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Modeling operations on suppression of forest fires on a helicopter training simulator

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The article discusses some scientific and technical issues (problems) and solutions on the example of the development of fixed base full flight Mi-8 helicopter simulator with the sling-load operator part-task trainer (SLOPTT), namely:

- creation of a mathematical model of the BB movement on the helicopter's external sling in all phases of flight (the rise of the unfilled BB, transportation to the pond and filling with water, the flight to the fire, pouring water on the fire), taking into account the actual characteristics of the BB, external sling load, the main rotor's inductive stream influence upon BB movement;
- modeling of forest fire spread taking into account actual characteristics of vegetable fuels, wind, terrain, weather conditions, the interaction of the water poured with the fire;
- modeling of thermal airflows and smokes over the fire zone;
- manufacturing of a stereoscopic visual system of the SLOPTT.

Introduction

Fighting forest fires has always been a topical problem for many countries in the world. And this is no coincidence, for forest fires are a natural disaster and are extremely hazardous both for the state's natural resources and human life. Entire cities, regions and ecosystems often appear under threat. The summer 2010 in Russia, forest fires in Europe and Israel proved that the problems of predicting forest fires emersion and development and also the methods of fighting them have recently gained even more importance.

Aviation technologies, including the use of transport helicopters, have recently acquired a greater role in open fire suppression in domestic and international practice. The «vertical way» of suppression, which consists of water being dumped from a special tank ("Bumby Buckets" (BB)), transported on a helicopter external cargo sling, is the most commonly used one (Figure 1).

Figure1: BB-5 on a helicopter external cargo sling

This technology is relatively new and, as practice shows, requires considerable aircrew experience and cooperation, which are often impossible to acquire in real-life conditions.

It should be mentioned that employing modern equipment (aircrafts and rotorcrafts) to fight the fires multiplies the cost of their suppressing and localizing; and it is only possible to bring costs down as long as it is used economically and effectively.

For the crew to acquire practical skills and to increase their psychological stability in special cases it seems reasonable to use a simulator appropriately reequipped for modeling fire suppression operations with the help of the bucket.

The crew's perception of the "flight" on a simulator largely depends on the adequacy of the modeling:

1. Flight dynamics of the helicopter with a bucket (BB) on an external cargo sling in the fire zone [1]
2. External (visual) conditions, including the effects connected with a forest fire burning in the helicopter's "flight" zone. smoke, flames and thermal flows above the fire zone
3. Crew's task activities when suppressing the fire (i.e. the quality of simulating the crew's workplaces)

We can only achieve the following result with an integrated solution of the above mentioned tasks : the crew "believes" the "flight" on the simulator real (Figure 2)

Next the present article considers certain solutions for these research and technology tasks using a fixed base full flight Mi-8 helicopter simulator with the sling-load operator part-task trainer (SLOPTT) employed in a Federal state unitary enterprise Training aviation center "Avialesookhrana" (Pushkhino city, Moscow region).

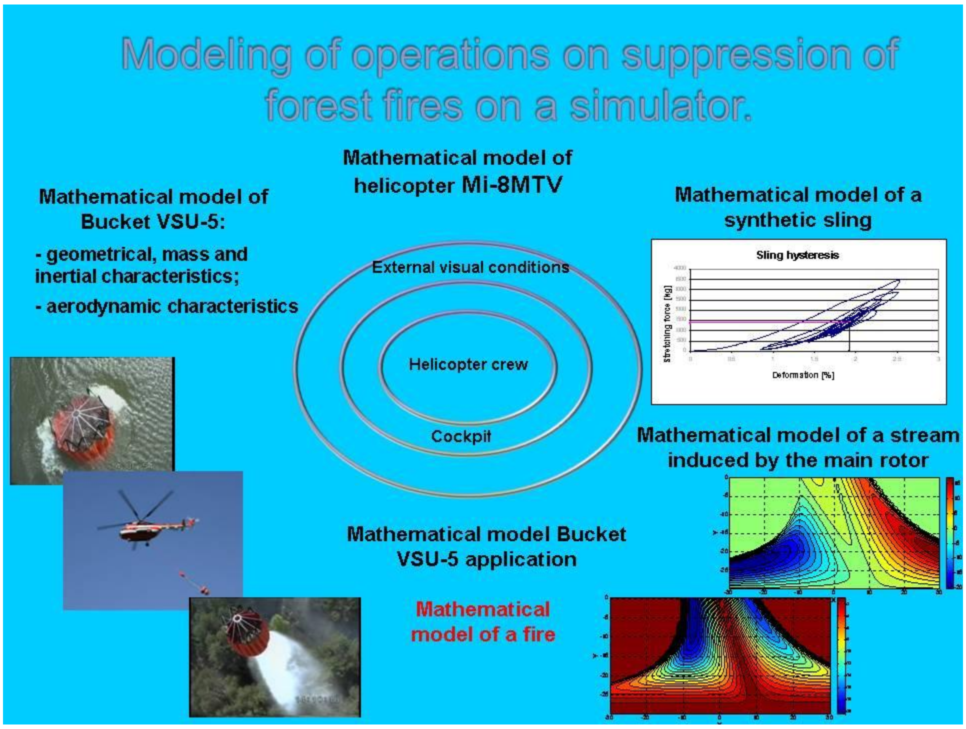


Figure 2: Modeling scheme

1. A Fixed base Mi-8MTV «Forester» Full Flight Simulator (Avialesookhrana Training Centre)

A fixed base Mi-8MTV «Forester» Full Flight Simulator consists of the following main parts:

- the helicoter's cockpit and cargo cabin (Figure 3,4)
- computing system
- a project visual system for the pilots (Figure 5)
- external conditions visualization system for the external cargo sling operator (Figure 6,7)
- working place for the instructor –training supervisor

Pilots' cockpit and cargo cabin have been made using the front part of the helicopter's Mi-8 fuselage (Figure 3). Two workplaces for the command pilot and second pilot have been equipped in the pilots' cockpit. The hardware has been reequipped for interaction with the simulator's computing system. The controls (the cyclic and collective, and the rudder pedals) are real Mi-8 controls. The interior of the cockpit is absolutely identical with the real cabin's one (Figure 4).

Figure 3:Cockpit and cargo cabin

Figure 4: Interior of cockpit

The digital computing system is based on IBM-compatible personal computers that form a computing local network by means of high-speed network interface cards.

The analogue equipment of the cockpit is connected to the computing system by means of a special computer unit – an equipment interface device.

External conditions visualization system for the pilots is a six-channel projective screen complex with a spherical screen and horizontal and vertical look-up angles of 220º and 70º respectively. The system projecting external conditions based on serial IBM-compatible computers is characterized by 1600x1200 pixel resolution and image frequency of at least 50 Hz. (Figure 5)

Figure 5: Project visual system

We have faced some difficulty while developing an external conditions visualization system for the external cargo sling operator, whose workplace is in the cargo compartment, besides, he monitors the outside of the compartment both through the cargo door and the compartment's side door, and the look-up angles should correspond to the real ones. As a result, we have found and implemented the following solution: the external cargo sling operator monitors the area outside the compartment through virtual reality glasses (which imitate protective glasses worn during real flights) with the look-up angles of ~32ºx24º in the direction of gaze, which is determined by the ultrasonic tracker system UM-16.Emitter block is fixed on the protective helmet, and the receivers are installed in the cargo compartment working area. Processing data concerning the distance between the emitter block and selected group of receivers provides information both on the position and the orientation of the operator's head in the cargo compartment. (Figures 6,7)

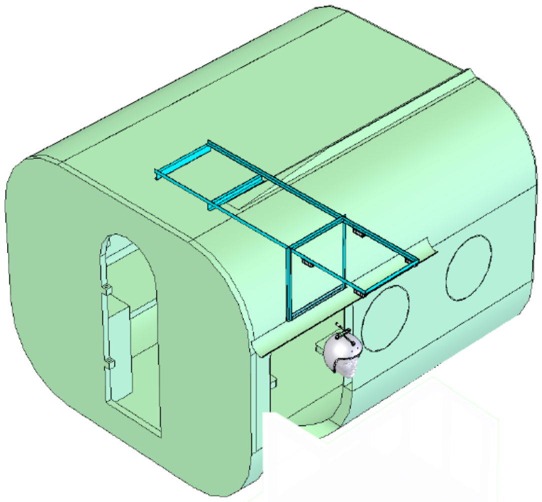


Figure 6: Ultrasonic tracker system UM-16

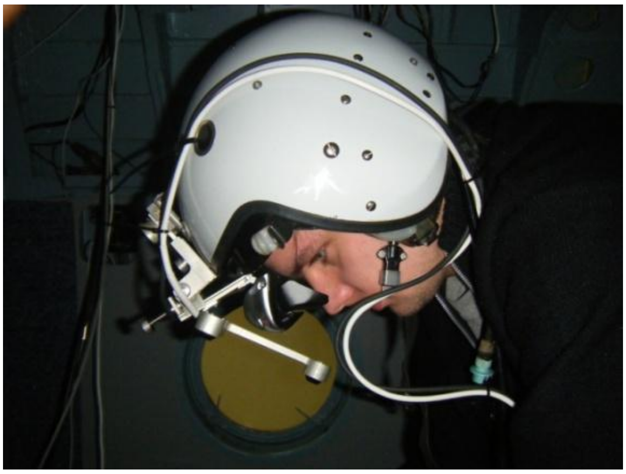


Figure 7: Cargo sling operator's visual system

The workplace of an instructor - a training supervisor – is a console with three monitors, a keyboard and a communication headset that allows him to control the training process:

- to observe what the trainees' are doing by means of a TV image from the cameras installed in the simulator's cockpit and cargo compartment
- to monitor the helicopter's flight both from the outside and from the pilot seat.
- to modify the training plan on-line, and in particular to enter the helicopter's systems failure, to change weather conditions etc.
- to establish voice communication with the trainees in the simulator

2. Modeling the Flight of a Helicopter With a BB

Modeling the motion of a helicopter with a BB on an external cargo sling is a rather complicated mechanical task, as, despite seemingly simple – the motion of a pendulum with a mobile pivot – the following factors have to be considered (I refer you to [1] for more detail]):

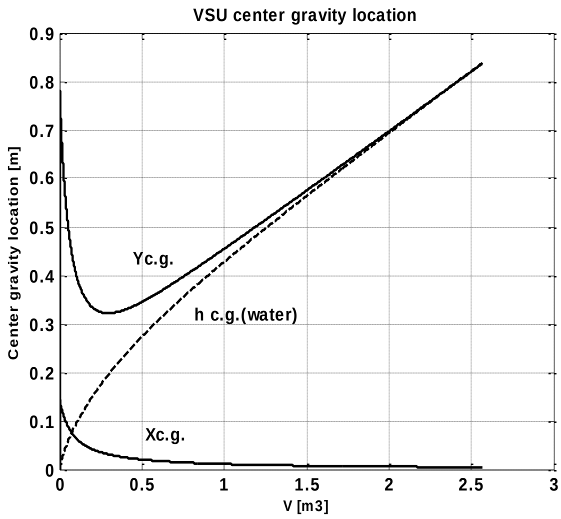
- a BB is a body with a changing form with variable aerodynamic, mass and inertial characteristics (Figure 8)

- a BB is transported by means of both steel cables and synthetic slings with essentially non-linear "deformation-force" characteristics, including hysteresis (Figure 9);
- On some regimes (lifting a BB, putting it on the ground, filing with water) the BB is in the zone of the helicopter's main rotor inductive stream influence (Figure 10).

Moreover, it turned out non-trivial to make the following adequate :

- the model of a BB motion during the lifting/putting on the surface, including dragging it on the ground
- the model of filling a BB with water from a pond and dumping it on the fire

It should be mentioned that considering the above listed factors will not make the mathematical model too complicated. Pilots and operators who have participated in assessing the simulator strongly feel the inadequacy of the "flight" with a BB, especially at the above mentioned regimes.



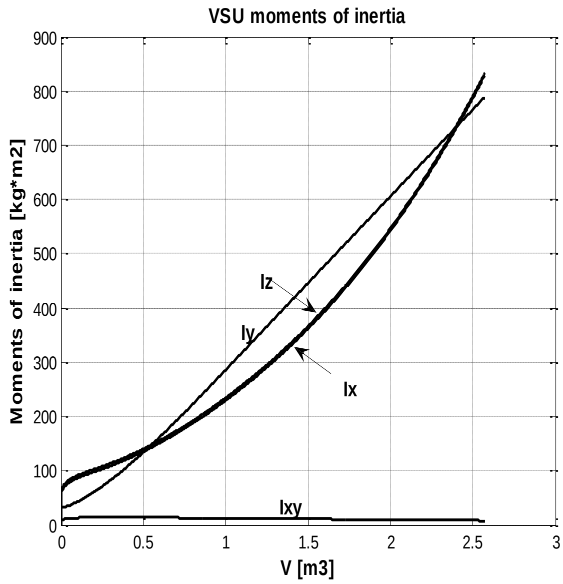


Figure 8: BB gravity centre location and moments of inertia changing against the amount of liquid

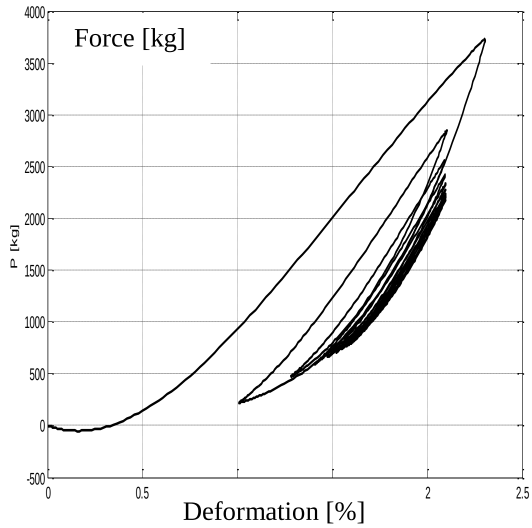
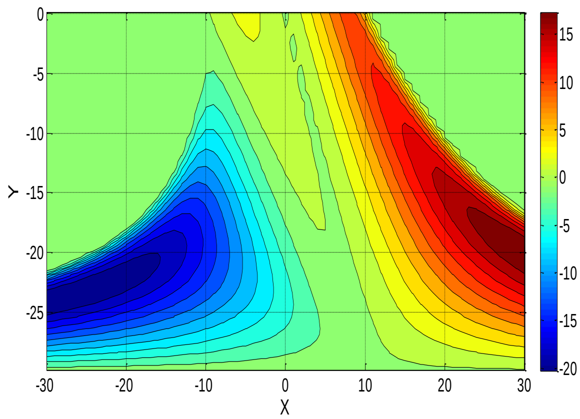
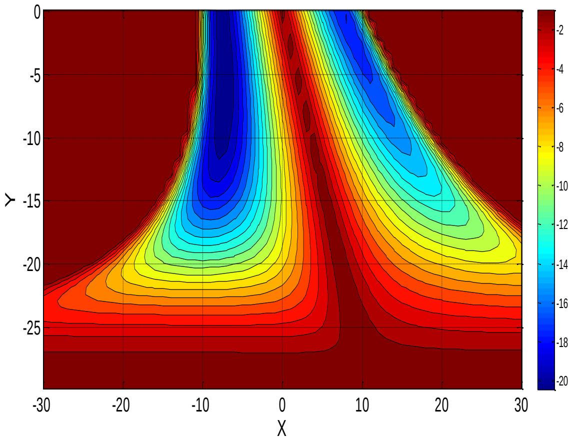


Figure 9: Elastic hysteresis of the sling LT-synthetic high-molecular fabric-48-600 (mathematical model)



a) longitudinal velocity Vx (m/sec)



b) vertical velocity Vy (m/sec)

Figure 10: Induced velocity isolines in the plane under the rotor with Z=0:

3. A forest fire model

3.1 A forest fire spread model

Adequate modeling of visual conditions in a forest fire zone (smoke, flames, thermal flows above the fire zone) is a prerequisite for a simulator, because, as has already been mentioned, it largely determines the crew's perception of a "flight" on the simulator

To solve this problem we have developed a mathematical model (algorithm) of a ground fire spreading on the basis of calculated and experimental data [2], which enables us to calculate the necessary fire parameters on-line during the "flight" on the simulator (Figure 11) The following ones are key:

- the fire zone coordinates and the speed of its spread;
- the intensity of flame and smoke;
- the fire zone temperature

The ability to adequately react on external influences in the course of the modeling process is also a prerequisite for the algorithm. Among such influences we could mention:

- changing wind power and direction
- water dumping on the fire zone
- setting new fire seats
- precipitation
- the creation of fire lines and counterfires

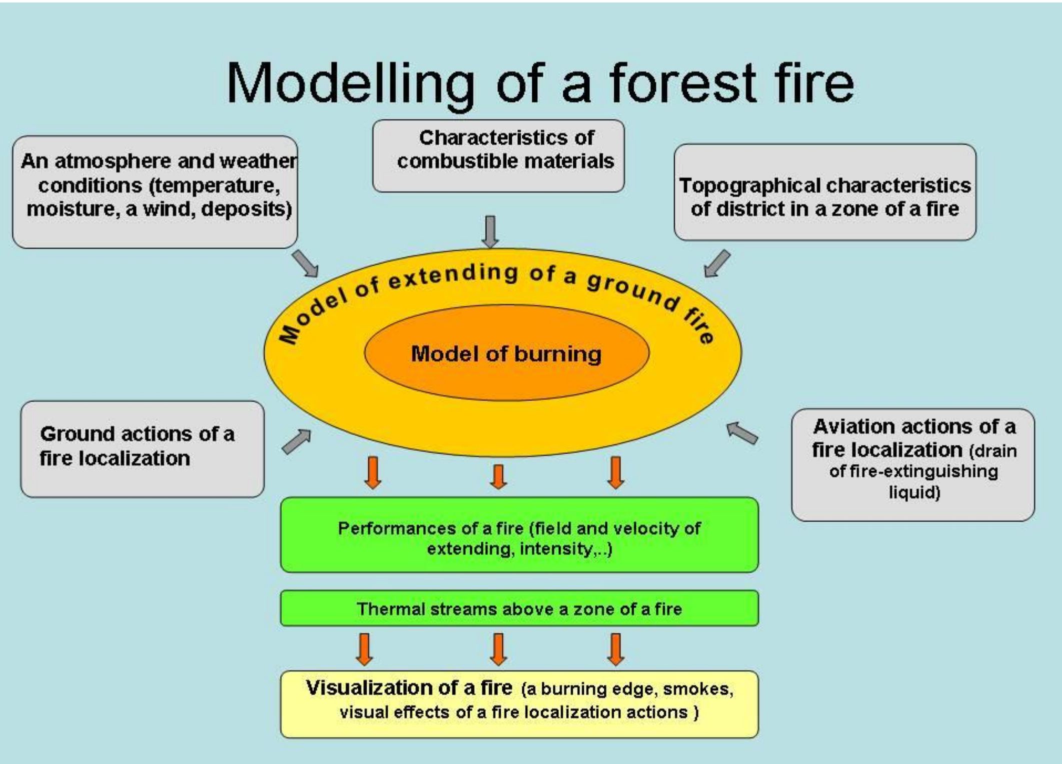


Figure 11: Forest fire spread model

The area (hereafter – polygon) on which the forest fire spread is modeled may be areas of various pyrologic properties (grass, shrublet, forest area, possibly with some non-burning areas – a river, a lake, rocky terrain, a swamp, a road). It is supposed that the area's map with a known set of vegetable fuel (and their pyrologic properties) is available in advance. The model contains the physical parameters of the vegetable fuel employed: heat capacity, firing point, specific heat, etc.

The fire spread model is represented as a cycle, with a time span corresponding to one iteration of it The polygon is divided into squares (cells) sized 2 x 2 meters, and each one possesses its own pyrologic characteristics known in advance. On each cycle step the program runs through the entire field of squares. Figure 12 presents the flowchart of the actions performed with each individual square.

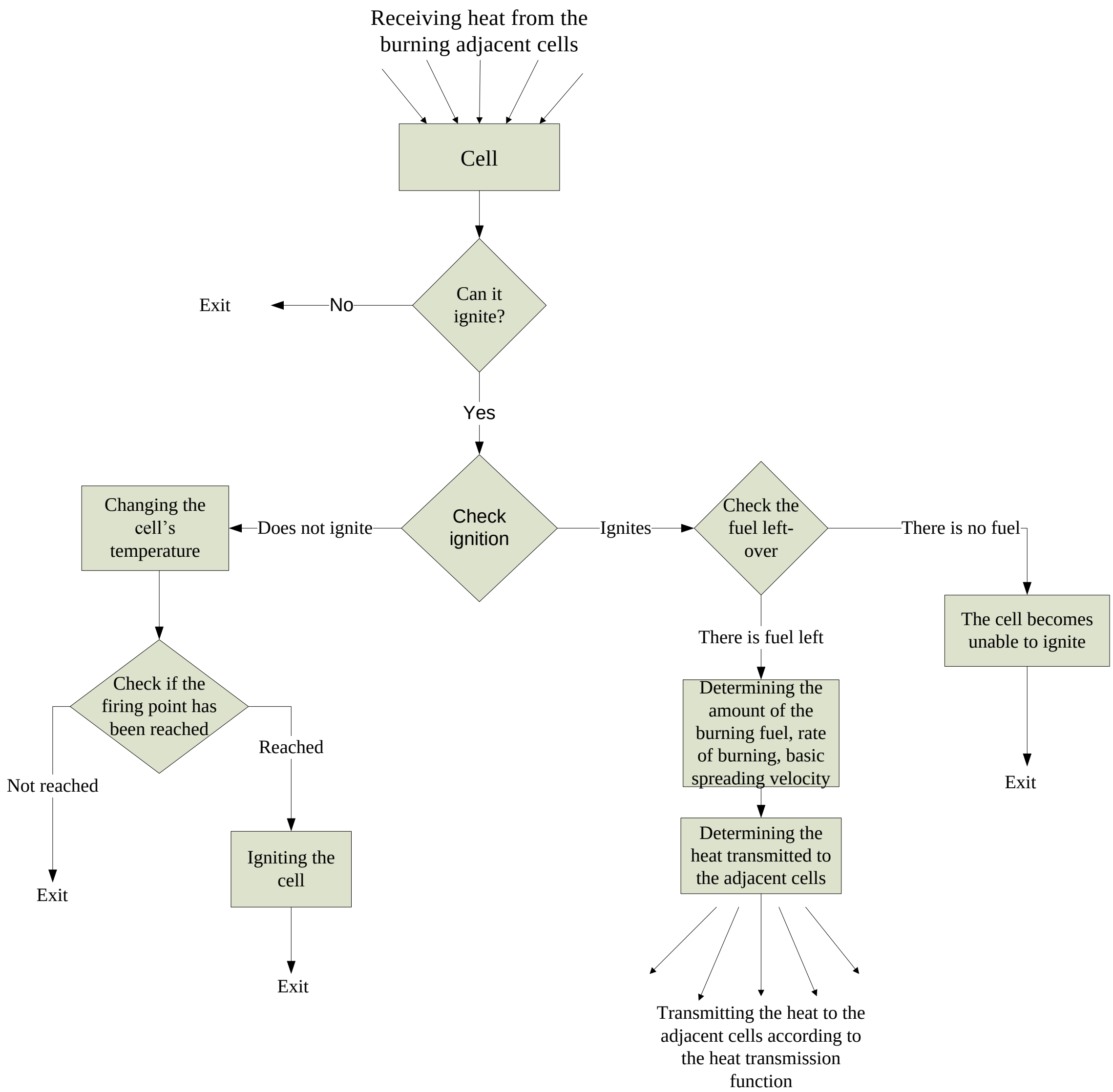


Figure 12: The flowchart of algorithm

Fire suppressing algorithm is integrated into the algorithm of predicting a forest fire spread Its main function is to determine the cell's state after some quantity of water (fire-suppressing liquid), which can be both water from the BB and precipitation.

The algorithm's realization lies in the fact that at each modeling step water dumping is checked for each cell. If some liquid gets into the cell, the suppressing algorithm is started.

The cell is considered suppressed if in the regime realization process one of the following conditions holds:

- the speed of steam formation is such that the entire volume within the vegetable fuel layer is occupied by the steam;
- moisture content in the cell does not equal zero;
- the cell's temperature is less than its firing point

3.2 A model of the atmosphere above the fire zone

It is necessary to develop a rather complicated mathematical model of the atmosphere above the fire zone due to the following factors:

- visible in the course of air patrolling form, density and the velocity of smoke spread above the fire zone are an important source of information about the fire and the tactics of its suppressing (localizing).
- disturbed atmosphere aerodynamics may considerably influence the flying rotorcraft

Under certain assumptions (we are considering moderately powerful fires on a relatively plain area) the distribution of gas flows above the forest fire can virtually always be represented as consisting of separate turbulent convectional columns. For that reason the disturbed atmosphere model is based on the convectional stream mathematical model, emerging above the forest fire in the boundary atmospheric layer.

The developed mathematical model of a convectional stream induced by the forest fire enables us to calculate the velocity vector (the average and turbulent components) and the temperature of the airflow at the current time at any point of its existence at the height range between 0 and 1500 meters. The following parameters have been taken for the input on-line changed model parameters: fire plan form and intensity, ground atmospheric temperature and blast wind direction.

The necessity to model objects with typical fluctuations of the meter parameter degrees on-line when describing big air quantities (dozens of cubic kilometers) imposes the use of analytic ratios based on semi empiric dependences, which are in turn based on experimental results and detailed mathematical modeling.

The flow in a heat convectional turbulent stream can be divided into several typical zones. In the first zone the air moves mostly horizontally along the surface to the stream's initial part. Above the area of the heat emission (burning) it becomes hotter, expands and floats upwards, accelerating under the flotation forces in the second zone. After reaching maximum velocity the stream moves into the next zone, in which it starts slowing down under the influence of turbulent viscosity.

Thus the convectional column description can de divided, firstly, into the nod motion description, and secondly, into the calculation of gas-dynamic parameters' three-dimensional field by analytic ratios for convectional turbulent streams and large turbulent vortexes. This enables us to abandon sending big three-dimensional data arrays via the net and to transmit only nod parameters, with the help of which any place from the entire stream picture can be restored.

The suggested technique for approximate description of gas-dynamic processes in convectional columns above a forest fire based on the turbulent stream approach enables us to calculate gas-dynamic parameters' three-dimensional distribution considering the fire's characteristics and weather conditions. This method enables us to calculate both averaged streams' characteristics and large-scale pulsations connected with the passing of big vortexes, i.e. it takes into account the main factors influencing the helicopter's flight above the fire zone.

Typical modeling results in general conform well to the known picture of smoke motion above a fire source (Figures13).

Implementing the described atmosphere model into the simulator's special software has confirmed that the algorithmic calculations do not affect the simulator's on-line performance.

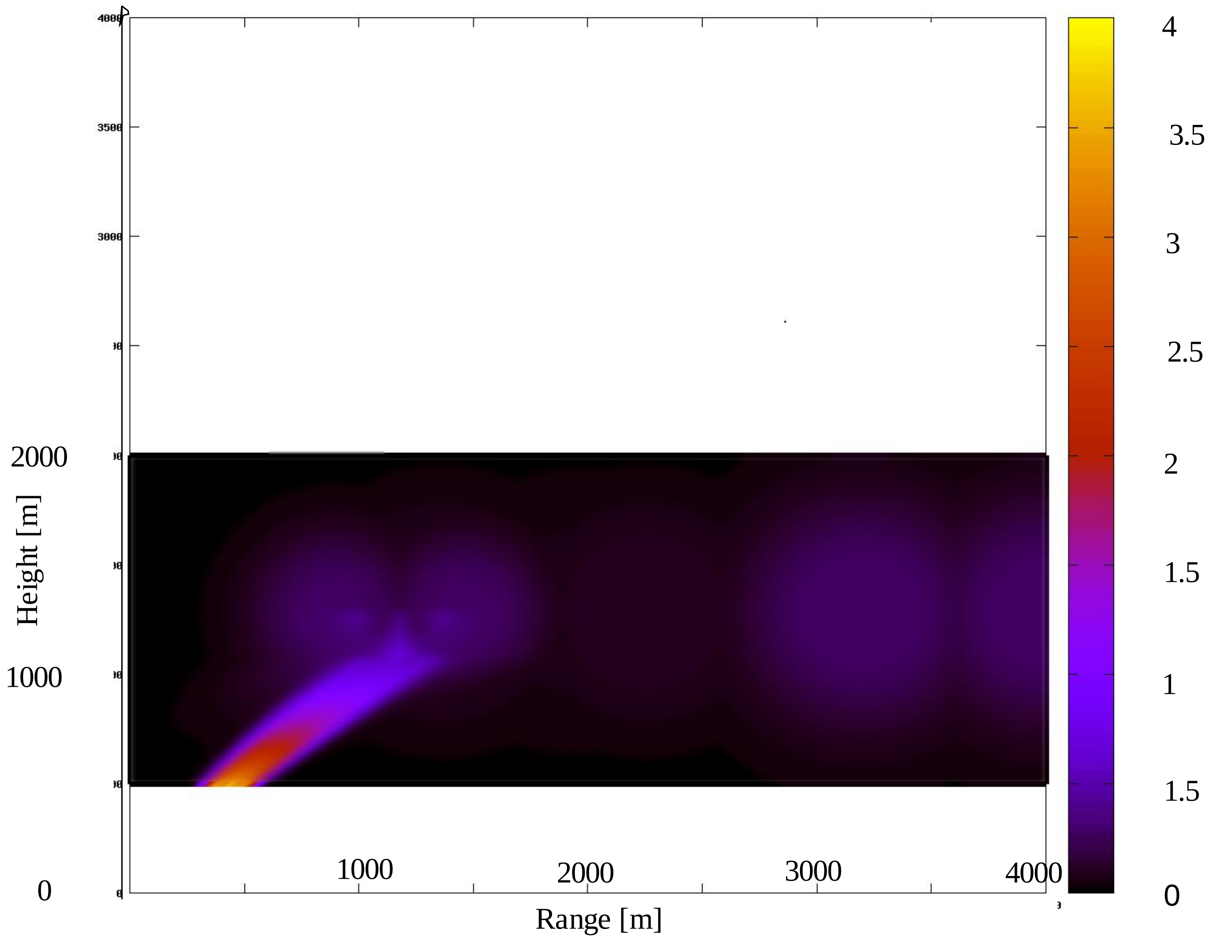


Figure 13: typical instant distribution of additional agents (~smokes) on the symmetry plane from three sources, each 10 meters far from the others, at side wind

Conclusion remarks

Now fixed base full flight Mi-8 helicopter simulator with the sling-load operator part-task trainer «Forester» is in pre-production operation in The Training aviation center “Avialesookhrana” (Pushkhino city, Moscow region).

However, process of operational development of mathematical models and certification of a simulator is not completed.

Film- and photo- materials of the most typical stages of «flight» of the helicopter with BB on a simulator are presented in presentations to this paper.

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