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A Comprehensive Review of Software and Tools for Fire and Safety Design and Calculations

Jatin Yadav[1], Arjun Sharma[2], Adwaita Gabhane[3], Udyanshu Katoch[4], Deepak Kumawat[5], N. Aravindan[6]
[1, 2, 3, 4, 5]*Student, Dept. of FIRE Engineering, National Fire Service College Nagpur, India*
[6]*Assistant Professor, Dept. of FIRE Engineering, National Fire Service College Nagpur, India*

Abstract: This review paper presents a comprehensive analysis of the computational tools of modern fire protection engineering (FPE). The paper categorizes and examines the primary tools used for fire-related calculations, providing a critical evaluation of their theoretical underpinnings, applications, and limitations. The review comprises five principal domains: (1) Fire and Smoke Dynamics Modelling, including a comparative analysis of Computational Fluid Dynamics (CFD) field models such as the Fire Dynamics Simulator (FDS) and zone models like the Consolidated Fire and Smoke Transport (CFAST) model, along with their associated graphical user interfaces (PyroSim) and visualization tools (Smokeview); (2) Egress and Evacuation Modelling, focusing on agent-based simulation platforms like Pathfinder, buildingEXODUS, and STEPS that are used to assess human behaviour and movement during emergencies; (3) Hydraulic Calculation Software, covering specialized tools for fire suppression system design (HASS, AutoSPRINK) and general water network analysis programs (Pipe Flow Professional, EPANET); (4) Consequence and Risk Assessment Tools, which are essential for analyzing high-hazard industrial scenarios using software such as PHAST, FLACS, and ALOHA; and (5) Foundational and Ancillary Resources, including the indispensable SFPE Handbook of Fire Protection Engineering and the utility and inherent risks of custom spreadsheets.
Keywords: Fire Protection Engineering, Computational Fluid Dynamics (CFD), Fire Dynamics Simulator (FDS), CFAST, Egress Modelling, Pathfinder, Quantitative Risk Assessment (QRA), SFPE Handbook.

I. INTRODUCTION

A. The Paradigm Shift in Fire Safety

The concept of fire protection engineering (FPE) is rooted in humanity's history with fire. Its origins can be traced to ancient prescriptive measures, for centuries, this prescriptive approach dictating specific materials, dimensions, and construction methods remained the dominant paradigm. However, a series of devastating conflagrations, particularly during the Industrial Revolution, exposed the limitations of this approach and catalysed the development of a more systematic, science-based discipline.

The Great London Fire of 1666, which destroyed over 80% of the city, led to London's first building regulations requiring stone and brick construction. In the United States, the tragic Triangle Shirtwaist Factory fire of 1911, which claimed 146 lives, spurred the creation of the NFPA Committee on Safety to Life, the precursor to the modern NFPA. These events underscored a critical reality: as buildings became larger, more complex, and housed new industrial processes, a reactive, purely prescriptive system was insufficient. This led to the formation of foundational organizations, often driven by the insurance industry's need to minimize property losses, such as the National Fire Protection Association (NFPA) in 1896, which sought to standardize fire safety practices, including the installation of automatic sprinkler systems.[1][2]

This historical trajectory reveals that the evolution of fire safety has not been a simple linear progression of technology [3][4]. The computational tools reviewed in this paper are the modern example of this cycle, representing the instruments developed to address the complex questions posed by this evolving field.

B. The Rise of Computational Engineering

The latter half of the 20th century witnessed a fundamental shift away from purely prescriptive codes toward performance-based design (PBD). This approach focuses on achieving explicit fire safety objectives (e.g., maintaining tenable conditions for occupant evacuation) rather than simply adhering to a set of prescribed rules [5]. The viability of PBD is entirely predicated on the ability of engineers to reliably predict the outcomes of fire scenarios through quantitative analysis. This created a need for the development and validation of computational models capable of simulating the complex phenomena of fire dynamics, smoke transport, structural response, and human behaviour. The successes of fire safety engineering research, particularly in understanding the fundamental physics and chemistry of fire, enabled the creation of these predictive tools.

The following sections will systematically explore the landscape of these tools, beginning with models that simulate the fire hazard itself, followed by those that simulate the human and system responses to that hazard, and concluding with a discussion of the foundational resources that guide their proper application.

II. DISCUSSION

The modern fire protection engineer's toolkit is a diverse ecosystem of software designed to address specific aspects of a fire scenario. These tools range from highly complex, first-principles-based models that demand significant computational resources and user expertise, to more simplified, empirically-derived models and design aids. This section provides a detailed analysis of the primary categories of these tools.

A. Fire and Smoke Dynamics Modelling: Simulating the Hazard

At the core of any fire safety analysis is the ability to predict the development of the fire itself and the transport of heat and smoke throughout a structure. Two primary computational paradigms have been developed for this purpose: zone models and field models (CFD).

1) Foundational Approaches: A Comparative Analysis of Zone and Field Models

The choice between a zone model and a field model represents a fundamental decision in fire simulation, balancing computational speed against predictive detail. Zone Models are based on the observation that in a compartment fire, buoyancy effects often lead to the sorting of gases into two distinct layers: a hot, smoke-filled upper layer and a cooler, clearer lower layer. A zone model simplifies the entire compartment into these two control volumes, or "zones." Within each zone, properties like temperature and species concentration are assumed to be uniform. The model solves a system of ordinary differential equations (ODEs) derived from the conservation of mass and energy, the ideal gas law, and relations for density and internal energy to predict the evolution of these zones over time [6][7]. The primary advantage of this approach is computational efficiency; simulations can often be completed in seconds or minutes, making zone models highly suitable for analysing multi-compartment buildings or conducting numerous runs for sensitivity or probabilistic analyses. However, their foundational assumption of uniform zones is also their greatest limitation. This approach is not well-suited for large-volume spaces where sorting may not occur, enclosures with complex geometries, or scenarios where detailed local effects (e.g., airflow around an obstruction) are critical to the outcome.

Field Models, which are almost exclusively based on Computational Fluid Dynamics (CFD), take a fundamentally different approach. Instead of simplifying the domain into a few zones, a CFD model represent the entire computational volume into a grid composed of hundreds of thousands, or often millions, of small control cells. The model then numerically solves a form of the fundamental governing equations of fluid dynamics the Navier-Stokes equations for the conservation of mass, momentum, energy, and chemical species within each cell [8][9]. This method provides a high-fidelity, three-dimensional, time-dependent prediction of the flow field, and capturing detailed phenomena such as turbulence, complex smoke movement, and heat transfer with a high degree of resolution. The global market for CFD software was valued at over USD 2.4 billion in 2023 and is projected to grow substantially, reflecting its widespread adoption in engineering disciplines where precise fluid dynamics simulation is critical, including building design and fire safety. The main drawback of CFD is its immense computational cost. A single, detailed simulation can require hours, days, or even weeks of processing time on powerful computers, making it less practical for projects requiring a large number of iterative runs [10][11].

The selection of the appropriate model is therefore a critical engineering decision, dictated by the specific questions being asked, the geometry of the space, and the available computational resources, as summarized in Table 1.

Table 1: Comparison of Zone vs. CFD Fire Models

Attribute	Zone Models (e.g., CFAST)	CFD Models (e.g., FDS)
Governing Principle	System of Ordinary Differential Equations (ODEs) based on conservation laws for discrete zones.	Numerical solution of partial differential equations (Navier-Stokes) across a discretized grid.
Computational Domain	A small number of control volumes (typically 2 per compartment).	Hundreds of thousands to millions of grid cells.

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Typical Run Time	Seconds to minutes.	Hours to days or weeks.
Required User Expertise	Moderate; understanding of model assumptions is key.	High; requires expertise in fluid dynamics, heat transfer, and numerical methods.
Ideal Applications	Initial design analysis, multi-compartment smoke transport	Detailed analysis of large/complex spaces (e.g., atria, tunnels)

2) Key Software Packages: FDS and CFAST

The U.S. National Institute of Standards and Technology (NIST) [12][13] has been a leader in the development of fire modelling software, providing two of the most widely used tools in the world, CFAST and FDS, to the public domain free of charge.

CFAST (Consolidated Fire and Smoke Transport) It is designed to rapidly calculate the evolving distribution of smoke, gases, and temperature throughout a multi-compartment structure during a prescribed fire. Its speed makes it an invaluable tool for engineers needing to evaluate numerous scenarios, such as assessing the impact of different ventilation conditions or fire locations, and for its use in probabilistic risk analyses that may require thousands of model runs [14][15]. The model's governing equations are derived from first principles of mass and energy conservation applied to the two-layer assumption [16][17][18]. However, users must remain cognizant of its limitations; CFAST cannot account for the presence of obstacles within a room, is insensitive to the specific location of the fire within a compartment, and may produce unreliable results in geometries with high aspect ratios (e.g., long corridors) or in large spaces where the two-zone assumption breaks down.

FDS (Fire Dynamics Simulator): It numerically solves a form of the Navier-Stokes equations optimized for low-speed, thermally-driven flows, making it particularly well-suited for simulating smoke and heat transport from fires. FDS employs a Large Eddy Simulation (LES) turbulence model, which resolves the large-scale turbulent eddies and models the smaller, sub-grid scale eddies. The software is under continuous development, with newer versions incorporating increasingly sophisticated physics, including detailed combustion chemistry, advanced models for pyrolysis (the thermal decomposition of solid materials), and multi-component species transport. The power and detail of FDS come at a price: it demands a high level of user competence. The official documentation explicitly warns that FDS is intended for use only by those proficient in fluid dynamics, thermodynamics, combustion, and heat transfer, as misapplication can lead to erroneous and unsafe conclusions [19][20].

3) The User Ecosystem: GUIs and Visualization with PyroSim and Smokeview

The complexity of setting up and interpreting CFD simulations has led to the development of a vital ecosystem of supporting software.

PyroSim is a graphical user interface (GUI) developed by Thunderhead Engineering that acts as a pre-processor for FDS. It dramatically lowers the barrier to entry and improves the efficiency of creating FDS input files, which are otherwise complex, text-based documents. PyroSim provides a CAD-like environment where users can import architectural models (e.g., IFC, DXF, DWG files), draw and edit geometry, define material properties, specify fire sources, and set up the computational mesh visually. It includes powerful features for managing multiple meshes to enable parallel processing, which can significantly reduce simulation time, and for modelling complex building systems such as HVAC networks [21][22].

Smokeview (SMV) is a visualization program, also developed by NIST, which serves as the primary post-processor for both FDS and CFAST. It reads the output files generated by the simulations and produces 3D animated visualizations of the results. Users can view smoke movement, temperature contours, velocity vectors, and other key variables, allowing for both qualitative understanding of the fire dynamics and quantitative analysis of the data. Smokeview is an indispensable tool for interpreting the vast amount of data produced by an FDS simulation and for communicating the results to clients, stakeholders, and authorities having jurisdiction (AHJs) [23][24].

The development of intuitive GUIs like PyroSim has been instrumental in the widespread adoption of FDS in the engineering community. By simplifying the process of model creation, these tools have access to advanced CFD analysis. However, this accessibility introduces a significant professional challenge. While a GUI can prevent syntax errors and streamline the workflow, it cannot substitute for the fundamental engineering judgment required to formulate a physically valid model. The explicit warnings from NIST regarding the necessary expertise to use FDS remain critically relevant.

B. *Egress and Evacuation Modelling: Simulating Human Response*

While fire dynamics models predict the development of the hazard, egress models simulate the human response to that hazard. The primary objective is to ensure that occupants can safely evacuate a building before conditions become life-threatening.

1) *Core Principles: Agent-Based Simulation and the ASET vs. RSET Paradigm*

The cornerstone of performance-based egress design is the comparison of ASET and RSET.

- ASET (Available Safe Egress Time) is the time from fire ignition until conditions in the building become untenable for occupants. Tenability limits are typically defined by factors such as smoke layer height, visibility, temperature, and concentrations of toxic gases (e.g., carbon monoxide). ASET is calculated using fire and smoke dynamics models like FDS or CFAST.
- RSET (Required Safe Egress Time) is the total time required for all occupants to travel from their initial locations to a place of safety. RSET is calculated using evacuation models and is typically broken down into several components: detection time, alarm/notification time, pre-evacuation time (also called pre-movement delay), and travel time.

The pre-evacuation period is often the largest and most uncertain component of RSET. It represents the time occupants spend on activities other than purposeful movement toward an exit, such as investigating the alarm, seeking information, alerting or assisting others, or collecting personal belongings. Accurately modelling this delay is a critical challenge in evacuation simulation.

2) *Leading Simulation Platforms: Pathfinder, STEPS, and buildingEXODUS*

Pathfinder, developed by Thunderhead Engineering, was identified as the most widely used model, with 35% of survey respondents indicating it as their primary tool [25]. It has become a leading choice for performance-based design and code compliance analyses. Pathfinder offers two distinct simulation modes [26][27].

SFPE Mode is a simplified approach based on the hydraulic flow-rate calculations outlined in the SFPE Handbook, where occupant speed is a function of density.

Steering Mode is a true agent-based model where each occupant uses a combination of steering behaviours to navigate toward their goal while avoiding obstacles and other occupants, resulting in more realistic, continuous movement paths.

buildingEXODUS, developed by the Fire Safety Engineering Group (FSEG) at the University of Greenwich, is one of the most sophisticated and behaviourally rich evacuation models available. It is a rule-based expert system that simulates the evacuation process through the interaction of five core sub models: Occupant, Movement, Behaviour, Toxicity, and Hazard. This structure allows it to model extremely complex human-environment interactions. For example, the Occupant sub model defines individuals with over 20 physical and psychological attributes. The Behaviour sub model can simulate complex actions such as family members searching for one another (group bonding), safety officers directing people (contra-flow), and the progressive incapacitation of occupants due to exposure to heat and toxic gases, calculated using a Fractional Effective Dose (FED) model.

STEP (Simulation of Transient Evacuation and Pedestrian movements) is another agent-based model. A key feature of STEPS is its use of a continuous, vector-based system for movement, rather than discretizing the space into a grid. This allows for very realistic and fluid interactions between agents and their surroundings. STEPS represents occupants as "learning-adaptive agents" with individual preferences and objectives, and it is capable of modelling complex crowd dynamics such as merging flows and counter-flows, making it particularly useful for analysing large and complex venues like transportation hubs and stadiums. A comparative summary of the features of these leading platforms is provided in Table 2.

Table 2: Feature Matrix of Leading Egress Modelling Software

Feature	Pathfinder	buildingEXODUS	STEPS
Modelling Paradigm	Agent-based & Simplified Flow	Rule-based, grid-based Agent model.	Vector-based, continuous space Agent model.
Fire Hazard Integration	Can import FDS data to	Integrated Hazard and Toxicity sub models that	Can model dynamic changes in conditions

	calculate tenability and model occupant response to smoke.	dynamically affect agent capabilities	during evacuation to simulate real-life events.
Validation Approach	Validation against published tests and standards.	Extensive validation against experimental data, including data from ship evacuations	Developed through mass observations of crowd behaviour
User Interface	Modern, graphical, CAD-like interface. Integrates with PyroSim.	Expert system interfaces; requires deep understanding of the rule-based structure.	Advanced 3D visualization for real-time simulation analysis.

C. Hydraulic Calculation Software: Designing Suppression Systems

Hydraulic calculation software is essential for the design and analysis of water-based fire suppression systems, such as automatic sprinklers and standpipes. These tools ensure that the system can deliver the required flow rate and pressure to control or suppress a fire, in accordance with established engineering standards.

1) Specialized Tools for Sprinkler System Design: HASS and AutoSPRINK

The design of fire sprinkler systems is a specialized field dominated by purpose-built software that integrates design and calculation. These tools are primarily used by fire protection design technicians and engineers to ensure compliance with standards like NFPA 13, Standard for the Installation of Sprinkler Systems.

HASS (Hydraulic Analyser of Sprinkler Systems) is a long-established software package used to perform hydraulic calculations for a wide range of water-based systems, including sprinklers, standpipes, and fire pumps. The user inputs the pipe network geometry (pipe lengths, diameters, fittings) and node data (elevations, sprinkler K-factors). HASS then solves the network to determine pressures and flows, verifying that the most hydraulically demanding sprinklers receive the required pressure (typically a minimum of 7 psi, depending on the sprinkler type). HASS includes advanced features such as the ability to model multiple water sources, automatically resize pipes for cost optimization, and integrate directly with AutoCAD to streamline the design-to-calculation workflow. It supports numerous international standards, including NFPA 13, FM Datasheets, and EN 12845.

AutoSPRINK is a comprehensive, 3D, object-oriented design platform that seamlessly integrates the entire workflow of sprinkler system design, from initial layout to hydraulic calculation, coordination with other building systems, and generation of stock lists for fabrication. Unlike traditional 2D drafting, AutoSPRINK uses intelligent 3D objects for pipes, fittings, and sprinklers, which contain all the necessary data for both drawing and calculation. This allows hydraulic calculations to be performed directly within the 3D model in seconds. The software supports both the

Hazen-Williams equation, the traditional industry standard for water-based systems, and the more rigorous Darcy-Weisbach equation, which is necessary when dealing with fluids other than water or when velocity pressure is a significant factor.

2) General and Water Distribution Network Tools: Pipe Flow Professional and EPANET

While not designed exclusively for fire protection, general-purpose hydraulic network solvers are powerful tools that can be effectively applied to fire-related calculations, particularly for analysing water supplies.

Pipe Flow Professional is robust software for modelling fluid flow in complex pipe networks. It can calculate flow rates, pressure drops, and pump performance for a wide variety of fluids and systems. Its calculation engine supports both the Hazen-Williams and Darcy-Weisbach methods. In the context of fire protection, it can be used to model a sprinkler system by defining individual sprinkler heads as custom components with a specified flow-versus-pressure-loss relationship, often defined by the sprinkler's K-factor using the equation $K=Q\sqrt{P}$.

EPANET, developed by the U.S. Environmental Protection Agency (EPA), is public-domain software for modelling water distribution systems [28][29]. While its primary purpose is for drinking water quality and network management, it is the industry standard tool for conducting. The distinction between these specialized and general-purpose tools is summarized in Table 3.

Table 3: Overview of Calculation Software

Software	Primary Application	Core Calculation Engine	Key Features
HASS	Fire sprinkler & standpipe system design.	Solves network hydraulics based on Hazen-Williams.	AutoCAD integration, pipe size optimization
AutoSPRINK	Integrated 3D fire sprinkler system design.	Hazen-Williams and Darcy-Weisbach	Full 3D modelling, integrated calculations,
Pipe Flow Professional	General-purpose fluid network analysis.	Hazen-Williams and Darcy-Weisbach.	Models any fluid, custom components, pump selection
EPANET	Municipal water distribution network modelling.	Hazen-Williams, Darcy-Weisbach,	Extended-period simulation, water quality tracking

D. Consequence and Risk Assessment Tools: Analysing Industrial Hazards

For industries that handle large quantities of flammable or toxic materials, such as oil and gas, petrochemical, and chemical manufacturing, fire safety engineering extends beyond building protection to include process safety and risk management. This requires specialized tools capable of modelling high-hazard, low-probability events like vessel ruptures, pipeline leaks, and large-scale explosions.

1) The Quantitative Risk Assessment (QRA) Framework

Quantitative Risk Assessment (QRA) is the formal, systematic methodology used to quantify the risks associated with hazardous industrial activities. Risk is defined as a function of both the frequency(or likelihood) of an undesirable event and the consequences (or severity) of that event. A Fire and Explosion Risk Assessment (FERA) is a specific type of QRA focused on those particular hazards.

The QRA process typically involves several key steps:

a) Hazard Identification: Identifying potential failure scenarios (e.g., loss of containment) using structured methods like a Hazard and Operability (HAZOP) study.
b) Frequency Analysis: Estimating the likelihood of these scenarios using historical data and techniques like Fault Tree Analysis (FTA).
c) Consequence Modelling: Using specialized software to predict the physical effects of a release, such as dispersion distances, thermal radiation levels from fires, or overpressure from explosions.
d) Risk Calculation: Combining the frequency and consequence results to calculate risk metrics, such as Individual Risk Per Annum (IRPA) or societal risk (F-N curves), which can then be compared against corporate or regulatory tolerance criteria to determine if the risk is As Low As Reasonably Practicable (ALARP).

2) Modelling High-Hazard Scenarios: PHAST, FLACS, and ALOHA

Several key software packages are used to perform the consequence modelling step within a QRA.

PHAST (Process Hazard Analysis Software Tool), from DNV, is one of the world's leading and most comprehensive tools for consequence analysis of industrial hazards. It is an integrated software package that models the entire chain of events following a loss of containment. This includes detailed discharge models (for leaks from vessels and pipes), dispersion models that account for two-phase flow, rainout of liquids to form pools, and heavy gas effects, and a suite of effects models for predicting the impact of fires (jet fires, pool fires, fireballs/BLEVEs), explosions (vapour cloud explosions), and toxic gas clouds.

FLACS (Flame Acceleration Simulator), from Gexcon, is a highly specialized CFD tool designed specifically for modelling flammable gas and dust explosions in complex and congested environments, such as offshore oil platforms and chemical processing plants. While general-purpose CFD codes can model combustion, FLACS is purpose-built for safety applications and has been extensively validated against large-scale explosion experiments. It solves the compressible Navier-Stokes equations and includes sophisticated sub-grid models for turbulence and combustion, enabling it to accurately predict flame acceleration and the resulting overpressures and blast waves generated by obstacles in the flame path.

ALOHA (Areal Locations of Hazardous Atmospheres) is a modelling tool developed by the U.S. National Oceanic and Atmospheric Administration (NOAA) and the EPA. It is primarily intended for emergency responders and planners and is available for free. ALOHA provides a more accessible, user-friendly platform for estimating the threat zones from chemical releases. It includes both a traditional Gaussian plume model for neutrally buoyant gases and a dense gas dispersion model for heavier-than-air releases. It can also model the hazards from common flammable events, including pool fires, jet fires, BLEVEs, and vapour cloud explosions [30]. While it is less complex and detailed than commercial packages like PHAST or FLACS, it serves as an excellent tool for initial screening, "what-if" analyses, and emergency response planning, where rapid assessment is critical.

E. Foundational and Ancillary Tools: The Engineer's Toolkit

Beyond specialized software, the practice of fire protection engineering relies on foundational reference materials and general-purpose calculation aids [31][32]. The proper use of these resources is as critical as the selection of advanced software.

1) The Definitive Reference: The SFPE Handbook of Fire Protection Engineering

The SFPE Handbook of Fire Protection Engineering is universally recognized as the authoritative and indispensable reference for the discipline. The 5th edition, published in 2016, and the forthcoming 6th edition, scheduled for 2025, represents a monumental collaborative effort, compiling the knowledge of hundreds of the world's foremost fire engineers and researchers. The handbook is organized into sections covering the entire breadth of the field, including:

- Fundamentals: Chapters on core engineering principles such as fluid mechanics, all modes of heat transfer (conduction, convection, radiation), thermochemistry, and structural mechanics.
- Fire Dynamics: Detailed treatment of fire phenomena, including fire plumes, ceiling jets, vent flows, ignition, flame spread, and smoke production.
- Hazard Calculations: Methods for quantifying fire hazards, including heat release rates, calorimetric, compartment fire modelling (both zone and CFD approaches), and toxicity assessment.
- Design Calculations: Engineering methods for the design of fire protection systems, including detection, automatic sprinklers, special suppression agents, and smoke control.
- Fire Risk Analysis: Principles and applications of risk assessment, human behaviour in fire, and emergency movement.

The handbook provides the theoretical basis and the validated empirical correlations that underpin the algorithms within virtually all the software tools discussed in this paper [33][34]. For a practicing engineer, it is not merely a reference but the ultimate source of the first principles that must be understood to apply any computational tool correctly and responsibly.

2) The Utility and Peril of Spreadsheets in Fire Calculations

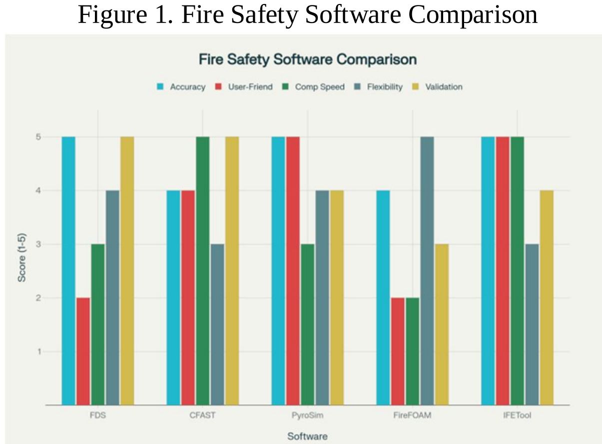
Spreadsheets are global in engineering practice due to their accessibility, flexibility, and ease of use for performing custom calculations. They are valuable for implementing simple equations from the SFPE Handbook, performing unit conversions, organizing data, or creating quick estimates.

However, relying on spreadsheets for mission-critical fire and life safety calculations is a practice fraught with significant and well-documented peril. Unlike formally developed and validated engineering software, spreadsheets lack inherent quality control and are exceptionally prone to error. Studies have shown that a vast majority—upwards of 80% to 90%—of all spreadsheets contain at least one error. These errors can range from simple typos in data entry to subtle but critical mistakes in formulas, which may go undetected and propagate through a calculation, leading to grossly incorrect results. The consequences of such errors in other industries have been severe, leading to multi-million dollar financial losses.

Beyond the risk of formula errors, spreadsheets suffer from a lack of version control, making it difficult to track changes or ensure that the correct version of a calculation is being used. They offer poor auditability, as there is often no record of who made changes and when, and they provide little to no protection for the intellectual property embedded in their formulas.

This distinction between validated software and uncontrolled spreadsheets is a central element in a broader hierarchy of computational tools. At the apex of this hierarchy lies the peer-reviewed, consensus-based knowledge in the SFPE Handbook—the source of fundamental truth. Below this are the specialized, validated software packages like FDS, Pathfinder, and PHAST. These tools represent a rigorous, controlled implementation of those fundamental principles and have undergone formal verification and validation processes. A step below are general-purpose tools like EPANET, which are robust within their own domains but require careful adaptation and independent verification by the user for fire protection applications. At the very bottom of this hierarchy are custom spreadsheets. Their reliability is entirely dependent on the diligence of the individual creator and is opaque to peer review, making them the tool with the lowest level of intrinsic trust for critical applications.

Figure 1. Fire Safety Software Comparison



III. CONCLUSION

This review has systematically categorized and analysed the primary software and resources used for fire-related calculations, from simulating the fundamental physics of fire and smoke to modelling the complex dynamics of human evacuation and the performance of suppression systems.

In fire dynamics, the choice between rapid zone models like CFAST and high-fidelity CFD models like FDS allows engineers to scale their analysis to the problem's complexity. Specialized hydraulic calculators like HASS and AutoSPRINK have become indispensable for the efficient and accurate design of suppression systems, while sophisticated consequence models like PHAST and FLACS provide the means to quantify and manage risks in high-hazard industries.

The core conclusion of this review is that computational tools are aids to, not substitutes for, engineering judgment. The validity of a simulation's output is inextricably linked to the user's understanding of the underlying physical phenomena, the model's inherent assumptions and limitations, and the quality of the input data.

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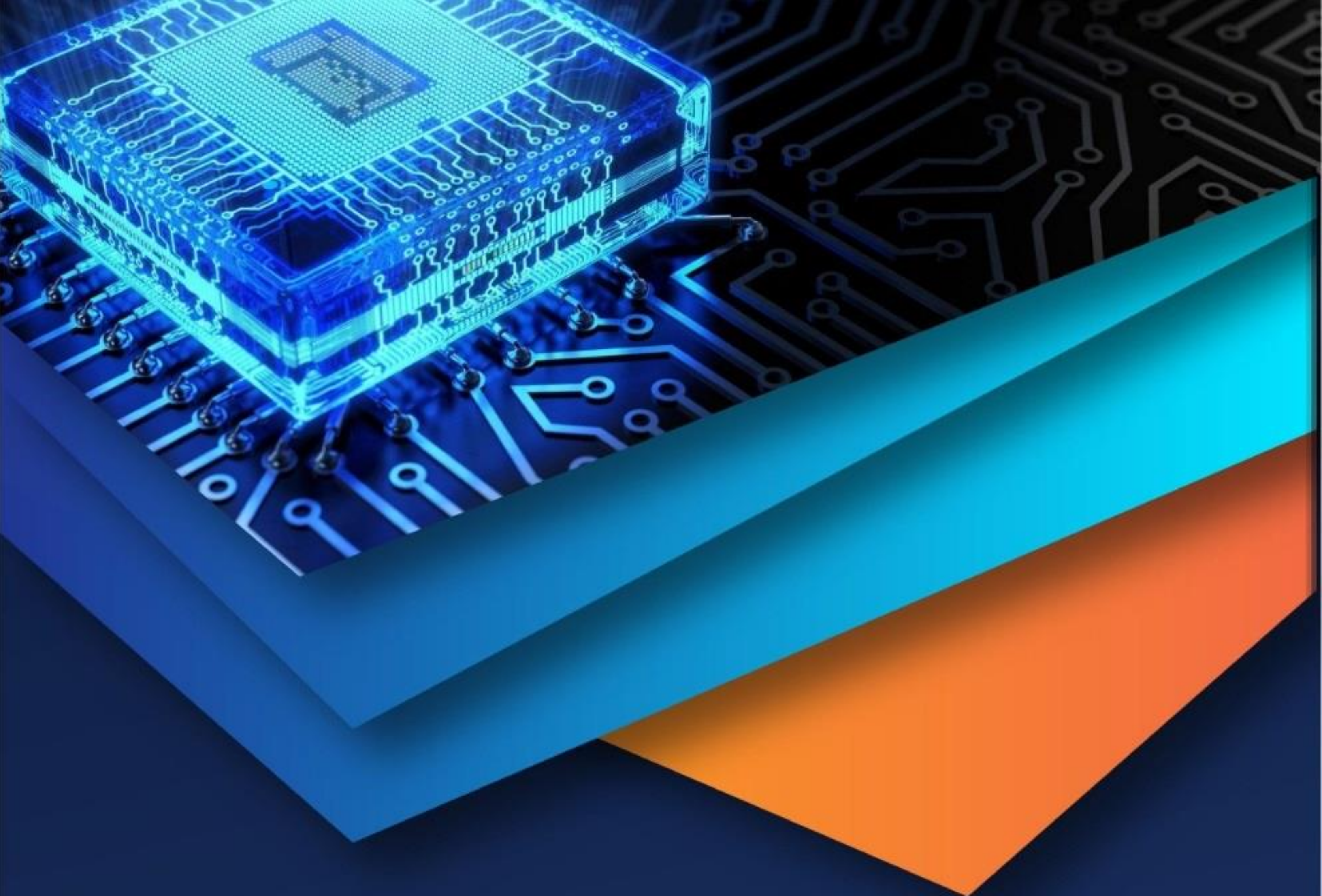

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