Computer-Aided Design, Pro/Engineer Overview & Some Practical Hints on Work with the Pro/E

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NSERC Design Engineering Chair

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Overview

- History
- Principles of the computer assisted mechanical design
  - *General design procedure*
  - *Design phases*
- The main aspects of the design with Pro/E
  - *Part modelling*
  - *Assembly*
  - *Motion analysis*
  - *Structural analysis*
- Some practical hints on the mechanical design
- Conclusion

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History

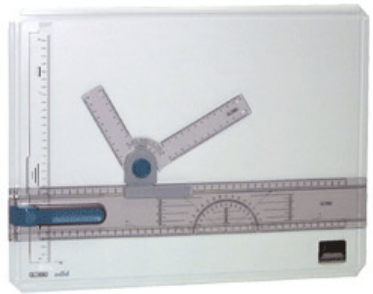
How was it going 20 or 30 years ago?

20...50 design engineers

- 2 years of work

- Tons of paper

- Drawing board and rulers



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History

And what is the result?

Will it work at all?

You never know before you build a prototype!

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History

It is like to meet a bear in a wood

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History

Will it attack?...

History

...or step back?

You will never know it before you meet!

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History

The same principle works in the

Mechanical Design

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History

Will it fly?

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History

Or won‘t?

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Will it stand for years and centuries?

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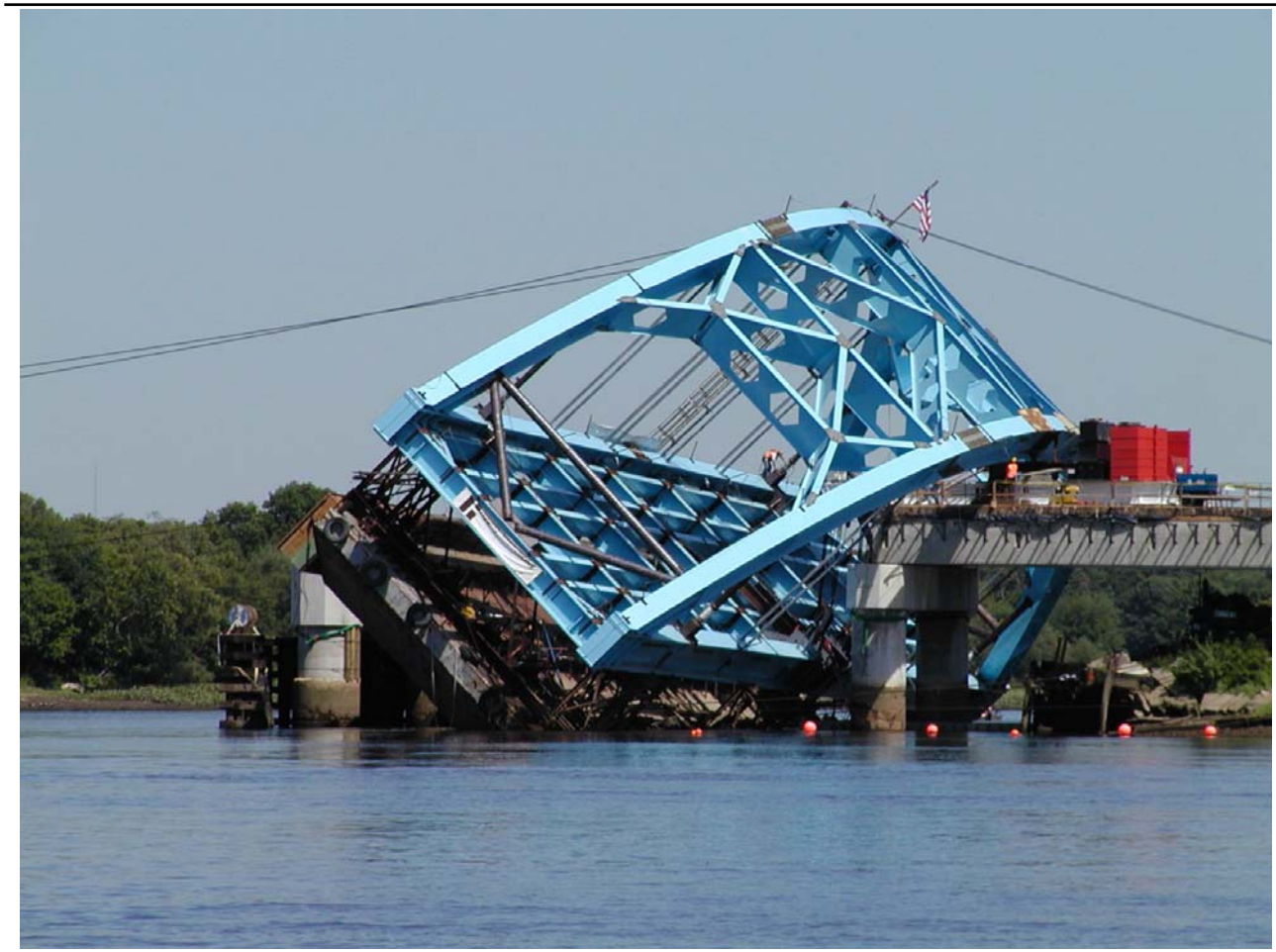
History



Or fall?

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History

To answer these simple questions engineers had to build and then to see what would happen

Do they still have to do this?

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Example: M^3 Project

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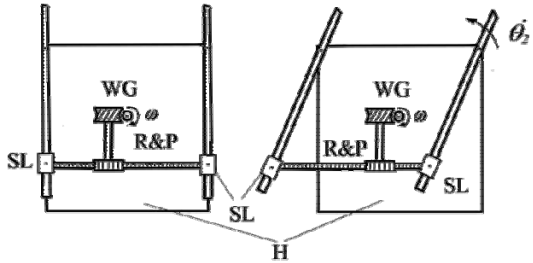
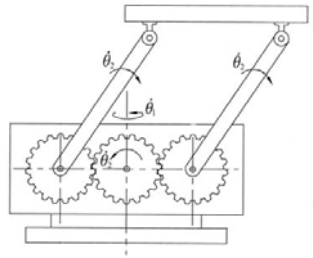
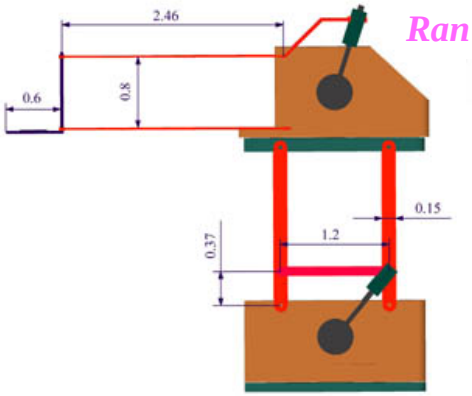
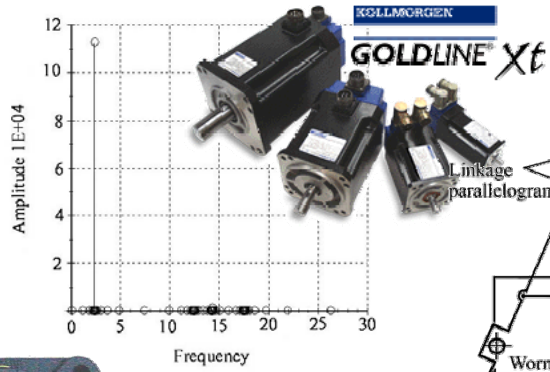


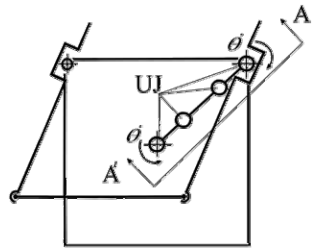


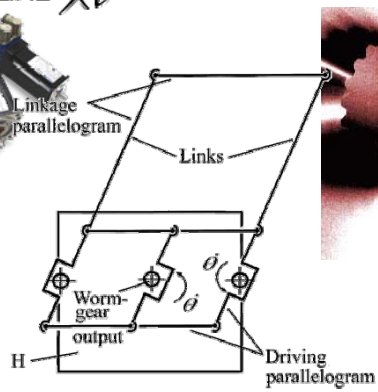


Ran different types of analyses



Modeled dozen of layouts





Proved concept

Selected materials & components

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Example: M^3 Project (cont'd)

The system has been built and installed in University of Western Ontario, London, Ontario

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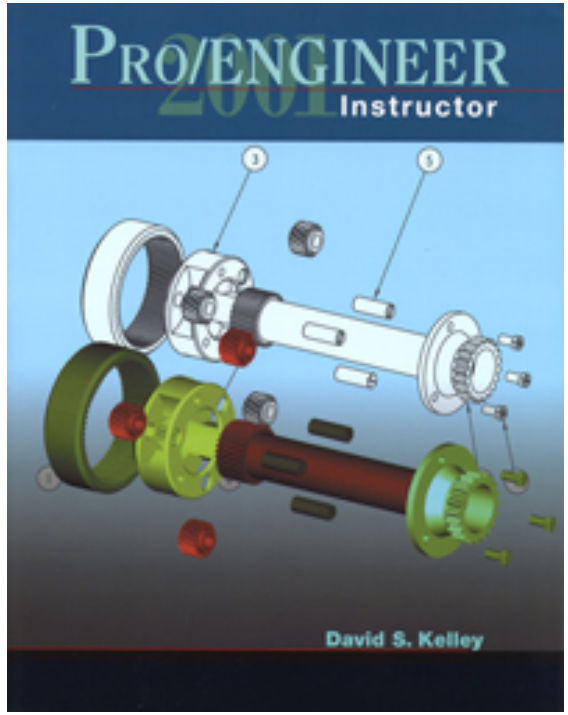
Pro/Engineer Introduction

Pro/Engineer *has all you need:*
from part modeling to animation,
structural analysis and drafting



Two things I want to give you:

- *General sense of the design process and its consistensy*

- *Some practical hints for different aspects of work & problem solution in the Pro/E*

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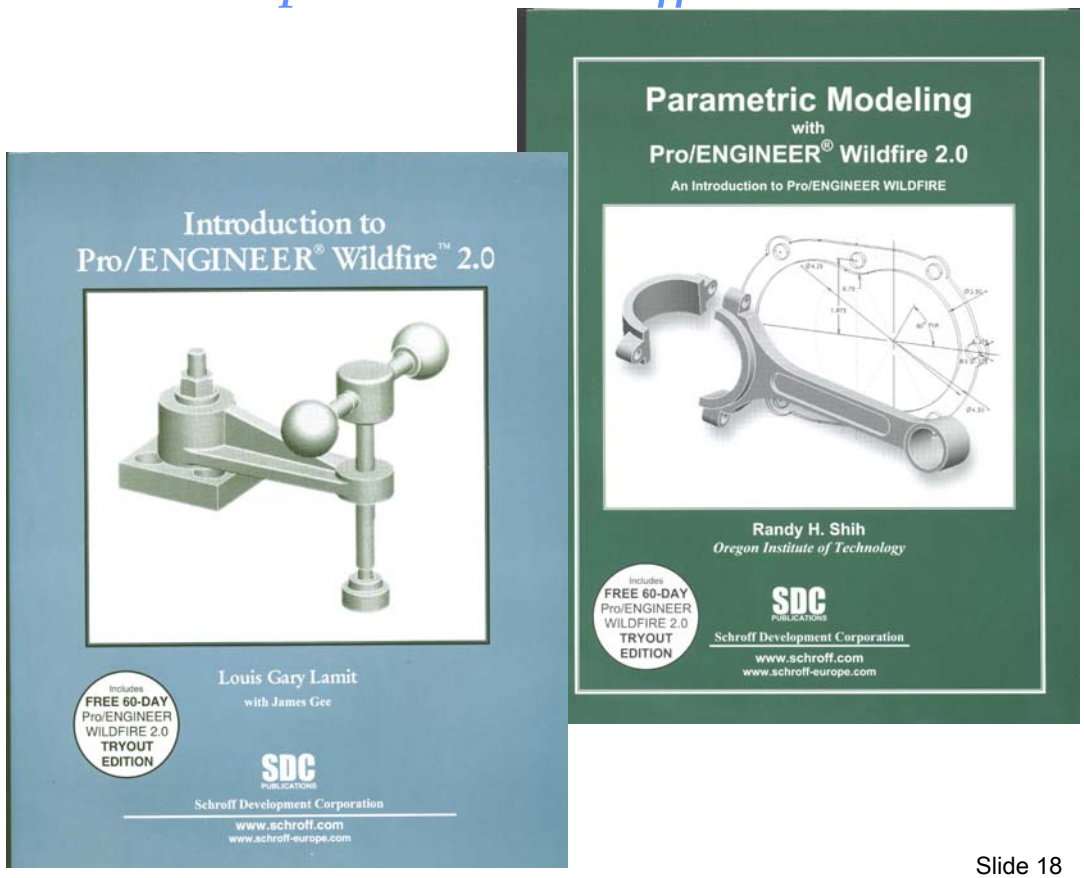
Pro/Engineer Introduction (cont'd)

Schroff Development Corporation *http://www.schroff.com*

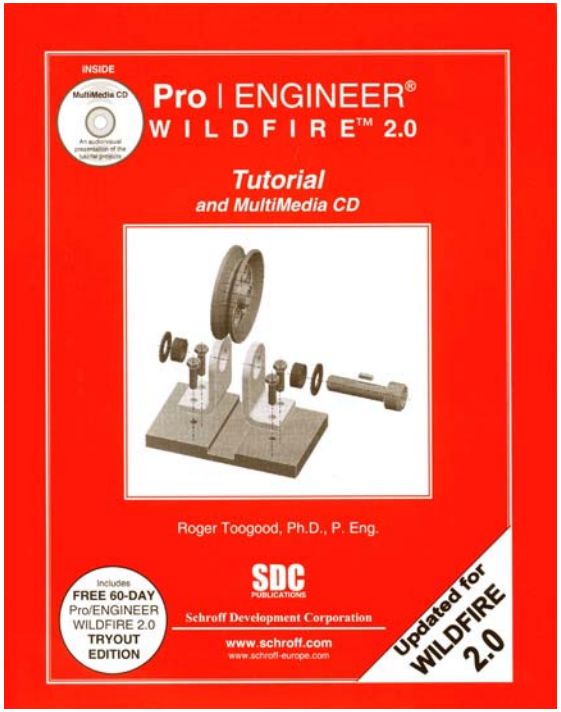
Introduction to Pro/Engineer WildFire 2.0,
Louis Gary Lamit

Parametric Modeling with Pro/Engineer WildFire 2.0,
Randy H. Shih



Pro/Engineer Introduction (cont'd)

Schroff Development Corporation *http://www.schroff.com*

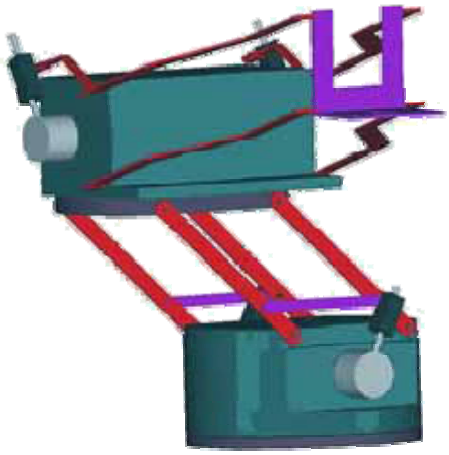


Pro/Engineer WildFire 2.0. Tutorial, *Roger Toogood*

Pro/Engineer WildFire 2.0. Advanced Tutorial, *Roger Toogood*

Pro/Engineer Introduction (cont'd)

How simple is it?

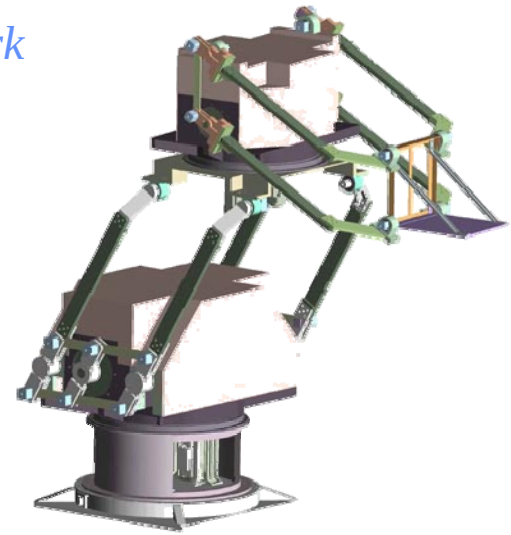


1st version of my model

- *Very simplified*
- *Took 3 weeks of work*

Last version of my model

- *400 components*
- *Took 1 week of work*



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Principles of the Computer Assisted Mechanical Design

General Design Procedure – 5 main goals:

- *simulation and visualization of the whole system and its operation before prototyping*

- *estimation of the main features of the competing layouts and selection of the one most suitable for the specifications*

- *designing the main units and the components of the selected layout*

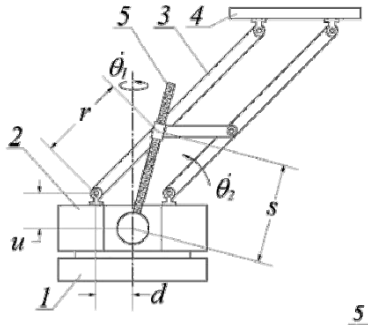
- *dimensioning the physical parameters of the manipulator for mathematical modeling in order to verify the strength of the individual components and to fulfill modal analysis*

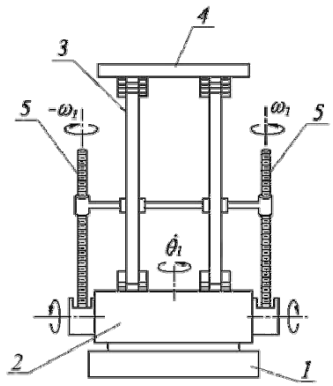
- *developing the detailed manufacturing drawings*

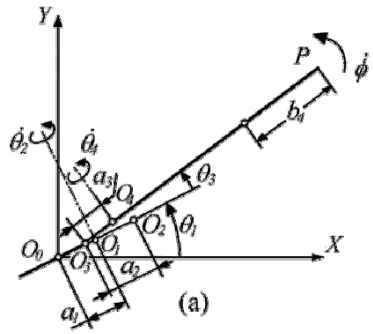
Principles of the Computer Assisted Mechanical Design (cont'd)

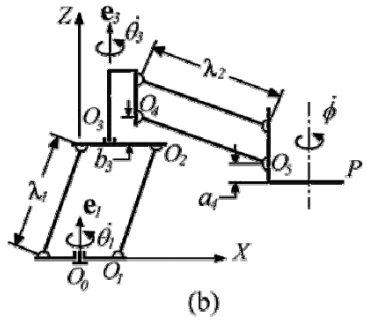
Design Phases

1. Simulation and visualization of the overall manipulator









On this phase we derive the general kinematics of the mechanism and produced a visualization of its workspace

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Principles of the Computer Assisted Mechanical Design (cont'd)

Design Phases

1. Simulation and visualization of the overall manipulator

Main Tasks:

- ❑ Simulation of the overall mechanism;
- ❑ animation;
- ❑ expert appraisal of efficiency and workspace;
- ❑ preliminary analysis of forces, torques, inertial parameters, speeds and accelerations

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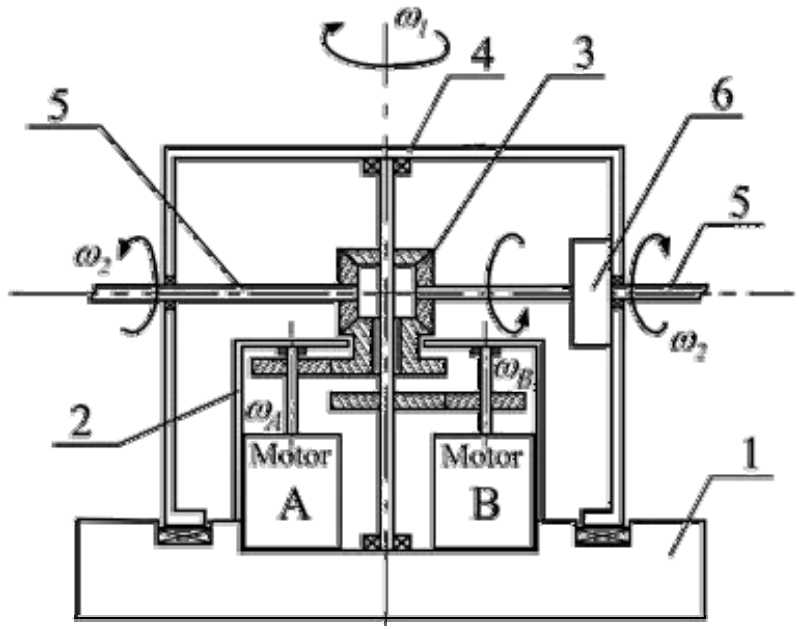
Principles of the Computer Assisted Mechanical Design (cont'd)

Design Phases

2. Simulation of the drive system in full detail and detailed design of the manipulator

Main Task:

- ❑ Detailed design of the driving system;
- ❑ expert appraisal of the design;
- ❑ preliminary kinetostatic analysis of the driving system



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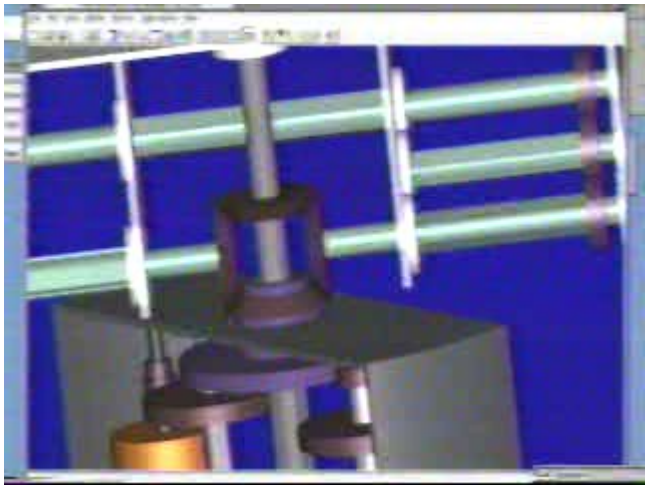
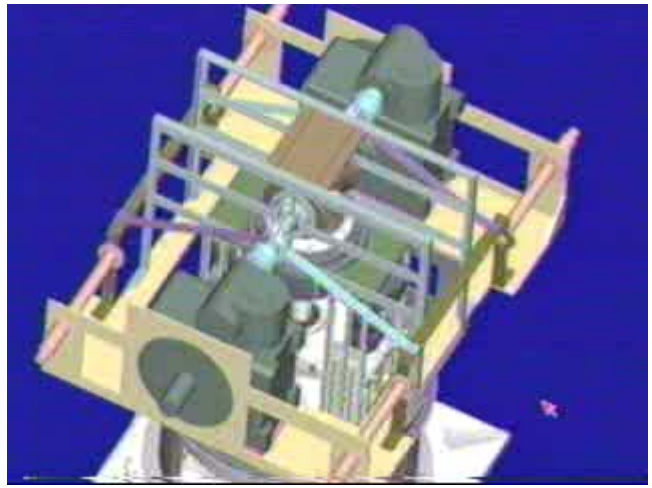
Principles of the Computer Assisted Mechanical Design (cont'd)

Design Phases

2. Simulation of the drive system in full detail and detailed design of the manipulator





This phase resulted in the detailed design of the drive system, the skeleton of the whole system, to which all other components and units were attached.

One of the most important steps in this phase is the complete dimensional design of the whole system.

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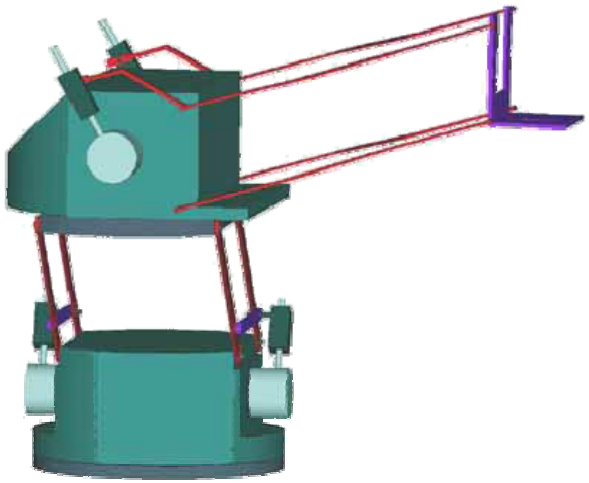
Principles of the Computer Assisted Mechanical Design (cont'd)

Design Phases

The first 2 phases of the design resulted in the developing systems with 2 different drive mechanisms

Ball-screw driven manipulator



Worm gear driven manipulator

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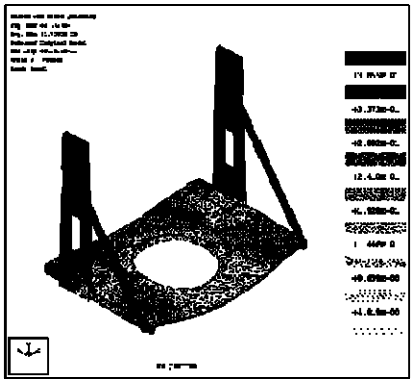
Principles of the Computer Assisted Mechanical Design (cont'd)

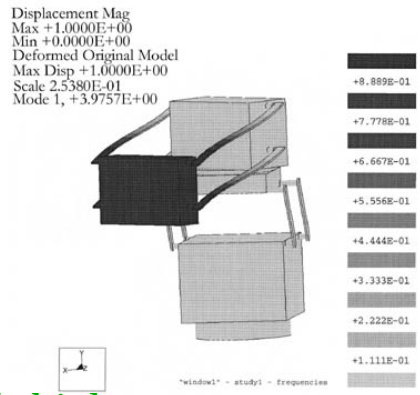
Design Phases

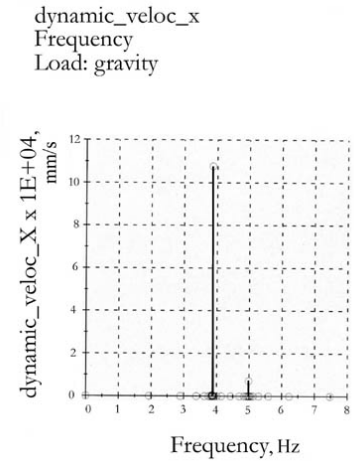
3. Structural analysis

After selection of the layout, modeling and assembling components into the mechanism, its mass, strength and inertial properties must be verified and corrected in this phase



The main purpose: material selection via the structural analysis of components





Here design solutions are verified:

- *adjustments of wall thickness,*
- *hole diameters,*
- *weight savings,*
- *strengthening with ribs,*
- *verification of material properties,*
- *material reselection, etc.*

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Principles of the Computer Assisted Mechanical Design (cont'd)

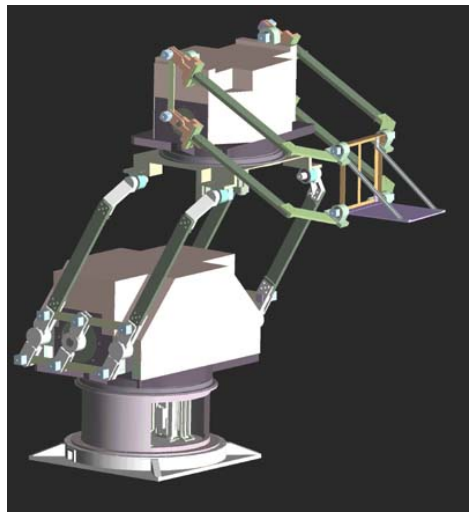
Design Phases

4. Preproduction corrections

This phase is devoted to issuing manufacturing drawings and to adjusting design details in terms of manufacturing processes

This phase is related not with the functional features of the design, but rather with manufacturing standards and technological processes

Do you see a difference between these two images?



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Principles of the Computer Assisted Mechanical Design (cont'd)

Design Phases

4. Preproduction corrections

?!

Which one will be cheaper for manufacturing?

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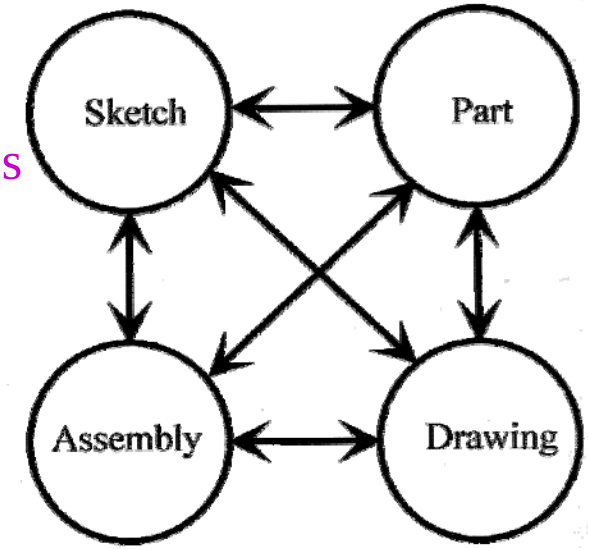
Main Aspects of the Design using Pro/Engineer

In Pro/E user can work in several modes

Some of the key modes are:

- *Sketcher* – for creating sections and sketches



- *Part* – for modeling parts

- *Assembly* – for assembling parts

- *Drawing* – for creating engineering drawings

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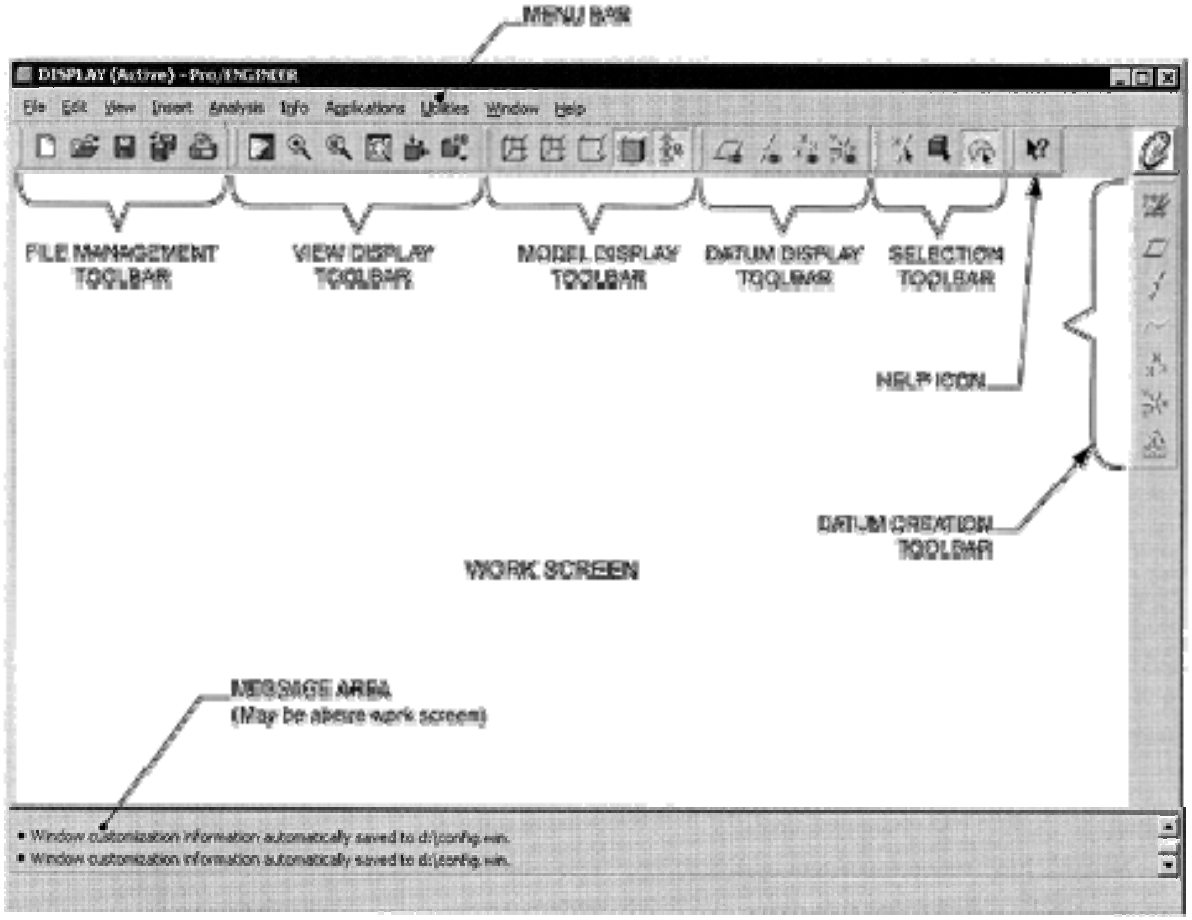
General Overview of Pro/Engineer



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General Overview of Pro/Engineer – Main Steps

❖ Solid Modelling

Where to start?

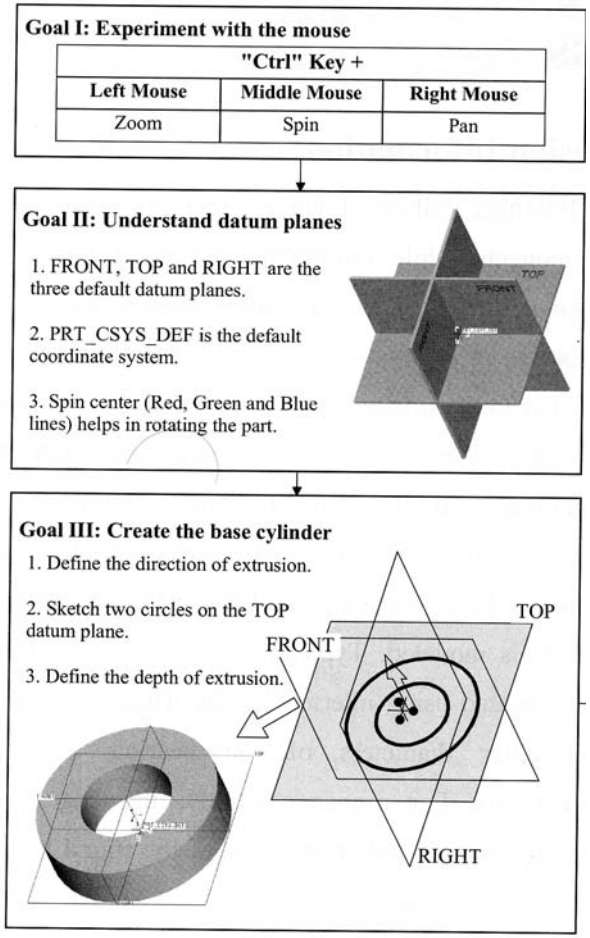
First 3 steps for the beginners:

- *Selection of units*
  - *Metric*
  - *Imperial*

Be ready to use both of them!!!

- *Creation of datum planes*

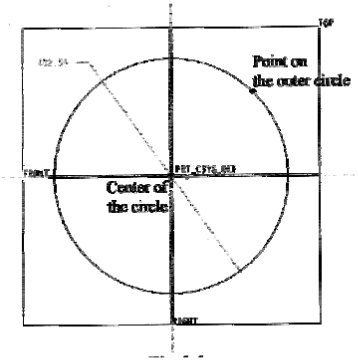
- *Protrusion: creation of simple part*

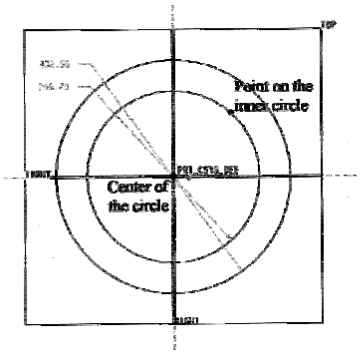


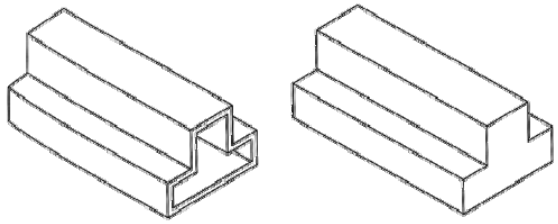
General Overview of Pro/Engineer – Main Steps

❖ Solid Modelling

Simple protrusion



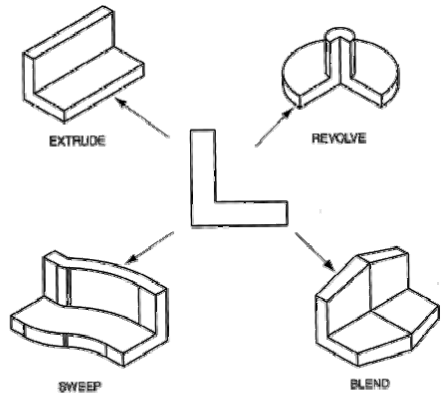




Thin versus solid feature

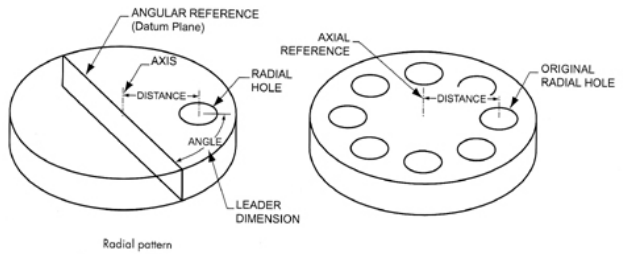
Solids and surfaces

Variations in menu option features



Variations in menu option features

Patterns from a single features



Radial pattern

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General Overview of Pro/Engineer – Main Steps

❖ Solid Modelling

How to start?

✓15-20 minute introduction lesson (with a person with experience or using the tutorial), about assigning units, creating datum planes, making protrusions and holes.

✓Take one of the books, for example, ***Pro/ENGINEER: WILDFIRE 2.0. Tutorial and Multimedia CD***, by Roger Toogood. SDC Publications, www.schroff.com.

✓Sit down at the computer and create the sample model from the book. In two days you will be fully operating.

✓Start work on your own project!

And that's it!

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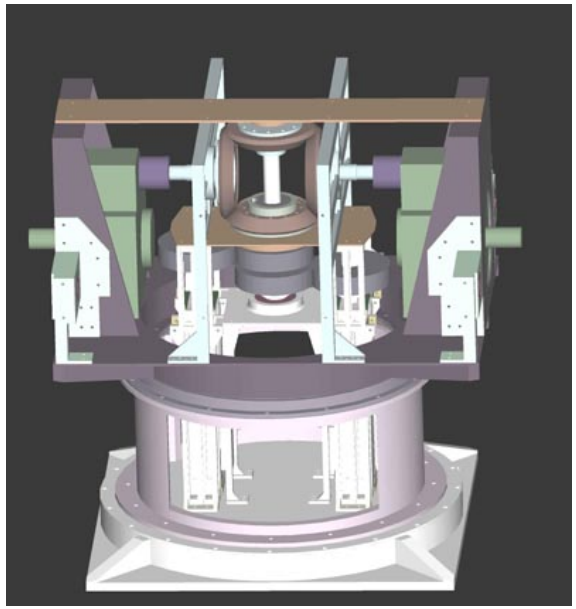
General Overview of Pro/Engineer – Main Steps

❖ Assembling



Purposes:

- ✓*Prove of concept;*
- ✓*Estimation of work zone;*
- ✓*Producing demo animation;*
- ✓*Running force/torque and velocity/acceleration analyses;*
- ✓*Running structure analyses, checking mass, vibration and dimensions, and verification of the selected materials.*

General Overview of Pro/Engineer – Main Steps

Useful feature

Pro/E can automatically calculate for you

- ✓*Volume,*
- ✓*Surface area,*
- ✓*Average density,*
- ✓ *Mass,*
- ✓ *Center of gravity,*
- ✓*Inertia tensors*

both for assembly and for individual components

```
VOLUME =  1.1985176e-02  INCH^3
SURFACE AREA =  9.7499328e-01  INCH^2
AVERAGE DENSITY =  1.0000000e+00 POUND / INCH^3
MASS =  1.1985176e-02 POUND

CENTER OF GRAVITY with respect to _FOUR_BAR coordinate frame:
X   Y   Z    -1.9945446e-01  1.8195779e-01  0.0000000e+00  INCH

INERTIA with respect to _FOUR_BAR coordinate frame:  (POUND * INCH^2)

INERTIA TENSOR:
Ixx Ixy Ixz  5.8457792e-03 -1.0863211e-03  0.0000000e+00
Iyx Iyy Iyz -1.0863211e-03  5.6215728e-03  0.0000000e+00
Izx Izy Izz  0.0000000e+00  0.0000000e+00  1.1462431e-02

INERTIA at CENTER OF GRAVITY with respect to _FOUR_BAR coordinate frame:  (POUND
* INCH^2)

-------------------------------------------

MASS PROPERTIES OF COMPONENTS OF THE ASSEMBLY
(in assembly units and the _FOUR_BAR coordinate frame)

  DENSITY             MASS          C.G.:  X        Y         Z

                    LINK_270NW              MATERIAL:
UNKNOWN
        1.00000e+00  1.19852e-02 -1.99454e-01  1.81958e-01  5.84604e-10
```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General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)

After initial or preliminary design of the components and making assembly you may run Animation of the assembly in Motion mode of Pro/Mechanica.

In this procedure you can

- *obtain forces and torques in all joints and even cross-sections,*
- *select proper motors, gears, bearings, basing on the obtained information*

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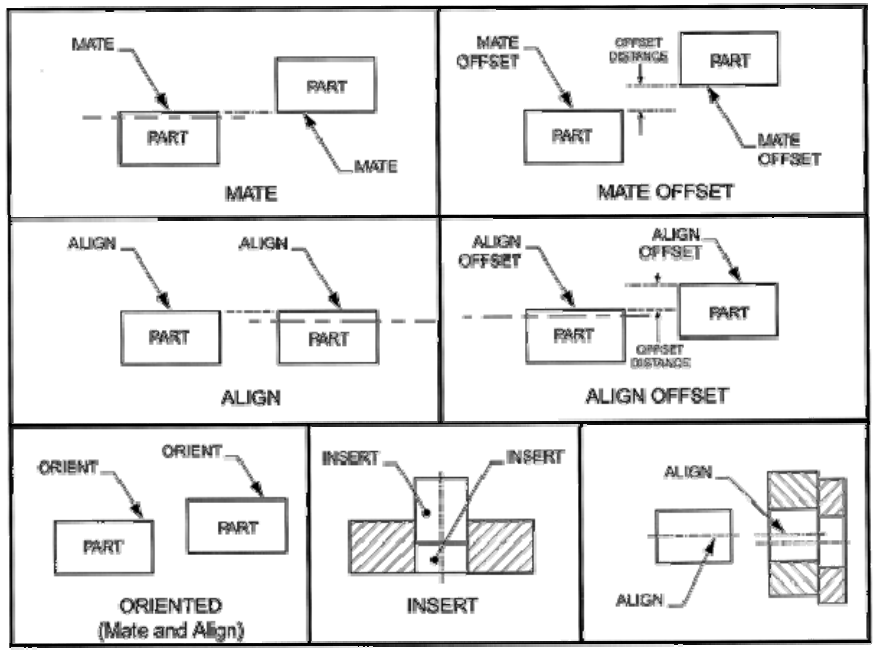
General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)

Very important constraints relating Assembly and Motion modes

a) all surfaces in assembly should accurately and precisely fit each other

b) all axes should accurately coincide



The least error leads to the model in Motion mode completely screwed up. Be extremely attentive and apply all restrictions to the model very carefully!

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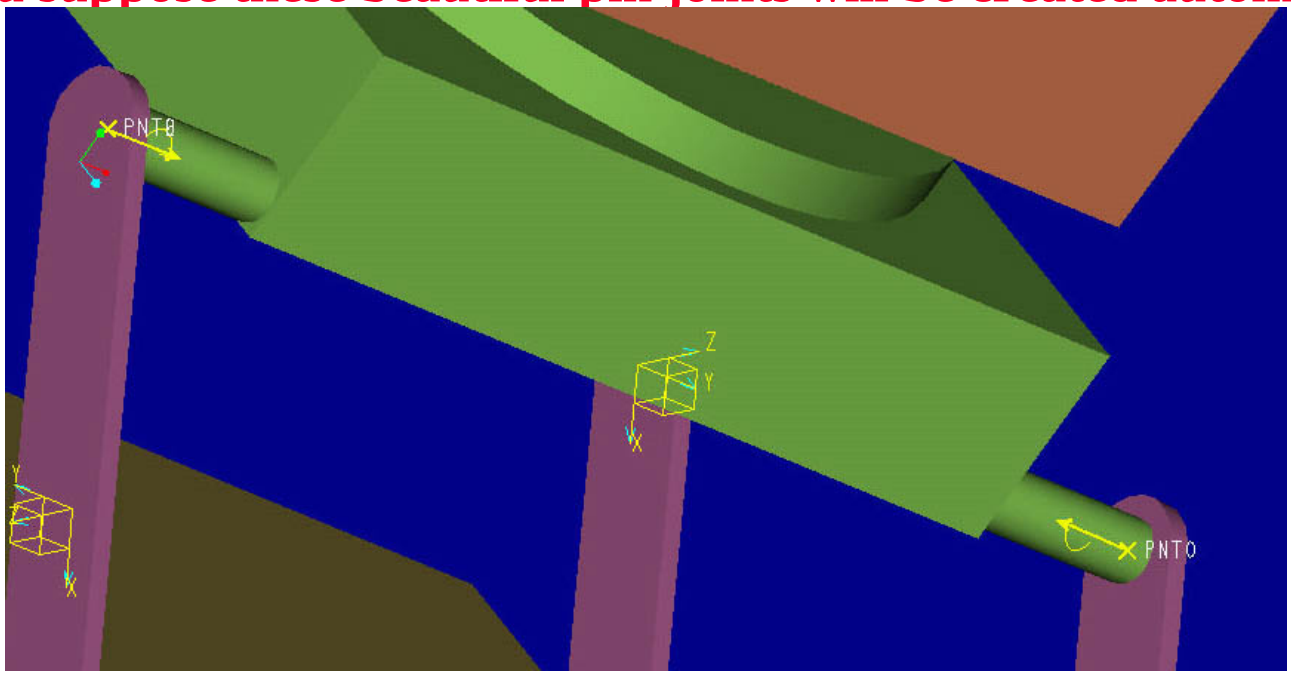
General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)

Creating pin joints in Motion mode

Do you suppose these beautiful pin joints will be created automatically?



If you assign an axis of a pin joint in Pro/E, where do you think it will be directed?

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General Overview of Pro/Engineer – Main Steps

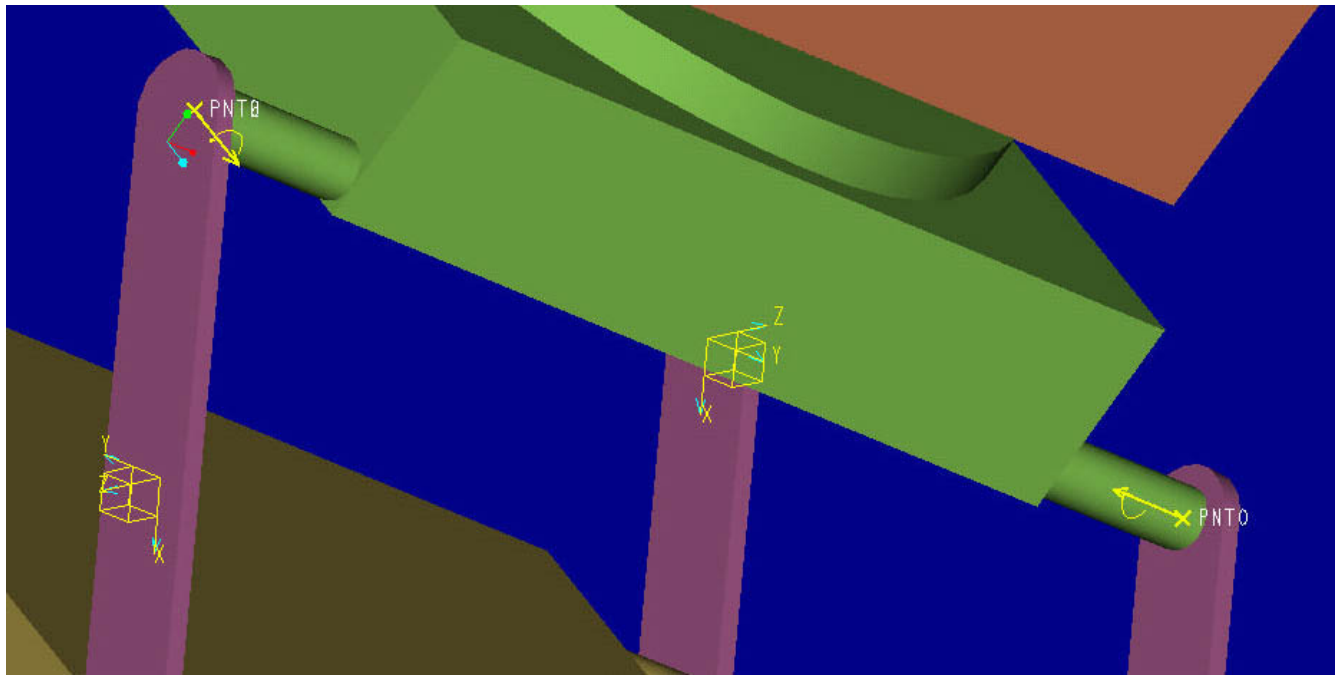
❖ Pro/Mechanica (Motion)

Don't trust the program and the computer!

After creation of a joint assume by default that the pin was created in a wrong way!

How to avoid this?

One of the easiest ways: to use datum points



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General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)

Be careful:

Do not use the option of creating datum points in the assembly mode!

The datum point created in assembly mode will be associated with the whole assembly.

You will not be able to associate individual components with this points!

Return to the part modeling mode and create all needed datum points for each component in their individual files.

Alexei Morozov

General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)

Very important rule when you work with Pro/Engineer:

Always remember that this is only a program,
and its abilities are restricted by several factors:

- **Power and capacity of the computer**

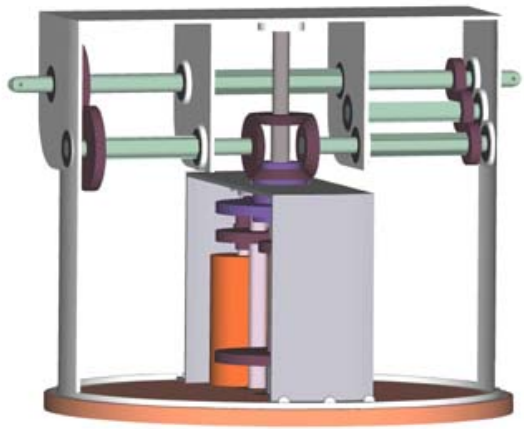
Example – Finite Element Method, developed in early 20th century and only in 60-s, when computers appeared, it became possible to use this method for applications

- **Qualification of a programmer who wrote this program**

You cannot do anything with this, except one thing: carefully estimate the abilities of the program you want to use. Pro/ENGINEER has enough capabilities to meet your demands and specifications.

General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Motion)



- **Mathematical apparatus and mathematical models used in the program**

Even the best software may have its limits and you will have to find your own way to outflank the obstacle

- **Your own qualification and experience**

Some problems can be avoided only by

a) method of poking and trying,
b) contacting PTC's technical support, or
c) consulting with manuals

The influence of this cause of problem will decrease with time passing and you only have to be patient and persistent

Alexei Morozov

General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Structure)

Purposes:

- ✓ *To find modes of natural frequencies*
- ✓ *To conduct stress analysis and find possible deformations of the structure, and as a result*
- ✓ *To verify selection of used materials, geometry of critical components, mass distribution*

Ways to do it

To run it

\# ***for the whole structure in general,***

\# ***for individual components.***

This is what will give you an idea about reliability of your mechanism without building a real prototype

General Overview of Pro/Engineer – Main Steps

❖ **Pro/Mechanica (Structure)**

If you feel that your model

- is too complex,
- has dozens or hundreds of components,
- has a lot of joints which are not significant in a particular type of analysis…

Substitute your model with a simplified equivalent model!

&

Make sure that main parameters of your simplified model are equivalent to the corresponding parameters of the actual one!

Alexei Morozov

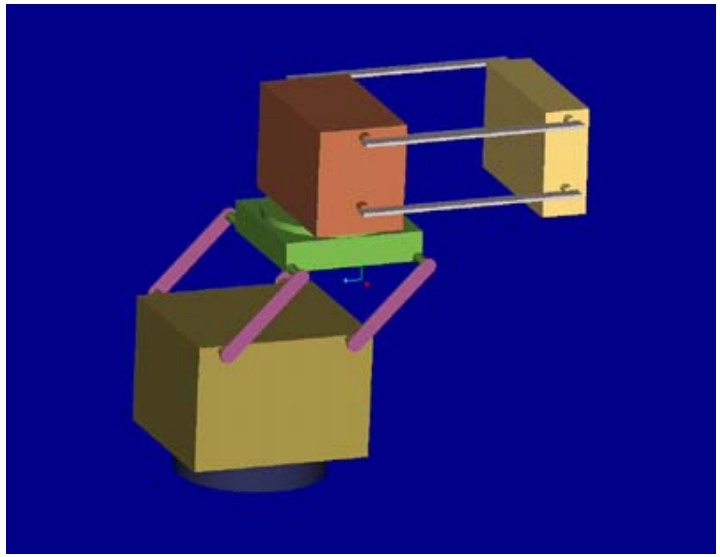
General Overview of Pro/Engineer – Main Steps

❖ Pro/Mechanica (Structure)

For this purpose I have

- *assigned to the solid modules the material with custom density,*
- *didn't care about the behavior of internal components,*
- *only was looking for vibrations and deformations of links,*
- *locked the hinges between the proximal and the distal modules and the linkages ,*
- *was not interested in behavior of pins and gear trains, considering the locked manipulator.*

Example:
simplified model of my manipulator



Practical Hints on the Mechanical Design

a) Always remember about manufacturing cost of your design.

b) Design your components as simple as possible. Sometimes it is cheaper to manufacture 15 small simple components instead of one intricate object.

c) Don't forget about the assembling procedure. The assembling people should be able to reach easily any component, any nut, screw, bolt, hole and thread.

d) The consistency of the assembling is important. Components should not become an obstacle for attaching of a following component to the previous one.

Simple Design - Simple Manufacturing - Simple Assembling

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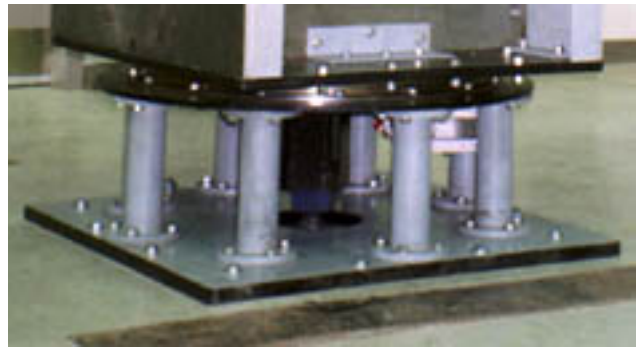
Practical Hints on the Mechanical Design

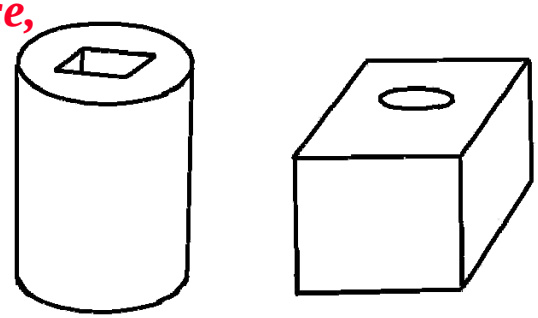
Remember this ?



Last question for today

What is better (cheaper) to manufacture

a round (or cylindrical) surface,



or a rectangular (plain) surface?

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Conclusion

Be persistent… Be inventive… Be rational… Be logical…

in your design!

And your solar car…

or snowmobile…

or steamer…

…even a mousetrap…

eventually will be roving Mars!

Alexei Morozov

McGill
NSERC Design Engineering
Chair

NSERC-McGill Chair of
Design for Extreme Environment