Modelovanie požiaru plávajúceho zariadenia

Fire modelling of a floating object

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Dorota Hodúlová pôsobí ako interná doktorandka na Katedre požiarneho inžinierstva Fakulty bezpečnostného inžinierstva Žilinskej univerzity v Žiline. Vo svojej dizertačnej práci sa venuje implementácii požiarneho inžinierstva do riešenia protipožiarnej bezpečnosti stavieb. Stanislava Gašpercová pôsobí ako docentka na Katedre požiarneho inžinierstva Fakulty bezpečnostného inžinierstva Žilinskej univerzity v Žiline. Svoju výskumnú činnosť orientuje na problematiku stavebných materiálov a konštrukcií, a ich vplyvu požiarov na ne. Ján Zoleík je študentom externého štúdia v programe Záchranné služby na Katedre požiarneho inžinierstva Fakulty bezpečnostného inžinierstva Žilinskej univerzity v Žiline. V rámci svojho štúdia sa zameriava na problematiku modelovania požiarov v uzatvorených priestoroch.

Abstrakt

Program CFAST je dvojzónový požiarny model využívaný na modelovanie požiarov v uzatvorených priestoroch. Požiarne modely slúžia na predpovedanie správania sa požiarov a prenosu dymu. Tento článok sa zaoberá aplikáciou program CFAST v dvoch simuláciách pri požiaroch v uzatvorenom priestore plávajúceho zariadenia. Prvá simulácia rieši požiar, kedy je plavidlu dodávaná elektrická energia, teda jednotlivé požiarnotechnické zariadenia sú aktívne. Druhá simulácia sa zaoberá prípadom, kedy je plavidlo odstavené od elektrickej energie a požiarnotechnické zariadenia sú neaktívne. Cieľom článku je zistenie vplyvu vybraného požiarnotechnického zariadenia, zariadenia na odvod tepla a splodín horenia, na teplotu horúcej a studenej vrstvy v priestore požiaru a výšku dymovej vrstvy.

Kľúčové slová: CFAST; Požiar v uzatvorenom priestore; Plávajúce zariadenie

Abstract

The CFAST program is a two-zone fire model used to model confined space fires. Fire models are used to predict fire behaviour and smoke transport. This paper discusses the application of the CFAST program in two simulations for confined space fires in a floating facility. The first simulation deals with a fire where electrical power is supplied to the vessel, i.e., the various fire protection devices are active. The second simulation deals with the case where the vessel is de-energised and the fire engineering equipment is inactive. The paper aims to determine the influence of the selected fire engineering equipment, heat and combustion products removal equipment, on the temperature of the hot and cold layers in the fire compartment and the height of the smoke layer.

Keywords: CFAST; Confined space fire; Floating object

1 Introduction

In today's technologically advanced age, we can see how modern technology is being incorporated into every aspect of our lives. It should be no different when it comes to security. One such technology in the field of safety is fire models, which are used to retell the behaviour of fires based on experiments or simulation programs. With simulation programs, we can effectively predict the behaviour of fires in confined spaces as well as with costly experiments. Simulation programs allow us to understand the situation during a fire safely and without risks. CFAST is one of these simulation programs [1 – 3].

The CFAST program is a two-zone fire model that is capable of predicting the environmental parameters of enclosed rooms during a fire. CFAST works on the principle of determining the evolution of the heat release rate over time, calculating the smoke generation of the fire compartment as well as of the surrounding rooms and the generation of combustion products in the modelled interface. The program works based on specific parameters and properties defined by the user. The parameters and properties include [1, 4]:

- Thermal properties of building materials.
- Dimensional properties.
- Openings in structures (horizontal and vertical).
- Fire.
- Targets.
- Fire engineering equipment.
- Interconnection of the different rooms of the simulations.
- Visualisation (2D, 3D).

The paper's main objective is to compare two simulations of confined space fires of a floating facility concerning layer temperature and smoke plume excursion when the type and location of the fire are changed.

Paul A. Reneke and his team undertook similar research in 2001 [5], focusing on *A comparison of CFAST predictions to USCG real-scale fire tests*. This research compared CFAST simulations with experimental results for diesel, polyurethane board, and wood crib fires using natural and forced ventilation, focusing on upper smoke layer heat, ceiling temperature, and smoke layer interface. It was shown that the results of the simulations and experiments were in general agreement and also that the heat release rate varied by up to a factor of three depending on the ventilation configurations [5].

2 Material and Methods

CFAST is one of the most widely used and widely used zonal models for modelling fires and tracking the movement of combustion products in a confined space. This model is one of the simpler ones as each room of a fire is divided into two layers, an upper and a lower layer. Each layer has a uniform temperature and its evolution is described by a set of differential equations that are derived from the fundamental laws of conservation of mass and energy. The transfer of smoke and heat from one layer to the other is given by empirical correlations [1, 2].

Modelling in CFAST is quite simple, it is based on the x, y, and z-axis coordinate system. The basic idea is to create Rooms with a custom name, which we use to determine their coordinates, i.e. their length, width and height. Based on the origin of the coordinate system with the points 0, 0, 0, the other rooms are further determined concerning the coordinates of the previous ones. When simulating the fire space, the CFAST program only works with simple orthogonal coordinate systems. The modelling of the constellations' openings works on the same principle as the modelling of the rooms. It is necessary to specify the room in which the opening will be located, its length, width and height, and distance from the floor and the wall [1, 2].

When defining a fire, it is necessary to determine the room in which the fire will be located. Then its position is determined based on the x and y coordinates, and the initiation time of the fire. Fires are defined based on the rate of heat release. There are validation studies that provide values for the progress of fires and hence their definition is simplified, but the user also can define the fire independently [1].

Targets are another important part of the simulations. A Target is any object in the simulation that, when a condition is met (e.g., a certain temperature is reached), triggers the next defined activity. A Target can be a window that will be set to open when the temperature in the fire area reaches 400 °C [1].

One of the important parameters of the program is the visualization based on Smokeview. Once a simulation has been created and run and then completed, a visualization of the fire in time and space based on the 3D model can be viewed in CFAST. Within the visualization, the movement of the hot and cold layers in the individual rooms and their smokiness can be observed. Based on the embedded multiple devices, the temperature at a specific point in the space can also be monitored. Based on the visualization, selected parameters and fire characteristics of the whole simulation can be monitored [1, 2].

Like any program, CFAST has its limitations. These limitations concern, for example, the possible simulation time, which is limited to 86 400 s, and the output interval of the resulting values, which must be greater than 0. In the context of room modelling, CFAST is limited to 100 rooms per simulation, which are assumed to be rectangular parallel shapes. When modelling, it is always necessary to be aware of which rooms we are going to investigate and what shape they are. Whether they are normal rooms or special rooms, such as narrow and long corridors or narrow and high elevator shafts, in which the fire movement behaves differently and therefore the room type in the program also needs to be changed. Further limitations of the program are described in [1, 2].

2.1 Fire area modelling

As already mentioned, the selected object for modelling was a floating device, which was a dredger performing an activity on the water surface. There were four rooms in the object. Each simulation structure had to be assigned a material and thickness in each room. Fig. 1 shows the floor plan of the floating device and Table 1 shows the materials used and their dimensions in the simulation of the object. Based on the individual distances in the floor plan, the floating device space was created in CFAST. The wall thicknesses were rounded to the nearest 0.12 m for simplicity of simulation.

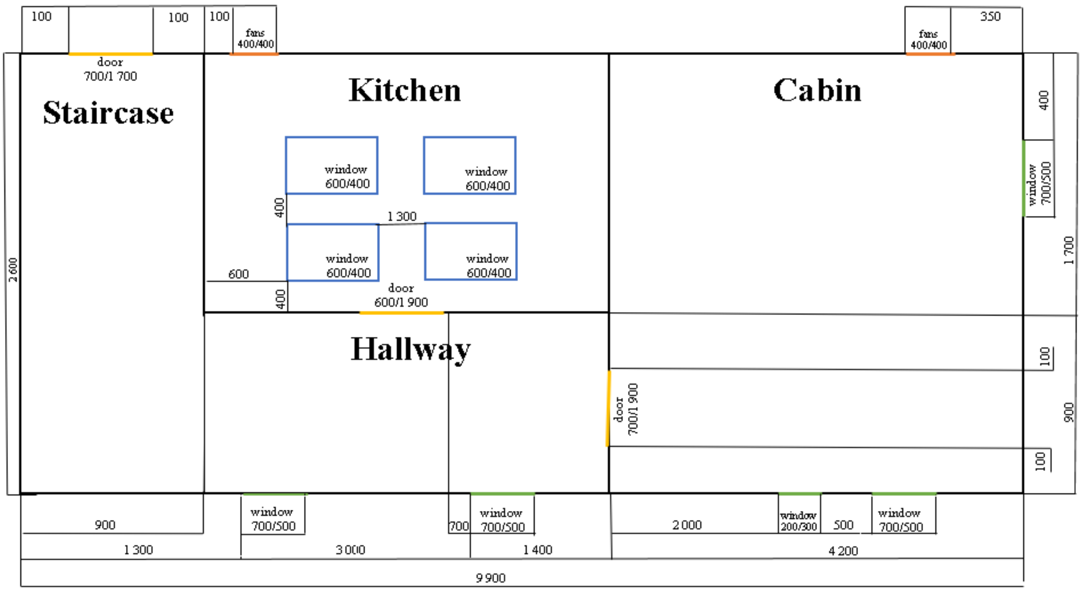

Fig. 1 Floor plan of the floating object

Tab. 1 Table of compartments and materials

Compartment	Ceiling	Dimension [m]	Wall	Dimension [m]	Floor	Dimension [m]
Cabin	Steel	0,01	Steel	0,01	Steel	0,01
	Mineral wool	0,1	Mineral wool	0,1	Plywood	0,03
	Sololite cladding	0,008	Sololite cladding	0,008	-	-
Kitchen	Steel	0,01	Steel	0,01	Steel	0,01
	Mineral wool	0,1	Mineral wool	0,1	Plywood	0,03
	Sololite cladding	0,008	Sololite cladding	0,008	-	-
Hallway	Steel	0,01	Steel	0,01	Steel	0,01
	Mineral wool	0,1	Mineral wool	0,1	Plywood	0,03
	Sololite cladding	0,008	Sololite cladding	0,008	-	-
Staircase	Steel	0,01	Steel	0,01	-	0,01
	Mineral wool	0,1	Mineral wool	0,1	-	0,03
	Sololite cladding	0,008	Sololite cladding	0,008	-	-

2.2 Defining fires

Two simulations were created as part of the research. The first simulation dealt with a fire where the crew of the vessel was on a floating device, and the vessel was connected to the power grid. The second simulation dealt with a fire during which the vessel was disconnected from electrical power and no crew members were on board. In both simulations, the bunk bed caught fire first and then after 100 seconds the fire was transferred to the couch. The fires were defined based on the attached CFAST file, which contains a large number of predefined fires. The bunk bed fire had a maximum output of 4,620 kW in 240 s, and the couch fire 3,447 kW in 400 s. Table 2 provides data to define the fire using the evolution of the heat release rate over time. Both fires were located in the cabin. The bunk bed fire had coordinates x = 3.5 m and y = 0.7 m. The couch fire had coordinates x = 0.5 m and y = 2.1 m.

Tab. 2 Heat release rate of fires

Bunk bed fire		Couch fire	
t [s]	**HRR [kW]**	**t [s]**	**HRR [kW]**
0	0	0	0
100	100	100	100
200	200	200	900
300	1 300	300	1 800
400	900	400	3 447
500	400	500	1 800
600	200	600	600
700	0	700	600
		800	400
		900	300
		1 000	200
		1 100	0

Based on the defined fires and situations, two scenarios were created:

- A fire broke out while the floating equipment was passing on the water surface, crew members were on board. After the fire broke out, the heat detector identified this fire, which triggered the cabin and galley ventilation, and the cabin ventilation grille. The windows of each room were closed. The doors from the deck to the corridor and from the corridor to the cabin were also closed, the door between the corridor and the galley was open.
- A fire broke out on the vessel during maintenance of the floating equipment. There were no crew members on board and the vessel was disconnected from the electrical alarm system. The fire was caused by a thief who, while exploring the vessel, left the door ajar and used the cabin window, which he had left open, to escape. As the vessel was disconnected from the electrical supply, the ventilation and fire detectors were not working.

2.3 Defining targets

The research used five targets in the simulations. The targets were located in the rooms where it was assumed that the fire intensity would cause the largest changes in space temperatures, i.e. the cabin and the corridor. The location of the targets is shown in Fig. 2. Targets were used to open windows and doors, were located in the centre of the opening and were activated at 150 °C (doors) and 330 °C (windows). These temperatures were intended to simulate the breakage of the glass moulding on the doors and windows in a fire of a given temperature.

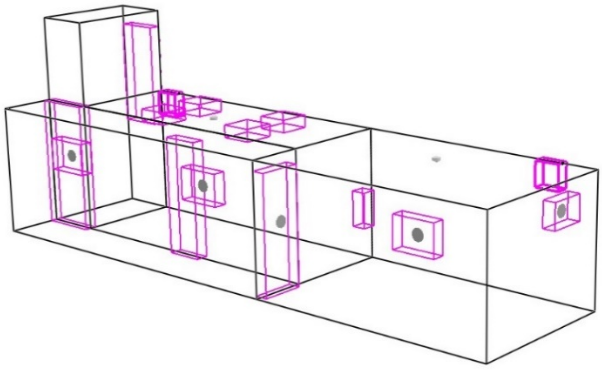

Fig. 2 Location of targets

3 Results and Discussion

Within the simulations, the monitored parameters were the temperature of the burning layer (°C), the temperature of the cold layer (°C) and the height of the smoke layer from the floor (m). Within the results, three graphs were created, in which the monitored parameter was always compared between the two simulations. The selected parameter was monitored not only during the fire but also after the fire was over and up to a time of 3 500 s after the start of the fire. The first monitored parameter was the temperature of the hot smoke layer, whose evolution graph in both simulations in the cabin space is shown in Fig. 3.

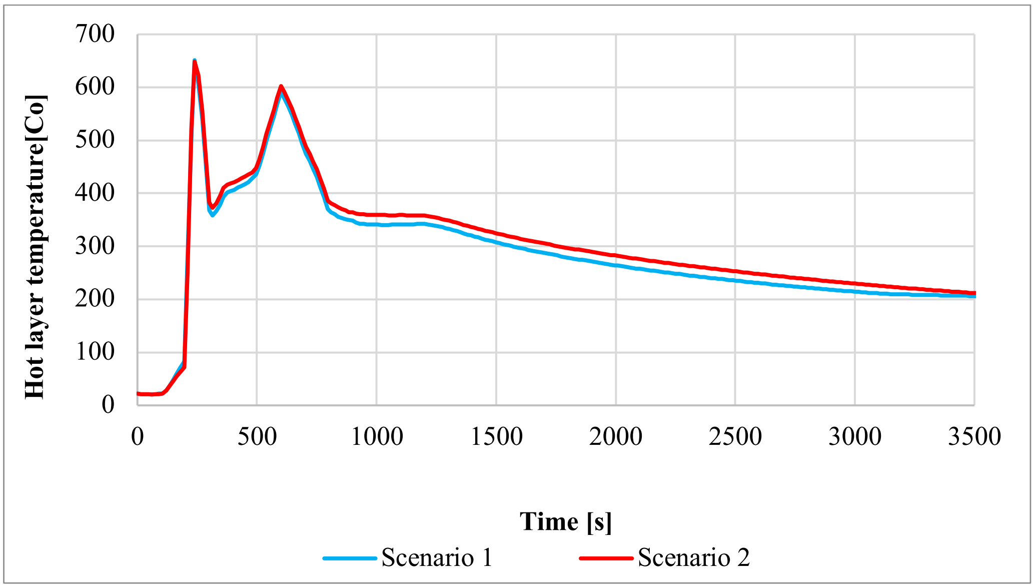

Fig. 3 The development of the hot smoke layer in both scenarios

As can be seen from the plot, the evolution of the temperature of the burning layer is approximately the same in both simulations. Up to 300 seconds, the temperatures evolved the same. From 300 seconds onwards, the temperature was lower in simulation 1. This difference was mainly because the vessel in the second scenario was disconnected from electrical power and thus the ventilation of the cabin space was not started. The windows and doors remained open anyway after the thresholds on the targets were reached. The maximum temperature reached in the space in both simulations is 650 °C. This temperature was probably reached at the moment when, after the transfer of the fire from the bed to the couch, the full-blown couch fire phase occurred. After the fire was over, the temperature of the upper smoke layer decreased steadily. The second parameter monitored was the temperature of the lower student layer, which contains fresh air. A graph of the evolution of this temperature is shown in Fig. 4.

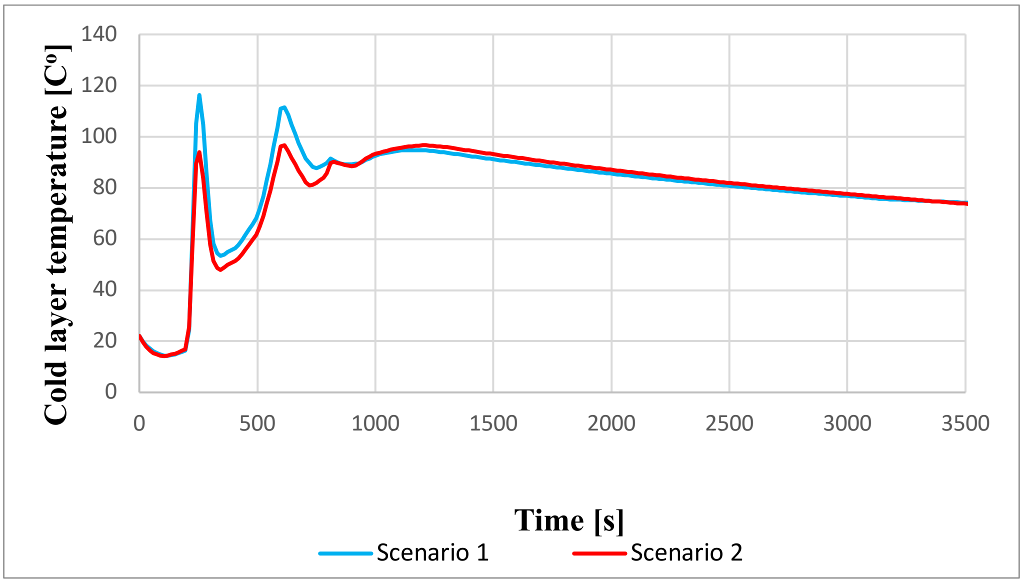

Fig. 4 The development of the cold smoke layer in both scenarios

The development of a cold layer of fresh air during a fire is similar to that of a hot layer. First, the temperature in the space reaches its two local maxima, then it drops slightly and rises again, and then it drops constantly. The main difference is that the temperature in the first scenario is higher than in the second fire scenario, despite the presence of a fan in the space to dissipate the heat. This fluctuation could be because the fans are located at the top of the steins, especially below the ceiling, thus the fans were removing heat from the upper hot layer of smoke and not from the lower cold layer of fresh air. However, at 960 sec the change occurred and the temperature of the cold layer in scenario 2 was higher. After the fire was over, the temperatures in the plume gradually became more uniform until they were the same at the end of the observed time, at 3,500 sec. The last parameter monitored was the height of the smoke layer from the floor. A graph of the evolution is shown in Fig. 5.

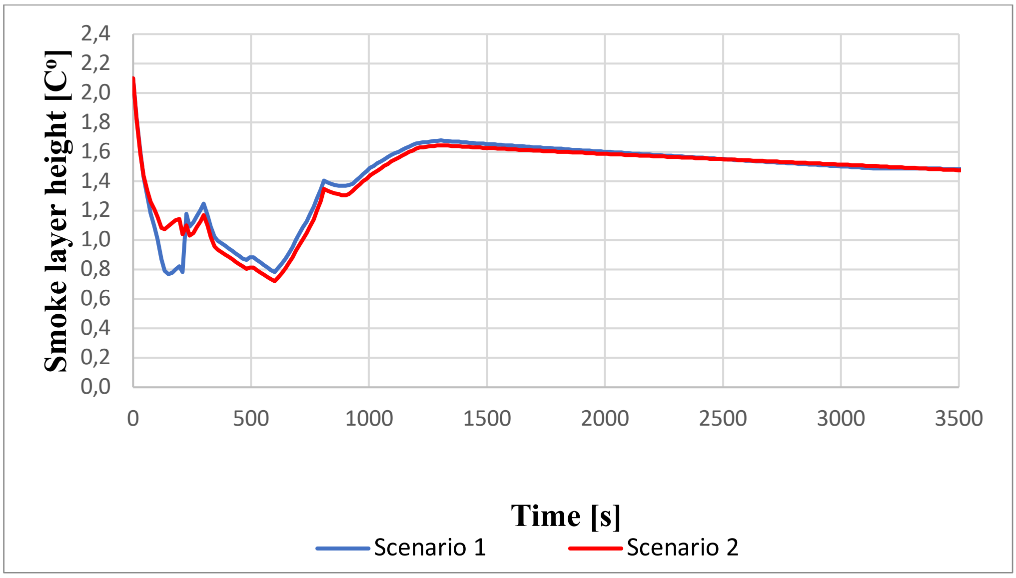

Fig. 5 The development of the smoke layer height in both scenarios

Similar to the tracking of the other fire parameters, the smoke layer height follows a similar pattern for both scenarios. At first, there is no smoke layer in the fire area, but it gradually starts to form and decrease. The smoke layer from scenario 2 is the lowest at 0.72 m from the floor. Since in this scenario the ventilation, the fan, was not running, there was not as much venting of combustion products from the area. After the fires were over and gradually the smoke layer stabilized and began to rise. However, at approximately 1,350 seconds the smoke layer began to slightly decrease again, which may have been due to the slight release of combustion products after the material had burned out.

4 Conclusions

Based on the results obtained, we can see how important fire protection equipment is in buildings. Already in the second scenario, when the vessel was not connected to the electrical power, it can be seen that when only one device, such as a fan, is not working, this has an impact on either the temperature of the individual layers or the height of the smoke layer itself. When the smoke layer is hot, the differences between the two scenarios are around 20°C, which is a big difference, and could cause potential harm to a person who would be in an area where fire engineering equipment is not in use. Overall, the paper provides insights into fire safety management on floating objects using fire simulation software. As part of further research work, it would be valuable to validate the simulation results obtained experimentally, focusing on a wider range of floating facility types.

Fire safety equipment is an important part of any building or structure. Sufficient electrical power is required for their operation and should be provided whether or not persons are present in the building. For the floating equipment itself, it would be advisable to have a backup power source to enable the operation of the fire protection equipment.

References

[1] Peacock RD, Reneke PA, Forney GP. 2017. CFAST – Consolidated Model of Fire Growth and Smoke Transport. (22 June 2023; https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1889v2.pdf)

[2] Peacock RD, Mc Grattan G, Forney GP, Reneke PA. 2015. CFAST – Consolidated Fire and Smoke Transport. (22 June 2023; https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1889v1.pdf)

[3] CFAST. 2023. Office of environment, health, safety and security. (22 June 2023; https://www.energy.gov/ehss/cfast)

[4] CFAST 6.2. 2023. Software. Informer. (22 June 2023; https://cfast.software.informer.com/)

[5] Reneke PA, Peatross MJ, Jones WW, Beyler CL, Richards R. 2001. A comparison of CFASRpredictions to USCG real-scale fire tests. (27 November 2023; https://www.researchgate.net/publication/245382716_A_comparison_of_CFAST_predictions_to_USCG_real-scale_fire_tests)