Efficient Topology, Topometry and Sizing Optimisation for LS-DYNA Analysis Problems

Coupling LS-DYNA to VR&D GENESIS

Martin Gambling

Managing Director

GRM Consulting Ltd, Leamington Spa, UK

Summary:

For a number of years the application of efficient gradient based design optimisation[1] has been available for Finite Element Analysis (FEA) working within the linear loading domain. Methods such as Topology optimisation have become common place in many industries, such as automotive, to determine the optimal load path distribution for a given component or assembly.

To date, methods such as topology optimisation have not been able to consider non-linear effects such as material non-linearity and contact, therefore limiting the application to many real world events such as dynamic impacts and quasi-static, non-linear problems.

This paper outlines the solution developed by GRM Consulting Ltd to allow the efficient design optimisation of LS-DYNA based problems by coupling directly to the efficient solvers within VR&D GENESIS[2]. The method allows for optimisation using all optimisation methods within GENESIS to be applied to LS-DYNA[3] problems including,Topology, Size, Shape and Topometry. Further to the support of LS-DYNA the interface has additionally been developed to couple to ABAQUS/Standard.

Keywords:

LS-DYNA, ABAQUS, GENESIS, Shape, Sizing, Topometry, Topology, Non-Linear, Optimization

1 Introduction

Due to the significant mass and cost targets of modern engineering design, optimisation techniques have become significantly more commonplace, offering engineers the opportunity to reduce development cycle times and provide minimum mass solutions.

Supporting Topology, Sizing, Shape, Topometry & Topography optimisation, a new interface has been developed by GRM Consulting Ltd available for VR&D GENESIS, allowing direct coupling to all aspects of LS-DYNA.

The key benefits of the coupled optimisation methodology are that design problems previously not feasible through optimisation methods such as Design of Experiments can now be considered. LS-DYNA impact examples are presented here considering in excess of 30,000 design variables, which are solved using less than 30 LS-DYNA simulations

2 Coupled Optimisation Methodology

Managed with GENESIS' optimisation environment, Design Studio, the process for coupling LS-DYNA simulations to GENESIS is defined in three key steps as shown in Figure 1 below. These are:

- Create Phase - At the create phase of the optimisation process the loading of the coupling interface runs each of the baseline LS-DYNA models to be considered, generating approximate load cases in GENESIS. The user is then prompted to define the optimisation problem within Design Studio considering both GENESIS internal load cases and LS-DYNA based cases.
- Check Phase - Once the optimisation is prepared the user can opt to run a CHECK run, which will execute only the first iteration of the optimisation. At this stage the user can check the LS-DYNA based responses in GENESIS to confirm that that are all as expected, prior to executing the complete coupled optimisation.
- Optimisation Phase - Once the user is satisfied that the optimisation is set-up correctly it can be submitted from within the Design Studio Console. Users of remote server systems can manage their optimisation studies from their workstations, using the remote submit capability.

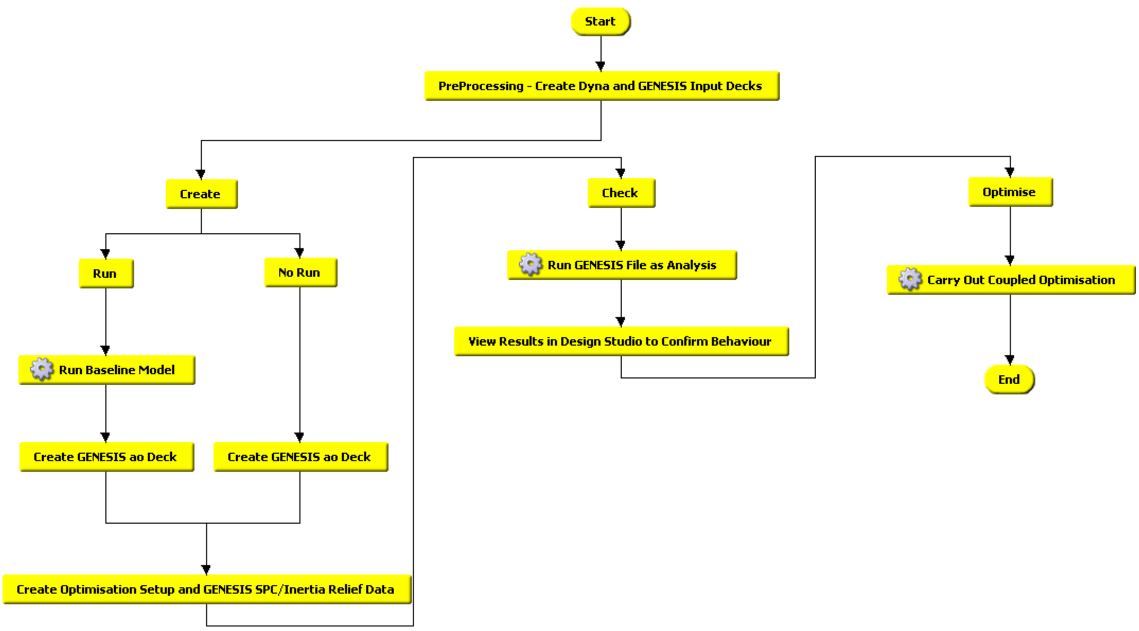


Figure 1: Coupled Optimisation Procedure

3 Implicit LS-DYNA Optimisation Problems

When considering quasi-static non-linear problems involving contact and small amounts of material non-linearity LS-DYNA's implicit solver is very well suited to provide efficient analysis solutions. Coupling this solver to GENESIS' optimisation routines has been defined in such a way as to minimise the number of LS-DYNA simulations required. Typically, topology type optimisation problems will require approximately 5 LS-DYNA simulations, whilst sizing and shape studies will require between 2 and 5 simulations. Using the same methodology, coupling of implicit non-linear problems is also fully supported with ABAQUS/Standard.

3.1 Topology Optimisation

For quasi-static Topology studies the primary benefit of coupling to implicit solvers such as LS-DYNA and ABAQUS/Standard is the ability to consider contact based problems. An example of such a problem is an internal gearbox parking brake system whereby components such as the locking arm,(shown in Figure 2) are not supported by any constraint and loads are only applied via contacts. In this condition conventional linear optimisation solvers cannot consider such problems without significant approximations by the user.

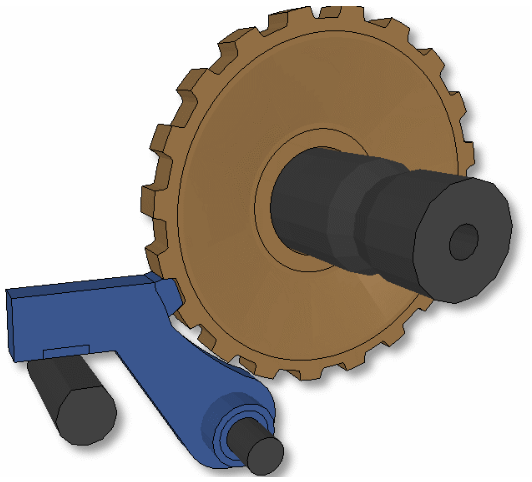


Figure 2: Implicit LS-DYNA Topology Optimisation of Gear Design Model

For the gearbox park brake system a topology optimisation was performed to determine the optimal material distribution for the locking arm and main gear, considering both clockwise and counter-clockwise torque loadings of the transmission. The optimisation therefore considered two implicit LS-DYNA models during the study.

The optimisation problem comprised 42,000 topology designable elements with the objective of minimising the strain energy of both LS-DYNA load cases. A constraint of a total mass fraction of the designable elements of 0.3 was applied.

The coupled optimisation converged on the solution shown in Figure 3, taking a total of 39 GENESIS iteration, requiring a total of 7 LS-DYNA simulations (per load case).

On completion of the design optimisation updated LS-DYNA models are available for the user to review and modify further, as appropriate.

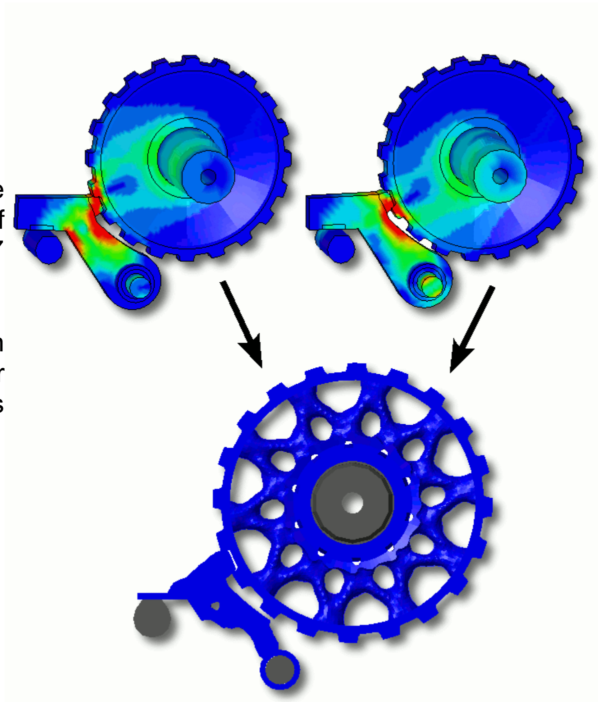


Figure 3: Implicit LS-DYNA Topology Optimisation of Gear Design Results

3.2 Shape and Sizing Optimisation

When considering shape optimisation of components, the design is very often well defined and close to its final form. As a result, the level of detail and complexity of the simulation models is of very high, including factors such as bolt pretensions,interference fits and loading conditions which require the modelling of contact.

In such instances non-linear solver codes such as Implicit LS-DYNA or ABAQUS/Standard are required to accurately simulate the loading. To perform shape optimisation with such models would typically require the application of methods such as Design of Experiments and Response Surface Methods. Using such methods would typically require approximately 50 to 70 simulations to consider design problems with 9 shape variables.

Using the coupling of LS-DYNA to GENESIS, such problems can be optimised with a significantly reduced number of non-linear simulations. A shape optimisation example is shown in Figure 4 below, which considers 9 design variables and stress constraints for 157,000 solid elements.

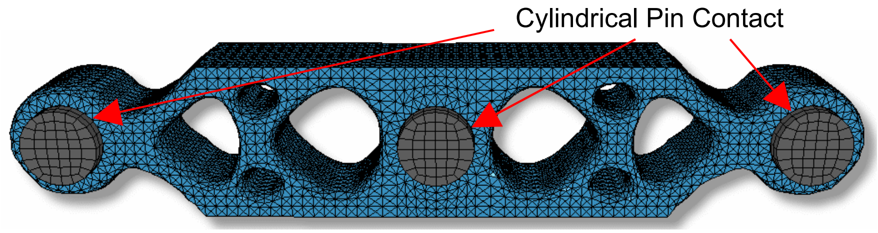


Figure 4: Implicit Shape Optimisation Example

Solving within GENESIS the LS-DYNA analysis model was optimised, requiring only 3 LS-DYNA simulations. Taking a total of 12 GENESIS iterations, the mass of the design was reduced by 18%, whilst reducing the maximum stress from 168MPa to the design constraint defined of 150MPa.

Figure 5 below shows the baseline and optimised forms of the design and the Von-Mises stress distribution under maximum loading.

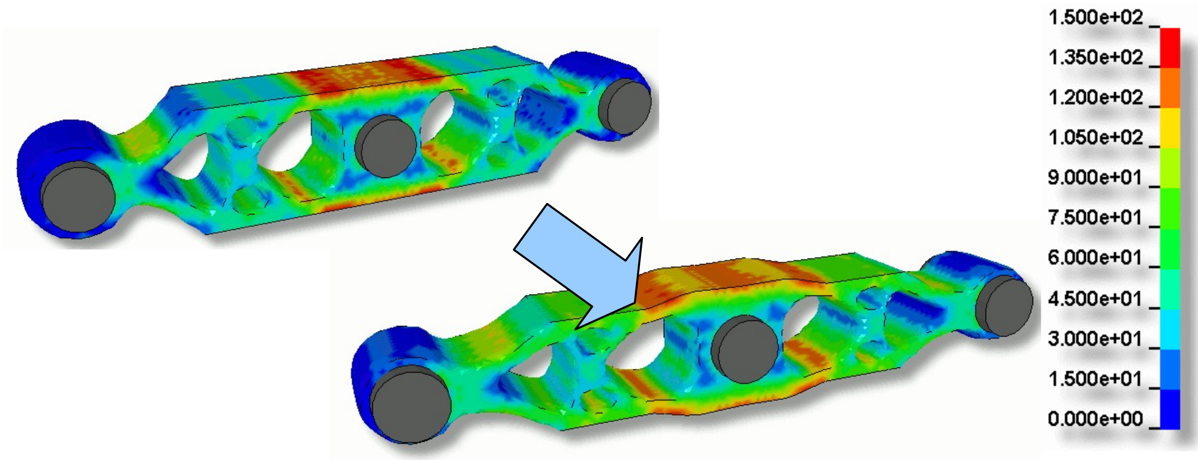


Figure 5: Shape Optimisation Results (Von-Mises Stress)

4 Explicit LS-DYNA Optimisation Problems

For the consideration of non-linear explicit impact based problems, the coupling method offers a unique advantage to engineers allowing, for the first time, the ability to consider topology optimisation on impact based loadings.

The following examples show the application of the coupling optimisation on example impact studies.

4.1 Topology Optimisation

When considering topology optimisation for crash type problems a number of technical hurdles must be considered, one of which is managing the numerical stability of the LS-DYNA simulations. A common problem for solid element based models in LS-DYNA is the occurring of negative volumes in very distorted elements. To minimise the risk of this occurring during the optimisation a number of steps have been considered in both the coupling program and in the recommended set-up of the LS-DYNA models.

When performing impact simulations using LS-DYNA the management of severely distorted solid elements to minimise the risk of 'negative volume' termination can be achieved by using the *CONTROL cards below.

```
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
      0.08         0    1.0e-3        0.        0.
*CONTROL_TIMESTEP
$   TDINT    TSSFAC      ISDO    TSLIMT     DT2MS      LCTM     ERODE     MSIST
                0.9         0        0.   -1.8E-6                   1         0
```

Further to the above LS-DYNA control parameters, an important factor to consider is that, typically, impact models are constructed using thin-walled shell structures and, when performing Topology optimisation we will be using solid element models. Through a number of test cases it was concluded that, in many cases, optimisation for impact problems resulted in the formation of topology results with very extremely low materials densities. As topology is a guide for load path definition, etc, a useful approach to defining the LS-DYNA problem is to factor the material properties of the designable elements by 0.1. This approach provides much more clearly defined solutions, as shown by the following example.

To demonstrate the application of the GENESIS coupling to impact based problems, a simple pole impact has been simulated with the objective of determining the optimal section geometry to support a maximum dynamic intrusion of 150mm. The model construction is shown in Figure 6.

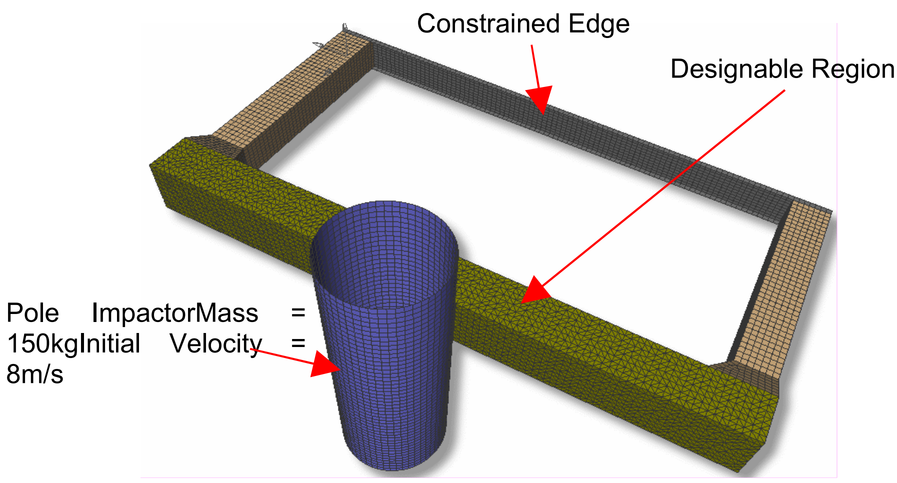


Figure 6: Pole Impact Design Space Model

The pole impact optimisation was performed initially considering no manufacturing constraints and, subsequently using Casting, Extrusion and Sheet Metal Topology manufacturing constraints. Figure 7 below shows the maximum dynamic intrusion results for the 'no manufacturing constraint' results, highlighting how the constraint limit of 150mm is exactly achieved.

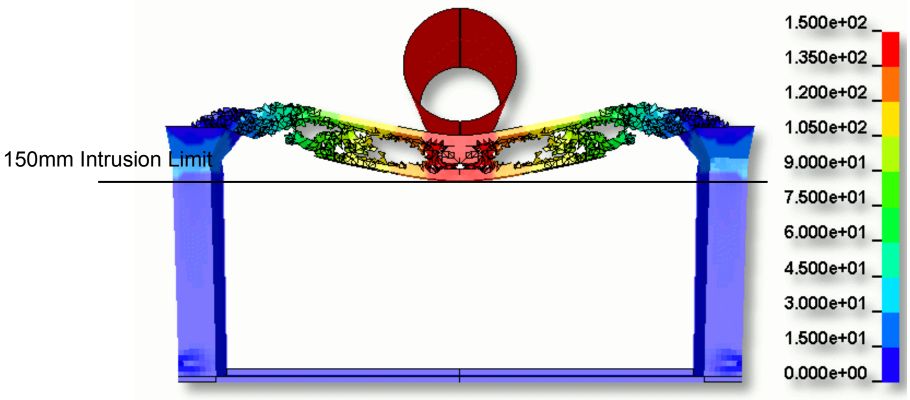


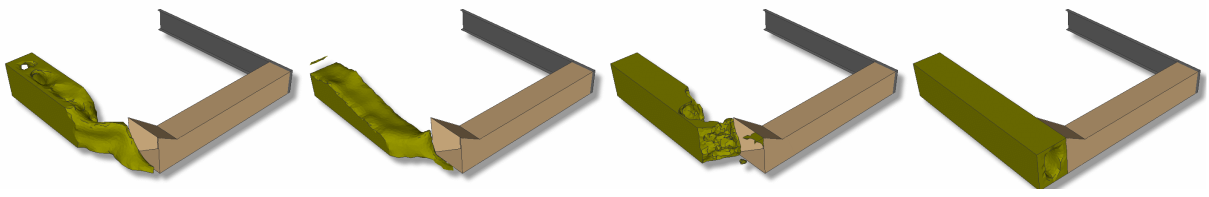
Figure 7: Maximum Dynamic Intrusion of Topology Pole Impact Result

The results shown in Table 1 show how the mass achieved for the 'no manufacturing constraint' solution is the lowest with the exception of sheet metal topology. The sheet metal topology solution is, however, a slightly different problem formulation as the power rule typically employed for Topology based problems has been removed. This allows material densities between 0 and 1 to form, which would signify thinner sheets than the maximum allowable. This feature would not normally be permitted when interpreting topology results into solutions such as castings or extrusions.

Figure 8 shows the iso-surface results for the different manufacturing constraints considered. The results show very clearly the unique ability of GENESIS to perform Topology optimisation studies on non-linear impact based problems.

	Manufacturing Constraint			
	None	**Casting**	**Sheet Metal**	**Extrusion**
Mass Fraction	0.39	0.42	0.3	0.53
LS-DYNA Simulations	22	20	14	15
GENESIS Iterations	35	91	60	92

Table 1: Pole Impact Topology Results Summary



(No Constraint) *(Casting)* *(Sheet Metal)* *(Extrusion)*

Figure 8: Pole Impact Topology Results for Different Manufacturing Constraints

4.2 Shape and Sizing Optimisation

When considering large scale non-linear impact based problems there are often many design variables to consider, making optimisation using methods such as Design of Experiments very costly, requiring many simulations in order to obtain such sufficient design sensitivity information. Such methods will typically require a minimum of 50 - 60 simulations in order to consider problems with less than 10 design variables.

Using the coupling to GENESIS a vehicle Body-in-White has been optimised to achieve a side impact intrusions limit of 300mm, whilst also maintaining the body's existing static torsional stiffness. The design problem considered the design of 59 body panel thickness, with the objective of minimising the total BIW mass. Such a problem would be very difficult to solve using traditional non-linear optimisation methods and would require a very large number of impact simulations.

The optimisation converged on a solution, requiring a total of 10 LS-DYNA simulations and 24 GENESIS iterations, taking significantly less time than traditional non-linear optimisation methods. Figure 9 below shows the baseline and optimised side impact performance, and the change in panel thickness for the updated design.

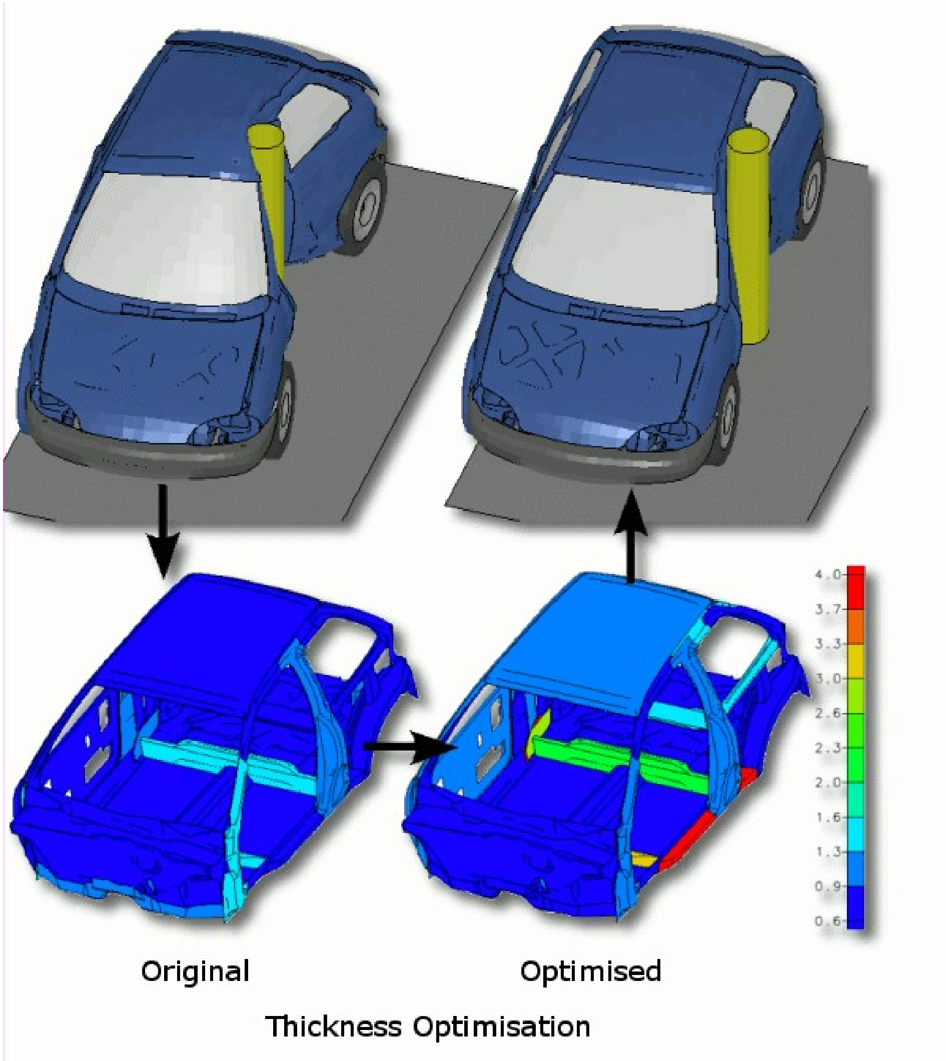


Figure 9: Sizing Optimisation Results of Vehicle Pole Impact & Body Torsion

5 Summary and Conclusions

A process has been developed for the direct coupling of LS-DYNA analyses to the advanced optimisation capabilities of VR&D GENESIS. The process, available as an additional module to VR&D's pre & post-processor Design Studio, has been demonstrated to support both implicit and explicit non-linear problems.

Through a series of examples the process has been shown to provide a unique advance in the process of non-linear design optimisation, allowing the consideration of methods such as topology optimisation to be considered for the first time.

For methods such are sizing optimisation the approach has been shown to provide optimised solutions with a significant reduction in the required number of non-linear simulations.

The interface has currently been developed to support both LS-DYNA and Abaqus/Standard, however, further solver interfaces are currently under development.

6 References

[1] Numerical optimization techniques for engineering design

[2] GENESIS Design Manual, Vanderplaats R&D Inc, Version 10.0, 2008

[3] LS-DYNA Keyword User's Manual, Livermore Software Technology Corporation, Version 970, 2003