Aerodynamic Design of the Reichstag

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The work was performed from 1995 to 1999 at the TU Dresden

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History + Situation in the year 1995

1894: Construction (including plenar hall + glass dome)

1933: Fire in the plenar hall

WW2: Strong destructions

1961 – 72: Partial rebuilding

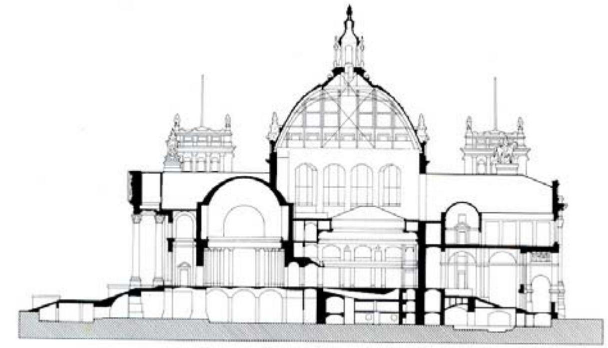
1990: Decision to use the Reichstag for the House of the German Parlament

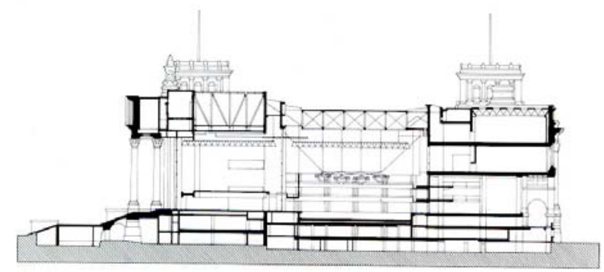
1992: Competition between 800 architects from 54 contries

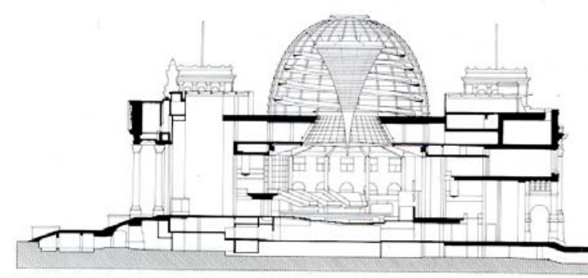
1995: Selection of the winner: Sir Norman Foster

1995 – 99: Extensive rebuilding

1999: First meeting of the Lower House of the German Parlament (Bundestag)


1894


1971


1999

Technical requirements

Dome:

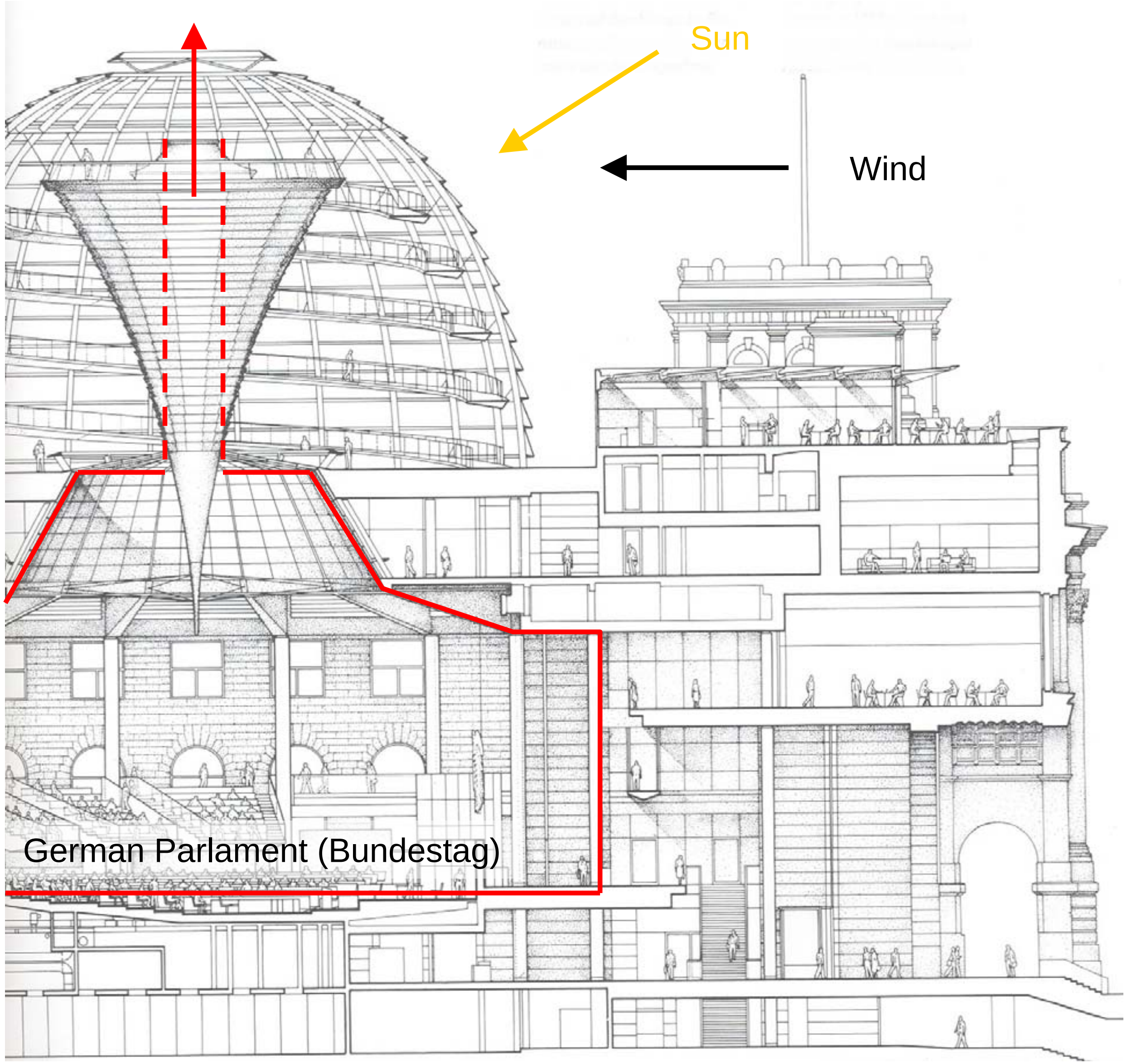
• Force / Pressure
• Icing of the glass
• Supply air / outgoing air

-> Wind tunnel tests + CFD

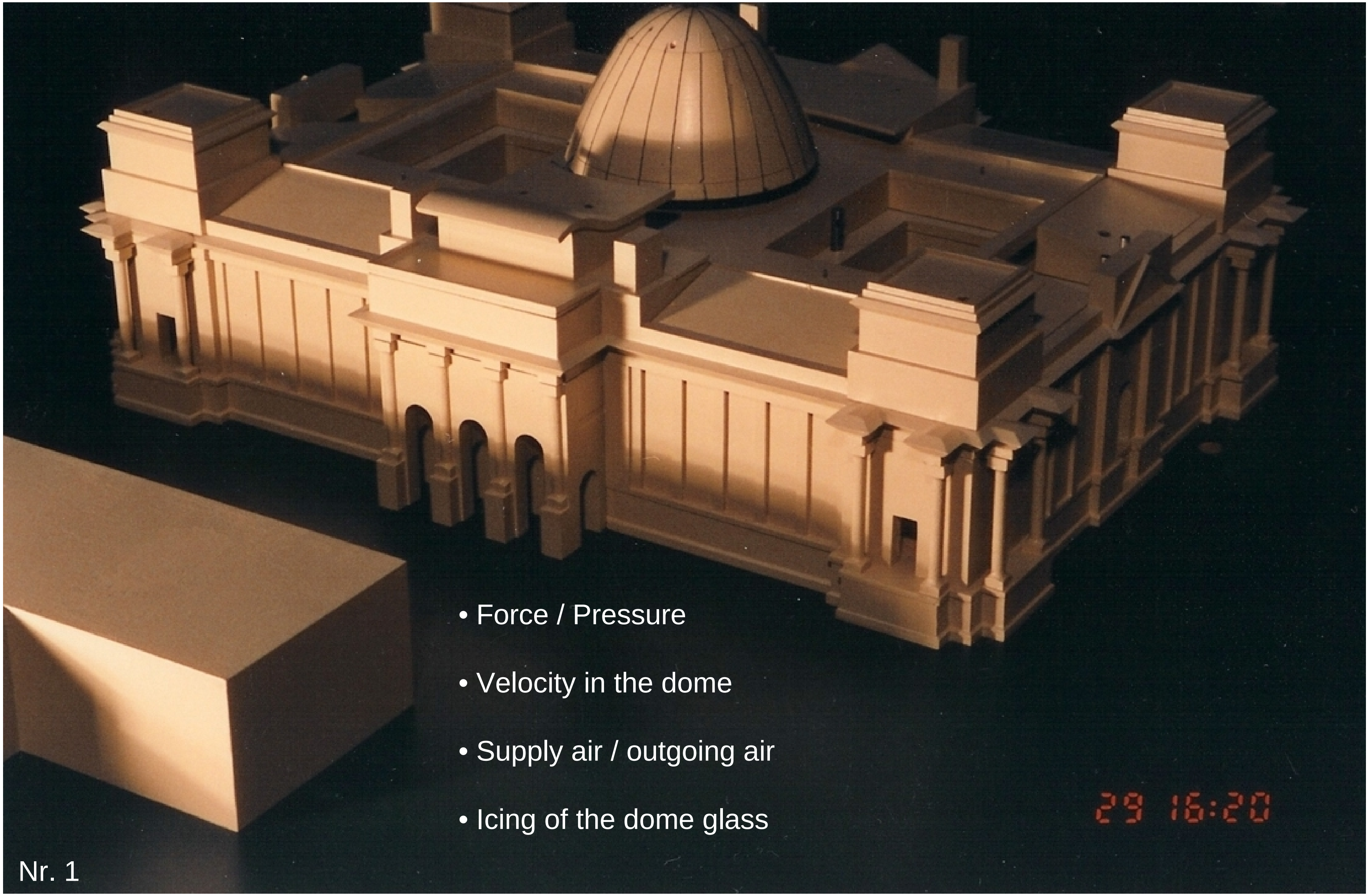
Plenar hall:

• Comfort
• Energy consumption

-> CFD + Original tests



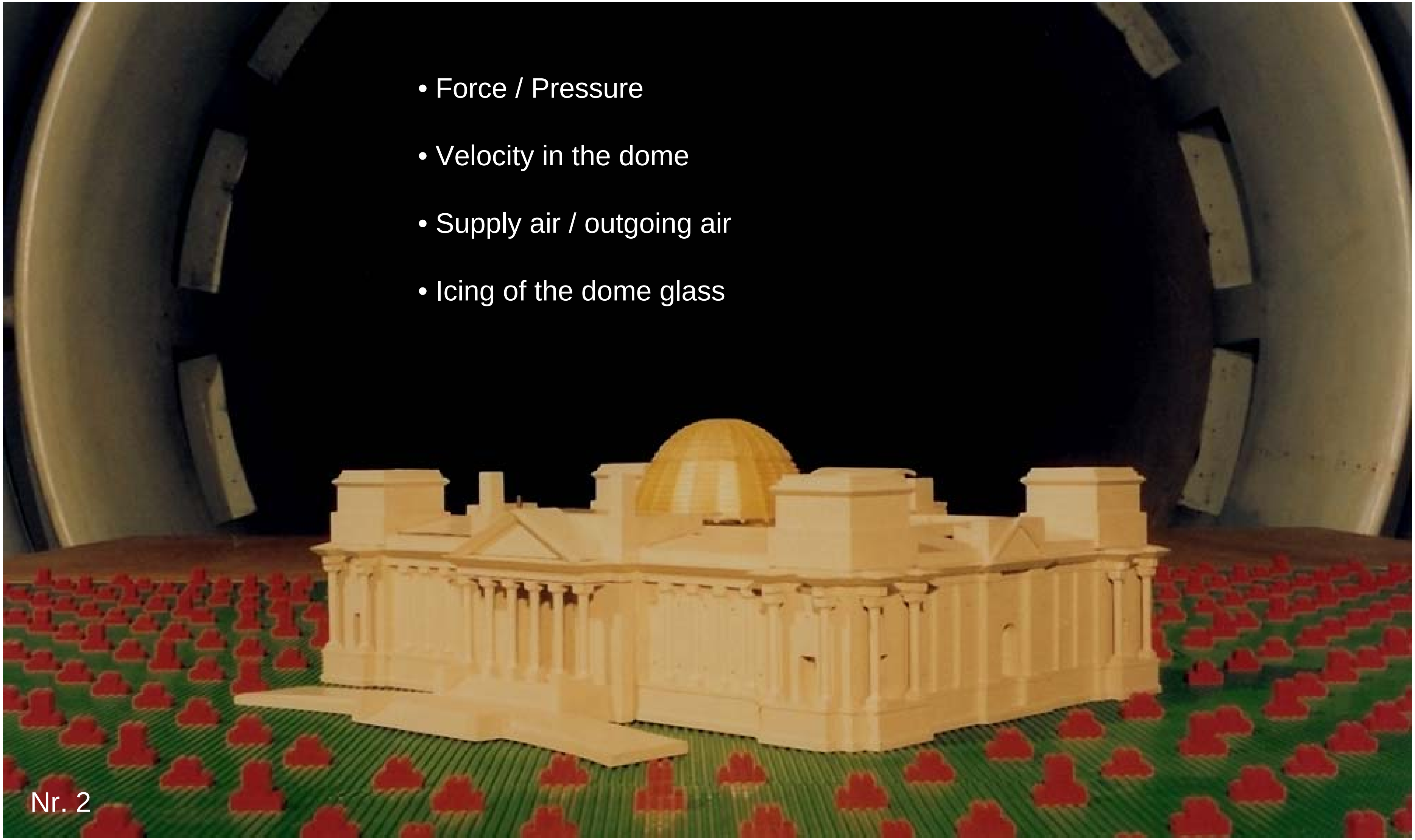
Wind tunnel tests – Reichstag dome



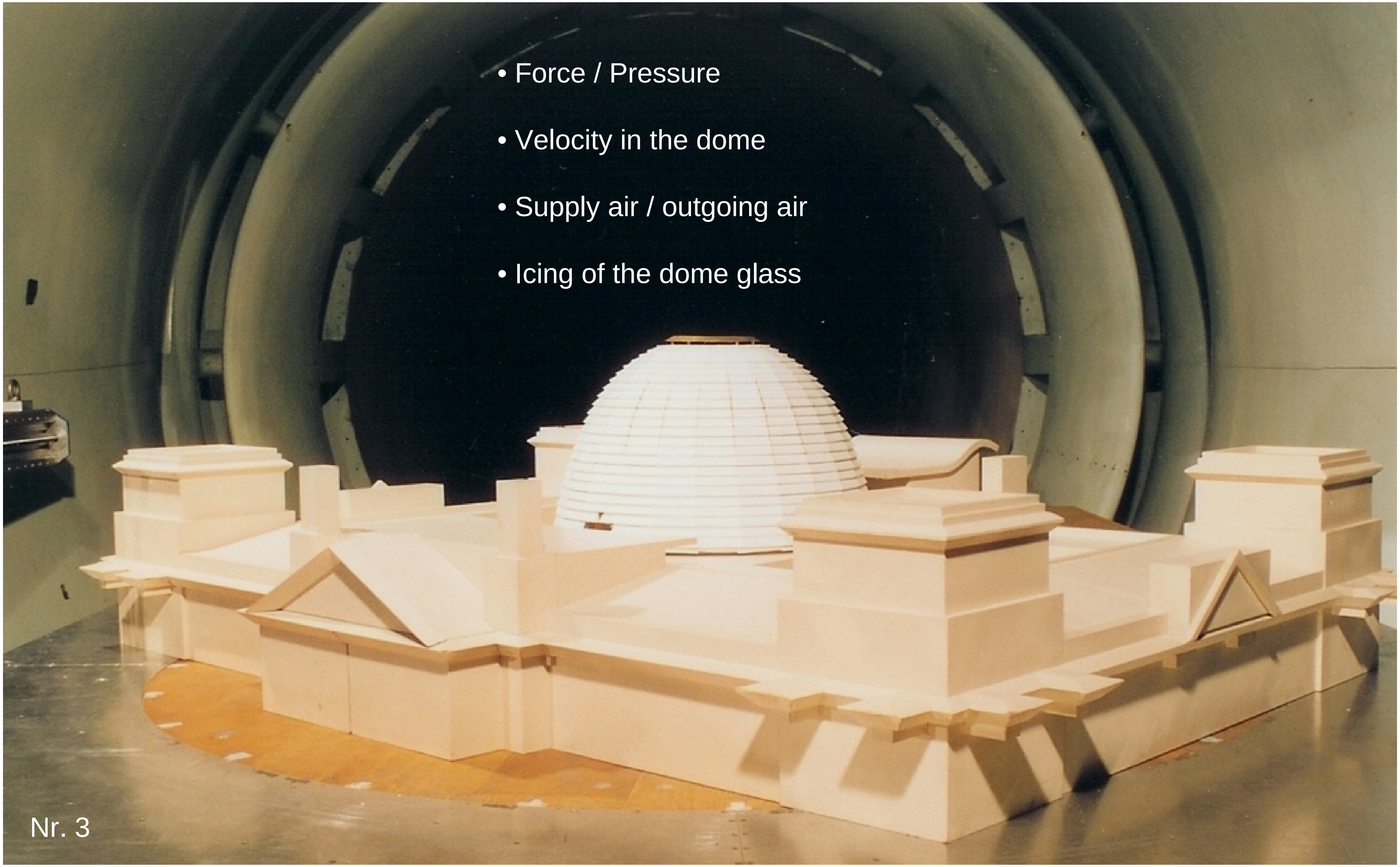
- Force / Pressure
- Velocity in the dome
- Supply air / outgoing air
- Icing of the dome glass

Nr. 1

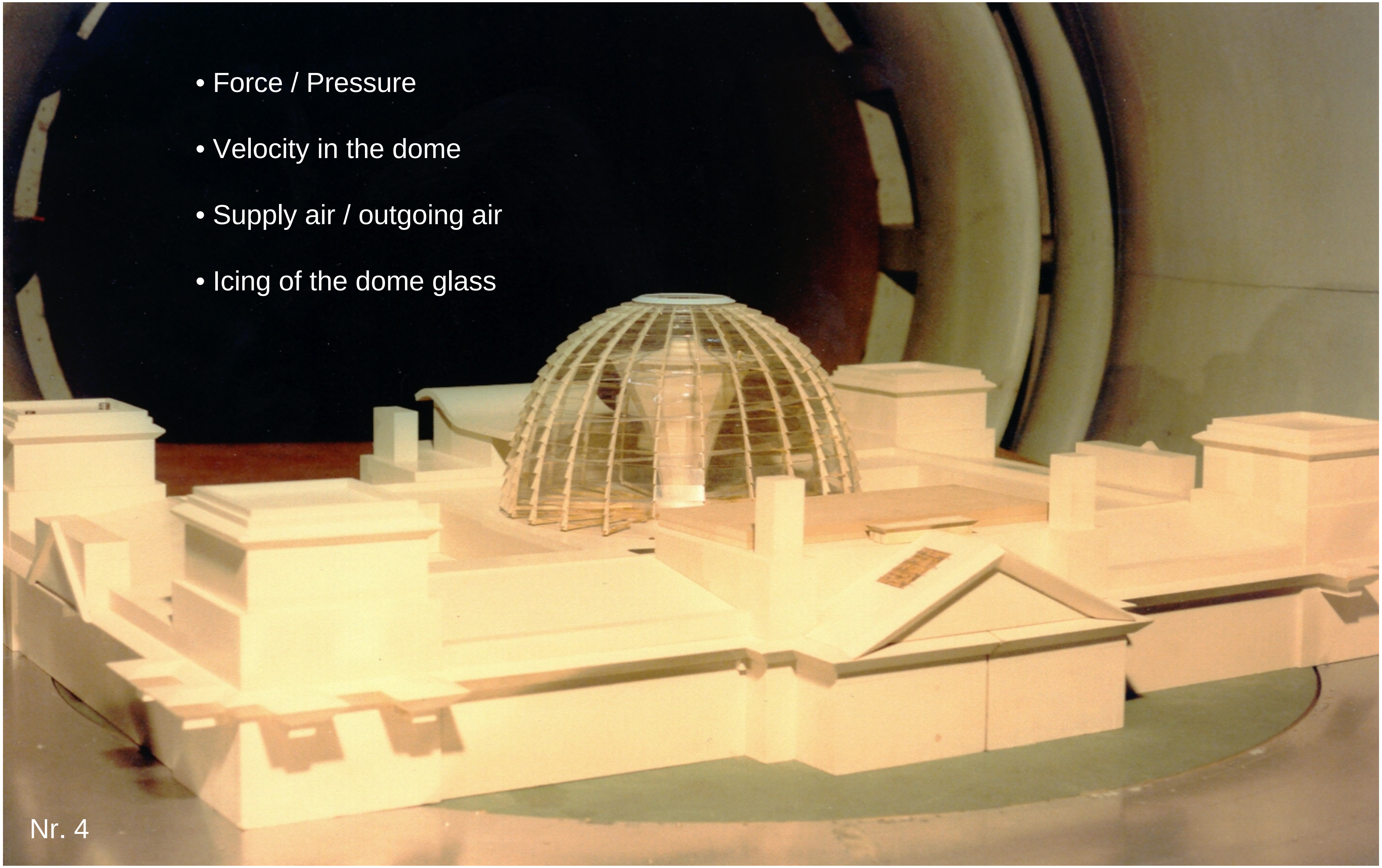
Wind tunnel tests – Reichstag dome



Wind tunnel tests – Reichstag dome



Wind tunnel tests – Reichstag dome

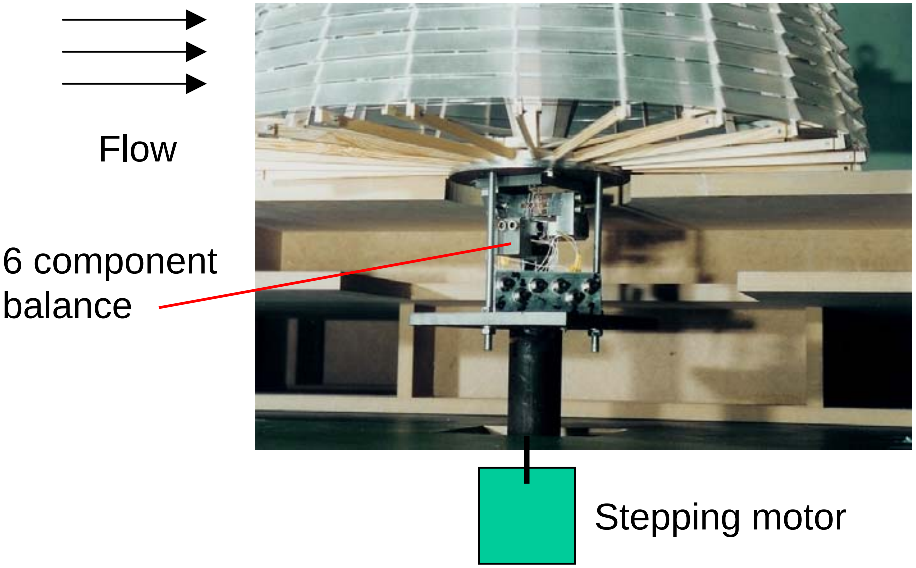


Wind tunnel tests – Reichstag dome

• Force measurements by 6 component balance

• Pressure measurements at one section

• Integration of 24 pressure sections

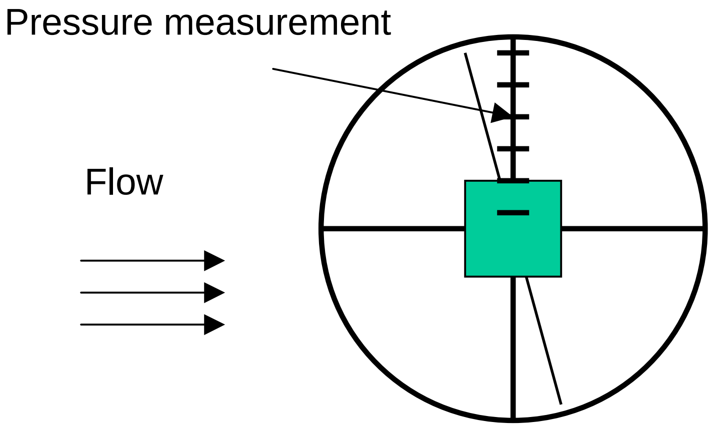


<u>Results were delivered to the:</u>

• Stress analysists / designer of the dome

• Glass suppliers (local pressure differences)

• Operator of the Reichstag (Comfort in the dome)

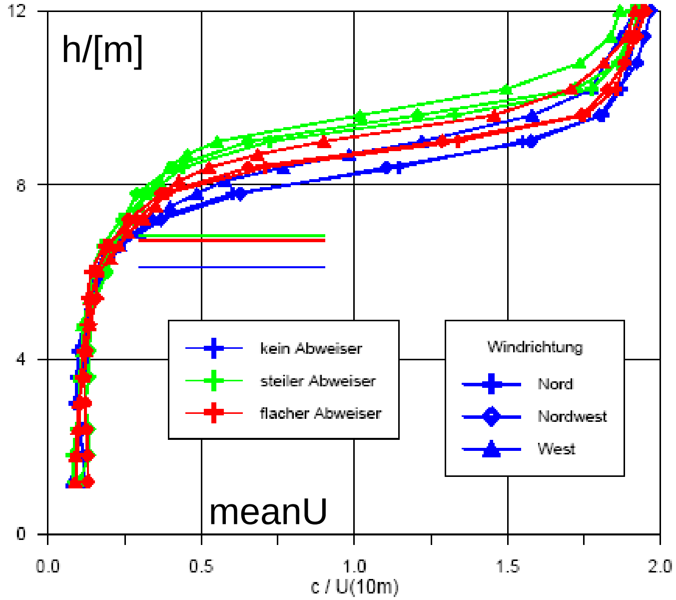


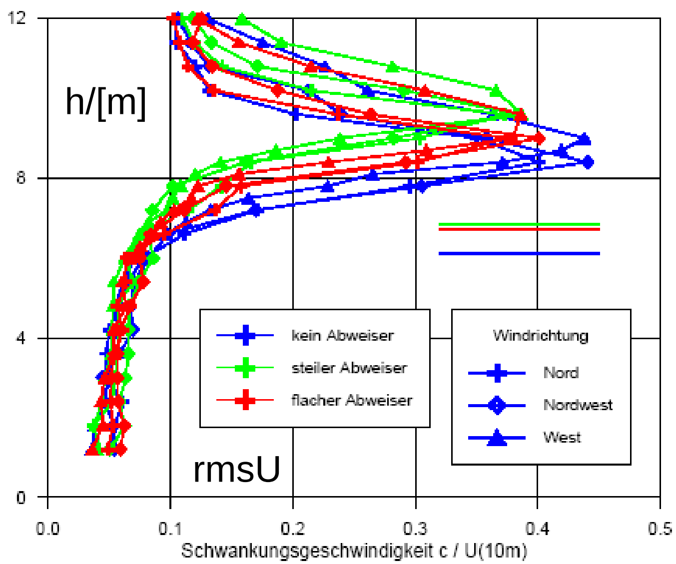
24 sections for pressure measurement

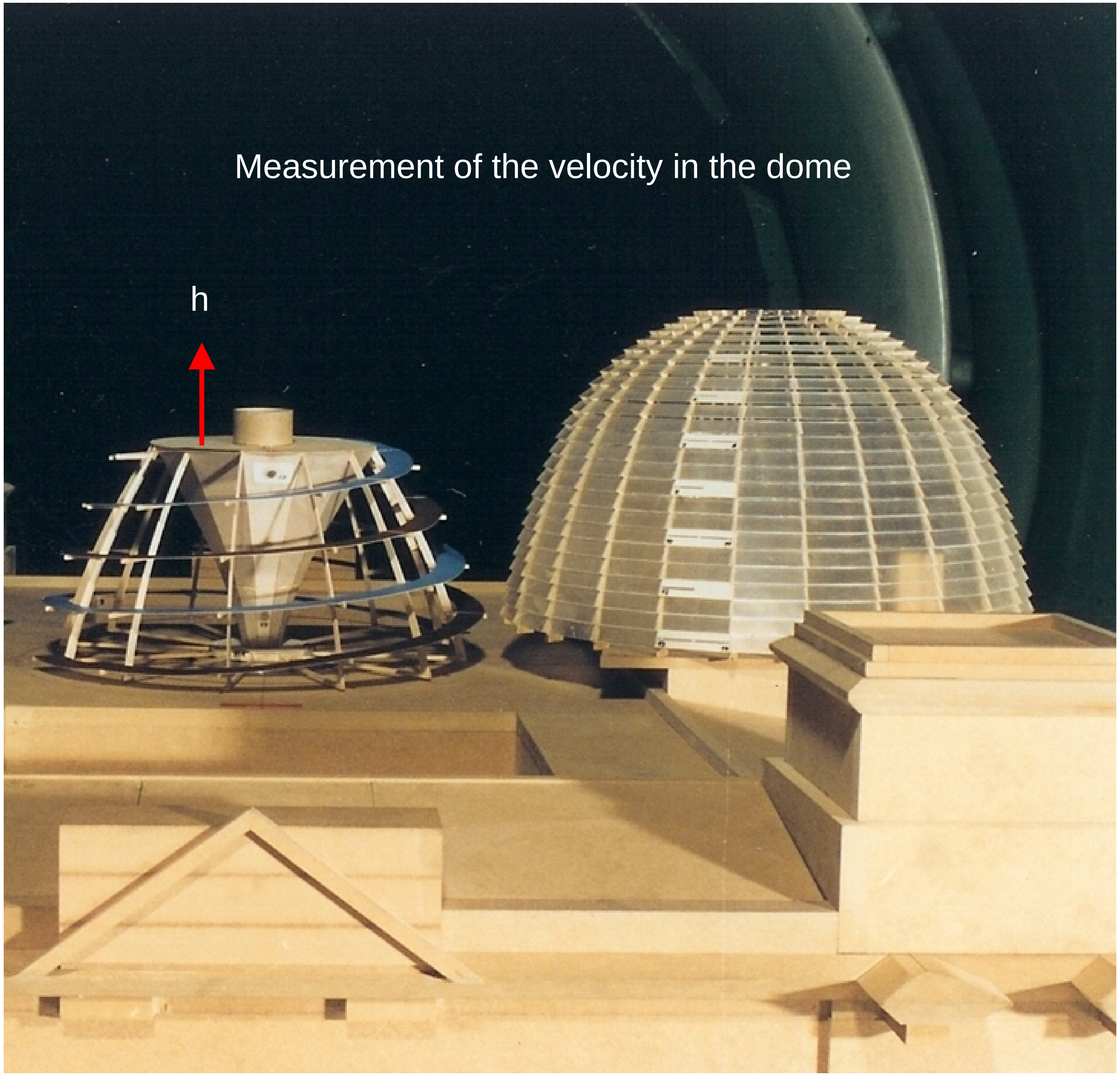
Expectet result for 42 m/s (maximum):

Fz = 1205 kN
Fges = 697 kN
M = 3197 kNm

Wind tunnel tests – Reichstag dome



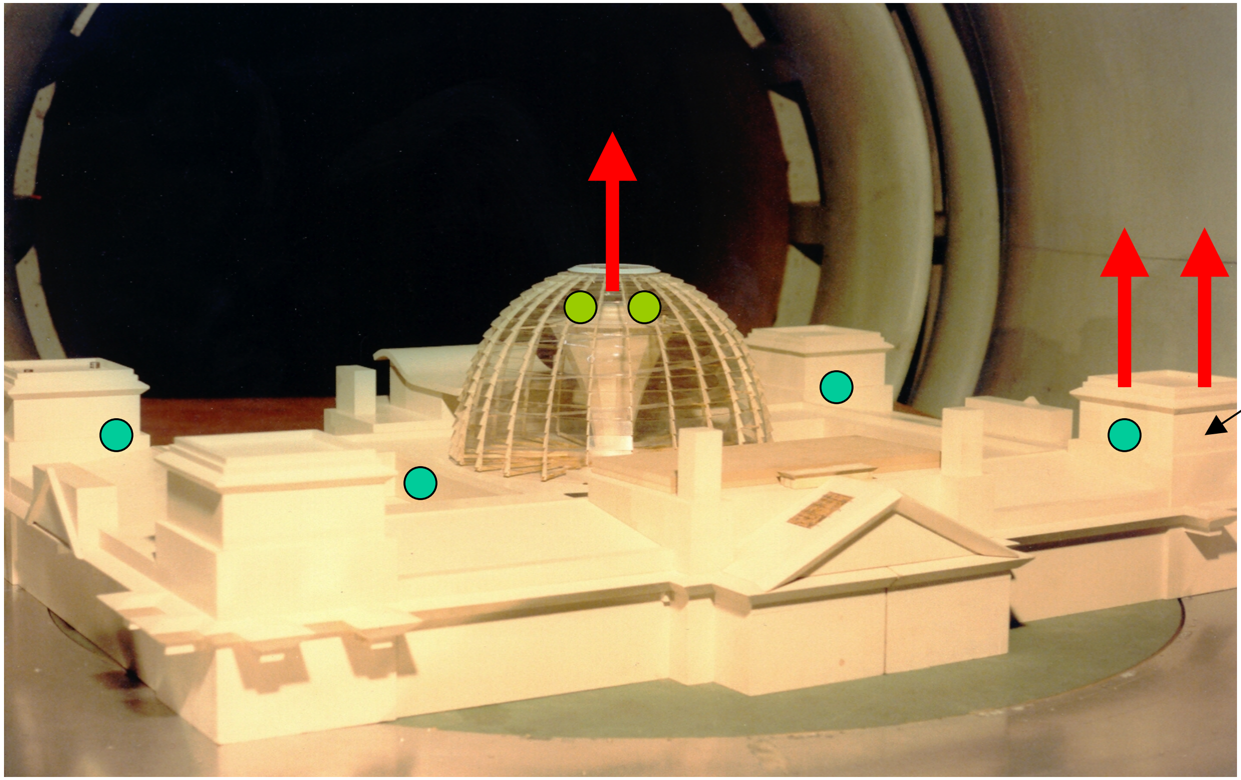




Wind tunnel tests – Reichstag dome

- Supply air / outgoing air

There are 2 major points for outgoing air an several for incoming air.



Incoming air points

Internal
Block power station

<u>Variation of:</u>

- Air speed
- Angles of the wind

The request was to avoid a „short cut“ in the air condition system.

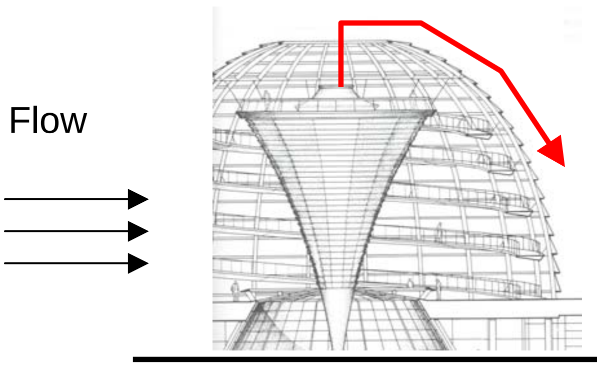
Wind tunnel tests – Reichstag dome

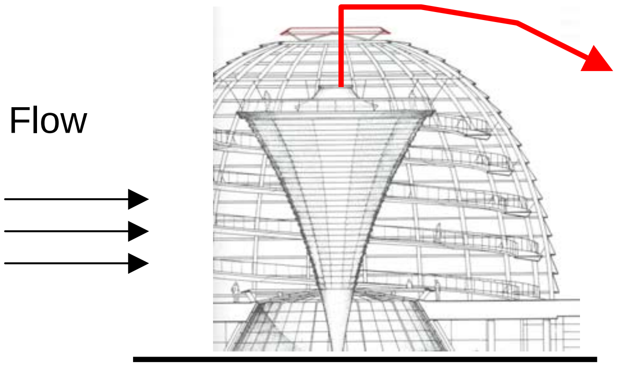
- Icing of the dome glass

The humidity of the outgoing air can touch the dome.

This can produce icing at the dome.

Thickness? Problems? Sun?



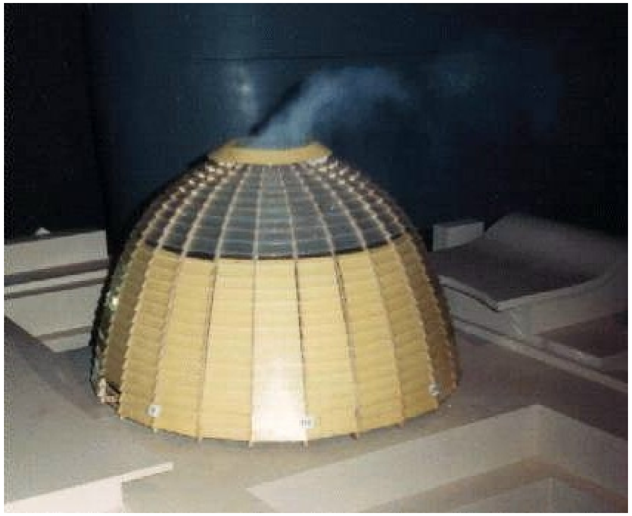


One request was to avoid this attached flow. (Difference to aircraft aerodynamics...)

Wind tunnel tests – Reichstag dome

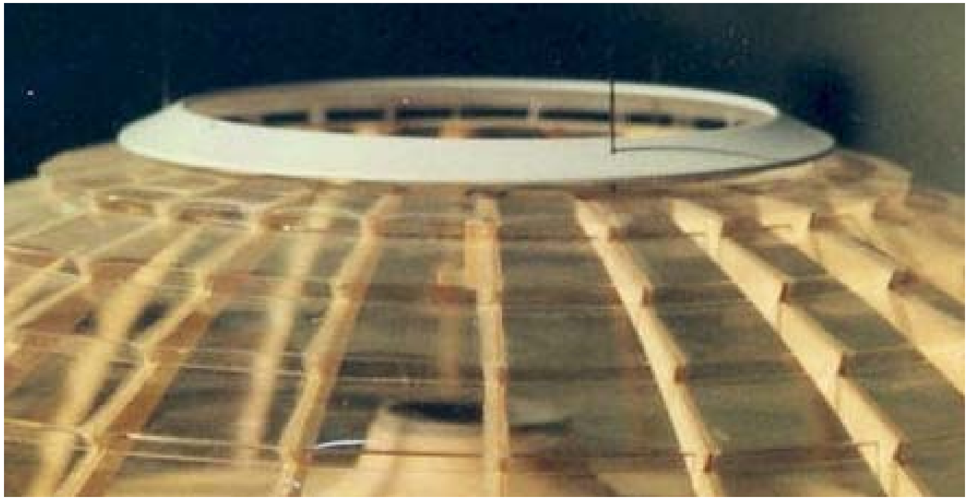
• Icing of the dome glass

First tests with the dome model



Several ring types and distances were tested.

The design was optimised with the final dome model.



Best solution was a ring from a used cat dish!

Original ring

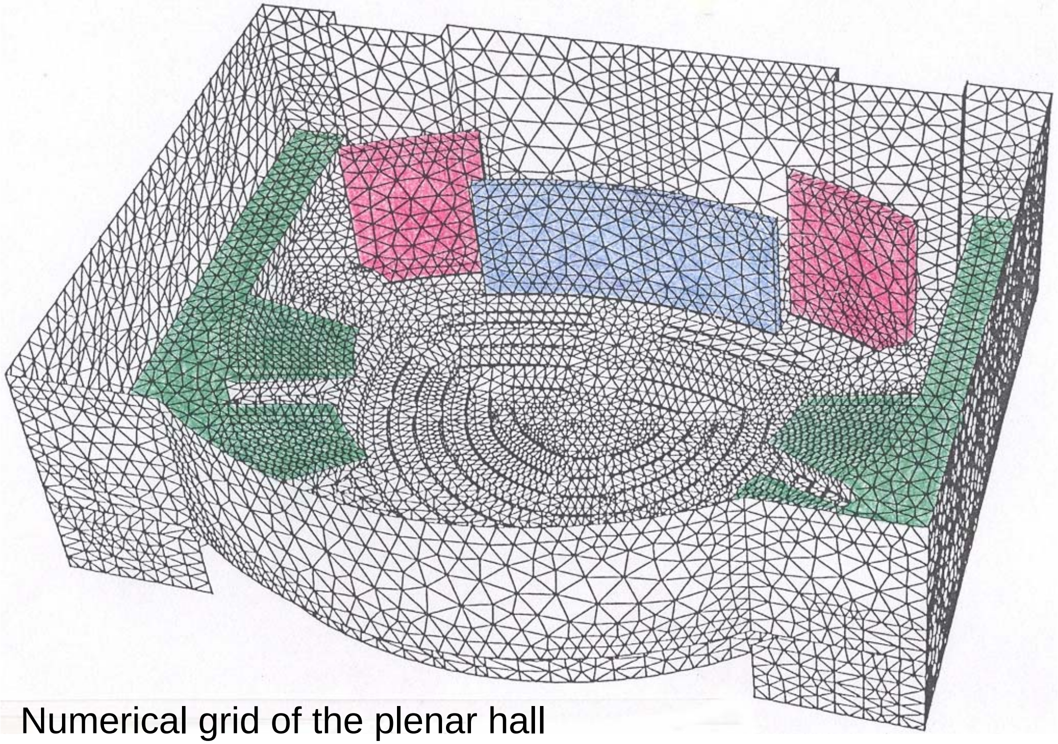
CFD tools for the plenar hall

Requirements to the CFD tools:

$R \sim dT * L^3$
$Re \sim U * L$
→ CFD

- Complex geometries (Fluent + own TU Dresden FVM + FEM -NS – solver)
- Incompressible flow solver
- Consideration of forced / free / mixed convection
- Consideration of various thermal stratification

→ New wall functions



Numerical grid of the plenar hall

Development of new wall functions

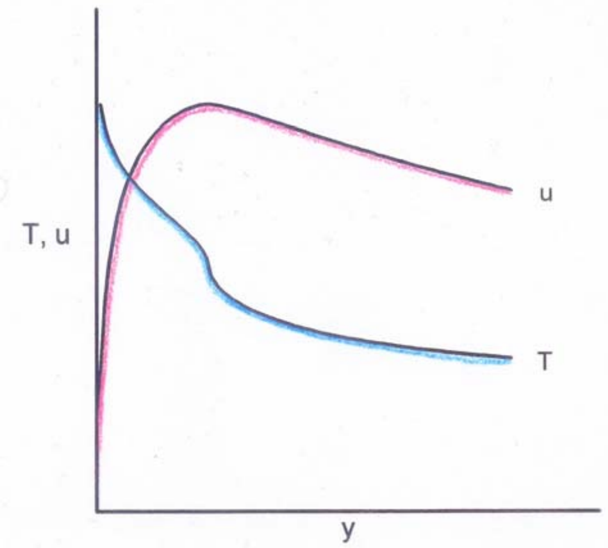
Situation 1995:

Standard wall functions predict
an incorrect heat flux.

Mixing length approach was not
working for free confection.

CFD hardware were not able to
use fine grids (+ to long CPU - times).

Mixing length approach (Prantdl): $\nu_t = K^2 y^2 \left|\frac{\partial u}{\partial y}\right|$

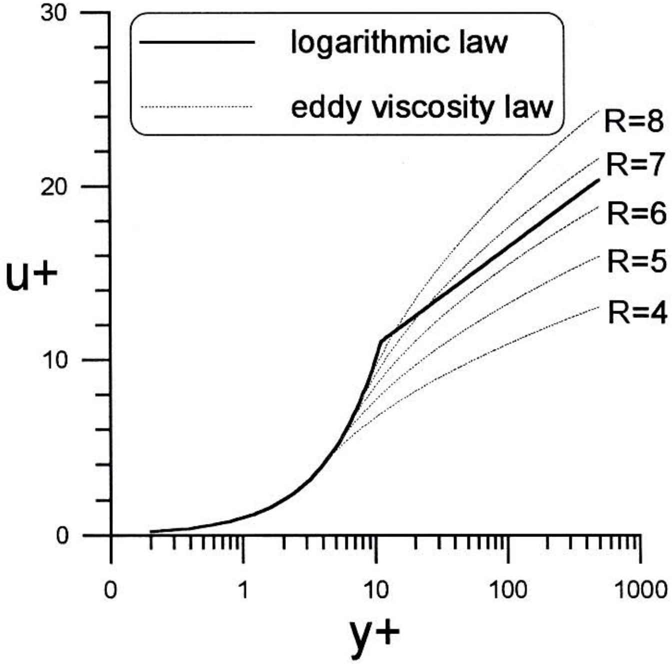


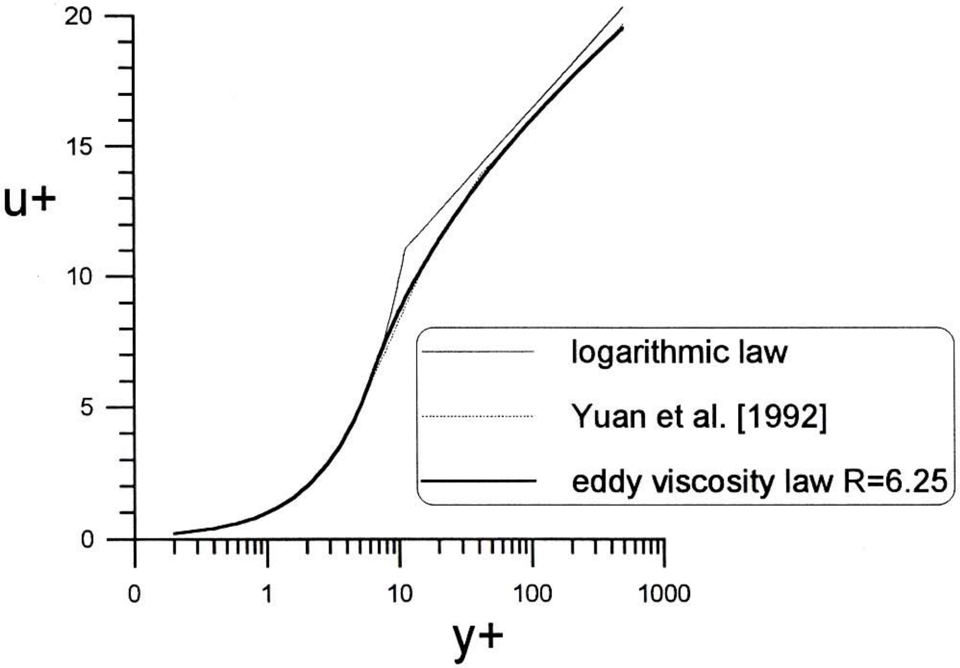
Development of new wall functions

Eddy viscosity approximation for ν_{turb} : $\nu_{turb} = \nu_{lam} \dfrac{\mathrm{Re}}{\mathrm{Re}_{min}}$, $R = \sqrt{\mathrm{Re}_{min}}$

Laminar layer: $u^{+} = y^{+}$ $\quad y^{+} \leq \mathrm{R}$

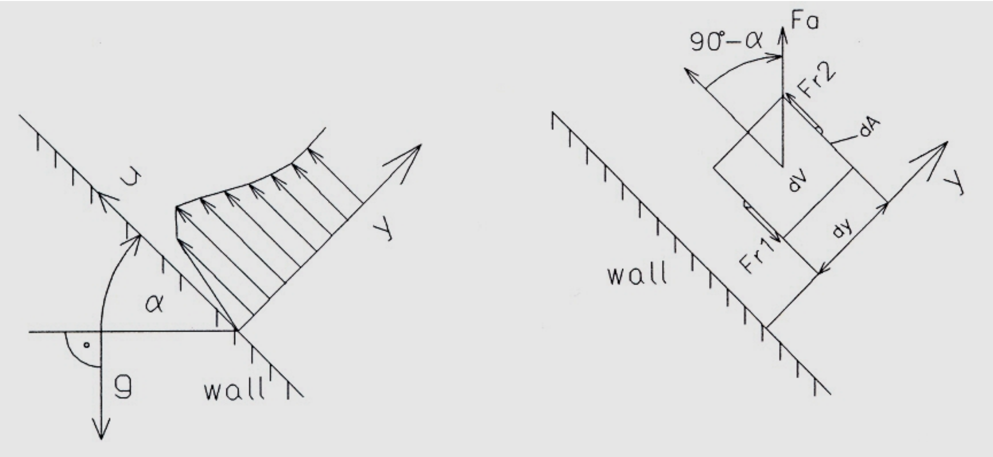
Turbulent layer: $u^{+} = R\sqrt{2\ln\left(\dfrac{y^{+}}{R}\right)+1}$ $\quad y^{+} > \mathrm{R}$





Wall function for velocity (forced convection)

Development of new wall functions



Equations:
- 2D boundary layer momentum equation
- 1D boundary layer energy equation
- with an eddy viscosity approximation for ν_{turb}

$$\nu_{turb} = \nu_{lam} \frac{\mathrm{Re}}{\mathrm{Re}_{min}}$$

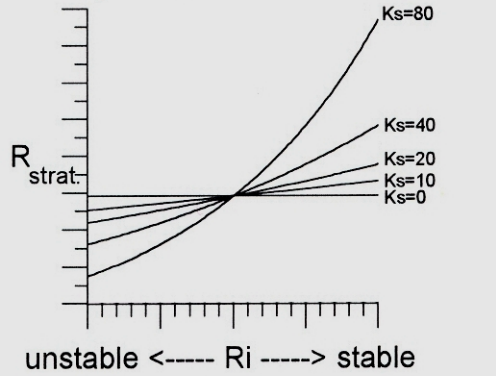
- evaluation of the constant $R_{stratification}$ which can be approximated by the function:

2D boundary layer equation
(including buoyancy)

\+ viscosity approximation for ν_{turb}
(including stratification)

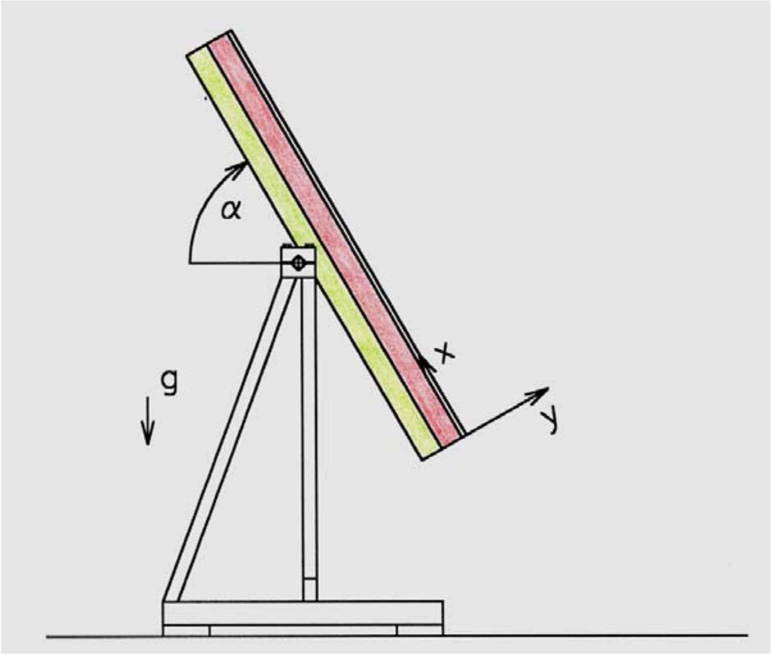
$\sum$ " wall calculation "

$$R_{stratification} = R \cdot e^{(K_s \cdot Ri)}$$

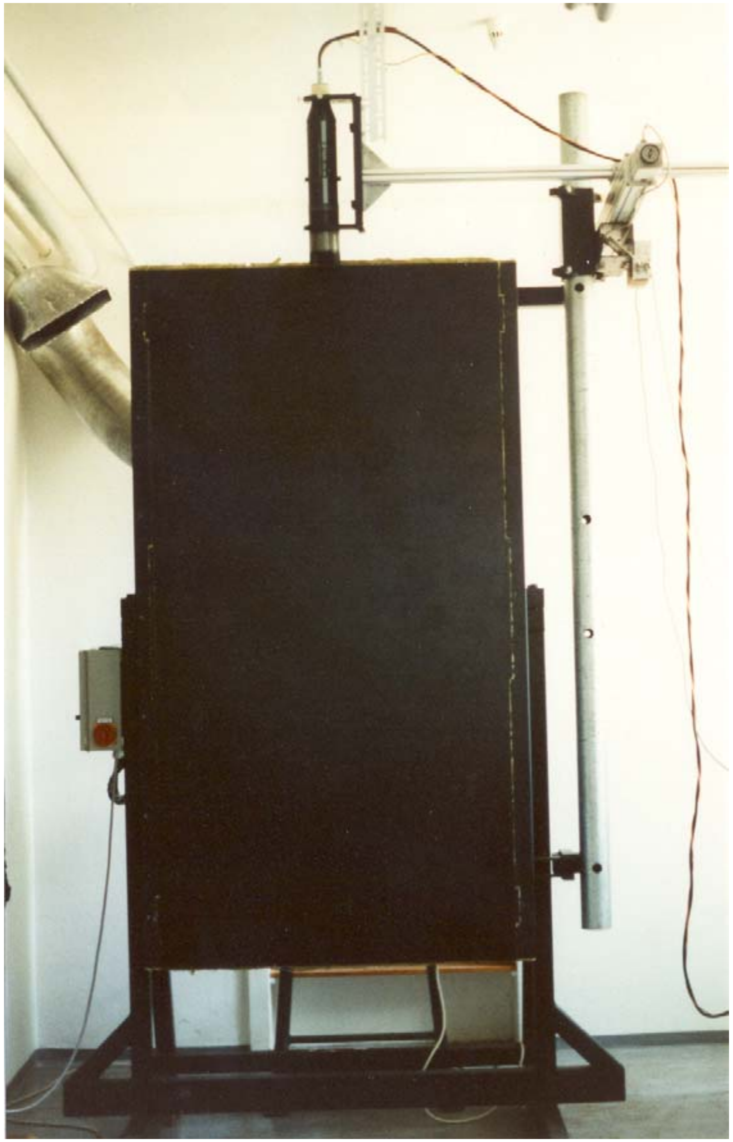


Validation of new wall functions

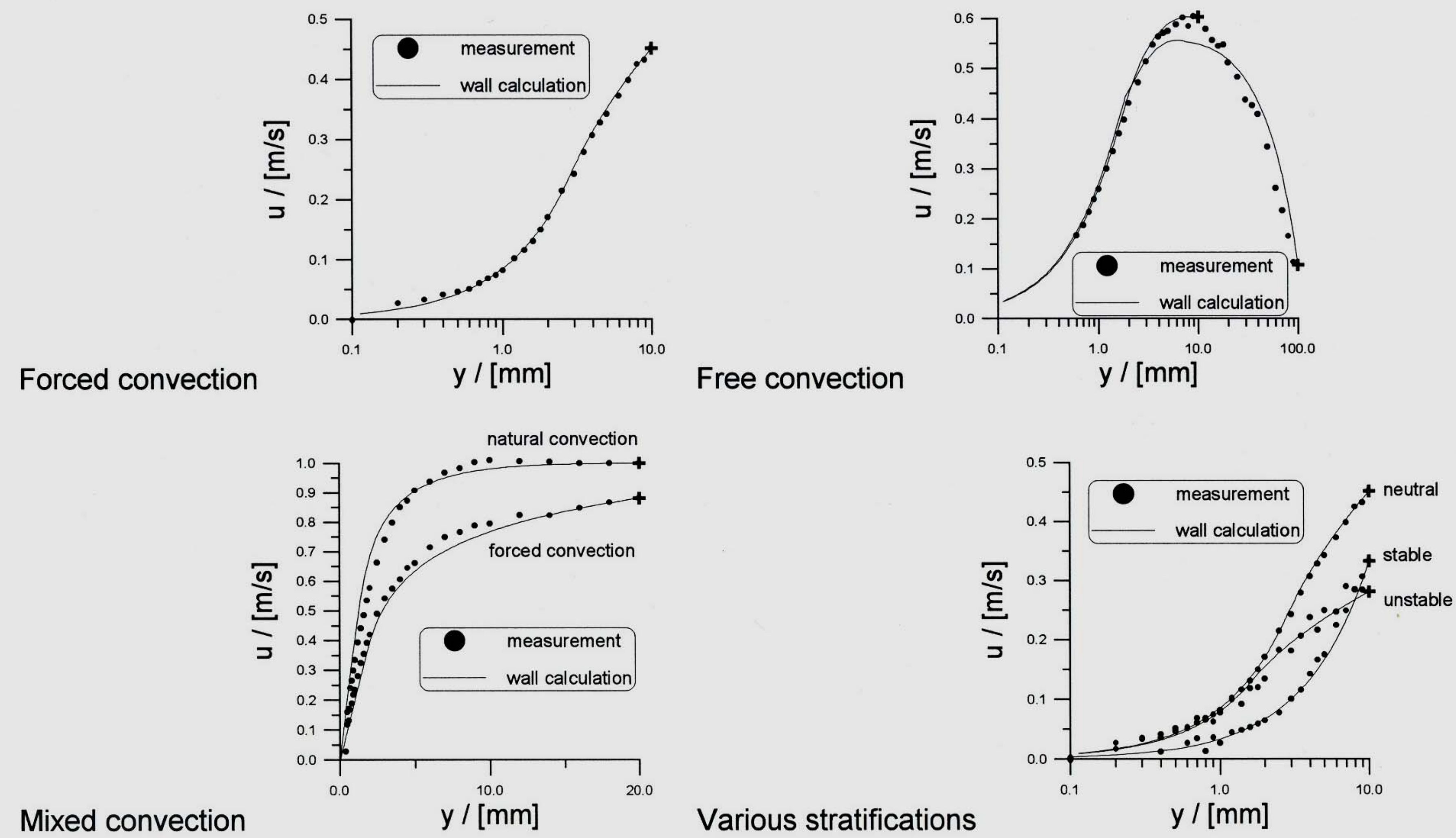
- Aluminium plate 20 mm
- 2 meter high, 1 meter wide
- Inclination alpha from 0 to 360 deg
- Heatet from the backside by electrical heating tubes
- Temperature difference up to 60 K



Experimental apparatus

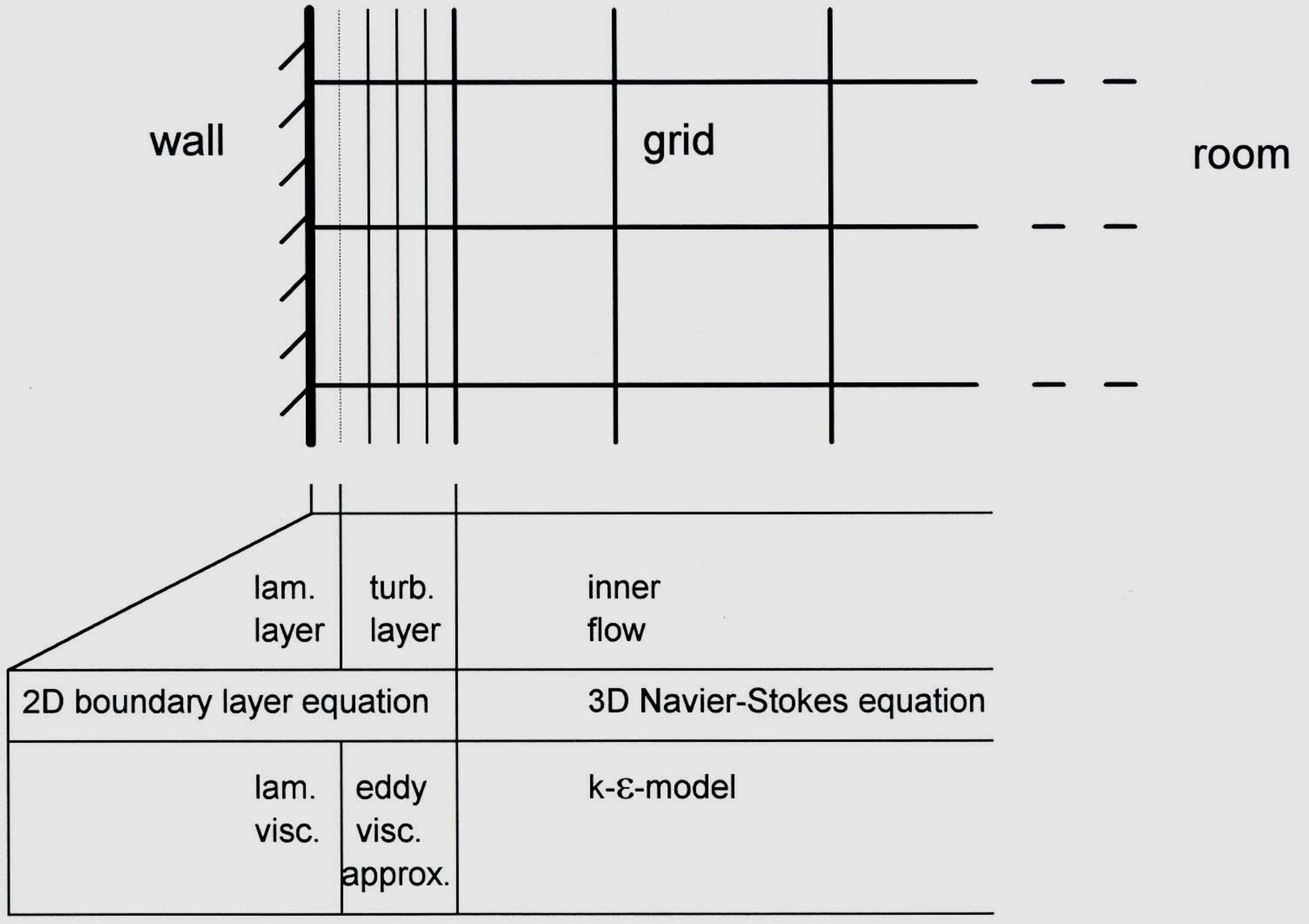


Validation of new wall functions



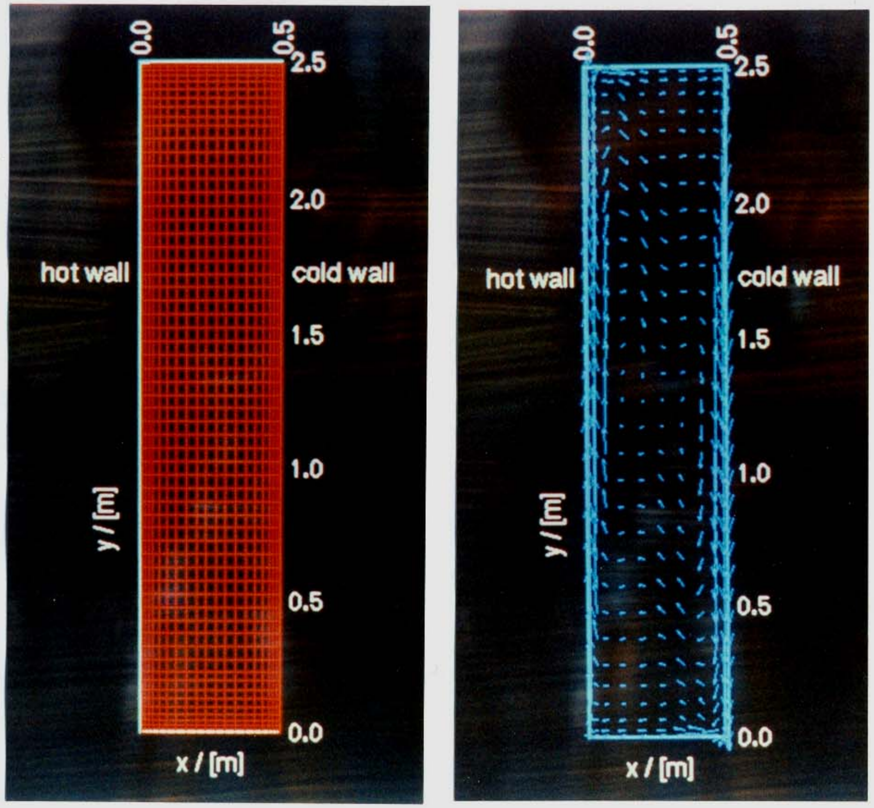
Velocity distribution results of the wall calculation in comparison with experimental data

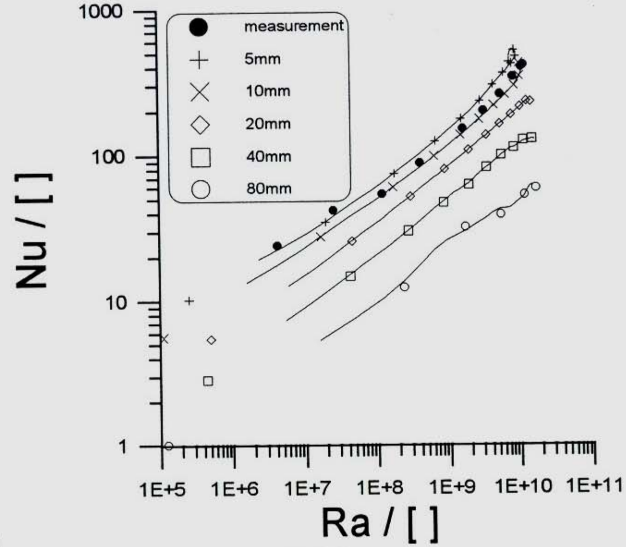
Validation of new wall functions



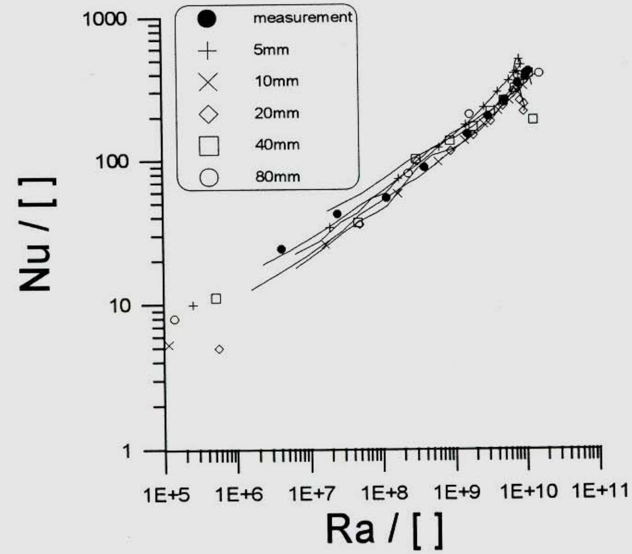
Regions of the FVM-code (Dresden University of Technology)

Validation of new wall functions





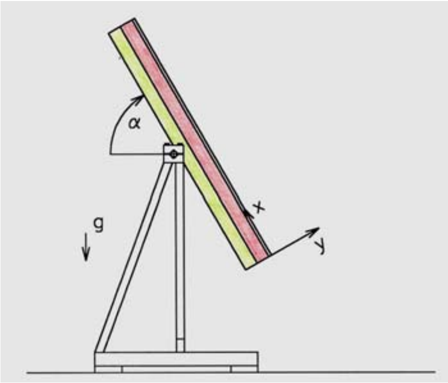
forced convection

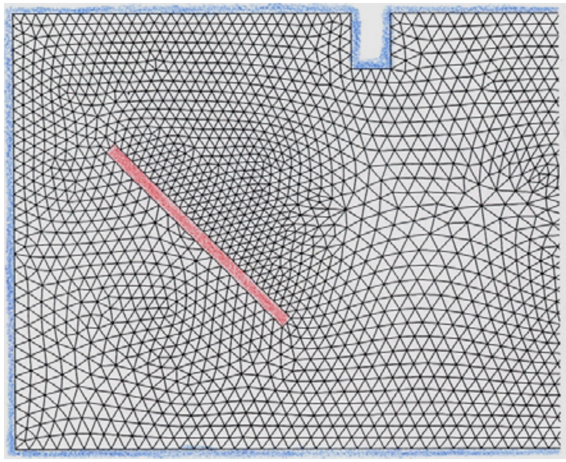


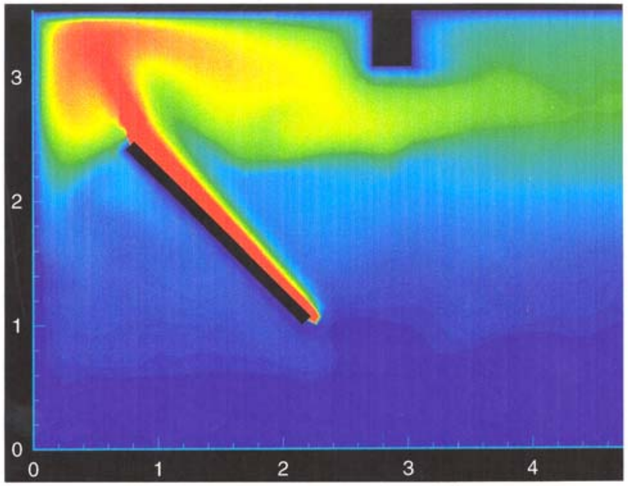
wall calculation

Test case: closed cavity flow (Cheesewright et al. 1986)

Validation of new wall functions







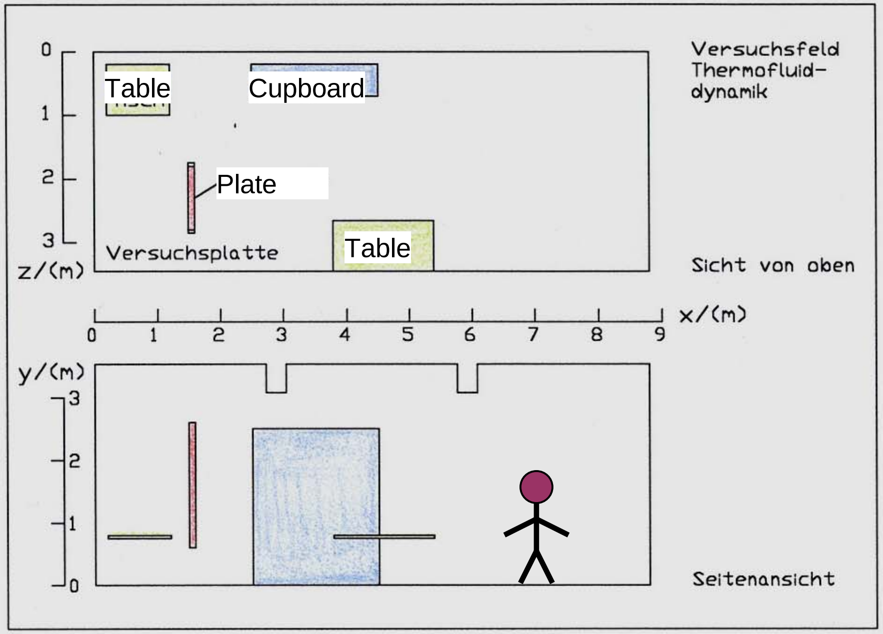
Comparison of the heating power of the inclined plate in the lab.

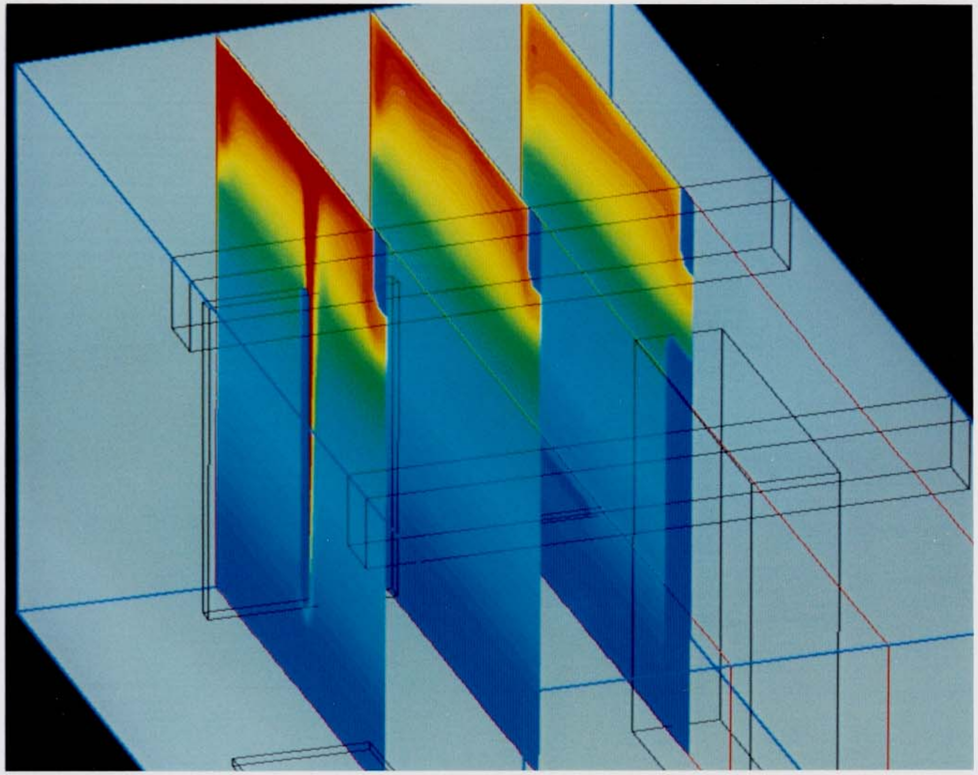
2D CFD

- CFD with standard wall functions: heating power prediction - 83 % to the experiment

- CFD with new wall functions: heating power prediction - 8 % to the experiment

Validation of new wall functions



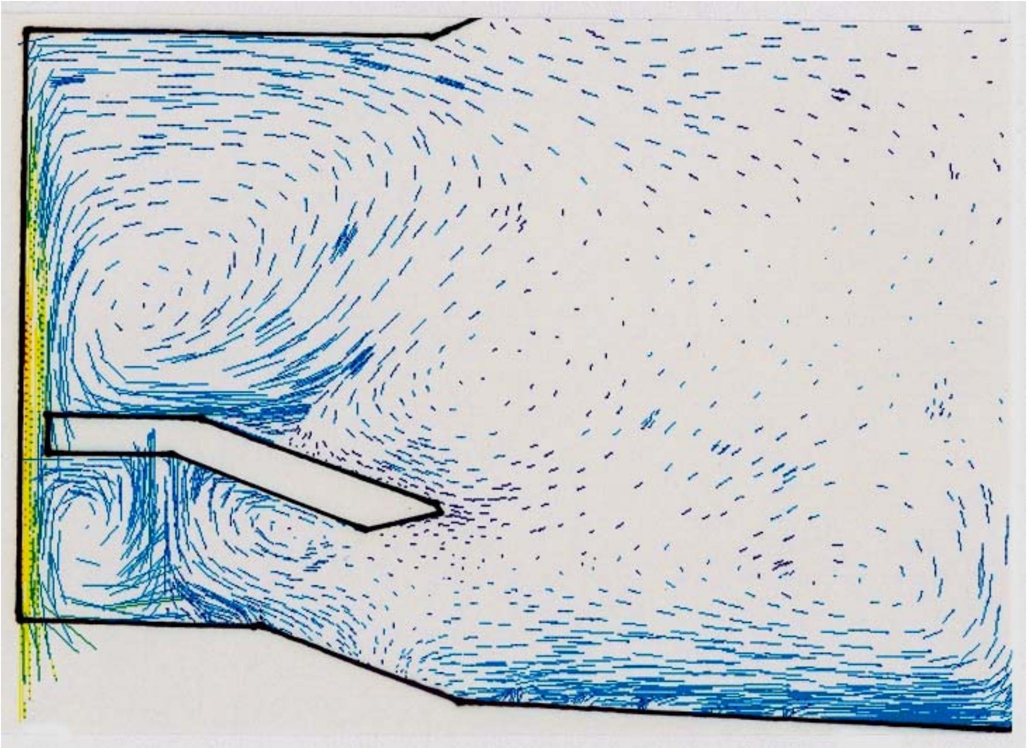


Comparison of the heating power of the vertical plate in the lab. 3D CFD

- CFD with standard wall functions: heating power prediction - 61 % to the experiment

- CFD with new wall functions: heating power prediction - 1 % to the experiment

Experimental tests in the plenar hall



<u>Final comparison CFD – experiment:</u>

- Temperatur measurements (thermocouples + IR)
- Flow visualisation (smoke)
- Global energy balance (heating + sun + people)

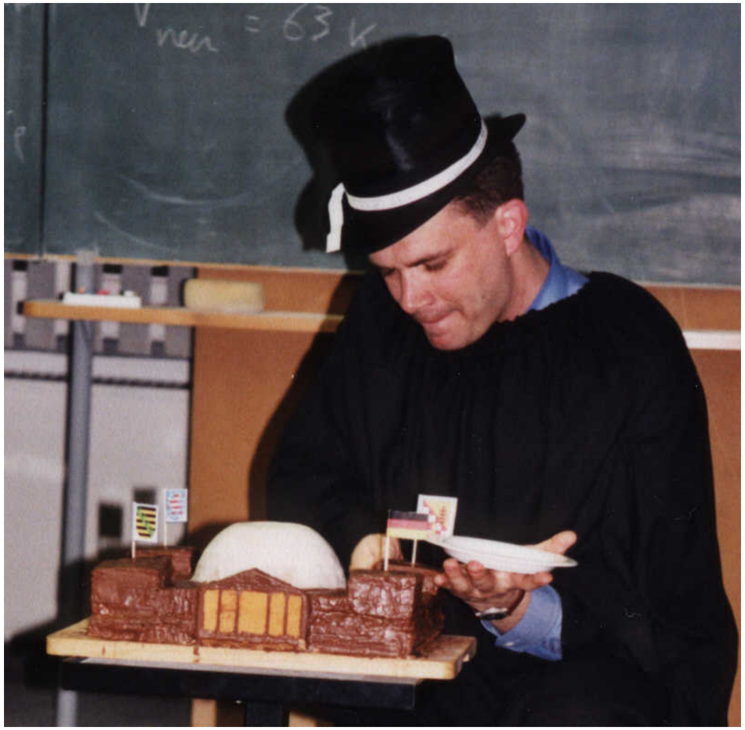
- Acoustic (Loudspeaker beam forming)

First meeting – 19 April 1999

Die erste Sitzung des Bundestages im Reichstag in Berlin 19.04.1999

First meeting of the Lower House of the German Parlament (Bundestag)

7 days later...



26 April 1999 – The author receives a „Reichstag cake“ from his students.

Summary

- Only the combination of wind tunnel tests, CFD calculations and original experiments were successful.
- For the CFD calculation new wall functions were developed. This new wall functions were validated in the laboratory.
- The requirements to the dome and the plenar hall were fulfiled.
- The internal / external aerodynamic of the Reichstag works since 8 years successfully.


The End


Thank you
for your attention