**Top Down Optimisation of a Car Frame**

**Principles**
Topology optimisation is an optimisation technique widely used in many industrial applications. Through an iterative process, topology optimisation distributes the material within a given design space taking into account a user defined objective and boundary conditions.

The method used by OptiStruct, the optimisation engine from the HyperWorks CAE suite, is called the density method. The density method assumes that the stiffness of the material is linearly dependent on its density. During the optimisation process, the material density of each element is used as a design variable and it varies between 0 and 1, representing void or solid states respectively. This is consistent with the understanding of common materials, forinstance steel is denser than aluminium and stronger than aluminium.

In practice, the optimisation process will generate large areas of intermediate densities, which represent fictitious materials that are meaningless for the topology of the material being used. Hence, a penalisation method is introduced to account for the stiffness values of the elements with intermediate densities. The penalisation method is called Power Law representation of Elasticity Properties. In the February 2010 tutorial, the principles of an optimisation problem were described and there is a reminder below:

- **Design Variable:** This is the density of an element which varies between 0 and 1 during optimisation.
- **Objective:** This is the goal of the optimisation process, i.e. reduce the mass or increase stiffness.
- **Constraints:** These are conditions that the optimisation problem must satisfy, i.e. maximum stress allowed when changing the elemental density.
- **Responses:** These are model parameters that are of interest for the optimisation and they are used to reference the objective and the constraints, i.e. displacement is a design response which is used to define the maximum displacement limit.

**Practical Case**
A motorsport company is in the initial stages of developing a new racing car. The design team wants to understand the material distribution of the racing car frame when this is subjected to torsional stiffness due to roads bumps or potholes. For this reason, topology optimisation is employed. The optimisation is defined as follows:

- **Design Variable:** Element density
- **Responses:** Displacement and Volume fraction
- **Constraints:** Displacement (17.25 mm)
- **Objective:** Reduce the Volume fraction

The volume fraction is an alternative definition of volume and it describes the volume of a body in terms of percentages this is a parameter synonymous of mass and volume. The initial mass of the vehicle is 2520 Kg; the racing car frame is made of aluminium (70000 MPa Young’s Modulus, 2.7e-9 Tonnes/mm3, 0.34 Poisson’s ratio). There are forces acting on the front side of the car and the back of the car is constrained.

In order to obtain a structure that can be manufactured, a manufacturing constraint will be implemented in the optimisation. The manufacturing constraint is called pattern grouping and it allows the definition of a plane of symmetry to distribute material symmetrically.

**Solution**
After the topology optimisation is finished, the results are reviewed using HyperView, HyperGraph and TextView. The topology optimisation reduces the mass of frame from 2520 Kg to 92.8 Kg. Figure 2 displays the optimisation result as well as the changes of responses during the optimisation.

**HyperMesh/OptiStruct Topology Optimisation**
The starting point of the optimisation is a finite element model of the car structure, this represent the design space. HyperMesh will be used to pre-process the model and also to set-up the optimisation. Then, the optimisation will be performed using OptiStruct. The results will be reviewed in HyperView.

**Phase 1 - Definition of the optimisation problem**
A finite element racing car model is supplied; the racing car is modelled using 3D Tetra elements. The optimisation problem requires to defining the four entities described in the Principles section.

1. Define the density design variable, the element property.
2. Define responses, displacements and volume fraction
3. Define constraint, max. total displacement (17.25 mm)
4. Define objective, minimise the volume fraction

**Phase 2 - Racing Car Optimisation**
The optimisation will be resolved using OptiStruct.

**Phase 3 - Extracting the Results from the Optimisation**
HyperView, HyperGraph and TextView will be used to post-process the results from the OptiStruct optimisation.

**OptiStruct Results**
The topology optimisation reduces the weight of the car from 2520 Kg to 92.8 Kg, a reduction of 96% of the initial mass. This method demonstrates the advantages of the optimisation method to understand mass distribution and loading paths when designing a car.

The layout of the racing car structure can be further defined by using other manufacturing constraints during the optimisation process. Why not try and use manufacturing constrains such as minimum/maximum member size to improve the final design.