The International Journal of Energy & Engineering Sciences, 2024, 9 (1) 12-28
ISSN: 2602-294X - Gaziantep University

GENERAL PURPOSE FIREFIGHTER HELICOPTER ACCORDION MODEL WATER TANK

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ABSTRACT

In this article, a unique internal tank and water discharge system are studied for the Sikorsky S-70 model general-purpose helicopter. A CAD design, CFD, and static structural analyses are shown in simulated real-life cases. This alternative design has been proposed to encourage aerial fire extinguishing efforts by using a simpler system at a lower cost and to convert general-purpose helicopters into fire helicopters when necessary. The examination of test methodologies simulating real-life scenarios was conducted using Ansys Fluent and Ansys Static Structural. Research findings indicate that the integration of the new generation water tank within the cabin has resulted in substantial enhancements and has diversified aerial extinguishing capabilities by discharging 4469 Liters of water volume in 2.26 seconds. Moreover, the implementation of the accordion breakwater is expected to prevent sloshing, and the symmetrical discharge characteristic of the tank model will minimize the negative impact on helicopter balance.

Keywords: Design, Helicopter, Firefighting, Computational Fluid Dynamics, Analysis.

1. INTRODUCTION

Forest fires are considered among the natural disasters that are difficult to prevent. The negative impact of climate change is increasingly evident, and it can be observed in the increase in forest fires. Rising temperatures cause more forest fires in the Mediterranean and Aegean regions [1,2,3]. Governments are using many different methods to deal with this disaster. Fires are becoming more intense and can often only be controlled by aerial means [4]. This way is known as a very effective method, and sometimes it is the only option for suppressing fire [4]. However, the high cost of materials used in aviation, makes aerial extinguishing efforts more difficult [5,6]. Among the many alternative methods in the literature, bambi buckets, internal tanks, and belly tanks have been selected as the most used methods to compare with a new approach. This paper investigates and describes an aerial firefighting process with the use of a helicopter equipped with a new internal water tank.

In aerial firefighting operations, water is taken from the water source and filled into the fixed tank inside the helicopter, a retractable mechanism connected below the helicopter body or a water bucket hanging from the helicopter itself. By releasing water on the fire, it aims to provide the most effective intervention to the fire in the shortest time [6].

Bambi buckets are mechanisms that are suspended under the helicopter with a steel rope and receive water by immersion. This system is widely used, but it has problems in terms of getting stuck in obstacles, disrupting the weight balance of the helicopter, restricting airspeed, constant water volume, and operational difficulties. Flights at low speeds and a minimum safe altitude are a prerequisite for delivering more liquid per m^2. Performing a run-over flight to determine the fire characteristics, the location of ground crews, and obstacles endangering flight safety in the area is needed [7,8].

Inelastic internal tanks are inventions that are placed into the aircraft cabin and filled with water with the help of a snorkel pump or hydrostatic suction. This method is successful in terms of stability but brings the problem of variable volume, an obligation to cut helicopter cabins, and cost [9,10].

Belly tanks are structures mounted on the bottom of the helicopter, and their volume is around 3000 L. Variable volume needs, sloshing of the water, and a shorter life span are the problems of this invention.

In this study, an alternative way is proposed for today's applications with an accordion model of a tank placed inside the helicopter. Unlike the fixed volume tanks used in the helicopter cabin, it is aimed to provide an advantage in terms of ease of use by combining the fixed water tank and the accordion mechanism. By having portable and foldable mechanisms consisting of four parts, it can be assembled and ready for duty in approximately 15 minutes. With the help of Water Glide Paths 1 and 2, water is released in a linear form and reaches the ground at an optimum level **Figure 1.** In order to simulate water dumps, a multiphase flow sub-model such as VOF (Volume of Fluid) has been applied [10].

This study aims to create a helicopter tank design that can efficiently contain and release the highest volume of water in the shortest amount of time. The tank's design is carefully crafted for quick and easy installation onto the helicopter body. To ensure optimal performance, the system underwent rigorous analysis using ANSYS Fluent and ANSYS Static Structural.

2. MATERIALS AND METHOD

Aerial fire-fighting options are quite limited; however, helicopters and aircraft have been preferred for many years. Due to the high costs associated with real-life helicopter tests, researchers opted to explore potential water dumping patterns and investigate the application of Computational Fluid Dynamics (CFD) and Finite Element Methods[10]. In this model, water discharge characteristics and static stress analyses of the water tank were discussed. ANSYS Fluent analyses were performed to determine the discharge duration and static structural analyses were utilized to evaluate load distribution on the tank walls. In order to minimize the discharge time and ensure homogeneity, the tank base has been designed as a triangle, and triangular height optimization has been made. The Volume of Fluid (VOF) simulation model has been used to observe the characteristics of water dumping and tank dimensions set at 3130 mm x 1500 mm x 1200 mm. A linear fluent CFD model has been used as a mesh solver and the element size kept as 12mm. In the static analyses section, the water-filled tank was treated as stationary with forces represented by gravitational acceleration force and hydrostatic water pressure.

2.1. CONCEPTUAL DESIGN

The system is designed as an in-cabin water tank placed inside the Sikorsky S-70 model helicopter cabin. The model consists of 4 main parts that can be assembled together: 1) Main Tank, 2) Main Chassis, 3) Glide Path-1, 4) Glide Path-2 as shown in **Figure 1**. Parts and dimensions of the system are designed to fit into the cabin and encircle the helicopter body appropriately as in **Figure 2.** The upper part of the Main Tank consists of a foldable accordion mechanism which is hermetically connected to the lower part of the tank. Connection ports positioned at the top end of the flexible tank are connected to the Main Chassis at the beginning of the operation. These ports allow the Main Tank to stand upright and provide the advantage of variable volume. Glide Paths go out from both sides of the helicopter cabin doors and connect to the outer base of the helicopter body. During the operation helicopter flies with its doors open and discharges the water by opening the dumping doors at the desired point. The filling operation is held from the required water source by using a snorkel pump. The bottom floor of the tank was designed considering the hydrostatic force and gravity. The optimization scheme for the triangular prism shape and dimensions are given below. The tank structure which aims to accelerate the flow prevents lateral forces by sitting on a second triangular prism geometry on the Main Chassis (Figure 3).

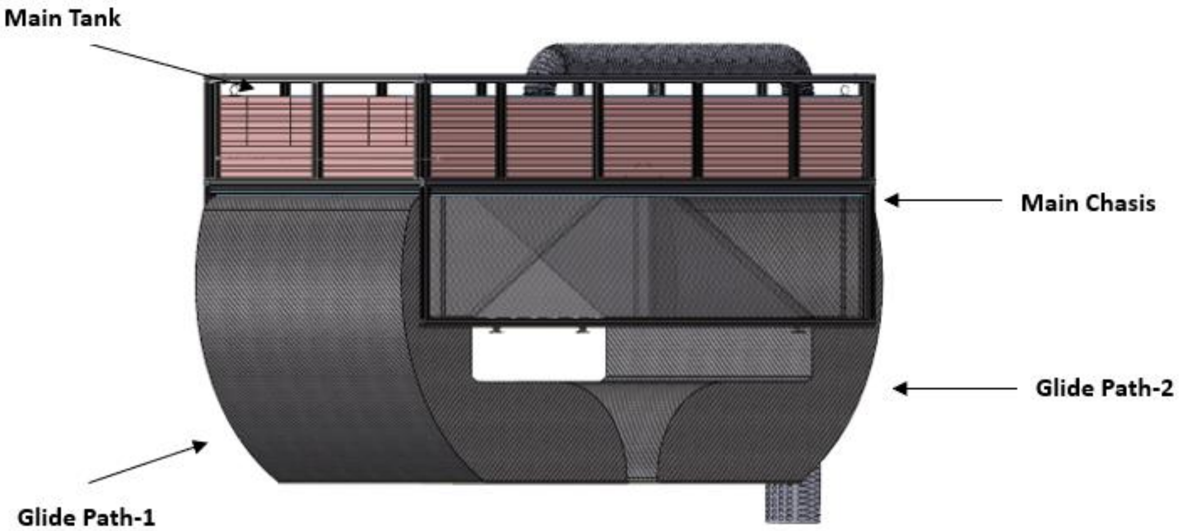
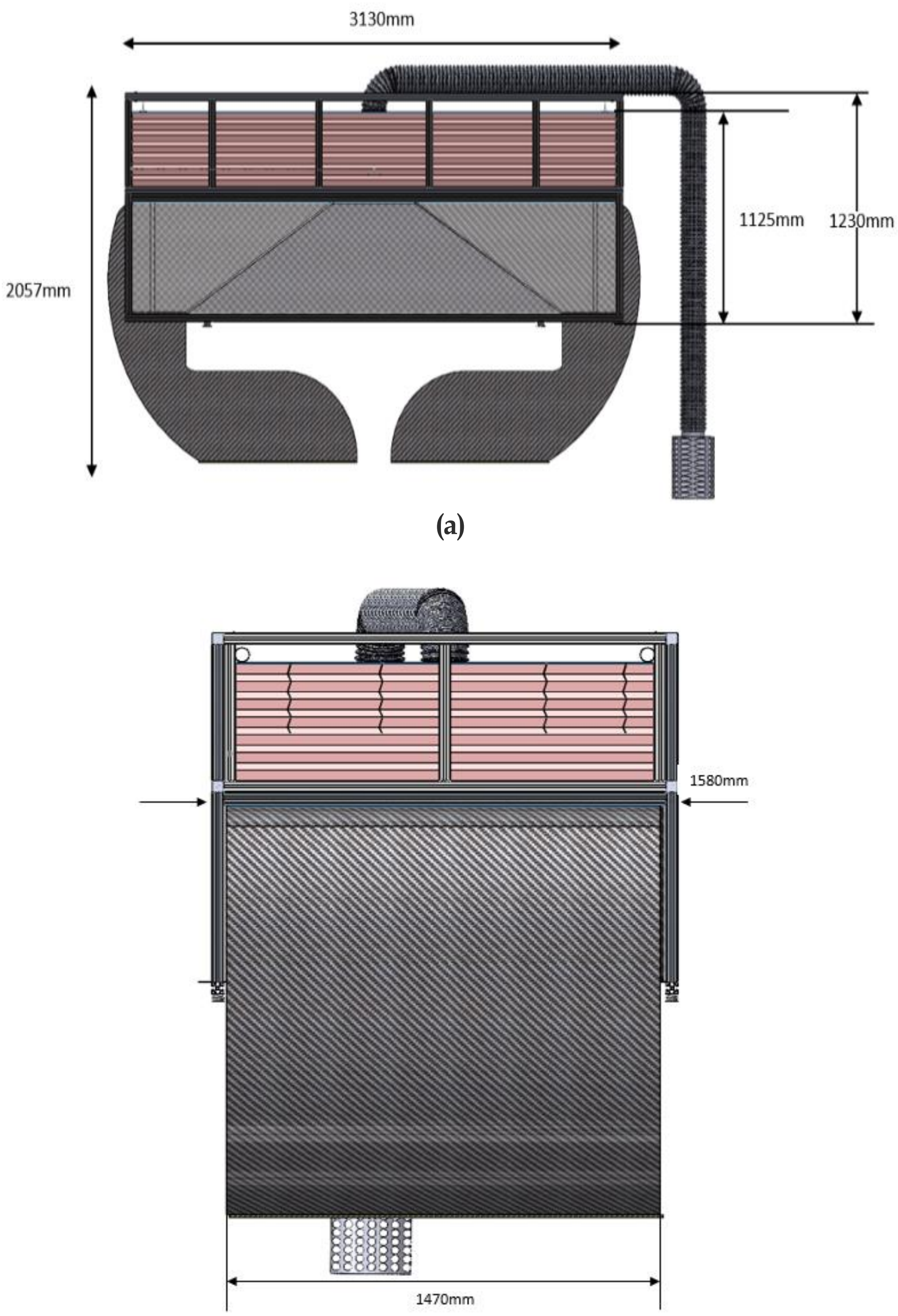


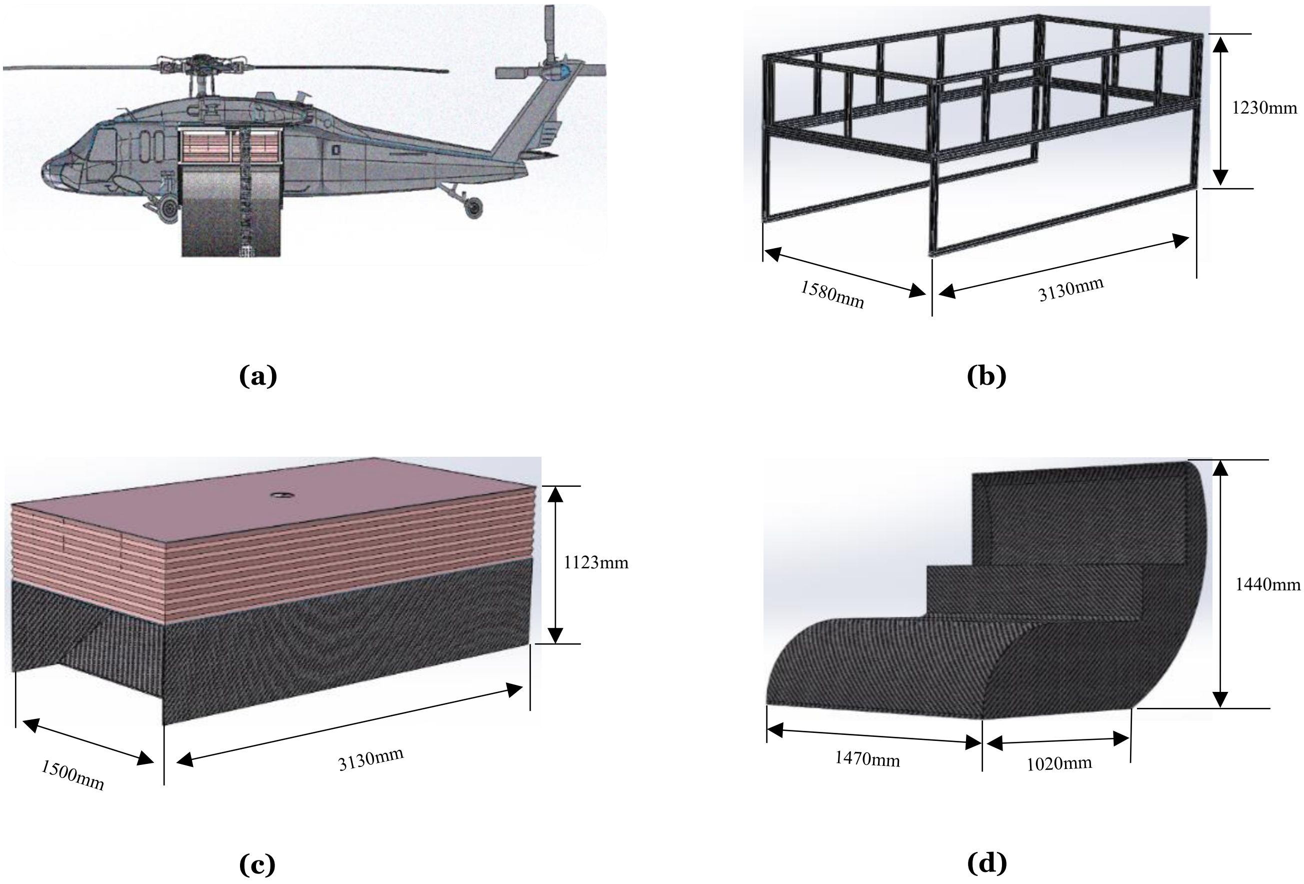
Fig. 1 Main parts of the designed system



(a)

(b)

Fig. 2 a) Dimensions of the system-1 **b)** Dimensions of the system-2



(a) **(b)** **(c)** **(d)**

Fig. 3 a) General View **b)** Main Chassis **c)** Main Tank **d)** Glide Path

2.2 TWO DIMENSIONAL CFD MODEL AND CASES

The primary objective of this study is to expedite the drainage process of a water tank. Roya Shademanis's research delves into fluid flow characteristics around a triangular obstacle [11]. With the help of this study, a triangular tank base was designed to decrease discharge time by following the undisturbed flow line. Following this approach, the height of the isosceles triangle representing the tank bottom was analyzed at 300 mm, 610 mm, and 800 mm. The results of these analyses are presented in **Table 1.** Between three different triangle heights, the 800 mm model provided the fastest flow time, and it was determined as the primary criterion for the final design (Figure 4).

$$Re = \frac{\rho v_s d}{\mu} = \frac{v_s}{v} \tag{1}$$

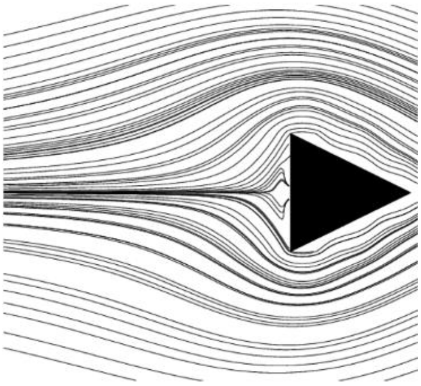


Fig. 4 Flow Past a Triangular Cylinder From Roya Shademani's Research [11]

The analyses reveal variations in flow times based on different height parameters. A decrease of 80.58% was found in flow times between the heights of 800 mm and 300 mm. Among the triangular profiles, the shortest flow time of 1.39 seconds was recorded at the height of 800 mm. As the height (h) increases, there is a corresponding increase in lateral forces on the water surface resulting in higher flow velocity. The flow profile of the triangular tank model is in agreement with the previous research findings. At the small Reynolds numbers such as Re=1.4, the air stream flows smoothly past the triangular obstacle with no separation as in **Figure 5, 6**. In the tank geometry with a similar triangular design, water flowed around the triangular profile without any observed instances of breakage or flow separation.

Table 1. (Triangle height optimization-water dumping duration)

Analyse Name	Turbulent Model	Height of 'h' (mm)	Data Sampling	Time Step Size (s)	Number of Time Step	Flow Time (s)	Total Water Volume (L)
Case-0	SST k-ε	0	OFF	0.0025	2000	5	5634
Case-1	SST k-ε	300	OFF	0.0025	1004	2.51	5182
Case-2	SST k-ε	610	OFF	0.0025	713	1.78	4569
Case-3	SST k-ε	800	OFF	0.0025	559	1.39	4270
Case-4 Completed	SST k-ε	800	OFF	0.0025	907	2.26	4469

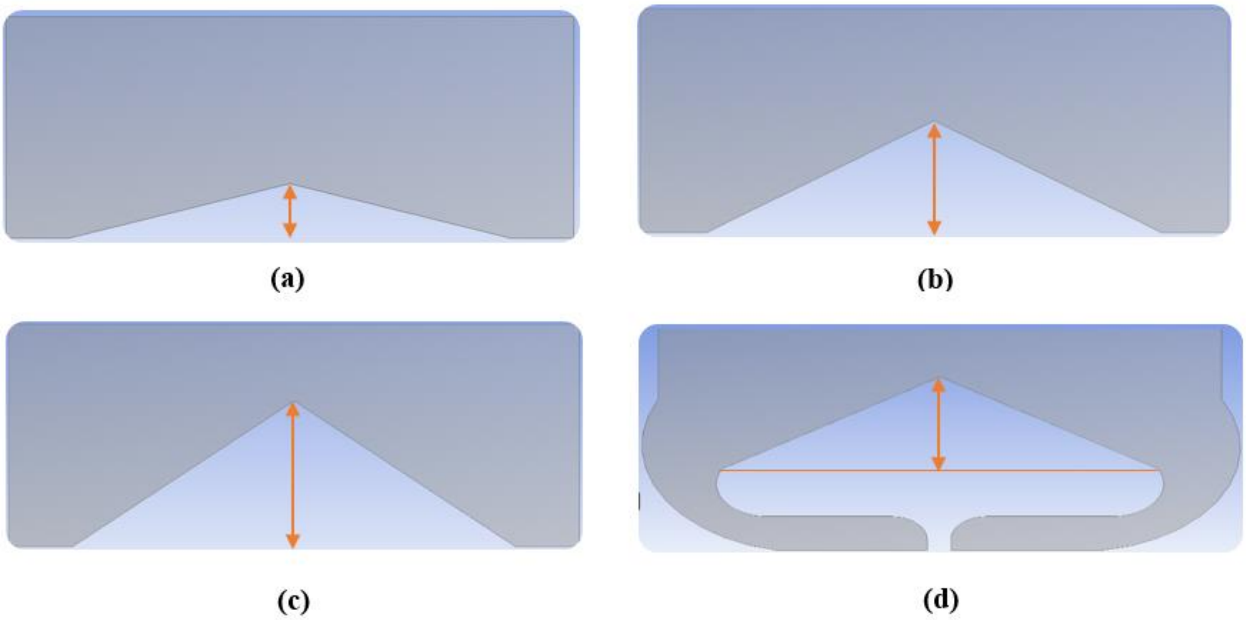
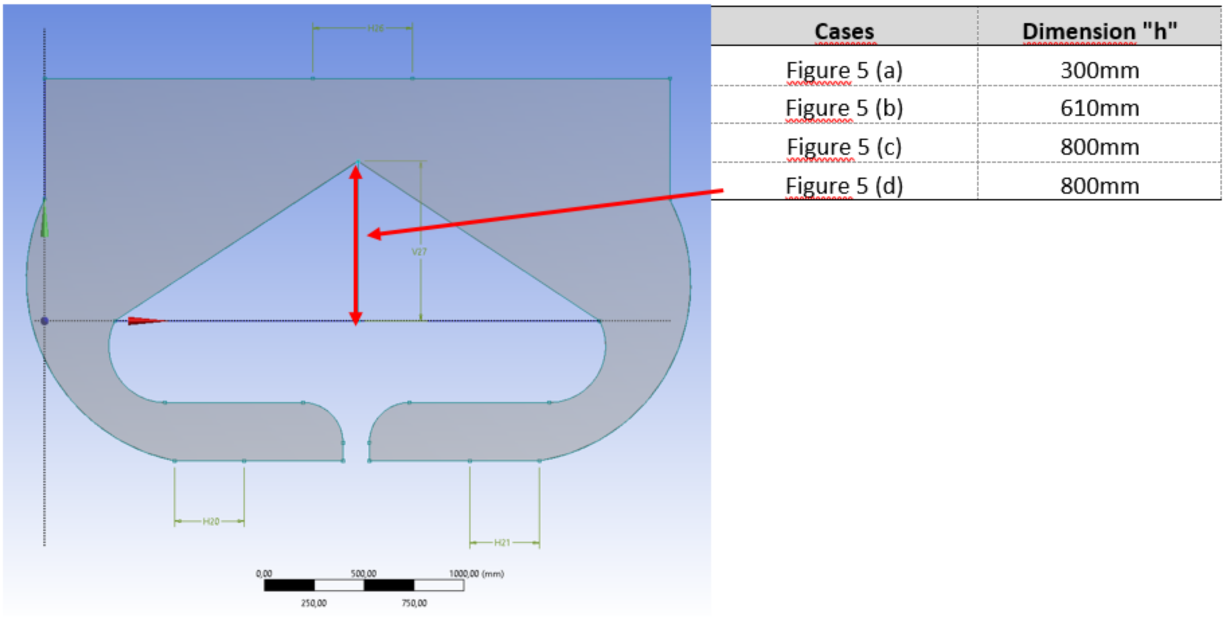


Fig. 5 a) Case-1 **b)** Case-2 **c)** Case-3 **d)** Case-4-Completed



Cases	Dimension "h"
Figure 5 (a)	300mm
Figure 5 (b)	610mm
Figure 5 (c)	800mm
Figure 5 (d)	800mm

Fig. 6 "h" Height of the Case-4-Completed

2.3 THREE DIMENSIONAL CFD MODEL

The water tank located within the helicopter cabin extends out beyond the cabin doors for water drainage **Figure 7 (b)**. In this scenario, it is necessary for the helicopter to operate with its cabin doors open. The external surface of the tank interacts with the surrounding air and generating a negative friction force. To substantiate this phenomenon, an analysis was conducted on representative helicopter geometry in two scenarios: with and without a water tank. The numerical findings present the disparity

between the friction and lift forces obtained in the analysis. Moreover, photographic evidence illustrates the variations in airflow resulting from the separate analyses.
As a result of the analyses, different values emerged, and these values were compared with each other. In the analysis performed without the water tank, the entire body was exposed to the following forces through X, Y, and Z directions: **X: 140.317 [N]**, **Y: -5101.42 [N],** and **Z: -3368.5 [N]**. In the analysis made by adding the tank, the entire body was exposed to these forces. **X: -14131.8 [N]**, **Y: 7269.82 [N],** and **Z: -68883.2 [N]** **Table 2.** When comparing the results, it was observed that the presence of a water tank resulted in a negative increase in the X and Z directions. Additionally, it generated a positive lift force in the Y direction, changing it from negative to positive. The addition of the water tank had a negative impact on the drag force, while the lift force showed a positive increase.

Table 2. (Forces acting on helicopter body with-without water tank)

Without Tank	With Tank
X: 140.317 [N]	X: - 14131.8 [N]
Y: -5101.42 [N]	Y: 7269.82 [N]
Z: -3368.5 [N]	Z: -68883.2 [N]

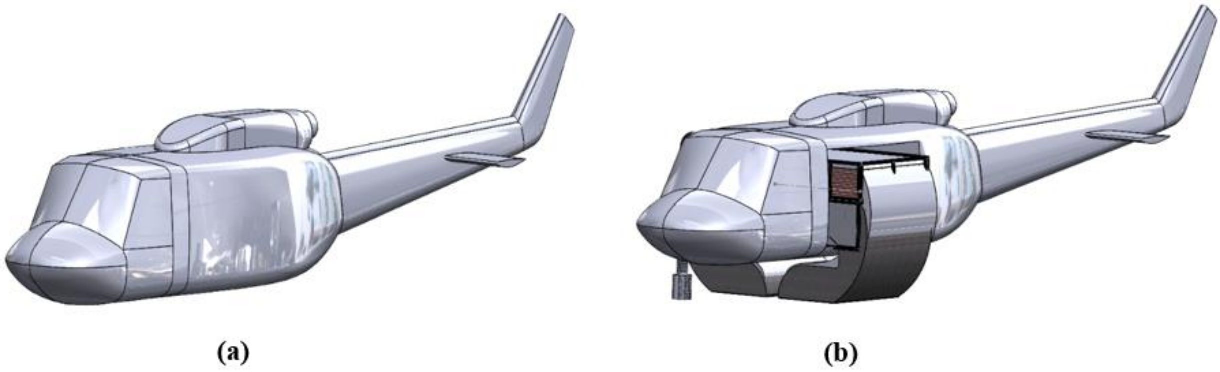
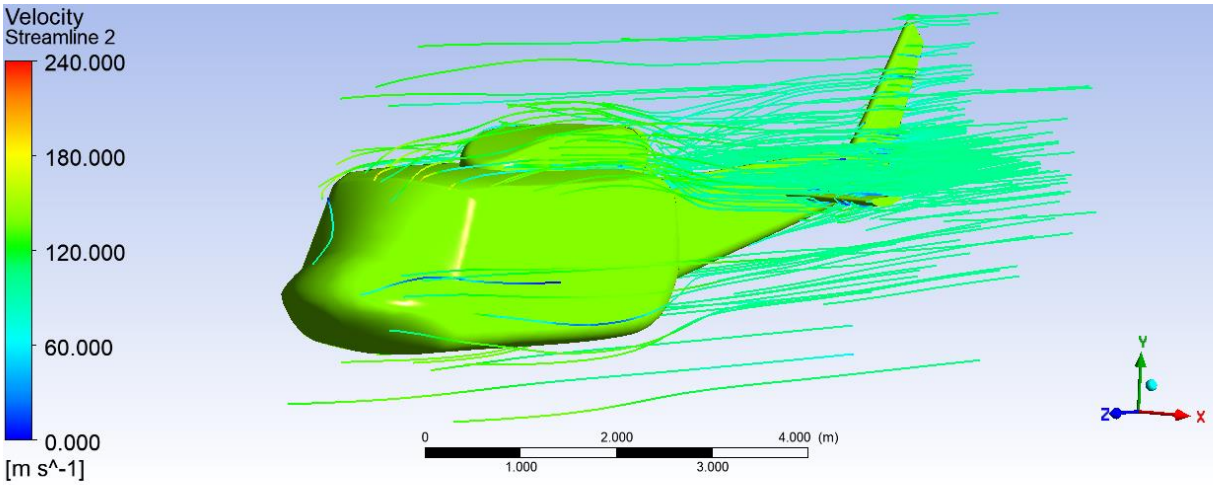
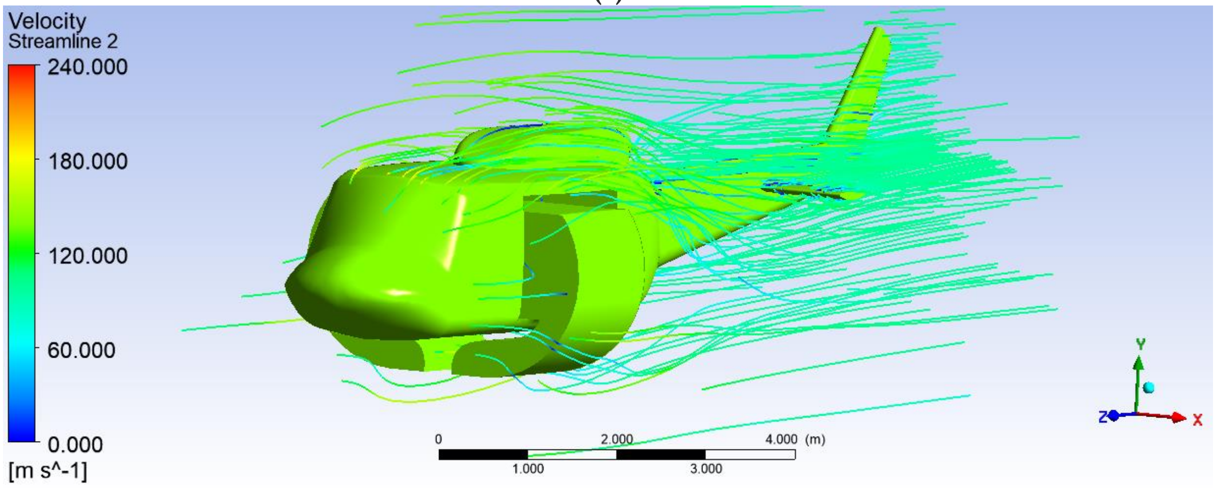


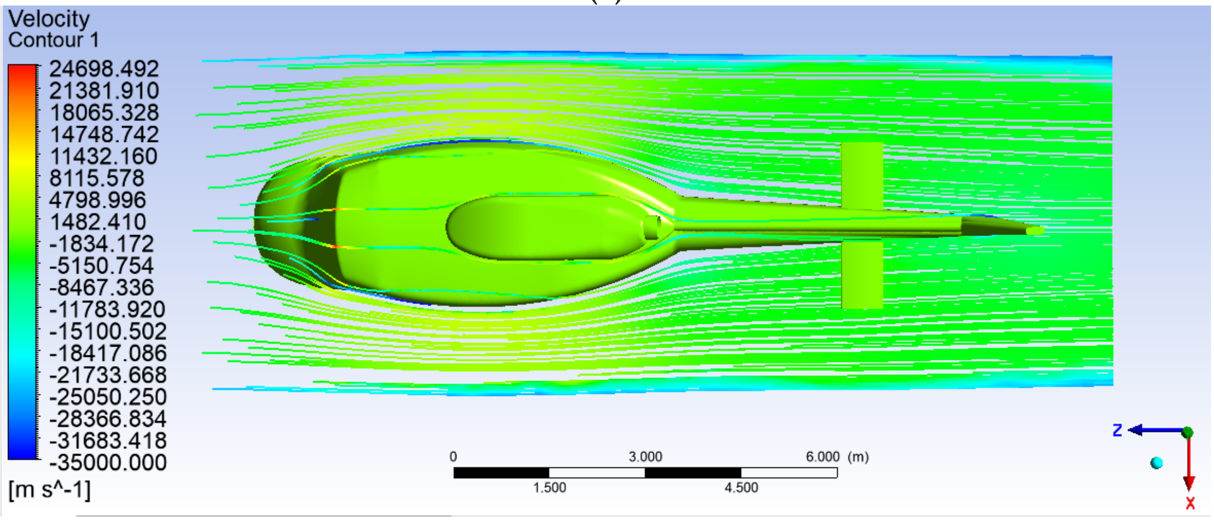
Fig. 7 a) Helicopter Model Without Water Tank **b)** Helicopter Model With Water Tank


Velocity
Streamline 2
240.000
180.000
120.000
60.000
0.000
[m s^-1]
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

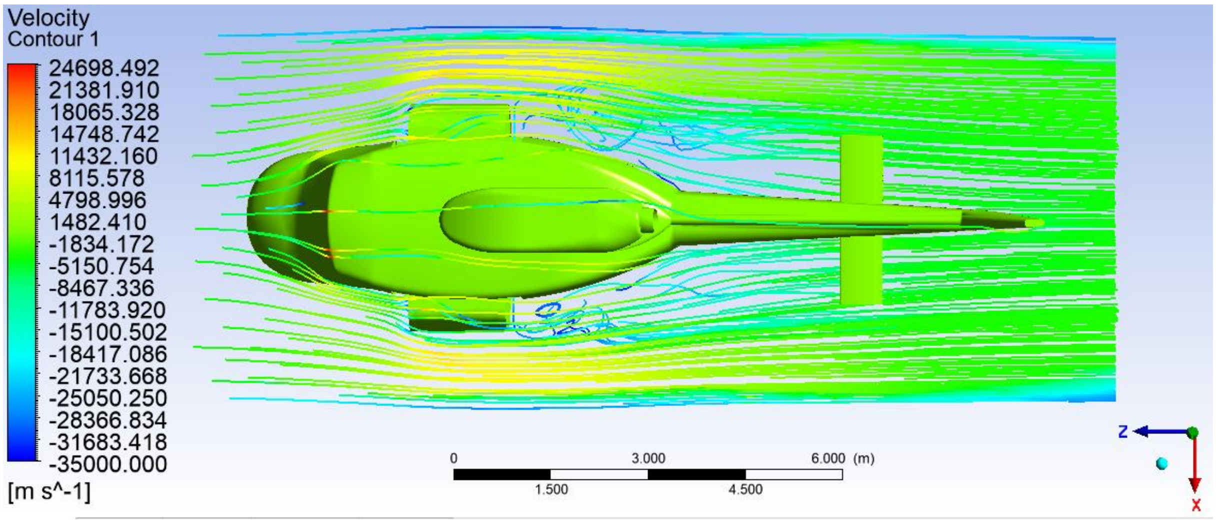
(a)


Velocity
Streamline 2
240.000
180.000
120.000
60.000
0.000
[m s^-1]
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

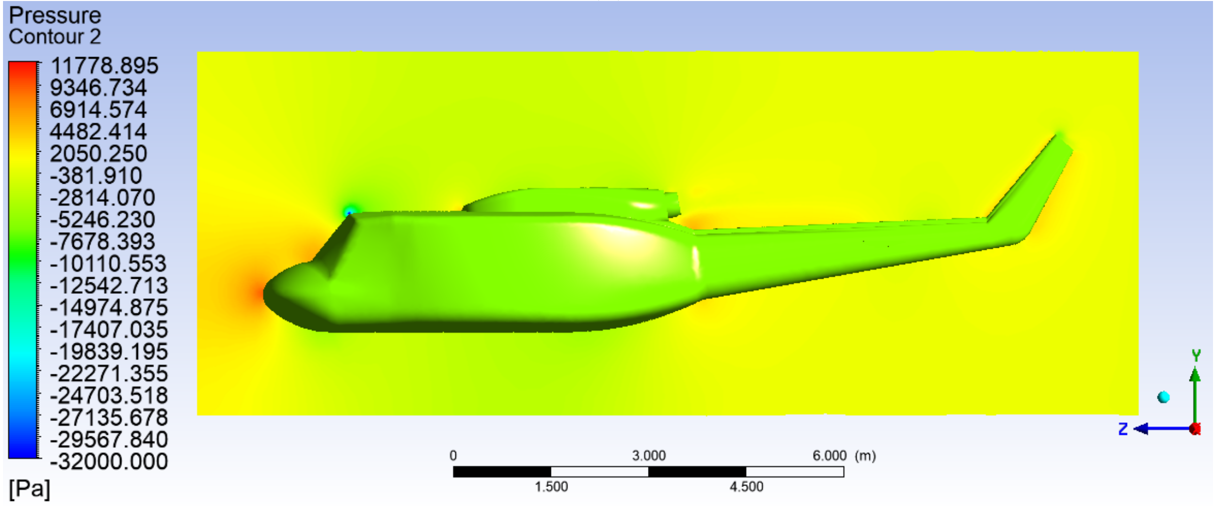
(b)


Velocity
Contour 1
24698.492
21381.910
18065.328
14748.742
11432.160
8115.578
4798.996
1482.410
-1834.172
-5150.754
-8467.336
-11783.920
-15100.502
-18417.086
-21733.668
-25050.250
-28366.834
-31683.418
-35000.000
[m s^-1]
0
3.000
6.000 (m)
1.500
4.500
Z
X

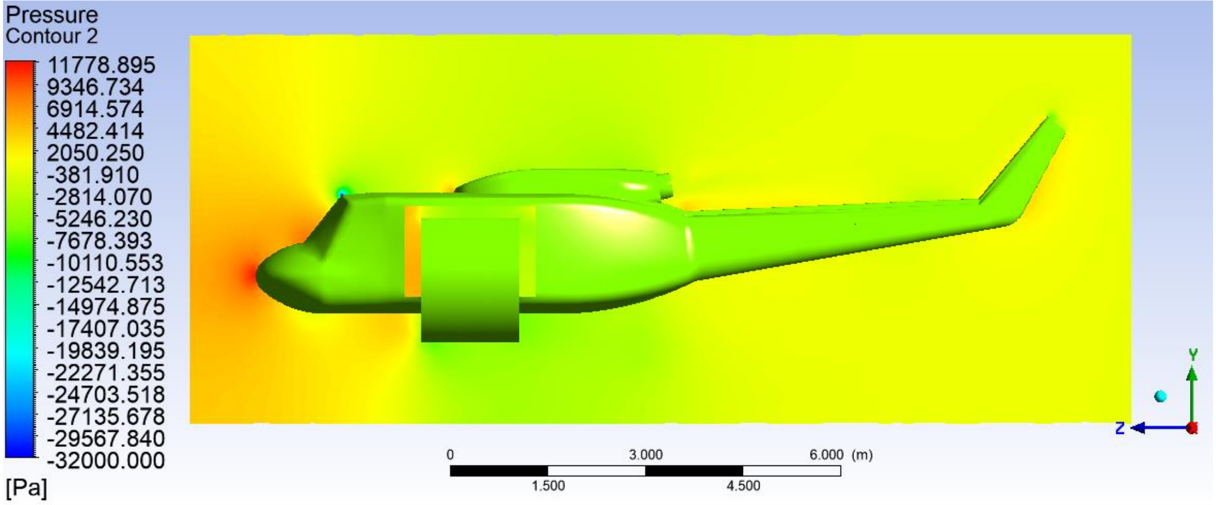
(c)


Velocity
Contour 1
24698.492
21381.910
18065.328
14748.742
11432.160
8115.578
4798.996
1482.410
-1834.172
-5150.754
-8467.336
-11783.920
-15100.502
-18417.086
-21733.668
-25050.250
-28366.834
-31683.418
-35000.000
[m s^-1]
0
3.000
6.000 (m)
1.500
4.500
Z
X

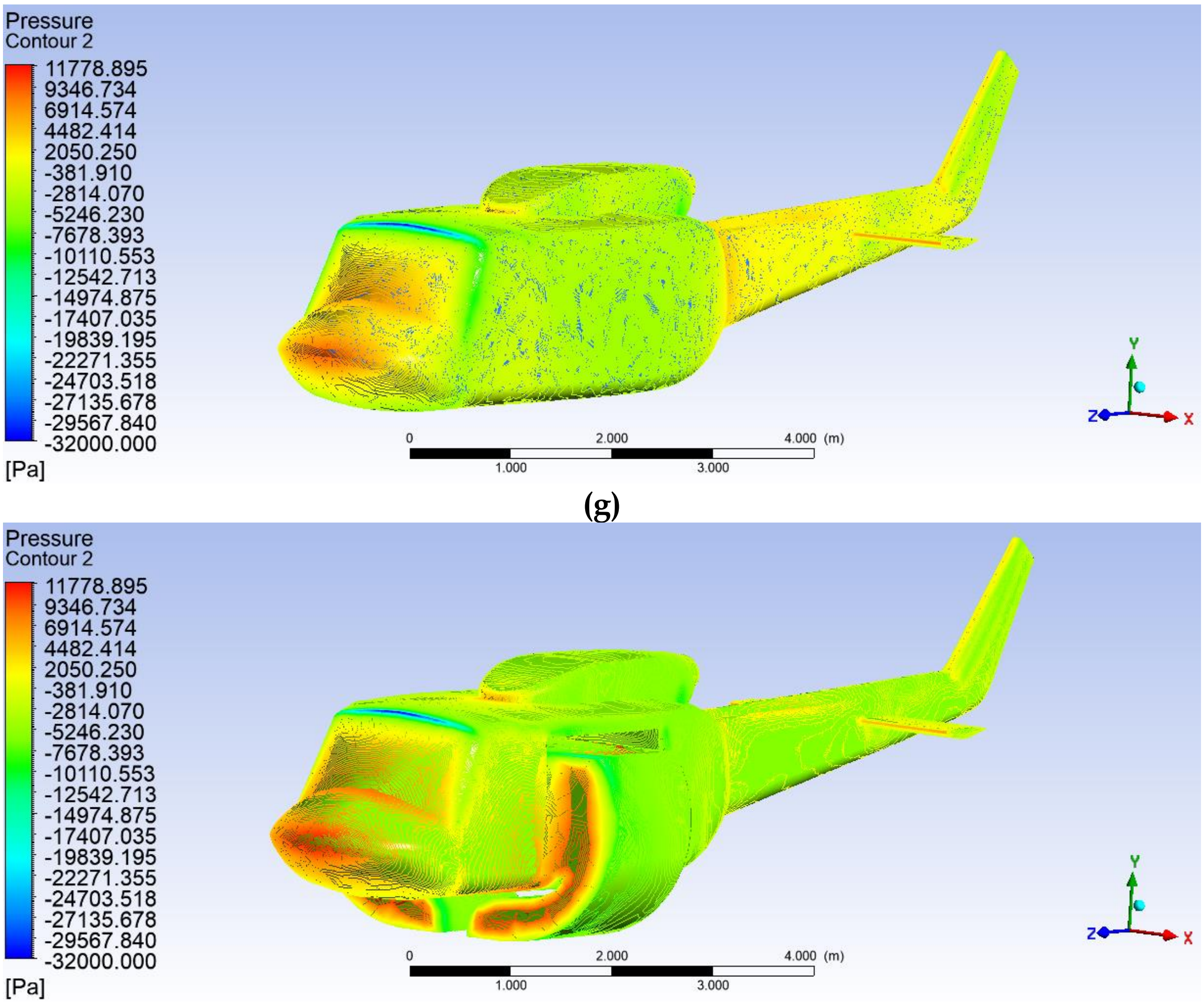
(d)


Pressure
Contour 2
11778.895
9346.734
6914.574
4482.414
2050.250
-381.910
-2814.070
-5246.230
-7678.393
-10110.553
-12542.713
-14974.875
-17407.035
-19839.195
-22271.355
-24703.518
-27135.678
-29567.840
-32000.000
[Pa]
0
3.000
6.000 (m)
1.500
4.500
Y
Z

(e)


Pressure
Contour 2
11778.895
9346.734
6914.574
4482.414
2050.250
-381.910
-2814.070
-5246.230
-7678.393
-10110.553
-12542.713
-14974.875
-17407.035
-19839.195
-22271.355
-24703.518
-27135.678
-29567.840
-32000.000
[Pa]
0
3.000
6.000 (m)
1.500
4.500
Y
Z

(f)



(g)

(h)

Figure 8 a) Velocity Streamline-1, **b)** Velocity Streamline-2, **c)** Velocity Streamline-3 **d)** Velocity Streamline-4 **e)** Pressure Contour Plane-1, **f)** Pressure Contour Plane-2 **g)** Pressure Contour Body-1 **h)** Pressure Contour Body-2

The addition of tank geometry to the helicopter has been observed to induce variations in the airflow patterns and flow velocity. The tests were conducted with and without water tanks under identical parameters. The input parameter was specified as the free flow speed of 100 m/s (360 km/h), which corresponds to the maximum speed of the Sikorsky S70 model general-purpose helicopter. Streamlined and contour images were obtained from the analysis as in **Figure 8**.

The images illustrate the helicopter body and external areas of the Glide Path 1-2 that come into contact with free airflow in **Figure 8 (a,b) and Figure 8 (b,c).** This affects an alteration in airflow direction on the faces touched by Glide Paths. The analysis revealed deceleration and alterations in the direction of the free airflow upon contact. Additionally, the airflow in contact with the tank surface showed a distorted turbulent flow in the area behind the object and changes in airflow velocity. Based on the images, it can be said that the tank geometry negatively distorted the smooth airflow. However, to reach a definitive decision and get more consistent results, more detailed analyses should be made by optimizing the geometry.

Figure 8 (e,f) and Figure 8 (g,h) illustrate the pressure contour distribution on various surface areas of the tank geometry integrated into the cabin. Significant pressure differences are observed across different surfaces of the tank, with the most notable variations concentrated on the Glide Path 1-2, which is located outside the helicopter body. This effect, resulting from the increased surface area exposed to the air, may negatively impact helicopter acceleration and increase stress on the components. However, more detailed analyses are necessary to reach a definitive conclusion and assess the risk posed by these acting loads. To mitigate these pressure differences, optimization of the aerodynamic structure of the tank shape is recommended.

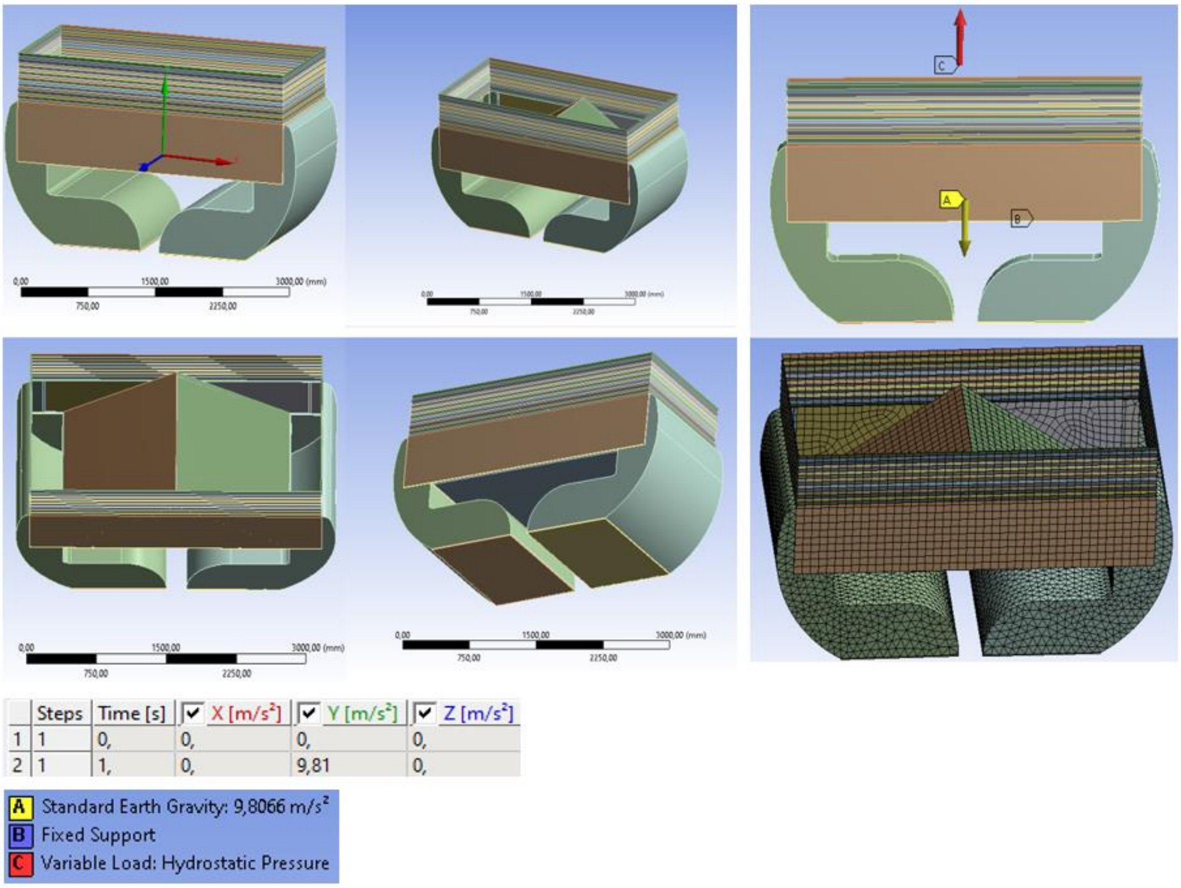
2.3 STATIC STRUCTURAL ANALYSES

The tank material was chosen as epoxy carbon woven, and a static structural test was carried out when the tank was filled with water. **Figure 9.** Applied forces were selected as gravitational force and hydrostatic pressure. Faces were chosen separately in these two analyses and the deformation behavior of the Water Tank was shown in **Figure 10**. Total deformation and equivalent stress values are examined and results are listed in **Table 3.**

Table 3. (Static Structural deformations)

Deformations	**Upper Tank Body**	**Lower Tank Body**
Total Deformation	2.7951 mm	8.0106 mm
Directional Def X-Axis	1.5902 mm	5.0627 mm
Directional Def Y-Axis	1.3124 mm	2.0392 mm
Equivalent Stress State	19.158 MPa	34.877 Mpa

Epoxy carbon woven tank was analyzed under static loads. Due to gravitational force and hydrostatic pressure, axial and bending types of stresses take place on 'Main Tank' and 'Glide Path 1-2'. This stress condition creates elongation in the X-Y direction and stress distribution on the tank walls. The highest amount of elongation and stress results were found as **8.0106 mm** in the total deformation state and **34.877 Mpa** in the equivalent stress state. Previous studies have confirmed that this amount of elongation remains within the normal limits of material property [12,13]. Another research also shows the material behavior of epoxy carbon woven (230 Gpa) Wet under similar stress conditions is quite reliable [12,13]. The detailed results are also listed in **Table 3.**



	Steps	Time [s]	☑ X [m/s²]	☑ Y [m/s²]	☑ Z [m/s²]
1	1	0,	0,	0,	0,
2	1	1,	0,	9,81	0,

A Standard Earth Gravity: 9,8066 m/s²
B Fixed Support
C Variable Load: Hydrostatic Pressure

Fig. 9 Static Structural Test Setup

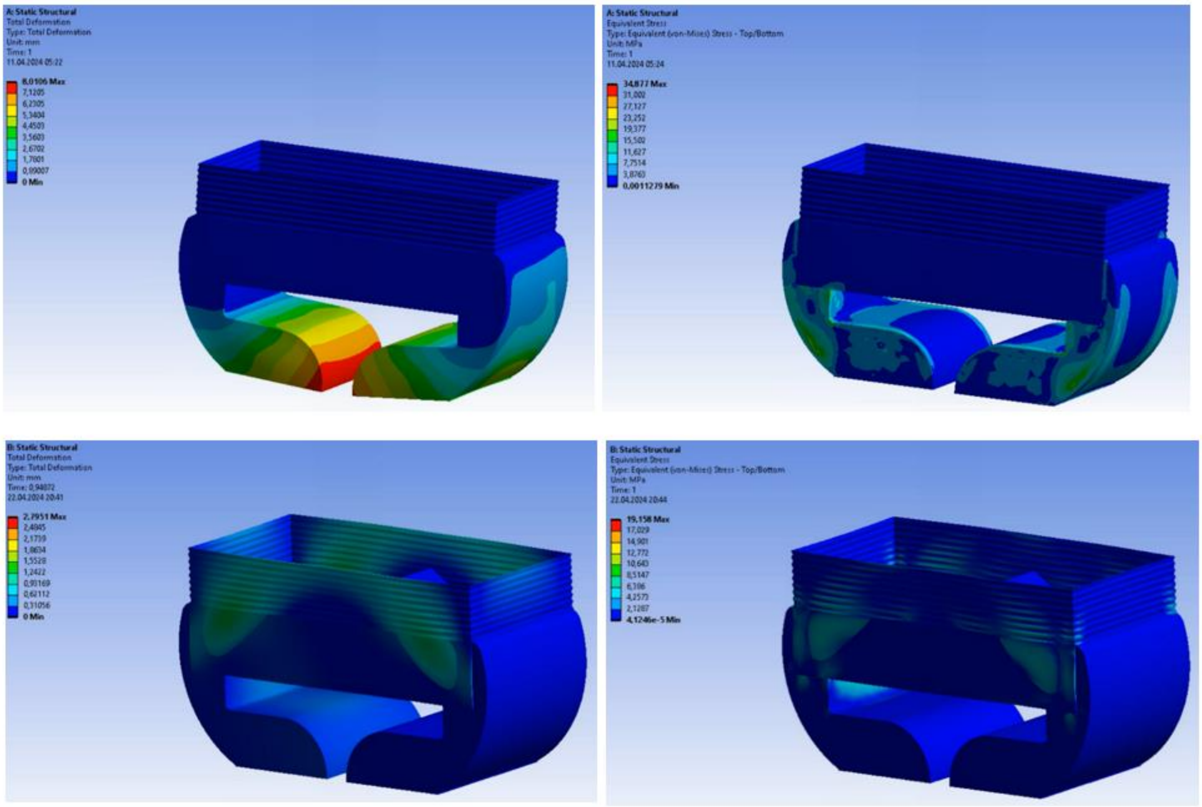


Fig. 10 Static Structural Results

2.4 SLOSHING ANALYSES

The phenomenon of water sloshing can destabilize the helicopter during flight and this may induce oscillation that poses a notable safety concern. In this study, the potential sloshing profile during the flight was simulated by applying a variable force along the X-axis. Analysis revealed that the sloshing was more pronounced on the upper surface of the water. To mitigate this effect and minimize sloshing, an Accordion Breakwater structure was considered in **Figure 11**. This new system of breakwater is designed to prevent the oscillatory movement of water by segmenting the tank volume into multiple compartments. Every breakwater line includes perforations to reduce agitation and facilitate the passage of water between the partitions. Consequently, the breakwater structure within the tank is strategically positioned in the upper region of the accordion mechanism (Figure 12).

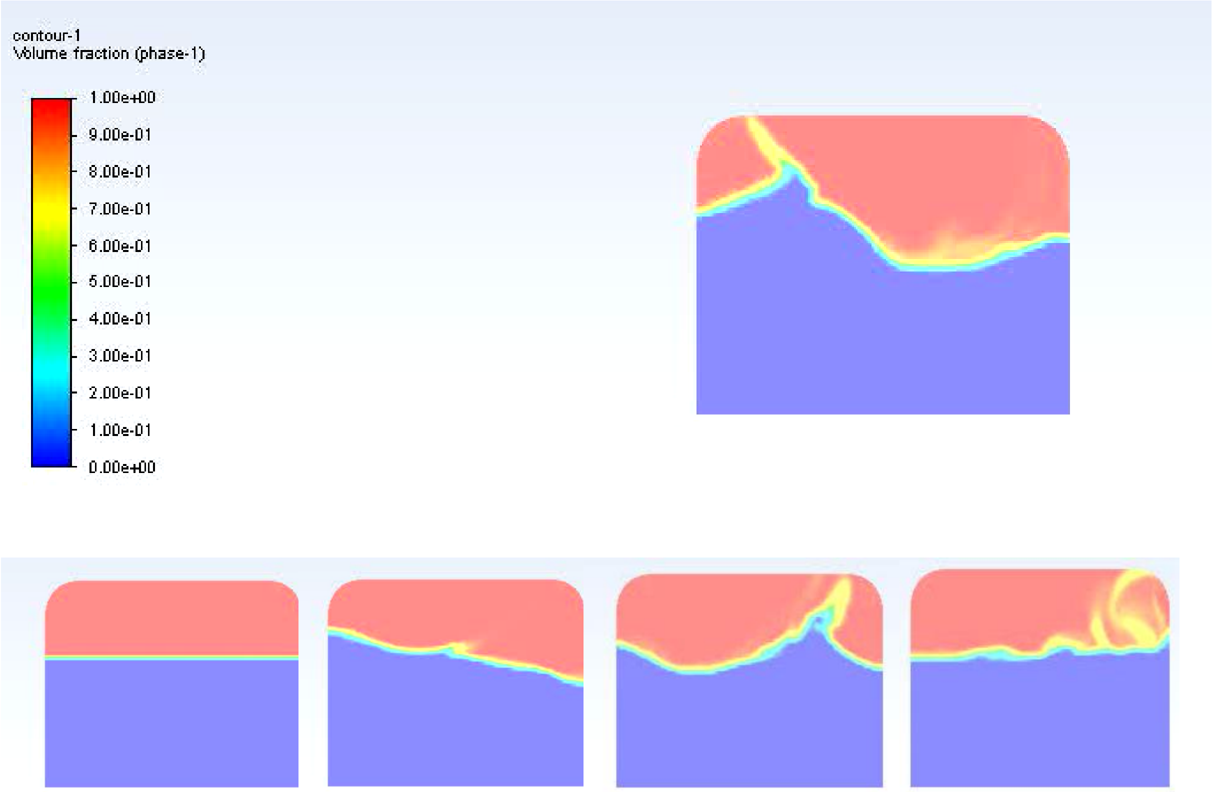


Fig. 11 In-Tank Sloshing Effect

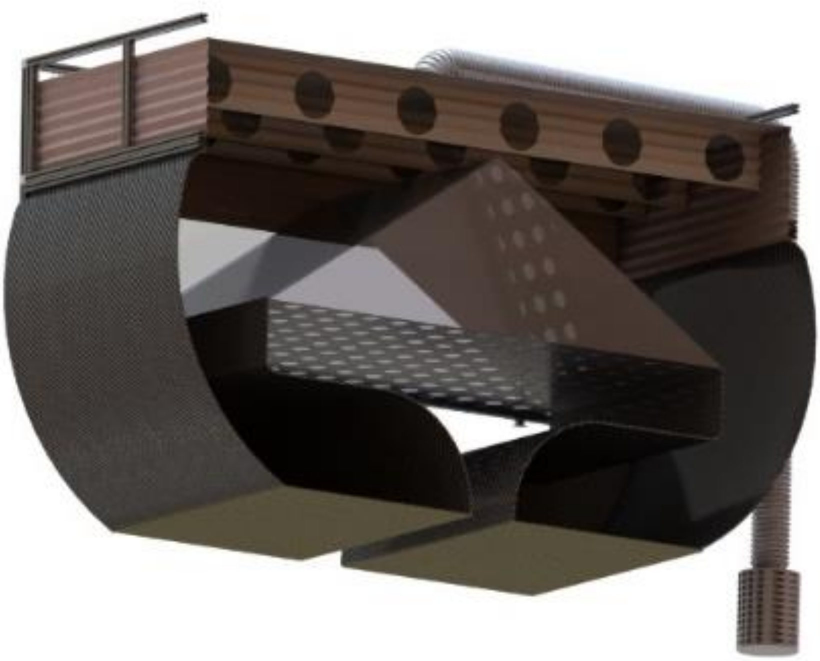


Fig. 12 Breakwater Design

3. CONCLUSIONS

Aircraft and helicopters play a critical role in forest fires. However, the current systems used in these operations have several limitations including variable volume, stability, airborne acceleration, and lifespan. To address these challenges a new design has been optimized to increase the capacity and stability of existing helicopters and play a more effective role in fire suppression. As a result of the conducted analyses, rapid and controlled discharge outcomes have been achieved. Alongside the variable volume capability, more stable tank model has been positioned within the helicopter. The innovative use of an accordion breakwater and a triangular tank base in a helicopter system offers numerous advantages such as faster discharge time and more stable water load carrying. When it's fully filled operational condition the amount of experienced deflection by the tank walls is less than 1cm. In brief, the new accordion tank of the latest generation has the remarkable ability to discharge its water storage of 4469 liters in 2.26 seconds. This technological innovation introduces an entirely new and advanced approach to aerial firefighting interventions in forest fires and provides an efficient and effective approach to fire suppression.

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