Design And Development of Nacelle Transport Carrier With Weight Optimization Using FEA

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Abstract- *This study presents finite element analysis based validation of a new nacelle carrier design. This study consists of understanding of transporting device of a wind turbine nacelle from manufacturing site to installation site. The methods of transporting the wind turbine nacelle and the modes of transportation for domestic road transportation conditions and toppling related issues of nacelle study and to overcome the toppling issue probable solutions are provided. Since the nacelle carrier is made up of fabrication process, the welding stability of the component is calculated. Also the stability of nacelle during transportation is important, since the most of the installation sites of wind turbine generator at hill stations there we cannot find a smooth road for the transportation, hence it is important to calculate the weld strength of the component, toppling angle of the component. The device used for transportation is made up of structural steel and is bulk in size of the cost is also increase, if the component of weight is increases. Hence in this work we are developing nacelle transportation device with weight optimization using finite element analysis method. Various designs concepts are prepared by bench marking compotators turbine. The nacelle carrier is safe for working load & experiences maximum 144 MPa of equivalent stress with minimum stress safety factor 1.41. Welds- Minimum stress factor (SFu) is 1.04 new design of nacelle carrier fulfils the structural strength requirements standard requirement. Weight optimization of nacelle carrier is achieved to 1.5 tonnes.*

Keywords- Wind Turbine, Nacelle, Transportation, Weight optimization.

I. INTRODUCTION

This work involved design and development of Nacelle transportation carrier with weight optimization using FEA, and also study of the issues involved in transporting heavy, bulk product like a wind turbine nacelle. This involves studying the existing literature and understanding the various factors that affect transportation of products over a long period of time and using different modes of transport. The current device used for transportation of a wind turbine nacelle is optimized in terms of weight and ergonomics. These suggestions to overcome the effect of such factors that have an effect on the shipping of the nacelle have proposed. One of the biggest cost components associated with transportation damage is warranty and replacement costs. Hence, the aim of this work is to find a trade-off between transportation device costs and damage costs. Nacelle with Nacelle transport carrier as shown in fig. 1.

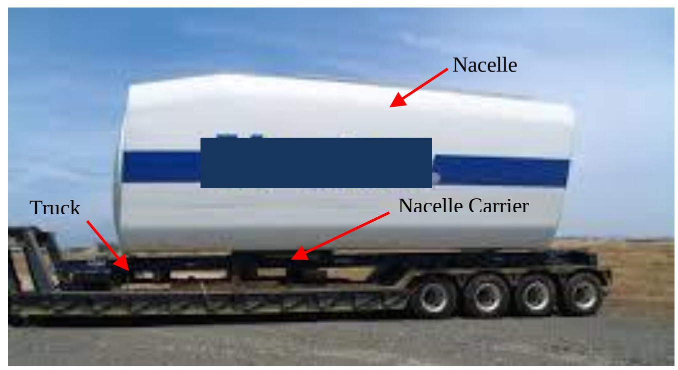

Fig.1. Nacelle with Nacelle transport carrier [7]

II. LITERATURE SURVEY

A comprehensive study and review of articles, books related to transportation, periodicals and research papers was conducted to understand the various factors that have an impact during transportation of heavy bulk goods. In addition to this, process specifications of the manufacturer of the wind turbine nacelle were studied to understand the measures taken during transportation. Further studies of the shipping practices of various cargo handling firms were carried out.

Mogens Christensen, Tjele, Lars Budtz [3], studied about wind turbine nacelle, and particularly, to a vehicle for transporting a wind turbine nacelle, a nacelle for being transported a method of transporting a nacelle and a method of loading a nacelle. nacelle that is releasable attachable from truck bed once it reaches the installation site, the nacelle being adapted for suspension of the nacelle between at least two wheel sets as completely or partly self-supporting suspension. They found an advantage that complete vertical extension of the vehicle may be reduced compared to traditional nacelle transportation setups due to the fact that frame structure of the nacelle forms part of the complete vehicle. According to invention the vehicle may advantageously comprise standard transportation components such as trailers suitable for other transportation purpose.

Rissi G. O. et. al. [5], analysed the vibration that occurs during truck transport in Brazil. The study was done using two types of trucks: small local trucks for local metropolitan distribution areas and larger tractor-trailers for cross-country transportation. Ten metropolitan areas in different regions of Brazil were selected for 1-day trips representing normal delivery. These trips encountered varying road surfaces (asphalt, concrete, stone and dirt). The long distance trips were done on highways that were more than 1200 km long. The vertical vibration levels were higher than the lateral and longitudinal levels as expected. Singh S. P. et. al. [6], described the vibration levels in truck and rail shipments of freight to various major metropolitan cities in India. The study also compared the vibration levels in trucks versus those in railcars and developed lab-simulated vibration test methods to simulate truck and rail shipments. The data recorders were mounted directly on to the vehicle (truck and rail) platform base. Two replicates were measured for all rail and truck shipments between certain distribution networks.

After reading the articles after reading the articles, it is understood that there are certain factors which have a direct effect in causing damage to the products during transportation. During intermodal transportation which involves transportation by truck and sea or truck and air, these factors must be considered and methods to measure such factors need to be implemented. Also techniques that could be employed to prevent damage must be put in place.

III. MATHEMATICAL FORMULATION

On nacelle carrier, 3 types of loads act which are mentioned below

A. Self-Weight of Nacelle

Times This load acts through C.G of nacelle in vertically downward direction (along Z axis).
Mass of nacelle = 78 tonne
Load safety factor = 1.5 as per [4]
Weight of nacelle = 78 tonne × 1.5 × 9.81 m/s^2 = 1148 KN

B. Longitudinal Direction Force+ Self Weight of Nacelle

During transportation, due to sudden application of truck brakes, nacelle experiences deceleration in truck moving direction. As per DIN EN 12195-1 load restraint assemblies on road vehicles – Safety [1], longitudinal acceleration coefficient is 0.8. Along with this force self-weight of nacelle also acts in vertically downward direction.
Longitudinal force = 1148 KN × 0.8 = 918 KN
Weight of nacelle = 1148 KN

C. Transverses Direction Force

During transportation, due to road curvature, nacelle experiences acceleration in transverse direction. As per DIN EN 12195-1 load restraint assemblies on road vehicles – Safety [1], transverse acceleration coefficient is 0.5. Along with force self-weight of nacelle also acts in vertically downward direction as shown in figure.
Transverse force = 1148 KN × 0.5 = 574 KN
Weight of nacelle = 1148 KN

Nacelle and nacelle carrier are connected together by using 16 numbers of M39 size bolts.

IV. FINITE ELEMENT ANALYSIS

The essential prerequisite of the FEA is the geometry of the part which is created by utilizing the product known as Inventor-2016, Analysis of optimized nacelle carrier of Suzlon wind turbine generator using Finite Element Analysis. Transportation load calculations are performed as

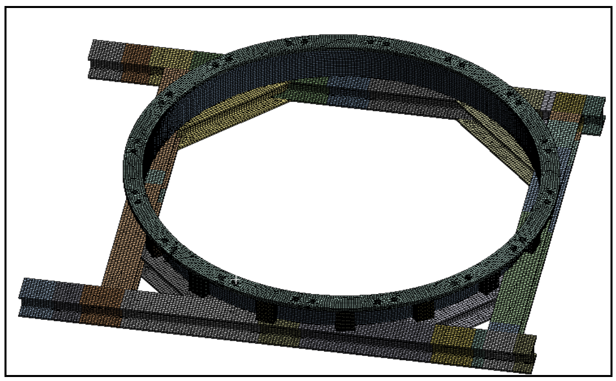

Fig.2. Finite Element mesh of nacelle carrier

Load restraint assemblies on road vehicles – Safety DIN EN 12195-1 [1]. Analytical welding calculation is performed as per DIN EN 1993-1-8 guidelines [2]. Mesh size is kept between 10 mm to 22 mm depending on the criticality of concerned area.

TABLE I Mesh Properties

Sr.No	Name of Components	No of Elements	No of Nodes
1	Nacelle Carrier	113337	524966
2	Gear rim	279276	431551

TABLE II Material Properties

Sr.No	Name of Components	Nacelle Carrier	Gear Rim
1	Material	S235JR	Dummy
2	Young's modulus, MPa	$210e^3$	$210\ e^3$
3	Poisson's ratio	0.3	0.3
4	Density, t/mm³	7.85^{e-9}	7.85^{e-9}
5	Yield strength, Rk=Rp0.2 MPa(>16 mm thickness ≤40 mm)	225	-
6	Allowable yield strength,	204	-

Nacelle carrier along with nacelle is mounted on truck bed in such a way that rotor side of nacelle is pointed towards truck cabin, while generator side is pointed towards tail of the truck. Therefore nacelle carrier is constrained from bottom in such a way that only displacement is restricted x and y direction, while in z-plane displacement is allowed as shown in fig. 3-4. Therefore in FEA, side faces of I beam are constrained in transverse and longitudinal direction (x and y direction), while z-plane direction displacement is kept free as shown in fig.3-4

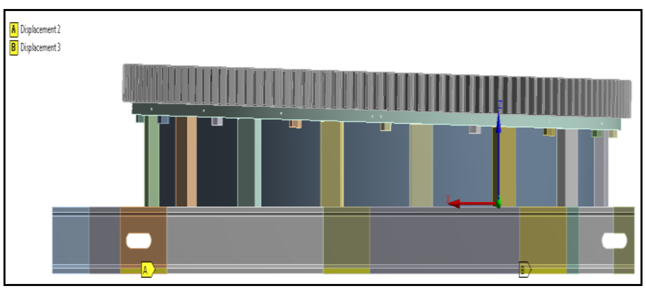

Fig.3.Boundary condition (X and Y axis) are restricted

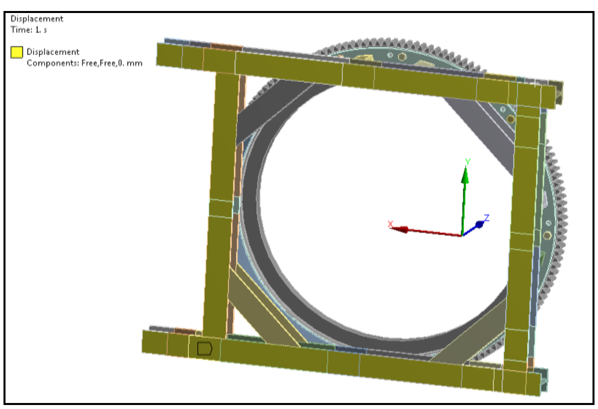

Fig.4. Boundary condition (Z-axis) is restricted.

D. Bolt Pretension

Nacelle is mounted on nacelle carrier with 16 numbers of M39 bolts. All these bolts are pretensioned with 1000 N-m of torque as shown in fig. 5.

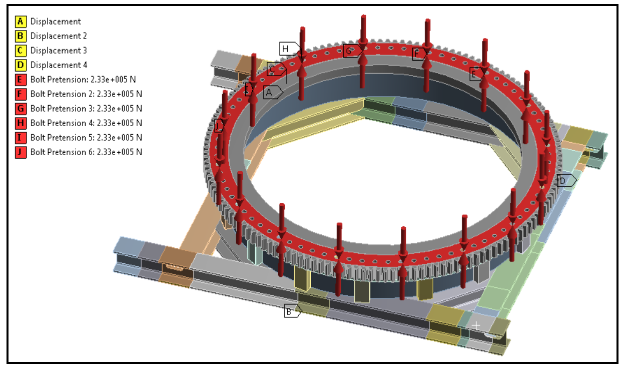

Fig.5. Bolt pretension

E. Self-Weight of Nacelle

Nacelle weight along with safety factor = 1148 KN this weight acted in vertically downward direction (Z axis) as shown in fig. 6.

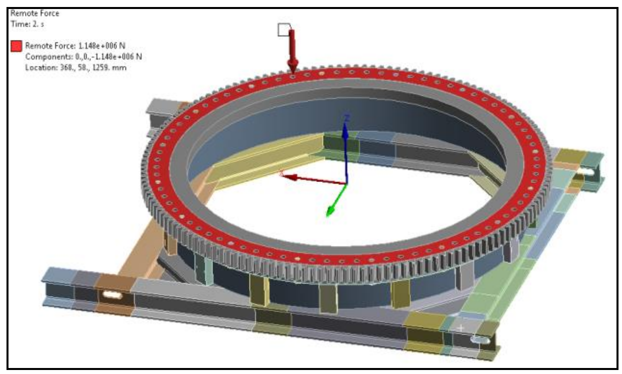

Fig.6. Weight of nacelle

F. Longitudinal Direction Force

During transportation along with self-weight of nacelle, longitudinal force also acts on nacelle carrier because of sudden truck braking as shown in fig. 7.

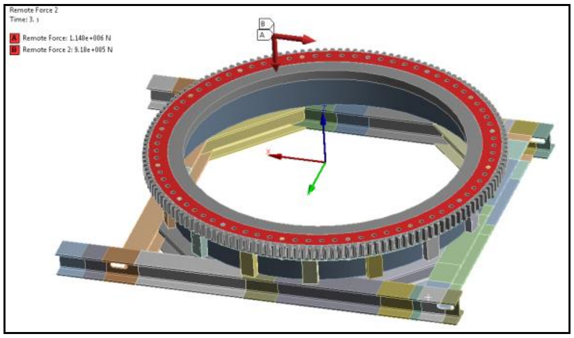

Fig.7. Longitudinal force along with self-weight of nacelle

G. Transverse Direction Force

During transportation along with self-weight of nacelle, transverse force also acts on nacelle carrier because of truck turning on a road as shown in fig. 8.

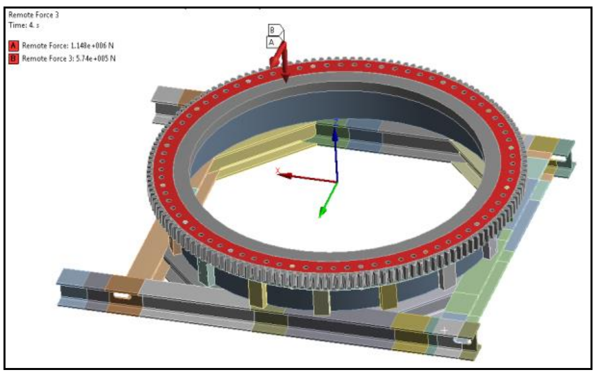

Fig.8.Transverse force along with self-weight of nacelle

H. Plausibility Check

Plausibility of result is checked by verifying FE model deformation for nacelle self-weight. Self-weight of nacelle is acted in vertically downward direction (Z axis) through C.G of nacelle. C.G of nacelle is shifted towards generator side of rotor therefore as expected; larger deformation is observed near generator side of nacelle carrier. Also observed deformation on I section of beam where C channel of nacelle carrier is in contact. Plausibility shows that all the contacts are working correctly as shown in fig. 9.

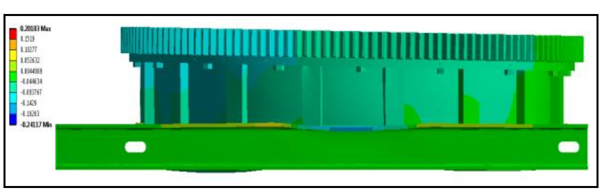

Fig.9. plausibility check

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I. Equivalent Stress

Equivalent stress is checked by verifying FE model deformation for nacelle self-weight. Self-weight of nacelle is acted in vertically downward direction (Z axis) through C.G of nacelle.

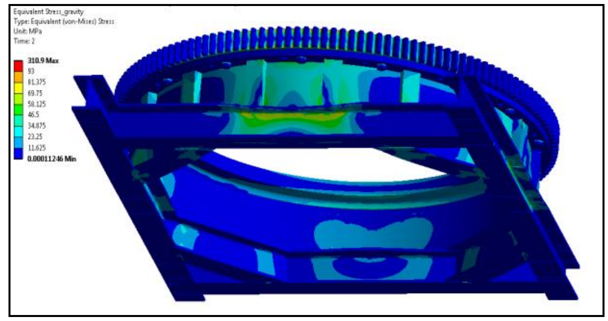

Fig.10. Equivalent stress

V. WELDING ANALYSIS

The evaluation of welding seams for static strength is performed according to the recommendation of DIN EN 1993-1-8 [2]. The fillet weld has been evaluated as per directional method.

Critical welding locations are identified and welding calculation is performed for those locations as shown in fig. 11-12 and welding section shown in fig.13.

Loads are found using ANSYS FSUM command executed on elements representing welded region. The summation point is centre of gravity of each weld. Coordinate systems used for extracting the FSUM results are local co-ordinate system at centre of gravity of each welding. The equivalent stress is calculated as follows:

$\sigma_{w,v,zd} = \sqrt{(\sigma^2 + 3 \times (\tau_1^2 + \tau_2^2))}$..............................[2]

where σ = Normal stress ,

τ_1 = perpendicular shear stress

τ_2 = parallel shear stress

According to [2] the allowable welding stress is evaluated via

$\sigma_{w,R,d} = f_u / (\gamma_{M2} \times \beta_w) = 360 / (1.25 \times 0.8) = 360$ MPa

where fu = minimum ultimate tensile strength of weaker part joined.

β_w = correlation factor

γ_{M2} = partial safety factor

For S235J0 material, allowable welding stress with normal loading

$\sigma_{Rd} = (0.9 \times f_u / \gamma_{M2}) = 0.9 \times 360/1.25 = 259.20$ MPa

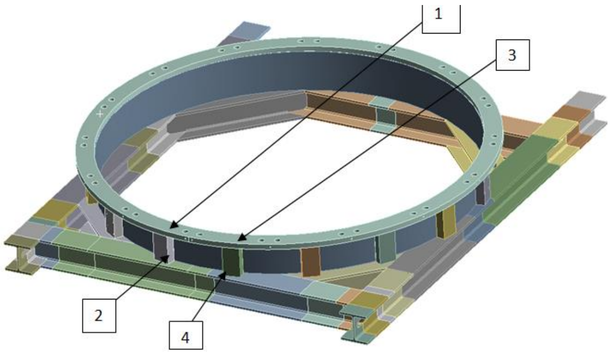

Fig. 11.Critical weld location

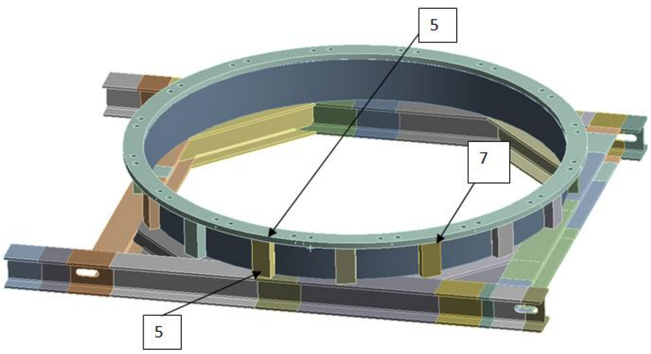

Fig. 12.Critical weld location

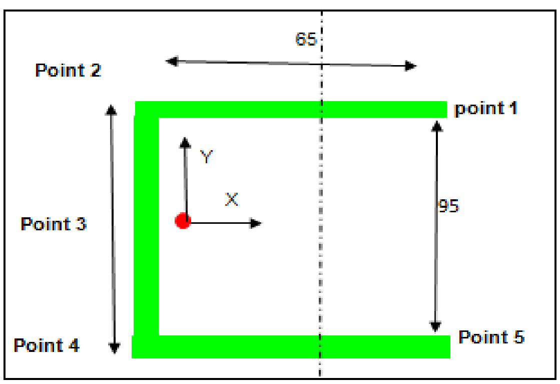

Fig. 13.Welding section

VI. TOPPLING ANALYSIS

The stability The stability of a load is determined both longitudinal direction (X-axis) and transverse direction (Y-axis) for new nacelle carrier design

Loads to be considered as per transportation guideline DIN EN 12195-1 (2004)(en) along with safety factors as per GL 2010 and guidelines.

A. Loads Acting On Nacelle Carrier

Weight of nacelle = 75 tonne * 1.5 * 9.81 = 1103.62 KN
Transportation load (longitudinal) = 75 tonne *1.5*9.81*0.8 = 883 KN

Transportation load (Transverse) = 75 tonne*1.5*9.81*0.5 = 552 KN

B. Stability Equation

$F_Z \,.\, b_{xy} > F_{x.y} \,.\, d$..[1]

$$b_{x,y} > \frac{Fxy}{Fz} \,.\, d$$

$$b_{x,y} > \frac{Cxy}{Cz} \,.\, d$$

Stability of Load in Longitudinal direction
1103.62 x 1918 > 883 x 1801
2116743.16 KN > 1590283 KN

Stability of Load in transverse direction
1103.62 x 1468 > 552 x 1801
1620114.16 KN > 994152 KN

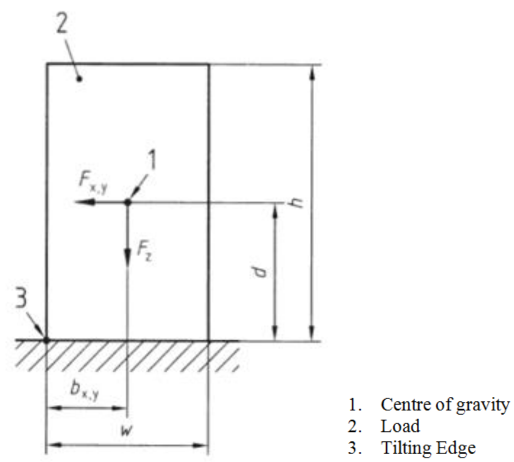

Fig.14. Stability of unlashed loads

The basic mechanics of stability of a block against toppling on an inclined plane are illustrated as shown in fig.14.

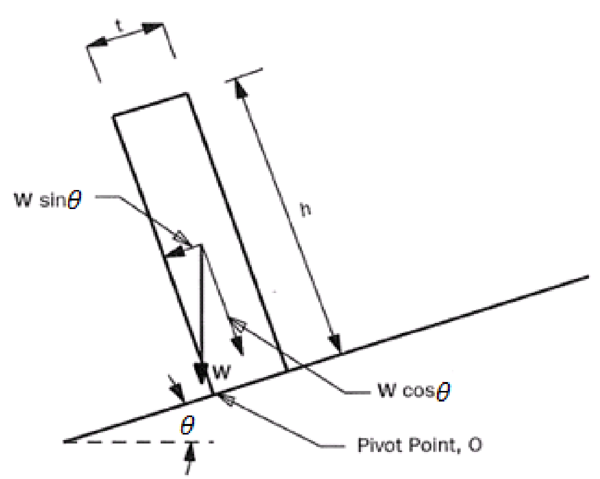

Fig.15. Stability of unlashed loads inclined condition

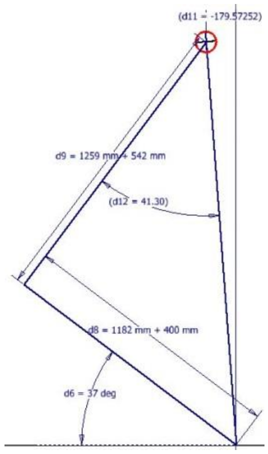

Fig.16. Toppling of Nacelle

If the angle of nacelle going more than 37 degree nacelle toppling is occuring as shown in fig.15-16.

VII. EXPERIMENTAL VALIDATION

Nacelle carrier proto model is fabricated by sheet metal & various standard steel profiles by which are readily available in market the manufacturing process for component is like simple bending, welding and machining.

After the proto manufacturing component is fitted in to wind turbine generator & checked for interface connection from assembly point of view, after the assembly the component is sent to installation site from manufacturing site, once the nacelle is reached the installation site nacelle carrier is disassembled from nacelle during commissioning of the turbine. Nacelle carrier experimental inspection completed for checking any damages or welding crack. No major observations are found. Based on proto feedback nacelle carrier is released for serial production as shown in fig.17-18

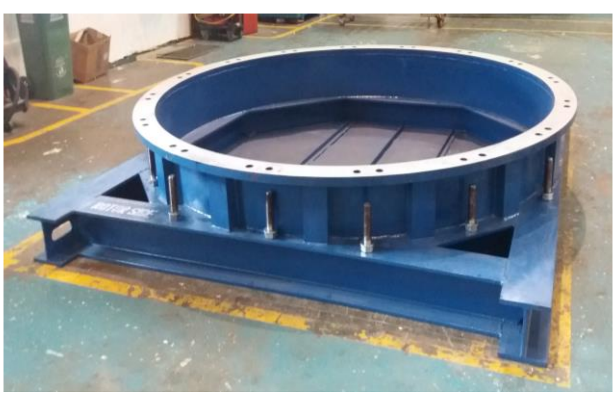
Fig.17. Nacelle carrier proto model


Fig.18. Nacelle carrier assembled in nacelle


Fig.19. Nacelle road transportation

Nacelle road transportation is shown in fig.19 nacelle is transported to installation site and observations were recorded during transportation the site feedback has been received and no observations are found.

VIII. RESULTS AND CONCLUSIONS

The nacelle carrier is safe for working load & experiences maximum 144 MPa of equivalent stress, as shown in above fig. 10 allowable stress is 204 MPa, minimum stress safety factor is 1.41.

Welds- Minimum stress factor (SFu) is 1.04. Nacelle carrier fulfills the structural strength requirements as per it is safe according to [4]. Final weight of nacelle carrier is achieved to 1.5 tonne by using FEA optimization method.

Damage cost of nacelle will reduce with new improved design of nacelle carrier.

IX. ACKNOWLEDGMENT

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