CFD-FE interaction
A particular one-way coupling

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This presentation is about ***one*** possible way of applying the one way coupling.

It has been implemented and applied with the CFD Jasmine from BRE and the FE software SAFIR from Ulg during the RFCS project FIRESTRUC.

It could be called the « invisible structure CFD »

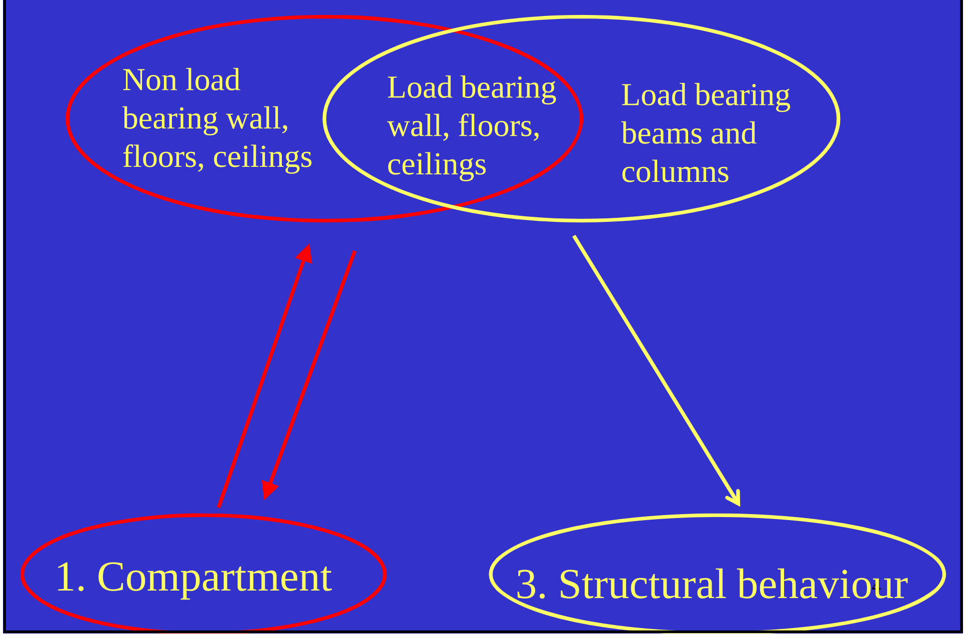
2

Essential features are:

1) Temperatures in load bearing elements are calculated by SAFIR
2) Temperatures in boundaries of the compartment are calculated by JASMINE

3

2. Temperatures in elements



Essential features are:

3) The structural elements are not present in the CFD analysis, exept for the boundaries of the compartment that are present in the analysis, possibly in an approximated manner.

5

How it works:

1. The CFD specialist and the FE specialist must agree on a common system of coordinates in which the compartment and the structure are described.
2. The CFD specialist makes his CFD model without considering the structure (except the walls). He refines the grid where the CFD requires (fine mesh required for convergence of the solution of when high gradients are expected in the results).
3. He writes the results (with refinement in zones of high gradients) in a file according to a well defined and standardised format. These results describe the thermal environment in the compartment (see below).

6

How it works:

4. The FE specialist makes his structural model without considering the fire. He refines the grid where the structural behaviour requires (fine mesh required for convergence of the solution of when high gradients are expected in the results).
5. He reads the results in the standardised file and use them to calculate the temperature in the structural elements.
6. Based on the temperatures in the elements, he calculates the structural behaviour.

7

What kind of information is transmitted in the exchange file?

1. The information is written at given time steps chosen by the CFD specialist (refined time steps when strong variations of the results with time are expected)
2. The information is written in a certain number of points of the space chosen by the CFD specialist (high spatial gradients of the results expected)

8

3. The information that is written at every point at every time step is:
   - The temperature of the air (used for convective exchanges)
   - The coefficient of convection (function of the air velocity, used for convective exchanges). Alternatively, a constant coefficient can be used, e.g., 35 W/m^2K
   - The radiative intensity for a given number of directions (e.g. 104 directions. 6 directions is much too poor).

9

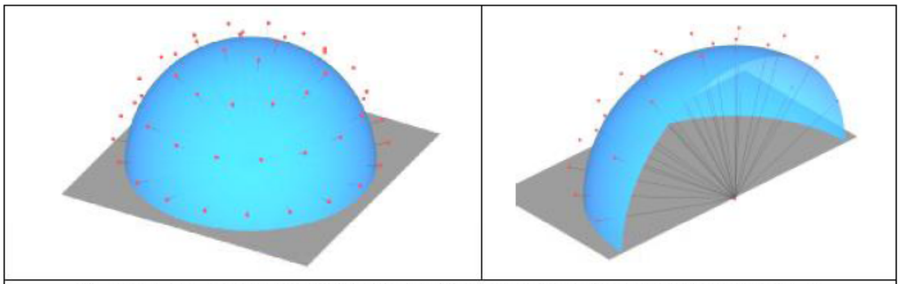


Figure D.13 - Incoming radiative flux directions on hemisphere and quartersphere

The radiative intensity for a given number of directions.

The flux received by a surface is calculated from:

$$\phi = \int_{2\pi} I \cos\vartheta \, d\Omega$$

10

Because the information is given at certain time steps, at certain locations in the space, and for certain directions, a three level interpolation must be made.

1. A Cartesian interpolation in space to have the information at the locations that are relevant for the structure(*). Requires a good spatial interpolation algorithm.
2. Interpolation in time to have the information at the relevant time step (easy).
3. Interpolation in spheric coordinates to have the radiation in the appropriate directions(**).

11

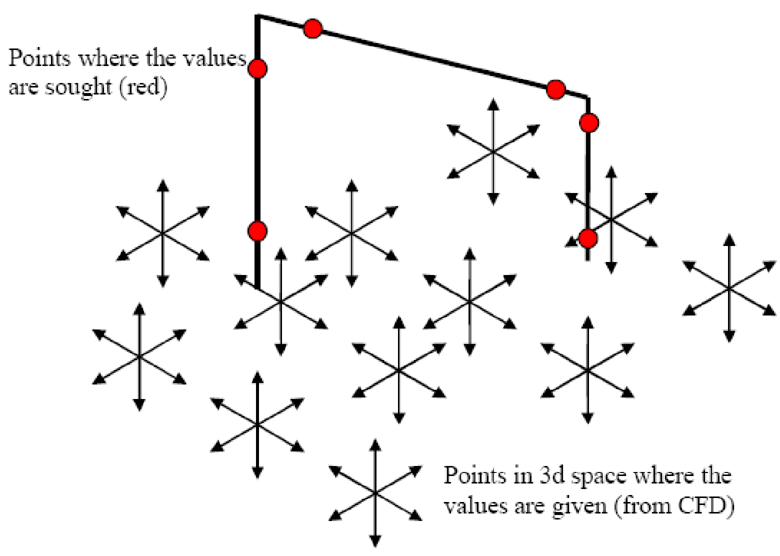


Figure D.17 - Cartesian interpolation

12

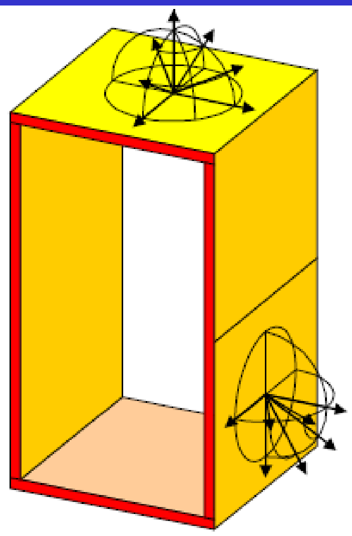
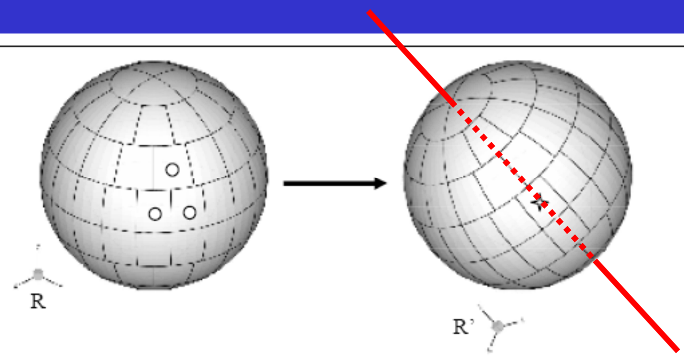


Figure D.18 - Spherical interpolation on a convex structural element

13



○ nearer known $I(\theta_i, \alpha_i)$ ✧ unknown $I'(\theta_i', \alpha_i')$

Figure D.15 - Change of coordinates system

Interpolation in spheric coordinates when the structural member is inclined.

14

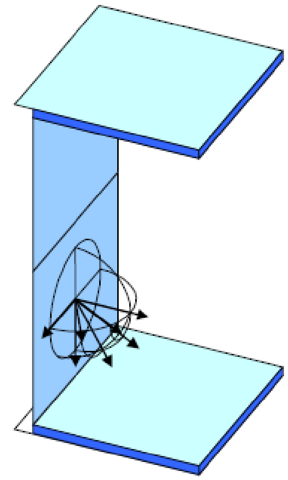
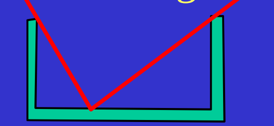


Figure D.20 - Spherical interpolation on a concave surface

15

View angle



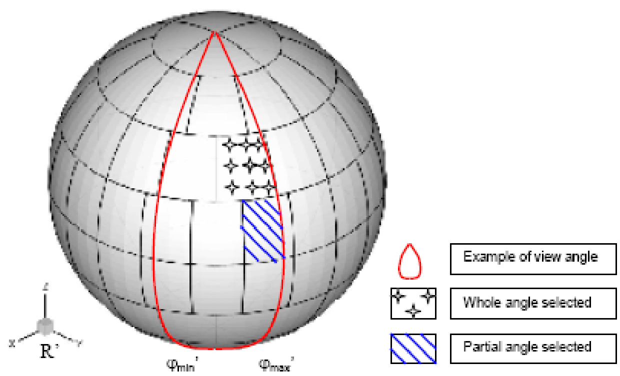


Figure D.16 - Choice of relevant solid angles

(*) In SAFIR, the temperatures are not calculated in the structure as a big 3D object. A series of 2D thermal calculations are made in the sections of the beams or across the thickness of the slabs. In order to reduce the number of spatial interpolation, the boundary conditions on the perimeter of a beam section can be taken from the value calculated on the node line.
(**) It is possible to interpolate the radiation intensities of the exchange file and then calculate the flux (prefered for concave sections), or to write the flux for different directions in the exchange file and interpolate on the fluxes.

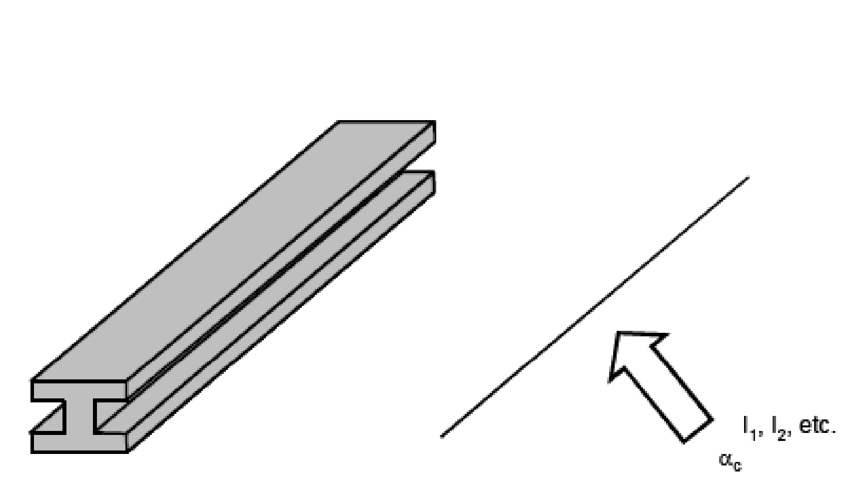
17

Limitation:

The interaction 2 -> 3 and 3 -> 2 must be limited.

1. Influence of air pressure variation on the structure must be limited (not OK for very flexible structures, e.g. fabrics).
2. Influence of the structural elements on the temperature and on the air flow in the compartment must be limited; the characteristic length of the elements and of their displacements perpendicular to their axis must be small compared to the characteristic length of the compartment.

18



19

Limitation:

Some cases where the second condition is not met.

1. A 1x1 m² concrete column in a 10x10 m² hall will influence the air flow significantly.
2. A 1 m deep concrete beam under the ceiling of a 3 m high car parc will influence the air flow significantly.
3. The vertical deflection of the ceiling of 1 m in an open space office will influence the air flow and, possibly, the fire development (tensile membrane action!).

20

This procedure is well adapted for a steel structure made of relatively thin members (frame, truss girders) and located in a very large compartment (railway or airport entrance halls, exhibition halls) where a localised fire is developing.

This scenario is one where CFD-FE interaction is most desired in order to calculate the level of protection of the structure (limitation of the Hasemi model for structural elements that are not located directly underneath the ceiling).

21

Advantages:

1. Any CFD sofwtare A, B or C can be combined with any FE software X, Y or Z
   - Each software uses its own time steps.
   - Each specialist works in his own field of expertise.
   - If new release of A is produced, this does not affect X, or vice versa.
2. Debugging of the model is made separatly in each code.
3. If p structures must be evaluated under q fire scenarios, only q CFD analyses must be performed, compared to pq coupled analyses in a coupled approach.

22

Structure of the exchange file. 1/3

FILENAME Cfd.txt	gives the name of the file
NSTEPS 6	gives the number of time-steps in the file
TIMES 30. test_example_30s.simd 60. test_example_60s.simd 90. test_example_90s.simd 120. test_example_120s.simd 300. test_example_300s.simd 600. test_example_600s.simd	lists the times where the fluxes and/or intensities are given, optional name of the files after each time.
NF 288	gives the number of transfer points where the flux is given (NF points)
XYZ_FLUXES 10.805 14.8 1. 0. -1. 0. 10.9 14.8 1. 0. -1. 0. 11. 14.8 1. 0. -1. 0. 11.1 14.8 1. 0. -1. 0. 11.195 14.8 1. 0. -1. 0. ...	NF lines, each containing the X, Y, Z location of a transfer point and the components (X, Y, Z) of the outward normal to the surface in the Global system of coordinate.

23

Structure of the exchange file. 2/3

...	
NP 144	gives the number of transfer points (NP points) where the radiant intensities are given
XYZ_INTENSITIES 10.7 14.72 1. 10.9 14.72 1. 11.1 14.72 1. 11.3 14.72 1. 10.7 14.92 1. 10.9 14.92 1. 11.1 14.92 1. 11.3 14.92 1. 10.7 15.12 1. 10.9 15.12 1. 11.1 15.12 1. 11.3 15.12 1. ...	NP lines. Each line gives the location X, Y, Z of the transfer point where the radiant intensities are given.
NI_DIRECTION 20	gives the number of radiant intensity directions (NI)
XYZ_DIRECTIONS 0.0000 0.3568 0.9342 0.0000 -0.3568 -0.9342 0.0000 0.3568 -0.9342 0.0000 -0.3568 0.9342 0.9342 0.0000 0.3568 -0.9342 0.0000 -0.3568 ...	NI lines. Each line contains X, Y, Z component of an incident radiant intensity direction viewed from point 'outwards'.

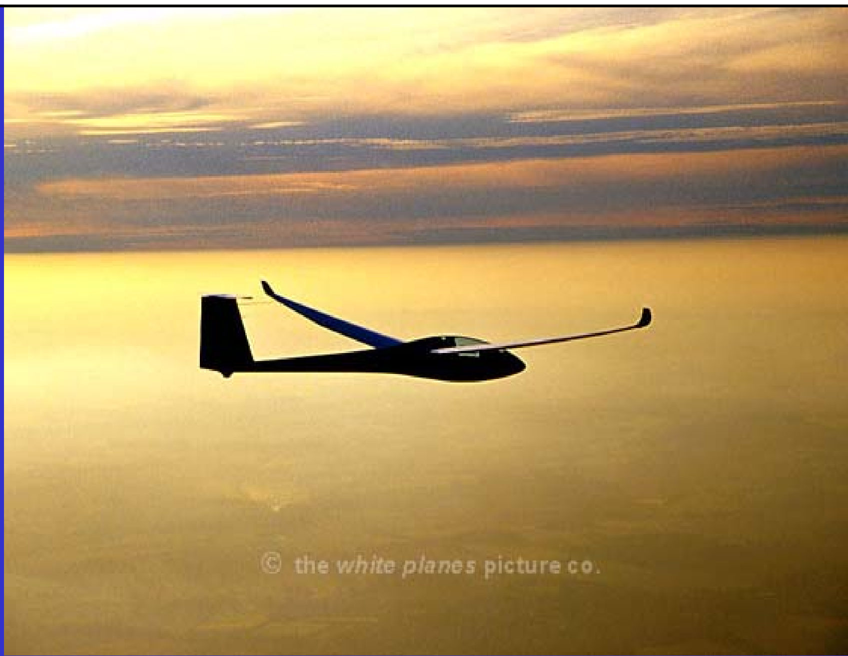
Note: NF or NP can be equal to 0.

24

Structure of the exchange file. 3/3

TIME 30	gives the time-step where the subsequent values of fluxes and intensities are given. This block and the two blocks that follow FLUXES and INTENSITIES are repeated NSTEPS time.
FLUXES 300. 10. 2500. 300. 10. 2500. 300. 10. 2500. 300. 10. 2500. 300. 10. 2500. 300. 10. 400. 300. 10. 400. ...	NF lines. Each line contains gas temperature in K, convection heat transfer coefficient and incident radiation flux.
INTENSITIES 300. 10. 125. 760. ... 125. 300. 10. 125. 760. ... 125. 300. 10. 125. 760. ... 125. 300. 10. 125. 760. ... 125. 300. 10. 125. 760. ... 125. 300. 10. 125. 760. ... 125. ...	NP lines. Each line contains gas temperature in K, convection heat transfer coefficient and NI incident radiant intensities.

25



Thank you.