A Hollow Structure Elevated Skid Design for Medium Size Unmanned Disaster Surveying Helicopter

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***Abstract*— Unmanned helicopters are trending platforms for quick post-disaster aerial surveying because of their improved safety, reduced operational costs and ability to access hazardous areas. Design enhancements in the existing aerial platforms to accommodate surveying functionality is a commonly practiced approach instead of developing surveying platforms from scratch. Skid elevation to accommodate additional equipment is one of the design enhancements done under this approach. This paper proposes a new hollow structure elevated skid design to address the problem of providing additional space to accommodate disaster surveying equipment (i.e., vision system, airdrop mechanism, extra fuel tank) under the medium-size helicopter. SolidWorks and ANSYS virtual platforms are used for the modelling and simulations of the proposed elevated skid structure, respectively. Static structural Finite Element Analysis (FEA) and Explicit Dynamic Analysis (EDA) are performed for aluminium and fibreglass materials and concluded that proposed structure is within the elastic limit of materials with safety factors within the aerospace range (1.2-1.5). Results for fibreglass material are reported slightly better than aluminium material. Comparative analysis is performed with existing skids and proposed design is capable of achieving desired payload capacity (i.e., 7kg) and space requirements (i.e., 195mm) by almost 160g reduced weight when compared with reference skid. Developed elevated skid will provide additional space for the attachment of equipment related to disaster relief, rescue and surveying.**

***Index Terms*— Radio Controlled Helicopter, Disaster Relief and Surveying, Design and Manufacturing, Mechanical Structure, Static Structural Analysis and Explicit Dynamic Analysis.**

Abbreviations:

UAS	Unmanned Aerial System
NUST	National University of Sciences and Technology
RC	Radio Controlled
CoG	Centre of Gravity
CAD	Computer Aided Design
EDM	Electrical Discharge Machining
CNC	Computer Numerical Control
R&D	Research and Development
FEA	Finite Element Analysis
EDA	Explicit Dynamic Analysis

I. INTRODUCTION

Natural disasters (e.g., earthquakes, floods, hurricanes) have become more frequent and damaging in nature since the last few decades [1, 2]. Increase in hydro-metrological natural disasters (i.e., floods, tsunamis, droughts) is associated with climate change and unplanned settlements in disaster vulnerable regions [3-5]. Asia is more vulnerable to damages from the occurrence of natural disasters because of the lack of available resources in responding to these events [6]. In post-disaster surveying, first three days which are also referred as "golden 72" [7] and are considered significant in saving victims because it is highly unlikely to find a victim alive beyond this period. Unavailability of quick surveying resources and a limited number of rescue teams most often lead to a significant loss in terms of precious lives in undeveloped countries. In Pakistan, conventionally, full-scale helicopters are used for the post-disaster surveying purposes [8], however, they are expensive to operate and slow in nature.

Unmanned Aerial System (UAS) has emerged as a potential platform to be used for quick, effective, and economical post-disaster surveying in recent years [9-15]. From a comparative study by Iqbal et al. [16], helicopters and multirotor copters are reported as suitable platforms for surveying because of their hovering capability, high maneuverability and low flight ability. Although, there are some companies such as YAMAHA manufacturing helicopters specifically for surveying purposes [17], however, they are expensive and not accessible to everyone. Alternatively, a potential approach adopted by researchers is to use commercially available existing platforms and enhance them to achieve the functionality of a disaster surveying helicopter [18]. Aerial Robotics Lab at National University of Sciences and Technology (NUST) is in the progress of developing an unmanned disaster relief helicopter by using Velocity90 nitro Radio Controlled (RC) helicopter as a base platform referred as "base helicopter" in this article. In a recent study, Iqbal et al. [19] highlighted essential equipment for a disaster surveying and relief helicopter including vision and data telemetry system, airdrop mechanism [20, 21], extra fuel tank and other

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sensory equipment. Furthermore, an emphasis on the importance of skid elevation as a structural enhancement for accommodating additional equipment was made.

There is limited related literature publicly available to mechanical designs of helicopter landing gears mainly because most of the research relevant to this topic is performed under the defence organizations. However, recent progress on the integration of civilian UAVs with the military has triggered the research in this field and few researchers have proposed different design and simulations for helicopter landing skids [19, 22-24]. Iqbal et al. [19] were the only to address the problem of skid elevation for attaching additional equipment beneath existing helicopter platforms. Authors proposed the 90mm elevated skid design by replicating the existing skid design and facilitated the attachment of vision and data telemetry system, however, the problem of accommodating airdrop mechanism and extra fuel tank persisted. Authors concluded that a further increase in the elevation using the existing design of skid will increase the overall weight and hence not a feasible solution.

This article proposes a novel hollow structure design of elevated skid to address the problem of attaching essential surveying equipment beneath the base helicopter. The idea of strengthening only the stress vulnerable regions of the skid by using supports and keeping the rest of the structure as hollow was used to optimize the weight of the skid structure. As a summary, following are the contributions of presented research:

1. A novel hollow structure elevated skid design for medium size base helicopter to address the additional space requirements for attaching essential surveying equipment.
2. Comparative analysis of the proposed skid design with existing skids to highlight the scope of the proposed design.

Rest of the paper is organized as follows: Section II presents the design requirements and adopted methodology in designing the proposed skid. Section III provides details about the tools and materials used in designing the proposed skid. Section IV presents the modelling of proposed elevated skid. Section V details the static structural Finite Element Analysis (FEA) and Explicit Dynamic Analysis (EDA) of the proposed design to validate its structural integrity. Section VI presents brief details about the manufacturing and expenses of the proposed skid design. Section VII presents a comparative analysis of the proposed elevated skid with the existing skid designs for the same functionality. Finally, Section VIII concludes the study with important insights and recommends potential future directions.

II. Design Requirements and Methodology

Design requirements are presented for the base helicopter for which the elevated skid design is proposed. Base helicopter weight is approximately 3.5kg without any additional equipment attached to it. The expected additional weight of essential surveying equipment is approximately 3.5kg. The breakdown for the weight of each essential equipment is as follows (a) approximately 1kg for the vision and data telemetry equipment (b) approximately 1kg for the additional fuel tank (c) approximately 0.5kg for the airdrop mechanism (d) approximately 1kg for the first aid box to be dropped. The proposed design is simulated to bear stresses generated by a 7kg load. Listed are the specific design requirements for the elevated skid design.

1. The overall weight of elevated skid should not exceed 300g.
2. Elevated skid should be capable of bearing stresses generated by 7kg load.
3. Center of Gravity (CoG) of overall helicopter should not be affected drastically by skid elevation.
4. Proposed elevated skid design should be able to provide enough space beneath to accommodate vision system, airdrop mechanism and additional fuel tank.

Elevated skid implementation has been carried out by using standard design flow and manufacturing process [25, 26]. Figure 1 shows the flowchart for the standard design and manufacturing process followed for the development of elevated skid. Selection of materials for the skid parts are based on the guidelines of Boyer et al. [27] for aerospace utility and the load profile. Proposed skid design is validated for structural integrity by performing static structural FEA and EDA.

III. Tools and Materials Identification

This section provides information about the tools and materials used in the design and manufacturing process of proposed elevated skid design. SolidWorks virtual platform was used to prepare the Computer Aided Design (CAD) model of the proposed skid while ANSYS was used to perform static structural FEA and EDA.

Selection of materials is often subjected to load requirements, stress distributions, weight limitation and other real-time constraints. However, the use of materials is highly dependent on the end-utility of the designed structure. For aerospace applications, materials with least weight and most strength are recommended. Following Boyer et al. [27] guidelines on the selection of materials, for this research combination of four different materials including structural steel, aluminium alloy 7071, A-grade fibreglass and ABS Plastic was used. Detailed properties of the above-mentioned materials are presented in Table 1. Listed are two material combinations used in this paper for the elevated skid simulations and analysis. For this investigation, it has been assumed that mechanical properties of used material are uniform across the structure and variation in structural strengths based on design are considered out of scope for this study.

- Material Combination 1: Structural Steel Rods + Aluminium Alloy Plates + ABS Plastic Supports

- Material Combination 2: Structural Steel Rods + Fibreglass Plates + ABS Plastic Supports

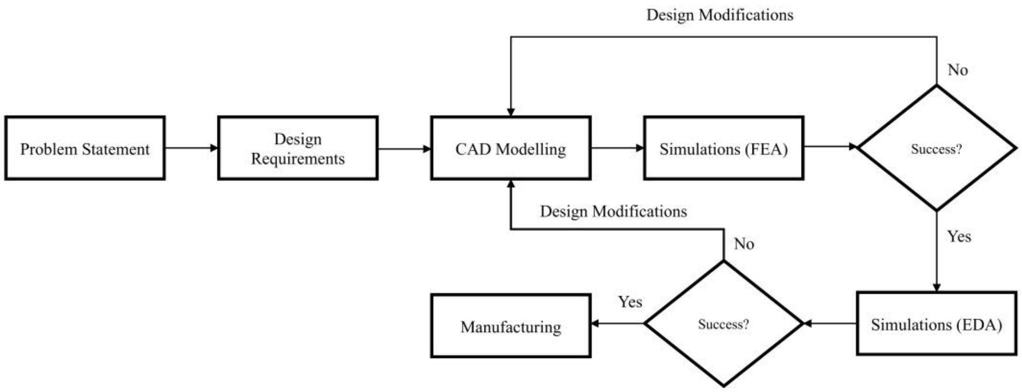


Fig. 1: Process flowchart for implementation of proposed elevated skid design.

TABLE I
Detailed Specifications Of Materials Used In Proposed Elevated Skid Design [28-30]

	Structural Steel	Aluminium Alloy	Fibreglass	ABS Plastic
Density ($kgmm^{-3}$)	7.85×10^{-6}	2.77×10^{-6}	2.44×10^{-6}	9.5×10^{-7}
Bulk Modulus (MPa)	$1.6\mathbf{7} \times \mathbf{10^7}$	69608	36225	2291
Tensile Ultimate Strength (MPa)	460	310	3310	33
Tensile Yield Strength (MPa)	250	280	300	25
Young's Modulus (MPa)	2×10^5	71000	68900	1100
Shear Modulus (MPa)	76923	26692	29121	387.3

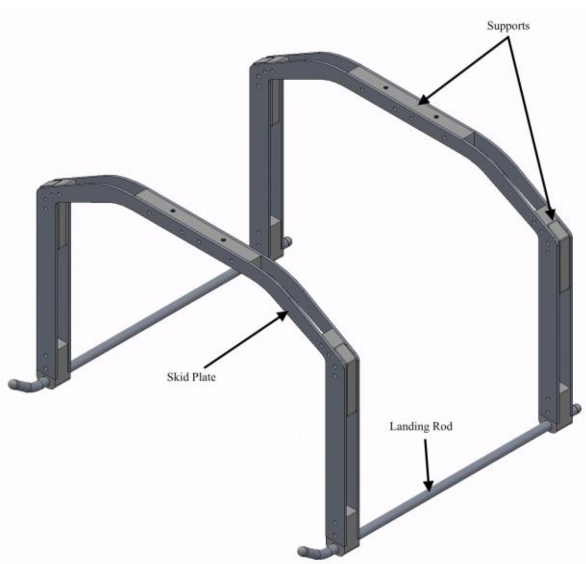


Fig. 2: Elevated Skid CAD Assembly.

IV. 195MM ELEVATED SKID MODEL

This section presents the CAD model of the proposed elevated skid design. In reference to the default helicopter skid (22mm elevation) and skid proposed by Iqbal et al. [19] (90mm elevation), the proposed design has been elevated to 195mm to accommodate additional surveying equipment. Proposed skid design consists of three main components, a plate, landing rods and support bosses. Figure 2 shows the CAD assembly of the proposed skid with all the components clearly labelled. The skid has been designed taking into consideration the local availability of materials and manufacturing resources. The design has been modelled to be fabricated by either Electrical Discharge Machining (DEM) or Computer Numerical Control (CNC). Proposed skid design shifted the overall CoG only in the lateral axis while CoG in the longitudinal axis was unaffected. Elevation of skid forced the CoG to shift higher when at the ground and introduced additional instability. However, during flight with additional equipment attached, CoG was lower than normal and resulted in improved stability.

V. SIMULATION AND ANALYSIS

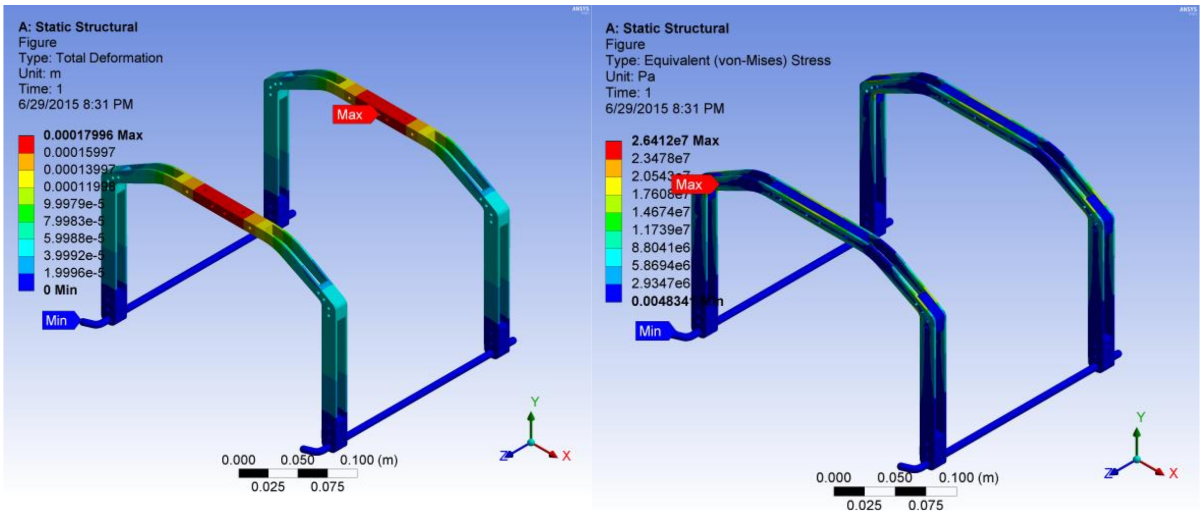
This section presents the details about the static structural FEA and EDA performed on the proposed 195mm elevated skid design to validate the structural stability under required loading conditions. All the simulations were performed using the ANSYS Workbench. All the simulations were performed on a computer with 3rd generation intel core i-5 processor and 4GB memory.

A. *Static Structural Analysis*

Static structural FEA analysis has been performed to validate the structure of the proposed 195mm elevated skid design under the steady load conditions. Since the load was applied instantaneously, ANSYS mechanical solver with a direct type of setting was used for the simulation. A load of 70N was applied in a single step from 0 to 1 second. Because of the use of direct solver type, single iteration was needed to solve the given model. Coarse meshing with fast transition and five number of layers was used. There were 96254 nodes and 24106 elements in the final mesh. Furthermore, the convergence criteria for the solver was defined as the independence of the solution from mesh size. For displacement value variation within 10^{-4}mm in relation to mess size, results were converged.

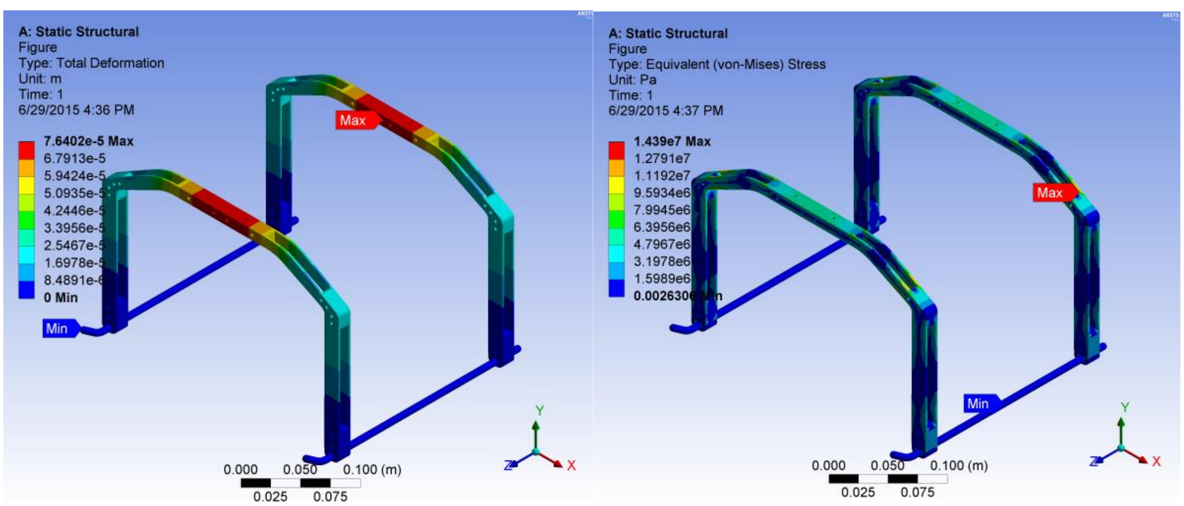
A single iteration of solver took around 5 hours to solve the given meshing model. There are no other significant loads on the helicopter other than the vertical load of helicopter structure. Although, the torsional forces are also involved due to rotary wing, however, given the scale of a helicopter, they are not considered for this investigation. Furthermore, the temperature may also alter the properties of the material but depending upon the flight elevation of the unmanned helicopter (i.e., not more than 500m), the atmospheric effects are almost negligible.

In terms of boundary conditions to perform static structural FEA analysis, skid assembly was fixed at landing gears and assembly was treated as a single part for simplicity (i.e., skid will not move in any direction). Forces of 70N were applied only in the vertical direction (corresponding to 7kg weight) to the centre of both the skid frames. These boundary conditions were defined based on the real-world observations where the only significant load on helicopter skid is vertical. Although, other forces are acting on the skid, however, are not significant in comparison to vertical load. Therefore, it has been assumed that if skid can bear the vertical load, it can bear other insignificant forces as well.



(a) Total Deformation (b) von-Misses Stress

Fig. 3: Static structural analysis results for material combination1.



(a) Total Deformation (b) von-Misses Stress

Fig. 4: Static structural analysis results for material combination2

Results of static structural FEA for the 195mm elevated skid for material combination1 and material combination2 are shown in Figure 3 and 4, respectively. Maximum deformation for aluminium under the specified load conditions has been recorded as 0.178mm, while Maximum equivalent stress has been recorded as 26.412MPa. Both values were under the safe limits of the aluminium and no visual deformation or buckling was observed. Furthermore, maximum stress was recorded at the position where the load was applied and proposed support at that position successfully strengthened the structure to avoid deformation. Safety factor, which is the ratio of yield material strength and maximum equivalent stress, for the aluminium material was calculated as 10.6 as shown in equation 1. A high value of safety factor suggests over-design, however, impact analysis presented in the next section are considered an actual measure for structural integrity.

$$\textit{Safety Factor} = 280/26.41 = 10.6 \tag{1}$$

Maximum deformation for fiberglass material has been recorded as 7.46×10^{-2}mm, while Maximum equivalent stress has been recorded as 14.39MPa. Both values were under the safe limits of the fibreglass and no visual deformation or buckling was observed. Identical behaviour to what was observed for aluminium was observed with only difference in magnitude of deformation and stresses. For fiberglass, the magnitude of stresses was less in comparison to aluminium suggesting fiberglass a better choice if the strength of the material is the priority. Safety factor for the fiberglass was calculated as 20.84 as shown in equation 2.

TABLE II
Static Structural Analysis for Proposed Elevated Skid Design

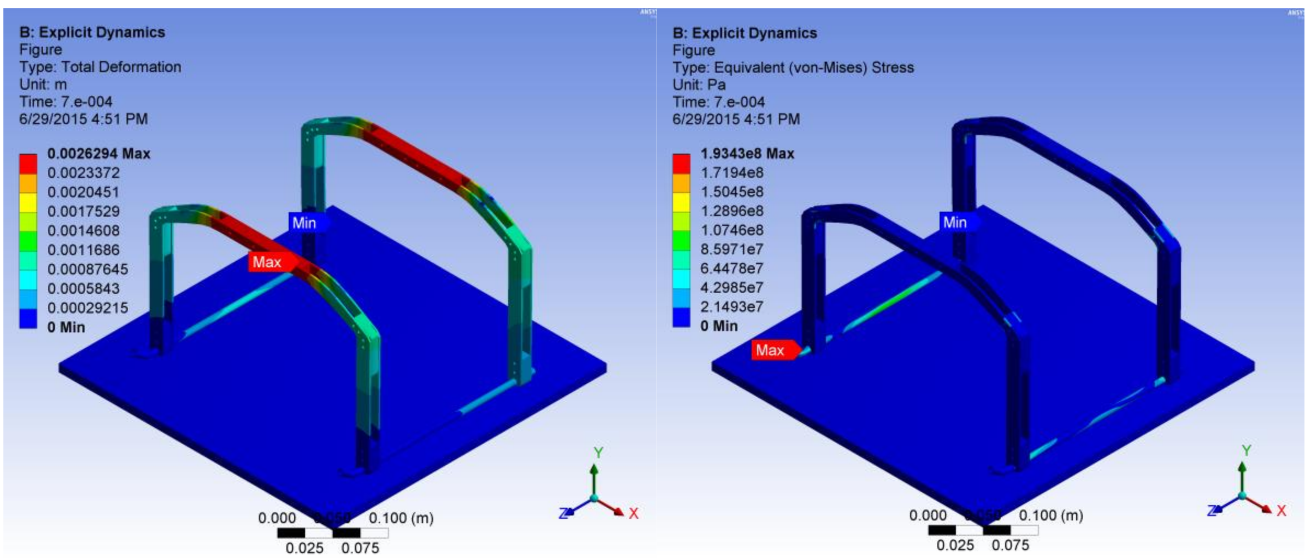
Parameter	Material Combination1	Material Combination2
Maximum Total Deformation (mm)	0.178	7.46×10^{-2}
Maximum Deformation along X	5.19×10^{-2}	2.21×10^{-2}
Maximum Deformation along Y	4.24×10^{-3}	1.89×10^{-3}
Maximum Deformation along Z	9.63×10^{-4}	1.112×10^{-3}
Maximum Equivalent Elastic Strain	1.74×10^{-3}	2.084×10^{-4}
Maximum Principle Strain	1.18×10^{-3}	1.75×10^{-4}
Maximum Shear Strain	2.76×10^{-3}	2.83×10^{-4}
Equivalent Stress (MPa)	26.412	14.39
Maximum Principle Stress (MPa)	17.292	12.06
Maximum Shear Stress (MPa)	13.611	8.36

$$\textit{Safety Factor} = 300/14.39 = 20.84 \quad (2)$$

Table 2 presents the summary of static structural FEA of 195 mm elevated skid for both aluminium and fiberglass materials. TABLE 2 compares the results of both materials and concludes that deformation and stresses for both material combinations were comparable with fibreglass on the slightly better end.

B. Explicit Dynamic Analysis

EDA is used to test the structure for impact load involving velocity and momentum. This section presents the results of EDA performed on 195mm elevated skid design. The analysis was configured with respect to the required load and velocity conditions. In an ideal condition, when helicopter touches the ground during landing, its vertical speed should be approaching to zero (i.e., normal landing vertical speed is 2m/s). However, in the hard landing scenario, the helicopter lands with an impact and hits the ground with some vertical velocity [31, 32]. Therefore, the skid structure was subjected to EDA to validate its integrity under high impact. Coarse meshing with fast transition and five number of layers was used. There were 96254 nodes and 24106 elements in the final mesh. In terms of boundary conditions to perform the impact analysis, skid has been dropped under the influence forces on a fixed plate and impact of stresses was observed. Forces of 70N were applied to the centre of both skid frames and all the assembly components were assigned with an initial velocity of 5km/s to mimic the worst-case landing scenario.



(a) Total Deformation (b) von-Misses Stress

Fig. 5: Explicit dynamic analysis results for material combination1.

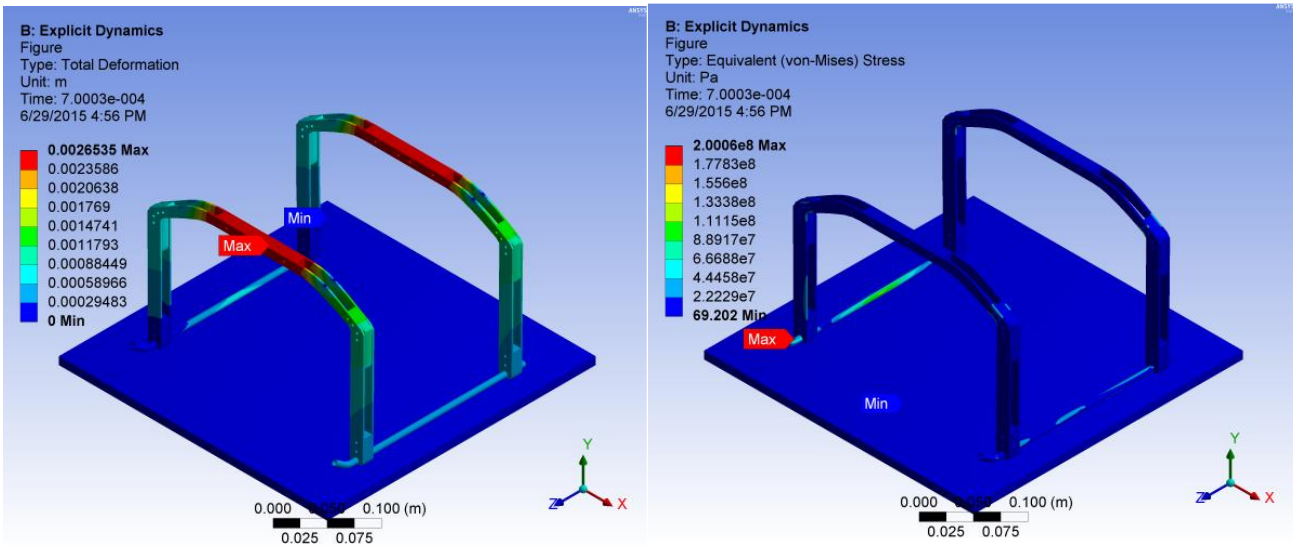
Results of EDA for the 195mm elevated skid for material combination1 and material combination2 are presented in Figure 5 and 6, respectively. Results include the total deformation and von-Misses. Maximum deformation for aluminium under the specified load and velocity conditions has been recorded as 2.629×10^{-3}mm while Maximum equivalent stress has been recorded as 193.43MPa. Both values indicated that the structure was within the elastic limits of aluminium. Safety factor for the aluminium material was calculated as 1.45 as shown in equation 3. Safety factor was within the ideal aerospace limit (1.2-1.5) and no visual deformation was observed.

$$\textit{Safety Factor} = 280/193.43 = 1.45 \quad (3)$$

Maximum deformation for fiberglass under the specified load and velocity conditions has been recorded as 2.653×10^{-3}mm, while Maximum equivalent stress has been recorded as 200MPa. Both values indicated that the structure was within the elastic limit fibreglass material. Safety factor for the fiberglass material was calculated 1.5 as shown in equation 4.

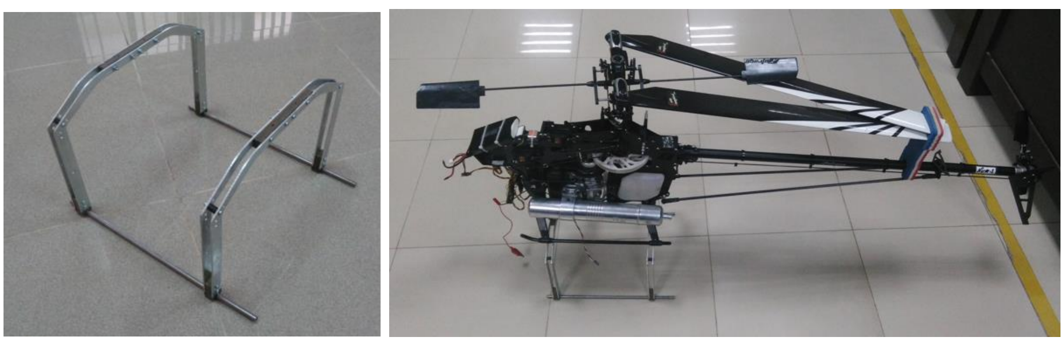
$$\textit{Safety Factor} = 300/200 = 1.50 \quad (4)$$

Table III presents the summary of EDA of 195 mm elevated skid for both aluminium and fiberglass materials. Table III compares the results of both materials and concludes that proposed hollow structure design could bear the stresses from worst-case landing impact analysis with no structural failure. However, results were presented for single drop-test and the investigation of structure life for multiple normal landings is not in the scope of the presented research. Comparable results were reported for both material combinations with fiberglass on the slightly better end, however, comes with the disadvantage of the specialized manufacturing process. Fiberglass skid was reported as 25g lighter in comparison to aluminium skid.



(a) Total Deformation (b) von-Misses Stress

Fig. 6: Explicit dynamic analysis results for material combination2.



(a) Standalone (b) With Helicopter

Fig. 7: Fabricated hardware assembly of proposed 195mm elevated skid design.

TABLE III
Explicit Dynamic Analysis for Elevated Skid Design

	Material Combination1	**Material Combination2**
Maximum Total Deformation (m)	2.629×10^{-3}	2.653×10^{-3}
Maximum Deformation along Y (mm)	7.79×10^{-4}	8.527×10^{-4}
Equivalent Stress (MPa)	193.43	200
Maximum Principle Stress (MPa)	0.2625	0.2612

VI. Fabrication and Expenses

This section presents the hardware fabrication and manufacturing results of the 195mm elevated helicopter skid. Manufacturing of the parts was carried out using the CNC machine. Fabricated 195mm elevated skid in standalone condition and with the helicopter is shown in Figure 7, respectively. Four identical elevated plates and respective attachment bosses were manufactured as the building blocks of the 195mm elevated helicopter skid. Pair of elevated plates were then assembled and screwed with the attachment bosses to prepare the elevated frame assembly. Two elevated frames and stainless-steel landing rods were assembled to make the final hardware assembly of elevated skid. 7071 aluminium alloy was used as the fabrication material for the manufacturing of the elevated plates and ABS plastic was used for attachment bosses. The prototype for the 195mm elevated skid was successfully fabricated as a possible solution for the facilitation of additional sensory and disaster operational equipment beneath the skid. Fabricated elevated skid structure was tested for a static load of 7kg and an original helicopter. No deformation or bucking was observed during the static load testing of fabricated helicopter skid.

Table IV presents the approximate expenditure for the development and fabrication of the proposed 195mm elevated skid design. From a Research and Development (R&D) perspective, total expenses of materials and manufacturing were reported as $60. It is important to mention that for the fibreglass material, manufacturing cost and material cost will increase accordingly.

TABLE IV
Expenditure on Fabrication Elevated Skid Design.

Part Description	Purpose	Price
Aluminium Alloy Sheet	Elevated Skid Design	$15
ABS Plastic Block	Skid Supports	$5
Manufacturing	Fabrication	$30
Others	Miscellaneous	$10
	Total	**$60**

VII. Comparison with Existing Skids

Proposed 195mm elevated skid design was subjectively compared with three existing skid models used for the same purpose. The comparison was performed based on features including mass, payload capacity, manufacturing technology, mounting options, reliability, design efficiency, dimensions and price. Existing skids include default 22mm elevated skid, reference 190mm elevated copper pipes skid and 90mm elevated skid proposed Iqbal et al. [19]. Since the helicopter platform used is a hobby RC model helicopter and not meant to carry any payload, therefore, default elevated skid is not elevated enough to accommodate any additional equipment. Reference elevated skid is a copper pipe made skid fabricated without proper design and analysis, approximately based on the load requirements. Reference elevated skid is elevated enough (190mm) to accommodate vision system, airdrop mechanism and extra fuel tank, however, the design is not efficient, and skid is too heavy. 90mm skid was able to bear the stresses caused by 7.5kg of load, however, skid design was not weight-optimized and with the given design, further elevation was not efficient. Furthermore, 90mm elevated skid was only able to provide the space for the vision system but not for the airdrop mechanism and extra fuel tank.

In terms of mass, the proposed design was almost the same as of 90mm elevated skid design but around 200g lighter than the reference skid. However, in terms of elevation, the proposed design was able to achieve 195mm, which is comparable to reference skid for accommodating additional equipment including airdrop mechanism and extra fuel tank.

Both, 90mm and 195mm elevated skid designs were modelled using standard procedures and are highly reliable and efficient. Overall, proposed 195mm elevated skid design was comparable to 90mm elevated skid design in terms of features, however, a major achievement in terms of design was to achieve 100mm additional elevation within the same weight limit and under same load conditions. Table V presents a detailed comparison of all four skid designs.

TABLE V
Feature Based Comparison of Existing and Proposed Helicopter Skid Designs.

	Default Skid	Reference Skid	90mm Elevated Skid [19]	195mm Elevated Skid
Mass (g)	120	450	285	291
Dimensions (mm)	330×203×22	330×280×190	345×261×90	330×257×195
FPV Mount	No	Yes	Yes	Yes
Airdrop Mount	No	Yes	No	Yes
Extra Fuel Tank	No	Yes	No	Yes
Price	Low	Medium	Medium	Medium
Manufacturing	Default	Mould + Welding	EDM	CNC
Reliability	Low	High	High	High
Payload Capacity (kg)	4	10	7.5	7
Design Efficiency	High	Low	High	High

VIII. Conclusion

Aim of the performed research was to investigate the skid elevation problem for mounting essential surveying equipment on the base helicopter, which was successfully addressed by proposing a hollow structure, 195mm elevated skid design. Hollow structure design provided weight optimization and fulfilled the desired load and impact requirements. The design did not affect the longitudinal CoG of the helicopter but lowered the lateral CoG, which improved the inflight stability of the helicopter.

Results of static structure FEA and EDA presented in Figures 3, 4, 5, 6, Table II and III show that the proposed structure is within the safe elastic limits of the material. The safety factor as a result of EDA was recorded as 1.45 and 1.5 for material combination1 and material combination2, respectively. The safety factor shows that the structure is safe for the required loads and within the limits of aeronautical factor safety limits (1.2 – 1.5). 25g mass difference has been observed between fiberglass and aluminium skids with almost the same structural strength. On the other hand, the manufacturing process becomes more complex and expensive for composite materials and design required to be more simplified if desired to be implemented using fiberglass material. The proposed structure also passed the hardware static testing phase and in-flight testing with no deformation or buckling. Proposed elevated skid is specifically designed for the 90 size helicopters and can be used to facilitate the additional equipment for civilian purposes other than disaster relief.

Future directions of research involve design simplifications and fabrication using the fiberglass material. Furthermore, material combination of fiberglass and carbon fiber for the skid is a potential future investigation towards achieving lightweight and strong helicopter skids.

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