AREVA

LOGISTICS

CFD design and mock up test for heat removal using cylindrical rods mounted on a vertical plate

O. Bardon, J. Bellanger, N. Zhari

LOGISTICS

Looking to the future PATRAM 2010

AREVA

CONTEXT

- **Need for high capacitive casks**
  - **High burn up + short cooling time (60 GWd/tu, 5%enrichment, 2 years cooling time)**
  - **Consequence : High thermal load up to 6 kW/assembly ->70 kW heat load for 12 spent fuel assemblies in a cask**

- **Maximum thermal power may sometimes be imposed by cooling performance with unexpected orientation of fins after accidental conditions**

- **Need for improved performance of heat convection**
  - **In normal transport conditions**
  - **In any configuration (horizontal / vertical)**
    - Transport / storage
    - Accidental configuration after 9m drop

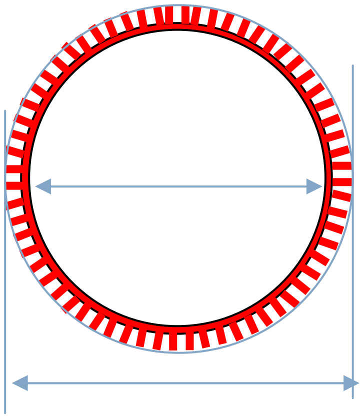
- **What we know about cask fin surfaces**
  - **Axial fin shape : good for storage / not optimal in transport**
  - **Radial or annular fin shapes : good for transport / not optimal for vertical cask**

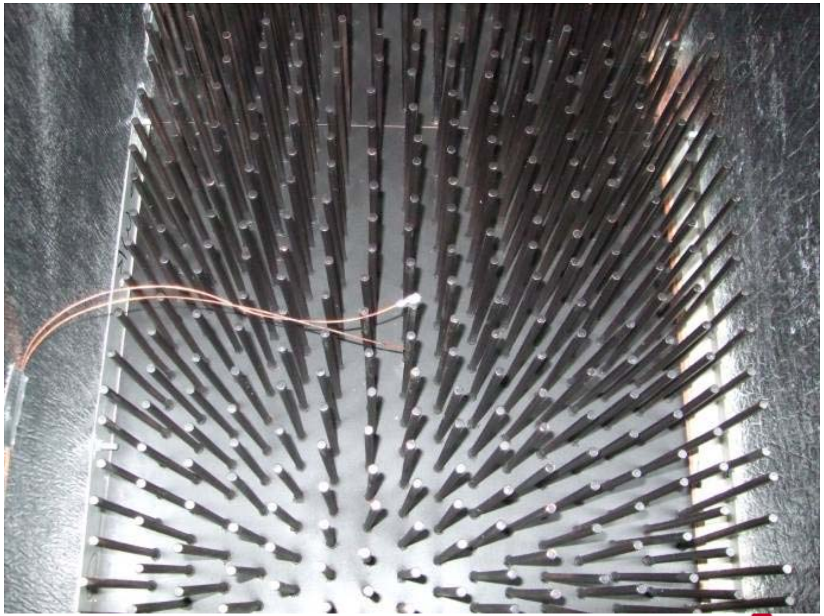
Our innovative idea: Rod shaped fins

- **Main requirements**
  - **Maximum diameter size available (defines max rod length)**
  - **Use standard diameter and material of rods**

- **Main benefits are**
  - **Adjustable increase of cask surface (depending on number and length of rods)**
  - **Relative independence of cask orientation : to be verified**

- **Main difficulty is**
  - **How to optimize the arrangement of the rods in the given space to get the best performance satisfying all the criteria?**
    - CFD (computational fluid dynamic) optimization
    - Mock up and thermal tests validation

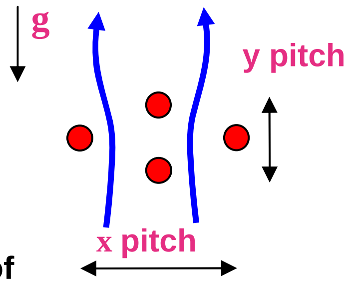




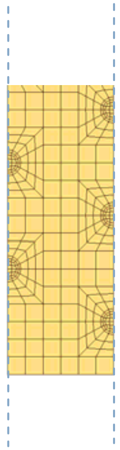
CFD design

CFD model

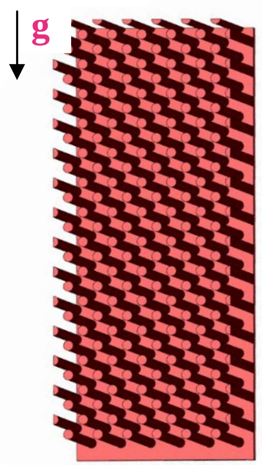
- 3D Model is built with a unit cell (x pitch, y pitch) limited by two symmetric conditions and repeated in the g direction to get the correct overall height (2m)



unit cell for one orientation and mesh


Front view of local mesh

  - Used of classic turbulent model K/ε with high Reynolds law functions
  - Imposed heat (W/m2) representative of the cask load at the back of the plate / ambient temperature fixed far from plate
  - Main result concerns average plate temperature: The lower the averaged plate temperature is, the better the configuration is.
  - Performance = coefficient ratio A/A* : improved heat convection coefficient relative to flat plate with no fins. The best configuration is defined by the highest coefficient ratio A/A*



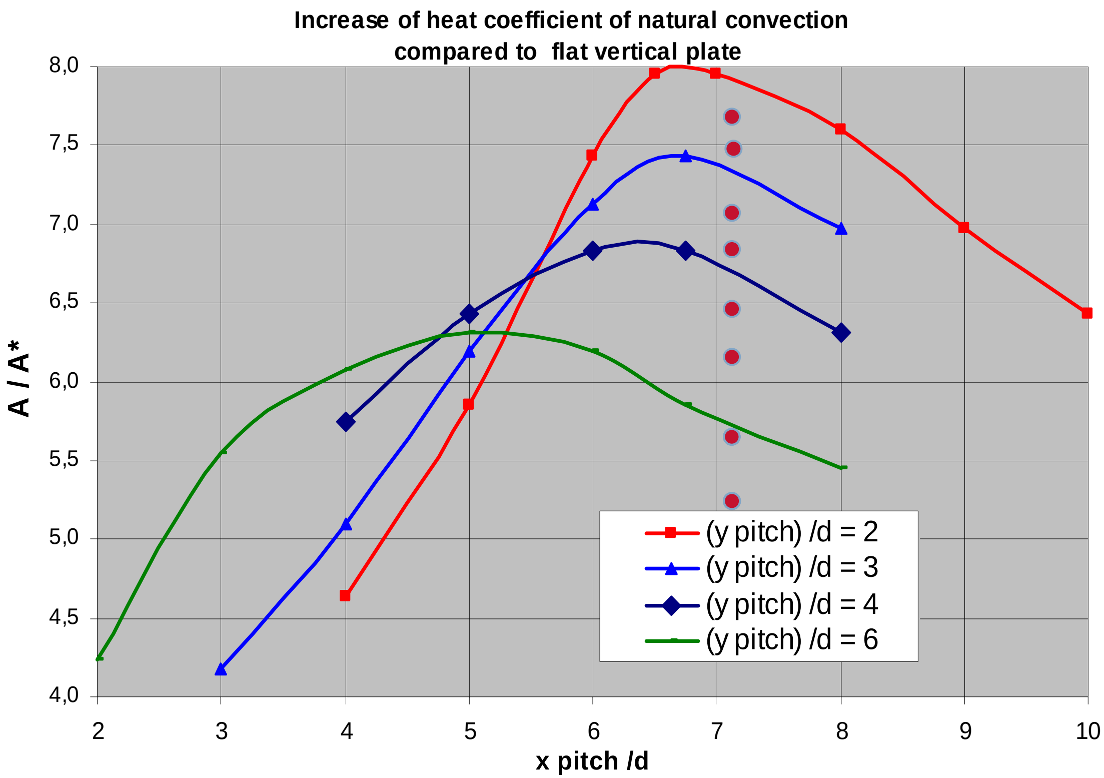
View of extended 3d model

(solid part)

- Calculations are carried out for defined y pitch with various x pitch -> graph for tracking maximum performance in the fixed volume

LOGISTICS

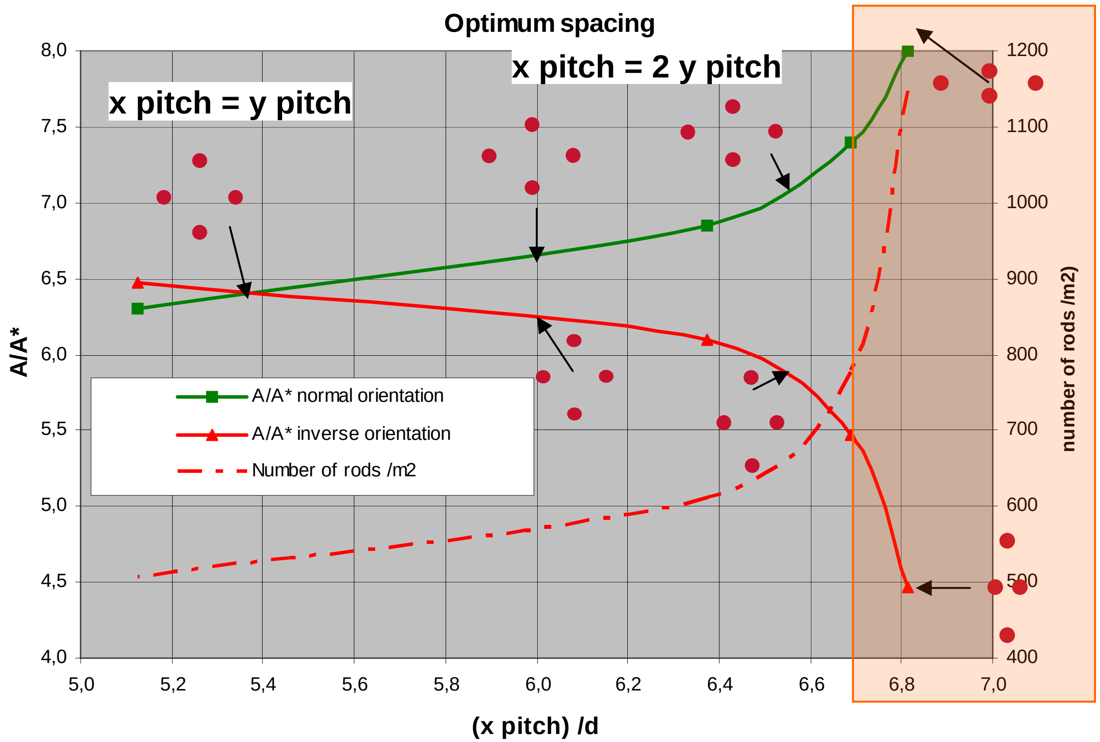
CFD model: calculation result



Key results

- Each y pitch corresponds to an x pitch optimum which maximizes A/A* (known result)
- Maximum performance increases with y pitch reduction but for larger x pitch
- Performance to flat plate may be increased about 7 to 8 times

CFD model: calculation result



- **Optimal path**
  - **Each gain in maximizing one orientation over performance for x = y pitch will lead to an almost identical same loss in the inverse orientation**
  - **Rod quantity increases rapidly when y/d < 3.2 and x/d opt > 6.7**

LOGISTICS

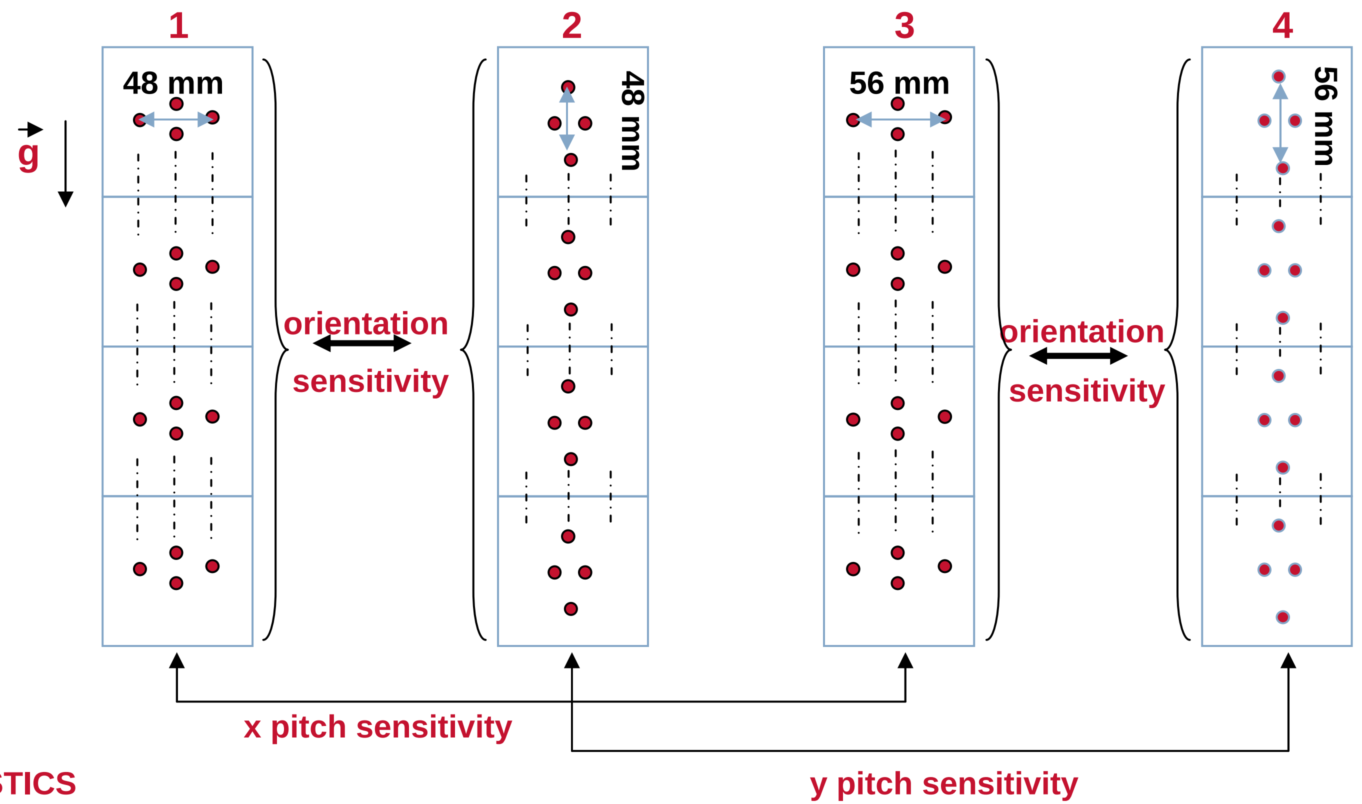
Conclusion of CFD design

- **Maximum performance can be increased compared to reference case where x =y pitch (A/A*max = 6) but it will come at a cost of a reduced performance in the inversed orientation**
- **The choice of x / y pitch must be consistent with both criteria in normal and inverse orientation**
- **x pitch = 2 y pitch is a good compromise between performance in normal and inverse orientation and number of rods**

Thermal tests

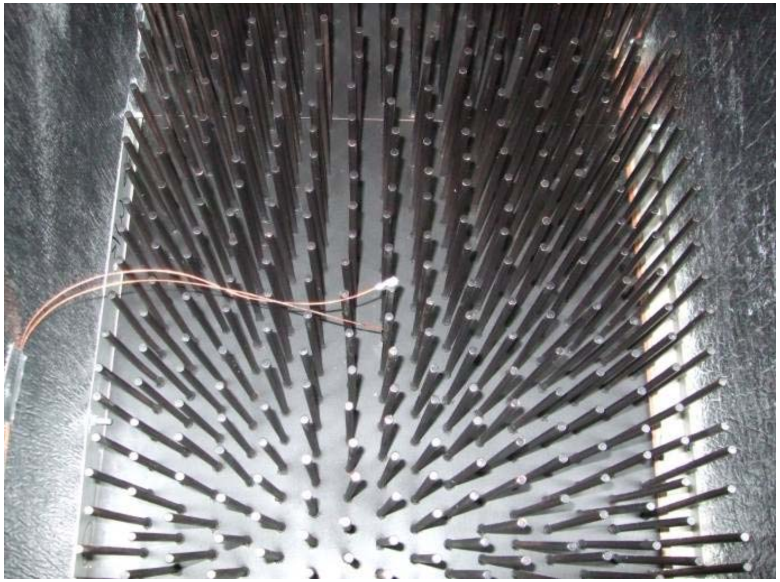
Configuration tests and objectives

- **Configuration tests:**
  - **Close to optimal calculated with x pitch ~ 2 y pitch (48 mm or 56 mm and y pitch = 24 mm)**
- **Main objectives:**
  - **Check that required performance is reached**
  - **Comparison to calculation : check the predictibility of CFD calculation for variation of performance relative to pitch sizes and orientation**



LOGISTICS

Test mock up



- **Rods fins welded on a vertical plate (2m high / 0.5m wide) /black coated with a known high emissivity**
- **20 thermocouples / 2 ambient temperatures / infrared thermography**
- **Thermal power controlled by four flexible heating mats (stuck to back of the plate) and insulated from ambient thermal losses**
- **Lateral foil deflector to prevent lateral aspiration flow**

Calculation compared to test results

Calculation results

A/A*": increase performance compared to vertical flat plate *based on $T_{averaged}$	y pitch/d			
x pitch/d		4	8	9.3
	4		*6.5*	*6.3*
	8	*7.5*		
	9.3	*7.1*		

Test results

A/A*": increase performance compared to vertical flat plate *based on $T_{averaged}$	y pitch/d			
x pitch/d		4	8	9.3
	4		*5.7*	*5.5*
	8	*6.4*		
	9.3	*6.1*		

- **Over estimate of about 15% of performance compared to test (but the objective performance is reached)**
- **Almost same variation of performance with y pitch (-3% (calc) / -3.5%(exp)), and with x pitch (-5%, -4.5%)**
- **The orientation change is correctly predicted (-13%(calc) / -10%(exp))**
- **Gap between calculation and test is acceptable**

- **Tests confirm the predictibility of the calculation and the precision of the absolute value with less than -15%**

Conclusion

- **Solution for heat removal in both horizontally and vertically orientated casks using long rod shaped fins has been developed and tested**

- **CFD helped to define:**
  - **Optimal arrangement of rods for maximal performance in horizontal configuration while controlling performance in the vertical configuration**
  - **Design parameters to reach expected performance for both configurations (choice must be consistent with thermal criteria of sensitive components in both NCT and ACT)**

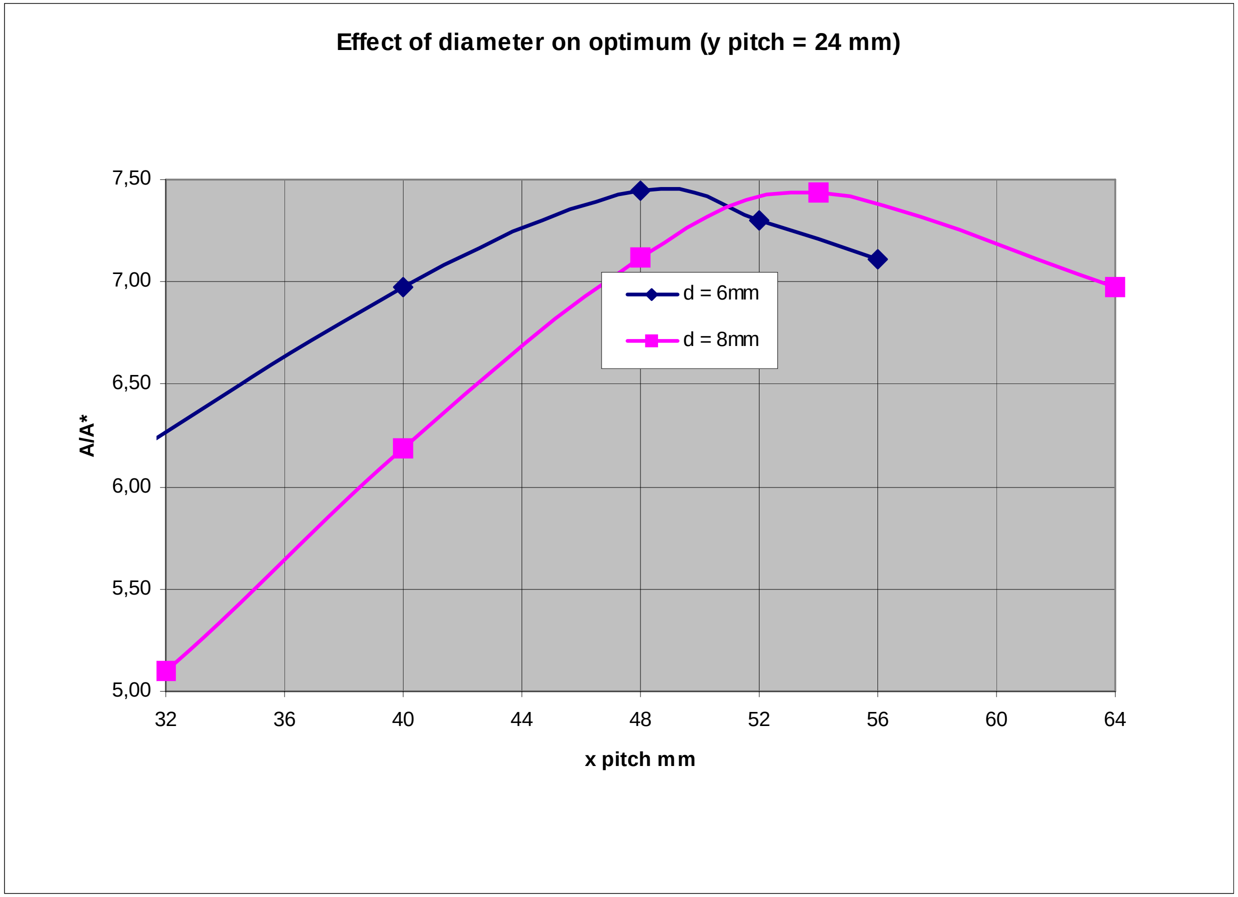
- **Comparison with mock-up tests shows a good correlation between tests and calculations which validates the concept**

- **A complementary realistic cylindrical mock-up has been built and tested which confirmed the performance on the plate mock-up (not shown here)**

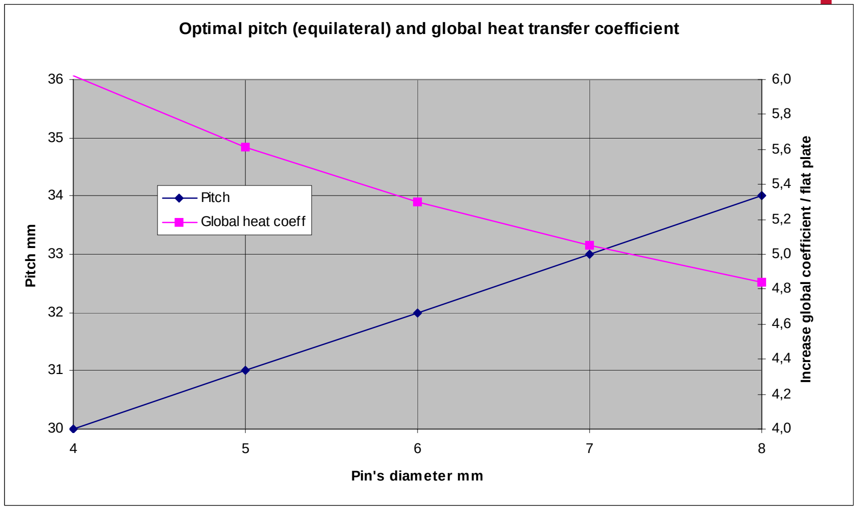
- **Further investigations should concern industrialization of this innovative solution**

APPENDIX

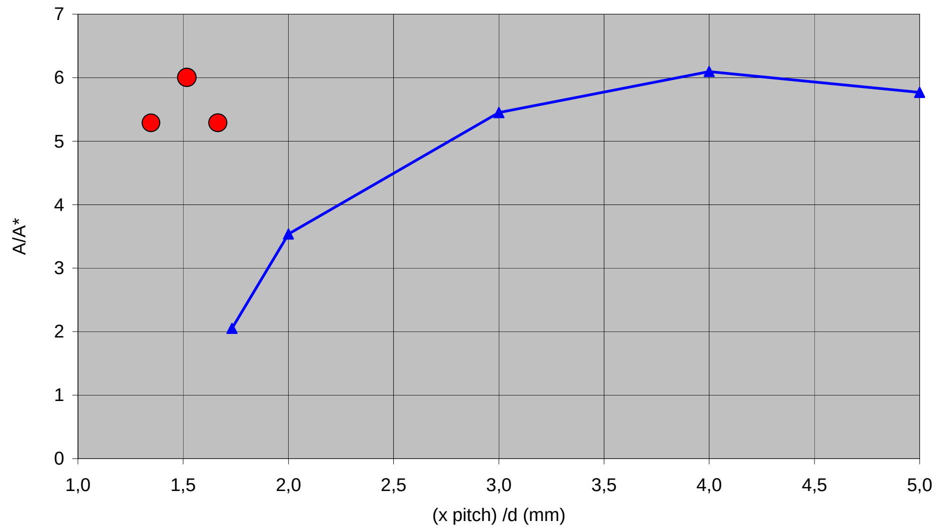
Effect of diameter on optimum



Analytical result for equilateral pitch in laminar flow



Increase of global heat convection coefficient compared to flat vertical plate for equilateral pitches

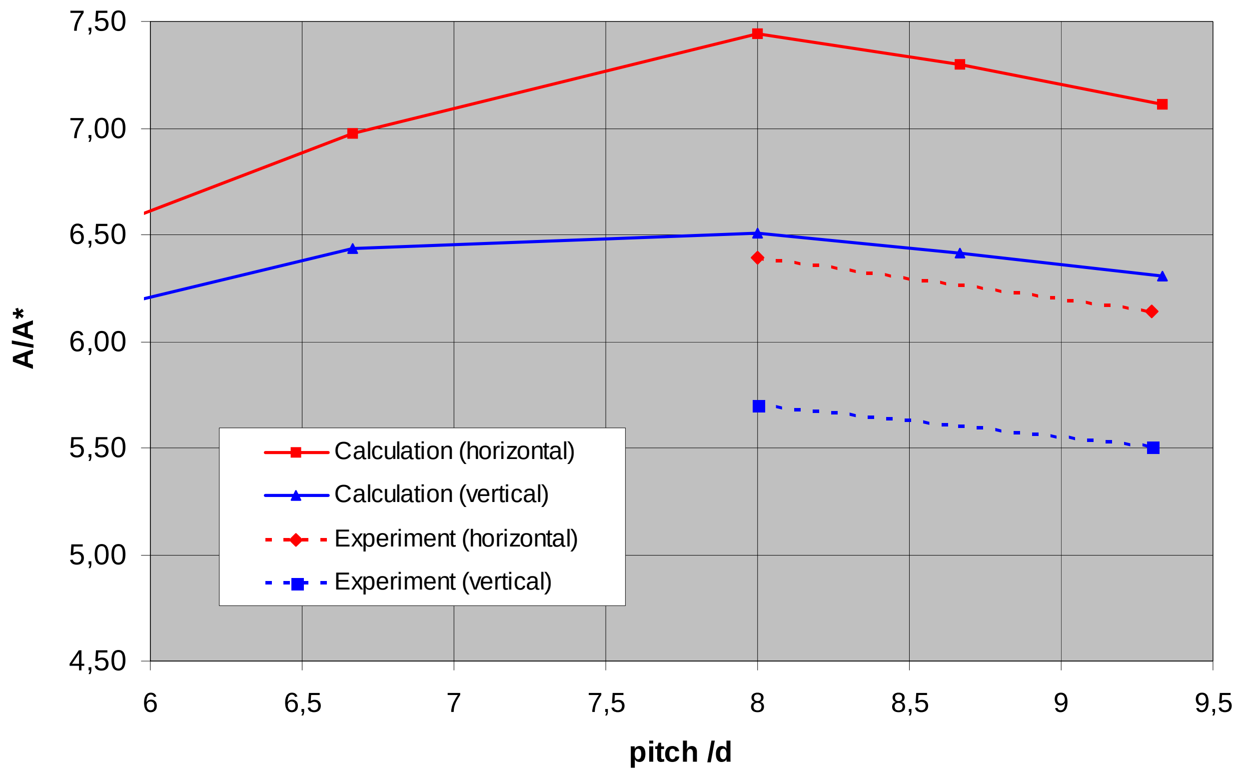


LOGISTICS

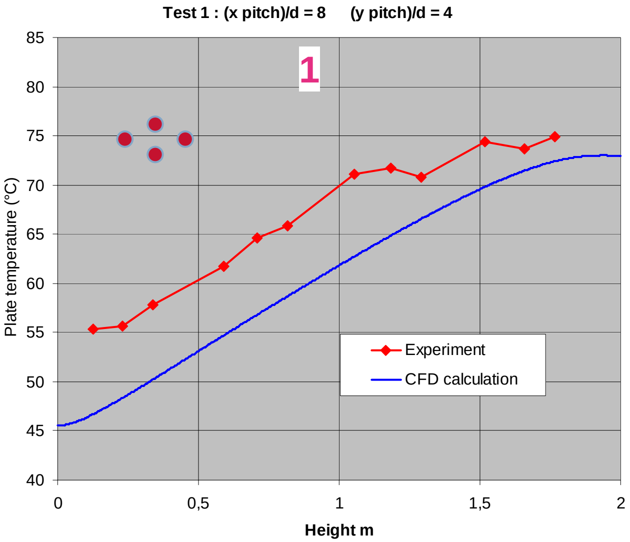
AREVA

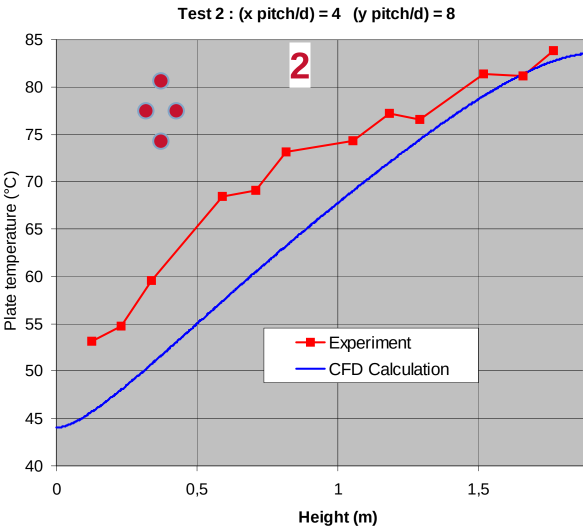
Comparison calculation / test

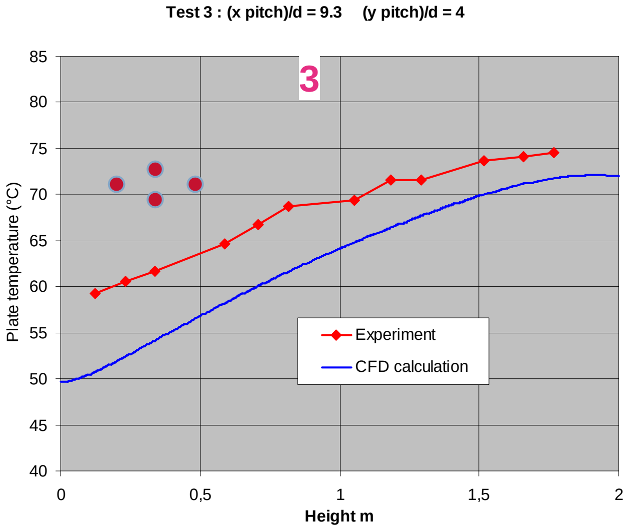
Increase performance of global heat convection coefficient compared to flat vertical plate (d = 6 mm)

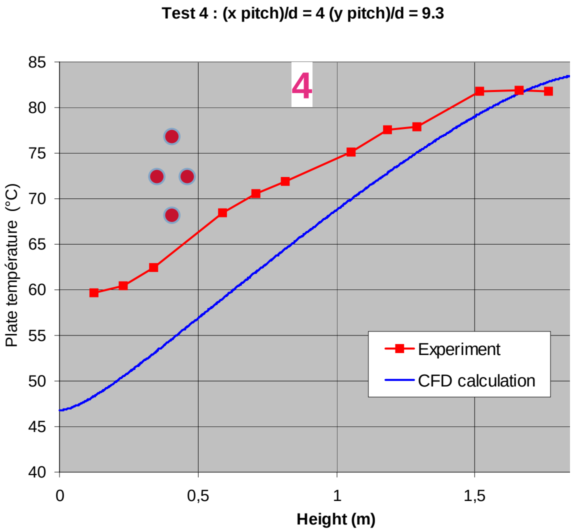


Test results / compared to calculation









- **Same trends are observed for both calculation and test even though the effect for calculation is a little bit stronger**
- **Under estimation of T calculated**
- **Significant increase in T in changing orientation**
- **Very slight rise in T in increasing x pitch or y pitch meaning we are close to maximum performance**

LOGISTICS

SCOPE

- CONTEXT
- OUR IDEA : ROD SHAPED FINS
- CFD DESIGN
- THERMAL TESTS
- CONCLUSION

AREVA