



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

FACE Research Colloquium

Dec 13th 2017

Prof Kelvin E Donne
Professorial Fellow UWTSD
Kelvin.donne@uwtsd.ac.uk

Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives



www.uwtsd.ac.uk

Structure of Talk

- Composite Materials research
- Auto windscreen impact research
- Usability analysis in Product Engineering Design
- Light-Tissue Interaction research

Acknowledgements:

PhD students:

Dr Gwen Daniel (Research Manager @ Belron Ltd

Dr Arnaud Marotin (SL @ UWTSD)

Dr Tim Bashford (SL @ UWTSD)

Dr Ross Head SL @UWTSD

Dr Derek Greenway Consultant

Dr Rob Trow (Energist Ltd)

Dr Mike Kiernan, CSO: Cyden Ltd

Dr Nick van der Beek, MD, ZBC Multicare Ltd, Hilversum

Dr Pavan Addepalli , Research Fellow, Cranfield University

Dr Paul Curnick ,Lecturer Coleg y Cymmoedd

Dr Godfrey Town, Consultant

Dr Andrew Abrons

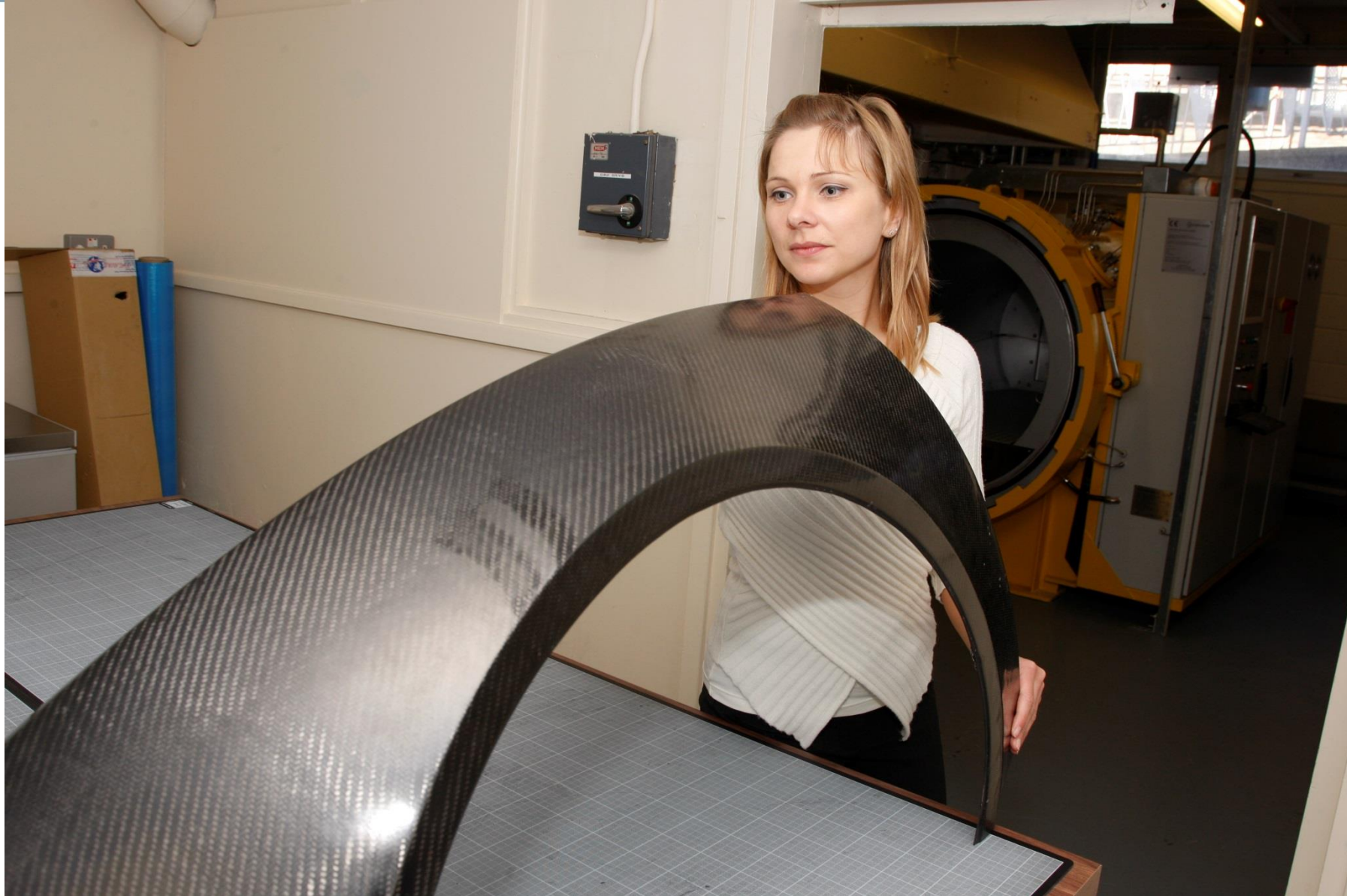
Also: Dr Ala Al-Hussany Senior Research Fellow @ UWTSD

Richard Thomas , Provost Bradford College

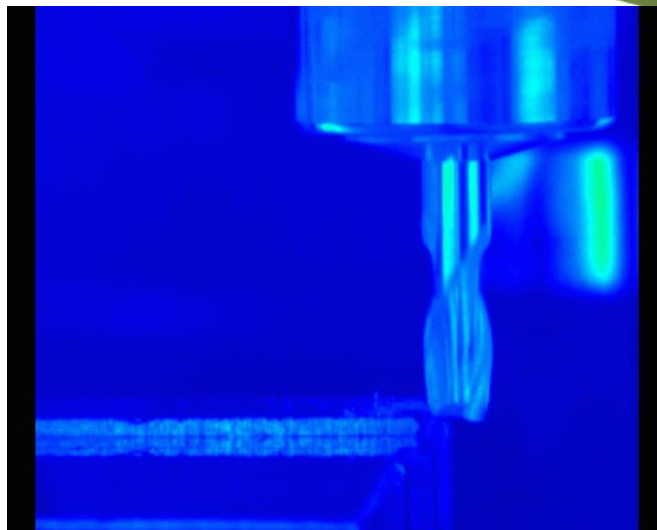
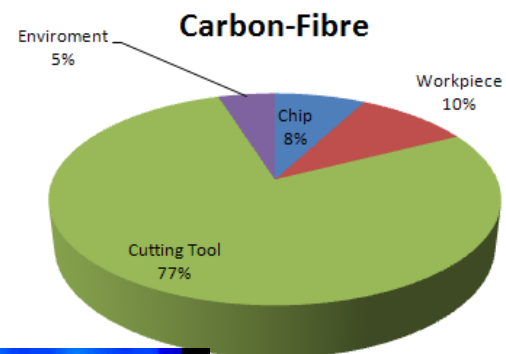
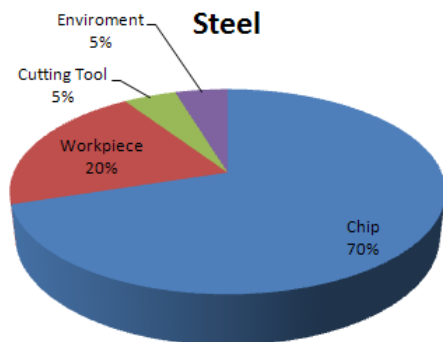
Composite Materials Research

- No Man is an Island (Donne early 17th C)
- Linking the CAD and CAM islands creates a whole greater than the sum of the parts.





Thermography in Composite Material Manufacture



Tooling for Milling of Composites (PC)



Carbide end Mill,
TiAlN Coated,
Three Flute, 30
degree helix



Polycrystalline
Diamond PCD
tool



Solid carbide router



CVD diamond coated end mill

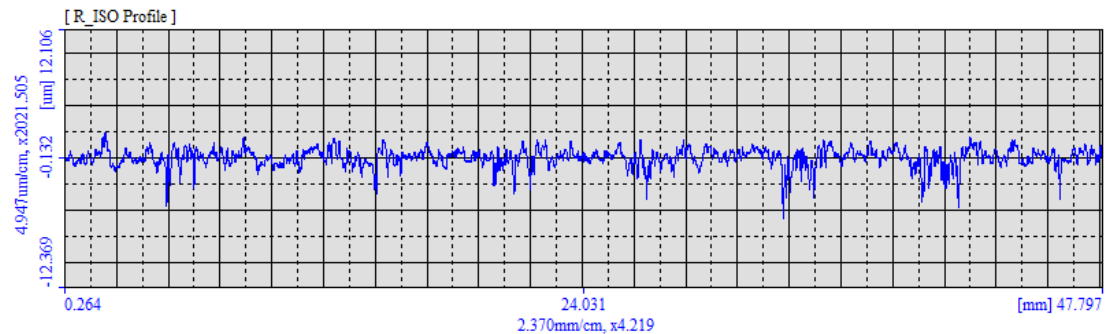
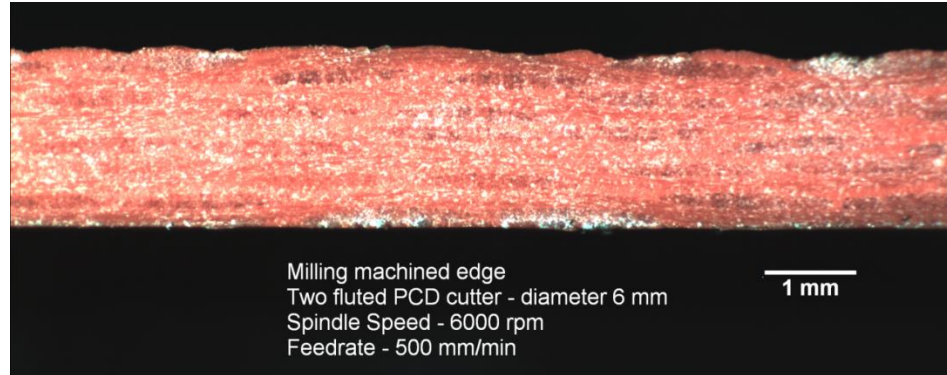


herringbone cutter

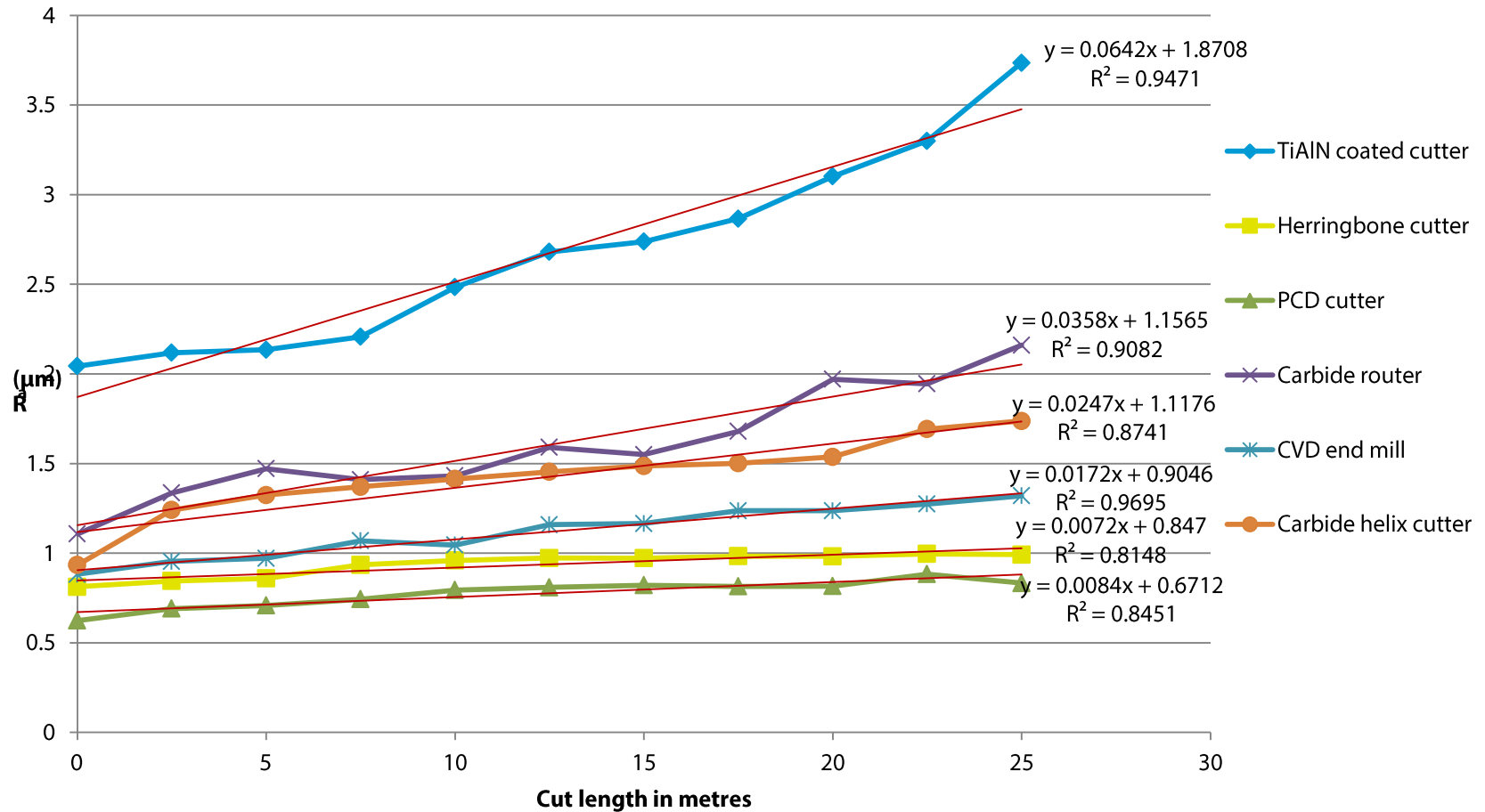


Solid carbide router

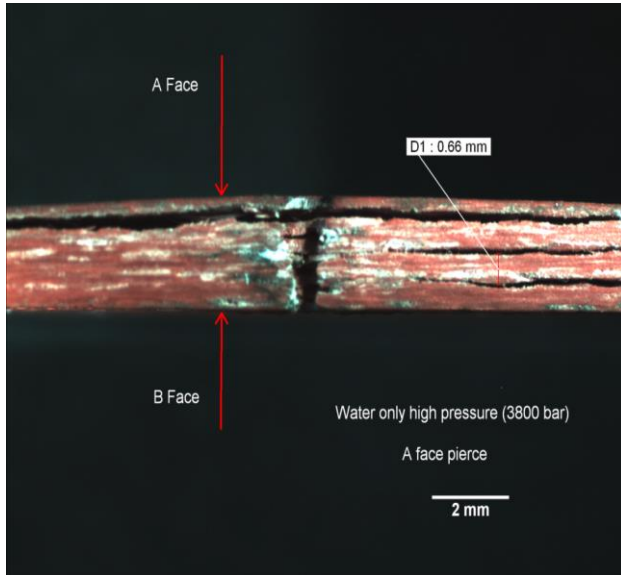
Measurement of surface roughness



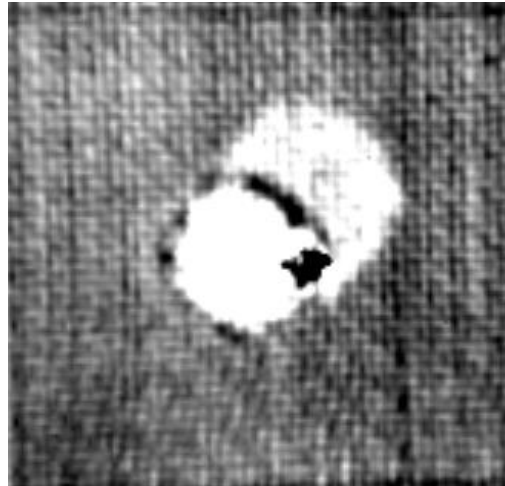
Degradation of surface roughness



Waterjet drilling of composites

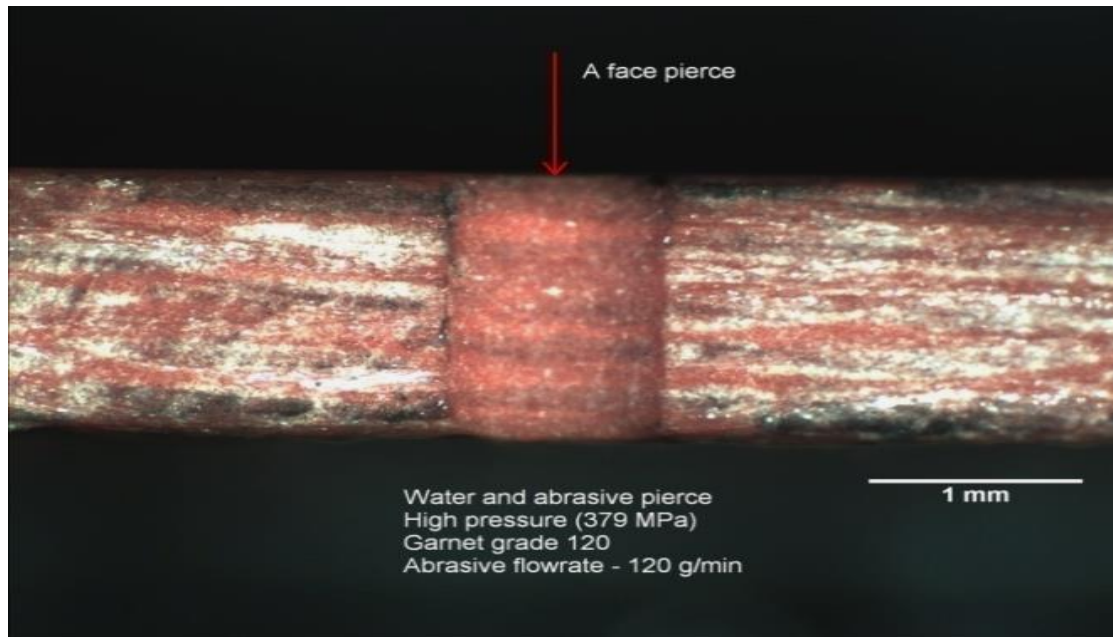


Water only

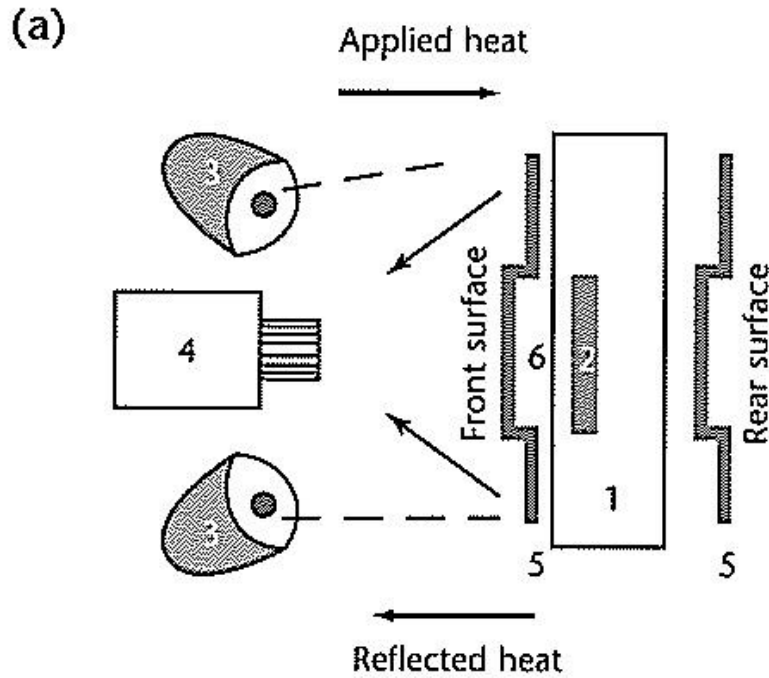


Thermograph of delamination produced by waterjet piercing at high pressure water only

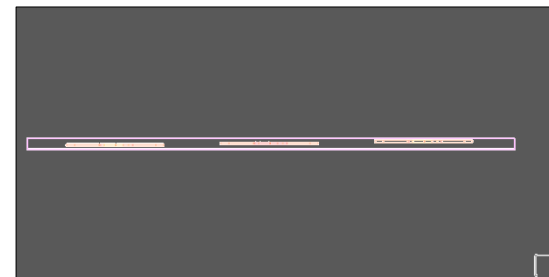
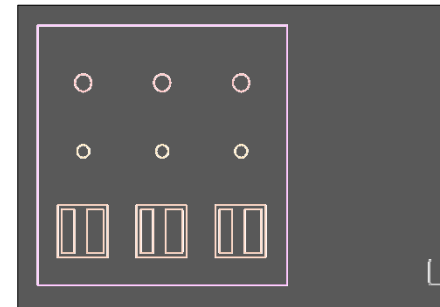
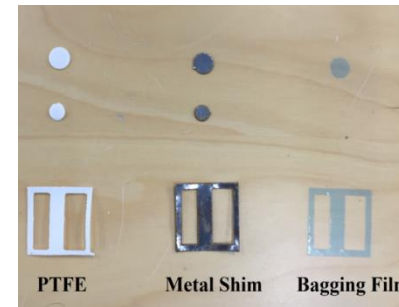
Addition of abrasive garnet to water

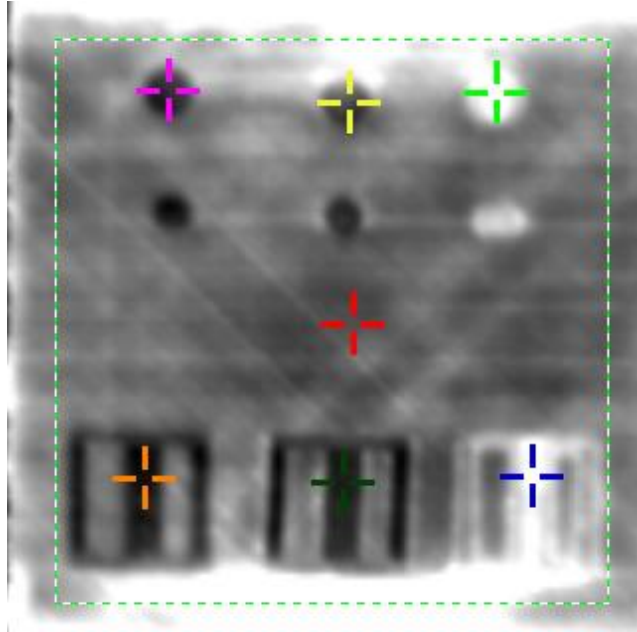


Detection of buried defects in CFRP using **Pulsed thermography**

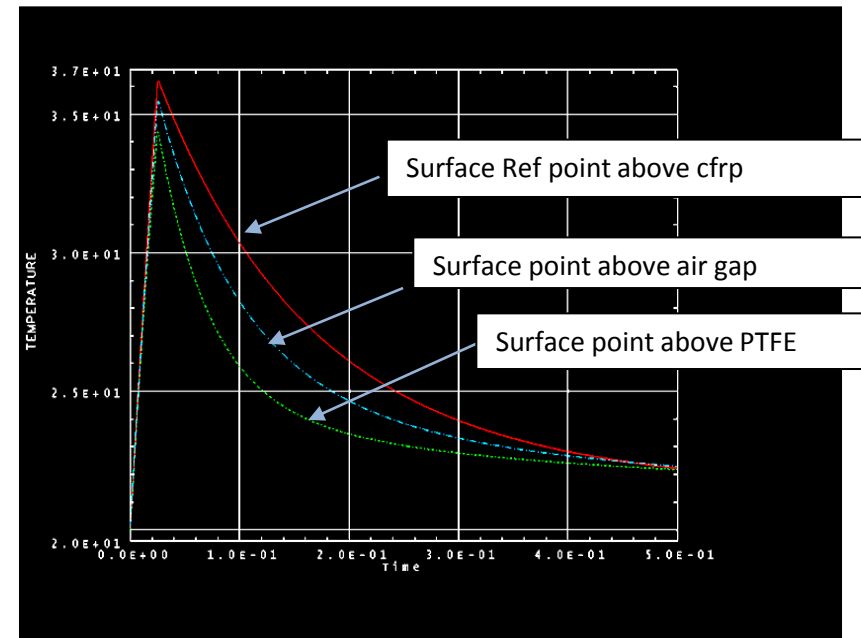


([Maldague, Beaudoin et al. 2001](#))

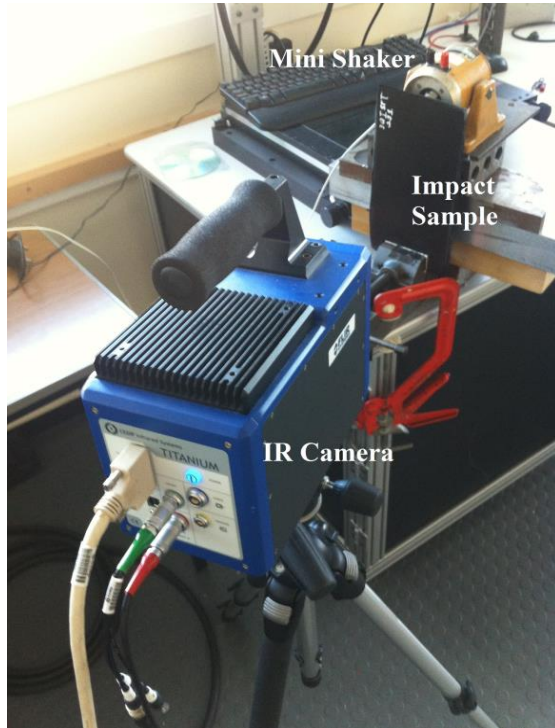




Surface temperature –time plots allow detection of sub-surface defects

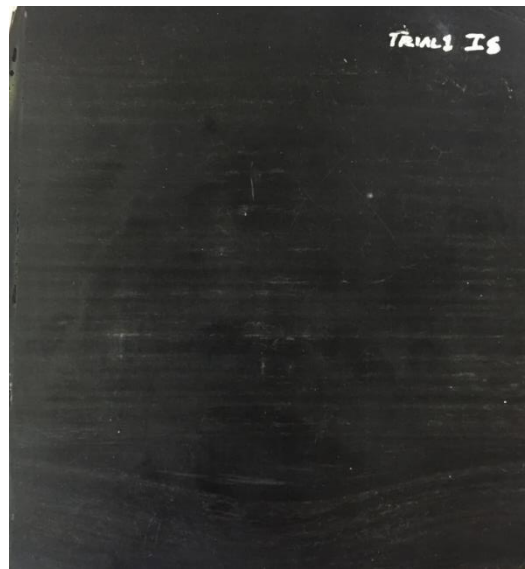


Lock-in Thermography to detect barely visible damage in CFRP (PA)

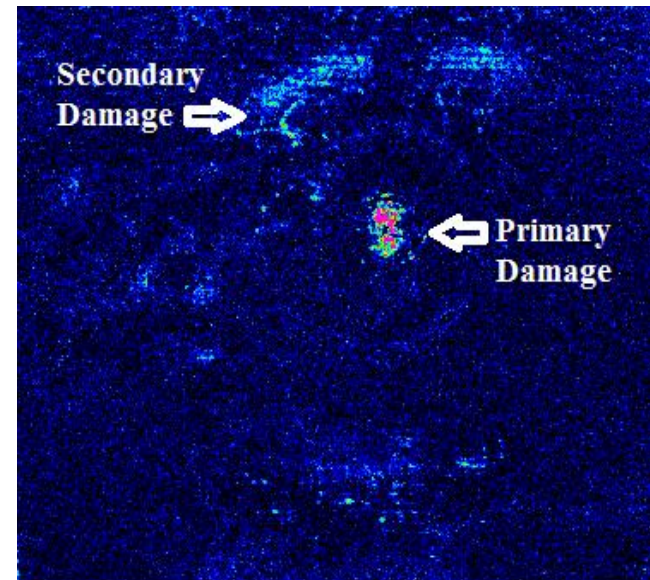


Sample excitation 10Hz,
25 Hz thermal sampling, synced

3 mm thick : $[0^\circ, 90^\circ, 0^\circ]_{2S}$.



Digital photograph



Thermogram after 50 s

Automotive Windscreen Research

- Two aspects:
 - The initial 'Chip' creation by stone impact , investigated through:
 - Ballistics experiments
 - Time dependent finite element analysis (ABAQUS EXPLICIT)
 - Chip to crack-off
 - FEA
 - Vibration machine

Typical Laminated windscreen

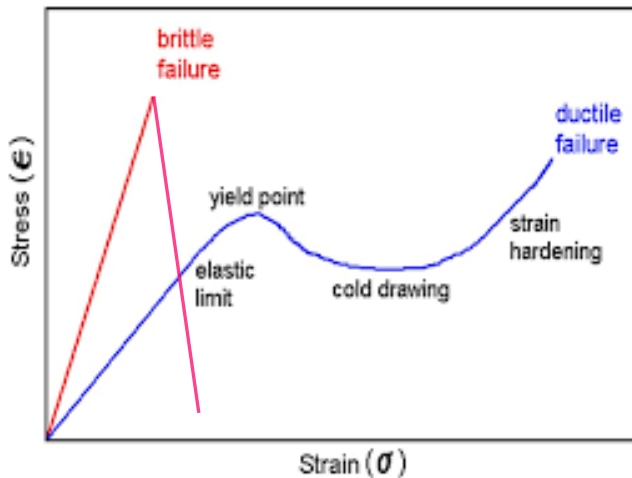
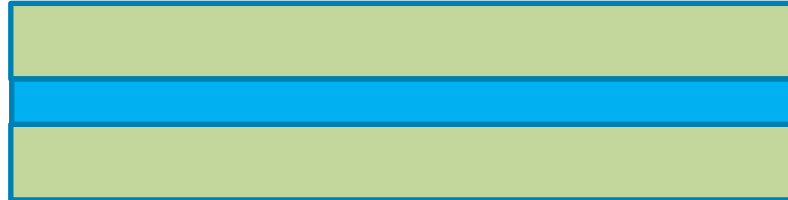
Soda- lime glass



PVB interlayer



Soda- lime glass

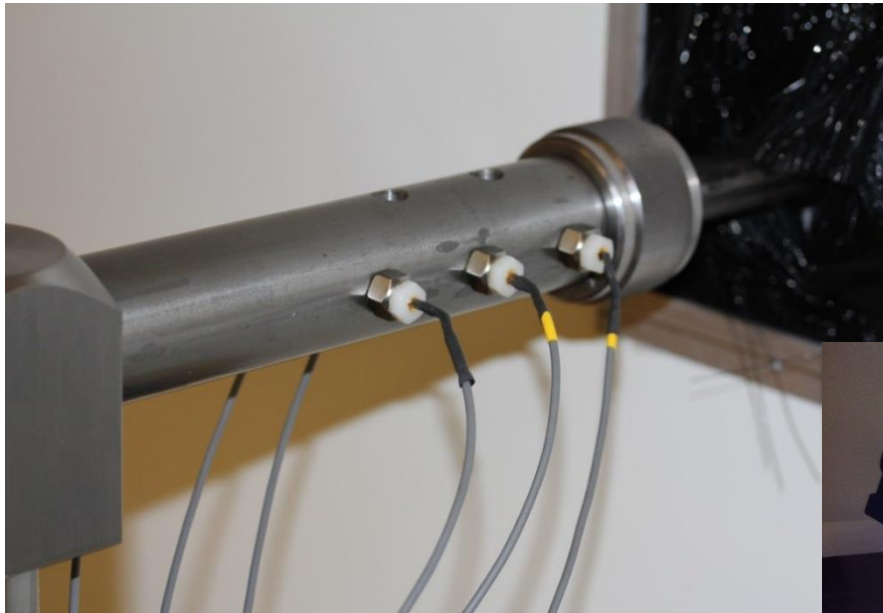


Gorilla glass



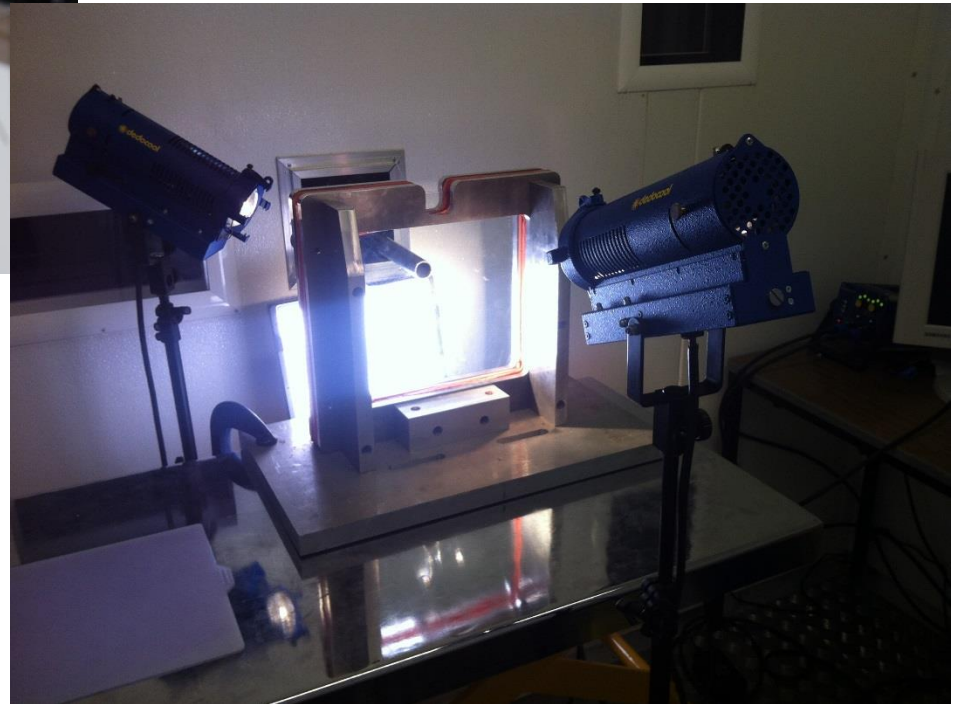
Ballistics facility



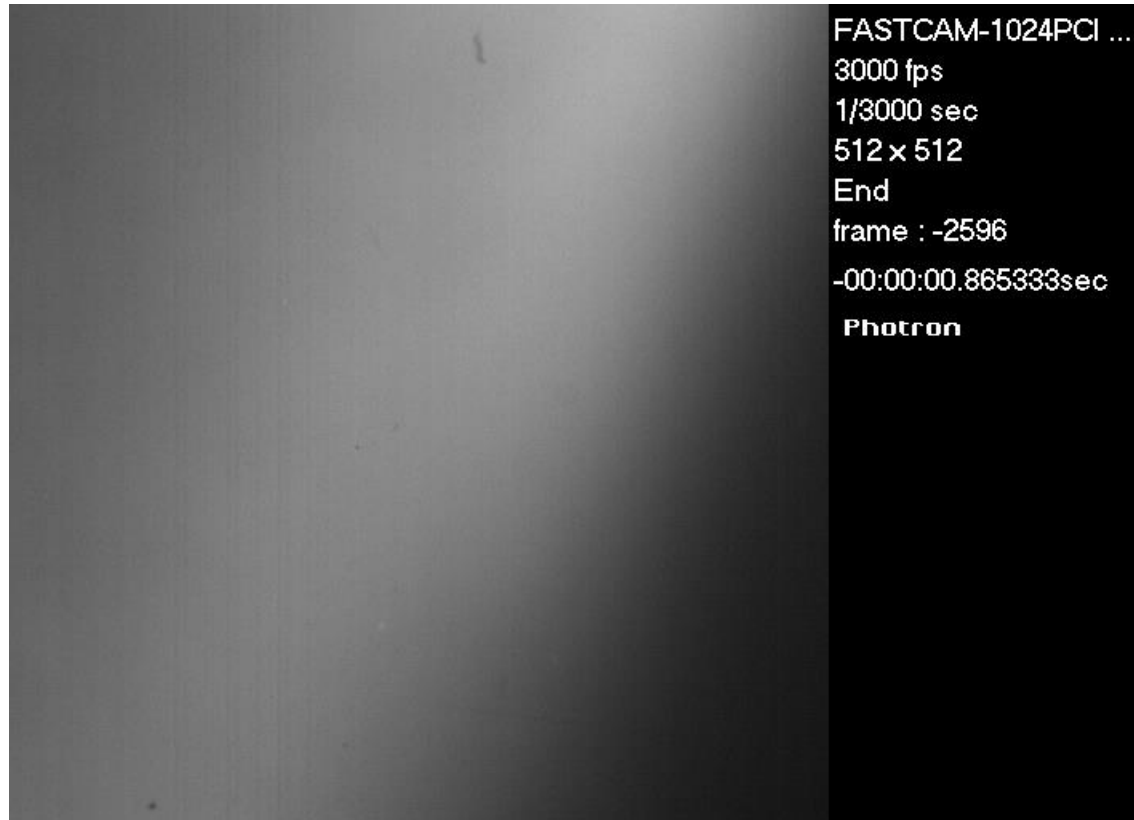


Time-of-flight

Target chamber :
-10C to 50C



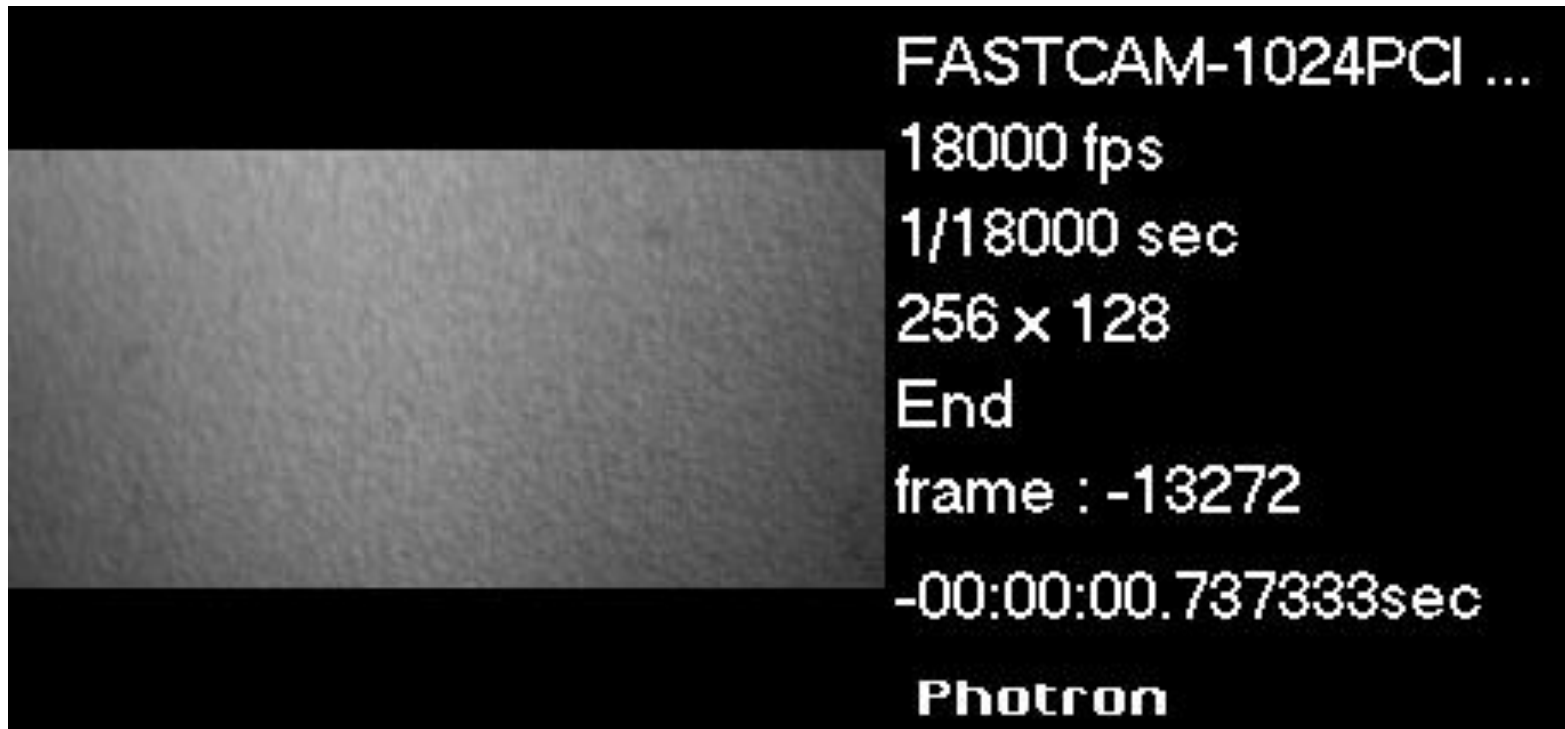
Ballistics experiments



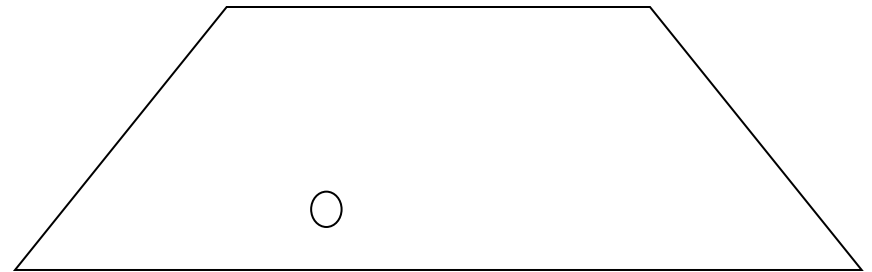
Note modes:

- Star
- Circumferential
- Bulls-eye

Sometimes no damage for same conditions! (Weibull and stone geom)



A typical windscreen chip



Location on windscreen

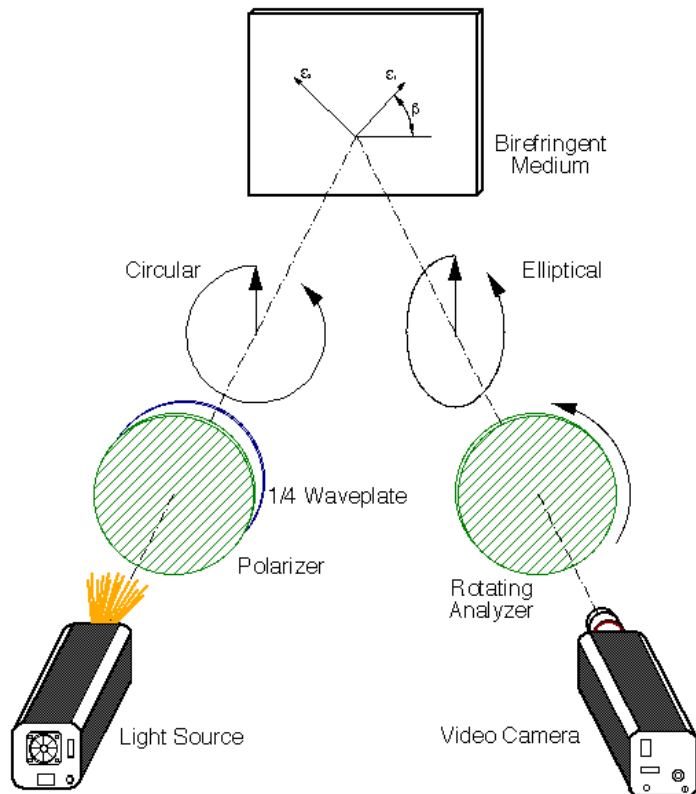
The BELRON Resin Injector



Experimental method

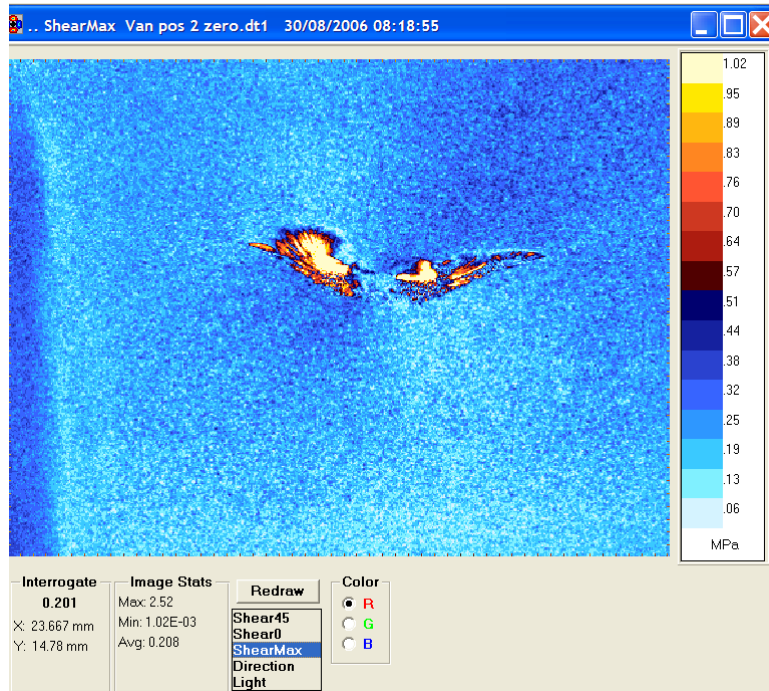
- Stress fields in chipped windscreens measured (in-vehicle) by photoelasticity prior to repair
- Windscreens repaired by resin-injection
- Stress fields measured again
- IR thermographic imaging used to map temperature distributions around chip

Photoelasticity equipment – schematic (Stress Photonics GFP 1200)

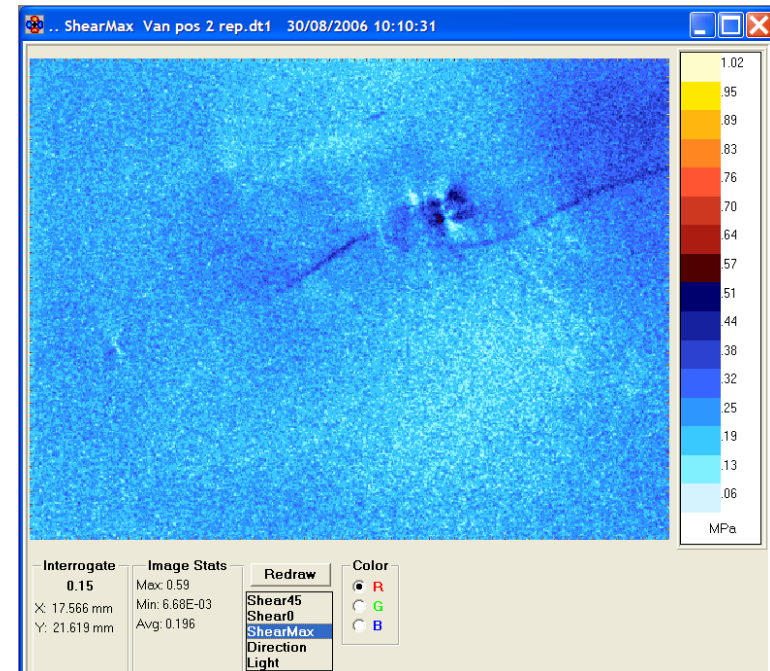


Polarimeter here shown
operating in reflection mode
(requiring birefringent coating)
but may also operate in transmission

Max stress reduced by over 75% after Belron repair



Before repair – max 2.52. MPa



After repair – max 0.59 MPa

Time-dependent FEA



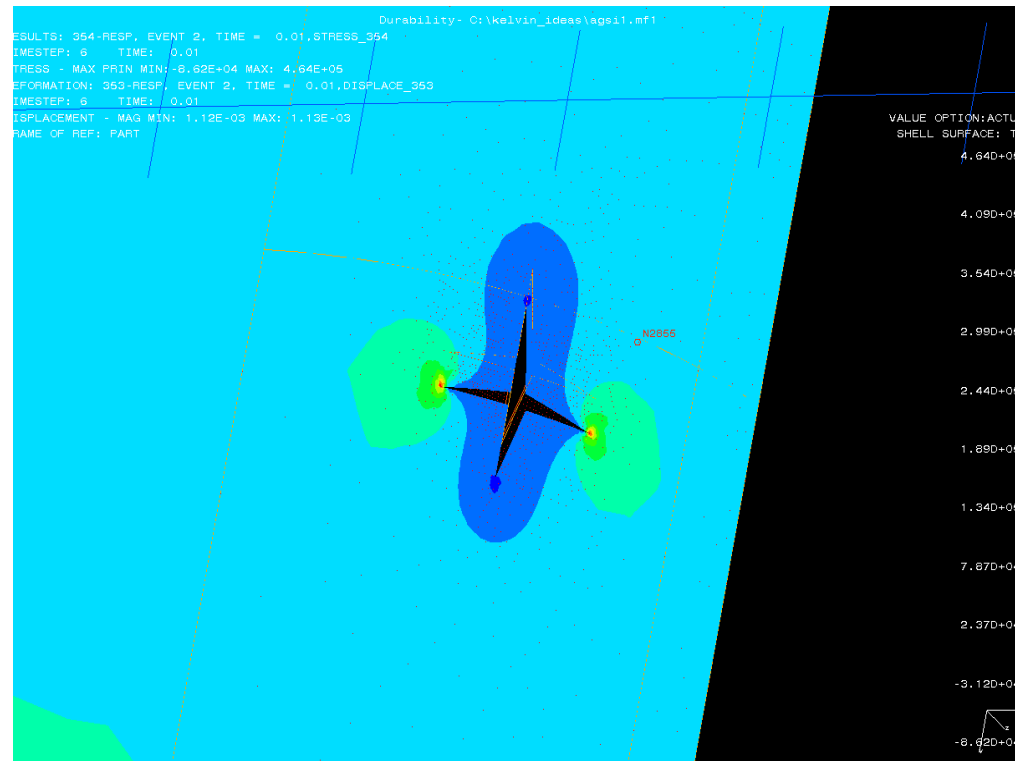
ONLY EXTERIOR GLASS
LAYER DISPLAYED
FOR CLARITY

Chip – to – full Crack

Primary causes:

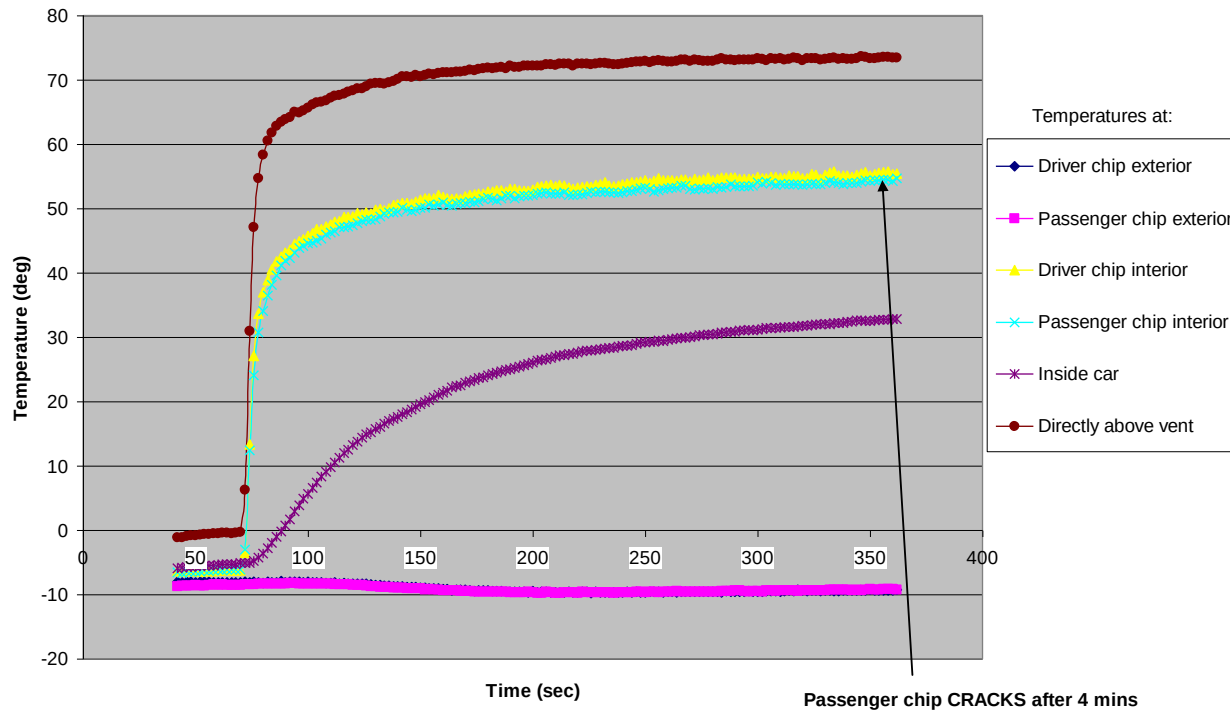
- Mechanical shock
- Transient thermal shock

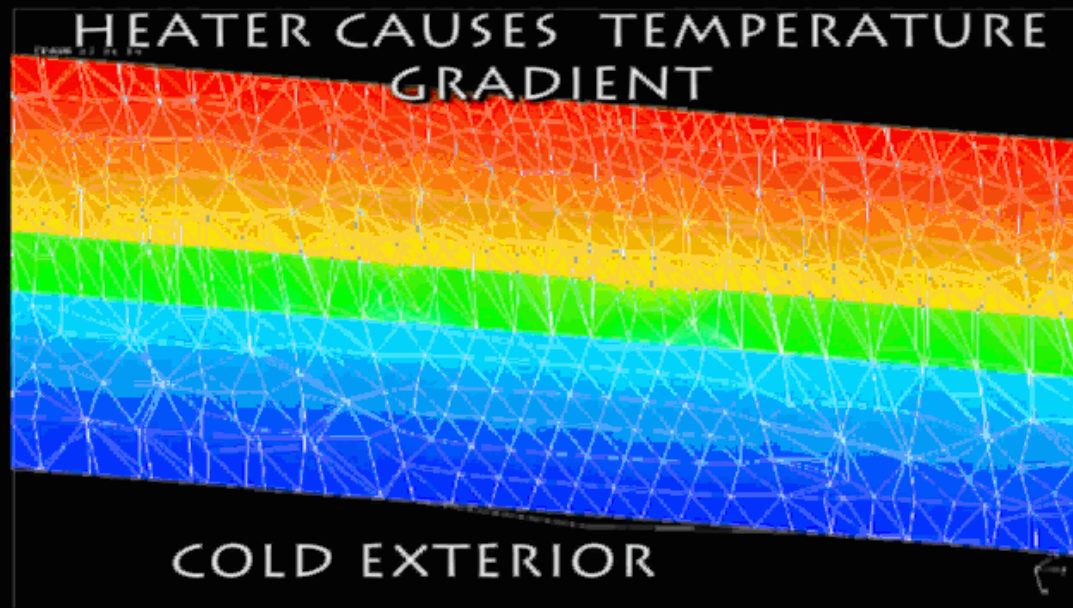
Stress due to 5g impulse on bottom edge

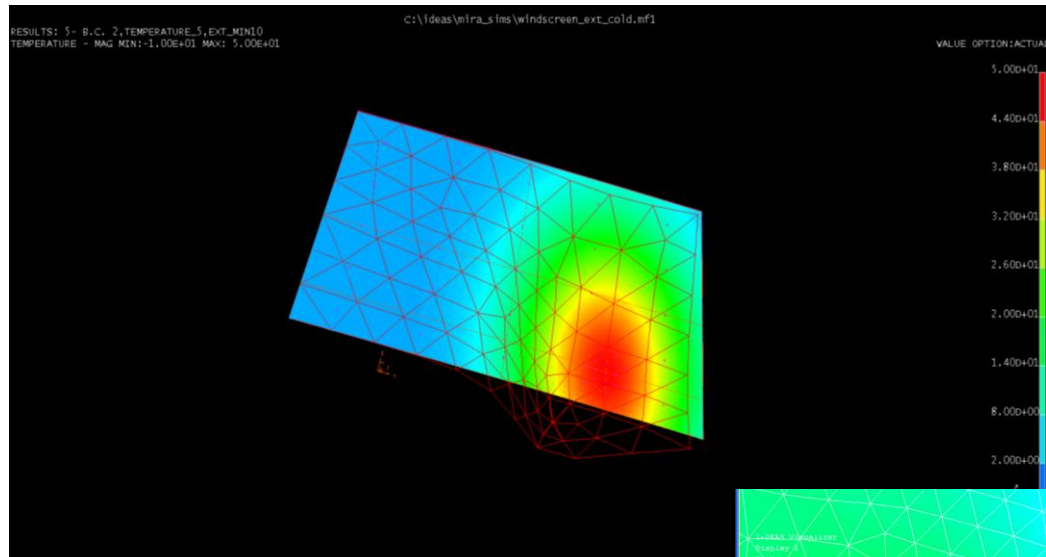


Thermal shock: fan heater on cold winter's day

Temperature rise - External temperature @ -10 degC
FORD FOCUS Ghia - LY 07 ERU

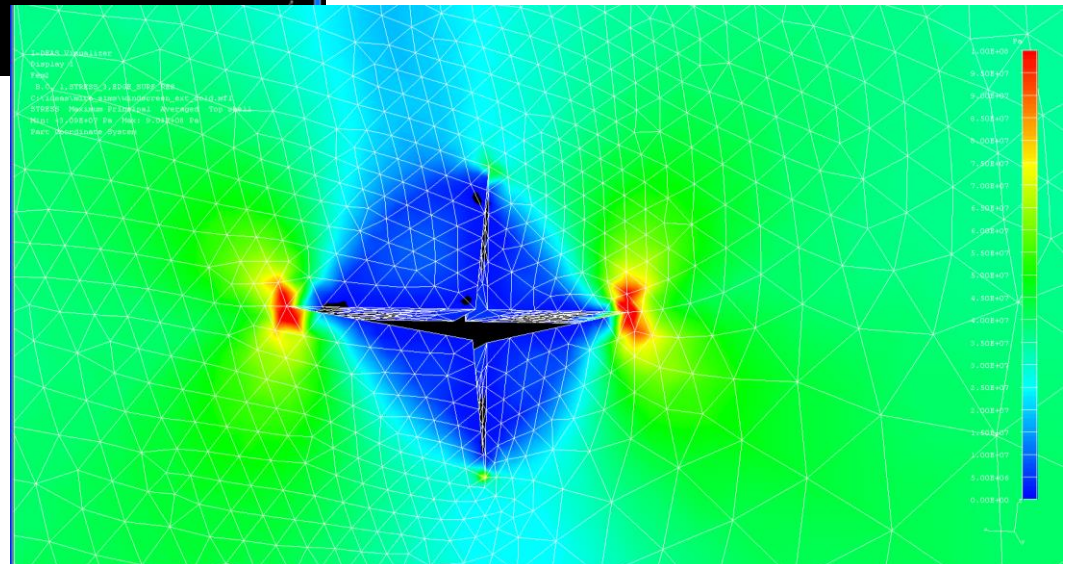


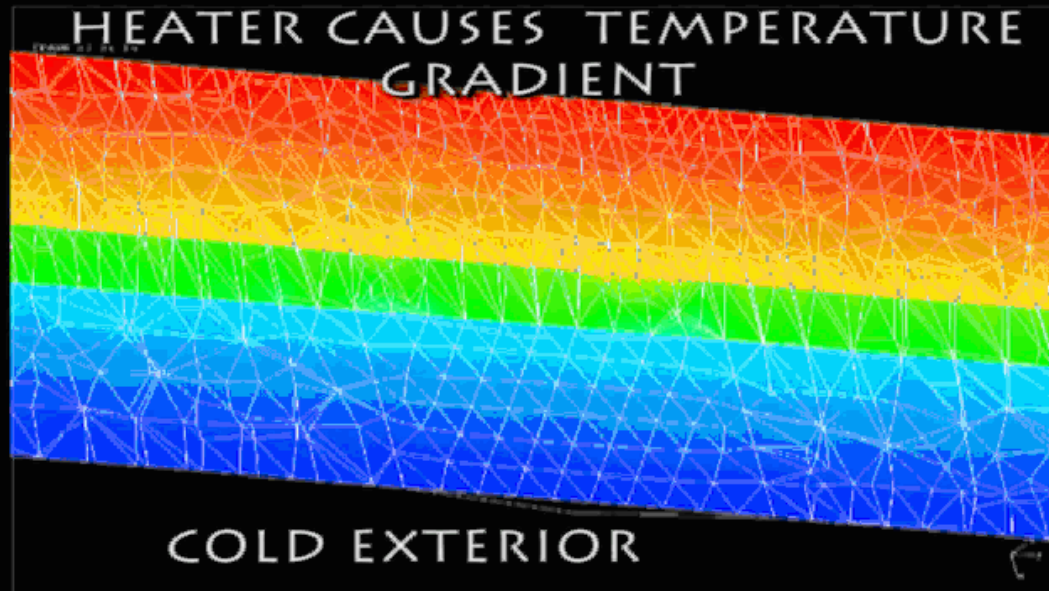




Gaussian heat flux on
interior windscreen

Resulting stress at chip tips



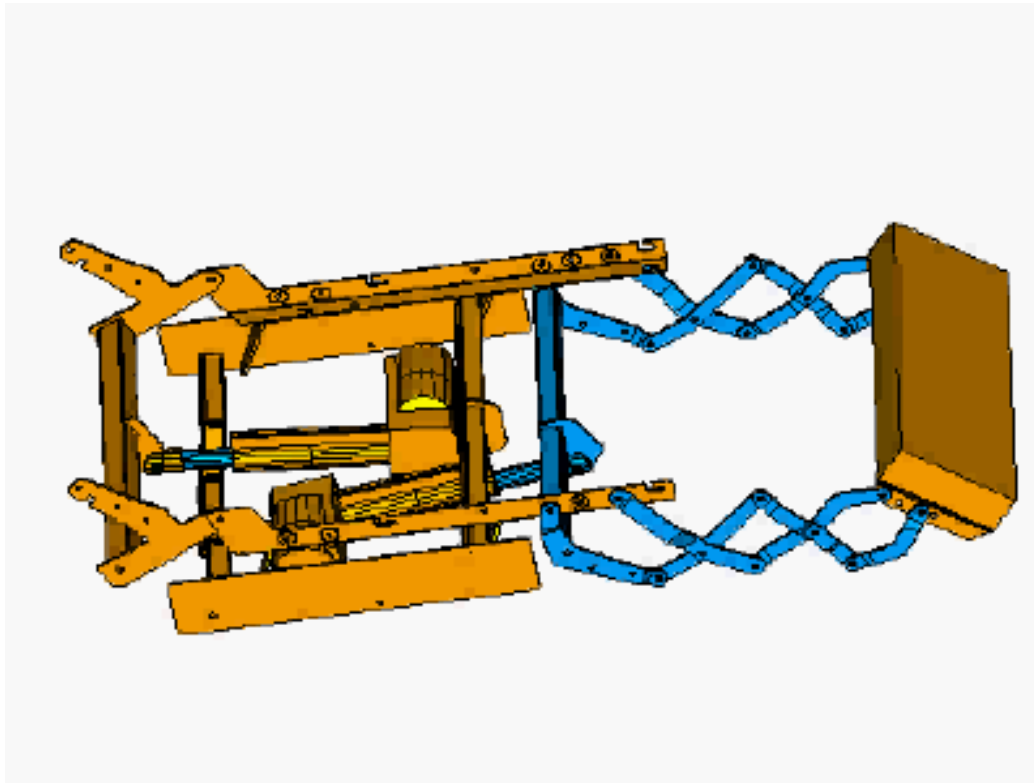


Usability Analysis

- Andrew Abrons PhD 1994 :
- Expert system for maintenance planning at Trostre
- Used well-established method for assessing user interaction with software environments

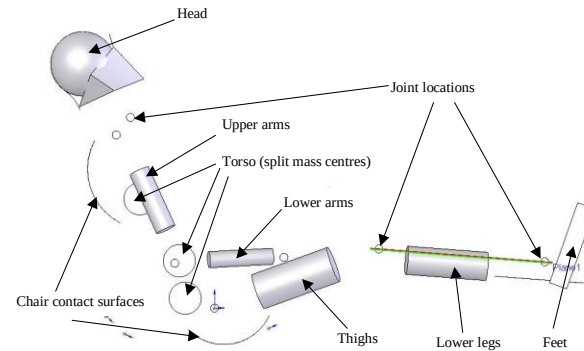
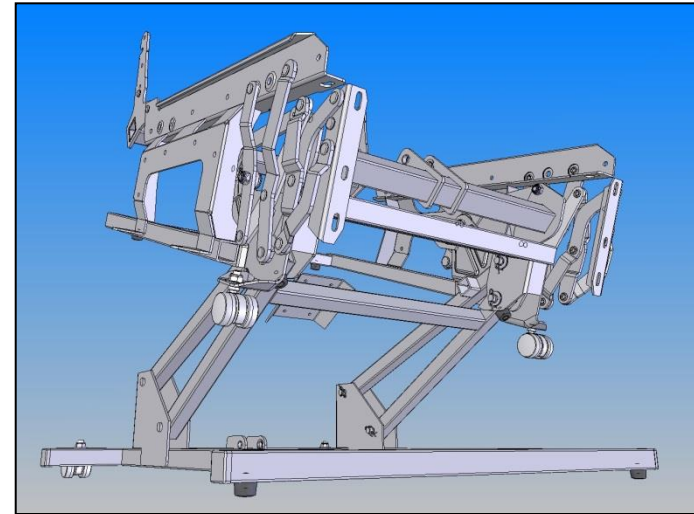
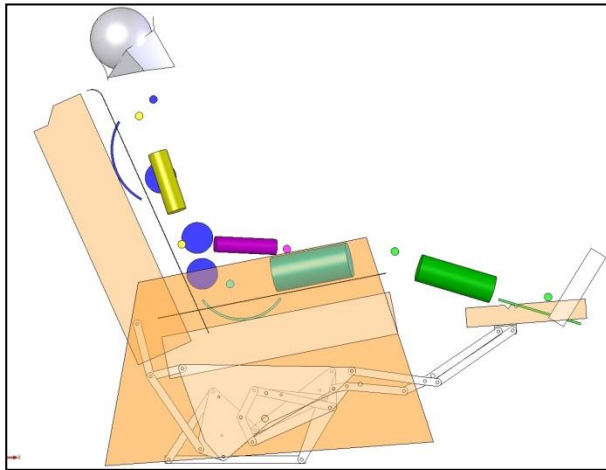
Usability Analysis in Product Engineering design (DG)

Design Factor analysis undertaken for action furniture design



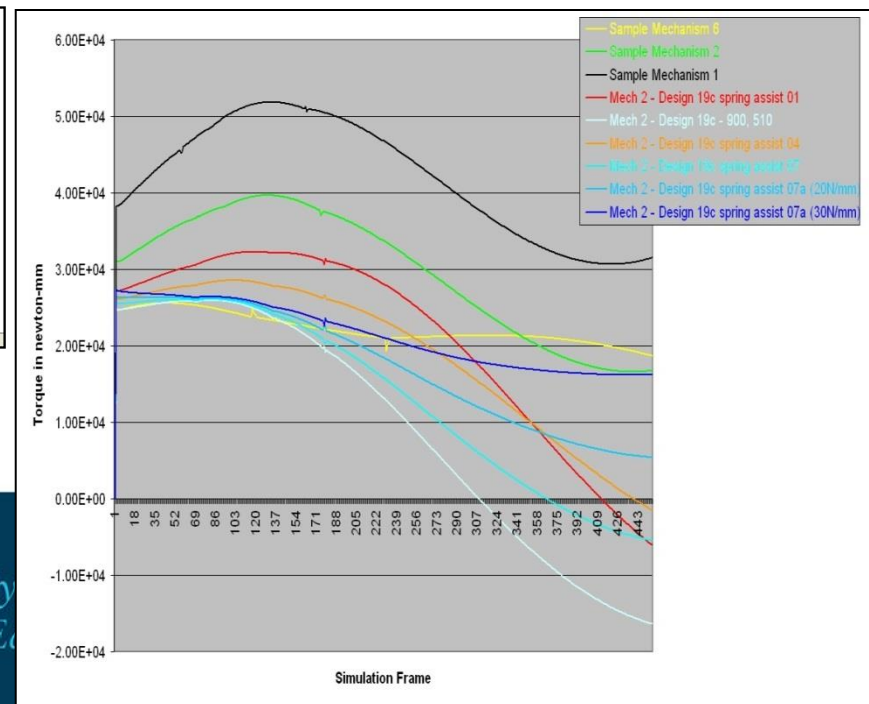
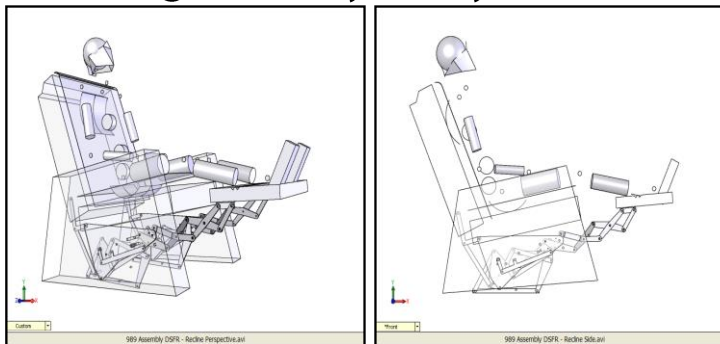
If a **virtual mannequin** is used in a mechanism simulation, the following values can be obtained:

- The reaction force values at joints for subsequent finite element analysis.
- The strength of actuator required to operate a motorised version.
- An indication of the effort required by the user to operate a manual version.

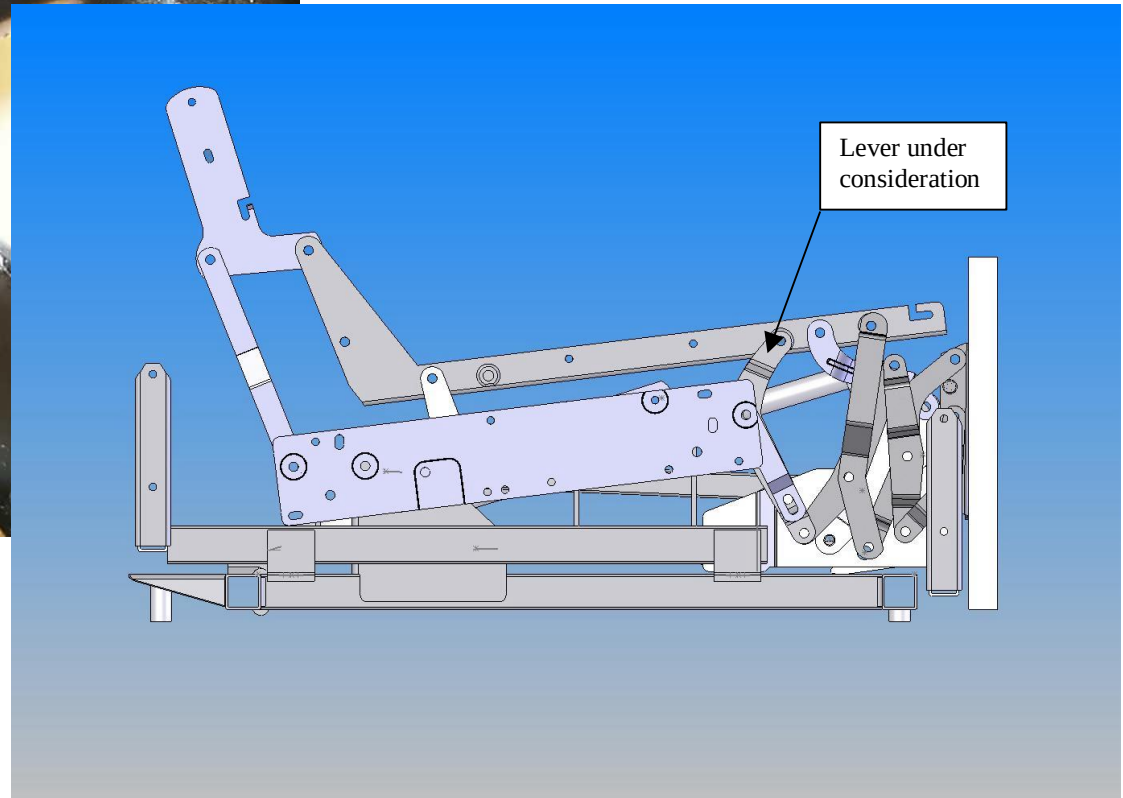


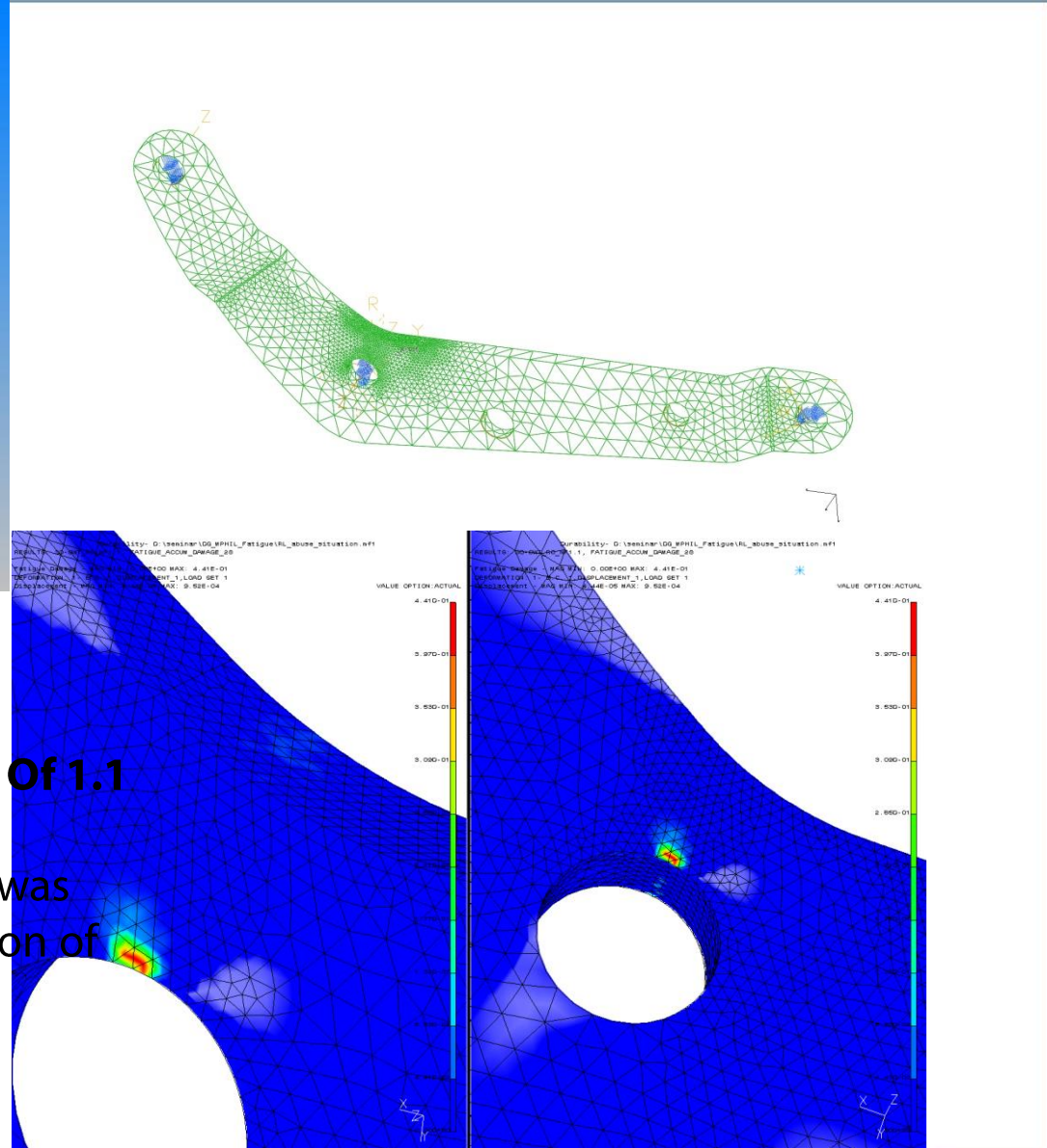
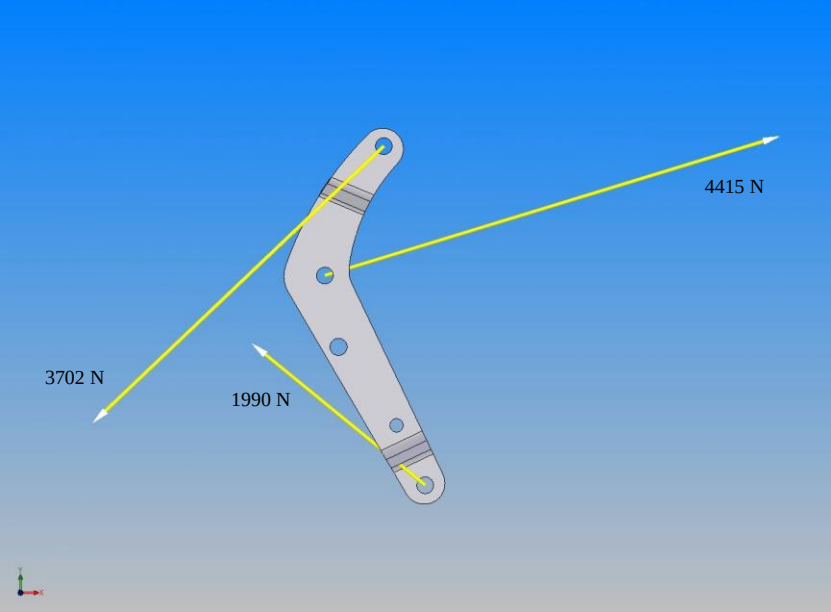
Mannequin Based Simulation

- Using the mannequin as a more active part of the simulation
 - Driving a manual system with the mannequin
 - Applying a 'motor' at the hip joint during the wall-hugger case study
- The torque required to operate the system is plotted for a number of benchmark designs
- New Design Brief: Concept designed using FEA and Rigid Body Dynamics but tested using Usability Analysis



Fatigue analysis also undertaken to simulate foot jamming abuse in motorised system





Smith-Watson-Topper, Ramberg-Osgood, But With A Notch Factor Of 1.1

A 10% increase in the notch factor was applied, which affects the application of Neuber's rule in the cyclic fatigue calculation

Usability Analysis of new prototype : statistical survey with 40 people

Initial survey identified Six Design Factors: S1,S2 S6, with relative weightings C1,C2... C6

1. It was easy to start reclining the backrest
2. It was easy to finish reclining the backrest
3. You were able to control the reclining motion
4. The reclined position was comfortable
5. It was easy to return to the upright position
6. You were able to control the return motion

$$U = \sum_{i=1}^6 C_i S_i$$

A 7 point Likert
questionnaire sampled 40
people's subjective opinion
on the new prototype
design against competitors

$$S_i = \frac{1}{7} \sum_{n=1}^N \frac{\text{each user's Likert response}}{\text{number of responses}}$$

Summary of S Values						
	DF1	DF2	DF3	DF4	DF5	DF6
Chair 1	0.673	0.681	0.722	0.890	0.722	0.747
Chair 2	0.490	0.471	0.567	0.752	0.645	0.694
Chair 3	0.641	0.660	0.710	0.845	0.620	0.629
Chair 4	0.894	0.857	0.870	0.886	0.869	0.869
Chair 5	0.788	0.815	0.865	0.833	0.898	0.873
Chair 6	0.845	0.840	0.710	0.727	0.672	0.667

DF1:Ease of starting the reclining
motion
DF2:Ease of completing the reclining
motion
DF3:'Controllability' of the reclining
motion
DF4:Reclined position comfort
DF5:Ease of returning to the upright
(TV) position
DF6:'Controllability' of the return
motion.

The usability function is defined as:

$$U = \sum_{i=1}^6 C_i S_i$$

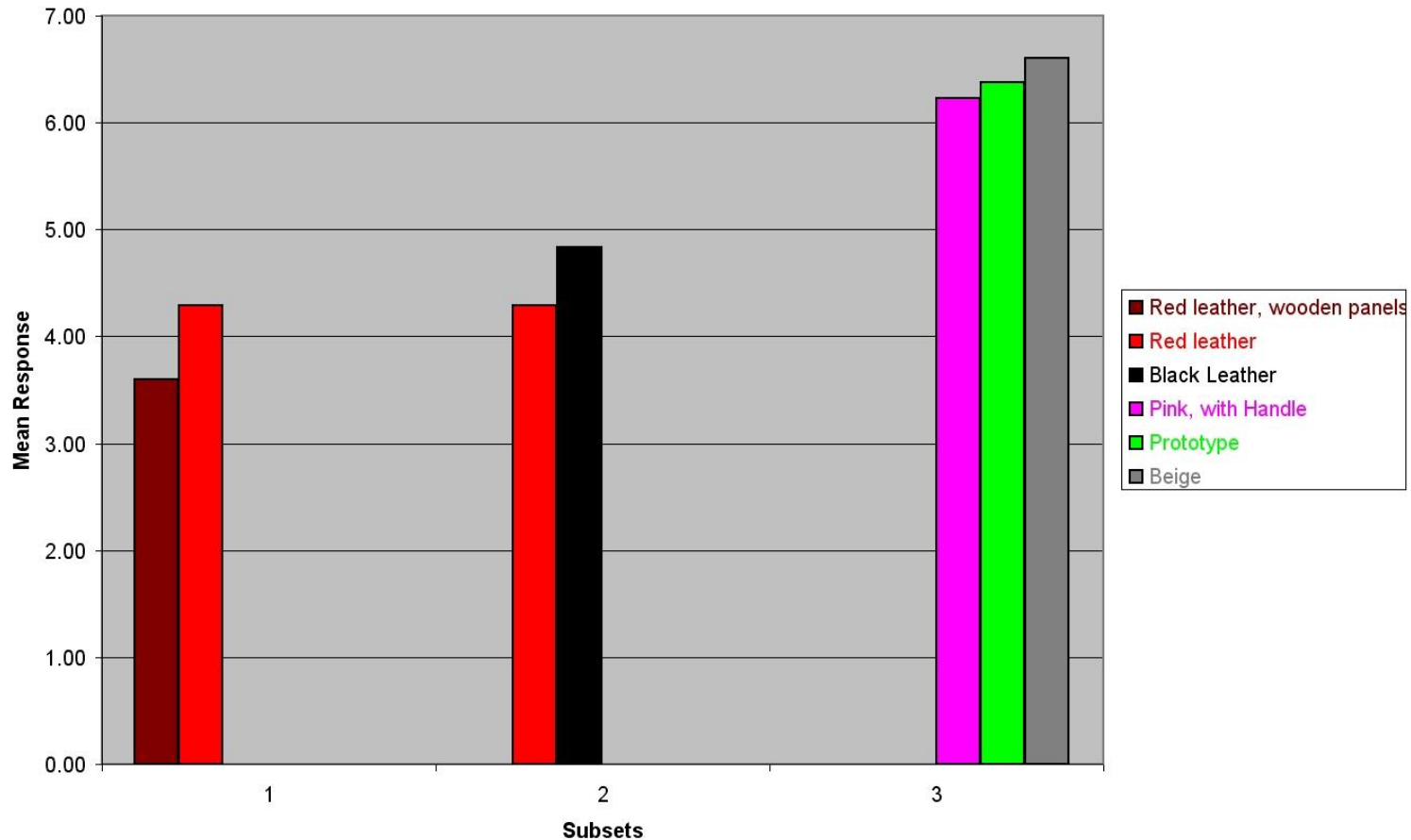
Where S_i ($i=1,6$) represents the average, normalised Likert response for the i^{th} design factor, and C_i ($i=1,6$) represents the weighting coefficients that control the relative influence each design factor has on the overall U-value.

The coefficients C_i represent the relative weighting or importance of each design factor, and are determined using **Thurstone's method of pair-wise comparisons**, as explained by **Gescheider**

C_1	0.1748
C_2	0.0905
C_3	0.1961
C_4	0.2723
C_5	0.1676
C_6	0.0987

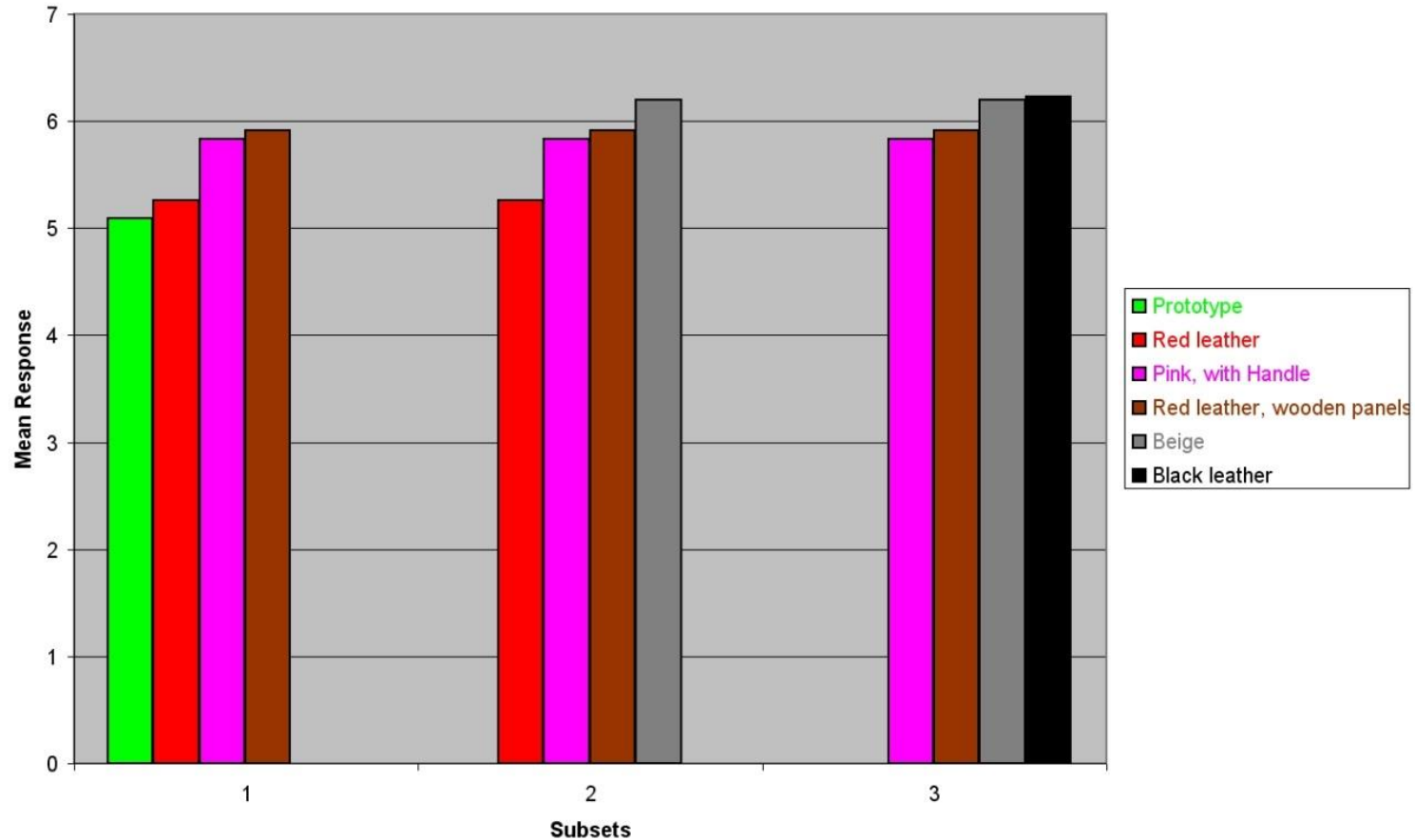
Statistically significant subsets of Prototype chair compared with 5 competitors : DF 1

Statement 1 - Homogenous Subsets for Tukey's B



Statistically significant subsets of Prototype chair compared with 5 competitors : DF 6

Statement 6 - Mean Subsets for Tamhane's T2



Usability Analysis to assess Representational modes of glass concepts (RH)

Stages in the product design development cycle

- Hand drawn sketches
- CAD rendered images
 - Rendered static image
 - Rendered animated image
 - Rendered using HDRI lighting
- Non-immersive VR viewed on screen
 - VR (interactive) dynamic model using Gouraud shading with material texture
 - VR (stereoscopic) dynamic
- Traditional RP techniques
- Hand made "one off" prototype
- A novel production technique for glass prototypes using graphite moulds



A concept will be assessed on 3 levels of physical and cognitive interaction:

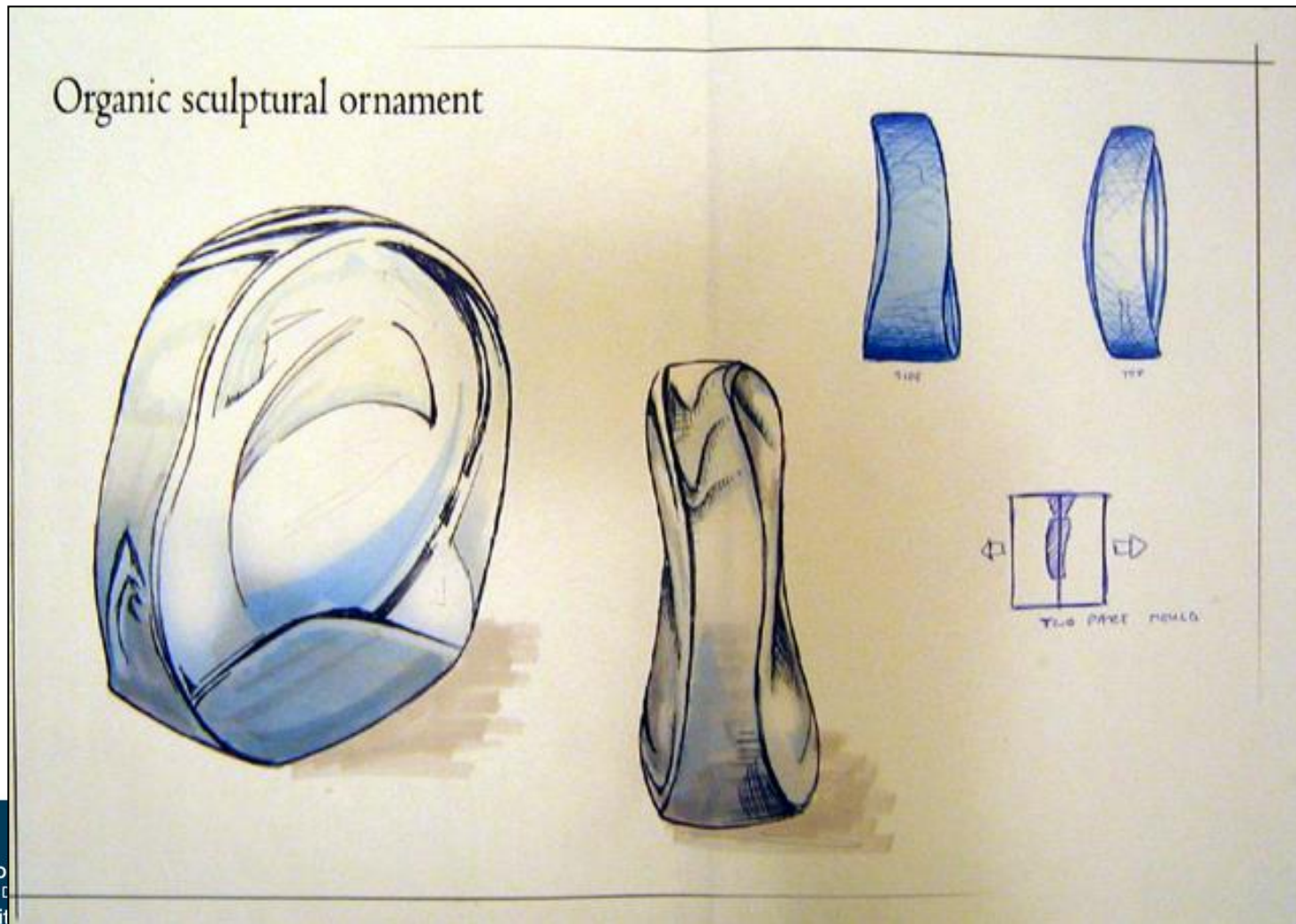
- **Denotative meaning-** immediate tangible response to its physical characteristics, the way it looks, its form and product recognition.
- **Connotative meaning-** including the function of the product, the benefits it holds over a competitive product.
- **Symbolic association-** the semantic reaction to a product, an intangible response to the emotion or symbolism portrayed by a product (Finn 1985)

However, little is known about the end-user emotional response to a product concept depicted by computer based representation compared with traditional product representations

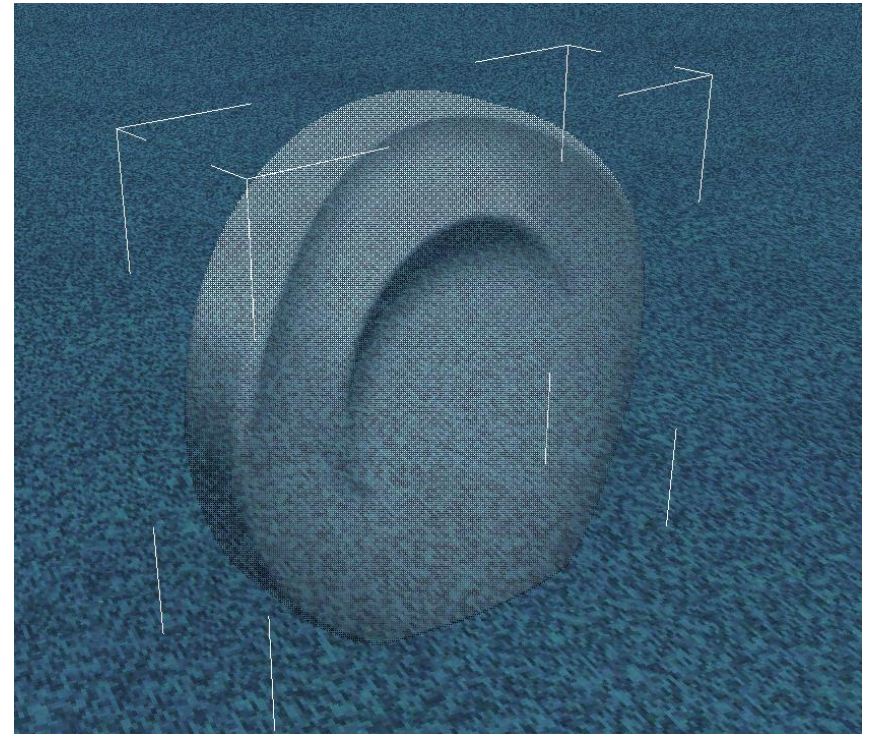
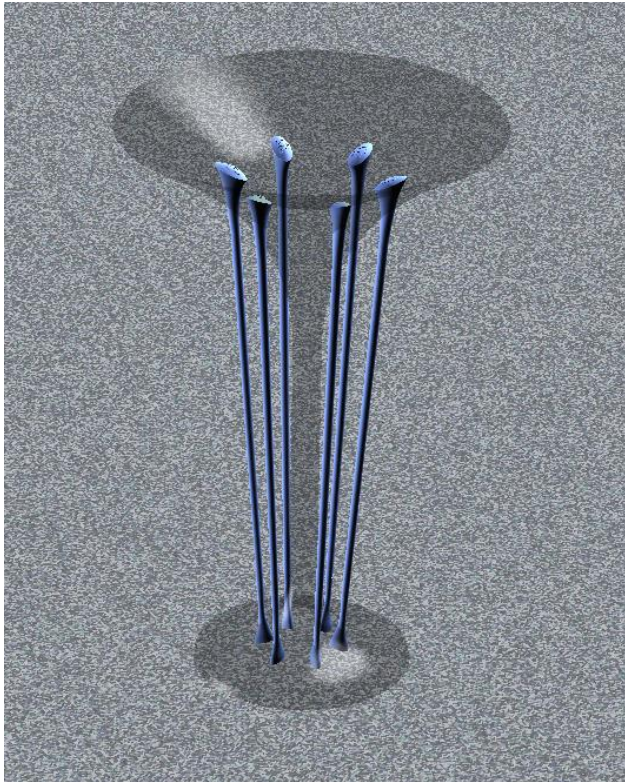
A range of virtual and physical prototypes have been investigated for their ability to convey glass concept design intent. These include:

- **Sketching**
- **Virtual reality Gouraud shading**
- **Virtual reality Stereoscopic Gouraud shading**
- **Virtual reality photorealistic static render**
- **Virtual reality photorealistic animated render**
- **Stereolithography rapid prototype**
- **Actual glass prototype, derived from digital design data.**

Sketch representation



Gouraud shading VR



Stereo Gouraud shading



Photorealistic rendering



These images are produced
using
Maya and 3D Studio Max.



Photorealistic animations

- It is also possible to create 3D photorealistic animations
- The aim is to enhance understanding of the product by showing 360° around the product.



Rapid Prototyping

- Using a Stereolithography rapid prototyping machine we are able to produce accurate, tangible 3D models in a short space of time.
- These can then be used to create silicone mould tools.
- From this we can produce castings in clear ABS plastic as a simulation of a glass product.

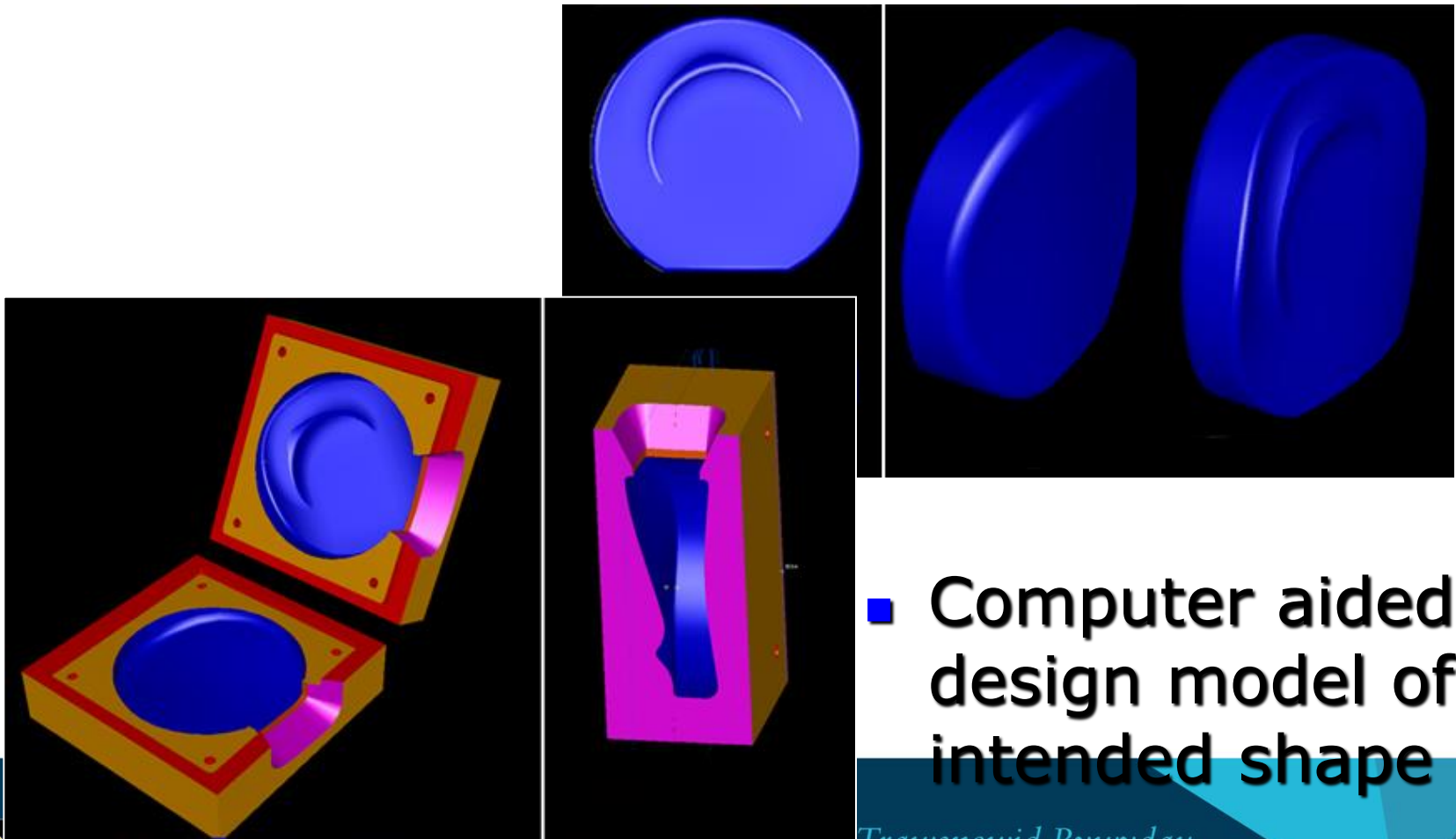


CAD-CAM cycle for glass ornament using graphite moulds

Conceptualised
in ALIAS



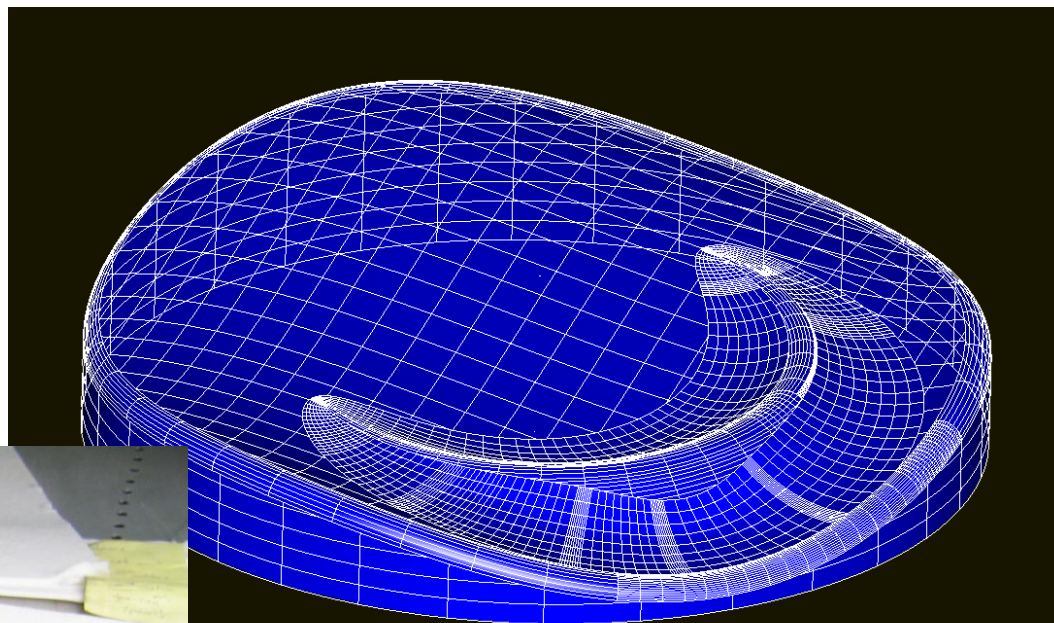
CAD model from which mould is machined

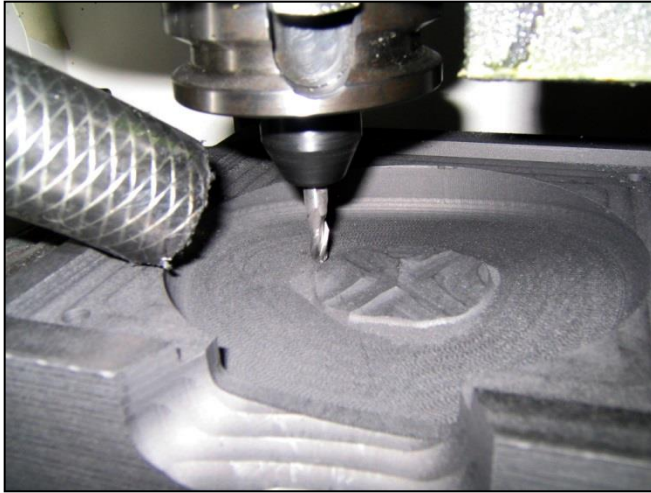


- Computer aided design model of intended shape



CAM generation of graphite moulds





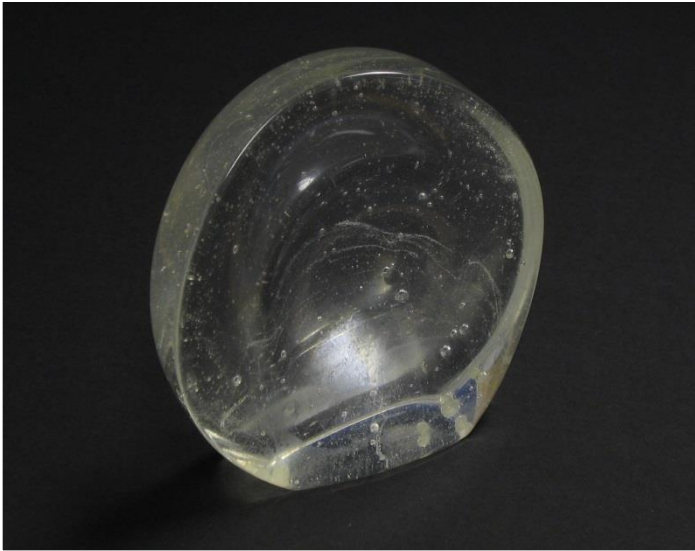
- CNC high precision moulds
- Highly polished for perfect surface finish
- Cast in an inert environment to prevent graphite oxidization
- Argon gas is used to fill a stainless steel container, within which the casting process takes place.



Graphite casting in an oxygen free kiln



Graphite casting/slumping in an oxygen free environment



Above: a solid cast sculptural organic ornament made using a 2 part graphite mould.

Below: a concept salad bowl developed for Jorn Uzten with Rodney Bender, slumped using graphite moulding techniques.



Design Factors considered covered the following categories:

- **Function**
- **Aesthetics**
- **Material choice**
- **Intended use**
- **Dimensional considerations**
- **Contextual circumstance or positioning**
- **Product semantics**

Statistical analysis

- Definition of Usefulness function;
- $$U = \sum_{i=1}^4 C_i S_i$$
- Where S_i $i=1,4$ are the design attributes
 - Form
 - Function
 - Scale
 - Material
- And C_i are the weighting coefficients determined by Geschieder's Psychophysical principle.
- 43 interviewees gave values for S_i ; non-parametric analysis in SPSS (Kruskal-Wallis and Mann-Whitney tests)

Typical output from SPSS nicely categorises each Representational Mode in groups of similar Statistical Significance.

M_1

Tukey B^a

Group	N	Subset for alpha = .05			
		1	2	3	4
GOURAUD VIEWING	43	3.42			
SKETCH	43		4.65		
STEREO VIEWING	43		4.77		
RAPID PROTOTYPE	43			5.79	
STATIC RENDER	43			6.02	
ANIMATED RENDER	43			6.23	
GLASS PROTOTYPE	43				6.84

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 43.000.

Usability analysis results for Utzon Salad Bowl

Utzon bowl			
Mode of representation	Normalised average		Usefulness Coefficient
Sketch	Aesthetics	0.52	0.48
	Function	0.5	
	Material	0.5	
	Scale	0.29	
Static render	Aesthetics	0.76	0.71
	Function	0.67	
	Material	0.78	
	Scale	0.41	
Animated render	Aesthetics	0.78	0.74
	Function	0.66	
	Material	0.83	
	Scale	0.47	
Gouraud shaded view	Aesthetics	0.35	0.32
	Function	0.46	
	Material	0.24	
	Scale	0.38	
Stereo view	Aesthetics	0.57	0.45
	Function	0.52	
	Material	0.33	
	Scale	0.36	
Glass prototype	Aesthetics	0.95	0.95
	Function	0.91	
	Material	0.96	
	Scale	0.96	

Conclusions from Hypothesis testing

- Animated rendered imagery is considered to be the most Useful method of representation.
- Physical prototypes score highly on form and scale, but occasionally low for material and function.
- Handmade glass suffers from lack of dimensional accuracy.
- RP suffers from poor material representation.
- Graphite moulding is considered successful although remains an experimental process.

Light Tissue Interaction (MK, GD, GT, AM, TB)

Therapeutic Context

- Light-based medical devices for:
 - Hair depilation
 - Port Wine Stains
 - Skin rejuvenation
 - Acne
 - Reduction/elimination of tumours e.g. Photodynamic Therapy (PDT)

Diagnostic Context

- Fluorescence techniques for early detection of Basal Cell Carcinomas (BCC)

Philosophical approach

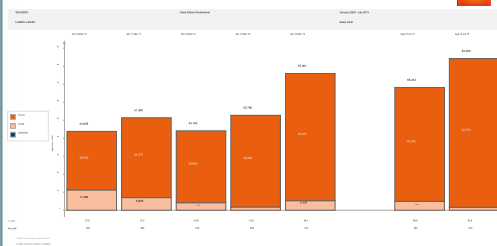
- Fully 3D, arbitrary geometry, taken from scan data
- Solution times for clinical problems ~minutes

Home-use depilators



Smoothskin Gold

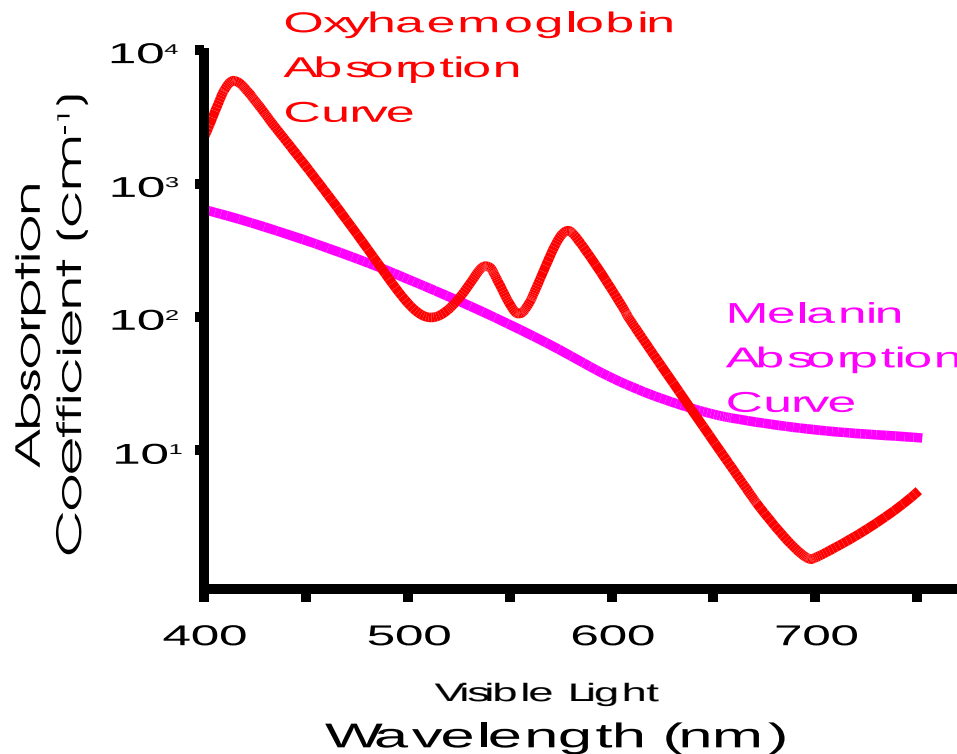
Market drivers



Note dominance of broad spectrum flashlamp over laser-based devices

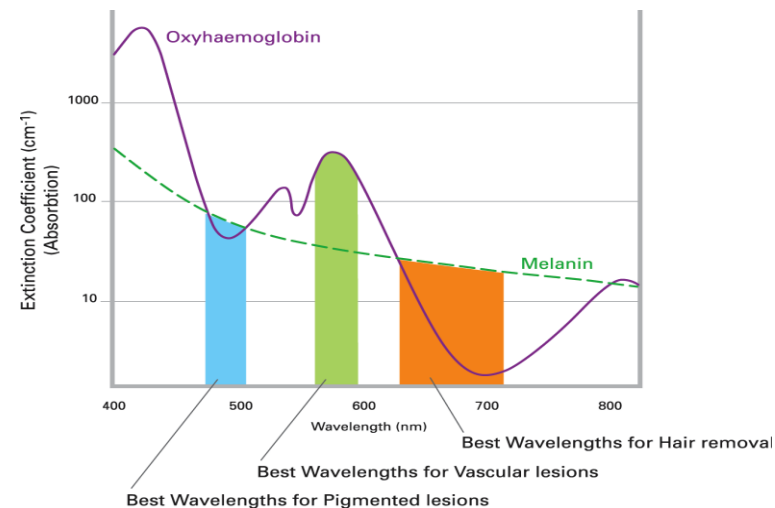
Some Physics:

Turbid tissue can absorb or scatter photons

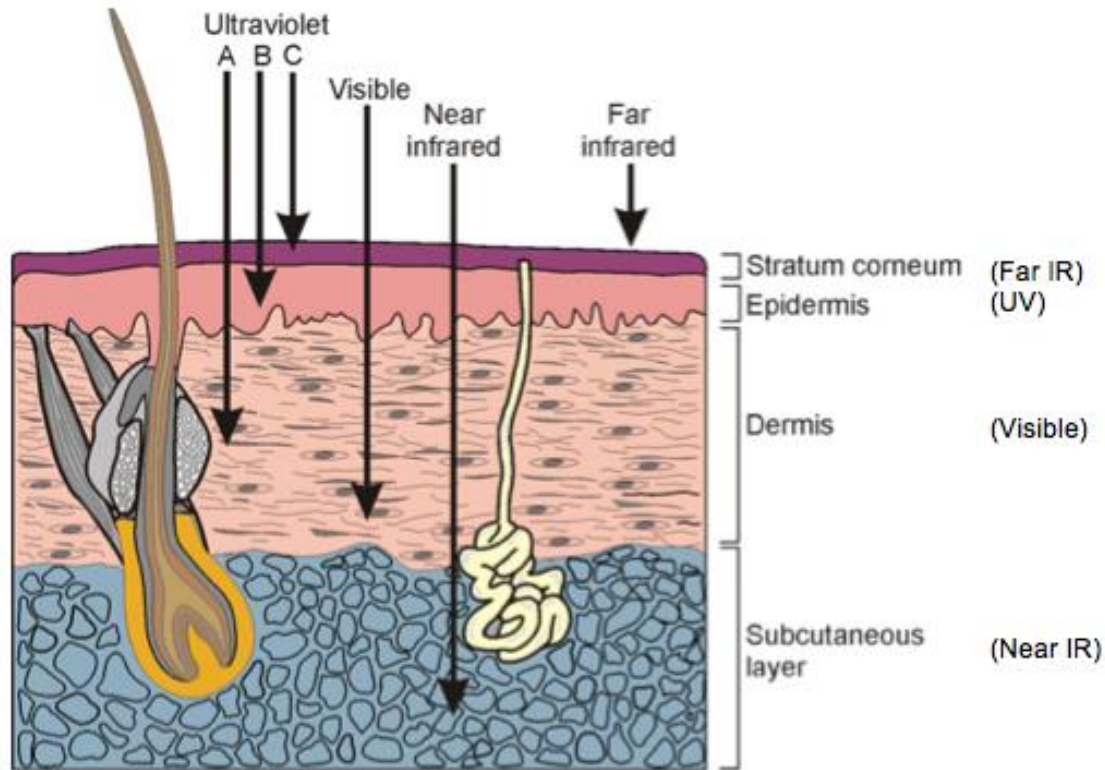


$$\mu_a = \frac{1}{\text{mean free path for absorption collisions}}$$

$$\mu_s = \frac{1}{\text{mean free path for scattering collisions}}$$



Penetration depth varies with λ



Radiation transport in tissue: Monte-Carlo simulation

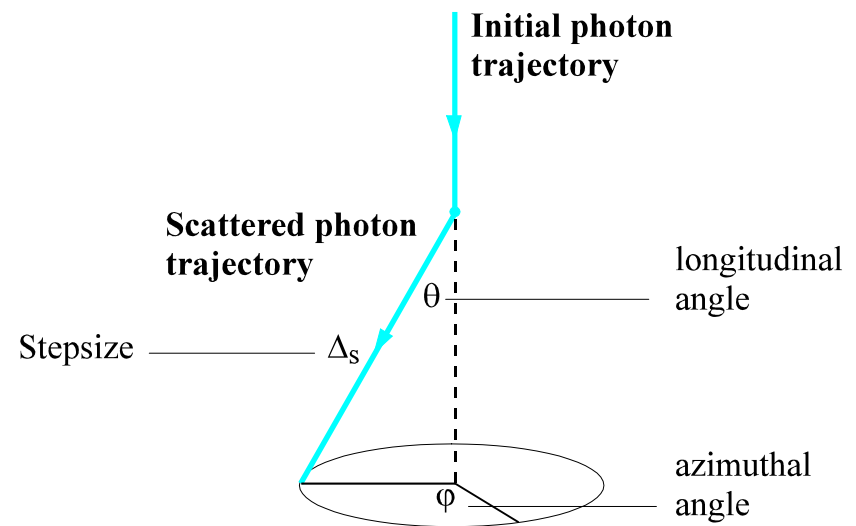
- determine photon **step size** Δs :

$$\Delta s = \frac{-\ln(R)}{\mu_a + \mu_s}$$

- determine **deflection angle** of scattering θ from phase function:

$$\cos(\theta) = \frac{1}{2g} \left[1 + g^2 - \left(\frac{1 - g^2}{1 - g + 2gR} \right)^2 \right]$$

- determine **azimuthal angle** of scattering φ : $\varphi = 2\pi R$



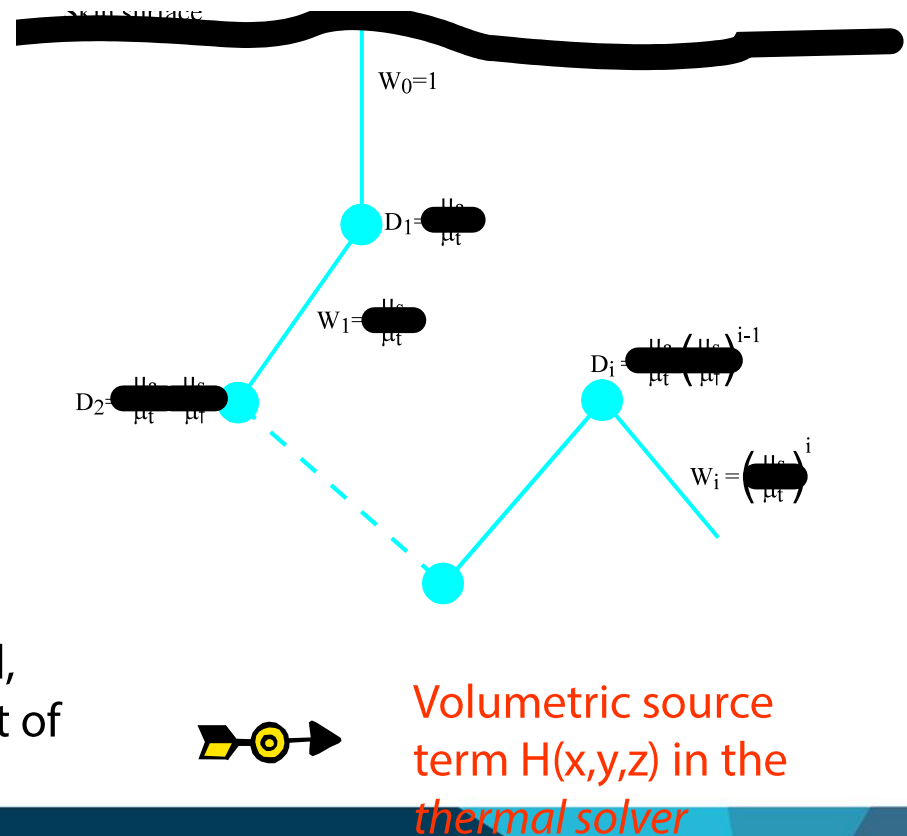
Monte-Carlo simulation (2)

- check for:
 - > layer crossing
 - > transmission out of tissue
 and update photon position accordingly

- deposit a fraction of photon weight ΔW at each interaction site:

$$\Delta W = W \frac{\mu_a}{\mu_T}$$

- repeat overall process until photon is terminated
- when all photons have been propagated, we obtain an array of accumulated weight of absorbed photons



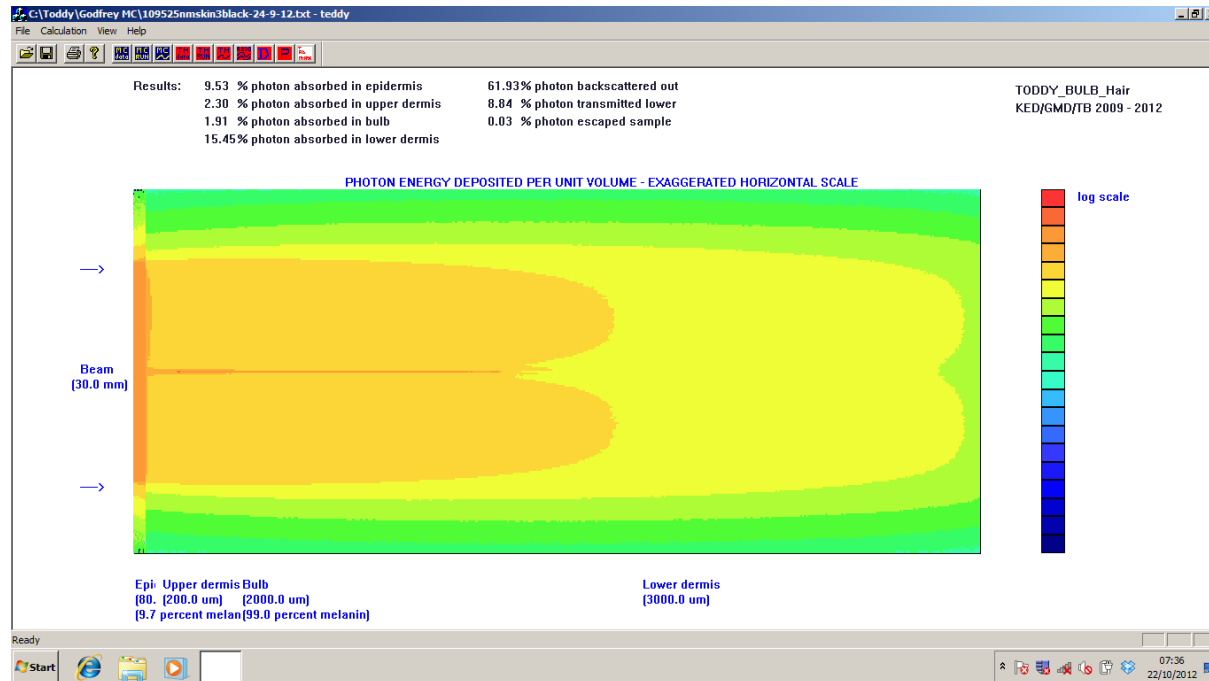
Modelling Strategy

- **Step1:** Determine the volumetric distribution of photon deposition by solving Boltzmann's Radiative Transfer Equation
- **Step2:** Determine the consequent thermal, chemical, mechanical effects due to photon absorption
- For short pulse durations, metabolic and perfusion terms can usually be ignored
- If temperatures remain modest, optical properties remain unchanged so Steady State solution for Step 1 is OK for transient thermal calculations in Step 2.

Modelling approach

- Two in-house models to solve the radiative transport equation:
 - Monte Carlo (tet mesh, octree decomposition)
 - Dual Reciprocity Boundary Element Method (DRBEM)
- One in-house model to take radiative source terms and solve for thermal transport:
 - Transient Thermal Boundary Element Method (TTBEM)
- On-going collaboration with local medical device companies, to calibrate computational model

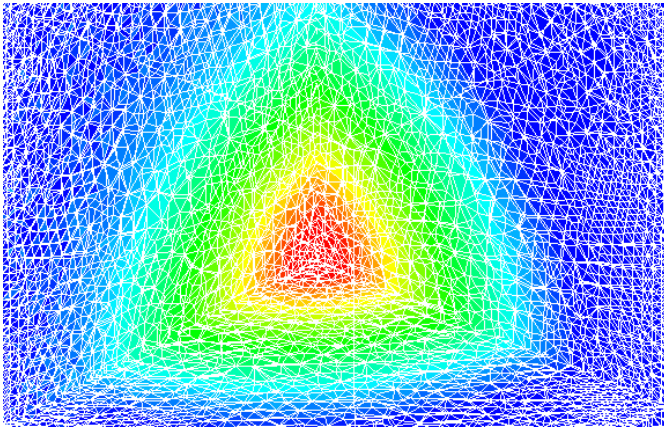
TODDY: 2D Monte Carlo (MPI + threaded) with FD ADI for temperature calc



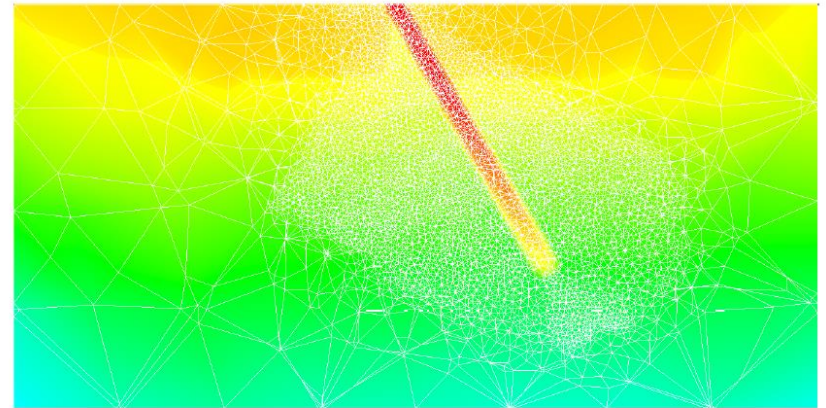
2D model useful in parametric sweep calculations

TEDDY: 3D Monte Carlo (MPI, Threaded, CUDA)

- Unstructured tet/tri mesh: Facilitates realistic organic structures
- Domain decomposition using Octree method



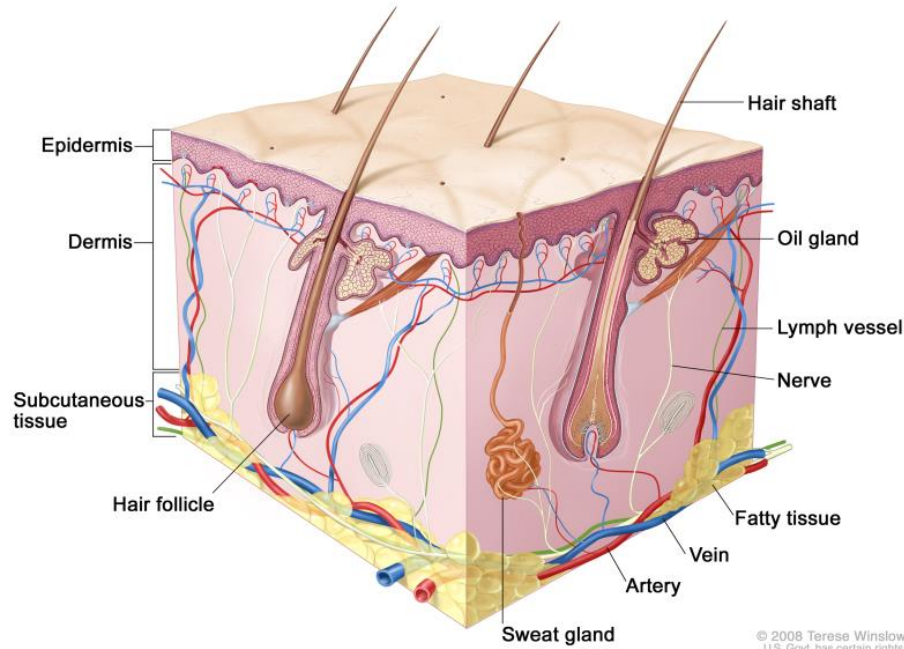
Simple isotropic source test



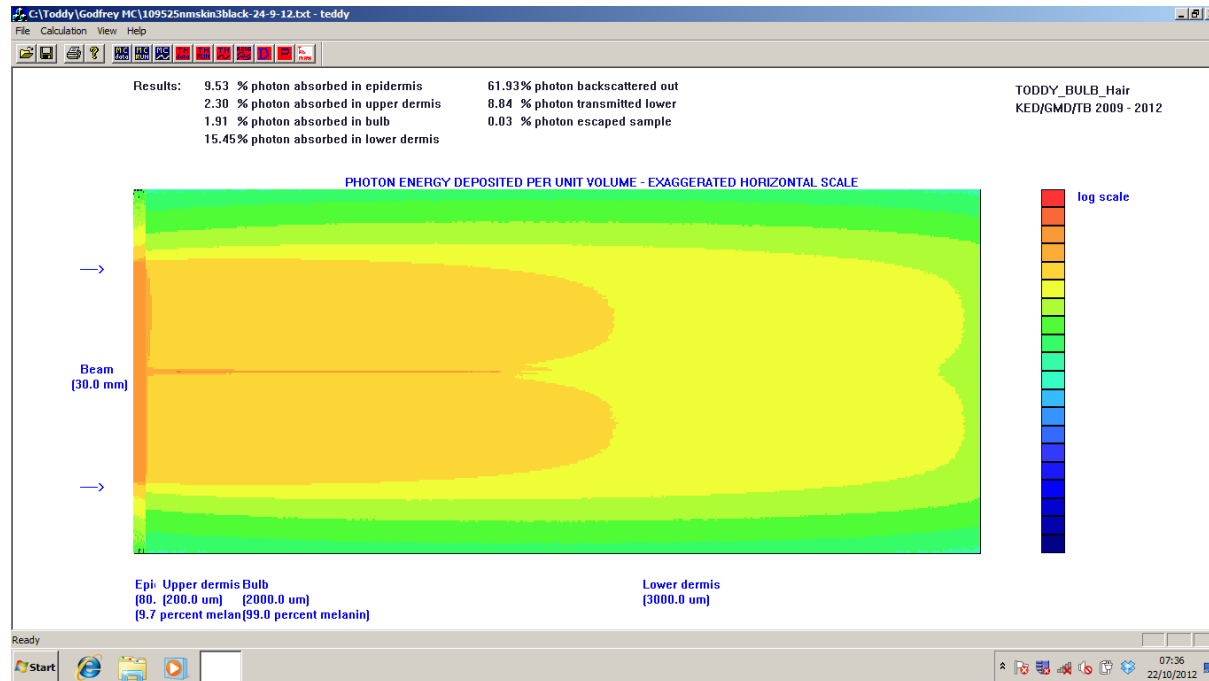
Oblique hair follicle

2D Monte-Carlo Case-Study: Hair removal

Chromophore is Melanin –present in skin and follicle



TODDY: 2D Monte Carlo (MPI + threaded) and ADI for thermal calculation

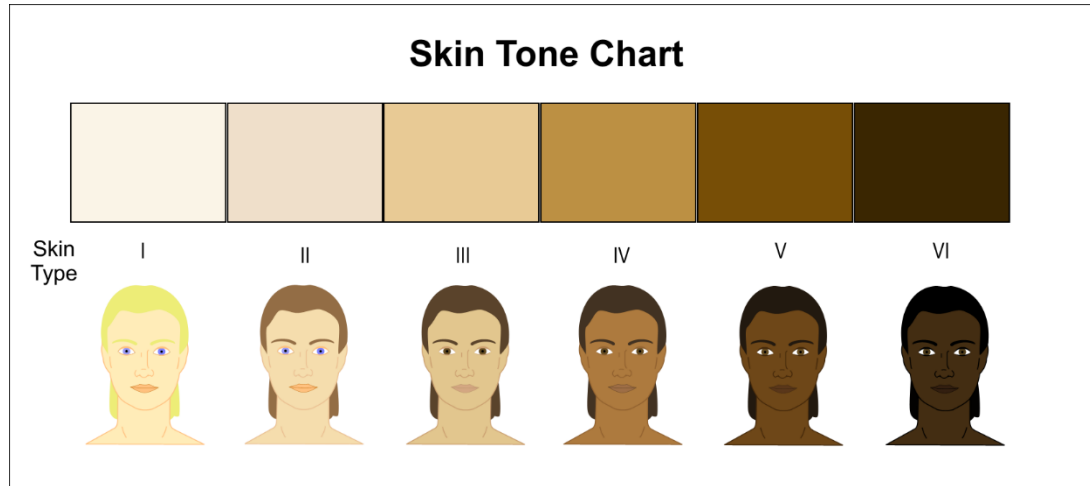


Thermal Damage ($T > 43^\circ\text{C}$)

- Photon fluence is high enough for absorbed photons to heat tissue
- As the temperature rises above 43°C , thermally induced damage can be described by the well-known **Arrhenius damage integral** Ω :

$$\Omega(r, \tau) = \ell n \left(\frac{n(o)}{n(\tau)} \right) = \int_0^\tau A_{freq} \exp \left[\frac{-E_\alpha}{RT(t)} \right] dt$$

The Fitzpatrick Skin tone scale

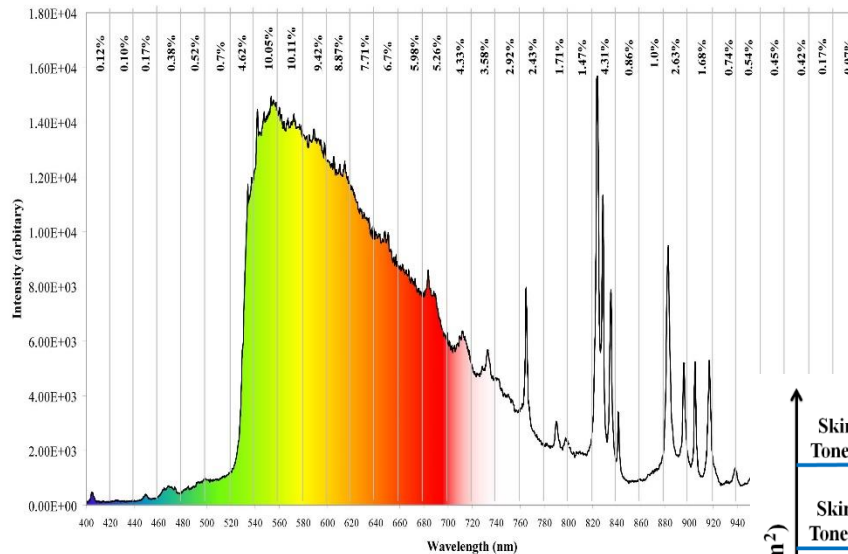


Challenge: hair removal in darker skin tones

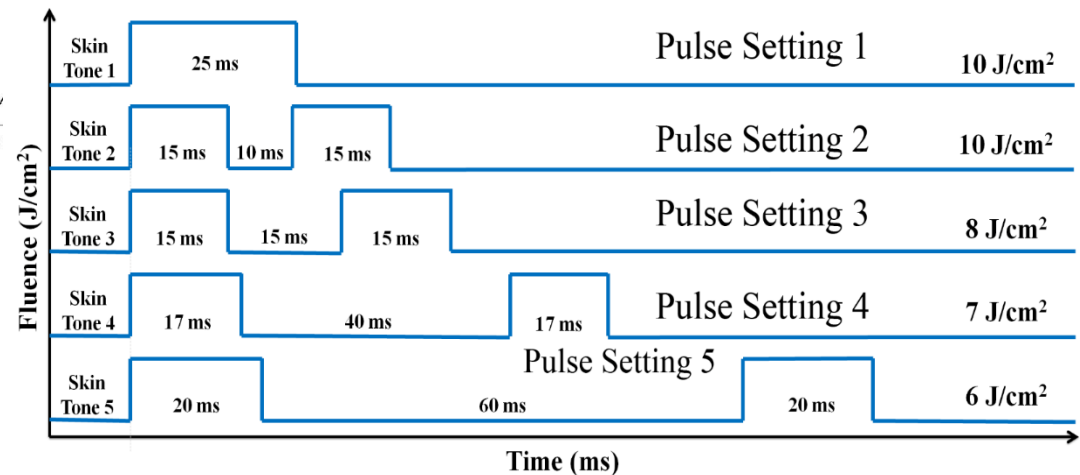
i.e can we maximise follicle temp while keeping skin temp below 43C ?

Parametric Study using TODDY

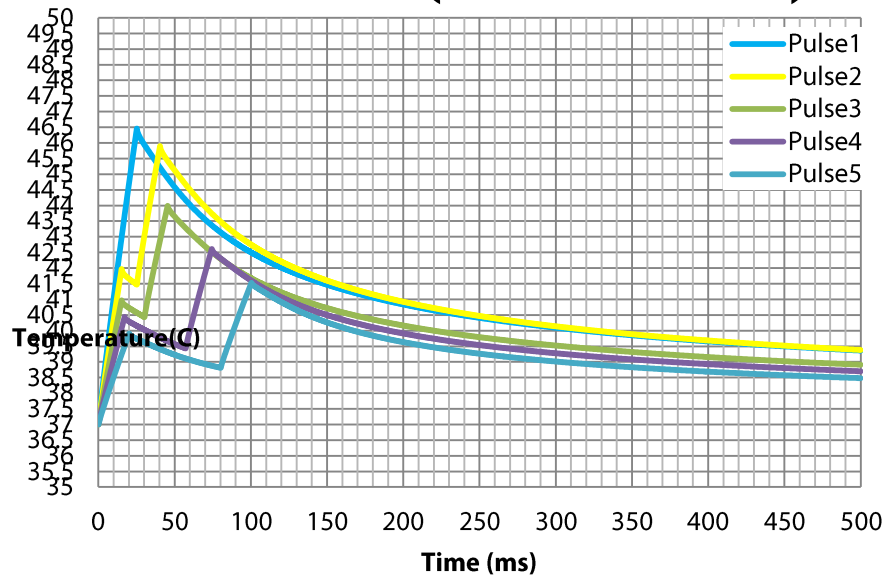
Distribution of Spectra Wavelengths of an iPulse IPL



Light source is flashlamp with the following pulse shapes:

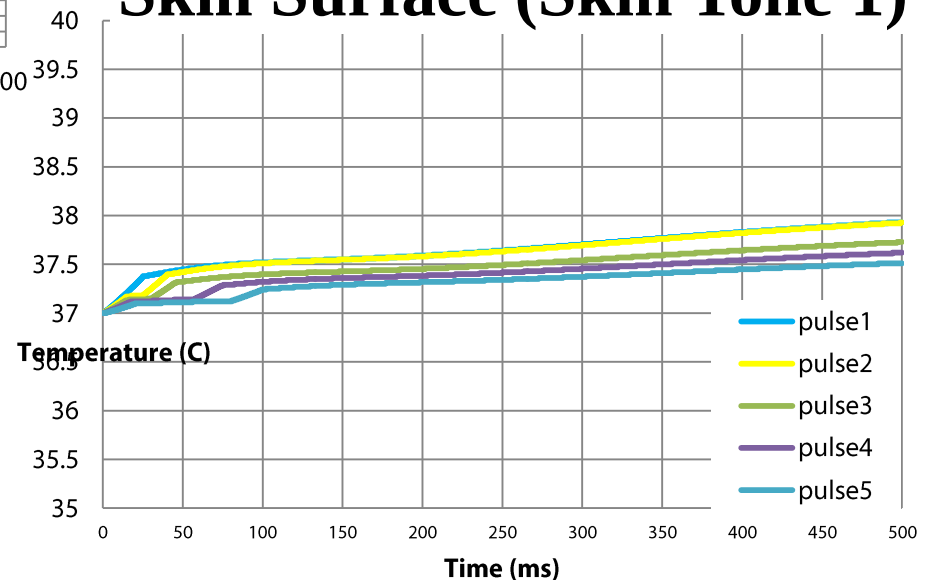


Follicle (Skin Tone 1)

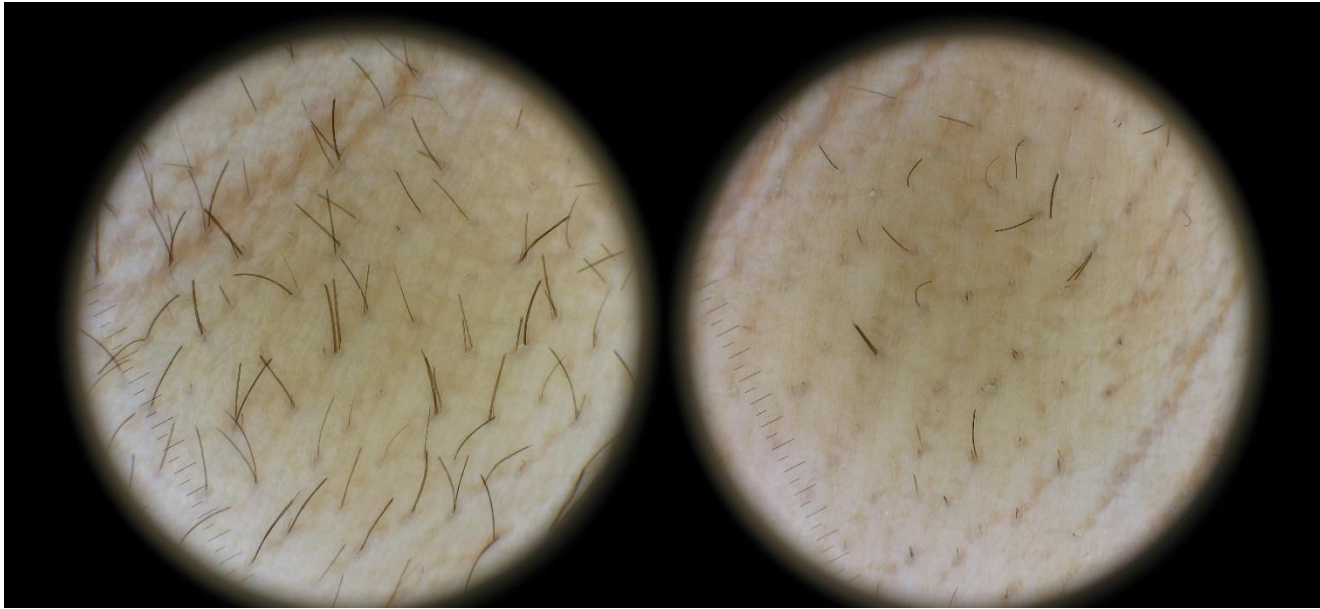


For light skin , it's easy to damage the follicle while keeping skin surface undamaged

Skin Surface (Skin Tone 1)



Type 1 skin : after three weekly treatments using Smoothskin IPL device



before

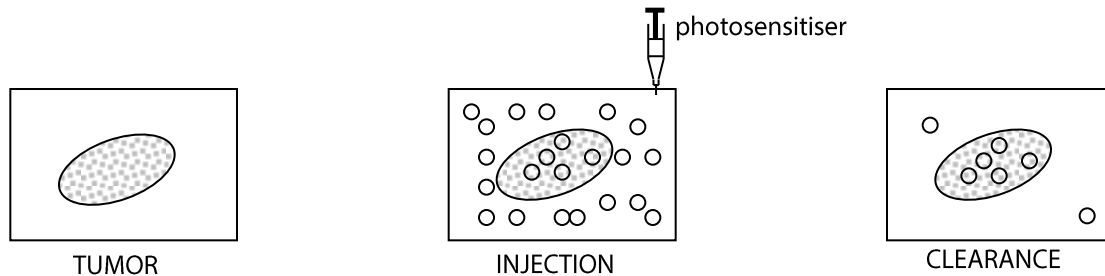
1 month following
treatments

Case Study -esophageal cancer (AM)

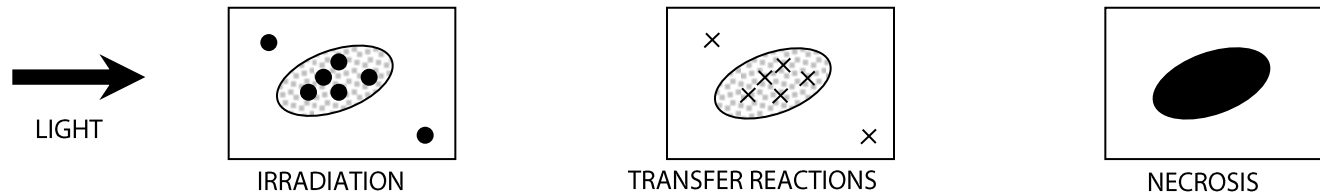
- The Clinical Problem –esophageal cancer
- The treatment modalities:
 - Photodynamic therapy (PDT)
 - Light-induced hyperthermia
- Modelling strategy:
 - CT/MRI scan data > STL >Cleanup STL>Surface definition for BEM
 - PDT modelled by solving radiative transfer equation plus chemistry kinetics of PDT process to determine PDT damage dose.
 - Hyperthermia modelled by two-step process:
 - **BEM used** for both photon deposition in tissue and thermal damage.
- MPI implementation on HPC under Windows Cluster Server

1. Description of PDT

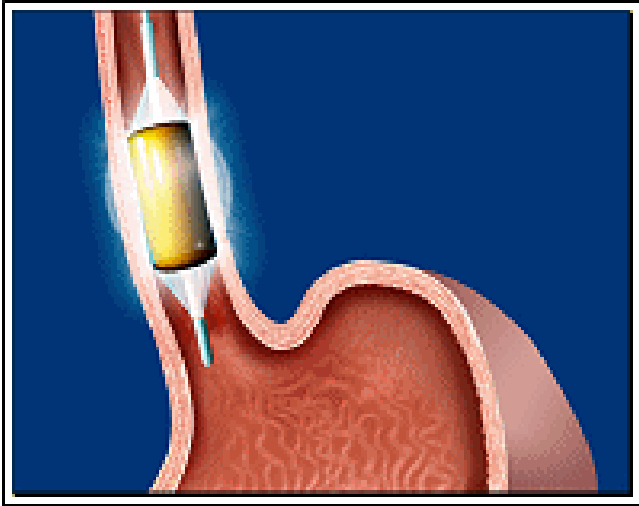
- **Step1:** Inject patient with photosensitive chemical , which is preferentially absorbed in tumour



- **Step2:** Irradiate the tumour region with light to activate the photosensitiser. This generates highly reactive singlet oxygen ($^1\text{O}_2$) that damages local cells.



PDT treatment involves irradiating the interior wall using a balloon catheter



The Photodynamic Damage Dose (PDD) at a given point r in tissue and specific irradiation wavelength λ , is defined by]:

$$PDD(t, \lambda, r) = k_D(\lambda) \int \phi(t, \lambda, r) \cdot P(t, r) \cdot O(t, r) dt$$

where:

$\phi(t, \lambda, r)$ is the fluence rate,

$P(t, r)$ is the photosensitiser concentration,

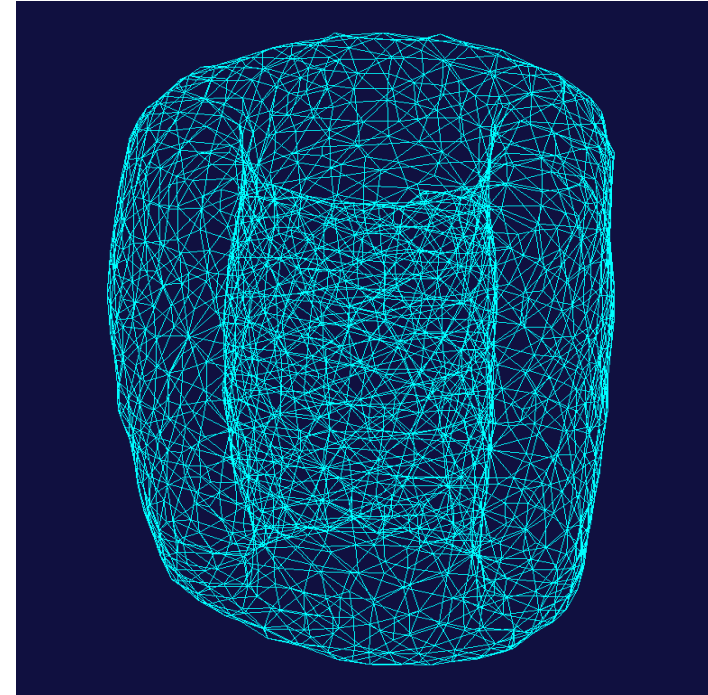
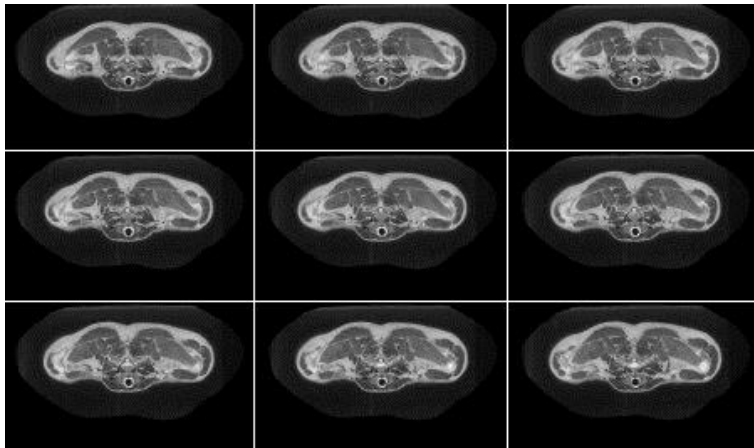
$O(t, r)$ is the oxygen concentration.

Hyperthermia

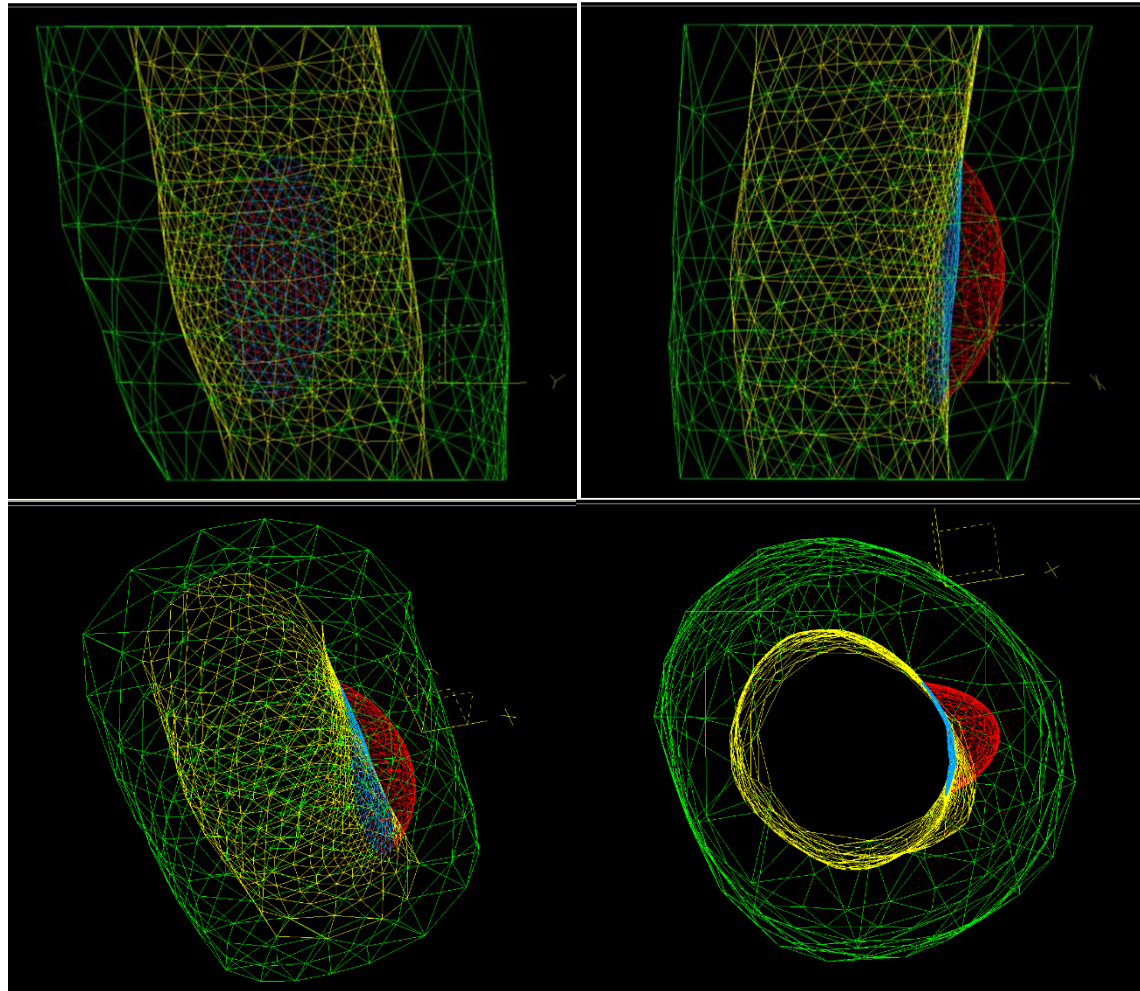
- Irradiate tissue with light source
- Light energy density is higher than in PDT, so we get tissue heating – photothermal process.
- Typically irradiate for 45 minutes to maintain tissue temperature at $\sim 47^{\circ}\text{C}$ to induce tissue necrosis.

Example results for oesophagus

Obtain CT scan data (DICOM file format) from the Visible Human Project.^[9]



Convert DICOM files into 3D CAD file format i.e. STL tessellated file
STL file cleaned in FLUENT TGRID, ALIAS

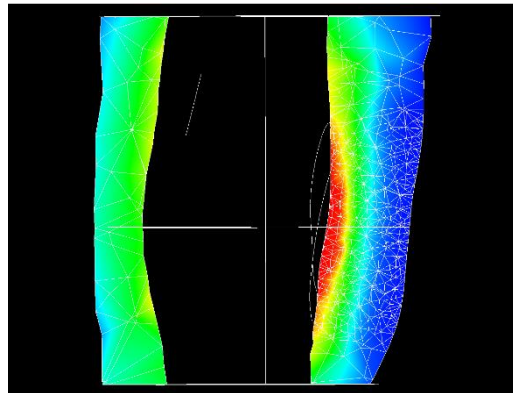
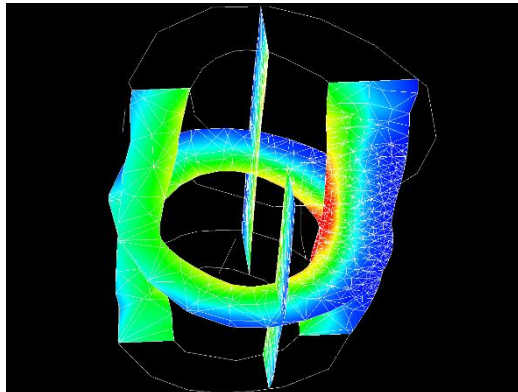
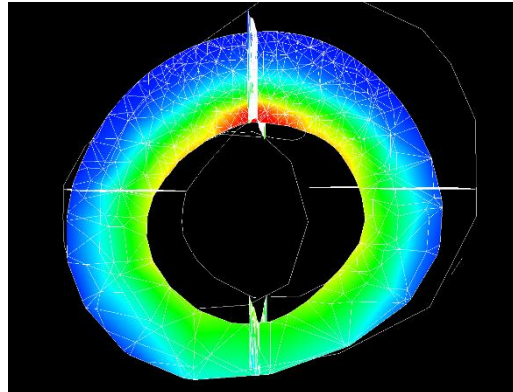
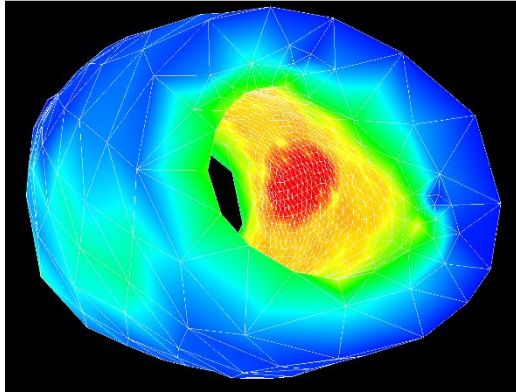


CT scan derived Esophagus with wall tumour (red).

PDT damage after 500 seconds

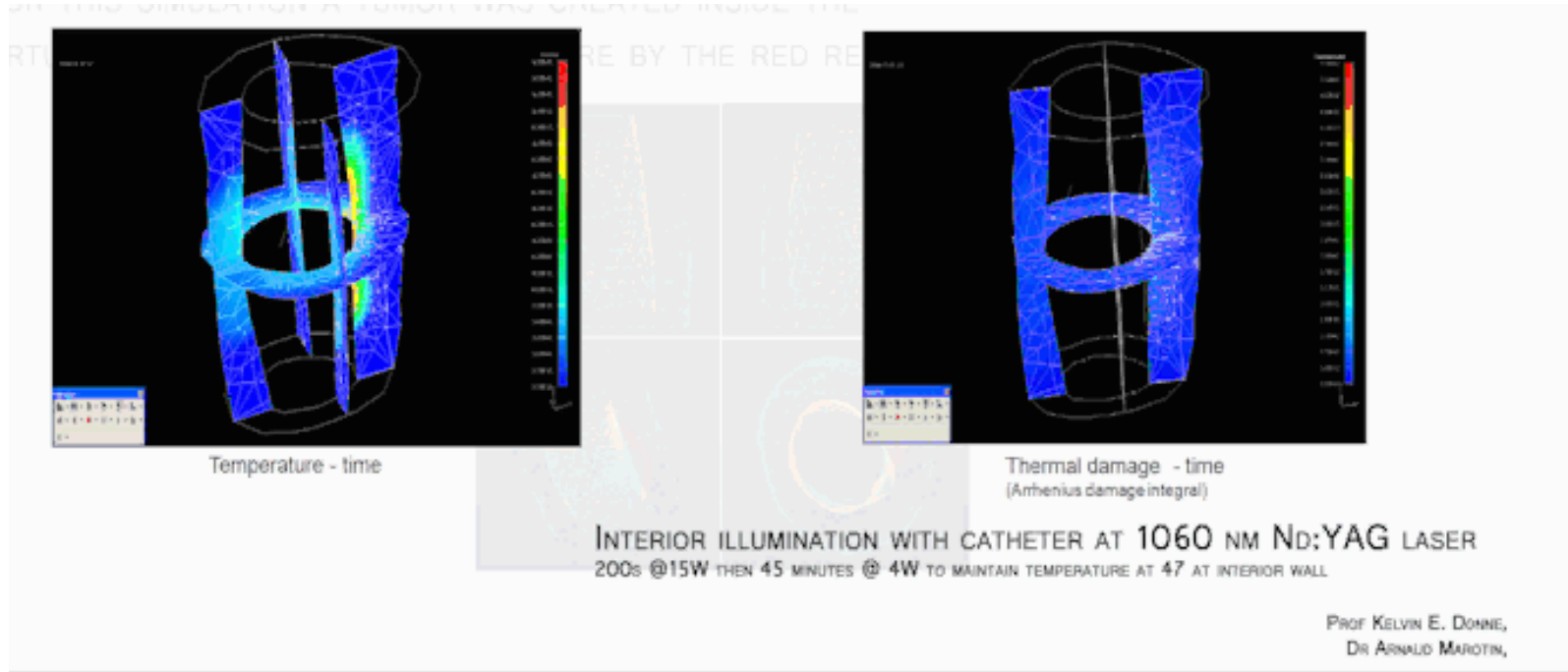
Parameters: $\lambda = 630\text{nm}$, $I_s = 68\text{mW.cm}^{-2}$ (diode laser / Power = 1.853W)

Photosensitiser concentration 3x higher in tumour compared to normal tissue



Temperature and thermal damage

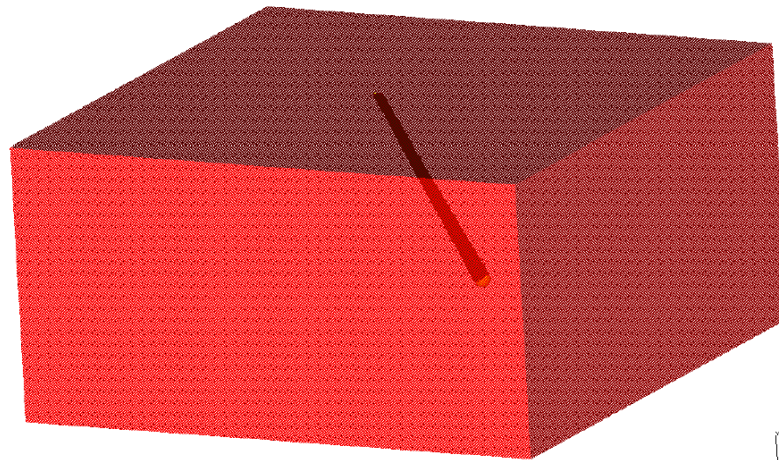
Hyperthermia damage determined from well-known Arrhenius damage integral.



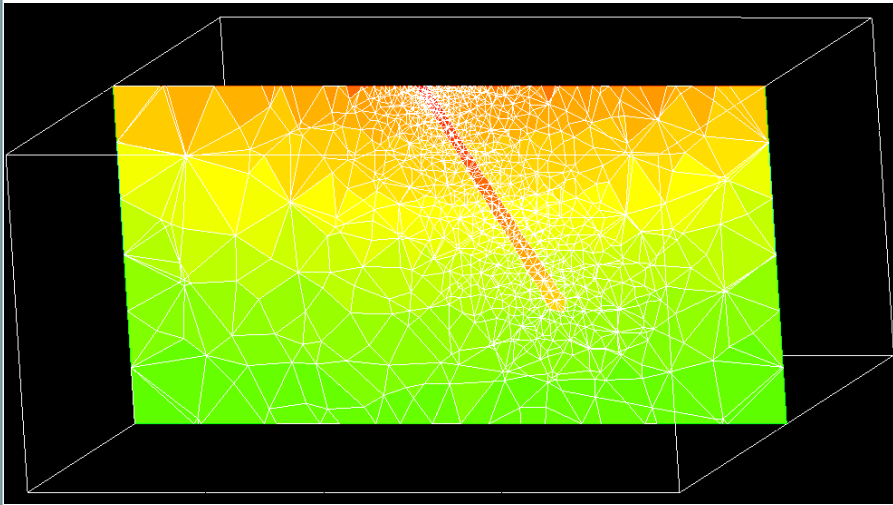
3D Case Study: hair removal

3D MC + TTBEEM (TB)

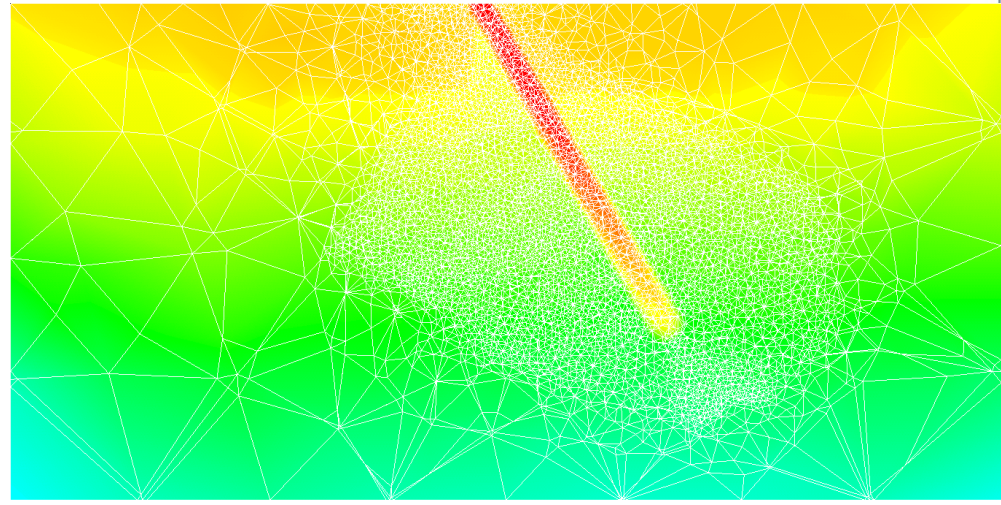
- Two homogenous regions: a hair follicle contained in a block of tissue.



Radiative results

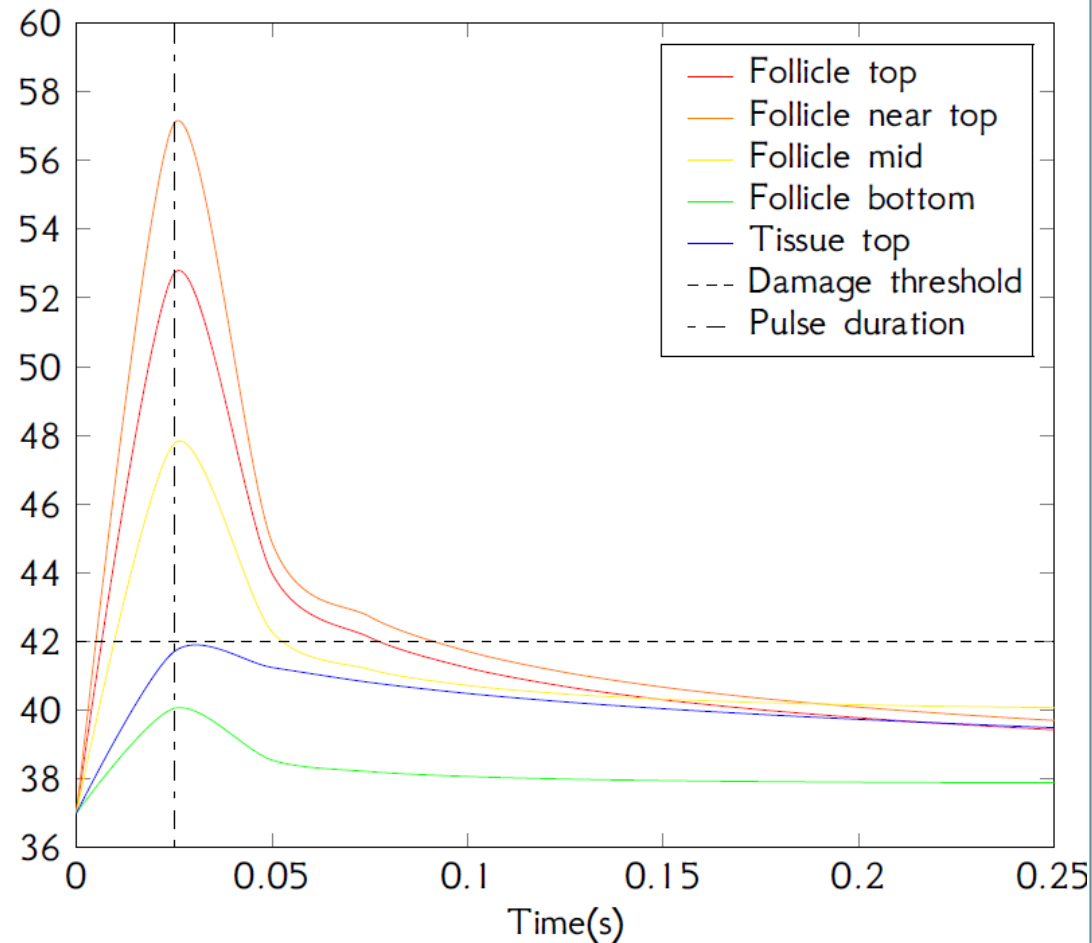
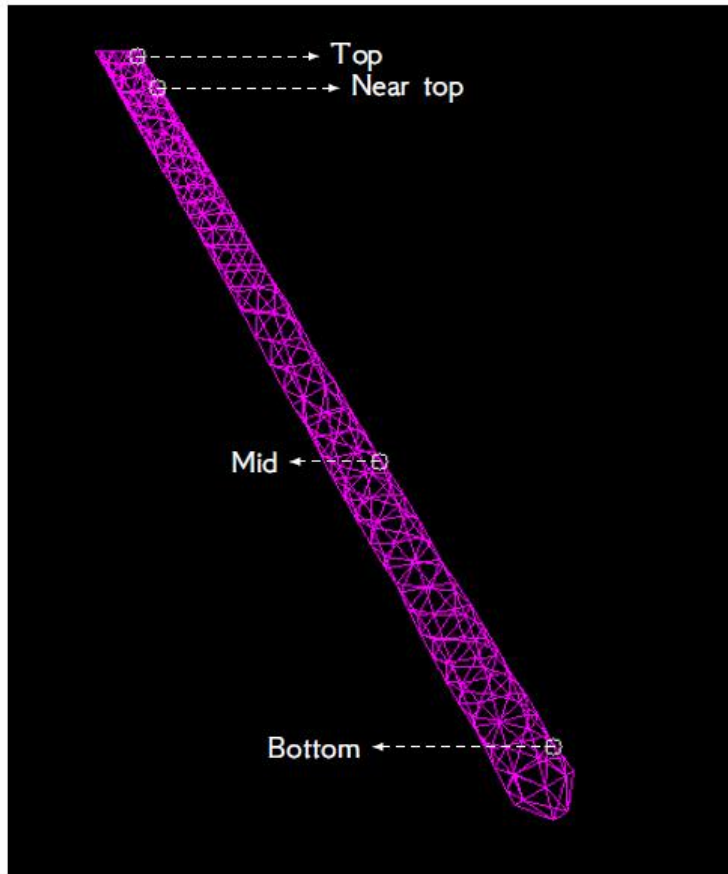


DRBEM

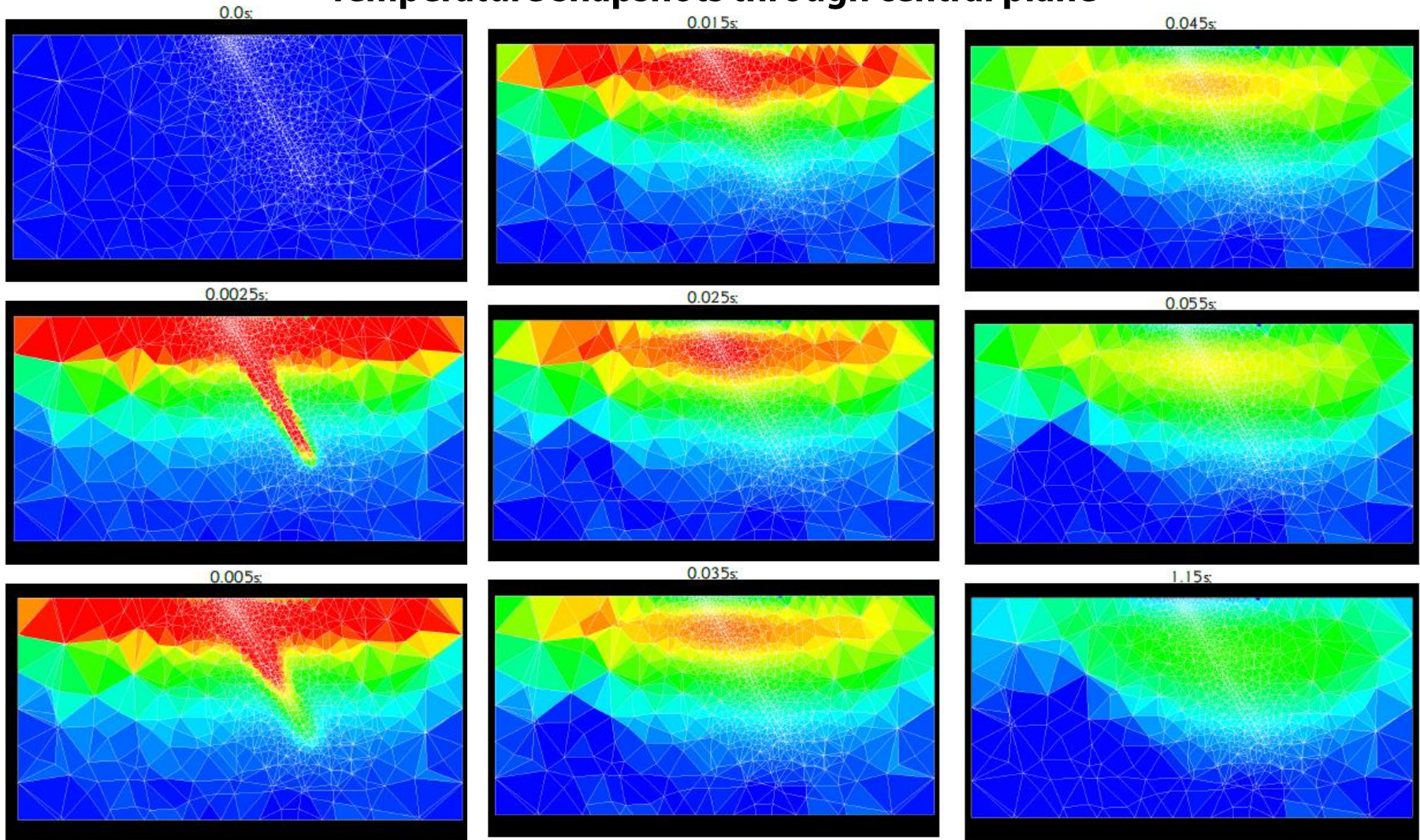


3DMC

Temperature predictions from TTBEM



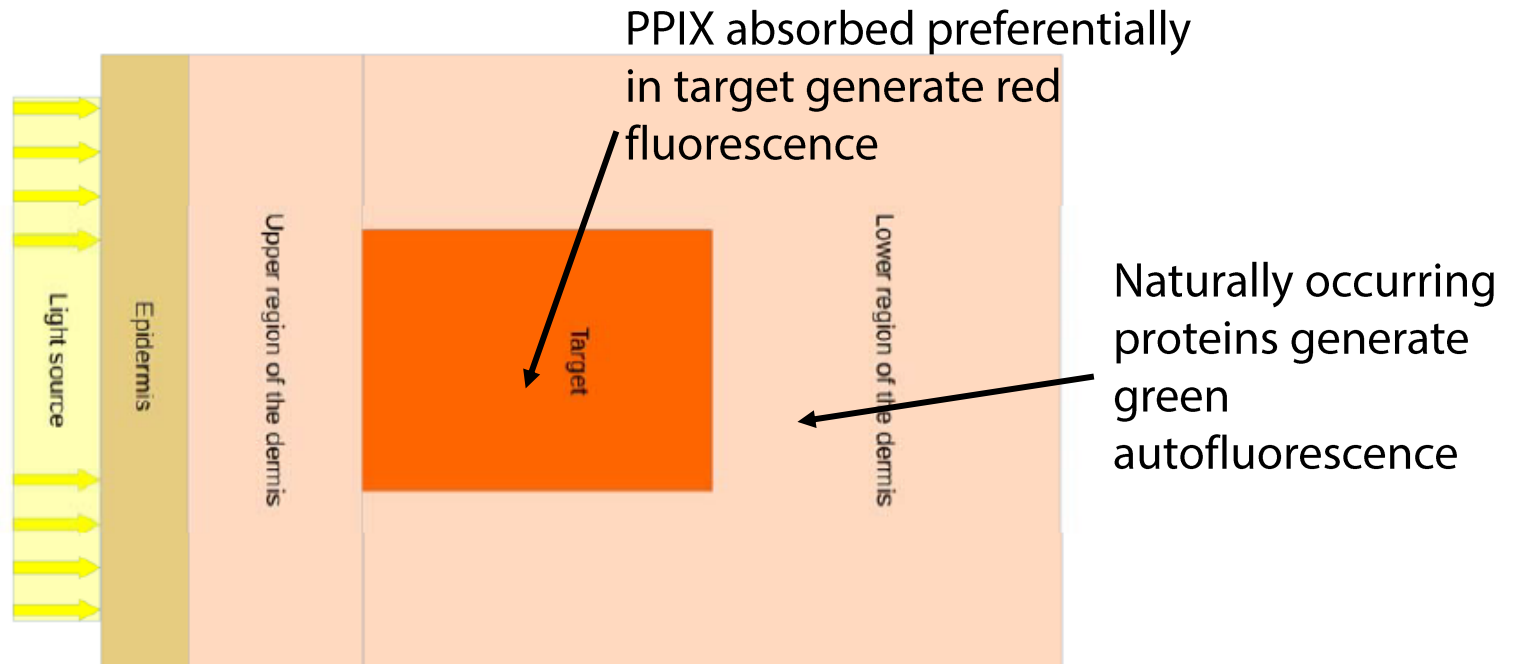
Temperature snapshots through central plane



Case Study : Fluorescence detection of skin cancers: Collaboration with ZBC Multicare Ltd, Hilversum (NVdB)

- Keratinocyte skin cancers (KSC), also known as non-melanoma skin cancers is a malignancy arising from the keratinocytes of the skin. KSCs are classified according to the cells of which they are comprised, such as basal cell carcinoma (BCC) and squamous carcinoma.

Fluorescence detection of BCCs



Three passes of MC algorithm:

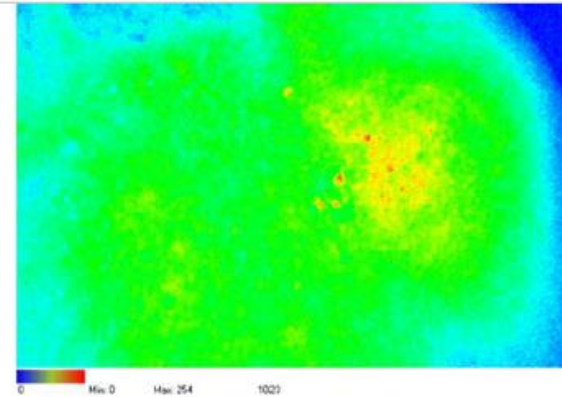
- Deposition of photons from incident 409nm photons
- Emission of fluorescence photons from absorbed PPIX photosensitiser
- Emission of autofluorescence photons from tissue proteins

Fluorescence detection of BCCs

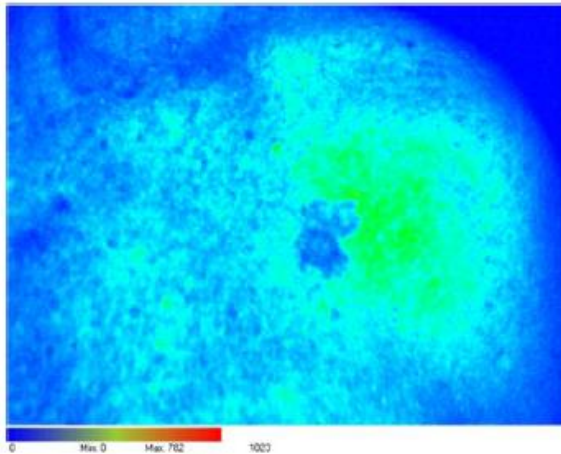




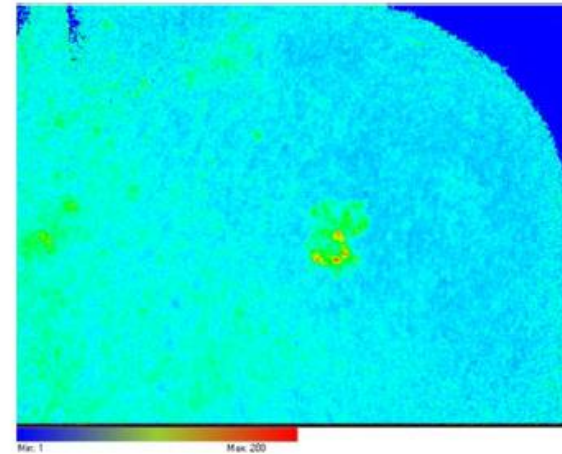
Colour image of sBCC



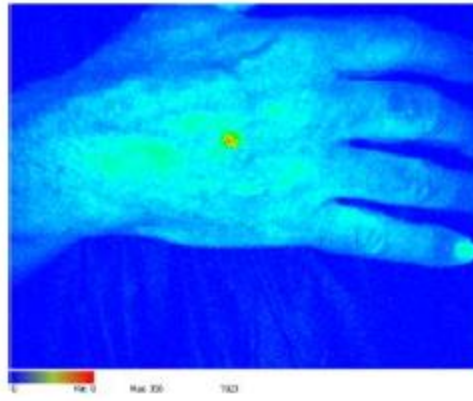
PpIX fluorescence



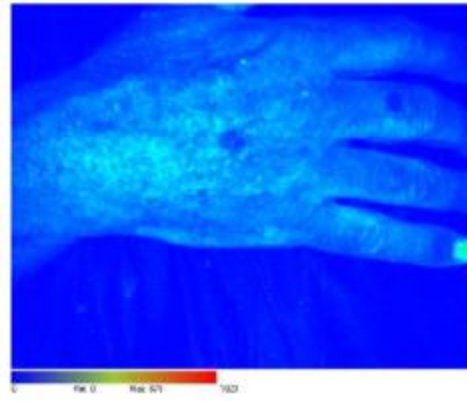
Auto fluorescence



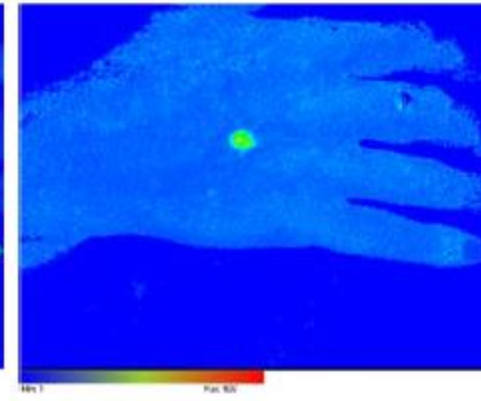
Combined fluorescence



PpIX fluorescence of KSC



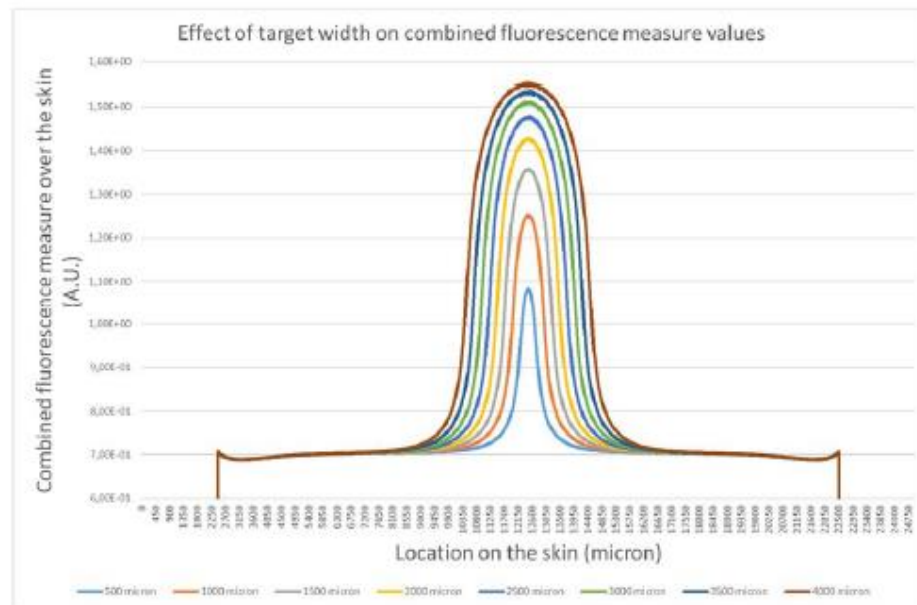
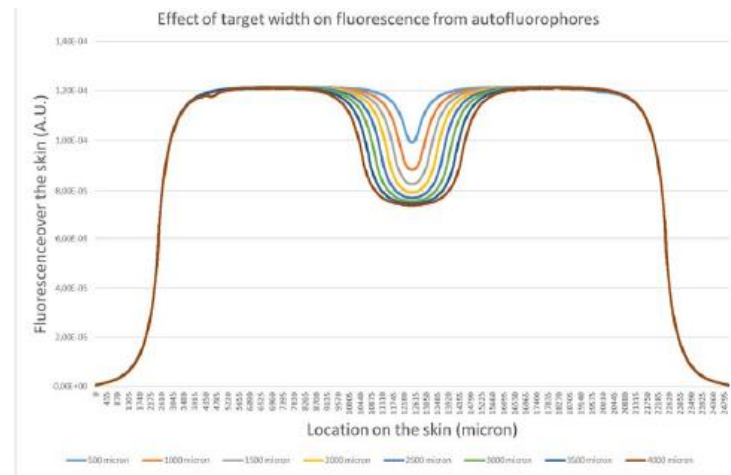
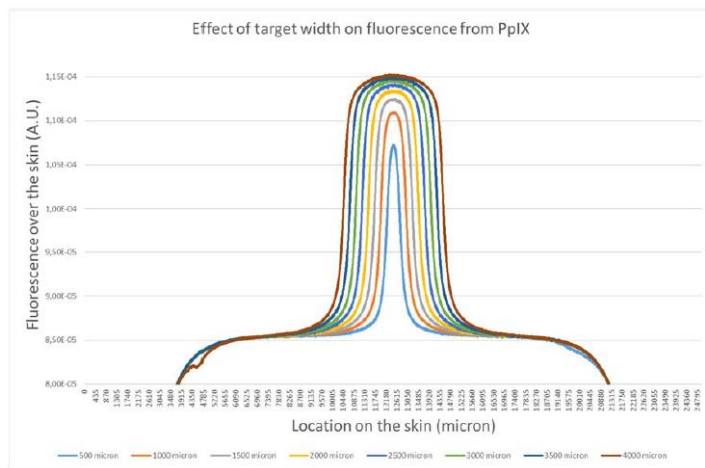
Autofluorescence of KSC



Combined measure
fluorescence of KSC

$$\text{Combined measure} = \frac{\text{Autofluorescence}}{\text{Autofluorescence} - \text{fluorescence}}$$

Plots of resulting fluorescence at skin surface due to PPIX, autofluorescence and combined



Future Plans

- Extension to time-dependent Monte Carlo to model transient fluorescence
- Further hybrid parallelisation schemes underway (DA)
- Investigation of operator interaction for cluster interaction, with Qt-based thin client uploading to Cluster scheduler/manager
- Collaboration with Cyden Ltd (Wales), ZBC Multicare (Hilversum) on EU project