

PTC has created a collection of 3D parametric computer models to illustrate physics concepts and principles. Using computer software to replicate the experiments carried out in school laboratories would be of limited use whereas changing the force of gravity, modelling large scale structures and real world applications provides teachers with examples that would otherwise be very difficult or impossible to show.

The software

PTC invented 3D Parametric modelling 30 years ago and their **Creo** suite of software is used by many of the largest design and manufacturing companies in the world. **Creo** is a powerful, feature-based, 3D parametric modelling programme and the software understands the physical properties of objects including; geometry, shape, volume, mass, inertia, etc. Models built with **Creo** can be configured with mechanical connections and the end result analysed under external forces including gravity, friction, etc.

Creo is available free to schools and information on this can be found on www.ptcschools.com

A number of pre-built virtual models are available with parameters that can be altered. For example, when a concept such as Hooke's law is being covered, the teacher opens a virtual model of a top-pan balance, runs the analysis with displacement/time graph and uses this to support discussion. A change is made to the model such as damping force and the analysis re-run to compare the results.

We do not envisage physics teachers will build their own models. PTC is able to create models and, as expertise develops, teachers and pupils may begin to develop their own models and contribute these to Learning Connector or Planet PTC.

The rest of this document explains how to interact with each model and an accompanying PowerPoint presentation has animations of the models.

For more information on the PTC Education Programme visit www.ptcschools.com or email tbrotherhood@ptc.com

Authors

The examples included here have been collated from a number of sources including;

Models	Author	Role/School
Scalextric, Water wheel (full-size), Tennis ball bounce, Gear mesh stress	Andy Deighton	Former Principal MCAD Specialist, PTC
Top pan balance	Mark Fischer	Education Program Manager, PTC
Science apparatus, Newton's cradle, Bouncing ball, Molecular models, Water wheel (scale), Roller coaster, Guitar, Sterling engine, Black box mechanisms, Floating and sinking, Rugby ball – moments of inertia	Tim Brotherhood	Curriculum Development Manager, PTC
Solid rocket, Guitar	Mike Brown	Former Education Programme Manager, PTC
FEA models	Dave Cheshire	Reader, Staffordshire University.
Torch – FEA	Stuart Douglas	D&T Subject leader - Ripley St Thomas School.
Bio-mechanics, Motor bike	Demo library	PTC
CFD flow examples	Mentor Graphics	Simon Hooker, Leek High School
Inner solar system	Petter Freiberg	PTC

Other examples we receive will be added to the collection and credited here.

Scientific apparatus

A library of scientific apparatus that can be used for several purposes including illustrating learning materials, 3D models for on-line instructions in learning platforms.

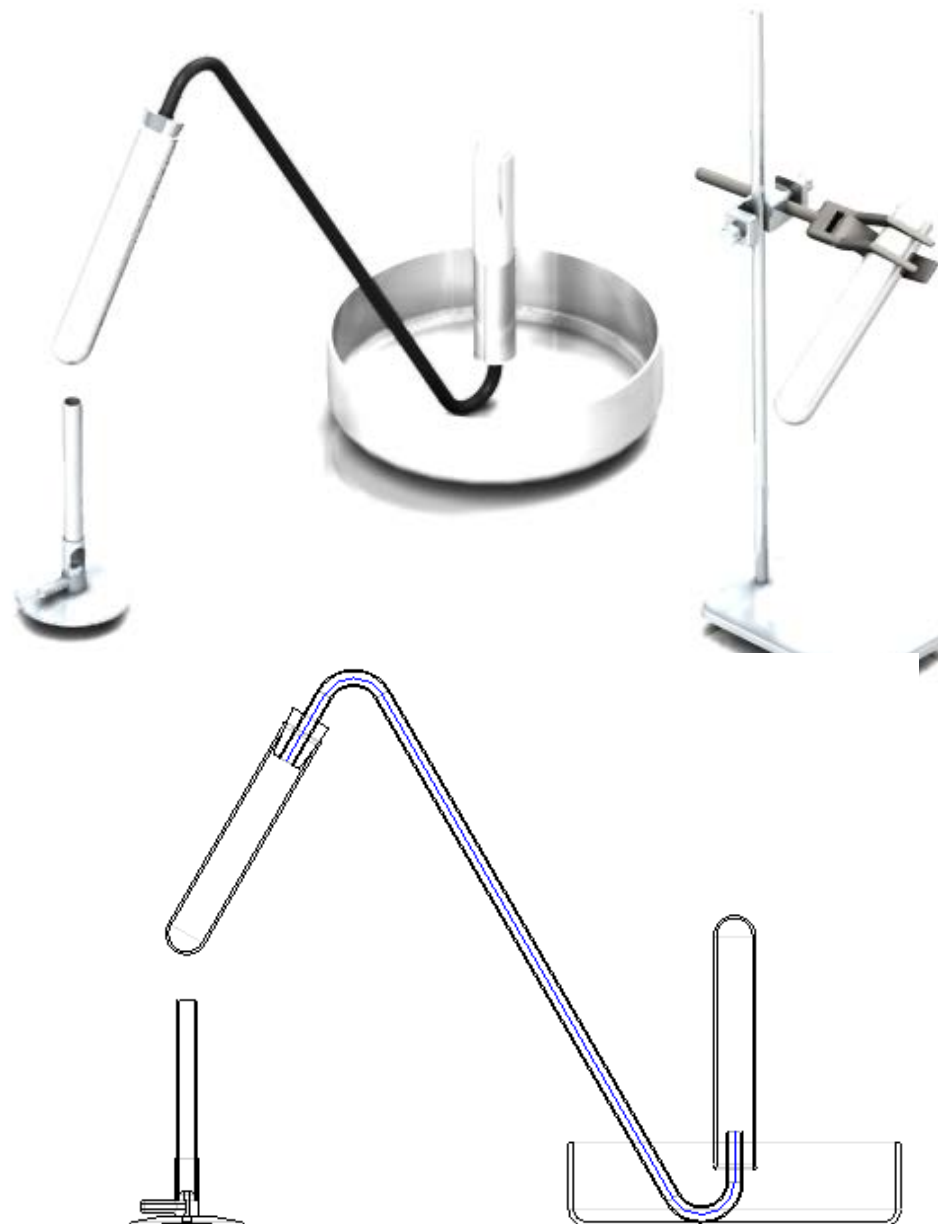
Exploring the model

1. Start **Creo Parametric**
2. Set working directory to **Apparatus**
3. Open the assembly **experiment_2.asm**
4. Use the mouse scroll wheel to **zoom** and MMB drag to **rotate** the view
5. From the In Graphics toolbar open the **Saved views** list  and try the **Isometric** and **Trimetric** pictorial views.
6. View tab > **Model Display** > **Section**  > Planar, and then select datum plane **ASM_RIGHT** datum to create cross **section**. From the **In Graphics** toolbar select **No Hidden**  line to generate conventional 2D line illustrations.

Further developments

The animation facility in **Creo** will create movie files showing pupils how to assemble and operate scientific apparatus.

Creo models will export as 3D PDF files offering viewing and interrogation of 3D models without having **Creo** installed.



Bouncing ball

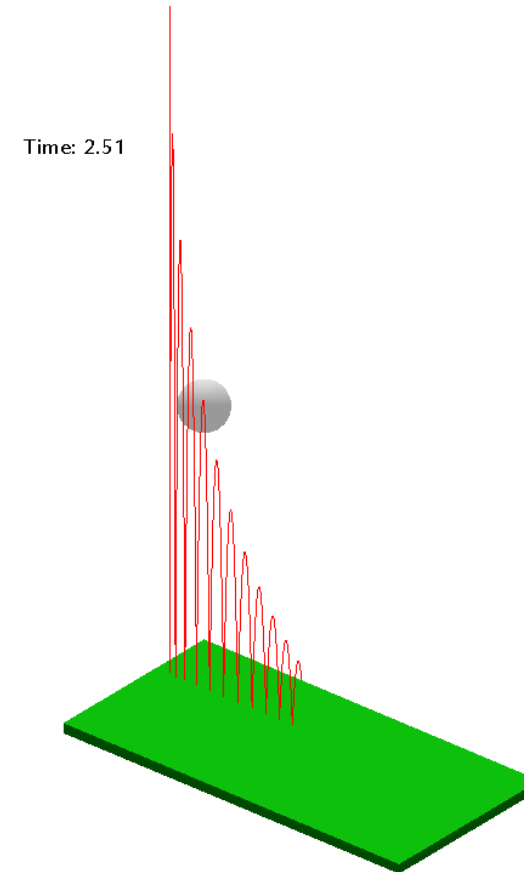
This investigation explores the coefficient of restitution or bounciness of materials and how this manifests itself in the height a ball will bounce. The coefficient of restitution depends on the material properties of both objects, in this case the ball and the floor.

If we know the height of two successive bounces the coefficient of restitution can be calculated for a given pair of materials.

$$\text{Coefficient of restitution} = \sqrt{\frac{\text{height of 2}^{\text{nd}} \text{ bounce}}{\text{Height of 1st bounce}}}$$

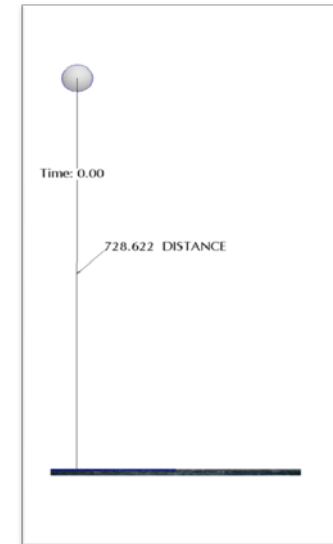
So if the two bounces were 90cm and 100cm then:

$$\text{Coefficient of restitution} = \sqrt{\frac{90}{100}} = \mathbf{0.95}$$



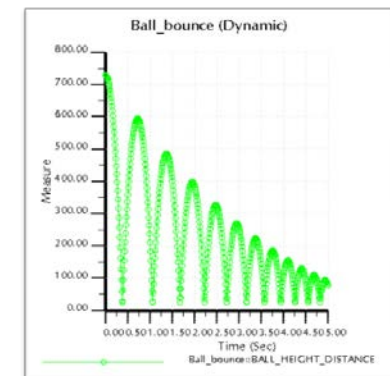
Perform analysis

1. Start **Creo**
2. Set the working directory to **02_Ball_bounce**
3. Open the file **Ball_bounce.asm**
4. **Applications tab > Mechanism** 
5. Expand **ANALYSES**, RMB on **Ball_bounce (DYNAMICS)** and select **Run**
6. **Mechanism tab > Measures** . In the measures dialog, select both **BALL_HEIGHT_DISTANCE** and **Ball_bounce**.
7. At top left of the dialog, select the graph  tool then click **Close**.



Playback

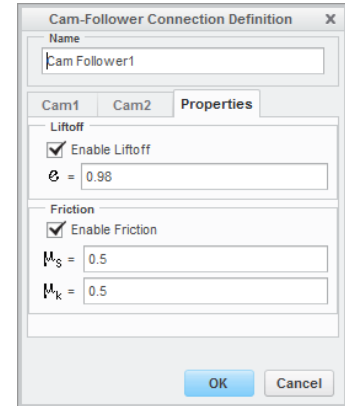
8. Expand **PLAYBACKS** then RMB on **Ball_bounce** and select **Run**.
9. Use the **Animate** tools to replay the analysis. You can zoom/spin the model during replay.
10. Click at any point on the graph and you can find the values for that point. This enables pupils to carry out their own calculations.
11. **Close** the Animate dialog.



Change coefficient of restitution (Lift off)

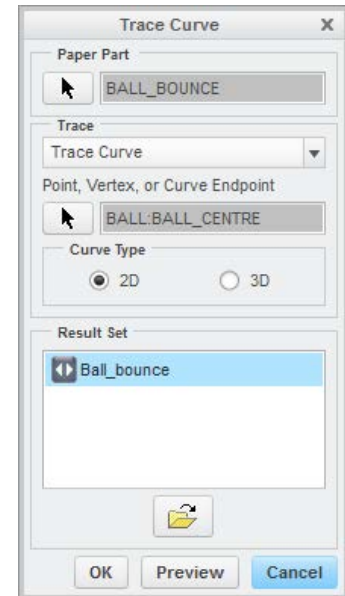
A cam connection exists between the ball and floor with lift-off enabled. The value called lift-off is in fact the coefficient of restitution and can be changed to alter the rebound behaviour of the ball.

12. In mechanism model tree, expand **Connections** > **Cams** > **RMB** on **Cam Follower 1** entry and select **Edit Definition**.
13. In the dialog select the **Properties** tab.
14. Change the ϵ value to a lower figure then click **OK** to close the dialog.
15. Re run the analysis (step 5 above onwards)



Drawing a trace curve (Loci)

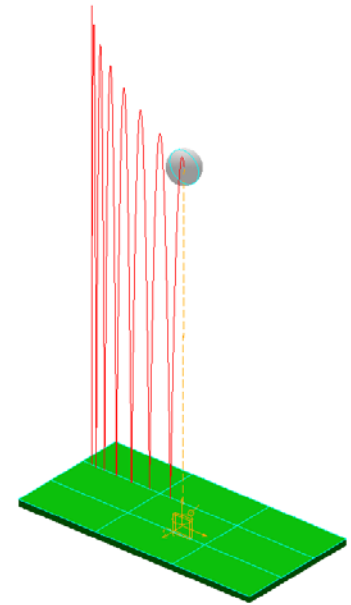
16. The playback from the last section must still be available for this section.
 17. From the **In Graphics** toolbar make sure **Datum Points**  are visible.
 18. **Mechanism** tab > **Analysis** group > **Trace Curve** .
 19. In the dialog, click on  under **Point, vertex....** then, in the graphics window, select the **BALL_CENTRE** datum point.
 20. In the dialog, select the Result set **Ball Bounce** then click **Preview**.
- A trace curve (loci) for the centre of the ball will be drawn in the graphics window.
21. Click **OK** to close the dialog and the trace curve will remain visible.



The trace curve shown here was created with a high value for the coefficient of friction.
This is clearly evident from the small loss of height after each bounce.

References:

<http://hypertextbook.com/facts/2006/restitution.shtml>



Top pan balance

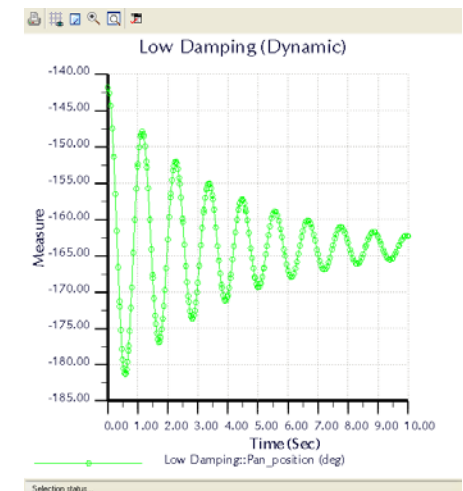
This model represents a top pan balance or weighing scales and can be used to demonstrate a number of things including; Hook's law, damping and the effects of gravity on mass and weight.

1. Set the working directory to **07 Weigh scales**.
2. Open the assembly **Scales.asm**
3. Show kinematic movement by **CTRL+Alt** the **LMB** dragging top pan
4. **Applications** tab > **Mechanism** .
5. Mechanism tab > Analysis group > select **Playback** .
6. In the dialog click **Open**  select **Bounce.pbk** and **Open**.
7. In the **Mechanism** tree > expand **Playbacks** > RMB  **Bounce** > **Play**.
8. Use the Playback controls to view the playback.
9. **Close** the controls panel and the Playbacks dialog.



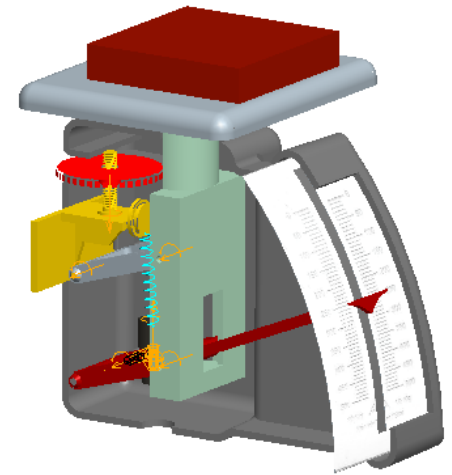
Playback

10. **Mechanism** tab > **Measures** .
11. In the measures dialog, select both **Pan_position** and **Bounce**.
12. At top left of the dialog select , the graph tool then click **Close**.
13. Open the **Bounce** playback and **play** to see the model and graph animate.



Change damping

14. **Ctrl+Alt + LMB drag** to move the pan to the top of its travel
15. In the Mechanism tree on the left of the screen, expand the **DAMPERS** heading, then **RMB** over the entry **DAMPER1 (SCALES)** and select **Edit Definition**.
16. In the **Damper** tab, change the value for **C** in the range **0.005** to **0.002**.
17. Re-run the Analysis named **Bounce (DYNAMICS)**.
18. Replay the **PLAYBACK Bounce**, observe how the model behaves then try to explain any differences in how the model behaves.

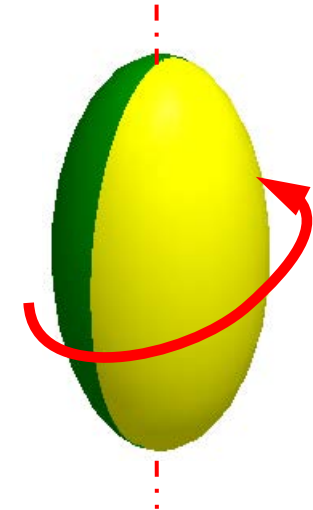


Rugby ball – moments of inertia

This model arose out of a request from Nick Fisher, Rugby School at an Institute of Physics workshop at Cambridge University in December 2009. The assembly has two rugby balls driven by force motors. The force motor in both examples has the same torque settings.

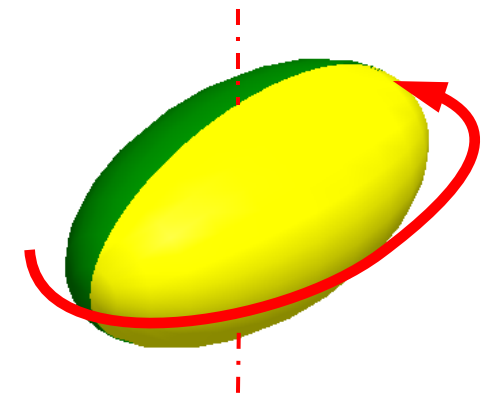
The left hand ball rotates about a vertical axis passing through the ball in the longest direction.

1. Start **Creo Parametric**.
2. Set the working directory to **08 Moments of inertia**.
3. Open the file **moments_of_inertia.asm**
4. Test the kinematic movement by holding down **Ctrl+Alt** and **left click**  **dragging** each of the balls in turn.
5. **Applications** tab > **Mechanism** .
6. In the **Mechanism** tree > **Analysis** group > select **Playback** .
7. In the dialog, click **Open**  select **Long_axis.pbk** and **Open**.
8. **Mechanism** tree > expand **Playbacks**  > **RMB Long_axis** > Play.
9. Use the playback controls to **play** the analysis results.
10. Experiment with the playback controls.
11. **Close** the Controls panel and the Playbacks dialog.



The right hand ball also rotates about a vertical axis but this time passing through the ball in the shortest direction.

12. In **Mechanism** tree > **Analysis** group > select **Playback** .
13. In the dialog, click  select **Short_axis.pbk** and **Open**.
14. **Mechanism** tree > expand **Playbacks**  > **RMB Short_axis** > Play.
15. Use the playback controls to **play** the analysis results.
16. Experiment with the playback controls.



17. **Close** the Controls panel and the Playbacks dialog.

Differences between the two analyses played individually may not be obvious so we have created a playback called 'Both'.

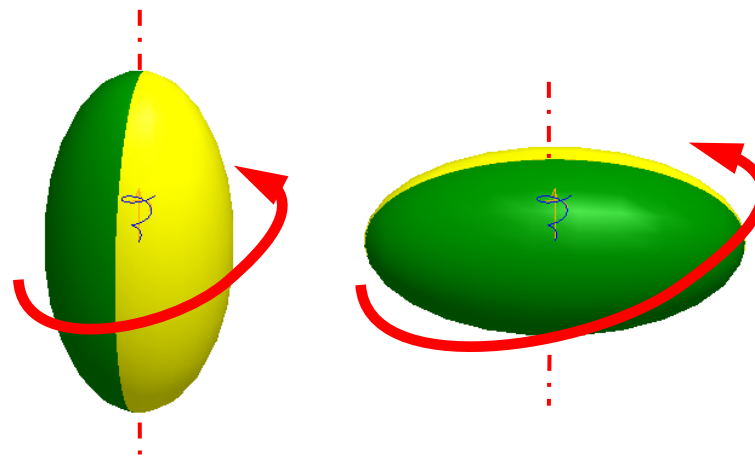
18. In **Mechanism** tree > **Analysis** group > select **Playback** .

19. In the dialog, click  select **Both.pbk** and **Open**.

20. **Mechanism** tree > expand **Playbacks**  > **RMB Both** > Play.

21. Use the playback controls to **play** the analysis results.

22. Experiment with the playback controls.



23. A clearer picture of what is going on including quantitative feedback is possible using the graphing tools in **Creo Parametric**.

24. **Mechanism** tab > **Measures** . Two measures have been created, one for the angular velocity of each ball.

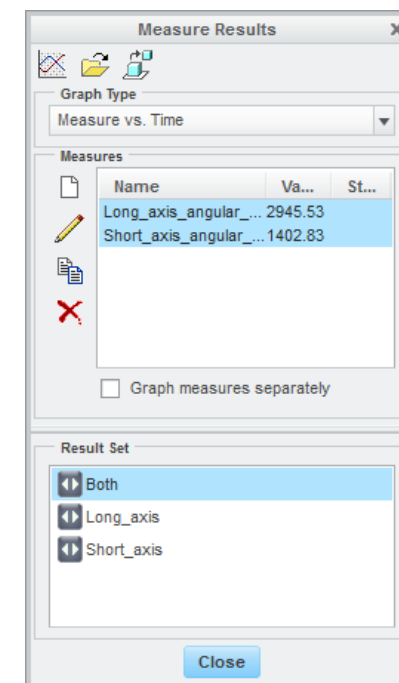
25. Hold **Ctrl** and, in the **Measure Results** dialog, **Measures** section, select both **Long_axis_angular_velocity** and **Short_axis_angular_velocity**. Release **Ctrl**

26. In the **Measure Results** dialog, **Results** section, select **Both**.

27. At top left of the dialog select **Graph** , to display the graph > drag it sideways and resize the graph to see the dialog and rugby ball models. then

28. You can now **Close** the Measure Results dialog but leave the Graphtool window open.

29. Open the **Bounce** playback and **play** to see the model and graph animate.



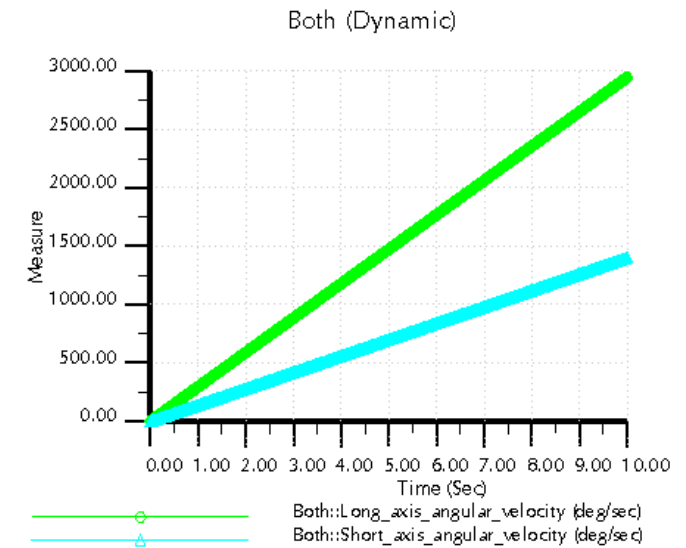
30. Mechanism tab > Playback  to open the playback controls then **play** the **Results Set** for **Both.pbk**.

Notice, as the results playback a cursor travels along the graph.

31. Move the mouse cursor over the traces on the graph and **left click**  to see the value at that point on the graph.

32. **Close** the controls panel and the Playbacks dialog.

33. **Close**  the model and **Erase Not Displayed** .



Molecular models

A **prototype** set of molecules to show component interfaces controlling bonds.

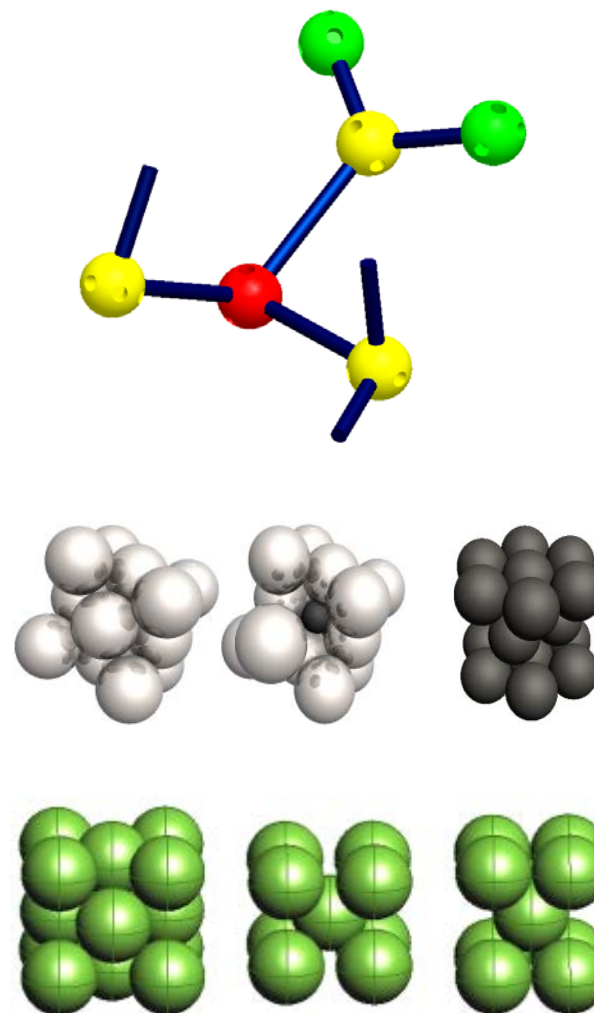
Note: The current molecular models need to be redesigned to represent correct molecular distances

1. Set working directory to **03 Molecules**
2. Open **Molecule_01.asm**
3. **Model** Tab > **Assemble**  to add a new part.
4. Select **Peg_medium.prt**
5. Click on **white dots** to add pegs to the red ball.
6. When finished adding pegs, in the **Assemble** tab, click **Complete Feature**  to finish adding pegs.
7. **Model** Tab > **Assemble**  to add another new part and this time select the file **green.prt**
8. Click on white dots to add balls to the end of pegs.
9. When finished adding green balls to the ends of pegs, click **Complete Feature** .
10. Repeat as required.

Component interfaces make assembly very quick and easy and can be used to limit assembly options.

Future development - molecules that only allow bonds that will work chemically.
Molecules that represent the correct inter-molecular distances.

Iron/titanium lattice structure
Andrew Fairbank - Cabramatta High School, Australia

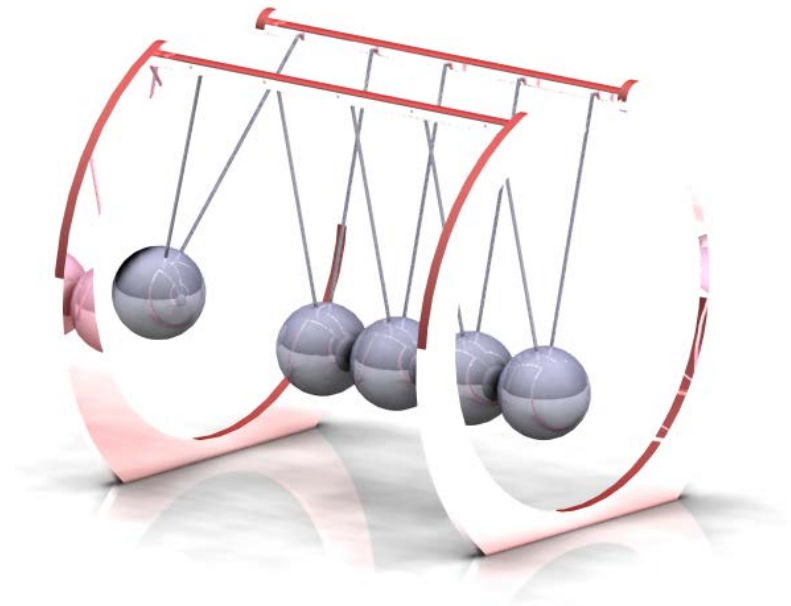


Newton's cradle

Demonstrates Newton's third law of motion "Every action has an equal and opposite reaction"

The **Creo Parametric** simulation is so realistic the middle balls begin to swing as the simulation progresses.

1. Set working directory to **05 Newton's Cradle**
2. Open **Cradle.asm**
3. **Applications** tab > **Mechanism** .
4. Mechanism tab > **Playback** .
5. In the dialog, click  select **One_ball.pbk** and **Open**.
6. In the dialog, click  to open the playback controls then **play** the analysis results.
7. Notice the gradual increase in movement of middle three balls due to minute **attraction forces** between objects.
8. **Close** Animate dialog
9. Open **Opposites.pbk** > playback and animate to show movement.



Solid Rocket

PTC has developed this in conjunction with Starchaser Industries.

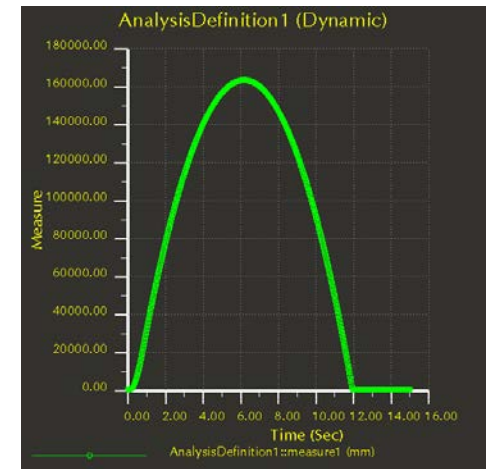
The mass of all the materials and thrust characteristics of the solid rocket motor are programmed into a **Creo Parametric** model.

A simulation launches the rocket and plots a graph of altitude against time to show the effect of rocket motor forces opposing gravity.

The simulation can be re-run with a gravity value for the moon or a planet and the flight profile will represent how the rocket would perform there.

- See detailed instruction in Starchaser rocket tutorial.

www.ptcschools.com



Scalextric4Schools

D&T staff at Edgecliff High School, Kinver, UK developed the original slot car project. PTC in partnership with Hornby has developed the project using Scalextric components and **Creo Parametric** to model and simulate the performance of a slot car.

The aspects of performance **Creo Parametric** can simulate include; torque characteristics of the motor, friction, acceleration, stability etc.

- See detailed instructions in the Scalextric4Schools booklets.

www.scalextric4schools.org



Water wheel

Paul and Ingrid Bromley own Pedley Wheels which designs and installs water wheels to generate electricity at commercial and private premises. Pedley Trust is a charity that uses the profits from commercial sales to build water wheels in remote locations around the world.

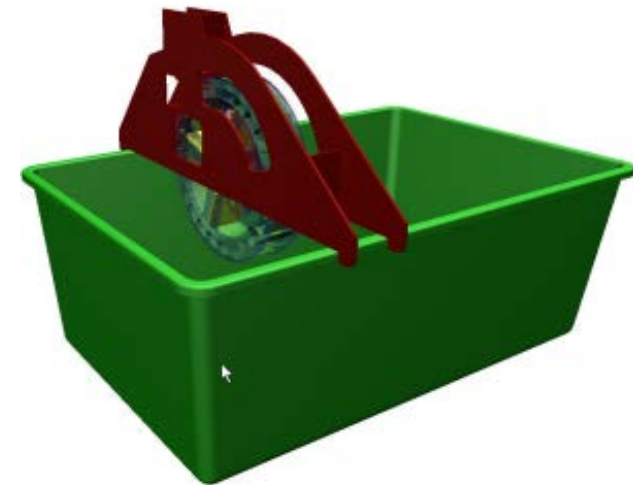
Pedley water wheels are designed using **Creo Parametric**.

With a known head of water and flow rate, the model will scale automatically and produce a complete set of engineering drawings. The model will also calculate the energy output for that wheel.

The Pedley wheel **Creo Parametric** model is available for pupils to explore as a precursor to experimenting with an acrylic model before designing and building their own wheel based on the results of their investigations.

- See detailed instructions in the **Water wheel tutorial**.

www.ptcschools.com



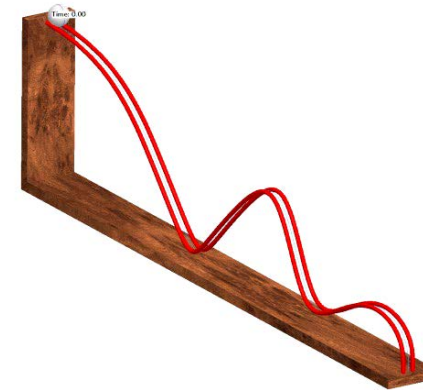
Roller Coaster

Rolling ball toy - £19.99 from all good gadgets shops! **Creo Parametric** simulation using mechanism dynamics

1. Set working directory
2. Open **Roller_coaster.asm**
3. Applications tab > **Mechanism** .
4. In the **Mechanism** tree > **Analysis** group > select **Playback** .
5. In the dialog, click **Open**  and select **Release the ball.pbk**
6. **In the dialog select**  and then use the Playback controls to view the analysis.
The ball does not reach the end of the wires.
7. Click **Close** > **Close**
8. **Mechanism** tab > click **Close** .
9. In the model tree, **Activate** the part **Wires.prt** > **Edit definition** for **Sketch 1** > smooth the curve > **Close** the sketch
10. Re-run analysis **Release the ball**
11. Playback the new results.

What other changes could be made? What effect would each have on the model behaviour?

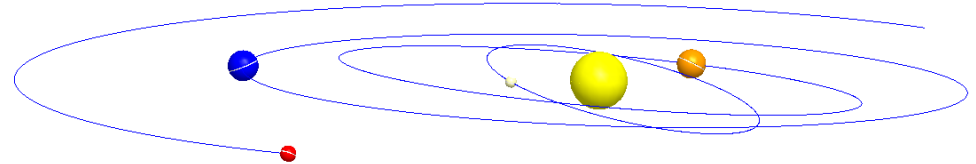
- Moon gravity...
- Change ball materials
- Increase friction
- Change liftoff (Coefficient of restitution)



Inner Solar System

Scale model of inner five planets of our solar system constrained to correct orbits. Some 'adjustments' have been made to make the models visible but the physics are correct.

- 1 day for time,
- 1 mass of Earth for mass
- Orbital distances such that 1 mm in ProE corresponds to 1 million km
- Time = 1*1days (d) = 86400 s
- Mass = 1*1Mass of Terra (Mt) = $5,974 \times 10^{24}$ kg
- Length = 1×10^{12} mm (I call the unit "mm12")
- $F = G \cdot m_1 \cdot m_2 / R^2$ (Newtons law of Gravity)
- $G = 6,6739 \text{E-}11$
- $F = m_1 \cdot R \cdot \omega^2$ (Centripetal Force, MDO takes care of this one, it should balance Gravity)
- $F = m \cdot a$ (Newtons umpteenth law)

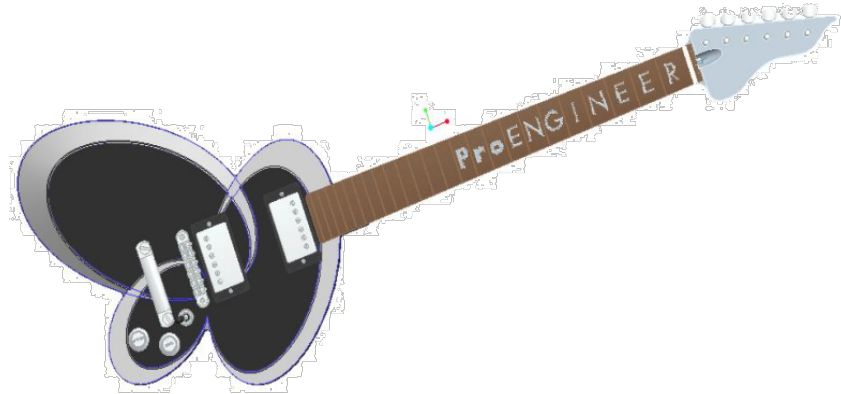


Future developments

The following are a collection of **Creo Parametric** models and ideas for simulations that might help explain key concepts in science. Ideas for development are most welcome and should be sent to tbrotherhood@ptc.com

Parametric guitar

Position of frets, bridge, nut etc are defined mathematically allowing the scale length and fret board width to be changed. When the model is regenerated all the components are updated automatically.



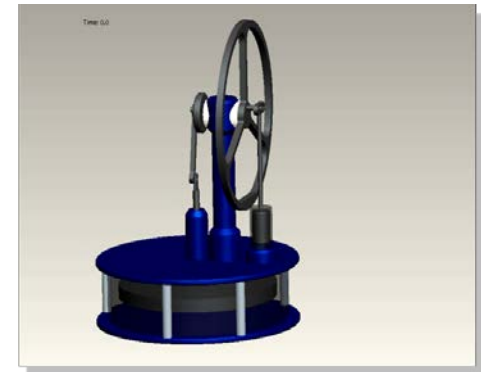
Sterling engine

The sterling engine is increasingly being used in heating systems operating on waste heat from the exhaust duct.

Micro power generation is seeing a revival of interest in these sterling engines with modern materials making them much more efficient.

This coffee cup model has carbon piston, borosilicate glass cylinder and low friction bearings. It will operate with a temperature difference of only four degrees.

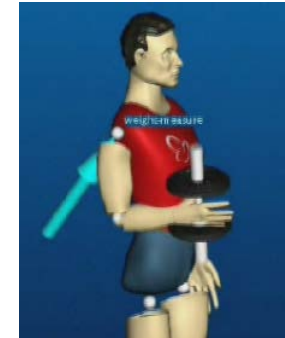
Undergraduate engineers at Cambridge University make a similar Sterling engine as part of their course.



Bio-mechanics

Forces and movement arrows can be set up to show magnitude and direction dynamically during animated simulations.

This still is taken from short sequence in the 17 minute Pro/E promotional video (550MB) available in the Windchill Project link Teachers' Portal.



Black box mechanisms

Students are first taught the principles of levers and mechanisms using physical models. CAD can enhance this experience.

Pupils investigate mechanisms covered by 'black' boxes hypothesising which mechanism is inside the box.

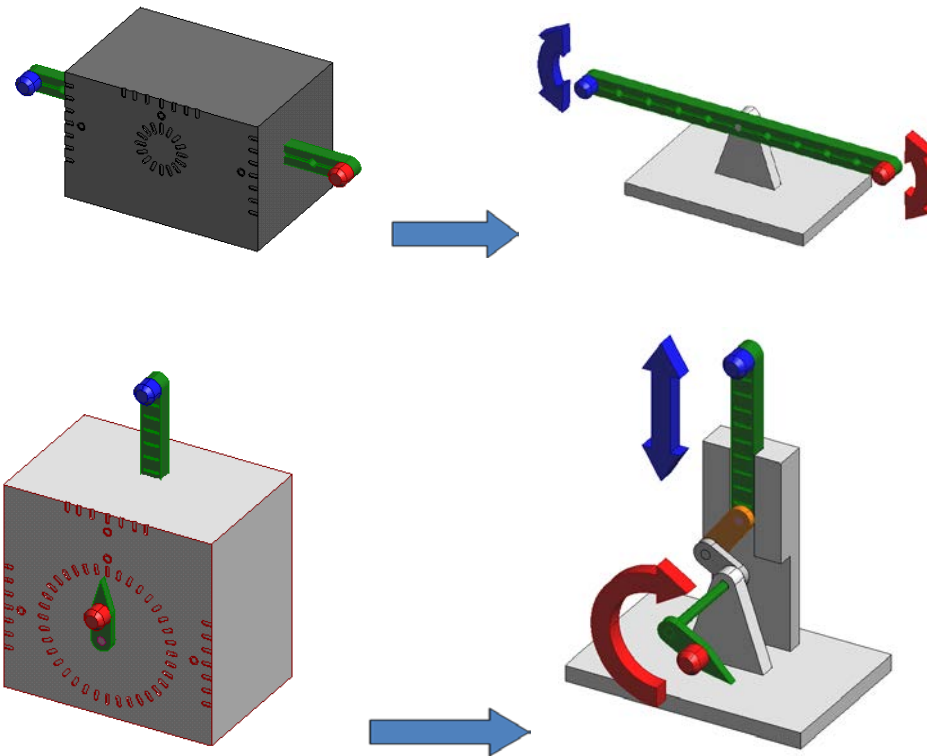
The box is hidden, revealing the mechanism, to check whether their hypothesis is correct.

These are Pro/DESKTOP models from materials originally written by Tim Brotherhood for a project with 3T Indigo and The D&T Association.

They are available here:

<http://webarchive.nationalarchives.gov.uk/20070112090624/http://www.teachernet.gov.uk/supportpack/module.aspx?t=2&s=5&m=21377&n=285749>

Using **Creo Parametric**, Mechanism Dynamics, we can show the direction and magnitude of motion, forces automatically.



Floating and sinking

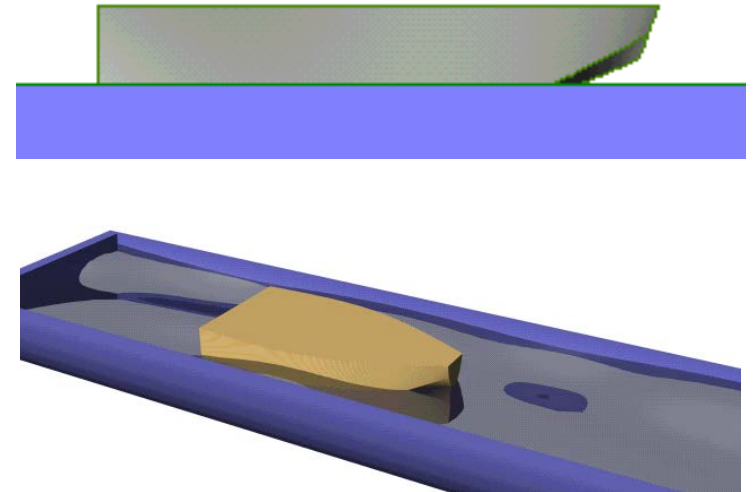
The science behind why objects float was first described by Archimedes.

Originally created in **Pro|DESKTOP**, this is a 'goal seeking' exercise to determine the position a boat will float in water.

The software knows the physical properties of all the materials and can find the point where the displacement equals the mass of the boat. This determines the height the boat hull will float in the water.

Students can experiment with different hull shapes, materials for the boat and different density liquids.

This exercise needs updating for **Creo Parametric**.



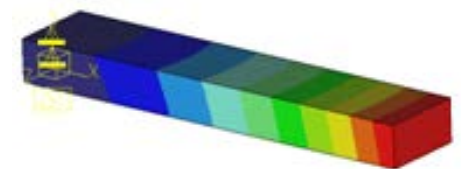
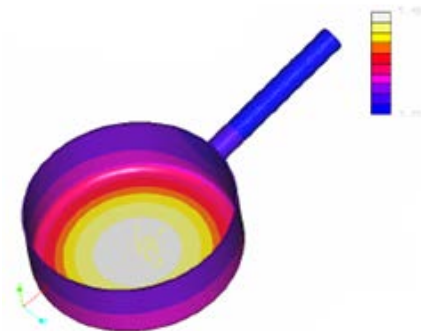
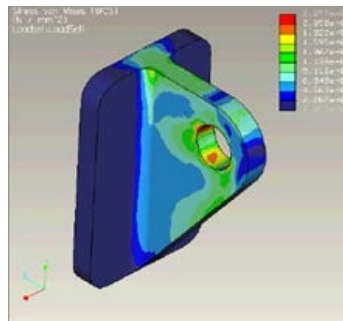
FEA – structural and thermal

These are illustrations of **Creo Simulate** analyses for thermal and structural.

All three are taken from tutorials by Dave Cheshire – Staffordshire University, UK.

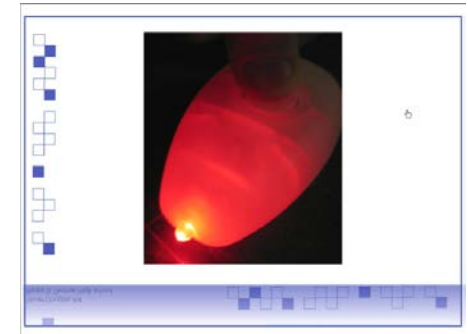
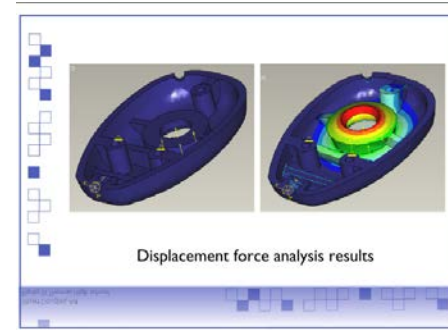
Available for Pro|ENGINEER Wildfire at:

http://www.cdcweb.co.uk/index.php?page=tutorials_wildfire.php



Stress on structures

These images are of work from Ripley St Thomas School in Lancaster where pupils use **Creo Simulate** to design flexible torch cases to avoid the need for moving buttons.



Music technology

Creo Simulate will calculate the resonant frequency of a model so we can tune a set of tubular bells or wind chimes.

Can we tune the column of air in a flute or ocarina and then RP the model to produce a perfectly tuned instrument...?



CFD – Flow simulation

Third party partner company – Mentor Graphics supplies Computational Fluid Dynamics (CFD) software called FloEFD.pro.

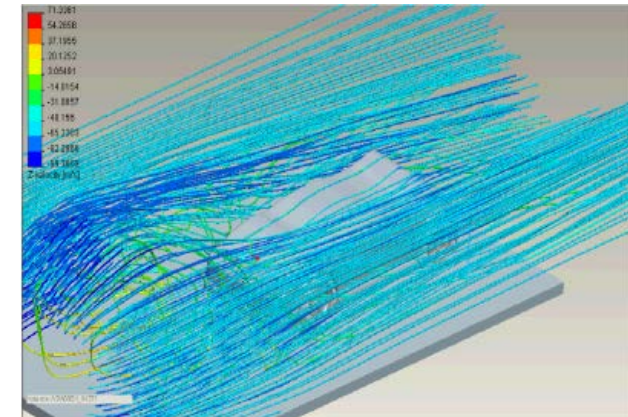
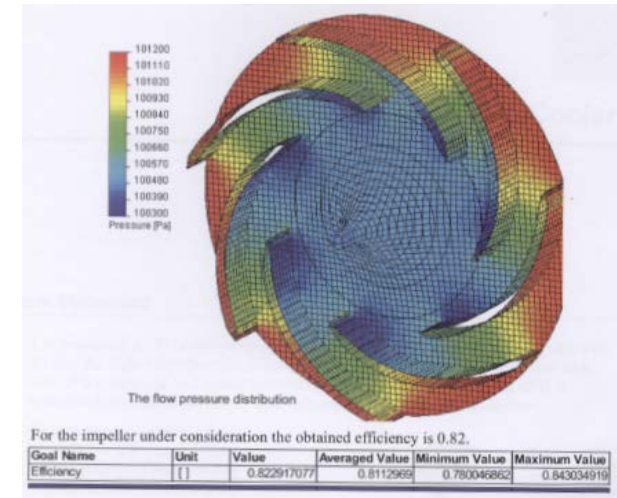
Schools in the UK are piloting its use for wind tunnel testing, e.g. Scalextric4Schools

Future developments

- Water wheel
- Wind turbine

The overall winners of the 2010 Scalextric4Schools Challenge were Sandbach School from Cheshire, UK.

The all girls team used Mentor Graphics FloEFD.pro software to test the aerodynamic efficiency of their design.



Bonus models

Schools Edition

- **Motorbike** – Dynamic simulation of bike riding off a ramp and breaking to a stop
- **Tennis Ball bounce** – undergraduate study of bounce with spin on different court surfaces.

Schools advanced Edition

- **Bracket** – FEA analysis of stress and deflection in a simple bracket.
- **Bimetal** – FEA analysis of the expansion of dissimilar metals bonded together when heated.
- **Gear mesh** – study of the stresses at the contact point in a gear tooth.
- **Light demo** – Toolkit add on created for defence customer that simulates 3D light paths through optics.

Further ideas

- **FEA – Concrete beam**
- **Yacht vectors**
- **Rates of cooling**
- **Lenses – 3D light paths**
- **Atomic models with correct mass/distances, etc**

Tim Brotherhood – August 2012

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