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Data Exchange between CFD and ESATAN in Case of Natural Convection

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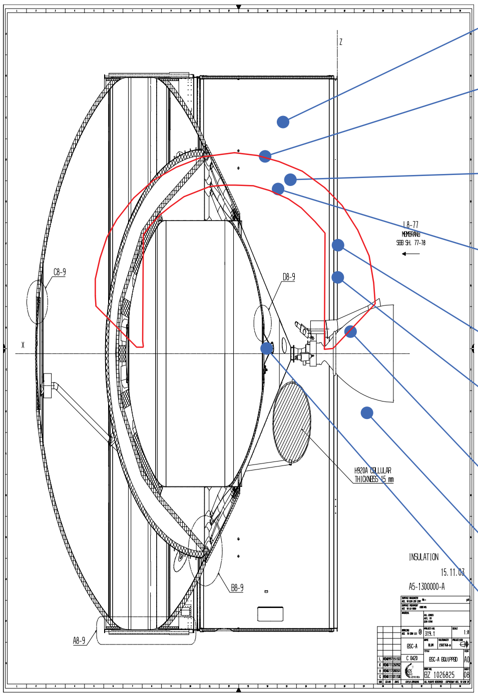
A5 ESC-A Intertank-Cavity



LH2-tank, liquid @ 20 K

Dacron w. Liner-Insulation: Inner Dome Insulation

Intertank-Cavity: Chinese Hat Cavity (CC) He-venting: 0.45 g/s

Intertank-Cavity: Upper Cavity w. Spacer (UC) He-venting: 0.5 g/s

MLI/Dacron-Insulation: Chinese Hat

Intertank-Cavity: Side Cavity (SC) He-venting: 0.5 g/s

MLI/Dacron-Insulation: Intertank-Membrane

Gas in Interstage-Cavity @ 244 K ... 274 K

LOX-tank, liquid @ 90 K

Order of Magnitude & Simplifications

Order of Convection in Cavity L = 80 ... 800mm

Gas: He @ 1atm, $\overline{T}^{gas} \approx 100K$
Wall: $\overline{T}^{wall} \approx 80K$
$\Delta T = 10 \ldots 50$ K

Rayleigh-Number: $Ra = Gr^*Pr = g L^3 \beta \Delta T / \nu^2 {}^* \nu/a = 10^6 \ldots 10^{10}$

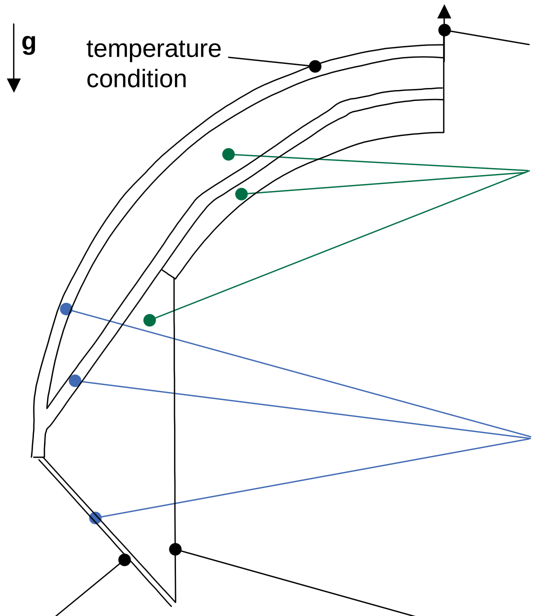
with $Ra < 10^8$: laminar

⇒ laminar / turbulent flow

Simplifications

- axisymmetric model
- spacers in UC have been neglected
- venting gas (0.5 ... 1 g/s) is assumed to enter and to leave the cavities homogeneously distributed with the temperature of the leaving gas at the mean temperature of the cavity
  ⇒ ventilation is solely considered as an energy source,
  the same approach has been used in the ESATAN stage model (SM)

CFD-Model (FLUENT): stationary case just before lift-off



temperature condition

axis of rotation:
symmetry condition

fluid: He, ideal gas

buoyancy: gravity in axial direction

turbulence modeling: k-ε

venting: energy source (via UDFs)

$\dot{m} / V^{gas} \; C_p (T^{in} - \overline{T}^{gas})$

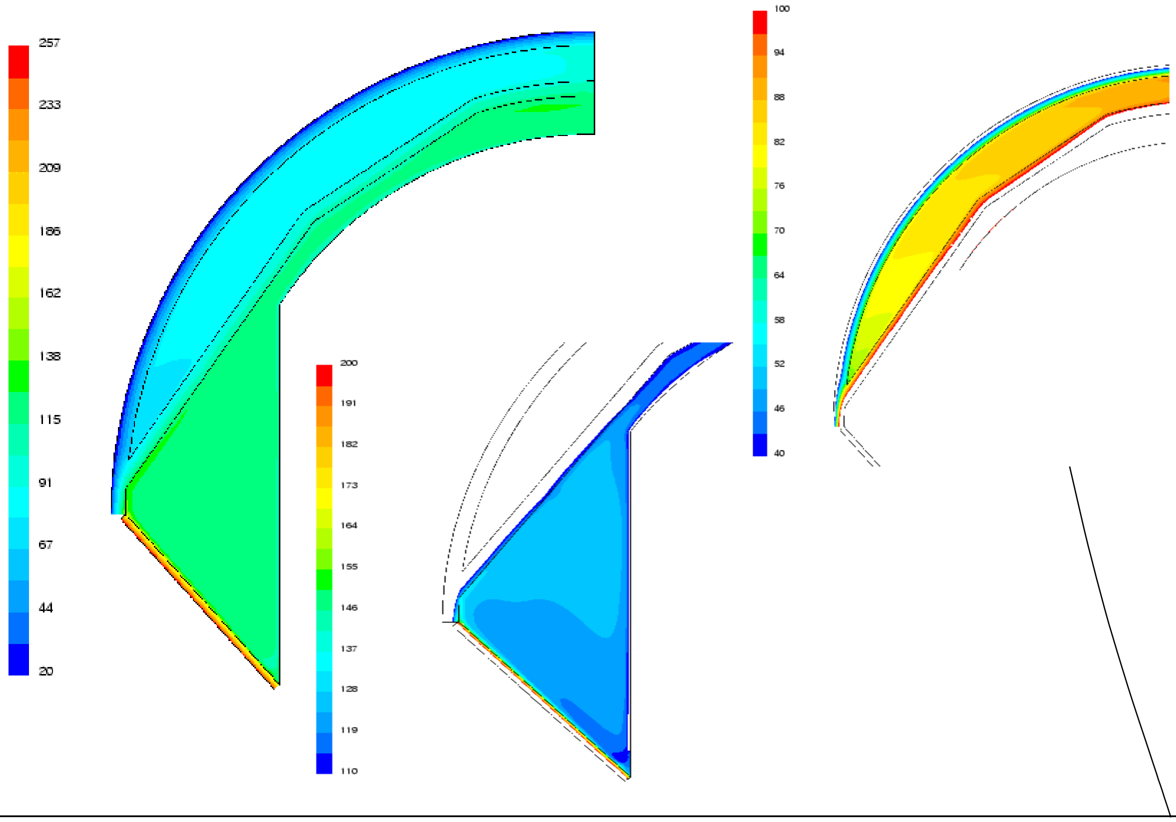
solid: open-pored Dacron felt
with conductivity uncertainty due to internal convection

⇒ extrem cases defined on the basis of the insulation conductivity range

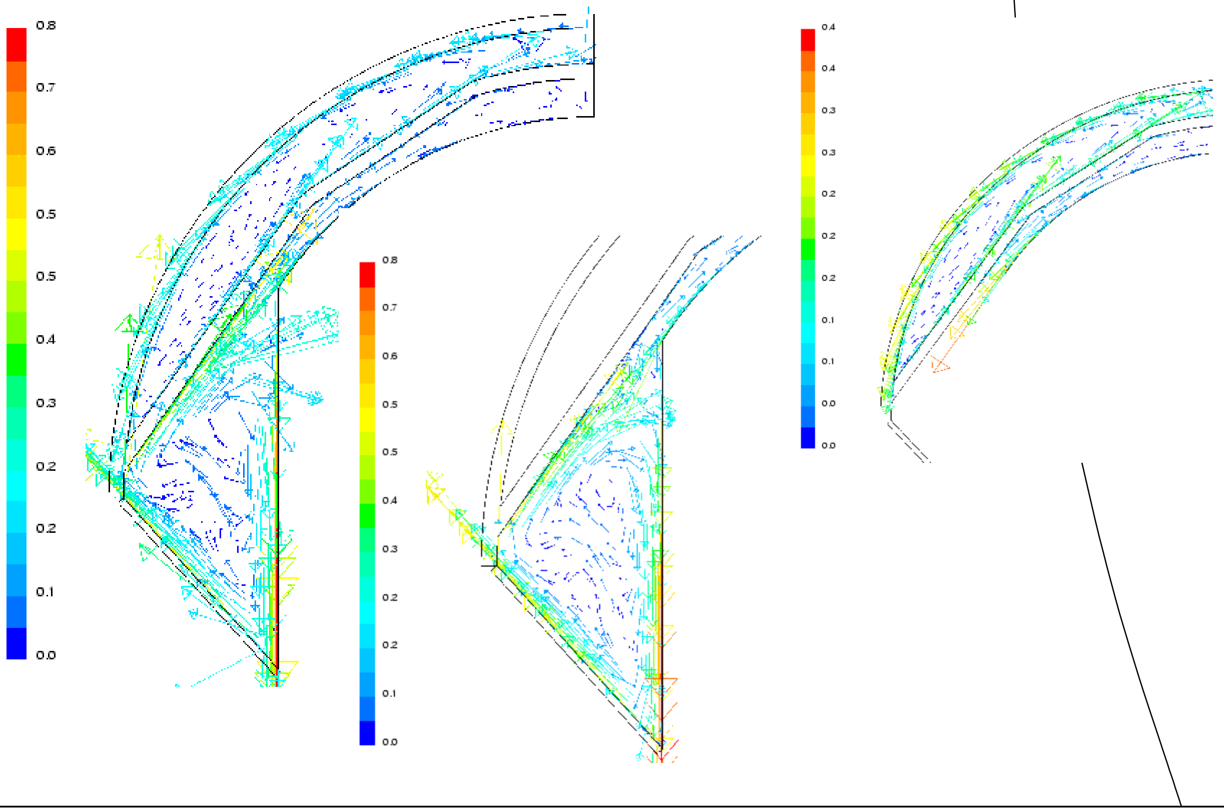
heat flux condition

temperature condition

CFD-Results: Temperature-Contours [K]



CFD-Results: Velocity Vectors [m/s]



Data Exchange between CFD and ESATAN

CFD-Results		ESATAN
volume-averaged temperature $\overline{T}^{gas}$ of cavity	≙	gas-node D^{gas} temperature of cavity
area-averaged temperature $\overline{T}^{wall}$ of certain wall section	≙	certain-wall node D^{wall} temperature
area-averaged convective wall heat flux $\overline{Q}^{conv}$ of certain wall section with area A^{wall}	$\overset{!}{=}$	convective heat flux of certain wall node D^{wall}
energy transport Q^{flow} between two cavities with volume-averaged temperatures $\overline{T}^{gas}_{1,2}$	$\overset{!}{=}$	energy transport between two gas nodes $D^{gas}_{1,2}$

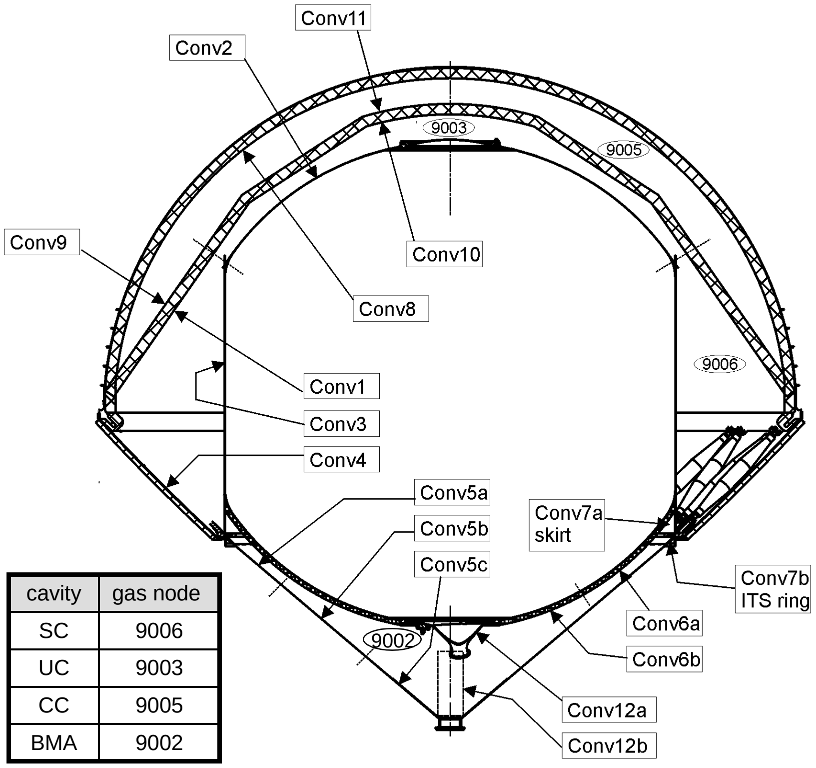
wall conv. heat transfer coeff.

$$h^{wall} = \overline{Q}^{conv} / A^{wall} / (\overline{T}^{gas} - \overline{T}^{wall}) \rightarrow GL(D^{wall}, D^{gas}) = h^{wall} * A^{wall}$$

inter gas conductance

$$H^{flow} = Q^{flow} / (\overline{T}^{gas}_1 - \overline{T}^{gas}_2) \rightarrow GL(D^{gas}_1, D^{gas}_2) = H^{flow}$$

Data Exchange between CFD and ESATAN (cont'd)



cavity	gas node
SC	9006
UC	9003
CC	9005
BMA	9002

Coefficient	[W/(m²K)]
CONV1	59.97
CONV2	9.97
CONV3	9.21
CONV4	13.79
CONV5A	14.41
CONV5B	11.39
CONV5C	19.66
CONV6A	10.30
CONV6B	15.31
CONV7A	2.62
CONV7B	4.07
CONV8	9.33
CONV9	77.03
CONV10	8.64
CONV11	6.06
CONV12A	6.25
CONV12B	0.48
Gas Conductance	[W/K]
9003 <-> 9006	162.73

Discussion

- because the h^{wall} refer to the average gas temp., unfamiliar high values may result in cases, where the wall temp. is near the average gas temp., e.g.

section	wall area A^{wall} $[\mathrm{m}^2]$	wall temp. $\overline{T}^{wall}$ [K]	conv. heat flux $\overline{Q}^{conv}$ [W]	average gas temp. $\overline{T}^{gas}$ [K]	conv. heat transfer coeff. $h^{wall} = \overline{Q}^{conv} / A^{wall} / (\overline{T}^{gas} - \overline{T}^{wall})$ $[\mathrm{W/(m^2K)}]$
conv1	11.52	121.2	1292	123.07	59.97
conv9	8.86	84.0	-732	82.9	77.03

- as long as the difference of the local gas temp. and the wall temp. has the same sign as the difference of the average gas temp. and the wall temp. the CFD derived h^{wall} lead to the correct ESATAN corresponding node temp. and heat fluxes, otherwise the gas cavity has to be subdevided and additional gas nodes have to be introduced in CFD and ESATAN, respectively
- if a cavity is subdevided into subdomains, for implementation of gas conductances in ESATAN the borderline between the subdomains should be set in a way, that heat is transferred from the subdomain with a higher average gas temp. to the subdomain with a lower average gas temp.

Summary

- natural convection is of great importance for the the thermal performance of cryogenic vehicles, as shown for A5 ESC-A Intertank-Cavity (IC): due to great temp. gradients the flow is locally turbulent in the IC
- an axisymmteric CFD model has been established using the commercial code FLUENT
- the ventilation has been implemented in the CFD model, where the same approach has been considered as used for ESATAN stage model (SM)
- from the CFD results convective heat transfer coefficients and conductances between gas nodes have been derived, which are now used in the SM
- unfamiliar high convective heat transfer coefficients may result, which can be lead back to the difference between the local and the average gas temperature
- in case of a cavity subdivision the borderline of the subdomains should respect the direction of heat transfer for solids