Lowest cost printer chassis design that would pass a series of transportation drop tests, utilizing design of experiments in conjunction with Abaqcus/ Explicit analysis.

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A printer chassis provides an important function of locating and securing the relative position of all the sub-systems that makeup a printer. The customer location could be thousands of miles away from the factory and many modes of transportation are required from ship, train, trucks, forklift, to pushing across corridors, stairs and elevators. The transportation loads are the most sever the printer would see in its life time. These include impacts on all sides at 3 MPH to an 8 inch vertical drop. In today's competitive market cost is as critical a function as performance to succeed in the market. To design the lowest cost chassis, 3 large highly stressed parts in the chassis were optimized for cost. Two parameters; sheet metal thickness, and material strength were used to minimize the chassis cost provided the combination passed each one of the six unique transportation tests. A six factor, two levels, Taguchi L12 matrix was utilized for the design of experiment (DOE). Abaqus/ Explicit analysis were used for virtual transportation testing to compute the output responses of the DOE. The design optimization exercise resulted in an addition 6% cost savings.

Keywords: Abaqus/Explicit, Abaqus/CAE, Chassis, Cost, Design of Experiments, Drop Test, Finite Element Analysis, Impact, Mild Steel, Noryl, Optimization, Plastic Strain, Printer, SECC, Structure, Simulation, Taguchi L12, Transportation Test, Welding, Wood

1. Introduction

A printer chassis is the backbone of the printer. Its function is to provide support and location to all of its subsystems, customer user interfaces like screens and keyboard but it also has to protect its content from abuse and damage during the life of the printer. The propensity and severity of damage is the largest during its transit from the factory to customer locations thousands of miles away. All modes of transportation are realized by the chassis during its life from fork lifting, truck ride, train haul, freight container across the oceans and pushing across the hallways to its final destination at the customer site. For the chassis to be robust against failures from vertical drops to accidental bumps on all of its sides and edges, a series of transportation tests have been defined for new design qualification.

2. Transportation Test

The transportation testing specifications is an internal Xerox document that defines a suite of tests both packaged and unpackaged. The testing is comprised of handling tests that require the product or package be dropped from different heights depending on product weight. The product or package has to be dropped on its bottom and also roll dropped on its four edges and four corners. Three miles per hour impact on all of its four sides and a random vibration test to a predefined power spectral density is also required. Table 1.0 summarizes the entire tests that were required for the particular chassis design.

Abaqus/Explicit was used to simulate the entire test suites defined in Table 1. Most of the chassis members were sized based on stress feedback from the simulations.

3. Chassis Design

The design is sized based on the constraints from the various subsystems and customer requirements. The chassis weight is determined by the subsystem mass added to the chassis structure. A typical office printer would weigh between 300-500 lbs and the picture of a typical printer and its chassis are shown respectfully in Figure 1., and Figure 2.

The chassis structural members are all constructed from electro galvanized sheet metal that is cut and bent into shape. The members are assembled together by a combination of methods that include, welding (TIG, MIG, Spot, Laser) and fastening, the methods selected are to minimize the overall assembly cost.

Table 1. Transportation tests considered for the particular product chassis

Test	Packaged	Unpackaged
Free Fall Height (inch)		
-Bottom	8.0	2.0
-Sides	6.0	2.0
-Corners	6.0	2.0
Incline Impact Speed = 3MPH		
-All Four Sides	Yes	No
Obstruction Crossing Speed = 3MPH		
-Barrier Height (inch)	No	0.5
-Gap Height x Width (inch)	No	2.0 x 1.75

Figure 1. Xerox Office Printer ColorQube 9303

Figure 2. Printer Chassis

The preliminary sheet metal thickness of the chassis members was done by hand calculations. The chassis was design using Wildfire 3.0 and was subsequently imported into Abaqus/CAE. Most of the sheet metal was already near the desirable 1.0 - 1.2 mm thickness. Three major structural components, base, mid-rails and vertical columns were still at the higher 2.0 mm thickness and were therefore selected for optimization, see Table 2.

Table 2. Chassis member's thickness and parts selected for design of experiments

Part Description	Quantity	Thickness (mm)	Thickness Change
Base	1	2.0	Design of Experiment
Lower Shear Panel	1	1.2	NO
Rear Left Side Column	1	2.0	Design of Experiment
Scanner Support beam	1	1.2	NO
Scanner Support Panel	1	1.2	NO
EB Rear Bracket	1	2.0	NO
EB Front Bracket	1	2.0	NO
Torque Tube	1	1.6	NO
Mid-Rail	2	2.0	Design of Experiment
Mid Panel	1	1.0	NO
Top Rear Rail	1	1.2	NO
Tray Left	1	1.2	NO
Tray Right	1	1.2	NO
Tray Support	1	1.2	NO
Back Panel	1	1.0	NO
Front Left Side Column	3	2.0	Design of Experiment
Right Shear Panel	1	1.2	NO
Display Panel	1	1.0	NO
Scanner Side Bracket	1	1.0	NO
PP Vertical	1	1.0	NO

4. Material Properties

The material used for the chassis structural parts was commercial grade Steel, electro galvanized cold rolled (SECC). Most of the chassis was made out of SECC and for higher strength SECC390 was considered. The true stress strain cure for both metals is presented in Figure 3. The entire chassis was modeled with three basic material, wood for the shipping pallet, mild steel for the all of the metal parts and Noryl 4025 for the plastic parts that included the castor wheels. The mechanical properties of the material are presented in Table 3.

Table 3. Material properties used for simulation

Material	E (MPa)	Density (Kg tonne/mm^3)	Poissons	Yield Strength (MPa)
Mild Steel	2.07E+05	7.80E-09	0.29	206
Noryl 4025	9.00E+03	1.43E-09	0.3	
Wood	3.73E+03	5.00E-10	0.3	

4.1 Design Allowable

Only a small percentage of printers in the field are subjected to the extreme drop and impact conditions and therefore an aggressive design allowable of 3.0% was used as the acceptable maximum equivalent plastic strain in any of the structural members. Provided the total plastic strain does not result in excessive permanent deformation that would cause any catastrophic failures, long term performance issues, are visually not detectable and are outside the customer field of view.

5. Design of Experiment

Three structural parts shown in Table 2, above were used and both material strength and thickness were varied at two levels, this resulted in a six factor two level DOE. Taguchi L12 DOE matrix was used for regression analysis as shown in Table 4.

The costs for each run were calculated from vendor data and were plugged into the DOE matrix in Table 4. All twelve simulations were run using Abaqus/Explicit which took approximately ninety hours. All simulations except the first one meet all of the structural design allowable requirements as define in section 4.1. Run 2 results in the lowest cost printer chassis about 6% lower than the baseline design without the optimization.

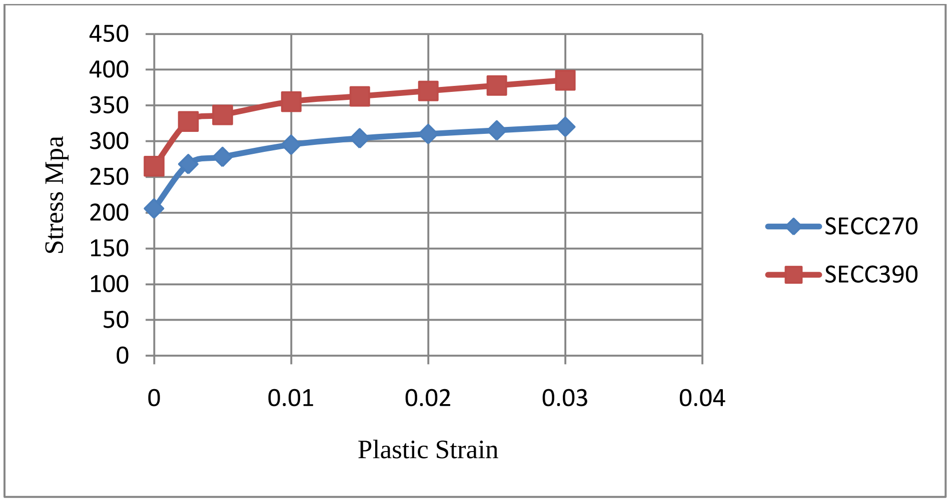

Figure 3. True Stress-Strain Plot

Table 4. Taguchi L12 DOE matrix with cost response

Factor	A	B	C	D	E	F	Cost($)
Row #	BeamT	BeamS	ColumnT	ColumnS	BaseT	BaseS	Y1
1	1.6	270	1.6	270	1.6	270	72.143
2	1.6	270	1.6	270	1.6	390	73.524
3	1.6	270	2	390	2	270	77.75021
4	1.6	390	1.6	390	2	270	75.668
5	1.6	390	2	270	2	390	78.48123
6	1.6	390	2	390	1.6	390	77.17021
7	2	270	2	390	1.6	270	76.02121
8	2	270	2	270	2	390	78.71323
9	2	270	1.6	390	2	390	77.61323
10	2	390	2	270	1.6	270	75.10858
11	2	390	1.6	390	1.6	390	75.38958
12	2	390	1.6	270	2	270	75.25758

6. Simulation Results

The simulations were done on a Dell Precision T7500 work station with two Intel Quad core Xeon processors each running at 2.2 GHz. Abaqus 6.10 running on Windows 7, with a 64 bit operating system was used. A typical output plot of von Mises stresses of the entire chassis is shown in Figure 4.

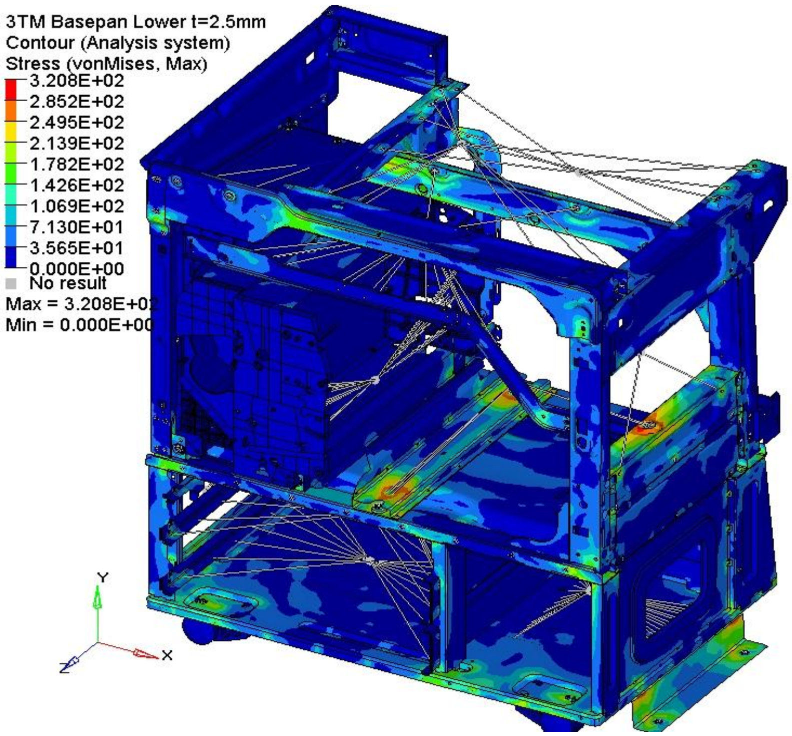

Figure 4. Typical chassis drop simulation results, von Mises Stress

The model contained about 200,000 elements and it required about 7.5 hours for each drop simulation run. The simulations were done utilizing Abaqus/Explicit and were used to screen out the DOE designs shown in Table 4. that did not meet the design allowable requirements as defined in section 4.1. All of the simulation except the first run passed the allowable test.

There were some interesting observations for the simulation runs a few are presented below;

1. Internal energy absorbed by various members of the chassis structure is shown in Figure 5. The wood pallet absorbs about 30% of the internal energy followed by 15% for the base pan and the rest is absorbed by the remaining components.
2. The thinner higher strength material base pan absorbs about 19% more internal energy than the thicker lower strength counterpart, see Figure 5.
3. The impact loads on the castors is about 8% lower with the thinner higher strength base pan compared to the thicker lower strength base pan, see Figure 6.

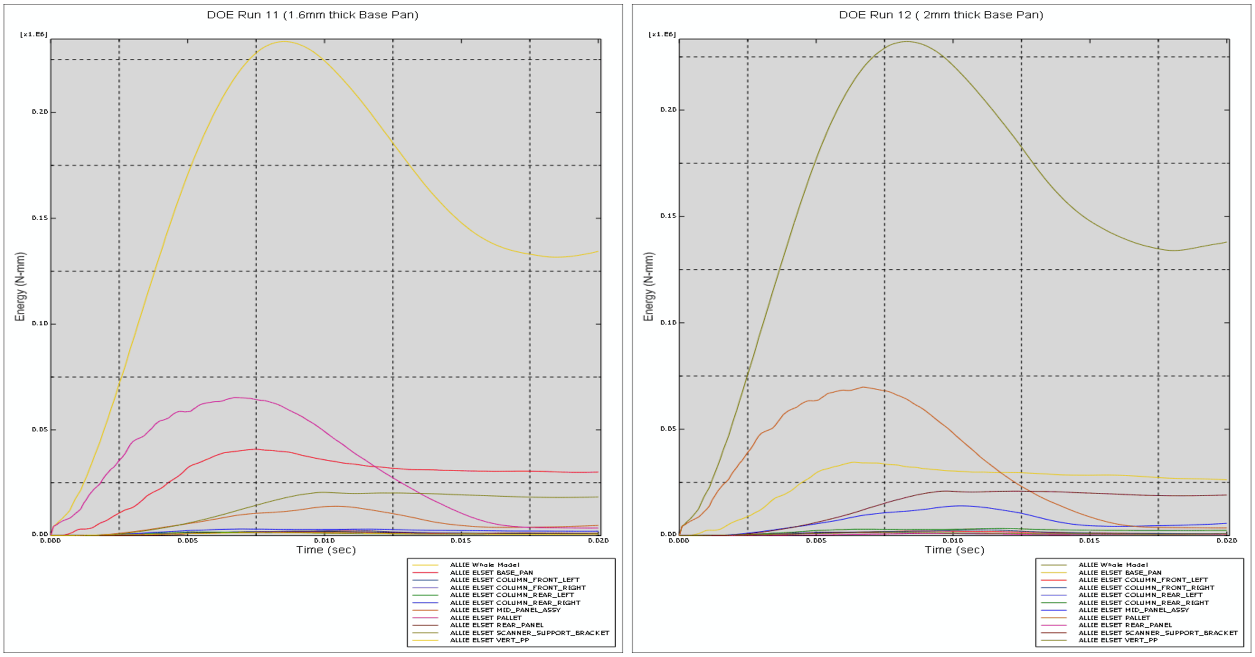

Figure 5. Internal energies of structural members, Base Pans 1.6mm (left), 2mm (right)

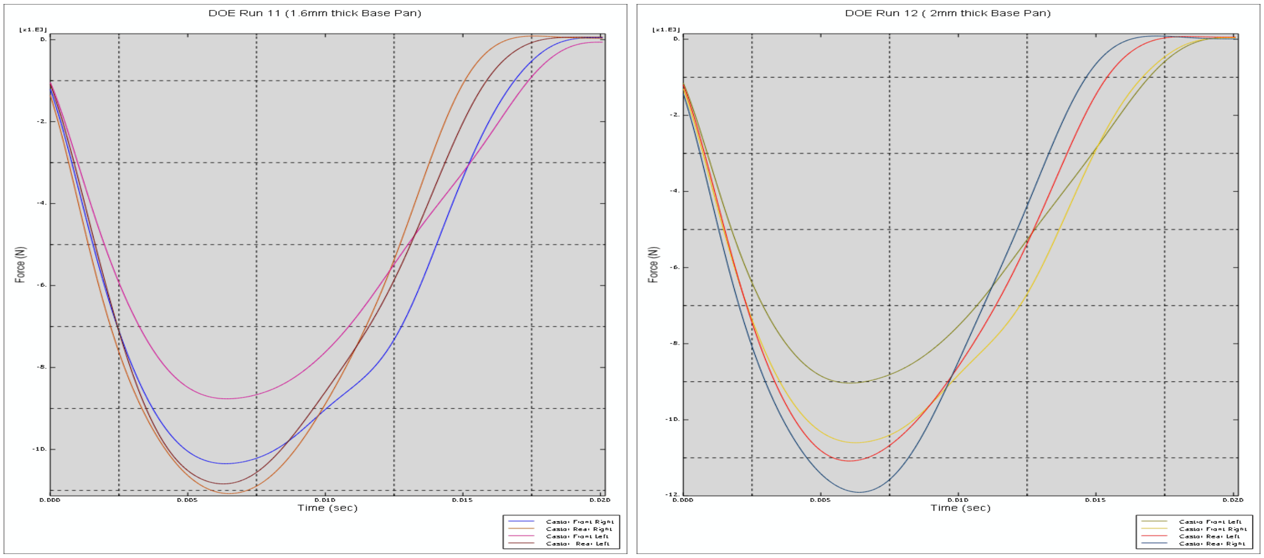

Figure 6. Loads on all four castors, Base Pans 1.6mm (left), 2mm (right)

6.1 Internal Loads

Internal loads both force and moments between major structural members were recorded during all of the simulations and then the peak loads were used to design the welded joints, see Table 5.

Table 5. Internal loads and moments

Interface	Side	Force (N)			Moment (N-M)		
		F1	F2	F3	M1	M2	M3
Column/Base	Front-Left	467.0	-2704.0	-395.0	-65.2	16.6	46.8
	Front-Right	402.0	-2618.0	-713.0	-62.0	16.4	-57.0
	Rear-Left	90.0	4207.0	1178.0	190.0	23.0	1.0
	Rear-Right	257.0	4720.0	1262.0	228.0	-2.6	31.0
Mid Rails/Column	Front-Left	2049.0	6015.0	1260.0	-24.0	32.0	90.0
	Front-Right	4114.0	3245.0	1878.0	32.0	-12.0	24.0
	Rear-Left	676.0	3616.0	313.0	-51.0	12.0	44.0
	Rear-Right	3178.0	5207.0	-1065.0	-25.0	-17.0	13.0

7. Conclusions and Next Steps

The chassis design was optimized for cost using design of experiments in conjunction with Abaqus /Explicit to validate the design robustness to transportation requirements. This strategy resulted in an additional 6% cost savings on top of the already cost reduced chassis design. The entire cost optimization exercise was conducted virtually; no actual parts were available for testing. This provided us with a head start in the design cycle and now the parts will be released with higher level of confidence. The aggressive design allowable requirements set for the chassis would have not been possible without detailed finite element analysis simulating the drop and impact of the chassis.

The next step is to build real parts and assemble them into an operational chassis and verify the results of the simulation. If there are no large surprises then the virtual optimization of the chassis would be a great success story in terms of design schedule and cost optimization.

8. References

1. Abaqus/Explicit: Advanced Topics, Lecture Notes
2. Xerox internal transportation specifications document
3. Xerox internal material data sheets