EC225, Water Bombing Helicopter

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Abstract

This paper first presents the forest fire problematic, and introduces the aerial fire fighting answers to this problematic. Key features for efficient aerial fire fighting tools are explained, as well as respective advantages and drawbacks of fixed and rotary wings solutions. Then, authors focus on the helicopter solutions, and present the way the EC225 water bombing helicopter was developed to cumulate the advantages of fixed and rotary wings.

Foreword

Every year, news reminds us the hazard of wild forest fires over the world. (North-America, Europe, Australia...). In ten years, the equivalent of the surface of France has burn out over the world in almost three millions of fires [ref.1].
Three key factors drive forest fire break-out and propagation ([ref.2]):

- The climatic conditions,
- The terrain relief,
- The human pressure.

If global warming and climate change influence over forest fire remain controversial, the global human pressure increase contributes - with no doubt – to the forest fire risk increase.

An increasing demographic pressure

Actual demographic increase endanger natural environment with respect to fire risk. In south part of France, (where fire risk is maximum on the territory) population increase is greater than the average of the country, due to the climatic attract of the area. As a consequence, cities widen and **interfaces between forests and towns** are more and more numerous. (Fig.1).

Fig.1: Urban area to forest interface (North America)
Source : Simplex Mfg

In addition, isolated inhabitation increase (Fig.2) causes inhabitations to scatter the landscape, which make rescue interventions more and more difficult.

Fig.2: Isolated houses (Vaufrege, France)
Source : L'express (dated July 30th, 2009)

Finally, the touristic pressure must be added to the resident population pressure. In France, most of tourism is concentrated toward climatic attractive areas, which increases the fire risk in the already most risky areas.

The agricultural factor

Agricultural activity of developed countries used to be split up in small parcels over the territories, providing natural fire barriers. Since agriculture is now more concentrated on largest areas, this has been causing the forests to overgrow, which provides the wild fires with more and more surfaces to burn. In France, the forest surface has been constantly increasing replacing agricultural areas. In the Mediterranean area, the forest surface has doubled in the latest century.

The fire causes

Only one third of forest fires in France have a cause that is reliably established. Even though, among this third, the great majority of the fires are caused by the human activity, either involuntarily (most of the cases) or voluntarily.
Main accidental causes are: agricultural or forestall work, cigarette end throw, barbecue or trash burn imprudence, power lines or train lines accidents, vehicle (exhaust and brakes) incident, inconspicuous trash disposal, etc... In dry areas where moisture is minimal, the smallest ignition point can be disastrous.

What are the solutions?

As the involuntary human cause is the main source of fires, education and prevention are the best keys for a successful fire fighting policy. Over the last decades, the prevention effort has been making large progresses, which fortunately helps to counter balance the factors that increase the fire risks. Nevertheless, despite of the prevention progresses, the curative solution development remains essential.

When comes the time to fight against a fire, the rapidity of intervention after fire breakout is critical. If a fire is taken care of immediately, a glass of water is enough. 1 minute after, a bucket is necessary. 5 minutes after, you will need 600 litres of water and passed that time, important means will become mandatory.

Fire fighting organisations deploy mainly on ground but also in flight forces to protect populations in priority, but also houses and facilities. Success is driven mainly by reactivity after fire break-out, but also by power of means, and global coordination.

History and current means

The Aerial fire fighting has first appeared during the 1950s in the US, with the use of former bombers that were converted. Helicopters appear in fire fighting more or less 20 years later, (Fig.3), first with the role of fire operations coordination.

Fig.3: Eurocopter Lama helicopter : One of the first helicopter used in France for fire fighting
Source : [ref.3]

A great diversity of vectors

A wide variety of helicopters and fixed-wing aircraft are used for aerial fire fighting in USA, Europe, Australia and Asia. In 2003, it was reported that "The US Forest Service and Bureau of Land Management own, lease, or contract nearly 1,000 aircraft each fire season, with annual expenditures in excess of US$ 250 millions in recent years".

Various aircrafts have been used over the years for fire fighting. Word War II era bombers were for a long time the mainstay of the aerial fire fighting fleet, and some of them are still in use.
The smallest water bombers are the Single Engine Air Tankers (SEATs, Fig.4). These are agricultural sprayers that generally drop about 3000 litres of water or retardant. (Chemicals used to fight fires may include water, water enhancers such as foams and gels, and specially formulated fire retardants).
Medium aircraft include the Grumman Tracker as used by the California Department of Forestry & Fire Protection (CDF) and French "Sécurité Civile", while the Bombardier Canadair CL-415, Douglas DC-4, the DC-7, the Lockeed C-130 Hercules, P-3 Orion and others have been used as heavy tankers.

Fig.4: PZL M18B dropping water
Source : www.wikipedia.fr

The largest aerial fire fighter currently in use is a Boeing 747 water bomber (Fig.5), known as the “Evergreen Supertanker” that can carry 90000 litres of water, fed to a pressurized drop system. The Supertanker entered in service for the first time in 2009.

Fig.5: Evergreen Supertanker retardant drop
© Evergreen DR

Fig.6: Mac Donnell Douglas DC10
© Getty Images

The next largest aerial fire fighter currently in use is the Tanker 910 (Fig.6). It is a converted Mc Donnell Douglas DC-10 that can carry 45000 litres of water.

The third aerial fire fighter was done converting the Martin Mars flying boat (Fig.7). Two are currently in use in British Columbia (one of which was brought to southern California in September 2007 to help battle the wild fires there), carrying 27000 litres of water or fire retardant each.

Fig.7: Martin Mars flying boat
© Photo Ralph.M.Pettersen

Similar in configuration to the World War II era PBY Catalina, the Bombardier Canadair CL215 Scooper and the CL415 Super Scooper (Fig.8) are designed and built specifically for fire fighting. The CL415 Super Scooper is the first widely spread water bomber airplane, with more than 70 units delivered since 1994. Between half and two third of this fleet operate in Mediterranean countries. (France, Italy, Greece, Spain…). In 2006, the French "Sécurité Civile" owned 11 units of this best seller that can scoop, store and drop 6000 litres of water.

Fig.8: Bombardier CL415 Canadair
© Photo LaProvence

Helicopters may be fitted with tanks or carry buckets. Buckets are usually filled by submerging in lakes, rivers, reservoirs, or portable tanks. The most popular of the buckets is the flexible “Bamby Bucket” (trade mark).

Tanks may be filled on the ground or water may be siphoned from lakes or reservoirs through a hanging snorkel. Popular fire fighting helicopters include variants of the Eurocopter Astar (1100 litres, Fig.9) and the Erickson S64 Aircrane Helitanker (10000 litres, Fig.10), which features a sea snorkel for in flight refilling.

Fig.9 & 10:
Left : Eurocopter Astar / Right : Erickson Helitanker
Source : www.wikipedia.fr © Photo Richard Brooks

<u>Why so many different means? Is one of them more efficient than the others?</u>
<u>What product development to enter the market?</u>

- The first performance indicator is the **water capacity**. Experts do not all agree with each other, but a minimum of 2500 litres is a good basis.
- The second indicator gives the **productivity** of the aircraft; It’s the amount of water delivered in tons per hour. This indicator is the product of the dropped water quantity by the number of rotations made in one hour. (A rotation being a complete bombing cycle, including ; refill, travel to the drop zone, drop, travel back to the refill point) This number accounts for the travel speed of the vector between the fire and the refill zone, the water refilling time and the distance that separates the fire and the refill zone).
- The third relevant indicator is the **drop pattern water density**, (Fig.11), more precisely the ground surface water density (amount of water in litres per m^2 along and across the pattern). Dropping too much water is a waste, whereas dropping too few water is useless. Also, the more the pattern is homogeneous, the more the system is said efficient. This criteria account for the drop time, and for the water flow through the doors system.

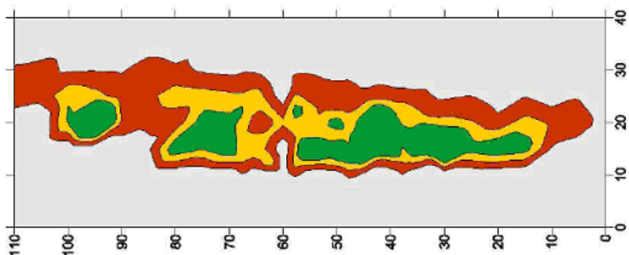

Fig.11: Illustration of a drop pattern : Colour indicates the water density
© CEREN database [ref.4]

What are the strengths and limitations of fixed wings?

Airplanes have a wide range and high speeds which allow them to cover large areas of territory.

For water supply, the fixed wings need an airport or large surfaces of water (lake and sea) for seaplanes.
These supply points are rarely near the fire scene, which can extend the time of rotation (often over 15 minutes).
Moreover, the maneuverability of airplanes gives them limits in mountainous areas, and for low altitude drops.
Finally, the high speed of release generates a blast on the ground. This is effective against fire, but this can be damaging in urban areas.

What are the strengths and limitations of helicopters?

Advantage of the helicopters is their ability to refill in hover flight in small tanks (Fig.12).

Fig.12: Eurocopter Super Puma refilling in a container
Source : [ref.3]

These tanks can be natural, permanently and preventively installed, or brought by ground teams of fire fighters during the fire. In this way, the rotation time between refilling and fire is very low (often less than 10 minutes).
The speed of helicopters is lower than the planes and it needs more time to reach a remote operational theater.
Its very high maneuverability, combined with its slow forward speed and low altitude capacity make it a good tool for high accuracy shots, including in urban areas.
In addition, helicopters can be deployed with minimal nomade infrastructures anywhere in fire prone areas, without the need of any heavy permanent infrastructure, like for airplanes.

Fig.13: Mi26 carrying a 10t water bucket
© Photo KEVREKIDIS 07

Apart of being simple and very inexpensive, soft water buckets (see Fig.13) have two disadvantages. The first one is that they behave like a parachute when flying empty. Air drag is important and the tank goes toward the tail boom. As a consequence, the speed limit is very low (around 80 Kts). The second disadvantage is that they can hook obstacles approaching the drop zone, such as electrical cables, power line tops (Fig.14), trees, etc...

Fig.14: Astar dropping beside power lines
© Photo Jean-Pierre Belzit

The rigid tanks (see Fig. 15 & 16) are fitted with a hanging hover refill pump. This pump is installed at the end of a pipe, several feet underneath the helicopter. When installed under the helicopter, they limit ground clearance.
During flight maneuvers in turbulent conditions, (near fires or close to the ground) the pump may impact the tail boom of the helicopter. Statistics show that refill pump impacts onto the helicopter is the main cause of accidents in fire fighting missions.

Fig.15 & 16:
Left : Bell209 / Right : Eurocopter Astar
Fig.15 : source : www.lesvieillestigesalat.blogspot.com
Fig.16 : © Photo Dominique Pipet

This large overview of strengths and weaknesses of fire fighting products demonstrate the complementarities of fixed wings and helicopters.

<u>Are dedicated systems a unique powerful solution?</u>

A "dedicated" vector means that the aircraft is used specifically for fire fighting missions.
Therefore, the profitability of the vector shall be met only through the fire fighting operations.

The Canadair CL415 Super Scooper refers worldwide. It is a dedicated machine. Its theoretical capacity is 6000 litres, but in practice, it scoops about 5000 liters in order to keep a power reserve, and in order to minimize the scoop time and distance.
This vector is recognized as effective, unless the fire season is too short, which make the aircraft profitability uncertain.

It is the same for dedicated helicopters such as the Erickson S64 Aircrane helitanker (Fig.17), which carries 10000 litres of water. Launched in 1992, this unit does not meet the expected commercial success, (26 units produced) because of its high operating costs and its dedicated mission.

Fig.17: Erickson Aircrane "Helitanker"
Source : The Press Enterprise

In addition, The SH 64 takeoff weight of 19 tons makes it less maneuverable in mountainous areas. (Fig.18).

Fig.18: Erickson Aircrane "Helitanker" drop (Corsica)
Source : www.wikimedia.org

However, the opportunity to cancel helicopter disadvantages could lead to a new generation of fire fighters.

As a synthesis, the specification of the best fire fighting helicopter product could be :

- No reduction of the airspeed,
- No pump suspended under the helicopter during flight and fire approach,
- Fuel tank capacity well above 2500 litres and closer to the best current aircraft (CL415),
- A helicopter that remains versatile for other missions,
- Ability to land on unprepared sites.

Product presentation

This very demanding specification has been fulfilled by Eurocopter, developing a 4 tons water soft internal tank.

What are the components of a Water Bombing Helicopter?

Apart the helicopter itself, a Water Bombing Helicopter is made of a **tank** that is aimed to receive and store water, drop **doors** located under the belly by which water evacuates, a **pump** that is used to refill the tank and miscellaneous accessories detailed further. (Fig.19).

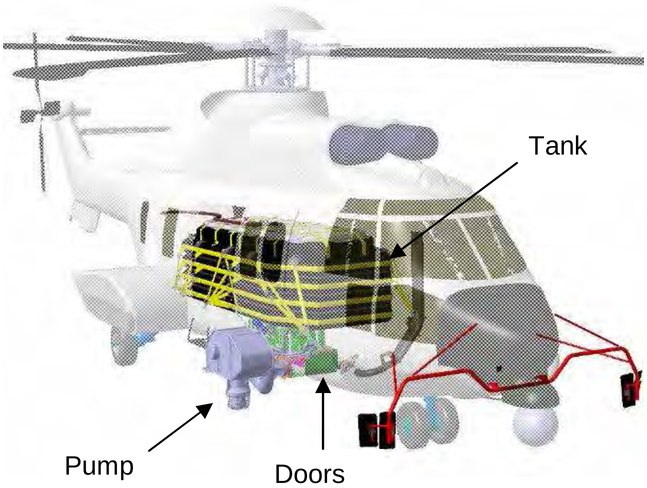

Fig.19: The EC225 Water Bombing Helicopter
© Eurocopter

Why an internal tank?

Fitted with external tanks, helicopters generally have a poor **ground clearance** that does not enable landings on unprepared sites.
However, open landing capacity is a key feature for a fire fighting helicopter, (Fig.20), for close to fire refuelling purpose, but also because it's the only aerial vehicle that can emergency evacuate ground personnel trapped in a fire.

Fig.20: Open landing for crew change (Korea - 2009)
© Korean National 119 Rescue Service

Why a soft tank?

In the world of "non-dedicated" fire fighting helicopters, the strong need for fast role change between two fire missions leads to a system that is first of all **easy to install and remove**.

The tank developed to answer this need is made of two parts (Fig.21):
- An inflatable container,
- The water tank itself and its inflatable top plate.

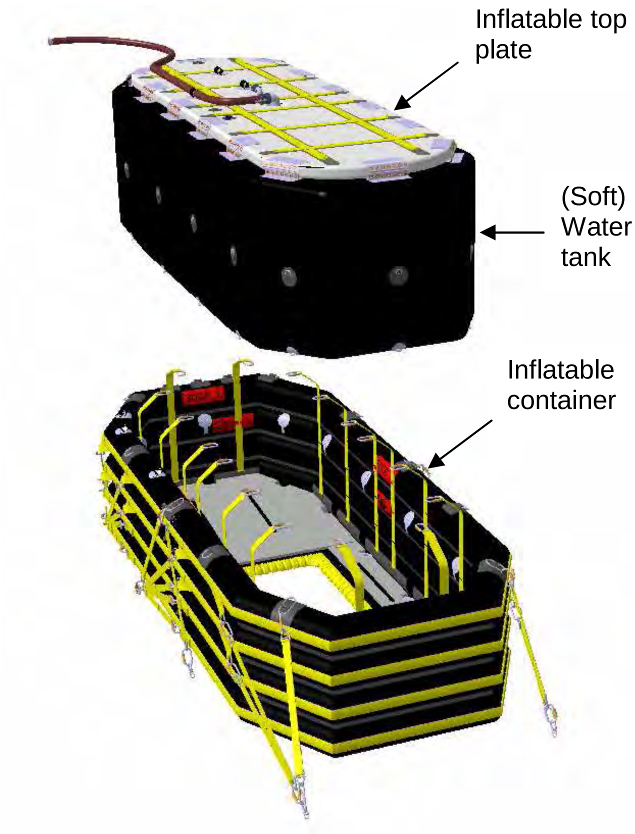

Fig.21: Container and water tank
© Aérazur / Eurocopter

Both parts are made of elastomeric cloth material. The primary function of the inflatable container is to retain the water and drain it out of the helicopter in case of main tank leak or failure.
Also, this part is strapped on the cabin floor, restraining the water tank. Its inflatable volumes ensure a flexible interface between the helicopter walls (interior panels) and the water tank.

When there is no water in the tank, the tank lies at the bottom of the container because it's soft (Fig.22). When water gets in the tank, the tank top plate goes up (Fig.23).

The upper surface of the tank is kept straight during water evacuation, thanks to the top plate that also provides a floor for stepping in the container.

Fig.22 & 23: Water tank kinematic ;
Left : empty tank / Right : full tank
© Eurocopter

Finally, a soft tank has the major advantage to **do not occupy any volume when not filled with water**. This cabin volume can be of great help when it comes to emergency evacuate ground personnel trapped in a fire. (Fig.24).

Fig.24: Emergency evacuation
© Eurocopter

However, this transport configuration features do not enable to make it certifiable with respect to airworthiness criteria.

How does water evacuate through cabin floor?

Between the floor fuel tanks, the EC225 has a rectangular hole used for various purposes, such as parachute drops, sonar use, extra fuel cell, etc…

For the water bomber mission, this hole is fitted with the drop doors. (Fig.25). Drop doors installation is performed from underneath, with helicopter on jacks.

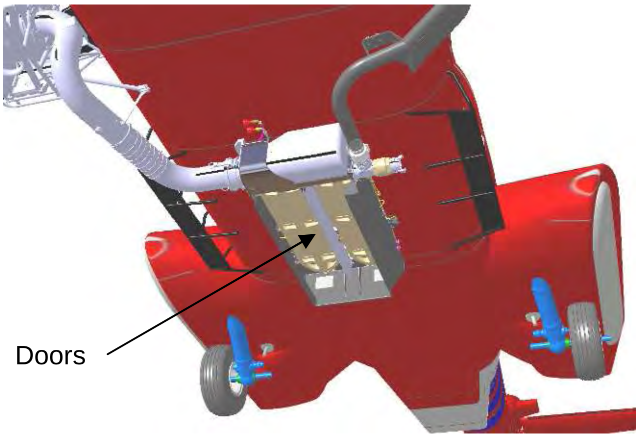

Fig.25: Drop doors
© Rafaut / Eurocopter

The water tank interfaces with the upper shrouded part of the drop doors and permanently remains attached to it. (Fig.26). The soft water tank folds inside the drop doors shroud for role change. (See role change chapter further).

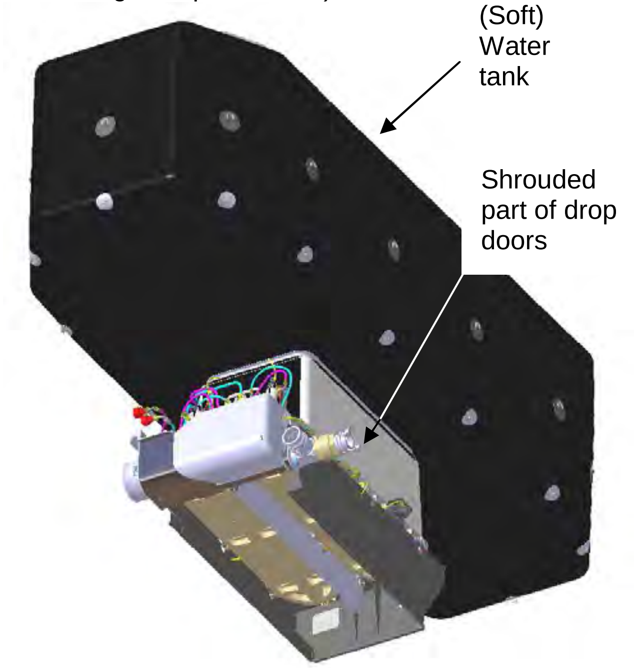

Fig.26: Drop doors / water tank interface
© Rafaut / Aérazur / Eurocopter

Drop doors are powered by the h/c hydraulic network and use a fail safe design.

How does the pump fill the tank?

The pump is of a retractable design. For retraction and extension, a flat soft hose is reeled on an electrically driven drum. Reel assembly is externally mounted on the right hand side of the helicopter. (Fig.27).

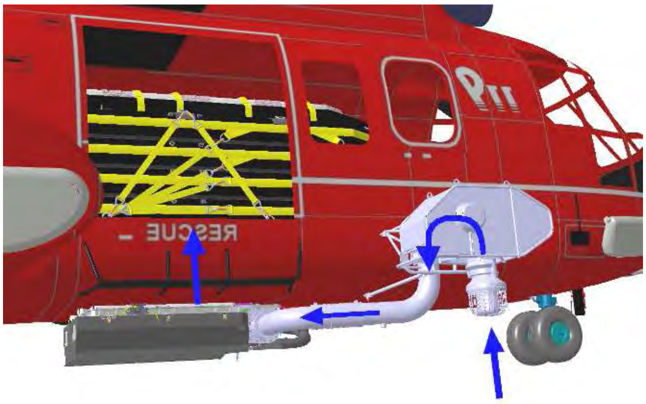

Fig.27: Pump drives water through an external pipe that pushes it to the tank, via the doors
© Rafaut / Aérazur / AeroUnion / Eurocopter

The pump motor and turbine assembly is fitted at the bottom of the refill hose. (Fig.28). It's of an immerged type, powered by the helicopter electrical network. It takes about 80 second to refill 4000 litres; Current draw is similar to the one required by a de-icing system.

Fig. 28: Ready to dip the pump for refill operation
© Korean National 119 Rescue Service

Pump is located on the starboard side of the h/c, as it's relevant that the pilot has a good sight on it during refill through cargo mirrors.

During refill phase, the pilot is helped by marks printed on the hose. The two yellow marks indicate the zone where the pilot shall keep the water level. The red mark at the bottom indicates the pump is about to defuse, should the pilot keep on climbing. With no assistance, keeping the necessary 10ft height above the water could be a difficult exercise, especially when the pilot has no external reference (refill in wide or open water surfaces).
In order to assist the pilot in this phase, the automatic pilot can be used in ground speed mode, (cyclic is managed automatically) or in hover mode (cyclic and collective are managed automatically).

How do the tank folds for role change ?

If not configured for fire fighting missions, the water tank remains onboard the helicopter (folded in the helicopter floor, Fig.29) whereas the inflatable container is removed.
It takes about 15 minutes to remove the items from the helicopter cabin, so that full usage of the cabin is possible.

Fig. 29 Water Tank Folding
© Eurocopter

Design phase challenges

Slosh phenomenon

Prior installing a soft tank with no baffles inside the helicopter, studies were performed to check that dynamic behaviour of the helicopter would not be affected by the presence of 4 tons of water.
The naval industry raises similar questions for the stability of tanker boats.

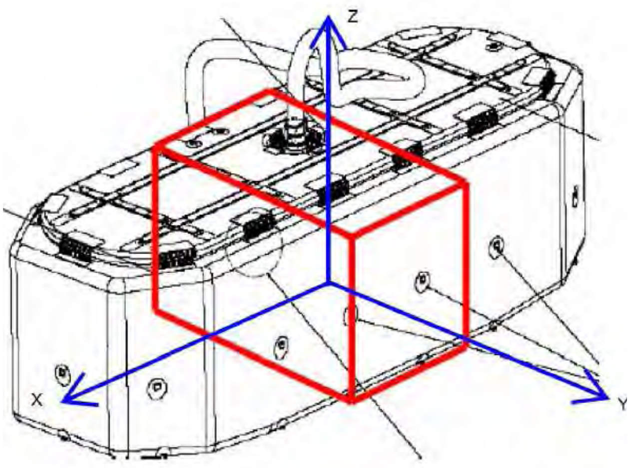

Fig.30: The representative slice of the water tank was considered for dynamic studies
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Models were built to evaluate the dynamic response of a soft tank under harmonic excitation.

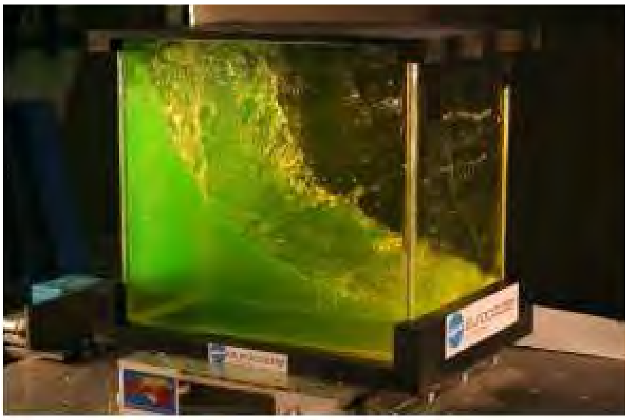

Fig.31: 50% filled tank
Glass vessel simulates the container only
Free water surface
© Eurocopter

Fig.32 & 33: 50% filled tank.
Left : soft tank / Right : soft tank + top plate
© Eurocopter

For 3 configurations (free surface / soft tank only / soft tank + top plate) and various filling levels, roll dynamic response (amplitude and phase) of the system was assessed. (Fig.34).

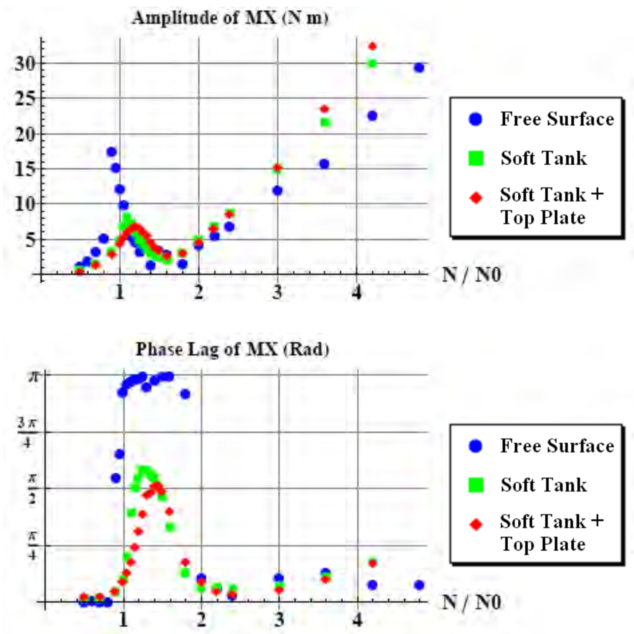

Fig.34: Example of dynamic response in roll
Top : amplitude / Bottom : Phase
© Eurocopter

This work has provided a tank dynamic model that was incorporated in a wider helicopter level dynamic model, which helped to conclude regarding the lack of risk linked to ground and air resonances.

This system is protected under:

- Patent application N° 05/12.706. filed on 14/12/2005, for the general architecture of the system (patent already granted in France under N°2.894.561)
- Patent application N° 06/05.933, filed on 30/06/2006, for the anti-shaking device.

Flight limitations

A fixed snorkel pump is generally a source of airspeed limitation, like any external sling load attached to a helicopter.
Incidents analysis and experience show that, even with a VNE reduction, hung refill hoses remain susceptible to contact the helicopter airframe with more or less hazardous consequences;
This generally occurs in the case an extreme manoeuvre is performed, in the case of turbulent aerologic condition, or in the case both events combine.
As it takes wind to build up a fire, the fire fighting helicopter is often performing its mission in windy conditions, which causes the wind factor to be generally present. The pilot challenge is then to do not perform any extreme manoeuvre likely to cause a refill pump to airframe contact.

In addition, fixed snorkel pump represent a danger with respect to power lines, trees, etc… during the flight, and make the helicopter landing more difficult, as the pilot first has to land the pump and then has to land the helicopter with the main landing gear beside the pump.

As a consequence, fixed snorkel pumps are considered as **limitation makers** and **unsafe**.

Therefore, the only way to remove this dangerous limitation is to retract the pump during the flight.

Controlling the on-board water quantity during each pumping

As the helicopter has a maximum take off weight (MTOW) that shall never be exceeded, managing the water quantity during refill operations is an important function that shall reliably ensure the respect of the MTOW limitation.
In hard tanks, water level gauge systems generally use float systems with transducers, or optic water level detectors. The hardware of both solutions has to be fitted on a hard supporting structure.

As the EC225 water tank is foldable, it was difficult to consider the installation of hardware inside the tank.
The solution that was preferred is to measure the water column height using pressure sensors at the bottom of the tank.

The main challenge was to establish experimentally the non linear law; water volume versus pressure, as additional pressure builds in the tank toward the end of the refill.

Operational feedback and lessons learned

The EC225 Water Bomber option was certified by EASA in November 2009. Since then, the first kit was shipped in December 2009 and the second in June 2010. The system delivered in December has been intensively used for training, with more than 31 flight hours, 21 flights 124 filling phases and 450000 litres of water dropped.

Prior to the certification, an EC225 water bomber was deployed in Corsica (Fig.35) for the account of French "Sécurité Civile".
The helicopter was based in Bastia from June 28^{th}, to September 3^{rd}, to cover the entire island (8700 km^2).

Fig.35: Corsica Island
Source : www.pacalove.com

During this overall period of 65 days, the EC225 performed:

- 98 flight hours,
- 310 operational water drops on fires,
- The delivery of 910000 litres of water,
- The extinguishing of 23 fires.

Fig.36: A drop during Vivario fire (Corsica)
© Eurocopter

For intervention on a fire, typical scenario is the following :

The machine must be **ready for take off** from 7am to 9pm, which requires a light and nightly maintenance.

In ground alert, the EC225 is fueled with 2200 kg of fuel, which gives it an autonomy of 4:20' flight hours. (20 minutes reserve included).

Once the alert is received, the GPS coordinates of the fire are entered into the navigation system. Before take off, the crew anticipates flight duration, as well as closest refilling points available near the fire, pre-recorded in the GPS. During the flight to the fire, crew contact by radio the ground personnel already on the fire scene (if any) and report to them their estimated time of arrival.

A first rotation of recognition is performed before the first pumping, during which the crew locates ground firefighter teams (if any), people and properties.

Fig.37 & 38: Refilling operations
© Eurocopter

Pumping system water management knows the weight of the helicopter in real time, through Vehicle Management System (VMS) input. This way, the pilot always fills an optimized quantity of water, depending on fuel already consumed (Fig.37 & 38).

With full fuel onboard, the first pumping is about 3000 litres of water (in ISA +20℃ conditions). After 2 hours of flight, the helicopter reaches its full 4000 litres water capacity (average fuel consumption 500 kg/h). During filling, the pilot can use the autopilot modes. At the end of pumping, the helicopter first limitation indicator gives the available margin. During this summer evaluation, the average time between the fire and the pumping area was always less than 5 minutes.

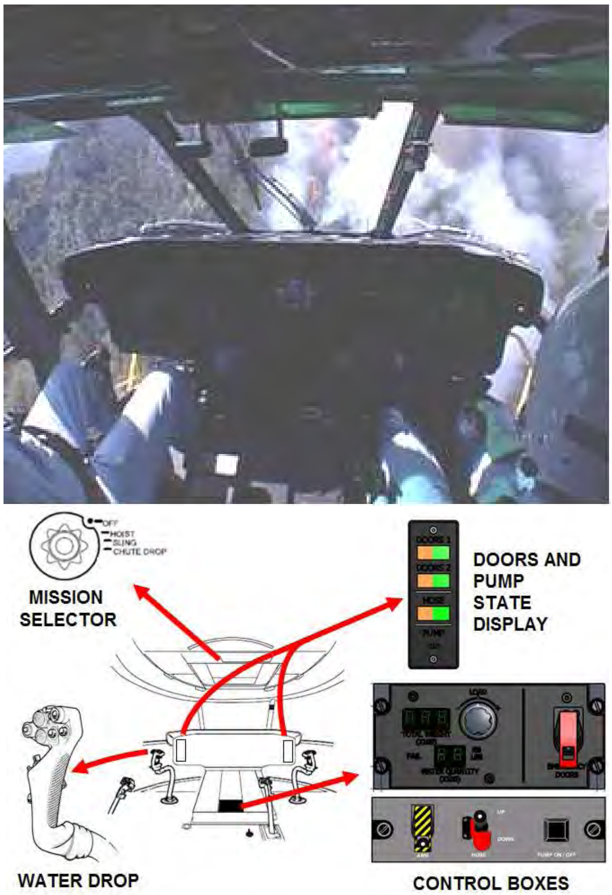

Fig.39: A cockpit view showing man machine interface
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Fire fighting technique used by the pilots is to reduce the rate of progression of the fire. With high winds, a fire progresses at the speed of 5 to 6 km/h. To slow a fire, bombing pilots water areas that have not burn yet (Fig.40).

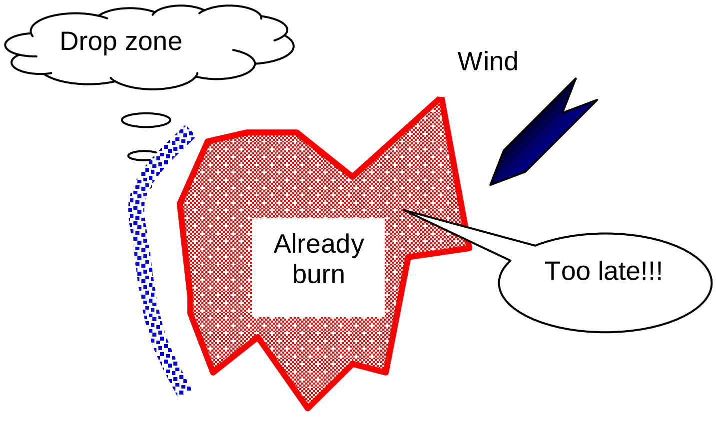

Fig.40: Typical fire fighting scene
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Fig.41: Arrival on a fire, Corsica
© Eurocopter

The goal is to bring the temperature on the ground down. Every drop of water must be sufficient to penetrate the vegetation. If the amount of water is not enough, water does not reach the ground and the drop is not efficient. The formation of white smoke indicates water vapor, which shows that the temperature is still too high. Then, another drop is necessary. When white fumes disappear, the fire is sufficiently watered, and the pilot can move to another area.
Choice of watered area is made with ground fire fighters, with the priority of protecting people and properties.

Key figures for airdrops are 60 feet height, 60 kts, 4,000 litres and 4 flight hours. With rotations of less than 5 minutes, this ensures a continuous presence on the fire.

Fig.42: A water drop seen through cargo mirrors
© Eurocopter

On large fires like in Vivario or Calenzana, the EC225 has recorded a drop performance of 35000 litres of water per flight hour.

Other roles during the fire; the helicopter has a permanent vision of the fire theater which can prevent hazards to people, fire fighters and equipment. In the same mission and in case of critical situation, the EC225 can evacuate up to 10 people, transporting them in the cabin (empty of water).

Conclusion

Starting with the observation of the current existing products, Eurocopter had the strong intent to innovate in the world of water bombing, creating a new kind of fire fighting tool.

The EASA certified EC225 water bomber mixes the high performance of dedicated tools, with the polyvalence of a multirole aircraft.

During the fire mission, the EC225 is able to perform emergency evacuation of people. During and after the fire season, the EC225 remains a large multirole vector that is able to perform SAR, cargo or personnel transport missions, sling missions, etc…

[ref.1] ; UNECE forest fire statistics – 1991 to 2001
Year 2002 Timber Bulletin
www.unece.org/trade/timber/ff-stats.html

[ref.2] ; Evaluation des dispositifs de détection des feux de forêt en France – Mémoire de 3^{éme} année formation des ingénieurs forestiers - Emilie Lafarge 2006
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[ref.3] ; Water Bomber Helicopters Evolution – Capitaine R. Raibaut – February 1991

[ref.4] ; CEREN = Centre d'Etudes et de Recherche de l'Entente
Website : http://www.valabre-ceren.org/