# Unmanned Aerial Systems for Supporting Decision Makers at Forest Fires

**Ágoston Restás**

H-3752 Szendrő, Nagyállomás 1/K; arestas@r-fire.hu

*Abstract: The author try to present the possibility of using an Unmanned Aerial Systems for supporting efforts to extinguish forest fires and demonstrate the viability of the notion on the basis of both economy and efficiency. The fact that the lecture concerns forest fires is no accident. The proportion of forested areas in the district of Szendrő – which was the duty place of the author -is well in excess of the national average and also includes about 90 percent of the Aggtelek National Park, parts of which feature on the UNESCO World Heritage list. Therefore, for the author, improving preventive measures against forest fires and efficiency in extinguishing them is not only an option but also an obligation.*

*Keywords: Unmanned Aerial System; forest fire; economically effective; operational use.*

## 1 Introduction

Taking a very broad definition of the term 'robot', we can claim that there are already some examples of robots already in use in fire protection. Such examples might include automatic fire alarm systems, fire alarm and extinguisher systems in addition to other, so-called 'fire engineering equipment', a category that includes automatic smoke extraction and smoke extraction and ventilation units, amongst others. Depending on their level of sophistication, some of these pieces of equipment could be termed 'intelligent'. Historically, such equipment has been being deployed for several decades. In the future, we can expect to see efforts to replace people in certain interventional activities and functions in order to increase the safety of those taking action and to reduce the risk to their lives in emergencies. Such activities might include protracted periods of work in intense heat situations and reclamation activities in the vicinity of explosive or hazardous materials. Support for intervention at oil and gas well explosions may furnish an example of the former, while gas leakages and the unintended release of highly toxic materials are examples of the latter kind of situation. Both offer justification for measures to reduce the level of human intervention.

Today, we may accept global warming as a fact, and the literature also demonstrates that periods of extreme weather conditions are also becoming increasingly frequent. Long periods of drought decrease the fluid content of vegetation and leads to desiccation. Such vegetation is more likely to combust and burn, and such conditions also favour the spreading of fires. Large fires occurring during periods of drought catch the attention of the media immediately, which allows the whole of society to come face to face with the extent of destruction they can cause. All of us can remember the many times that the media has focussed on illustrating the destructive force of forest fires.

When forests are destroyed, the damage should not be measured only as the financial value of the quantity of timber that is lost; an entire biosystem is destroyed and lost either temporarily or permanently. The destruction of forests is not merely a financial or economic issue; it is also a problem from the perspectives of nature protection and environmental pollution. When a forest is destroyed by fire, a tremendous quantity of carbon dioxide is released into the atmosphere, which deteriorates the balance of gases and thereby contributes to the greenhouse effect. Based on international data, some 20 percent of the carbon dioxide released into the atmosphere is attributable to forest fires! [1]

In Hungary alone, the damage caused by vegetation fires is some million euros every year. Forest fires cause the decisive majority of that damage. The production value of one acre of forest is around four thousand euros. The intangible value destroyed is generally estimated at around ten times the production value [2]. Accordingly, forests as living environments have an intangible value that certainly justifies measures to protect them from fire. The extent of the damage is increased further at the level of national economy by the cost of extinguishing those fires.

In summary, we may state that global warming is increasing the frequency of extreme weather conditions. This results in an increase of protracted periods without precipitation. Consequently, we may expect increases in the number of, and the level of destruction caused by forest fires, which generally occur during dry periods. Fires affecting large areas are leading news items in the media day after day. It is clear that defence against the destructive power of forest fires is a serious problem awaiting solution not only in Hungary but also worldwide. The importance of fighting vegetation fires, and forest fires in particular, is such that the latest developments of science and technology must be deployed in order to improve the efficiency of our defences. In what follows, I would like to describe the opportunities for using robot technology to fight forest fires and the way in which the use of such technology can improve the efficiency of intervention significantly. Improving the efficiency of intervention is extremely important because it can reduce the area destroyed by the fire considerably.

# 2 The Damage-Time Function

In general, the development of a fire can be characterised by the so-called *damage-time function*. The vertical axis shows the amount of the damage, the horizontal one shows the passage of time. In an enclosed area, if the fire is allowed to spread freely, the function shows a sharp increase at first, then, as the stock of combustible material is depleted, the function levels off. When the combustible material runs out, the fire stops spontaneously and the curve ends.

When assessing efficiency, it is usually the return on investment and the period of time required for such returns to be realised that we take into account. The concept of efficiency is applicable to fire fighting, but the way it is applied differs from the traditional interpretation. In the case of fire-fighting and other interventions, efficiency is measured either by the quantity of value saved, which is often very difficult to assess objectively, or by the actual damage, which, of course, should be as small as possible. A fire-fighting measure can be said to be efficient if the available resources and equipment were used to achieve the highest possible value saved or the smallest possible amount of damage possible. Let us look at this curve in the case of a forest fire. Amongst other things, we need to make the following assumptions for the purposes of the review:

- The composition of the forest is homogeneous;
- Meteorological conditions such as temperature, humidity, etc. are known and constant;
- There is no wind;
- The forest is assumed to be infinite and located on a plane area

With those assumptions, the damage-time function gives an exponential curve that diverges to infinity. The rise of the curve is determined by two factors. One of them is derived from the area of the circle already covered by the fire and is proportional to the square of the radius of the circle. The other is derived from the velocity of spread of the fire over a unit of time. The two are not really independent of each other. To be concise and clear: the area burnt in a unit of time is dependent on the velocity of spread of the fire, which changes in proportion to the square of the time already elapsed. The faster the fire spreads, the larger the area that is burnt. If the above assumptions all pertain, the process continues to infinity. It is easy to see that if for any period $\Delta t$ is reduced, the area burnt and thereby the damage caused is reduced exponentially. The smaller the area affected by a fire when extinguishing commences, the smaller the quantity of resources and equipment that are required to extinguish it. Therefore, the application of any method that allows fire fighting to begin earlier will result in an increase in the relative productivity or efficiency of fire fighting.

# 3 The Reconnaissance of Forest Fire

Now let us look at the process of fire fighting based on the Fire-fighting Regulations [3]. For the fire service, the process begins when a fire is reported. At the point when an alarm is received by the fire service, the fire will have already started and obviously also have been detected. Then a few additional steps are taken before fire-fighting units arrive on the scene, but these are only important for specialists in the subject. Once on the scene, the first important task is reconnaissance. Reconnaissance comprises of data collection and orientation required for defining the tasks associated with the saving of lives and the extinguishing of the fire, along with their safe implementation; it extends from the fire report until supplementary work is concluded.

Reconnaissance has to support the following functions:

- Assessment of the current and anticipated future situation;
- Selection of the right solution and the tasks that need to be performed;
- Solutions for the special tasks that may arise in specific phases of the fire-fighting effort;
- Implementation of the protective measures required to protect those taking action.

The command to commence intervention cannot be issued without reconnaissance!

"Reconnaissance must assist the commander of fire-fighting operations in making the correct decision in choosing a method of extinguishing that does not endanger human life or risk bodily injury, and which will allow the fire to be extinguished in the shortest possible time, with the smallest amount of damage and the application of the smallest possible amount of resources and equipment in the most economical manner." That sentence is a quotation from the Hungarian Fire Fighting Regulations.

The following problems are frequently associated with the reconnaissance of forest fires:

- The fire may cover such a large area that reconnaissance requires touring around the entire affected area. Natural conditions may mean this cannot be done in a motor vehicle. Walking around it may also be hindered by terrain topology and vegetation. It should be taken into account that circumambulating an area with a radius of 300 m involves a distance of almost 2 km!
- If the commander of fire-fighting operations is at the scene, he is too close to the fire to be able to manage it along with its environment. Quite literally, he cannot see the forest for the trees! As the extinction of forest

fires is a protracted process in time, and since during that time the fire will continue to spread, the ability to manage a fire together with its environment is an indispensable precondition for the efficient extinguishing of a fire.

# 4 Reconnaissance by Manned Aircraft

The above problems can be solved using a tool that can rapidly provide accurate information about the entire fire zone. The use of personal reconnaissance from the air is a logical solution. It is possible to use the emergency police force helicopter for reconnaissance [4], but there are several problems associated with that solution:

- An excessively bureaucratic procedure to obtain the aircraft;
- Obtaining permission is time-consuming;
- It takes too long to reach the scene;
- Firefighters have no experience of air reconnaissance.

Despite the above problems, helicopters have been used on several occasions to assist with the reconnaissance of forest fires. However, those fires covered very large areas and putting them out took several days, and the fire-fighting action was managed at higher levels of the organisation, usually at executive staff level. Experience indicates that air reconnaissance is effective!

It is efficient because obtaining an overview of several hundred or even thousand hectares of forest allows intervention measures to be co-ordinated. Without air reconnaissance, co-ordination of measures can only be based on the information circulated between the commanders of individual units at various locations. But the assessment of the gravity of their individual situations by commanders located at various sites may be completely subjective and not made in relation to the other sites. Air reconnaissance helps to eliminate subjectivity in such judgements and to rank the individual sites in relation to the others. Air reconnaissance may also eliminate the effects of terrain topology that otherwise hinder or prevent visual access to the area concerned. If we accept the above, our task is to find a solution that allows us to take advantage of the benefits of air reconnaissance in the case of smaller fires as well. That would also facilitate the application of efficient measures to smaller fires and thus prevent them from becoming large ones.

It is quite obvious that the maintenance and operating costs of manned aircraft are not proportional to the value saved in the case of the efficient extinction of smaller forest fires. The only possible justification would be that the extinction of such fires at an early stage prevents there covering larger areas, but the value involved can only be estimated in a rather subjective manner. Therefore we can retain the benefits of air reconnaissance at a relatively low cost if visual inspection by staff is replaced by the acquisition of image data.

# 5 Reconnaissance by Unmanned Aerial Systems

In my opinion, the replacement of inspection by staff by machine data acquisition does not reduce the efficiency of reconnaissance or prevent the facilitation of more efficient fire fighting. In short, machine reconnaissance can support the achievement of criteria required for greater efficiency to a similar degree. And it does not require manned aircraft. An unmanned aircraft that is controlled from the ground by personnel can perform machine data acquisition meeting the above criteria. There are several examples of such systems already in operation. Today, cameras attached to model aircraft controlled from the ground can transmit photos and live images of excellent quality. Trained personnel control them. Their application can have great benefits in natural disaster situations that develop or occur slowly. Typical examples are the reconnaissance of floods and the assessment of dykes.

In those situations, there is time to transport the model aircraft to the site, to find an area that is suitable for the launching of the machine and for providing support, etc. Those aircraft are usually flown by dedicated personnel or may be located at specific bases. Staffs fly them for sport, as a hobby, but on a regular basis in order to maintain precise navigation and flying skills.

Such model aircraft carrying cameras are potentially suitable for the reconnaissance of fires. The quality of the image data they acquire is mostly dependent on the type of camera that is fitted to them. They meet the requirements of reconnaissance that can improve the efficiency of fire fighting. Their relatively low cost of operation is their greatest advantage. Given the above advantages, a question suggests itself: if that tool is so efficient, and if it has proven its efficiency in the case of floods, why is it not being used for the reconnaissance of forest fires whose dimensions do not warrant the deployment of manned reconnaissance aircraft?

The answer comes in several factors. One of these is the time factor. As it was already mentioned, such machines are generally flown by specific personnel and are located at specific stations. The extinction of a medium size forest fire takes from a couple of hours to at most half or a whole day. The use of model aircraft flown by specific personnel would take too long relative to the total timescale of the intervention. Alerting the model plane unit would only be justified after land reconnaissance on foot, but as a result, the model plane would be too late to perform early reconnaissance.

Application could still be justified but the fact that no application protocol has been developed means that it is not practical. Reaching the location, finding a suitable site for take-off, the installation of support takes too long compared to the time the intervention usually takes. Making the corresponding efforts as early as possible best supports maximum efficiency. A model plane being operated by the fire service could solve that problem. But I have also mentioned that in order to maintain suitable navigation and flying skills staff would have to fly the aircraft on a regular basis. The machines are fairly expensive and so are repairs. For the fire service, introducing such a system would involve the provision of a single training course and long-term opportunities for practice to many people.

The smaller the fire department, the more it needs initial assistance, but it is precisely small fire departments for whom training personnel would pose the greatest problem. And anyway, in my opinion the mentality of fire fighters is far from ideal for the above scenario. The question of responsibility for damages to the machine resulting from improper use might result in fire fighters being ambivalent, passive or even hostile towards the idea. And I think we all agree that maintaining dedicated staff is not a task that the fire service can undertake.

# 6 Reconnaissance by Robot “Drone” Aircraft

Based on the above considerations, an instrument suitable for the reconnaissance of fires would need to have the following characteristics:

*A flying unit capable of transmitting image data:* it is basically importance to able using informations.

*Capable of immediate deployment to the scene of the fire*: The requirement for immediate deployment should be understood in terms of the time-scale of traditional reconnaissance and fire-fighting measures. In my opinion, that should correspond to a deployment time of approximately 5 minutes.

*It should not require terrestrial control staff, but rather be a robot plane*: This requirement is one that can be met by a piece of robotic equipment. This is required to ensure that controlling or supporting the aircraft occupies none of the fire fighters. As a result, the use of the robot will not reduce the number of staff available for fire fighting whilst providing additional information. In short: it provides extras without taking anything away. This is particularly important in the case of small fire departments where only a few people are available for fire fighting.

*Specifying the flight path for the robot should be as simple as possible*: This could mean the setting of some points or a curve on a digital map. This operation should not require too much background knowledge or any special skills. It goes without saying that a single member of staff, the commander of fire fighting, should be capable of performing this task.

*The robot should be able to fly along the path automatically, without assistance, and at a height suitable for providing image data with respect to terrain topology:* I believe that the digital, three-dimensional maps in use today along with satellite navigation systems allow this requirement to be met.

*Managing the image information should be simple:* If a digital camera used and an on-line connection is possible, the fire-fighting commander should have the opportunity to view the image continuously on a screen. It would be advantageous if it were also possible to save the image data in a database for later evaluation.

*Launch and landing should require a minimal area, the unit should preferably take off vertically:* This is important because in a forest it would be very difficult to find a suitable take-off location for a traditional model plane. The forest road along which the fire department vehicle or all-terrain vehicle approached the site is probably the best option. When selecting a suitable area, terrain topology must also be taken into account. The distance to the edge of a larger forest can make controlling the robot from there impracticable.

*With a single charge, the robot should be capable of flying around a circle of 1 km radius in about 10-15 minutes:* The above requirement derives from the assumption that the first unit to arrive on the scene with a robot would generally find a relatively small area affected by the fire. A circle of 1 km radius corresponds to an area of approx. 300 acres, which, in Hungary, would be considered a rather large fire. In such a case, external assistance must certainly be obtained. The extinction of a sufficiently large fire may be protracted and shall require measures to pool resources to an extent that may warrant the use of manned reconnaissance aircraft.

Those are perhaps the most fundamental criteria. Several other requirements can also be formulated, but we shall not go into the details of those. The relatively low flight performance requirement reflects the preference for a really small robot craft that can provide efficient support for the reconnaissance activities of even the smallest fire-fighting unit rather than a tool with excess capacity. Excess capacity is unnecessary as the requirements of efficient reconnaissance can even be met by a single image from a suitable perspective. As the fire spreads relatively slowly, a second flight can furnish precise information to the fire-fighting commander.

If we can find a robot that can be used by even the smallest units, a number of incidental benefits will also accrue that would not be furnished by larger tools. They include the fact that once the robot is used in the field, the everyday practice of the smallest units would provide support for the viability of the robot in a very short time. The frequent calls that fire brigades receive in dry periods would allow a tremendous quantity of experience to be collected. Aircraft with large flight potential are only deployed in emergencies of a magnitude that is relatively rare.

As a result, the experience of application would be of an inferential nature rather than one of statistical certainties. On the other hand, the use by small units of a robot of limited capabilities would provide a quantity of data sufficient for statistical analysis in a single year.

Naturally, this does not mean to say that every single fire brigade needs to have one of these robots. In my view, the use of the robots would be justified in areas with a significant proportion of forested areas, and perhaps in areas with particularly valuable natural assets where terrain conditions are also unsuitable for land reconnaissance and for fire fighting.

# 7 The Process

After the fire brigade receives the fire report, single section fire fighters would set off for the scene of the forest fire. Due to terrain conditions, the fire-fighting vehicle would not be the traditional "big red truck", but a highly mobile vehicle with all-terrain capabilities. This will allow the team to reach the best location, to which access is usually afforded by forest paths.

In terrain of medium articulation, topological conditions do not allow the area to be viewed as a whole, but based on the smoke; the fire-fighting commander believes that thorough reconnaissance is in order. Therefore the commander defines the point of control on a section of forest path that is in a safe location relatively close to the fire and the robot drone is prepared for flight. In effect, preparation for flight shall only involve the removal of the drone from its storage location on the vehicle and placing it on the ground.

Based on the visible smoke, the commander of fire fighting can give a rough estimation of the extent of the fire. In our example, the fire is assessed as being of medium severity. Due to terrain conditions, the direction of spread and the extent of the fire cannot be assessed with any accuracy. The laptop transported on the vehicle is used to display a digital map of the area. A special pencil is used to draw a curve starting from and returning to the point of control. Alternatively, some points may be defined, which would be connected to obtain the flight path, this time as straight sections connecting the turning points. The robot, which would be connected to the laptop by a cable, would convert the flight path to the digital map that it stores in its own memory.

Experience indicates that it is not difficult to draw a curve that is certainly significantly larger than the actual extent of the fire. This will ensure that the robot flies around the fire in the way that the commander of fire fighting would have to walk around it. Using its built-in GPS unit, the robot flies along the specified flight path, transmitting images from its digital and thermal cameras to the screen of the laptop. As a result, the fire-fighting commander can see perspective images of the area affected by the fire in real time. If possible, the precise image and thermal data transmitted by the robot would be mapped onto the digital map displayed on the screen of the laptop.

If the thermal camera is capable of using an algorithm for connecting the hottest points, the precise line of the fire can be drawn on the map straight away. If the above equipment were part of an integrated system, it would also be possible to define the present and expected future parameters of the fire in an objective manner. The algorithms already in international use would only have to be adapted to local conditions and supplied with meteorological data in order to support such functions.

From the moment of launch, the robot would supply data continuously; therefore within in the first few minutes it would provide information of a quantity and quality that would provide effective support for the decisions of the commander of fire fighting. One such element of decision support is that even before the robot returns, it will be possible to establish the extent of the burning area and to request the assistance of further units. This will save a significant amount of time. Also, as it was already mentioned, the amount of damage prevented is proportional to the square of any amount of time saved.

Another example of decision support: if we are able to manage the entire area in a complex manner, it may well be the case that protecting the area where the fire is currently most intense is the most important task. It is possible that our forces need to be concentrated in a location other than that furnished by the initial assessment. While fire-fighting is in progress, the fire continues to spread in the areas where no countermeasures are taken, and indeed it may meet natural obstacles or barriers. A river, a wider road or glade may stop the fire as a natural barrier, so beginning fire-fighting measures at a distance of 100 or 200 metres from such a natural barrier can only be considered efficient if we have plenty of resources and equipment not needed elsewhere. On the other hand, it is also possible that in a direction which currently has low parameters for spread and is thus assessed as lower priority, there lies a much more valuable area, such as a highly protected plant community, a habitat of protected animals, or perhaps an area of vegetation with higher parameters for spread. The proximity of a pine forest is an example of the latter scenario.

The above examples show that the most efficient intervention is not necessarily the same as intervention at the point where the fire is the most intense. In order to make the best decision, the area of the fire must be managed in a complex manner, together with its environment.

## Conclusions

The above considerations lead to the conclusion that we should always attempt to extinguish forest fires so as to consume the smallest possible quantity of resources. The opportunities offered by technology and information technology must be utilised in order to meet that requirement.

The tool of air reconnaissance, which has proven effective, can be made available to even the smallest fire brigades through the use of robot reconnaissance aircraft. Traditional reconnaissance no longer provides information of a quality and quantity sufficient for today's applications. I believe that the introduction of robot aircraft suited to the needs of even the smallest fire departments would make a great contribution to the solution of that problem.

Increasing the efficiency of reconnaissance will result in increasingly efficient interventional measures. This will increase the area of forests saved while reducing the areas destroyed. It can be demonstrated that at the level of the national economy, the costs of development and implementation would be returned in a short period of time.

The workload of fire fighters may be reduced, in many instances there may be no need to mount a response at all. The elimination of unnecessary responses will reduce the level of risk to citizens, resulting in a higher level of fire safety.

As a last comment, let us not forget that the everyday work of fire fighters is very much like the work of soldiers gaining combat experience in the front line during a war.

## References

[1] E. Kürt, T. Benhke, H. Jahn, H. Hetzheim, J. Knollenberg, V. Mertens, G. Schlotzhauer: Autonomous Early Warning System for Forest Fire Tested in Brandenburg (Germany), International Forest Fire News No 22 April 2000, pp 84-90, ISSN 1020-8518

[2] Patricia Klijn et all: Hot spot in New Mexico, Fire Prevention, July 2000, pp 27-28, ISSN 0309 6866

[3] Fire Fighting and Technical Rescue Regulations, Ministry of the Interior Decree No 1/2003 (January 2003), Hungary

[4] Rules of staff helicopter applications, General Captain of National Police Headqarters Decree No 36/1997 (September 1997) Hungary