HTCO GmbH

Strömungsphysik - Strömungssimulation

Sunburned Products:
Numerical Aging caused by Sun Exposition

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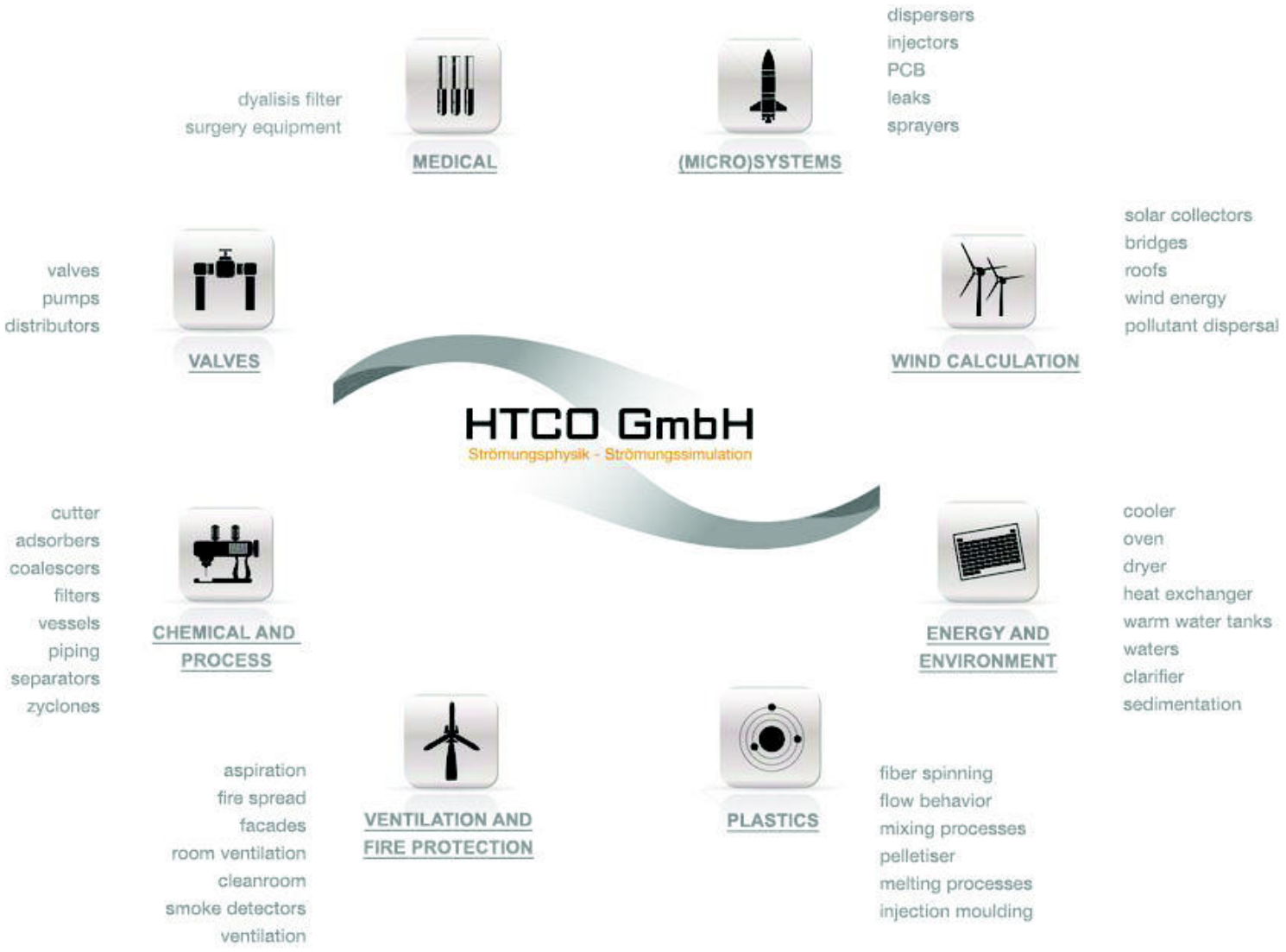
Rotterdam, Netherlands

HTCO: Expertise

Application Fields



Sunburned Products

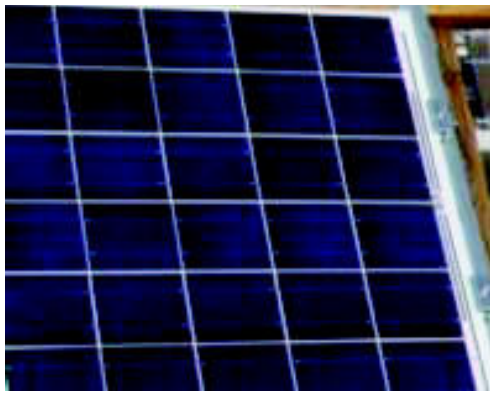
A new Simulation Approach

What is a sunburned product?

It is a product which is exposed to the sun and shows change of its material properties (aging), e.g.

- colour
- gloss
- cracks

over time.



What is numerical aging?

A way to predict material aging caused by environmental impacts, e.g.

- temperature
- solar radiation
- humidity

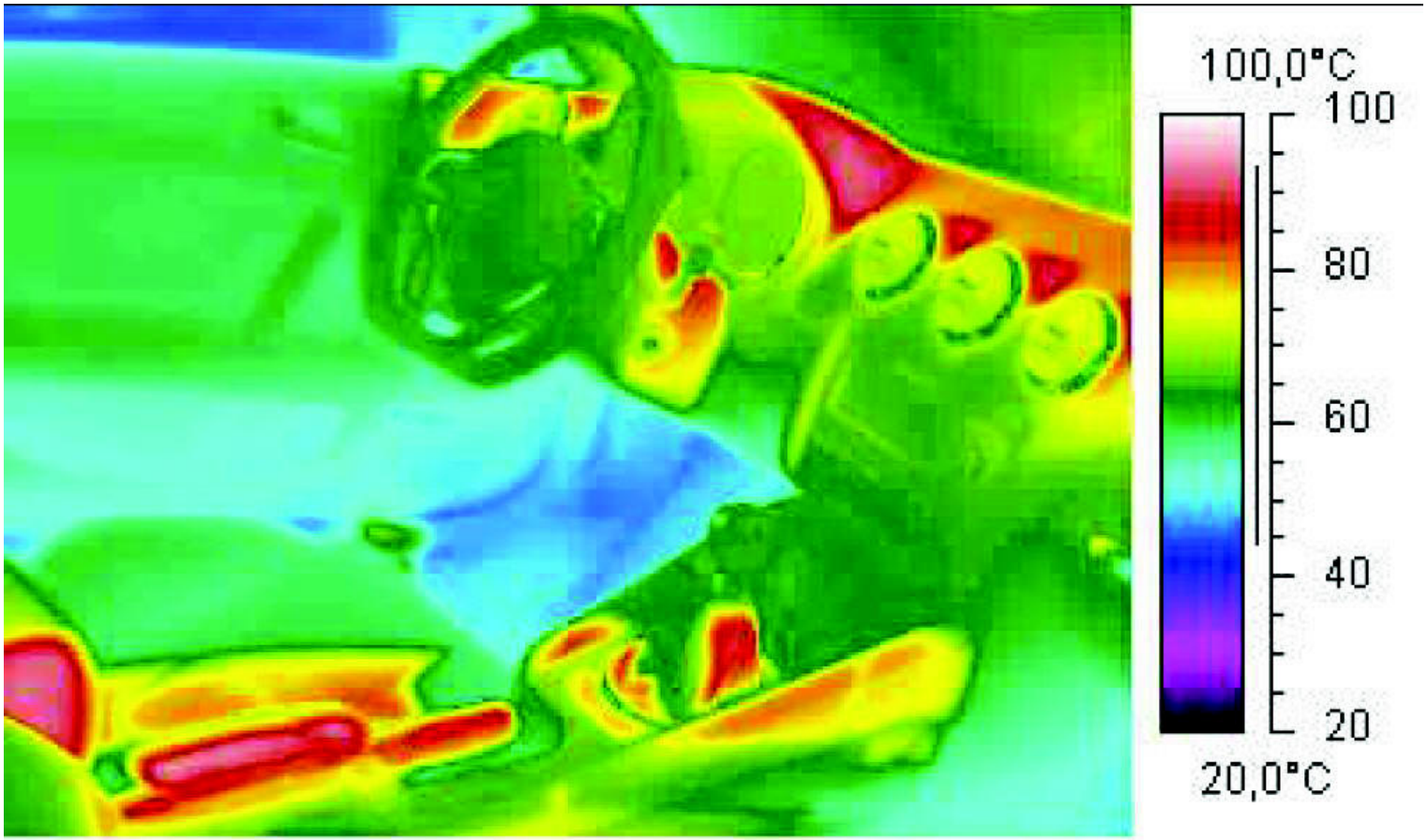
by numerical simulation on the basis of geographical, geometrical, environmental, material data, and time.

**** Source: Fraunhofer Institute for Solar Research (ISE), Freiburg, Germany***

How important is Aging to Industry?

Motivation

Temperature distribution in a car standing in the sun



** Source: ATCAE Conference Oxford, England, 2008, Dr. Stahl, Audi AG*

How important is Aging to Industry?

Motivation

Instrument panel in an IP/DP-box

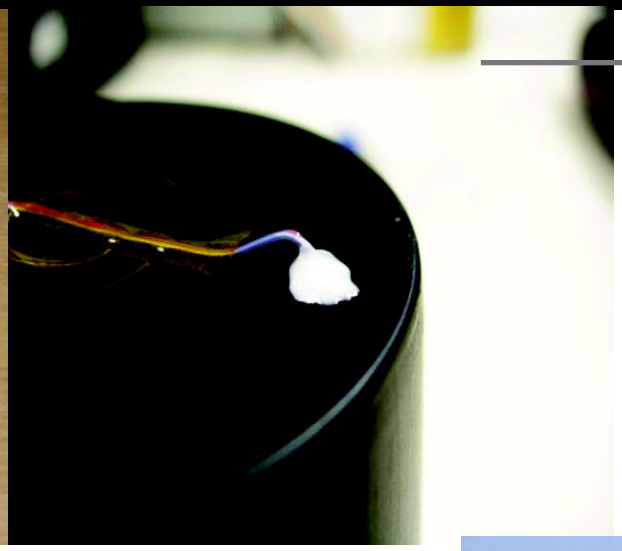
It is very important!

Costly experimental outdoor weathering tests

***Source: ATCAE Conference Oxford, England, 2008**
Dr. Stahl, Audi AG

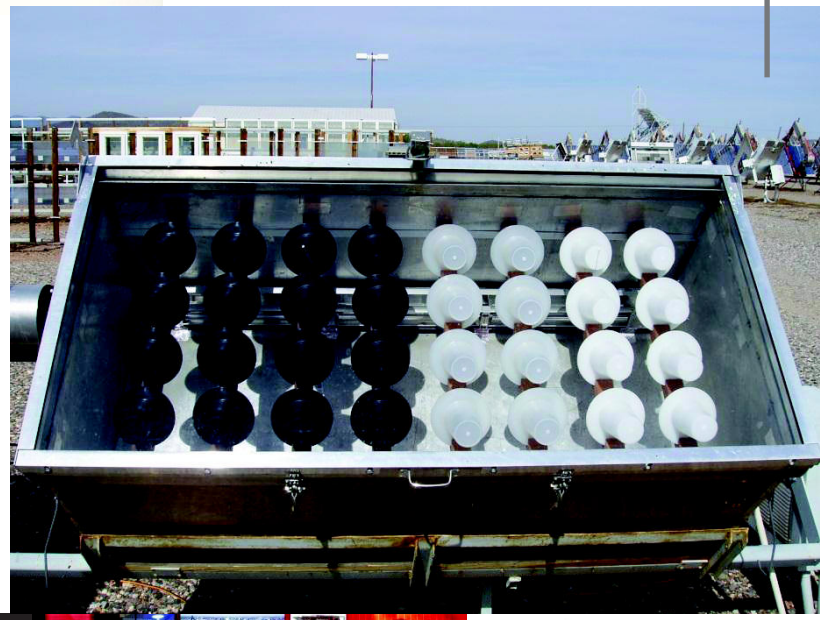
Research Project VipQuali

Experimental Part



The research specimen is a polypropylen hat (black and white). Its surface teperature is being measured by temperature sensor.

Outdoor weathering tests in IP/DP-box in Phoenix, Arizona



VipQuali Consortium

Fraunhofer

HTCO GmbH
Strömungsphysik - Strömungssimulation

ATLAS
MATERIAL TESTING SOLUTIONS

BAM

Clariant

Bundesministerium für Bildung und Forschung

pt
Projektträger im DLR

Research Project VipQuali

Input

What is needed to simulate Aging ?

1) Temperature Distribution on the Specimen and in the Box

2) Radiation of the Sun and the Environment

3) Positions of the Sun

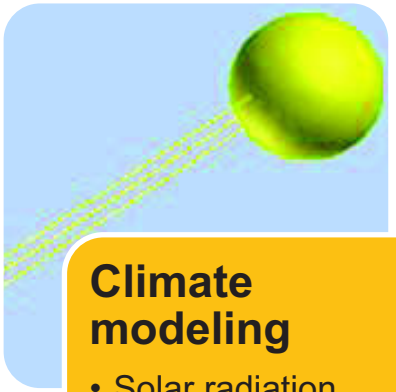
4) Dose-Effect-Relationship (change of the material as a function of Irradiation, Temperature, etc. and Time)

5) Method to visualise the change of the material

Methodology and Tools

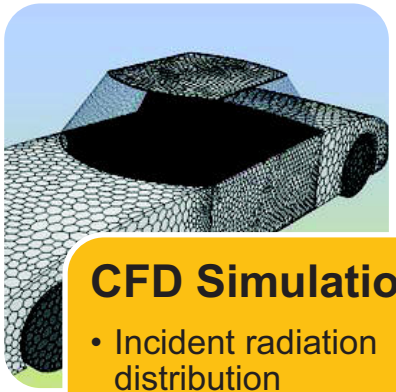
The numerical Aging Approach

Aging simulation workflow and modules



Climate modeling

- Solar radiation
- Radiation of the environment
- Environmental temperature



CFD Simulation

- Incident radiation distribution
- Velocity distribution
- Temperature distribution

Aging Simulation

- Dose-effect-function
- Material change (crack probability, color, gloss)
- Visualization

Solution approach

Similarly to computational fluid dynamics the complex and continuous aging process can only be numerically treated and solved by means of intelligent discretization methods

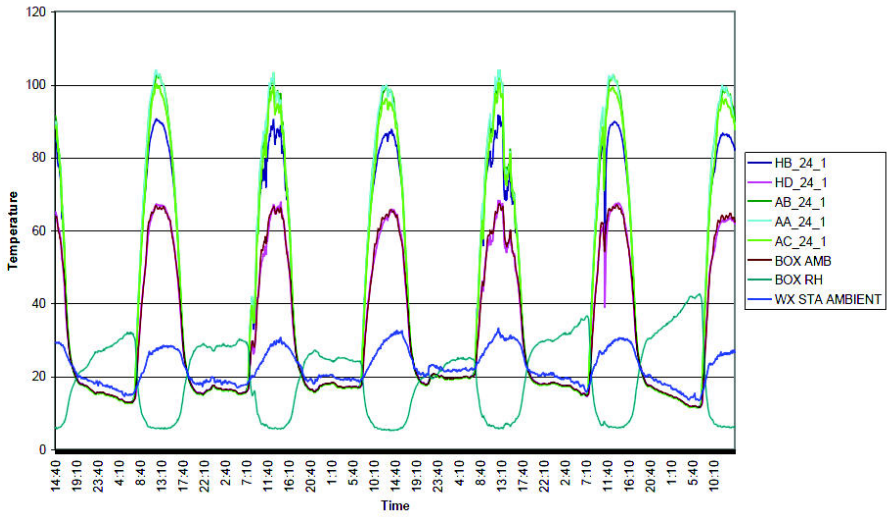
Climate Modeling

Data Acquisition and Preparation

Climate data acquisition

- Ambient temperature
- Solar radiation (direct, diffuse, environmental) on horizontal surfaces
- Wind
- …

Temperature data measured in Arizona



Data preparation tool

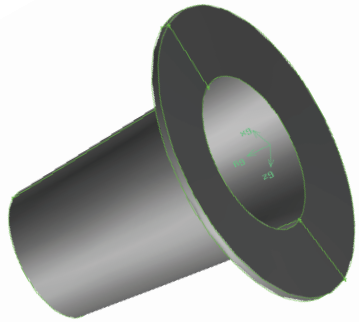
Measurements have to be translated into boundary conditions required for the simulation

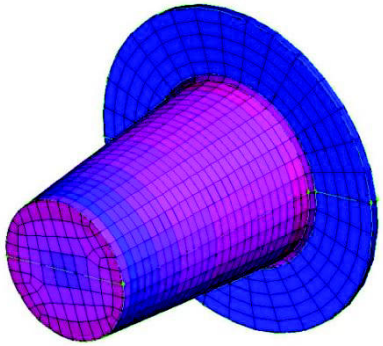
- Radiation on inclined external surfaces
- Calculation of sun position for specific location and time
- ...

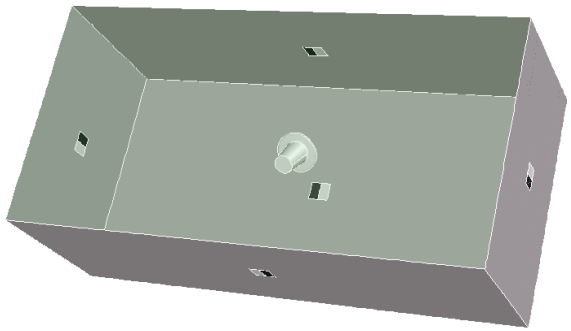
CFD Simulation

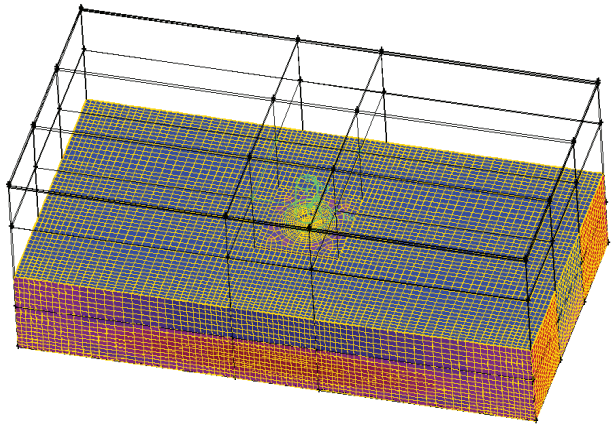
Numerical Model

Buildup of the Models for the Simulation (CFD)









CAD- Model

Finite-Volume-Mesh

CFD Simulation

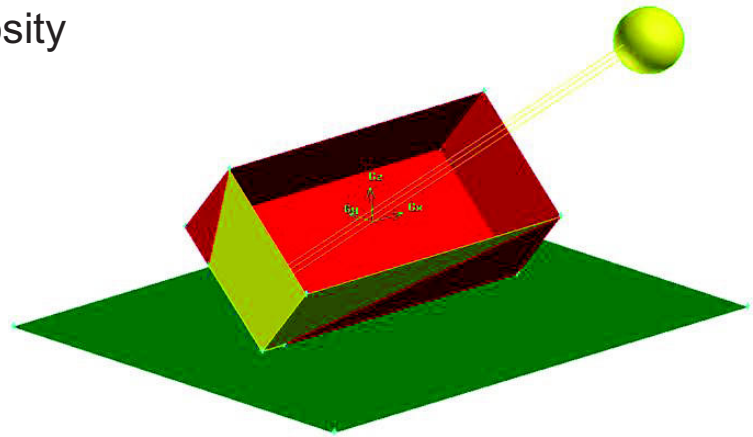
Boundary Conditions

Materials

- Window – glass
- Hat – black (white) polypropylen
- Box – silver aluminium

Material properties

- Emission- and transmission coefficients
- Heat conductivities
- Viscosity
- …



Solar load

- Direct and diffuse radiation
- Azimuth and altitude angle of the sun

Boundary conditions on external walls

- Effective radiation temperature
- Environmental temperature
- Heat tranfer coefficient

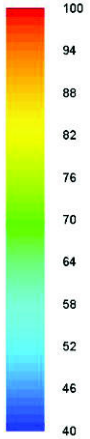
Boundary conditions on internal walls

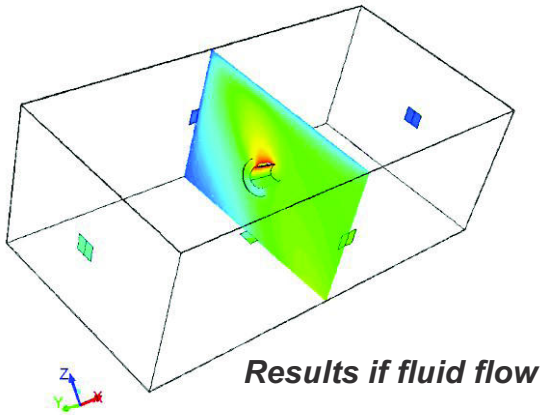
- None (calculated by solar load)

CFD Simulation

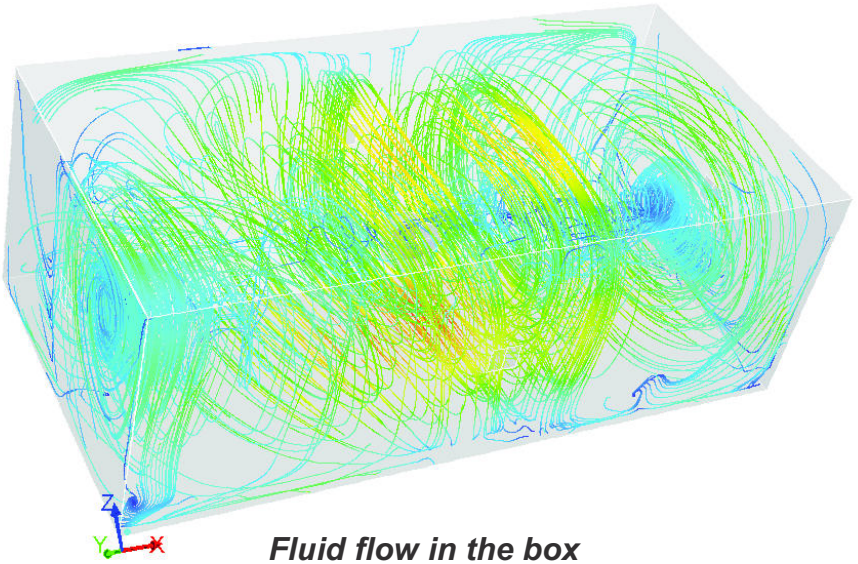
First Results

Temperature Distribution for the Hat and the Box

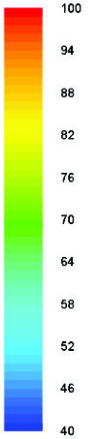


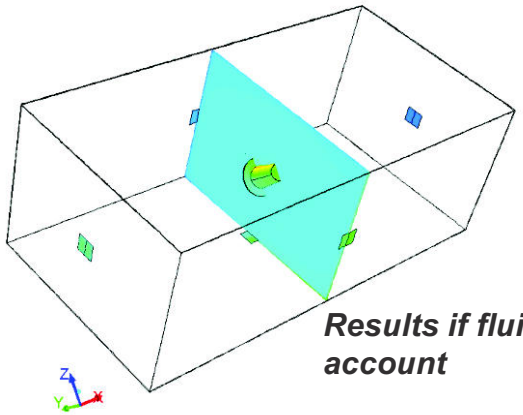


Results if fluid flow is neglected



Fluid flow in the box



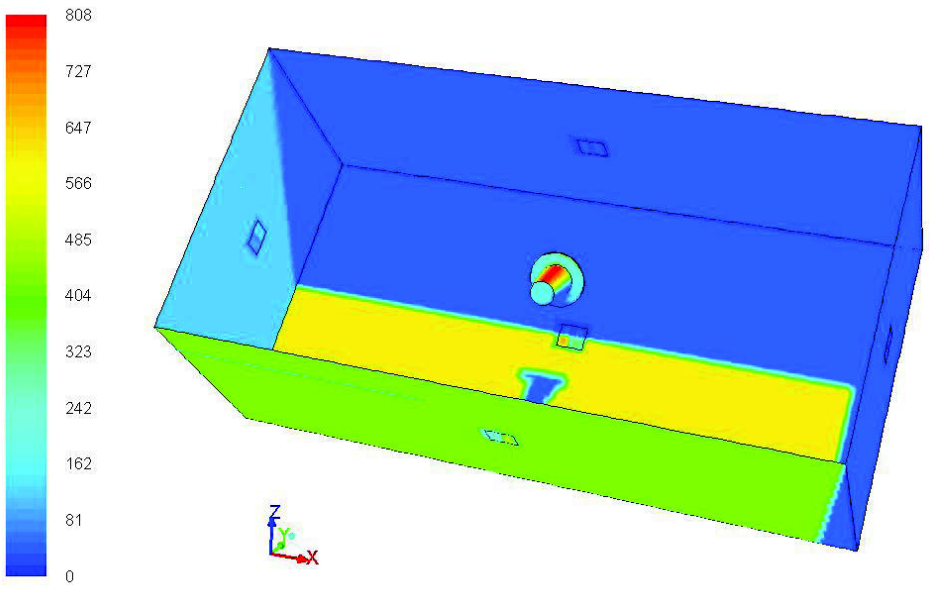


Results if fluid flow is taken into account

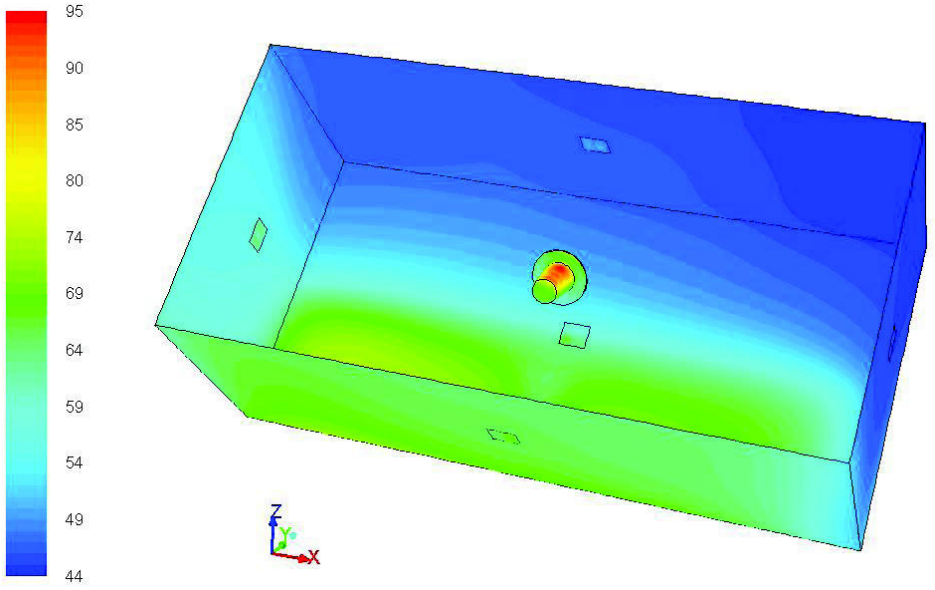
CFD Simulation

Results

Solar Irradiation and Temperature Distribution for one Sun Position



Solar Irradiation



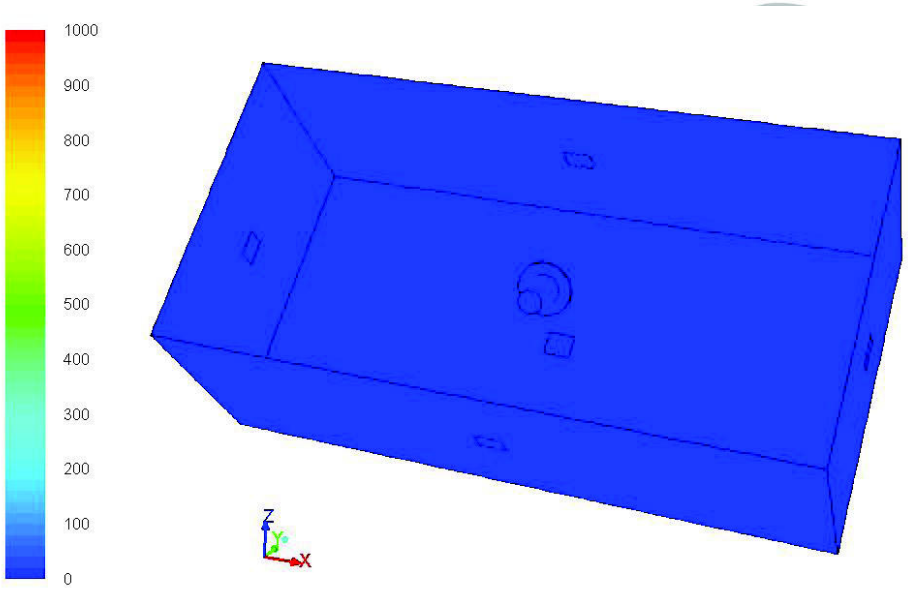
Temperature Distribution

June, 24, 2008, 12:30

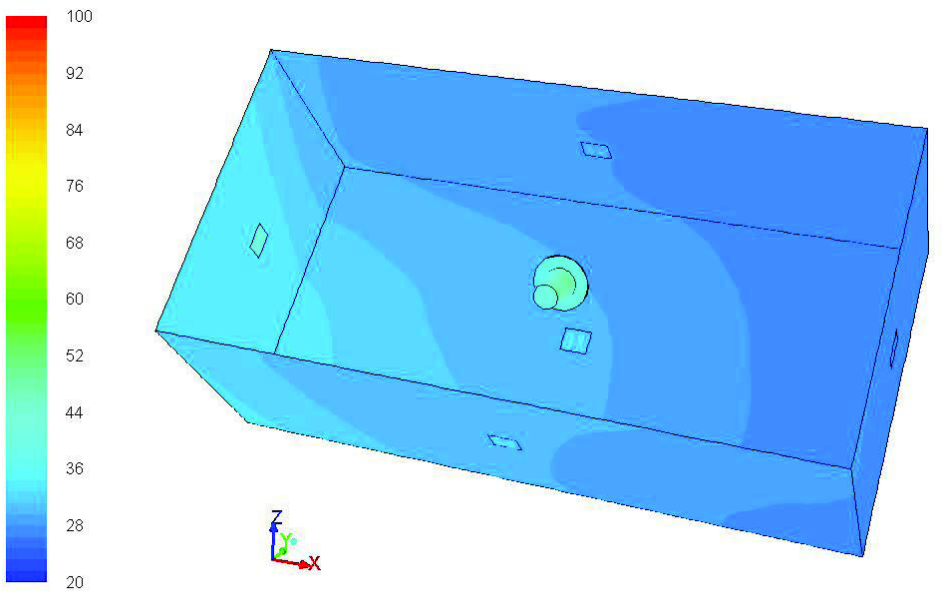
CFD Simulation

Results

Absorbed Radiation and Temperature Distribution for one day



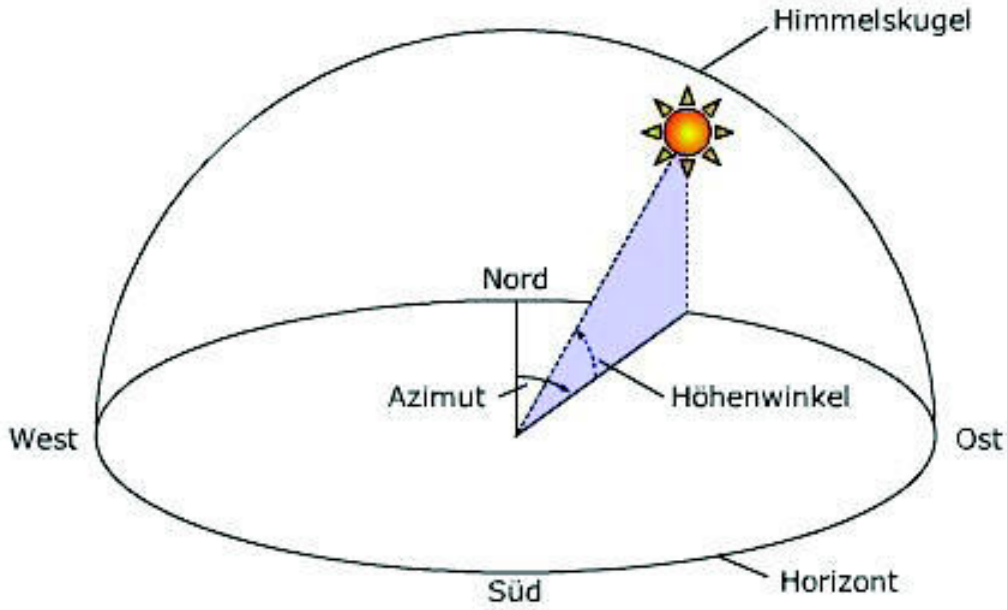
Contours of Solar Heat Flux (w/m2)



Contours of Static Temperature (c)

June 2008, 24, Arizona

Sun Positions



Azimuth of the Sun ***Height of the Sun***

Discretization Approach

Sun Positions

Challenge

Aging under sun exposition is a continuous (transient) process since

- the sun continuously changes its position during the day and the year
- the boundary conditions for the simulation continuously change

How to handle this?

- Reduction to a finite number of relevant situations and performing stationary simulations for each one of them
- Combination of similar situations (sun positions) in clusters
- Representation of each cluster by one characteristic sun position and its frequency and the corresponding ambient temperature

Discretization Approach

Characteristic Sun Positions

Sun positions occuring in Arizona and cluster representatives

Discretization Approach

Interpolation

Calculation for every finite element of the surface

Absorbed Radiation [E] of one surface element

14	10						
35	5	9					
56	72	94	18	37			
77	138	179	97	24	68		
97	205	264	177	112	122	155	
118	272	348	256	200	175	172	172
139	338	433	336	289	229	208	172
	405	518	416	294	282	244	172
		603	495	299	335	281	172
		603	575	305	389	317	172
		603	654	310	390	353	172
			734	316	391	389	172
			734	321	392	389	172
		557	655	326	393	351	171
		557	576	332	394	314	169
		557	497	337	348	276	168
	277	479	418	342	301	239	166
0	232	402	339	348	255	201	165
4	188	325	259	255	208	164	164
7	143	247	180	162	162	163	
11	98	170	101	70	115		
14	54	93	22	69			
18	9	15					
21	15						

Resulting Temperature [T] on this surface element

42	43						
41	43	46					
40	45	48	52	58			
39	47	51	54	59	63		
38	49	54	56	63	65	68	
37	51	57	57	66	67	70	70
36	53	60	59	70	69	71	70
	55	63	61	70	71	72	70
		66	62	71	74	73	70
		66	64	71	76	74	70
		66	66	71	76	75	70
			67	72	76	76	70
			67	72	77	76	70
		64	67	72	77	75	70
		64	66	73	77	75	71
		64	65	73	76	74	71
	52	63	64	73	75	74	72
31	52	62	64	74	73	73	72
35	52	61	63	71	72	73	73
39	52	59	62	68	71	72	
43	52	58	61	66	69		
46	53	57	60	65			
50	53	56					
54	54						

Temperature and solar Radiation for the Clusterrepresentatives were directly simulated

Temperature and solar Radiation for all other positions were interpolated

Aging Simulation

Dose-Effect-Relationship

Probability of crack formation*

This dose-effect-relationship (w) describes the material change as a function of irradiance (E) and temperature (T) over the time.

$$w_0(t) = \int_{t_0}^{t} \int_{\lambda_0}^{\lambda_E} \frac{0.0218}{1+\exp\left(\frac{\lambda - 324.8}{20.3}\right)} \cdot E_\lambda(t) \cdot d\lambda \cdot 1900 \cdot \exp\left(\frac{-2464}{T(t)}\right) \cdot dt$$

Wavelenght integration

Arrhenius-factor

Time integration

Aging algorithm

Calculation of w(t) for all specimen surfaces by summation over all occuring sun positions and their frequencies

** Source: German Federal Institute for Materials Research and Testing BAM, Berlin, Germany, Dr. Anja Geburtig)*

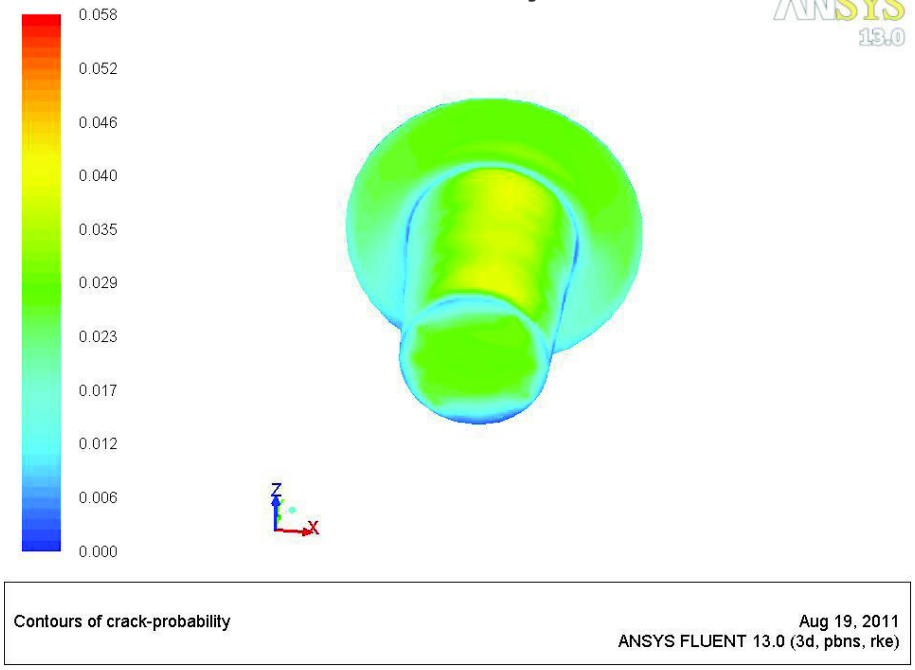
Aging Simulation

Results

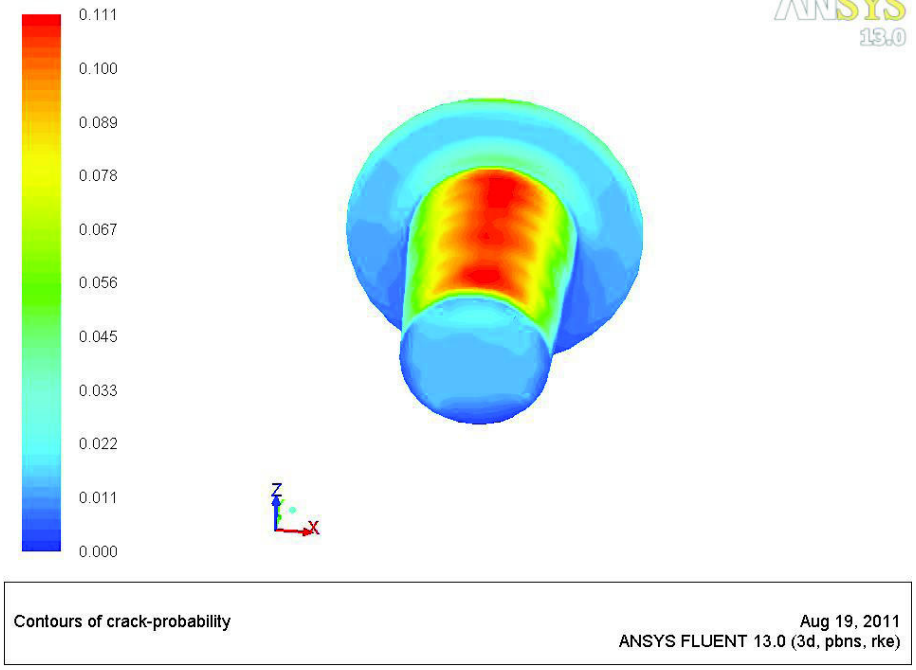
Monthly Contributions to the Crack Probability

Summation of the contributions to the Dose-Effect-Relationship with their monthly appearing frequency

February



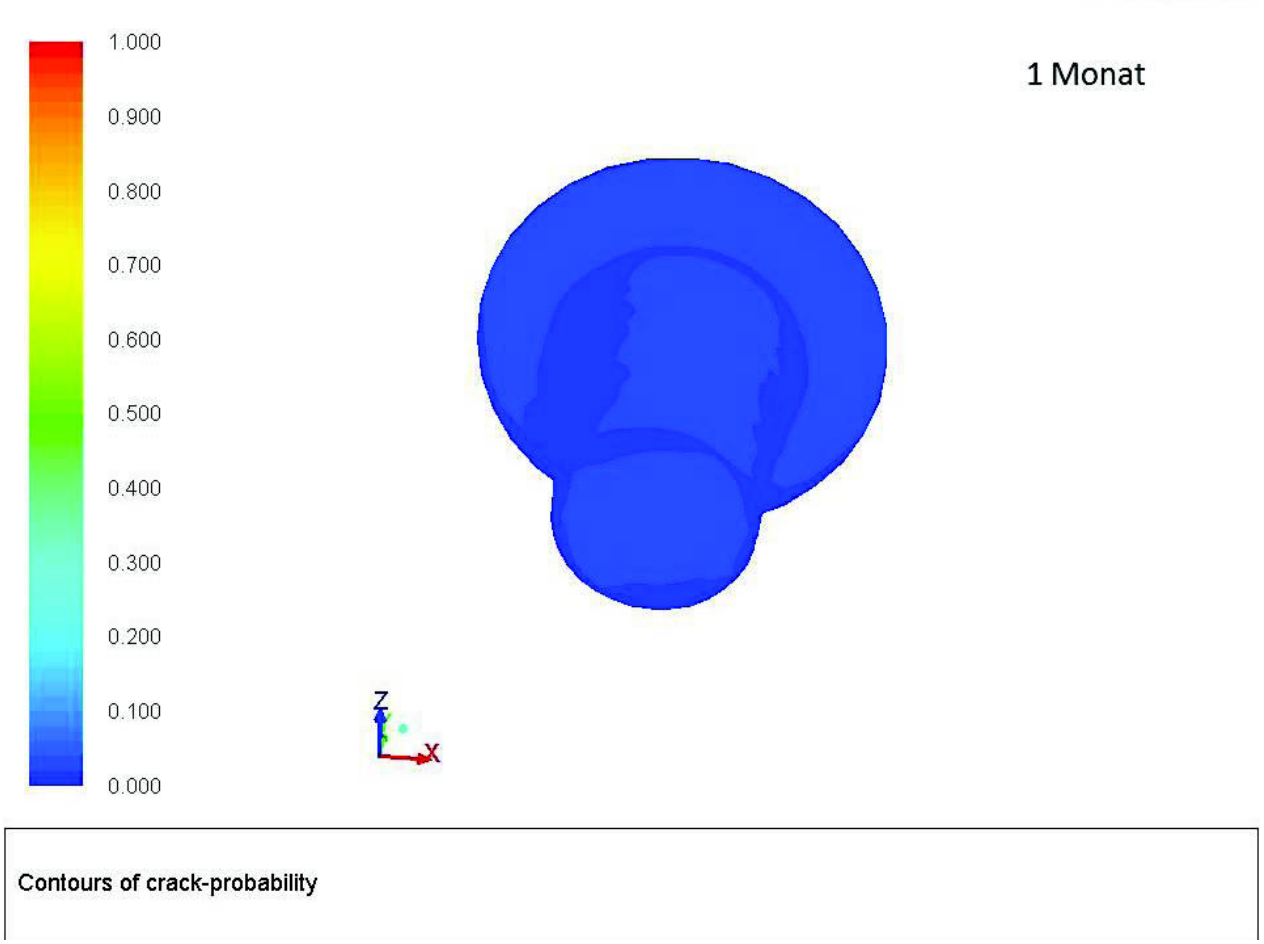
July



Aging Simulation

Results

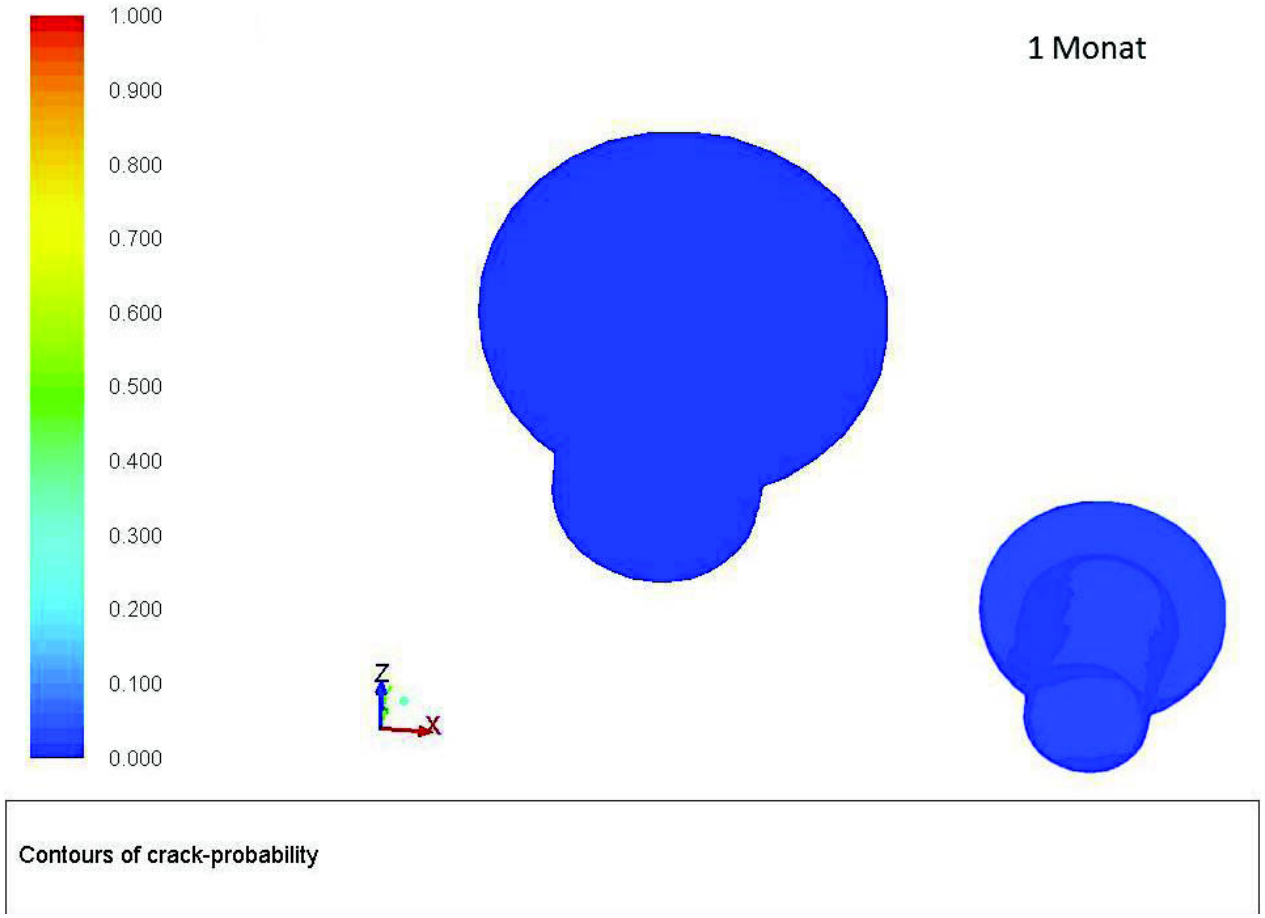
Crack Probability of the black hat in time



Aging Simulation

Results

Crack Probability of the white (large) and black (small) hat in time

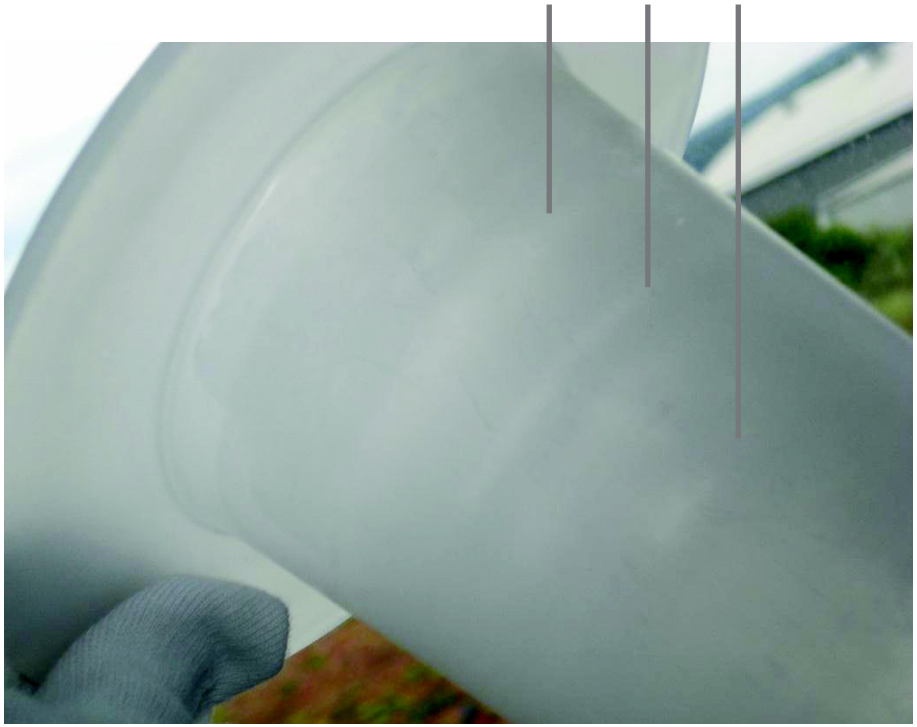


Research Project VipQuali

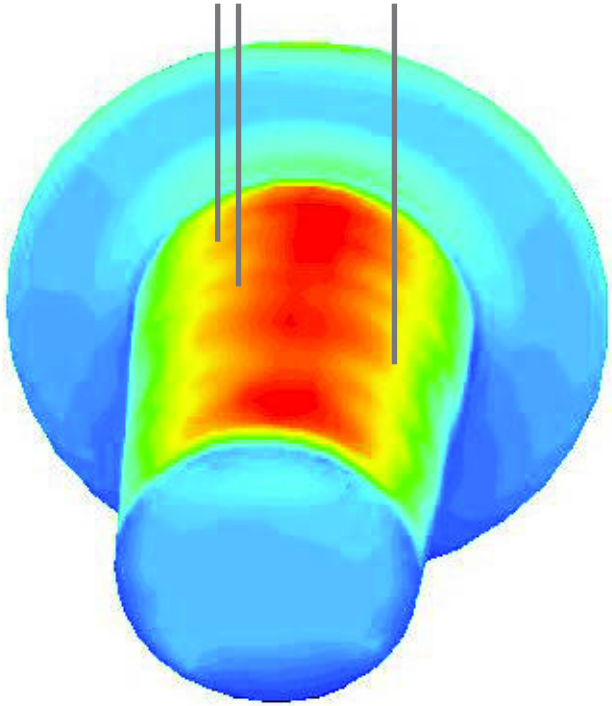
Experiment vs. Simulation

Material damage of the specimen after 2,5 years exposition in the sun

Material damage stripes



Experimental results

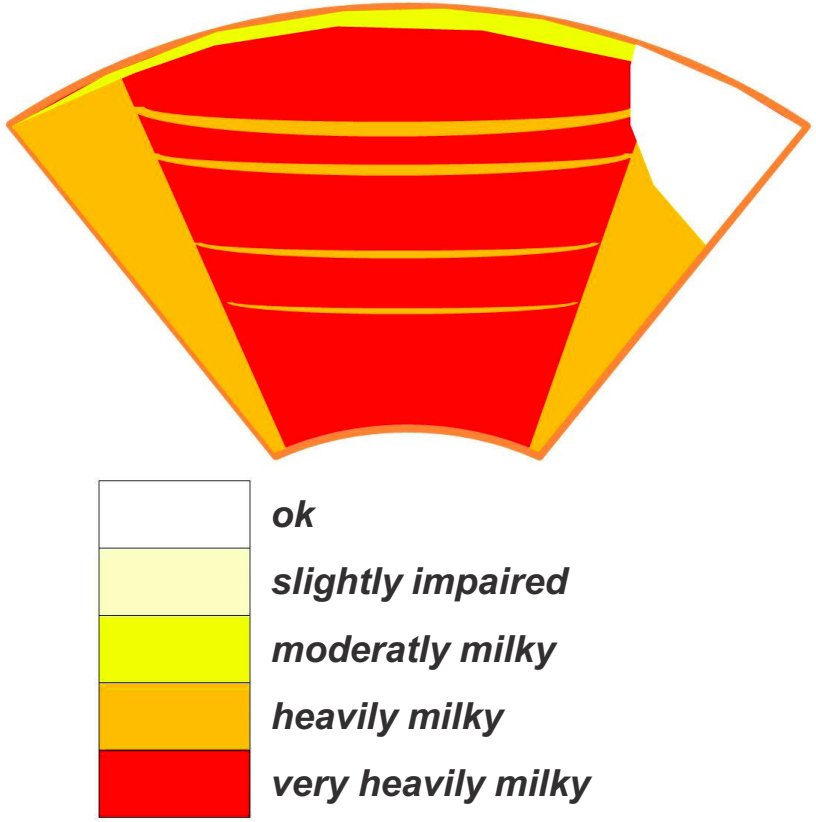


Simulation results: crack probability

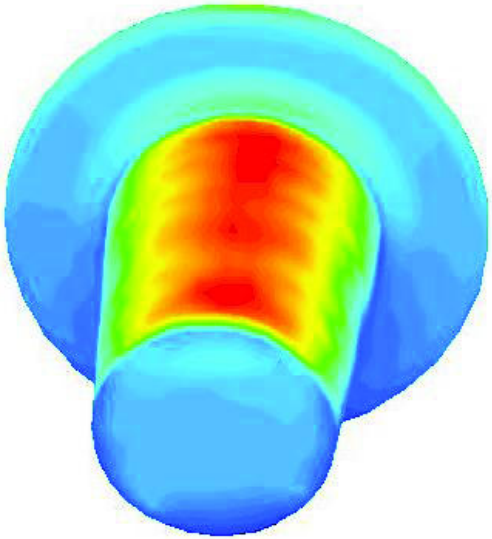
Research Project VipQuali

Experiment vs. Simulation

Material damage of the specimen after 2,5 years exposition in the sun



Experimental results

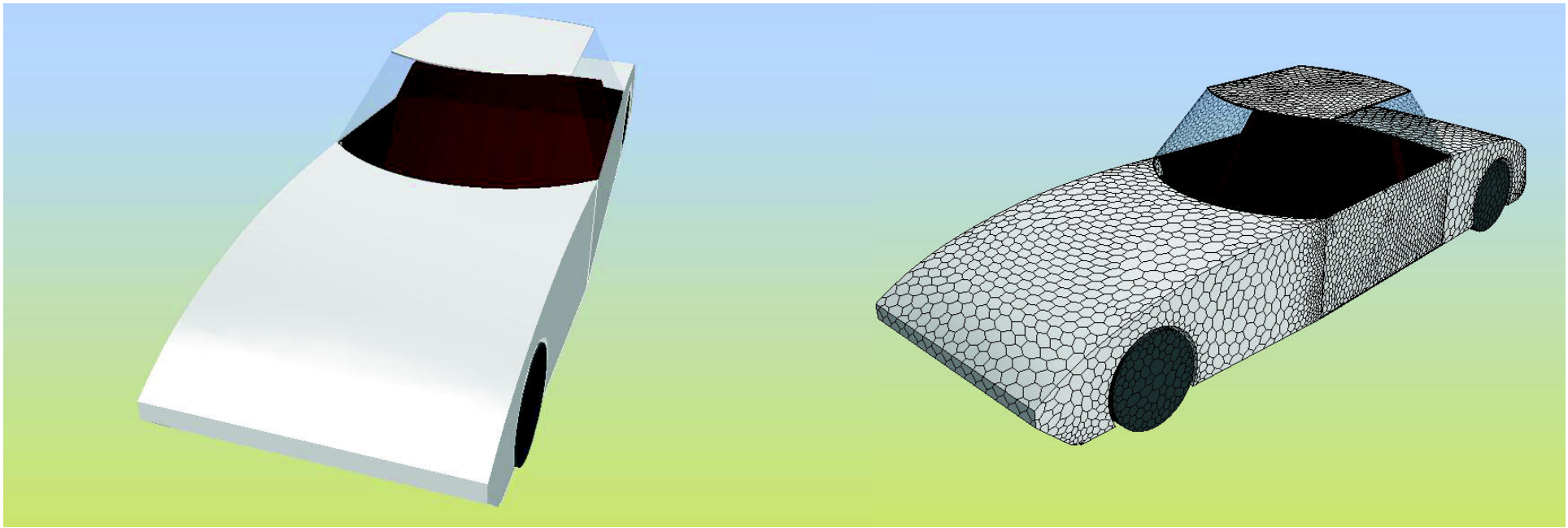


Simulation results: crack probability

Industrial Application

Aging Simulation in a Car Cabin

Methodology transfer to a real problem



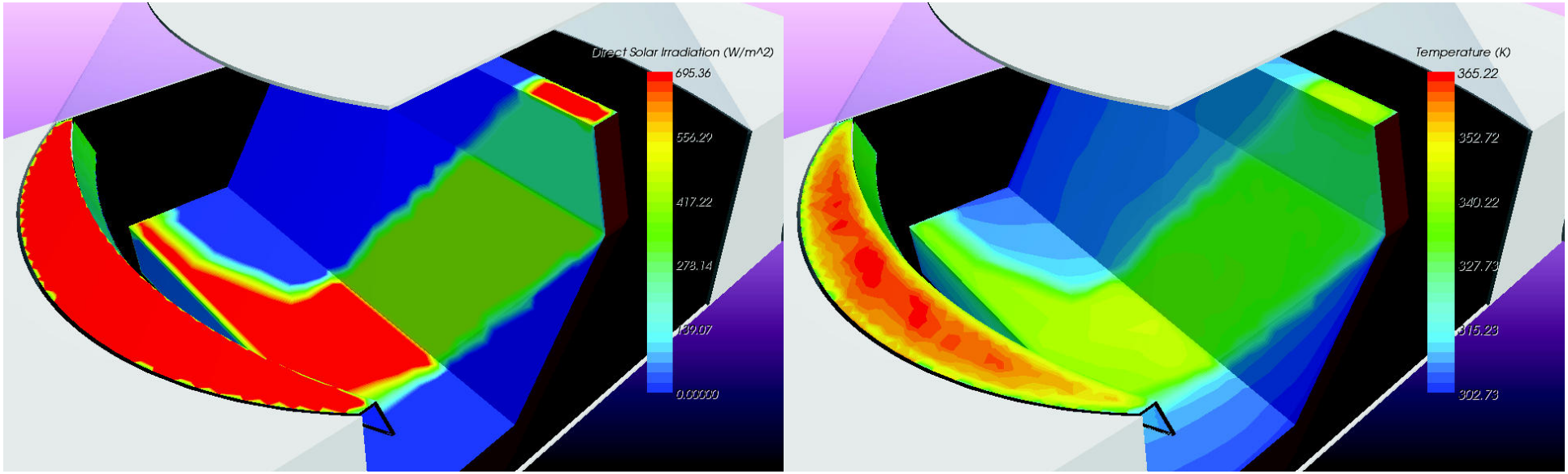
Geometrical model

Finite volume mesh

CFD Simulation

Results

Irradiation and temperature distribution for a given sun position

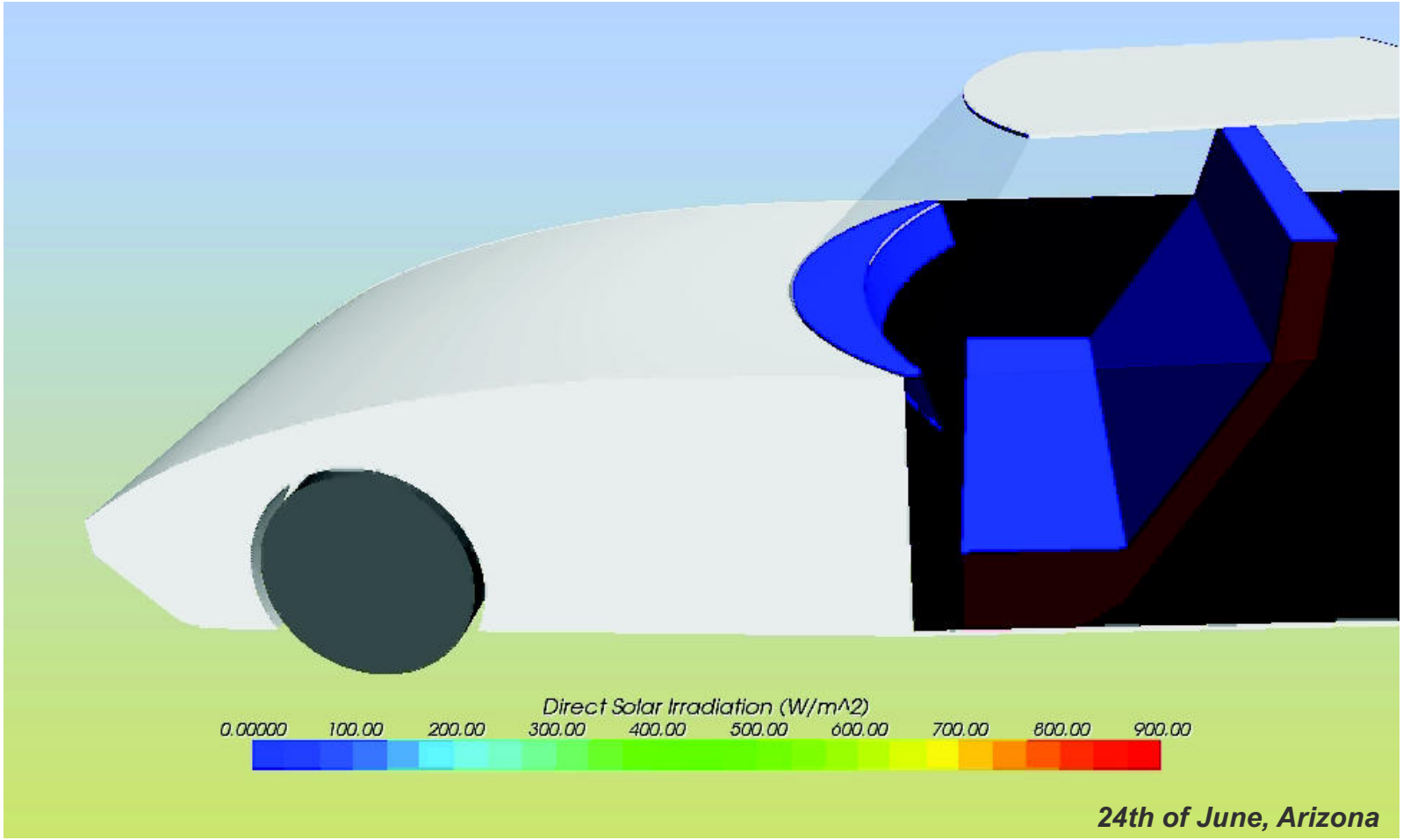


10:10 a.m., 24th of June, Arizona

CFD Simulation

Results

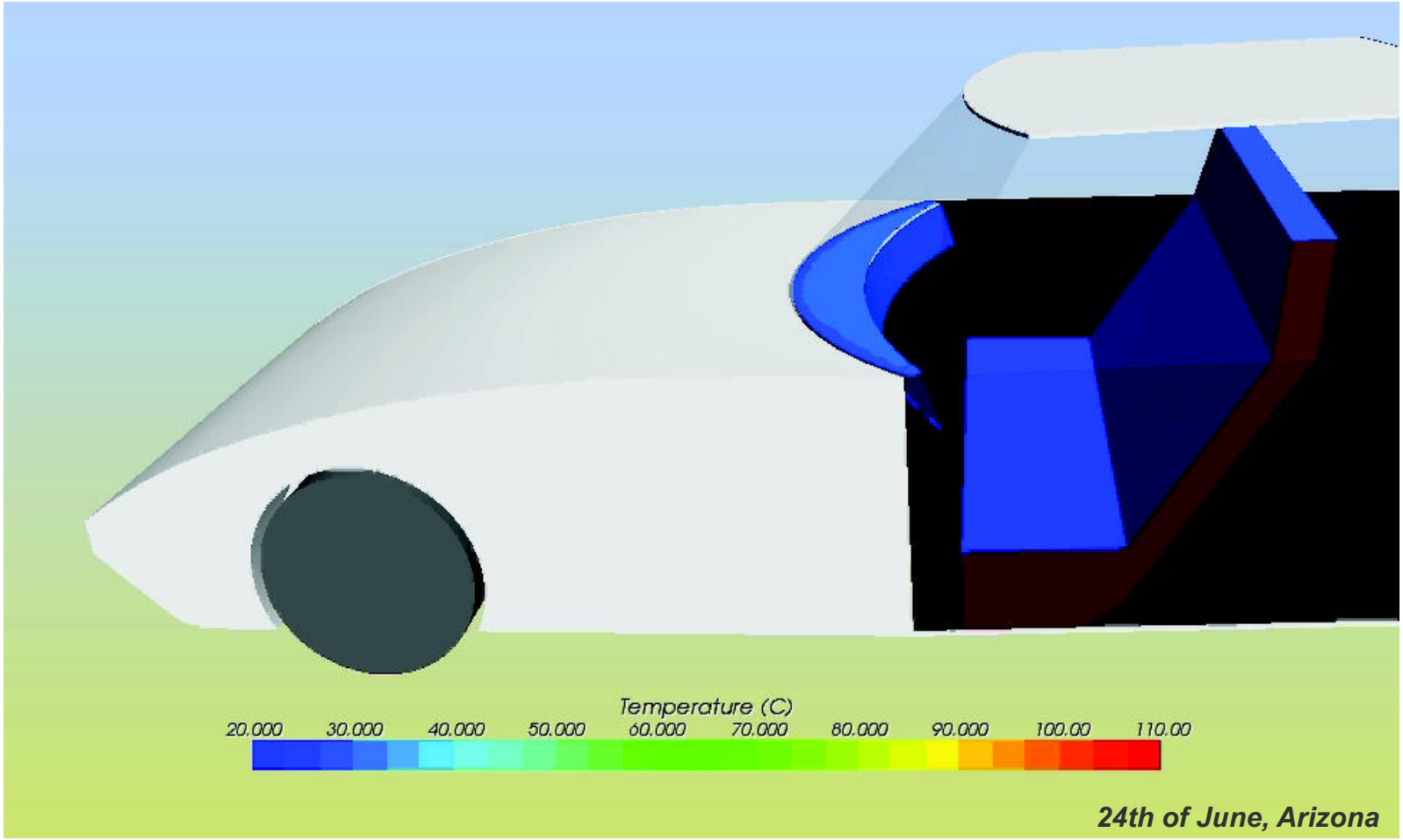
Irradiation distribution for one day



CFD Simulation

Results

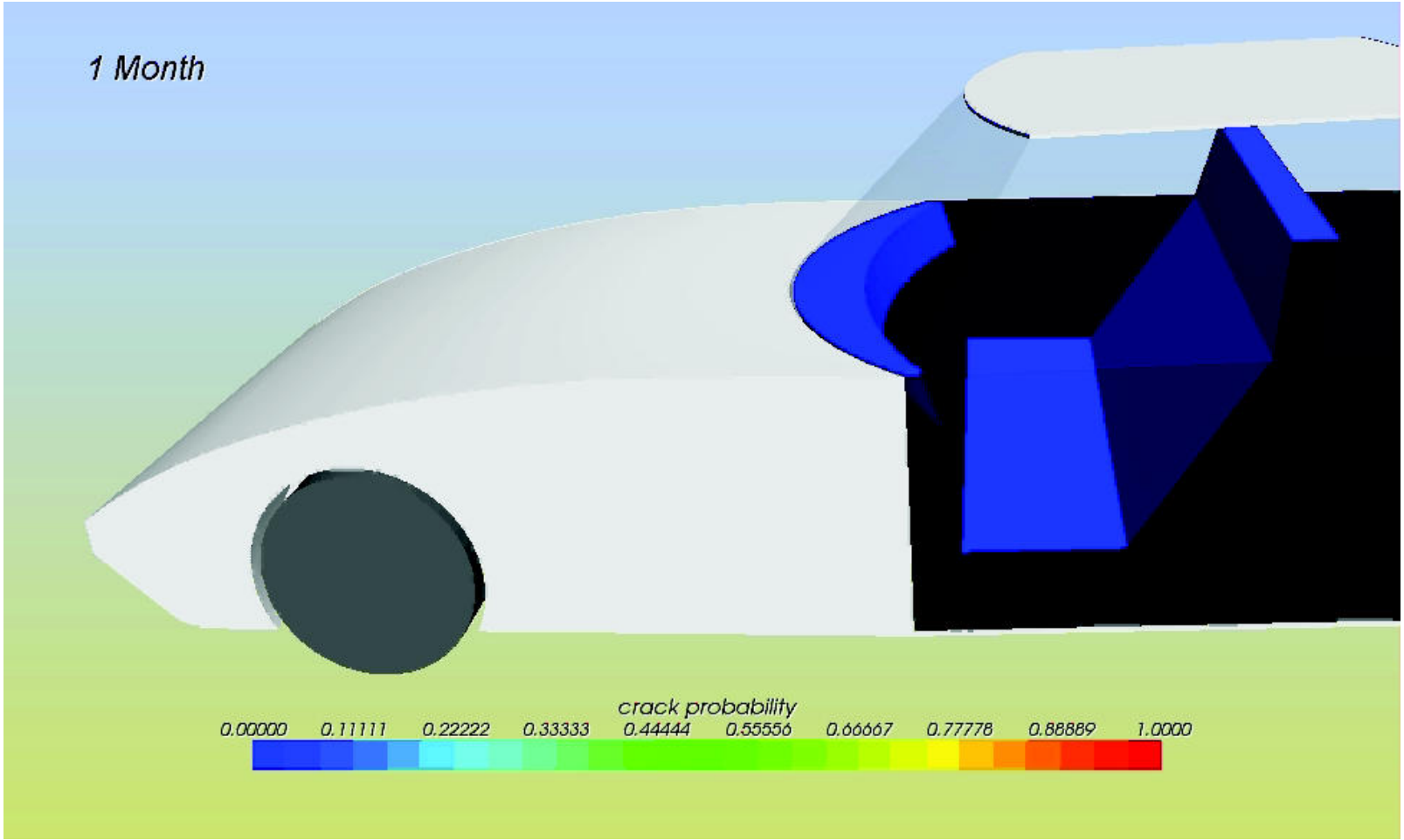
Temperature distribution for one day



Aging Simulation

Results

Probability of crack formation over two years



The Numerical Aging Tool

Modules

Climate Module

- Calculation of all occurring sun positions (azimuth and altitude) at an arbitrary geographical location
- Calculation of direct and diffuse solar radiation for an arbitrary geographical location, sun position and wall orientation
- Calculation of effective radiation temperature on the external walls of an arbitrary specimen
- Discretization of sun positions into characteristic clusters and interpolation of simulation results for all occurring sun positions

CFD Modul

- FLUENT, STAR CCM+

Aging Modul

- Calculation of the dose-effect-function by means of summation over all occurring sun positions and their frequencies
- Visualization tool

Applications and Research

Outlook

Application of the methodology for every product exposed in the sun

- Temperature, radiation and velocity distribution can be calculated for an arbitrary product at any geographical location and climate
- Accumulation of the effects of these physical quantities over time

Perspectives

- Correct aging simulation of other materials requires additional experimental research in order to find a real dose-effect-relationship for these materials
- Future cooperation with companies interested in industrial and scientific projects on this topic

cogito ergo sim

think and simulate