Modeling and Virtual Prototyping

Mathematical Modeling

A mathematical model can be

- Analytical
- Numerical
- Fuzzy model

A mathematical model can be governed by

- Fluid mechanics
- Heat transfer
- Thermodynamics
- Solid mechanics
- Solid model

Example of mathematical models

- Cross-sections of a beam under bending.
- A simple cylindrical bar loaded with torsion
- A beam loaded with direct shear
- To determine the maximum bending (axial) stress which develops in the beam due to the loading

Example of mathematical models

- Estimate the volume flow rate to select a pump for a prototype hydraulic system
- Estimate the bird-striking force to design a prototype protecting structure for an airplane
- To estimate the work done by a prototype engine

MODELING OF PHYSICAL SYSTEMS

A SIMPLE MODEL TO ESTIMATE AIR FLOW RATE

The model for powder mass flow rate (g/s) can be estimated to be

$$\dot{M} = 2\rho A_{\mathrm{d}} r V_{\mathrm{m}}$$

where

r = feed screw helix lead (mm)

ρ = powder density (gm/mm^3)

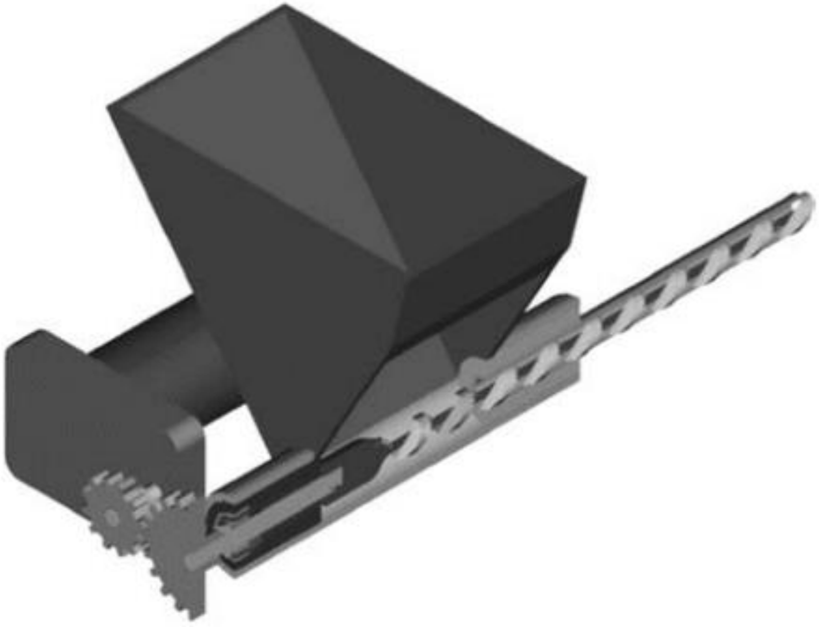
A_{d} = the cross-sectional area (mm^2)

V_{m} = motor speed (rev/s)

An air flow meter

MODELING OF PHYSICAL SYSTEMS

DESIGN AND PROTOTYPE A POWDER FEEDER



Design a screw-type powder feeder

If a high-school student wants to choose between different colleges, when considering college ranking, location, specialty, expense, try to find the relative importance of the following criteria: college ranking, location, specialty, and expense. Complete the following table.

	College Ranking	Location	Specialty	Expense	Total
College ranking					
Location	0				
Specialty	1	1			
Expense	0	1	0		

Continuing the last question, if another student wants to select one of these four colleges but the four factors in sequence are: college ranking, specialty, location, and expense, help him to make the selection.

	College Ranking	Location (mile)	Specialty	Expense ($) (per year)
A	3	2200	Satisfying	55,000
B	35	1100	Very good	34,000
C	48	Local	Good	18,000
D	120	600	Very good	8,000

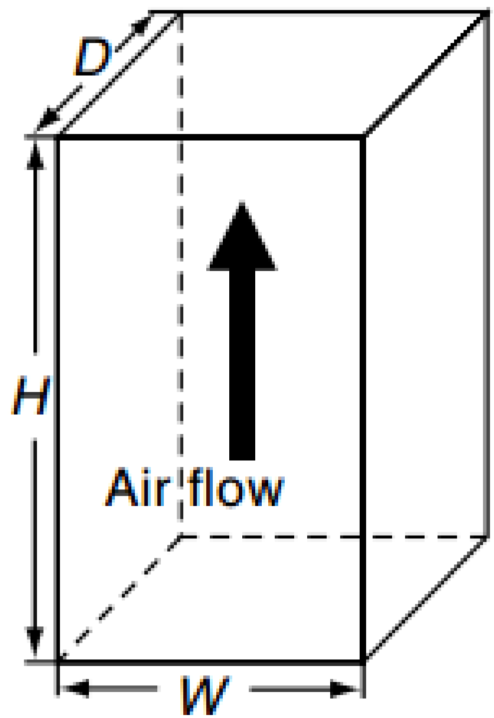
A SIMPLE MODEL TO ESTIMATE AIR FLOW RATE

This example is to find the air flow volume of a chamber with a ventilation dock

It is necessary to find the flow in order to determine the fan required to pump the air out of the chamber

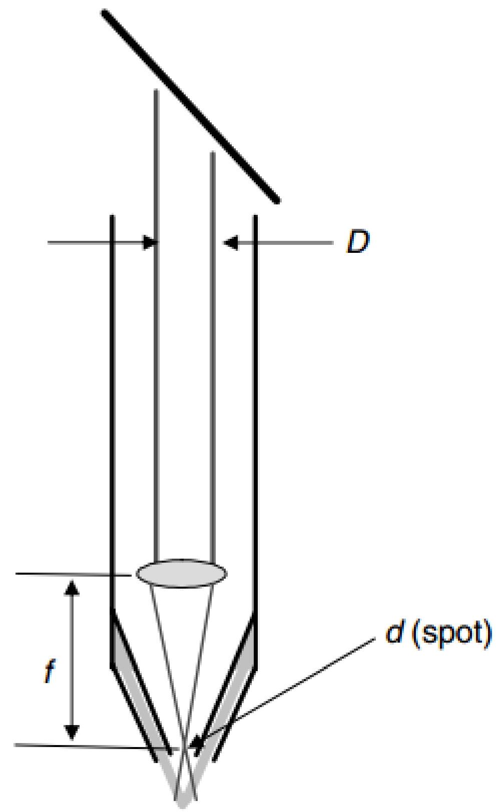
the air flow is equal to DW(dH/dt).

the flow velocity ,H, per unit time or dH/dt.



The air flow model: Volume $(V) = H \times W \times D$ per unit time.

USE A LASER BEAM MODEL TO REDESIGN A NOZZLE



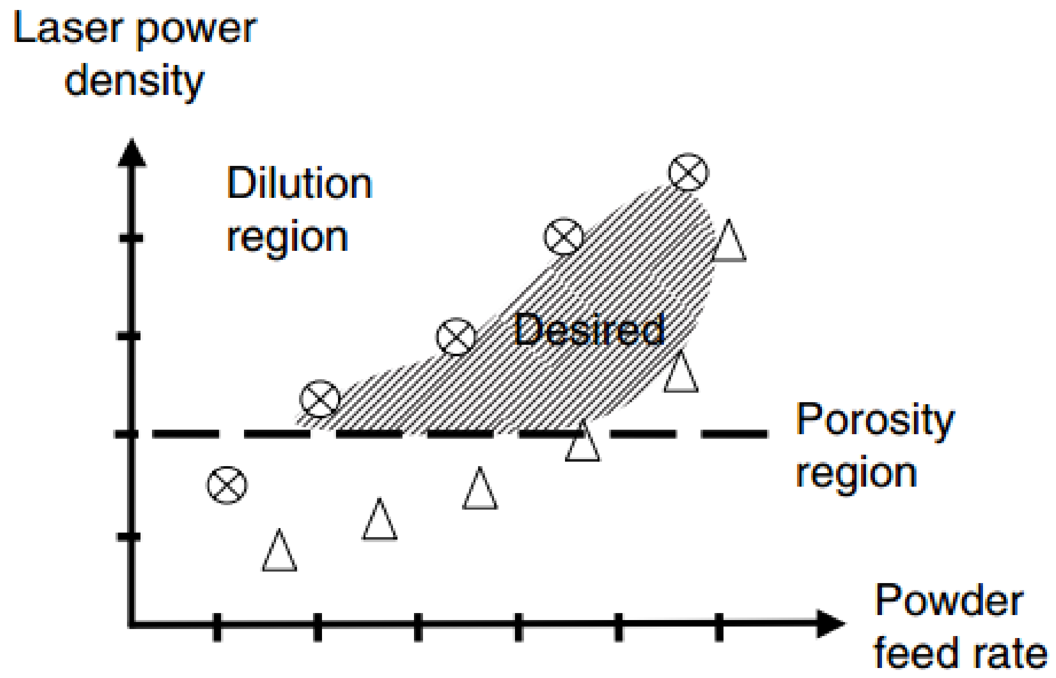
A schematic diagram of a nozzle assembly for a laser deposition system.

CONTROL OF DEPOSITED BEAD IN LASER CLADDING

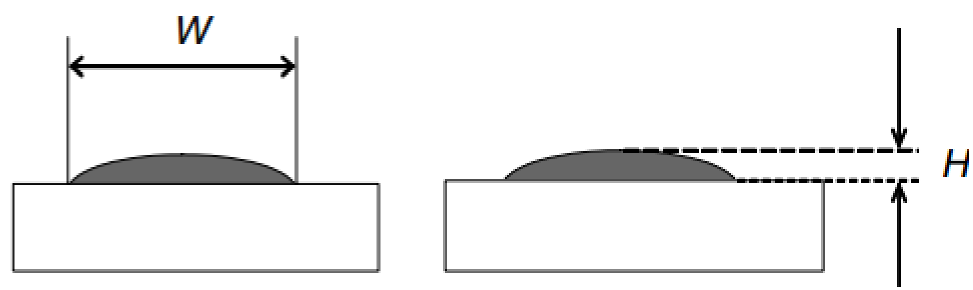
Summary of Experimental Results for a Laser Deposition Process

Heating Times as a Function of Power for a 0.025 mm Melt Depth in Nickel

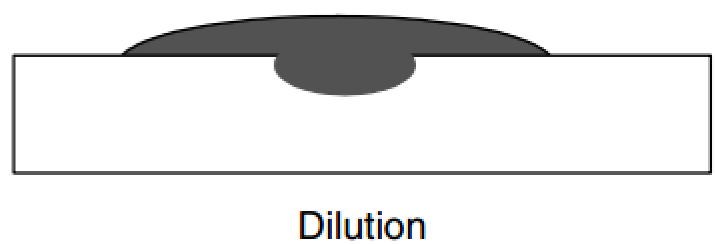
Power density (W/mm^2)	5	50	500	2000
Surface temp (°C)	1456	1469	1590	1960
Melting time (s)	23.1	0.236	2.8E−3	2.6E−4



Desired parameter graph for laser–material interaction.



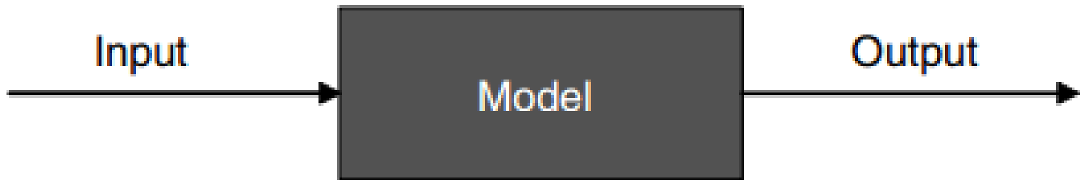
Model of a laser deposited bead.



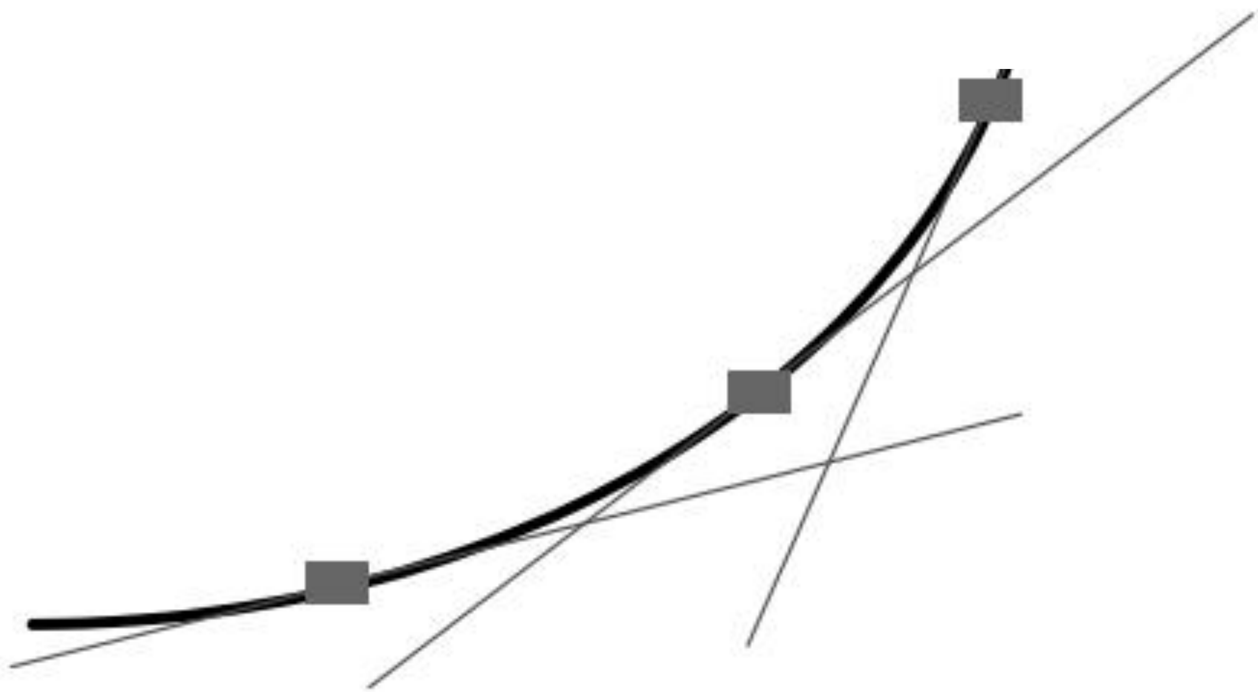
Dilution in laser cladding.

The properties of the model can be one or a combination of the following:

- Continuous or discrete time
- (Non) linear
- (Non) stationary
- (Non) causal
- (Non) deterministic
- (Un) stable
- systematic error
- Variance or random error



A black box model.



Piece-wise linearization of a function.

PRODUCT MODELING

A product model is a model of a product metric that is a representation, simplification, or estimation of a product's realization to aid in making product decisions.

PRODUCT MODELING

A product model is a model of a product metric that is a

- **Representation**
- **Simplification**
- **Estimation of a product's realization**

to aid in making product decisions

To prepare a product model, the following steps can be followed:

Step 1: *Model preparation* to map or relate the customer need/weights to the product functions

Step 2: *Model prioritization* to identify the functions that relate most strongly to the customer needs

Step 3: *Model quantification* to choose the metrics (engineering characteristics) that may be used to quantify the material, energy, or signal flows for these functions, and to identify target values for these metrics based on benchmarking results

Questions such as the following should be examined:

- What is the problem really about?
- What implicit expectations and desires are involved?
- Are the customer’s needs, requirements, and constraints truly appropriate?
- What characteristics or properties must the product have?
- What characteristics or properties must the product not have?
- What are the technical conflicts inherent in the design task?
- What aspects of the design task should be quantified now?
- Are there any other features of the product?

EXAMPLE 3.15: PRODUCT MODELING FOR RETRACTABLE EARPHONES

What is the problem really about?

- The real reason this product is needed is that earphones are often removed when users are using the product
- They should not get caught on something.
- When the earphones are removed and stuffed into a pocket
- The cord should not get tangled.

What implicit expectations and desires are involved?

- It is expected that the usability, comfort, and portability of the device will not be affected by using this product.
- Assume the circular part of the device must be less than 1.5 in.
- It must be less than 0.75 in. thick.

Are the customer’s needs, requirements, and constraints truly appropriate?

Yes.

Generally the reason MP3 players and pocket radios are chosen in the first place is that they are small and light weight, which make them comfortable and easy to accommodate on the go.

.

What characteristics properties must the product have?

The product must be comfortable and easily operated.

What characteristics properties must the product not have?

The product must not be bulky and awkward for the user.

The retractable device must not make it feel like someone is trying to pull the earphones out of the user’s ears while he or she is using them.

.

What are the technical conflicts inherent in the design task?

- one will probably use a coil spring to provide the rotational reaction to wind the cord. The coil to only accommodate as few rotations as possible in winding and unwinding, but to do this the diameter of the spool that the cord is wound around needs to be large.
- Making the spool large means that the package size must increase.

What aspects of the design task should be quantified now?

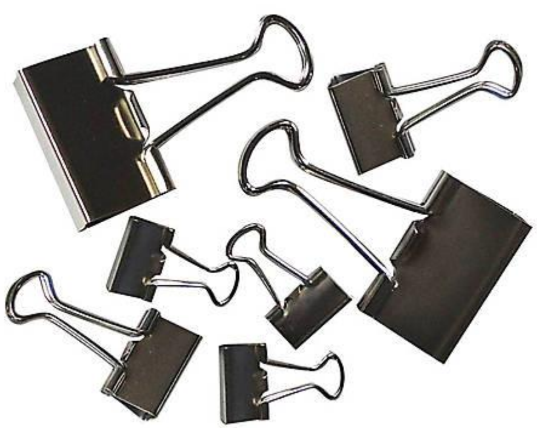
- The total length of the cord,
- The envelope for the retracting device.
- Acceptable tension on the cord the retracting device can exert while the earphones are in use.

Technical Details

Item Weight	99.8 g
Item model number	Retractabe Earphones
Special features	In-ear
Weight	99.8 Grams
Colour	White

PRODUCT MODELING FOR A BINDER CLIP

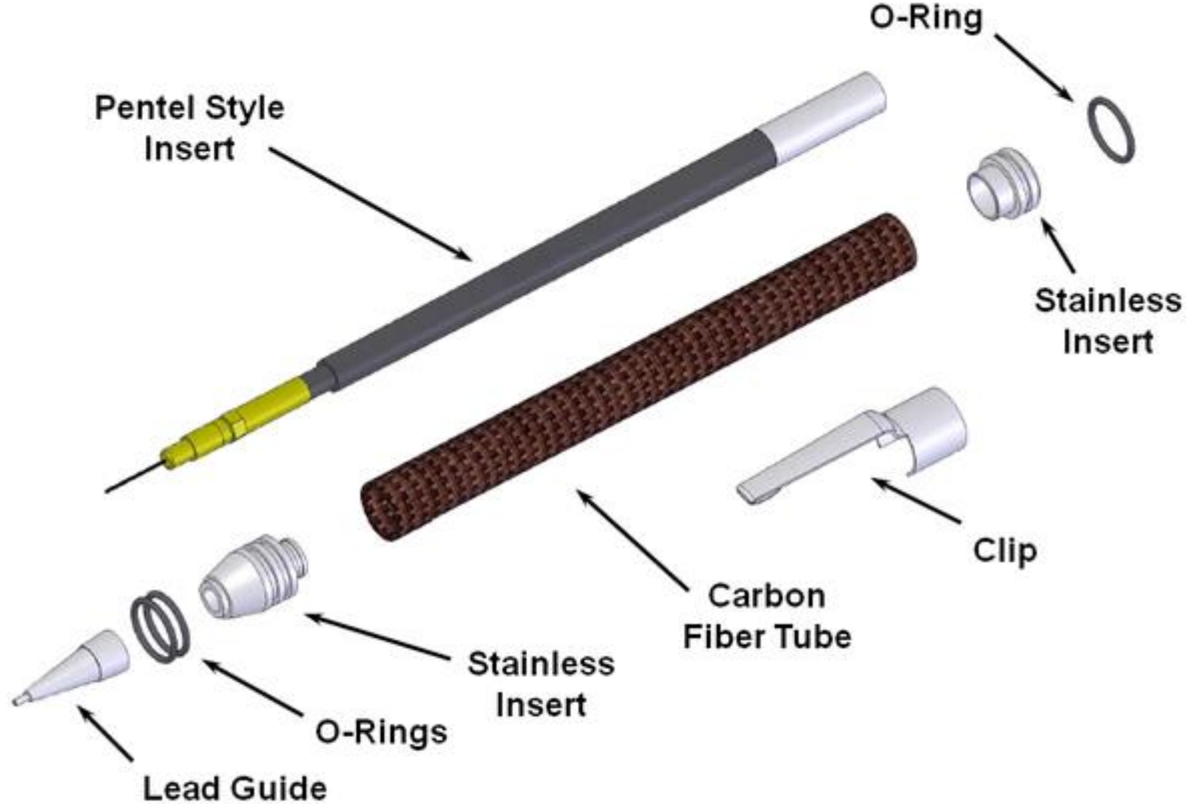
Questions	Answer	Interpretation
1. What is the need?	Binder clip	Clip together papers that other paperclips cannot handle
2. For official use or personal use? "For official use" needs to be formal and not	Official	
3. For use where people can see or general use?	General	Need not be exclusive
4. For holding how many pieces of paper?	50–100	Should be rigid and probably hold 150 pieces of paper
5. Ease of use?	Easy	Should have good leverage
6. Compactness?	No concern	Can give enough length for leverage and strong material for rigidity
7. Cost?	Average	Metal should not be too costly and should not have a complicated design procedure or manufacturing technology



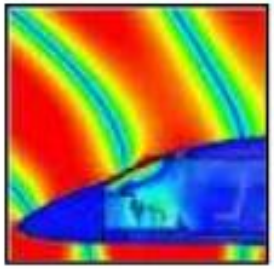
Find Solution

- A new computer mouse pad will be designed. Use this mouse as an example to write down technical questions (What is the problem really about? What implicit expectations and desires are involved?

- Develop a product model for a mechanical pencil.

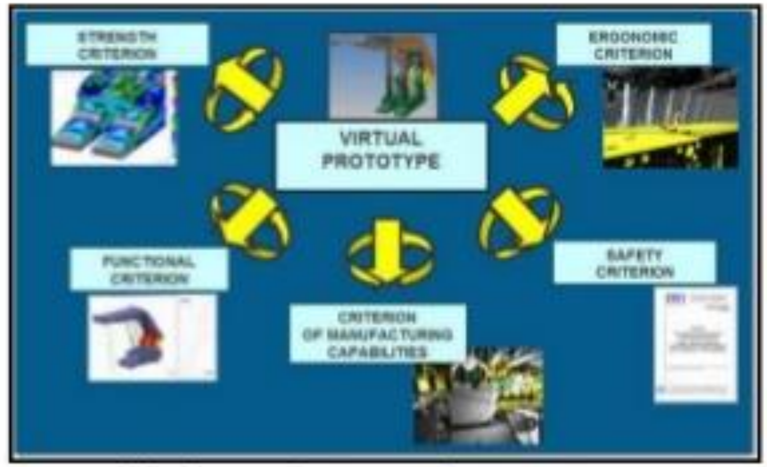

O-Ring
Pentel Style
Insert
Stainless
Insert
Clip
Carbon
Fiber Tube
Stainless
Insert
O-Rings
Lead Guide

Why Virtual Prototyping?



- Multiphysics software can also be imported into the prototype for assessing phenomena such as static and dynamic structural forces
- Effects of electromagnetic radiation from radar, either onboard or from external sources can be solved

Advantages of Virtual Prototyping



- Instrumental tool in shortening time to market
- Allows design, manufacturing, and marketing to work in parallel rather than in series
- As parts are designed, they become part of a database that can be used for inventory management

USING COMMERCIAL SOFTWARE FOR VIRTUAL PROTOTYPING

Many types of commercial software are excellent virtual prototyping tools, and often they start with a CAD (computer aided design) model to define the product geometry.

CAD models could be wire frame, surface model, or solid model.

Virtual prototyping software

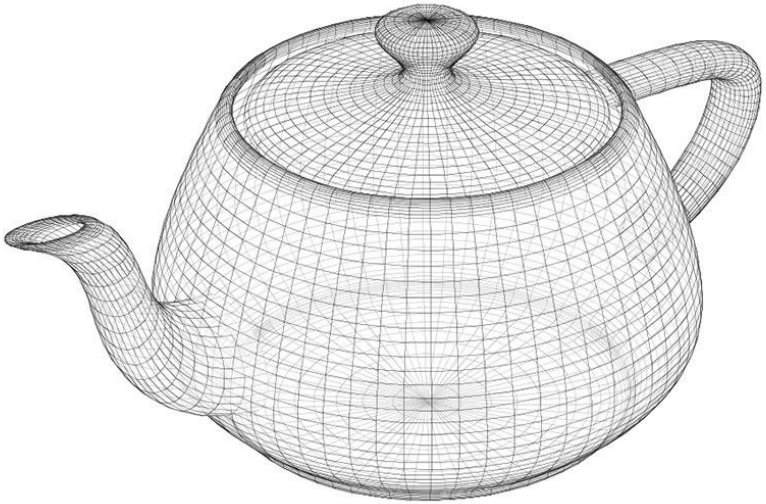
MASTER CAM	DEL CAM

Modeling Software

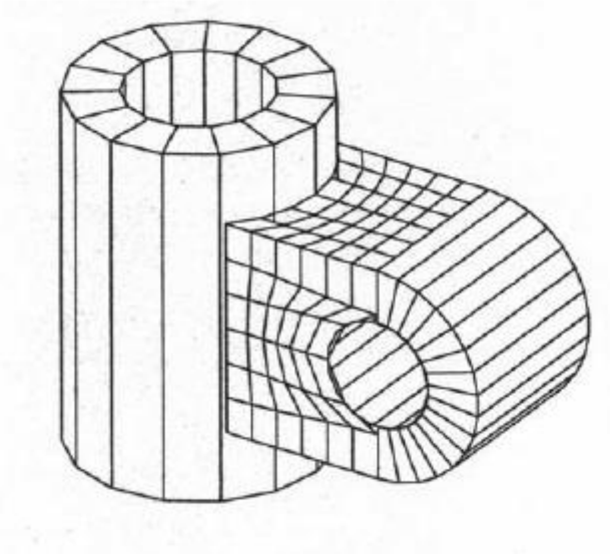
CATIA	PROE	UNIGRAPHICS

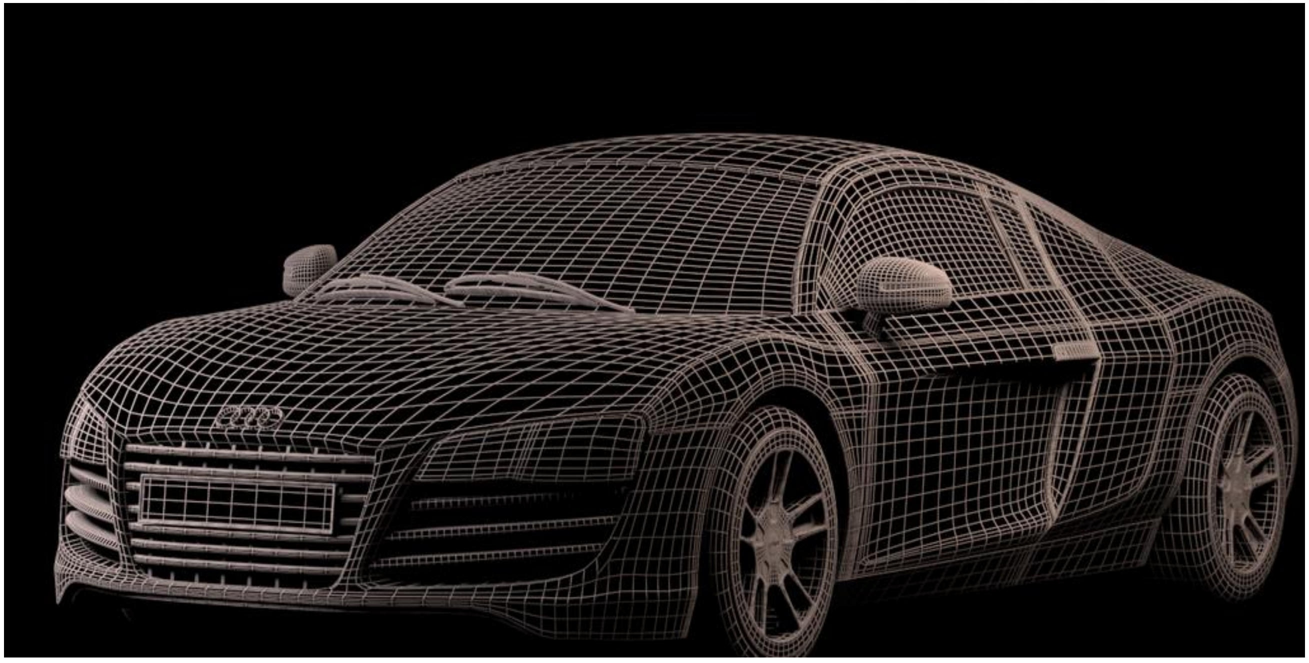
Analysis software

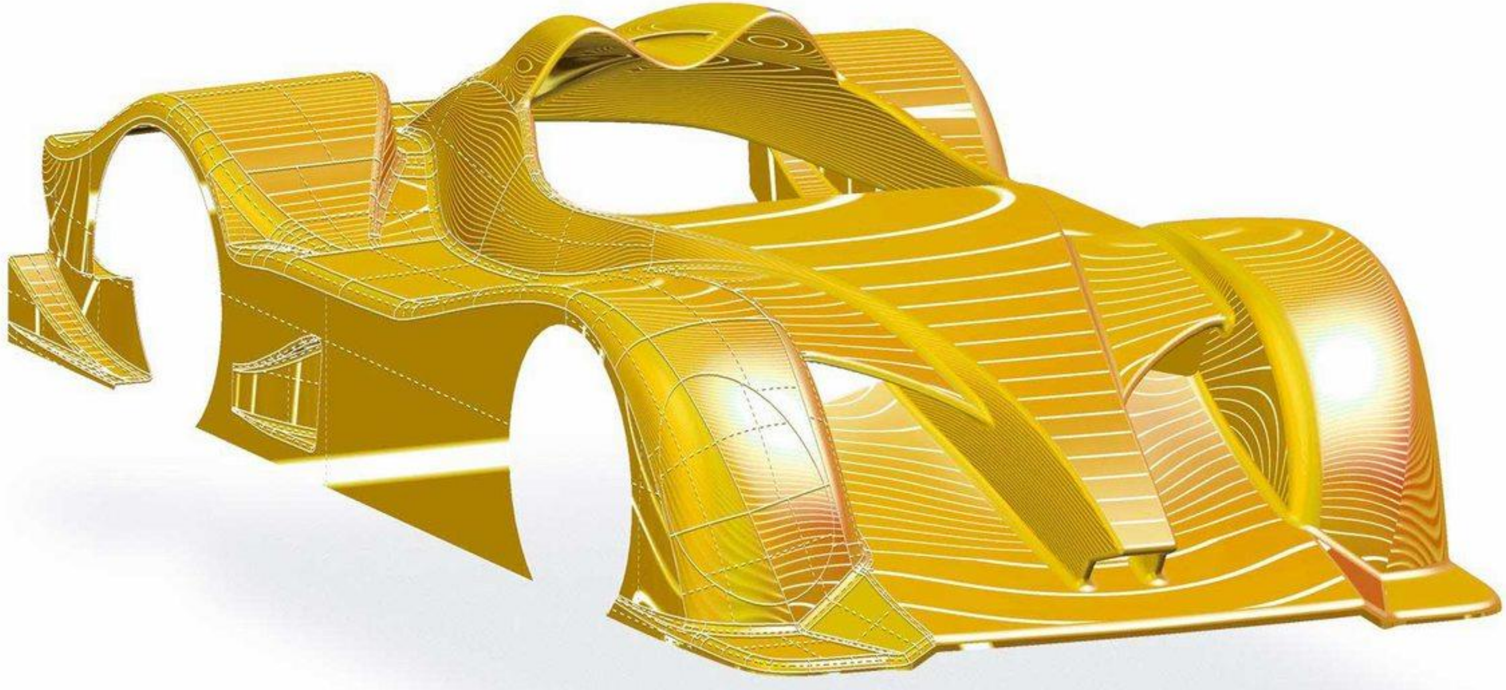
ANSYS	DEFORM 3D	Hypermesh



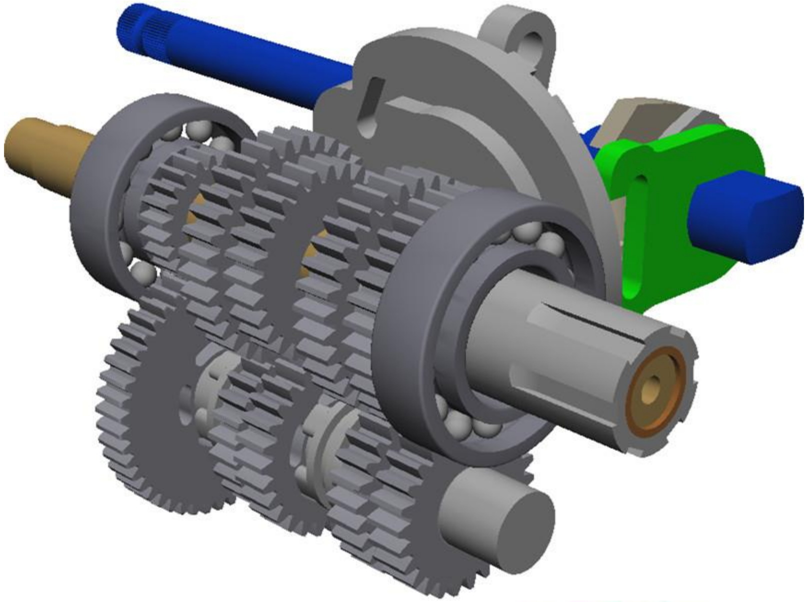
Wireframe

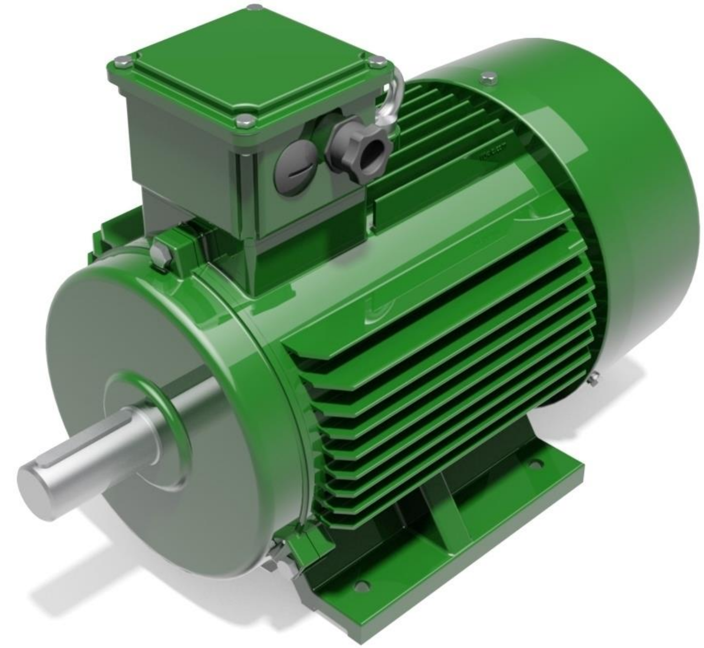






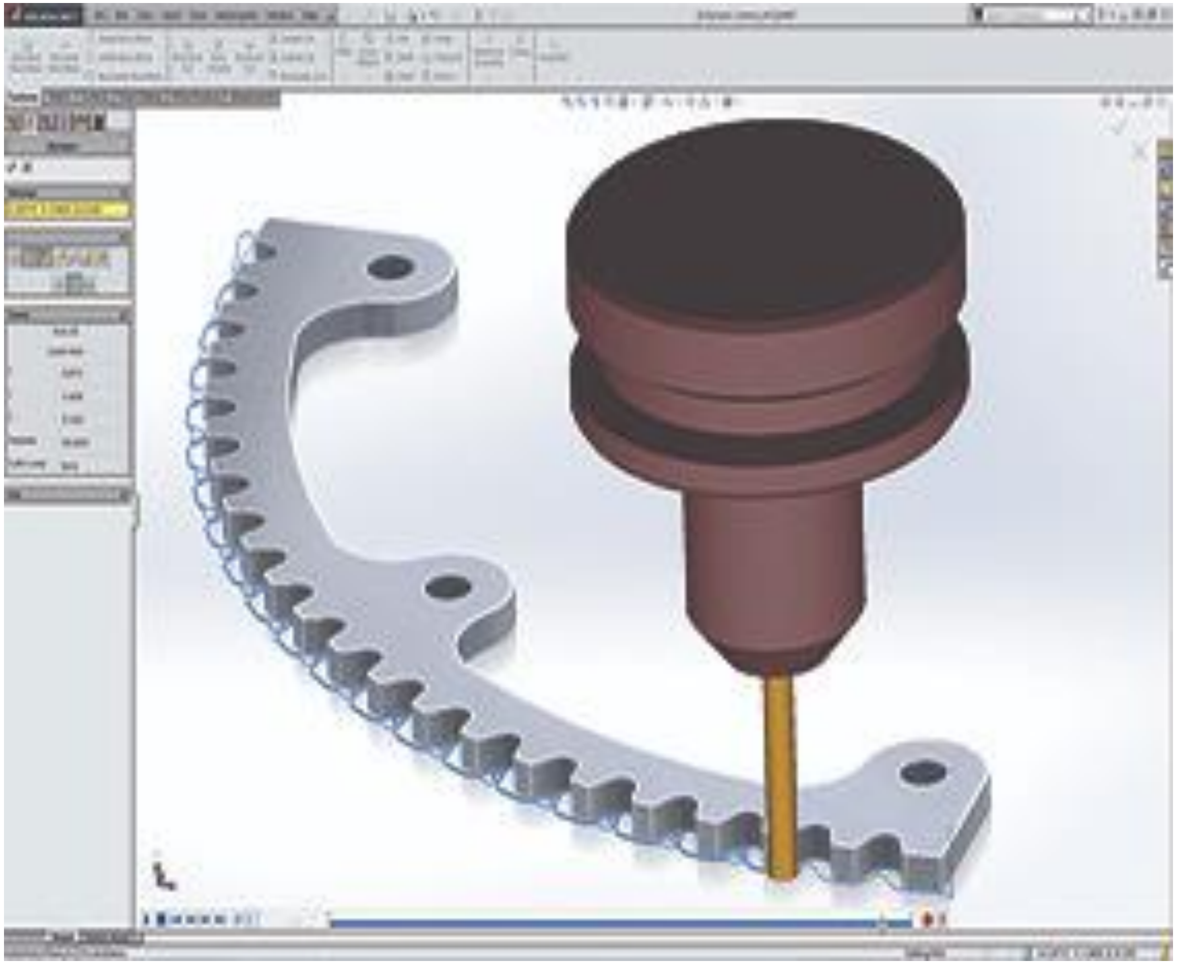
Surface model



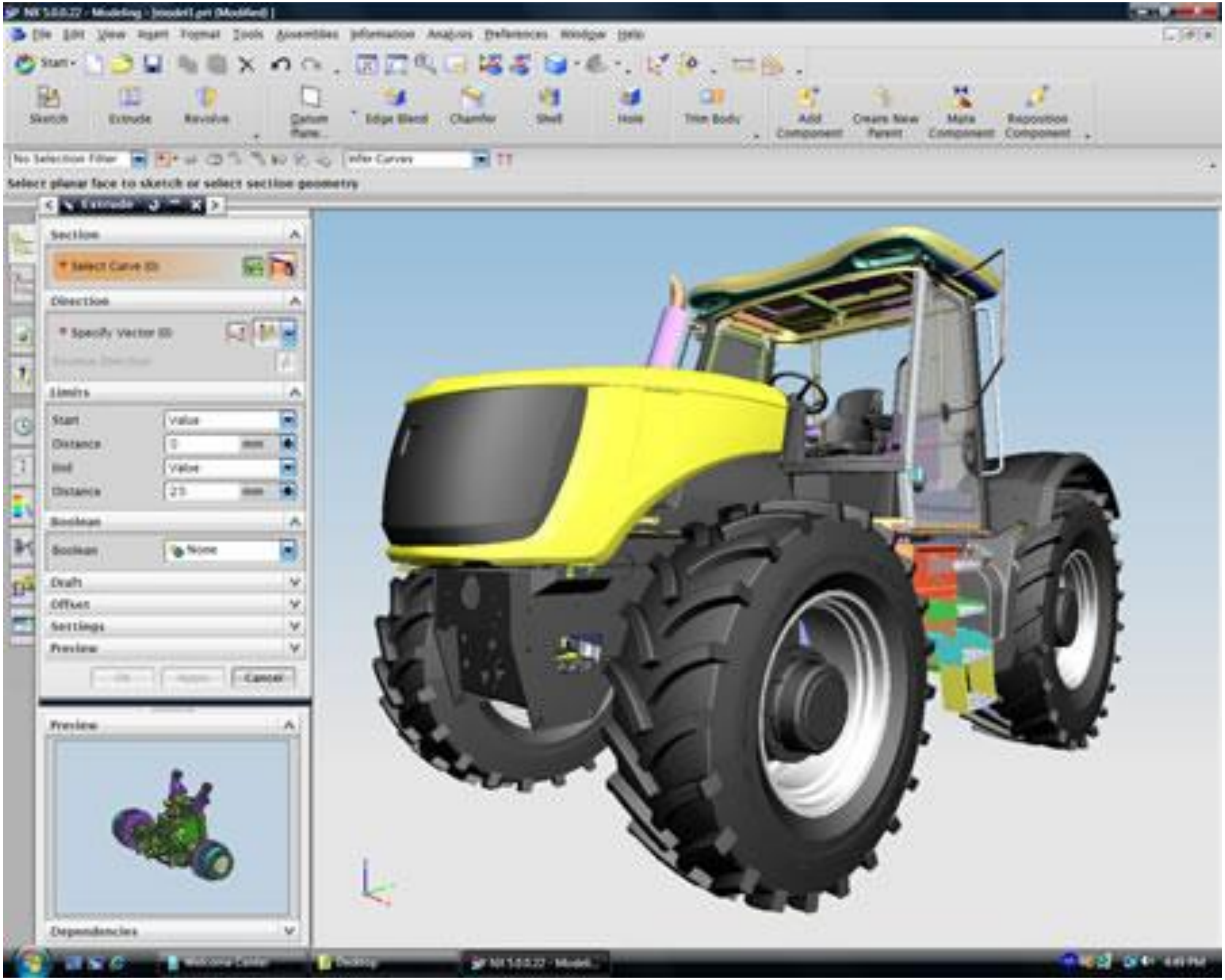


Solid model

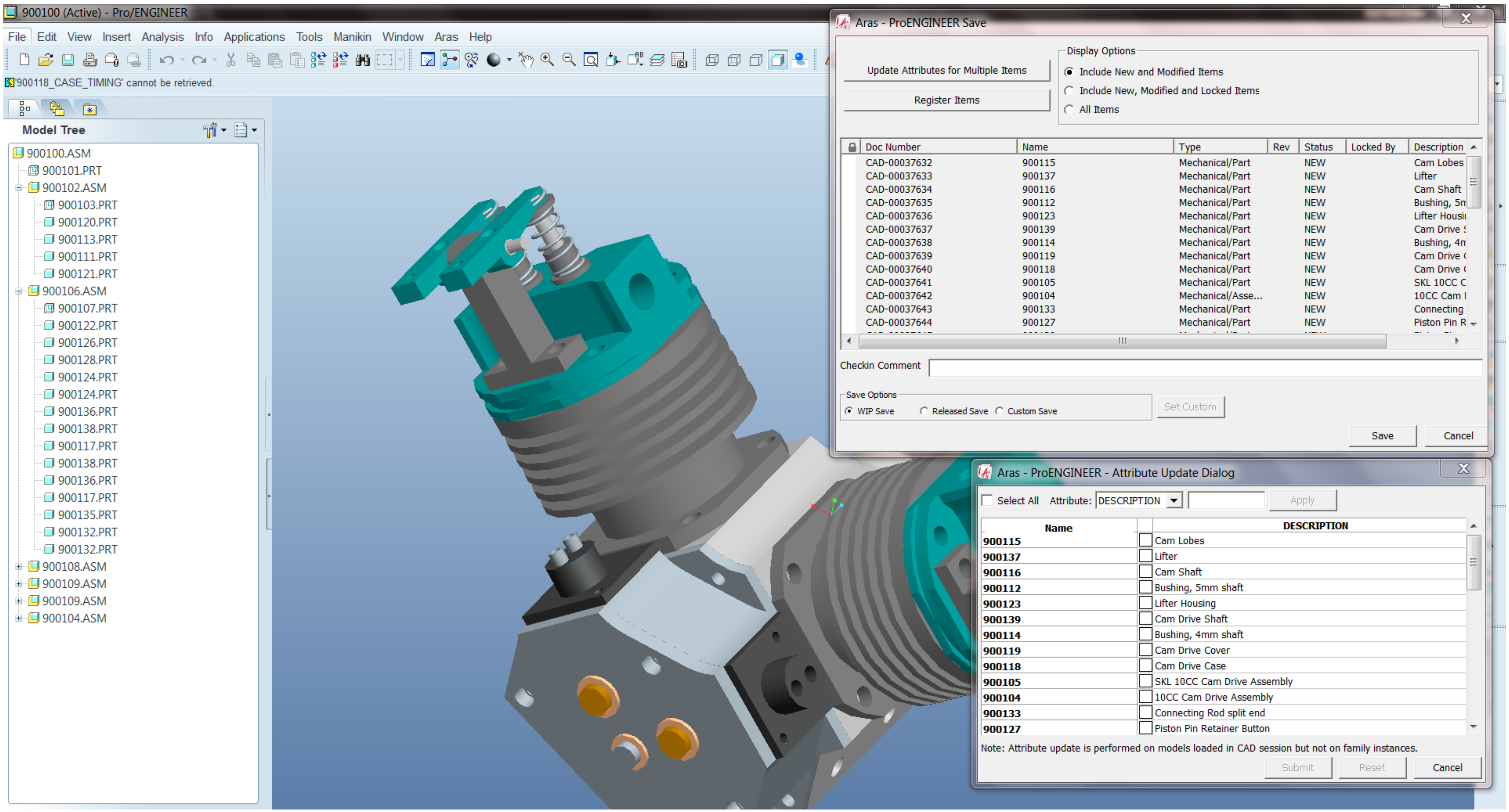
Master CAM



Unigraphics



PRO-E


900100 (Active) - Pro/ENGINEER
File Edit View Insert Analysis Info Applications Tools Manikin Window Aras Help
'900118_CASE_TIMING' cannot be retrieved.
Model Tree
900100.ASM
900101.PRT
900102.ASM
900103.PRT
900120.PRT
900113.PRT
900111.PRT
900121.PRT
900106.ASM
900107.PRT
900122.PRT
900126.PRT
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900117.PRT
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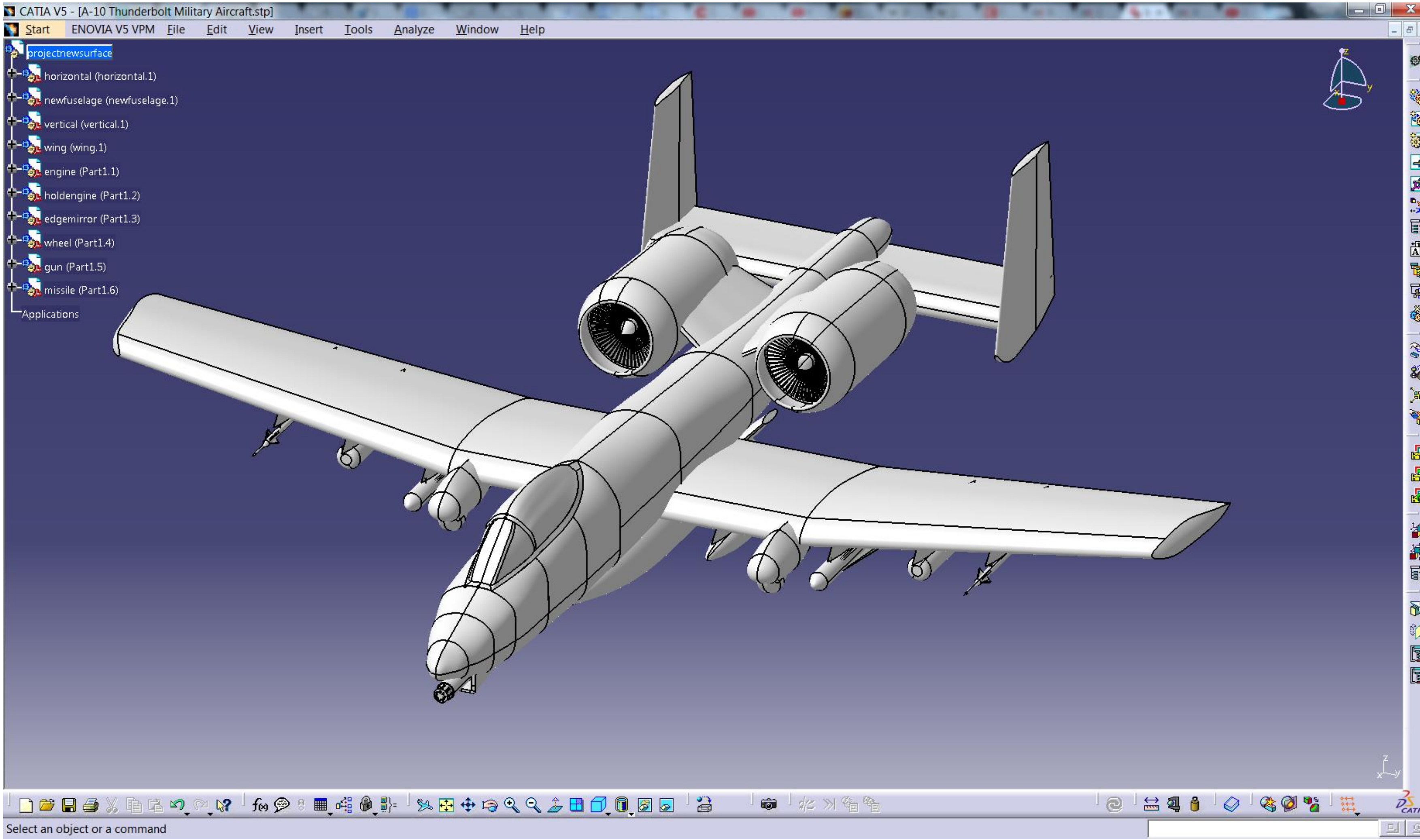
900117.PRT
900135.PRT
900132.PRT
900132.PRT
900108.ASM
900109.ASM
900109.ASM
900104.ASM
Aras - ProENGINEER Save
Update Attributes for Multiple Items
Register Items
Display Options
Include New and Modified Items
Include New, Modified and Locked Items
All Items
Doc Number Name Type Rev Status Locked By Description
CAD-00037632 900115 Mechanical/Part NEW Cam Lobes
CAD-00037633 900137 Mechanical/Part NEW Lifter
CAD-00037634 900116 Mechanical/Part NEW Cam Shaft
CAD-00037635 900112 Mechanical/Part NEW Bushing, 5n
CAD-00037636 900123 Mechanical/Part NEW Lifter Housi
CAD-00037637 900139 Mechanical/Part NEW Cam Drive
CAD-00037638 900114 Mechanical/Part NEW Bushing, 4n
CAD-00037639 900119 Mechanical/Part NEW Cam Drive
CAD-00037640 900118 Mechanical/Part NEW Cam Drive
CAD-00037641 900105 Mechanical/Part NEW SKL 10CC C
CAD-00037642 900104 Mechanical/Asse... NEW 10CC Cam I
CAD-00037643 900133 Mechanical/Part NEW Connecting
CAD-00037644 900127 Mechanical/Part NEW Piston Pin R
Checkin Comment
Save Options
WIP Save
Released Save
Custom Save
Set Custom
Save
Cancel
Aras - ProENGINEER - Attribute Update Dialog
Select All
Attribute: DESCRIPTION
Apply
Name
DESCRIPTION
900115 Cam Lobes
900137 Lifter
900116 Cam Shaft
900112 Bushing, 5mm shaft
900123 Lifter Housing
900139 Cam Drive Shaft
900114 Bushing, 4mm shaft
900119 Cam Drive Cover
900118 Cam Drive Case
900105 SKL 10CC Cam Drive Assembly
900104 10CC Cam Drive Assembly
900133 Connecting Rod split end
900127 Piston Pin Retainer Button
Note: Attribute update is performed on models loaded in CAD session but not on family instances.
Submit
Reset
Cancel

CATIA



CATIA V5 - [A-10 Thunderbolt Military Aircraft.stp]
Start
ENOVIA V5 VPM
File
Edit
View
Insert
Tools
Analyze
Window
Help
projectnewsurface
horizontal (horizontal.1)
newfuselage (newfuselage.1)
vertical (vertical.1)
wing (wing.1)
engine (Part1.1)
holdengine (Part1.2)
edgemirror (Part1.3)
wheel (Part1.4)
gun (Part1.5)
missile (Part1.6)
Applications
Select an object or a command

The traditional model of industrial operation starts from the following sequence:

1. Sales and marketing
2. Product development
3. Design
4. Analysis
5. Release the design
6. Planning
7. Tooling
8. NC program
9. Product control
10. Fabrication
11. Inventory

The impact of the current technology has changed the way industry operates, and the steps have been greatly reduced

1. Sales and marketing
2. Product definition
3. Product and process definition
4. Pre-assembly
5. Build inspection

One major application of CAD is in concurrent engineering:

A systematic approach to creating a product design that considers all elements of the product life cycle from conception through disposal.

Concurrent engineering defines simultaneously the product:

- Its manufacturing processes.

- All other required life-cycle processes, such as logistic support.

- It allows different groups to create individual parts of a mechanical design at different locations and at different stages of the design process.

For instance,

one user might be designing an electrical component.

Another person is testing it for installation or maintainability.

A third person is performing training on that same component.

The benefits of concurrent engineering include

- Reduction of the time needed for implementing a new product into production
- Reduction of the time-to-market
- Substantial improvement of product quality
- Quicker reaction to customer requirements
- Cost reduction
- Profitability improvement.

DYNAMIC ANALYSIS FOR PROTOTYPE MOTION EVALUATION

The simulation includes real-time collision detection and dynamic response.

Simulate the test dummy's response during collision to understand how the human body may be impacted during a car accident.

FINITE ELEMENT ANALYSIS FOR PROTOTYPE STRUCTURE EVALUATION

FEA is a computer-based numerical technique for calculating the strength and behavior of engineering structures.

It can be used to calculate

- Deflection
- Stress
- Vibration
- Buckling behavior
- Elastic deformation
- Plastic deformation

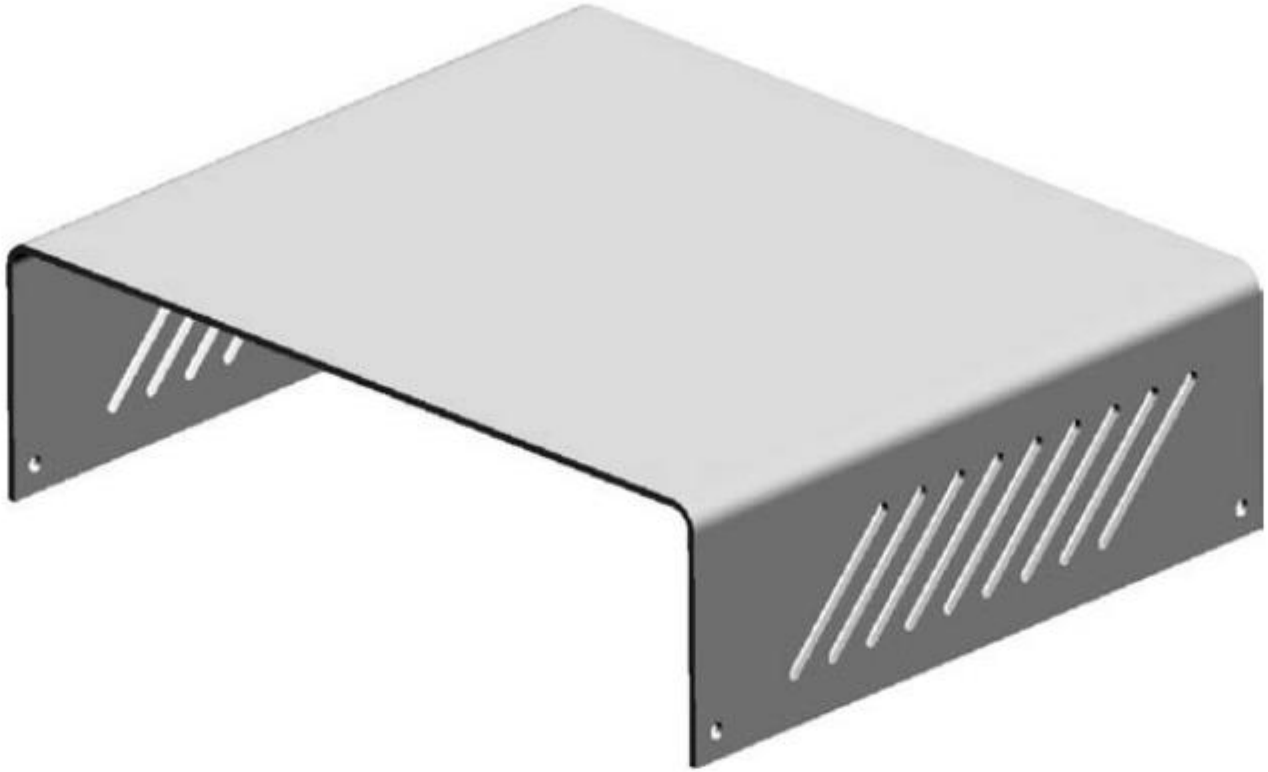


FIGURE 3.49 Top section of the box assembly.

SL7520, the following properties were inputted:

Mass density = 0.0426 lbm/in.^{3}
Young's modulus = 450,000 psi
Poisson's ratio = 0.33
Shear modulus = 415,000 psi
Yield strength = 9,200 psi

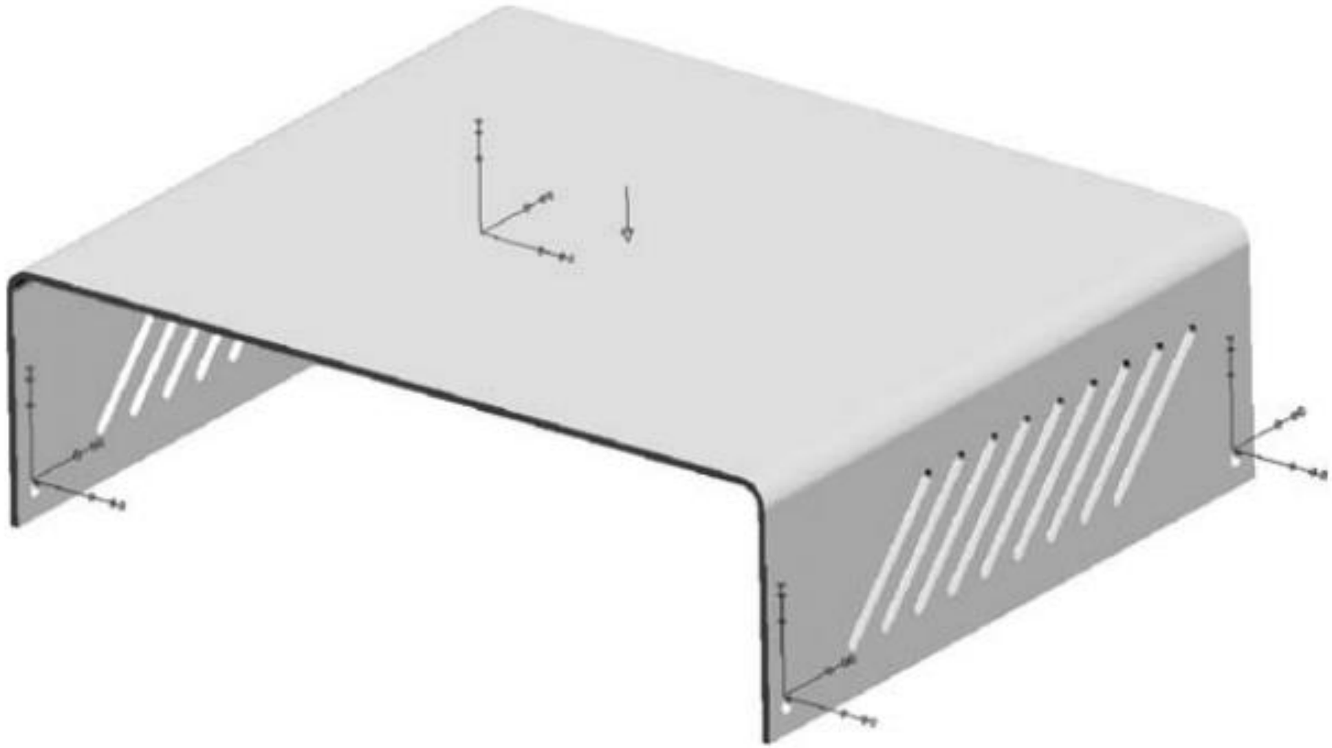


FIGURE 3.50 Load and boundary condition for FE on upper section.

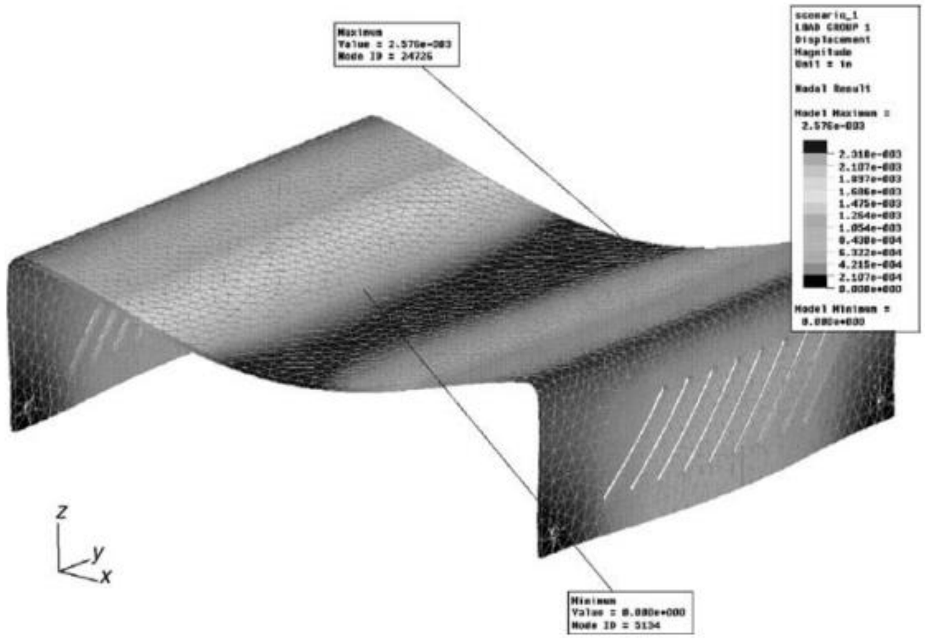


FIGURE 3.51 Finite element run with initial boundary conditions.

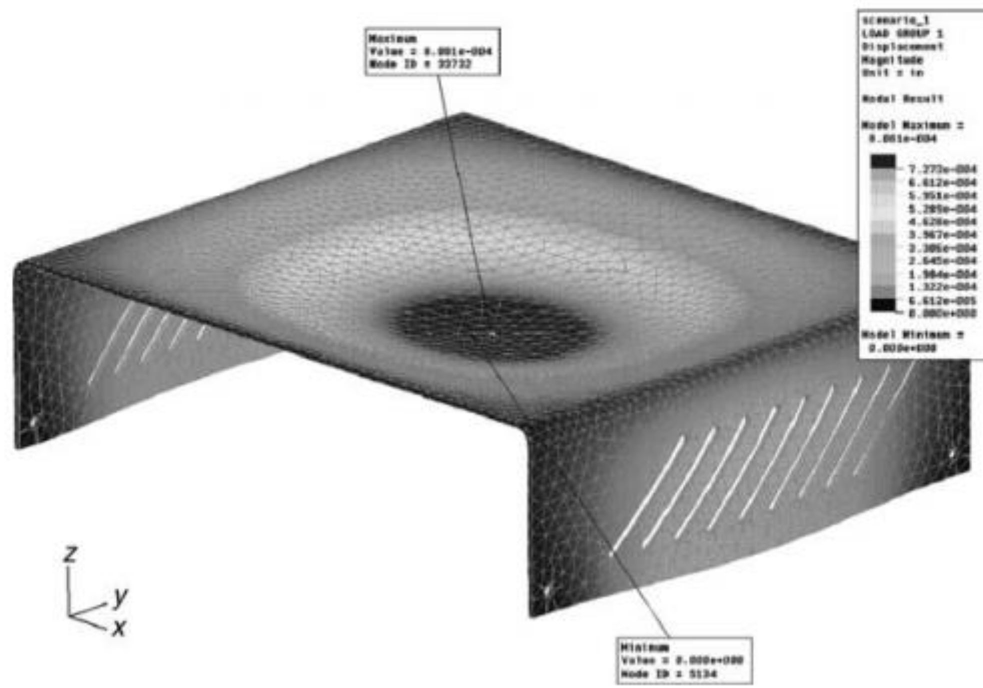


FIGURE 3.53 Finite element deflection model.

Virtual prototyping is combining the virtual environment with engineering design to allow a designer to play an active role in the design sensitivity and optimization process.

Virtual reality is a system that provides a non-real environment but gives the feeling of real sense.

An example of a virtual reality application

- Training program to train drivers on safe operation of a forklift truck in a busy and complex real warehouse environment.
- Biogen demo was created to visualize the process of how the patient's health improved when he took new drugs and how the these drugs reacted with DNA and brain cells.
- Virtual real estate is another such example to visualize different properties on a 3D map where the user can move around the plots and look for desired features.

Technology requirements

- Hardware capable of rendering real-time 3D graphics and stereo sound.
- Input devices to sense user interaction and motion.
- Output devices to replace user's sensory input from the physical world with computer-generated input.
- Software to handle real-time input/output processing, rendering, simulation, and access to the world database

A virtual environment for this type of application may involve all or part of the following functions:

(1) The designer can observe a visual representation of the virtual parts and equipment involved;

(2) The designer can interactively manipulate a virtual part or equipment component through interface devices, and the virtual part or component will react according to the force or motion the designer provides;

(3) The designer can feel the objects and hear sounds from the virtual work cell

To implement a virtual environment system for parts handling applications, at least two major enabling technologies are needed:

1. Simulation technology to model and process the interaction between objects in the virtual world.

2. Human–machine interface technology to effectively generate the appropriate sensory output of the simulation system to the user, and receive the input command from the user.

- What can commercial software do in a product design and prototyping process?
- Can the current software replace a physical prototype? If yes, to what level?
- What types of software are available for virtual prototyping?
- How can the dynamic behavior of a product be simulated in a CAD model?
- How to evaluate the response of a part subjected to an external load?