**White Paper**

# *Multi-Disciplinary Design of an Aircraft Landing Gear with Altair HyperWorks*

*Altair Engineering,*
*October 2008*

**Task:**
*To design an aircraft landing gear that meets design requirements of several disciplines*

## Introduction

NAFEMS invited several software vendors to a roundtable in 2007 to demonstrate their best processes in the design of a realistic aircraft landing gear system. (Figure 1). The emphasis was on simulation processes that can make problem solving innovative, accurate and efficient. This paper explains the processes followed by engineers at Altair and should help increase awareness regarding the powerful tools available for solving realistic design problems.

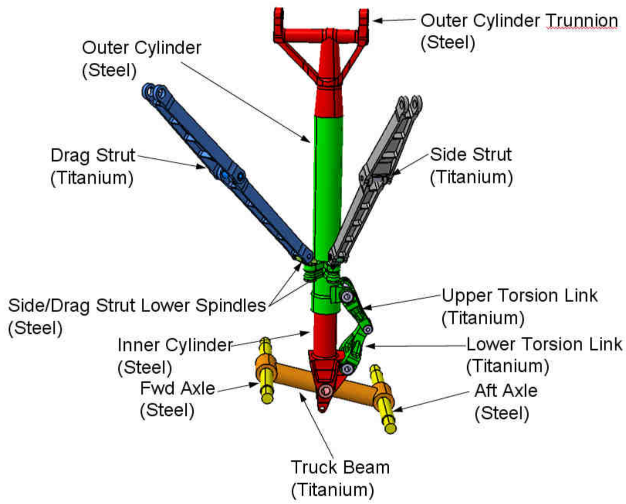


Figure 1: Aircraft landing gear and its components

## Problem Definition

The two main considerations in a landing gear design are the landing and taxiing events. 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. This reaction load, as a function of landing gear stroke, is referred to as the Dynamic Load-Stroke Curve. The taxiing event is simulated as two discrete static events: braking and turning. These events generate high stresses in the torsion links and lugs. The objectives of the landing gear design for these two events can be grouped into three categories:

1. Determination of damping profile:

The damping profile is to be designed to ensure that the Dynamic Load/Stroke Curve always stays within the Dynamic Loads Envelope during the landing simulation.

2. Concept design and optimization of torsion links:

Design the torsion links, which are critical for fatigue as a result of braking and turning while taxiing, such that they meet the stress and manufacturing requirements.

3. Shape optimization of lugs:

Evolve the design of the integrated lug on the lower outer cylinder, which is also critical for fatigue as a result of the taxiing event.

**Design Process and Results**

Optimization of damping curve

This problem is a system level multi-body dynamics optimization problem. Steps taken to solve this optimization problem are explained below.

**Objective 1:**
*Determine the damping profile of the landing gear.*

A multi-body dynamics model is built by importing the CATIA model into HyperMesh/MotionView. The deformable components are modeled as flexible bodies and the IMPACT type of contact is used to model the contact between the tires and the ground. MotionSolve is used to solve the problem.

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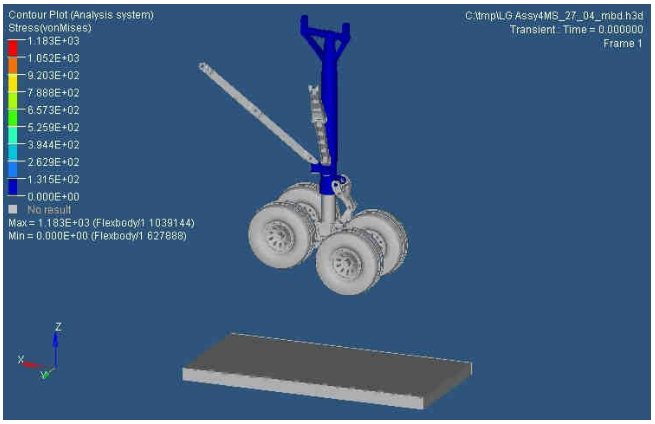


Figure 2: Multi-body dynamics model of the landing gear

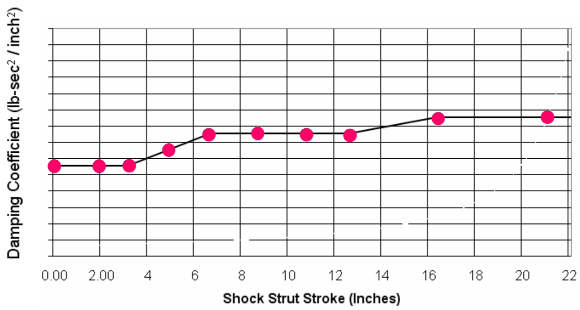


Figure 3: Damping curve; damping coefficient vs. strut stroke

As shown in Figure 3, ten coefficients on the damping curve are used as design variables in HyperStudy. All these variables are real, continuous variables. The objective function is to maximize the stroke and the dynamic load corresponding to six different strokes are constrained with the values from the envelope (Figure 4). In addition, the maximum dynamic load is constrained to be below 200 kips.

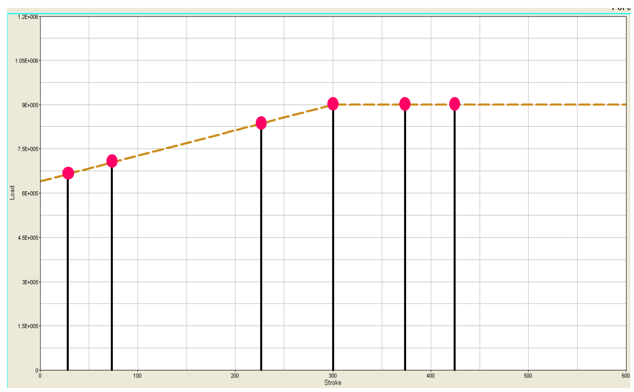

Figure 4: Design Constraints

Adaptive response surface method (ARSM) is used to solve the optimization problem. ARSM is a response surface-based (global approximation) algorithm and is the suggested method in HyperStudy because of its superior efficiency. In ARSM, the system responses are approximated by a quadratic polynomial that is determined at each iteration step from the results of the current and previous iterations. A least-squares method is used to define the polynomial.

**Results:**

*Using multi-body dynamics optimization the optimum damping profile is obtained efficiently.*

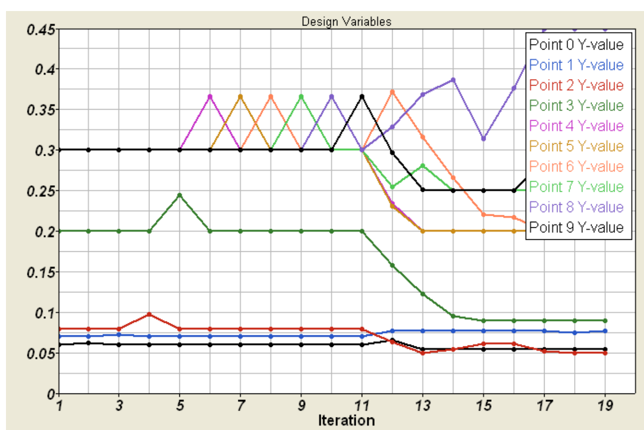


Figure 5: Optimization solution convergence history

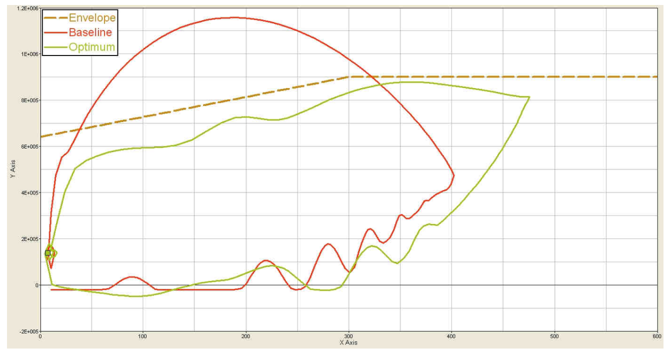


Figure 6: Comparison of Dynamic Load/Stroke Curves and Dynamic Loads Envelope

The optimization run converged in 19 iterations as shown in Figure 5, and the damping characteristics are optimized to have vertical load values with in the dynamic load envelope (Fig. 6).

*Reliability-based design optimization is required when there are large variations in design and operating conditions or the design is highly sensitive to these changes.*

Next, the search for a reliable optimum is performed for the damping curve such that the constraints are 95% reliable given the variations in the design variable values. Normal distribution with 0.1% standard deviation is used for all the design variables. Safety margin approach (SMA) is used as the reliability-based optimization method. Within the SMA, Krigging response surface is utilized. SMA converts the initial probabilistic problem of:

min f(x) [1]

such that (probability of (g(x) ≤ 0.0) ≥ 0.95

to a new deterministic problem of

min f(x) [2]

g'(x) = g(x) + safety_margin_on_g ≤ 0.0

The safety margins on constraints are initially evaluated by doing a scatter analysis on them considering the variations in the design variables.

A reliable optimum is found after 360 multi-body dynamics simulations.

**Objective 2:**
*Find a new torsion link design that meets stress requirements and weighs less.*

Concept design and optimization of torsion links

This problem is a component level topology and shape optimization problem. Steps taken to solve this optimization problem are explained below.

The landing gear is modeled with tetrahedral elements. Nonlinear gap elements are used to model the contact and load transfer between interfacing components. Landing events do not create high stresses in the torsion links and therefore only the braking and turning conditions are considered in this process.

*A high fidelity mesh and an accurate model are essential l for obtaining a meaningful concept design.*

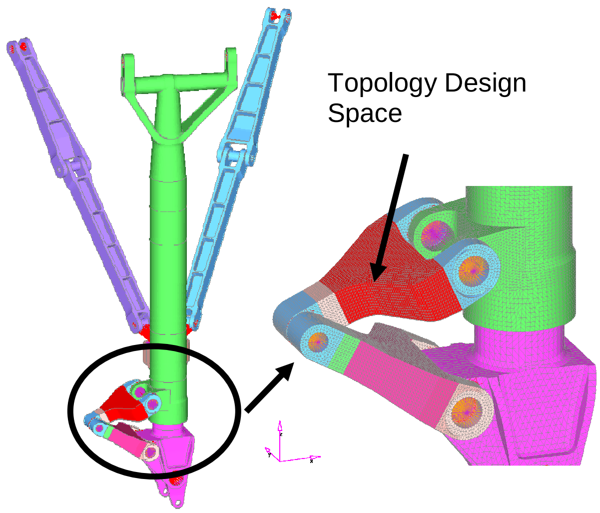


Figure 7: Design space for topology optimization of torsion links

Design space is defined for topology optimization (top left image in Figure 7). Topology optimization is a concept level design method that determines the optimal material distribution for a given optimization problem within the identified design space. The density of each element is a design variable. The problem is solved using several problem formulations to have a better understanding of the underlying physics. Mass or weighted compliance is used as the objective along with stress and volume fraction constraints. Manufacturing constraints (draw direction and extrusion) are used to guarantee a manufacturable and interpretable design proposal. From the interpretations of several topology optimization runs, two designs are proposed, one a heavier more conservative design, another a lighter more less conservative design.

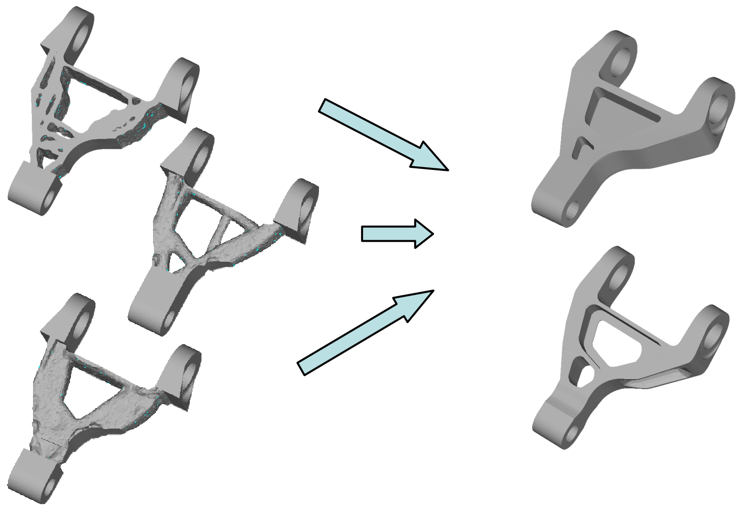

Figure 8: Topology optimization interpretations

*Shape morphing is a key technology for fine-tuning a design.*

To further reduce weight in the conservative proposal or to meet the stress requirements in the lighter proposal, shape optimization is used to fine tune the design. In shape optimization, the outer boundary of the structure is modified to solve the optimization problem. Shape variables are created using morphing technology that is available in HyperMesh. Morphing is a mesh-based parameterization technique and therefore does not require CAD data. Several shape changes are defined as design variables. The link proposals are optimized to minimize the mass and meet the stress constraint. As shown in Figure 9, the total mass of the upper and lower links without the pins is reduced from 240 lbs to 176 lbs, a 25% reduction while satisfying the stress requirements.

**Results:**

*Torsion link mass is reduced by 25% using an optimization driven design process.*

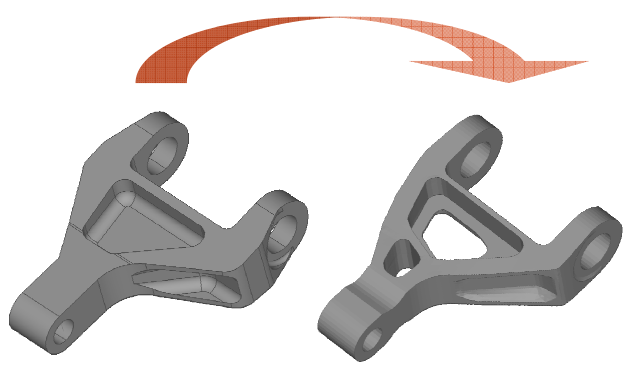

Figure 9: Mass reduction through topology optimization

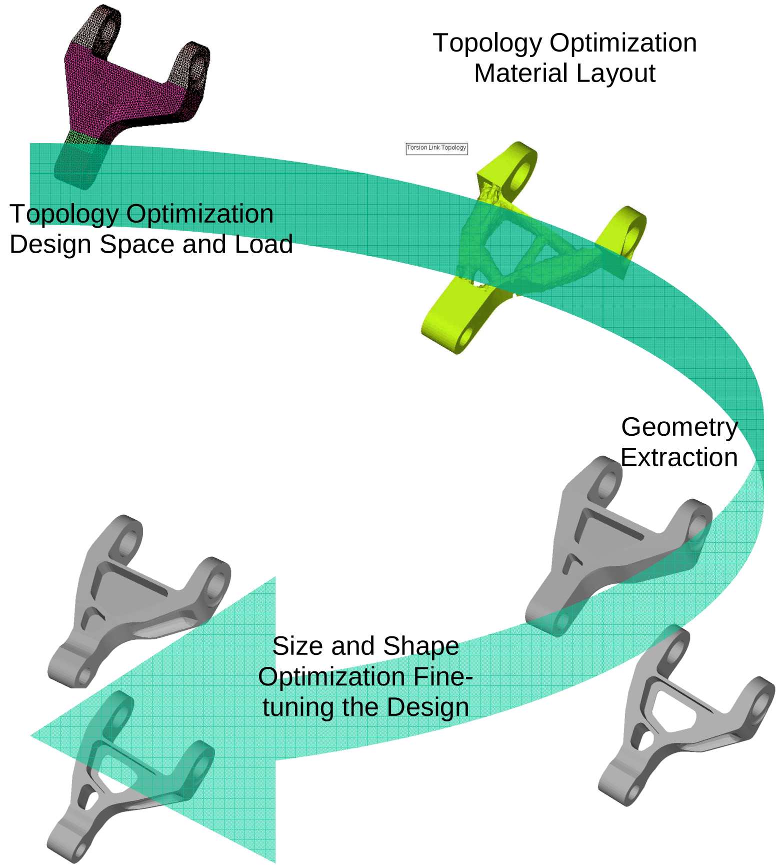


Figure 10: Concept design and optimization process for torsion links

*Concept design technology embedded directly in the CATIA V5 environment enables designers to achieve innovative designs.*

Concept design of torsion links can also be performed in the CATIA V5 environment using HyperShape/CATIA. The steps of this process are:

1. Starting with CATIA geometry (CATParts + CATProduct), geometry is defined.
2. Constraints are modeled to capture behavior of the landing gear.
3. Using these constraints the landing gear is positioned in the stroked configuration very quickly.
4. Unnecessary parts such as tires are removed from the model.
5. The following analysis connections are defined:
   - Rigid virtual meshes to model connection to the plane
   - Rigid virtual mesh to model connection to wheels
   - Rigid meshes to model connection between struts and outer cylinder
   - Contact connection elsewhere
6. A HyperShape/CATIA case is defined and the topology optimization is performed on the torsion links.

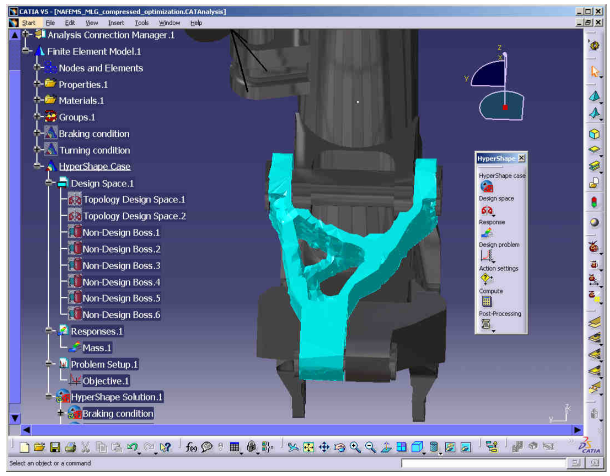

Figure 11: Topology optimization using HyperShape/CATIA

**Objective 3:**
*Re-design the lugs to reduce the critically high stresses.*

<u>Lug redesign using shape optimization</u>
This problem is a component level shape optimization problem. The lugs are under high-stresses only for the static turning and braking events. The dynamic event of landing does not cause high stresses and is therefore not critical for lug redesign. However, in order to demonstrate a new method for designing for dynamic loads, this problem is solved separately for the static and dynamic events. Steps taken to solve this optimization problem are explained below.

*Free-shape optimization provides an efficient process for reducing stress and decreasing weight.*

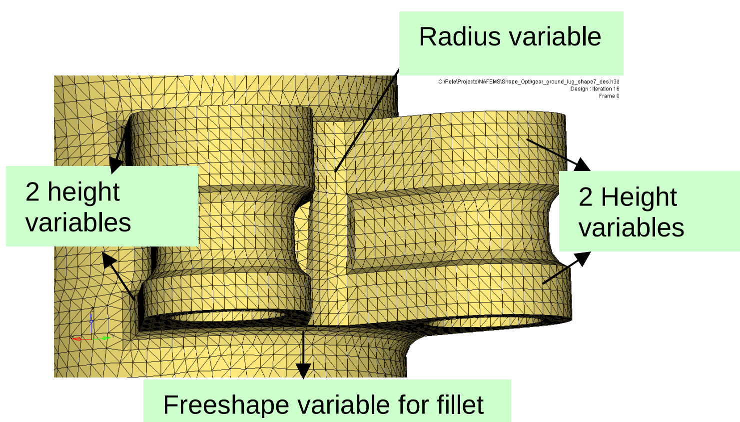


Figure 12: Shape variables lug redesign

<u>Designing for static loading:</u>
Several shape changes are defined as design variables. Free-shape optimization is also used to change some contours. Free-shape optimization uses a proprietary optimization technique developed by Altair Engineering Inc., wherein the outer boundary of a structure is altered to meet with pre-defined objectives and constraints. The essential idea of free-shape optimization, and where it differs from other shape optimization techniques, is that the allowable movement of the outer boundary is automatically determined, thus relieving users of the burden of defining shape perturbations. In addition, the optimization problem becomes truly unbiased as it does not have to fit into any predetermined shapes and their combinations.

**Results:**
*Using optimization methods, the stress of the lugs were reduced by %59 from 294 ksi to 120 ksi.*

The lug is optimized to minimize the lug mass and to satisfy the allowable stress constraint. Optimization reduced the stress from 294 ksi to the allowable stress level of 120 ksi (Fig 13) with a small penalty on the lug mass; lug mass increased by 5.2 lbs.

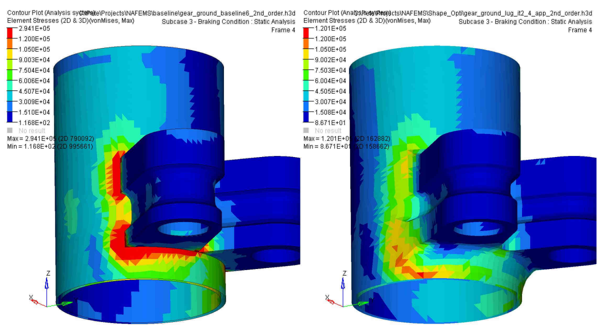

Figure 13: Stress contours before and after optimization for static loading

<u>Designing for dynamic loading with Equivalent Static Load Method (ESLM):</u>

*Equivalent Static Load Method, is used to optimize flexible bodies subjected to transient loading.*

In most practices, one of two processes is used for optimization of structures under transient loading. The first process involves running the transient analysis and picking peak loads to apply as static loads. However, the design changes during optimization leading to changes in where the peak occurs, its magnitude and more importantly in a system, the configuration in which it occurs. To guarantee a feasible design, the optimum design should be analyzed again under transient loading. If a feasible design is not obtained and/or if further improvements in the objective function is needed, the user needs to repeat the optimization process and verification analysis. This entire process is cumbersome and not guaranteed to converge to a feasible and/or better design. Alternatively one can couple the transient analysis with a solver neutral optimizer such as HyperStudy. This however will be limited to design fine-tuning with size and shape-optimization and will be computationally expensive. ESL method is an accurate and efficient alternative to the two processes explained above. This method converts dynamic loading to a series of static loads calculated at each time step such that the displacement fields are the same (Fig. 14). Equivalent static loads are calculated from deformations from an MBD analysis or transient analysis.

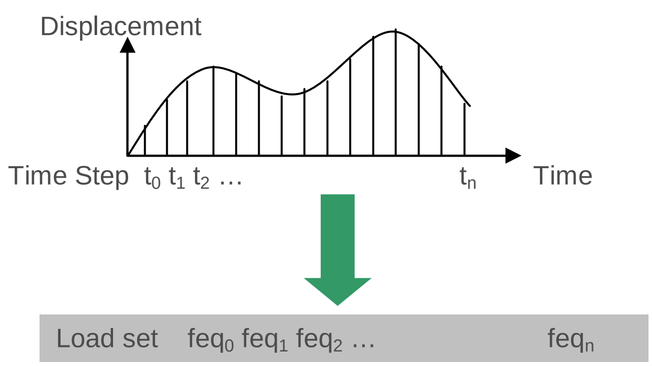


Figure 14: Equivalent static load method

*OptiStruct automatically manages the ESLM process.*

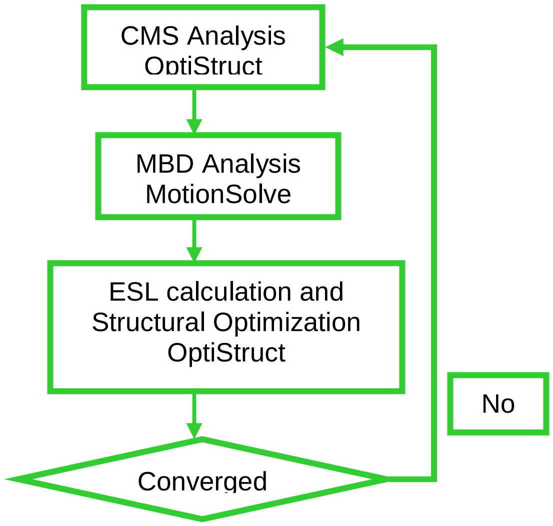


Figure 15: Automated ESLM process

Stress comparison of designs before and after optimization for the lugs is shown in Fig. 16. As there are no stress violations in the baseline design under the dynamic loading, optimization reduced the lug mass by 4.6 lbs.

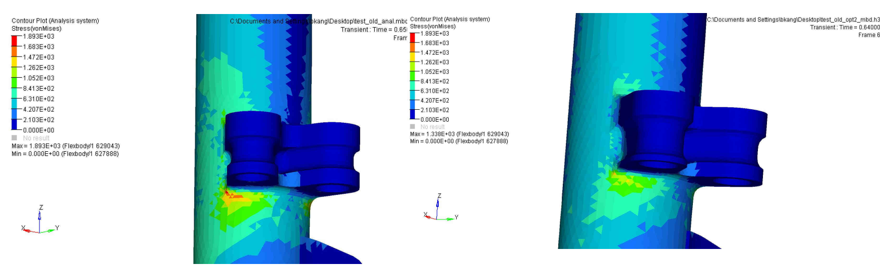

Figure 16: Stress contours before and after optimization for dynamic loading

## Summary and Conclusions

In this paper, the CAE-driven design process to design a high-performance, low-weight aircraft landing gear system was presented. This process was led by concept design and optimization techniques along with advanced innovative analysis methods. As a result, multi-disciplinary design requirements of the landing gear were met and the landing gear weight was reduced. This efficient and effective CAE-driven design process is applicable to all practical engineering problems.

The three tasks in this design problem involved a system level deterministic and reliability-based optimization and component level concept design and optimization.

Including requirements on reliability and robustness is critical especially where large variations are expected in the design parameters and/or design operating conditions. However, as seen in this paper, including targets on reliability and/or robustness increases the number of simulations needed. As such, it is strongly suggested to study the design problem using exploration techniques and reduce the problem size for stochastic studies.

Using concept design and optimization techniques, the weight of the torsion links were reduced by 27% which is a significant weight savings which in turn reduces the material cost and improves the fuel efficiency. In addition, this process was completed in less than two weeks which is a significant reduction in design and engineering time.

For lug redesign under transient loading Equivalent Static Load Method (ESLM) is used. ESLM is an innovative, accurate and computationally efficient method for transient optimization of flexible bodies. ESLM can be used with topography, shape, free-shape, size and free-size optimization.