LS-TaSC™ Version 2.1

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Abstract

This paper gives an overview of LS-TaSC version 2.1, a topology optimization tool using LS-DYNA® for the analysis of nonlinear structural behavior. The focus is on its capabilities, current development directions, and integration into an industrial design environment. Examples of using the new developments such as dynamic load scaling are given.

Overview

The goal of topology optimization is to find the shape of a structure with the best use of the material. An alternate view of the process is that of selecting the best load path for the specified use of the structure. It must of course be possible to manufacture the final structure, and the tool can impose various requirements ensuring this.

The overall LS-TaSC [1] process consists of (i) the design problem definition, (ii) performing the design optimization iteratively using LS-DYNA [2], and (iii) post-processing the results.

The topology design problem is defined by (i) the allowable geometric domain, (ii) how the part will be used, and (iii) properties of the part such as manufacturing constraints. Additionally, you have to specify methodology requirements such as termination criteria and management of the LS-DYNA® evaluations.

The initial parts specify the design domain – the optimum parts computed will be inside the boundaries delimited by the initial parts. The parts must be modeled using solid or shell elements. The part may contain holes; a structured mesh is accordingly not required. Geometry constraints such as being an extrusion or a casting direction may be specified.

The use of the part is described by LS-DYNA input deck. The design process aims for a uniform internal energy density in the structure as computed by LS-DYNA using this input deck.

The final shape of the part is described by the subset of the initial elements used. This is outputted in the form of an LS-DYNA input deck.

Version 2.1 was created from version 2 by adding features such as forging geometry definitions and dynamics load case weighing as described in later sections together with an enumerations of the current capabilities.

Methodology

The typical goal of topology optimization is to obtain maximum utility of the material. Obtaining uniform internal energy density in the structure together used as the objective for optimization.

The objective is typically modified by the use of the SIMP (solid isotropic material with penalization) algorithm [3] to ensure that the structure is a solid. This follows the formulation proposed by Patel [4], with the resulting implementation being similar to the fully-stressed design and uniform strain energy density approaches (Haftka and Gurdal [5], Patnaik and Hopkins [6]).

The use of an element is controlled by changing the amount of material in the element. This is achieved by assigning a design variable to the density of each element. The material is parameterized using a so-called *density approach*. In this approach, a design variable is directly linked to the individual material element such that each cell has its own material model. The design variable *x*, also known as relative density, varies from 0 to 1 where 0 indicates void and 1 represents the full material. The material properties corresponding to the values of design variables are obtained using an appropriate interpolation model as described in the manual [1].

The optimization problem is formulated as,

$$\min_{x} \sum_{i=1}^{N} \sum_{j=1}^{L} \left(U_{ij}(x_i) - U_j^* \right)$$

$$\text{subject to} \sum_{i=1}^{N} \rho(x_i) V_i \le M^*$$

$$C_j^l \le C_j \le C_j^u;\ j = 1,2,\ldots J$$

$$x_{\min} \le x_i \le 1.0$$

where U represents the internal energy density of the i^{th} element, V_i is the volume of i^{th} element, U^* represents internal energy density set point, and C_j is the j^{th} constraint. There are L load cases with a total of J constraints. The superscripts '*l*' and '*u*' represent lower and upper bounds on the constraints, respectively.

The change in the design variable of i^{th} variable (Δx_i) is computed as,

$$\Delta x_i^t = K\left(U_i^t - U^*\right)/U^*.$$

where K is a scaling factor and U^* denotes the internal energy density set point. The design variable is updated as,

$$x_i^{t+1} = x_i^t + \Delta x_i^t.$$

Overview of current capabilities

LS-TaSC is developed for the topology optimization of non-linear problems involving dynamic loads and contact conditions. It is used to find a concept design for structures analyzed using LS-DYNA.

General capabilities

- Solid design using first-order hexahedrons, tetrahedral, and pentahedral elements
- Shell thickness design using first-order quadrilateral and triangular elements
- Global constraints
- Multiple load cases, including dynamic load case weighing
- Tight integration with LS-DYNA®
- Large models with millions of elements

Geometry definitions

- Multiple parts
- Extrusions
- Symmetry
- Casting, one sided
- Casting, two sided
- Forging

Postprocessing

- Design histories
- LS-PREPOST plots of the geometry evolution and the final design

New capabilities in version 2.1

The following capabilities were added to create version 2.1:

- ***Dynamic load case weighing*** Dynamic load case weighing is used to ensure that a part performs equally well for all design scenarios.
- ***Forging geometry definitions*** This geometry definition is set to obtain a part that can be manufactured using a forging process.
- ***Minor features:***
    - Castings can have interior holes.
    - Pentahedral elements are supported.
    - The memory footprint is reduced more than a factor of 2 and an option is provided which can be set to reduce memory use by a further factor of 2.
    - *MAT_ELASTIC is supported for the design part.
    - Lightly used elements can be kept instead of deleted.
    - The SIMP algorithm can be switched on and off.
    - Coordinate systems are no longer limited to DIR=X.
    - Restarting was improved to be faster by using more archived results.
    - A fringe plot of the material utilization as considered in the design process can be viewed.
    - The fraction of the original number of elements used in the design can be viewed as a history.

Forging

This geometry definition is to create a structure that can be manufacture using a forging process. Material is removed only from the sides of the structure. This is similar to a two-sided casting definition, except that a minimum thickness of material will be preserved. The geometry definition will therefore not create holes through the structure. This capability is available only for solids.

Dynamic load case weighing

It can happen that a single load case dominates the topology of the final design making the structure perform badly for the other load cases. This can be resolved by assigning different weights to the load cases, but it is difficult to know good weighing values in advance. Dynamic weighing of the load cases is used to select the load case weights based on the responses of the structure as the design evolves, thereby resulting in a design that performs well for all load cases.

The dynamic weighing is done by defining a desired relationship between the responses of all the load cases. The algorithm will scale the load case weights to achieve this relationship. Say we have constraint C_1 from the first load case and constraint C_2 from the second load case, then we write our desired behavior as $k_1C_1 + offset_1 = k_2C_2 + offset$ with C the constraint value, k a scale factor, and an offset added. The weight w_i of load case i is adjusted to change constraint C_i. The target value is computed as

$C_{target} = \dfrac{\sum_{i}^{i=n} k_iC_i + offset_i}{n}$ from which we compute $\Delta w_i = (C_{target} - k_iC_i - offset_i) / \partial C_i / \partial w_i$ with the derivative approximated as ±1 and a maximum bound is place on Δw to ensure convergence in a reasonable number of iterations.

The final weights found are not suitable for restarting. They can be examined though for an indication of good values of the weights, but usually the final weights found using dynamic weighing are too large.

Examples

Forging example

This example is a solid part to be manufactured as a forging, which was accordingly imposed as a forging geometry definition including a minimum web thickness. The geometry and loading conditions for this component are shown in Figure 1. The FE model has about 60 000 elements and a single linear implicit load case as shown was considered.

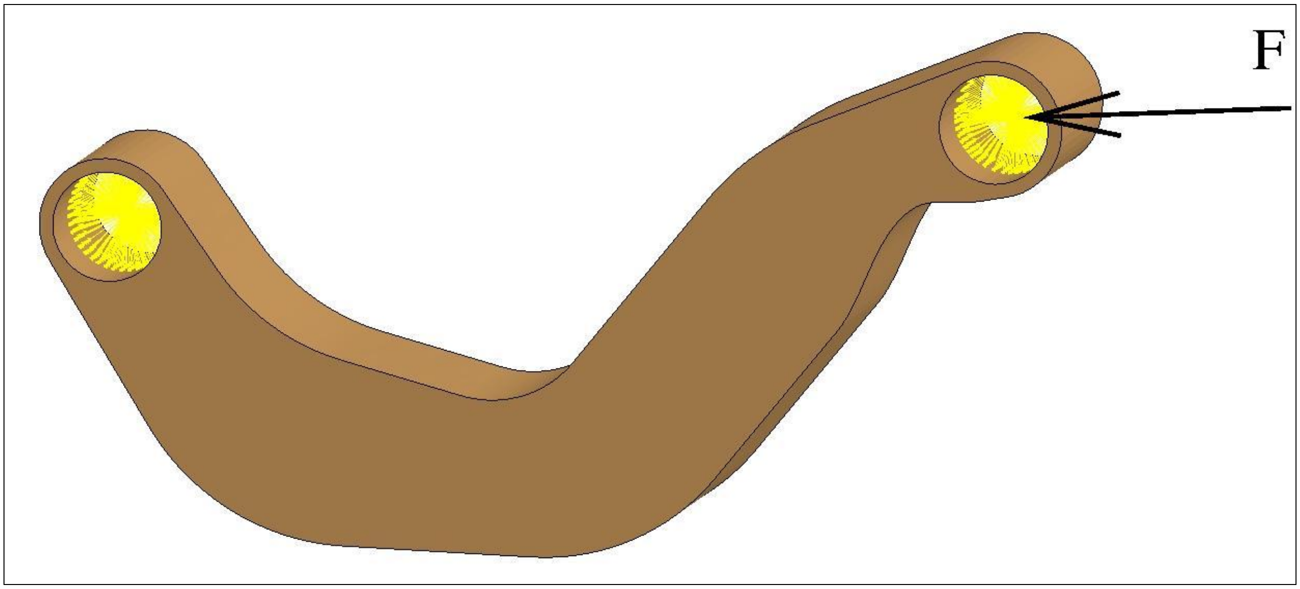

Figure 1: The initial geometry and loading conditions.

The final design is shown in Figure 2. Note the web that is required for forging manufacturing. Flanges and a rib were created to carry the bending load efficiently.

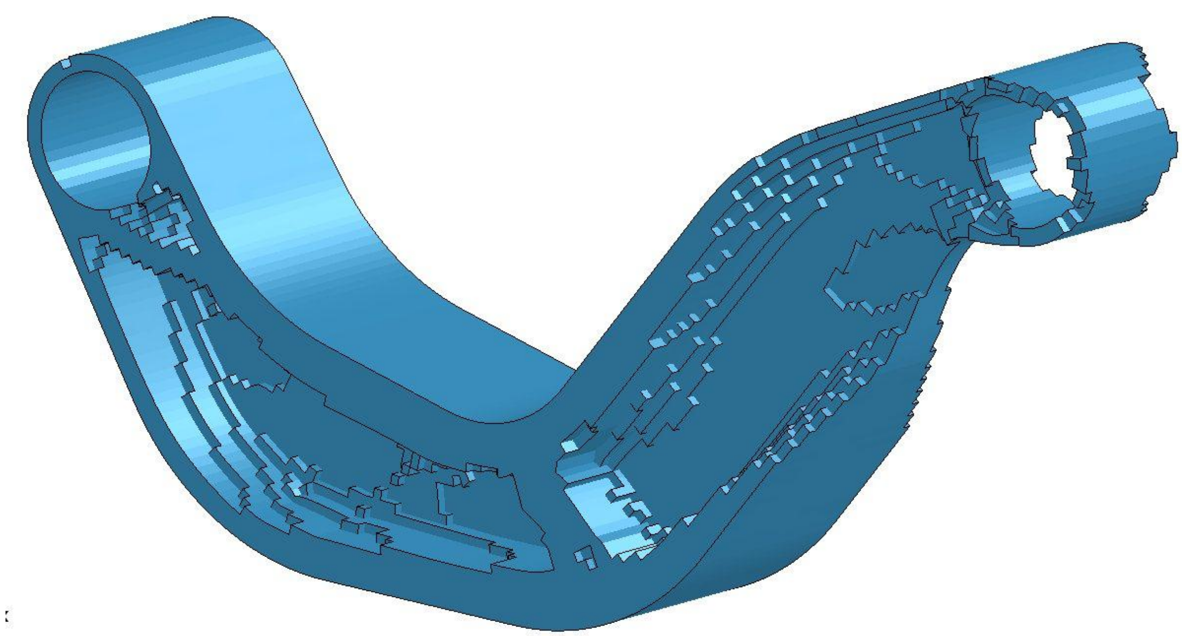

Figure 2 Design with forging geometry definition. Note the web that is required for forging.

Dynamic load scaling

This is a nonlinear structure compressed by an impactor in two load cases as shown in Figure 3. A symmetry geometry definition requiring symmetry around the center was imposed to remove the need for a right load additional to the shown left load. The center load case dominates the geometry of the final design if the load cases are not scaled – without load case scaling the design is much stiffer for the center load than for the left load. It is difficult to know up front which values of the load case weights to use in order to have a balanced design. In this example it is shown how dynamic load scaling creates a balanced design.

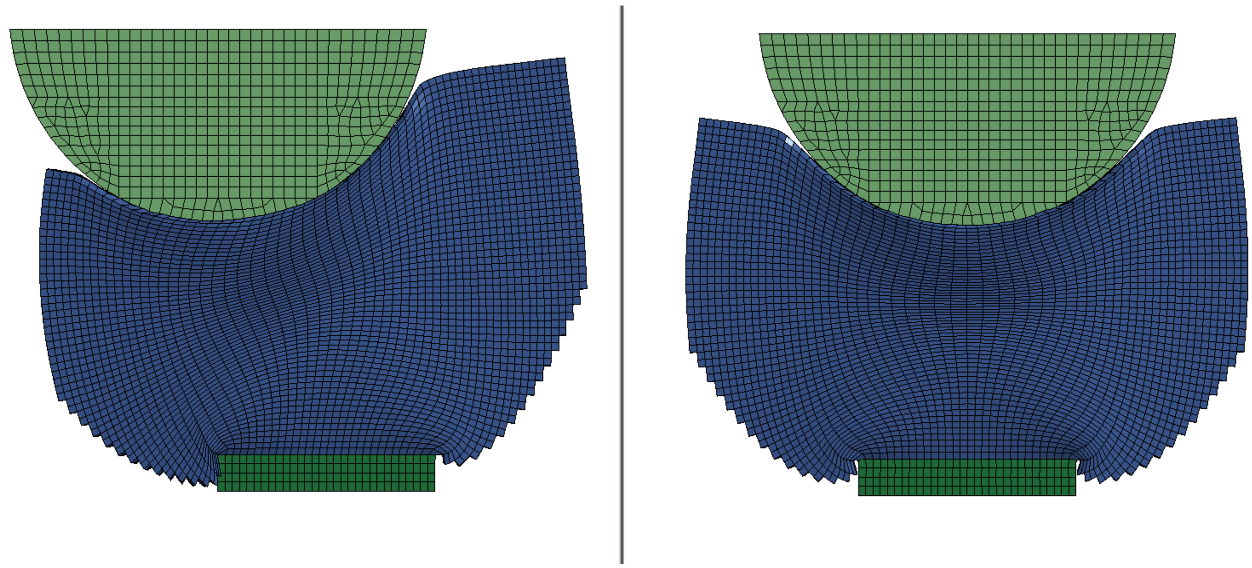

Figure 3 The geometry and loading conditions of the dynamic loading example. A left load, a center load, and symmetry around the center are applied.

In the following pictures we show the results from a standard study with both load case having equal weights, and a study with dynamic load balancing. In Figure 4 to the left we show the reaction forces for the standard design study in which the load cases were weighed equally. The dynamic load balancing was then set to have the final results for these two reaction force to be the same for both load cases, which allowed us to achieve the reaction force curves as shown to the right of Figure 4 for the balanced design.

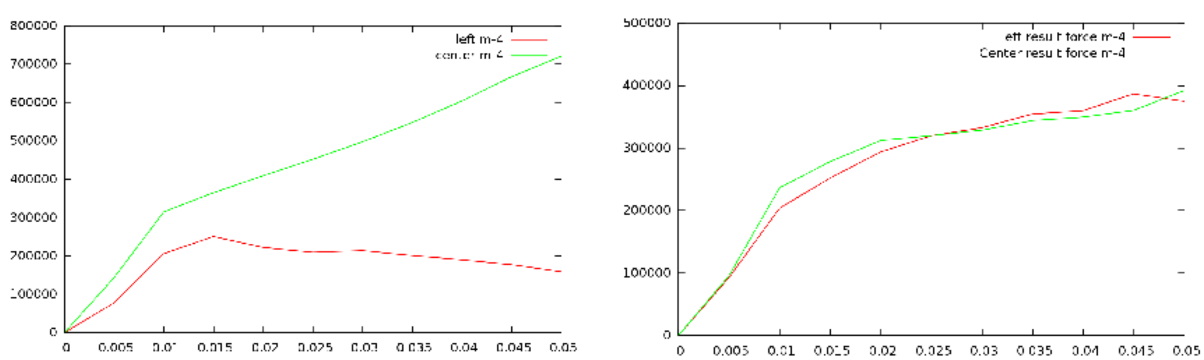

Figure 4: The reaction forces for the two load cases. To the left are the results from the original problem statement, from which it can be seen that the reaction forces differs greatly for the two load cases. To the right are the results with dynamic load scaling, from which it can be be seen that the reaction forces are now similar.

The designs obtained have different topologies as shown in Figure 5.

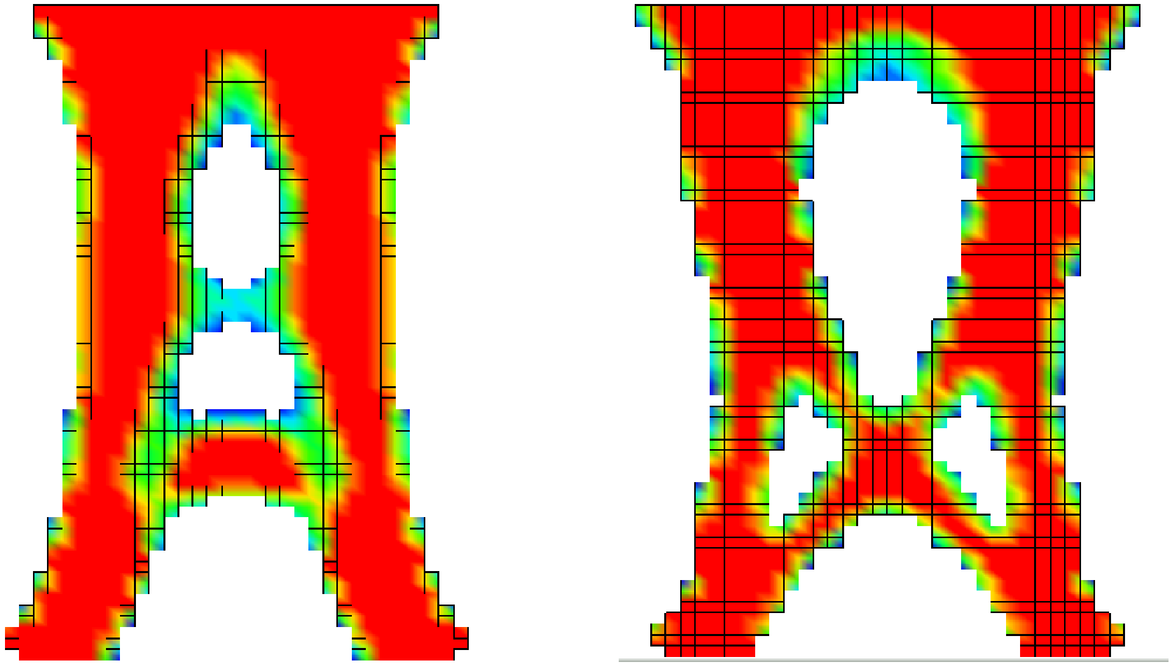

Figure 5 Final designs. The design using equal weighing is shown on the left, while the design using dynamic weighing is shown on the right. Note the bottom of the designs differ: the dynamic scaling has the pillars connected using a truss structure in order to provide more support for the offset load.

The convergence of the maximum reaction force value for both load cases is shown in Figure 6. The final weights are 0.12 for the center load case and 7.2 for the right load case.

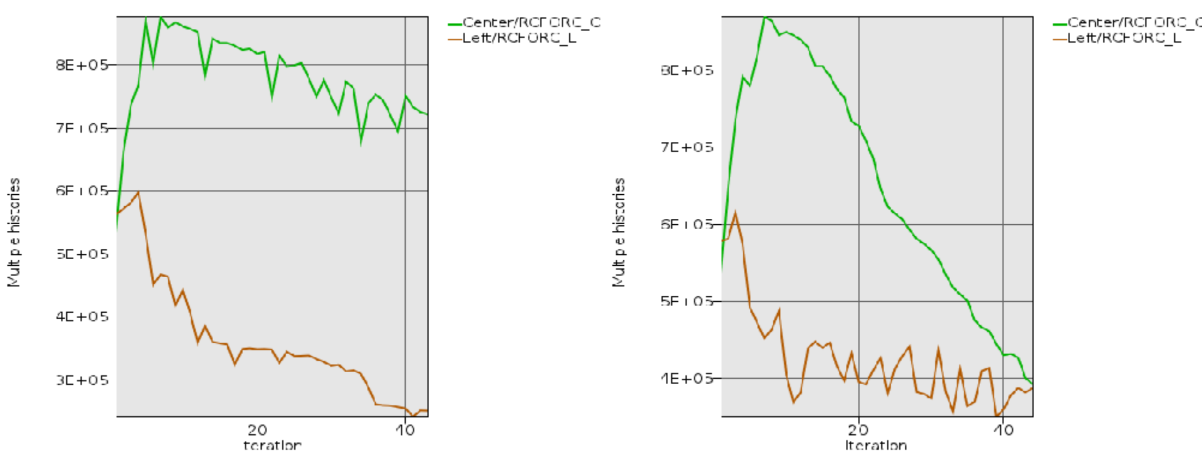

Figure 6 Convergence of the reaction forces. The plots are that of the maximum reaction force for each load case versus the iteration number. The equally weighted design study is shown to the left, while the results for dynamic weighing are shown to the right.

Current Developments

Improvements currently under investigation are:

- Shape optimization. Both solid and shells structures will be considered. For solid structures the outer surface will be modified to relieve stress concentrations, while shell structures will receive geometric features to be stiffer and for buckling specific designs.
- Integration with geometry. The user interface with be unified with the LS-PrePost capabilities, which will give a smoother ability for tasks such as defining coordinate systems and visualizing results.

Summary

LS-TaSC computes the shape of a structure with the best use of the material. It has been developed for non-linear structures analyzed in an industrial environment and is accordingly suitable for large linear problems. This tool considers solids and shells, global constraints, multiple parts, and manufacturing constraints. This tool has been extended to load case weighing and forging geometry definitions.

References

[1] Livermore Software Technology Corporation, LS-TaSC™: A Topology and Shape Computations for LS-DYNA, User's Manual, Version 2.1, Livermore Software Technology Corporation, Livermore, CA, 2011.

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[5] RT Haftka, Z Gurdal, MP Kamat, *Elements of Structural Optimization*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2nd ed., 1990.

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