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AERAZUR
Helicopter Flotation & Life Raft Systems

EASA.2007.C16
« Study on Helicopter Ditching and Crashworthiness »

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Introduction

This report presents the work done in the framework of the project EASA 2007.C16 on helicopter ditching[1] and crashworthiness.

Helicopters operating over water can experience water impact[2] events and emergency situations may arise which require an immediate ditching. Fitment of emergency equipment (emergency floatation system[3], life rafts …) is normally required[4] in order to ensure that the helicopter remains upright on the water, enabling the occupants to egress the helicopter safely. However, due to the generally poor sea keeping ability of the helicopter, capsize events can happen and fatalities are not prevented in these cases. Previous research by both the UK-CAA and the FAA has shown that the majority of fatalities following a ditching / water impact event were due to drowning following helicopter capsize.

Previous studies on helicopter ditching and crashworthiness have shown the potentially significant safety benefit of locating additional floatation devices high on the fuselage in the vicinity of the main rotor gearbox (the "Side-floating concept"). Such devices prevent a total inversion of the helicopter in event that the existing EFS is damaged or the sea is beyond the certified conditions and ensures the retention of an airspace inside the cabin. Moreover, they increase floatation unit redundancy. The redundancy is especially needed in the case of survival water impact events where the standard floatation devices are susceptible to damage.

The main purposes of this work are
- To establish the design objectives for additional floatation devices to implement the side-floating concept
- To identify possible retrofit solutions, using EUROCOPTER helicopters AS355 and EC225 as the basis.
- To analyse the safety benefits and economic impacts.
- To study the technical feasibility of the side floating concept.

In section I, previous research on the additional floatation devices are presented, as well, as the study on the egress from side-floating helicopters. The results of the operators' interviews performed by Eurocopter in July 2007 are presented in section II.

In section III, the design objectives and principles for the additional floatation devices are presented. A preliminary design is presented for a helicopter of the Ecureuil family, the AS355. Two possible solutions are presented: the first a symmetrical layout with two floats, one located on each sides of the cabin; and the second an asymmetrical layout with a single float on one side of the cabin.

The particular analysis of the EC225, the most common helicopter operating in the North Sea offshore industry, is shown in section IV. Various configurations of additional floatation devices are presented, with a stability analysis of each of them. The experimental investigations done in a wave tank to check the performance of the configurations are reported.

Finally, the integration of floats attached along the upper cabin walls is studied for the EC225 in section V. The main constraints are identified, a first technical solution is proposed based on existing floatation systems, and the integration problems remaining unsolved are discussed, presenting possible further study areas.

[1] Ditching may be defined as an emergency landing on the water, deliberately executed, with the intent of abandoning the rotorcraft as soon as practical.
[2] Water impact refers to an uncontrolled landing on water where the probability of sustaining floats damage is high.
[3] EFS denotes Emergency Floatation System in the document.
[4] See Jar OPS 3,3.843 All helicopters on flight over water - Ditching

I. Previous research

I.1. Water impact crashworthiness

Investigations into water-related impacts over the period 1982-1989 (ref [6] and [7]) were conducted by the Federal Aviation Administration (FAA). Similar investigations were performed by Westland Helicopters Limited (WHL) over the period 1971-1992. Both studies concluded that drowning is the main post-impact hazard to occupant survivability, especially in the cases where the helicopter overturned immediately.

The water-related accidents found in the Eurocopter accident database over the period 1996-2007 are reported in Appendix 1.
Since the Eurocopter procedure is to inflate the floats prior to landing, the crash events with no inflated floats do no appear in the table. 25 accidents were identified with inflated floatation. 7 of them were with fatal issues (14 fatal issues).
Among the accidents with fatal issues, 5 are identified as uncontrolled ditching (water impact), 1 as ditching, and it is not possible to conclude for 1 of them (exact conditions of landing are unknown)

If we consider all the landing with inflated floats (7 cases), 14 fatal issues are found:
- 2 are due to drowning in the cabin
- 3 are due to exposure at sea
- 1 is due to injuries due to the crash
- 1 not recovered body
- 7 have unknown cause

As, a conclusion, considering the fatalities with known causes, drowning is the second cause of death (2/6) after exposure at sea (3/6).

If we consider the only identified ditching event with fatal issues, one of the two fatalities is due to drowning in the cabin, the other one to exposure.

I.2. Additional buoyancy: Possible solutions

The idea to introduce floatation systems to avoid the total inversion of the helicopter is found in the BMT Offshore review for the CAA on helicopter ditching performance (1993, reference [2]) and in an FAA review in ref. [9].
In 1995, 10 solutions have been proposed and analysed in ref. [8]. The Westland EH101 was chosen for the study. Among the ten solutions, the three solutions shown in figure 1 to 3 were retained.

- Buoyant foam-filled engine cowling panels (see figure 1)
- Long buoyancy bags along upper cabin wall (see figure 2)
- Tethered inflatable flotation units (see figure 3)

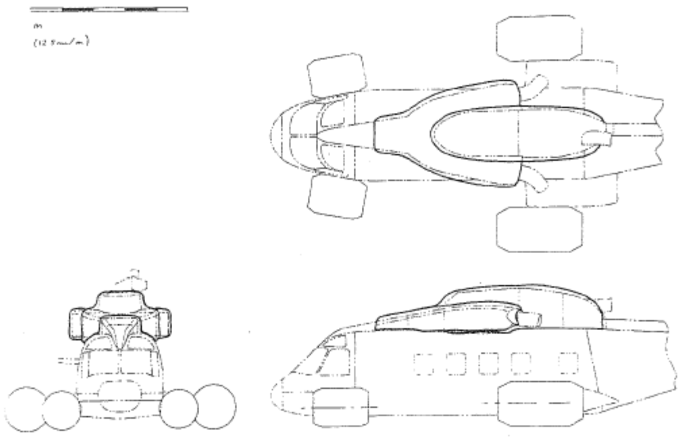

Figure 1: Foam-filled cowling panels

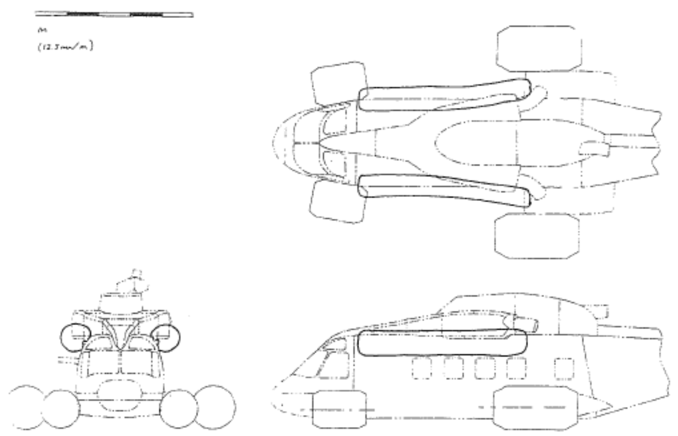

Figure 2: Long buoyancy bags attached along upper cabin wall

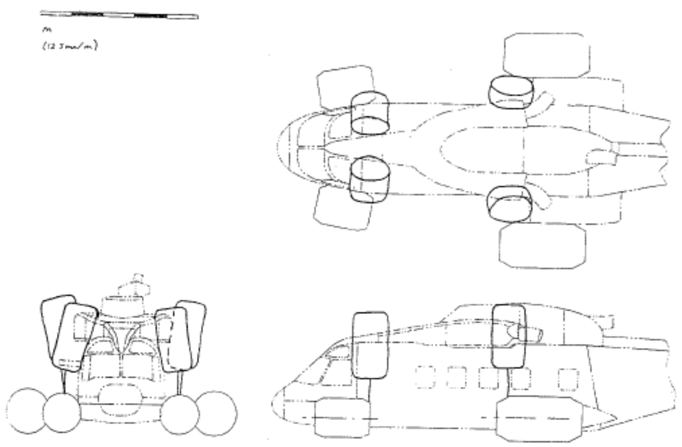

Figure 3: Tethered inflatable floatation units

A scaled model of a EH101, equipped with the 3 floatation systems of figure 1 to 3 has been tested in waves in a model basin (ref [11]). The most effective configurations have been found to be the addition of 6 m^3 buoyant elements on cowling panels and the addition of 7.9 m^3 cabin walls floats. Good response in waves has been observed too for 5 m^3 buoyant cowling panels. The tethered units have been found to be the less effective of the three systems.

The required buoyant volumes needed for the additional systems are highly dependent on the buoyancy already existing in the upper part of the helicopter. In ref. [9], upper floats are designed to provide 125% GTOW buoyancy. In ref. [8] and [11], for the EH101 study***, 70% of the engine cowling volume has***

been supposed to be a buoyant volume. With this hypothesis, a preliminary estimation of the volumes of the additional systems gave $6m^3$.

For each helicopter type, a particular analysis of the inherent buoyant volumes existing in the upper part of the helicopter is important. It is a crucial issue when studying the behaviour of the capsized helicopter.

I.3. Egress from side-floating helicopter

In ref. [12], six critical stages which influence the egress ability of passengers after a forced landing on the sea are detailed:

- Impact of helicopter with the sea
- Stability of helicopter upon entering water
- Unfastening of safety belt
- Reaching an exit
- Opening an exit
- Using an open exit to make a safe escape

The main objective of this study was to determine what type of egress procedure could be performed when the helicopter is side-floating and to compare it to the egress of completely inverted cabin. The choice was made to perform egress trials on a cabin representative of a Super Puma, as it is one of the most commonly used for offshore operations. Moreover, taking into account the previous studies on means to prevent helicopter inversion, it was decided to perform 150° and 210° side-floating attitudes (which correspond to the concept of buoyant foam-filled cowling panels and one long inflated bag on the upper side of the cabin).

Two types of tests were performed:
Trained staff trials
Naïve subjects trials

It was noted by the trained people that there may be an important risk that when an occupant in an upper seat release their harness, their legs may fall with considerable force toward the person in the lower seat on the opposite side of the cabin.
Moreover, it was suggested that, in such a position, an individual might be inclined to make an immediate underwater escape from the exit next to them instead of first rising to the air pocket. Going to the air pocket and then making an underwater escape was found to be problematic due to inherent buoyancy.
Another point concerned the harness, which could be difficult to release in such a position and which might get caught around the neck of someone twisting to get clear of the harness and rise to the air gap.
Handholds and footholds were found to be of interest.
Finally, 210° capsize was found to cause the greatest disorientation.

Taking into account these results, to avoid risk of injury, it was decided that there would be only two naïve subjects in the cabin at the same time.
The feeling of greatest disorientation at 210° was found to be due to the habituation to be exposed to 180° roll.

For the naïve subject trials, the escape procedures chosen were those in which subjects would take advantage of the benefits of escape from side-floating helicopter, namely the air pocket and the fact that exits on one side are above the water. It was also decided that people should rise to the air pocket before escaping from an above water exit.
The trials were evaluated through many issues:

- Swimming
- Holding breath
- Disorientation
- Release harness
- Clearing seat
- Finding exit

- Remember instructions
- Bumping
- Snagging
- Exiting window

The conclusions of these naïve subjects' trials tended to say that side-floating escape was easier. However, 10% preferred fully inverted cabin escape.

The report ends with recommendations as follows:
Flotation systems should be improved by the incorporation of means to achieve a side-floating attitude in order to improve the chances of survival of the occupants in the event of a ditching and capsize
The flotation system should be designed so that the cabin floats with the top of the inverted exits at water level, thereby ensuring ease of escape
The carriage and release of life rafts from a side-floating helicopter needs further assessment
More work is required to make firm conclusions about the effects of an uneven load on a 4-point harness buckle
The provision of a hand hold next to the emergency exits would assist in the location of the exit and provide a leverage or reaction point for anyone trying to operate a push-out window
Consideration should be given to the appropriate training program for helicopter passengers who may find themselves fully inverted or on their side in the event of a helicopter capsizing.

II. Operators interviews

In July 2007, Eurocopter had a meeting with operators in Stavenger Norway to get their point of view on helicopters for offshore operations.
These were their main observations:

In general:
The higher the sea state capability, the better
2 life rafts are enough for everybody
There are no specific requirements for aircrew evacuation. They can either slide on a float (emergency evacuation) or go through the cabin (controlled evacuation) to reach the life raft. There is no specific need for a handle for them.

Concerning the evacuation procedure, the evacuation signal is given by the pilots.
If the helicopter is stable and floating, a decision might be taken to stay on-board.
If sea state is high, with a big risk of turning upside down, the procedure consists in waiting for the helicopter to roll, wait for all the water to get into the cabin and then, while the helicopter is stable, evacuate and meet on the belly, then blow the life rafts
No automatic command to inflate life raft: it is pilot's decision (due to roll over risks, blades movements that can damage the raft…)

Their requirements for evacuation of the helicopter while upside down are as follows:
They would like to have the possibility to blow the life raft while the helicopter is upside down: people on the belly must have access to the handle (40cm max under the water, easy access). Locate signs or markers would be of interest for rescues to find the handle easily

They would like to demonstrate 2 stable positions: the normal one and the capsized one. The risk is in the transition phase (disorientation can lead to fatalities in this phase)

They also would like to have 3 actuation devices to blow the life rafts: one in the cockpit, one on the outside of the cabin but accessible from the inside (to avoid accidental inflation) and one accessible from the belly. They do not want any handle inside the cabin.

For them, it is not a problem if the life raft inflates over someone in the water. The life raft must allow an easy access from the water, even when persons are wet. They would require roofs on the rafts but manually and easily deployable upon request, and from both sides (if possible for better access). To have the raft positioned alongside the airframe is not a priority at all. It would be acceptable to have people boarding the life raft from the water

Training for evacuation is done every 4 years. Passengers wear new survival suits with emergency frequency locator (permanently located inside the helicopter, which the passengers place in the survival suit only while boarding and leave it while disembarking) and air re-breather. The operational rules are to egress through the nearest emergency exit.
They have no requirement concerning the level of water in the helicopter: the more water, the better stability. However, the maximum water level they would accept in the cabin corresponds to: "the person sat in the lower seat must not have water above chest level".

The side-floating concept is an interesting solution from an operational point of view because some air stays trapped in the cabin.

III. Design of an additional emergency floatation system (EFS)

III.1. Design objectives

The additional flotation system should satisfy the following points:

Ditching:

For the side-floating concept (without standard EFS failure), the design objective should be for the helicopter to have all its windows on one side above the water level with the lowest part of the window (the top if the helicopter is rolled more than 90°) at water level, and the air gap has to be sufficient for a full load of passengers.

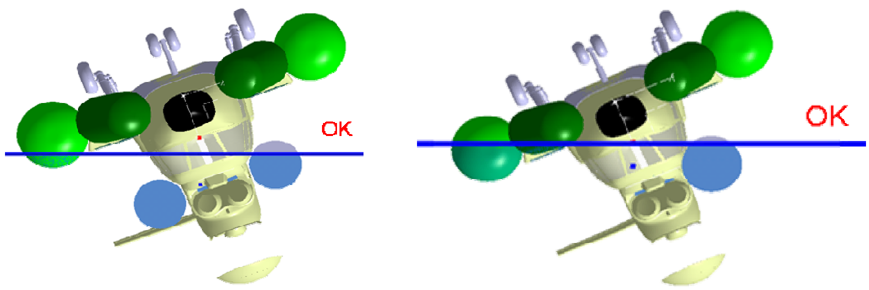

Figure 4: EC225 – Design objectives for symmetrical and asymmetrical configurations

Investigations have to be made in the side-floating configuration of what will be the attitude when one float compartment is lost (the most critical, including any additional floats added).

Water impact events:

With additional buoyancy added, calculation must prove that the helicopter floats with one of the existing floats (the most critical one) lost.
An estimate of the available cabin air gap and helicopter attitude would be advantageous

Validation

The validation by hydrodynamic tests should prove the buoyancy of the modified helicopter, that the side floating attitude attained meets the design objectives, that the side floating attitude is stable and that the helicopter will not keep on rolling when subjected to reasonably expected sea conditions associated with hostile areas (e.g North Sea)

The study should focus on the passenger cabin. The cockpit and flight crew egress are not specifically included.

III.2. Hypotheses

When designing the standard EFS of a helicopter, the mass that has to be considered is the MTOW[5] and the only elements of the helicopter that can participate to the total buoyancy, together with the floats, are the fuel tanks, if they are under the waterline. The weight of fresh water displaced by fully submerged floats is greater than 1.25 times MTOW[6].

The process is more complex when designing the additional EFS. A special care should be paid to the following points:

- Buoyant elements of the helicopter

When the helicopter is inverted, fully or not, the upper part of the helicopter is inside the water. A lot of elements can participate to the buoyancy. Some air could also be entrapped in the cabin and upper structure, producing some additional buoyancy. These elements can strongly affect the final inclined equilibrium position of the helicopter, and should be identified.

- Passengers

Passengers too do float. Their weight (77kg/person[7]) could therefore be deduced from the MTOW since the purpose of the additional EFS is to save people remaining inside the cabin after capsize.

- Blades

If intact, blades do float too. However, if they are damaged during the capsize process, the honeycomb inside can be flooded and the buoyancy they produce is extremely reduced. Therefore, the blades' buoyancy will not be considered for the design process of the additional EFS. However, their weight will be included in the helicopter design weight.

- Centre of gravity.

The highest the centre of gravity, the most stable the fully-inverted helicopter i.e. the most difficult to incline to have a side-floating helicopter. Therefore, a first approach is to consider the highest centre of gravity for the design, even at MTOW. However, the height of the centre of gravity decreases when the mass increases. An analysis is needed on the different mass-CG configurations.

III.3. Stability analysis

A useful tool to study the behaviour of the helicopter in the water and evaluate the stability of the different equilibrium positions is to analyze the stability curves of the different configurations.

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[5] Maximum Take-Off Weight
[6] See AC-29-2C MG10
[7] See CS-27 (27.25) and CS-29 (29.785)

Figure 5 shows a typical stability curve for a helicopter of the Super Puma family. It is obtained by inclining the helicopter at increased roll attitude (heel angles) and then by measuring for each one the righting moment. This is done for roll motion since it is the most critical degree of freedom of the helicopter. The resulting curve gives precious information on the stability of the helicopter.

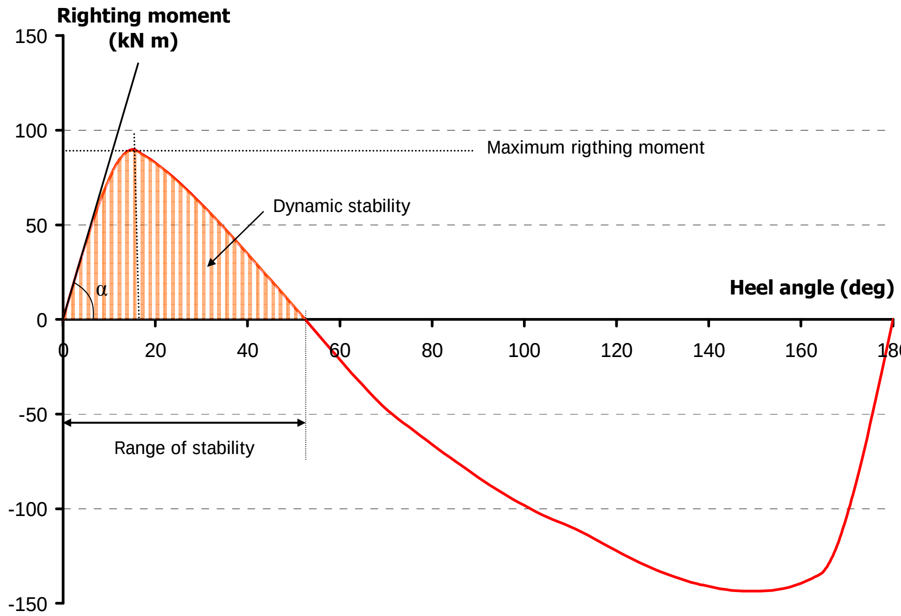

Figure 5: Typical stability curve for a helicopter

Firstly, the intersections of the curve with the X-axis give the equilibrium positions. They are statically stable if the steepness is positive and statically unstable if the steepness is negative.
The distance between the first two equilibrium points gives the **range of stability** of the helicopter. Typically, it is between 40 and 60 degrees for a Super Puma with standard EFS. It means that the helicopter needs to be inclined further than this value to capsize. Conversely, once inverted at 180°, the helicopter needs to have an inclination lower than this value to move to its up-right position. As expected due to the high position of the centre of gravity, the fully inverted helicopter is much more stable than the up-right one.
The **righting moment** will reach a **maximum** at some specific heel angle and gives information on the maximum inclining moment admissible. The steepness of the tangent to the curve at the origin is the **metacentric height** and indicates how the helicopter behaves in roll for low heel angles. Finally, even if the curve is obtained only from hydrostatic calculations, the area under the curve between two angles gives the work of the righting moment, which is equal to the energy absorbed by the helicopter when passing from one position to another. The area under the curve is called the **dynamic stability** of the helicopter.

The stability curve depends on the geometry of the helicopter, its displacement and the position of the centre of gravity. In the naval field, a ship's construction criteria imposed by the International Maritime Organisation (IMO) consist of restrictions on the aforementioned characteristics of the stability curves (for instance, see the resolution A.749: Code on intact stability for all types of ships covered by IMO instruments). In the framework of this study, the stability curves give information on the equilibrium positions of the helicopter, and their stability. However, it is not possible to directly link them to the dynamical behaviour of the helicopter at a given sea state.

III.4. Application of the design principles to the AS355-N

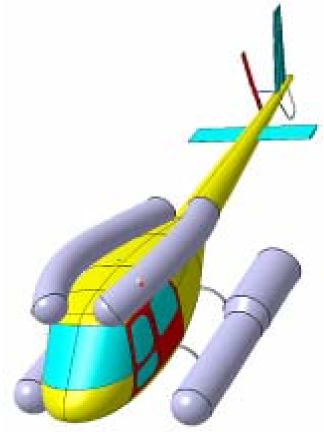

Figure 6: AS355 with upper floats

The characteristics of the helicopter used for the design are the following:

- MTOW: 2600kg
- Passengers: 2+5
- Minimum mass: 1200kg

Applying the design principles aforementioned, the mass of the helicopter for the analysis is reduced by 500kg (7x77kg), corresponding to the passengers' weight.
In the case of the AS355, when the helicopter is inverted, the whole structure produces buoyancy that helps to reach the side-floating position. The material volume of the helicopter is approximated by 250L, supposing an average density of 5kg/m^3 (approx 1200kg/5kg/m^3). It is a conservative value since the minimum mass is considered, and no detail of the buoyant elements has been done (done for the EC225, Table 1)
Therefore, supposing that the centre of buoyancy of the structural volumes is close to the CG, the design mass is reduced by 250kg.

The final considered mass for the design of additional EFS is 1850kg.

Now let us consider a symmetrical configuration of the upper floats. Because of the symmetry, the fully inverted helicopter will always be an equilibrium position. A sufficient amount of buoyancy should be produced by the upper floats in order to makes the 180° position unstable, and have another stable equilibrium position at a lower angle, where the windows on one side would be above the waterline.

To have an estimation of the necessary volume in the upper floats, stability curves are plotted for different configurations. A stable equilibrium at 150° has been obtained with two 1000L floats on each side of the cabin. The equilibrium position is shown in Figure 7and the stability curve corresponding to this configuration is shown in Figure 8. There, the stable position of the helicopter at a roll angle 150° can be observed, and it can noticed that this position presents a lower stability than the up-right helicopter. A lower work (linked with the area under curve) is needed to pass from this position to the other one, symmetric with respect to the XY plane. This later position corresponds to a -150° roll angle and is not plotted for symmetry reason.

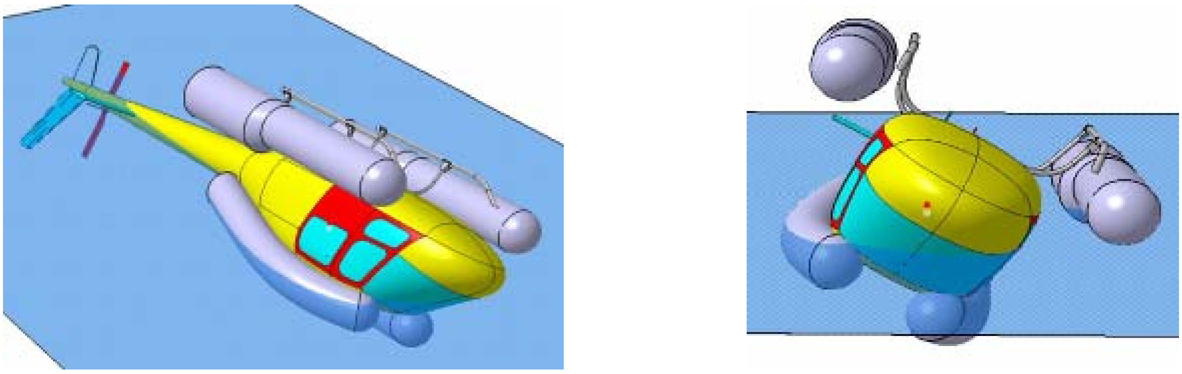

Figure 7: AS355 – Inclined position with 2x1000L upper floats

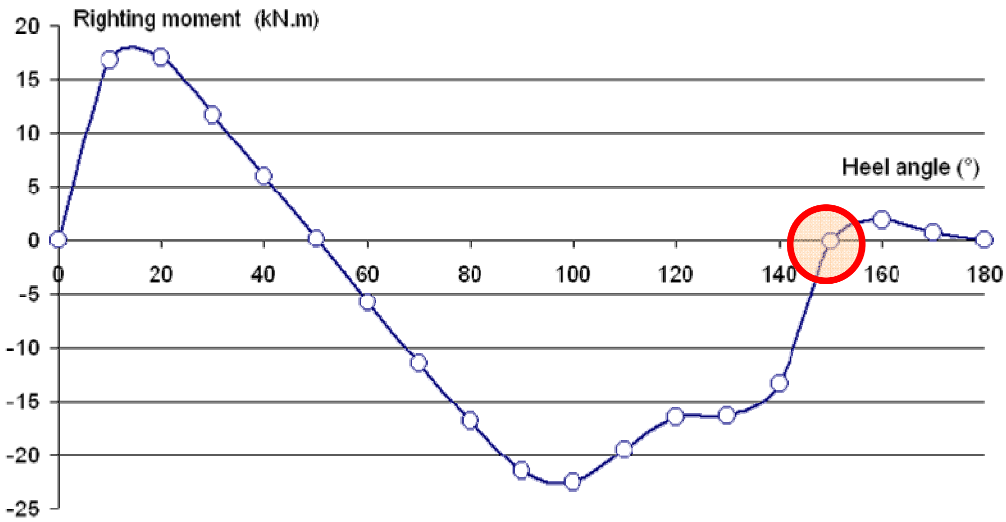

Figure 8: AS355 – Stability curve with 2x1000L upper floats

For an asymmetrical configuration of the upper EFS, the design process is slightly different. Any buoyant volume placed at one side of the helicopter produces a shift of the stable position at 180°. Here again, the design principle is to find the appropriate volume of the upper float in order to have a single inclined stable position at an angle such that all the windows on one side are above the waterline. This volume has been found to be about 1500L. The stability curve for this configuration, plotted from -180° to 180° due to the asymmetry, is shown in Figure 9. For negative heel angles between 0° and -50°, the moment is negative. However, since the heel angle is negative to, it corresponds to a restoring term that makes the helicopter going back to the upright position. Comparing with Figure 8, the 180° position is no more an equilibrium position. This ensures that no oscillation between two inclined positions is possible with such a design.

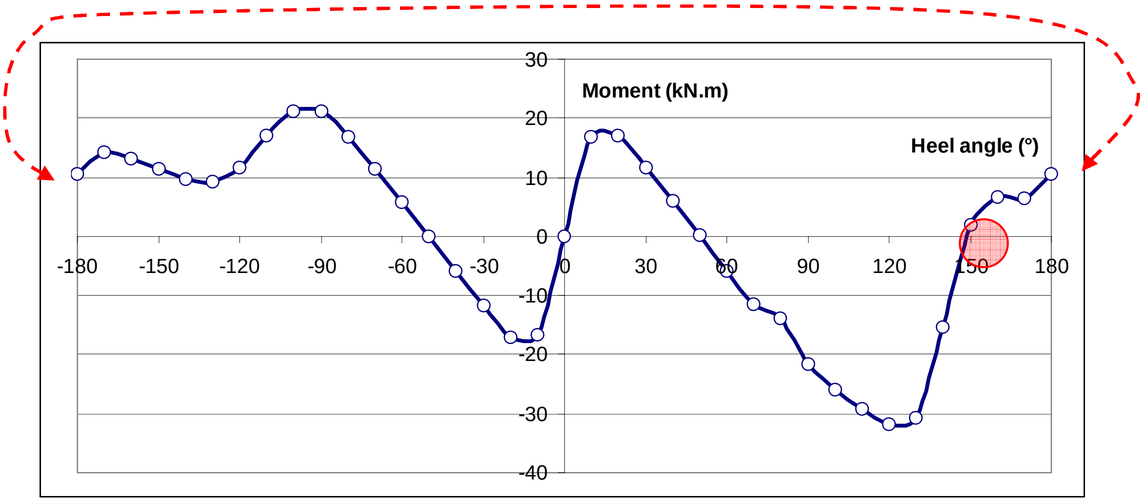

Figure 9: AS355 - Stability curves with one 1500L upper float

The stable equilibrium position at 150° is shown in Figure 10. As for the symmetrical configuration, in the inclined position, an important part of the cabin is above the waterline, increasing the possibility for occupants to escape and survive, even after a capsize event.

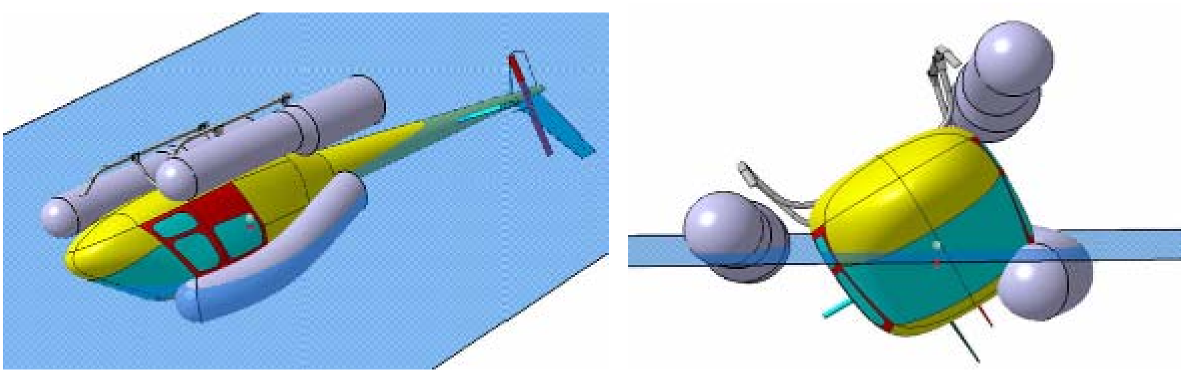
Figure 10: AS355 – Inclined position with one 1500L upper float

IV. Design of additional EFS for the EC225

IV.1. EC225 – Applicable regulation

The EC225 flotation system is compliant with following regulation:
JAR 29 § 21, §45, §49, §141, §143, §181, §241, §251, §305, §307, §337, §563, §601, §603, §605, §607, §609, §801, §807, §1301, §1309, §1322, §1323, §1325, §1353, §1357, §1505, §1527, §1555, §1561, §1581

The paragraphs 563 and following should be amended to mention the additional flotation units if a regulation should be developed for such equipment.

IV.2. EC225 –Hypotheses

IV.2.a. Inherent buoyant volume of the EC225

Collecting information from different Eurocopter departments, the following inherent buoyant elements in the upper part of the helicopter have been identified.

Element	Volume (L)
Main & Secondary Gear Box	700
Engine and MGB panels	300
Hydraulic systems	100
Radiators & extinction bottles	25
Protection motor & cupola	15
Blades	800
Other	320
Total	**2260**

Table 1: EC225 – Inherent buoyant volumes of the helicopter

The volume of all the others elements in the upper part of the helicopter (main rotor hub, engines, structure, mechanics…) has been approximated using the total mass of these elements, and supposing an average density of 6 kg/m^3. The corresponding volume is 320 litres.

Due to the closed type geometry of the upper panels, one can supposed some air can be entrapped after capsize, increasing the buoyant volume of the inverted helicopter. However, no air-entrapping seems the most conservative hypothesis for the design.

Blades could easily break during the capsize process, and in order to consider the worst situation, their buoyancy has not been taken into account for the inherent buoyancy of the helicopter. Consequently, the blades' volume being 800L, **the final inherent buoyant volume in the upper part of the EC225 and considered for the design is 1500L.**

One can, as done earlier for the AS355, introduces the inherent buoyancy of the helicopter by decreasing the total weight for the design. However, the description in Table 1 focuses on elements located in the upper part of the helicopter. Therefore, in order to be closer to what actually happens, a 1500L buoyant volume, centred in X and Y directions, has been placed at the level of the mechanical floor, instead of decreasing the helicopter's weight.

IV.2.b. Mass & Centre of gravity

Table 2 shows the extreme points of the mass/CG diagrams for the EC225.

Configuration	Weight	CG position			Inertias		
	(kg)	Xg (m)	Yg (m)	Zg (m)	Ixx (m^{2}kg)	Iyy (m^{2}kg)	Izz (m^{2}kg)
AV1	*11000*	*4.60*	*-0.05*	*0.85*	*13865*	*62935*	*52981*
AV2	*7000*	*4.41*	*-0.06*	*1.18*	*10491*	*54972*	*46857*
AV3	*6000*	*4.40*	*-0.06*	*1.32*	*9247*	*48645*	*41510*
AR1	*11000*	*4.87*	*-0.05*	*0.86*	*14163*	*63556*	*53968*
AR2	*10500*	*4.95*	*-0.05*	*0.91*	*14326*	*65913*	*57526*
AR3	*6000*	*4.95*	*-0.06*	*1.33*	*8795*	*53702*	*46195*

EC225 weight and CG domain (including rotor blades)

Configuration	Weight	CG position			Inertias		
	(kg)	Xg (m)	Yg (m)	Zg (m)	Ixx (m^{2}kg)	Iyy (m^{2}kg)	Izz (m^{2}kg)
AV1	*10310*	*4.553*	*-0.054*	*0.698*	*9812*	*54881*	*48946*
AV2	*6310*	*4.315*	*-0.070*	*0.956*	*7350*	*47603*	*42592*
AV3	*5310*	*4.291*	*-0.072*	*1.081*	*6494*	*41646*	*37227*
AR1	*10310*	*4.843*	*-0.055*	*0.702*	*10123*	*55721*	*50140*
AR2	*9810*	*4.931*	*-0.056*	*0.748*	*10444*	*58278*	*53738*
AR3	*5310*	*4.911*	*-0.072*	*1.084*	*6051*	*47202*	*42402*

EC225 weight and CG domain (without rotor and blades)

Table 2: EC225 - Extreme points of the Mass-CG diagrams with and without rotor and blades

Since the upper EFS makes sense if passengers are inside the cabin, and since they float, their mass, approximated by 2 tons, is reduced from the total mass. Therefore, the maximum mass of the helicopter for the study is 9 tons.

In order to define the most critical points of mass & CG for the design, stability curves have been plotted in figures 11 to 13 in order to see the influence of the helicopter's mass and the CG position on the stability.

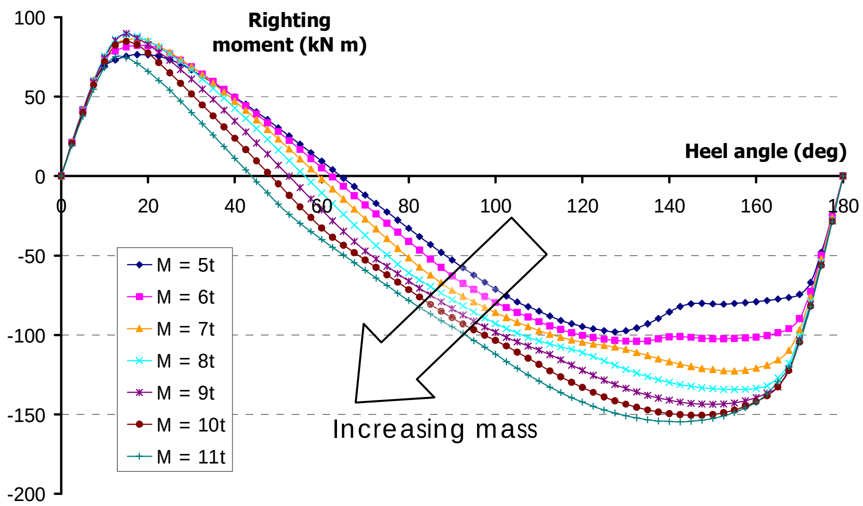

Figure 11: EC225 - Influence of the mass on the helicopter stability

In Figure 11, the stability curves are plotted for a given CG position and different helicopter masses from 5 tons to 11 tons. When the mass increase, the upright helicopter gets a lower position in the water and consequently has a lower reserve of buoyancy i.e. a smaller part of the floats are above the waterline. For this reason, the stability range, i.e. the angle for which the upright helicopter loses stability, decreases as the mass increases. Conversely, it means that the inverted helicopter is more stable as mass increases.
However, when the helicopter has a lower position in the water, its centre of gravity is closer to the water level. It has the effect to increase the stability of the helicopter. For this reason, for low heel angles (lower than 20°) where all the configurations still have buoyancy reserve, the influence of mass on stability is marginal.

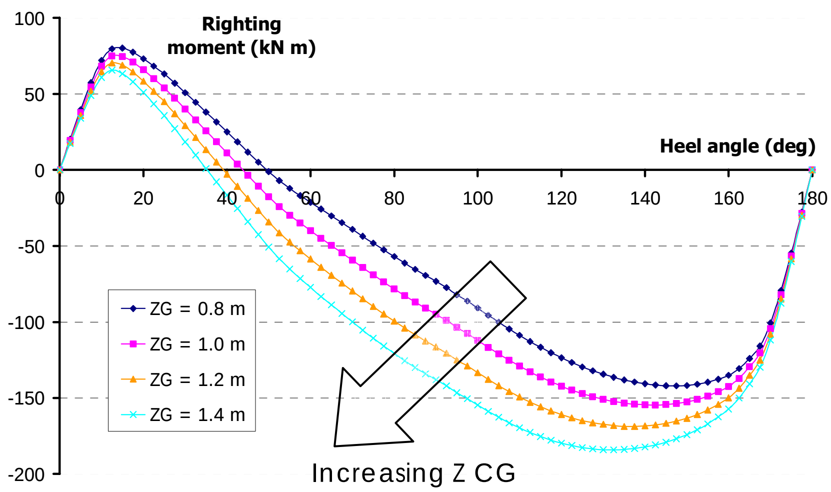

Figure 12: EC225 - Influence of the CG's height on the helicopter stability

In Figure 12, the stability curves are plotted as a function of vertical CG position with mass, and X and Y CG positions held constant. For heel angles greater than 20°, a high CG position has a similar effect as an increase of the helicopter mass: The stability range of the upright helicopter decreases, and conversely the inverted helicopter becomes more stable.

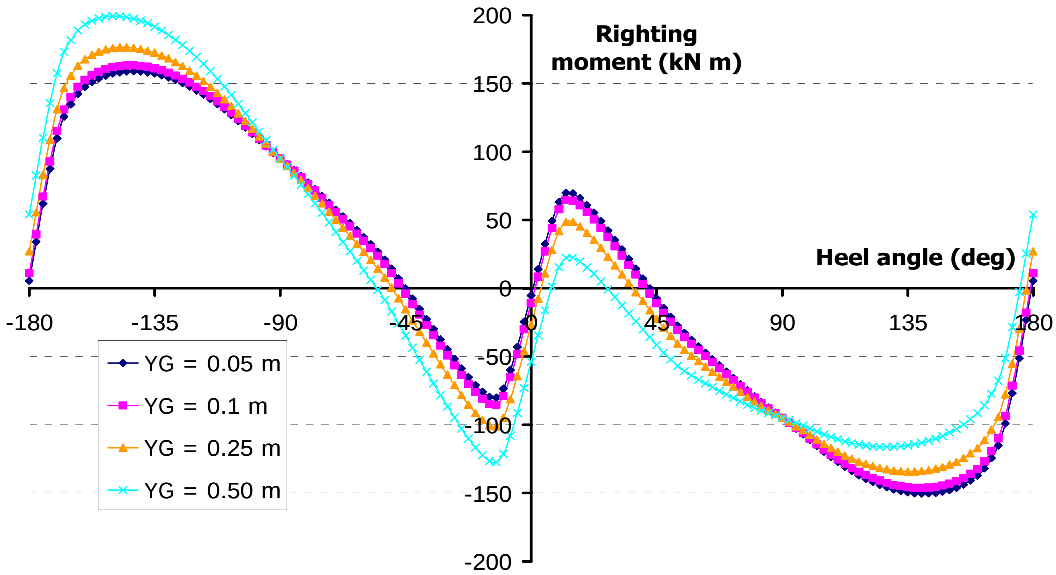

Figure 13: EC225 - Influence of the Y CG on the helicopter stability

In Figure 13, the stability curves are plotted for different lateral positions of the centre of gravity, at constant mass, X and Z of the CG. The curves are plotted from -180° to 180° because the behaviour is not symmetrical anymore with respect to the longitudinal plane of the helicopter. The upright helicopter is not stable at 0° but with a little heel angle. In order to obtain significant differences, the Y of the centre of gravity needed to be shifted by 0.5m, which corresponds to an unrealistic position of the centre of gravity (the maximum variation of the Y CG for the EC225 is 0.05 cm). Therefore, the lateral position of the centre of gravity is not considered as an issue for the design of the additional EFS of the EC225.

Concerning the longitudinal position of the centre of gravity, it appears that it is more difficult to locate the additional EFS in the forward part of the helicopter. Hence, as it will be shown by the model tests, the inverted helicopter tends to pitch nose down. Therefore, a forward CG position is the most critical and will be considered for the design.

To summarise, the heaviest helicopter and the one with the highest CG are the ones for which the upright helicopter is the least stable and the fully-inverted position is the most stable. Consequently, a first conservative approach is to consider the heaviest helicopter with the highest centre of gravity. However, this is an unrealistic configuration since the heaviest configuration corresponds to the lowest vertical position of the centre of gravity.

In order to cover the two worst cases, two configurations will be studied: one with the MTOW (minus 2 tons), forward centred, and the other one corresponding to the lightest helicopter. The stability curves corresponding to these configurations are plotted in Figure 14, showing a similar range of stability for both configurations.

- **AV1' : Modified AV1 configuration** (see Table 2):
  CG = {4.6 ; 0 ; 0.85} ; M = 9 tons
- **AV3** (see Table 2):
  CG = {4.4 ; 0 ; 1.32} ; M = 6 tons

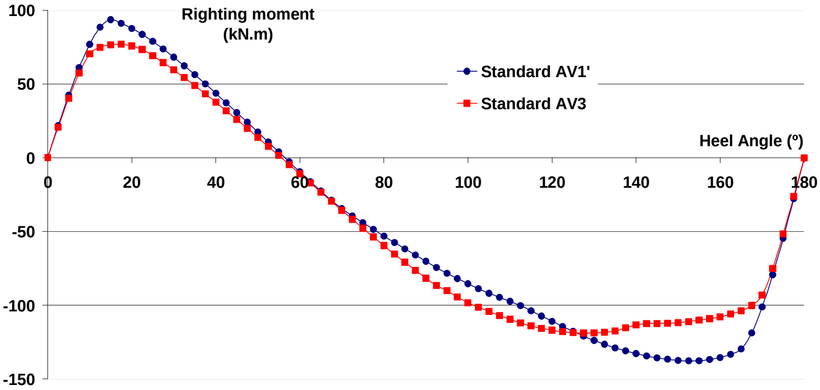

Figure 14: EC225 – Stability curves for the two mass-CG configurations of the analysis

IV.3. EC225 – Studied solutions

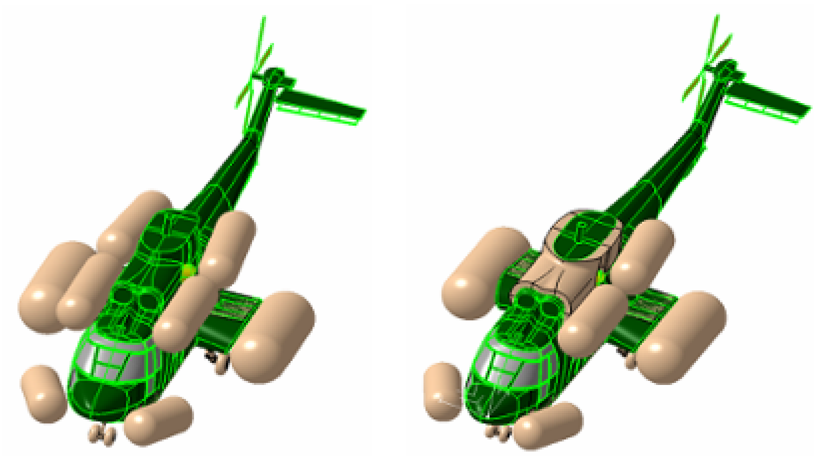
Figure 15: EC225 - Views of the helicopter with additional EFS

Two solutions are studied in this work: cabin wall floats and foam-filled cowling panels.
A particular design feature of the EC225 is that in the engine nozzles are positioned longitudinally above the cabin doors. For this reason, the high level cabin wall floats are designed as two separate floats, one before and one after the nozzle, as observed in figure 15.

The surface of the EC225's panels is approximately 15m². Their thickness varies from 12 to 32 mm, depending on the longitudinal position. They represent a volume of 300L, and this volume can be increased by 1500L increasing the thickness by 10cm, and 3000L increasing the thickness by 20cm.
With the hypotheses presented in section III.2, the necessary volume to make unstable the fully inverted position has been found to be greater than 6500L. Such a volume cannot be achieved by the only foam filled cowling panels. However, if used together with floats, the floats' volume could be reduced, that is an advantage from the feasibility point of view.
The cowling panels are important for the thermal exchanges between engines and the exterior and for the air flow under the rotor. It is difficult to quantify the impact of increasing the thickness of the cowling panels without costly numerical and experimental studies.
Therefore, it seemed to EUROCOPTER a good compromise to test the mixed solutions with 10cm foam filled cowling panels and symmetrical and asymmetrical floats.

Two types of solutions have been designed:

- Cabin wall floats
- Cabin wall floats + foam filled cowling panels.

Both solutions have been studied for symmetrical and asymmetrical configurations.

In the case of symmetric cabin wall floats without foam filled cowling panels, two different floats volume have been designed: One with the minimum volume to have an inclined stable position and another one with a higher margin in order to increase the stability of the inclined position.

Finally, the six selected configurations for tests in model basin are the following:

C1	**Helicopter with no additional buoyancy**
C2	**Two upper floats on one side**
C3	**Four upper floats – Two on each side** **Floats' volume: 7550L**
C4	**Four upper floats – Two on each side** **Floats' volume: 6660L**
C5	**Foam filled cowling panels + two floats on one side**
C6	**Foam filled cowling panels + four floats, two on each side**

The floats definition for each configuration is defined in Table 3.

CONFIGURATIONS FOR WAVE TESTS																							
Conf	Name	Foam Filled Cowling Panels	Sup Float FWD LEFT					Sup Float AFT LEFT					Sup Float FWD RIGHT					Sup Float FWD RIGHT					TOTAL ADDED VOL. (L)
		Vol (L)	V (L)	L (mm)	R (mm)	P1 (mm)	P2 (mm)	V (L)	L (mm)	R (mm)	P1 (mm)	P2 (mm)	V (L)	L (mm)	R (mm)	P1 (mm)	P2 (mm)	V (L)	L (mm)	R (mm)	P1 (mm)	P2 (mm)	
1	Standard	0	0	0	0	-	-	0	0	0	-	-	0	0	0	-	-	0	0	0	-	-	**0**
						-	-				-	-				-	-				-	-	
						-	-				-	-				-	-				-	-	
2	ASYM 4600L	0	2310	3200	500	1100	4300	2310	3200	500	5086	8273	0	0	0	-	-	0	0	0	-	-	**4620**
						-1150	-1150				-1260	-981				-	-				-	-	
						1780	1780				1780	1780				-	-				-	-	
3	SYM 3750L	0	1888	3200	450	1100	4300	1888	3200	450	5081	8269	1888	3200	450	1100	4300	1888	3200	450	5081	8269	**7552**
						-1100	-1100				-1210	-931				1100	1100				1210	931	
						1780	1780				1780	1780				1780	1780				1780	1780	
4	SYM 3000L	0	1665	2850	450	1450	4300	1665	2850	450	5081	7920	1665	2850	450	1450	4300	1665	2850	450	5081	7920	**6660**
						-1100	-1100				-1210	-961				1100	1100				1210	961	
						1780	1780				1780	1780				1780	1780				1780	1780	
5	C1500L + ASYM 4000L	1500	1996	2800	500	1500	4300	1996	2800	500	5086	7875	0	0	0	-	-	0	0	0	-	-	**5492**
						-1225	-1225				-1260	-1016				-	-				-	-	
						1780	1780				1780	1780				-	-				-	-	
6	C1500 + SYM 3000L	1500	1506	2600	450	1700	4300	1506	2600	450	5081	7671	1506	2600	450	1700	4300	1506	2600	450	5081	7671	**7524**
						-1172	-1172				-1210	-983				1172	1172				1210	983	
						1780	1780				1780	1780				1780	1780				1780	1780	

Table 3: Description of the float configurations tested the wave tank

When inverted, even with the modelled inherent buoyancy and the lightest configuration (AV3), windows are statically fully submerged when no additional EFS is installed.

Figure 16: EC225 - Fully inverted position (C1)

In Appendix 2, the equilibrium positions and the stability curves for all the configurations are presented with a view of the interior of the cabin to evaluate the air remaining inside the cabin. This is done for both mass-CG configurations AV1 and AV3, defined earlier.

Looking at the equilibrium positions and the stability curves, the following points can be noticed:

- For the heaviest helicopter (AV1) and for all the configurations, there is a stable equilibrium point between 150 and 160 for which the main part of all the windows are above the waterline.
- For the lightest helicopter (AV3) and the asymmetrical configurations (C2 and C5), a similar equilibrium position, more stable, does exist at a similar angle (between 150 and 160°)
- For the lightest helicopter and the symmetrical configurations (C3, C4, and C6), the fully inverted helicopter (180°) is a stable equilibrium position, but the only upper floats are big enough in those cases to make the helicopter float. The difference is illustrated in Figure 17. This fully inverted position is acceptable from the evacuation and air inside the cabin point of view. More over, they are more stable than the up-right helicopter because of the high position of the centre of gravity (i.e. low when inverted).

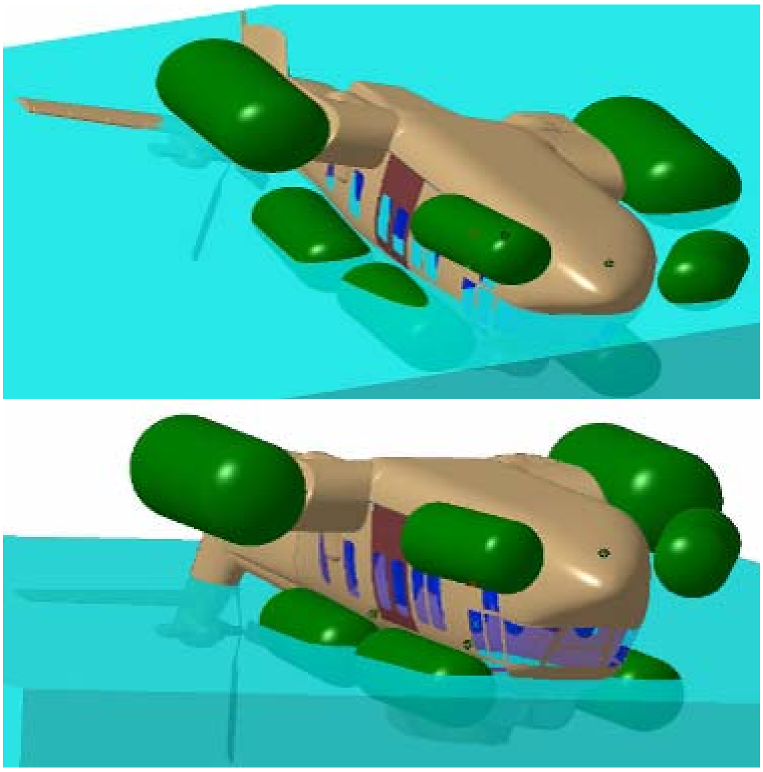

Figure 17: EC225 – Equilibrium positions for configuration 3. Up: AV1. Down: AV3

- The airspace inside the cabin is greater for AV3 than for AV1. In order to quantify this, the number of seats totally dry at the inclined equilibrium position has been plotted in Figure 18, for all the configurations. It can be seen that this number is higher for the symmetrical configurations (C3, C4 and C6). This can be explained by the fact that a symmetrical configuration requires more additional buoyant volume to obtain the wanted inclination. As a consequence, the helicopter is higher in the water and more air remains inside the cabin.

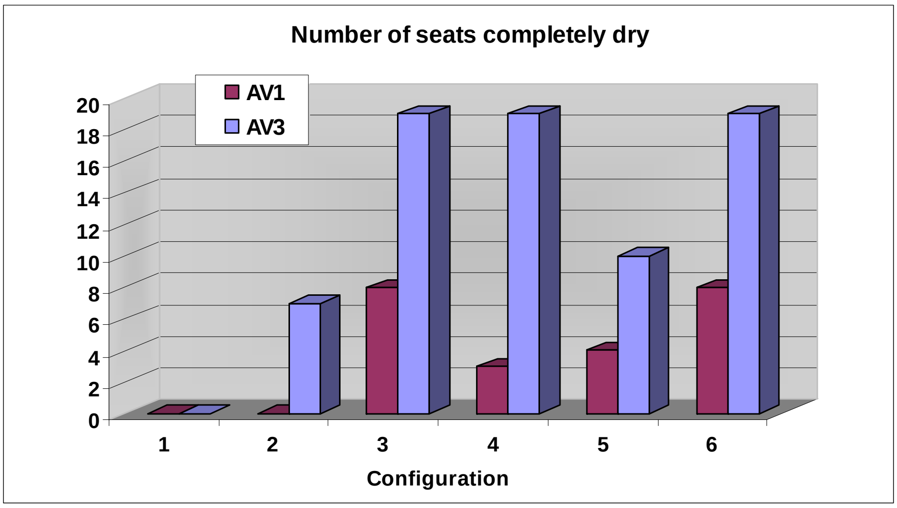

Figure 18: EC225 – Number of seats totally clear for the different configurations

IV.4. EC225 – Model basin tests

IV.4.a Presentation

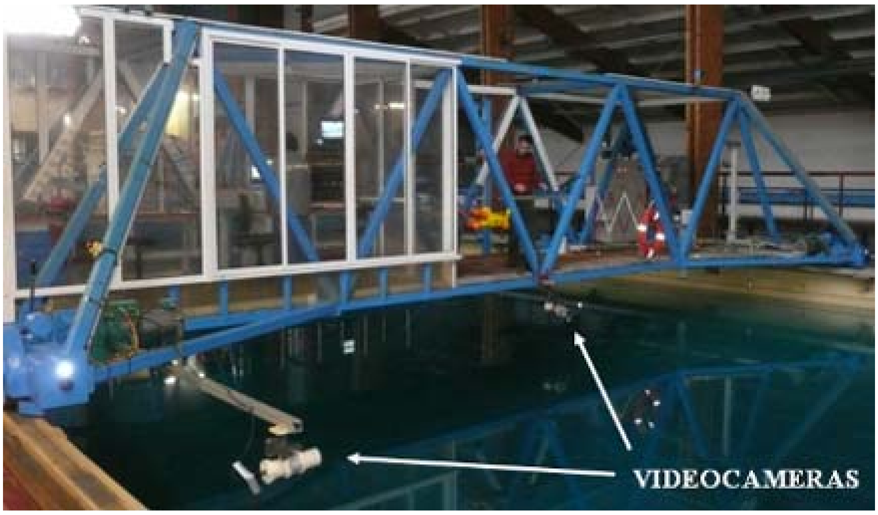

Figure 19: Model basin

In order to check the behaviour in waves of the configurations presented in the previous section, model tests have been performed in a wave tank. (Figure 19).

Tests for comparisons of the different configurations have been performed in irregular waves at a sea state near to 5.

The tests programme is reported in Appendix 3.

IV.4.b Waterlines comparisons

A special attention has been paid to the comparison between calculated waterlines with the supposed buoyant elements and the measured waterlines in fresh water. The waterline comparisons are discussed in Appendix 4.

IV.4.c Results of the standard tests

In order to quantify the efficiency of the additional EFS, the windows of the cabin have been numbered in order to define a level of flooding for each window after each run.

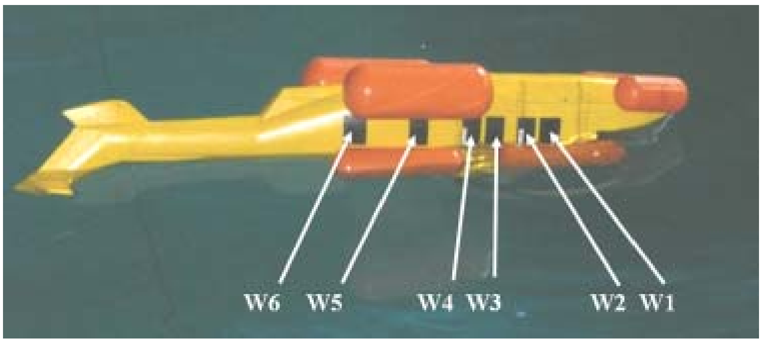

Figure 20: EC225 - Numbering of the windows

For the mass-CG point AV1, the damaged configuration has also been studied. As defined in the design objectives (III.1), the damaged configuration consists of a degradation of the most critical float

compartment. Once inverted, the helicopter tends to float more nose down in the water (see Figure 20). This is due to the limitations of the forward position of floats (more details in section IV). Therefore, the most critical compartment is the forward compartment of one upper forward float.
Tests with one damaged float have been done for the mass-CG point AV3 only for the last 2 configurations C5 and C6 since they have been found to be the most promising.

The results of the tests in terms of windows above the waterline and behaviour is presented in the following table

Conf.	AV1		AV3	
	Intact	Damaged	Intact	Damaged
2	W12 up to 100% W34 up to 50% W56 dry Better behaviour with the emmerged windows facing the waves	W12 up to 100% W34 up to 50% W56 dry	All windows dry	_
3	STABLE W1 up to 75% W2 up to 25% W3456 dry Better behaviour with the emmerged windows opposed to the waves	STABLE W1 up to 100% W2 up to 75% W3456 dry Better behaviour with the emmerged windows opposed to the waves	All windows dry	-
4	UNSTABLE W12 up to 75% W3 - W6 dry	UNSTABLE W12 up to 100% W34 up to 30% W56 dry	All windows dry	
5	W1 up to 50% W2 up to 20% W3456 dry Better behaviour with the emmerged windows facing the waves	W12 up to 50% W34 up to 20% W56 dry Better behaviour with the emmerged windows facing the waves	All windows dry	All windows dry
6	STABLE W1 up to 30% W23456 dry Better behaviour with the emmerged windows opposed to the waves	STABLE W1 up to 30% W2 up to 10% W3456 dry Better behaviour with the emmerged windows opposed to the waves	All windows dry	W1 up to 10% W23456 dry
	Percentages refer to the part of the windows that has been submerged at least once during the run			

Table 4: Summary of the results of the nominal tests

The main conclusions are the following:

- Windows W1 and W2 are the mot commonly submerged due to the position of the helicopter with its nose down in the water. Conversely, windows W5 and W6 have been found to be the driest in waves.

- Tests have been performed with the windows above the waterline facing the waves and in the opposite direction. When the windows above the waterline face the oncoming waves, they can be submerged directly by the waves when they arrive. When the windows above the waterline are opposed to the incoming waves, they can be submerged just after a wave crest. There, the helicopter move down and the water can pass between the floats and the fuselage and submerge the windows.

  For the asymmetrical configurations C2 and C5, the highest percentages of the windows that have been submerged during the run is greater with windows above the waterline opposed to the wave. For the symmetrical configuration C3 and C6, the percentage is greater with windows above the waterline facing the waves. No significant difference was observed for configuration C4.
  The differences between both positions were found in all the cases to be little. For this reason, only the highest percentages have been reported in Table 4.

- All the configurations showed a very good efficiency for the lightest helicopter (AV3)

- Configuration 4 (symmetrical floats) has been found to be unstable i.e. the helicopter can go from one inclined position to the symmetrical one on the other side.

- Configurations with buoyancy attached to the cowling panels have been found to be the most efficient with respect to stability and windows above the waterline. At equivalent total buoyancy, this is due to the fact that the buoyant elements are in these cases further from the centre of gravity.

- Configurations C5 and C6 showed their ability even with a damaged float.

IV.4.d Complementary tests

Complementary tests have been performed on the selected configurations C5 and C6 in order to study the behaviour of the capsized helicopter in different conditions that are not covered by the previous tests.

N°	PARTICULARITY OF THE RUN	OBSERVATIONS		CONCLUSIONS
		CONFIG 5 ASYMMETRICAL (AV1 unless precision)	CONFIG 6 SYMMETRICAL (AV1 unless precision)	
1	IRREGULAR WAVES SEA STATE 3	W1 to W6 dry	W1 to W6 dry (AV1 and AV3 tested)	The systems work for a less sever sea state
2	INITIAL POSITION WITH RESPECT TO THE WAVE DIRECTION :0°	Model turns to 90°	-	For the config 5, with no wind, the inverted helicopter has a stable position when perpendicularly oriented with respect to the waves
3	INITIAL POSITION WITH RESPECT TO THE WAVE DIRECTION :180°	Model turns to 270°	-	
4	1 OPENED DOOR	No significant wave in the cabin during the run	No significant wave in the cabin during the run	Opened doors have not an important impact on the behavior of the system.
5	2 OPENED DOORS	1 significant wave in the cabin during the run	1 significant wave in the cabin during the run	
6	CRASH	Standard rear portside float removed : Starboard windows statically above the waterline. In waves, W5 and W6 up to 100%, W3 and W4 up to 50% Standard rear starboard float removed : Portside windows statically over the waterline. In waves, W2 to W6 up to 100%, W1 up to 50%	Standard rear starboard float removed : Portside windows statically over the waterline. In waves, W5 and W6 up to 100%, W3 and W4 up to 75%, W1 and W2 dry	Without wave, both systems, with one standard rear float removed, allow passengers escape. In waves, symmetrical system (config 6) presents a better behavior regarding passengers escape
7	WIND	-	Test done for AV3 (highest wind exposed surface). All windows dry. High drift. The model reached the end of the basin before the end of the run	Runs performed with irregular waves need to be long in time (more than 200sec.). If they are performed with wind, the drift of the model becomes an important issue that needs further investigations

Percentages refer to the part of the windows that has been submerged at least once during the run

Table 5: Summary of the results of the complementary tests

The most relevant conclusions are the following:

- With no wind, the model tends to turn perpendicular to the waves' direction.
- This is not true with wind. With only wind and no waves, the model tends to minimize the surface exposed to the wind. Therefore, it tends to get aligned with the wind.
  With wind and waves having the same propagation directions, the model tends to an intermediate position.
- With wind, there is a high drift of the model such that it reached the end of the basin before having seen half the irregular waves' packet.
- Opened doors do not affect significantly the behaviour of the inverted helicopter. Due to the high altitude of floatation, no important waves were observed inside the cabin

Water impact

In the cases of water impact, there is a high possibility to damage standard EFS. Since one the objective of the additional EFS is to provided buoyancy redundancy, different cases have been studied with one of the standard float removed. They are described in the following.

Configuration C5

Removing the standard rear starboard float, the helicopter stabilises with a heel angle of about 90° with all the port windows clear. Approximately half the cabin is above the waterline. The process is illustrated in Figure 21.

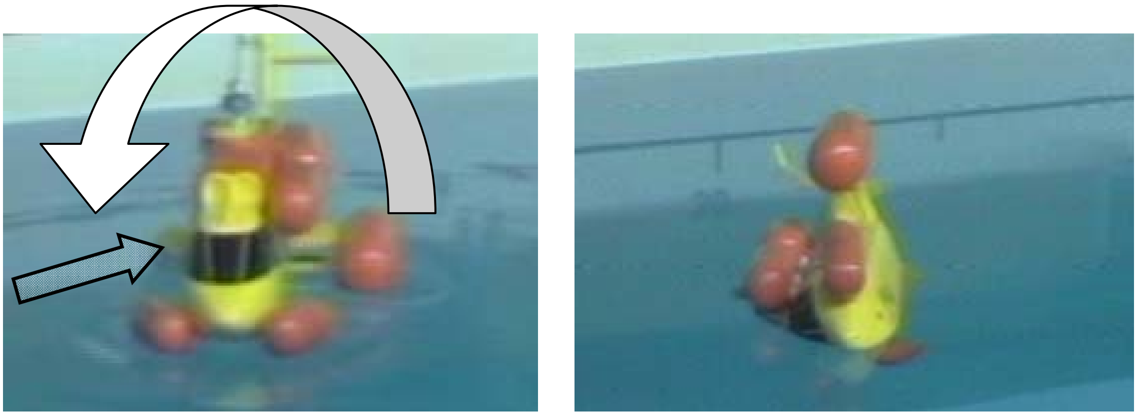

Figure 21: EC225 – Water impact - Config C5 – Rear port side float removed.

Once in waves, the windows are periodically submerged by the water, but the helicopter remains in this 90° position.

Removing the port rear starboard float, the helicopter stabilises with a heel angle of about 45° with all the starboard windows clear. Approximately half the cabin is above the waterline. The process is illustrated in Figure 22.

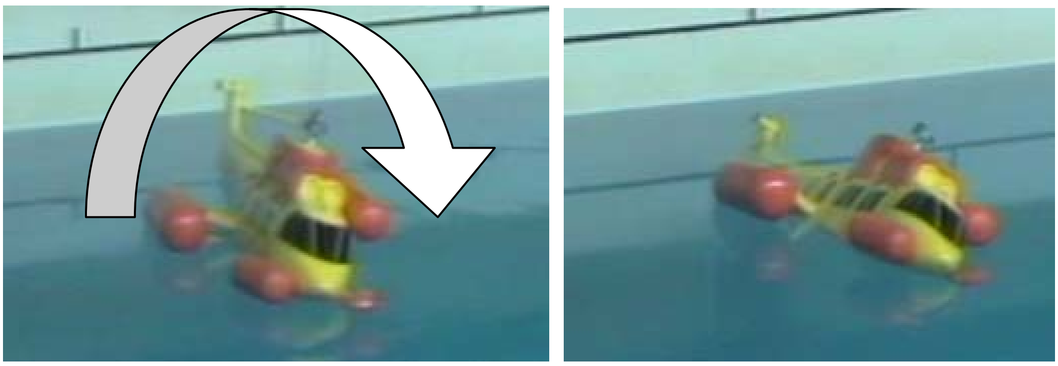

Figure 22: EC225 – Water impact - Config C5 – Rear starboard float removed.

As for the previous configuration, in waves, the windows are periodically submerged, but the helicopter remains in the position of Figure 22.

Configuration C6

Due to the symmetry of the upper floats, to remove the port or starboard side float is equivalent. The inversion process is illustrated in Figure 23. It is similar to the previous case for configuration C5, the helicopter stabilises with approximately a heel angle of 45° and remains in this position in waves, with the windows periodically submerged.

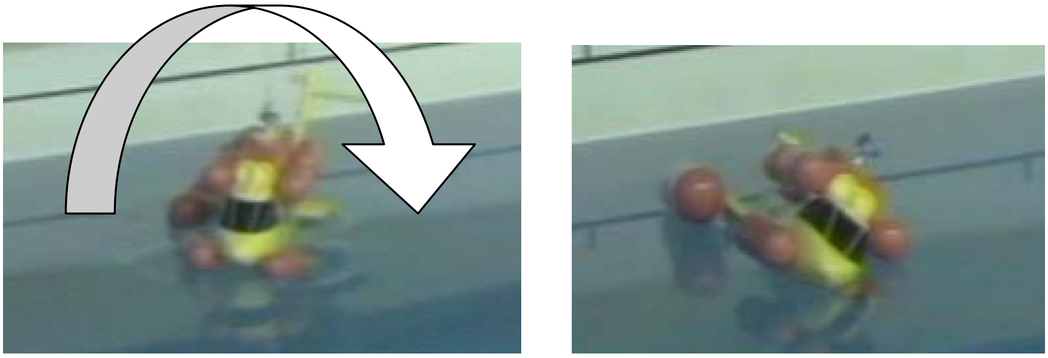

Figure 23: EC225 – Water impact - Config C6 – Rear starboard float removed.

Both configurations C5 and C6 presents acceptable floatation levels when one of the standard float is removed, showing the gain obtained by providing buoyancy redundancy. However, configuration C6 stabilises at a 45° position, with more airspace in the cabin than the 90° position, whatever the side of the removed float. In waves, the windows are submerged, but the helicopter stays in a position for which egress would be possible.

V. EC225 - Technical Feasibility

V.1. Constraints

The main constraints of the installation of the floatation system in the upper part of the helicopter are the following:

- Interaction with blades
- Fixation and loads on the structure
- Emergency exits clear
- Temperatures
- Aerodynamics impact
- Compatibility with other equipments
- Location of the bottles
- Inadvertent deployment
- Access to the upper deck
- Fairings opening
- Retro-fit

V.2. Interaction with blades

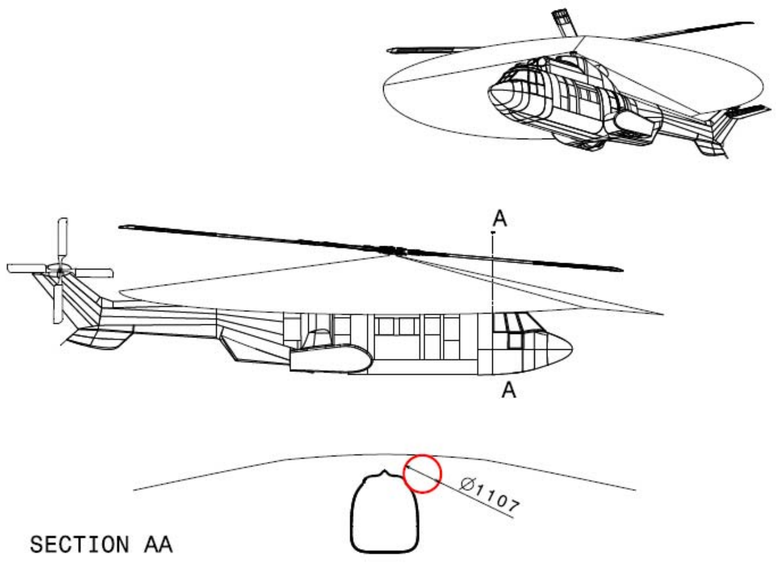

Figure 24: EC225 – Possible interaction with blades

Figure 24 shows the lowest blade position for the EC225. At the frame AA on the figure, the minimum distance from the helicopter to the blades is 1.1m. Considering the fixation of the EFS, a maximum float diameter of 1m has been defined at this frame. This is the reason why the additional EFS can lack buoyancy in the front part of the helicopter and why the most critical damaged compartment has been found to be the most forward one, from a floatation point of view.

Blades present another problem since they can break during the ditching or capsize event with the potential to consequential damage upper floats. This problem is difficult to assess and would need further developments.
The smallest balloons in the upper part present the lowest risk to be damaged when ditching.

V.3. Fixation on the structure

The nozzles of the EC225 are located on both sides of the helicopter, longitudinally near the rotor position. As a consequence, it is not possible to have a single float on each side along the structure. Two floats are necessary, one before and one after the nozzle, as illustrated in the following figure

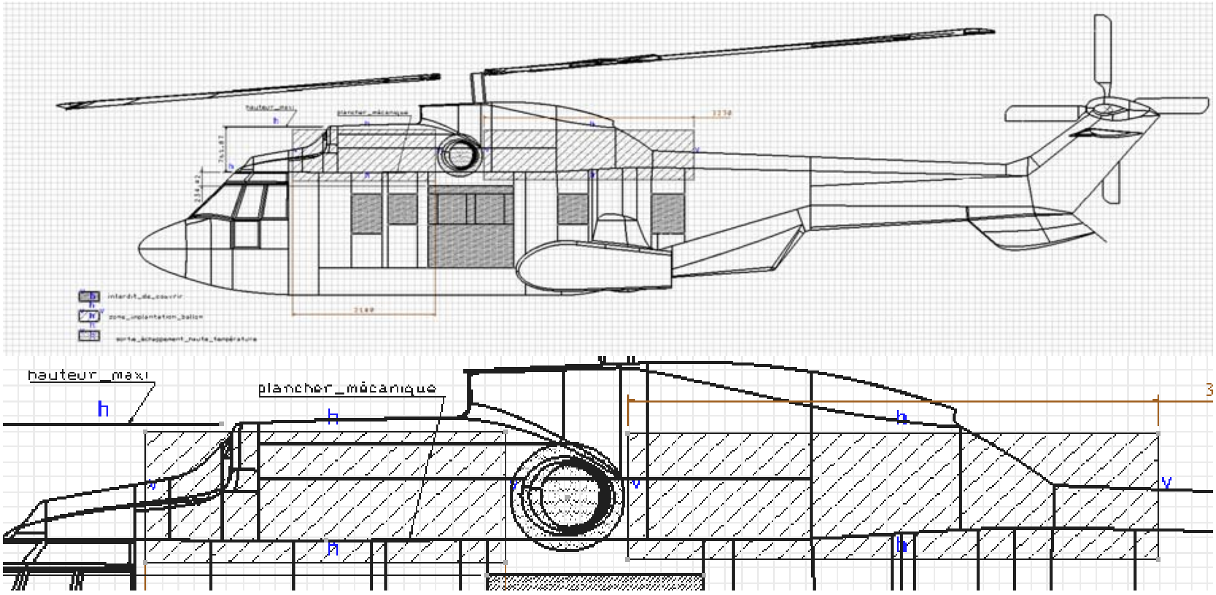

Figure 25: Lateral views of the EC225 with the possible locations of additional floats

The additional EFS could be attached 4 identified frames (2 before the nozzle and 2 after). The attachment should resist to tension loads when the floats are inflated.

V.4. Temperature constraints

The temperatures encountered on the structure are shown in Figure 26. The figure on the top shows the temperatures for an OAT (outside air temperature) of 50°C. Values up to 120°C are found after the nozzle in the location zone of the additional EFS. The figure on the bottom shows the maximum values obtained in the most critical conditions i.e. at zero ground speed with maximum load and lateral wind. Higher temperatures are found there, up to 200°C.

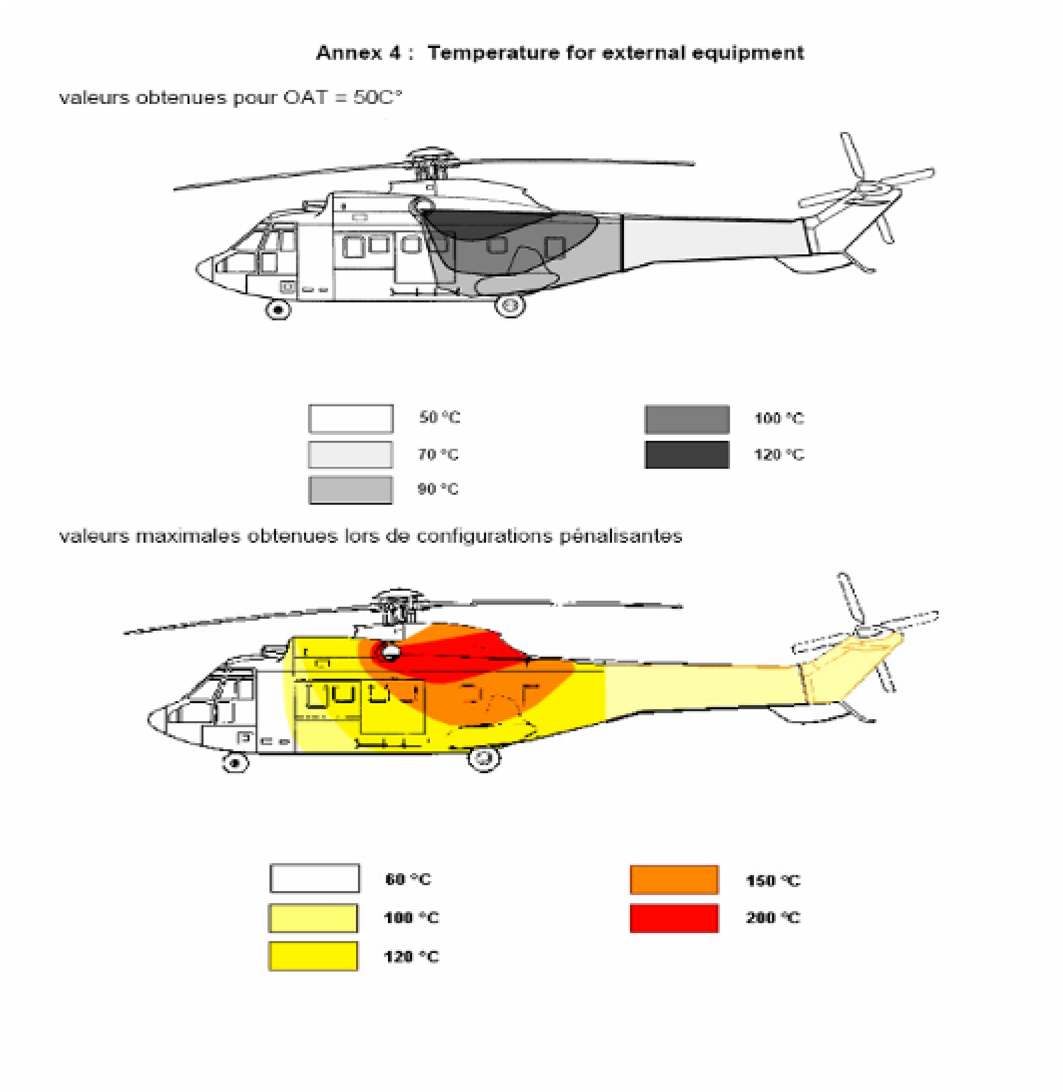

Figure 26: EC225 - Temperatures on the structure

The usual environmental conditions for qualification of EFS equipment range from -40°C to +70°C in operation and -55°C to +85°C in storage. Standard such as MIL-STD-810, RTCA-DO160 and GAM-EG13 are used for this purpose. Therefore, as a first conclusion, materials used in the standard EFS are not qualified for temperatures described in Figure 26.

Furthermore, a standard float design with a standard pressure of 150hPa at 20°C is made of a fabric composed of polyamide coated with polyurethane and has a melting temperature around 220°C. In the high temperature environment aft of the engine exhaust, an atmospheric temperature of 200°C will lead to more than 800hPa in the floats (close to or more than the burst pressure), and an environment close to melting point of fabric. Mechanical parts should not suffer from such high temperatures but mechanical strength will be reduced. Inflation hoses can sustain up to 200-230°C whereas operating temperature for float hoses is up to 95°C.

As a conclusion, no standard floats currently developed by AERAZUR are able to sustain an atmospheric temperature of 200°C.
The main path toward a solution would be in defining/developing a float fabric that could handle the temperature requirements.
This study could start by:
- A specific definition of the temperature requirement.
- An analysis of the fabric that exists on the market
- A trade off between qualification requirement, weight, foldable ability and cost

- Test identified solutions with the global system

Then, others studies could be lead in different ways:
- Thermal protection for packed EFS
- Thermal protection for inflated EFS
- Float fabric able to handle high temperatures in packed configuration
- Float fabric able to handle high temperatures when float inflated

This research and development would need to be undertaken as part of another study. However, based on AERAZUR experience we can already conclude in the following ways:
- Type of tests in high atmospheric temperature based on RTCA-DO 160E section 4 and 5 with maximum operating temperature of 200°C should not be selected for the reasons previously described (melting point of fabric, thermodynamic aspect…).
- Thermal protection should be promoted instead of specific float fabric for an acceptable cost and research time.
- Inadvertent inflation and such temperatures should have a sufficiently low probability to be considered as impossible.
- None valuable cost and mass impacts can be advanced before proceeding more deeply in these researches.

V.5. Proposed technical solution

The technical solution envisaged for the integration of additional EFS on the EC225 is illustrated in Figure 27. It is based on existing solutions (EC120, EC130) which are skid equipped.

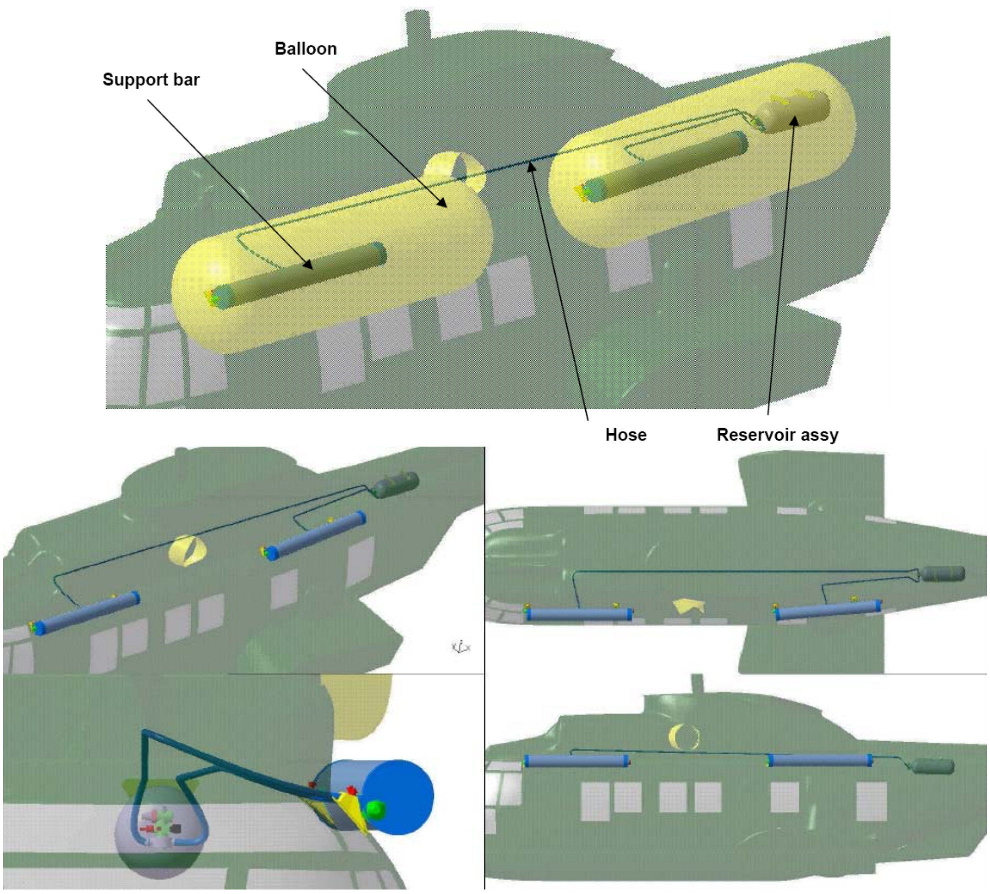

Figure 27: EC225 – Technical solution for the integration of additional EFS

The system should be removable in order to be compatible with the opening of the cowling panels and should have the necessary degrees of freedom to allow retrofit. This is achieved with the following fixations.

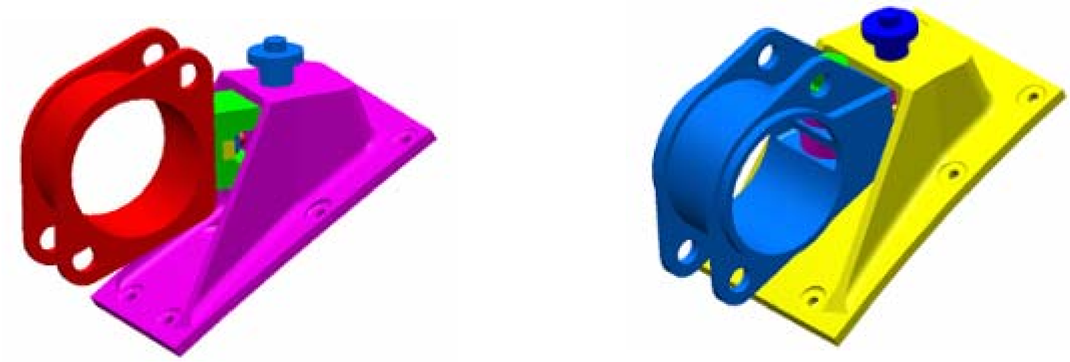

Figure 28: EC225 – Fixations on the structure (Left: front, right: rear)

V.6. Mass impact

V.6.a Floats & Inflation

Concerning the floats themselves, AERAZUR uses mainly two kinds of fabric, a lighter one and a stronger one. In all the configurations both fabrics can be used, adapting size of girts and drag patches for each configuration.
Main differences between fabrics are mass, strength, easiness to fold and colour. The most adapted fabric for an additional upper floatation device can only be decided in accordance with a detailed specification and is specific for each helicopter.
In the case of EC225, both fabrics have been considered to be able to sustain constraints by adapting the size of girts in each case.
Cylinders considered have been chosen among existing AERAZUR reference; these cylinders are certified by DOT, composed of aluminium liner and carbon-wrapped.

Results of system mass are presented in table 6 for both fabrics.

System mass has been divided in two main parts:

- Float assembly composed of :
  - Equipped float: float, float hose, sealant element.
  - Metallic parts assembly: bar, fittings and bolts.
  - Cover assembly: cover, front cap, rear cap and bolts.

- Inflation system composed of :
  - Equipped cylinder
  - Inflation hoses
  - Cylinder brackets
  - Clamps
  - Bolts

The mass impact of the system for the different configurations presented in sections III is summarized in the following tables. It does not include all the modifications to the structure of the helicopter nor the impact of the foam filled cowling panels, if relevant.

It is based on current technology used for standard EFS, and does not included the impact of fabrics' modifications.

Config	fwd L/H upper float assembly	fwd R/H upper float assembly	aft L/H upper float assembly	aft R/H upper float assembly	Inflation system	Total
	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)
1	0	0	0	0	0	**0**
2	19,9	0	19,9	0	21,0	**60,8**
3	17,7	17,7	17,7	17,7	38,9	**109,6**
4	17,2	17,2	17,2	17,2	33,4	**102,4**
5	17,9	0	17,9	0	19,4	**55,3 ***
6	16,6	16,6	16,6	16,6	33,4	**99,8 ***

Mass of one equipped cylinder
Weight (Kg)
0
14,3
12,7
10,0
12,7
10,0

Table 3: Weight estimation of tested configurations for the lightest fabric

Config	fwd l/h upper float assembly	fwd r/h upper float assembly	aft l/h upper float assembly	aft r/h upper float assembly	Inflation system	Total
	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)	Weight (Kg)
1	0	0	0	0	0	**0**
2	20,9	0	20,9	0	21,0	**62,8**
3	18,7	18,7	18,7	18,7	38,9	**113,6**
4	18,2	18,2	18,2	18,2	33,4	**106,4**
5	18,9	0	18,9	0	19,4	**57,3 ***
6	17,6	17,6	17,6	17,6	33,4	**103,8 ***

Equipped cylinder
Weight (Kg)
0
14,3
12,7
10,0
12,7
10,0

Table 4: Weight estimation of tested configurations for the strongest fabric

Table 6: EC225 – Mass impact of each proposed EFS configuration
(* means that the foam-filled cowling panels mass impact is not included)

V.6.a Total impact

Table 7 presents an estimation of the total mass impact of the additional EFS.

	Local Reinforcement	Fixed Part	Removable part
EFS	4 kg	10 kg	See table 6
Cowling panels	5 kg	15 kg	60 kg
Thermal protection	1 kg	2 kg	7 kg
Electrical (wire control)		1 kg	
Cabin equipments		2 kg	

Table 7: EC225 – Estimation of the total mass impact of the additional EFS

For the two configurations selected in the previous section (C5 and C6) the mass impact is

- 150 kg for the asymmetrical configuration C5 with two floats.
- 200 kg for the symmetrical configuration C6 with four floats.

These values do not take into account the possible resort to new material for the floats, due to high temperatures, that could increase the total mass impact of the system.

V.7. Aerodynamic impact

Upper floatation devices have impact on helicopter performance, as it increases helicopter drag and weight.

V.7.a Drag impact

An estimate of the additional fuselage drag can be determined by considering the components of the upper floats separately.

- impact of thickened cowlings:

  An increase of 10cm of cowling thickeness leads to an increase of airframe cross-section from 6.6 m^2 to 6.9 m^2. Considering that the drag of bare airframe is of 1.5m^2, the increase of cowling thickeness leads to an increase of helicopter drag. of SCx=(6.9*1.5)/6.6 – 1.5 = 0.07m^2.

- impact of upper floats support bars:
  Drag of support bars has been evaluated with the "Hoerner drag" book, that provides experimental drag results for huge amount of body shapes.
  The support bars are four cylinders, with a diameter of 180mm, and a length of 1625mm (forward ones) and 1500mm (aft ones). Their length/diameter ratio is thus between 8 (aft ones) and 9 (forward ones).

  For a cylinder with a blunt nose and a length/diameter ratio between 4 and 10, the "Hoerner Drag" provides a drag coefficient of 0.8.

  Thus, for the four support bars, the drag effect is assessed to be of:

$$SCx=4*\pi*0.09^2*0.8 =0.08m^2$$

Hence, the impact of upper floatation devices on fuselage drag has been assessed to be (0.08m^2 + 0.07m^2) = 0.15m^2 or a 10% increase.

V.7.b Impact upper floatation devices on Performance

Upper floatation device will have an impact of performance because of both drag penalty and weight penalty.

- drag penalty effect

  A drag penalty of 0.15m2 will induce a decrease of maximum speed and of best range speed by 2kts.

  When considering level flight at constant speed, it will thus induce an increase of fuel consumption. For example, for level flight at 145kts S.L. ISA, and a helicopter weight of 9T, this drag penalty will induce 6kg/h more of fuel consumption.

- weight penalty effect

  A weight penalty of 100kg will induce either a 100kg penalty in payload, or a range penalty of 50km.

V.7.b Cowling panels

A higher thickness of the upper panels influences the gas exhaust and could affect the engine performance. The shape of the panels influences the air flow under the rotor. Complementary studies are needed to quantify the influence of the foam-filled cowling panels on the helicopter performances.

V.8. Deployment

The inflation of the additional EFS can be done at three different moments
Inflation in flight
Inflation after ditching
Inflation after capsize

Situation 1: inflation in flight
Advantage:
- It can be done together with the inflation of the standard floatation. No differentiation is made between ditching/ water impact event.
Disadvantage:
- Deployed float deployment can cause difficulties for helicopter piloting.
- Floats are more vulnerable to damage when ditching. (upper floats are exposed due to their vicinity to the blades and temperatures near the engine exhaust nozzles)
- Unintended inflation is not avoided entirely (same risk as the standard floatation)

Situation 2: Inflation just after landing
Advantage:
- Better handling qualities prior to landing
- Minimises the potential for float damage when landing
- Possibility to arm the system just after landing → Better control of the unintentional inflation. The additional floatation system can be armed only when the standard floats are inflated. Then, another command controls the inflation of the upper floats.
Disadvantage:
- The crew may not have time to inflate the upper floats before a rapid capsize.
- No consideration of water impact events.

Situation 3: Inflation in capsize position
The deployment is done automatically after capsizing trough sensors (angle, immersion).
Advantage:
- No modification of the ditching procedure
- Better handling qualities prior to landing
- Minimises the potential for float damage when landing and capsizing
Disadvantage:
- If sensors do not work properly, inflation may not happen or contrarily could happen inopportunely.
- The system is vulnerable to electric breakdown.

The consequence of inadvertent deployment of the upper floats on the safety of the helicopter must consider the effects on helicopter handling qualities, stability and control and the further consequences of a float becoming detached and/or torn and subsequent entanglement with flight control components or rotating parts. Since no elements are today available to conclude on the effect of an unintentional deployment of the upper floats while flying, an inadvertent deployment must be considered a catastrophic event. Consequently, a 10^{-9} probability of inadvertent deployment should be the design and certification objective. This would be possible by linking the deployment of the additional EFS to both the deployment of the standard EFS and the rotor velocity. Since the rotor velocity is a well controlled parameter, probabilistic study showed that it would be possible to reach the wanted probability proceeding this way.
The inflation would be done after landing (situation 2), but automatically when the rotor velocity becomes lower than a value to be defined. This way, the upper floats are less exposed than if inflated in flight (temperatures, interaction with blades when landing) and no modification of the standard ditching procedure is needed (inflation of the standard floats before ditching).

V.9. Compatibility issues

V.9.a Cowling panels & Hoist

The technical solution proposed in this section for the upper floats is incompatible with the hoist installation, and does not allow a complete opening of the upper fairings. An improvement of the installation is needed to ensure theses compatibilities.

V.9.b Standard EFS

Standard EFS of the EC225 and their fixture to the helicopter are already designed to withstand high transient loads arising from ditching impact because of the EUROCOPTER ditching procedure (inflation before landing). No additional fixation on the structure is needed in order to support loads due to the inverted position of the helicopter.

V.9.c Life raft deployment

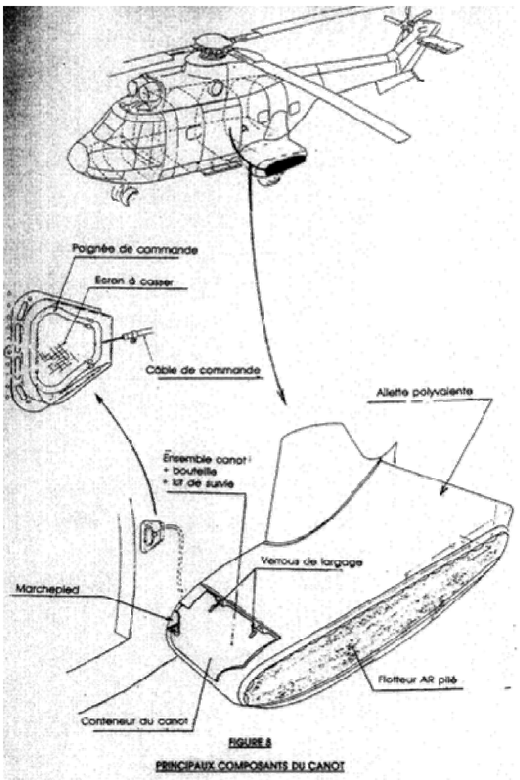

Figure 29: EC225 – Life rafts

The location of the life rafts in the EC225 is shown in Figure 29. They are located in the winglets and can be activated:

- Through a handle in the cockpit
- Through a handle in the fuselage
- Directly on the liferaft container.

They are designed for the upright helicopter. If inverted with an inclined position, one liferaft is under the water level and the other one above the water. Their correct deployment is not guarantied. The one under water can be blocked while inflating; the one above the waterline could be inverted after deployment.

Tests at full scale should be performed in order to determinate the deployment of the life raft from the inverted helicopter.

V.9.d Equipments inside the cabin

Handles inside the cabin should be installed in order to facilitate passengers egress in the inclined position. A modelling of the cabin in the inclined position is needed to perform an ergonomic study of the evacuation for the selected configuration.

For the EC225 harness, there is a requirement for a maximum force (30 lbs (or 30 in-lbs for rotary buckle)) to actuate the buckle release when there is a 170 lb (77 kg) loop load on the restraint.

V.10. Costs

The non recurrent costs (NRC) of the full development of the additional EFS are estimated in Table 8.

	Description	NRC (k€)
Additional EFS - EC	Specification	500
	Tender	
	Flight tests	
	Certification	
Additional EFS - Suppliers	Study	800
	Prototype	
	Equipement qualification tests	
	Qualification documentation	
Fairings	Study	1600
	Engine air intakes	400
	Aerodynamics interaction	400
	Flight control & Autopilot	320
	Thermal efficiency inside the fairings	160
Total		**4180**

Table 8 : EC225 - Cost impact

An estimation of the price of the additional EFS is 300 k€.

VI. Conclusions & Future works

VI.1. Side floating concept

The side floating concept has been presented in this work and the consequent design principles of additional emergency floatation systems have been introduced. It consists in the addition of floats along the top of cabin walls, alone or together with foam-filled cowling panels.
This has been done for both light (AS355) and heavy (EC225) helicopters. For the later, 5 configurations of additional buoyancy have been tested in model basin with irregular waves (sea state 5). Both symmetrical and asymmetrical configurations have shown their efficiency in terms of evacuation possibilities and airspace inside the cabin.
For the symmetrical configurations, if not enough buoyancy is provided, the model has been found to pass from one inclined position to the other one (symmetrical with respect to the fully inverted helicopter). This problem is solved by increasing the amount of buoyancy, or by having buoyancy in the cowling panels i.e. the farthest possible from the centre of gravity.
The additional floatation system in the upper part of the helicopter also provides redundant buoyancy in cases of water impact, where the probability to damage the standard floats is high. Tests have been performed removing one the standard floats and showed that evacuation is possible and air is found inside the cabin.

VI.2. Retained configuration

Among the different configurations of additional EFS for the EC225 presented in section III, the one preferred by EUROCOPTER is the configuration C6 i.e. the one with 1500L foam-filled cowling panels and two floats on each side. The reasons are the following:

- The model test campaign showed the better behavior of the additional EFS configurations with foam-filled cowling panels together with symmetrical and asymmetrical floats.
- Floats in the upper part of the machine present risks due to the environment and the vicinity to the blades. The presence of foam filled cowling panel allows reducing the floats volume. The risks of floats damaged are therefore reduced.
- However, the foam-filled cowling panels can affect the engine and rotor performance. In this study, their thickness has been limited to 10cm.
- The symmetrical solution is preferred to the asymmetrical one for the following reasons:
    - Floats on one side have lower volume with a symmetrical configuration.
    - The inclined position with a symmetrical configuration is higher in the water, with more airspace inside the cabin.
    - An asymmetrical configuration implies that there is a different level of safety depending on the side of the helicopter.
    - Better redundancy in cases of water impact with floats damage with a symmetrical configuration.

	Symmetrical C6	Asymmetrical C5
+	Redundancy in case of damage Independent of port/starboard capsize Smaller floats on one side (lower probability to damage) No preferable seats Higher position in the water	Lower total buoyancy is needed (mass impact) Better stability of the inclined position Compatibility with hoist
-	Higher total buoyancy is needed (mass impact) Incompatibility with hoist	Bigger floats on one side (higher probability to damage) No redundancy in case of damage Dependence on the size of capsize Preferable seats Lower airspace in the cabin

Table 9: Symmetric/asymmetric solutions

VI.3 Integration

The integration of additional EFS has been studied for the EC225, presenting a technical solution for cabin wall floats. The following conclusions can be drawn from the integration study:

- Weight penalty of additional EFS is greater than 2 passengers.
- Temperature constraints need further developments to be solved. Emergency floatation balloon technologies compliant with the thermal constraints are not yet available.
- A complete new design of the cowling panels and the gas exhaust would be mandatory.
- Compatibility with other optional equipments has to be done.
- Safety analysis leads to a catastrophic event. It is a challenge to effectively reach 10-9 probability of inadvertent deployment.
- Development costs for retro-fit are estimated to cost several millions euros.

VI.4. Future work

Further developments are needed in order to go ahead with the integration of additional EFS in the helicopter.

- Developments of new tissues fabric due to the high temperatures in the upper part of the helicopter
- Analysis, by modeling, of the interaction between the blades and the floats in the upper part of the helicopters at ditching.
- Evaluation of the blades' break possibility when the helicopter capsizes and the consequences for both standard and additional EFS.

- Aerodynamic study with the new cowling panels.
- Modeling of the inside of the cabin for ergonomic study of the egress in the inclined position.
- Life rafts deployment for both upright and inverted positions.

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Appendix 1: Statistics on the EUROCOPTER fleet

The Eurocopter accident database over the period 1996-2007 is presented here. 25 accidents due to an impact on water with inflated floats have been found over this period. The characteristics of the accidents are summarized in Tables 10 to 13. Since the EUROCOPTER standard procedure consists in inflating the floats before landing, the landings without and with the inflated floatation are differentiated.

Helicopter type	Number of landings with inflated floatation
Alouette	1
Ecurueil	9
Dauphin	6
Puma / Super Puma	9

Table 10: Landing with inflated floatation against helicopter type

25 landing events with inflated floatation have been found. For 9 of them, the helicopter sank or capsized instantaneously or before the end of the evacuation. Fatal issues happened for 7 of them. 2 deaths due to drowning in the cabin are found among the 14 deaths.

Normal ditching	16
Capsized helicopters	9

Table 11: Landing types

Number of accidents with fatal issues	7
Total of fatal issues following a ditching	14
Total of fatal issue due to drowning	3

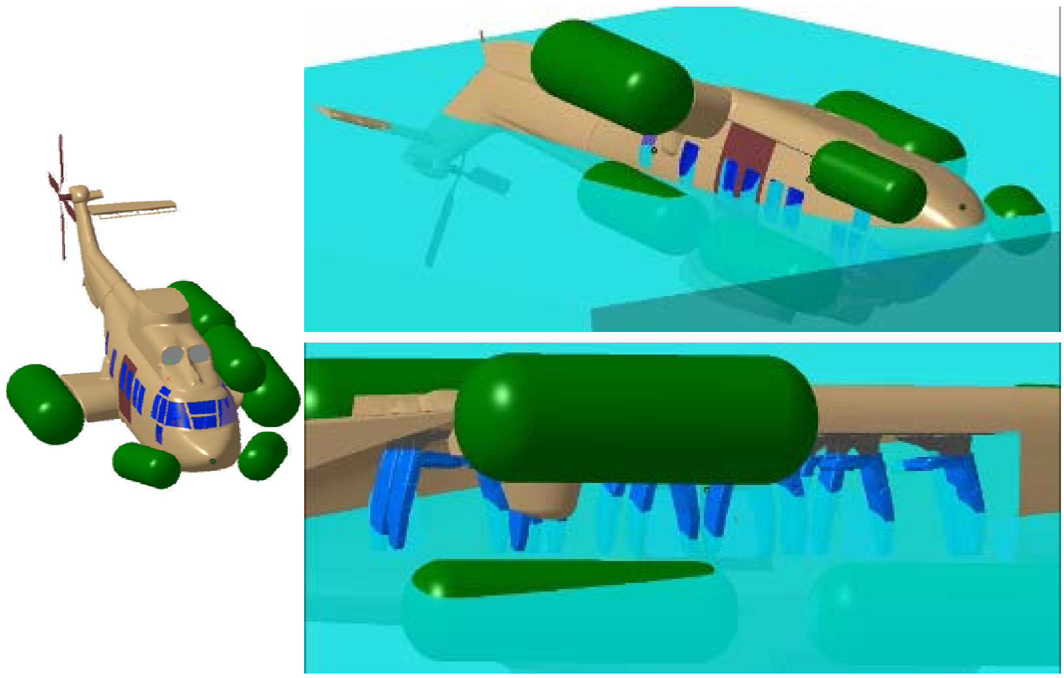
Table 12: Fatalities following landings on water

H/C family	Place	Capsize before end of evacuation	N° of persons	Fatal issues	drowned in the cabin	Sea State	Water Impact / Ditching
Alouette	China sea	No	3 crew			N/A	Ditching
Dauphin	Iceland	No	3 crew			N/A	Ditching
Dauphin	Indonesia	No	2 crew + 4 passengers			N/A	Ditching
Dauphin	USA	No	3 crew.			stormy sea	Ditching
Dauphin	Cameroon	No	2 crew + 6 passengers			N/A	Ditching
Dauphin	India	No	2 crew + 8 passengers			N/A	Ditching
Dauphin	Monaco	Yes	1 crew + 9 passengers	2 passengers	1	wind 18-24kts, gust 36kts, wave height of 0,5-1,5m	Ditching
EC120	USA	Yes	1 pilot			N/A	Water Impact
EC130	New York	No	1 pilot + 7 passengers			N/A	
Ecureuil	Gulf of Mexico, offshore	Yes	1 crew	1		wind 12kt, sea 3-4 feet	
Ecureuil	Italy	No	1 pilot + 2 passengers			N/A	Ditching
Ecureuil	France	Yes	1 pilot + 4 passagers	5		N/A	Water Impact
Ecureuil	Greenland	Yes	1 crew + 1 passenger	1 passenger		stormy sea	Water Impact
Ecureuil	USA	No	1 pilot + 4 passengers			N/A	Ditching
Ecureuil	New Caledonia	No	1 crew			N/A	Ditching
Ecureuil	Quiberon, France	Yes	1crew + 3 passengers			N/A	Ditching
Puma	Indonesia	No	4 crew + 12 passengers			N/A	Ditching
Puma	China sea	No	3 crew + 12 passengers			N/A	Ditching
Puma	Argentina	Yes	2 crew + 4 passengers	2 crew		Wave height 5m	Water Impact
Super Puma	Malaysia	Yes	2 crew + 8 passengers	1 passenger	1	Sea level 3 et wave height of 3 metres. Wind 20kt	Water Impact
Super Puma	Chile	Yes	2 crew + 3 passengers	1 pilot + 1 passenger		N/A	Water Impact
Super Puma	Holland	No	4 crew + 13 passengers			N/A	Ditching
Super Puma		No	3 crew + 5 passagers			N/A	Water Impact
Super Puma	Shanghai	No	2 crew +10 passengers			N/A	Ditching
Super Puma	North Sea	No	2 crew + 16 passengers			wind 25-30kts, wave height of 3-4m	Ditching

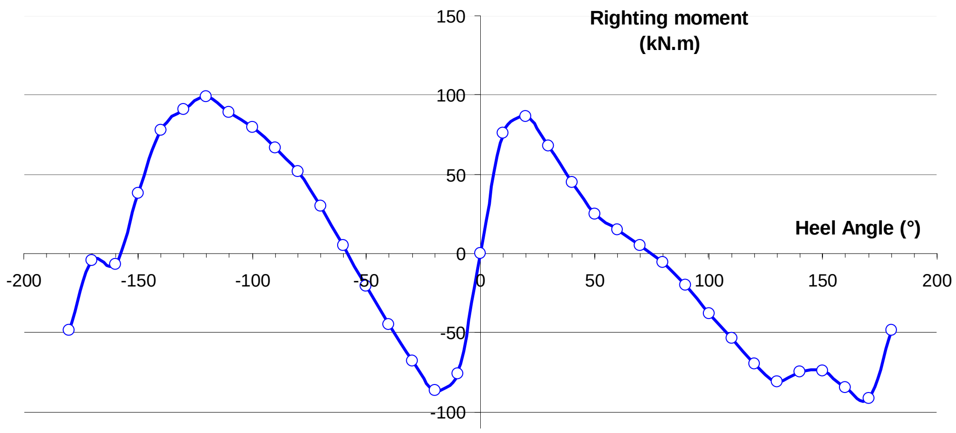
Table 13: Landings with inflated floatation over the period 1996-2007

Appendix 2: Configurations tested in the wave tank

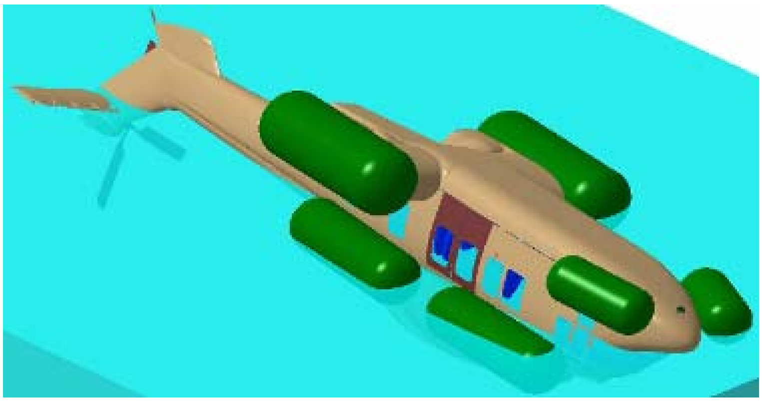
Configuration 2

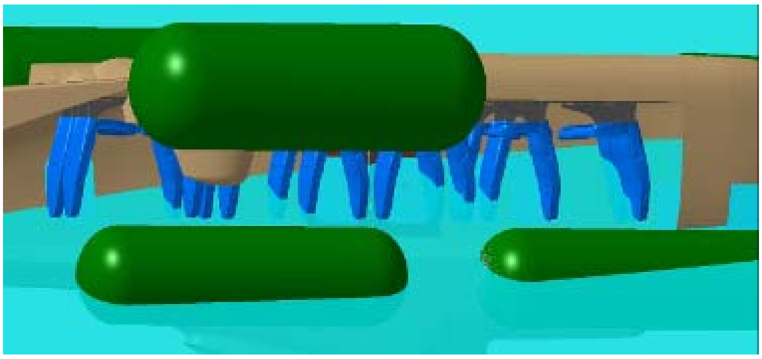


AV1: Equilibrium position

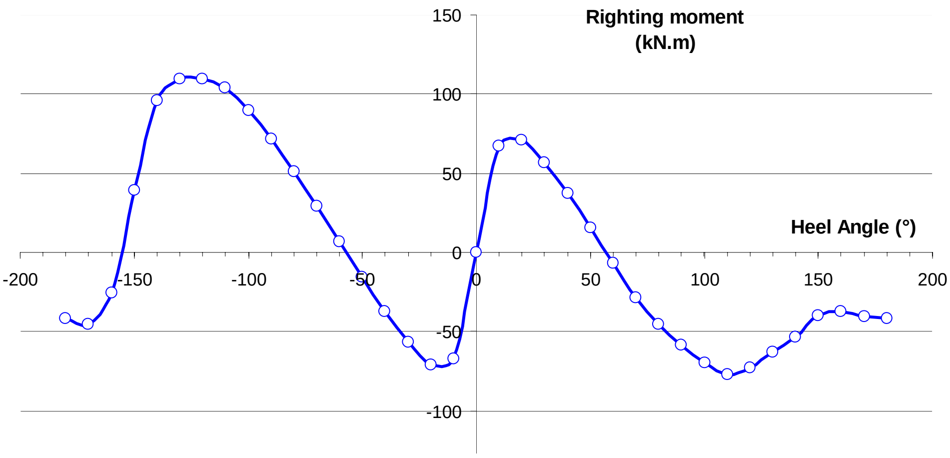


AV1: Stability curves



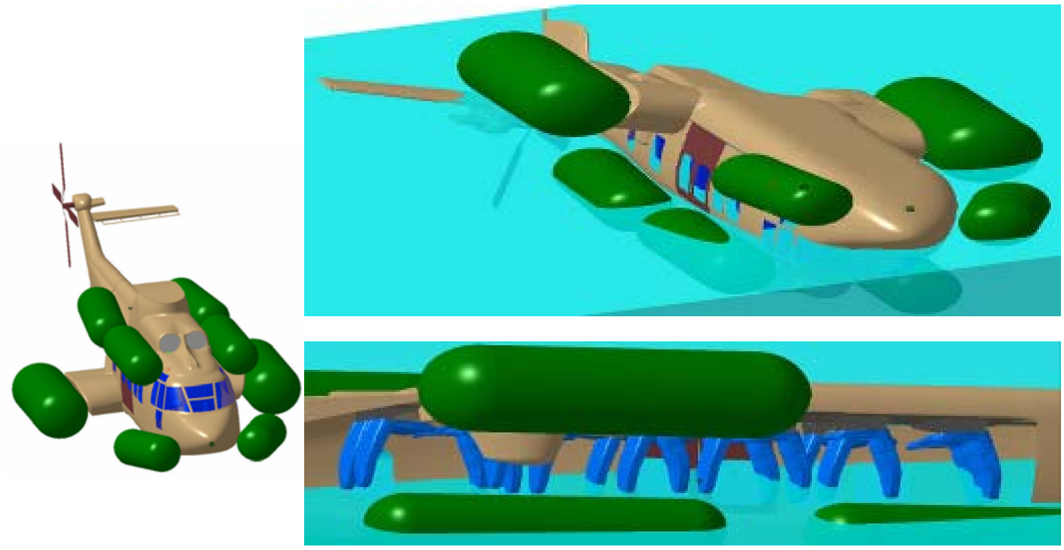


AV3: Equilibrium position

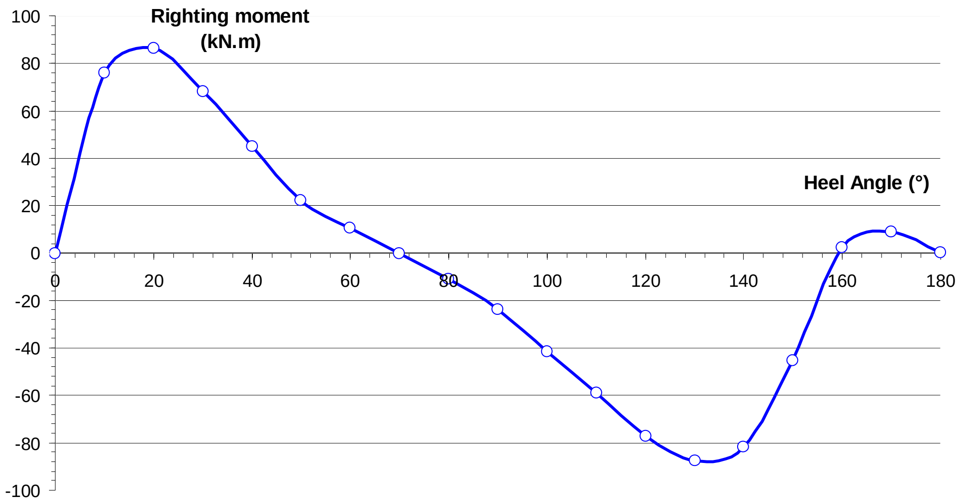


AV3: Stability curves

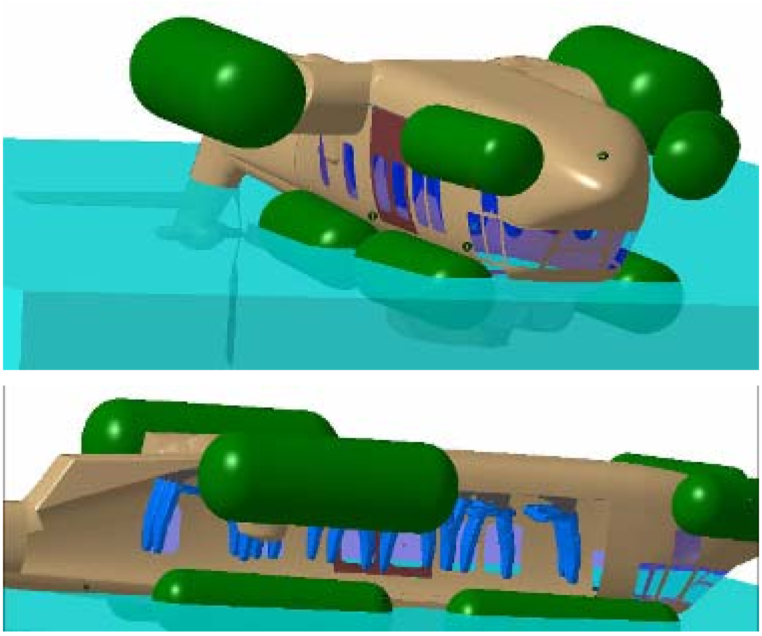
Configuration 3



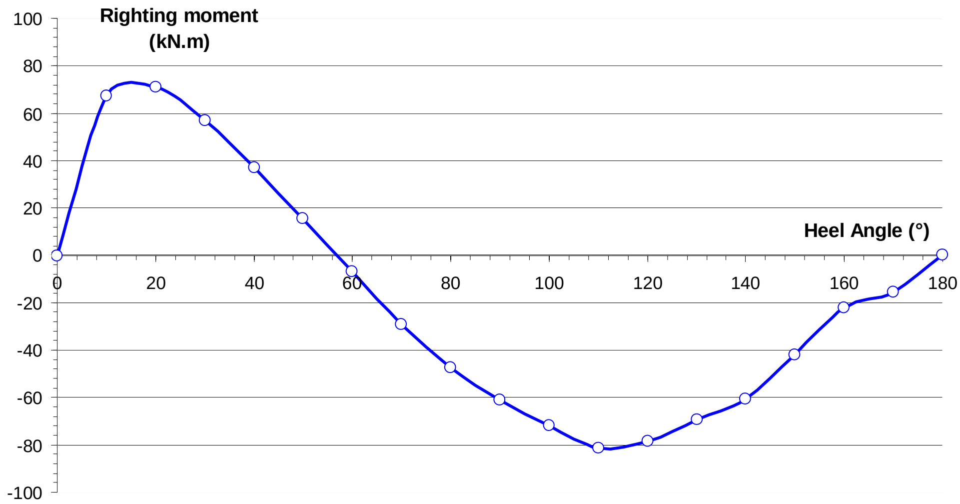
AV1: Equilibrium position



AV1: Stability curves

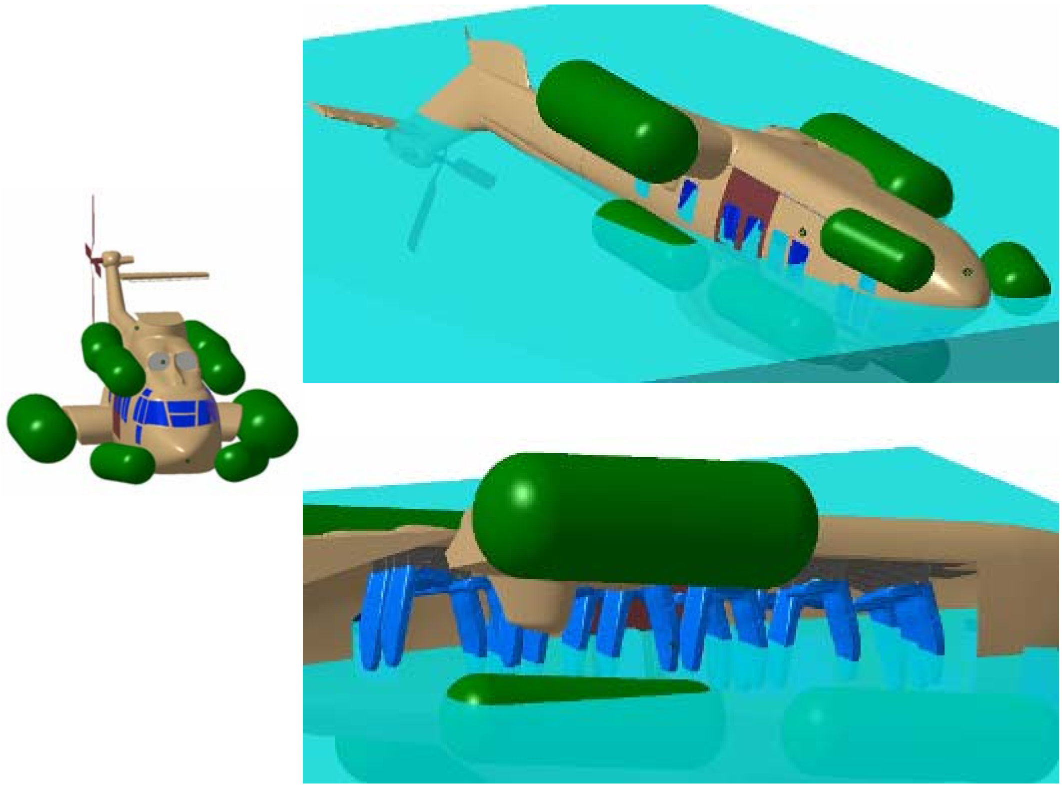


AV3: Equilibrium position

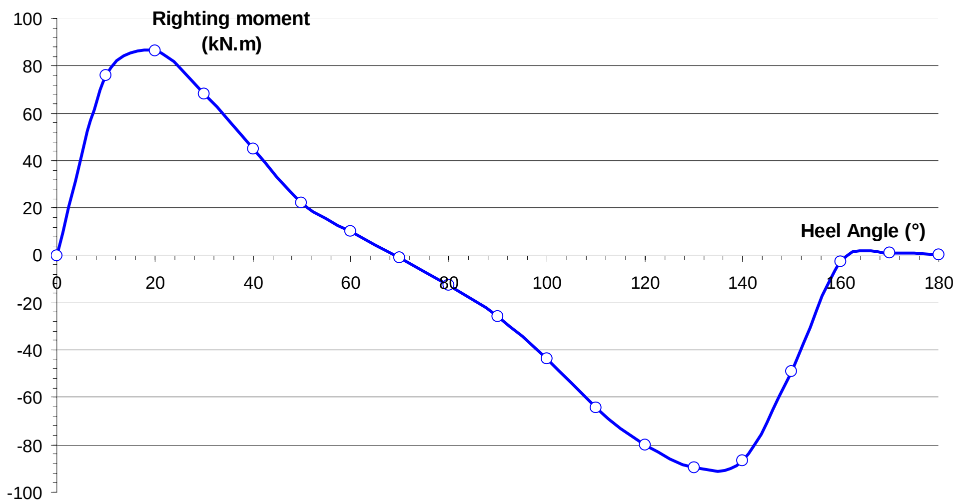


AV3: Stability curves

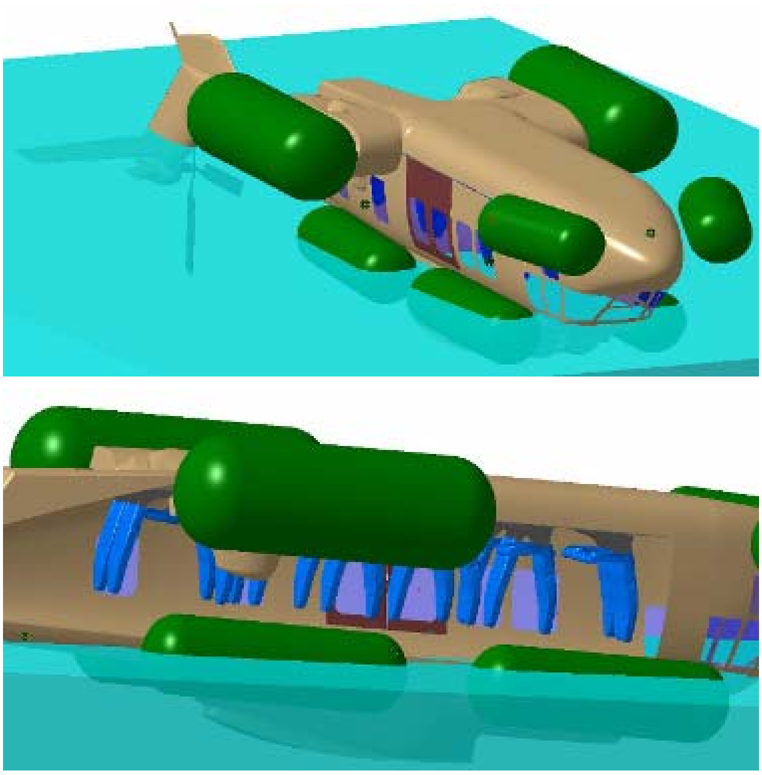
Configuration 4



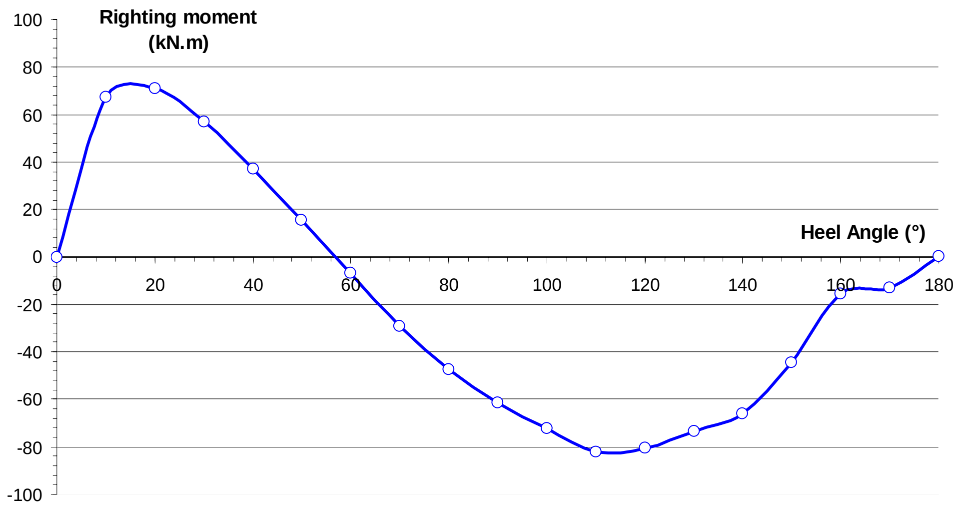
AV1: Equilibrium position



AV1: Stability curves

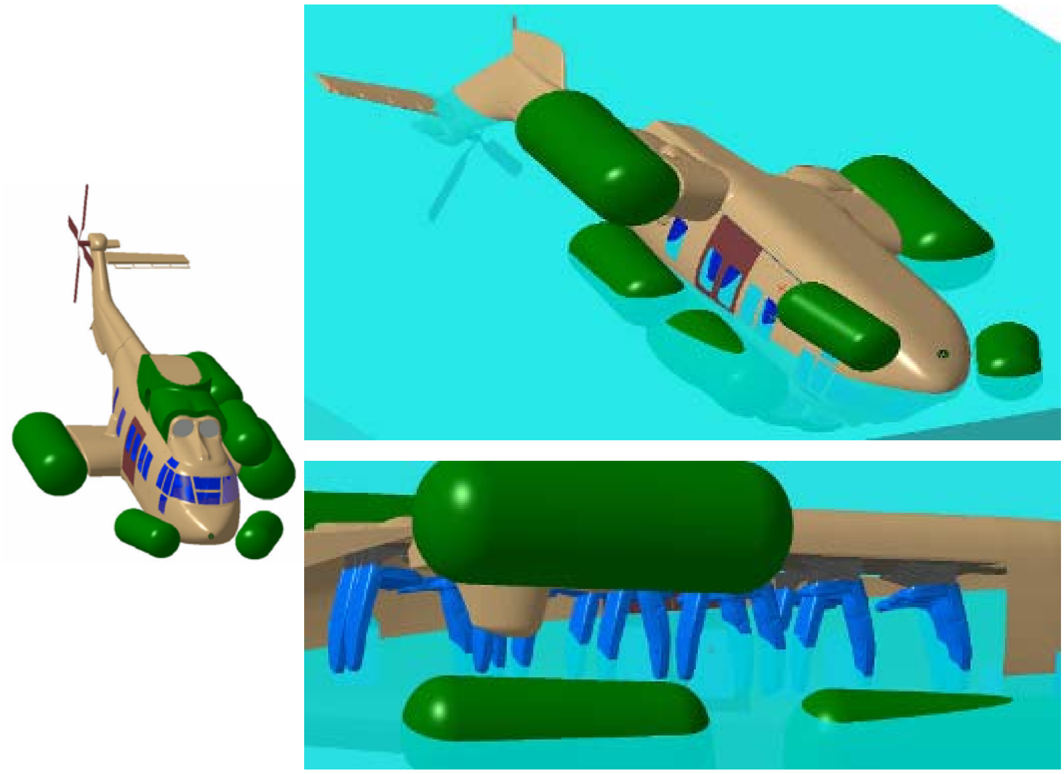


AV3: Equilibrium position

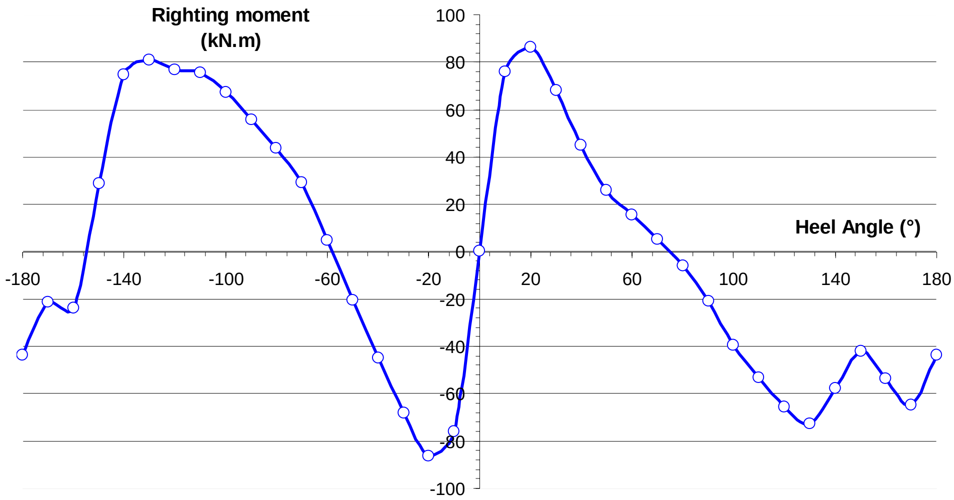


AV3: Stability curves

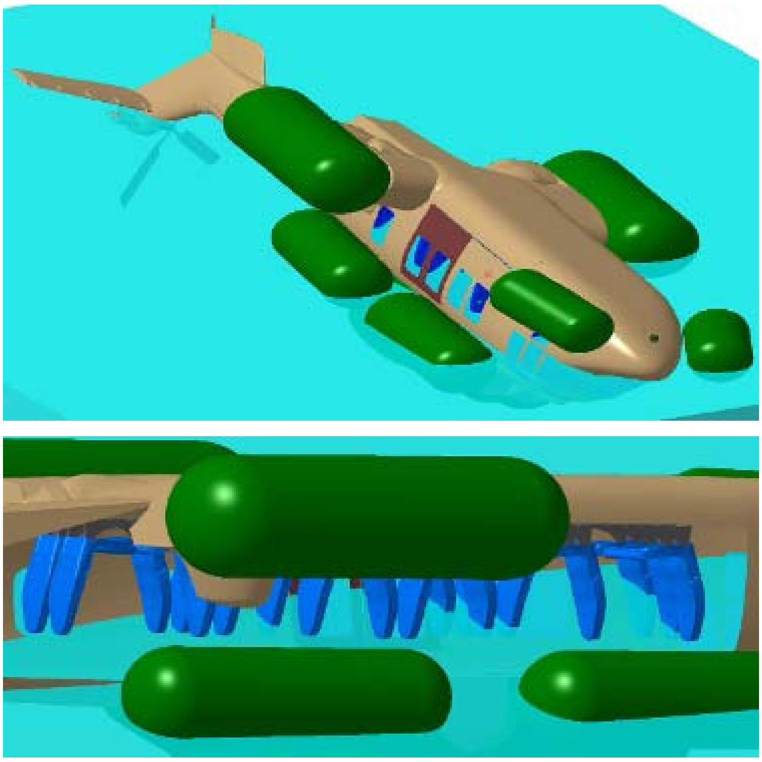
Configuration 5



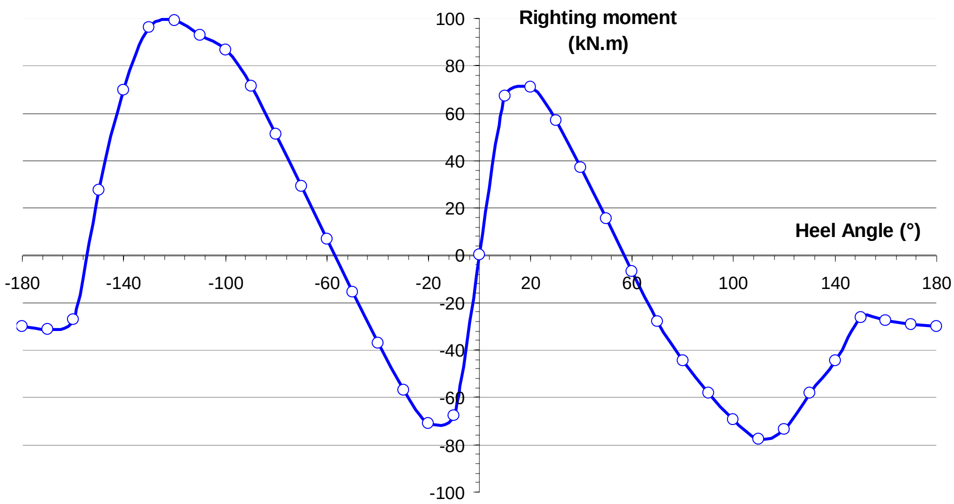
AV1: Equilibrium position



AV1: Stability curves

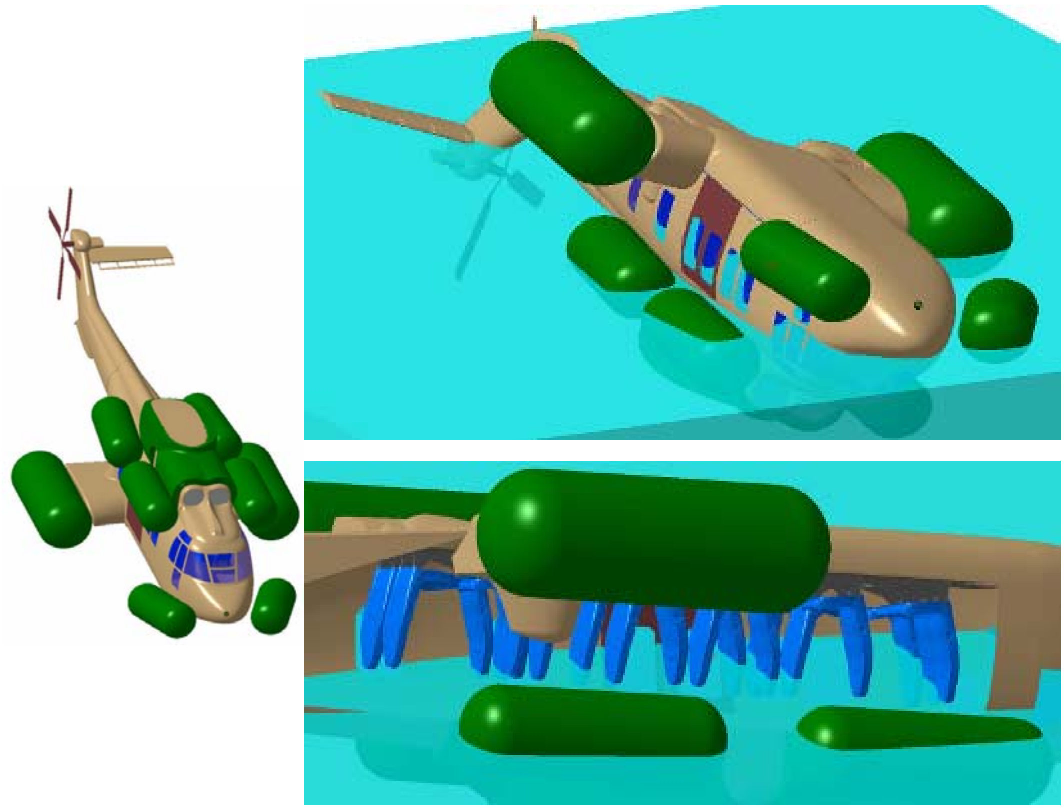


AV3: Equilibrium position

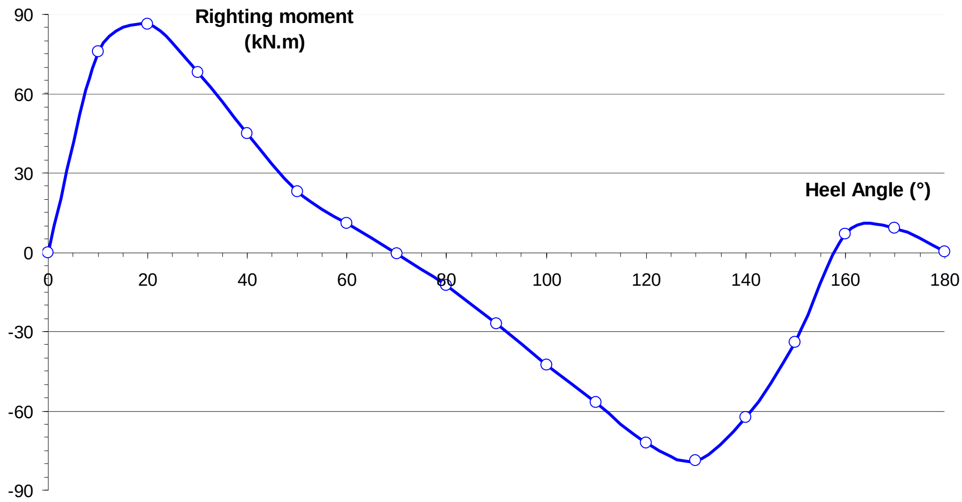


AV3: Stability curves

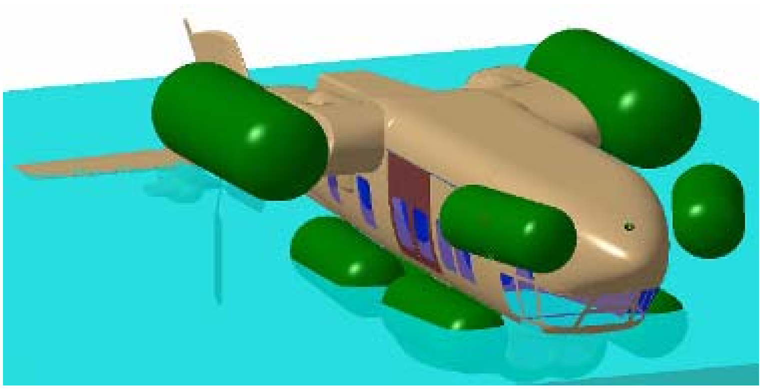
Configuration 6

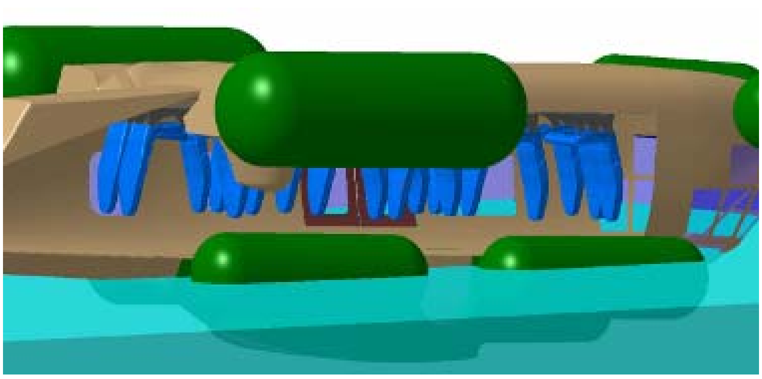


AV1: Equilibrium position

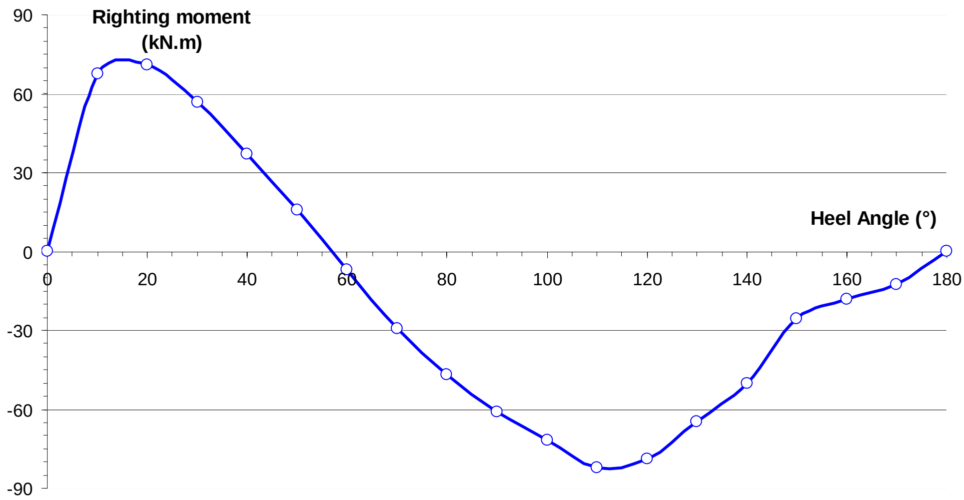


AV1: Stability curves





AV3: Equilibrium position



AV3: Stability curves

Appendix 3: Wave tank programme

Introduction

The goal of the wave tests was to analyse the behaviour of the inverted helicopter with different additional floatation device located in the upper part of the helicopter.

Mass – Centres of gravity

Two configurations were considered. The first one corresponded to the heaviest helicopter with the passengers' weight reduced (AV1'). The second one corresponded to the lightest helicopter with the highest position of the centre of gravity. Masses, CG positions and inertias of theses configurations are summarised in the following table.

WEIGHT AND CG DOMAIN							
WITH ROTOR AND BLADES							
		CG position			Inertias (kg m2)		
Ref	Masse (kg)	Xg (m)	Yg (m)	Zg (m)	Ixx	Iyy	Izz
AV1'	9000	4.6	0	0.85	12178	58953	49919
AV3	6000	4.4	0	1.32	9247	48645	41510

The buoyancy due to the blades should not be taken into account. Therefore, tests were performed without blades and rotor installed, but with the equivalent weight, included in the previous table.

Tail rotor: A hypothesis similar to the main blades can be done. No tail rotor will be placed on the model.

Inherent floatation of the helicopter

When inverted, the buoyancy of the helicopter itself (with no float) has been approximated to 1500L located at the level of the mechanical floor.

The volume used for calculation is the following one:

- Dimensions: X : 4m ; Y : 0.75m ; Z : 0.5m
- Centre : X = 4.6m ; Y = 0m ; Z = 1.78m

Model

Tests have been performed with the mock-up model used for the EC225'certifcation.
Model Scale: 14:1.

A critical issue is the volume of the model, with no float, in order to have consistency between the analytical study and the experiments.
The volumes of the buoyant elements of the EC225 with no floats are the following

- Volumes in the fuel tanks and in the lower part of the helicopter, used for the design of the floatation emergency system: 6200L.
- Volume approximated in the upper part of the helicopter : 1500L
- **Total (target) : 7700L**

At model scale, 7700L corresponds to 2.806L.

Nevertheless, the scaled model itself has additional buoyant elements that become important when translated to real scale (fibre glass + masses for calibration).
The total volume of the scaled model has been measured. 3.1L have been found.

- 2.37 L for the structure itself.
- 0.73 L for the elements used for equilibrating the helicopter.

This volume was reduced to 2.8L and its geometrical centre located at the highest possible, centred on Y and the nearest possible to the CG position in X.

The resulting experimental waterlines have been checked and compared with the theoretical ones. Volumes representing the buoyancy of the helicopter could be moved if the comparison between theoretical and measured was not satisfactory.

Waves

JONSWAP wave spectrums, typical of the North Sea, was used for modelling the irregular waves.

Tests were performed at sea state 5 (maximum of the model basin for the considered scale). Other tests were performed at a lower sea state in order to investigate the influence of the sea states on the selected designs.

Initial positioning

Since the aim of the study was to look at the efficiency of upper floatation devices, the helicopter could be already inversed when the waves are launched.

Two directions of the model with respect to the waves were tested, with the windows above the waterline both facing towards and away from the oncoming waves.

Wind

Since the helicopter is inverted, no wind is necessary because of the little surface exposed to the wind

Doors

Tests were performed with both closed and open doors.

Damaged configurations

For the ditching tests involving a damaged float compartment, the forward part of the forward upper float was selected since it appears to be the most critical for the possible escape out of the cabin.

Visualisation

Two video cameras were used to record the motion of the helicopter, the second focusing on the windows to check the possibility to escape.

Number of built upper floats

Conf 1:	0	
Conf 2:	2 intact floats	1 damaged float
Conf 3:	4 intact floats	1 damaged float
Conf 4:	4 intact floats	1 damaged float
Conf 5:	2 intact floats	1 damaged float
Conf 6:	4 intact floats	1 damaged float
Total	**16 intact floats**	**5 damaged floats**

Number of tests

- 6 configurations
- x 1 sea states
- x 2 points mass-CG
- x 2 initial positions (90° – 270°)
- x 2 (damaged – maybe not for all the configurations -)

= 44 runs (no damaged cases for the configuration 1)

Other tests were performed at a lower sea state when time was available.

Nomenclature of the runs

The reference of each run had the form:

Conf_WaveType_SeaState_InitialPosition_MassCG_Damaged

Where:
Conf is
"C1" for the first configuration and so on
Wave Type is
"RW" for regular wave and
"IW" for irregular waves
Sea State is
"SS1" for sea state 1, "SS2" for sea state 2 and so on
Initial position is
"W90" if the outside part faces the waves
"W270" if the outside part does not face the waves
Mass CG is
"MCG1" for the point AV1
"MCG3", for the point AV3'
Damaged is
"IF" for intact floats
"DF" for damaged floats

This nomenclature was used for the videos of the runs.

Success criterion

Criterion:
- Windows sufficiently clear for escape.
- Sufficient air-gap for 19 passengers.
- Stability of the inclined equilibrium position.

Appendix 4: Waterlines comparisons


Pictures of the model used for the experiments

Comparisons have been performed between the waterlines calculated by software and the ones measured before each run in fresh water. The measurements have been done through 3 rulers placed on the fuselage.

The difficulty to reproduce exactly the waterlines when the helicopter is inverted is mainly to the important part of the fuselage that is immerged. The model used has been the one used for the up-right experiments. It had buoyant elements in the upper part and in the tail boom, mainly to ensure the stiffness of the model. These elements has been removed, and replaced by a foam piece corresponding to the 1500L inherent buoyant elements of the EC225 that have been identified (section III.2). Doing this, the model floated at a higher level than predicted because the calculations do not take into account the fuselage while, if passed from model scale to real one, it represents approximately 300L. To solve this problem, what has been done is to remove 300L from the block representing the inherent buoyancy of the helicopter, as illustrated in the following figure.

Foam block representing the inherent buoyancy of the helicopter

The agreement between measured waterlines and the theoretical ones was improved. However, another element is source of error when the helicopter is inverted. The stabilizer plane is made of wood in the model, and when immerged, it creates an amount of buoyancy that causes differences with respect to the calculated waterlines since no buoyancy is supposed there.

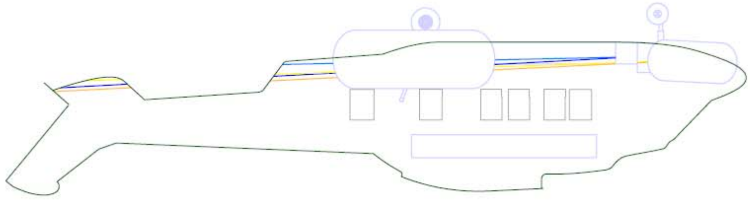
At model scale, the difference is usually of order of some millimetres and goes up to 13mm. At real scale, it corresponds to difference up to 19cm (average difference is about 5cm).
For a conservative reason, the fuselage has been supposed to not produce any buoyancy for the design. Calculations are possible with this hypothesis, but not experiments. However, the fuselage do produce some buoyancy at real, difficult to quantity.

Since the aim of the tests is to compare the different configurations of additional EFS, these difference do not alter the results.

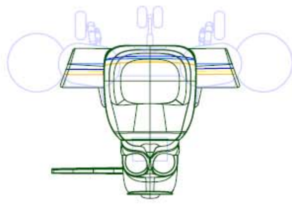
The following figure presents the final comparisons. There, colours refer as follows:

- Blue: Software – AV1
- Dark blue: Measured – AV1
- Yellow: Software – AV3
- Orange: Measured – AV3

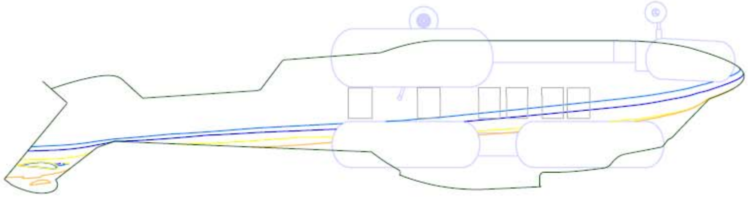
Configuration 1



Configuration 1



Configuration 2



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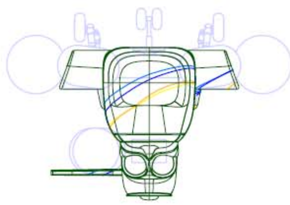

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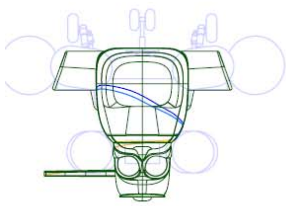

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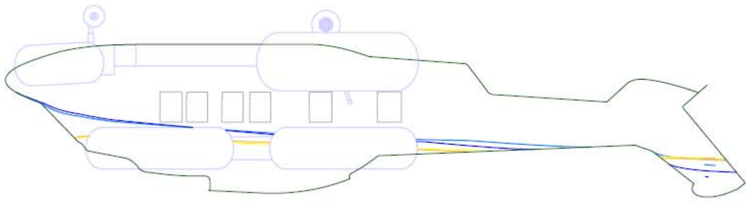
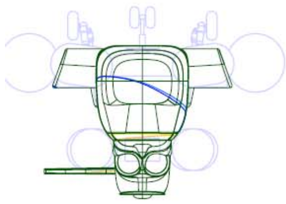
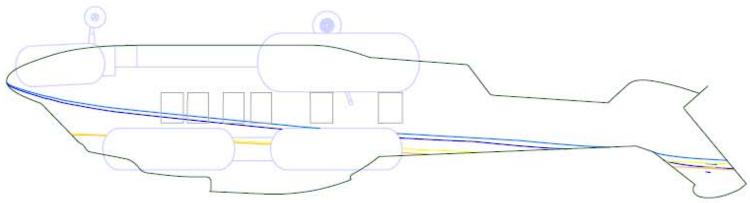


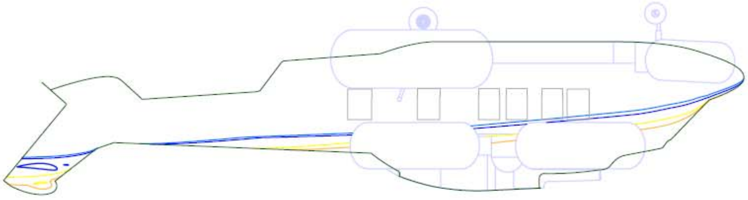
Configuration 4



Configuration 4



Configuration 5



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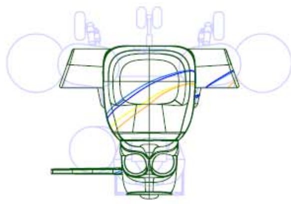
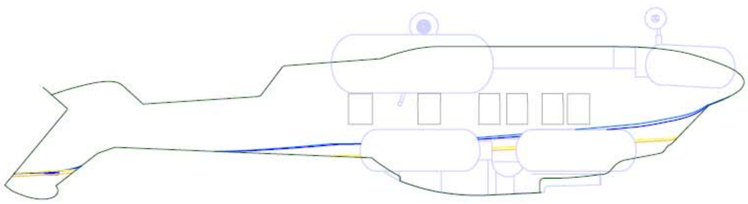


Configuration 6



Configuration 6