CITY COLLEGE

CITY UNIVERSITY OF NEW YORK

Final Project

Structural Integrity
Of Nose Landing Gear of Boeing 747-400

ME 371: Computer Aided Design

Spring 2011

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Submitted By:

Group 1

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May 31, 2011

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Nomenclature

$R_{ny} = vertical\ reaction\ on\ rear\ wheel\ (lbf)$

$R_{my} = vertical\ reaction\ on\ front\ wheel\ (lbf)$

$W = weight\ of\ aircraft\ (lbf)$

$a = decending\ acceleration\ \frac{ft}{s^2}$

$g = \ acceleration\ due\ to\ gravity\ \frac{ft}{s^2}$

$L = center\ to\ center\ length\ of\ gears\ (lbf)$

$M = moment\ due\ to\ decending\ velocity\ (lbf - ft)$

$R_{nx} = horizontal\ reaction\ due\ to\ friction\ \ (lbf)$

$\mu = coefficient\ of\ rolling\ friction$

$r = radius\ of\ wheel\ (inch)$

1. Objective

The landing gear system consists of various components that incorporate hydraulics such as shock absorber piston and struts, and electromechanical sub-assemblies, such as actuators, valves, accumulators and pylons. The primary objective of the aircraft is to absorb the load during landing and provide safe braking, and the secondary objective is to support the aircraft during ground maneuvering such as taxing. It comprises structural and hydraulic items composed of landing gear leg strut, shock absorber, wheel, tire, break, beams, up and down lock actuators and retraction actuator. In this analysis it is considering that the Oleo cylinder-piston hydraulics system have complete failed, the oleo struts comes in complete contact with wheel hubs and the doesn't produce and sort of damping effect in reducing the inertia load of the aircraft. Because of the complex of geometries, the system is statically indeterminate and the Strength of Material Theory is not accurate enough to evaluate stress results which produced the necessity of the use of finite element tools. Hence, the Oleo cylinder of the Nose Landing gear of the Boeing 747-400 is analyzed for this case and FEM analysis is run to validate the design structural integrity. In this project, stress analysis of Oleo cylinder was evaluated using Solidworks COSMOS Simulation and result were used to optimize the critical stress.

2. Problem Statement

- The purpose of this project is to study and optimize the Oleo–pneumatic shock absorber in the nose landing gear of Boeing 747-400, considering the worst case senior of failure.
- The assembly of landing gear was studied in solidworks simulation and its stress analysis was used to re design the lug.

3. Introduction

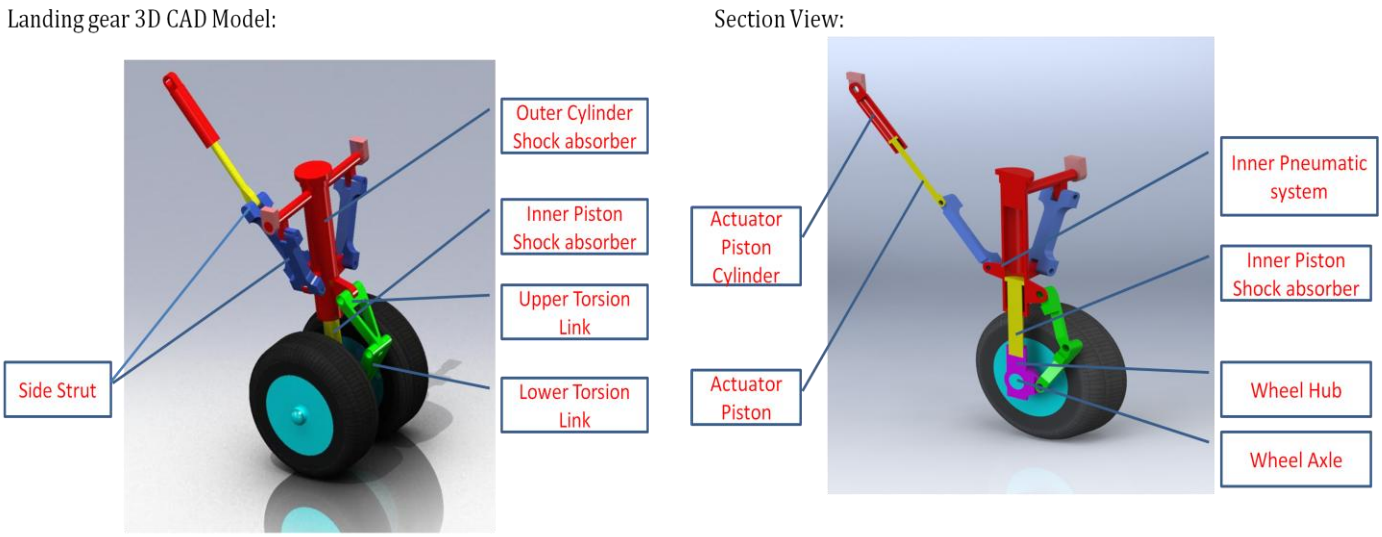


Fig 1: Schematic FBD of a Boeing 747-400 with its dimension

Landing gears are legs and wheels aircraft use for landing and taking off. Landing gear struts act as shock absorbers, reducing impact and providing softer landings. During flight the landing gears are retracted into the body of the aircraft to reduce drag and improve fuel efficiency. Aircraft extend their landing gear as they approach a landing strip. Once the aircraft has landed, the landing gears are used to taxi off the runway and steer the aircraft into its designated parking slot. Because of the enormous strain landing gears have to absorb, it is necessary for the landing gear to be overhauled after a specified amount of landings.

An aircraft's landing gear is otherwise known as the undercarriage. This is the part of the airplane which is a structure made of several parts that supports it while on the ground. With it an aircraft can land, take off, and taxi. The most common type of undercarriage everyone is familiar with is a landing gear wheel. The other types of landing gears include floats and skids.

The design and integration process encompasses numerous engineering disciplines, e.g., structures, weights, runway design, and economics, and has become sophisticated in the last few decades. Landing gear design considers an aircraft landing and force generated during impact landing. In the landing event, energy of the descending aircraft must be absorbed by the landing gear without generating reaction loads that exceed the design limit loads.

Things to be taken in account:

The location of the aircraft center of gravity (cg) is critical in the design and location of the landing gear. The nose and main assemblies must be located within specific distances from the aircraft cg, in both the longitudinal and lateral directions, such that the aircraft is in no danger of tipping back or turning over on its side over the full range of cg locations under static or dynamic conditions. Another issue to be considered is the distribution of the aircraft weight, which is dependent on the distances between the aircraft cg and the nose and main assembly.

4. Mathematical Analysis

To understand the application of forces on the landing gear, an understanding of the theory behind the forces produced must be taken account. Modeling the dynamics problem as comparable quasi static problem concerning with the analysis of load such as weight and inertia mass along with moment and torque. Static equilibrium refers to a state where the relative positions of subsystems do not vary over time, or where components and structures are at rest under the action of external forces of equilibrium.

By Newton's Second law, static equilibrium dictates that the net force and net moment on everybody in the system is zero. In other words for every force there is an equal but opposite force acting on it.

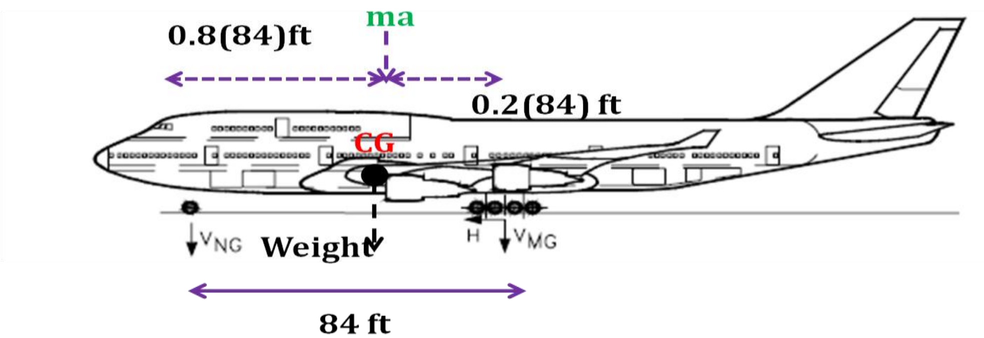


Fig 2: Schematic FBD of a Boeing 747-400 with its dimension

For Nose Gear,

Weight of Aircraft (W) $= 845{,}000.00$ lbf
Landing Acceleration (a) $= 1.8 * g \ \frac{ft}{s^2}$
Acceleration due to gravity (g) $= 32.2 \ \frac{ft}{s^2}$
rolling friction coefficient between wheel and asphalt (μ) $= 0.02$
Radius of wheel (r) $= 25$ inch

By Equation of Equilibrium for just at instance of landing

$$\sum f_y = 0$$

$$W - R_{ny} - R_{my} + \frac{W}{g} * a = 0$$

$$R_{ny} + R_{my} = W - \frac{W}{\cancel{g}} * 1.8 * \cancel{g}$$

$$R_{ny} + R_{my} = W(1 + 1.8)$$

$$R_{ny} + R_{my} = 2.8 * W ------------------------(1)$$

$$\sum M_{CG} = 0$$

$$R_{ny} * 0.8 * L - R_{my} * 0.2 * L = 0$$

$$R_{ny} * 0.8 * \cancel{L} = R_{my} * 0.2 * \cancel{L}$$

$$R_{my} = \frac{0.8}{0.2} * R_{ny}$$

$$R_{my} = 4 * R_{ny} --------------------------(2)$$

Solving the equations (1 and 2) simultaneously we get

$$R_{ny} = 2.8 * \frac{W}{5} = 490{,}000.00 \ lbf$$

$$R_{nx} = R_{ny} * \mu = 4.9 * 10^5 * 0.02 = 9800 \text{ lbf}$$

$$M = R_{nx} * r = 9800 * 25 = 245{,}000 \text{ lbf} - \text{inch}.$$

5. Implication of Design

Step 1: Suppressing the components which are not significantly related in the simulation.

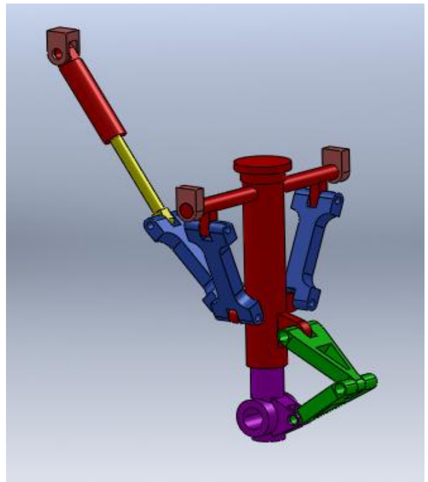
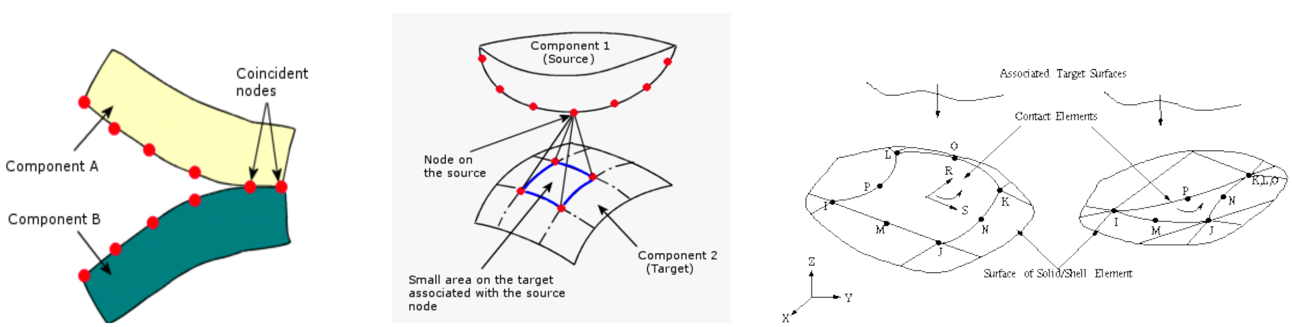


Fig 3: Suppressed Geometry for FEM analysis

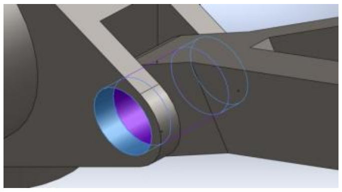
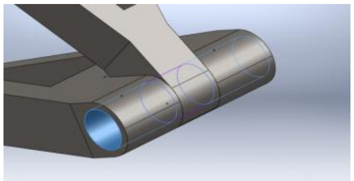
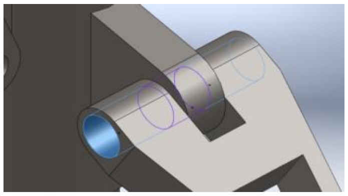
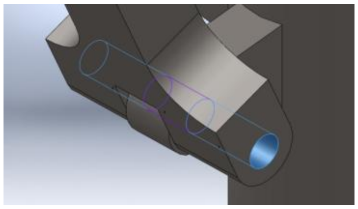
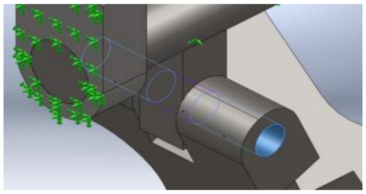
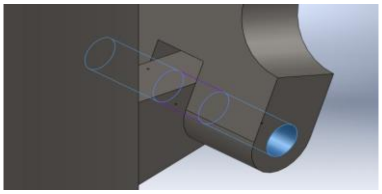
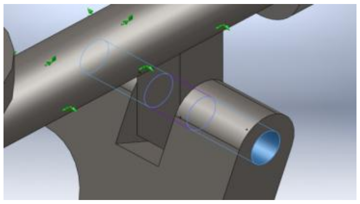
Step 2: Step us contact sets between the geometry. Solidworks gives three options for contacts set which depends option not only the geometric links and mate type but also on the contact between two components during motion. For our study surface to surface contact has been taken into account as each component are connected with standard nuts and bolts with pre specified torque for stability hence displacement in one component induce contact and transfer load and surface to surface contact actually represent this phenomena with perfection to reality.

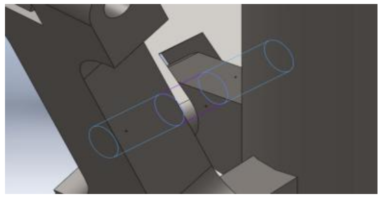
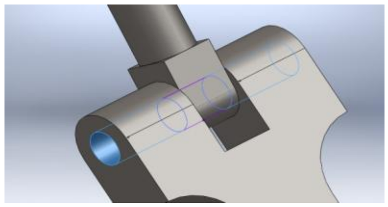
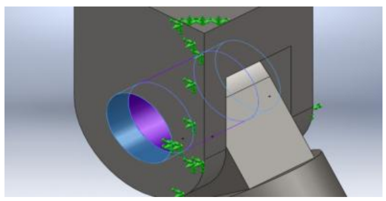
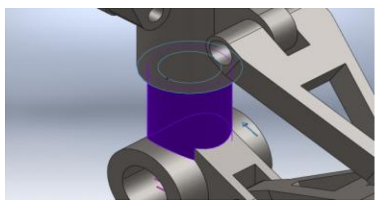
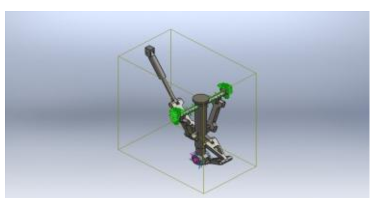


(a) (b) (c)

Fig 4: Types of contact in solidworks (a) node to node, (b) node to surface and (c) surface to surface

Contact Information

Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-2		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-3		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-4		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-5		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-6		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-7		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface

Contact	Contact Image	Contact Properties
Contact Set-8		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-9		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-10		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Surface to surface
Contact Set-11		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Step4: Material Properties:

ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	movable mount	Cast Carbon Steel	1
2	movable mount 2	Cast Carbon Steel	2
3	actuator cylinder	AISI 4340 Steel, An	1
4	actuator piston	AISI 4340 Steel, An	1
5	oleo strut cylinder	AISI 4340 Steel, No	1
6	oleo strut piston	AISI 4340 Steel, An	1
7	wheel hub	AISI 4340 Steel, An	1
8	upper sway link	AISI 4340 Steel, No	2
9	strut 2	AISI 4340 Steel, An	3

Table 1: Part Name and associated Material

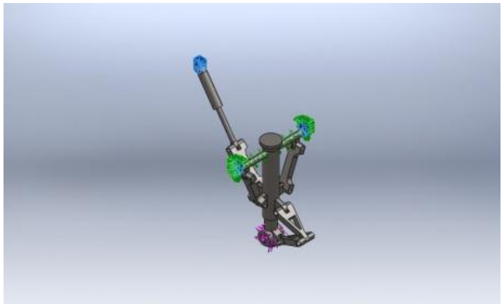
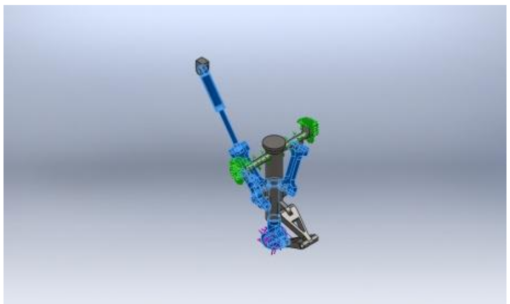
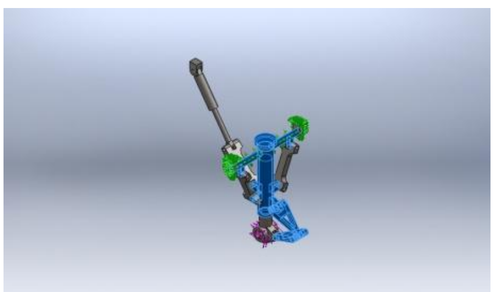
Model Reference	Properties
	Name: **Cast Carbon Steel** Model type: **Linear Elastic Isotropic** Yield strength: **2.48168e+008 N/m^2** Tensile strength: **4.82549e+008 N/m^2** Elastic modulus: **2e+011 N/m^2** Poisson's ratio: **0.32** Mass density: **7800 kg/m^3** Shear modulus: **7.6e+010 N/m^2** Thermal expansion coefficient: **1.2e-005 /Kelvin**
	Name: **AISI 4340 Steel, annealed** Model type: **Linear Elastic Isotropic** Yield strength: **4.7e+008 N/m^2** Tensile strength: **7.45e+008 N/m^2** Elastic modulus: **2.05e+011 N/m^2** Poisson's ratio: **0.285** Mass density: **7850 kg/m^3** Shear modulus: **8e+010 N/m^2** Thermal expansion coefficient: **1.2e-005 /Kelvin**
	Name: **AISI 4340 Steel, normalized** Model type: **Linear Elastic Isotropic** Yield strength: **7.1e+008 N/m^2** Tensile strength: **1.11e+009 N/m^2** Elastic modulus: **2.05e+011 N/m^2** Poisson's ratio: **0.32** Mass density: **7850 kg/m^3** Shear modulus: **8e+010 N/m^2** Thermal expansion coefficient: **1.2e-005 /Kelvin**

Table2: Material Mechanical Properties

Step 5: External Loading

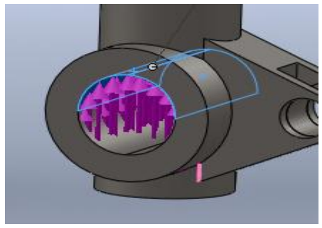
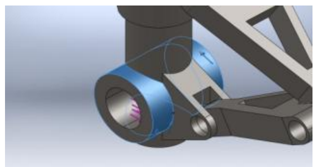
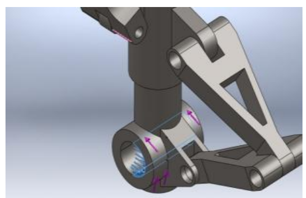
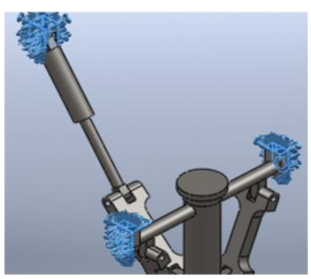
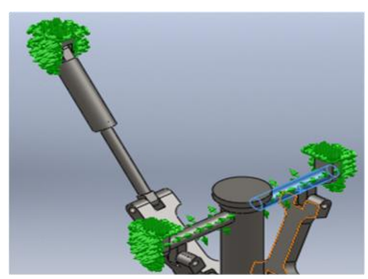
Load name	Load Image	Load Details
Force-1		**Entities:** 2 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---, ---, 490000 lbf
Force-2		**Entities:** 2 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---, ---, 9800 lbf
Torque-1		**Entities:** 1 face(s) **Type:** Apply torque **Value:** -245000 lbf-in

Table3: Applied Load on the Model

Step 6: Fixtures



Fixed Support Mount



Fixed Hinged

Fig 5: Boundary condition for Fixtures

Fixed support for the mount was used as the landing gear assembly is held into the structure of the aircraft such that it can retract and extend during takeoff and landing. This support is fixed however the sub component of the landing gear that is the shock absorber has and cylindrical support as to along its external arm such that it rotates about that axis/arm on the fixed mount during extension nd retraction. Hence fixed hinged support is used in this case to eliminate any torque resistance in its arm. Also the actuator is also supported by fixed support as the actuator is hold in its position with electrically control motor which resists and change in the position of landing gear other than desire angle during landing which is in our case is perpendicular to the surface.

6. Analysis of Data

Fig 6: High Quality Fine Mesh

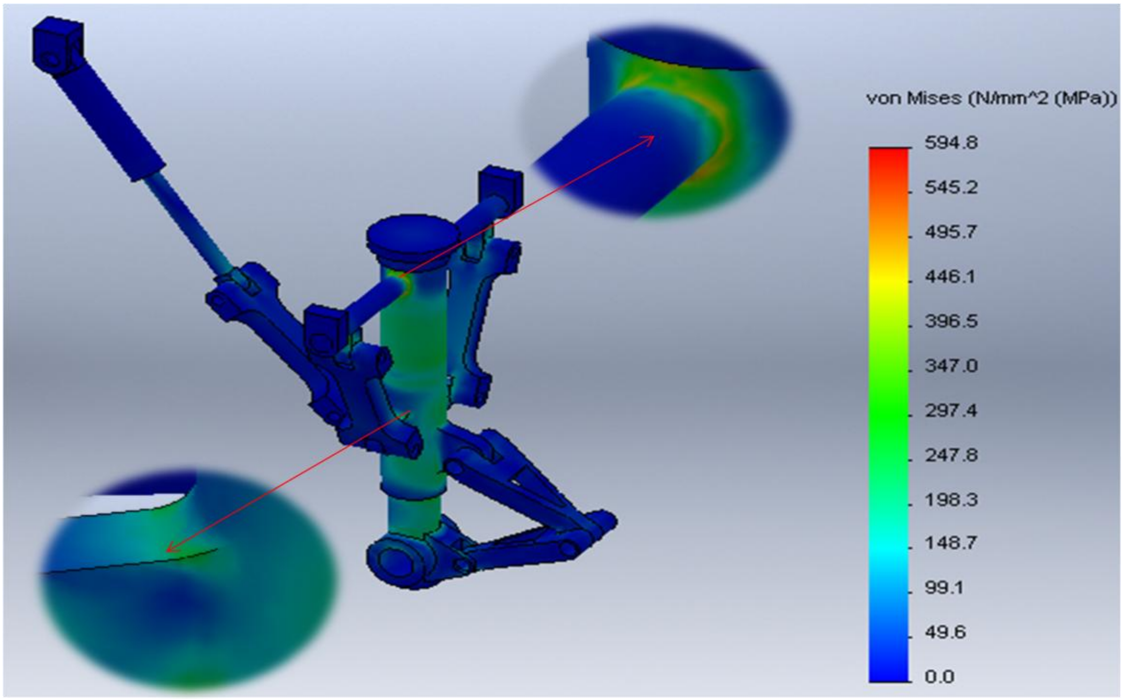
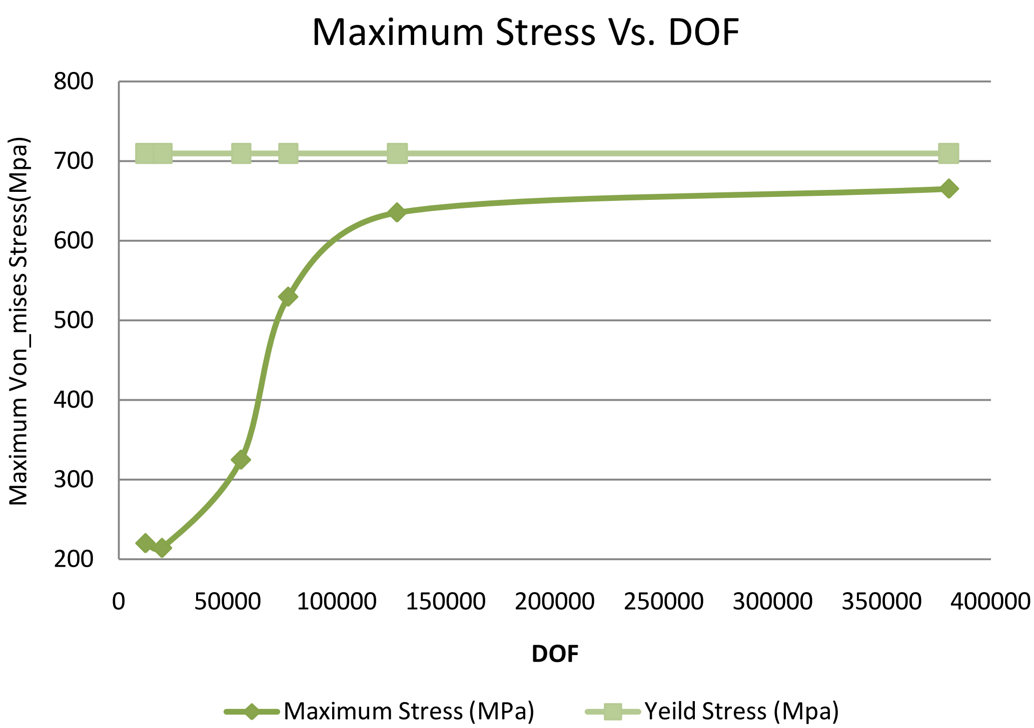


Fig 7: Stress Analysis result

As learned from FEM project 1 and 2 it was expected that most stress are induced in the area of sharp corners and edges where the internal forces vector are force to move close creating resultants force on the surface inducing critical stress. In figure 6, we see the high quality that is p-type of order 2 mesh with small element size offered as fine (h-type) is chosen. The result in figure 7, i.e. FEM analysis shows the critical stress at arms and the extrusion from the Oleo Cylinder.



Graph 1: The Convergence Plot for Maximum Stress of Oleo Cylinder before Optimization

From the graph above we can see that the value has converged to constant value of 680 MPa which is above the design allowable stress of 355 MPa with minimum factor of 2. However the body is before permanent deformation that is the maximum stress is well below the yield stress limit of 710 MPa. This design is failed with respect to the minimum factor of safety however the material are still in elastic region.

7. Optimization

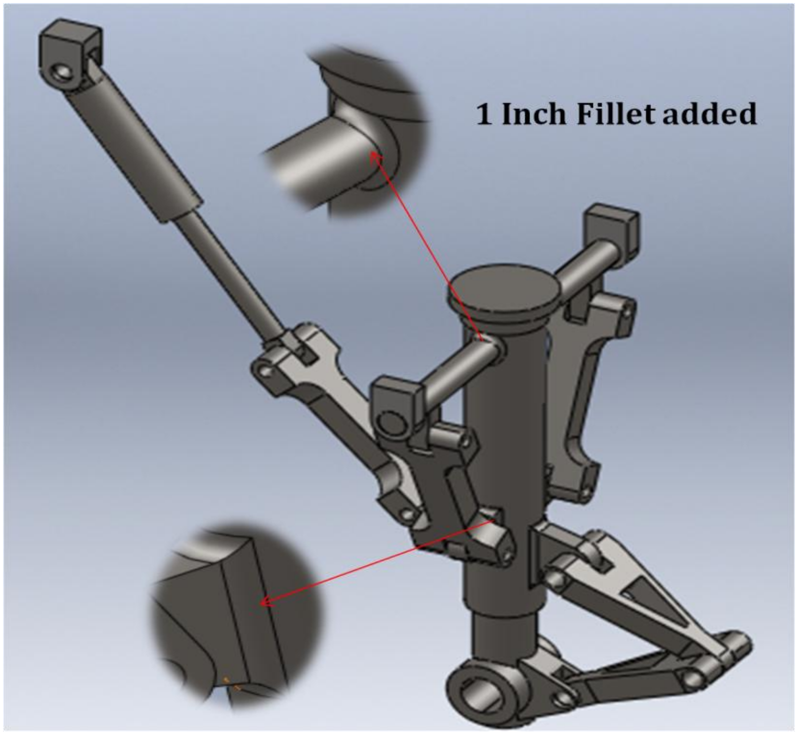


Fig 8: Optimization of Oleo Cylinder by adding 1 inch fillet

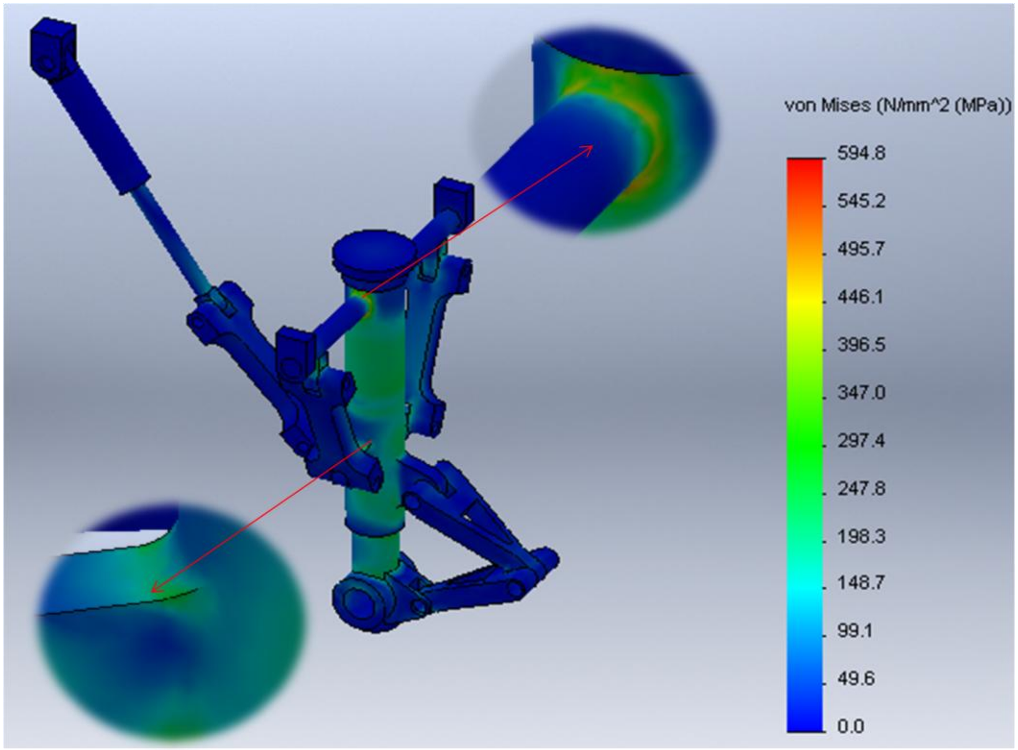
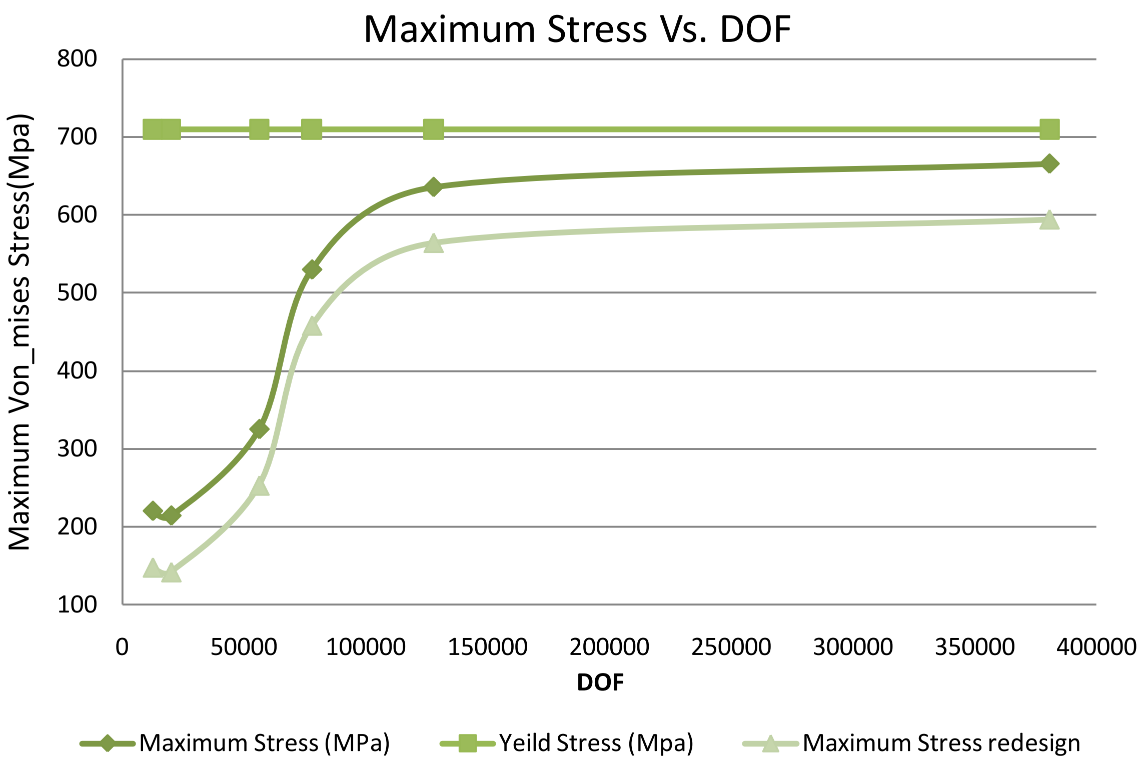


Fig 8: Stress analysis result after Optimization



Graph 2: The Convergence Plot for Maximum Stress of Oleo Cylinder before and After Optimization

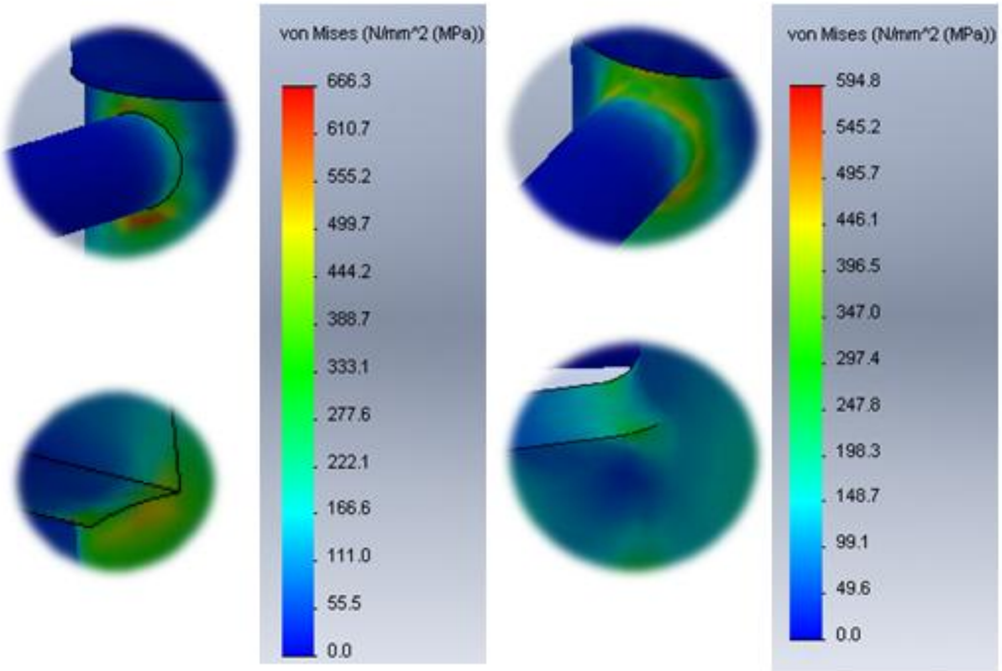


Fig 9: Comparison of Stress analysis result before and after Optimization

In graph 2, we can see that the result has converged, and there appear a significant amount of stress reduction that is of 60 MPa, however the stress are still above the desire safety factor which implies that the adding fillet reduce the stress however the model still fail such loading condition. Figure 9 shows the comparison of two condition of same loading however, we can see that simplify by adding an inch fillet to the part where the critical stress are induce, a significant reduction in stress are observed. Such modification can be achieved via computer simulation rather that rigorous scale modeling and experimentation before prototyping or full scale mockup.

8. Software

- Easy model simplification and integrated design development with general and advance mates.
- Absence of non-linear damping support or connection types.
- Effective meshing tool with curvature based mesh and fast solver FFEplus.
- Modification of geometric of parts in subassembly immediately updates the assembly file.
- Model reusability and open environment to design variables.

Problem and Difficulties with software

- Defining contacts sets.
- Dynamic studies from Drop Test.
- Non-linear damping shock absorber and torsion link study.
- Weight optimization

9. Conclusion

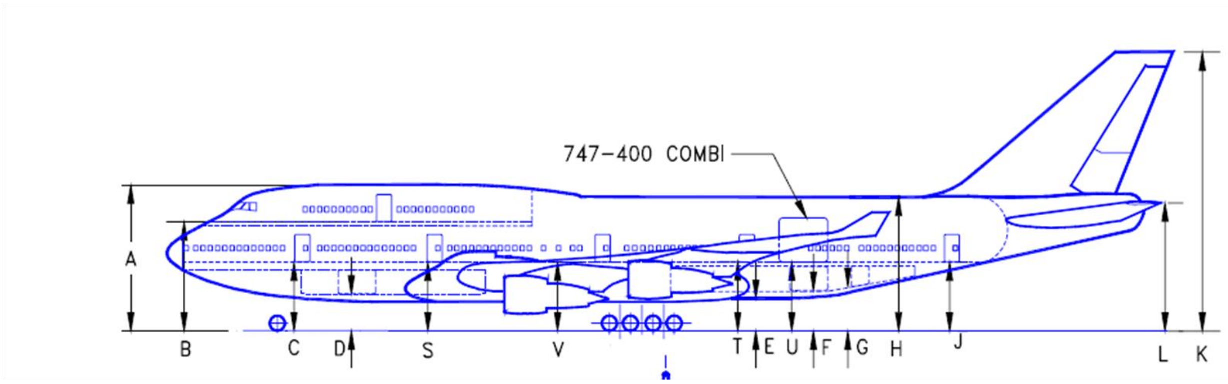
- Under design of landing gears is potentially dangerous and may result in severe damage to the aircraft. Therefore, it should be an important consideration in the design of a landing gear.

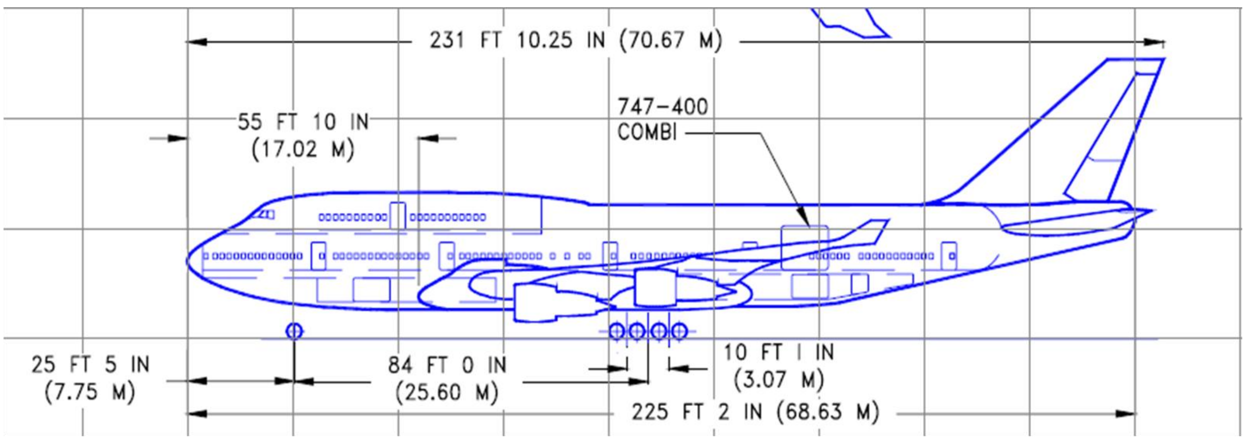
- This analysis showed the possibility to do a finite element model of complex system with multi body dynamics in single study.
- It is possible also to preview stress results, reducing time of the Landing Gear prototype development.
- Disfeatured and Suppress Geometry implies not a real physical condition is depicted.
- Under the most unlikely loading case studied showed that the model fail the safety factor, hence depending upon the requirement and safety consideration composite material with high yield stress can be used rather than isotropic material like titanium which are expensive as well as have high mass density.

10. Reference

- Bruhn. (1993). Analysis and Design of Flight Vehicle Structure.
- Cook, Robert D. (1995). Finite Element Modeling for Stress Analysis.
- Paul Kurowski (2006) Engineering Analysis with COSMOSWorks Professional: Finite Element Analysis with COSMOSWorks 2006. Mission, KS: Schroff Development Corp.
- http://www.boeing.com/commercial/airports/acaps/747_4.pdf
- Google images

11.Appendix





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