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Proceedings on the Damage Control/Fire Fighting into the 21st Century Workshop

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A workshop was held at the Naval Research Laboratory, 8-10 June 1994, to identify all technologies that could make an impact on innovative damage control concepts and systems, specifically fire fighting, so the Navy can move out smartly in its approach to damage control in the 21st century. The workshop was used to identify the critical component technologies and potential players that can support an integrated science and technology program in fire protection and damage control. In this type of forum, the relevant science and technology issues were addressed, and related work in government, commercial and university environments was identified. The technology limitations, needs and integration issues were also identified.

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EXECUTIVE SUMMARY

Aegis-equipped ships are capable of multi-target tracking, both incoming and outgoing, through computers, sensors, and software. Why not bring damage control into the 21st century with numerical simulations and computers to predict and follow shipboard damage? Currently there is room for more innovation in the techniques that the Navy uses to actively and passively protect its platforms against fire and also train its personnel to fight fires. There have been very few fire fighting advances since World War II, namely, Aqueous Film Forming Foam (AFFF), Naval Fire fighter's Thermal Imager (NFTI), HALON 1301, and an Integrated Ship Management System (ISMS) that is currently under development to assist in shipboard damage management.

The changing Navy mandates necessitate that we rethink our approach to Survivability and Damage Control. Specifically, readiness is receiving increased focus by emphasizing better preparation through cost effective training and virtual rather than real danger in training. Environmental issues and constraints are constantly being raised and are becoming severely restrictive. The government is placing higher constraints on insult to the environment and restricting the smoke and water additive release into the atmosphere. With downsizing of the military forces, there will not only be fewer ships but also fewer people to perform damage control operations. Finally, the time has come to exploit commercial technological advances in this shrinking fiscal environment. Advances in computational hardware and techniques are occurring at an explosive rate. We have to leverage against these advances that are occurring in game/entertainment/education simulators.

An integrated science and technology (S&T) strategy has been developed at the Naval Research Laboratory which describes an approach to fire protection and damage control (FP/DC) that takes advantage of the extremely rapid growth of computer hardware, reduction of cost and innovations in software. The advancing technology of numerical modeling has been used as the basis in this strategy to develop tools that simulate damage spread on Navy platforms and will be applied to passive and active fire protection, training, and design of ships. Given that high speed graphics hardware can be harnessed, with the development of new

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software, a multi-layered, three-dimensional animation of the spread of the fire can be provided. The visual display can be used to guide the development of models and simulations and be translated into the context of virtual reality for use in assessment, rehearsal and training for the fire fighter(s). The strategy proposes a truly integrated program in that the 6.1, 6.2, and 6.3A research areas of numerical simulation, information technology management, sensors, and display for development of tools were included. The ultimate objective of this proposed strategy is the use of virtual environment as a means for DC training without costly and dangerous live fire testing.

Based on the technologies that were identified in this strategy, a workshop was conducted to identify all technologies that could make an impact on innovative DC concepts and systems, specifically fire fighting, so the Navy can move out smartly in its approach to damage control in the 21st century. The workshop was used to identify the critical component technologies and potential players that can support the strategy. In this type of forum, we assured ourselves that we were addressing all the S&T issues, that we were fully aware of other related work ongoing in government, commercial and university environments; and that we were identifying all the technology limitations, needs, and integration issues.

The overall objectives of the workshop were to:

(a) Establish a clear understanding of responsiveness of proposed strategy to changing Navy mandates and requirements and how it integrates with current Strategy (JMA/SA) and Round Table discussions.

(b) Describe the deliverables/products/prototypes that will result from the integrated S&T strategy to ascertain that its scope is broad enough to encompass all of the user requirements.

(c) Assess where the component technologies are (state of the art), where we need to go to deliver our desired products (S&T issues), and how do we get to where we want to be (R&D Program Plan).

SUMMARY OF FINDINGS OF WORKSHOP DISCUSSION GROUPS

The **Damage Control Requirements for 21st Century** Group identified damage control needs that would transition into the 21st Century. These were grouped as follows:

Design

- -Simulation techniques
- -CAD ship drawings
- -Increased damage tolerance in platforms

Tactical Aids (Active/Passive Fire Protection/Fire Fighting)

- -Cheap, reliable sensors
- -Means for inerting unmanned spaces
- -Remote fire fighting capability
- -Replacement agents for Halon and AFFF
- -Smoke management techniques
- -Improved communication at all levels
- -Information management and filtering systems
- -Integrated management of shipboard systems
- -Simulation techniques
- -Alarm limits for personnel

Training

- -Alarm limits for personnel
- -Standardization
- -Individual/Team Capability
- -Trainers with realism

The Group then summarized the role that application of Virtual Environment Technology could play in fulfilling each of these needs. In the ***Design*** area, VE would be beneficial in the ship layout, especially of equipment and resources. Through VE, this process could be augmented as much as needed to obtain whatever detail desired. To increase the damage tolerance of ships, ways of designing passive fire protection into the ship could be investigated through studying the physics of an unlimited number of fires in a multitude of designs. VE would be of benefit in all aspects of Damage Control as a ***Tactical Aid.*** For information management during a casualty, its implementation would allow a look at the communication flow at any level. In the case of a fire, it would allow the fire physics to be studied and varied infinitely, then display the best DC option based on decision aids. VE is particularly useful in implementing reduced manning by providing options that would give the best and most practical way to downsize. VE ***in Training*** would bridge the gap very effectively between the classroom and the live trainer. Again, VE would provide the opportunity in individual and team training for exposure to unlimited fires, to study the fire physics of each, and to evaluate the DC options that can be taken.

The **Hardware/Software Technology for the Virtual Environment** Group identified a number of issues that need to be addressed in this technology area. These are summarized below:

- Simulation/simulators/trainers
  - -Since VR simulators are not trainers, it is imperative that the training community participate in the development of VR training tools to ensure that VR is used effectively.

  - -What-if simulation in VR would be very beneficial for training purposes.

- Level of Immersion/Realism
  - -Cognitive skills are unaffected by force feedback.
  - -Force feedback systems teach psychomotor skills.
  - -Force feedback reinforces sense of realism.
  - -80% realism is effective; the last 20% would be too expensive to achieve.
  - -Unnatural visual/audible/force feedback may be effective enough to achieve effective training.

- VR Equipment Issues
  - -Delicate equipment has reliability problems.
  - -R&D needs for input devices require long term funding.

- Crew Doesn't Always Know Ship
  - -Architectural walk-through would be very beneficial.
  - -Immersion may not be necessary.

For an assessment of the state-of-the-art and where R&D is needed, this group divided the VR technology areas into several sub-areas: graphics, visual immersion, position and orientation tracking, sensory feedback, and software. For the graphics, the main constraint is polygon (vertex) count. An architectural walk-through is doable now with sufficient detail that the user feels "there". The visualization of multidimensional data for fire modeling is more difficult but the bottleneck is the development of the numerical fire model that provides sufficient physics for realism. The immediate need in graphics is to develop more capability and increased speed.

To provide visual immersion, the main components must be wide field of view and stereo representation. The disadvantages with helmet-mounted displays are their poor resolution and tethering. One person's view may be displayed to others through the use of walk-in environments. There are several problems encountered in the tracking of position and orientation. The methods used now are either noisy, inaccurate or too confining. To achieve the level of realism needed in the training environment, you will need to embed the individual into a fire-fighters suit for augmented reality.

The sensory feedback in VR is not as advanced as the graphics. Touch feedback is available through bladders in gloves. Force feedback devices are small scale. For the training application for fire fighter(s), weight and hose forces are needed to reinforce realism. Although smell is possible with sampled scents, for this training application smell is not considered important since self-contained breathing apparatus is usually donned. Data gloves are usually used with awkward, non-intuitive gestures, but probably will not be very useful in this application. Two possible techniques available for providing radiant conditions that exist in fire environments are the use of hot water in a space-type suit and the use of heated socks.

VR Software has developed significantly because of the large commercial interest. Distributed processing is well known to obtain the computational speeds required for these applications. Tool kits are available, but application code must be added. The obvious R&D need here is to develop application-specific models and unique I/O requirements.

The **Fire and Smoke Spread Simulation Technology** Group reported that a general problem, but one of the most significant ones facing the modeling community, is that damage scenarios need to be postulated for models to address. The general consensus was that we seem to be fighting the wars of the past rather than preparing for possible future conflicts. It was suggested that the Ship Vulnerability Model (SVM) group could provide, to the fire modeling community, possible scenarios for current ships, ships under design and future ships that would give the initial conditions available to a fire model following a weapons hit. From the Fleet perspective, one of the concerns that needs immediate attention is to increase the confidence level and reliability of model predictions. This goal can be achieved through cooperative research programs that include both theoretical model development and experimental validation. To achieve confidence in models, the question was raised (but not satisfactorily answered)-"What sort of data should be derived from full scale tests that would be beneficial to the modeler?"

The most important short term goals identified by the modeling community are the development of:

(a) *training* tool based on current modeling capability and
(b) *design/investigative* tool, once again based on the current capability.

Both of these goals are important in order to instill confidence in the predictive capabilities of computer-based models. These tools should be designed by (or at least specified by) those who do training, keeping in mind the level of realism available now. The actual building of these tools should be a cooperative effort between those who use them, those who develop such training aids and those who develop the models. Close cooperation with model developers is crucial for this endeavor.

The long-term goals were split into two categories:

(a) Improvements achievable in the 1 to 3 year time frame to impact on a *tactical aid*, and
(b) Improvements >3 year time frame to impact a *training tool*

Tactical Aid - The following phenomena must be investigated and implemented:

- entrainment at hatches,
- effect of suppression, by sprinklers and by hand held nozzles,
- energetic materials and metal fires must be included as fuel packages,
- horizontal heat transfer (ignition on the far side of a bulkhead, and the necessity for cooling by an attack party)
- more spatial detail of boundaries (separate walls into four components) and allow for odd geometry's.
- include geometrical interaction of fuel packages

Training - for the training simulation, steam generation of splashing water is important, although it might not be important for the fire dynamics. Additional future R&D required for the training application involves development of decision aids. Types of issues and phenomena that need this approach are:

- decision to 'button-up' or ventilate (importance of saving fire-involved space)
- decision to use positive ventilation
- timeline for event occurrence during casualty with and without intervention

The **Training Technology** Group chose to approach their charge by pointing out the training opportunities in VE for Damage Control/Fire fighting. Their approach involved identifying four (4) issues, along with the need, opportunities and action to be taken.

Issue 1 : Immediate and long-term support is required from Damage Control/Ship Survivability at CNO level to promote technology innovations.

Need - Compelling arguments to offset the syndrome "If it ain't broke, don't fix it".

Opportunities -Reduced manning
Improved readiness
Environmental concerns
Safety
Cost reductions
Team Training
Exploit new technology (VE)

Action - Matrix of arguments with supporting recommendations and potential sponsors.

Issue 2 : "If we build it, they will come.."

Need - Prototype of VE using ex-SHADWELL as model. Compelling and convincing demonstration of VE tied to training need.

Opportunities -Realistic scenarios
Emphasis on training under supra-realistic conditions, especially confusion
Utilization of weapon's effect data
Collaboration with ship design community

Action - Identification of audience for training (e.g. on-scene/team leader) and selection of training objective(s) to satisfy performance deficiency.

Issue 3 : VE applications for DC

Need - Optimization of VE technology

Opportunities -Basic to advanced navigation and investigation training
Intelligent Tutoring System coupled with VE to accentuate team training
Embedded entities within VE for group task performance
Mass Conflagration training

Action - Design list of VE unique applications to focus on pierside trainer/on-board trainer utilization.

Issue 4 : Continued Collaboration

Need - Unique contribution of each community needed to analyze, design, develop, implement, evaluate, support, and transition VE DC training technology.

__Opportunities__ -Synergy among communities
Improved funding profile
Respond to technology demand
Utilization of existing resources
Strength in numbers

__Action__ - Form "Working group" via Internet to keep participants appraised at ongoing/planned work. Goal of making a presentation at '94 CNO DC/FF Working Group Conference in Nov. 1994.

INTRODUCTION

Conceptually, the strategy that has been developed is designed to capitalize on the rapid growth occurring in computing capabilities and to develop tools that will incorporate numerical simulations of fire environments with graphics, decision aids, and virtual environments. These tools can then be used in the military (with civilian applicability) for design aids, tactical operational aids during casualty events, and training aids without insult to the __environment__ or hazardous exposure of personnel to live fires (fire safety). The strategy is divided into three stages, each designed to use modeling capabilities for applications that differ in the computational speed required and the tools needed for visualization, animation and virtual reality. The first stage will provide aids to the naval architect to fire harden ship design and to the fire investigator for post mortem analysis. This stage of development can also be useful to the researcher in visualizing real or abstract datasets for insight into sensory feedback issues that need resolution in implementing the virtual reality concept in Stage III. In Stage I computational time requirements can be relaxed so that the component of urgency is removed. The critical issue in this stage would be creation of the necessary detail to accurately represent the simulation to the intended user and the ability to view that information in a manner that makes sense for the architect and fire investigator.

In Stage II the tool developed would be a decision aid for shipboard fire fighting and onboard embedded training for the fleet unit (fire fighter(s) and DCA). An interactive tool that provides tactical support for real time damage control must predict in faster than real time to give the platforms a look at the future if damage is to be mitigated. It would integrate all sensor and intelligence information, permit forecasting and hypothetical analysis and guide the further development of fire-fighting strategy as well as sensor development. With the downsizing in the military and the emphasis on conducting more training at sea via embedded training, this stage can also provide a means for damage control training without costly live fires.

The third stage takes advantage of an emerging technology, virtual reality, for individual and/or team training in fire fighting. In this application a human operator can be immersed in a realistic environment to develop damage control skills without safety and environmental concerns being issues. This technology differs from conventional interactive computer simulation found in trainer simulators in that virtual environment creates a much stronger illusion of actually being there and being able to generate changes. With its interactive capabilities, an environment is provided in which new sensors attached to the fire fighter(s) suit can be tested and tuned for optimal performance.

The key technology requirements identified as major players in attaining the tools desired in each Stage were:

(a) Fire simulation - What are our current capabilities and limitations; what modeling approach should be taken to adequately describe the fire physics in each Stage?

(b) Computing capability - What hardware/software approach(es) should be taken to achieve the speed and detail required?

(c) Display capability - How should the issues of imagery, objects resolution, tracking, and hypermedia integration (video, still, simulations, audio) be resolved to achieve the desired operator/training effects?

(d) Virtual reality - What are the human factors and sensors issues that must be resolved to achieve a state of immersion that is as effective for training as real life? How successful have other applications of virtual reality been in other training environments?

Virtual reality, which is the preferred commercial sector terminology, will be used interchangeably with virtual environment (academia) and synthetic environment (military). Each terminology refers to the process by which immersion occurs, with realism and interaction being important features.

The workshop was structured in two parts. The first half of each day consisted of presentations in each of the identified technology areas and on selected applications of the virtual environment technology. The second half of each day involved workshop discussion groups which covered the topics:

Damage Control Requirements for 21st Century
Hardware/software Technology for the Virtual Environment
Fire and Smoke Spread Simulation Technology
Training Technology

Each of these groups were charged with responding to the three objectives identified in the "Executive Summary" in their respective technology area. Summary reports were presented by each Discussion Group Leader to the entire Workshop audience on the final day of the workshop.

DAMAGE CONTROL REQUIREMENTS FOR 21ST CENTURY

To keep the workshop focused on the Navy needs and requirements in the Damage Control/Shipboard Fire fighting Area, the Fleet Perspective was given on the first day by the former Director of the Damage Control School, Surface Warfare Officers School, Newport, RI. One of the main concerns in training for casualty situations is realistic creation of the damage control environment. The Navy's attempt to address this issue is the full-scale damage control test ship, ex-USS SHADWELL. The SHADWELL concept states that "damage control cannot stand in isolation". It is the functional combination of personnel, equipment, facilities, information, and materials, with the essence of time being paramount. The SHADWELL provides the environment in which all of the above concepts can be integrated and followed in time as a damage control evolution progresses. The ship's operational systems include safety, firemain (30, 100, 1000 gpm pumps), internal communication (1MC, SP, WIFCOM), ventilation, collective protection system (one zone, DDG-51), and repair lockers (3). There is a wide array of instrumentation located in the ship control room for documenting experiments: video (visible and infrared), radiation, total heat flux, smoke density, closure, liquid flow, gas concentration (CO, CO_2, and O_2), pressure, and temperature. In the manned R&D experiments that are conducted onboard, the fire fighting "basics" invoke the philosophy of (a) developing an envelope of containment so that real estate can be regained and (b) developing a preference for indirect attack (horizontal or vertical). Some of the basic actions that are taken in various combinations by the fire fighter(s), depending on the conditions, are direct or indirect fire fighting attack, smoke and heat management, and containment. In any given set of SHADWELL experiments, participants may come from the laboratories, commands, and operators. They bring together a number of disciplines and resources that help make the SHADWELL successful.

One of the more recent advances in Damage Control Technology is the development of the Integrated Survivability Management System (ISMS), which is applying today's technology to advance damage control. The ISMS provides decision support to key damage and casualty management personnel aboard ship; training and administrative support are also included. ISMS consists of automated display units with embedded computers and software that are interfaced by a survivable communications network. One of the key problems in any shipboard casualty situation is the slowness of DC communications. Through sound-powered phones, messages are passed from the bridge via Damage Control Central, to the Repair

Locker, and finally via WIFCOM or messengers to the on-scene leader. One of the solutions to the DC communication problem is transmittal of information via LAN-connected computers using DC databases to display electronic DC plots. In addition to DC plate markup, ISMS provides casualty decision aids (stability prediction, boundary setting, and OBA management), administrative aids (compartment checkoff list, damage control logs, DC equipment records, DC personnel records), built-in training (Battle Damage Estimator), communications improvements via electronic mail, on-line documentation (kill cards), and asset management (DCAMS). The ISMS is currently being implemented in the Fleet in the following ship classes:

- FFG 32 - Nov 93
- CG 72 - June 94
- CG 55 - June 94
- CG 73 - Jan 95
- ECP for DDG 51 Flight IIA approved
- LPD 17 (LX)
- CVN 76 Mod Repeat
- Initiating SHIPALTS for other classes

There are a number of capabilities in ISMS that exist for forward fit:

- Direct connection of DC sensors
  - -Fire
  - -Flooding
  - **-Intrusion**
  - **-CBR**
  - **-Sensor Correlation**
  - **-CCTV**

- Casualty decision aids
  - -Stability prediction
  - -Boundary setting
  - -OBA management
  - -Smoke ejection
  - -Vital system reconfiguration
  - **-Personnel and hose routing**
  - **-Readiness assessment**
  - **-Automatic casualty response**
  - **-CBR prediction**
  - **-Fire spread prediction**
  - **-Combat system casualty control**
  - **-Hull survival system**
  - **-Real-time stability status**

- Administrative aids
  - -Compartment checkoff list
  - -Damage control logs
  - -DC equipment records
  - -DC personnel records
  - **-PMS scheduling**

- Built-in training
  - -Battle damage estimator
  - **-Real-time simulation**

- Direct connection of DC actuators
  - -Fire pumps, firemain, and wash down countermeasures
  - -Ventilation and smoke management

- Communications improvements
  - -Electronic mail
  - **-Repair team terminal**
  - **-Voice recognition**
  - **-Eye tracking**
  - **-Flat screen**
  - **-Copernicus interface**

- On-line documentation
  - -Kill cards
  - **-Repair party manual**
  - **-NWP 62-1D**
  - **-Interactive electronic technical manuals**

- Asset management

* **Projected ISMS (year 2000) augmented capabilities are given in bold.**

FIRE AND SMOKE SPREAD SIMULATION TECHNOLOGY

These presentations were structured to provide an overview of the state of the art of current modeling capabilities. The purpose of modeling is 1) to test our understanding of the world and 2) to answer specific questions. The two general types of models that are developed are field models (based on computational fluid dynamics (CFD) and zone models. They each have advantages and disadvantages, and hence are used for different applications. Zone models are often used to develop a model of a building composed of several adjoining compartments, where each compartment is subdivided into control volumes or zones. All quantities of interest are uniform within each zone; conservation of mass, energy and momentum is applied to each zone using algebraic representations of ordinary differential equations. The advantages of zone models are the low memory requirements, speed, presence of large structures, apriori assumptions, structured output, understanding of global issues, and "intuitiveness." Because this type of model does require apriori assumptions, this becomes a disadvantage also. On the other hand, field models are based on the numerical solution to a set of partial differential equations representing conservation of mass, energy, momentum and chemical species. Field models are usually based on the discretization of a volume into a large number of computational cells and the application of finite difference techniques to solve for the appropriate quantities in each cell. These models provide very detailed answers and are often based on first principles, and therefore require fewer assumptions. Field models are often used for ab initio calculations, answer the question of completeness, and make new phenomena easier to add. The disadvantages of field models are the requirements for large memory and set-up time, extensive interpretation, and the need for sub-grid models (such as turbulence models) if the grid resolution is not sufficiently small. This type of model is very computationally intensive and is generally only used when details of the fluid flow are needed.

A numerical simulation of a diffusion flame using CFD techniques was overviewed with the emphasis on some applications for which this technique can be used. Some of these applications are studying the effects of radiation transport on heavily sooting ethylene jet diffusion flames; studying the mechanism of flame lift-off and stabilization; and investigating the causes for enhanced soot production in time-varying (flickering) flames. There were a number of courses of action that were recommended to pursue if this type of fire model is pursued as input to a virtual environment. These code enhancements include:

- Expand the computational domain (3-D fire in a room)
- Optimize/parallelize (clustered workstations) in 3D to achieve a significant increase in computation time (Major 6.1 R&D issue). This has been achieved in 2D
- Increased robustness to quickly adapt to abrupt changes in conditions (Major 6.1 R&D issue)
- Visualize flow in 3D as computation proceeds, a process which is easily achievable in 2-D
- Simulate multi-fires in multi-compartments
- Handle complex fuels and complex geometry's
- Model suppression by chemical and physical mechanisms.

Another numerical simulation using CFD techniques was discussed as a method to investigate the interaction of water mist with a diffusion flame. Water mist is being considered as a total flooding replacement agent for halon 1301 in Navy ships. An understanding of the mechanism(s) by which water mist works would aid significantly in designing a total flooding system for optimal performance. This research effort encompasses not only the development of combustion and spray sub-models for integration into an overall simulation model but also experimental validation of the overall simulation model. The combustion model contains the phenomena of convection, chemical reaction, species diffusion, thermal conduction, viscosity, radiation, gravity and wall effects. The physical phenomena that must be accounted for at the pool surface are radiative heat transfer and thermal conduction through pool depth as they affect fuel evaporation rates. In the process of coupling the combustion model with spray model, effects that must be accounted for are water droplet size and number density; water droplet transport and lifetime; entrainment effects, and geometry effects (e.g. obstacles). The approach that was taken in adapting this type of modeling effort to damage control involved:

(a) Use of simple/available sub models to simulate a specific scenario;

(b) Comparison with experiments;

(c) Refinement of sub-models to add complexities as necessary for satisfactory agreement;

(d) Invoking of parallel computing as required for speed and efficiency.

The Weapon Fire Safety Program at Sandia National Laboratories is scoped to understand the behavior of missiles that are either fully engulfed, shielded, self-shadowed, or short-duration directly impinged by a fire environment. The goal of this multi-year program is to develop validated numerical tools that predict the fuel-fire thermal environment resulting from an aircraft or ground transportation accident. Two types of tools are being developed to support this type of activity:

- Tools that model, from first principles, the detailed physics of the problem

- Tools that model only the dominant physical phenomena--compatible with the methodology of a Probabilistic Risk Assessment (PRA)

The theoretical development in the program is tightly coupled to an analytical and experimental program that acquires experimental data to characterize the fire environment and to validate and develop fire modeling tools. The advanced fire physics model being developed uses a CFD model known as SINTEF which was developed at Norwegian Technical Institute (NTH) and SINTEF Foundation. SINTEF uses a Patankar-Spalding-based flow solver, turbulence model, eddy dissipation concept combustion model, soot model, open boundaries, and has very few "free" input parameters. The simulations performed with SINTEF Fire have been compared to large scale fire data from jet, pool, and pool with wind and objects fires.

Initial versions of the model used calculations based on complete-combustion predictions. These calculations predicted pool fire temperatures 200-300K higher than data. The development and implementation of an incomplete-combustion model resulted in calculated flame temperatures in good agreement with data.

Another area of improvement in the advanced fire physics model was achieved through the time-averaged nature of the turbulence model. The results of comparisons between predicted flame shapes in zero, low, and high winds to experiments show good to excellent agreement to time-averaged data. The model simulations of open pool fires demonstrate good prediction of:

- Flame temperatures (without wind present)
- Time-averaged flame shape (with and without wind)
- Steady, large-scale turbulent structures (with and without objects in fire)

There are R&D areas that have been identified to continue the development of the advanced fire physics model:

- Continue development of existing sub-models for fundamental fluids, radiative heat transfer, soot, fuel pool, and multi-block grid.

- Continue to validate model to further understand limitations

  - Calculations for class of fire problems of interest
  - Comparison of heat flux calculations to data
  - Time-averaging of calculated results to ease comparison to data
  - Development of a virtual sensor for temperature comparisons, to avoid injury using "real" heat
  - Sensitivity analysis
  - Development of advanced diagnostics and methods to obtain necessary data (e.g. soot, combustion vorticity)

- Expand capabilities of research code (e.g., transient object thermal response, convective heat transfer) to capture thermal impact on objects

- Begin development of simulators (streamlined versions of research code) for specific classes of problems

Conceptually, the zone model approach was reviewed and contrasted with field models. The capabilities of a well-developed zone model, CFAST, were characterized and will be repeated in detail here to give a comprehensive evaluation of the state-of-the-art of zone modeling. The phenomena currently included in CFAST are:

- Multiple compartments (currently 15)
- Multiple fires (currently 16) - can be specified with "other" objects,
- Vitiated or free burn chemistry in the lower layer, the upper layer, or in the vent flow,
- Correct chemistry - consistent production and transport of species,
- Generalized species (10) transport,
- Four-wall and two-layer radiation to be extended for the pyrolysis model,
- Four-wall conductive heat transfer through multilayered walls, ceilings and floors in each compartment,
- Convective and radiative heat transfer applied to both inside and outside boundaries,
- Wind effects included - ASHRAE formula for wind with the NOAA integral for lapse rate of the standard atmosphere,
- Fire plume and entrainment in vent flow (doors and windows only): Fire plume is split into entrainment in the lower layer and the upper layer,
- 3-D specification of the location of the fire and non-uniform heat loss through boundaries,
- Generalized vent flow: Horizontal flow (doors, windows, etc.) - up to three neutral planes; mixing between the upper and lower layers; Vertical flow (through holes in ceilings and floors),
- Separate internal and external ambient (elevation, temperature, and pressure specification);
- HCl deposition,
- Mechanical ventilation - complex building structure: 5 fans, 44 ducts, 3-way joints; vertical ducts interact with both layers, and
- Heat transfer (conductive) through barriers.

Specific areas that need to be addressed to extend CFAST capabilities to be useful in the proposed S&T Strategy are:

- Real time data analysis to provide information on the time scale needed by the fire party,

- Material analysis applications to improve performance of the model (i.e. how good are the materials properties data used as input to the model),

- Parametric study to do sensitivity analysis of input parameters, and

- Decision aids to implement risk analysis and maximum probable loss analysis.

There are a number of planned R&D efforts that will be included in CFAST in the future. The ones listed below will meet some of the modeling needs for the proposed S&T strategy:

- Intercompartment heat transfer (specifically horizontal),
- Pyrolysis and flame spread (ignition),
- Corridor flow (hybrid model),
- Structural effects (burning wood walls, shattering gypsum, breaking concrete),
- Planning for structural degradation and intercompartment heat transfer,
- Particulate agglomeration and settling,
- Open/close of mechanical ventilation and horizontal vents (vertical flow),
- Additional species, and
- Entrainment of particulates into plumes.

One of the issues raised by the users and potential users of models is "How can confidence be achieved in models?". One of the concerns that needs immediate attention is to increase the confidence level and reliability of model predictions. This goal can be achieved through cooperative research programs that include both theoretical model development and experimental validation. This approach is being taken by validating CFAST predictions with experimental data from ex-USS SHADWELL tests. There have been a series of experiments conducted on SHADWELL that investigated the effectiveness of a Smoke Ejection System installed in a simulated DDG-51 area to remove smoke generated during a shipboard fire. This comparison checked the shipboard-related phenomena included in CFAST, specifically those of vertical flow as through hatches and scuttles and mechanical ventilation for smoke removal. Through an iterative procedure, these validation tests improved model algorithms that describe the vertical flow in CFAST. Currently undergoing validation is the algorithm in CFAST that describes vertical heat transfer. The SHADWELL data being used in this case are from the Internal Ship Conflagration Control (ISCC) Project, which simulated the fire conditions that occurred during the 1987 USS STARK incident. The ISCC experiments were conducted on the port wingwall of SHADWELL because of the particular configuration of this section of the ship. The four compartments of interest for the validation were aligned in the vertical direction. The fire was contained in the bottom compartment. Interior gas temperatures, as well as bulkhead and deck temperatures, were used to compare the actual heat transfer between the fire compartment and the other compartments to the model predictions. Agreement was much improved over previous versions of CFAST. With the inclusion of additional phenomena currently under development, i.e., horizontal heat transfer and smoke movement down long passageways, CFAST will be ready for transition to advanced development.

Another analysis that has been performed with data from the ISCC area of the SHADWELL proposed techniques that can be used to prevent or retard fire spread by heat transmission through steel bulkheads and decks. The immediate benefits of "buying time" during a fire scenario can be seen if data are given to show the effects of thermal exposure, radiant heat and/or temperature on electronics, various materials and human tolerance. The ISCC data were ideal to evaluate these techniques since the ISCC experiments were designed to look at these effects in a compartment directly overhead and a compartment directly adjacent to a compartment containing a post-flashover fire. The design fire in the compartment of fire origin was totally involved with temperatures over $1000^{o}C$. Based on the temperatures (air, deck, and bulkhead) and radiant heat fluxes (deck and bulkhead) generated during the fires, times were estimated for ignition of various combustibles and estimated effects on personnel and equipment. Methods by which these effects could be mitigated were evaluated and included the use of a raised floor, deck/bulkhead cooling, and insulation. Areas that require further study include investigation of the "big match" (burning propellant), "long burn" (flashover of contents and "tendency to spread"), and propagation beyond compartment of origin.

SENSORY REQUIREMENTS

One of the broad science and technology issues raised was the need for practical sensory and feedback devices for the simulation of fire in a synthetic training environment for use by shipboard fire fighting and damage control personnel. A wide range of such devices is required to dynamically simulate the changing multimedia inputs of sight, sound, temperature, tactile sensation and smell for individual trainees or trainee teams during immersive training sessions. Most important to the long range damage control readiness of the fleet, the results of such immersive virtual environment simulations must be positive learning and training experiences for the trainees. Sensory and feedback devices are required having ample display speed, level of detail and multi-variable coordination to effect such positive training outcomes.

The initial step is to define the type and amount of sensor information that is required by the user from the system (actuator transducer requirements), by the system from the user (sensor transducer requirements during simulation), and by system developers to quantify fire characteristics (sensor transducer requirements for fire analysis). Tables 1 through 3 summarize the sensor and actuator information needs for simulation of fire in a virtual environment.

TABLE 1
Information to Virtual Environment User
(Actuator Transducer Requirements)

Sensory Mechanism	User Requirements	System Requirements
1. User vision	• view global coordinates • observe smoke, steam • observe flame	• high speed • small, light, flexible
2. User touch	• feel temperature profile • feel objects	• multiplexable • high speed
3. User hearing	• hear combustion process • hear ship noise • hear communications	• small, light
4. User smell/taste	• smell/taste smoke • smell/taste steam	• chemical specific

TABLE 2
Information from Virtual Environment User
(Sensor Transducer Requirements During Simulation)

Measurand	User Requirements	Systems Requirements
1. Position	• global user position and orientation • glove motion (displacement, twist open-and-close)	• high speed • multiplexed • integrated with communications network
2. Temperature	• temperature in suit	• distributed, multiplexed
3. Humidity	• relative humidity in suit	• single measurement
4. Audio signals	• user voice signals	• low speed channel

TABLE 3
Information to Virtual Environment Developers
(Sensor Transducer Requirements for Fire Analysis)

Sensor Mechanism	User Requirements	System Requirements
1. Vision	• view global coordinates • quantify smoke, steam • quantify flame	• high speed • small,light • flexible • spectral response
2. Thermal mapping	• quantify spatial T profile	• ΔT resolution • spatial resolution
3. Audio	• quantify combustion and ship sounds	• small,light
4. Gas analysis	• analyze smoke • analyze steam	• chemical specific

Possible approaches that can be used to meet each of these sensor and actuator needs are CCD array to digital storage (vision); electrical or optical (position-displacement, strain, velocity, acceleration, rotation); electrical or optical thermocouples (temperature); electrical or optical strain gages (strain); and absorption or transmission-based spectral analysis (chemical). Of the candidate approaches, the optical-fiber based methods appear to be most promising. Some of the advantages provided by fiber optical technology are:

- small, lightweight, flexible
- no electromagnetic interference, i.e., high signal-to-noise ratio even in electrically noisy environments
- high resolution, large dynamic range, high speed
- capability for "absolute" measurements with negligible drift
- environmentally robust, i.e., 10 million+ fatigue cycle lifetimes for some designs
- capability for multiplexing sensor elements or response along a single fiber
- multimeasurand capability - strain, temperature, position, "vision," pressure, acceleration, other
- capability for integrating with high speed networking
- potential for realistic cost-per-networked sensor element

Several fiber optical techniques have been demonstrated successfully in the laboratory that have potential application to the fire problem: intrinsic Fabry-Perot interferometric (IFPI) sensor, fiber Bragg grating (FBG) sensor, and extrinsic Fabry-Perot interferometric (EFPI) sensor. There have been at least two applications of optical fiber sensors during fire simulation, both which have been demonstrated on ex-USS SHADWELL: one uses silica and sapphire optical fibers for high temperature measurements and the other uses a fiber-based smoke detector for smoke analysis.

Another approach to the sensory needs and requirements problem related to fire protection is the use of micro sensors. The advances in microprocessors memory capacity have been slow because of size incompatibility and poor interfacing between the controller and its environment. Recent developments in micro sensor and micro actuator technology use new IC technologies to place sense/interface/control on a single chip. A micro sensor is defined as part of a micro-electro-mechanical system (MEMS), where MEMS has many features:

• Small-scale mechanical components ranging in number from a few to as many as tens of thousands, fabricated by a broad range of micro machining processes, usually monolithically integrated with electronics and/or optics, and capable of sensing, processing, monitoring, altering and/or controlling itself and its environment.

• A miniature device or an array of devices combining mechanical and electrical components fabricated with IC batch processing techniques. A single micro sensor can be as small as one micron or less, with the entire device ranging from tens of microns to a few centimeters.

• There are many examples of the use of MEMS for actuators (flow controllers, steering mirrors, heaters/coolers, miniaturized manipulators, fluid pumps, micro-positioners) as well as sensors (humidity, chemical, biological, radiological, acoustic, optical, pressure, temperature, heat flux, acceleration).

Currently the trends and implications for fire protection and damage control support the application of micro sensors to fire fighter(s) training. Implementation of the micro sensor technology would provide the following benefits to the fire fighter(s) and training communities and equipment:

- Provide more realistic and safe training
- An example: Virtual reality simulator with embedded sensors in trainee suit to provide:
  - Real time feedback
    - Trainee status (pulse, breathing rate, and stress)
    - Suit environment (temperature, pressure, humidity)
    - Trainee and fire fighting equipment position
  - Real time control
    - Simulation response
    - Suit environment (raise/lower temperature)
  - Remote data transmission to/from embedded sensors
    - RF
    - IR

- Improved post-simulation review

- Provide greater safety margin and more effective utilization of assets (personnel and equipment)

- Example: Replacement of NFTI thermal imager
  - Helmet mounted sensors
    - IR
    - Camera
    - Chemical
    - Temperature/heat flux
    - steam

- Projection of data inside of O_2 mask

- Integrated communications/data link

- Ability to monitor fire fighter(s) status and environment
  - Rate of O_2 consumption
  - Exposure time to fire

- Reduced size/weight/power requirements

- "Smart" sensors to aid in decision making processes

- Improved maintainability/reliability

- Reduced per unit cost

- Micro robot for damage assessment or fire fighting in severe environments

- Upgrades tailored to HAZMAT, structural, and crash suits
  - AC system
  - Chemical

- Dual use technology

Additional benefits can be derived by application to shipboard installed FP/DC systems:

- Provide more rapid identification of and automated response to fire, flooding and CBR threats
  - Ship wide sensor coverage tailored to compartment (magazine, machinery space, berthing,..)...Multisensor integration
  - Real time management of water tight integrity
  - Distributed processing and redundancy to enhance survivability
  - Maintainability/reliability through sensor intelligence and self diagnostics
  - Reduced power requirements
  - Solid state - damage resistant (blast/thermal)

- Reduced false alarm rate (sensitivity, selectivity and intelligence)
- Improved control of AC system during fire
- Enhanced command and control of FP/DC assets

• Improved shipboard fire protection training (simulated sensor input and system response)

In conclusion, micro sensor technologies will have a revolutionary impact on future designs for FP/DC applications. Sensor coverage can be greatly enhanced by increasing the types of parameters sensed and the density of sensor coverage. Smart sensors can support reduced manning by allowing crew reduction without compromising damage control capabilities. They can also enhance survivability through reduced response times, enhanced coordination and control of FP/DC assets, and increased fire fighter(s) safety and effectiveness.

TRAINING TECHNOLOGY AND VIRTUAL ENVIRONMENT APPLICATIONS

The ARPA Maritime Systems Technology Office (Ship Systems Automation) has the objective of demonstrating automation technologies that will address the affordability issue through drastically reducing manning and reducing acquisition costs by various methods. These include distributed development, integration and training, multi-platform application, and multi-utility software usage. One of the concepts that permeates this program is the use of force multipliers for manpower intensive functions, such as damage control. Although an order of magnitude reduction in manpower will occur in the future, reliability through total situation awareness and information integration, resulting in a pro-active response, can be obtained from small teams with force multipliers for damage and casualty control.

The Manned Flight Simulator at Patuxent River, MD is under the ownership of Naval Air Warfare Center Aircraft Division. This is an AH-1W deployable simulator which has a fiber-optic helmet mounted display system. The display field of view is approximately 130° X 70°. Based on this capability and other hardware and software associated with the facility, there is expertise in (a) man-in-the-loop simulation; (b) helmet-mounted display system; (c) deployable simulators; (d) visual system experience, and (e) prototyping capabilities.

A training tool, known as Total Ship Survivability (TSS), has been developed under the sponsorship of OPNAV N86D and NAVSEA 03 to be used by Fleet Training Commands for Refresher Training. The current version of TSS is a PC-based probabilistic model, not in a virtual environment, that has damage files incorporated from the Ship Vulnerability Model (SVM) using pre-determined weapons-hit scenarios. The PC program developed has the following capabilities:

- Selects threat/hit location
- Selects vital component/crew/air conditioning/chilled water/firemain/electrical/air screen
- Displays damage level by level
- Lists inactivated equipment/system/mission area
- Lists inactivation by damage
- Displays deactivation diagrams/shows vital component inactivated
- Displays flooding/opened compartments/lost vital component
- Secondary fire spread
- Secondary flooding

The ship classes that have been modeled are: FFG-7, DD-963, DDG-993, DDG-51, CG-26, CG-47, CGN-38, and LHD-1. The weapons that have been modeled are: Exocet, Harpoon, cruise missiles, surface-to-air missiles, contact mine, influence mine, Stinger, and projectiles. The weapon effects modeled include: shock, blast (external and internal), penetration (shaped, armor piercing), fragmentation (primary and secondary), hull whipping (ship hinging), flooding (time based), and fire spread (time based).

An application for virtual reality would be to take the existing TSS and expand the ships' databases into VE for more effective training. In VE the visualization of conventional weapons effects would be more realistic. High fidelity cause-and-effect deactivation diagrams resulting from a weapons hit could be produced in VE.

Currently undergoing testing at the Damage Control School of Surface Warfare Officers School, Newport, RI, is the Integrated Damage Control Training Technology (IDCTT). This product consists of interactive, multi-media software and hardware for dynamic real-time simulations of surface ship damage control and combat systems during hostile attacks. It was developed to satisfy a demonstrated need to integrate damage control, engineering, and combat systems in an effective team response to hostile attack through multi-media team training technologies. The time was right to produce IDCTT because (a) current "live fire" training facilities have limited availability and high cost; (b) integrated damage control and combat systems are required by littoral combat; and (c) advanced training and interface technologies are ready for transition. IDCTT presents a technology challenge. It is currently an interactive courseware that is mature and low cost, but non-immersive. The next step in its development would be production of interactive training software that would be multisensory, near immersive and semi-portable. The ultimate goal would be to involve the virtual environment, which is maturing, immersive, deployable, and cost effective. Such an implementation would allow the tool to go shipboard to create an embedded training capability.

An overview of the state-of-the-art of virtual reality was given to set the stage for the magnitude of the task being undertaken in the proposed S&T Strategy. A basic definition of virtual reality is "creation of the effect of operating in a 3D environment in which objects have a spatial presence--including the ability to interact in "real-time" with such objects." To create this effect, the illusion of immersion is required. Immersion gives one the sense of being "surrounded" by virtual objects, which can be described as having presence. The environment must be able to react to the user (interactive). The performance requirements are then set based on the effects that are being created, i.e., frame rates of > 10 frames/second to maintain sense of "presence"; delays of <0.1 to have acceptable interactive control; user's actions must be tracked accurately; and computer system must have computational power, data storage, and access to support task. There are several issues that make the implementation of VR difficult. The performance requirements dictate the necessity for something other than the usual hardware. There are many pieces that must work together, satisfying many criteria at the same time. To further complicate matters, the interface and human factors are not clearly understood. Several of the successful applications of VR technology include architectural walkthroughs, medical training, aircraft design, virtual wind tunnel, scientific visualization, and treating phobias. Some of the benefits that have been derived through these applications are (a) becoming skillful at navigation through known, fixed scenery; (b) learning the difficulty of dealing with non-real (e.g. scientific) datasets; and (c) understanding the enormous computational cost of dealing with moving objects. The projected trend, which is being driven by the entertainment industry, predict enormous growth in the VR over the next decade. Some of the research/technology areas that have been identified in VR are:

- Hardware requirements and deficiencies: human computer interface (HCI), visual displays, auditory displays, sound generation for VE, position and movement trackers, visual display generation, haptic interfaces, tele-robotic manipulators, mobile systems, parallel processing, motion bases, large-scale database hardware technology, evaluation and test technology, turnkey systems.

- Software requirements and deficiencies: Software for generation of VE's, HCI software, models for VE hypermedia integration, computer and systems architecture, real-time operating systems, modularity and interface standards, program languages, rapid prototyping support software, navigation software, dynamic functionality of objects, collaborative and work group software, and formal validation and verification methods.

- Network requirements and deficiencies: Current network technology and bandwidths, telecommunications, wireless and satellite extensions, distributed database access.

- Basic research and human research: Motion sickness understanding, physiological response technology, psychomotor models, cognitive models, models of individual differences, training models, models of tasks and environments, and ubiquitous evaluation methods in HCI.

The specific application of virtual reality to shipboard damage control was addressed by identifying some of the science and technology issues associated with the key technology requirements; i.e., modeling/simulation, multidimensional visualization in 3D, user interaction, and decision aids. In the modeling/simulation area, the major issue is the need for a high- or low-fidelity model. Each has its own advantages, disadvantages, and, hence, useful applications. For a high-fidelity model, the main emphasis is accuracy, so computationally intensive algorithms are required, which will give high resolution in significant detail. Since the detail is so great, the calculations occur in non-real time but the slow response is acceptable. Various techniques can be used to visualize these data, one of which is multidimensional visualization to see relationships among various parameters. The questions are raised "What parameters need to be displayed to provide the most useful information." Also "What significant information can be derived from the display of invisible parameters, such as O_2, CO, and CO_2. This type of presentation is very useful in assessing design and its effectiveness in improving fire protection/safety. As we move toward the modeling requirements for real-time shipboard applications, e.g., operational or decision aids, computational constraints imposed by speed makes it necessary to use low-fidelity models. Computational techniques that utilize approximations result in low resolution and less detail, but are acceptable since the speed must reach levels greater than real time. In order to convey large volumes of data very rapidly, the display of multidimensional data may be very useful in decision aids. User interaction requirements present a host of challenges that involve implementation of sensors for position, force, sound, heat, smoke, humidity and methods by which these outputs can be effectively represented to the user. Different levels of interaction are required for different users, the extreme being immersion for the training application.

One of the proposed methods of achieving a virtual environment suitable for shipboard damage control is to develop a distributed architecture consisting of the basic elements:

- Computational (modeling) system
- Image generation system
- Input/output system
- Data management system
- Local Area Network (LAN)
- Performance management (control) system

Some of the advantages of approaching the problem in this manner are:

- Appropriate assignment of tasks to processors
  - Super computers can be used for computation-intensive algorithms
  - Graphics engines can be used for image processing
  - PCs can be used for most I/O device interfaces

- LAN architecture can be expanded to use Internet resources

- Shared environments easily expanded
  - Data are already transferred across network
  - Same remote resource can be used by multiple sites

- I/O systems and graphics systems can be tailored to local capabilities without loss of high fidelity model

- Large on-line databases can be used directly instead of copying to local files

Some of the future directions identified for this technology area were:

- New visualization techniques are required for the dynamic multidimensional data

- New interaction techniques and devices are required to manipulate dynamic multidimensional parameters

- New hybrid modeling techniques may be needed to achieve a satisfactory fidelity/speed tradeoff

- New sensors and sensory feedback devices need to be developed to produce a convincing environment

- Current multi-user VR systems are inadequate for realistic team training

The U.S. Army Research Institute has a number of research efforts that investigate immersive training systems. One of the basic questions that needs to be answered in VR is how much immersion is necessary to be effective. To answer this question, the psychological behavior of individuals have to be addressed. To succeed in psychologically creating immersion the cognitive sciences must be integrated with VR. Research required in the cognitive sciences includes understanding the implications in virtual environment of: (a) human interactive visualization, i.e., the ability to understand and reason about dynamic, data-rich environments based on the capacity to interact with, move among, and actively manipulate objects and processes represented within the display; (b) the ability of the human sensory and cognitive systems to adapt to and effectively interpret unnatural (distorted or augmented) displays or sensory-motor relations; (c)sensory substitution, i.e., the use of sensory inputs through one modality as a substitute for inputs normally available through another modality; (d) limitations in human attention and information-processing capacity and their effects on perception, learning and memory; and (e) the determination of optimal transfer-of-training, i.e., what factors optimize transfer and how can they be incorporated into the VE interface? One of the broad goals in this area is understanding what information virtual environment displays must supply to the human perceptual and cognitive systems to support mental representations needed for complex skill acquisition and maintenance, spatial reasoning, and remote object manipulation.

The Naval Postgraduate School has developed a networked software architecture for large scale virtual environments known as NPSNET. This system is a low-cost, networked, 3D visual simulator for virtual world exploration and experimentation. The goal of the project is to develop a basic virtual world shell that allows one to visit any area of the world for which a terrain database is available and to interact with any interactive or autonomous players found "in the system". An additional goal is to make NPSNET interoperable with the DARPA SIMNET system and the DIS networking standard. Some of the current capabilities of NPSNET include:

- Real-time scene management,
- Collision detection,
- Aural cues in NPSNET,
- Dynamic terrain (bridges that can be driven over and under; craters, and beams that affect vehicle motion),
- Physically-based modeling (aircraft flight modeling and ballistic projectiles)

There are several areas in which work is planned to enhance the capabilities of NPSNET:

- Real-time scene management (physics-based animations).
- Large-scale networking/inter networking of NPSNET,
- Human figure integration into NPSNET-DI/DI-WISE,
- Autonomous players (ModSAF programs with DIS interfaces),
- Constructive model integration (JANUS with DIS interface),
- Hyper-NPSNET

Inserting the human into the synthetic environment of NPSNET is one of the current major endeavors. The technology of instrumenting the upper and lower body of humans is being explored. Part of this program is the construction of a walk through system for the instrumented human (building interior and ship interior spaces). The driving problems that the enhanced NPSNET hopes to support are medical corpsmen rescue training, ship's force training, small arms training and other similar "human-in-the-synthetic-environment" domains.

The ARPA Maritime Systems Technology Office is conducting a Simulation-Based Design (SBD) program to investigate the potential of introducing technologies in the acquisition process. SBD integrates advanced computational and distributed interactive simulation technology enabling remotely distributed, collaborative teams to respond to requirements and conceive, design, build, test, and operate complex systems in a computer prior to actual construction. The Vision in the SBD program is truly revolutionary. The initial FY94 demonstration in the program illustrated:

(a) Interoperability of Heterogeneous CAD Data in Virtual Environment
(b) Incorporated True Kinematic Motion in Virtual Environment
(c) Parametric Modeling with Seamless Linkage to Analytic Tools
(d) Use of Simulation/visualization to Plan Assembly Sequences

The June 1994 Demonstration showed the feasibility of using a generic 3D ship design database for requirements, machinery design, arrangements simulation, damage control, cost/risk assessment, DIS-based vehicle loading, structural analysis, manufacturing, and coupled field. SBD will act as the mechanism for the infusion of new technology and as a comprehensive system model for complete life cycle support.

VE technology has been used very successfully in the aerospace industry. The Software Technology Branch at NASA/Johnson Space Center in Houston, TX, is actively involved in the "development, integration, and application of artificial intelligence, simulation, hypermedia, virtual environment, and other advanced software technologies to produce autonomous systems for training personnel in the performance of complex, procedural tasks associated with both ground-based and on-orbit operations of current and future space missions." This group has found several benefits derived from training their personnel in the virtual environment. These include:

(a) Magnify the efforts of trainers to deliver training, capture perishable training expertise, and enhance the maintainability of training systems:

(b) Provide uniform and verifiable training, enhancing safety and the probability of mission success;

(c) Significantly reduce the time required for trainees to achieve given levels of proficiency in a task;

(d) Be used for in situ "refresher" training, thereby reducing the time required to perform infrequent but complex tasks and increasing mission safety and success probability;

(e) Be delivered in both dedicated training environments and in situ;

(f) Be applied throughout NASA operational centers, all government agencies, industry, and educational institutions.

Some of the research issues that are in the proposed S&T Strategy for Firefighter Training were also identified as issues in the NASA Training Program: (a) measuring training effectiveness; (b) determining needed degree(s) of fidelity; (c) integration with other systems; (d) communications/shared environments; and (e) integration of haptic feedback. One of the applications of the virtual environment training by NASA was Hubble Space Telescope Repair and Maintenance Mission Training.

This was the first large scale VR training project and received favorable comments from the flight team members who stated that training in the virtual environment improved their job performance. The success of this project has contributed to NASA/Johnson Space Center concluding that VR can be an effective medium for training delivery. It is a cost-effective development environment and has the potential to minimize cost and risk to overall training operations.

Virtual Environment Training Technology (VETT) is an ONR sponsored program that resides in the Naval Air Warfare Center Training Systems Division in Orlando, FL. This technology is being developed to eliminate deficiencies that have been identified in current military training systems. These deficiencies have been divided into the two areas of costs and training. The costs issues are:

- Instructional personnel
- Ranges, range maintenance personnel, instrumentation
- Simulators, simulator maintenance, modifications
- Schoolhouse infrastructure
- Student/dependent travel, housing and subsistence

The training issues are:

- Maintenance of skill proficiency while deployed
- Team training (local)

- Changing role of military
- Individual combatant in VE
- On-the-job training
- Learning vs real world environment
- Performance measurement
- Diagnostic feedback

The objective of the VETT is "to develop, demonstrate and evaluate the capability of Virtual Environment Training Technology to provide a dynamic, multimodal, interactive environment in which an individual or team can learn, exercise and rehearse the skills necessary to perform real world tasks". This objective is being achieved by using an iterative process to develop, integrate and evaluate VETT in the contexts of progressively more complex learning environments and human-computer interfaces (HCI). The approach being taken is (a) to develop those component technologies which are critical to VETT success and aren't available from or being developed by industry or other R&D projects; (b) to integrate component technologies into systems which can identify technology deficiencies and performance shortfalls; and (c) to evaluate the capability/feasibility of VETT training effectiveness through behavioral research experiments which compare VETT-based training delivery to current simulator (or other) training delivery systems.

The component technologies that comprise VETT are:

- Displays - visual, auditory, and haptic
- Transducers - position, force, and speech
- Learning environment - synthetic team members, instructors, coaches, and adversaries; scaling space; scaling/reversing time; cue augmentation and substitution; and diagnostic feedback.

Some of the current development activities include instructional techniques, haptic display requirements, effects of spatial and temporal distortion, effects of virtual accelerations, dynamic human figure modeling, immersion, and side effects. These development activities are being evaluated through ACM air crew debrief, circuit board fault diagnosis, and ship piloting. The expected payoffs from implementation of VETT vs using simulators for distributed interactive simulation are:

- Decreased trainer development and acquisition costs
- Decreased trainer operation and maintenance costs
- Reduced physical requirements: size, weight, power
- Deployable, available
- Enhanced training

HIGH TECHNOLOGY SHIP

On the final morning of the workshop, before the Summary reports were presented by each Discussion Group Leader, Mr. James Gagorik, ONR Program Manager for the "Surface Ship Technology Area", requested a block of time to discuss a future vision of a "High Technology Ship." The objectives that provided the driver in the design of the "High Tech Ship (HTS)" were:

(a) Provide a vision of the future

(b) Show how technology can improve capability

(c) Show how technology can improve affordability

The steps that were taken in this design process involved:

(a) Identification of technologies in the 6.2 block, 21st century destroyer working group, and industry;

(b) After a first cut evaluation of these technologies, invoke a conceptual design;

(c) Conduct trade-off analysis of conceptual design, along with assessments of missions requirements and design requirements;

(d) Assess ship impact in the areas of naval architecture, military effectiveness, and cost;

(e) Evaluate the impact on the ship of implementing new/alternative technologies; and

(f) Development of RDT&E priorities investment strategy based on assessments and evaluations.

The objective intended in making this presentation was to show how a tool like the HTS can be used to evaluate the impact of 6.2 technologies on a ship of the future; to build a rationale for development strategy; and to prioritize technology developments.

INTEGRATED S&T STRATEGY

The research and development challenges posed by innovative damage control/fire protection technologies make them a perfect choice for an integrated science and technology investment. The R&D issues cut across a broad spectrum of disciplines (chemistry, physics, materials, engineering) and require the full spectrum of basic research to engineering development.

The development and advancement of these technologies will benefit from a joint program between academia, government and industry. The program has potential dual use as well as DoD impact:

DoD:

- Design codes which predict fire/smoke growth and containment and which permit functional (survivability vs other performance characteristic) trade-offs during ship design without the need for costly (and environmentally constrained) live testing.

- Real-time damage control assessment and action recommendations to platform commander.

- Re-evaluation of fire fighting techniques and doctrine without the need to expose personnel to hazardous conditions.

- Virtual reality approaches to fire fighting which enable apparent realistic conditions without the danger and cost of real fires.

Dual Use:

- Architectural/building design codes incorporating fire safety trade-offs for high rise apartment/office/factory complexes.

- Decision aids for command centers at major building fires.

- Fire sensor technology for private, public and business structures.

- Cheaper/safer training capability for State and Local firefighters.

Appendix A

Damage Control / Firefighting for the 21st Century Workshop Agenda

8-10 June 1994

8 June 1994

0800-0830	Registration (Bldg 34 Annex, ITD Visualization Laboratory) – Sign up for discussion groups –
0820-0830	Welcome & Introductory Remarks **Dr. James S. Murday**, Naval Research Laboratory **Dr. Randall P. Shumaker**, Naval Research Laboratory
0830-0900	Advanced Concepts For Training and Operational Aids **Dr. Patricial A. Tatem**, Naval Research Laboratory
0900-0930	**Fleet Perspective** **CDR John Farley,** Naval Research Laboratory (former Director of Damage Control School, Surface Warfare Officers School)
0930-1000	**NPSNET A Netork Software Architecture for Large Scale Virtual Environments** **Dr. Michael Zyda,** Naval Postgraduate School
1000-1030	**Information Technology at the Naval Research Laboratory Dr. Randall Shumaker,** Naval Research Laboratory
1030-1050	Break
1050-1100	**Virtual Environment Technology for Damage Control / Firefighting** **Mr. David Tate**, Naval Research Laboratory
1110-1140	**Sensor Requirements for Simulation of Fire in a Virtual Environment** **Dr. Richard Claus**, Virginia Polytechnic Institute and State University
1140-1200	**Application of Microsensor Technology to Problems in Fire Protection** **Mr. Les Bowman**, Naval Air Warfare Center
1200- 1230	**Current and Future Capabilities of the Integrated Survivability Management System** **Mr. William Davison**, Naval Sea Systems Command
1230-1330	Lunch (Executive Dining Rooms - Main Cafeteria, Bldg 28)
1330-1530	Discussion Groups **Damage Control Requirements for 21st Century** **Dr. Fred Williams / CDR John Farley** **Hardware/Software Technology for the Virtual Environment** **Dr. Michael Zyda**
1530-1600	Break
1600-1700	Discussion Groups (continued)

Appendix A

Damage Control / Firefighting for the 21st Century Workshop Agenda

__9 June 1994__

0800-0820	**Numerical Simulation of Diffusion Flame** **Dr. Carolyn Kaplan**, Naval Research Laboratory
0820-0840	**Numerical Simulation of Interaction of Water Mist with Diffusion Flame** **Dr. K. Kailasanath**, Naval Research Laboratory
0840-0900	**Modeling Fire Growth and Smoke Transport** **Dr. Walter Jones**, National Institute of Standards and Technology
0900-0920	**Experimental Validation of CFAST with *Shadwell* Experiments** **Ms. Jean Bailey**, Naval Research Laboratory
0920-0940	**Field Model Simulation of Hydrocarbon Fuel Fires** **Dr. J. Moya**, Sandia National Laboratories
0940-1000	**Interactive Training Aid** **Mr. Mark McLean**, Naval Sea Systems Command
1000-1020	Break
1020-1040	**Ex-USS *Shadwell* Experience** **Dr. Fred Williams**, Naval Research Laboratory
1040-1110	**Virtual Reality - State-of-the-Art** **Dr. Larry Rosenblum**, Naval Research Laboratory
1110-1130	**Benefits of Immersion for Training** **Dr. Joseph Psotka**, US Army Research Institute
1130-1150	**Virtual Environment for Aerospace Training** **Dr. Robert T. Savely**, University of Houston
1150-1210	**Virtual Environment Training Technology** **Dr. Dennis Breglia**, Naval Air Warfare Center
1210-1230	**Manned Flight Simulator Facility** **Mr. John Kotch**, Naval Air Station, Patuxent River
1230-1330	Lunch (Executive Dining Rooms - Main Cafeteria, Bldg 28)
1330-1400	**Ship System Automation** **CAPT R. L. Lowell, Jr.**, ARPA/MSTO
1400-1530	Discussion Groups **Fire and Smoke Spread Simulation Technology** **Dr. Walter Jones** **Training Technology** **Dr. Bernard Ulozas**
1530-1600	Break
1600-1700	Discussion Groups (continued)

__10 June 1994__

0800-1000	Summary and Recommendations from Discussion Groups
1000-1030	Wrap-Up (Dr. Patricia A. Tatem)

Appendix B

PARTICIPANTS LIST
DAMAGE CONTROL - FIRE FIGHTING FOR 21ST CENTURY
8-10 JUNE 1994

NAME	ORGANIZATION
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