EXPLOSION AND FIRE SIMULATION

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF COMPUTER APPLICATIONS

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"EXPLOSION AND FIRE SIMULATION"** in partial fulfillment of the requirement for the award for the degree of **MASTER OF COMPUTER APPLICATION** submitted in the Department of Mathematics, Indian Institute of Technology Roorkee, Roorkee is authentic record of my work carried during the period of January to May 2002 under the supervision of **Dr. (Mrs.) Kusum Deep**, Assistant Professor, Department of Mathematics, Indian Institute of Technology Roorkee, Roorkee-247667 and **Mrs. Alka Diwan** (Scientist E), Head of the computer group, **Mr. G. Anil** (Scientist B), Center for Environment and Explosive Safety (CEES),DRDO, Delhi-54.

The matter embodied in this project has not been submitted by me for the award for any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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This is to certify that ***Mr. Kumar Pal Singh,*** final year MCA studying at Indian Institute of Technology Roorkee, Roorkee has undertaken his dissertation/training during his final semester (VI Semester), at **Center for Environment and Explosive Safety(CEES), Defense Research and Development Organization (DRDO), Ministry of Defence** and has developed a software for Explosion and Fire Simulation.

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(Mr. J.C. Kapoor)
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It is my proud privilege to express my profound gratitude to my guide **Dr. (Mrs.) Kusum Deep**, Assistant Professor, Department of Mathematics, Indian Institute of Roorkee, Roorkee. **Mrs. Alka Diwan** (Scientist E), Head of Computer Group, Center for Environment and Explosive Safety (CEES), **Mr. G Anil** (Scientist B) for their invaluable inspiration, guidance and continuous encouragement throughout this project work.

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I would like to thank all my friends for their help and constructive criticism during the development of this work.

In the last but not least I am short of adequate words in expressing thankfulness to my parents and brother who is the constant source of encouragement to me. It loves care and understanding of my parents who have placed me at the present level of academic career.

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ABSTRACT

The work presented in this thesis is based on the work carried out at Center for Explosive and Environmental Safety (CEES), DRDO.

For safe handling of explosives and flammable substances, as well as dimensioning explosive protected equipment's and protection systems, it is important to recognize the possible dangers involved to the individual, which through technical safety parameters, are characteristically quantified.

There are two sections of this project. Explosion Simulation and Fire Simulation. In first section, there are three modules. The first module is on deciding the categories of explosion, module second is on evaluating the post explosion parameters and finally module third is the simulation of TNT explosion model. In second section the fire model Quientiere/Dillon Fire Model is simulated. This model is zone model capable of predictive the environment in a compartment structure subjected to a fire.

A software FireExpro (Explosion and Fire Simulation) has been developed to simulate the above models to observe the behavior of fire and explosion incidents and their effects in the environment. The coding of the FireExpro software has been done using visual C++, Microsoft Foundation Classes (MFC) version 6.0 as shared DLLs and WIN 32 Software Development Kit (SDK) functions for those requirements which are not available through API.

A set of comparisons between model and a range of real-scale experiments is presented in this thesis. In first section comparison between the results calculated by TNT explosion model and experimental data given by Kingery and Bulmash and also the experimental data given by Kinney and Graham is presented. In second section comparison between the results calculated by Quintiere/Dillon fire model and the experimental data given by Janssen is presented. The results of this project show that it is possible to learn about the behavior of the fire and explosion and expected performance of materials. The results of both the mathematical models are very near to experimental data given by Kingery and Bulmash in case of explosion model and the experimental data given by Janssen in case of fire model.

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CHAPTER 1

INTRODUCTION

1.1 THE ORGANIZATION

Center for Environment and Explosive Safety (CEES) is a department under the **DEFENCE RESEARCH AND DEVELOPMENT ORGANISATION (DRDO), MINISTRY OF DEFENCE,** which undertakes projects related to sensor technology, intelligence fire detector system, toxic release of gases, and release of dense gases. Under the fire and explosive safety development project, **C.E.E.S** has undertaken a project on development of simulation and modeling on fire and explosion.

ORGANIZATION PROFILE

Name of the Organization:	**D. R. D. O.**
Year of Establishment:	**1958**
Departments:	1. C. E. E. S. 2. L.A.S. T. E. C. 3. I. S.S.A. 4. S.A.G. 5. DESIDOC 6. DTRL
Motto:	Professional Perfection
Objective:	To provide high value, high quality solutions in the field of research.

D.R.D.O.

DEFENCE RESEARCH AND DEVELOPMENT ORGANIZATION

The government of Independent India set up the Defence Science Organization in 1948 to advise and assist the Defence Services on scientific problems and to undertake research in areas related to defence. The Defence Research & Development Organization (DRDO) was set up in 1958, by merging the units of Defense Science Organization with the then existing Technical Development Establishments of the three Services. Subsequently, a separate Department of Defence R&D was formed in 1980, to improve administrative efficiency.

The mission of the Department is to attain technological self-reliance in defence systems and weapons. To accomplish this, the Department has the mandate to design, develop and lead on to production of the state-of-the-art weapon systems, platforms, sensors and allied equipment to meet the requirements of the Armed Forces and to provide support in areas of military sciences to improve combat effectiveness of the troops.

The Department of Defence R&D executes various R&D programmes and projects through a network of 49 laboratories/establishments of the DRDO located all over India and a Center for Military Airworthiness and Certification (CEMILAC). It also administers the Aeronautical Development Agency (ADA), a society funded by the Department, which is engaged in design and development of the Light Combat Aircraft (LCA). These laboratories and establishments execute programmes and projects in diverse fields of aeronautics, armaments, missiles, combat vehicles, electronics and instrumentation, advanced computing and networking, engineering systems, agriculture and life sciences, advanced materials and composites and Naval R&D. They also conduct specialized training programmes in these areas. The programmes are carried out by a workforce of about 30,000 including more than 6,000 scientists and engineers, supported by a budget of the order of Rs. 30,000 million.

To fulfill its objectives DRDO has a strong partnership with about 40 academic institutions, 15 national S&T agencies, 50 PSUs and 250 private sector enterprises. This has enabled the organization to minimize the effects of sanctions and technology denials, imposed by technologically advanced countries from time to time.

During its first decade, between 1948 and 1957, DRDO was mainly engaged in activities related to clothing, ballistics, operations research, and general stores. During the next decade 1958-68, many products, including small and medium weapon systems, explosives, communication systems and cipher machines were developed. The important achievements of the next decade (1969-79), during which DRDO addressed major hardware systems included, field guns, sonar systems, radar and communication equipment and aeronautical systems. Between the years 1980-90, it embarked on programmes of a multi-disciplinary nature for the development of complex and sophisticated weapon systems having latest technology. The contribution of DRDO towards self-reliance in defence systems became evident with the development of flight simulators for *Ajeet* and *Kiran* aircraft, air launched missile target *Fluffy* and various other types of ammunition, low-level surveillance radar *Indra*, electronic warfare (EW) systems and sonars. During the decade of 1990-2000, certain major programmes undertaken during the previous decade culminated in weapons and systems, like the Ballistic Tank (MBT) *Arjun*, missiles *Prithvi* and *Agni*, pilotless target aircraft *Lakshya*; combat improved T-72 tank *Ajeya*, bridge layer tank on T-72; *Sarvatra* bridging system, artillery combat command and control system, 5.56 mm INSAS rifle; light machine gun and ammunition; the super computer PACE+, sonar systems and Naval mines.

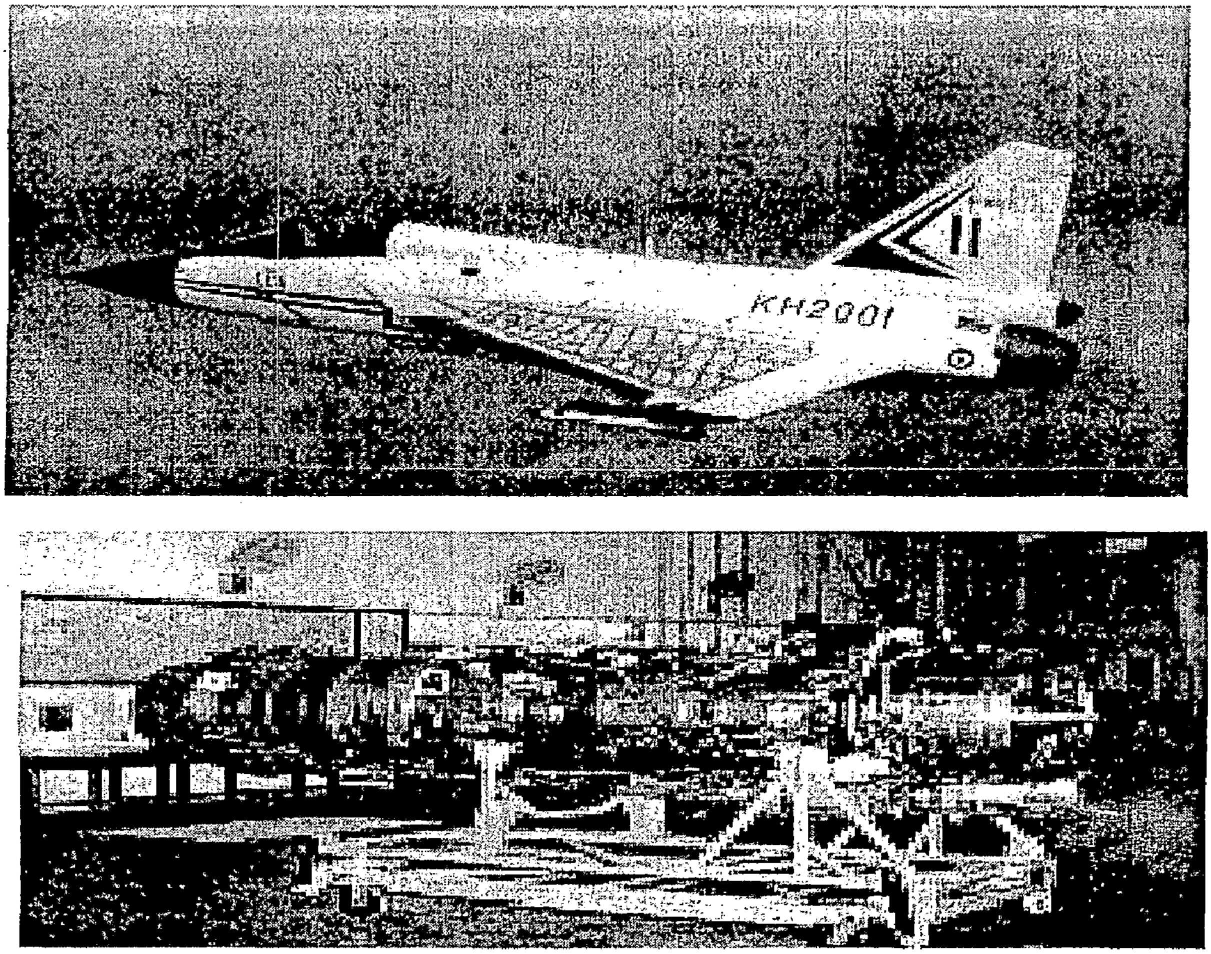


Fig. 1.1 Light Combat Aircraft and its Kaveri engine

ACHIEVEMENTS AND PROGRAMMES

Aeronautical Systems: DRDO has already delivered pilotless target aircraft *Lakshya*, aircraft arrester barrier, a variety of brake parachutes and balloon barrage system to the Armed Forces. The Light Combat Aircraft (LCA) programme, under execution at Aeronautical Development Agency (ADA), has led to he development of several state-of-the-art aeronautical technologies and the creation of a necessary infrastructure, despite the constraint of sanctions imposed by the advanced countries and the country's industrial base unprepared for the requisite components and advanced materials. The first LCA Technology Demonstrator (TDI) has undergone a number of successful test flights. The remotely piloted vehicle *Nishant*, is at an advanced stage of evaluation. Certain crucial elements, of the modernized avionics of Su-30 MKI aircraft being acquired by the IAF, have been supplied and successfully integrated.

Armaments: DRDO has achieved a high degree of developmental self-reliance in the area of armament and ammunition. More than 300 ammunition items based upon DRDO technology worth Rs. 50,000 million have been manufactured by ordnance factories. These include 5.56 mm caliber rifle and machine gun, anti-tank ammunition, illuminating ammunition, mines and a variety of bombs for the Air Force.

Missile Systems: DRDO has established core competence in the area of surface-to-surface missiles, which has been demonstrated through development of *Prithvi* missile and its variants, demonstration of re-entry and related technologies for *Agni-I* and development of the longer range version, *Agni-II.* The surface-to-air missiles *Trishul* and *Akash* and anti-tank missile *Nag* are at an advanced stage of flight evaluation. For the first time in the world, the indigenously developed capability to hit a target at 4.18 km in top attack.

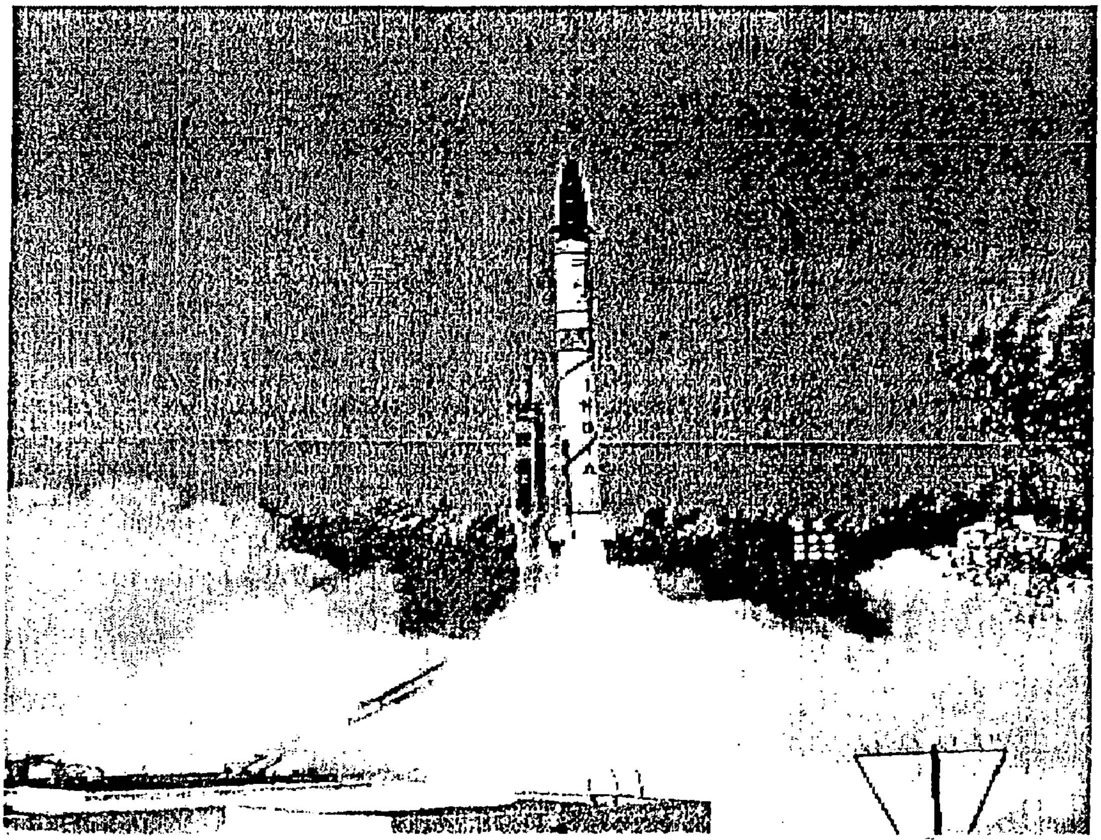


Fig. 1.2 Agni missile

Radar and Communication Systems: In spite of the non-availability of indigenous microelectronic devices and components, DRDO laboratories have successfully developed and delivered a variety of systems falling under this group including INDRA PC radar, equipment for Army Radio Engineered Network (AREN), very low frequency receivers, satellite communication terminals and secure telephones. A number of projects, for development of other radar and communication systems, are being carried forward.

Electronic Warfare (EW) Systems: DRDO developed a number of EW systems with considerable success. These include *Ajanta, Coin, Vikram* and Radar Warning Receiver (RWR) for MiG-23 and MiG-27 aircraft, which have been delivered to the Services. In addition, the self protection jammer for MiG-27, is ready for delivery. Development of an advanced RWR for MiG-21 aircraft has been completed. The current EW projects, Samyukta and *Sangraha* for the Army and the Navy are at an advanced stage and should reach the Services in the next few years. India is now capable of developing any type of state-of-the-art EW system for the Services.

Combat Engineering Systems: DRDOs efforts have to successful development of a variety of complex multi-disciplinary systems including bridge layer tanks, mat fording vehicles, mine field marking equipment, mortar carrier vehicles, armored engineering race vehicle, armored amphibious dozer, operation theatre complex on wheels, ward container and mobile water purification systems. The R&D expertise in DRDO and the production infrastructure in the country can now be brought together for world class engineering systems for Defence Services.

Main Battle Tank: *Arjun*, and its derivative systems have met stringent requirements of the Army successfully. This tank is contemporary to world class tanks like M1A2 of the USA and Leopard 2 of Germany. The bulk production of MBT *Arjun* is now at an advanced stage. Based on the experience gained during the development of MBT *Arjun*, DRDO has successfully integrated a 155 mm SP turret on *Arjun* derivative chassis for development of a 155 mm self-propelled weapon system. It has also modernized the T-72 M1 tank to improve its fire power, mobility and protection.

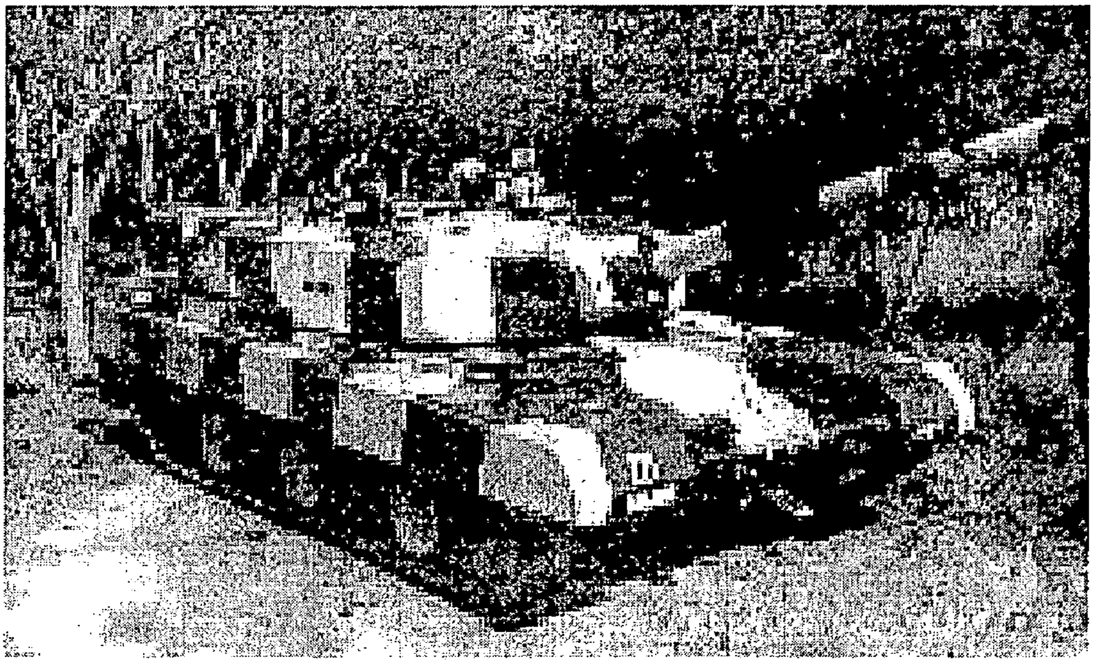


Fig. 1.3 Arjun Tank

OTHER ACHIEVEMENTS

Advanced Computing and Software Products:

DRDO has successfully developed Supercomputer PACE+, consequent to the denial of such a computer by the advanced countries. DRDO's expertise in software has been demonstrated through the development and commissioning of war games *Shatranj* and *Sangram* for the Army; *Sagar* for the Navy and air war game software for the Air Force. A landmark toward self-reliance in microprocessor technology has been achieved through development of ANUCO, a floating-point coprocessor and a 32-bit RISC processor ANUPAMA. Its processing speed is being further enhanced from 33 MHz to 350 MHz. In addition, a three-dimensional medical imaging system "ANAMICA" has been developed. Software called GITA(Graphical Interactive Three Dimensional Applications, a general purpose CAD software and AUTOLAY, a design for software manufacture is being marketed internationally. DRDO has also set up a Very Large Scale Integrated Circuits (VLSI) design facility, which has been used for developing a number of Application Specific Integrated Circuits (ASICs) like the digital signal processing chip.

Explosive Detection Kit: DRDO has developed a kit for detection and identification of explosives. It can detect and identify explosives based on any combination of nitro esters, nit amines, trinitro-toluene (TNT), dynamite or black powder. The testing requires only 3 to 5 mg of suspected sample and only 3 or 4 drops of reagents.

Critical Electronic Components: Initiatives to achieve self-reliance in the field of electronic components has been taken by setting up facilities for production of Gallium Arsenide and Silicon devices. Under the programme, CODE, several types of components have been indigenized, like integration components, microwave components, millimeter wave components and other special types of components required for various ongoing DRDO programmes. A facility has been created to lead to fabrication of Gallium Arsenide wafers and Monolithic Microwave Integrated Circuits (MMICs) in 1-18 GHz range. Under a co-operative venture with other S&T Departments and Industry, DRDO has contributed in setting up a silicon foundry which has the potential of making the country independent of foreign sources in respect of most of the VLSI requirements.

Missile Technologies: During the execution of IGMDP programme, DRDO developed several technologies that have gone into various missile systems. These include: strap down inertial guidance system, high strength low weight magnesium alloy wings; maneuverable trajectory; accurately deliverable high lethality field interchangeable warheads; multiple target tracking; composite airframe; nitramine based smokeless propellant; ram rocket technology; three beam command guidance system; carbon-carbon technology; and maneuverable re-entry guidance and control for ONG range missions.

DEPARTMENT NAME: CENTER FOR ENVIRONMENT & EXPLOSIVE SAFETY (CEES)

Department objective: To provide integrated advice on safety matters with sound scientific and technical backup in the areas of environment, explosives and fire safety to all establishments under Ministry of Defence (MOD) in handling explosives, ammunition and other hazardous materials.

ACHIEVEMENTS

❶ Explosive Safety

Design of Blast-Resistant Structures

The use of novel constructional materials and techniques such as lacing and steel fibres reinforcement in concrete has been investigated. Adequate competence has been generated to design buildings for containment of internal and external blast loads. A new concept for storage of propellants, based on unit risk principle, which restricts the loss of valuable stocks to the affected location only, has been validated by field trials. A design manual for the guidance of users has been issued. Design of blast-resistant structures has been carried out.

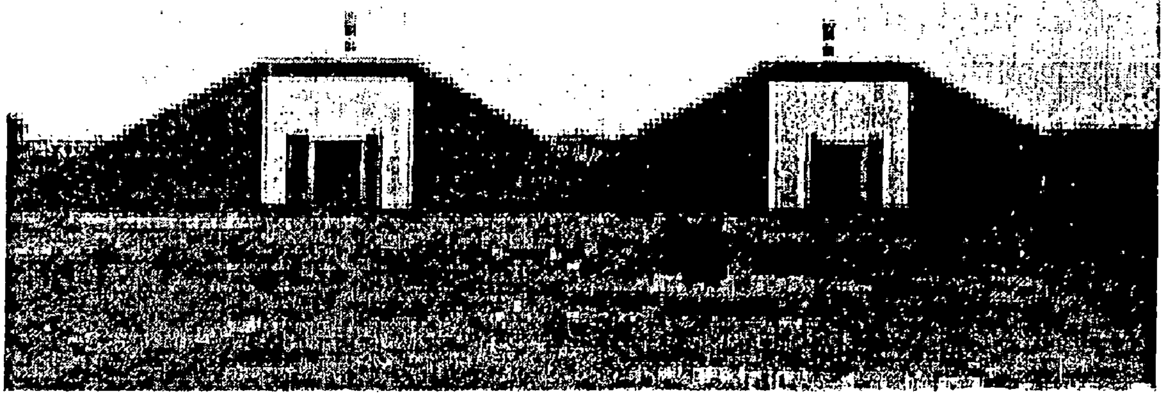


Fig. 1.4 Testing Compartment for Fire and Explosion

Hazard Classification, Testing of Ammunition and Explosives

Propagation mechanism of detonation and methodology of hazard classification of explosives were studied. Guidelines have been finalised to predict non-propagation of explosion from one cluster of ammunition to adjacent clusters. These norms have resulted in optimum utilisation of existing explosives facilities.

Safety Surveillance Systems

Established a three-tier safety surveillance system for the enforcement of mandatory requirements of safety standards and regulations. Periodic safety reviews of MOD establishments are conducted every year.

❷Environment Safety

Environment Testing Laboratory

Established a well-equipped modern instrumental analysis laboratory for trace determination of environmental pollutants in water, soil and air. The laboratory has obtained accreditation from Central Pollution Control Board (CPCB) as the Environmental Testing Laboratory under Environment Protection Act (EPA), 1986 and is recognised as the institution for higher learning by Punjab University, Chandigarh and Delhi University.

Efficient Waste Treatment

R&D studies were conducted in the field of waste management for minimising the release of hazardous pollutants into the environment from Defence production units and DRDO establishments. Processes being developed include dynamic adsorption on granular activated carbon, advanced photo-catalytical oxidation using UV irradiation, ozonation, and exchange processes on natural and synthetic zeolites.

Strategic & Special Materials

Development of strategic and special materials for Defence applications including development of ABC powder for fire extinguishing as replacement of ozone-depleting Halons, and activated carbon for removal of toxic gases.

Risk Hazard Analysis

Development of expertise in risk and hazard analysis (RHA) and pollutant dispersion modelling for applying these techniques for evaluation of existing and planned facilities. Development of know-how for design of ground water monitoring network and monitoring of DRDO facilities.

❸Fire Safety

Consultancy on fire protection and prevention measures to all establishments under MOD. Comprehensive fire safety reviews are carried out regularly to point out areas where the fire safety augmentation is needed.

Areas of work

- Providing integrated advice and creating safety awareness on environment, explosives and fire safety in all establishments under the Ministry of Defense handling explosives/hazardous materials.
- Providing guidance to these establishments on manufacture, handling, transportation, storage and disposal of hazardous materials.
- Undertaking R&D to augment/improve safety in the areas of environment, explosives, and fire science.
- Approving/reviewing explosives and fire safety aspects of plans for sitting and construction of new facilities and modifications/alterations of existing facilities.
- Enforcing compliance of statutory rules, safety standards.
- Providing consultancy to Government departments, public and civil sector units on explosives/ fire/environment safety and related matters.

1.2 SIMULATION AND MODELING

OVERVIEW

Modeling and Simulation (M&S) have become important tools for analyzing and designing complex systems in a broad array of disciplines ranging from business and engineering to biology and psychology. For example, in engineering design M&S can be used to evaluate the effectiveness of a new product concept, verify whether all the functional design specifications are met, or suggest modifications for improving the manufacturability of a product. By using simulations in this fashion, designers can achieve significant reductions in design cycle time and overall lifetime cost of new products. In other disciplines, simulations allow us to perform experiments that cannot be realized in the real world due to physical, environmental, economic, or ethical restrictions. However, simulations are only meaningful if the underlying models are adequately accurate and if the models are evaluated using the proper simulation algorithms. To accomplish this, a systems engineer requires a variety of knowledge and skills in different disciplines.

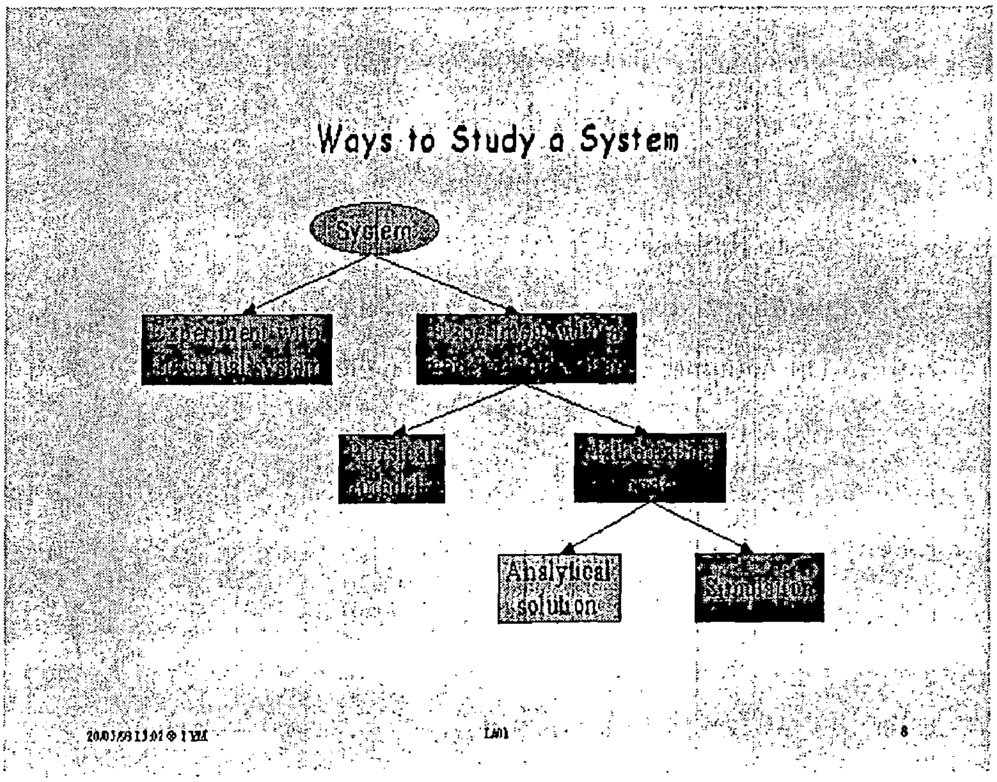


Fig 1.5 Ways to Study a System

WHAT IS SIMULATION

Simulation is the process of design a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of calculating various strategies (within the limits imposed by a criterion or set of criterion) for the operation of the system.

WHY SIMULATION

Simulation is done because:-

- When real system does not exist. Simulation is performed on the model of the system not on the actual system.
- Trail by implementation too costly, or too time consuming, or even too dangerous
- Time scale too long to get real measurement

STEPS IN SIMULATION

To carry out simulation, the following steps are performed:-

1. Problem formulation
2. Setting of objectives and overall project plan
3. Model conceptualization
4. Data collection
6. Verification

ADVANTAGES AND DISADVANTAGES OF SIMULATION

Main advantages of simulation are followings:-

- Controlled experimentation
- Time compression
- Easy to conduct sensitivity analysis
- Doesn't disturb the real system
- An effective training tool

Disadvantages:

Main disadvantages of simulation are followings:-

- Time consuming for training and development
- Costs for developing a simulation capability
- Difficult to produce exact results

Each model within a simulation has a number of parameters associated with it, which describe the model's behavior. They include things like protocol, channel speed, frame size, and simulation run time. In addition, there are global simulation parameters that apply to all individual models. The simulation model parameters combined with the network definition parameters provide the necessary information for simulation execution.

A model is a high level specification to abstract from reality a despcription of a dynamic system.

TYPES OF MODELS

There are two major types of models:

- Physical Model : Scale models, prototypes plants etc.
- Mathematical Model: Analytical queing models, linear programs, simulations, etc.

1.3THE PROJECT

For safe handling of explosives and flammable substances, as well as dimensioning explosive protected equipment's and protection systems, it is important to recognize the possible dangers involved to the individual, which through technical safety parameters, are characteristically quantified. These parameters are not physical components, but are conventional quantities, which are in particular reproducible and comparable, tied to a set testing method.

There are two way of performing any experiment, firstly by performing experiments in laboratory with all necessary equipments and materials needed for experiments. But these may not be feasible economically; these may consume more time and man power, if the experiments are on explosion and fire then obviously these may be dangers for human, buildings and environments.

The second way is simulation, which is performed on computer. Typically the simulation is performed when

- When the real system doesn't exists. Actually the simulation is performed on the model of the system not on actual system.
- Experimentation with system is too expensive.
- Experimentation with system is too time consuming.
- Experimentation with system is too dangerous.

There are two major section of this project Explosion Simulation and Fire Simulation. In first section (Explosion Simulation), there are three modules the first module is on deciding the categories of explosion, module second is on evaluating the post explosion parameters and finally the module third is the simulation of TNT explosion model.

In second section the fire model Quintiere/Dillon Fire Model is simulated. This model is a zone model capable of predicting the environment in a compartment structure subjected to a fire. It calculates the time evolving distribution of smoke and fire gases and the temperature throughout a building during a user-specified fire. A set of comparisons between the model and a range of real-scale fire experiments is presented. In general, the model compares favorably with the experiments examined. Although differences between the model and the experiments were clear, they can be explained by limitations of the model and of the experiments.

1.4 THE PLATFORM

The coding of the FireExpro (Fire and Explosion Simulation) has been done using visual C++ as programming language, Microsoft Foundation Classes (MFC) version 6.0 as shared DLLs, WIN 32 Software Development Kit (SDK) functions for those requirements which are not available through API.

For optimal performance, this software exploits the feature of Object Oriented Analysis like single level Inheritance, Constructor, Destructor, Encapsulation, Abstraction, Classes, Objects, Pointers, Switch Statements, Conditional Statements, and Recursive Calls etc.

Introduction to VC++ Architecture

Visual C++ is a powerful and complex tool for building 32-bit applications for Window 95 and Windows NT. These applications are far larger and more complex than their predecessors for 16-bit Windows, or older programs that did not use a graphical user interface. Yet as program size and complexity has grown, programmer effort has actually decreased, at least for programmers who are using the right tools.

Visual C++ is one of the right tools. With its code generating Wizards it can produce the shell of a working Windows application in seconds. The class library included with Visual C++, the Microsoft Foundation Classes, has become the industry standard for Windows software development in a variety of C++ compilers. The visual editing tools make layout of menus and dialogs a snap.

Visual C++ doesn't just compile code, it generates code. You can create a Windows application in minutes by telling AppWizard to make you a "starter app" with all the Windows boilerplate code you want. AppWizard is a very effective tool. It copies code that almost all Windows applications need into your application. An application with resizable edges, minimize and maximize buttons, a File menu with Open, Close, Print Setup, Print, and Exit options etc.. AppWizard makes skeleton, executable Windows programs in less than a minute.

Other Applications AppWizard Can Make

Other application generating wizards can make DLLs, ActiveX controls, console applications, libraries, makefile, Internet Server extensions and filters, and more. Microsoft Windows was designed long before the C++ language became popular. Because thousands of applications use the C-language Windows application programming interface (API), that interface will be maintained for the foreseeable future. Any C++ Windows interface must therefore be built on top of the procedural C-language API. This guarantees that C++ applications will be able to coexist with C applications.The Microsoft Foundation Class Library is an object-oriented interface to Windows that meets the following design goals:

- Significant reduction in the effort to write an application for Windows.
- Execution speed comparable to that of the C-language API.
- Minimum code size overhead.
- Ability to call any Windows C function directly.
- Easier conversion of existing C applications to C++.
- Ability to leverage from the existing base of C-language Windows programming experience.
- Easier use of the Windows API with C++ than with C.
- Easier-to-use yet powerful abstractions of complicated features such as ActiveX, database support, printing, toolbars, and status bars.
- True Windows API for C++ that effectively uses C++ language features.

MFC: Overview

The Microsoft Foundation Class Library (MFC) is an "application framework" for programming in Microsoft Windows. Written in C++, MFC provides much of the code necessary for managing windows, menus, and dialog boxes; performing basic input/output; storing collections of data objects; and so on. All you need to do is add your application-specific code into this framework. And, given the nature of C++ class programming, it's easy to extend or override the basic functionality the MFC framework supplies.

The MFC framework is a powerful approach that lets you build upon the work of expert programmers for Windows. MFC shortens development time; makes code more portable; provides tremendous support without reducing programming freedom and flexibility; and gives easy access to "hard to program" user-interface elements and technologies, like ActiveX, OLE, and Internet programming. Furthermore, MFC simplifies database programming through Data Access Objects (DAO) and Open Database Connectivity (ODBC), and network programming through Windows Sockets. MFC makes it easy to program features like property sheets ("tab dialogs"), print preview, and floating, customizable toolbars.

What MFC Can Do for You

The classes in MFC, taken together, constitute an "application framework". It is the framework of an application written for the Windows API. Your programming task is to fill in the code that is specific to your application. Despite its generality, MFC does support you in many specialized ways support for

- OLE visual editing.
- Automation.
- ActiveX Controls
- Internet programming.
- Windows Common Controls.
- DAO Database Programming.
- ODBC Database Programming.
- Multithreaded Programming.
- Windows Sockets for Network Programming.
- Portability

General Class Design Philosophy.

MFC supplies class CWnd to encapsulate the HWND handle of a window. The CWnd object is a C++ window object, distinct from the HWND that represents a Windows window but containing it. Use CWnd to derive your own child window classes, or use one of the many MFC classes derived from CWnd. Class CWnd is the base class for all windows, including frame windows, dialog boxes, child windows, controls, and control bars such as toolbars.

MFC uses classes CFrameWnd, CMDIFrameWnd, and CMDIChildWnd to represent single document interface (SDI) and multiple document interface (MDI) frame windows.

MFC manages windows, but you can derive your own classes and use CWnd member functions to customize these windows. You can create child windows by constructing a CWnd object and calling its Create member function, then manage the child windows with other CWnd member functions. You can embed objects derived from CView, such as form views or tree views, in a frame window. And you can support multiple views of your documents via splitter panes, supplied by class CSplitterWnd.

Each object derived from class CWnd contains a message map, through which you can map Windows messages or command IDs to your own handler functions for them.

Messages and Commands: Overview

In traditional programs for Windows, Windows messages are handled in a large switch statement in a window procedure. MFC instead uses message maps to map direct messages to distinct class member functions. Message maps are more efficient than virtual functions for this purpose, and they allow messages to be handled by the most appropriate C++ object-application, document, view, and so on. You can map a single message or a range of messages, command IDs, or control IDs.

WM_COMMAND messages-usually generated by menus, toolbar buttons, or accelerators-also use the message-map mechanism. MFC defines a standard routing of command messages among the application, frame window, view, and document objects in your program. You can override this routing if you need to.

MFC Fundamentals

MFC's strong suit is its fundamental support for programming for Microsoft Windows. The following programming areas are of common interest:

- Frame windows
- Documents
- Views of documents
- Multiple views
- Special view types, such as scroll views and form views
- Dialog boxes and property sheets
- Windows Common Controls
- Mapping Windows messages to handler functions
- Toolbars and other control bars
- Printing and print preview
- Serialization of data to and from files and other media
- Device contexts and GDI drawing objects
- Exception handling
- Collections of data objects
- Diagnostics
- Strings, rectangles, and points
- Date and time
- And considerably more.

MFC Portability

MFC has been designed to be portable to a number of platforms, allowing applications written to MFC to target a variety of different platforms. MFC is also portable to a variety of compiler implementations, and the many companies who have licensed MFC have made it a standard application framework for Windows-based development. Microsoft plans to keep extending and evolving MFC to support new functionality for applications and to exploit new functionality in the operating system.

1.5 ORGANIZATION OF THIS THESIS

The present chapter is introductory in nature. There are nine chapters in this project report and two appendices in the end. The second chapter describes the theory of explosion in details. The third chapter is based on the effect of the explosion when it occurs and the calculations of important post explosion parameters which are necessary for the simulation of the TNT explosion. In the fourth chapter the theoretical concepts and calculation are given. The fifth chapter is similar to chapter four in nature but in this chapter the theoretical concepts and calculations necessary for fire simulation are given. In sixth chapter the general concept of software engineering is given which is applied through development of software. In the seventh chapter verification and testing of the software is given. In this chapter the calculated results by empirical equations are compared with experimental data. The eighth chapter is based on the scope and developments of the models, which are simulated in this project. Finally in chapter nine the conclusions and suggestions for future work are given.

In appendix A description of symbols and abbreviations are given for both explosion and fire models. In appendix B some important snap shot of the software are given with explanation.

CHAPTER 2

THEORY OF EXPLOSION

2.1 INTRODUCTION

The explosion is a major hazard. Explosion in the process industries causes fewer serious accidents than fire but more than toxic release. When it dose occur, however, it often inflicts greater loss of life and damage than fire. Explosion is usually regarded as having a disaster potential greater than that of fire but less than that of toxic release.

In the case of flammable materials, the greatest threat arises from the sudden massive escape of those volatile liquids, or gases, which cloud produce a large cloud of flammable, possibly explosive vapour. If the cloud were ignited, the effects of combustion would depend on many factors including wind speeds and the extend to which the cloud is diluted with air. The worst consequence cloud is large number of casualties and wholesale damage on site and beyond its boundaries. Nevertheless where combustion has taken place it has generally been on or in the immediate vicinity of the site. The important feature of this threat is the small time interval between the initial escape and the fire or explosion, which could be less than a minute.
The Flixborough disaster was primarily due to an unconfined vapour cloud explosion. It was this explosion, which caused most of he casualties.

2.2 WHAT IS EXPLOSION

2.2.1 THE EXPLOSION PROCESS

Explosion is a sudden and violent release of energy. The violence of the explosion depends on the rate at which the energy is released. The energy stored in a car tyre, for example, is capable of causing an explosive burst, but it can be dissipated by gradual release.

There are several kinds of energy, which may be released in an explosion. Three basic types are (1) physical energy, (2) chemical energy, and (3) nuclear energy.

Physical energy may take such forms as pressure energy in gases, strain in metals or electrical energy. Examples of violent release of physical energy are explosion of a vessel due to high gas pressure and sudden rupture of a vessel due to brittle fracture. Another important physical form is thermal energy. This is generally important in creating the condition for explosion rather than as a source of energy for the explosion itself.

Chemical energy derives from a chemical reaction, chemical reaction are (1) uniform explosions and (2) propagating explosions. An explosion in vessel tends to be a uniform explosion, while an explosion in a long pipe gives a propagating explosion.

The nuclear energy is released from an nuclear explosion it is also a chemical reaction which produce a very large amount of energy. The nuclear energy is more dangerous than both physical and chemical energy.

2.2.2 DEFLAGRATION AND DETONATION

Explosions are of two kinds: (1) deflagration and (2) detonation

In a deflagration the flammable mixture burns relatively slowly. For hydrocarbon-air mixture the deflagration velocity is typically of the order of 1 m/s.

A detonation is quite different. In a detonation the flame front travels as a shock wave followed closely by a combustion wave, which release the energy to sustain the shock wave. At steady state the detonation shock front reaches a velocity equal to the velocity of sound in the hot products of sound in the unburnt mixture. For hydrocarbon-air mixtures the detonation velocity is typically of the order of 2000-3000 m/s. for comparison the velocity of sound in air at 0°C is 330 m/s.

A detonation generates greater pressure and is more destructive than a deflagration. Whereas the peak pressure caused by the deflagration of a hydrocarbon-air mixture in a closed vessel at atmospheric pressure is of the order 8 bars, a detonation may give a peak pressure of the order Of 20 bars

A deflagration may turn into a detonation, particularly when traveling down a long pipe. Where transition from deflagration to detonation is occurring the deflagration velocity naturally exceeds that quoted above.

2.2.3 CONFINED AND UNCONFINED EXPLOSION

A basic distinction is made between (1) confined explosions and (2) unconfined explosions.

Confined explosions are those, which occur within vessel sort of containment. Often the explosion is in a vessel or pipe work, but explosions, which occur in buildings, also come within this category. Explosion, which occur in the open air, are unconfined explosions. These two types of explosion have rather different characteristic and require separate treatment.

2.3 EXPLOSIVE

Explosives are relevant to loss prevention in two areas in particular. These are (1) estimation of effects of explosions and (2) control of manufacture and storage of explosives.

Many of the data available on explosion and their effects relate to explosives. In particular the methods developed for calculating the effects of explosion are based mainly ion the high explosive trinitrotoluene (TNT). In an explosion caused by a high explosive the rate of energy release is particularly rapid and the explosion has high shattering power, or 'brisance'.

A high explosive produces, therefore, a quite distinct type of explosion. The shock wave from such an explosion has a very short duration time. Differences in the types of explosion are a weakness in the application of correlation based on explosions of high explosive to other explosion situations.

Nevertheless, the TNT explosion model is much the most widely used in explosion calculations for estimating the effects of explosion on process plant. A principal parameter, which characterizes an explosion, is its overpressure.

2.3.1 CUBE ROOT LAW

The variation of peak overpressure p° with mass of explosive W and distance r is given by a law that is called cube root law, which explained below.

Over a limited range

$$\frac{p_1^0}{p_2^0} = \left(\frac{W^\circ 1}{W1/31}\right) \qquad \text{.............2.1}$$

Where p° is the peak overpressure, W the mass of explosive and r the distance. The value of n varies from about 1.6 between overpressure of 1 and 10 psi to about between overpressure 10 and 100 psi. Equation (2.1) represents a cube root law relating distance to charge for a given overpressure.

$$r \propto W^{1/3} \qquad \text{...........2.2}$$

It should be noted that equation (2.2) implies that at given values of p^0, r is proportional to $W^{1/3}$, but not that p^0 is proportional to $W^{1/3}$ or inversely proportional to r.

2.3.2 CATEGORY OF EXPLOSION

The quantity-distance relations, which are used in handling explosives, are relevant to separation distances on process plant. An account of the quantity distance relations used in the U.K. has been given by Jarret (1968).

The principal explosion effects of the different categories of explosive are

Category X: Missiles and slight blast effects, projected ammunition.
Category Y: Radiant Heat.
Category Z: Missiles and major blast effects, cratering, earth shock.
Category ZZ: Major blast effects, cratering earth shock.

The quantity-distance relations used are for (1) storage distances, (2) process building distances and (3) public building and traffic distances. The process building distances are also known as intraline distances.

For the intraline and public building distances for category Z explosive the basis of separation is blast effects. For the case Jarret gives the relation.

$$R = \frac{kW^{\frac{1}{3}}}{\left[1+\left(\frac{7000}{W}\right)^2\right]^{\frac{1}{6}}} \qquad \text{...........} 2.3$$

The constant k in above equation (1,2.3) describes the degree of damage which may be expected to the average British dwelling house. It is based on an anlysis of damage in 24 well documented explosions and wartime bombing. The follwing categories of damage defined.

Table 2.1 Category of explosion

CATEGORY OF EXPLOSION	DEGREE OF DAMAGE	JARRET CONSTANT *k*
A	**Almost complete demolition**	**$0 < k \leq 9$**
B	**50-70% external brickwork destroyed**	**$9 < k \leq 14$**
Cb	**Partial or total collapse of roof**	**$14 < k \leq 24$**
Ca	**Minor structural damage**	**$24 < k \leq 70$**
D	**More than 10 % window glass broken**	**$70 < k \leq 100$**

2.4 EXPLOSIVE ENERGY

The energy released in an explosion on a process plant is normally one of the following: (1) chemical energy, (2) fluid expansion energy, or (3) vessel strain energy.

2.4.1 CHEMICAL ENERGY

In considering the energy release in a chemical explosion, it is convenient to consider first high explosives and the flammable gases and liquids.

The energy release in a chemical explosion is a function of the nature and state if the reactants and of the products. In general, the explosion products are not well defined. As the gas mixture cools, the chemical equilibrium shifts and the transition products disappear.

A high explosive contains its own oxygen so that it can explode even in the absence of air. It is conventional to assume certain normal products of explosion. Explosives may be classified on the basis of the normal oxygen distribution. An oxygen-rich explosive has excess oxygen and the nominal products contain molecular oxygen and incombustible gases such as CO_2 and H_2O. An oxygen-deficient explosive gives combustible gases such as CO and H_2 among the normal products. The actual gases generated by explosives contain a mixture of all these products.

For all these materials the heat of explosive Q_c correspond to the internal energy change for the explosion ΔE ($Q_c = -\Delta E$).

The energy of explosion is the work of expansion of the explosion W_e

$$W_e = \int^{2} P dv \qquad \text{..............} 2.4$$

Where P is the absolute pressure, v the volume and W_e the work of expansion.

2.4.2 FLUID EXPANSION ENERGY

Explosion can also be caused by gas or liquid under high pressure. The energy released in an explosive expansion of a compressed gas is given by equation (1.3.1)

The limiting value of the energy of explosion of 1 mol of gas, assuming an ideal gas and isothermal expansion, is

2.5 EXPLOSION EFFICIENCY

If the explosion occurs in an unconfined vapour cloud, the energy in the blast wave is generally only a small fraction of the energy theoretically available from the combustion of all the material, which constitutes the cloud. The ratio of the actual energy released to that theoretically available is sometimes referred to as the 'explosion efficiency'.

Usually it is assumed that all the flammable material in the cloud is available for combustion and the energy theoretically available is the product of the total quantity of flammable material in the cloud and the heat of combustion. On this basis, explosion efficiency is typically in the range of 1-10%.

2.6 GROUND LEVEL EXPLOSION

If an explosion charge is exploded at ground level, the ground forms a barrier to the explosion energy absorbed by the ground may vary from none up to one-half. Thus the energy in the blast wave from an explosion at the ground level, i.e. of hemispherical symmetry, exceeds that for an explosion of spherical symmetry by a yield ratio, which lies between one and two.

In principle, the yield ratio for such an explosion is a function of the height of charge. Yield ratios for TNT explosion at or near ground level frequently lie in the range 1.5 – 2. In an unconfined vapour cloud explosion at ground level the proportion of the total explosion energy absorbed by the ground is generally smaller than in a TNT explosion. The value of the yield ratio, therefore, lies nearer to two.

In a confined explosion, such as the bursting of a pressure vessel due to high gas pressure at ground level, the explosion energy absorbed by the ground is again generally smaller than in a TNT explosion. Again the value of the yield ratio lies nearer to two:

2.7 CONFINED EXPLOSIONS

The explosion of a flammable mixture in a process vessel or pipe work may be a deflagration or a detonation. These two types of explosion differ fundamentally and require different countermeasures. Both types, but particularly detonation, can be very destructive.

The conditions for a deflagration t occur are that the gas mixture is within the flammable range and that there is a source of ignition or that the mixture is heated to its auto ignition temperature. The conditions for a detonation to occur are similar except that in this case the mixture should be within the detonable range. If the source of ignition is sufficiently strong, detonation may be initiated directly. Alternatively, a deflagration may undergo transition to a detonation. This transition occurs in pipelines but is most unlikely in vessels.

2.7.1 SOURCE OF IGNITION

The sources of ignition usually considered are those outside the process plant. But ignition sources can occur inside the vessels and pipe work also. These include.

(1) Flame and hot surfaces.

(2) Sparks.

(3) Chemicals

    (a) Unstable compounds

    (b) Reactive compounds and catalysts
    (c) Pyrophoric iron sulphide.
(4) Static electricity.
(5) Compression.

This list is sufficient to show that there is no shortage of possible ignition sources inside the plant.

If a flammable mixture may be present, precautions should be taken to eliminate all sources of ignition. But it is prudent to assume that, despite these efforts, a source of ignition will at some time occur. Ignition can also occur if the flammable mixture is heated to its auto ignition temperature.

2.7.2 PRESSURE PILING

If explosion occurs in a system in which there are interconnected spaces, a situation can arise in which the pressure developed by the explosion in one space causes a pressure rise in the unburnt gas in an interconnected space, so that the enhanced pressure in the latter becomes the starting pressure for a further explosion. This effect is known as pressure piling. The type of geometry in which this is liable to occur is illustrated in following figure (Fig. 2).

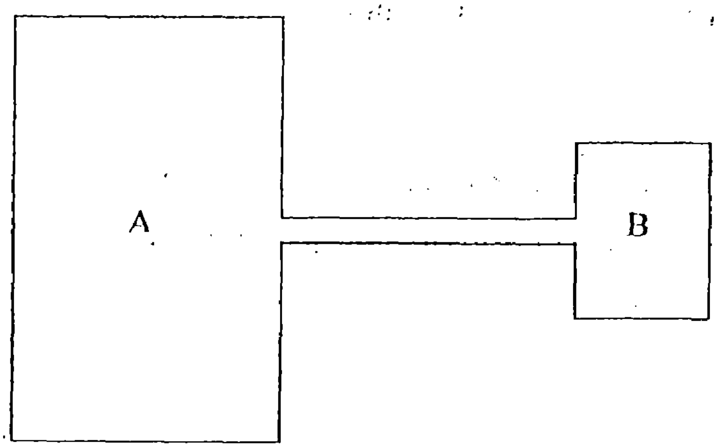


Fig. 2.1 Plant configuration to illustrate pressure piling.

In space A, this may cause pressure piling in space B. Then in the worst case, if the final pressure in A is x times the initial pressure, the final pressure in B would be x^2 times the initial pressure in both spaces.

This pressure piling can give an enormous increase in the maximum pressure rise occurring in the plant. The possibility of pressure piling should be given through consideration.

2.8 DETONATION

Detonation of gas-air mixture or explosive material may occur by direct initiation of detonation by a powerful ignition source or by transition from deflagration. Transition from deflagration to detonation requires a strong acceleration of the flame front. It occurs in pipelines but is very improbable in vessels.

The nature of the transition process may be illustrated by considering the combustion in a tube of a flammable mixture, which is initially at constant pressure. If ignition occurs and energy is released at one end of the tube, the burnt gases expand. The deflagration front moves at a flame speed which is the sum of the burning velocity and of the velocity of expansion of the burnt gases. If the flame speed is sufficiently high for momentum changes to exercise a significant effect, pressure disturbances are created. In this latter case the flame front accelerated and travels as a combustion wave preceded by a shock wave. Further acceleration of the flame front may cause the deflagration to turn into a detonation. The detonation front then travels with a velocity greater than that of sound in the unburnt gas.

The transition from deflagration to detonation is a complex process. The properties of the detonation however, are fairly well defined and depend essentially on the properties and condition of the unburnt gas.

CHAPTER 3

EFFECTS OF EXPLOSION AND POST EXPLOSION PARAMETERS

3.1 EXPLOSIVE SHOCK IN AIR

One of the main effects of an explosion is the generation of a shock wave or blast wave. This blast wave generates overpressure, which may injure people and damage equipment and buildings.

The description given of the explosion is based, unless otherwise stated, on an explosion of a high explosive such as TNT.

THE BLAST WAVE

An explosion in air is accompanied by a very rapid rise in pressure and by the formation of shock wave. The shape of the pressure profile near the center of the explosion depends on the type of the explosion involved.

With all types of explosion the shock wave travels outwards with the higher pressure part moving at higher velocity. After it has traveled some distance the sock wave reaches a constant limiting velocity which is greater than the velocity of sound in the air, or in the unburnt gas in the case of vapour cloud. The shock wave has a profile in which the pressure rises sharply to a peak value and than gradually tails off. At the shock wave travels outwards the peak pressure at the shock front falls.

At some distance from the explosion center the region pf positive pressure, or overpressure in the shock wave is followed by a region on negative pressure, or underpressure. The underpressure is usually quite weak and does not exceed about 4 psi.

An idealized representation of the blast wave is given in the following figure Fig 3.1.

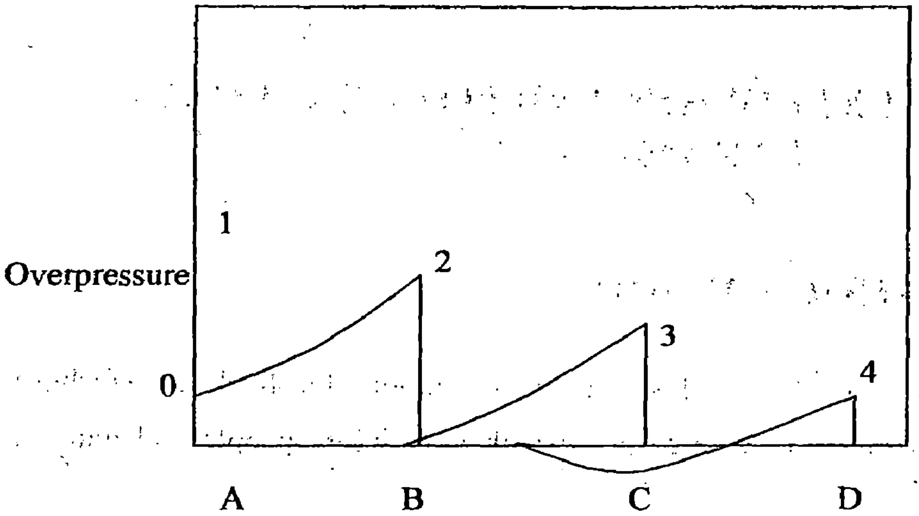


Fig. 3.1 Distance from explosion center

This figure shows the pressure pulse as function of distance from the explosion center with time as parameter. The shock wave reaches points A-D at time 1-4, respectively , and at these times its pressure profiles is illustrated. The shape of the curve at the point A is not shown, since it depends on the type of explosion. As the wave moves outwards, however the influence of the nature of the explosion declines and the wave establishes a profile which is common to all types of explosion. The curve at points B-D and times 2-4 show the decreases in peak overpressure. The curve at point D and time 4 shows both positive and negative pressures.

The variation of overpressure with time at such a point is illustrated by the following figure 3.2.

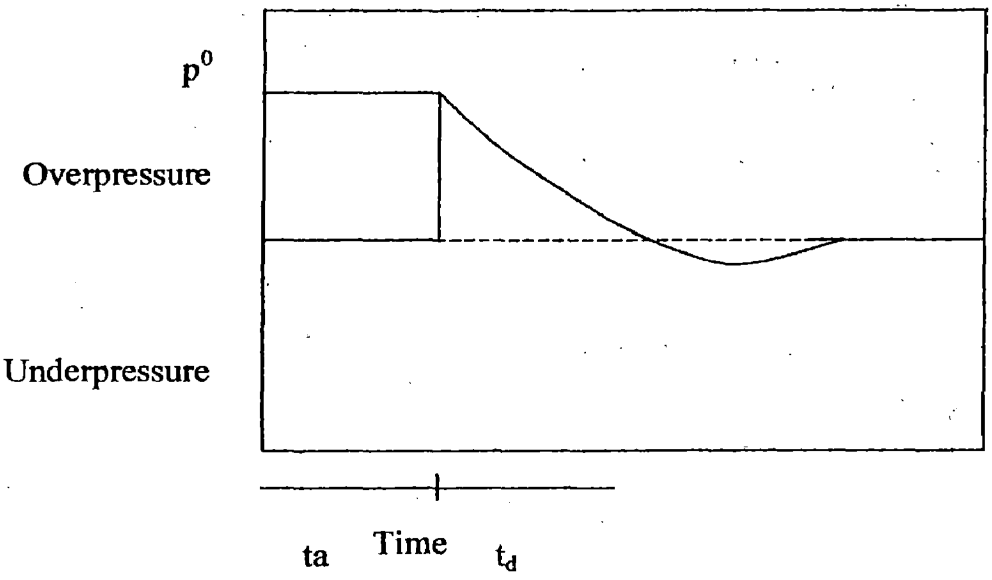


Fig. 3.2 Variation of overpressure from a blast wave with time at a fixed point

3.2 POST EXPLOSION PARAMETERS

When an explosion occur it causes several effects in the surrounding this effects can be measure by some parameters. The important parameters are as follows.

1. **Overpressure**
   The overpressure created by an explosion is given by

   $$p = p^0 (1 - t/t_d) \exp(-\alpha t/t_d) \qquad \text{...........3.1}$$

2. **Shock Velocity**

   The shock velocity is given by

   $$U = c_0 \left(1 + \frac{y+1 p^0}{2 y p_a}\right)^{\frac{1}{2}} \qquad \text{...........3.2}$$

3. **Particle Velocity**

The particle velocity is given by

$$u = \frac{c_0 p^0}{yp_a}\left(1+\frac{y+1p^0}{2yp_a}\right)^{\frac{1}{2}} \qquad \text{............3.3}$$

4. **Peak Dynamic Pressure**

The Peak Dynamic Pressure is given by

$$q^0 = \frac{p^0}{2yp_a+(y-1)p^0} \qquad \text{............3.4}$$

5. **Peak Reflected Overpressure**

The peak reflected overpressure p_r, which occurs if the blast wave strikes a flat surface at normal incidence, is

$$p_r = 2p^0 + (y+1)\,q^0 \qquad \text{............3.5}$$

6. **Scaled Distance**

The scaled distance is defined as

$$z = \frac{r}{W^{\frac{1}{3}}} \qquad \text{............3.6}$$

3.3 BLAST SCALING

The characteristics of the blast wave produced by an explosion are generally determined by the application of the scaling laws.

For the blast wave from an explosion the scalling relation which is much the most widely used is the cube root law, which was first enunciated by Hopkinson(1915). This law states that when two charges of the same explosive and geometry but of different size are detonated in the same atmosphere, self-similar shock waves are produced at the same scaled distances. The scaled distance is defined as

$$z = \frac{R}{W^{\frac{1}{3}}}$$

where R is the distance, W is the mass of explosive and z is the scaled distance. It should be noted that scaled distance is not dimensionless.

CHAPTER 4

EXPLOSION SIMULATION: TNT EXPLOSION MODEL

4.1 THE MODEL

The blast characteristics of a TNT explosion are important in their own right and are also sometimes used in modeling other types of explosion. There is available much more information on explosions of explosives, particularly TNT, than for other cases.

In principal, the blast characteristics of a TNT explosion depend on the mass and shape of charge and also on the point(s) of ignition. For a TNT explosion the two standard types of reference data are those for explosion from a point source and from a spherical charge. The blast parameters for the two explosions are slightly different. For overpressure, for example, the initial effect of a finite charge size is to reduce the overpressure very close to the charge relative to that from a point source. This effect holds for a distance of some five-charge parameters. At greater distances, however, the overpressure from a spherical charge is greater, being approximately equivalent to that from a point source with one-third greater energy release.

Other features, which affect the blast characteristics, include the location relative to sea level and the metrological conditions.

The principal parameters of the blast wave from a TNT explosion are the peak side-on overpressure p0, the impulse of the positive phase i_p, the duration of the positive phase td and the arrival time t_a. Values of these parameters may be presented in scaled or unscaled form. These are given by the equation described in the section 4.2 'Predictive Equations Used by the Model'.

4.2 PREDICTIVE EQUATIONS USED BY THE MODEL

Kinney and Graham have given their values of the peak overpressure, impulse and duration time from an explosion of TNT in the form of network equations.

In SI units for the scaled peak overpressure p_s

$$p_s = \frac{808\left[1+(z/4.50)^2\right]}{\left[1+(z/0.048)^2\right]^{\frac{1}{2}}\left[1+(z/0.32)^2\right]^{\frac{1}{2}}\left[1+(z/1.35)^2\right]^{\frac{1}{2}}} \qquad \ldots\ldots\ldots 4.1$$

For the impulse

$$i_p = \frac{0.067\left[1+(z/0.23)^2\right]^{\frac{1}{2}}}{z^2\left[1+(z/1.55)^2\right]^{\frac{1}{2}}} \qquad \ldots\ldots\ldots 4.2$$

and for the scaled duration time

$$\frac{t_d}{W^{\frac{1}{3}}} = \frac{980\left[1+(z/0.54)^{10}\right]}{\left[1+(z/0.02)^3\right]*\left[1+(z/0.74)^6\right]^{\frac{1}{2}}*\left[1+(z/6.9)^2\right]^{\frac{1}{2}}} \qquad \ldots\ldots\ldots 4.3$$

Where p_s is the scaled peak overpressure, i_p is the impulse (bar ms), t_d is the duration time (ms), W is the mass of explosive (kg) and z is the scaled distance (m/kg$^{\frac{1}{3}}$).
The unscaled and scaled forms of the parameters in SI units are:

Table 4.1 Scaled Vs unscaled post explosion parameters

PARAMETER	UNSCALED	SCALED
Peak Overpressure	p^0 (Pa)	$p_s = p^0/p_a$
Impulse	i_p(Pa s)	$i_s = i_p/W^{\frac{1}{3}}$ (Pa s/kg$^{\frac{1}{3}}$)
Duration Time	t_d (s)	$\tau_d = t_d/W^{\frac{1}{3}}$ (s/kg$^{\frac{1}{3}}$)

Where p_a is atmospheric pressure (Pa) and W is the mass of explosive (kg).
where $p_a = 1.01 * 10^5$ Pa.
The following graphs given by Kingery and Bulmash are showing the variation of the scaled parameters with scaled distance z.

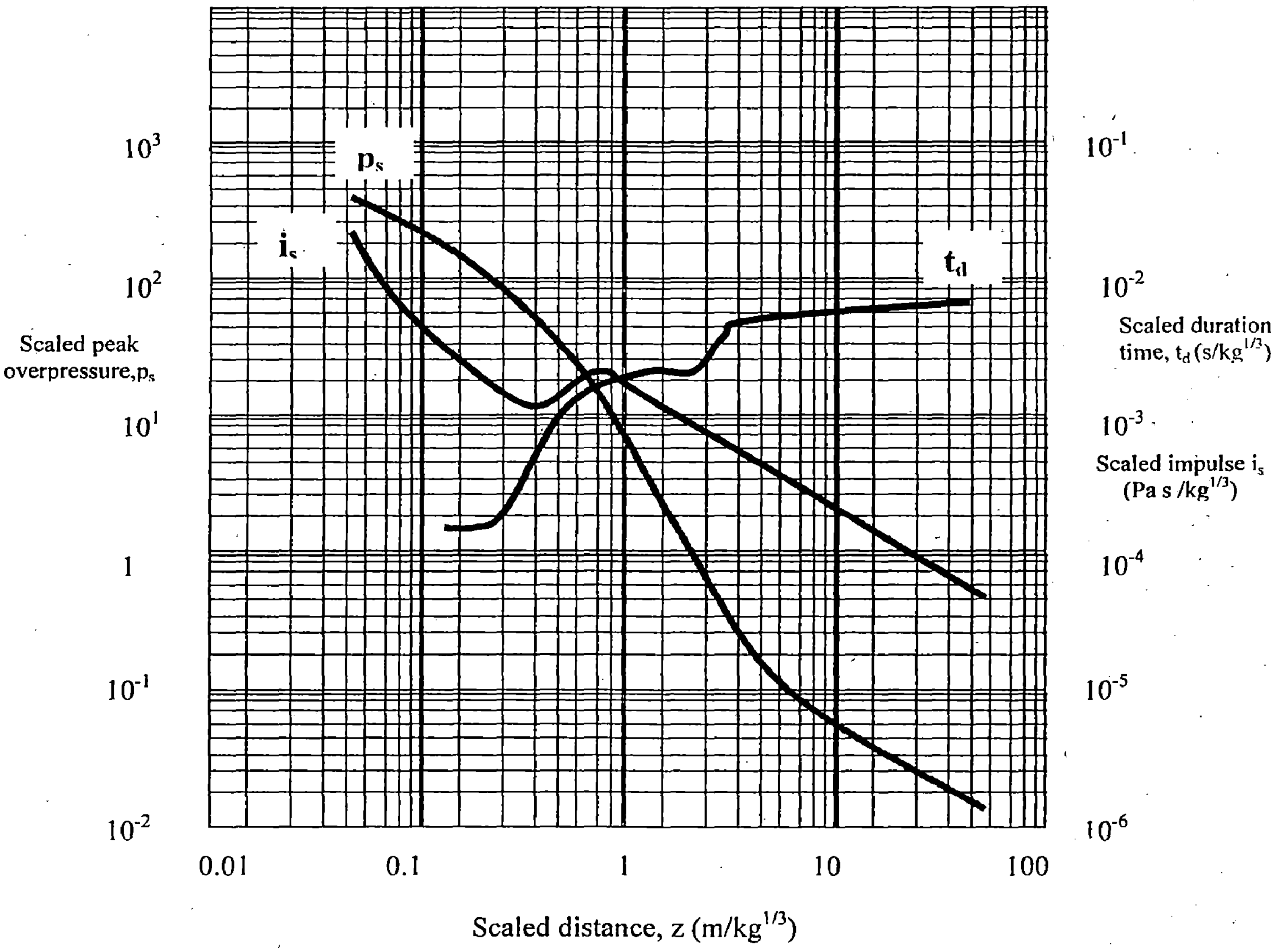


Fig 4.1 Variation of the scaled parameters with scaled distance z.

The variation of the blast parameters may also be expressed in the form of the equations. Kingery and Bulmash use for the peak overpressure p^0, impulse i_p, and duration time t_d and arrival time t_s of a 1kg explosion of TNT correlation of the following form. For a given

$$U = a + b \log_{10} z \qquad \text{.........4.4}$$

$$\log_{10} \phi = \sum_{i=0}^{n} c_i U^i \qquad \text{.........4.5}$$

Where a, b, c are the constants, the values of the constants in these equations given by Kingery and Bulmash are given in the following table.

Table 4.2 Constants in correlations of side-on blast parameters for an explosion of TNT of Kingery and Bulmash for Free air explosion.

RANGE	**CONSTANT**	p^0 (k Pa)	i^p (kPa ms)	t^d (ms)
1		0.0531≤z≤40	0.0531≤z≤0.792	0.147≤z≤0.888
2		-	0.792≤z≤40	0.888≤z≤2.28
3		-	-	2.28≤z≤40
1	a	-0.214362789151	2.34723921354	2.26367268496
2		-	-1.7530566031	-1.3336120671
2		-	-	-3.1300580534
1	b	1.35034249993	3.24299066475	5.11588554305
2		-	2.30629231803	9.2996288611
3		-	-	3.1524725364
1	c_0	2.611368669	2.38830516757	-0.6866085504
2		-	1.55197227115	0.23031841078
3		-	-	0.621036276475
1	c_1	-1.6901280139	-0.4437493776	0.164953518069
2		-	-0.4046329208-	-0.02979442689
3		-		0.096703199555
1	c_2	-0.0080497359195	0.168825414684	0.127788499497
2		-	-0.01427219460	0.0306329542941
3		-	-	-0.008013020596
1	c_3	0.336743114941	0.0348138030308	0.00291430135946
2		-	0.00912366316617	0.0183405574074
3		-	-	0.00482705779732

Contd…

1	c_4	-0.0051162263513	-0.010435192824	0.00291430135946
2		-	-0.0006750681404	0.0183405574074
3		-	-	0.00482750779732
1	c_5	-0.0809228619888	-0.008008637189	0.0018795749227
2		-	-	0.017396466286
3		-	-	0.00187587272287
1	c_6	-0.0047850726674	0.0031419515931	0.0173413962542
2		-	-	-0.0010632196357
3		-	-	-0.0024673850932
1	c_7	0.00793030472242	0.00152044783382	0.00269739758043
2		-	-	0.0056206003128
3		-	-	-0.00084116668
1	c_8	0.0007684469735	0.0007470265899	-0.0036197650279
2		-	-	0.0001618217499
3		-	-	0.0006193291052

4.3 ASSUMPTIONS AND LIMITATIONS

In this explosion model it is assumed that it is a free air explosion so the effect of ground on the explosion is negligible

- This explosion model is based on the criterion of unconfined explosion
- The post explosion parameters are calculated during positive phase of the explosion.
- All the post explosion parameters are calculated using scaled distance so that the effect of the quantity of the explosive (TNT) can not make effect on the values of the post explosion parameters, so this explosion model may be used in modeling of other types of explosion.

CHAPTER 5

FIRE SIMULATION: QUINTIER/DILLON FIRE MODEL

5.1 THE MODEL

The Quintiere/Dillon Room/Corner Fire Model is implemented as computer program. However, the level of complexity varies significantly, the input data reduction methods vary considerably, and the detail of the model for component phenomena differ widely. Generally speaking, the Quintiere/Dillon Model is the appropriate fire model to predict the actual behavior of the fire. This model includes consideration of flame spread on the wall and ceiling portions of a compartment. The heat flux in each of the regions is assumed to be constant. Girding is effectively not used in this approach, though the burning region is dynamic. The room environment is modeled using a simple correlation approach, which has been successfully used for a wide range of room fire scenarios. The model as used in this work is modified from the prior Quintiere/Dillon Model based on the shortcomings identified in this project. Changes were made to the methods of determining ignition and flame spread properties. The model was changed to use Cone Calorimeter data directly instead of using the heat of gasification approach previously used, and smoke production prediction was added to the model. These modifications resulted in significant improvements in the performance of the model.

MODEL INPUTS

The basic Quintiere/Dillon Room/Corner Model uses standard data reduction method in the Cone Calorimeter Method to obtain ignition and flame spread inputs. However, the modified method used in this work uses a different means to determine ignition properties in the Cone Calorimeter. The method used to deduce ignition properties differs from the algorithm used in the model itself. This can lead to inconsistent results. The modified ignition data reduction methods used resulted in critical heat fluxes that were generally less than the measured results. For Materials 3-9 (table 5.1), the deduced critical flux was 0-5 kW/m $_2$ less than measured. For Materials 1 and 2, the critical heat fluxes were about 20 kW/m^2 less than measured. While the 1200 second test duration in the Cone Calorimeter Test may be too short, it is unlikely that the experimental critical heat fluxes would be reduced to the deduced values by longer test durations. The heat release rate model used in the modified Quintiere/Dillon Model uses 50 kW/m $_2$ incident flux Cone Calorimeter data directly, without regard for the actual heat flux. This input is used in lieu of the heat of gasification normally used in the Quintiere/Dillon Model. This modification was made as a result of initial simulations using the Quintiere/Dillon Model, which generally underestimated the experimental results. It was concluded that the excessively high heats of gasification were responsible for this behavior. This conclusion was reached despite the fact that the heat of gasification is likely underestimated by the Quintiere Method due to the use of the maximum Cone Calorimeter heat release rate in the determination of the heat of gasification.

MODEL RESULTS

The model results are summarized in Table 5.1.Table 5.1 shows comparisons of experimental and model flashover times. The experimental flashover times are based on the time to reach one MW heat release and are generally somewhat less than the time to flames out the door. In the case of material 5, flames were observed at the door but the heat release rate never reached 1 MW, so the heat release rate criterion used was reduced to 750 kW. This illustrates the somewhat arbitrary nature of the heat release rate criterion. As can be seen in the table, the model does an excellent job in predicting flashover. Only for Material 5 is there a significant difference in the flashover times.

Table 5.1 also shows the peak and average heat and smoke release results for materials that did not cause flashover in the test. The heat release results are generally quite good and the smoke release predictions tend to be low.

Table 5.1. Summary of experimental result (ISO Room/ Corner Test Results) and Quintiere/ Dillon Model results.

High Speed Craft Material	Time to flashover t_f (1MW)		Experimental Heat release Rate (kW)	Predicted Heat Release Rate (kW)	Experimental Smoke Production Rate (m^2/sec)	Predicted Smoke Production Rate (m^2/sec)
	Experimental Value	Model Value				
1. Wood	∞	∞	62	36	1.5	2.0
2. Fire restricted material	∞	∞	31	47	0.2	0.1
3. FR Polyester	342	345	191	140	10	9.1
4. FR Vynilester	306	305	190	150	9	11
5. FR epoxy	978	666	115	54	6.5	1.6
6. Coated FR epoxy	∞	∞	28	8	1.5	0.3
7. Textile wall covering	∞	∞	17	48	0.1	0.4
8.Polyester	102	56	170	130	2.3	5.4
9. FR acrylic	672	611	109	102	0.4	0.64

Here ∞ means very large amount comparing to other given value of this parameter.

5.2 PREDICTIVE EQUATIONS USED BY THE MODEL

Karlsson (1992) described a mathematical model, which uses the rate of heat release and time to ignition results from Cone Calorimeter as input and predicts full-scale fire growth on combustible linings in room/corner configuration. The analytical model calculates the concurrent flow flame spread, gas temperatures, materials surface temperatures, and heat release rate of combustible lining materials mounted under ceiling and wall-ceiling interactions in enclosure. Karlsson developed a single analytical expression for time to flashover by running the model with 600 combinations of input parameters, and fitting the results of these numerical experiments to the following power law expression:

$$t_{fo} = 0.326\,(\dot{Q}_{max})^{-1.14}(\lambda)^{0.085}(k\rho c)^{1.07}(T_{ig})^{2.19} \qquad \text{.........5.1}$$

Where t_{fo} is the predicted time to flashover (sec), $\dot{Q}_{max}$ is the peak heat release rate in the Cone Calorimeter at 50 kW/m² heat flux (kW/m²),

λ Is the average decay coefficient (1/sec), calculated for each measured value of heat Release in the Cone Calorimeter from the following expression:

$$\lambda(t) = \frac{\ln\left(\dfrac{\dot{Q}_c(t)}{\dot{Q}_{max}}\right)}{t} \qquad \text{.........5.2}$$

Where $\dot{Q}_c$ is the time dependent heat release rate in kW/m².

t is the corresponding time in seconds. $k\rho c$ is the thermal inertia (kW²-sec/m⁴-K), and T_{ig} is the ignition temperature.

5.2.1 EVALUATION OF FLAMMABILITY PARAMETER CORRELATIONS

Flammability Parameter Derivation and Formulation

The process of fire development involving interior finish materials is dominated by concurrent flame spread and subsequent burning. Concurrent flame spread is simply flame spread in the same direction as the prevailing fluid flow. Concurrent flame spread occurs when the flame directly contacts the material's surface ahead of the pyrolzing region. This occurs for upward flame spread on walls and flame spread on ceilings. Concurrent flow flame spread rates depend on the flame length, so that it is not a unique function of the material being burned. The flame spread model equation given by Mowrer and Williamson (1991) is based on the approach presented by Quintiere, Harkleroad, and Hasemi (1986). The model includes consideration of the finite burning time, t_b, of thin fuels. The consumption of the all fuel results in burnout of the flame at each location, which is an important aspect of the flame spread on thin fuels.

In this model, the flame-spread rate is defined as the rate of advance of the pyrolysis front:

$$V_p = \frac{dx_p}{dt} \cong \frac{x_p(t+t_p)-x_p(t)}{t_f} = \frac{x_f(t)-x_p(t)}{t_f} \qquad \text{.........5.3}$$

The characteristics flame spread (or ignition) time is defined in terms of a simple thermal model of heating a wall with constant thermal properties:

$$t_f = k\rho c\left(\frac{T_{ig}-T_s}{\dot{q}_{net}}\right)^2 \qquad \text{..........5.4}$$

Once burnout begins, the velocity of the burnout front can be expected as

$$V_b = \frac{dx_b}{dt} \cong \frac{x_b(t+t_{b0})-x_b(t)}{t_{b0}} = \frac{x_p(t)-x_b(t)}{t_{b0}} \qquad \text{..........5.5}$$

After burnout begins, the dimensionless flame height is expressed as:

$$\frac{x_f-x_b}{x_p-x_b} = k_f\,\dot{E} \qquad \text{..........5.6}$$

The parameter, k_f is a correlating factor used to define the flame length. Cleary and Quintiere (1991) suggest a value of approximately 0.01 m^2/kW for k_f. Using Equation (5.4) for times $t<t_b$ Equation (5.1) can be rewritten as:

$$\frac{dx_p}{dt} = k_f\left(k_f\,\dot{E} - 1\right)\frac{x_p}{t_f} \qquad \text{...........5.7}$$

Equation (5.6) can be integrated, with limits $x = x_{p0}$ at $t = 0$ and x_p at t:

$$x_p = x_{p0} \exp\left(\frac{\left(k_f\,\dot{E} - 1\right)t}{t_f}\right) \qquad \text{..........5.8}$$

Equation (5.6) and (5.7) together, with Equation (4) suggest that, before burnout, the flame spread rate will be acceleratory if $x_f > x_p$ and decelerator if $x_f < x_p$. After burnout, at times $t > t_b$, the net rate of flame propagation can be expressed as the difference in pyrolysis front velocity and burnout front velocity:

$$V_b(t) = V_b(t) = \frac{d(x_b - x_p)}{dt} = \frac{x_p(t) - x_b(t)}{t_{b0}} \qquad \text{......5.9}$$

Using Equation (5.5), Equation (5.8) can be rearranged to:

$$\frac{d(x_b - x_p)}{dt} = \left(x_b - x_p\right)\left(\frac{\left(k_f\,\dot{E} - 1\right)\left(t_{b0} - t_f\right)}{t_f t_{b0}}\right) \qquad \text{.........5.10}$$

Equation (9) can be integrated, with the limit of $(x_p - x_b) = (x_{pl} - x_{b0})$ at $t = t_b$ and $(x_p - x_b) = (x_p - x_b)$ at time t, to yield the pyrolysis zone height:

$$\left(x_b - x_p\right) = \left(x_{pf} - x_{p0}\right)\exp\left(k_f\,E - \frac{t_f}{t_{b0}} - 1\right)\left(\frac{\left(t - t_b\right)}{t_f}\right) \qquad \text{..........5.11}$$

5.2.2 CORRELATION OF SMOKE PRODUCTION USING THE FLAMMABILITY PARAMETER

With the specific extinction area (f) from the Cone Calorimeter, smoke production rate (SPR) has be calculated using peak or average heat release rates from full-scale Room/Corner Fire Tests as follows:

$$\dot{m} = \frac{\dot{Q}}{\Delta H_c} \qquad \text{..........5.12}$$

where $\dot{m}$ is the mass loss rate of the material (kg/sec),

$\dot{Q}$ is the peak or average heat release rate from full-scale Room/Corner Test (kW), and ΔH_e is the effective heat of combustion from Cone Calorimeter Tests (kJ/kg).

Now the predicted smoke production rate $(SPR)_{pred}$ can be estimated as:

$$(SPR)_{pred} = \dot{m}\,\sigma_f \qquad \text{...........5.13}$$

where $(SPR)_{pred}$ is the predicted smoke production rate (m^2/sec), and σ_f is the specific extinction area from the Cone Calorimeter (m^2/kg).

5.3 ASSUMPTIONS AND LIMITATIONS

The Quintiere/Dillon Model consists of a collection of data and computer programs which are used to *simulate* the important time-dependent phenomena involved in fires. The major functions provided include calculation of:

- The time to flashover (sec).
- The value of heat release.
- The flame-spread rate.
- Velocity of the burnout front.
- Pyrolysis front velocity
- Flame height
- The mass loss rate of the material (kg/sec)
- Smoke production rate

The assumption are made as follows

This model includes consideration of flame spread on the wall and ceiling portions of a compartment. The heat flux in each of the regions is assumed to be constant. Girding is effectively not used in this approach, though the burning region is dynamic. The room environment is modeled using a simple correlation approach, which has been successfully used for a wide range of room fire scenarios.

Specified Fire Limitations

1. For a large-scale calorimeter, a product (e.g., chair, table, bookcase) is placed under a large collection hood and ignited by a 50 kW gas burner (simulating a wastebasket) placed adjacent to the item for 120 s. The combustion process then proceeds under assumed "free-burning" conditions, and the release rate data are measured. Potential sources of uncertainty here include measurement errors related to the instrumentation, and the degree to which "free-burning" conditions are not achieved.
2. Where small-scale calorimeter data are used, procedures are available to extrapolate to the behavior of a full-size item. These procedures are based on empirical correlations of data which exhibit significant scatter, thus limiting their accuracy.

CHAPTER 6

SOFTWARE REQUIRMENT ANALYSIS AND DESIGN

6.1 SOFTWARE REQUIRMENT ANALYSIS

6.1.1 FEASIBILITY STUDY

Problem Identification: The computerized models are to be generated/implemented that would predict the behavior of of explosion and fire when these occur in the environment. A physical model would require the well-designed laboratory with all equipments and with necessary to detect the various parameters of the experiment. Metrological parameters are very hard to control or keep constant during the duration of the experiment. In all it is prohibitory expensive to put in place the infrastructure to study the properties through actual experiments.

Problem Analysis: A number of explosion and fire models were referred to from the libraries at Defence Science Centre, and the Internet. The best approach that came as a result of going through the models was the use of conservation equations for explosion and fire model would accurately calculate and hence predict closely the behaviour of explosion and fire and the materials.

Existing software: The existing software is dos based which takes parameters in an input file and generates a final output file after completing the required processing. This form input and output is not very user friendly apart from some design flaws requiring a total redesign of the models. An additional requirement of being able to port the results of the models to the overall models on fire and explosion conclusively swayed the opinion for a more portable and user-friendly models.

6.1.2 REQUIREMENTS ANALYSIS

Domain Understanding: Being a highly technical field, this is probably the most important part of the designing the model. A large number of books/reports and microfaces on explosion and fire were referred to along with search on the Internet producing a wealth of information regarding the subject domain. Using this raw data, a theoretical model was generated.

Requirement Validation: The theoretical models were then circulated among the end users and the feedback was used to improve the models. On approval of the theoretical models, the actual implementation of simulation modules were initiated.

Prioritization: The most urgently required sub-modules required for the explosion model were identified and their implementation speeded up. This required interaction with team members for other modules to decide on a joint strategy for efficient implementation of the overall model.

Hardware and Software Requirements: Since the end-users used standard office workstations for user friendliness and ease of future modifications all simulation models were by common agreement picked Visual C++ MFC programming as a means to implement the respective theoretical models.

Visual Studio Version 6.0 was already available in the simulation, dense gases, toxic release of gases and other labs participating in the creation of the modules.

6.1.3 REQUIREMENTS SPECIFICATION

Functional Requirements: The services that the simulation models should provide are;-

a. The report should be easy to use with dialog boxes and windows to be used for input and displaying output.
b. Invalid data should be taken care of with appropriate warnings and error messages. The module should only gracefully degrade when encountering incorrect data and should not crash fatally causing loss of data.
c. At all times referential integrity between the various tables must be maintained with all dependent data of a record being deleted also being removed.

Non-functional Requirements: Constraints on the module

a. Module has to be completed in five months from date of commencement.
b. Constraints on platform, it should be Visual Studio with MFC to compile and run the modules.

6.2 SYSTEM DESIGN

6.2.1 GENERAL

The process of design starts with "*conceiving and planning in the mind*" and then "*making a drawing or sketch of*". System design is followed after the detailed study and analysis of explosion and fire.

After the detailed analysis of the software requirement, it has been planned to develop the software in the following steps :

6.2.2 DESIGN SPECIFICATION AS PER PROPOSED SYSTEM

The system is designed using Visual C++ with MFC (Microsoft Foundation Classes) language. Modular design approach (Top down approach) has been used throughout the software development and modules are defined on the basis of their functionality. The user-friendly software has been developed in VC++ language using some of the libraries of C++. The interactive user-interface has been designed using dialog boxes and windows with MFC objects so that it can be handled/operated by even a non-professional. The software is based on event driven programming and an action can be invoked at a key-press besides the mouse clicks. The software exploits the features of open system enhancement.

6.3 DETAILED DESIGN

6.3.1 CLASS VIEW OF THE PROJECT

Following figure (Fig 6.1) shows the class view of project.

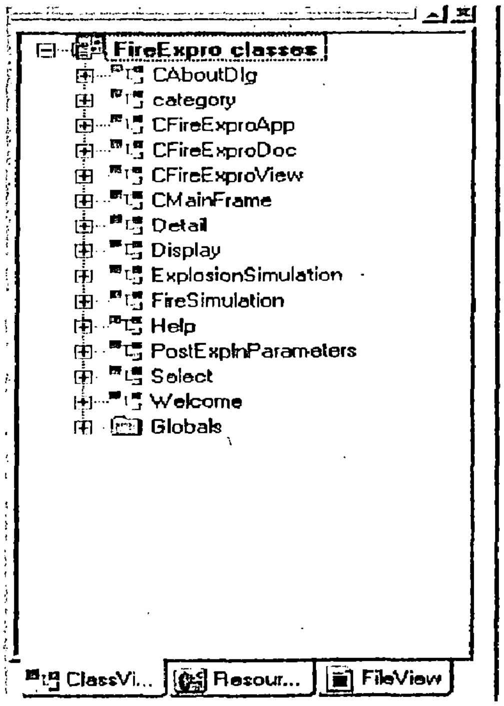


Fig. 6.1

6.3.2 RESOURCE VIEW OF THE PROJECT

Following figure (Fig 6.2) shows the resource view of the project

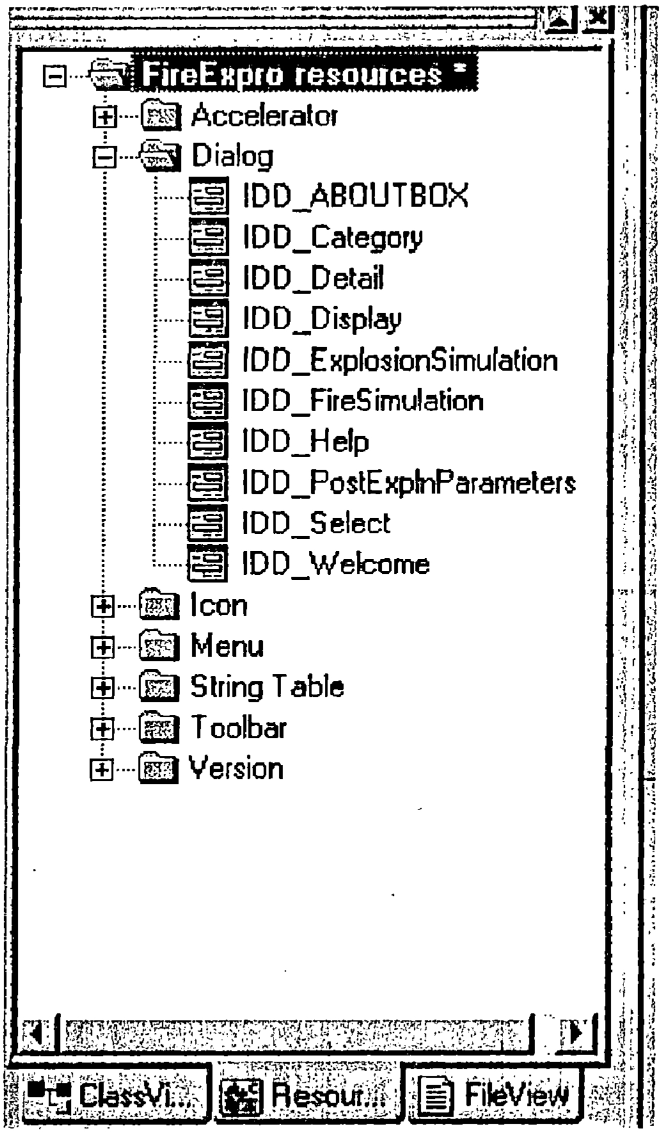
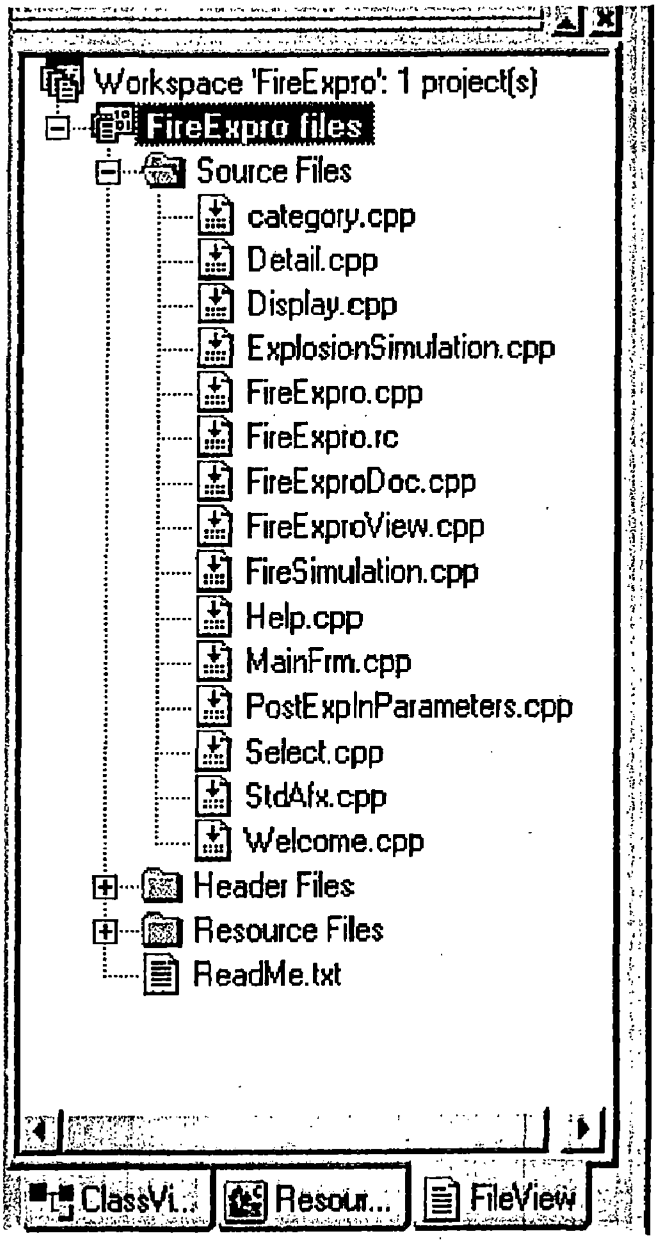


Fig. 6.2

6.3.3 FILE VIEW OF THE PROJECT

Following figure (Fig 6.3) shows the file view of the project.



```
Workspace 'FireExpro': 1 project(s)
  FireExpro files
    Source Files
      category.cpp
      Detail.cpp
      Display.cpp
      ExplosionSimulation.cpp
      FireExpro.cpp
      FireExpro.rc
      FireExproDoc.cpp
      FireExproView.cpp
      FireSimulation.cpp
      Help.cpp
      MainFrm.cpp
      PostExplnParameters.cpp
      Select.cpp
      StdAfx.cpp
      Welcome.cpp
    Header Files
    Resource Files
    ReadMe.txt
```

Fig. 6.3

CaboutDlg Class: CAboutDlg is the Dialog Box, which displays information about the user's copy of FireExpro, including the version number and the copyright.
Base Class for CAboutDlg is CDialog and most class members have been used.

Category Class: This class designed for displaying the category of explosion on basis of the degree of damage by an explosion when it occurs. Here the criteria of category is based on the experiments which was performed in English dweling house.

Welcome Class: This class has been developed to displayed a message at very starting of the software package then user can enter inside pressing get inside button available on corresponding dialog box.

Select Class: This class is made for the dialog box, which is junction dialog for all the sub-module of the software package. User can select a sub-module by selecting any option available on this dialog box.

CfireExproApp Class: This class is derived from the class WinApp. The WinApp class, derived from the CwinThread class, represents not only the progrma's main thread of execution, but also the application itself. As result, there is only one CwinApp object in any MFC application..

CfireExproDoc Class: This class is for creating the documentation. This class is derived from the class Cdocument which first handles the message itself and then passes the message to its document template class.

CfireExproView Class: This class provides the necessary functional elements that each view must use to function properly. This class is derived from the class Cview.

CMainFrame : This class is derived from the class CframeWnd, which first passes to the active view, tries to handle the message itself, and finally passes message to the CwinApp-derived object.

Detail class: This class is dialog based class in which the detail explanation of the algorithm is given and user can see the detail about the procedure and about that dialog box.

ExplosionSimulation: This class is dialog based class in which all the calculations needed for the explosion simulation, firstly user enter the input necessary for the model, which is simulated and press any appropriate button to see the concerning output and finally there are two main button managed in this class those are for showing the graphical show of the simulation and in last run the simulation to see the dynamic view of the explosion simulation.

FireSimulation: This class is dialog based class in which all the calculations needed for the fire simulation, firstly user enter the input necessary for the model, which is simulated and press any appropriate button to see the concerning output or effect.

MODULES OF THE SYSTEM

Each subsystem/module has its own specific domain in which takes input and generates output to the screen. There are total 4 subsystems available in this software package. Subsystem I decide the category of the explosion, subsystem II calculate the post explosion parameters, subsystem III is for simulation of TNT explosion model and in the last the subsystem IV is for simulation of fire model.

6.4 DATA FLOW DIAGRAMS (DFDs)

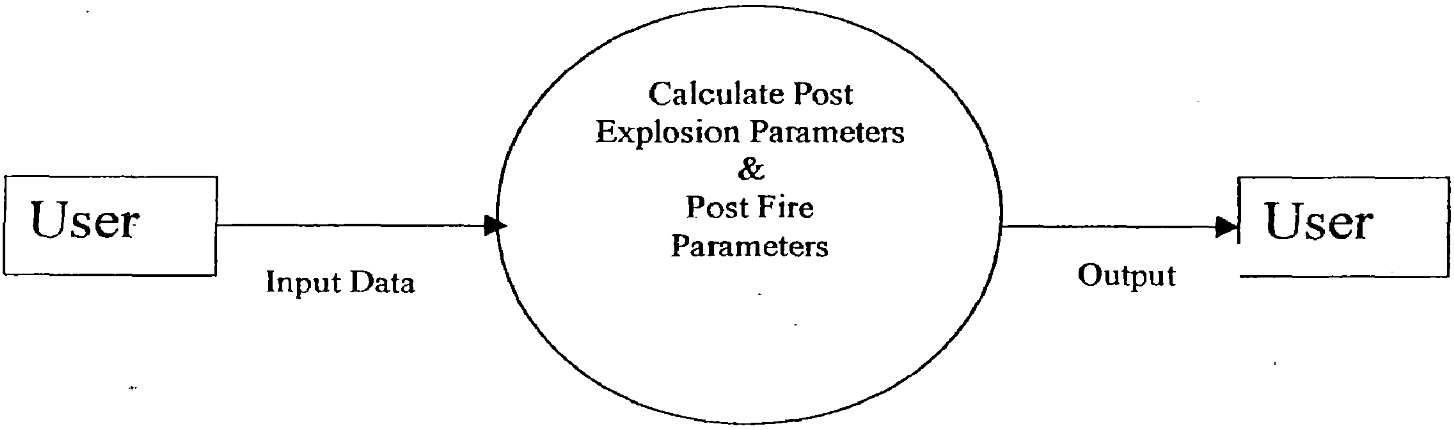


Fig 6.1 Zero Level DFD (Basic level DFD)

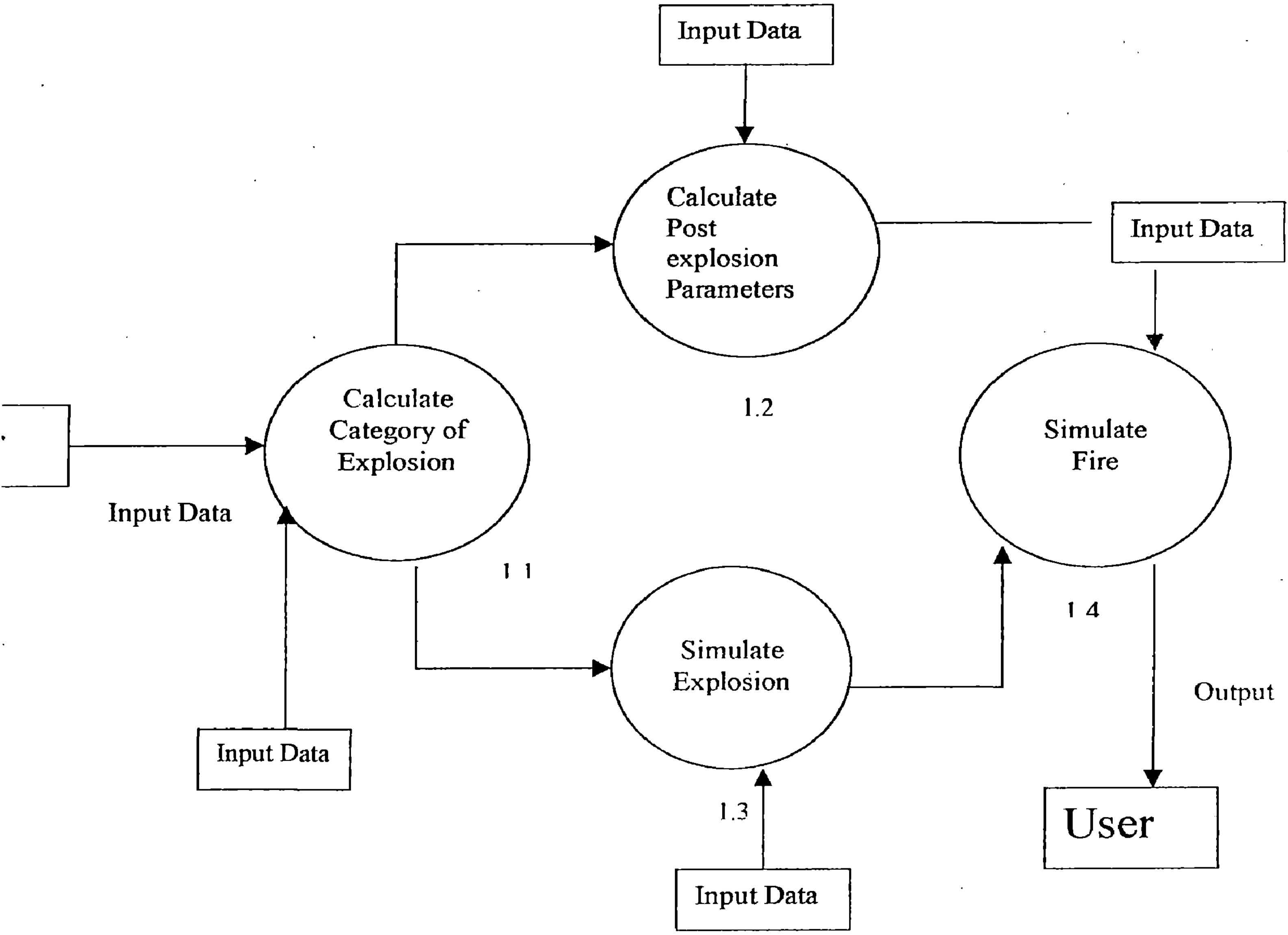
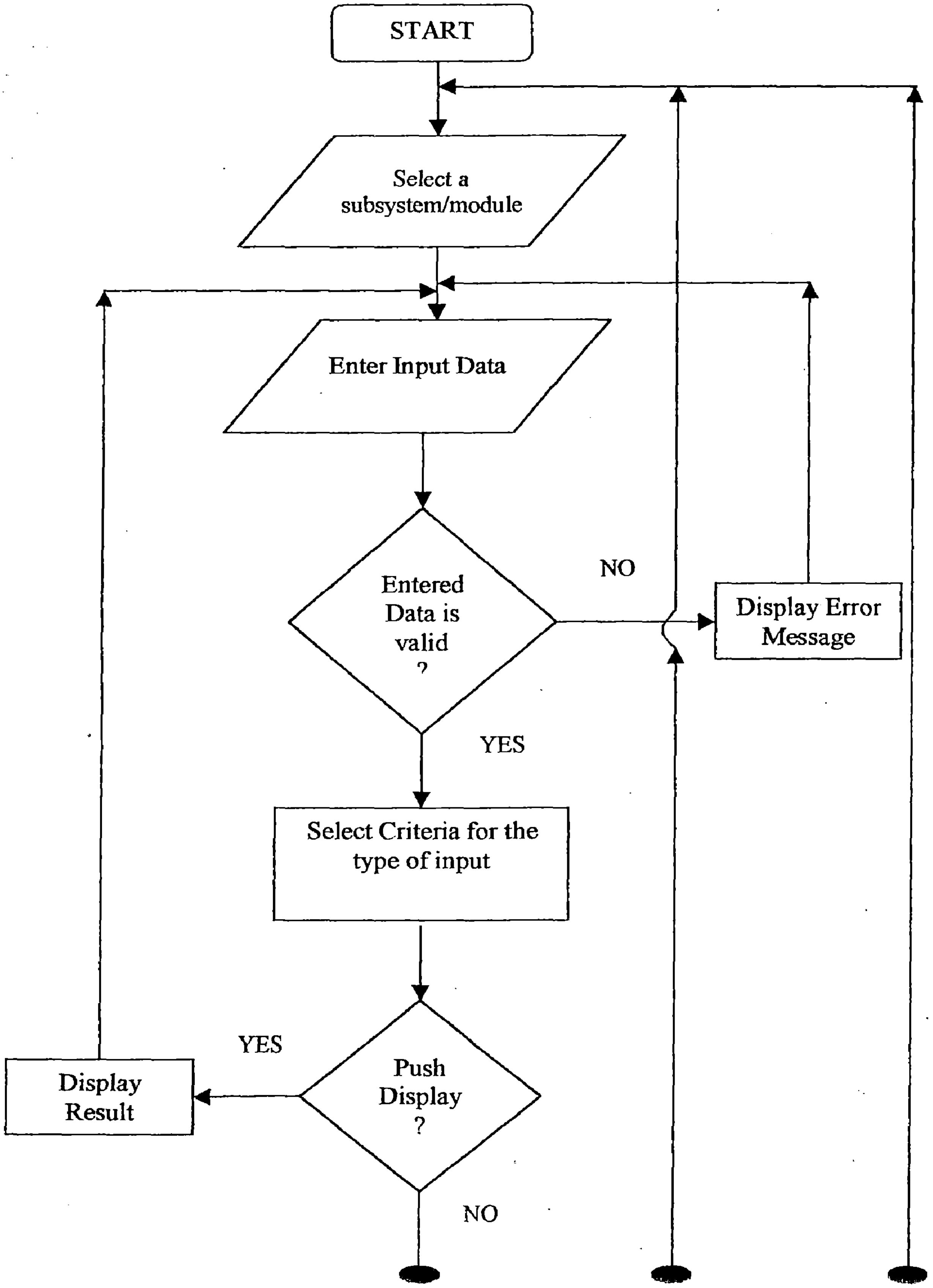


Fig 6.2 First level of DFD

6.5 FLOW CHART



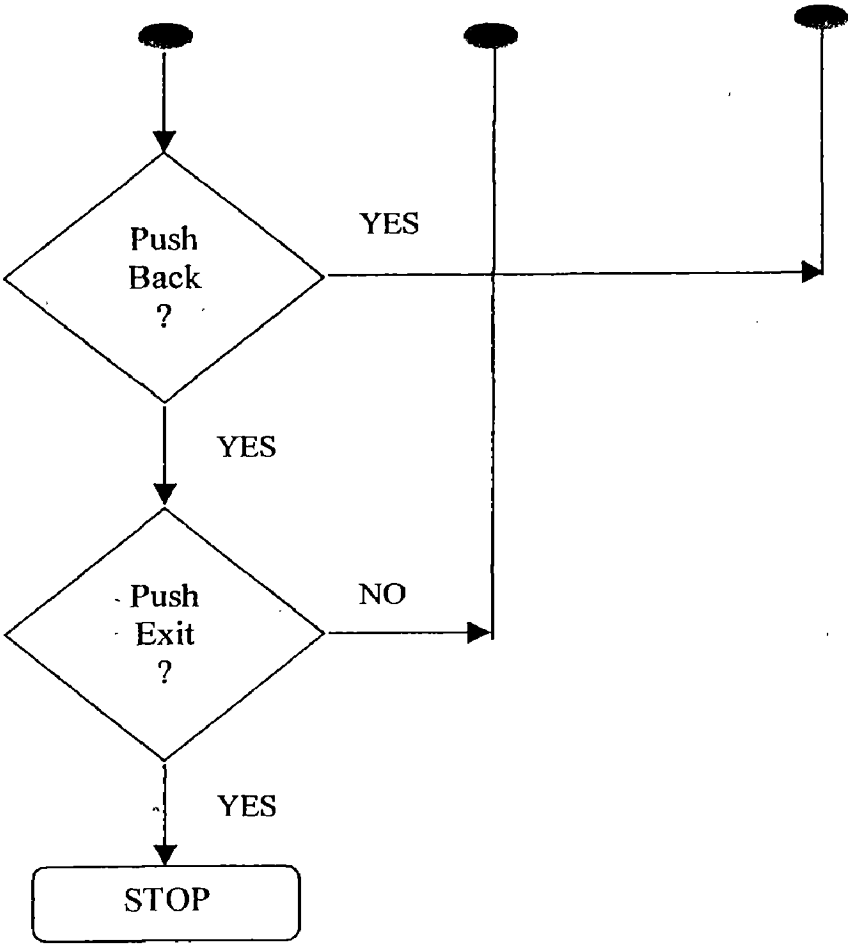


Fig. 6.3 Flow Chart

CHAPTER 7

VERIFICATION AND TESTING

7.1 VERIFICATION OF TNT EXPLOSION MODEL

7.1.1 MODEL PARAMETERS SELECTED FOR COMPARISON

The following model parameters are selected for the comparison

- Peak Overpressure (p^0).
- Impulse (i_p).
- Duration time (t_d).

7.1.2 AVAILABLE DATA FOR EXPLOSION SIMULATION

Table 7.1 The experimental data given by Kingery and Bulmash.

SCALED DISTANCE. $z(m\cdot kg^{1/3})$	PEAK OVERPRESSURE p^0 (Pa)	IMPULSE i_p (Pa s)	DURATION TIME t_d (s)
0.5	$38.8 * 10^5$	$1.41 * 10^2$	$3.20 * 10^{-4}$
1.0	$9.35 * 10^5$	$1.75 * 10^2$	$1.79 * 10^{-3}$
5.0	$0.313 * 10^5$	$4.06 * 10^1$	$3.33 * 10^{-3}$
10.0	$0.111 * 10^5$	$2.11 * 10^1$	$4.20 * 10^{-3}$
40.0	$0.017 * 10^5$	5.30	$6.16 * 10^{-3}$

Table 7.2 The experimental data given by Kinney and Graham.

SCALED DISTANCE. $z(m/kg^{1/3})$	PEAK OVERPRESSURE (Pa)	IMPULSE i (Pa s)	DURATION TIME t_d (s)
0.5	$39.0 * 10^5$	$1.07 * 10^2$	$0.84 * 10^{-4}$
1.0	$9.83 * 10^5$	$1.02 * 10^2$	$0.52 * 10^{-3}$
5.0	$0.285 * 10^5$	$3.0 * 10^1$	$2.47 * 10^{-3}$
10.0	$0.097 * 10^5$	$1.51 * 10^1$	$3.47 * 10^{-3}$
40.0	$0.021 * 10^5$	4.0	$4.15 * 10^{-3}$

7.1.3 THE COMPARISION OF CALCULATED DATA WITH EXPERIMENTAL DATA

Table 7.3 The predicted data calculated by TNT explosion model

SCALED DISTANCE z(m kg$^{1/3}$)	PEAK OVERPRESSURE p^0 (Pa)	IMPULSE i_s (Pa s)	DURATION TIME t_d (s)
0.5	$39.9079 * 10^5$	$1.280 * 10^2$	$0.830 * 10^{-4}$
1.0	$10.0555 * 10^5$	$1.171 * 10^2$	$0.524 * 10^{-3}$
5.0	$0.2914 * 10^5$	$3.880 * 10^1$	$2.598 * 10^{-3}$
10.0	$0.0995 * 10^5$	$1.960 * 10^1$	$3.036 * 10^{-3}$
40.0	$0.0211 * 10^5$	4.907	$1.745 * 10^{-3}$

7.2 VERIFICATION OF FIRE SIMULATION MODEL

7.2.1 MODEL PARAMETERS SELECTED FOR COMPARISON

- The time to flashover
- The value of heat release.
- The mass loss rate of the material.
- Smoke production rate.

7.2.2 AVAILABLE EXPERIMENTAL DATA

Table 7.4 The experimental data given from USCG ISO 9705 Tests performed by Janssens *et.al*. (1998).

High Craft Materials	Time to flashover t_f (1MW)	Heat release Rate (kW)	Smoke Production Rate (m^2/sec)	Mass Loss Rate (kg/sec)
1. FR phenolic	∞	62	1.5	0.0075
2. Fire restricted material	∞	31	0.2	0.0032
3. FR Polyester	342	191	10	0.1600
4. FR Vynilester	306	190	9	0.0141
5. FR epoxy	978	115	6.5	0.0132
6. Coated FR epoxy	∞	28	1.5	0.0036
7. Textile wall covering	∞	17	0.1	0.0018
8.Polyester	102	170	2.3	0.0078
9. FR acrylic	672	109	0.4	0.0088

7.2.3 THE EVALUATED DATA FROM MODEL FOR COMPARISON

Table 7.5 The predicted data calculated by Quintiere/Dillon Fire model.

High Craft Materials	Time to flashover t_f (1MW)	Heat release Rate (kW)	Smoke Production Rate (m^2/sec)	Mass Loss Rate (kg/sec)
1. FR phenolic	∞	∞	2.0	0.019
2. Fire restricted material	∞	∞	0.1	0.013
3. FR Polyester	342	345	9.1	0.060
4. FR Vynilester	306	305	11	0.039
5. FR epoxy	978	666	1.6	0.048
6. Coated FR epoxy	∞	∞	0.3	0.017
7. Textile wall covering	∞	∞	0.4	0.0014
8.Polyester	102	56	5.4	0.0026
9. FR acrylic	672	611	0.64	0.0066

7.3 TESTING OF THE SOFTWARE

Bottom up approach is used for the testing of the software. First the workings of all the modules (the output of module after providing valid input data is compared with experimental data available for appropriate parameters). At last the software is validated against the requirements.

CHAPTER 8

SCOPE OF DEVELOPMENT

8.1THE EXPLOSION MODEL: TNT Explosion Model

In the present explosion model it has been assumed that the explosion occurs in free air but it may be assumed that the explosion occurs at ground level, the ground forms a barrier to the explosion. In principal, the proportion of the explosion energy absorbed by the ground may vary from none to one-half. Thus the energy in blast wave from an explosion at ground level, i.e. hemisphere symmetry exceeds that for an explosion of spherical symmetry by a yield ratio which lies between one and two.

In present work the post explosion parameters are evaluated based on the physical scenario but there may be some parameters which are based on the chemical scenario like heat release in an explosion, change in enthalpy, the internal energy change for the explosion, the entropy of the explosion, heat produced in combustion etc. Also if the explosion is confined than there is one more parameter that isvessel strain energy.

8.2THE FIRE MODEL: Quintiere/Dillon Fire Model

Quintiere/Dillon Fire Model used to calculate the flashover time distribution of smoke and heat release from fire mass loss rate of materials during a fire. Although it may not be all inclusive, Quintiere/Dillon Fire Model has demonstrated the ability to make reasonably good predictions. Also, it has been subject to close scrutiny to insure its correctness. Thus it forms a paradigm for what constitutes a reasonable approach to modeling fire growth and the spread of smoke.

With this level of detail, researchers not intimately involved in the development of Quintiere/Dillon Fire Model should be able to add to the model in a straightforward manner. Independent or cooperative efforts to enhance the capabilities of the model are encouraged. Model developers can use this version of the model for open or proprietary additions to the model or as the basis for new models. While encouraging additions to the model, the role of the National Institute of Standards and Technology (NIST) in the development must be clearly defined. NIST will continue to develop and document algorithms and the model in total. Thus, non-developers will continue to have access to an increasingly capable model from NIST, and perhaps from others as well.

The quest is to develop a tool which will help improve the understanding of fires. This is not an attempt to make the application of models trivial, but rather to provide a mechanism to allow researchers, fire protection engineers, and others access to the most current understanding of the behavior of fires. With this version of the model, we hope to provide a framework for cooperative development of the model by outside researchers. To reach this goal, the possible directions outlined for the future development of the model.

8.3 CAPABILITY AND PROCESSING ABILITIES

For fire investigation, there could portable computers (hand held) which allowed one to walk through a building (before or after) and catalog the contents of a building. This could be brought back to the office and used directly as input to the model for geometric specification and data initialization. As the model becomes more sophisticated, and the complexity increases, researchers, code officials, and others may need to depend on such stratagems. There simply is not enough time to fuss with all of the details. This is the arena which should allow one to pursue the goal of a better qualitative understanding of fires, and well as doing more of it faster.

All large buildings have breakout panels for various alarms. Indeed, some fire departments can display floor plans of buildings in the command center at a fire. It is a logical step to plug these building detections and alarm systems into Quintiere/Dillon Fire Model for obtaining the current status and predictions of the building environment as the fire develops.

Another area is that of risk. Risk is the next step up from a hazard calculation, and requires a much more general understanding of the parameters which affect the outcome of a fire and its impact on humans and structures. This application would require an automated application of the model over types of fires, day and night scenarios, position of the fire and so on. The number of such calculations can become enormous.

8.4 MODEL IMPROVEMNTS

This deals with improvements in the model itself. Beyond what we have today, we see the following as minimum improvements to present the concept to the whole of the fire related community.

Suppression - include fire size, drop size and distance effects, geometry of the fire (hidden) Multiple layers and zones (hybrid modification) - a must for detector siting Experimental correlations for flow up shafts and *stairways* Modifications to all modules to utilize databases

Corrosion - important for semiconductor industry and warehouses Simple (and quick) estimates The accuracy of the current procedure is limited by the fire being uninfluenced by radiation from its surroundings, and by our inability to quantify accurately the effects of fire on people and their actions. Research is underway to better understand radiation enhanced burning under post flashover conditions, and
predict fire growth and spread, fuel mass loss rate and combustion product generation rates under those conditions.

In general, the Quintiere/Dillon Fire Model 1 provides reasonable predictions of the several experiments examined here. Although differences between the model and the experiments are clear, they can be explained by limitations of the model and of the experiments.

Several areas, which need additional research, are apparent:

- **Entrainment** – fire plume and doorway jet entrainment are based on the same experimental correlations. The fire plume (for large spaces) and the doorway jet (in general) are often used outside the normal range of validity of these correlations.

- **User specified fire** – the level of agreement is critically dependent upon careful choice of the input data for the model. A validated fire growth model would allow prediction of pyrolysis rate and species yields consistent with changing conditions during the fire. A better understanding of typical fire induced leakage in buildings would facilitate more accurate description of the building environment.

- **Statistical treatment of the data** – presentation of the differences between model predictions and experimental data are intentionally simple. With a significant base of data to study, appropriate statistical techniques to provide a true measure of the "goodness of fit" should be investigated.

- **Experimental measurements** – measurement of leakage rates, room pressure, or profiles of gas concentration are atypical in experimental data. These measurements are critical to assessing the accuracy of the underlying physics of the models and of the models ability to predict toxic gas hazard. As with any theoretical model, there are pieces which have been omitted and others which could be implemented more completely. However, with an understanding of the relative weaknesses and strengths of both the model and of the experiments used to verify the model, the user can develop confidence in using such models for a wide range of simulations.

CHAPTER 9

CONCLUSION

9.1 DISCUSSION / RESULTS

It is clear that by simulation of a model of any real system (here for explosion and fire), all the effect and behavior of that process can be measured easily. Also the result come out from a model can be compare with actual experimental data for verification of the model. In this thesis the process of an explosion and fire and effect of the process in the environment is discussed in detail so one can understand the behavior of these incidents easily. Also various parameters can be evaluated by giving valid input to the models or to the module which evaluate the parameters.

The results of this project show that it is possible to learn about the behavior of the fire and explosion and expected performance of materials. The results of both the mathematical models (i.e. the calculated values of various parameters; overpressure, impulse, duration time and arrival time in case of explosion and time to flashover, heat release, smoke production rate and mass lose rate in case of fire) are very near to experimental data given by Kingery and Bulmash in case of explosion and the experimental data from USCG ISO 9705Test performed by Janssen (1990) in case of fire.

9.2 SUGGESTIONS FOR FUTURE WORK

- Present graphical output of the explosion simulation shown in two dimensions. It may be improved so that the graphical output of explosion simulation can be shown in the three dimensions.
- In present work the post explosion parameters are evaluated for free air i.e. the effect of all the parameters increases in spherical form but the post explosion parameters may be evaluated for ground level explosion i.e. the effect of all the parameters increased in hemispherical form
- Model developers can use this version of the model for open or proprietary additions to the model or as the basis for new models.

REFRENCES

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APPENDIX A

LIST OF ACRONYMS, ABBREVIATIONS

EXPLOSION SIMULATION

p^0	Peak Overpressure (bar, Pa)
W	Weight of the Explosive (kg)
r	Distance of effect of explosion (m)
k	Jarret Constant
P	Absolute pressure (Pa, bar)
v	Volume ($m^{3)}$
W_e	Work of expansion (Nm)
p	Overpressure (bar)
t	Time (sec,ms)
t_d	Duration time (sec, ms)
α	Decay Parameter
U	Shock velocity (m /sec)
p_a	Absolute ambient pressure (bar , Pa)
γ	Ratio of the specific heat
q_0	Peak dynamic pressure (bar. Pa)
u	Particle Velocity (m/sec)
p_r	Peak reflected overpressure (bar, Pa)
z	Scaled distance ($m/kg^{1/3}$)
t_a	Arrival Time (sec)
i_p	Impulse (Pa ms)
a,b,c_i	Constants
p_s	Scaled overpressure ($Pa/kg^{1/3}$)
i_s	Scaled impulse (Pa ms $/kg^{1/3}$)
τ_d	Scaled duration time (sec $/kg^{1/3}$)

FIRE SIMULATION:

$k\rho c$	Thermal inertia [(kW/m^2-K)^2 sec]
k_f	Flame height parameter (m^2 /kW)
FSP	Flame spread parameter
$\dot{Q}$	Heat release rate (kW)
q_{net}	Net heat flux (kW/m^2)
m_f	Mass loss rate (kg/sec)
SPR	Smoke production rate (m^2/sec)
t	Time (sec)
t_b	Burning duration (sec)
t_{bo}	Burning duration (sec)
t_f	Flame spread time (sec)
t_{fo}	Time to flashover (sec)
t_p	Pyrolysis time (sec)
t_{ig}	Time to Ignition (sec)
T_{ig}	Ignition temperature (K or °C)
V_p	Pyrolysis velocity (m/sec)
x_b	Burnout height (m)
x_f	Flame height (m)
x_p	Pyrolysis height (m)
V_b	Velocity of burnout (m/sec)
λ	Decay coefficient (1/sec)
σ	Specific extinction area (kg/m^2)
Δ	Density (kg/m 3)

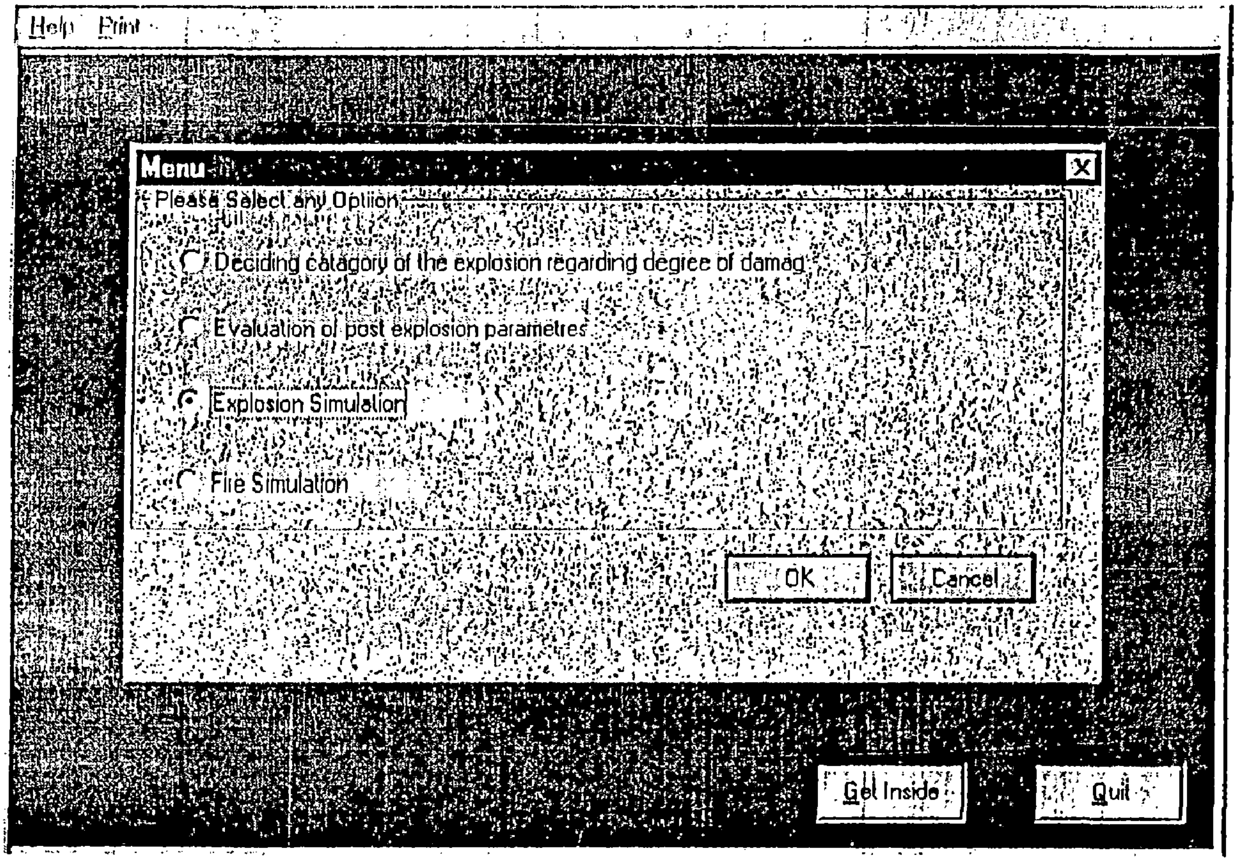
APPENDIX B

SNAPSHOTS OF THE SOFTWARE PACKAGE

STARTING OF SOFTWARE PACKAGE

Snapshot 1

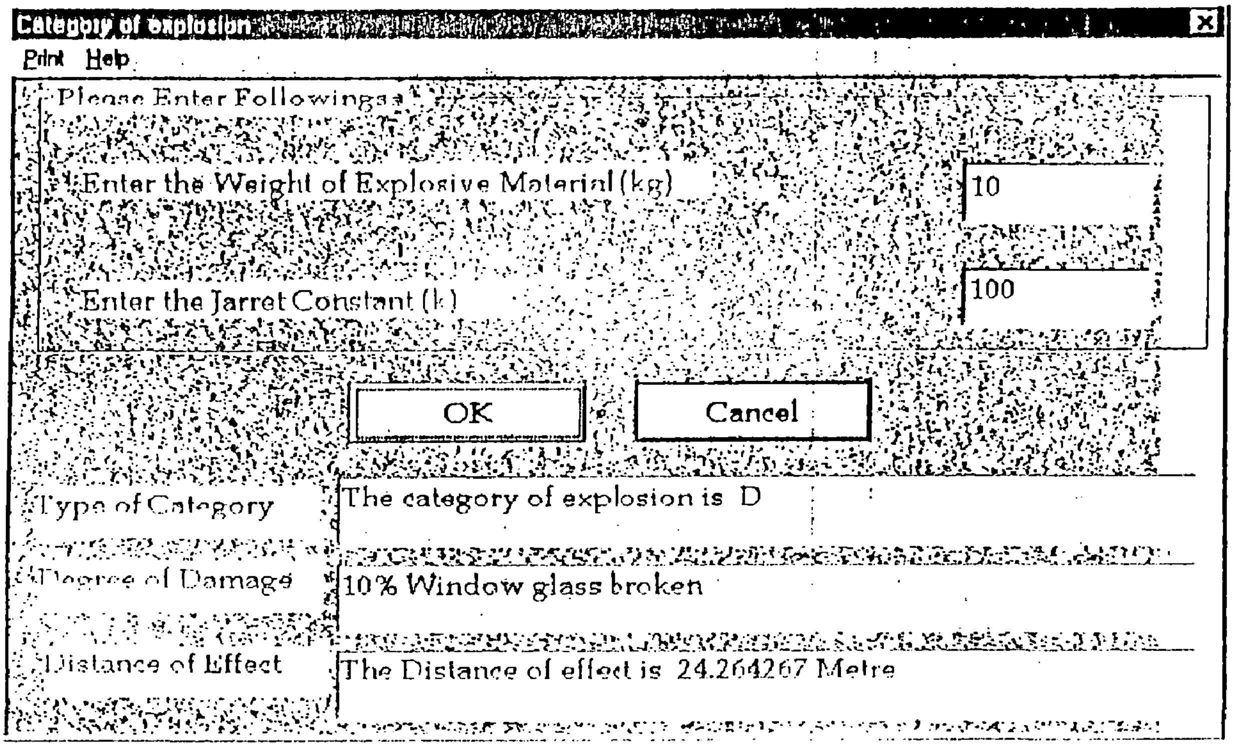
The snapshot 1 is very first view of the window when user execute the software package on this dialog box there are two buttons 'Get Inside' and 'Quit' so here user can enter inside the software package or user can exit it by pushing 'Quit' button.



Please Select any Option
○ Deciding catagory of the explosion regarding degree of damag
○ Evaluation of post explosion parametres
● Explosion Simulation
○ Fire Simulation

Snapshot 2

Snapshot 2 in next seen when user push 'Get Inside' button here a new dialog box appears on that there are four options available so user can choose any one and can seen the execution of that module.



Please Enter Followings

Enter the Weight of Explosive Material (kg): 10

Enter the Jarret Constant (k): 100

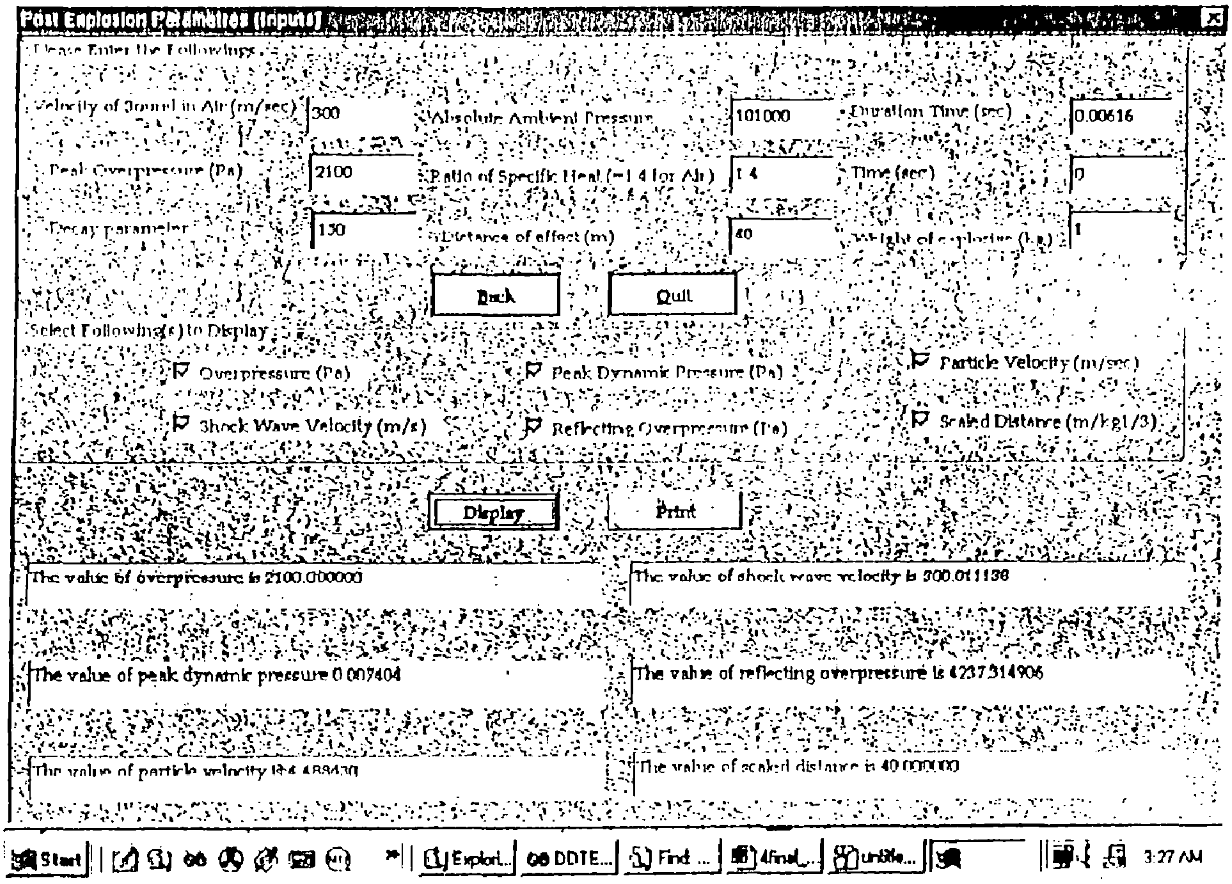
Type of Category: The category of explosion is D

Degree of Damage: 10% Window glass broken

Distance of Effect: The Distance of effect is 24.264267 Metre

Snapshot 3

Snapshot 3 is the dialog box appears when user choose the first option (module) available on previous dialog box. This dialog show the category of the explosion on the basis of input given by the user and also display the distance of effect when a explosion occurs.



Please Enter the Followings

Velocity of Sound in Air (m/sec) 300

Absolute Ambient Pressure 101000

Duration Time (sec) 0.00616

Peak Overpressure (Pa) 2100

Ratio of Specific Heat (=1.4 for Air) 1.4

Time (sec) 0

Decay parameter 130

Distance of effect (m) 40

Weight of explosive (kg) 1

Select Following(s) to Display

☑ Overpressure (Pa)
☑ Peak Dynamic Pressure (Pa)
☑ Particle Velocity (m/sec)
☑ Shock Wave Velocity (m/s)
☑ Reflecting Overpressure (Pa)
☑ Scaled Distance (m/kg1/3)

The value of overpressure is 2100.000000

The value of shock wave velocity is 300.011138

The value of peak dynamic pressure 0.007404

The value of reflecting overpressure is 4237.314906

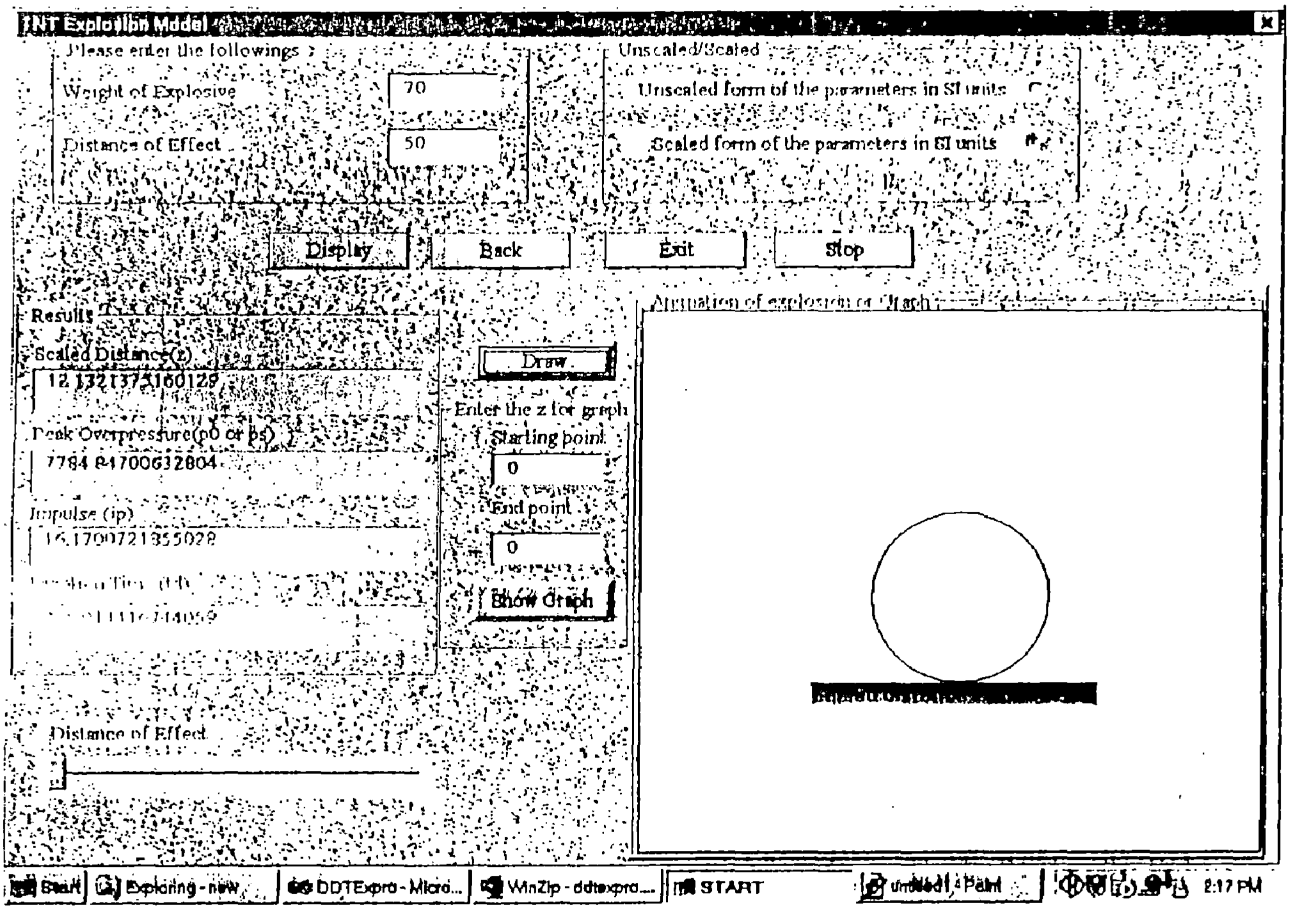
The value of particle velocity is 4.488430

The value of scaled distance is 40.000000

Snapshot 4

Snapshot 4 is appears when user select the second option from the menu (snapshot 2). In this window user can get the calculated value of the post explosion parameters on the basis of given input then select any single parameters or any combination of the parameters than push the 'Display' button to see the value (s) of the checked parameter(s).

SOME SNAP SHOTS OF EXPLOSION SIMULATION

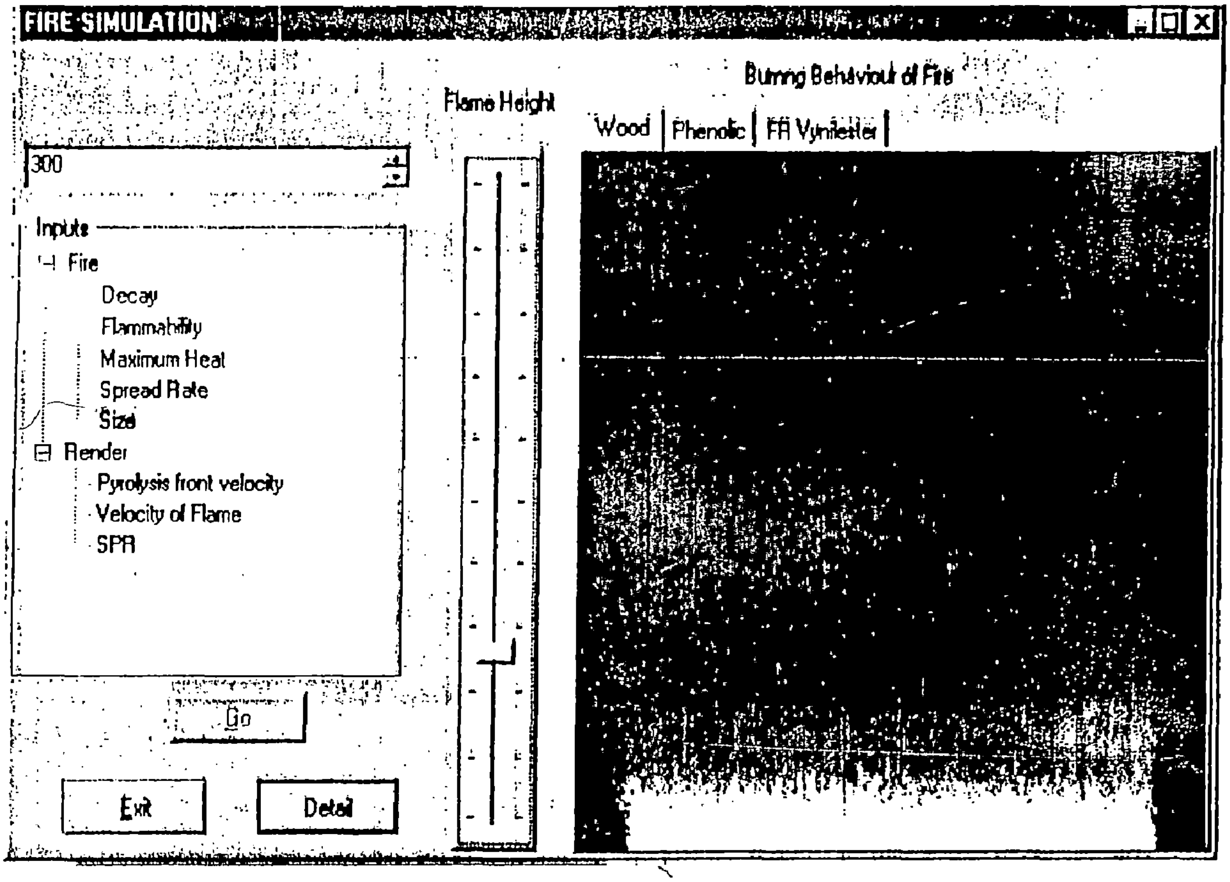


Weight of Explosive: 70
Distance of Effect: 50
Scaled Distance(z): 12.1321373160129
Peak Overpressure(p0 or ps): 7784.84700632804
Impulse (ip): 16.1700721355028
[illegible]
Starting point: 0
End point: 0

Snapshot 5

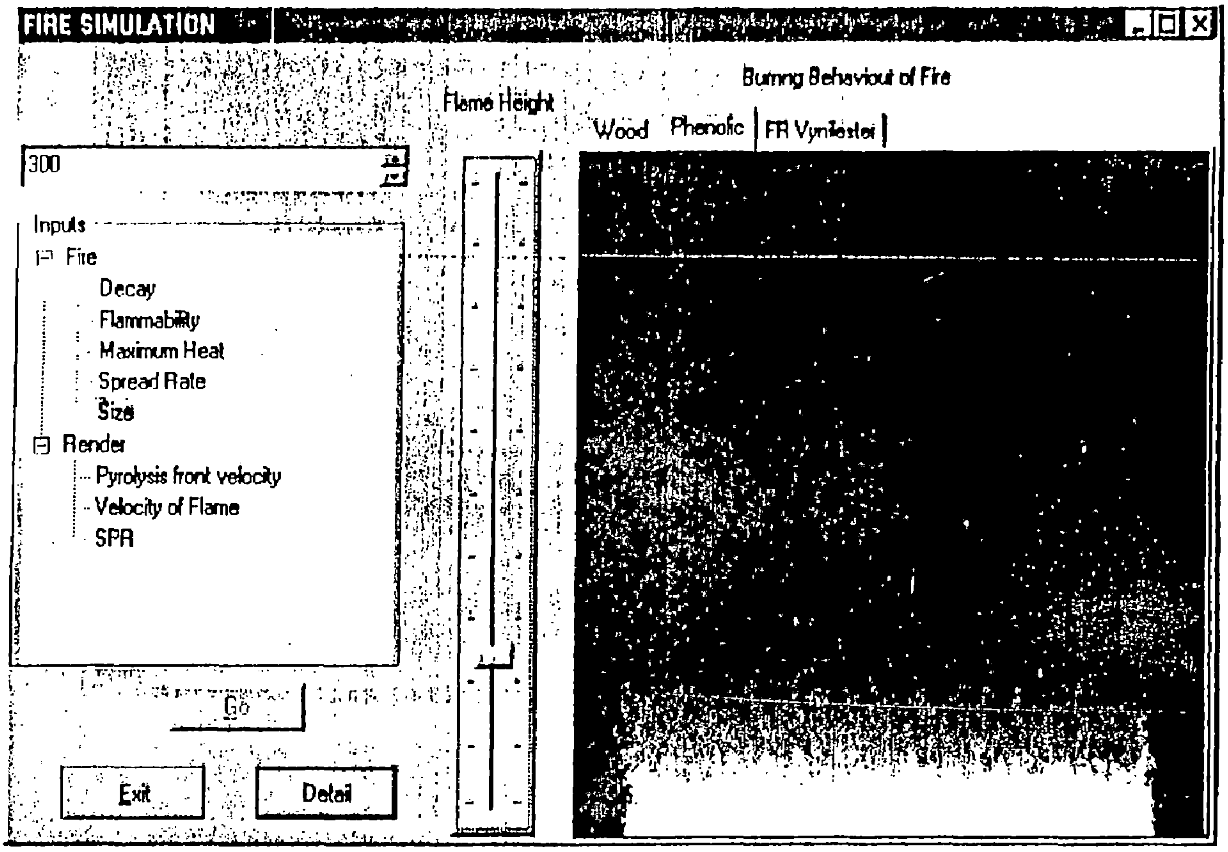
The snapshot 5 shows the simulation of explosion. In this dialog box a circle is available this circle is based on the data calculated by the model, it's radius define the distance of effect, it's width of line defined by power of explosion, there are two colored circle are shown in this view red for overpressure, blue for impulse.

SOME SNAP SHOTS OF FIRE SIMULATION



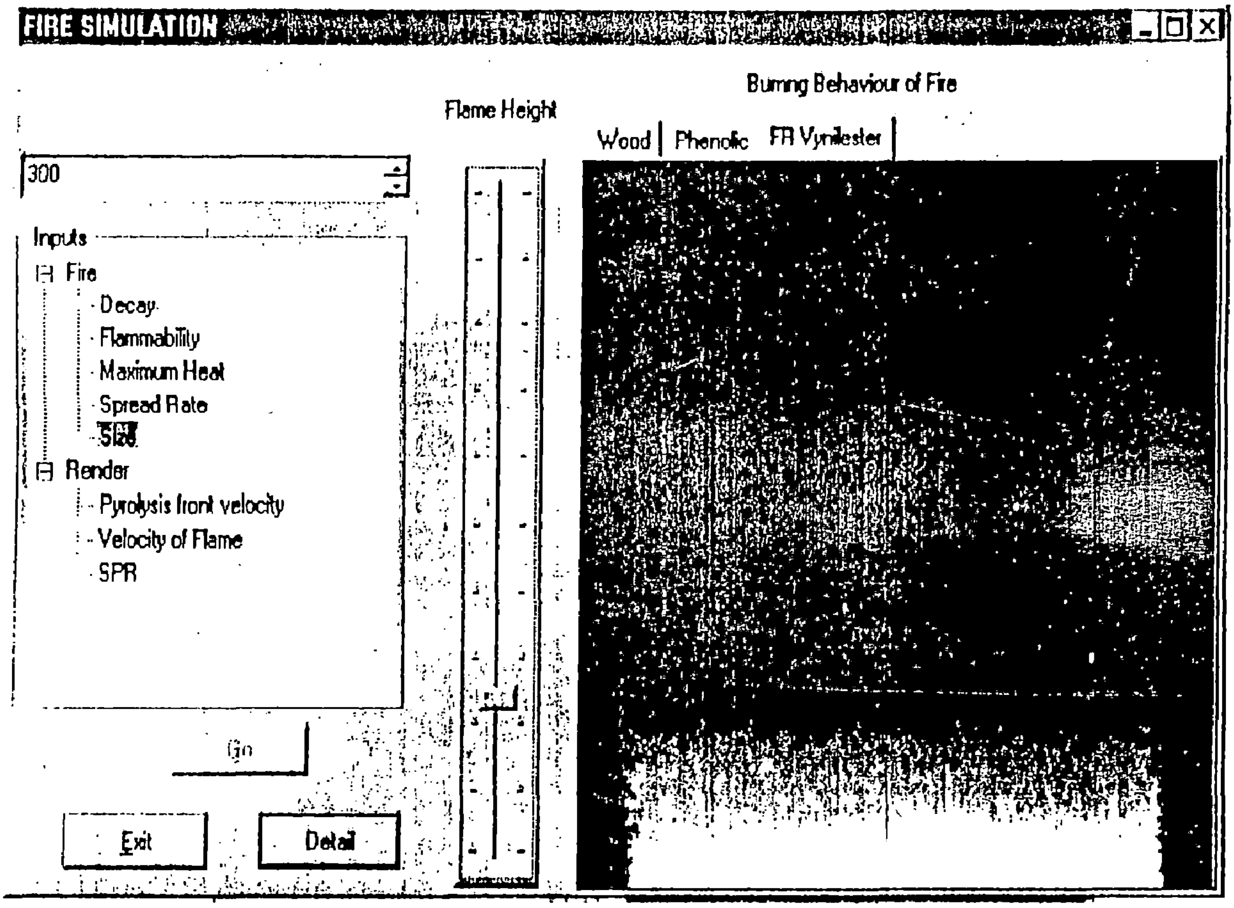
Snapshot 6

Snapshot 6 is the dialog box appears when user chooses the last (fourth) option available on the 'menu' (snapshot 2). In this seen the behavior of the fire is displayed when wood is burned, simultaneously user can see the different effects of fire giving the appropriate input like size, flammability, spread rate, velocity of flame etc.



Snapshot 7

Snapshot 7 shows the behavior and color of the fire when the phenolic burn. Here too user can see the different effects of fire giving the appropriate input like size, flammability, spread rate, velocity of flame etc.



Snapshot 8

Snapshot 8 shows the behavior and color of the fire when the FR Vynilester burn. Here also user can see the different effects of fire giving the appropriate input like size, flammability, spread rate, velocity of flame etc.