eberth	FLIR Systems
Andrew Owen	Inframetrics
Ken Hartman	Rockwell/Collins

Observations made during this demonstration support the following recommended features for the DEVS night vision system:

1. The night vision system should have automatic gain and level controls to provide hands-free optimal performance.

2. The night vision system should not be affected by the sudden temperature/humidity changes that ARFF vehicles are subject to as they leave a firehouse.

3. The night vision system should operate in the 8-12 μm wavelength region of the infrared spectrum.

4. The night vision system should have a horizontal Field Of View (FOV) of at least 30°, and a vertical FOV of at least 20°.

5. The night vision system should use the entire display screen. An aspect ration of 4:3 is recommended.

Observations made during this demonstration support the following recommended features for the DEVS navigation/mapping system.

1. The map displays in ARFF vehicles should be clear and uncluttered. Only planimetric data (roads, runways, taxiways, key buildings, etc.) should be displayed.

2. All message traffic transmitted between the base and remote computers should be time stamped. All operator initiated messages should be time stamped and logged automatically.

Notes

The following notes provide a more detailed accounting of the daily activities which occurred during this trip.

Monday, 4/11/94

FAATC research team arrived at Logan around 3:00 PM and performed the following tasks:

- Calibrated Astronautics mapping system
- Installed Rockwell base station and started survey data collection

Tuesday, 4/12/94

8:00 AM. Restarted survey data collection at Rockwell base station. For some reason, data collection stopped around 6:00 am.

8:30 AM. Installed Rockwell mapping system remote unit in Massport van.

9:00 AM. A meeting was held in the media room (see Attachment A for list of attendees). Joe Wright gave a presentation on the DEVS program and details of the activities to be performed at Logan were discussed.

10:30 AM. Mr. Bryan Corbett gave a tour of the operations room on the 16th floor of the control tower. This room also serves as the backup control tower. Representatives from Norden Systems gave a brief demonstration of the ASDE-3 radar. Norden has a small office on the 16th floor where they have installed the Airport Movement Area Safety System (AMASS). The AMASS was not operating at the time of the tour due to a problem with the datalink to the ARTS radar.

11:30 AM. Installed FLIR Systems Inc. SA FLIR and monitor on FAA research vehicle.

1:00 PM. Performed dry run of burn test, re-calibrated Astronautics mapping system and debugged Rockwell mapping system.

4:30 PM. Installed Inframetrics IRIS FLIR on FAA Research vehicle.

7:30 PM. Made final preparations for burn tests. All FLIR cameras were adjusted and tuned. A dry run of the simulated response was made. The run was from the firehouse to the training facility over the perimeter road.

8:45 PM. Fire #1 was lit. Conditions were as follows: Temperature was around 44°F, winds were from the South East at 15 mph gusting to 40. Visibility was very good. The fire was easily visible with all four FLIR cameras and the naked eye from the firehouse. When the research vehicle got to a point in the response where a hill was between it and the fire, the heat from the fire could be seen on the FLIRs. The fire was not visible to the naked eye from this location. Attachment B is the tape log for data collected during this effort.

9:45 PM. Fire #2 was lit with results very similar to fire #1.

10:30 PM. The FAA research vehicle was positioned to have a good view of the harbor where the Massport rescue boat was conducting operations. Chief Donahue donned a wet suit and jumped into the water. The temperature of the water was approximately 43°F. All four infrared cameras were able to detect Chief Donahue in the water despite the fact that the wet suit provided excellent insulation. This demonstration clearly showed that FLIR technology can be used to locate accident victims in water.

Wednesday, 4/13/94

6:00–7:30 AM. Drove FAA Research vehicle around airport to observe the ability of FLIR cameras to detect aircraft under the following conditions: Temperature 43°F, Humidity 97%, cloudy, light rain. The principle observation positions were at the side of taxiway B near the hold point for runway 4L and near the RVR equipment at the intersection of runway 15 and 22. The FLIR cameras performed slightly worse under these conditions than the conditions of yesterday.

10:00 AM. FLIR cameras and mapping system were demonstrated to Mr. Joe Lawless, Director of Public Safety for Massport.

11:00 AM. The rain stopped and was replaced with fog. Conditions were as follows: Temperature: 43°F, Humidity: 100%, RVR <500 ft. The airport was operating in the low visibility configuration: Landings were on runway 4R and takeoffs were on runway 9. Preparations were made to light a test fire. In the mean time, the FLIR cameras were used to locate aircraft in the fog. It was usually possible to detect the engines of aircraft that were no longer visible to the naked eye.

11:35 AM. Fire #1 was lit at the CFR training site. RVR was still <500 ft. The fire was made using three pans, covered an area of about 25' by 4', and used approximately 37 gallons of jet fuel. The FAA Research vehicle observed the fire on the FLIR cameras from the fire house (a distance of approximately 4300 ft). The fire was detectable on the FLIRs but was not visible to the naked eye. The fire was observed with the FLIRs from several locations on the simulated run from the fire house to the CFR training site.

12:30 PM. Fire #2 was lit at the CFR training site. RVR was 1800 and it was raining and foggy. The same procedure used for fire #1 was repeated with similar results.

5:00 PM. The Inframetrics IRIS camera was removed from the FAA research vehicle and replaced with the 3-5 μm Infracam.

8:00 PM. Fire #3 was lit. The same response from the fire house to the CFR training facility was made. Conditions were as follows: Temperature 40°F, steady rain. Picture clarity was slightly degraded on all cameras due to water on the lens surfaces. The Infracam displayed severe blooming when aimed at the fire or jet engines.

9:00 PM. Vendor equipment was removed from FAA Research vehicle and Massport fire house.

DEVS MEETING ATTENDEES

Name	Agency/Company	Telephone
Robert Donahue	MPA Fire Rescue (Deputy Chief)	617-561-1903
Richard Winnie	Westinghouse	407-856-2072
Michael McElwain	Westinghouse	617-890-9370
Ken Hartman	Rockwell International	319-395-5079
Rick Lewis	Galaxy Scientific	609-645-0900
Larry Hampton	FAA Tech Center	609-485-5318
Joseph Wright	FAA Tech Center	609-485-5131
Franz Eberth	FLIR Systems Inc.	508-458-4400
Joe Lawless	MPA Director Public Safety	617-561-1607
Jack Kreckie	MPA Fire Rescue	617-561-1906
Robert Larsen	MPA Fire Rescue (Chief)	617-561-1902
Robert Brown	MPA Fire Rescue (Deputy Chief)	617-561-1904
Paul Moore	MPA Fire Rescue (Training officer)	617-561-1914
Phil Olandella	MPA Public Affairs	617-561-1818
Gary Tobin	MPA Airport Facilities	617-561-1956
Richard Dalton	MPA Facilities	617-561-1957
John Duval	MPA Operations	617-561-1922
Paul Zrinsch	FAA Boston Automation	617-561-5781
Bob Sgroi	FAA Boston ATCT	617-561-5781
Bryan Corbett	MPA Operations	617-561-1922

TAPE LOG

The following table catalogs tapes recorded at Logan Airport.

Source	Tape #	Start Date/Time	Stop Date/Time	Summary
Video Cam	1	12 Apr 1430	12 Apr 2130	First burn test
Video Cam	2	12 Apr 2130	12 Apr 2300	Second burn, man in water
Video Cam	3	13 Apr 0630	13 Apr 0830	Aircraft in 97% humidity
Video Cam	4	13 Apr 0930	13 Apr 1330	Burns in fog
Video Cam	5	13 Apr 1930	13 Apr 2100	Burn in rain
Westinghouse FLIR	1	12 Apr 1430	12 Apr 2130	First burn test
Westinghouse FLIR	2	12 Apr 2130	12 Apr 2300	Second burn, man in water
Westinghouse FLIR	3	13 Apr 0630	13 Apr 0830	Aircraft in 97% humidity
Westinghouse FLIR	4	13 Apr 0930	13 Apr 1330	Burns in fog
Westinghouse FLIR	5	13 Apr 1930	13 Apr 2100	Burn in rain
OMI FLIR	1	.12 Apr 1430	12 Apr 2130	First burn test
OMI FLIR	2	12 Apr 2130	12 Apr 2300	Second burn, man in water
OMI FLIR	3	13 Apr 0630	13 Apr 0830	Aircraft in 97% humidity
OMI FLIR	4	13 Apr 0930	13 Apr 1330	Burns in fog
OMI FLIR	5	13 Apr 1930	13 Apr 2100	Burn in rain
Astro GPS	1	12 Apr 1430	12 Apr 2130	First burn test
Astro GPS	2	12 Apr 2130	12 Apr 2300	Second burn, man in water
Astro GPS	3	13 Apr 0630	13 Apr 0830	Aircraft in 97% humidity
Astro GPS	4	13 Apr 0930	13 Apr 1330	Burns in fog
Astro GPS	5	13 Apr 1930	13 Apr 2100	Burn in rain
FSI/Inframetrics FLIRs	1	12 Apr 1430	12 Apr 2130	First burn test
FSI/Inframetrics FLIRs	2	12 Apr 2130	12 Apr 2300	Second burn, man in water
FSI/Inframetrics FLIRs	3	13 Apr 0630	13 Apr 0830	Aircraft in 97% humidity
FSI/Inframetrics FLIRs	4	13 Apr 0930	13 Apr 1330	Burns in fog
FSI/Inframetrics FLIRs	5	13 Apr 1930	13 Apr 2100	Burn in rain

TRIP REPORT
DEVS - 1014.2.12.1

Location: Seattle, WA
Dates: February 15-17, 1994
Purpose: Westinghouse FLIR Demonstration
Travelers: R. Lewis

Summary

The purpose of this trip was to observe the performance of the Westinghouse Micro FLIR in fog. Port of Seattle (POS) officials wanted to see if objects obscured by fog (RVR 300 ft) can be detected by the FLIR camera. A recording of the FLIR was made under the following atmospheric conditions: Ceiling 200 ft, visibility ½ mile, light rain, fog, temperature 45 °F, relative humidity close to 100 percent. These conditions represented the lowest visibility during the trip and were only available for about 40 minutes.

Atmospheric conditions were not foggy enough to determine if the Micro FLIR meets POS needs. Rich Winnie, the Westinghouse sales representative committed to returning to Seattle at a later date when fog is thicker.

The FLIR camera was able to detect heat from the engines of aircraft leaving the airport after the aircraft were no longer visible to the naked eye. By the time aircraft were no longer visible to the eye, however, they were far enough away to not be distinguishable as aircraft on the FLIR display to untrained observers. The heat from the aircraft engines looked like two or three small white dots on the FLIR display.

Rainwater on the Micro FLIR's Germanium window reduced the clarity of the FLIR images. For example, the structural cross members of a radio tower were not visible until after the Germanium window was wiped dry. A protective shroud made of cardboard and duct tape was attached to the Micro FLIR in an effort to keep rain off of the window. This technique worked well as long as the vehicle was not moving forward. These experiences re-emphasize the need to have a windshield wiper or some other device on ARFF FLIR cameras to keep the windows dry.

The conditions in Seattle during this demonstration were almost a "worst case" example in terms of FLIR camera performance. The temperature varied less than 10°F and it rained constantly for 3 days. Objects that did not generate heat were all very close in temperature. For example, roadways were not always clearly distinguishable from the sides of the road etc.

There are two different groups interested in FLIR technology at Seattle: ARFF services and airport operations. ARFF services see the FLIR primarily as a tool for locating fires and accident victims. Airport operations see the FLIR as a tool to help them navigate vehicles during low visibility conditions. Representatives from both groups have looked at other FLIR cameras besides the Westinghouse Micro FLIR. Attachment A is a list of people who looked at the Westinghouse Micro FLIR.

Airport officials in Seattle do not seem very interested in vehicle navigation/tracking based on GPS at this time.

Attachment B is a log of video tapes made during this demonstration.

The following people supported this demonstration:

Name	Agency/Company
Don Axt	Port of Seattle
Larry Hampton	FAATC/ARFF research group
Bill Dawson	FAATC/ACM-411B
Rich Winnie	Westinghouse/Orlando
Tom Kilbane	Westinghouse/Seattle
Rick Lewis	Galaxy Scientific

Observations made during this demonstration support the following recommended features for the DEVS night vision system:

1. The night vision system should have automatic gain and level controls to provide hands-free optimal performance.

2. The night vision system should provide a way to keep water and ice from accumulating on the window or lens.

3. The night vision system should be mounted such that it can be panned from side to side from within the vehicle. There should also be an indication of which way the system is pointed inside the vehicle.

Notes

The following notes provide a more detailed accounting of the daily activities which occurred during this trip.

Tuesday, 2/15/94

The Westinghouse Micro FLIR and other equipment from FAATC arrived in Seattle one day late due to a storm that closed FAATC on Friday, February 11. All equipment was installed on a POS ramp inspection van by 4:00 p.m.

A demonstration was given to Jim Serrill, Manager of Technical Services. During this demonstration, the POS vehicle was driven around the ramp areas. Hot aircraft engines and terminal buildings showed up well. The vehicle was driven down taxiway A to observe how the FLIR displays taxiway lights. The lights were visible on the display but were not very clear. Many of these built-into-the-runway lights were submerged in puddles.

At 7:20 p.m., conditions were as follows: Temp 45°F, dew point 41°F, visibility 7 miles, light rain, night time. The POS van proceeded South down the vehicle access road between the gates and taxiways/runways. FLIR images were recorded on the Westinghouse SVHS recorder during this time. Some hot asphalt near the Alaska Air terminal was observed as were many planes. Airplanes that had been parked on the ramp for a long time did not show up very well.

POS Van proceeded along perimeter road to western side of airport. On a dark section of the road, Rich Winnie exited the van and walked about 150 yards down the road. He was easily visible on the FLIR display.

The landing lights of aircraft approaching runway 16R were visible long before the aircraft showed up on the FLIR display. The lights could be seen while the aircraft were an estimated 4 to 5 miles away. The aircraft did not show up on the FLIR display until they were on the runway (probably about 1 mile away).

The VCR batteries went dead after approximately 50 minutes of recording. After this, the POS van went down runway A again. Five to Seven of the blue taxiway lights in front of the van could be seen on the FLIR display.

Driving on the airport surfaces requires a great deal of situational awareness. Drivers must constantly check both sides and their rear for oncoming vehicles and aircraft. A fixed mounted FLIR is not adequate for this purpose. This observation supports the idea that a FLIR should be mounted on a moveable platform. It does not seem necessary to require this platform to tilt up and down if the FLIR's vertical FOV is at least 30°. The FLIR should be able to pan side-to-side, however, and there must be a way to tell where the camera is pointed from inside the vehicle.

Wednesday, 2/16/94

The same route driven the previous night was driven during the day. Conditions were similar to yesterday.

Bill Dawson from the FAATC video lab explained that the Westinghouse FLIR camera (and most others) output data in RS-170 format (composite video). A better format is the newer RS-170A (component video) standard. RS-170A provides a much higher resolution image than RS-170.

The FLIR image seems to make more sense to me when it is black hot during the day, and white hot at night. Black hot makes the sky look white like it is during the day. White hot makes the sky look black like it is at night. Regardless of day or night, the white hot image always looked sharper on the Westinghouse Micro FLIR.

Careful observations of the effect of water on the Germanium window were made during the day. The window was wiped dry and then wet by rain repeatedly. Using the FLIR image with the dry window as a baseline, the clarity of the image was reduced by about 30 percent when the window was wet.

Before night time operations, a shroud of cardboard and duct tape was made to provide some protection from the rain. This technique seemed to work when the vehicle was still. The window still got wet, however, when the vehicle was moving.

Night time operations involved following the same route used the previous night and earlier today. After all recording was finished, Joe Fulton, Operations Supervisor, was taken for a ride in the van.

Thursday, 2/17/94

At 9:30 am conditions were as follows: Ceiling 200 ft, vis ½ mile, light rain, fog, temperature 46°F, dew point 45°F. Chief Barrett was in the van as we recorded airport operations in light fog.

A United 737 was followed northbound on taxiway A. The heat from the engines was detectable with the FLIR after the aircraft was no longer visible.

Other aircraft departing on runway 16L were observed. The engines were visible on the FLIR after the planes were obscured by fog.

Chief Barrett would like to see the FLIR operate in much denser fog but was happy with what he saw today. He said Seattle gets about 40 foggy days a year. He also thought it would be a good idea to compare the heat of jet engine exhaust and compare it to the heat of a jet fuel fire. According to Chief Barrett, a fuel pit burns at about 2000 to 2500°F. Jet engines are 1000°F or less according to General Electric.

DEVS DEMONSTRATION ATTENDEES

Name	Title/Occupation
Mark Coates	Manager, Airfield Airport Operations *
Joseph Lee	Airport Certification and Safety
Don Axt	Operations Supervisor, Airport Operations
T. A. Barrett	Assistant Fire Chief
Joe Fulton	Operations Supervisor, Airport Operations
Jim Serrill	Manager of Technical Services
Jeff Finch	Manager of Aeronautic and Technical Operations *

* Observed tape—did not actually view live demonstration

DEMONSTRATION TAPE LOG

Number	Date	Description
G-1	2/15	SVHS tape in Westinghouse VCR. Recorded afternoon night time FLIR images.
G-2	2/16	SVHS tape in Westinghouse VCR. Daytime/nighttime FLIR images.
G-3	2/16	Beta FAATC tape. 30 minutes of FLIR images between 10 and 11 am.
G-4	2/16	Beta FAATC tape. 30 minutes of FLIR images started at 11:05 am.
G-5	2/16	Beta FAATC tape. 30 minutes of FLIR images started at 6:05 p.m.
G-6	2/16	High-8 FAATC tape. FLIR images out the window until around 6:30. After Beta tape ran out, FLIR images were recorded on High-8.
G-7	2/17	High-8 FAATC tape. View out the window between 9:30 and 10:30 am. Fog.
G-8	2/17	Beta FAATC tape. FLIR images between 9:30 and 10:30 am. Fog.
G-9	2/16	High-8 FAATC production camera. Day/night operations recorded primarily from inside POS van.

TRIP REPORT
DEVS - 1014.2.12.1

Location: Atlanta, GA
Dates: January 11-15, 1994
Purpose: DEVS Operational Demonstration
Travelers: R. Lewis

Summary

The operational demonstration of the ARFF research group Driver's Enhanced Vision System (DEVS) at the Hartsfield Atlanta International Airport (ATL) was a success. All aspects of the system were demonstrated to the list of people included as Attachment A.

Most people who saw this demonstration, including members of the NFPA ARFF vehicles task group and Atlanta Fire Department Officials, were impressed with the technology and saw a clear need for this type of equipment on ARFF vehicles.

ATL is taking steps to comply with the Federal Aviation Administration (FAA) Advisory Circular 120-57, Surface Movement Guidance and Control System (SMGCS), which goes into effect on January 1, 1995. ATL has developed a SMGCS plan that addresses ARFF operations when conditions are RVR 1200 or less. At the direction of ARFF research group, Galaxy developed an attachment to the ATL SMGCS plan which addresses DEVS. This attachment was provided to ATL operations and fire department personnel for review.

ATL currently possesses six (6) FLIR Systems Incorporated (FSI) infrared cameras. The DEVS demonstrations revealed that improvements can be made to enhance the effectiveness of these devices. ARFF research group/Galaxy makes the following recommendations:

1. Monitors for the FLIR cameras should be mounted near the ceiling of the ARFF truck cabs and directly in front of the driver instead of in the corner. Mounting the monitors directly in front of the driver should improve his/her ability to drive by the FLIR image.

2. FLIR cameras should be mounted as close to the driver's head as possible to improve alignment between the camera's line of sight and that of the driver. Ideally, these cameras should be mounted on the roof of the truck directly above the driver. ATL can not mount FLIR cameras on top of their ARFF vehicles because they would obstruct other fire fighting equipment. ATL's FLIR cameras are mounted on ARFF vehicle bumpers. We suggest that these bumper mounted FLIR cameras be placed as close to where the vehicle driver is as possible.

3. The FLIR cameras currently owned by ATL should be modified to allow them to become operational in 30 seconds or less. These camera currently require about 5 minutes to "cool down" to an operational temperature.

4. ATL should improve training on the proper operation and use of the FLIR cameras they currently own.

The following notes provide a more detailed accounting of the daily activities which occurred during this trip.

Tuesday, 1/11/94

Arrived at ATL around noon—just after arrival of the ARFF research group research vehicle. Weather conditions were light rain and cool temperatures.

Performed checkout of DEVS equipment in research vehicle at Fire Station 35. The Westinghouse FLIR system worked but produced a substandard image. The Astronautics mapping system came up but got a floating point run time error shortly after starting.

Set up Rockwell base station at Fire Station 40 with assistance from Ken Hartman and Steve Boerhave from Rockwell/Collins. The watch room on top of station 40 does not have access to the roof so the base station was set up in an office on the first floor. After installation of the GPS and RF antennas on the roof, the base station was put into self survey mode and allowed to run over night.

The Rockwell remote mapping system was installed in Joe Wright's rental van and demonstrated to members of the NFPA ARFF working group. The FLIR in the ARFF research group research vehicle was also demonstrated.

Wednesday, 1/12/94

Went to the airport early (around 7:30) because conditions were foggy. A tape of the FLIR was made for Rich Winnie to take back to Westinghouse. The image was still not very good. Another tape was made for ARFF research group to keep. The weather cleared up later in the day.

Rockwell base station was successfully set up to broadcast differential corrections.

Met with B. T. Burley, airport operations manager. The DEVS system was explained to him and he was given copies of the Preliminary DEVS Requirements Definition Document and DEVS SMGCS plan.

A demonstration of the Rockwell mapping system was given to Major Shannon, and Shirley Crenshaw from the Atlanta Police Department, and Kimberly Wade from the airport operations office.

A demonstration of the Rockwell mapping system was given to Officer Bill Carr from the Atlanta Police Department. Officer Carr is the communications officer for the airport.

Arrangements were made with Captain Mitchell (fire department training officer) for burn tests on Thursday.

Software for the Rockwell mapping system was loaded onto the Galaxy laptop. Maps of Atlanta and Atlantic City were included.

Thursday, 1/13/94

Weather was mixed clouds and sun with no fog.

The Astronautics mapping system was finally brought on line. The problem was a corrupted calibration file. Astronautics personnel accidentally plugged a 5V power supply into keyboard output of the computer originally on loan to ARFF research group. This computer was replaced with a spare brought by Doug Cotton. Doug Cotton plans to come to the FAATC the week of January 24 and would like to swap computers at that time.

The DEVS system was demonstrated to Patricia Kline, an FAA Southern Region safety inspector. She thought the Rockwell mapping system was too complicated but liked the Astronautics map display.

A scan converter and VHS recorder were installed at fire station 40 to record the Rockwell base station.

Installed the Rockwell mobile system on ATL fire truck Y-12. This truck also has a FLIR camera. One burn test was conducted with a simulated response from fire station 32 to the abandoned Eastern Airlines maintenance hanger ramp. A test fire was lit using four 2' by 3' pans supplied by ARFF research group. The FLIR and video camera images from the ARFF research group test vehicle were recorded during this exercise. The Rockwell base station at fire station 40 was also recorded.

The Rockwell base station was taken apart and the computers were shipped back to Rockwell. The suitcases, antennas, cables and mobile GPS receiver were turned over to ARFF research group for demonstration at FAATC.

Friday, 1/14/94

A third VHS recorder was installed in the ARFF research group research vehicle to record the Astronautics mapping system.

The ARFF research group research vehicle was taken to downtown Atlanta to show to Fire Chief Chamberlin and other Atlanta Fire Department officials. The members of this group were impressed with the system and thought the technology applies to some projects they are currently working on.

A meeting was held with Bill Ward, FAA Southern Region Safety Inspector. Mr. Ward was concerned that ARFF crews at ATL do not get sufficient training for low visibility operations and was glad to hear ARFF research group was providing guidance for this type of training.

Six burn tests were held starting at 8:30 PM. Recordings of FLIR, video and the Astronautics mapping system were made. The trip from fire station 35 to station 32 which took the ARFF research group research vehicle across taxiways and past aircraft gates was recorded. Six responses from station 32 to the Eastern hanger were also recorded. Chief Chamberlin participated in one of the tests.

Saturday, 1/14/94

All equipment was packed and loaded onto the ARFF research group research vehicle except for the Westinghouse FLIR camera. This camera was sent to Rich Winnie at Westinghouse for troubleshooting.

DEVS DEMONSTRATION ATTENDEES

Name	Title/Occupation
D.M. Chamberlin	Fire Chief, Atlanta Fire Department
J.G. Stephens	Assistant Fire Chief, Atlanta Fire Department
Chief Wade	Assistant Fire Chief, Atlanta Fire Department
F. C. Vossen	Chief Management Analyst, Atlanta Dept. of Finance
Steven Haber	Grants Management, City of Atlanta
Gerry Rusinski	Captain of R&D, Atlanta Fire Department
Allen C. Bryant	Head of Communications, Atlanta Fire Department
C. L. Duncan	Battalion Chief, Atlanta Fire Department (Airport)
R. L. Ellington	Battalion Chief, Atlanta Fire Department (Airport)
Captain M. Mitchell	Training Officer, Atlanta Fire Department (Airport)
Captain Cudger	Captain, Atlanta Fire Department (Airport)
Captain Moore	Captain, Atlanta Fire Department (Airport)
Jeff McNair	Lieutenant, Atlanta Fire Department (Airport)
Booker T. Burley	ATL Airport Operations Manager
Kimberly Wade	Assistant Airport Operations Manager
Major Shannon	Atlanta Police Department (Airport)
Bill Carr	Communications Officer, Atlanta Police Department
Shirley Crenshaw	Atlanta Police Department
William Ward	FAA Southern Region Safety Inspector
Patricia Kline	FAA Southern Region Safety Inspector
Victor Hewes	Airport Safety Services, NFPA 414
Edward Anderson	NY Port Authority, NFPA 414
David Lenz	Oshkosh Truck Corp, NFPA 414
Edward B. Aksim	Principal, NFPA 414
Paul Blankenship	Hypro Corp, NFPA 414
Robert Donahue	Massport Fire Department, NFPA 414
Georges Gulvarch	Sides Company, NFPA 414
Tony Johnson	Unipower Vehicles Ltd, NFPA 414
D. Robin Maryon	Simon Gloster Saro Ltd, NFPA 414
John J. O'Sullivan	British Airways, NFPA 414
Lee Prazer	Akron Brass Co., NFPA 414
Robert E. Reyff	US Air Force, NFPA 414
John M. Schuster	3M Company, NFPA 414
William J. Wenzel	NFPA 414
Richard G. Winnie	Westinghouse, NFPA 414
Gaetan Perron	Canadian Department of National Defense, NFPA 414
Robert G. Relyea	NFPA 414
Bertrand F. Ruggles	FAA, AAS-120, NFPA 414
David F. Short	Carmichael International, NFPA 414
Ronald O. Wikander	Lockheed Aeronautical Systems Co.
Mark T. Conroy	NFPA staff liaison

SUMMARY OF ACTIVITIES

Rockwell Collins DGPS/FLIR Demonstration

10/20/93 - 10/21/93

Installation Notes: Installed Rockwell P&IES system in High Performance Research Vehicle (HPRV). Equipment consisted of a suitcase of electronics containing power supplies an FM radio, and a modem, a Lowrance GPS receiver, and a Toshiba laptop computer. The GPS receiver and an FM antenna were mounted on top of the HPRV. The suitcase of electronics was laid on the right rear seat and a little shelf was made for the laptop to sit on. This shelf was attached to the dashboard in front of the other right side passenger seat. In addition to Rockwell's equipment, ARFF research group supplied a fourteen inch VGA color monitor which was connected to the laptop. This monitor was mounted to a shipping container placed on the floor on the passenger side of the HPRV. The Rockwell equipment was powered with 12VDC from the HPRV.

The Rockwell FLIR was installed on the metal shelf on top of the HPRV. The camera had to be installed upside-down due to the lens used. The lens had a 40° Field of View. Controls for the FLIR were available inside the HPRV cab.

The Rockwell P&IES base station was installed in the observation booth on top of the Hanger building. The GPS antenna was placed on an antenna mast that was surveyed in by the FAATC. The coordinates of this antenna mast are:

N 39 26.979' = 39 26' 58.74"
W 74 34.0005' = 74 34' 0.03"
Altitude: 44.28 M HMSL

The FM antenna was attached on top of the observation booth. The FM broadcast frequency was set at 153.1 MHz. There was some slight interference at 153.0 MHz. The base station PC and suitcase of electronics was set up on a table in the observation booth. A Galaxy scan converter and VCR were used to record images from the base station screen. The Video lab supplied a small color monitor for viewing these images.

10/20/93

1. Performed Map calibration exercise. HPRV drove to Glasgow monument. There was an offset in displayed position on the map. This discrepancy was the result of an incorrect survey point for the base station antenna. The original point was available in degrees , minutes and fractional minutes. The P&IES program required the point to be entered in degrees, minutes, seconds and fractional seconds. After the survey point was updated, the icon was much closer to actual point on map. Further fudging would be required to perfect position solution.

2. Run #1. HPRV proceeded from firehouse to location of Convair 880 near burn site. A crash site icon was transmitted from the base to the remote in the HPRV. Location of burn site is N39 27

34.08, W 74 33 28.59. When the HPRV arrived at the Convair, a position mark was sent back to base. The system currently uses a 2400 baud modem and updates the position on the screen every 4 seconds. The icon of the remote drove through the crash site icon and erased it. The crash site icon was re drawn when the window was re-drawn (zoom out and back in). The icon vector jumps around when remote is still. This is due to little errors in DGPS solution that contribute to track history.

3. Run #2. Same run as #1. HPRV drove from firehouse to Convair 880.

4. Run #3. HPRV drove from firehouse to the end of taxiway B near runway 13. The base sent the crash site icon the remote when the HPRV was leaving the FAA ramp area. The HPRV drove quickly (70 mph) down the taxiway. When the HPRV reached the crash site, a position mark was sent back to the base.

5. Run #4 was a repeat of Run #3. The remote was not in differential mode for this run.

6. Run #5 was a repeat of Runs 2 and 3. The remote was back in differential mode for this run.

7. Run #6 was to Glasgow again. The driver was not informed of the crash site location ahead of time but found the location easily. A request for an ambulance was sent back to the base from Glasgow.

Evening Activities

8. Run #7 was a repeat of the taxiway B runs conducted during daylight. This run was repeated in the dark for comparison.

9. Run #8 was also a run down taxiway B. This time, the crash site location placed at the intersection of B and C. When the truck was proceeding down B, the crash site location was re-located at the end of B.

10. Run #9 was a burn test. Once in position to start the test, the HPRV sent a mark to the base. The base then sent the crash site icon to the truck when the fire started. The HPRV drove to the crash site, and marked to location. The FLIR performed well until close to the fire. The same problems with blooming seen in other 3-5 micro meter FLIRs were evident in this camera as well. The temperature, dew point and humidity conditions for this day are included in the attachments.

10/21/93

1. Run #1 was a repeat of the run down taxiway B to the end of runway 13. The main difference is that the screens on the laptop in the HPRV were recorded instead of the base station screens. A Beta recorder was installed in the HPRV and used to record all test runs this day. FLIR and video images were also recorded for all runs this day.

2. Run #2 was a simulated response from the FAA firehouse to a location outside of the airport boundary. The crash site icon was transmitted from the base to the remote for a location off of Pomona Road. The icon in the remote did not move for the first 2/3 of the trip to the site. P&IES

was iconized, a window stating "respond to crash site" was closed, and then P&IES was re-opened. After this, the icon moved as expected.

3. Run #3 was a simulated response from the FAA firehouse to a location near the VOR site off of Tilton Road. The icon in the HPRV moved for this demonstration.

4. Run #4 was a simulated response from the FAA firehouse to the same location used for Run #2. The icon moved the whole time for this run.

5. Run #5 was problematic. A crash site was located in the R&D area near Lake Harvey. The HPRV responded but was not easily tracked from the base near the crash site. The icon did not seem to update. We even had to ask the HPRV occupants where they were. This run was abandoned before successful completion.

6. The fireman driving the HPRV today made some good suggestions regarding the DEVS map display.
   The map should be color
   The display should be a touch panel
   The "mark" feature is nice but should have a very simple interface.
   All displays (HUD, FLIR, map) should be tilted in towards the driver.
   Directional arrows highlighting a preferred route to crash site would be helpful.
   An arrow or some other indication of the crash site location if it is off the map would be helpful.
   Glare reduction measures should be taken.
   The touch panel display should be located near the steering wheel.
   There should be more of a handshake between base and remote for transmitted messages. For example, if the remote requests an ambulance, the icon should flash until acknowledged by the base.

7. My overall impression of the Rockwell system: The FLIR unit provided a very good picture the second day. It looked like black and white video. Like the other 3-5 micrometer units we've seen, however, the image is overwhelmed by the heat of the fire. Blooming distorted the image in close proximity to the fire. Because of this blooming, this FLIR is not suitable for the DEVS application. The Rockwell/Collins DGPS system was impressive but also has some shortcomings. The windows interface is simple and easy to use but must be made even simpler for use in an operational DEVS. The features such as resource request and position mark were well received and seem to be useful. The accuracy of the DGPS system is more than sufficient to support DEVS operations. The update rate of the remote unit position (4 seconds) is too slow. The icon jumps and lags the actual vehicle position. The data link requires other work as well. A handshaking scheme must be worked out to ensure more effective exchange of information between remotes and the base. Provisions for more than one remote must be incorporated. In general, the data link must be made more robust. It must have increased bandwidth and speed. The topographic map used by DDS is too detailed. The contour lines and some of the labels on the map make it too busy. The aerial photograph was nice but requires enhancement such as highlighting roads. In conclusion, the system is impressive but requires further development to meet the operational needs of the DEVS.

DEMONSTRATION PARTICIPANTS

Name	Organization
Dung Do	FAA/ARFF research group
Larry Hampton	FAA/ARFF research group
Joe Wright	FAA/ARFF research group
Jack Berkowitz	Galaxy
Ted Grant	Galaxy
Carrie Mannis	Galaxy
Rick Lewis	Galaxy
Ken Hartman	Rockwell
Vince Koch	Rockwell
Y. C. Loh	Rockwell

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Dew Point	Humidity
1000	63	62	96.5
1100	63	62	96.5
1200	64	63	96.5
1300	63	63	100
1400	63	62	96.5
1500	63	63	100
1600	63	62	96.5
1700	62	62	100
1800	62	62	100
1900	61	61	100
2000	61	61	100

SUMMARY OF ACTIVITIES

GEC Marconi PYRO-2000 Evaluation II

09/08/93

Installation notes: Installed camera on Pan & Tilt because Westinghouse Micro FLIR was not installed. Ran PYRO-2000 off of 12VDC battery. Used same video terminal that was used for last GEC test. Installed PAL compatible VCR to account for the European video standard.

1. First test ran without incident. FLIR image was a little better than the last time GEC was out here but still not even close to Westinghouse. People walking out from the Fire were somewhat hard to see.

2. For the second test, Joe W. adjusted contrast and brightness on video monitor for this run and was able to improve picture quality considerably. This time the picture was almost good enough to drive by. The picture was still a little grainy, however. Another point to remember is that in an emergency, the driver will not have time to adjust the video terminal. Also, atmospheric conditions may be even worse.

3. Drove around the R&D area looking for deer. None were found. Also looked for EPA test wells. The test wells showed up on the screen but did not "jump out of the picture." We also did a test were a person got out of the truck and walked straight down the road for a distance of about 5 telephone poles. This test should show sensitivity to people at different distances.

4. My overall impression of this camera: The picture quality is not quite good enough yet to support this application. The camera has many other positive qualities, however. It's small, light weight, affordable, requires no cool down and has a better MTBF than most cooled cameras by a factor of about 4. I think this FPA technology is the way to go in the future. The technology is not mature enough at this point to support the ARFF application.

TEST PARTICIPANTS

Name	Organization
Dung Do	FAA/ARFF research group
Joe Wright	FAA/ARFF research group
Larry Hampton	FAA/ARFF research group
Rick Lewis	Galaxy
John Pringle	GEC Marconi
Firemen	

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Dew Point	Humidity (%)
1900	74	66	76
2000	69	65	87
2100	65	64	100
2200	64	64	100
2300	65	65	100

Sky: Sky was partly cloudy between 7:00 and 8:00. Between 8:00 and 9:00 the sky was clear. Between 9:00 and 11:00, fog was forming.

SUMMARY OF ACTIVITIES

Inframetrics IRIS-T Evaluation

08/16/93

1) Problems with IRIS-T installation:
Initial installation went smoothly. IRIS powered up from battery power and ran for about ½ hour before experiencing problems. Video on terminal appeared to be scrambled. This problem was attributed to weak battery packs. Because IRIS-T is designed to accept voltages between 11 and 32-VDC, it was connected to 28V from the truck power supply at the terminal box in the cab. IRIS never powered up in this configuration and it was soon discovered that a fuse was blown. The blown fuse was temporarily replaced with a similarly rated fuse (125V, 2A) in an in-line fuse holder. IRIS powered up using 12VDC from the truck.

2) Run #1: IRIS was aimed too low to see fire very much of the time on the approach trip. There was one good scene where people were walking in front of fire and the camera detected them.

3) Run #2: IRIS aim was adjusted but "scrambled video" problem occurred again. After IRIS was powered off for about 10 to 15 minutes, the problem cleared up. At this point, the problem no longer appears to be power related. The fire was in view for much of this run.

4) Run #3: No new problems. The fire was in view for much of this run.

5) My overall impression of this camera: This camera seems to have the best thermal sensitivity of all the cameras I've seen to date. Before the test started, when Do put his hand on his chest and then removed it, the heat from his hand was still visible on his chest. People show up very well at night. There was more bluming than other 8 to 12 units we've seen but it was tolerable. People were visible in the vicinity of the fire. The current configuration of this camera with the 7X telescopic lens and the 3 by 4° field of view makes it very difficult to compare with the Westinghouse and other cameras that have been in house. The picture was crisp and clear and free of noise.

TEST PARTICIPANTS

Name	Organization
Dung Do	FAA/ARFF research group
Joe Wright	FAA/ARFF research group
Larry Hampton	FAA/ARFF research group
Rick Lewis	Galaxy
Andrew Owen	Inframetrics
Tim Bozarth	Astronautics
Mike Austin	Astronautics
Firemen	

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Dew Point	Humidity (%)
1900	76	73	87
2000	75	73	93
2100	75	73	93
2200	74	73	95
2300	74	73	95
0000	74	71	90

Sky: Sky was completely overcast with scattered showers until around 8:00. After 8:00 the cloud cover started breaking up but visibility remained only 5 miles.

SUMMARY OF ACTIVITIES

GEC Marconi Pyro-2000 Evaluation

08/04/93

1) Strange happenings occurred during pre-test checkout in afternoon. We couldn't turn off Westinghouse MicroFLIR. Power switch on MicroFLIR was turned off but image remained on display.

2) Problems with DC power supply during evening checkout. When power was turned on in truck, equipment did not operate correctly. PC did not boot. FLIR display did not show anything. DC power supply indicated it was providing 10VDC and 10 amps. All equipment was shut off. Power supply indications did not change. Westinghouse MicroFLIR was disconnected. Power supply indications did not change. Portable Honda generator on truck roof was supplying 110VAC to DC power supply and AC power conditioner. Power supply was replaced. Backup power supply worked correctly.

3) Truck Driver made the traditional test run.

4) Fire #1 was lit. Joe W., John Pringle and Joe Cuzzupoli rode in truck. Larry, Do and myself lit fire and walked to truck from fire.

5) Fire #2 was lit. Larry, John Pringle and myself rode in truck. Pyro-2000 appeared to have a clearer image than the previous night. John P. said he increased the gain slightly. Atmospheric conditions were also slightly different. Driver was not comfortable driving by PYRO-2000 image. Driver was more comfortable driving by MicroFLIR image but said it would take some practice to become proficient. Driver did not like transparent display. Green image was actually too bright. He complained of the glare off the glass.

6) Fire #3 was lit. Joe W., John Pringle and myself rode in the truck with results very similar to other two tests.

7) My overall impression of Pyro-2000 unit:
This unit does not suffer from bluming problem seen on 3-5 micron hand held systems. Picture quality is not good enough for this application. Other factors are favorable, however. Time to become operational is very good—about 20 seconds. Estimated MTBF is very good—about 10,000 hours. Small size and compact design are a plus. Price seems reasonable. John Pringle said they typically sell for 25K. Quantity price (100 units) is about 17K. GEC would be willing to sell a similar unit with higher resolution for the 17K price. He's looking into the possibility of bringing out a prototype of the higher resolution unit. The higher resolution unit will have a 200 by 200 array versus the 100 by 100 array used tonight.

TEST PARTICIPANTS

Name	Organization
Dung Do	FAA/ARFF research group
Joe Wright	FAA/ARFF research group
Larry Hampton	FAA/ARFF research group
Rick Lewis	Galaxy
John Pringle	GEC Marconi
Joe Cuzzupoli	American Pacific
Firemen	

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Dew Point	Humidity (%)
1900	80	61	52
2000	74	61	64
2100	72	62	71
2200	69	62	72
2300	70	61	73
0000	69	61	79

Sky: Scattered clouds at 12,000 ft, broken clouds at 25,000.

SUMMARY OF ACTIVITIES

FLIR SA/Prism Evaluation

07/28/93

1) Made test run in Crash Fire Rescue (CFR) High Performance Research (HPR) vehicle with three operational FLIR systems (FSI SA, FSI Prism, Westinghouse MicroFLIR) tied into one display through two switches. FLIR images were recorded on High 8mm recorder.

2) Positioned truck ¾ mile away from burn area. Fire was lit. Switched between all three FLIRs on run to fire. Jack and Rick positioned about 300 yards from fire. Fire died out before truck got to Jack and Rick.

3) Same run as before with the following differences: Truck experienced power problems. Problems appeared to be caused by FSI SA unit. Problems initially cleared up when FSI SA was switched off. Fire died out again before truck got close.

4) Same run as before with the following differences: Only had FSI Prism and Westinghouse MicroFLIR on line. Fire was very large and burned for a long time. Aircraft fuselage burned.

TEST PARTICIPANTS

Name	Organization
Dung Do	FAA/ARFF research group
Joe Wright	FAA/ARFF research group
Jack Berkowitz	Galaxy
Ted Grant	Galaxy
Rick Lewis	Galaxy
Franz Eberth	FLIR Systems
Dick Carlson	Astronautics
Firemen	

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Humidity (%)	Sky
1900	85	58	Cirrus Clouds
2000	80	67	at 25,000 ft.
2100	78	67	Less than 1/2
2200	77	70	sky coverage
2300	76	69	
0000	75	71	
0100	75	74	

SUMMARY OF ACTIVITIES

FLIR SA/Prism Evaluation

07/27/93

1) Made test run in Crash Fire Rescue (CFR) High Performance Research (HPR) vehicle with two operational FLIR systems tied into one display through a switch. One system was the FLIR SA system and the other was the Westinghouse MicroFLIR. At end of test run, Franz Eberth from FLIR mounted handheld FLIR PRISM unit on top of video camera (on top of truck). This unit was displayed on small LCD display normally used for video camera. Began recording trip back to start position. Westinghouse/SA shared a recorder and the PRISM used another recorder.

2) Positioned truck ¾ mile away from burn area. Fire was lit. FLIR SA and PRISM were used for entire run. Heat from fire was visible on FLIRS before fire was visible to naked eye. After driving about 150 to 200 yards, could see fire with eye. Stopped at a point about 300 yards from fire and a person (me) walked up to fire. Fire died out before I got too close to it.

3) Same run as before with the following differences: Switched back and forth between FLIR S/A and Westinghouse unit on approach to fire. This time Jack got to run up to fire. Fire stayed lit. Blume problem was more pronounced with PRISM system. No Blume problem with SA system.

4) Same run as before with the following differences: Rick got to run up to fire again.

5) Drove around R&D area looking for deer. Saw deer on the edge of the woods. They showed up great way before we could see them. Recorded all this too.

6) Got Frank Holiday, the fire truck driver, to record his impression of the systems on Jack's evaluation sheets.

TEST PARTICIPANTS

Name	Organization
Rick Lewis	Galaxy
Jack Berkowitz	Galaxy
Joe Wright	FAA/ARFF research group
Larry Hampton	FAA/ARFF research group
Dung Do	FAA/ARFF research group
Franz Eberth	FLIR Systems
Frank Holiday	FAA/CFR
Other Firemen	

ATMOSPHERIC CONDITIONS

Time (local)	Temp (°F)	Humidity (%)	Sky
1951	80	79	Scattered Clouds
2050	76	87	Scattered Clouds
2150	75	87	Scattered Clouds
2251	75	86	Scattered Clouds

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