European Union Aviation Safety Agency

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RESEARCH PROJECT [EASA.2020.C02]

D13 FINAL PUBLIC REPORT

Helicopter Off-Shore Operations – New Flotation Systems

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SUMMARY

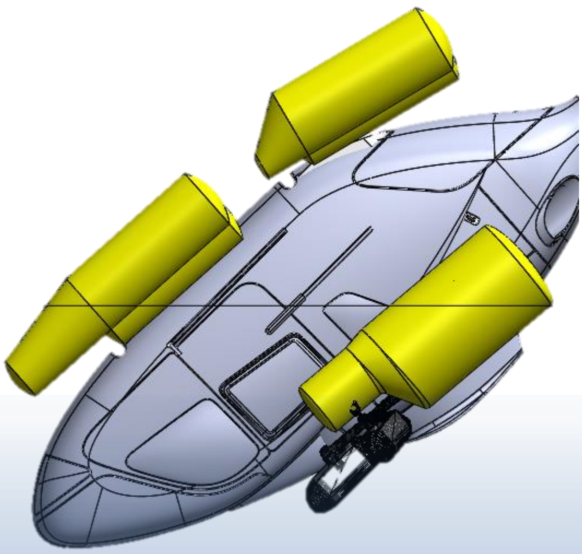
This research project is an integral part of the agreement between the European Commission and the European Union Aviation Safety Agency (EASA) within the framework of Horizon 2020 Societal Challenge 4 'Smart, green, and integrated transport.' The impetus for this initiative stems from the imperative to address key research and innovation needs in aviation safety, responding to incidents, accidents, and emerging threats.

Problem area

The problem area addressed in this project revolves around the unique challenges faced by helicopters engaged in specialized operations, such as offshore transport, where emergency water landings, known as 'ditching,' are a critical aspect of certification. Despite the implementation of safety measures like Emergency Flotation Systems (EFS), which deploy inflatable units during emergencies, the inherent high center of gravity in helicopter design poses significant obstacles to achieving effective capsize resistance for increased likelihood of occupant survival. Emergency scenarios that surpass practical design parameters for water landings present additional complications, with regulatory requirements specifying specific speed envelopes for successful ditching. Incidents have highlighted the tragic outcome of occupants surviving the initial water impact only to face drowning due to difficulties in swift escape from a capsized helicopter.

Regulatory efforts have focused on enhancing occupant escape speed, but practical limitations persist, compounded by factors like cold shock and disorientation. Acknowledging this long-standing issue, extensive research has already previously been conducted to find a viable solution to improve occupant survivability in capsizing events during emergency water landings. The proposed approach seeks to maintain a capsized floating attitude, creating an air pocket—a portion of the passenger cabin above the water line—in the event of ditching or a survivable water impact. This air pocket will be achieved by installing an additional emergency floatation system mounted high on the helicopter fuselage and allows occupants to survive within the helicopter until escape into life rafts is possible.

Despite these previous advancements, some technical issues have been highlighted, which require further investigation before it would be appropriate for regulatory action to be taken. This research project investigates the highlighted technical issues, ensuring a comprehensive understanding before implementing regulatory measures.



Objective

The overarching objective of this research project is to address technical challenges associated with the introduction of Emergency Flotation Systems (EFS) units mounted high on the helicopter fuselage. The project aims to determine the technical and regulatory feasibility of this innovative approach, specifically focusing on improving occupant survivability following helicopter capsizing by implementing an enhanced air pocket scheme by means of additional buoyancy in critical locations. The research seeks to identify any unforeseen technical issues and assess the magnitude of challenges they may pose to a potential certification program. Ultimately, the goal is to establish, with confidence, that high-mounted EFS pose a cost-effective and technically feasible solution without introducing undue negative impacts on helicopter operation. The identified technical challenges include issues related to the deployment of high-mounted EFS (HEFS), such as inadvertent inflation and potential damage to the floats due to rotor blade debris. Other challenges encompass heat resistance of materials located near engine exhausts, aerodynamic impact of stored HEFS, and overall integration considerations (including construction issues, maintenance access, continued emergency exit functionality and potential interference with ancillary equipment).

Description of work

As part of this research into a new flotation system for helicopter off-shore operations, DART Aerospace has designed and studied a High-mounted Emergency Flotation System (HEFS) for two reference helicopters, representing CS27 Cat A and CS29 helicopters. The high-mounted floats were designed to achieve an (improved) air pocket for a partially or fully capsized helicopter. A buoyancy analysis was performed for the CS27 Cat A and CS29 reference helicopter including primary EFS and HEFS, assessing the (improved) air pocket in different scenarios by means of a simulation tool. The tool has been validated with a full-scale buoyancy test, also including tests of dynamic aspects.

Thereafter, the challenges highlighted in the section above have been addressed. A HEFS deployment system has been designed and analysed for the probability of inadvertent deployment and failure to deploy by means of safety assessments. Since the HEFS are located near the engine (exhaust), a selection of materials potentially suitable for the system has been analysed for heat resistance by means of material tests. An assessment of the aerodynamic impact in normal flight - when the HEFS are in stowed state - on helicopter performance and handling quality has been performed by means of Computational Fluid Dynamics. Finally, overall integration issues have been addressed, analysing the impact of implementing a HEFS on aspects such as maintenance, continued functioning of emergency egress, cost-effectiveness and potential interference with other ancillary equipment.

This report summarizes the work done and results found during the research project, describing the foreseen improvement in the airpocket for capsized CS27 Cat A or CS29 helicopters and arguing the technical feasibility of implementing HEFS by addressing the aforementioned technical challenges.

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Results and application

The results of this research project have shown that indeed a High-mounted Emergency Flotation System can increase the occupant survivability in capsizing events by providing an airpocket in a partially or fully capsized helicopter. Table 1 presents the main findings of the research, making a distinction between the CS29 and CS27 Cat A fleet and a retrofit scenario or implementing HEFS directly into a new design.

OVERALL PROJECT OBJECTIVES – FINAL CONCLUSIONS HEFS ON OFFSHORE FLEETS					
Description	**Retrofit CS29**	**Retrofit CS27 Cat A**	**New Design CS29**	**New Design CS27 Cat A**	**Remarks**
HEFS Design and Air Pocket	Feasible	Feasible	Feasible	Feasible	Tapered air pocket recommended, no stable side float position for CS27 Cat A ref. helicopter found.
Deployment Safety Aspect	Feasible	Feasible	Feasible	Feasible	Simple design with annunciation of active and failed states, reliability and availability targets are achievable.
Heat Resistance	Feasible	Feasible	Feasible	Feasible	Suitable combination of composite and float bag material found that can withstand the worst-case heat scenarios, optimization needed to improve thickness/weight ratio etc.
Aerodynamic Aspects	Feasible	Challenging	Feasible	Feasible	Need for sufficient physical design space on upper cowling for aerodynamic optimization of HEFS pod.
Overall Integration Aspects	Feasible with challenges	Challenging	Feasible	Feasible with challenges	Limited physical space for integration will pose challenges for retrofitting on specific CS27 Cat A helicopters.

Table 1 Project objectives summary of conclusions: retrofitting HEFS versus implementing HEFS in a new helicopter design

In conclusion, the research project has yielded significant insights into the technical and economic viability of High Emergency Flotation Systems (HEFS) for offshore helicopters, whether retroactively installed or integrated into new designs. A tapered airpocket volume was recommended and proven to be achievable with the introduction of HEFS.

The research also demonstrated the feasibility of developing a HEFS deployment system that meets stringent requirements for the probability of inadvertent deployment and reliability. Calculated reliability aligns with the project's objective, taking into account both the failure to inflate and the probability of capsize during a defined exposure time.

Preliminary endurance testing indicates the promising performance of industry-standard fabric and composite materials for HEFS in elevated temperatures. Computational Fluid Dynamics (CFD) analyses suggest that HEFS installation can comply with relevant CS27 Cat A and CS29 requirements with minimal impact on aircraft performance. Additionally, survey results highlight challenges in retrofitting HEFS on existing CS27 Cat A offshore fleets, while retrofitting CS29 helicopters is considered more feasible. Importantly, implementing HEFS directly into new designs is deemed feasible for both CS27 Cat A and CS29 helicopters.

This research project underscores the potential for improving helicopter safety through the introduction of HEFS. The findings provide valuable contributions to the aviation industry, offering a pathway to enhance occupant survivability in offshore helicopter operations, particularly in challenging offshore conditions.

CONTENTS

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ABBREVIATIONS

ACRONYM	DESCRIPTION
ASD-STAN	AeroSpace and Defence Industries Association of Europe Standards
CAD	Computer Aided Design
CCA	Common Cause Analysis
CFD	Computational Fluid Dynamics
CoG	Center of Gravity
CS	Certification Specifications
DAL	Design Assurance Level
EASA	European Union Aviation Safety Agency
EFS	Emergency Flotation System
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility
ETSO	European Technical Standard Order
FH	Flight Hour
FHA	Functional Hazard Assessment
FMEA	Failure Mode & Effect Analysis
FMECA	Failure Mode, Effect & Criticality Analysis
FTA	Fault Tree Analysis
HC	Helicopter
HEFS	High mounted Emergency Flotation System
HIRF	High Intensity Radiated Fields
HOGE	Hover Out of Ground Effect
LH	Left Hand
MR	Main Rotor
MTOW	Maximum Take Off Weight
NPA	Notice of Proposed Amendment
OEI	One Engine Inoperative
PAX	Passengers
RANS	Reynolds Averaged Navier Stokes
RH	Right Hand
ROC	Rate of Climb
RFM	Rotorcraft Flight Manual
RPM	Rotations Per Minute
SAR	Search And Rescue
SSL	Standard Sea Level
SST	Shear Stress Transport
TC	Type Certificate
TPP	(rotor) Tip Path Plane
WP	Work Package

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1. Introduction

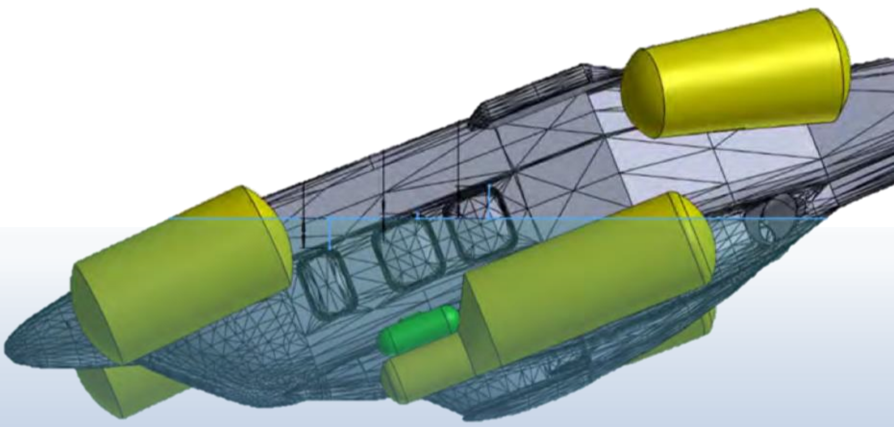
1.1 Background

The impetus for this research project emanates from the *Horizon 2020 Work Programme Societal Challenge 4 'Smart, green, and integrated transport'.* Specifically tailored to address crucial research and innovation needs in aviation safety and environmental impact assessment, the initiative responds to imperatives arising from the mitigation of accidents/incidents, emerging threats, and international obligations of the European Union Aviation Safety Agency (EASA) and EU Member States. These obligations are situated within the context of the developing standards of the International Civil Aviation Organization (ICAO).

The distinctive capabilities of helicopters have given rise to a substantial fleet engaged in specialized operations, such as transporting personnel to and from offshore oil and gas installations, wind turbines, and sea pilot transfers. Particularly crucial is the certification of these helicopters for 'ditching'—an emergency water landing executed according to rotorcraft flight manual (RFM) procedures, aimed at swiftly abandoning the rotorcraft. This is usually achieved by the deployment of an emergency flotation system (EFS), consisting of inflatable units stored deflated during normal operations and inflated in emergencies using high-pressure gas cylinders.

Despite these safety measures, the inherent high center of gravity in helicopter design poses significant challenges to achieving the desired capsize resistance. Emergency scenarios that exceed the practical design parameters for water landings present additional complications. Regulatory requirements dictate specific vertical and horizontal speed envelopes for successful ditching, outside of which the helicopter is at risk of immediate capsizing upon water entry. Tragically, past incidents have witnessed occupants surviving the initial water impact only to succumb to drowning due to the difficulty of escaping from a capsized helicopter swiftly. Regulatory efforts have focused on enhancing occupant escape speed, but practical limitations persist, compounded by factors like cold shock and disorientation.

Recognizing this longstanding issue, extensive research has already been undertaken to identify a viable solution. The proposed approach seeks to maintain a capsized floating attitude, creating an air pocket—a portion of the passenger cabin above the water line—in the event of ditching or a survivable water impact. This air pocket allows occupants to survive within the helicopter until escape into life rafts is possible.
Key accomplishments in this pursuit already include the demonstration of the feasibility of a satisfactory air pocket through enhancements to current EFS configurations, evaluating sizing and location of additional flotation units, and validating the solution's feasibility through wave tank testing and human subject trials. Despite these previous advancements, some technical issues have been highlighted which require further investigation before it would be appropriate for regulatory action to be taken. This research project addresses those technical issues.



1.2 Objectives

The over-arching objective of this project is to provide insight into technical issues raised by the introduction of High-mounted Emergency Flotation Systems units, as well as determine its technical and economical feasibility. The specific objectives for the project were defined as follows:

I. To select two reference helicopters representative of CS29 and CS27 Cat A helicopters respectively.
II. To design a HEFS for each of the reference helicopters and demonstrate the feasibility of achieving an (improved) airpocket to increase occupant survivability.
III. To demonstrate that a HEFS deployment system can be designed such that requirements with respect to probability of inadvertent deployment and failure to deploy are reached.
IV. To assess the heat conditions at the mount location of the HEFS, select materials for the system and demonstrate heat resistance of selected materials.
V. To assess the aerodynamic impact of stowed HEFS in normal flight operations with emphasis on continuing airworthiness and potential cost penalties for operations.
VI. To assess whether the implementation of HEFS will pose significant challenges with regards to overall useability and integration.

1.3 Scope of Work

To achieve the project objectives, HEFS have been designed and studied for a CS27 Cat A and CS29 reference helicopter. The project has involved design activities and a feasibility study of two High mounted Emergency Flotation Systems, but not the actual development and production of these systems.

Scope of the research:

- Occupant survivability in the scope of this research refers to passengers in the cabin, and not helicopter flight crew.
- The work has involved the definition of two reference helicopters and design activities for the HEFS of the two reference helicopters which has resulted in various 3D CAD designs of the system and a selection of the main components of the system. As part of the design activity of the HEFS, a buoyancy analysis has been performed by means of simulation tools and a full-scale buoyancy test.
- The HEFS deployment system has been designed and extensive safety analyses have been performed including Functional Hazard Analyses (FHA) and Failure Mode and Effects Analyses (FMEA).
- In order to select appropriate materials for the HEFS components, heat resistance and puncture tests have been performed on various samples.
- The aerodynamic impact has been assessed by evaluating the aerodynamics of the reference helicopters including the HEFS (stowed) by means of Computational Fluid Dynamics (CFD) simulations.

1.4 Overall Approach

The assessments performed have been applied to a selected reference helicopter representative of CS27 Cat A helicopters (EC135) and a selected reference helicopter representative of CS29 helicopters (AW139). HEFS have been designed and assessed for these two helicopters, whereafter final generalized conclusions could be drawn for the CS27 Cat A offshore fleet and the CS29 offshore fleet. Impact assessments, such as the aspects related to the aerodynamic or maintenance activities and costs, have been performed by means of delta analyses. Delta analyses involved comparisons of a baseline case (reference helicopter including only the primary EFS) versus a retrofitted case (reference helicopter including the primary EFS and retrofitted HEFS).

1.4.1 Baseline Reference Helicopters

The AW139 was selected as reference for the CS29 helicopters, as it is a typical model currently often in service for operations which require ditching certification. Similarly the EC135 was selected as reference for the CS27 Cat A helicopters, as this is a typical model currently often in service for operations which require ditching certification. The CS27 Cat A reference helicopter did not include the new engine inlet configuration of the EC135 (larger engine inlet), but the original configuration was assumed. For both reference helicopters, models have been provided by the TC HOLDERs for the purpose of this research. Data of the reference helicopters used for this project – provided either by the TC HOLDER or obtained through dedicated measurements – included outer fuselage and rotor dimensions, cabin dimensions, location of emergency exits, CoG envelopes, location of inlets and outlets, location of ancillary equipment, fuel tank and locations and dimensions of seats in the cabin. The reference helicopters are shown in Figure 2 and Figure 3. Both baseline references cases include the primary EFS, which is mounted into the lower part of the CS29 reference helicopter and onto the skids of the CS27 Cat A reference helicopter.

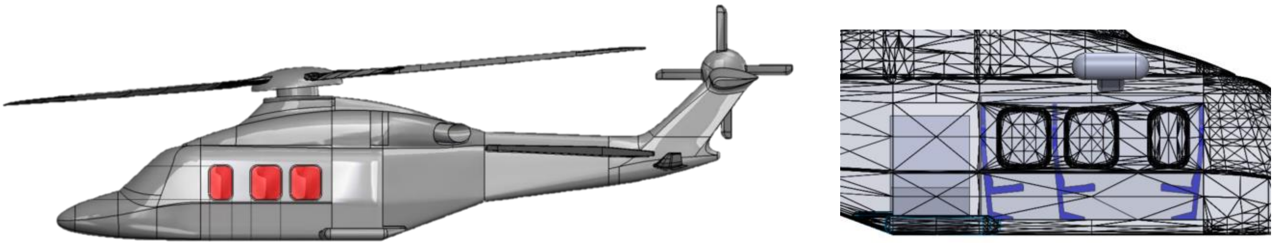


Figure 2: CS29 Reference Helicopter (AW139) with emergency exits in red (left)

The primary EFS assumed to be on the baseline helicopters have been certified according to specifications dating from before (the more stringent) Amendment 5. Depending on the analyses performed, different worst-cases have been assumed in terms of gross weight and CoG location, flight attitude and altitude (when relevant). Details on the assumptions can be found in the related chapters.

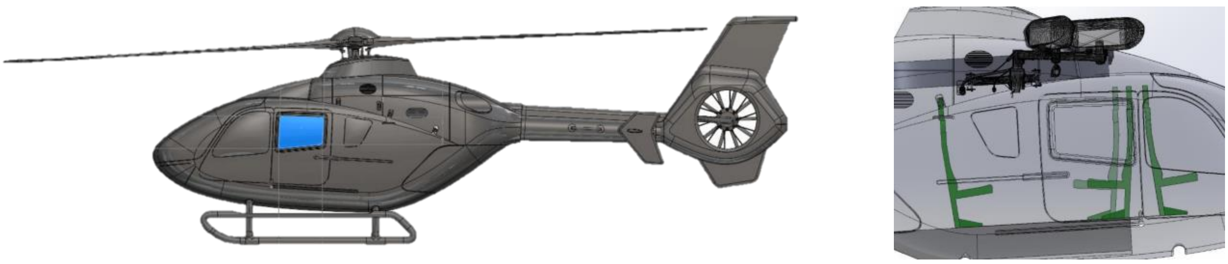


Figure 3 CS27 Cat A Reference Helicopter (EC135) with emergency exits in blue (left) and seat configuration in green (right)

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2. System Design and Air Pocket Evaluation

2.1 Objective

The objective of the system design and air pocket assessment was to design a HEFS for each of the reference helicopters and demonstrate the feasibility of achieving an (improved) airpocket to increase occupant survivability. This included the definition of the key components of the HEFS and the design of the float size, shape and location. The detailed design of the HEFS pods have been created by taking aerodynamic considerations into account, details can be found in section 5.3.

2.2 Approach

A flow chart of the high-level approach is shown in Figure 4. By detailing the reference helicopter configurations, as introduced in paragraph 1.4.1, the design constraints of the HEFS (stowed and inflated) have been brought forward. A worst-case weight and CoG-location with regards to buoyancy was selected for both reference helicopters: forward-heavy CoG at 7000kg and 2980kg max gross weight for the CS29 and CS27 Cat A reference helicopters respectively. A buoyancy analysis was performed for the baseline cases with primary EFS only. Then, the HEFS floats volume, location and shape have been designed in an iterative loop involving buoyancy analyses (reference helicopters with EFS + HEFS) and airpocket analyses. It was assessed whether the airpocket volume as recommended by EASA's Notice of Proposed Amendment 2016-01 *Helicopter ditching and water impact occupant survivability* (EASA, Notice of Proposed Amendment 2016-01 Helicopter ditching and water impact occupant survivability, 2016) could be achieved.

The buoyancy analyses have been performed by means of a simulation tool which was validated with a full scale buoyancy test which included a static buoyancy test as well as a dynamic loads analysis on the floats. A checklist has been established assessing the potential impact of HEFS on certification and finally a final float design was achieved for the CS29 and CS27 Cat A reference helicopters achieving an (improved) air pocket.

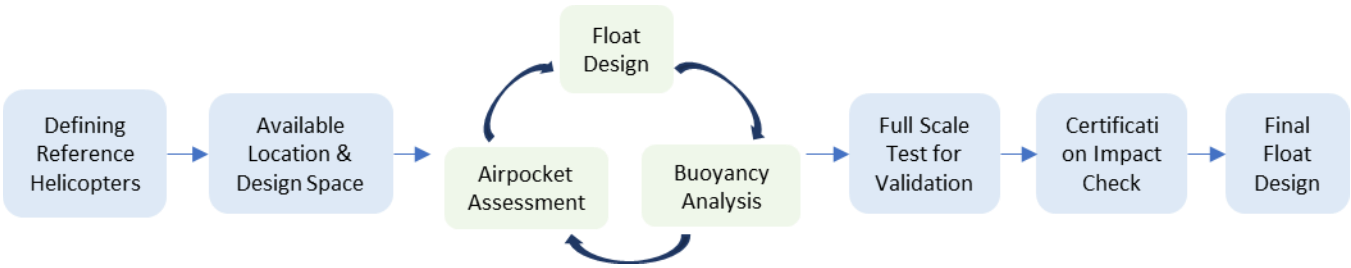


Figure 4 Approach HEFS design and airpocket evaluation

2.3 Baseline Buoyancy Analysis with Primary EFS Only

In Figure 5 and Figure 7, the current buoyancy is shown of the reference helicopters in upright position with primary EFS only (certified against specifications before more stringent amendment 5). Experience and research have shown that, the chance of CS29 and CS27 Cat A helicopters to remain in an upright position after a water impact is extremely small due to the high CoG in relation to the center of buoyancy. Figure 6 and Figure 8 show the buoyancy attitude of the CS29 and CS27 Cat A reference helicopters after capsizing in the current situation, with a primary EFS only. It can be seen that there is no airpocket available in capsized position, which is also not a required function of the primary EFS according to current CS27 Cat A and CS29 standards. Research has shown that this severely impacts the occupant survivability after a survivable water impact (EASA, Notice of Proposed Amendment 2016-01 Helicopter ditching and water impact occupant survivability, 2016).

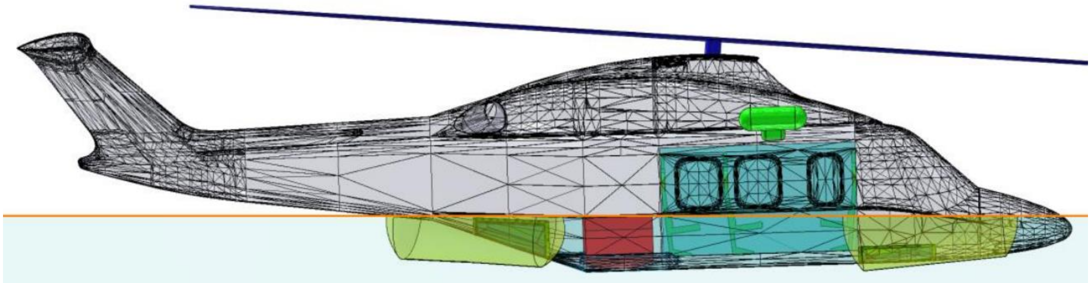


Figure 5 Upright attitude of ditched CS29 Reference helicopter baseline with primary EFS

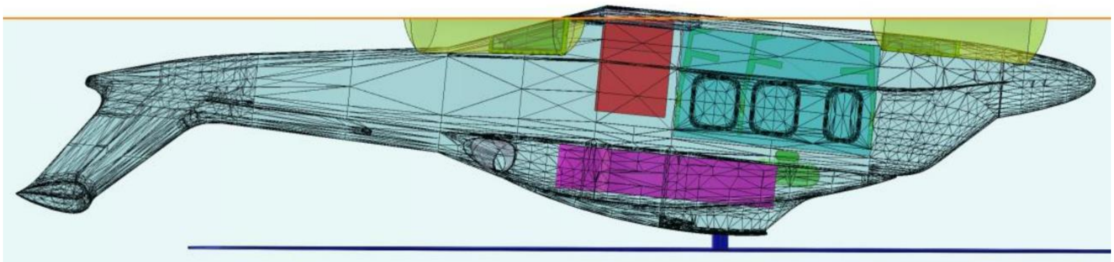


Figure 6 Capsized attitude of ditched CS29 Reference helicopter baseline with primary EFS

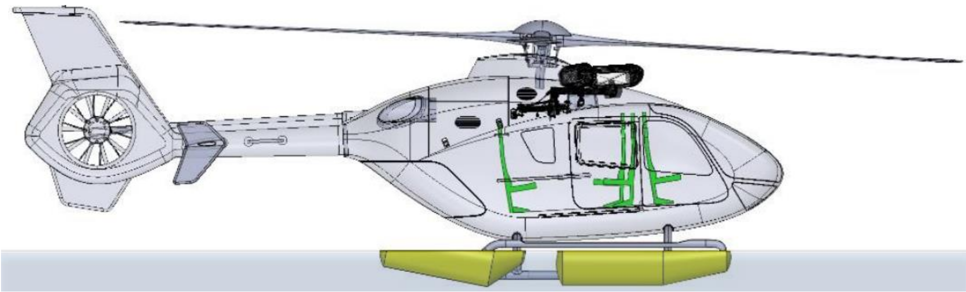


Figure 7 Upright attitude of ditched CS27 Cat A Reference helicopter baseline with primary EFS

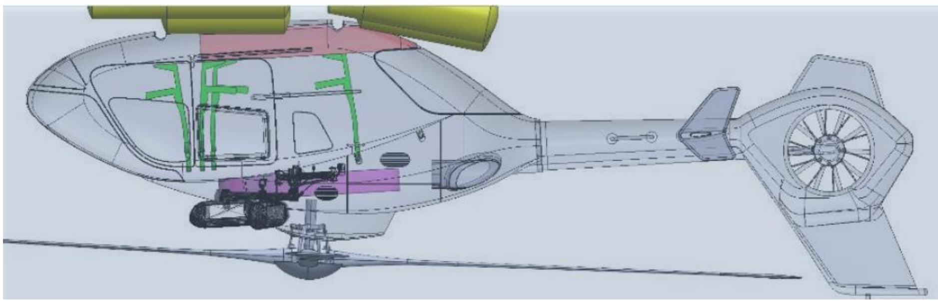


Figure 8 Capsized attitude of ditched CS27 Cat A Reference helicopter baseline with primary EFS

2.4 Overall HEFS Design

The High-mounted floats aim to achieve a survivable air pocket within the cabin in capsized position of ditched helicopters for increased occupant survivability. The design of the floats and main components of the system which have been designed for the reference helicopters are presented in this section. The float concept main design considerations are listed below:

- Geometrical constraints posed by the current configuration of the reference helicopters: provision of rescue hoist, inlet and outlet vanes, lowest rotor position (rotor interference is to be avoided at all times)
- Natural nose-down position when capsized due to inherent buoyancy, fuel tank location and helicopter CoG.

Initially, an asymmetrical HEFS configuration was considered, having the advantage of bringing the buoyancy more forward without being obstructed by the rescue hoist. This concept was discarded for a HEFS designed for retrofit with one of the reasons being aerodynamic considerations. An asymmetrical HEFS design implemented in new helicopter designs is still considered optional and should be explored. Due to the natural nose-down position of capsized helicopters, the ideal location of the HEFS was found to be a placement as forward and as high as possible on the cowling, without interfering with the rescue hoist or lowest rotor position. Figure 9 and Figure 10 show the final high float designs, placed as forward and high as possible without interfering with the main rotor and rescue hoist in inflated state. The floats design was shaped with a smaller cylinder in the front area such to avoid the contact with the hoist but still to provide additional buoyancy in the most forward position where buoyancy was most needed.

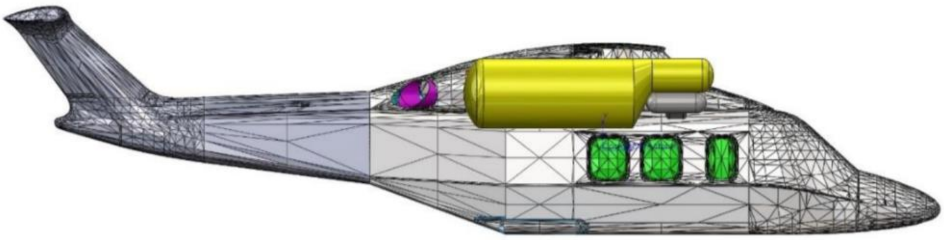


Figure 9 CS29 Reference helicopter HEFS float design

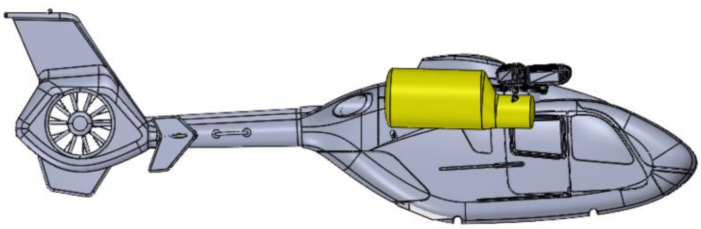


Figure 10 CS27 Cat A Reference helicopter HEFS float design

The floats will consist of four chambers, each with a separate pressure release valve and inlet for inflation through hoses that are connected to an inflation reservoir, the arrangement is shown for a generic float shape left in Figure 11. The float is kept in position with a restraint system as shown on the right in Figure 11.

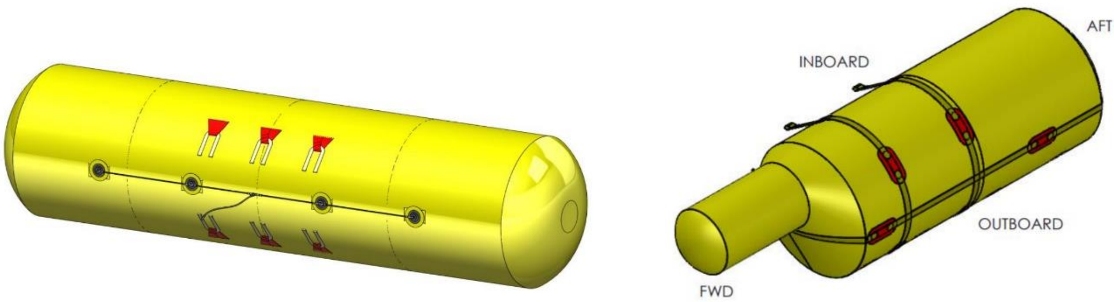


Figure 11 Example of float inlets and hoses arrangements and restraint system

During normal operation, the floats will be contained in composite pods, with a cover that disconnects once the floats are inflated after ditching. The pod designs for the reference helicopters are shown in Figure 12 and Figure 13. The pod structure shown in green, must be tied into primary structure and its size is based on established float-to-pod volume ratios. The exterior cover of the pod is optimized to minimize drag and maximize downstream pressure recovery and to avoid interference with any critical sensors, components and inlets or outlets. It can be seen that the physical design space for the CS29 reference helicopter is larger compared to the CS27 Cat A reference helicopter, which resulted in a more aerodynamically optimized design of the CS29 pod compared to the CS27 Cat A pod. In Figure 14 a cut-through of the HEFS on the CS29 reference helicopter is shown, including the inflation system and arming module.

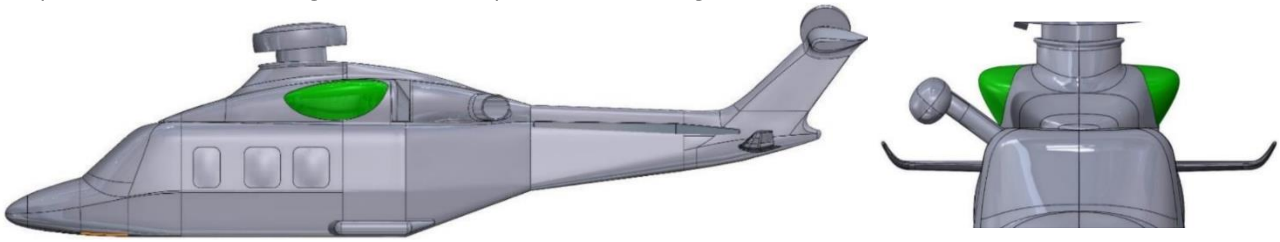


Figure 12 CS29 reference helicopter HEFS pod design

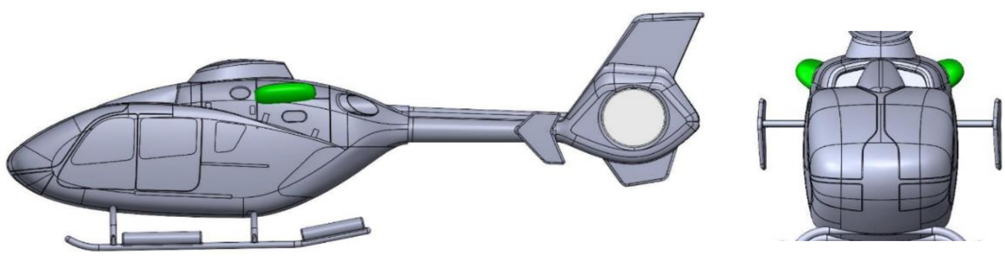


Figure 13 CS27 Cat A reference helicopter HEFS pod design

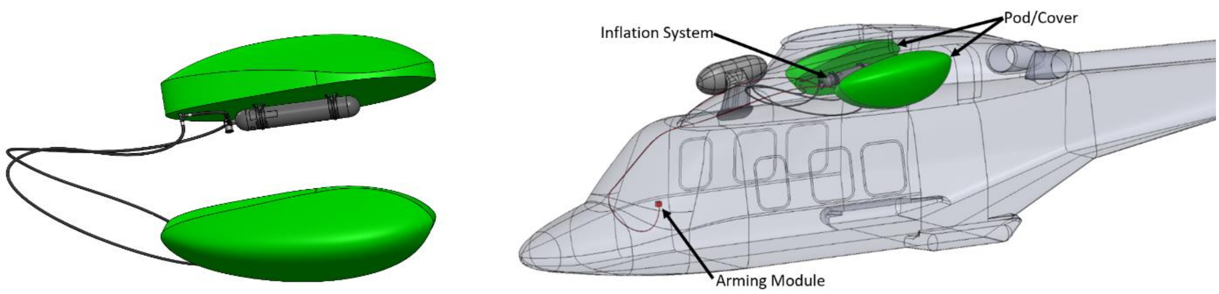


Figure 14 CS29 reference helicopter HEFS pod/cover, inflation system and arming module

2.5 Buoyancy and Air Pocket Analysis

A buoyancy analysis and airpocket assessment of the CS29 and CS27 Cat A reference helicopters has been performed by means of a buoyancy simulation tool, which was validated by a full scale buoyancy test. The simulation tool uses the worst-case weight and CoG-location with regards to buoyancy as described in section 2.2 and takes the rotorcraft inherent buoyancy into account. For more details on the buoyancy test results please refer to Annex A and for more details on the full scale buoyancy test please refer to Annex B.

2.5.1 Buoyancy Analysis

The purpose of the buoyancy analysis was to determine the stable resting position of the rotorcraft in water after ditching. Different scenarios have been evaluated to ensure a thorough analysis. The worst-case scenario for buoyancy which was evaluated has been the 'critical compartment damaged' case, where the critical compartment has been identified as the left hand most forward compartment of the floats. The following configurations have been analysed:

- Baseline case: capzised with primary EFS only
- HEFS and EFS: capsized with all floats intact
- HEFS and EFS: capsized with HEFS critical compartment damaged
- HEFS and EFS: capsized with EFS critical compartment damaged

The analysis results indicate that the CS29 reference helicopter including the normal EFS and the HEFS can maintain a stable side-floating position (partial capsize) as well as a stable fully capsized. For the CS27 Cat A reference helicopter however, there is no stable side-floating position. Upon capsizing, the CS27 Cat A reference helicopter will rotate to a stable but fully capsized position with a nose-down attitude.

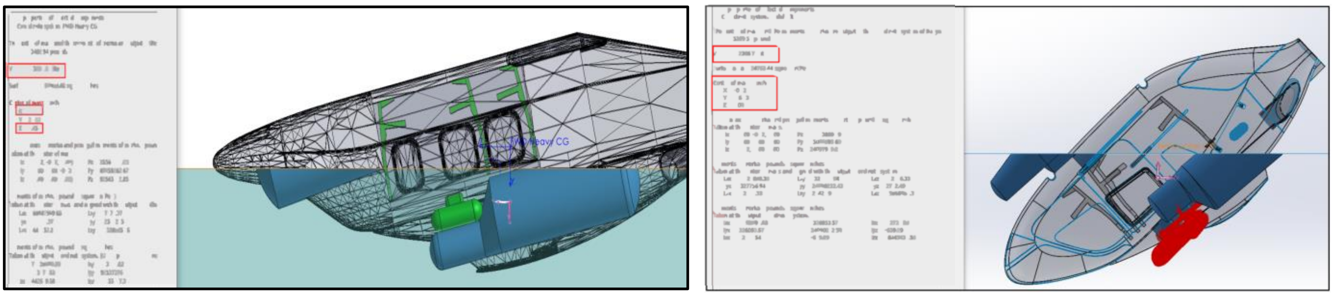


Figure 15 Buoyancy analysis simulation tool

2.5.2 Airpocket Assessment

The objective of the HEFS is to create an airpocket in the cabin for increased occupant survivability after a survivable water impact. EASA's NPA 2016-01 (EASA, Notice of Proposed Amendment 2016-01 Helicopter ditching and water impact occupant survivability, 2016) recommends a minimal elliptical airpocket volume per occupant as presented in Figure 17 (left). For the scenarios analysed in the buoyancy simulations an assessment has been made of the airpocket based on the following assumptions:

- Occupant airpockets may not overlap with other airpockets
- Occupant airpockets may not overlap with seats
- Occupants will not cross seat rows
- Full body dimensions of occupants have been taken into account with a neutral buoyancy (Figure 16)

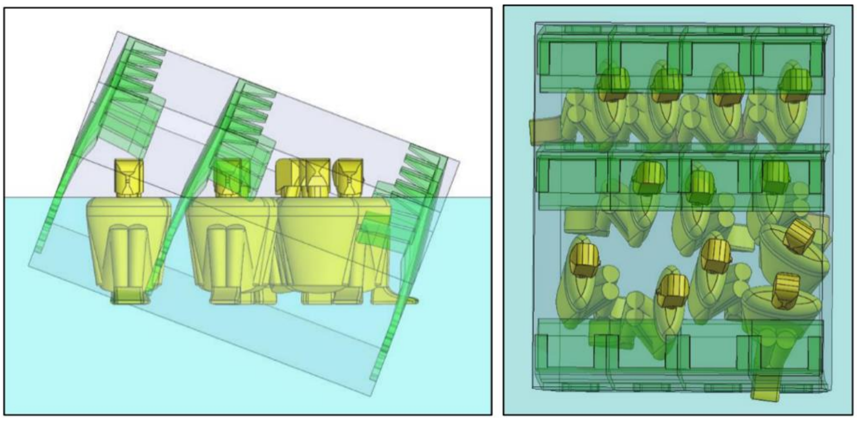


Figure 16 CS29 reference helicopter fully inverted in full scale test with HEFS critical compartment damaged – full body dimensions

The preliminary air pocket results showed that in various scenarios, overlap occurred between air pockets and also with the rotorcraft itself (seats), see Figure 17. Based on the preliminary air pocket results which indicated overlap between air pockets and the rotorcraft, a new recommended airpocket volume (different from the original recommended volume in the NPA 2016-01) and shape has been defined based on a 95th percentile of male head dimensions[1]. This resulted in a tapered shape airpocket as illustrated in Figure 18, which will still ensure increased occupant survivability as there is sufficient air within the volume to fullfill the airpocket purpose.

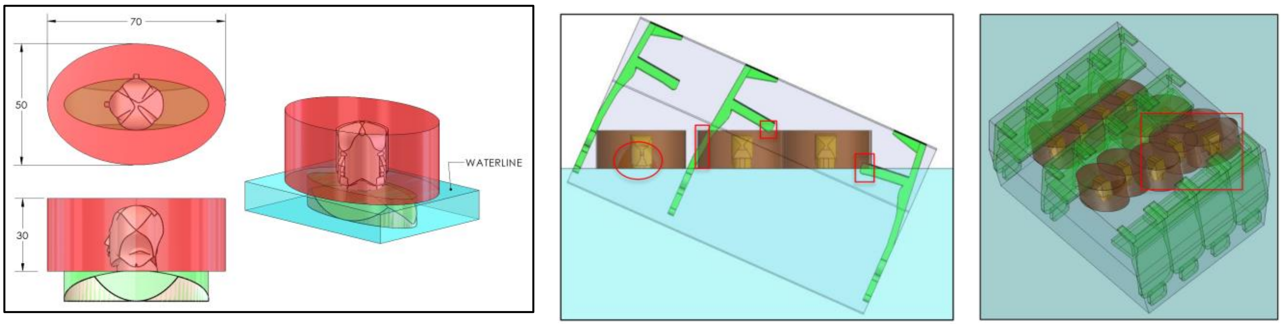


Figure 17 NPA 2016-01 airpocket volume (left), CS29 reference helicopter airpocket assessment of 'capsized, all floats intact' (right)

[1] C. C. Gordon, "2012 Anthopometric Survey of U.S. Army Personnel: Methods and Summary Statistics, NATICK/TR-15/007," *United States Army Natick Research, Development and Engineering Center,* 2014.

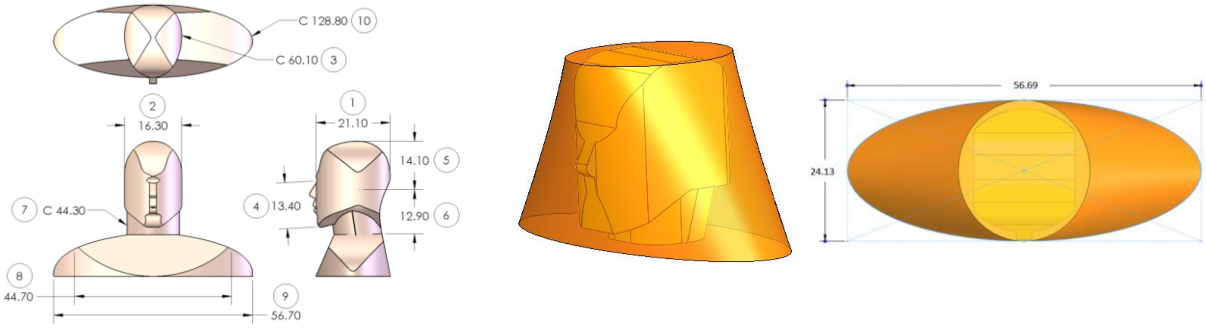


Figure 18 95th percentile of male head dimension (left), new airpocket objective: tapered shape (right) [units cm]

The airpocket analysis of the recommended tapered air pocket volume demonstrated no air pocket interference for all analysed scenarios for both the CS27 Cat A and CS29 reference helicopter. So the tapered shaped airpocket volume has shown to be feasible for the CS29 and CS27 Cat A reference helicopters after installation of the HEFS, even in the most conservative case with a critical float compartment damaged. The tapered airpocket assessments for the CS27 Cat A and CS29 reference helicopter scenario with all floats intact are shown in Figure 19 and Figure 20 respectively. It can be seen that no overlaps occur between airpockets or with seats.

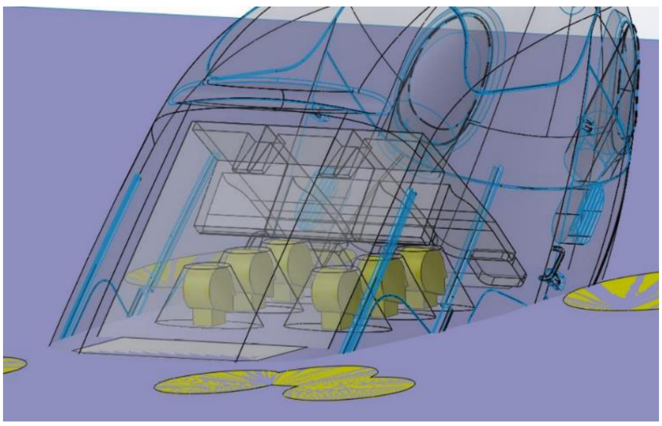


Figure 19 CS27 Cat A reference helicopter, EFS + HEFS all floats intact. Tapered airpocket feasible

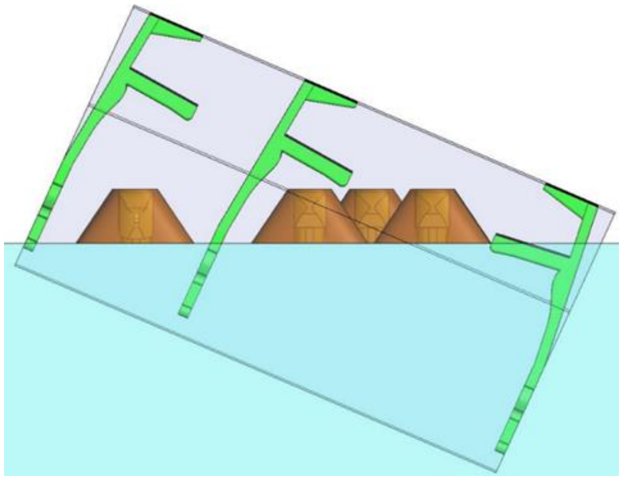


Figure 20 CS29 reference helicopter, EFS + HEFS all floats intact. Tapered airpocket feasible

2.5.3 Full Scale Buoyancy Test

In order to validate the buoyancy simulation model and to test dynamic aspects, a full scale buoyancy test was performed with a fixture based on the CS29 reference helicopter. The testing encompassed the validation of the upright floating position, the side floating position and the fully inverted position. These tests were performed for both the scenario in which all floats remain intact, and for the two damaged critical compartment scenarios (damaged EFS, damaged HEFS). Dynamic aspects such as stability of the floating positions and impact resistance of the HEFS were tested by forced perturbations (dropping the fixture from various angles) replicating the rotorcraft capsizing. For more details, please refer to Annex B.

The full scale buoyancy test has demonstrated that the buoyancy simulation tool is sufficiently representative of the full scale test results. It was shown that even for significant forced perturbations in roll angle, the full scale fixture will return to the stable side-floating position. During the tests, it was observed that while the HEFS restraints and design effectively withstood impact loads, they allowed for excessive movement of the HEFS. The main deviations between the full scale test and the simulation tool resulted from this deflection of the HEFS compared to rigid floats in the simulation model. This has demonstrated the importance of sufficient restraints in the final HEFS design to minimize deflection of the inflated floats upon contact with the water.

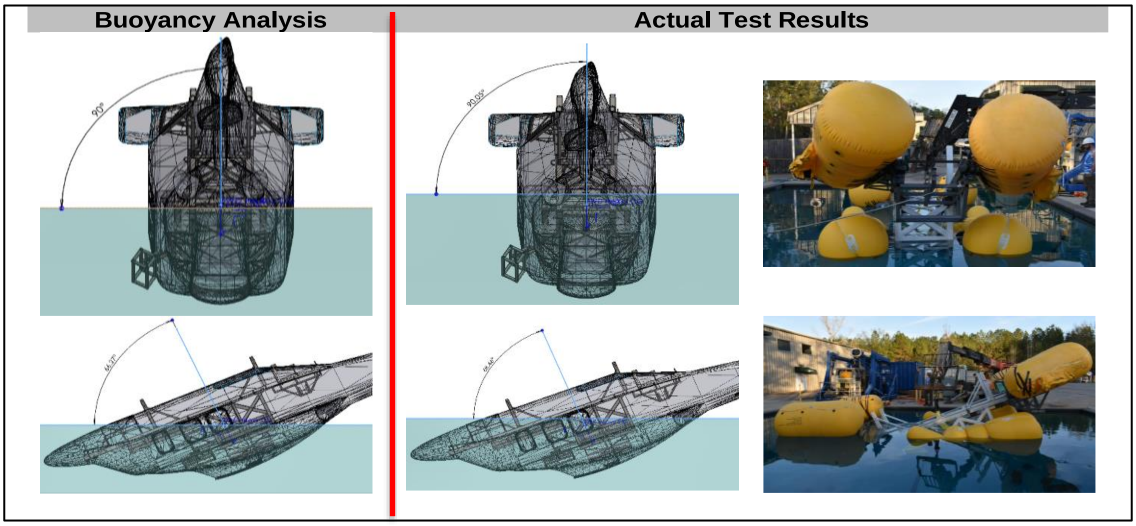


Figure 21 Full scale buoyancy test vs simulated buoyancy (fully capsized with all floats intact)

2.6 Impact on Certification

It is important to assess if and how the HEFS concept impacts the compliance to the general certification base of helicopters, or if there are certification requirements that impact the HEFS concept. Therefore a the CS27 Cat A and the CS29 have been reviewed and a checklist has been established to highlight the initial relevant certification constraints to be considered in determining the feasibility of a HEFS. Risks of non-compliance to certification specifications due to implementation of HEFS have been identified and were analysed as a part of this research. The checklists for CS29 Amendment 11 and CS27 Amendment 10 are added in Annex C.

2.7 Conclusion

The results of the buoyancy analyses have demonstrated that the CS29 reference helicopter with EFS and HEFS can maintain a stable side-floating position as well as a stable fully capsized postition. The CS27 Cat A reference helicopter with EFS and HEFS cannot maintain a stable side-floating position, only a stable fully capsized position. The preliminary airpocket assessment analysed the original recommendation for an air pocket volume by EASA's NPA 2016-01 (EASA, Notice of Proposed Amendment 2016-01 Helicopter ditching and water impact occupant survivability, 2016), however it was concluded that this elliptical air pocket volume was not achievable with the HEFS. A new airpocket volume has been defined (tapered shape) which still ensures increased occupant survivability by still providing sufficient air per passenger. It has been demonstrated that for the CS29 and CS27 Cat A reference helicopters it is feasible to design a HEFS which ensures the tapered air pocket availability to all occupants after a survivable water impact, even in the most conservative case in which the critical compartment of the HEFS is damaged. Another important observation made during the full scale buoyancy tests is the effect of deflection of the float on the available airpocket. It is of importance to sufficiently restrain the floats to avoid deflection of the floats upon contact with the water.

3. Deployment Safety Aspects

3.1 Objective

The objective of the assessment of deployment safety aspects was to establish the practicability of designing an inflatable EFS deployment system that could be integrated into the reference helicopters and that meets the following requirements:

1. The probability of inadvertent deployment of the HEFS is *extremely improbable*: 1E-09/flight hour (related to a catastrophic failure condition in accordance with CS27/29.1309)
2. The probability of failure to deploy of the HEFS when the trigger criteria are fulfilled is *extremely remote*: 1E-07/flight hour (related to a hazardous failure condition in accordance with CS27/29.1309).
3. The design shall ensure protection from damage to a float element caused by main rotor debris during a capsize event that would prevent it from performing its intended function

It should be noted that the requirement for the probability of failure to deploy (2) is set very stringent for the purpose of this research, whereas the final expectation will most likely be less demanding. For this requirement (2) it was also agreed with EASA to use a 30% probability for capsize in the first five minutes after ditching.

3.2 Approach

In order to establish the feasibility of a deployment system design that complies with the safety requirements as set for this research project, the flow in activities as represented by the flow diagram in Figure 22 was followed. A deployment system logic has been designed which was assessed for the level of safety by means of a Functional Hazard Analysis (FHA), Fault Tree Analyses (FTA), Failure Modes and Effects Analysis (FMEA) and a Common Cause Analysis (CCA). Furthermore, the rotor clearance of the inflated HEFS was assessed for the worst-possible rotor deflection to ensure rotor clearance at all times, even in the extremely improbable case of inadvertent inflation. The puncture resistance of the HEFS against floating rotor debris was assessed by means of a puncture test.

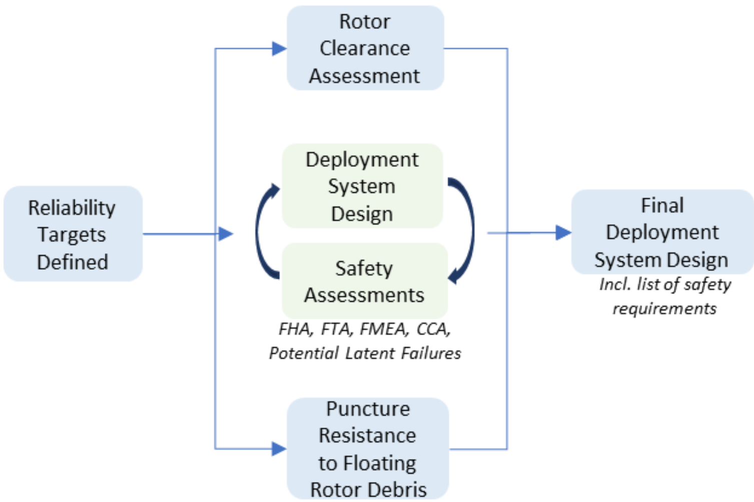


Figure 22 Approach HEFS deployment system design and safety evaluation

3.3 Deployment System Design

Besides the reliability requirements as introduced in 3.1 the following design objectives were adhered to:

- Utilization of existing sensors for water immersion and rotorcraft sensors for main rotor RPM switch
- Utilization of common float arming switch or logic with the primary EFS
- Achieving the reliability requirements without invoking DAL requirements (no complex hardware)
- Balancing reliability versus availability and tying into existing rotorcraft EFS sensors
- Ensuring annunciation of any active input path
- Ensuring that no pilot action is needed during ditching / a survivable water impact event

In order to meet the required reliability targets, the HEFS is designed with durable inflatable materials to withstand punctures and maintain positive rotor clearance.

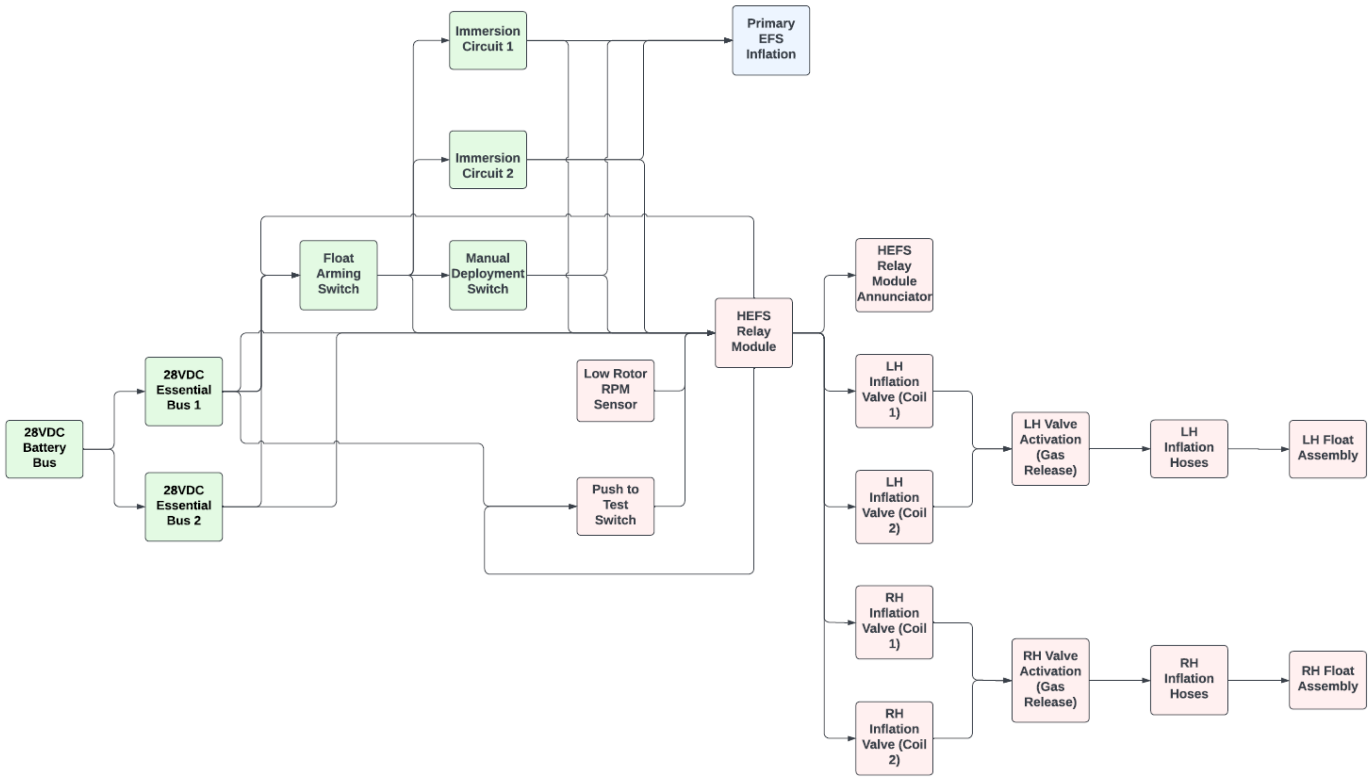


Figure 23 HEFS Deployment system logic diagram

Figure 23 shows a logic diagram of the HEFS deployment system where it can be seen that there are two options for system activation. Both of these paths require the float arming switch to be active and providing power to the system.

1. Float Immersion Circuit 1 / 2 AND Low Rotor RPM → leading to HEFS Relay Module input
2. HEFS Manual Deployment Switch AND Low Rotor RPM → leading to HEFS Relay Module input

The first path is an automatic activation that requires no pilot intervention whereas the second path is a manual activation through the HEFS manual deployment switch. Figure 24 shows the block diagram of the HEFS deployment system.

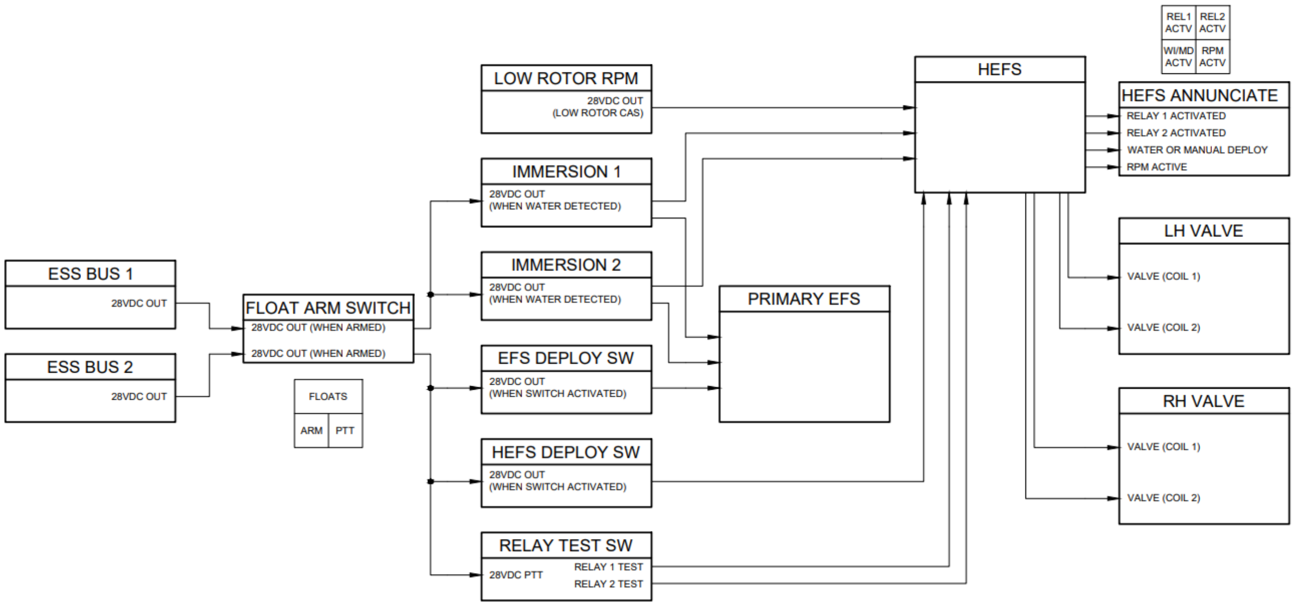


Figure 24 HEFS Deployment system block diagram

3.4 Safety Assessments

The deployment system underwent an initial evaluation for functional failure cases following the procedures outlined in SAE ARP4761, ensuring compliance with CS27 Cat A and CS29 for the requirement CSXX.1309. Both inadvertent deployment and failure to deploy scenarios were systematically addressed through a completed FHA, accompanied by FTAs, which provided the foundation for the initial design path and requirements.

The functional severities that were assessed at major, hazardous, or catastrophic have been further assessed using quantitative analysis though FTA, FMEA, and CCA once the design was developed. The design has been assessed to ensure no single failure, or combination of failures, not shown to be extremely improbable shall result in any catastrophic failure conditions. For a ditching event, the HEFS floats will be deployed once there is low rotor RPM and the rotorcraft is on the water, prior to a capsize event, and shall not impede egress. For a survivable water impact, the floats will deploy when the rotorcraft is in potentially various orientations once the deployment conditions are met.

As per CS29 Amendment 5 and onwards, and specifically AMC 29.801(e) and 29.802(c) model test method for flotation stability, capsize is considered “Hazardous”. The same target probabilities for failure are reflected as well for the HEFS. Note that CS29 Amendment 11 and CS27 Cat A Amendment 10 have been complied with.

EMI/EMC considerations are addressed through the use of components qualified to RTCA DO-160 or equivalent accepted standards. The installation of the system in each applicable rotorcraft necessitates meeting HIRF and Lightning qualifications for the rotorcraft environment.

3.4.1 Functional Hazard Assessment

Key to the success and safety of the HEFS is the necessity to define the trigger criteria for deploying the HEFS to allow a design to be created to meet the requirements. This involves creating a design that aligns with the requirements to ensure proper activation and prevent inadvertent deployment. Activation events for the HEFS are defined by criteria including armed floats (Primary EFS and HEFS) with a single switch and dual poles, the helicopter being in or on the water (utilizing existing float immersion switches), or activation via the HEFS Deploy Switch. Deployment is contingent on the rotor having stopped rotating (low rotor speed rpm < 5%). This design approach minimizes the risk of inadvertent deployment during take-off, landing, or airborne operation, with additional safeguards against catastrophic effects from a single point failure. Table 2 shows the target reliability summary extracted from the FHA for the cases of HEFS deployment and prevention of inadvertent inflation in flight. The full FHA can be found in Annex D.

Function	Description	Target Reliability
Inflated HEFS when required	The HEFS shall function according to design when the trigger criteria are fulfilled. The functional failure shall be demonstrated to be extremely remote in accordance with the guidance associated to CS27/CS29.	Failure to deploy is Hazardous (<1E-07/FH)
Inadvertent inflation of HEFS in flight	The HEFS shall not activate in flight or prior to the trigger criteria being fulfilled. The functional failure shall be extremely improbable in accordance with the guidance associated to CS27/CS29 and shall not result from a single failure point.	Inadvertent inflation is Catastrophic (<1E-09/FH)

Table 2 HEFS functions and target reliabilities resulting from FHA

3.4.2 Fault Tree Analysis

Fault tree analyses were performed for the inadvertent deployment scenario as well as the failure to deploy scenario. The full FTA can be found in Annex D. Subsequently, failure event tables were created which resulted in various safety requirements for the deployment system.

3.4.3 Failure Modes and Effects Analysis

The failure modes and effects analysis was completed in accordance with SAE ARP4761, and represents the bottom-up analysis to show that “No single Failure” can lead to a Catastrophic event that is not shown to be extremely improbable. Each component was assessed for the possible failure modes to ensure no unintended consequences exist. The FMEA for the system based on the initial design is included in Annex D.

3.4.4 Common Cause Analysis

The design has been reviewed for common cause failures that can lead to hazardous or catastrophic failure events. Once the design is fully developed, the potential common causes have to be reviewed in the context of Zonal Safety and Particular Risks (on a per installation basis). A Common mode analysis has been addressed as part of this research in accordance with SAE ARP 4761. For more details please refer to annex D.

3.4.5 Potential Latent Failures

The design has been reviewed for potential latent failures that can lead to hazardous or catastrophic failure events. Potential latent failures have been identified as part of this report. Periodic inspection intervals have to be developed as the design is completed. These potential latent failures have to be reviewed as the design is developed to ensure they comply with the requirements.

3.5 Main Rotor Clearance

Even though inadvertent deployment is considered a catastrophic event, one of the design objectives for the HEFS was to ensure main rotor clearance of the inflated HEFS at all times. Both for the CS29 and CS27 Cat A reference helicopters, the main rotor clearance of the inflated HEFS was assessed for the worst-case scenario, i.e. the lowest downward deflection of the main rotor blades in combination with the inflated high float position prior to water contact. For the analysis in the research project, a rigidly attachted HEFS was assumed (no deflection). For a HEFS certification project, it is recommended to assess deflection and HEFS location selection in relation to rotor clearance and performance in realising the desired air pocket. For both the reference helicopters a positive clearance was present as illustrated in Figure 25, Figure 26, Figure 27 and Figure 28.

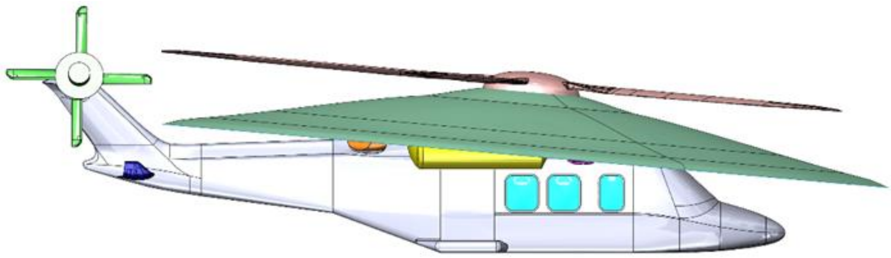


Figure 25 CS29 Reference helicopter lowest main rotor position

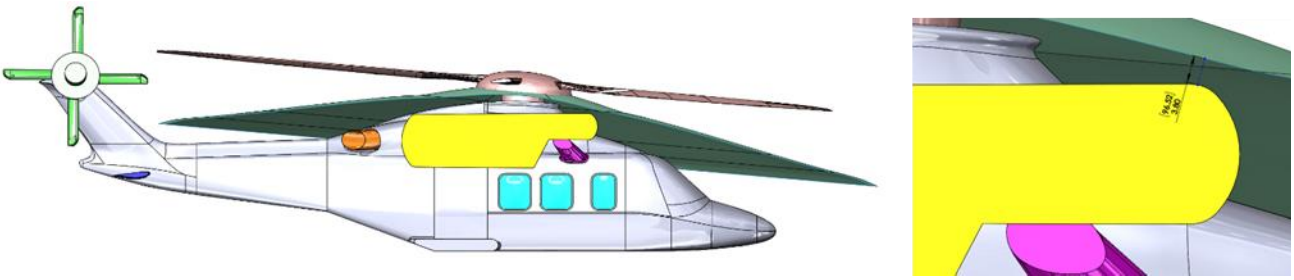


Figure 26 CS29 Reference helicopter section view of lowest main rotor position, 97 mm distance at closest point of high float

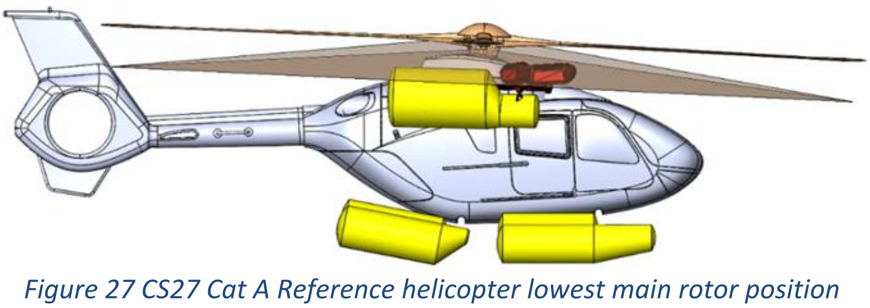


Figure 27 CS27 Cat A Reference helicopter lowest main rotor position

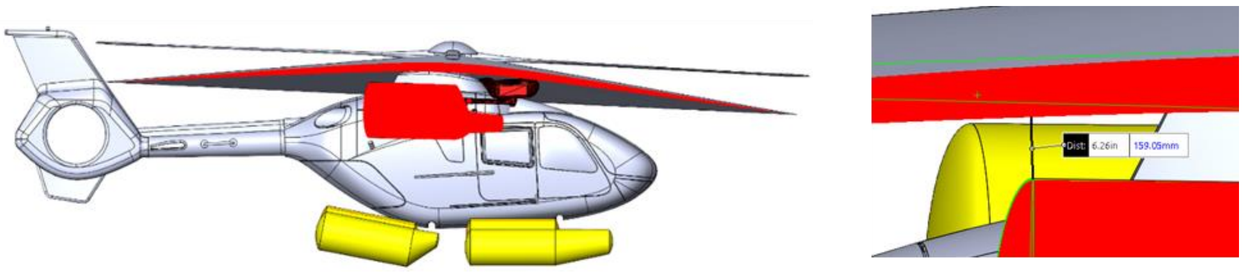
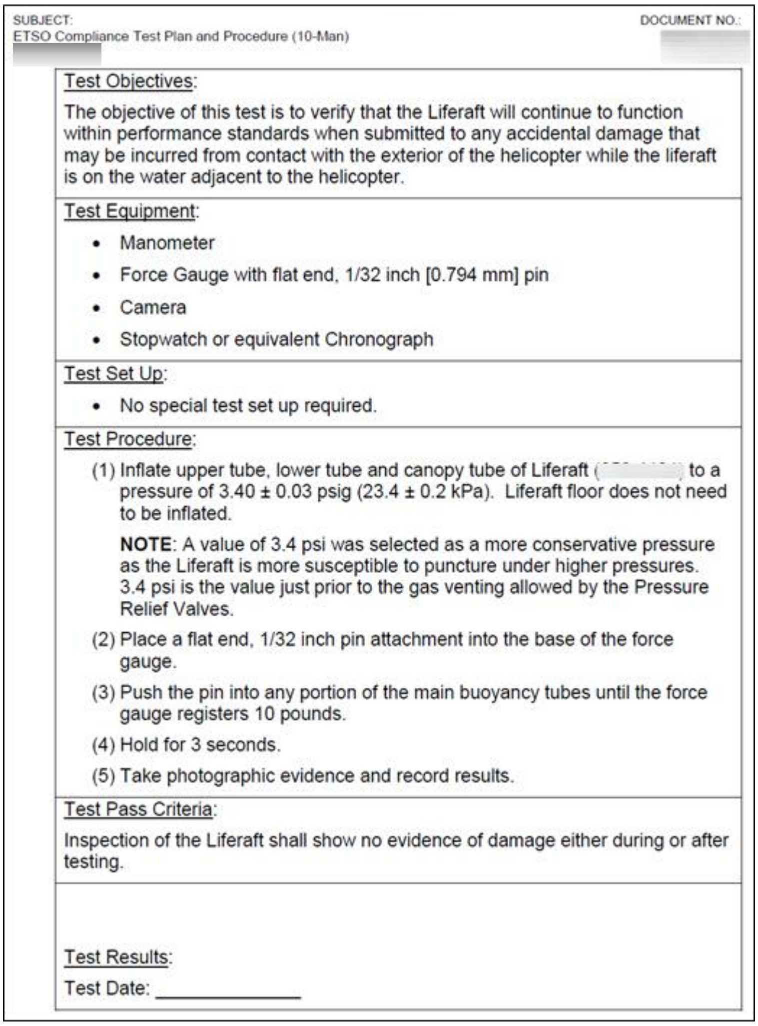


Figure 28 CS27 Cat A Reference helicopter section view of lowest main rotor position, 159 mm clearance at closest point to high float

3.6 Puncture Resistance to Floating Rotor Debris

In order to ensure protection from damage to a high float element potentially caused by main rotor debris during a capsize event, the selected float bag material from the heat resistance tests (i.e. the existing float bag material, see Chapter 4) has been tested for puncture resistance. Currently, the float bag material has been tested in accordance with the ETSO-2C505 standard following the procedure as shown in Figure 29. The material has demonstrated results that exceed the test requirements by a factor of >6x: the maximum value which was achieved was 300 N (67.44 lbf). It should be noted that future tests will need to be conducted in accordance with the newly developed liferaft standard ASD-STAN prEN-4886.



SUBJECT:
ETSO Compliance Test Plan and Procedure (10-Man)

DOCUMENT NO.: [illegible]

Test Objectives:

The objective of this test is to verify that the Liferaft will continue to function within performance standards when submitted to any accidental damage that may be incurred from contact with the exterior of the helicopter while the liferaft is on the water adjacent to the helicopter.

Test Equipment:

- Manometer
- Force Gauge with flat end, 1/32 inch [0.794 mm] pin
- Camera
- Stopwatch or equivalent Chronograph

Test Set Up:

- No special test set up required.

Test Procedure:

(1) Inflate upper tube, lower tube and canopy tube of Liferaft ([illegible]) to a pressure of 3.40 ± 0.03 psig (23.4 ± 0.2 kPa). Liferaft floor does not need to be inflated.

NOTE: A value of 3.4 psi was selected as a more conservative pressure as the Liferaft is more susceptible to puncture under higher pressures. 3.4 psi is the value just prior to the gas venting allowed by the Pressure Relief Valves.

(2) Place a flat end, 1/32 inch pin attachment into the base of the force gauge.

(3) Push the pin into any portion of the main buoyancy tubes until the force gauge registers 10 pounds.

(4) Hold for 3 seconds.

(5) Take photographic evidence and record results.

Test Pass Criteria:

Inspection of the Liferaft shall show no evidence of damage either during or after testing.

Test Results:

Test Date: ______________

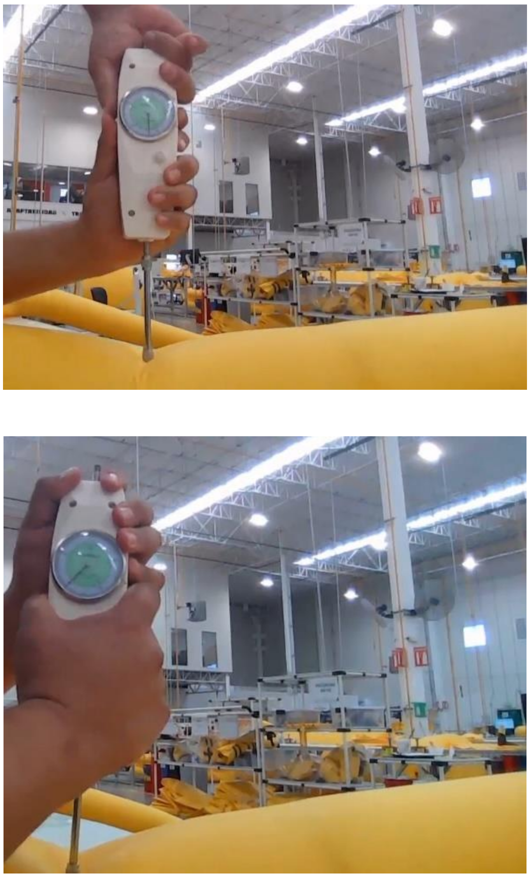


Figure 29 Puncture Test Procedure and Result

3.7 Conclusion

The analysis has shown that achieving an inadvertent deployment rate of 1E-09 per flight hour is feasible and the conceptual deployment system design can even exceed the target. Likewise, it has been determined that a failure to deploy rate of 1E-07 per flight hour is also feasible when factoring in a 30% chance of capsizing within five minutes or 4.1E-06 per flight hour when not factoring in a 30% chance of capsizing within five minutes. It has been established that these reliability targets in the activation system can be achieved without the need for complex software or hardware. Furthermore, it has been demonstrated that main rotor clearance by the inflated high floats can be achieved with the reference helicopters HEFS design.

4. Heat Resistance

4.1 Objective

The objective of the heat resistance assessment was to ascertain whether or not the current state of the art in materials and inflatable structures will enable a flotation unit to be stowed in proximity to the helicopter engine/transmission heat sources without unacceptable degradation. This encompassed the assessment of all components of the HEFS: float bag material, composite pod / cover material and any hardware such as valves.

4.2 Approach

Figure 30 illustrates the activities performed to analyse the effect of elevated temperatures on possible primary materials utilized in the HEFS construction. First the temperature requirements were determined. This was followed by selecting a series of materials to be tested for the float bags and composite pod / cover. The various fabrics and composite materials were then exposed to elevated temperatures in order to down select the optimal materials. The down selected materials were then subjected to one simulated flight thermal cycle. Finally, the best performing materials were exposed to thermal cycle testing which was followed by a simulated inflation of the float bag. The float bag and composite materials were tested for heat transfer characteristics and physical deterioration after heat exposure. Additionally, the float bag fabric was tested for the ability to retain air after heat exposure.

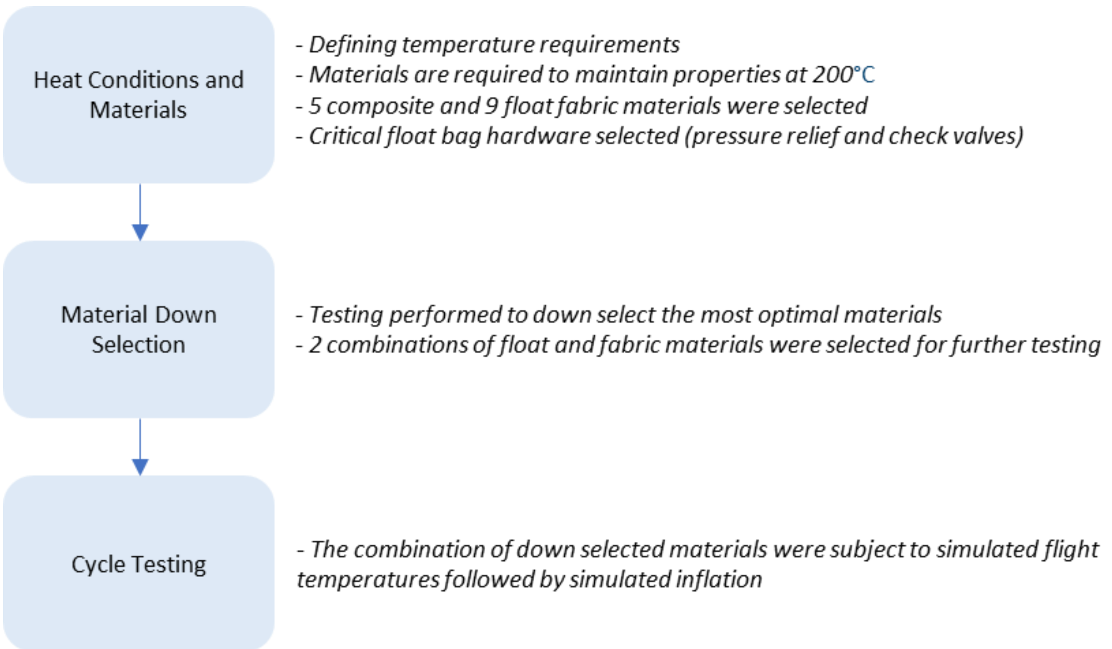


Figure 30 Approach heat resistance testing in three stages

4.3 Temperature Requirements

The hottest region on the helicopter upper cowling can be expected directly around and downstream of the engine exhaust. Different helicopters in the CS29 and CS27 Cat A fleet have their engine exhausts in different locations, making it plausible that for some helicopters in the current fleet the HEFS pods would have to be installed close to the engine exhaust. Therefore, the worst case temperature to which the HEFS could potentially be exposed was considered the temperature found right downstream of the engine exhaust. This most conservative scenario in terms of heat conditions has been used during the heat resistance tests, on the HEFS in stowed state (floats stowed within composite pod). The heat map of an EC225 from a relevant research study (Eurocopter & Aerazur, 2007)was made available for the purpose of the project and was transposed onto the CS29 reference helicopter as illustrated in Figure 31. Subsequently, the heat map was transposed forward on the CS29 reference helicopter to represent the worst-case scenario applicable to the current CS29 fleet, shown in Figure 32 where the approximate pod location is indicated in green.

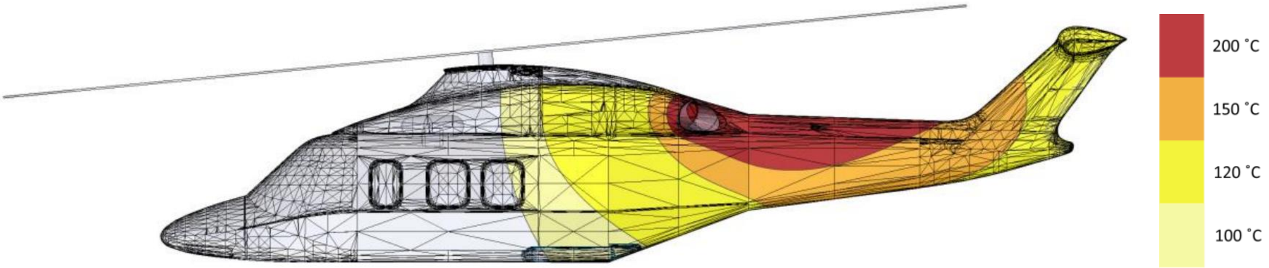


Figure 31 CS29 reference helicopter heat map using EC225 data

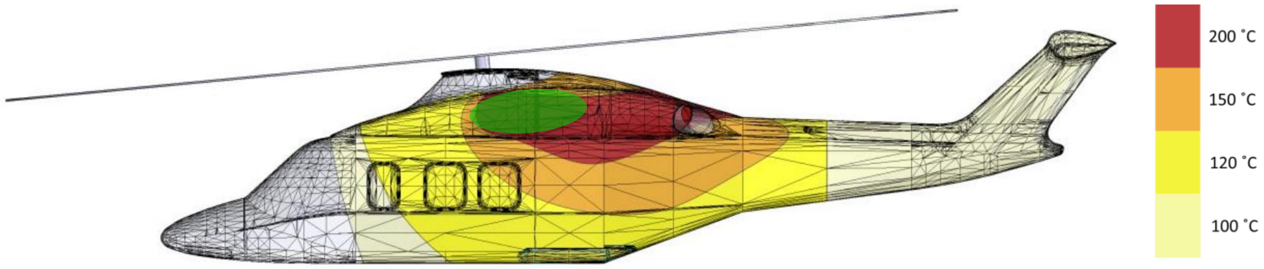


Figure 32 CS29 reference helicopter heat map transposed forward to represent the worst-case for CS29 fleet

Similarly, the heat map as assumed for the CS29 reference helicopter was also used for the CS27 Cat A reference helicopter scaled to the size of the rotorcraft. Again, the heat map was transposed forward to represent the worst-case scenario applicable to the current CS27 Cat A fleet, as shown in Figure 33. So, both for the CS29 and CS27 Cat A reference helicopters, a worst-case peak surface temperature of 200°C around the HEFS pod location was assumed.

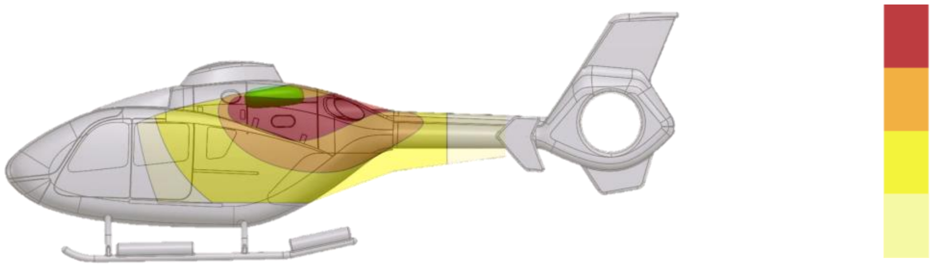


Figure 33 CS27 Cat A reference helicopter heat map transposed forward to represent the worst-case for CS27 Cat A fleet

4.4 Material Down Selection Tests

During the material down selection tests, 5 composite coupons and 9 float bag fabric coupons were tested for their resistance to heat. Figure 34 depicts the schematic of the experimental configuration, highlighting specific temperature measurement points and illustrating the layered arrangement of composite and fabric materials. In order to simulate the stowed state of the HEFS, the float bag material and composite material were layered (see Figure 34). The various materials were tested for heat transfer and physical deterioration by exposing the materials to a temperature of 200°C for a duration of 30 minutes. Thereafter the ability of the float fabric to retain air was assessed at a pressure of >2.0 PSI and the materials were visually assessed for physical deterioration.

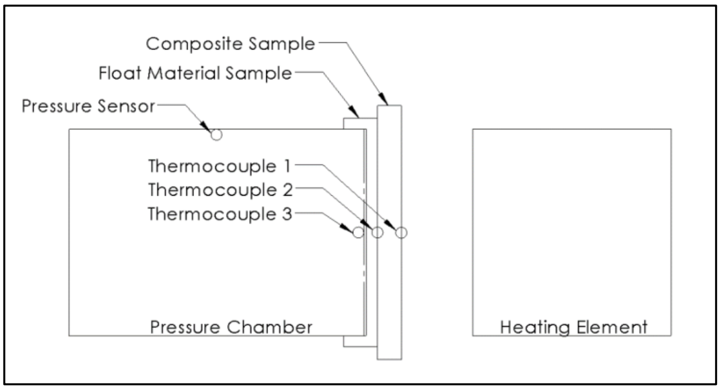


Figure 34 Heat resistance testing set-up representing stowed

Table 3 shows the results of the heat resistance tests performed for the initial composite and fabric material down selection. Composite material E demonstrated the greatest ability to reduce heat transfer and fabric material C demonstrated no visual deterioration or loss of air retention properties. Those materials were selected as most promising for the HEFS and were further tested for their performance in heat conditions. For more details about the test results, please refer to Annex E.

Coupon Type	Coupon Identification	Coupon Material	Air Retention	Thickness (in)	Avg Delta T	Avg Delta T per Thickness
Composite	Material A	Epoxy Carbon Prepreg	N/A	0.084	32.07	381.78
	Material B	Epoxy Carbon Prepreg	N/A	0.084	36.26	431.70
	Material C	Epoxy Carbon Prepreg	N/A	0.140	43.60	311.44
	Material D	Epoxy Fiberglass Prepreg	N/A	0.145	41.06	283.16
	Material E	**Epoxy Fiberglass Prepreg**	**N/A**	**0.065**	**32.70**	**503.09**
Fabric	Material A	Silicone Coated Woven Nylon	No	0.027	N/A	N/A
	Material B	Woven Nylon	Yes	0.024	N/A	N/A
	Material C	**Urethane Nylon**	**Yes**	**0.009**	**N/A**	**N/A**
	Material D	Silicone Coated Fiberglass	Yes	0.047	N/A	N/A
	Material E	Silicone Coated Fiberglass	Yes	0.048	N/A	N/A
	Material F	Silicon Coated PTFE	No	0.011	N/A	N/A
	Material G	Silicone Coated Fiberglass	No	0.014	N/A	N/A
	Material H	Silicone Coated Fiberglass	No	0.013	N/A	N/A
	Material I	Woven Fiberglass	Yes	0.021	N/A	N/A

Table 3 Results heat resistance test for initial material down selection

4.5 Simulated Flight Test Procedure

The down selected materials from the first heat tests were in the next stage of testing subjected to one simulated flight thermal cycle. This involved exposing the materials to a temperature of 200°C for 2.5 hours and then inspecting for physical deterioration and air retention properties of the fabric after inflation to 2.00 PSI. For the test results, please refer to Annex E.

4.6 Thermal Cycle Tests Procedure

Finally, the best performing materials were selected and tested for their performance during and after multiple thermal cycles. For this test, a representative peak temperature of 150°C was used and the materials were tested in 15 heat cycles of 2.5 hours. After the test the materials were inspected for physical deterioration and air retention properties of the fabric after inflation to 2.00 PSI. For the test results, please refer to Annex E.

4.7 Hardware Tests

In addition to testing the potential materials to be used for the HEFS, the main HEFS hardware, which will possibly be exposed to elevated temperatures, were also tested for their functioning after heat exposure. The tested hardware involved the pressure relief valve and the inflation valve, whereas hardware such as the Kevlar webbing and the Stainless steel girts have not been tested since they have established heat resistance that exceeds the worst-case heat condition defined for this study. The valves are integrated in the tested fabric (still simulating the stowed HEFS condition) and subjected to one thermal cycle to a temperature of 200°C for 2.5 hours. After the thermal cycle, the valves were inspected for visual damages and leaks. For the test results, please refer to Annex E.

Figure 35 Float bag inlet valve (left) and float bag pressure relief valve (right)

4.8 Conclusions

Industry standard fabric and composite materials have demonstrated the ability to retain performance at elevated temperatures and preliminary endurance testing has demonstrated favorable results. Industry standard hardware and manufacturing techniques used in conjunction with these materials remain operational after having been subjected to high-heat conditions. Thermal cycle testing has been performed as part of this research and has demonstrated that fabric material is available on the market which can maintain its air retention properties in a simulated ditching scenario after being exposed to the prolonged heat. For an actual certification project of a HEFS system, it is recommended to conduct comprehensive Highly Accelerated Life Testing (HALT) of materials being considered for the HEFS in order to rigorously assess thermal resilience and optimal weight to heat resistance of the materials.

5. Aerodynamic Aspects

5.1 Objective

The objective of the aerodynamic study was to determine if the aerodynamic impact of the HEFS on CS27 Cat A and CS29 certified helicopters will result in unsurmountable degradation of performance and handling qualities. 'Unsurmountable' has been defined as impact that causes the helicopter to lose compliance with airworthiness requirements that cannot be mitigated without severe engineering work (such as modifying and re-certifying the flight control system), or the aerodynamic impact leads to unacceptable cost penalties for the TC HOLDER or the operators. As part of the assessment, the following aerodynamic aspects have been evaluated:

- FLowfield characteristics – Wake cross-sectional area, vortex shedding, engine inlet flow disturbances
- Handling quality – static stability and aerodynamic forces and moments
- Performance – drag impact and One Engine Inoperative Rate of Climb

The handling quality and performance aspects have been evaluated in accordance with relevant CS29 and CS27 Cat A articles (*CS29.67, CS27.67, CS29 Appendix B IV*). For more details about the aerodynamic impact study, please refer to Annex F.

5.2 Approach

The aerodynamic impact has been assessed by means of a 'delta' analysis, see Figure 36, comparing a baseline helicopter (i.e. the reference CS29 with primary EFS internally and CS27 Cat A helicopters with primary EFS external on skids) to a retrofitted helicopter (i.e. the reference helicopters including primary EFS and HEFS). The aerodynamics of the baseline and HEFS-retrofitted helicopters has been analysed by means of Computational Fluid Dynamics (CFD) for three different flight speeds for which the CFD model was validated: 80 kts, 110 kts and 140 kts. Where relevant also different altitudes were considered from SSL upto 5000ft.

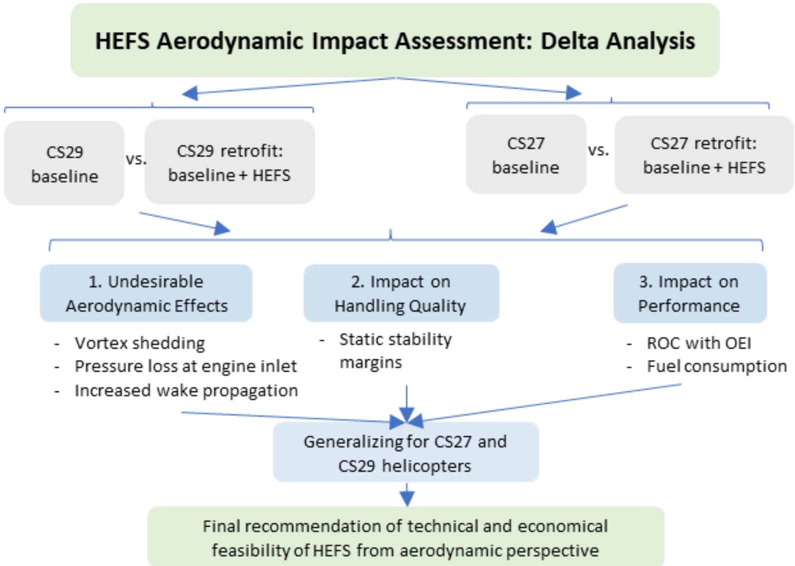


Figure 36 Approach for aerodynamic impact assessment of stowed HEFS

The reference helicopter models used in the CFD simulations are presented in Figure 37. The CFD model included modelled main rotor downwash and modelled engine inlet and outlet flows. The scenario assumed for the stability analysis was a medium TOW of 5900kg for the CS29 reference helicopter and a medium TOW of 2600kg for the CS27 Cat A reference helicopter, both with an aft-CoG. For the performance analysis a maximum TOW of 6400kg was taken for the CS29 reference helicopter (EASA, Type Certificate Data Sheet for AW139, 2021) and maximum TOW of 2800kg (EASA, Type Certificate Data Sheet for EC135, 2022) for the CS27 Cat A reference helicopter.

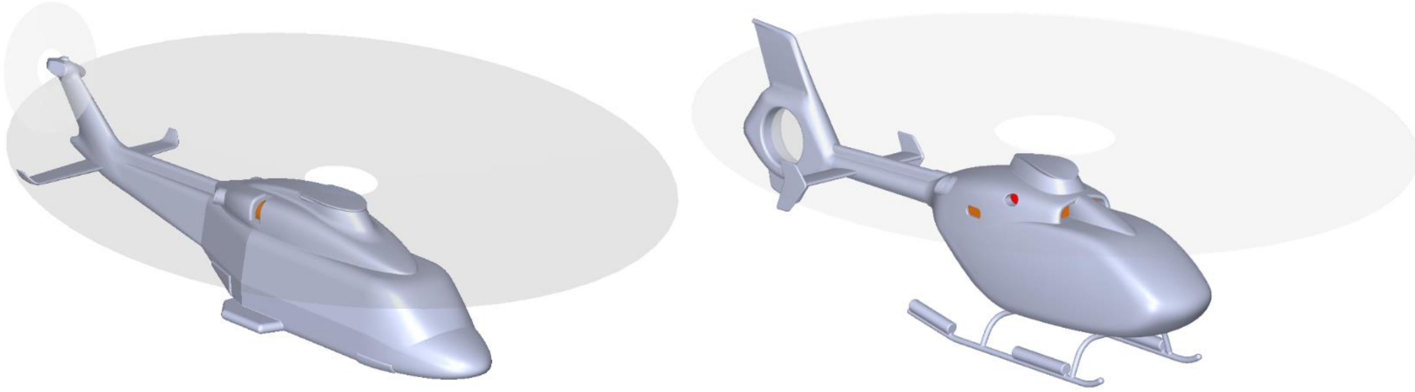


Figure 37 CS29 (left) and CS27 Cat A (right) reference helicopter models used for CFD with inlets and outlets highlighted in orange and red

5.3 HEFS Pod Design

The installation of the HEFS must not affect the normal safe operations of the helicopter and should not pose any unproportional engineering challenges when retrofitted. Therefore, the design of the HEFS pod - in which the high mounted floats are stowed during normal operations – have to adhere to a number of physical constraints. The final pod design for the CS29 and CS27 Cat A reference helicopters is shown in Figure 38. The differences in physical design space resulted in a more aerodynamic final pod design for the CS29 reference helicopter and a more blunt pod design for the CS27 Cat A reference helicopter. The designs adhere to the following physical design considerations:

- The pod shall not cover or interfere with any critical sensors, components or inlets
- The pod will remain clear of the rotor blades at all times
- The pod covers the HEFS components with sufficient margin (float, inflation reservoir)
- The location of the pods has to satisfy the aimed buoyancy and will not interfere unacceptably with maintenance access

Within these constraints, the HEFS pods were aerodynamically optimized in order to minimize the aerodynamic impact as follows:

- The frontal area of the pod has been maintained as small as possible to reduce the drag impact
- The vertical area has been maintained as small as possible and as close to the main rotor mast as possible, where the rotor inflow is at the minimum
- The shape and orientation of the pod has been designed such that minimal forces and moments are generated in the longitudinal vertical plane during ‘position hold HOGE’ (SAR mission). This can be achieved by longitudinally symmetrical pods, with the symmetry plane perpendicular to the TPP (similar to the hoist main body)
- The design has facilitated maximum pressure recovery downstream of the pods

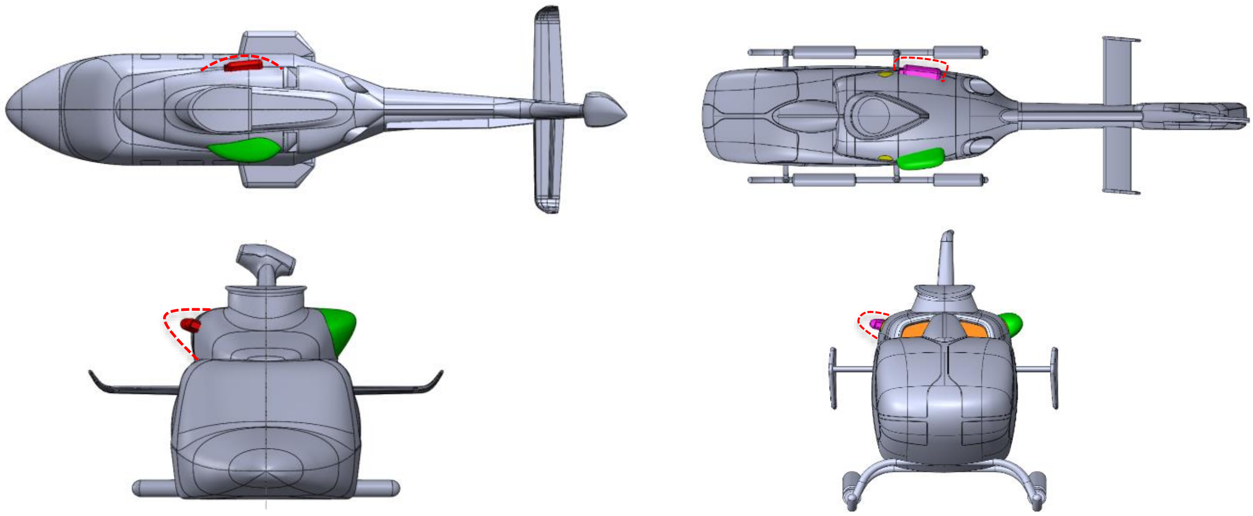


Figure 38 Front and top view reference helicopters HEFS inflation reservoir (red/pink) and HEFS pod (green), CS29 (left) and CS27 Cat A (right)

5.4 Computational Fluid Dynamics

In order to assess the aerodynamic impact of the stowed HEFS in normal flight operations, the aerodynamics around the reference helicopters (baseline and HEFS-retrofitted) has been evaluated by means of a steady-state RANS CFD model, developed in the open source CFD software *OpenFoam*. This CFD methodology is a static model approximating the mean flow field and modelling turbulence with a k-Omega SST model. The advantage of using steady-state CFD over windtunnel or full scale tests is the wide variety of scenarios which can be relatively easily evaluated. However, steady-state CFD has its limitations with respect to accuracy and estimations of unsteady flow features. The CFD model has been validated and verified with open source data and data made available by the TC HOLDERs. Forces and moments have been computed with the CFD model for the aforementioned different flight speeds (80, 110, 140 kts) and for various helicopter attitudes and flight altitudes. Conclusions have been drawn by looking at delta's in contrast to absolute values, which are considered to be more reliable in terms of accuracy. The list below includes some of the steps that have been taken to validate and verify the CFD model. More details about the validation are included in Annex F.

1. Mesh sensitivity analysis, discretization scheme sensitivity analysis
2. Verification of turbulence model, comparing k and omega profiles at boundaries to experimental data, as shown in Figure 42.
3. Sensitivity analysis k and omega values
4. Convergence study (virtual time step, number of iterations)
5. Validation of CFD results with qualitative and quantitative data received from the TC HOLDER (drag curves, power curves and static pressure fields). An example is given in **Error! Reference source not found.**, the static pressure distribution obtained by the CFD model was compared to data received from the TC HOLDER.

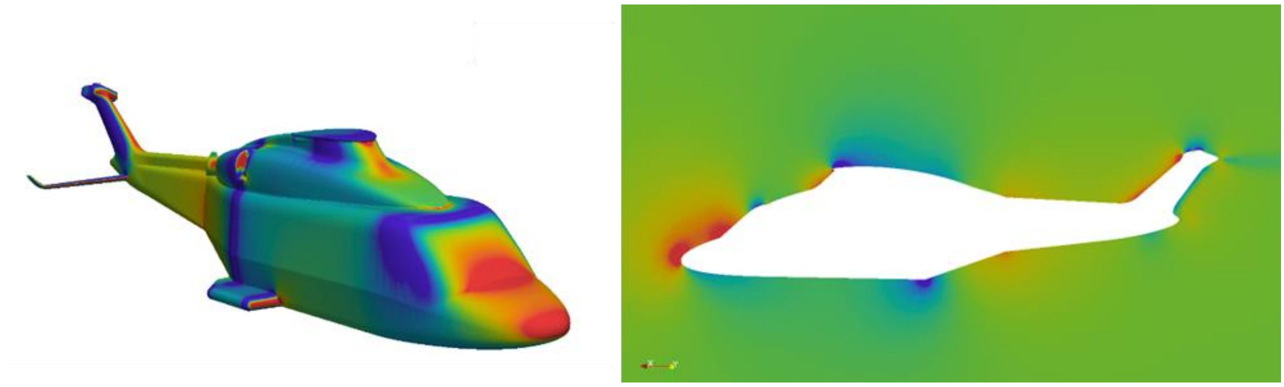


Figure 39 Static pressure distribution CS29 reference helicopter using the OpenFoam CFD model developed

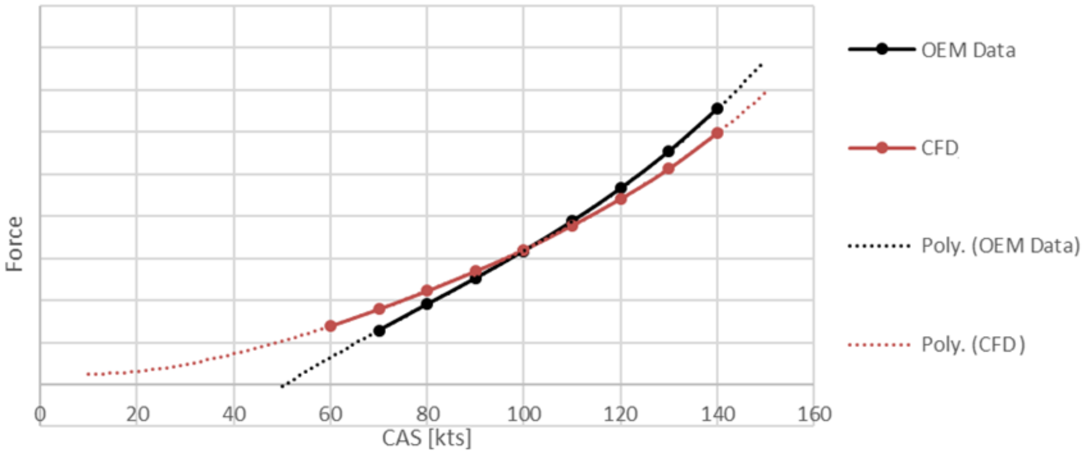


Figure 40 Reference drag (from TC holder) compared to the drag according to selected turbulence model

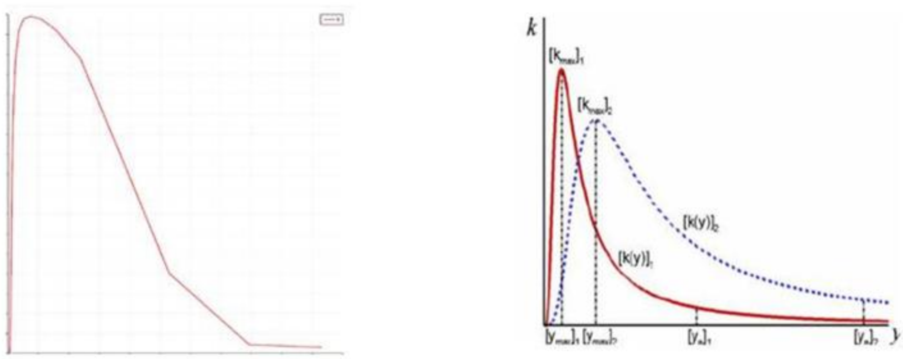


Figure 41 Turbulence kinetic energy (k) profile of developed CFD model (left) compared to experimental data from literature (right) (Shur, Spalart, Strelets, & Travin, 2011)

5.5 Flowfield Characteristics

By visualizing the flowfield velocity in vertical cross-sections, the impact on the wake due to the pods propagating downstream has been assessed. Figure 42 shows a sample of the wake-propagation analysis. It can be seen that the impact of the HEFS on the wake near the vertical tail is negligible.

Besides the HEFS impact on the wake, also the quality of the engine inlet flow has been evaluated for the CS29 reference helicopter (since the engine inlet of the CS29 reference helicopter is located downstream of the HEFS pod) by looking at the total pressure recovery on a plane close to the inlet. The pressure fields near the right engine inlet extracted from CFD simulations at 110 kts at various yaw angles were assessed. It was found that the HEFS pods have a minimal impact on the quality of the inlet flow for this reference case, which can be attributed to minimal disturbance of the flow downstream of the pod (negligible recirculation region). Detailed results on the flowfield characteristics are included in Annex F.

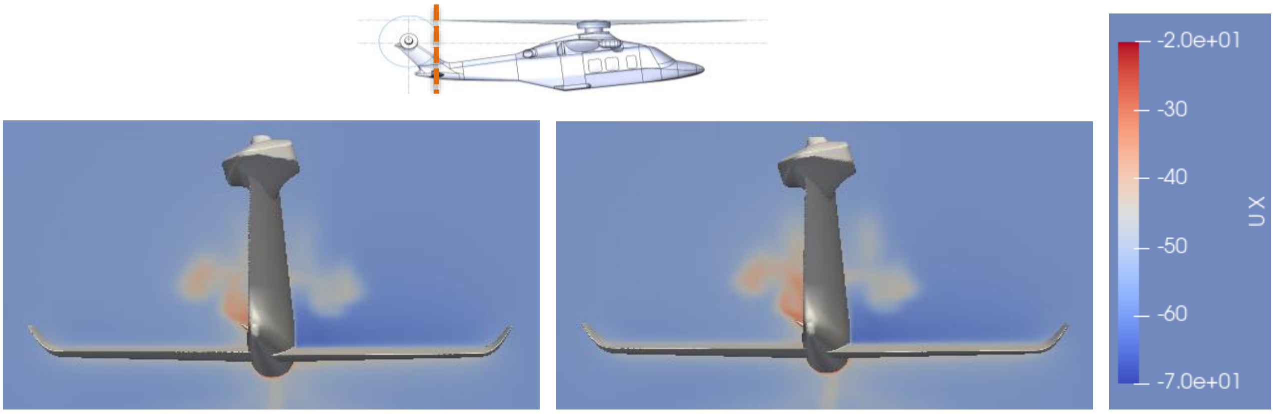


Figure 42 Wake assessment (U_x [m/s]) at vertical tale CS29 baseline (left) and CS29 HEFS (right)

5.6 Helicopter Handling Quality & Helicopter Performance

Two initial observations can be made without going into CFD and post-processing results:

- The HEFS pods are retrofitted bodies positioned onto the upper cowling, positioned rearward and above the helicopter CoG. The lever arms with respect to the helicopter's body x axis and z axis likely create a pitch up attitude, an increased dihedral effect of the fuselage and offer resistance in pitch rates, irrespective of the helicopter configuration or flight condition.0
- When comparing the HEFS pods to similar certified installations (e.g. rescue hoist) on CS29 and CS27 Cat A offshore helicopters, it can be expected that the aerodynamic impact of the HEFS will be similar or less severe.

By post-processing the computed forces and moments resulting from the CFD simulations, the above two statements have been quantified by calculating the delta in static stability margins, delta in the ROC with OEI and delta in drag. Detailed results on the handling quality & helicopter performance are included in Annex F.

5.6.1 Handling Quality

The aerodynamic impact of the HEFS pods on the static stability has been assessed by looking at the delta which the pods impose on the following:

- The longitudinal static margin dB_{1s}/dV , the absolute value should be positive in a stable situation: a forward cyclic stick input $(+B_{1s})$ results in an increase in velocity $(+V)$
- The longitudinal static margin dB_{1s}/dq , the absolute value should be negative in a stable situation: a forward cyclic stick input (+B) results in an increase in 'nose-down' pitch rate (-q)

After interpretation of the results, it has been concluded that it can be expected that for all types of helicopters, the HEFS pods will create slightly more resistance when accelerating (a positive delta in dB_{1s}/dV). The delta has been found to be in the order of less than 1%, a negligible effect for both reference cases. Furthermore, it can be expected that for all types of helicopters, the HEFS pods will create slightly more resistance in pull-up and pull-over manoeuvres (a positive delta in dB_{1s}/dq). The magnitude of the effect will depend on the aerodynamic optimalization of the pods design. The impact of the HEFS found for the CS27 Cat A reference case (blunt pod design) has been found to be larger than the CS29 reference case (aerodynamic pod design). The delta in dB_{1s}/dq found for the CS27 Cat A reference case was in the order of a few percents, while the delta found for the CS29 reference case can be considered negligible.

5.6.2 Performance

The aerodynamic impact of the HEFS pods on the performance has been assessed by looking at the following:

- Delta/increase in drag, which is translated into an estimation of the increase in fuel consumption due to the increased necessary thrust
- Delta in rate of climb with one engine inoperative, due to the delta in drag

For both the reference cases, it has been found that the increase in fuel consumption due to additional drag imposed by the HEFS pods can be expected to be less than 1% compared to the baseline, where in the CS29 reference case it was even less than 0.2%. It was also found that the degradation in ROC performance with OEI can be expected to be negligible for both the reference helicopters, for both altitudes analysed (SSL upto 4000ft). For the CS29 reference case (at SSL, 80 kts) the degradation in ROC with OEI was in the order of 3 ft/min (a delta of 0.39% compared to the baseline). For the CS27 Cat A reference case (at SSL, 80 kts) the degradation in ROC with OEI was in the order of 5.5 ft/min (a delta of 1.46% compared to the baseline). The fuselage drag curves of both reference helicopters (so excluding rotor contributions) have been extrapolated from the CFD data upto the V_{NE} speeds, these can be found in Figure 43 and Figure 44.

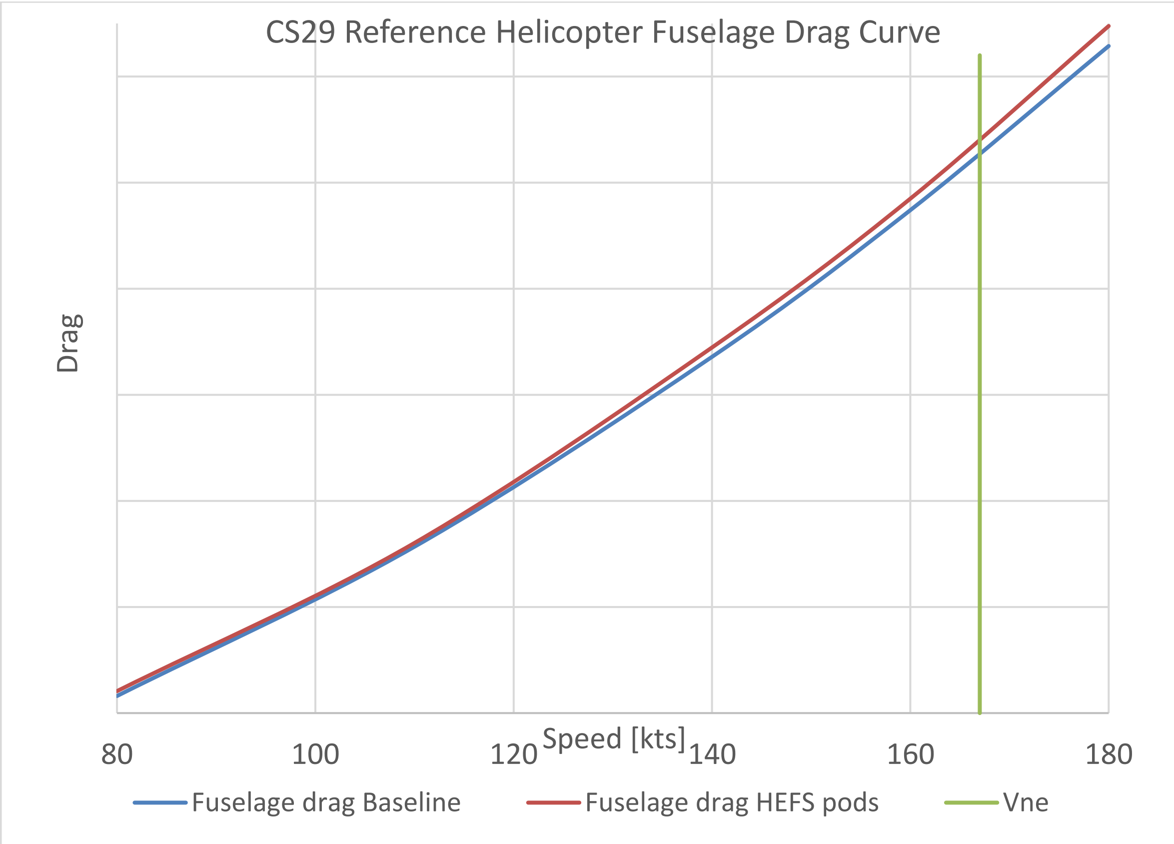


Figure 43 CS29 Reference Helicopter extrapolated fuselage drag curve, delta between baseline and retrofit

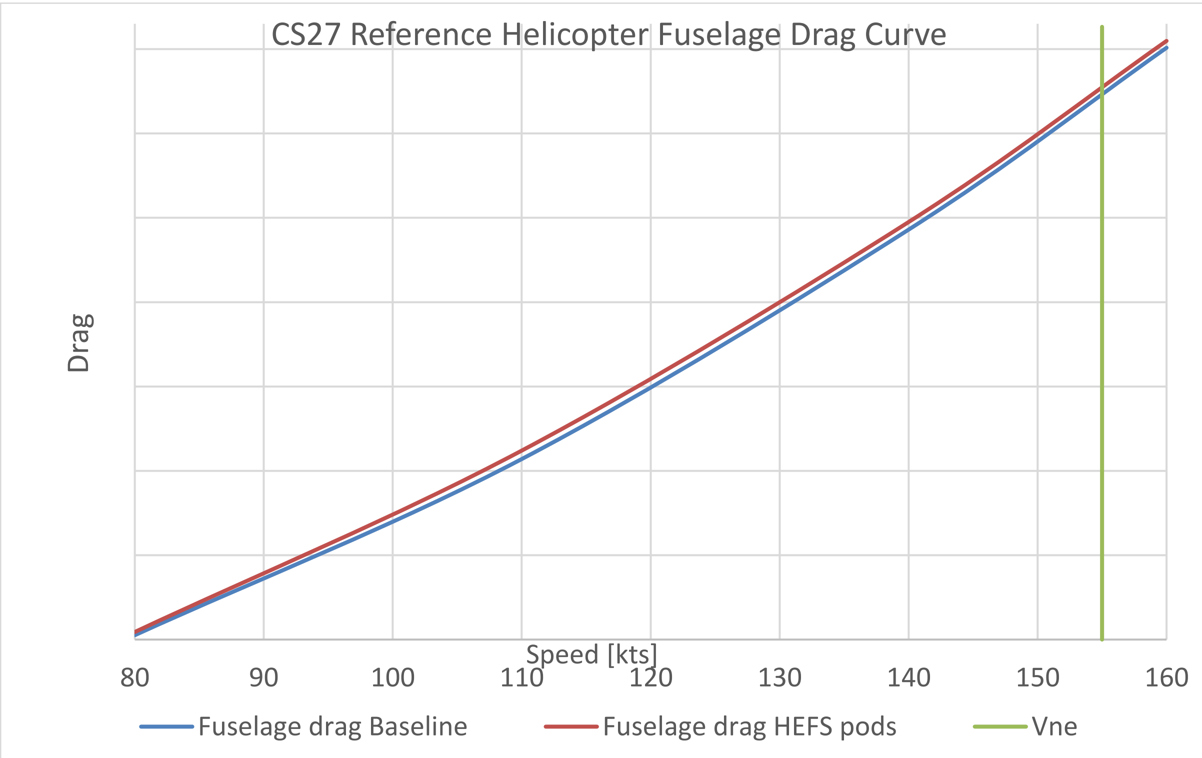


Figure 44 CS27 Cat A Reference Helicopter extrapolated fuselage drag curve, delta between baseline and retrofit

5.7 Conclusion

Based on the aerodynamic assessment, it can be concluded that it is not likely that the HEFS units will create disproportionate aerodynamic challenges to helicopter designers when directly taken into account in the design of newbuilt helicopters. When qualitatively comparing a HEFS retrofit scenario to existing offshore equipment, the aerodynamic impact of the HEFS installation is expected to be less intrusive than existing certified helicopter equipment such as the rescue hoist. Based on the results obtained in the study, retrofitting of HEFS pods for CS29 helicopters is considered feasible from an aerodynamic perspective. For CS27 Cat A helicopters it is foreseen that retrofitting HEFS will be more challenging considering minimization of aerodynamic impact due to the restricted physical design space which will likely result in blunt pod designs. The following recommendations have come forward:

- Potential disturbance of engine inlet flow has been identified to be helicopter-specific and should be assessed case by case (e.g. in the case that design constraints force a blunt pod design and the inlet is directly downstream of the pod)
- The magnitude of the impact on handling quality (stability) should be validated in flight tests for the final optimized pod design
- Optimization of the pod design from an aerodynamic perspective is recommended per helicopter type to minimize the impact

6. Overall Integration Aspects

6.1 Objective

The objective of the assessment of the overall integration aspects is to give consideration to the spectrum of potential issues associated with the integration of HEFS elements on a helicopter and other aspects relevant to their operation. Finally this assessment will lead to a fully argued position on whether the installation of a HEFS is likely to produce any significant challenges regarding overall usability where a distinction is made between retroactive installation of HEFS on the current CS29 and CS27 Cat A fleet and integration of HEFS in a new helicopter design.

6.2 Approach

In addressing the comprehensive integration aspects of the HEFS, the following aspects are taken into account:

1. **Design and Construction Issues:** This involves considerations such as the structural integration into the cowling and potential interaction with ancillary equipment or intakes/exhausts.
2. **Continued Functionality of Emergency Egress:** Ensuring the ongoing effectiveness of emergency egress is a crucial aspect in the overall integration process of the HEFS, which has been assessed for the reference helicopters.
3. **Maintenance and Continuing Airworthiness:** A pivotal focus in integration of the HEFS on current or future rotorcraft lies in minimizing the impact on routine maintenance activities on the rotorcraft. An approach is proposed to ensure minimal interference with existing maintenance practices, thereby safeguarding the continuing airworthiness of the aircraft.
4. **Cost-Effectiveness:** The assessment of the HEFS's cost-effectiveness involves a comparison of costs with a primary EFS program. Additionally, an estimation of the system weight is provided as part of the evaluation.

6.3 Design and Construction Issues

Issues related to design and construction of the HEFS are most challenging for retroactive installation of the HEFS in contrast to integrating HEFS into a new helicopter design. The main considerations related to the physical integration of the HEFS on an existing rotorcraft (retrofit), also taking into account aspects discussed in previous chapters, are identified a follows:

- HEFS should be installed in most ideal location for buoyancy (high up on cowling and forward)
- Existing inlets, outlets and ancillary equipment cannot be covered or obstructed
- The outer shape of the pod should be aerodynamically optimized
- Structural integration into the upper cowling region
- Egress routes should not be obstructed by inflated floats
- Vibration and shock spectrum should be evaluated
- Interference with fire zones should be evaluated

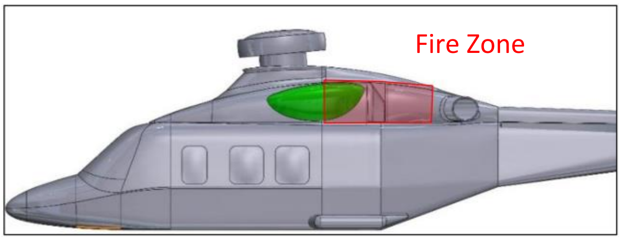


Figure 45 HEFS will likely have to be installed adjacent to dedicated fire zones

6.3.1 Structural Integration for Retroactive Installation

The structural integration solution for retroactive installation of the HEFS will differ per helicopter type. Depending on the specific helicopter, pods may have an internal support bracket (left of Figure 46). Inside the cowling an internal support structure could be designed for loads distribution. If the upper cowling of the rotorcraft has appropriate hard points, integration would be simplified as it would eliminate the need for an internal support structure.

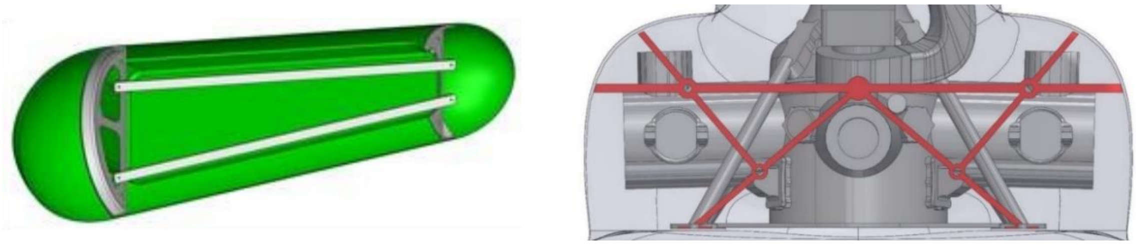


Figure 46 Internal pod support bracket (left), internal support structure inside cowling for pod attachements (right, aft looking forward)

6.3.2 Interference with Ancillary Equipment and Inlets/Outlets

For the reference helicopters, the HEFS pods were designed such as not to interfere with existing inlets/outlets. Figure 47 shows the reference helicopters with inflated floats (HEFS + EFS) including the most prevalent ancillary equipment typically installed on offshore helicopters in the viscinity of the floats, including for example the rescue hoist, antennas and bubble windows. It can be seen that the HEFS can be designed without interfering with existing ancillary equipment. A typical example is the lobe shape on the forward side of the HEFS floats, which eliminates interference with the rescue hoist whilst still bringing float capacity forward for favourable buoyancy.

6.3.3 Survey current CS29 and CS27 Cat A Fleet for Retrofit

Since the configurations of the CS29 and CS27 Cat A offshore fleets can vary significantly, a high level survey has been performed on the feasibility of retroactive installation of the HEFS on the current fleets. This survey has only take design and constructive issues into account, i.e. assessment on availability of physical space on the upper cowling in favourable location for the HEFS (high and forward mount). The main constraints are the provision of a rescue hoist, inlets, outlets, other ancillary equipment and the main rotor. The survey has pointed out that for the majority of the CS27 Cat A helicopters, retroactive installation of the HEFS is going to be very challenging with regards to physical space for integration. For the majority of the CS29 helicopters, likely retroactive installation of the pods will be feasible but still quite challenging.

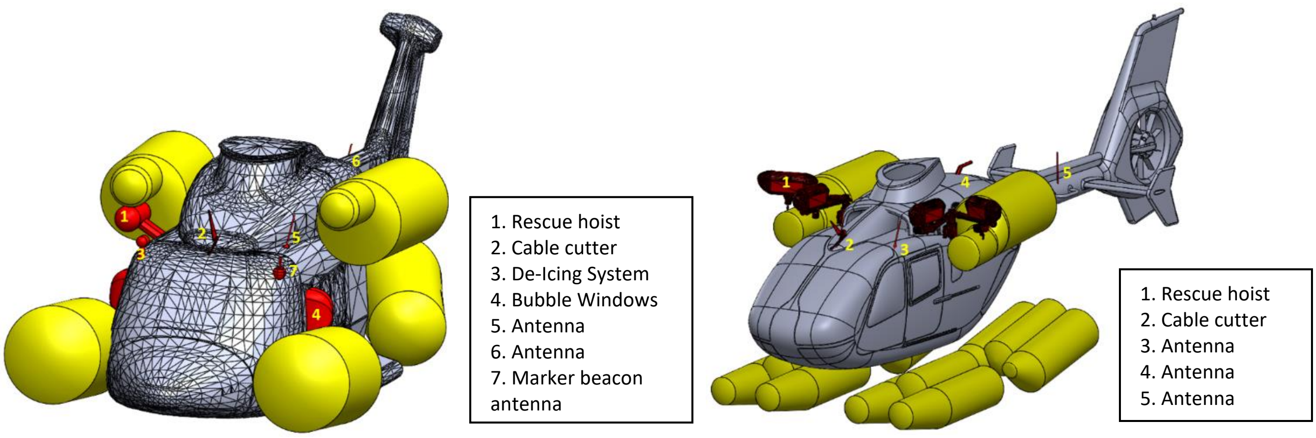


Figure 47 CS29 (left) and CS27 Cat A (right) reference helicopters - most prevalent offshore ancillary equipment

6.4 Continued Functionality of Emergency Egress

Verifying the continued functionality of emergency egress is a vital element in the integration process of the HEFS. Two main considerations are important:

- Distance of emergency egress handle[2] may not be too far under waterline
- Floats may not obstruct the emergency egress path

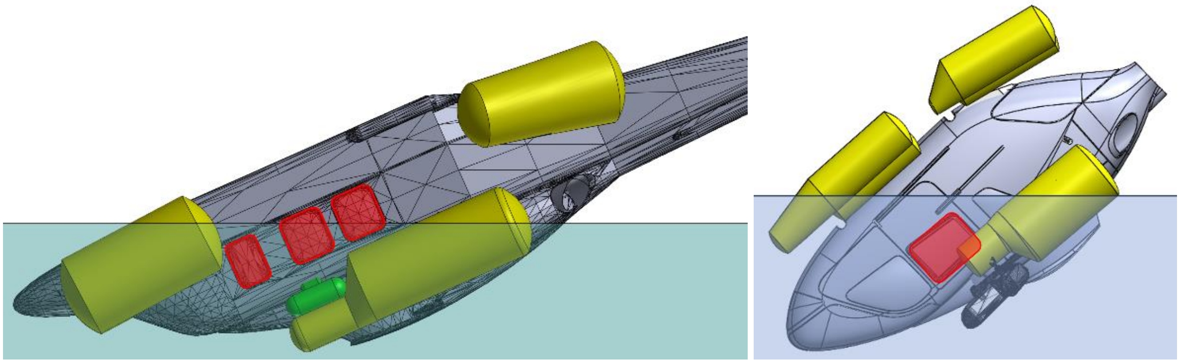


Figure 48 Capsized CS29 (left) and CS27 Cat A (right) reference helicopters with emergency exits shaded in red

These considerations have been assessed for the reference helicopters for various scenarios, including the fully inverted scenario with all floats intact Figure 48 and the damaged floats scenarios. The fully inverted CS29 reference helicopter has the forward-most emergency exit handle 20.4 cm under the waterline and all the remaining emergency exits are partially or fully above the water line and the floats are not obstructing the exit path, ensuring continued functionality of emergency egress. Also Figure 49 continued functionality of emergency egress is ensured. The fully inverted CS27 Cat A reference helicopter has the emergency exit handle 29cm. under the waterline and the floats are not obstructing the exit path. Note that for the CS27 Cat A reference helicopter no stable side floating positing was found. Float retention straps prevent the floats from deflecting towards the exits. For details on the results of all scenarios assessed, please refer to Annex G.

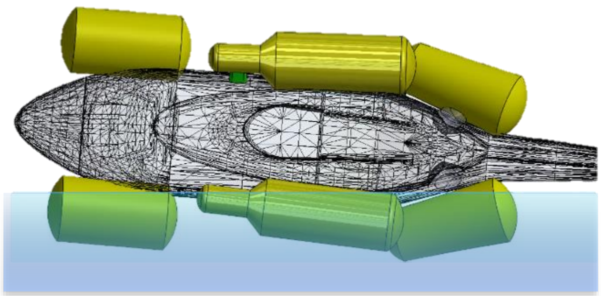


Figure 49 CS29 reference helicopter stable side float position ensuring continued functionality of emergency egress

6.5 Maintenance and Continuing Airworthiness

The main considerations related to maintenance aspects are the maintenance activities foreseen for the HEFS and also the impact of retroactive installation of HEFS on routine maintenance of other systems. Most maintenance tasks of the HEFS will be comparable to the tasks for the primary EFS. All maintenance tasks of the HEFS will be possible to be performed during scheduled maintenance intervals. Design and retention methods utilized on each platform may vary drastically, however the intent of the HEFS, is to limit the impact on routine maintenance actions and to have a removal / installation time that is comparable to or less than a

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[2] Emergency egress handles are typically located on the bottom edge of emergency exits (as seen from upright attitude)

standard EFS pod. It is anticipated that a HEFS can be designed for existing rotorcraft to avoid removal in order to perform routine daily maintenance on a CS29 rotorcraft however this design objective and may be considerably more challenging on a CS27 Cat A platform due to space restrictions. This requirement will be more feasible on newly developed rotorcraft.

6.6 Cost-Effectiveness

The cost-effectiveness of the HEFS is assessed by comparing various cost categories of a HEFS development program to a primary EFS development program as presented in Table 4. The cost comparison presented in Table 4 is visualized in the graph shown in Figure 50. A distinction has been made between cost categories: development cost, kit cost and maintenance cost. The following scenarios can be found in the columns of Table 4:

- *Baseline:* A helicopter undergoing a 'normal EFS' development program
- The added cost of HEFS when combining with a EFS program
- HEFS only program, which refers to a helicopter already having primary EFS installed, only receiving a retrofitted HEFS

	Baseline **Normal EFS Program**	**HEFS added cost in EFS + HEFS combined Program**	**HEFS only Program**
Project Cost	100 %	45 %	90 %
Kit Cost	100 %	102 %	118 %
Maintenance Cost	100 %	60 %	60 %
Fuel Consumption Cost CS29	100 %	0.1 %	100.1 %
Fuel Consumption Cost CS27 Cat A	100 %	0.6 %	< 100 %

Table 4 Cost comparison of HEFS program to primary EFS program

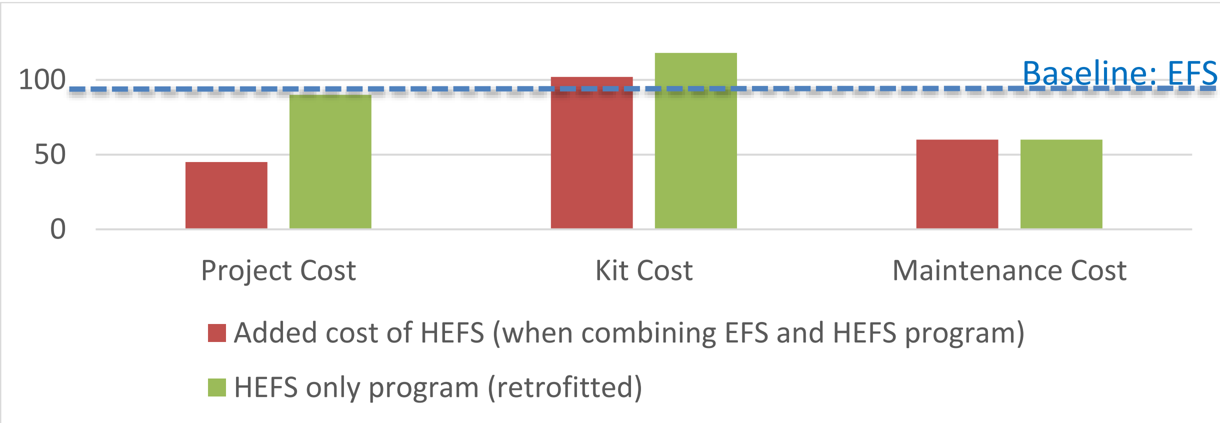

Figure 50 Cost comparison of HEFS program to primary EFS program

Note: this cost analysis is considering a baseline cost of the EFS not including any composite part, while the HEFS will need a pod and a cover of composite material.

The cost-effectiveness of designing and manufacturing a HEFS is more favourable when executed in conjunction with the development of a standard EFS, as opposed to introducing the HEFS independently through a retrofit on a helicopter already having a standard EFS installed. This is mainly because of the feasibility of conducting a unified flight test and certification campaign. Although the kit cost may see a slight elevation due to the integration of necessary structural provisions, maintenance costs are anticipated to be in proportion to those associated with a standard EFS pod.

In Table 5 a preliminary estimate of the HEFS weight is shown, which is subject to change depending on the final float and pod dimensions.

EASA CS27 Cat A & CS29 HEFS Estimated Weight		
Description	**CS27 Cat A Weight [kg]**	**CS29 Weight [kg]**
Float and Pod Assembly (2x)	22	26
Gas Reservoir Assembly (2x)	19	21
Installation Kit (no structural provisions at aircraft level)	8	8
TOTAL HEFS System Weight	**49 kg**	**55 kg**

Table 5 CS27 Cat A & CS29 HEFS Preliminary weight estimate

6.7 Conclusion

The HEFS can be designed such that obstruction of emergency egress routes is avoided, however it is important to design suitable retention methods to avoid deflection of the inflated floats once in contact with water. The survey has pointed out that for the majority of the CS27 Cat A helicopters, retroactive installation of the HEFS is going to be very challenging with regards to physical space for integration. For the majority of the CS29 helicopters, likely retroactive installation of the pods will be feasible but still quite challenging. Implementing HEFS directly into a new design is considered to be feasible for both CS27 Cat A helicopters and CS29. HEFS maintenance effort and intervals is expected similar to normal EFS maintenance.

7. Final Conclusion

The over-arching objective of this project was to provide insight into technical issues raised by the introduction of Emergency Flotation Systems units mounted high on the helicopter fuselage as well as to determine its technical and regulatory feasibility. The specific objectives of the project are listed below, which have been addressed by selecting two reference helicopters, considered sufficiently representative of the CS29 and CS27 Cat A fleet for the purpose of this research project.

I. To design a HEFS for each of the reference helicopters and demonstrate the feasibility of achieving an (improved) airpocket to increase occupant survivability.
II. To demonstrate that a HEFS deployment system can be designed such that requirements with respect to probability of inadvertent deployment and failure to deploy are reached.
III. To assess the heat conditions at the mount location of the HEFS, select materials for the system and demonstrate heat resistance of selected materials.
IV. To assess the aerodynamic impact of stowed HEFS in normal flight operations with emphasis on continuing airworthiness and potential cost penalties for operations.
V. To assess whether the implementation of HEFS will pose significant challenges with regards to overall useability and integration.

OVERALL PROJECT OBJECTIVES– FINAL CONCLUSIONS HEFS ON OFFSHORE FLEETS					
Description	**Retrofit CS29**	**Retrofit CS27 Cat A**	**New Design CS29**	**New Design CS27 Cat A**	**Remarks**
HEFS Design and Air Pocket	Feasible	Feasible	Feasible	Feasible	Tapered air pocket recommended, no stable side float position for CS27 Cat A ref. helicopter found.
Deployment Safety Aspect	Feasible	Feasible	Feasible	Feasible	Simple design with annunciation of active and failed states, reliability and availability targets are achievable.
Heat Resistance	Feasible	Feasible	Feasible	Feasible	Suitable combination of composite and float bag material found that can withstand the worst-case heat scenarios, optimization needed to improve thickness/weight ratio etc.
Aerodynamic Aspects	Feasible	Challenging	Feasible	Feasible	Need for sufficient physical design space on upper cowling for aerodynamic optimization of HEFS pod.
Overall Integration Aspects	Feasible with challenges	Challenging	Feasible	Feasible with challenges	Limited physical space for integration will pose challenges for retrofitting on specific CS27 Cat A helicopters.

Table 6 Project objectives summary of conclusions: retrofitting HEFS versus implementing HEFS in a new helicopter design

In conclusion, the research project has provided valuable insights into the technical and economical feasibility of HEFS for offshore helicopters, either retroactively installed or implemented into a new design. The revised tapered air pocket definition has enabled the design of a HEFS that ensures an adequate air pocket, enhancing occupant survivability in both CS27 Cat A and CS29 reference helicopters. Notably, the buoyancy analysis has pointed out that the CS27 Cat A reference helicopter with HEFS and EFS can achieve only a fully capsized attitude without stable side floating attitude, while the CS29 reference helicopter demonstrates stability in both side and fully capsized floating attitudes.

The research has pointed out that the development of a HEFS deployment system capable of meeting stringent requirements for the probability of inadvertent deployment and reliability is feasible. The calculated reliability aligns with the research project objective, addressing both the probability of failure to inflate and the probability of capsize during a defined exposure time.

Favorable results from preliminary endurance testing of industry-standard fabric and composite materials in heat conditions, indicates the capability of these materials to retain performance at elevated temperatures. Computational Fluid Dynamics (CFD) analyses suggest that HEFS installation can comply with relevant CS27 Cat A and CS29 requirements, with minimal effects on static stability, rate of climb, and fuel consumption. Also the impact of HEFS on inlet flow quality downstream of the HEFS is expected to be minimal with an aerodynamically optimized design.

A survey of the current CS27 Cat A offshore fleets highlights challenges in installing a retrofit HEFS on these helicopters, while retrofitting CS29 helicopters is deemed more feasible. Importantly, implementing HEFS directly into new designs is considered feasible for both CS27 Cat A and CS29 helicopters. Therefore, it is recommended to include the requirement for an airpocket scheme into future rulemaking for new helicopter designs both for the CS29 and CS27 Cat A. This research has shown that retroactive installation of HEFS on existing CS27 Cat A helicopters is very challenging while retroactive installation of HEFS on existing CS29 helicopters is considered feasible. For future rulemaking, it is adviced to take into account that the primary EFS system that might already be present on the rotorcraft is not generally designed to be loaded in capsized of side-floating attitude, therefore it would be important to re-evaluate the EFS functioning in parallel to HEFS. For both primary EFS and HEFS input on loads may be needed in future rulemaking. Furthermore, it is recommended that for further rulemaking EASA assesses the safety benefit to establish if retroactive installation of HEFS is justified for the current offshore fleet.

Based on the results of the research a number of proposals of changes to the Notice of Proposed Amendment 2016-01 by EASA (EASA, Notice of Proposed Amendment 2016-01 Helicopter ditching and water impact occupant survivability, 2016) can be made:

- **Air pocket size and shape**
  The original recommended air pocket size and elliptical shape required for each individual passenger as described in the NPA-2016-01 was not achievable for the chosen reference helicopters and HEFS design. A new air pocket size and shape is recommended, which has been defined based on a 95th percentile of male head dimensions. This air pocket has a tapered shape and the size still ensures increased occupant survivability as there is sufficient air within the volume to reduce the required breath hold time for egress of the helicopter and sufficient space beneath the air pocket to fit the occupant body. References to the air pocket size and shape in the NPA 2016-01 are made amongst others on p. 78 and p. 229.
- **Emergency exits (and opening handles)**
  The NPA 2016-01 advices to ensure that all emergency exits remain a significant portion above the water line after a survivable water impact and that the opening handles are not under an appreciable water depth. The research has shown that retroactive implementation of HEFS will – after a survivable

water impact - likely not ensure a stable side-floating position at all times for all helicopter types, neither will HEFS ensure all emergency exits to be a significant portion above the waterline in fully inverted attitude for each helicopter type. It is recommended to change the original NPA 2016-01 text in this case to focus more on the main functionality of the HEFS being to introduce an air pocket scheme to reduce the required breath hold time for egress. It should also be added that the emergency exit opening handles have to be either above the waterline or an acceptable depth below the waterline, which is possible to reach without having to dive underwater, both in upright and inverted attitude. It has been shown that this is feasible by retroactive implementation of HEFS. References to the emergency exit and opening handles location in the NPA 2016-01 are made on p. 78.

- **Side-floating helicopter scheme**
  The NPA 2016-01 refers multiple times to the ‘side-floating helicopter scheme’ or ‘side-floating attitude’. The research has shown that a stable side-floating attitude is not always ensured after retroactive implementation of HEFS. It is recommended to revise some (only when applicable) of the referrals to ‘side-floating helicopter scheme’ in the NPA2016-01, to e.g. ‘air pocket scheme’. The advantage of the HEFS comprises the introduction of an (improved) air pocket after capsize and an acceptable depth of emergency exit opening handles below the waterline or handles completely above the waterline. References to the side-floating helicopter scheme which may have to be adjusted in the NPA 2016-01 are made amongst others on p. 158, p. 159 and p. 207.

In summary, this research project underscores the potential for enhancing helicopter safety through the incorporation of a HEFS. The findings contribute valuable knowledge to the aviation industry, offering a pathway for improving occupant survivability in offshore helicopter operations, particularly in the challenging conditions often encountered in the offshore environment.

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