UAV APPLICATION IN HIGHRISE BUILDING FIRES

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Abstract: *With the development of society, tall and very tall buildings became a common form of architecture. To extinguish the fires that occur in these types of buildings, special vehicles and newer drones are needed, the latter facilitating a much more effective reconnaissance, a much more successful intervention and the elimination of dangers (requesting and exposing crews to work at height) . Saving the lives of people and animals, respectively material goods are the main objectives that firefighters must meet in any type of intervention.*

Keywords*: building, height, fire, intervention, special vehicle, drone.*

1. INTRODUCTION

For working at height, firefighters use intervention vehicles that allow the rescue of stranded people, locating and extinguishing fires that broke out on the upper floors of tall and very tall buildings. Recently, drones/UAV(Unmanned Aerial Vehicle) have also started to be used for fire detection (eg forest fires in Greece, this summer), equipped with thermal imaging cameras, respectively drones for extinguishing fires.

2. USE OF HEIGHT INTERVENTION TRUCKS

According to the Fire Safety Regulations of buildings, indicative P 118 of 1999 [1], a tall building is an above-ground civil (public) construction, in which the floor of the last usable level is located more than 28 m from the land (roadway) accessible to vehicles firefighters on at least two sides of the building.

According to the Fire Safety Regulations for Buildings, indicative P 118 of 1999 [1], a very tall building is a civil (public) building in which the floor of the last usable level is located at a height of 45 m or more from the land accessible to motor vehicles. firefighters.

The operations for height intervention performed by firefighters on the spot consume time and are limited by the position of the truck in the field. In order to be able to intervene, it is necessary to ride the truck, provide rescuers and perform work at height.

In order to work with the escalator, it is necessary to maneuver the control panel for the operation of the riding supports.

FIG. 1. Escalators used by firefighters in intervention

FIG. 2. Control panel with remote control for the operation of riding supports

The mounting brackets can be positioned freely according to the working situation, using the bearing control buttons or levers. The system takes into account the position of the supports and immediately shows the maximum possible range of action regardless of the direction of the work platform, for the selected load [2].

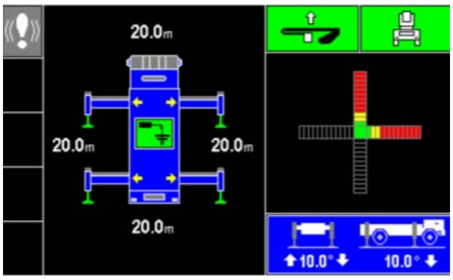

FIG. 3. Riding support window

FIG. 4. Control panel for arm operation

After running the truck, the crane arm is maneuvered using the control panel so that rescue personnel can reach the area affected by the fire.

After performing the operations presented above, you can start working on the truck itself, but unfortunately all this requires significant time, the rescuers being limited in terms of working at height.

FIG. 5. Rescue intervention using escalator

FIG. 6. Positioning of the escalator in order to use

The positioning of the truck in order to perform the work at height is performed according to a simple procedure based on Pythagoras' theorem.

Using Pythagoras' theorem, the relationship between these three variables is:

$$C^2 = A^2 + B^2 \tag{1}$$

Working at height becomes a challenge once the maximum height to which an intervention escalator can operate is exceeded, thus creating difficulties for rescuers.

MAGIRUS has designed the world's tallest lifeline, the Magirus M68L, which can reach a height of 68 m [3].

FIG. 7. MAGIUS M68L escalator

According to the European standards EN 1846 and DIN EN 14043 this special vehicle complies with all the requirements necessary to fulfill its duties: rescue people from heights, extinguish fires and provide technical assistance [3].

FIG. 8. Lifting and stretching the ladder package of the MAGIRUS M68L escalator

FIG. 9. MAGIRUS M68L escalator mounting system

This escalator is equipped with an XLL VARIO riding system, specially designed by MAGIRUS to offer maximum stability to escalators that rise more than 55 m [3].

The truck also has an RC 300 type platform that withstands a load of 300 kg and has various systems necessary to work at height [3].

FIG. 10. MAGIRUS M68L6 escalator platform

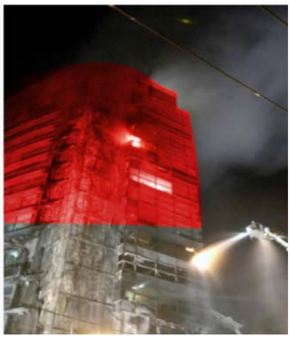

FIG. 11. Height from which it is no longer possible to intervene with the intervention escalator (red color)

But a very important detail is the presence of the RE300 rescue lift that allows the evacuation of a maximum of 3 people from a height, with a load capacity of up to 300 kg [3].

Although this escalator reaches an impressive height, there are constructions that exceed it, making the intervention of firefighters much more complex.

Tall and very tall buildings are a big challenge in terms of extinguishing fires, because firefighters cannot always control them because of the height at which they occur.

FIG. 12. High altitude fire

FIG. 13. Sky Tower Building

The tallest building in Romania, Sky Tower with a height of 137 m in Bucharest, is a good example of a building in which intervention becomes difficult when a fire occurs on the upper floors exceeding the lifting limit of the intervention escalators used by firefighters [4].

To solve this problem, various technologies have been developed for locating and extinguishing fires, in order to reduce risks and increase the level of efficiency. In order to ensure the intervention at high altitudes, drones for fire detection and drones for firefighting were developed.

3. USE OF DRONES FOR FIRE DETECTION AND EXTINGUISHING

The drone is an unmanned aerial vehicle (UAV). Drones can be completely or partially autonomous, but most often they are controlled remotely by an operator. As a result of research, various uses of UAVs have been developed in various areas of study [5].

FIG. 14. Drone (UAV) [17]

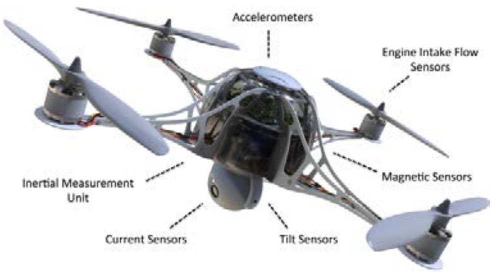

FIG. 15. The equipment of a drone

The front or back of the drone is where all the sensors and navigation systems are present. The technical materials used to build the drone are extremely complex composites, designed to absorb vibrations, which are very light [6].

The drones are controlled by a remote ground system (GSC). A UAV has two parts, the drone itself and the control system [7, 15].

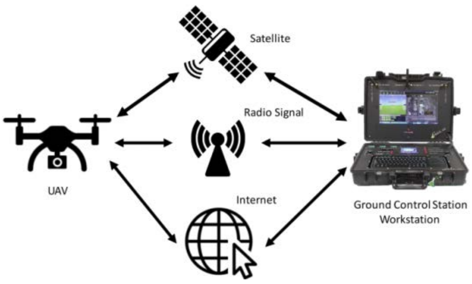

FIG. 16. Drone control

3.1. Drone classification

3.1.1. Fundamental classification

At the basic level according to [7], drones can be classified into: fixed wing drones; multirotor drones; hybrid drone.

Fixedwing drones need more space to launch, because their wings need speed to generate lift.

FIG. 17. Fixed wing drone [18]

FIG. 18. Multirotor drone

Multirotor drones use rotating wings to lift and do not need much space to launch because they are capable of vertical take-off and landing (VTOL)and they can also float vertically, but have autonomy and limited flight time.

Hybrid drones have the characteristics of both fixed wing and multirotor drones, for example rotor to perform VTOL and wings to navigate longer distances.

FIG. 19. Hybrid drone

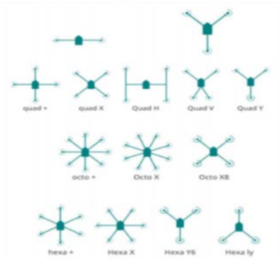

FIG. 20. Methods of assembling the shape of drones

The most used, multirotor drones, can be classified according to the number of propellers: bicopter - 2 propellers; tricopter - 3 propellers; quadcopter - 4 propellers; hexacopter - 6 propellers; octocopter - 8 propellers.

3.1.2. Classification by weight

As there is currently no internationally recognized system for drone categories, they are classified by weight according to different country-specific criteria. For example, the Australian Civil Aviation Safety Authority (CASA) classifies drones by their weight into: micro: weight equal to or less than 100 g; very small: weight between 100 g and 2 kg; small: weight between 2 kg and 25 kg; averages: weight between 25 kg and 150 kg; large: weight greater than 150 kg.

3.1.3. Classification by level of autonomy

Depending on the level of autonomy, drones can be classified into:

- system piloted by an operator, the operator has full control over the system;
- system delegated by an operator, the system may perform certain actions alone that the operator can activate or deactivate;
- operator-supervised system: actions based on certain data that can be initiated by the operator or the system;

• fully autonomous system: the system converts (transforms) the commands given by the operator into actions, the actions can be modified by the operator.

3.2. Concept

The added value of using drones is given by the significant improvement of the analysis of the situation by obtaining accurate, geo-referenced and real-time information, access to difficult areas for intervention, thermal / spectral assessment of fire and intervention area, firefighting actions, search and rescue [8, 16].

At the third conference "International Conference for Convergence in Technology" held in Pune, India, in 2018 it was proposed the conceptual design of a "Fire Brigadier Quadcopter" that can be used to find people caught in the fire and save them. in a safe way. The concept describes a four-rotor drone, built on an X-shaped housing with 3 wing propellers or 4 wing propellers, on which a fireproof carrier is mounted.

FIG. 21. Concept Fire Brigadier Quadcopter

FIG. 22. Forest fires in Greece in 2021

The concept uses a USB webcam for directional control and live video streaming, while the thermal camera aims to find people in danger due to low body temperature compared to hot surroundings. The conveyor can be used for various accessories, such as fireproof blanket or fire extinguisher. This concept was designed to help potential victims in an emergency, not necessarily to extinguish the fire itself [9].

This year, Romanian firefighters were seconded to help extinguish forest fires in Greece. They were provided with a drone for fire detection.

Similar to the drone used by Romanian firefighters in Greece, the T60 drone produced by the JTT company is equipped only with a fire detection and search-and-rescue system, being specially designed in case of forest fires. Thus, rescuers can easily identify the burned areas and people within range of the fire development area.

FIG. 23. JTT T60 drone

FIG. 24. Detection of fire risk areas using JTT T60 drone

These UAVs have reliable performance: flight control, GPS positioning, data recording, digital communication systems through ground control systems, mounting equipment next to conventional aerial speakers, high definition cameras, UAV capture network, image Infrared thermal, powerful light reflector and other functions, can be equipped with microwave, 3G / 4G and other transmission equipment, performs the transmission of high-definition analog or digital images.

The detection of the burned areas is performed on the basis of the mounted camera, obtaining a detailed recognition on the indicated area [10].

On July 31, 2020 the Chinese company, EHang announced the launch of the world's first fully autonomous high-load UAV EHang 216F, based on an older model EHang 216, designed to fight high flames. This model was developed with the increasing appearance of tall and very tall buildings, the company plans to distribute these UAVs in most fire departments in China and globally [11].

FIG. 25. EHang 216F fire extinguishing drone

At the launch ceremony in Yunfu, China, the company demonstrated the drone's functionality and efficiency. The EHang 216F model has a maximum flight height of up to 600 m and can carry up to 150 l of aeromechanical foam,respectively6 dry powder based fire extinguishers. The aircraft uses a light zoom camera to locate the exact position of the fire and then begins moving to the established location. Using a laser device, it triggers the window breaker after which it activates the fire extinguishing module by dropping the extinguishing bombs and pushing the aeromechanical foam from the equipment to the place affected by the fire [11].

Aeromechanical foam is the extinguishing agent that neutralizes the fire by separating the ignition source from the burned surface and cooling the flammable material. It is advantageous for extinguishing class fires (A, B).

Depending on the nature of the materials or combustible substances, fires are classified according to the European standard SR EN 2-2004 in fire classes.

In Romania, fire classes are divided as follows [12]:

- Class A - combustible solid materials (wood, paper, rubber products);
- Class B - flammable liquids (oil, gasoline, alcohol);
- Class C - flammable gases (butane, methane, hydrogen);
- Class D - combustible metals and their alloys (sodium, potassium, aluminum);
- Electrical equipment (formerly called Class E);
- Class F - vegetable or animal oils and fats from cooking media.

FIG. 26. EHang 216F drone intervention scenario at a tall building

FIG. 27. EHang 216F aircraft at a fire station in China

These UAVs were distributed to fire stations in China, and are used for intervention in the district of each station, over a distance of 5 km.

Using the advanced technology of this concept, a "swarm of drones" can be launched to the intervention site by remote maneuvering, which can reach the intervention site before firefighters [11].

The extinguishing method used for this drone is performed by automatically removing the aeromechanical foam from the tank to cover the affected area in about 3.5 s through the discharge hose provided.

FIG. 28. EHang 216F drone extinguishing hose

3.3. Drone specifications

The aircraft has the following technical specifications [11]:

Table 1- EHang 216F drone characteristics

Length	7.33 m	Battery power time	120 min
Width	5.61 m	Flight time	21 min
Height	2.20 m	The volume of aeromechanical foam	150 l
Maximum flight speed	130 km/h	Number of projectiles	6

3.4. Drone construction

When designing a drone specially designed to extinguish fires, the main risk factor that may impose difficulties in achieving the objective, namely fire, must be taken into account.

Fire is the process of rapid oxidation with light emission. When a fire breaks out, it forms the basis of the burning triangle.

The fire breaks out when the three factors (energy source, fuel, oxidizer) come together and create a chemical reaction that favors the beginning of the combustion process.

FIG. 29. The burning triangle

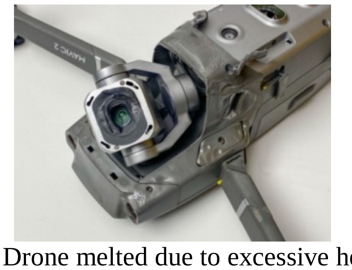

FIG. 30. Drone melted due to excessive heat, [19]

The strategy by which the fire can be annihilated is to eliminate one of the three factors: material cooling; decrease in oxygen concentration; removal of the ignition source.

The fire affects the drone by changing the air currents that cause turbulence and potential damage caused by the drone's heat.

The turbulence is generated by the fire, because the hot air of the fire creates the air flow upwards towards the drone. Drones are traditionally light and fragile, so turbulence can have a major impact on its navigation process. Heat can also cause damage to mechanical and electrical components if overexposed.

Most drones have a plastic frame and body, as the plastic provides a strong enough and lightweight base. However, plastic has a lower melting point (70 - 1200C) compared to other materials, such as metals, and this can cause problems if the drone stays around the fire for too long.

There are several ways to solve the problem of turbulence. An example would be the solution of the Navier-Stokes equations, with conservation of mass [13]:

$$\frac{\partial}{\partial t}(\rho \mathrm{u_x}) + \nabla(\rho\vec{\mathrm{u}}\mathrm{u_x}) = \nabla(\mu\,\nabla u_x) - \frac{\partial p}{\partial \mathrm{x}} + \rho \mathrm{g_x} \quad (2)$$

$$\frac{\partial}{\partial t}\left(\rho \mathrm{u_y}\right) + \nabla\left(\rho\vec{u}\mathrm{u_y}\right) = \nabla\left(\mu\,\nabla u_y\right) - \frac{\partial p}{\partial \mathrm{y}} + \rho \mathrm{g_y} \quad (3)$$

$$\frac{\partial}{\partial t}(\rho \mathrm{u_z}) + \nabla(\rho\vec{\mathrm{u}}\mathrm{u_z}) = \nabla(\mu\,\nabla u_z) - \frac{\partial p}{\partial \mathrm{z}} + \rho \mathrm{g_z}\ , \quad (4)$$

where:

μ - dynamic viscosity;

ρ - density;

g - gravitational acceleration in each direction.

3.4.1. System architecture

When designing a drone, different situations that may arise when using it are taken into account. All calculations are performed using a series of normal parameters.

Table 2 - Air parameters

Property	Value	Property	Value
Air density ρ	1,205 (kg/m^3)	Air temperature T	293 (K)
Kinematic viscosity v	15.11e-6 (m^2/s)	Thermal conductivity λ	0.0257 ($W/(m \cdot K)$)
Specific air heat cp	1,005 ($J/(kg \cdot K)$)	Acceleration g	9.81 (m/s^2)

Most often, drones are equipped with a water-based extinguishing system because it is easy to purchase, cheap and has a high capacity to neutralize the fire by cooling the materials.

When designing the extinguishing system for a drone, the most important element for its efficiency is the value of the critical flow of water used.

Critical flow of water(CF) is the water flow required to neutralize the fire on a certain number of linear meters or on the entire surface of the fire.

For example, this flow rate can be calculated according to the size of the fire, using Hansen's method [14]:

$$CF = \frac{1}{\eta_{water} \cdot L_{v,water}}\left(\left(\phi \Delta H_c - L_v\right) \cdot \dot{m}''_{cr}\right) + \dot{q}''_E - \dot{q}''_L\ , \quad (5)$$

in which:

CF - critical water flow;

η_{water} - applied water efficiency;

$L_{v,water}$ - enthalpy of water exchange at 283 K and vapor at 373 K;

ΔH_c - effective ignition heat;

L_v - heat when vaporizing the fuel;

$\dot{m}''_{cr}$ - speed of mass combustion on a unit surface of the fuel at the critical point;

$\dot{q}''_E$ - external heat flow;

$\dot{q}''_L$ - heat loss at the surface.

Through this formula it is possible to establish and design an extinguishing system, finding out the minimum capacities that it must present.

4. PROBABLE EVOLUTIONS

According to [14], theoretical and experimental studies conducted in the United States and the European Union show that although the hand-operated drone model has certain benefits, it is often limited in efficiency, the concept requiring improvements taking advantage of technological developments in communications and IT.

More advanced concepts consider the intervention with "swarms of drones" able to interact with each other and to coordinate the intervention by using artificial intelligence algorithms, with the ground support of an operational center; automation in the supervision of fire risk areas; rain simulation by using multiple ,,swarms of drones”; automated response to fire detection based on predictive analysis that includes elements of topology, meteorology, probabilistic calculation, etc.

Vulnerabilities such as the low speed of data transfer from the UAV human operator to the intervention team, the impossibility of real-time compilation of data from several drones to raise awareness, as well as their saving for further audit of the intervention can be overcome by use of integrated drone control software platforms.

5. CONCLUSIONS

From the experience of the interventions it was found the good complementarity of the two variants of extinguishing at height, by using the intervention vehicles and drones, special results are obtained. Their use provides special support to firefighters in order to extinguish fires in tall and very tall buildings, by providing an overview of the affected area and coordinating a much more effective intervention by the intervention commander.

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