# Multiphysics design optimization for aerospace applications: Case study on helicopter loading hanger

Hui Xue, H. Khawaja, and M. Moatamedi

---

**Articles you may be interested in**

Survey of Multiscale and Multiphysics Applications and Communities
Comput. Sci. Eng. 16, 34 (2014); 10.1109/MCSE.2013.47

Study on mechanical properties of carbon-carbon composites developed for aerospace applications
AIP Conf. Proc. 1538, 163 (2013); 10.1063/1.4810049

Application of the Wire Ablation Dynamics Model to the Design and Optimization of Wire Array Loads of Complex Geometry
AIP Conf. Proc. 1088, 45 (2009); 10.1063/1.3079750

Case studies of design applications of impulse response tests
J. Acoust. Soc. Am. 100, 2705 (1996); 10.1121/1.416087

Importance of Superimposed Acoustic, Static, and Dynamic Loadings and Their Application to Aerospace Structural Testing
J. Acoust. Soc. Am. 36, 1046 (1964); 10.1121/1.2143363

---

# Multiphysics Design Optimization for Aerospace Applications: Case study on Helicopter Loading Hanger

Hui Xue[1, a)] H. Khawaja[2, b)] and M. Moatamedi[3, c)]

[1]*Master Student, Faculty of Technology, Narvik University College, Narvik, Norway.*
[2]*Associate Professor, Department of Engineering and Safety, University of Tromsø, Tromsø, Norway.*
[3]*Professor, Faculty of Technology, Narvik University College, Narvik, Norway.*

[a)]501948@student.hin.no
[b)]Corresponding author: hassan.a.khawaja@uit.no
[c)]moji@hin.no

**Abstract.** This paper presents the Multiphysics technique applied in the design optimization of a loading hanger for an aerial crane. In this study, design optimization is applied on the geometric modelling of a part being in an aerial crane operation. A set of dimensional and loading requirements are provided. Various geometric models are built using SolidWorks® Computer Aided Design (CAD) Package. In addition, Finite Element Method (FEM) is applied to study these geometric models using ANSYS® Multiphysics package. Appropriate material is chosen based on the strength to weight ratio. Efforts are made to optimize the geometry to reduce the weight of the part. Based on the achieved results, conclusions are drawn.

## INTRODUCTION

Aerial cranes are being used in the wide variety of applications such as in construction, transport, emergency, military etc. [1-3]. Figure 1(a) shows an aerial crane operation. Aerial crane operation involves helicopter, loading hanger and the lifted weight. Loading hanger is comprised of parts, such as loading line, attachment plate, slings, etc. Figure 1(b) shows a close-up view of the loading hanger [4].

In this work, focus is on the loading hanger. The loading hanger is connected between helicopter and the load. This connection is activated using electromagnetic switch, which can be detached on unloading or emergency in case of unstable helicopter flight. The objective here is to design this part, select appropriate material and use multiphysics tools for optimization. This work presents three phases, which includes (1) geometric modeling, (2) material selection and (3) optimization phases.

The geometric modelling phase begins with a sketch of the attachment plate. Figure 2(a) and fig. 2(b) show the top and side views of the attachment plate based on pre-set design requirements. A set of requirements is provided to enclose a physical problem [5]. There are four sling holes surrounded by an attachment area. Each sling hole has a diameter of three centimeters. In addition to that, each hole needs to be thirty centimeters from the center of the attachment plate and equidistant from each other. The center area is for joining the attachment plate with the helicopter. It is also pre-set to 100 cm². Only requirement here is that this area should be axisymmetric to the center of the attachment plate. The helicopter maximum loading capacity is up to one metric ton (1000 Kg).
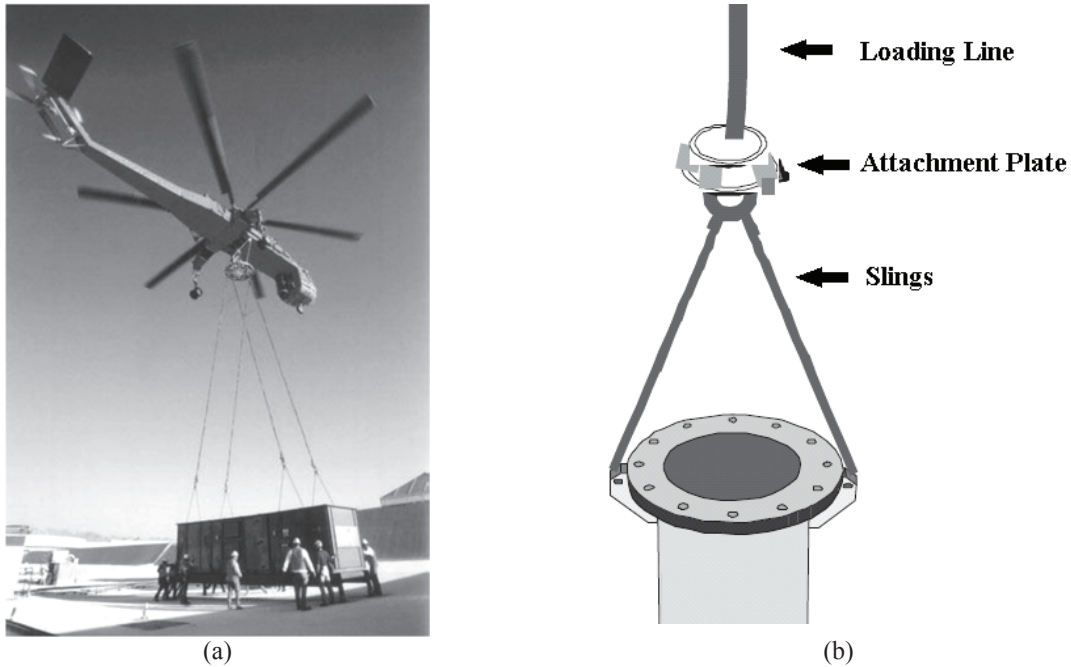
**FIGURE 1.** Aerial crane operation is shown in (a). A zoom in view of loading hanger is shown in (b), comprising of three main segments, loading line from the helicopter, the attachment plate and slings to attach the weight [6].
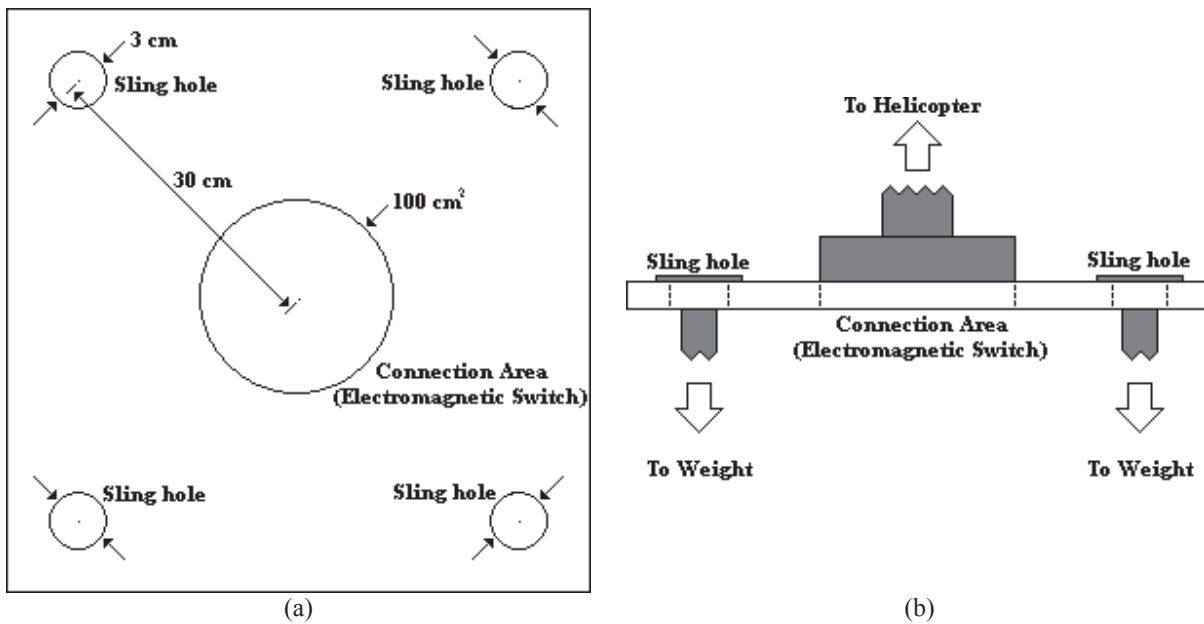


**FIGURE 2.** The attachment plate with pre-set dimensions requirements. Top view is shown in (a) and side view is shown in (b).

Material selection phase is the choosing of an appropriate material for the attachment plate. It is desired that the designed part is efficient and safe. In this case, strength and stiffness are both important. In this work, appropriate material is chosen from a list of available materials (table.1). Another important selection criterion is strength to weight ratio. The factor of safety is considered to be three in the selection process [5, 7].

The optimization phase includes modifications in the geometry of the attachment plate while fulfilling all of the above given requirements. The focus is on the structural stresses and displacements. The aim is to reduce the weight of the attachment plate [8].

# METHODOLOGY

The methodology followed in this study involves development of CAD models using SoildWorks® [9] and analysis using ANSYS® Multiphysics [10, 11]. These are followed by evaluation of the obtained results against requirements of an aerial crane operation and repeating these steps until most optimized part is obtained. Figure 3 shows the road map of the methodology.
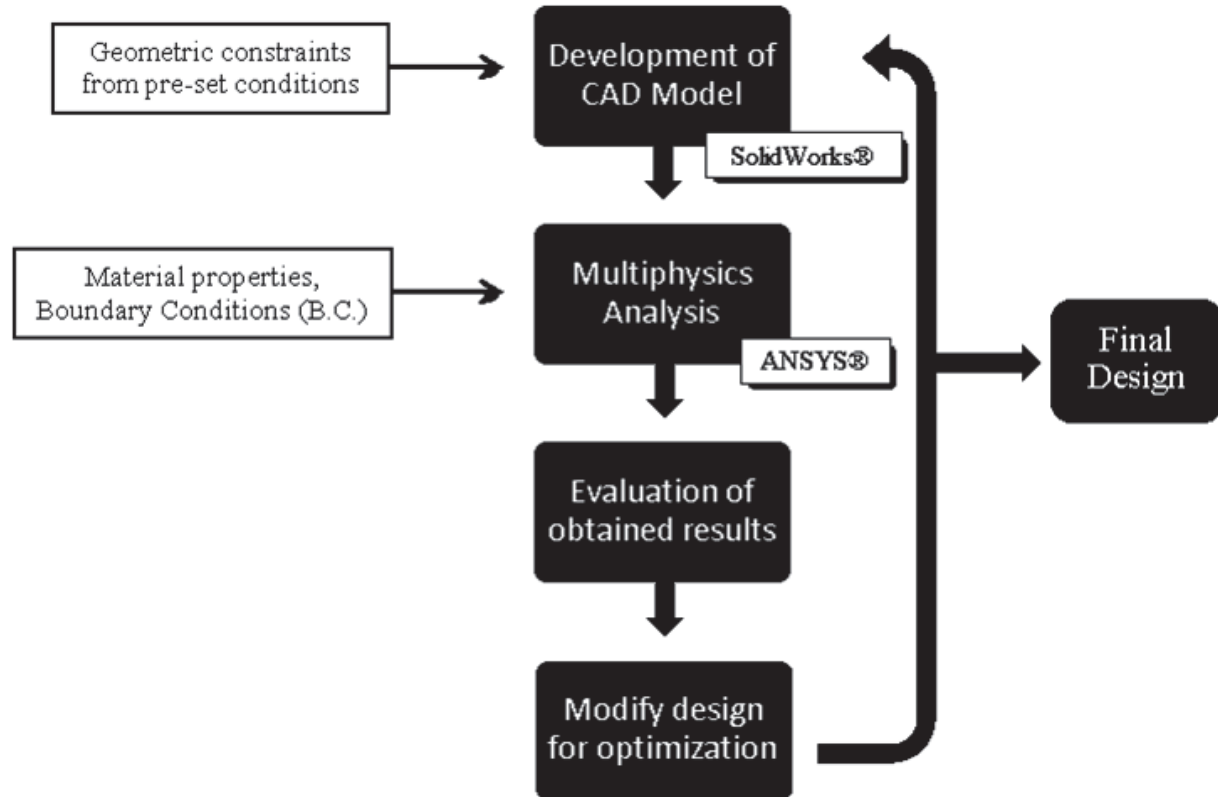


**FIGURE 3.** Roadmap of methodology adopted for design optimization

The development of CAD model includes building of 3D models using SolidWorks® CAD package [9]. Various parts are built as shown in fig. 4. All of these parts meet the dimensions stated earlier.

Multiphysics analysis is conducted using ANSYS® Multiphysics package [10, 11]. Two types of boundary conditions are applied, that are displacement constraint and distributed forces (pressure). The forces are equally distributed in each sling line and applied on the edge of each sling hole. The boundary conditions are illustrated in fig. 5.
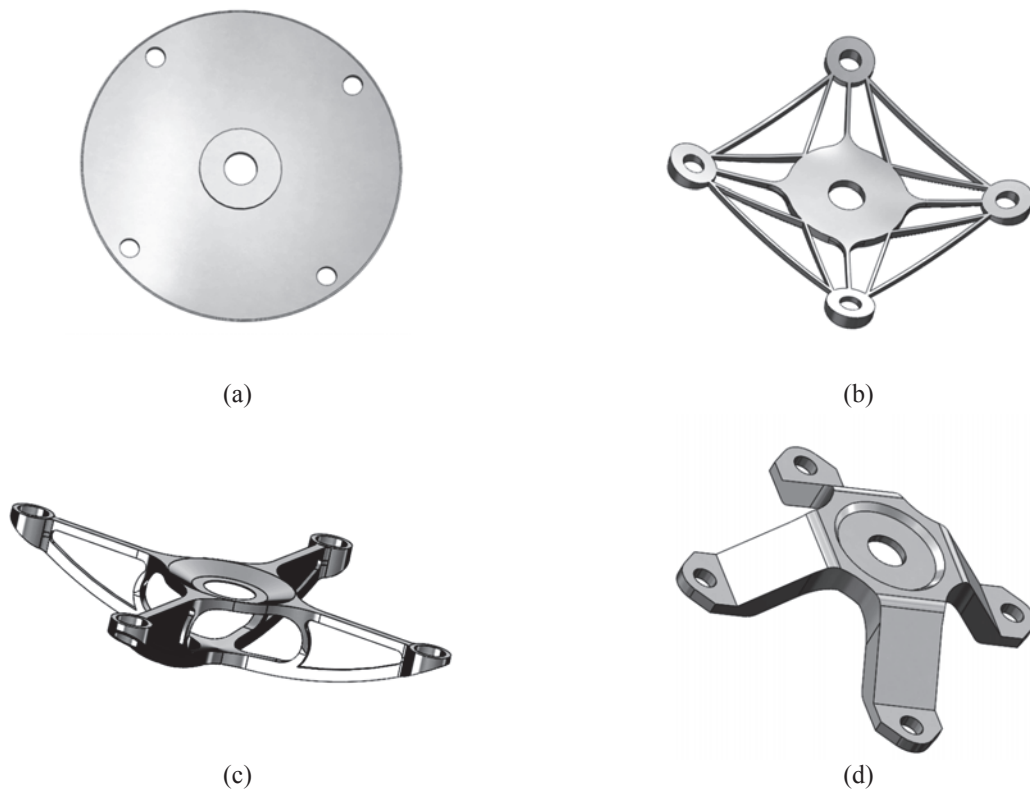
(a)

(b)

(c)

(d)

**FIGURE 4.** Various 3D parts built in SolidWorks® [9] for the attachment plate [12].
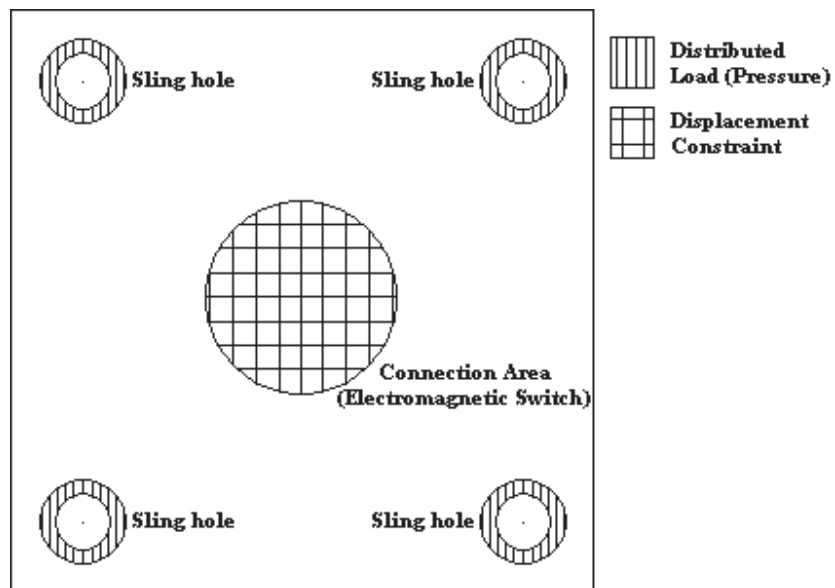


**FIGURE 5.** Boundary conditions applied to the model. (a) Displacement constraint applied at the connection between helicopter and the attachment plate. (b) Distributed load (pressure) is applied at the sling holes.

The multiphysics analysis is performed by applying linear, elastic, isotropic and homogeneous materials. The list of materials used are given in table 1. The von-Mises yield criterion [13, 14] is employed for detecting the failure. The use of isotropic model for composite materials is questionable; however, one of the requirement is to have effective stresses as low as one-third of the yield strength (factor of safety equal to three). At low values of effective stresses, von-Mises criterion [13, 14] is close to Tsai-Wu criterion [15] which is valid over anisotropic materials such as carbon reinforced fiber polymer (CRFP) [16].

**TABLE 1.** Properties of materials; yield strengths, densities and specific strengths.

| Materials | Yield Strength (Mpa) | Density (Kg/m$^3$) | Specific Strength (Yield Strength/Density) |
|---|---|---|---|
| Aluminum Alloys | 120 | 2700 | 0.04 |
| Stainless Steel Alloys | 500 | 8000 | 0.0625 |
| Titanium Alloys | 600 | 4500 | 0.13 |
| Nickel Alloys | 900 | 7800 | 0.115 |
| Carbon Reinforced Fiber polymer (CRFP) | 320 | 1800 | 0.17 |

# RESULTS AND DISCUSSION

The results from earlier tests (as shown in fig. 4) show high stresses in the sharp corners. This clearly indicates that sharp corner produces stress concentration points which must be avoided [17]. It is also realized that the problem is analogous to a simple bending beam considering that the attachment plate is quad symmetric. Solution to such a problem can be found by applying Euler-Bernoulli bending theory [18, 19]. The Euler-Bernoulli equation for the quasi-static bending of slender, isotropic and homogeneous beams under a transverse load is given in eqn. 1.

$$\frac{d^2}{dx^2}\left(EI\frac{d^4w(x)}{dx^4}\right) = EI\frac{d^4w(x)}{dx^4} = q(x) \qquad (1)$$

Where x is a unit dimension in longitudinal direction, q(x) is a distributed load, E is the Young's Modulus, I is the area moment of inertia and w(x) is the deflection from the neutral axis of the beam.

Similarly, bending moment M(x) and shear force Q(x) can also be expressed in terms of Young's Modulus E, the area moment of inertia I and deflection w(x) as given in eqn. 2 and eqn. 3 [18, 19].

$$M(x) = -EI\frac{d^2w(x)}{dx^2} \qquad (2)$$

$$Q(x) == -EI\frac{d^3w(x)}{dx^3} = \frac{dM(x)}{dx} \qquad (3)$$

For the beam cross-sections that are symmetrical about the plane parallel to the transverse direction, it can be shown that the bending tensile stress is as given in eqn. 4 [18, 19].

$$\sigma(x) = -Ey\frac{d^2w(x)}{dx^2} = \frac{M(x)y}{I} \qquad (4)$$

Where $\sigma$(x) is the bending tensile stress and y is a unit dimension in the transverse direction.

It is shown from eqn. 4 that the bending tensile stress is directly proportional to the moment. The value of moment is proportional to applied force and distance between the constraint and the loading point. Hence, by reducing the distance between constraint and loading point, the stresses can be reduced. Keeping this in consideration, the models are re-built and tested for stresses.

The final optimized three dimensional CAD model of an attachment plate is shown in fig. 6 (a). Figure 6 (b) and fig. 6 (c) show the von-Mises stress and displacement contours. The material of choice is CRFP, since it has the highest strength to weight ratio. The net weight of the optimized model is 0.25 Kg. The maximum stress is about 48 Mpa, which is less than a half to the requirement (one-third of yield strength of CFRP = 107 Mpa; table 1). This gives factor of safety (FOS) of six. Higher FOS is also an advantage against aging failures such as fatigue and creep [17]. Maximum displacement is about 0.034 mm, which is very small in comparison to the part dimensions.
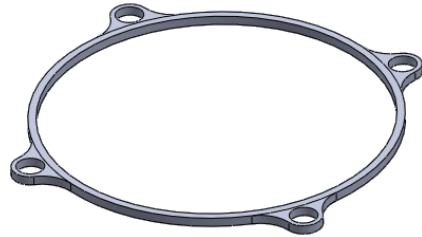
(a)
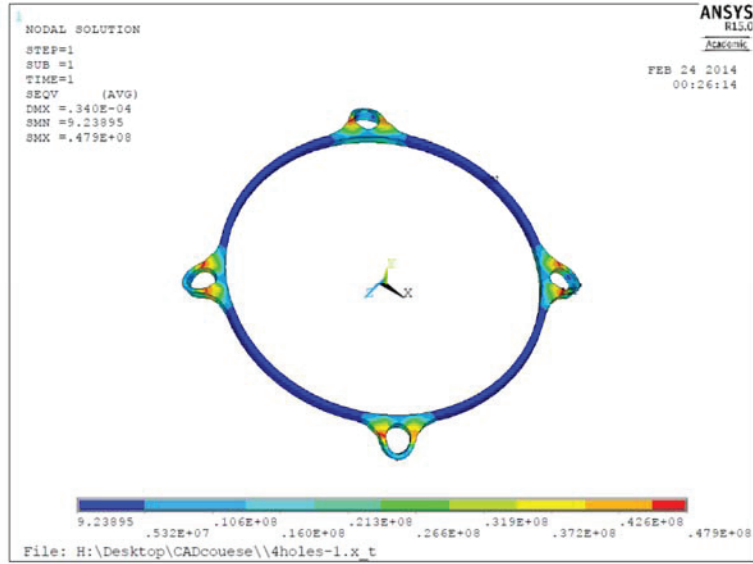


(b)
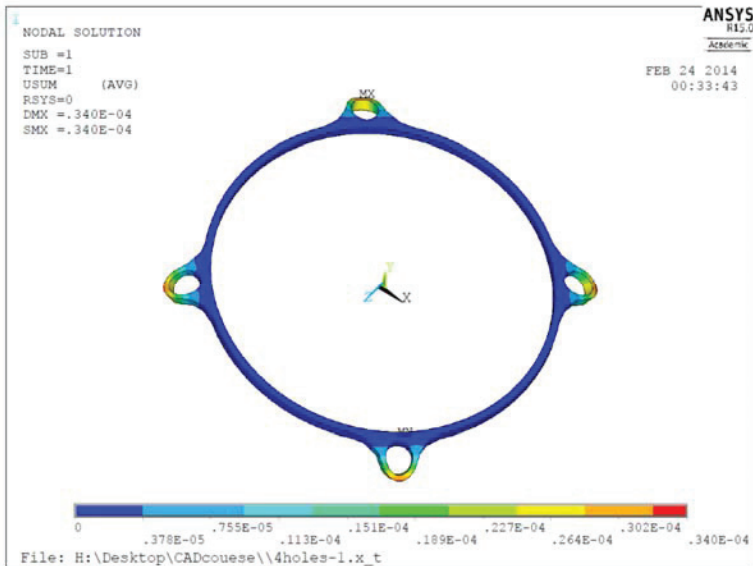


(c)

**FIGURE 6.** (a) Optimized CAD model. (b) The von-Mises stress (N/m$^2$ = 10$^{-6}$ Mpa) contours. (c) The resultant displacement (m) contours.

## CONCLUSION

The optimization methodology is a cyclic iterative process. Computer aided design (CAD) model and Multiphysics analysis (for example: finite element methods (FEM)) are the key inputs for the optimization process. In addition, knowledge from an engineering area is required to understand the problem and its solution. Given work presents an optimization of an attachment component of a loading hanger with set of requirements. Discussed methodology is tried and proved to be effective. The knowledge from mechanics of materials is the key to understand the problem and its solution.

## ACKNOWLEDGMENTS

## REFERENCES

1.  Lancashire, T., et al., *Investigation of the Mechanics of Cargo Handling by Aerial Crane-type Aircraft*1966: Defense Technical Information Center.
2.  Webster, L.F., *The Wiley Dictionary of Civil Engineering and Construction*1997: Wiley.
3.  Arora, K.C. and V.V. Shinde, *Aspects of Materials Handling*2007: Laxmi.
4.  (IHSA), I.H.S.A., *Construction Health and Safety Manual: Helicopter Lifting*, 2007.
5.  Khawaja, H., *CAD-CAM (STE-6209) MS Excersice*, N.N. Narvik University College, Editor 2013.
6.  Xue, H., *Helicopter Loading Hanger*, 2013, Narvik University College, Norway.
7.  Khawaja, H. and M. Moatamedi, *Selection of High Performance Alloy for Gas Turbine Blade Using Multiphysics Analysis.* The International Journal of Multiphysics, 2014. **8**(1): p. 91-100.
8.  Khawaja, H., et al., *Optimization of elstomeric micro-fluidic valve dimensions using non-linear finite element methods.* The International Journal of Multiphysics, 2009. **3**(2): p. 187-200.
9.  Systèmes, D., *SolidWorks®*, release 2012.
10. ANSYS®, *Academic Research*, release 14.0.
11. ANSYS®, *Academic Research, Theory Reference*, in *Structures, Static Analysis* release 14.0.
12. Dinesen, B., *Design of lifting frame for helicopter*, 2013, Narvik University College, Norway.
13. Mises, R.v., *Mechanik der festen Körper im plastisch- deformablen Zustand.* Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse, 1913. **1913**: p. 582-592.
14. Cook, R.D. and W.C. Young, *Advanced mechanics of materials*1999: Prentice Hall.
15. Tsai, S.W.a.W., E. M., *A general theory of strength for anisotropic materials.* Journal of Composite Materials, 1971. **5**: p. 58-80.
16. Oller, S., E. Car, and J. Lubliner, *Definition of a general implicit orthotropic yield criterion.* Computer Methods in Applied Mechanics and Engineering, 2003. **192**(7–8): p. 895-912.
17. Gere, J. and B. Goodno, *Mechanics of Materials*2012: Cengage Learning.
18. Timoshenko, S., *History of Strength of Materials: With a Brief Account of the History of Theory of Elasticity and Theory of Structures*1983: Dover Publications.
19. Gere, J.M. and S. Timoshenko, *Mechanics of materials*1990: PWS-KENT Pub. Co.