University of BRISTOL

Department of Mechanical Engineering

VIRTUAL PRODUCT DEVELOPMENT (MENGM6049) – Lecture 5 Interrogation of Solids (Engineering surface & Shape Analysis) 2017-2018

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The Purpose of the Lecture

- The use of surfaces in CAD/CAM applications.
- Give you a brief on types of surfaces such as extruded, revolved, ruled, single or double curved, free form curve-mesh or sculptured.
- Developable surfaces, (single or double curved).
- Examples of sheet metal fabrication.
- Interrogation methods such as contouring, reflection lines and Gaussian curvature analysis followed with examples.
- In sheet metal fabrication, curved panels are made of flat sheets. No stretching, tearing or wrinkling is allowed.
- Sheet fabrication is used extensively in aircraft or ship hull skin structures, automobile body parts and leather for shoes, hand bags, automobile upholstery and garment manufacturing.

Intended Learning Outcomes

After taking the unit the students would be able to:

1. Draw, manipulate and analyse advanced engineering curves including splines and Bezier curves on a Computer Aided Design system.

2. Create a machining process plan for a part and perform virtual machining of the product based on this process plan on a Computer Aided Manufacturing system.

3. Design and optimise a mechanical product from concept to full digital prototype in an integrated Product Lifecycle Management environment.

Å To complement the unit, 9 lectures with a series of laboratories (24 hours) are provided to support the unit.

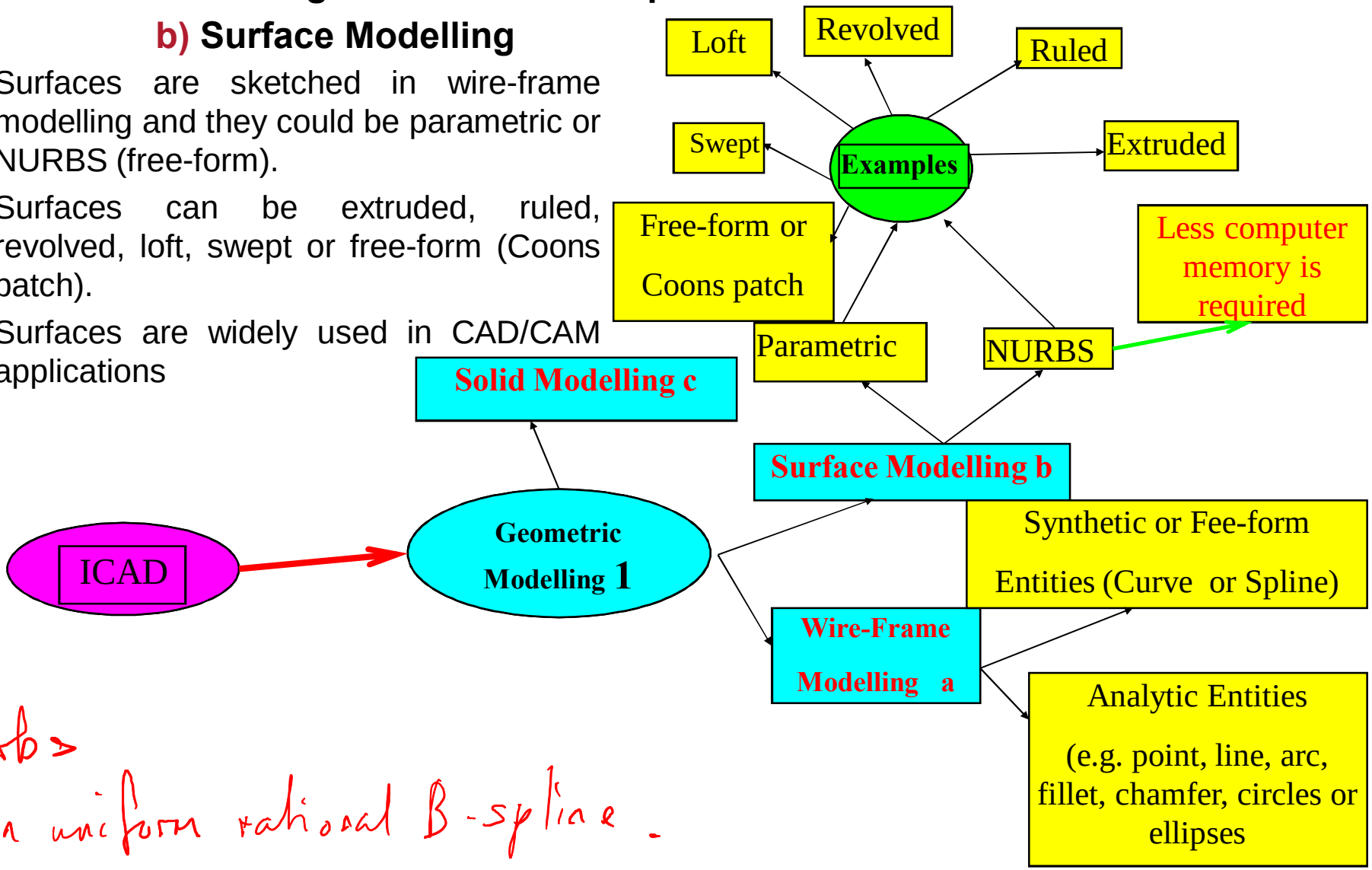
Unit – Supporting Lectures

- Lecture 0 Introduction to coursework/assignment;
- Lecture 1 Introduction to VPD and PLM.
- Lecture 2 CAD Overview & Intro. to Engineering Curve.
- Lecture 3 Reverse Engineering.
- Lecture 4 Curve Analysis.
- Lecture 5 Interrogation of Solids.
- Lecture 6 Design for Machining & CNC Machining.
- Lecture 7 Process Planning for Machining.
- Lecture 8 Virtual Machining.
- Lecture 9 Iterative design, analysis and Optimisation in PLM.

Overview of an integrated CAD Techniques

b) Surface Modelling

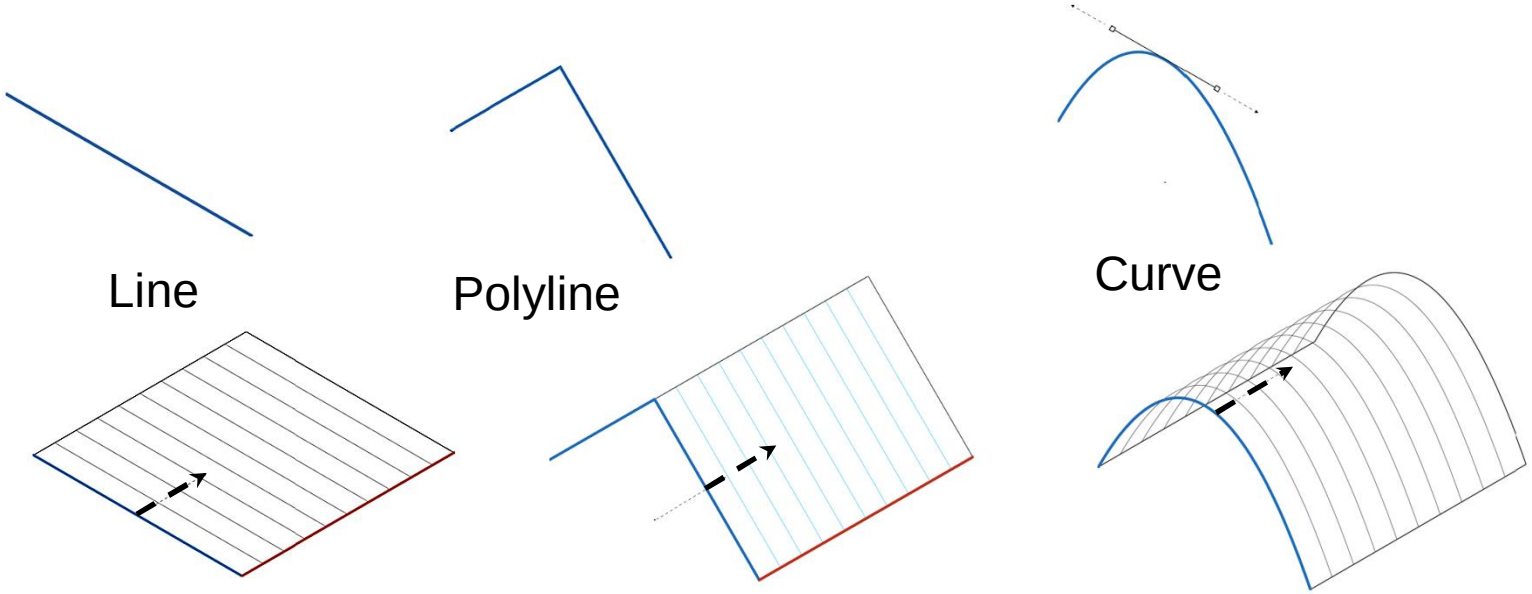
- Surfaces are sketched in wire-frame modelling and they could be parametric or NURBS (free-form).
- Surfaces can be extruded, ruled, revolved, loft, swept or free-form (Coons patch).
- Surfaces are widely used in CAD/CAM applications



Nurbs
↳ non uniform rational B-spline.

Parametric Surfaces - Extruded surface

- An ‘**extruded surface**’ moves a line, polyline or curve along a straight line.

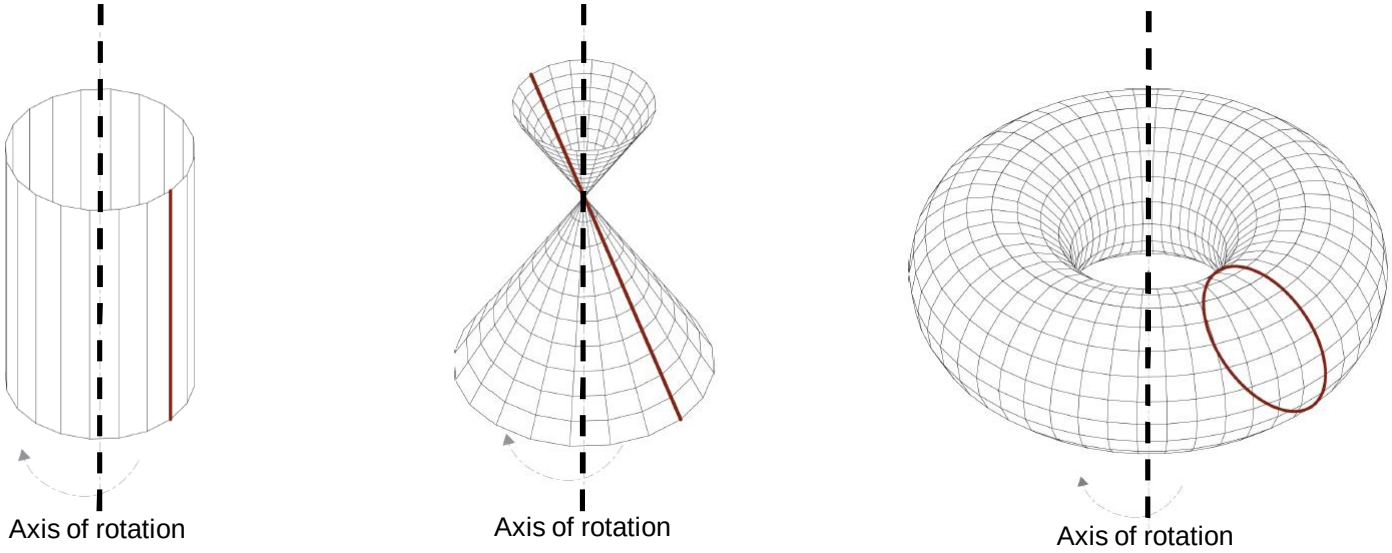


Extruded Surfaces

http://unitec.researchbank.ac.nz/handle/10652/2576

Parametric Surfaces - Revolved

- A ó**revolved surface**ô rotates a line/curve around a straight line or óaxisô



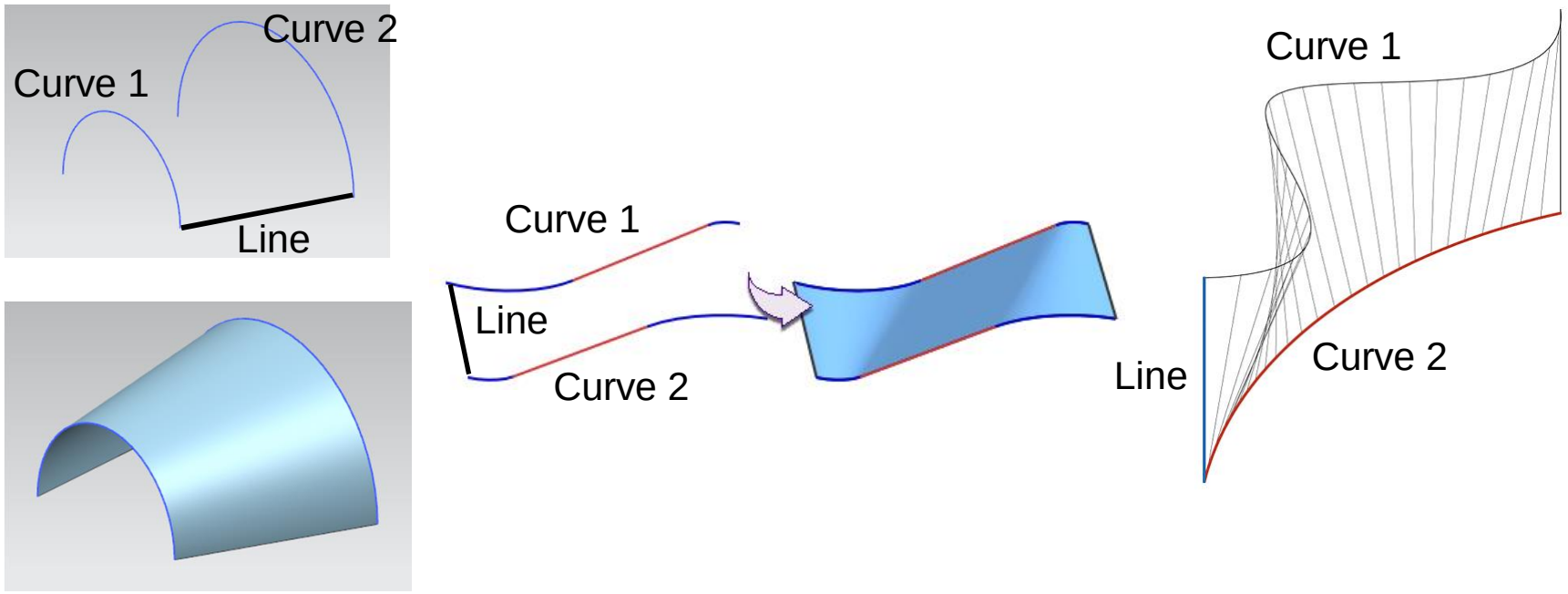
Cylinder Cone Torus

Revolved Surfaces

http://unitec.researchbank.ac.nz/handle/10652/2576

Parametric Surfaces – Ruled

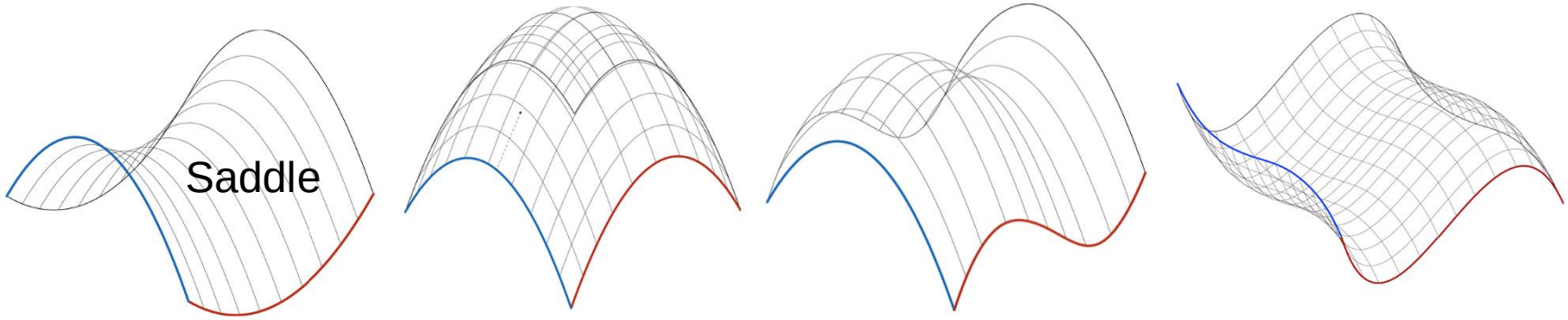
- A ruled surface moves a straight line along a curve.



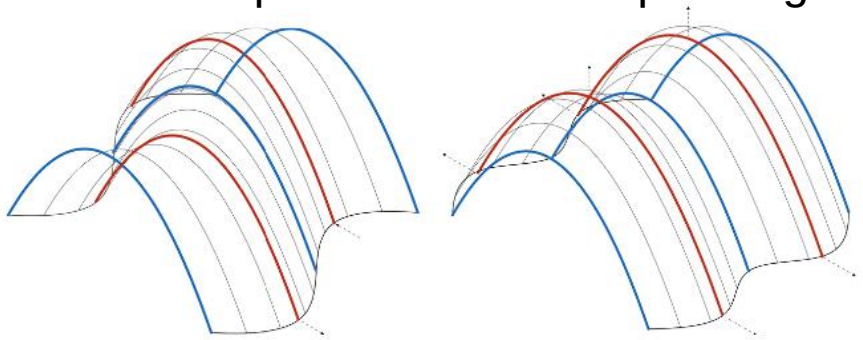
Ruled Surfaces

Surfaces – Complex Translated

- Figure shows various transformations of a curve into a surface along another curve, such as variational sweep or lofting.



variational sweep ï a curve is swept along another curve

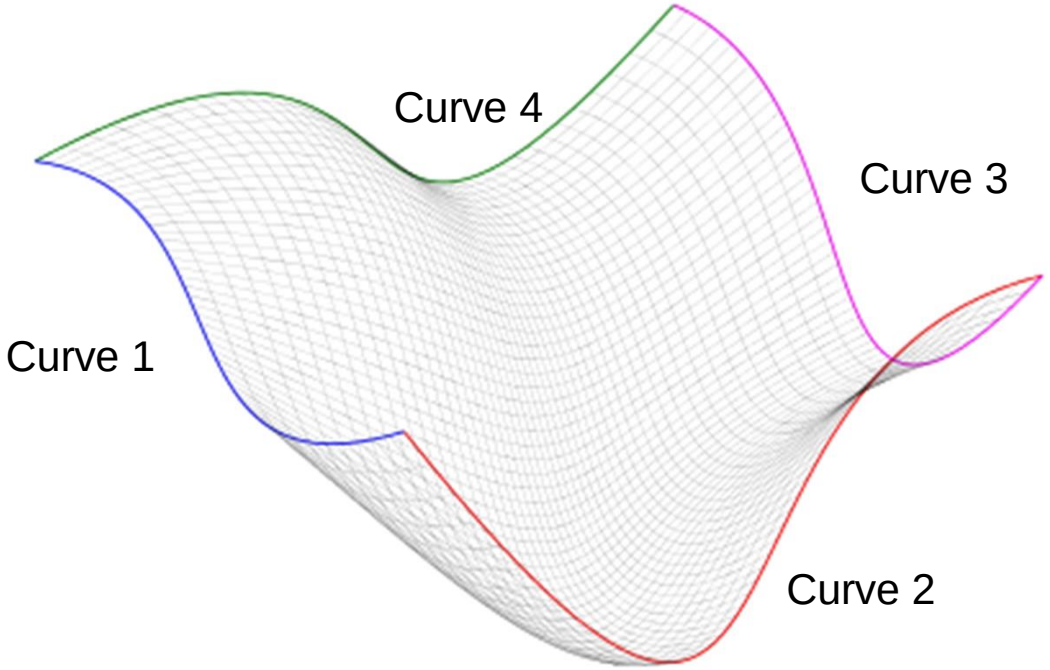


Lofting uses cross-sectional curves

http://unitec.researchbank.ac.nz/handle/10652/2576

Curve-mesh or Sculptured (free-form)

- Figure shows complex free-form surfaces, such as sculptured (Coons patch).
- Curve-mesh or sculptured surface (Coons patch) uses four boundary curves.

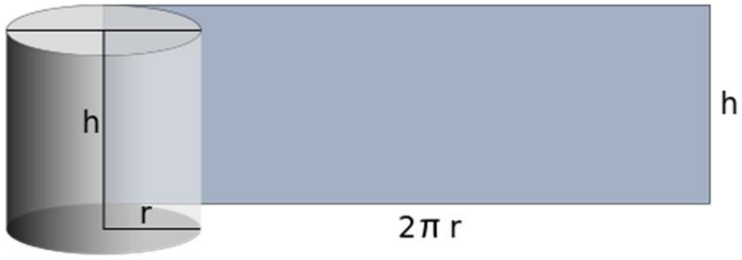


https://en.wikipedia.org/wiki/Coons_patch

Developable Surfaces in Engineering

- A developable surface is a surface which can be unfolded (developed) into a plane without stretching, tearing or wrinkling.

- A cylinder is one of them:



https://en.wikipedia.org/wiki/Developable_surface#/media/File:Kreiszylinder.svg

- Developable surfaces can be flattened using exact solutions.

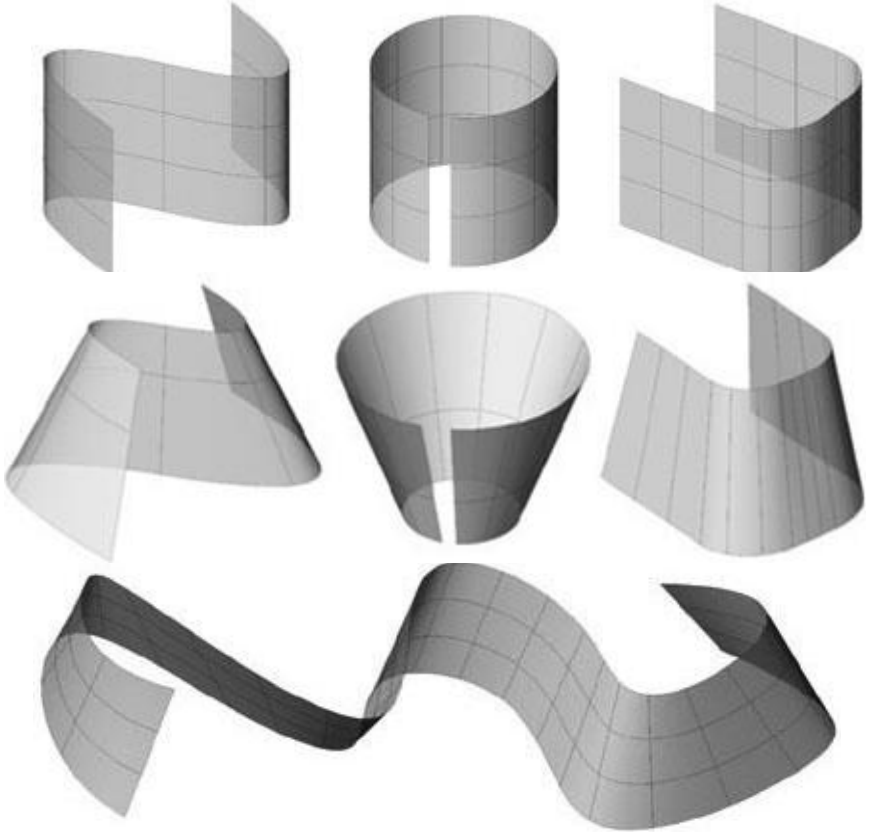
- Developable surfaces are useful because they allow round forms to be made out of flat materials like sheet metal, plywood, or cloth.

Developable surface is a surface with zero Gaussian curvature.

Gaussian curvature will be explained later.

Developable Surfaces – Single Curved

- **Cylindrically developable**: A curve extruded straight, creating a surface with a constant section.
- **Conically developable:** A curve extruded towards a focal point results in a surface with a section varying in size.
- **Poly-conically developable:** when conical (and cylindrical) segments join together, creating a composite surface.



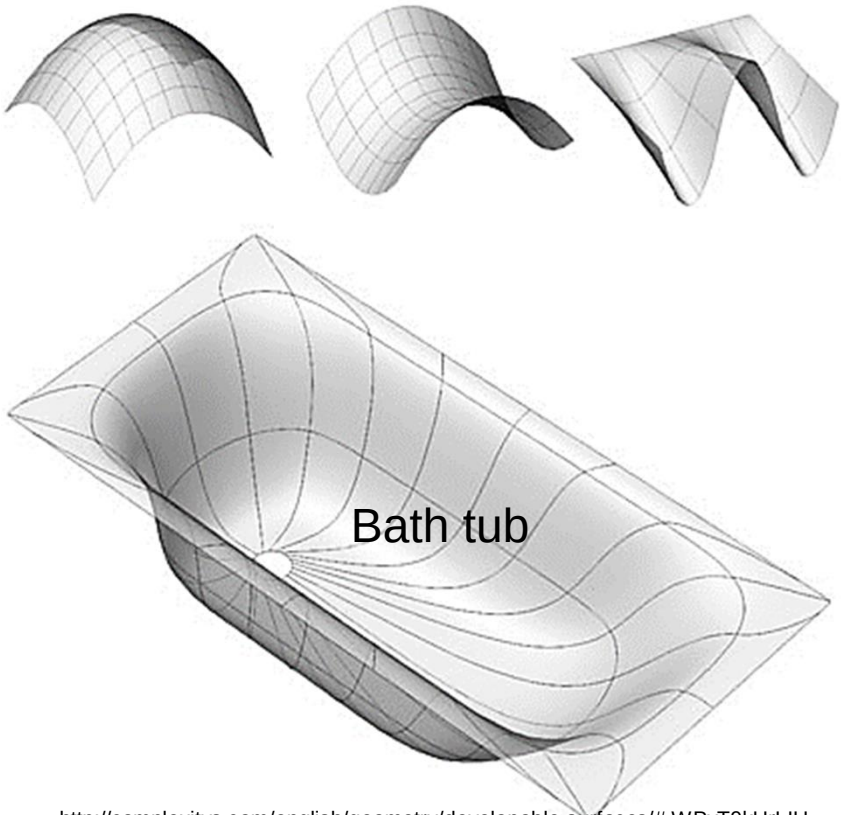
http://complexitys.com/english/geometry/developable-surfaces/#.WPvT9kUrLIU

- The above three surfaces are called ósingle curvedô These surfaces are characterized by **only bending in one direction at a time,** like the cylinder or the cone.

NX : Wrap/Unwrap Curve on Developable Surfaces
https://www.youtube.com/watch?v=ZObJhvJosTo , [accessed May. 23, 2017], 3.40 m

Non-Developable Surfaces – Double Curved

- Surfaces that **bend in two directions at the same time and cannot be made out of a flat material are called 'double curved'.** They are non-developable.
- Non-developable surfaces cannot be flattened accurately without knowing something about the characteristics of the material (amount of stretching or shrinking available to eliminate any distortion as a result of tearing or wrinkling).



http://complexitys.com/english/geometry/developable-surfaces/#.WPvT9kUrLIU

- Single or double curved surfaces are used for aircraft or ship hull skin structures, automobile body parts, leather for shoes, hand bags, automobile upholstery and garment manufacturing, etc.

Sheet Metal Fabrication - Aircraft

- Aircraft disaster due to square window design:

https://en.wikipedia.org/wiki/De_Havilland_Comet

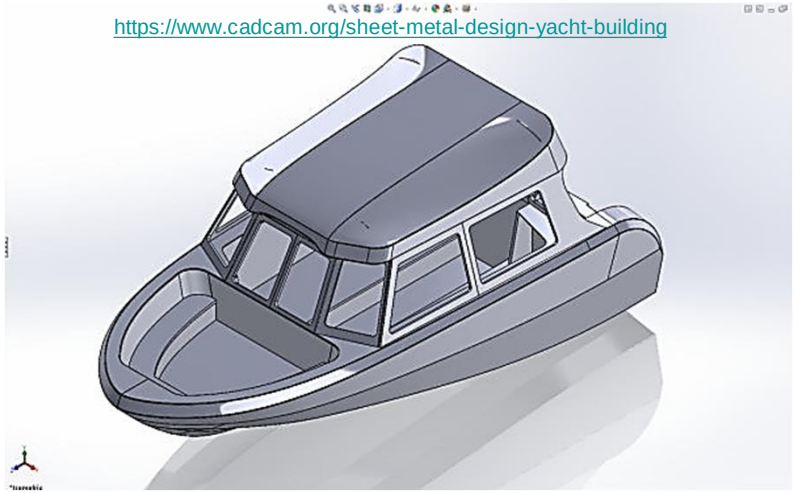
Stress distribution at 56.9 kPa cabin pressure and 1.3 g inertia loading

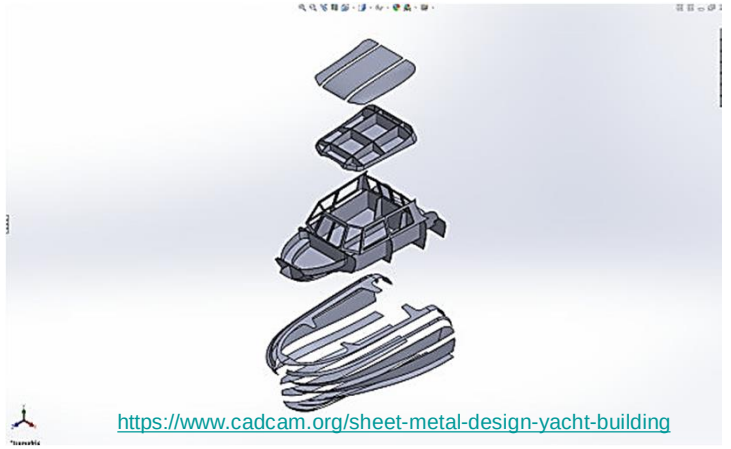
http://www.cracked.com/article_19623_6-small-math-errors-that-caused-huge-disasters.html

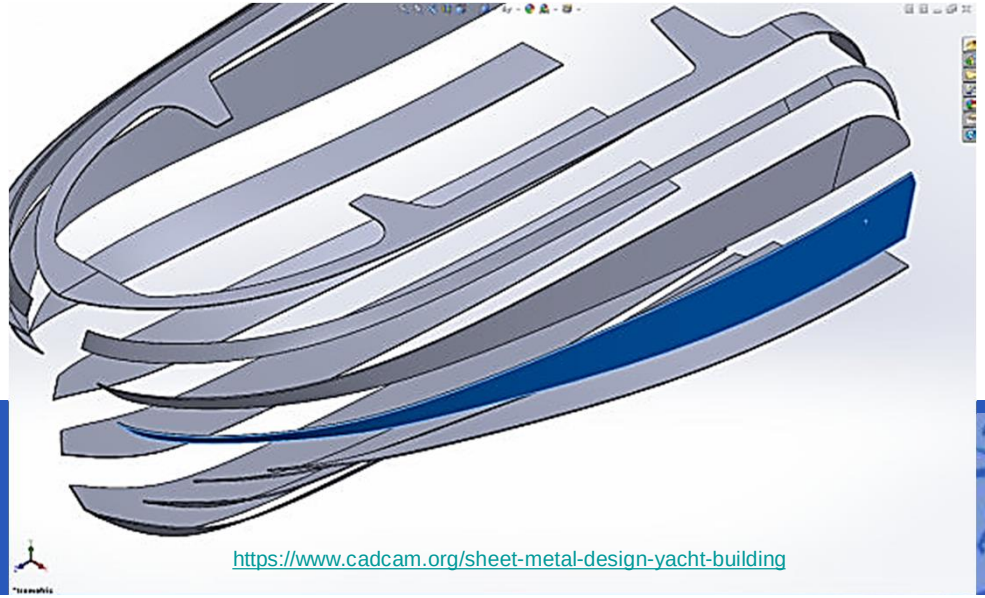
http://aerospaceengineeringblog.com/dehavilland-comet-crash/

Sheet Metal Fabrication - Shipbuilding

- In shipbuilding, having the ability to flatten, modify and reform curved surfaces to its original shape is very important. — Why?
- Below is a yacht example with a number of curved panels.







NX: Flattening and Forming
https://www.youtube.com/watch?v=RHNJqv4keOU, [accessed May. 23, 2017], 5.35 m

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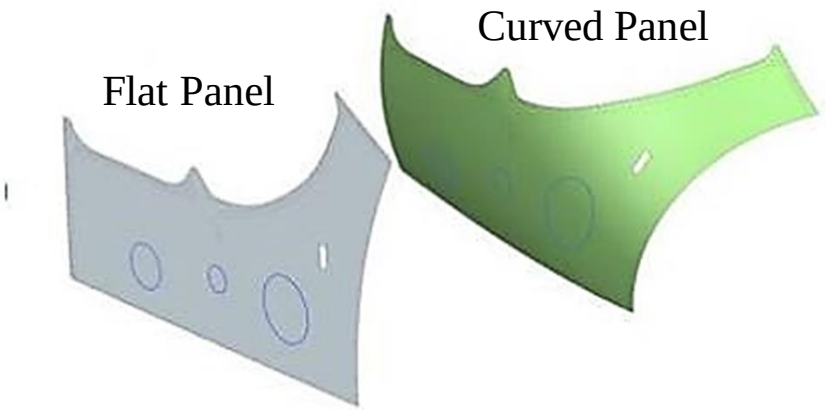
Sheet Metal Fabrication – Car

- Today, products such as cars are not only designed to function, but their aesthetic look also is as important as their function.
- Most of the shape on car body panels is complex shape and has to meet class A surface specification.

- Class A surfaces are free-form surfaces with an optimal aesthetic look/shape and high surface quality with no undesirable waviness.

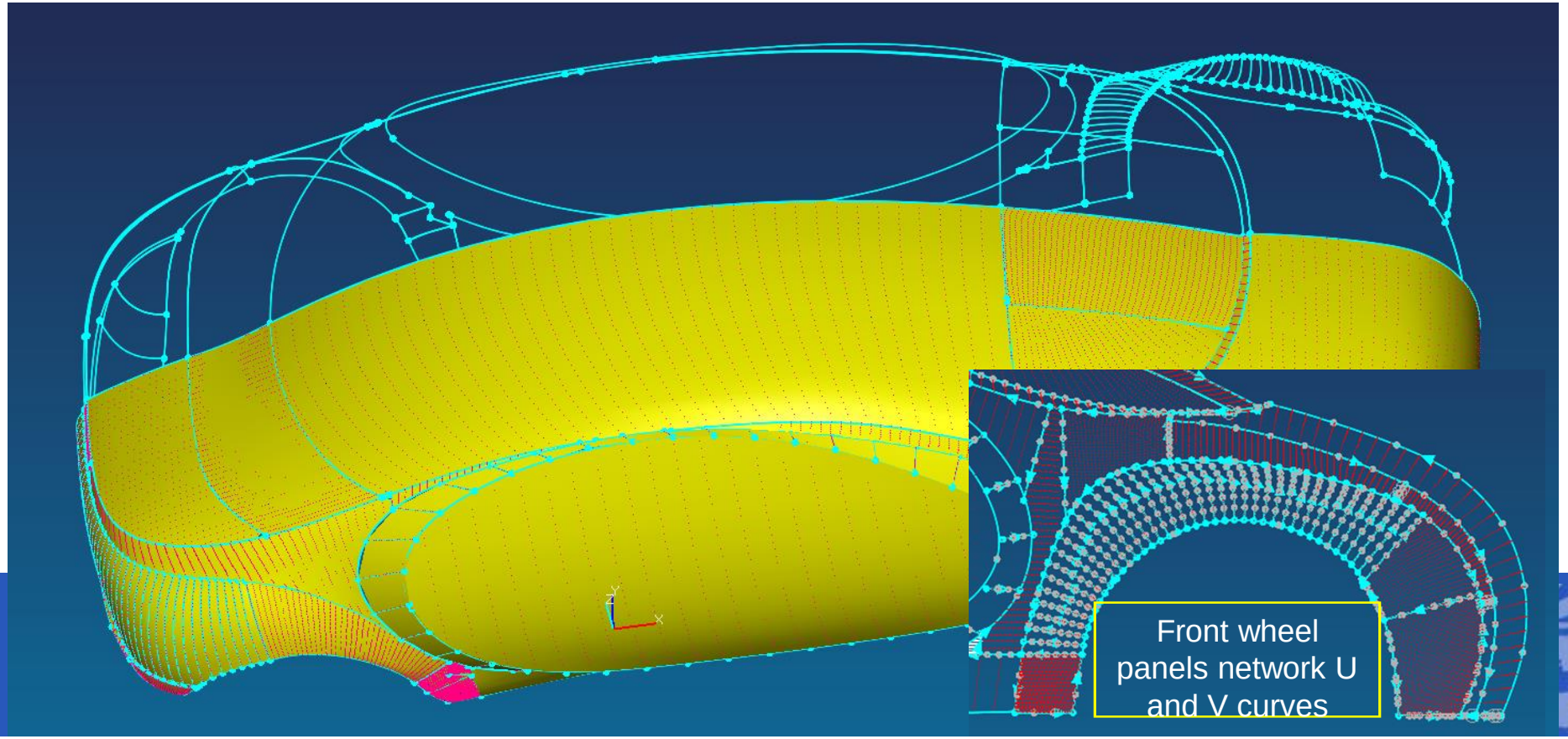


Flatten and re-form curved surfaces in NX 11

http://www.siemensnx.com/1320/whats-new-in-nx-11-for-design-engineering

Class A Surfaces - Cars

- The Class A surfaces are made of U and V curves and mathematically they may have a continuous curvature to positional continuity of 1 µm (0.001mm) and with tangency of 0.016 degrees.
- Class A surfaces are applied to other products too.
- Class B & C surfaces are also exist for less accurate products.



Double Curved Surfaces

- Any surface distortion should be eliminated otherwise it will result in tearing or wrinkling the surface as shown in the example below.
- Surface interrogation methods are used to identify surface abnormality and distortion.

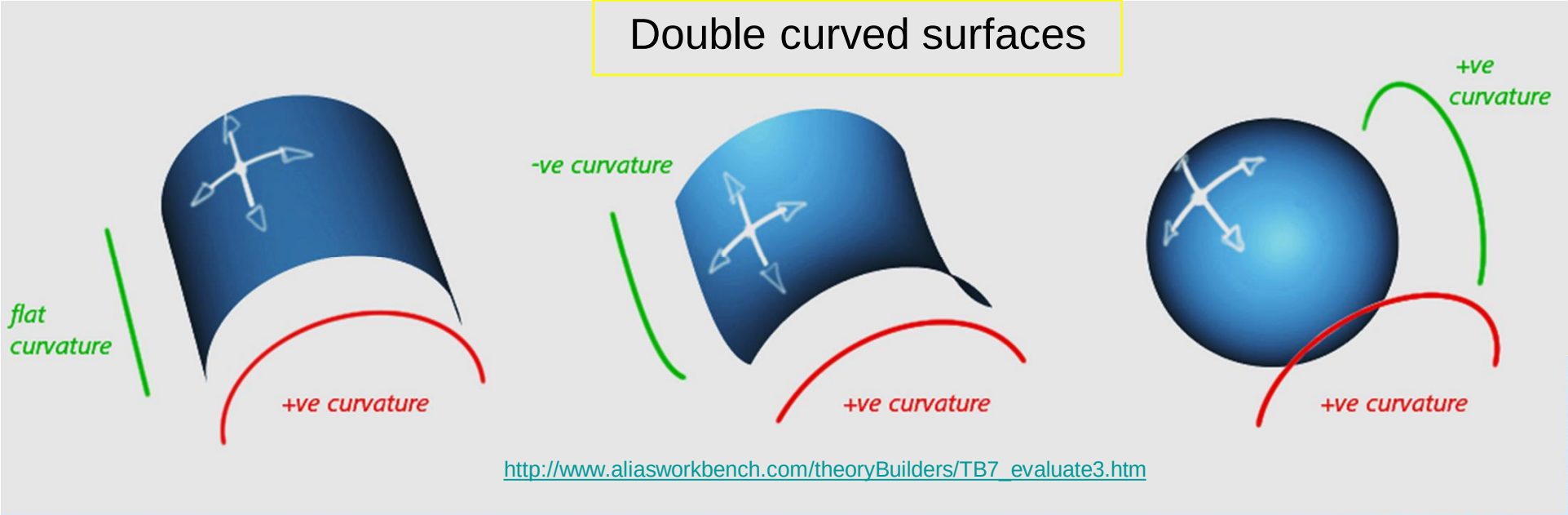
http://www.tuvie.com/bmw-gina-light-car-concept/

Exaggerating tearing or wrinkling on car body panels

Surface/Shape Interrogation Methods

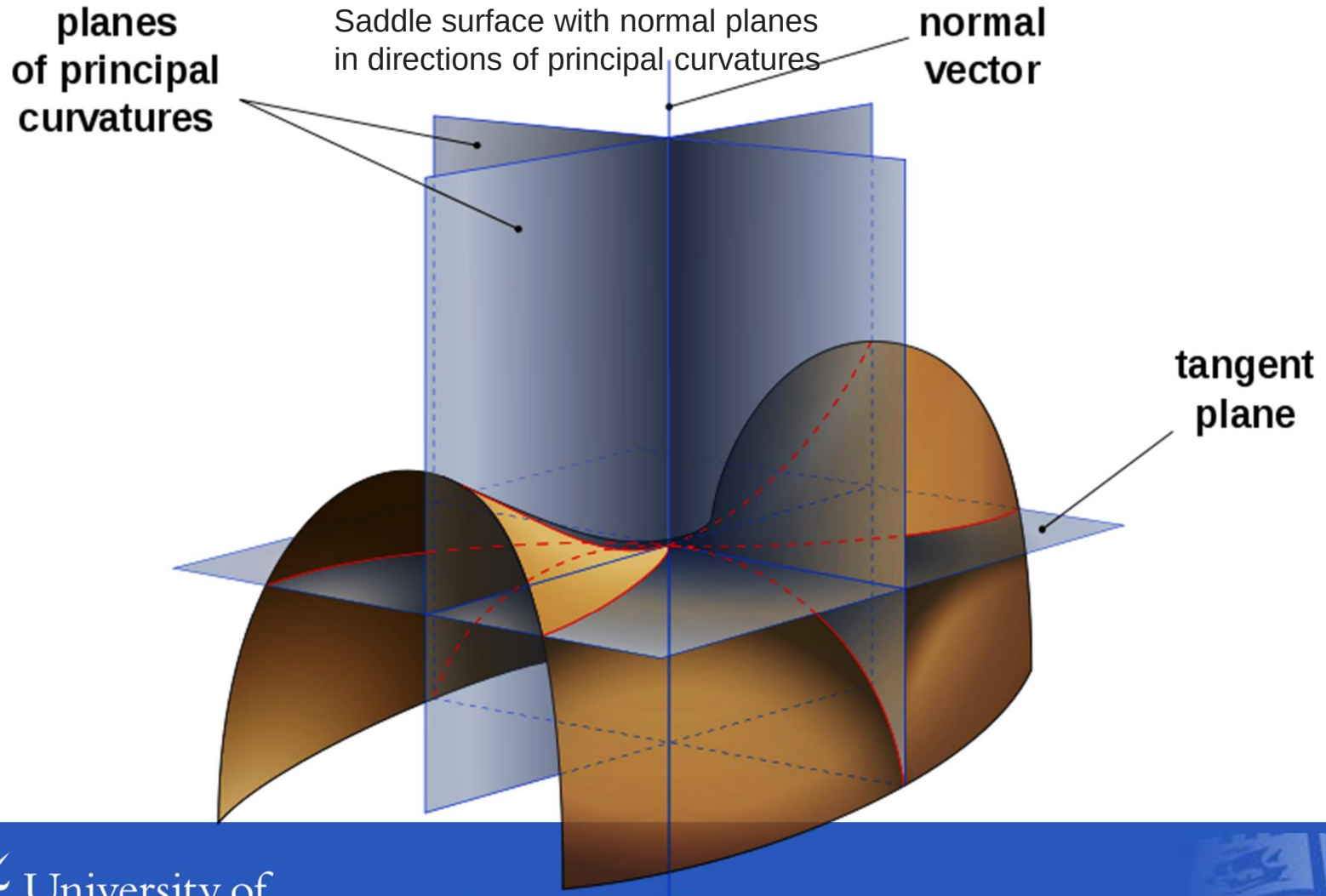
- Surface interrogation methods provide important tools in analysing the shape and curvature properties of double curved surfaces, where curvature is a measure of how quickly a tangent line turns on a curve.

- Examples below show curvatures on double curved surfaces - curvature can be flat (being zero), -ve or +ve.



Surface/Shape Interrogation Methods

- A saddle surface is a double curve which shows the flat (being zero), -ve and +ve curvature.



https://en.wikipedia.org/wiki/Gaussian_curvature

Surface/Shape Interrogation Methods

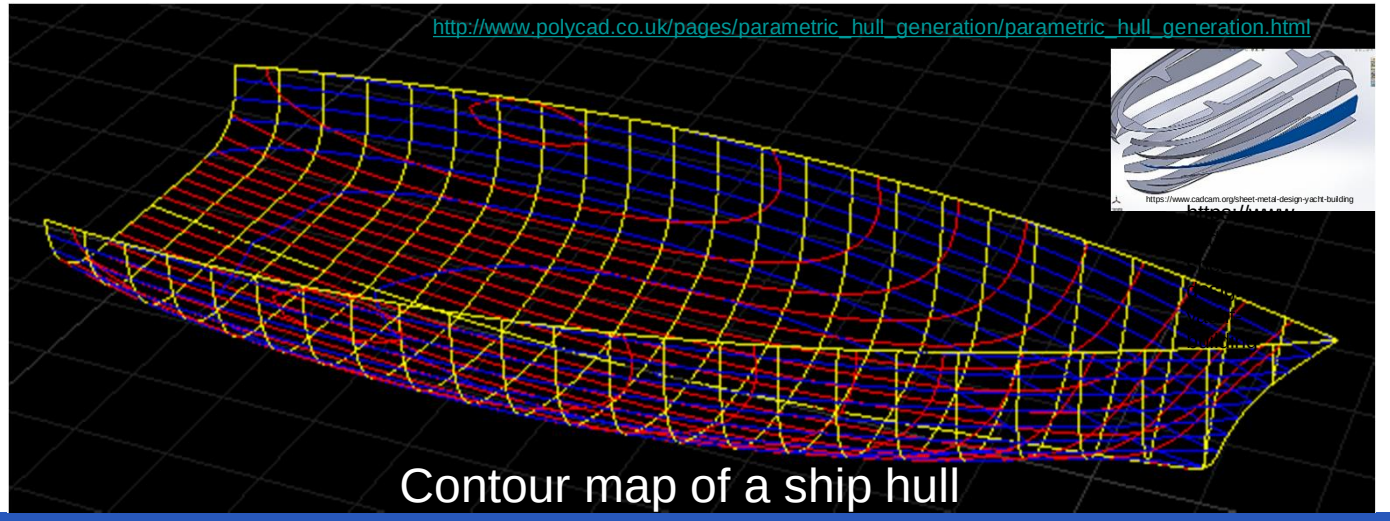
- Due to technical suitability for different applications, various methods of interrogation are used - no method is optimal for all applications. Here are a few;
  - Zero-order, Wireframe & Contouring
  - First-order, Shading & Refection lines
  - Second-order, Gaussian curvature analysis/plot

http://web.mit.edu/hyperbook/Patrikalakis-Maekawa-Cho/node141.html

Interrogation Methods - Zero-order

Wireframe & Contouring

- Wireframe: gives you rough idea, not very good to judge the surface abnormality.
- A contour map can identify maxima, minima and saddle points of a surface and it used in ship hulls, aircraft fuselage and propeller & turbine blades. Below shows a shipôs hull:

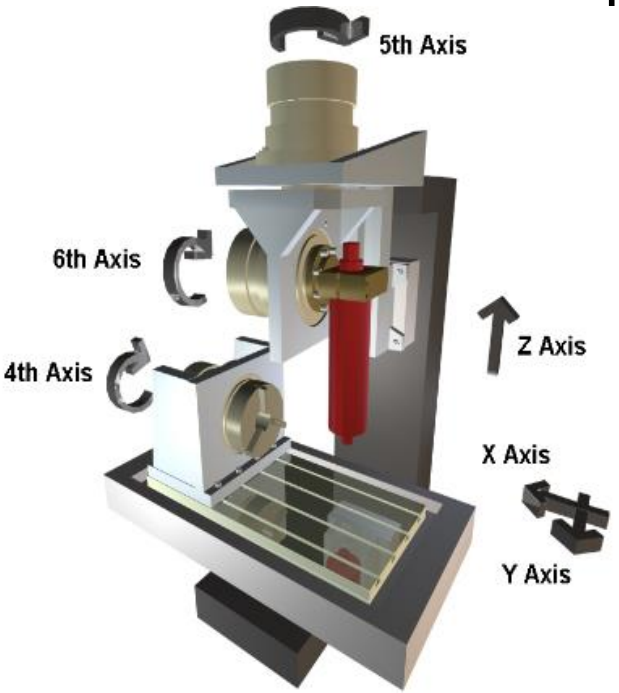


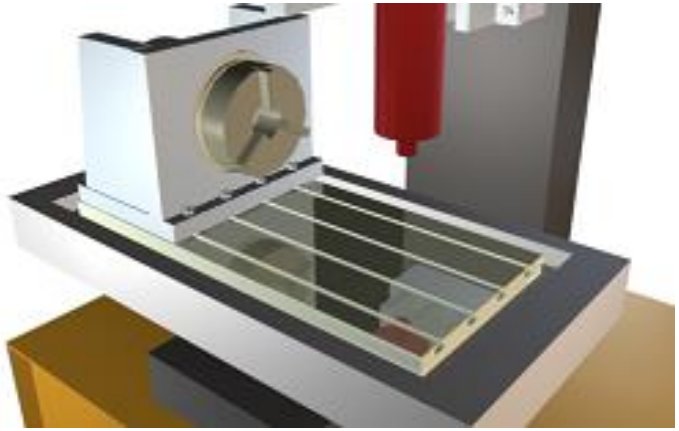
Contour map of a ship hull

Interrogation Methods - First-order

Shading

- Shading ï shaded image of a surface usually gives a more realistic visual presentation.





6 Axis CNC Milling Machine

with shaded and reflection effect

Interrogation Methods - First-order

Refection lines

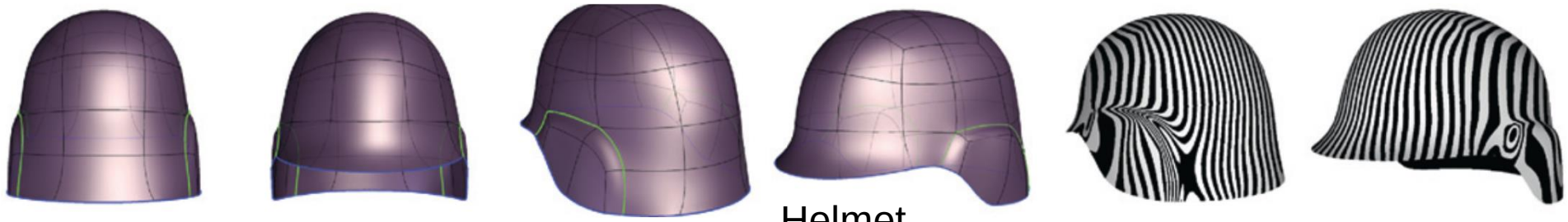
- Reflection lines are used in the automotive industry to interrogate the behaviour of the form or shape of class A surface for quality of surface or any undesirable waviness.
- Reflection lines simulate the mirror images of a number of parallel, straight, fluorescent lights on an automobile surface.
- A Reflection line plot is sometimes called a Zebra/Highlight plot.

Reflection lines/Zebra/Highlight plot
for car body panel surfaces

Interrogation Methods - First-order

Refection lines

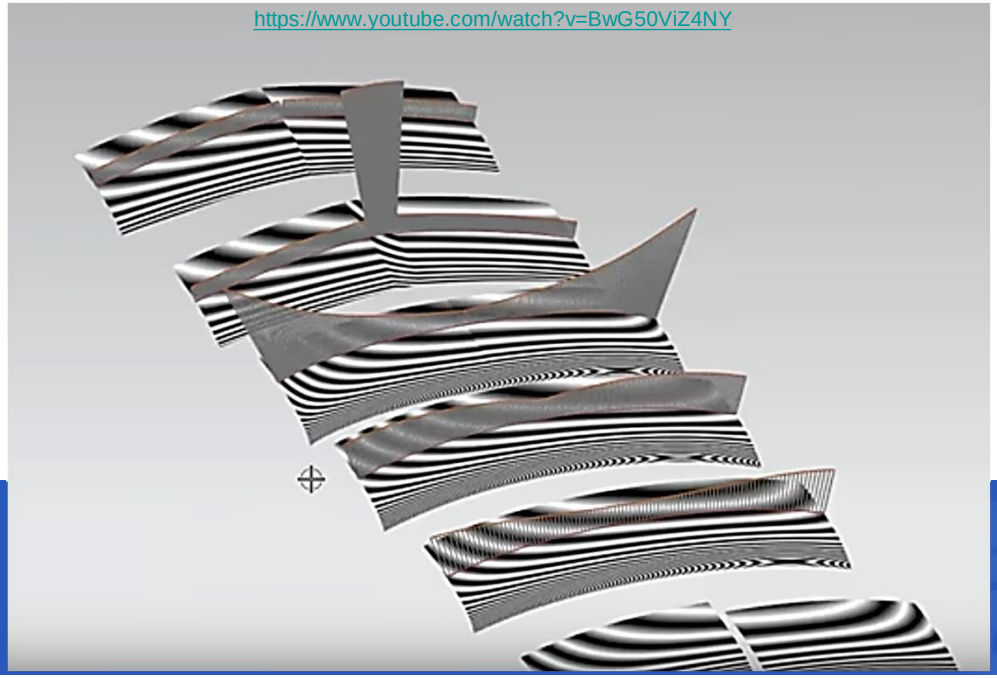
- Reflection lines are also used for other products:



Helmet

http://vdel.me.cmu.edu/publications/2012cgv36/paper.pdf

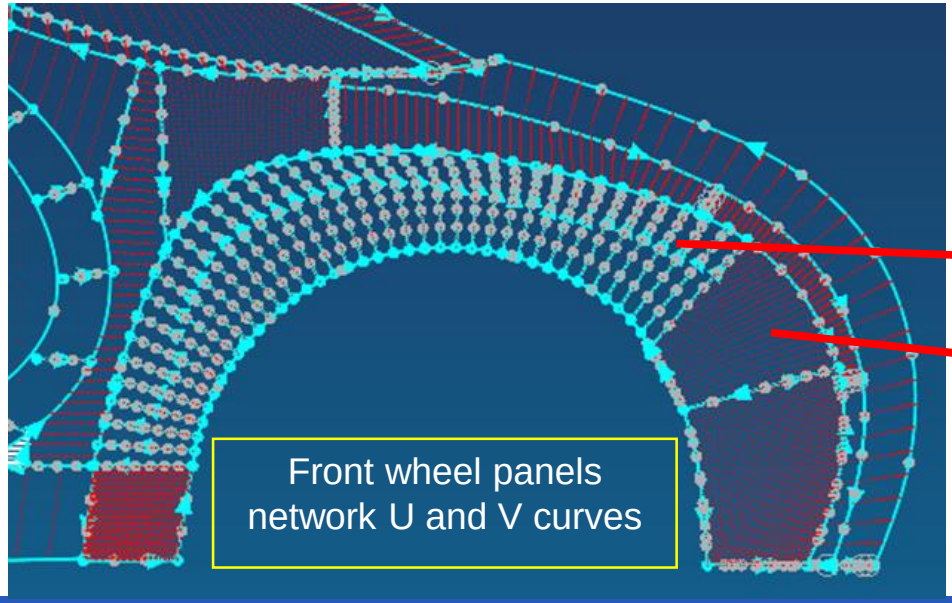
https://www.youtube.com/watch?v=BwG50ViZ4NY

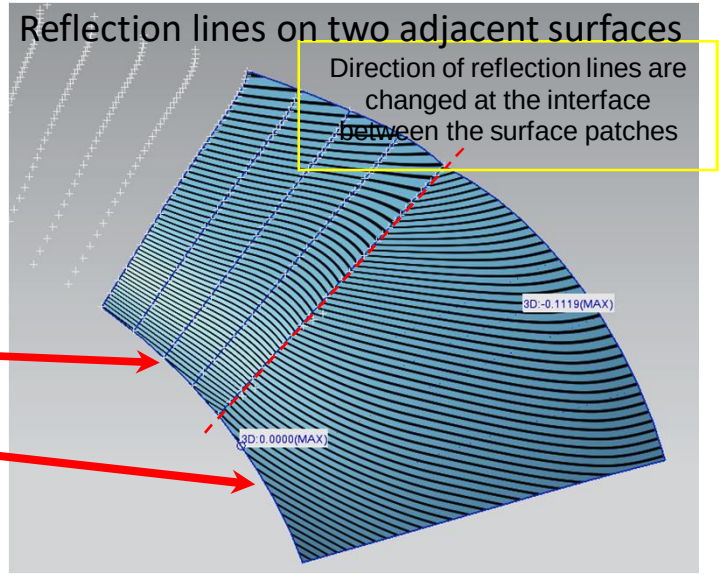


Interrogation Methods - First-order

Refection lines

- Here is an example of a car body panel above the front wheel, using reflection lines to identify abnormality between two adjacent surfaces.

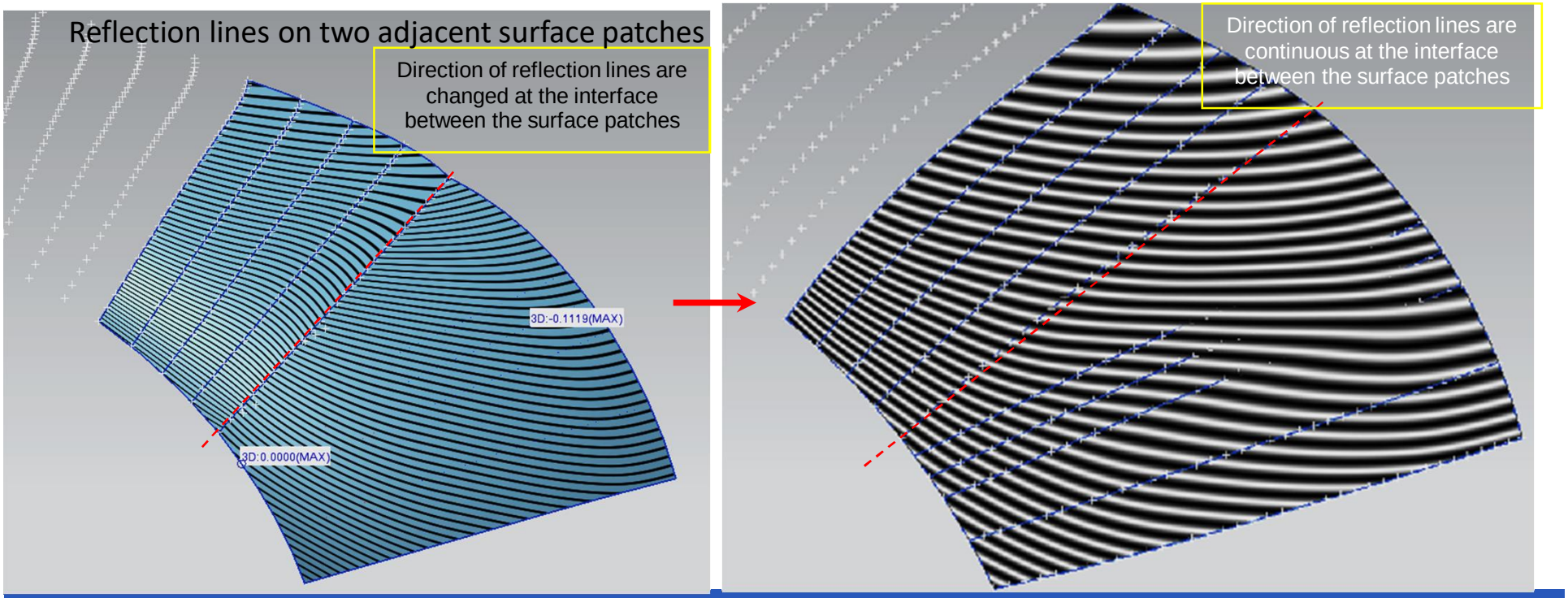




Interrogation Methods - First-order

Refection lines

- Here is an example of a car body panel above a front wheel using reflection lines, left image abnormality identified & right image abnormality rectified.



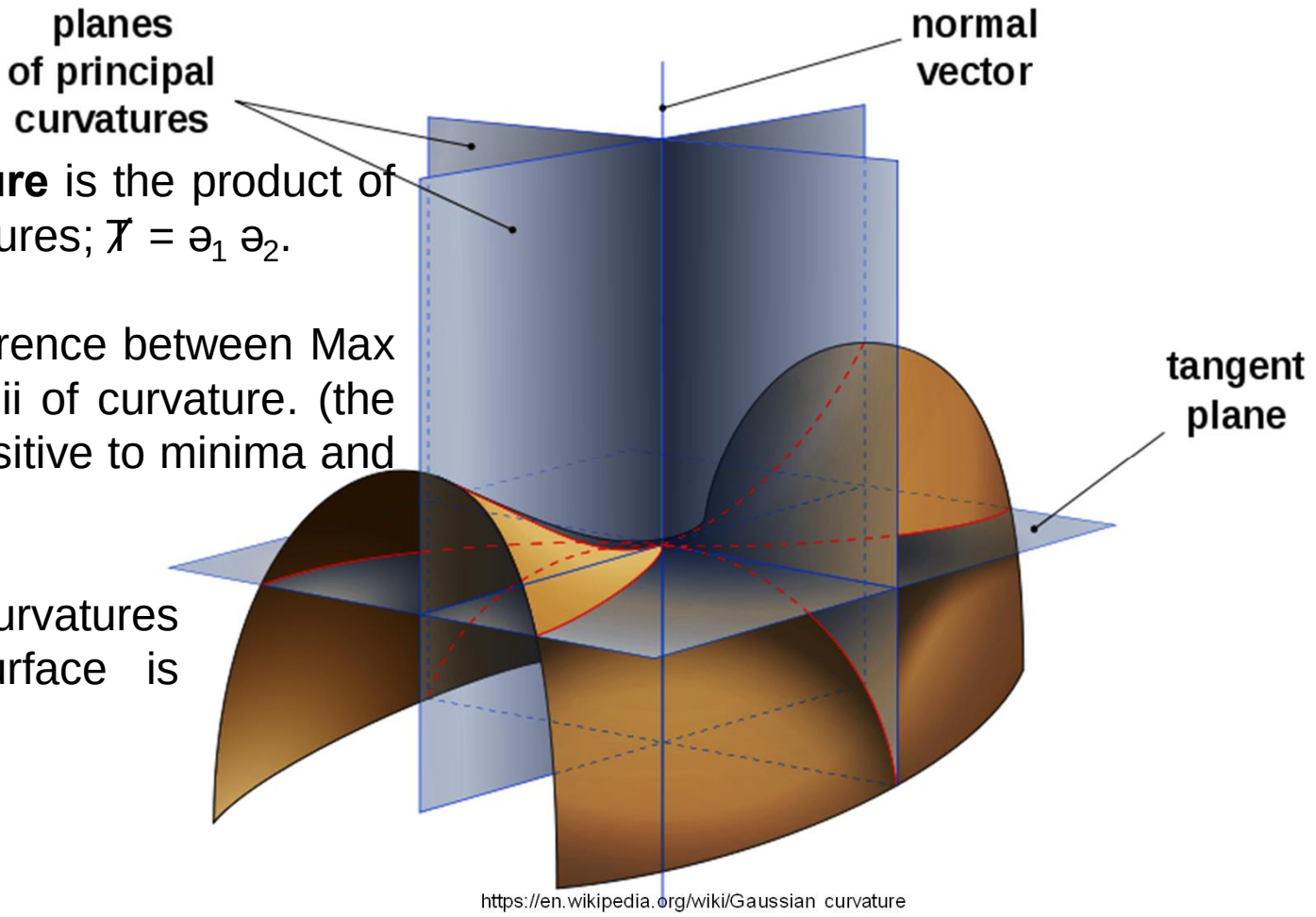
Interrogation Methods – Second-order

- The **Gaussian curvature analysis/plot** can determine which area of a surface has double curvature and is not developable using the two principal curvatures.

- Letôs look at a saddle surface example that you have seen earlier and the definition of the Gaussian curvature analysis.

Interrogation Methods – Second-order

- A saddle surface is a double curve which shows the flat (being zero), -ve and +ve curvature.



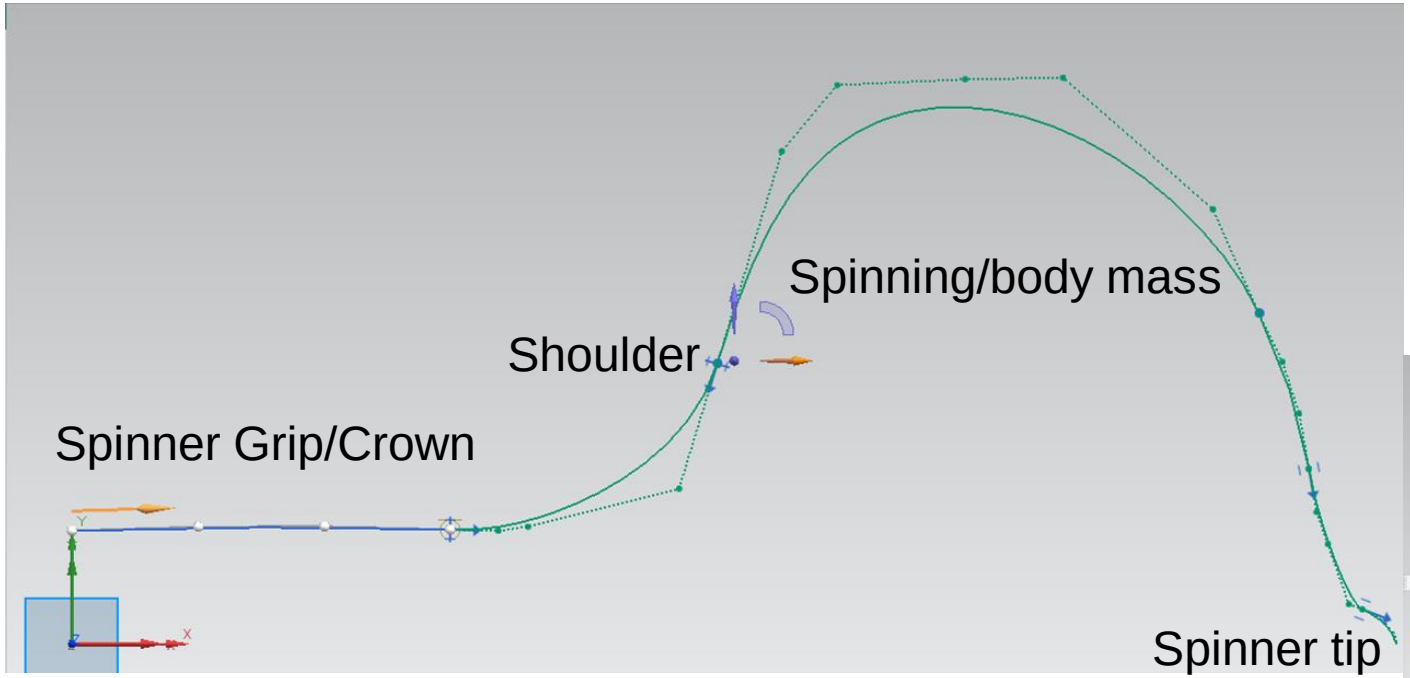
The **Gaussian curvature** is the product of the two principal curvatures; $K = \kappa_1 \kappa_2$.

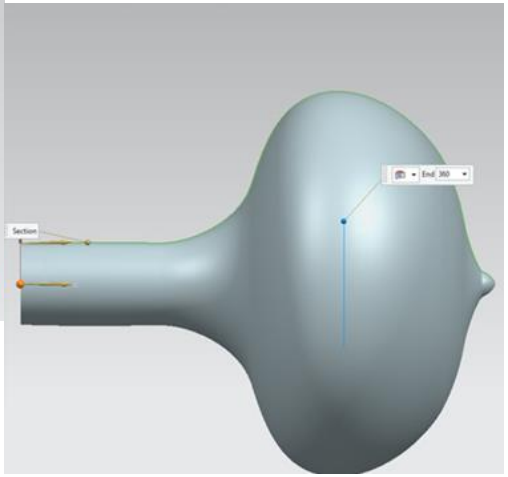
Mean value is the difference between Max & Min of Gaussian radii of curvature. (the human eye is very sensitive to minima and maxima curvature).

If one of the principal curvatures is zero then the surface is developable.

Spinning Top Example – Top's Profile

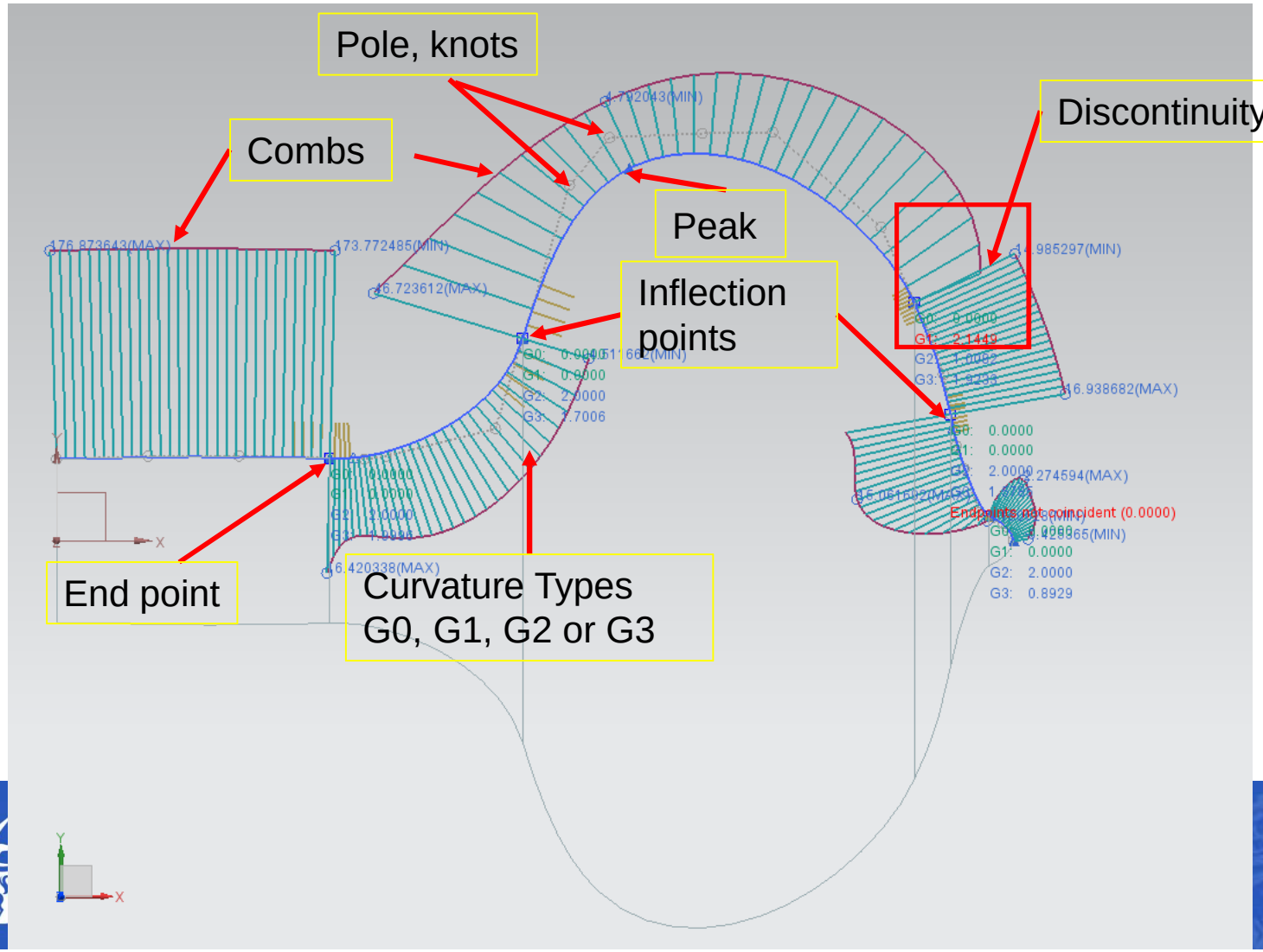
- A spinning top's profile has four main features: "Spinner Grip/Crown", "Shoulder", "Spinning/body mass" and "Spinner tip".
- It is represented by 4 separate but constraint splines, shown below:





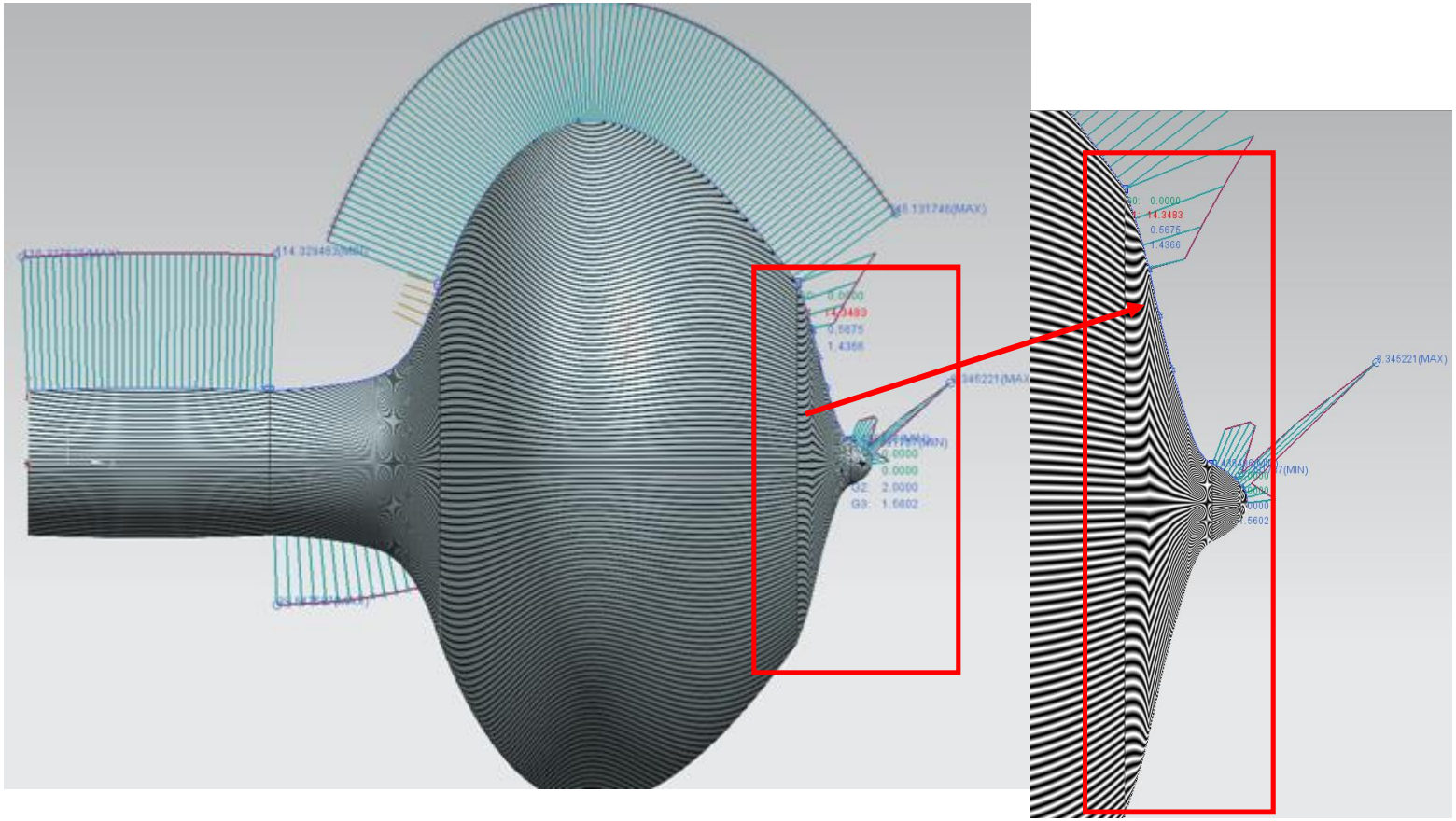
Spline/Surface Analysis of a Spinning Top

- Visualisation Analysis can display/revile abnormality: Go to Menu, Analysis, Curve, Show (Combs, Peaks, and Inflections), Continuity.
- Go to Menu, Analysis, Shape, Show (Pole (this is the method of how splines have been designed in this example), Knots and End Points).



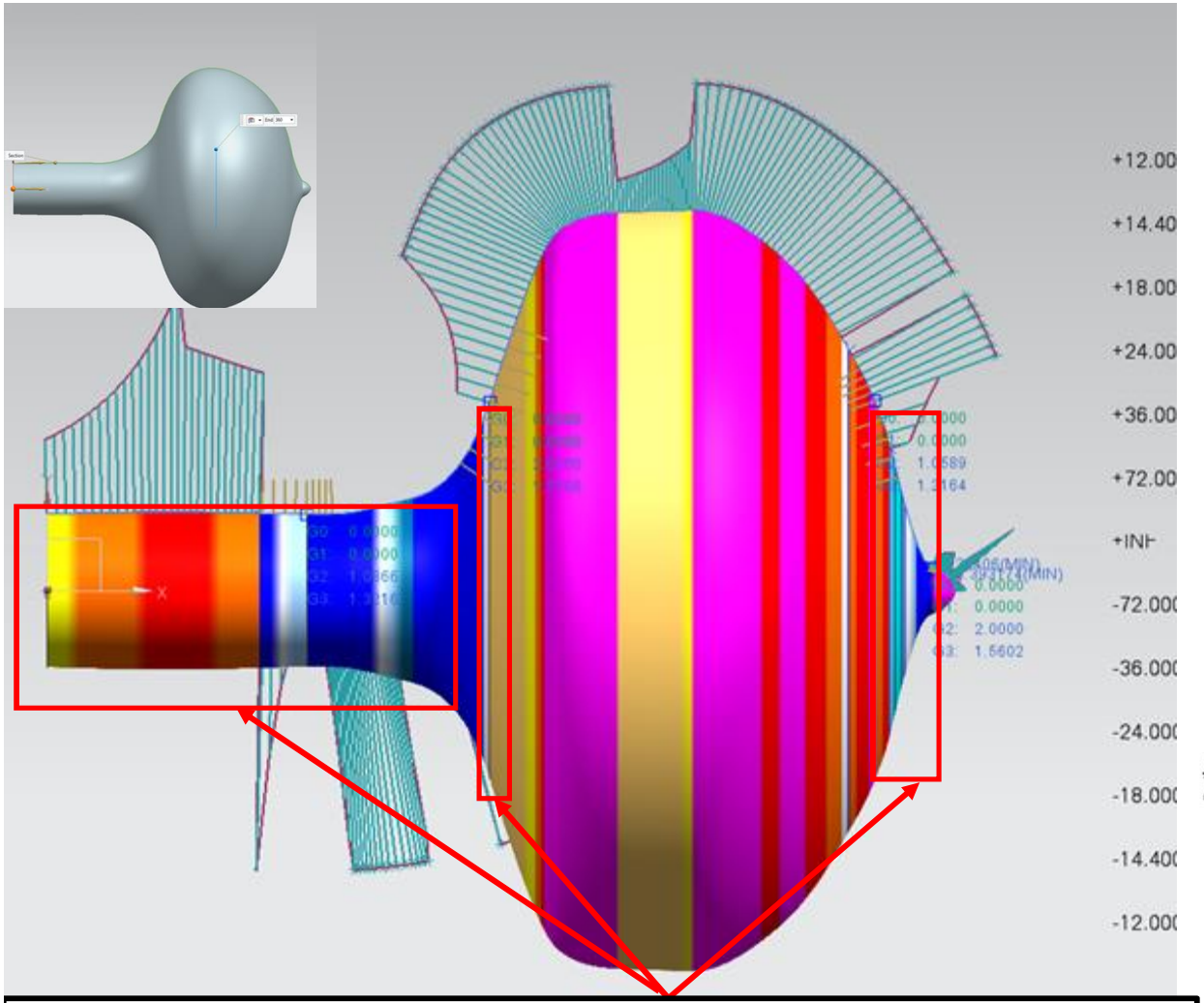
Face Analysis – Reflection Lines

Colour map identifies discontinuity problem:



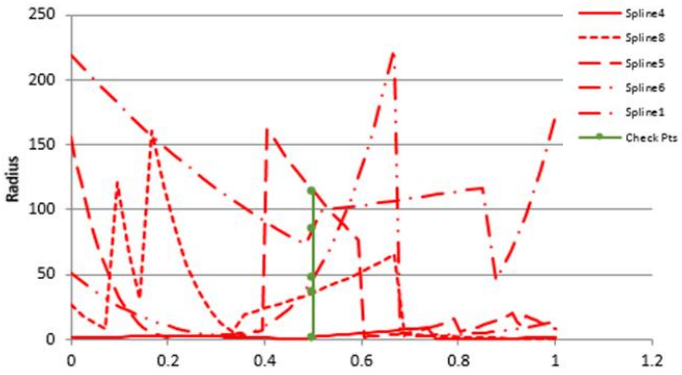
Face Analysis using the Gaussian Radius of curvature

Colour map also identifies fairing problem - the images below show a colour map and the Gaussian radii of curvatures:



Fairing problem area and the effect on the surface features when not having smooth splines

Below shows the spinning top graphical representation of radii of curvatures versus the arc lengths of the splines. Ideally curvature radii should be constant to remove fairing problem.



Interrogation of Solids Presentation

Any questions?