Development of a Two-Phase Mechanically Pumped Loop (2ΦMPL) for the Thermal Control of Telecommunication Satellites

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Presentation plan

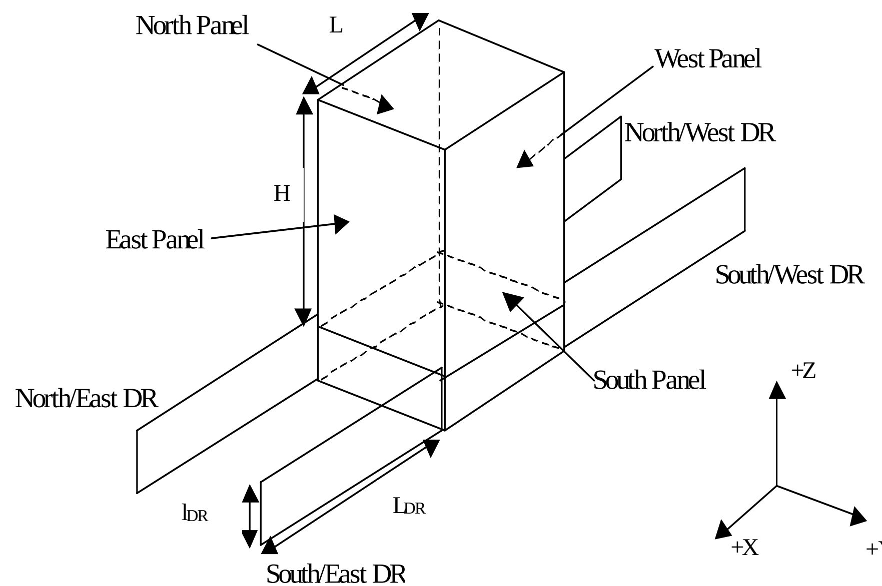
- Background
- Architecture/thermal hypothesis and requirements
- 2ΦMPL hydraulic scheme
- 2ΦMPL components
- Mathematical modeling
- 2ΦMPL overall mass budget
- 2ΦMPL ground prototype
- 2008 perspectives

Background (1/2)

The future large and powerful telecommunication satellites could need the use of large deployable radiators (DPR) and efficient thermal loop to transport large amount of heat on long distances

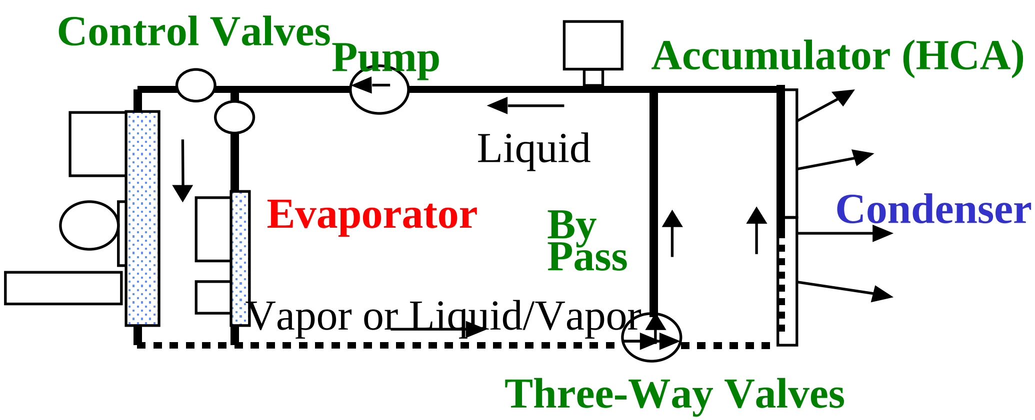
<u>Main original need</u> : @bus Extended Range

<u>Other potential applications</u> : very dissipative units like active antennas

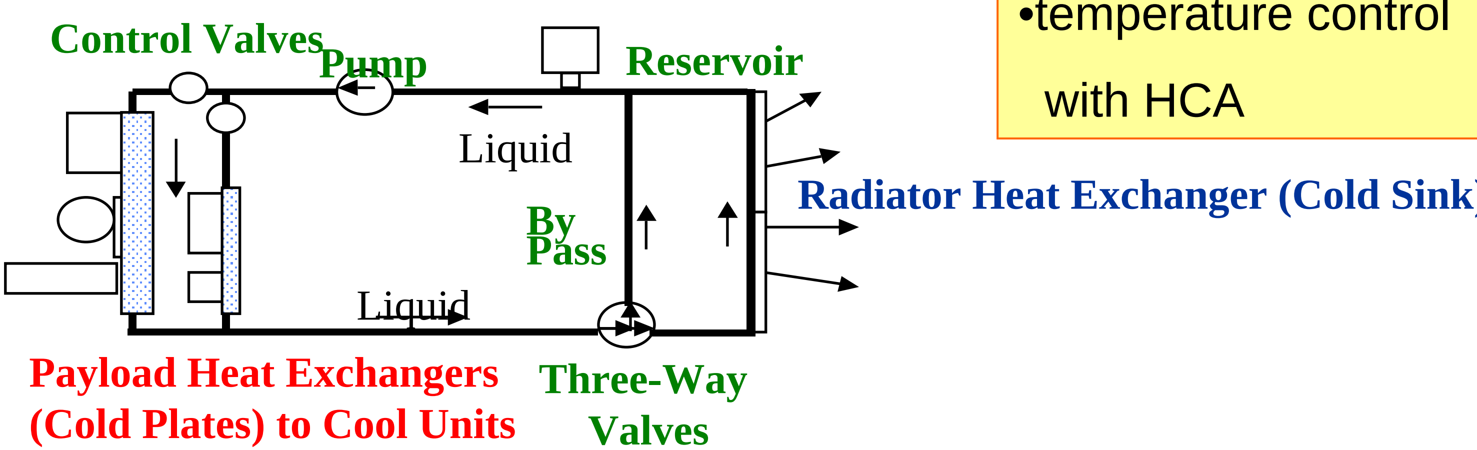


About Mechanically Pumped Loops

2ΦMPL Scheme



Single Phase Loop (SPL) Scheme



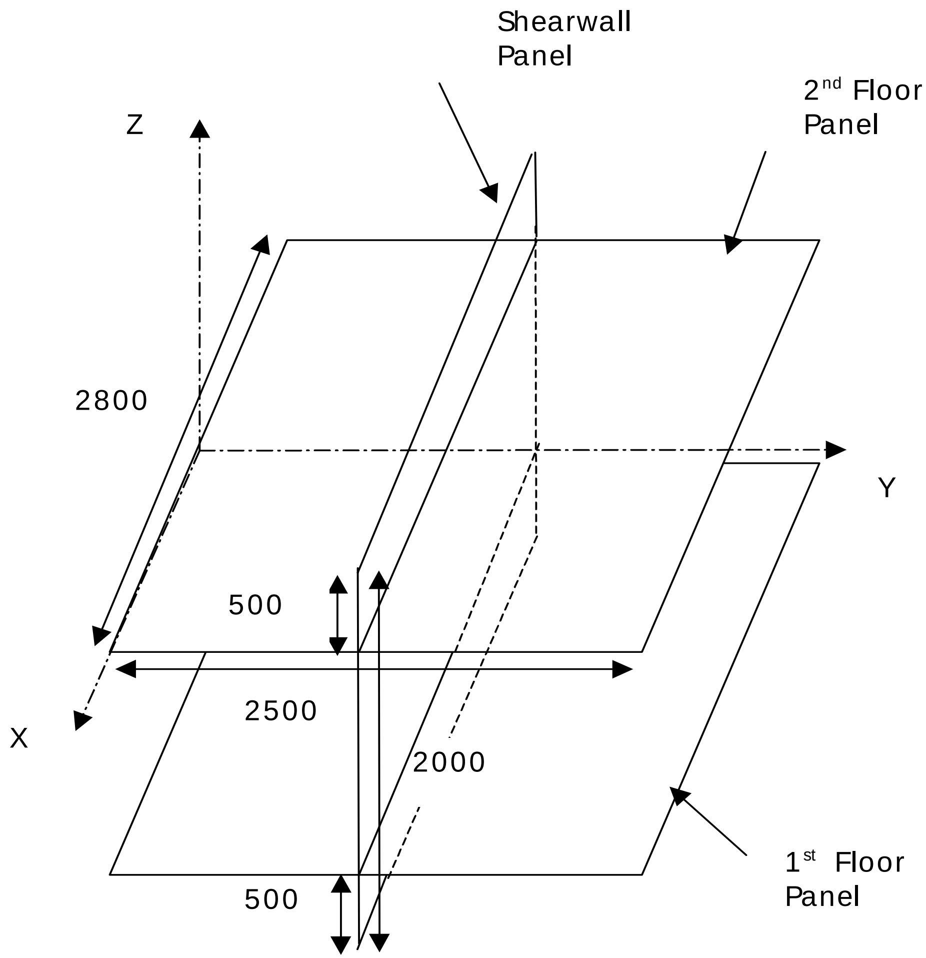
Main 2ΦMPL advantages wrt to SPL :

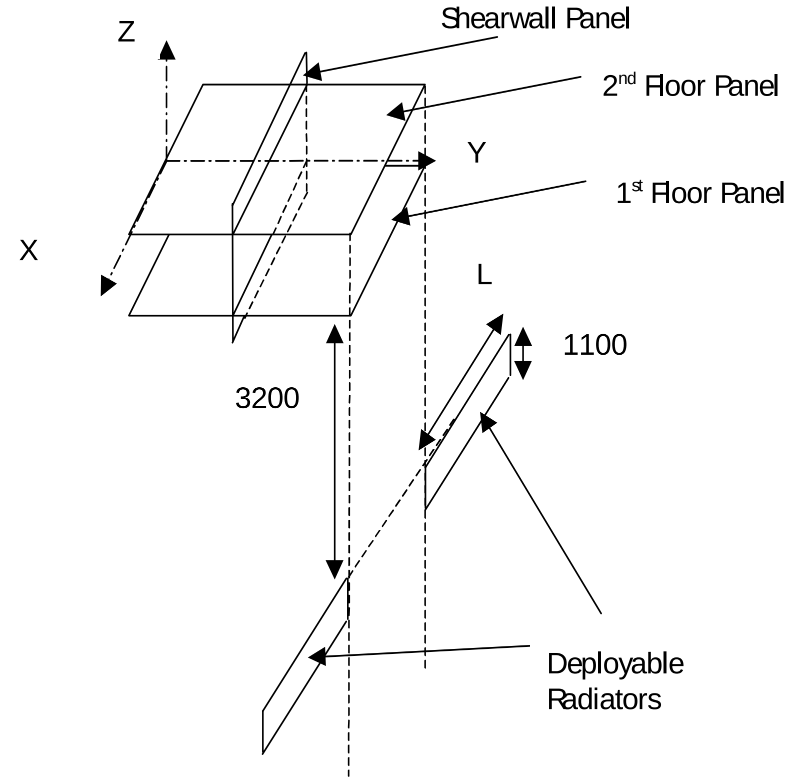
- isothermallity
- mass
- pump power consumption
- temperature control with HCA

Background (2/2)

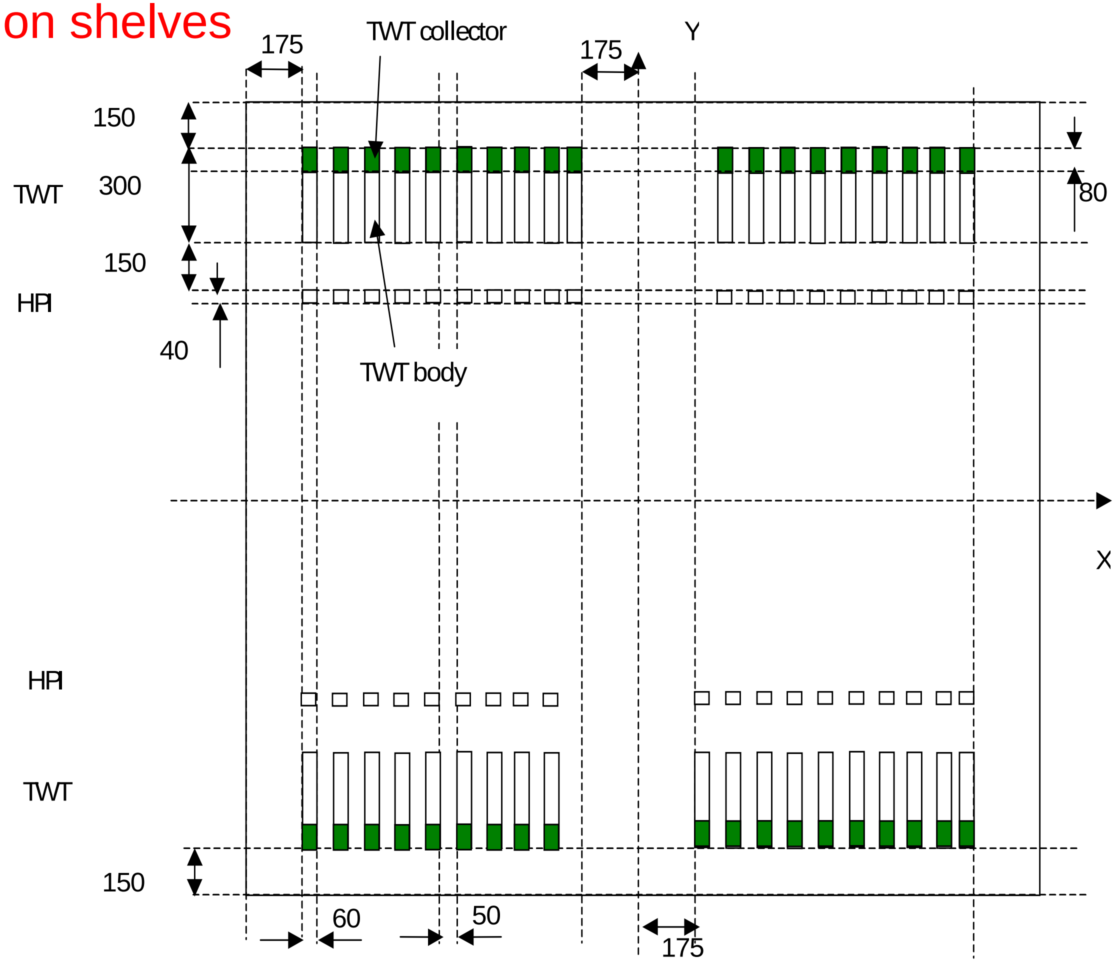
- A two-phase TCS was developed in the 90's for ISS Russian Segment
- In 2002, Russian/Ukrainian experience on both products has been investigated by ThAS through a Trade-Off study with mass as the main criterion : 30% mass saving with a two-phase system was demonstrated
- In 2005, ThAS/CNES, through a R&T program, started a development phase with the first step consisting in the evaluation of an Ukrainian NH_3 2ΦMPL prototype to be designed, manufactured and tested by the Kharkov Aviation Institute according to ThAS requirements

Platform with shelves





Units layout on shelves



TWT and HPI units layout and dimensions on an horizontal panel
(+ / -Z symmetric layout)

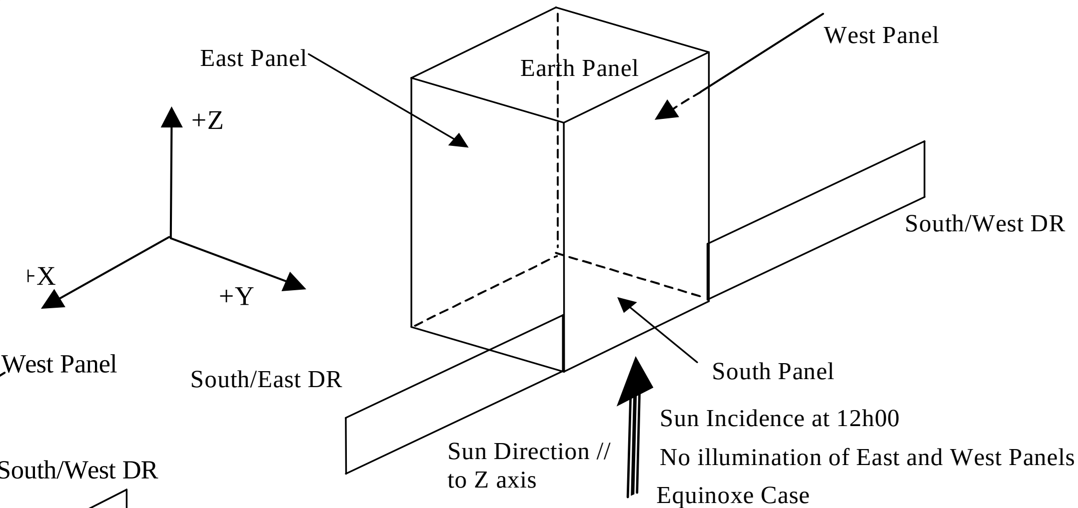
Units thermal characteristics

	Number of Active Components	Dissipation per Unit (W)	Total Dissipation (W)
TWT 1st Floor *TWTA*	60	50	3000
TWT 2nd Floor *TWTB*	60	30	1800
OMUX Lower Shearwall Part *OMUXA*	30	22	660
OMUX Upper Shearwall Part *OMUXB*	30	18	540
	Total Heat Load (W)		6000

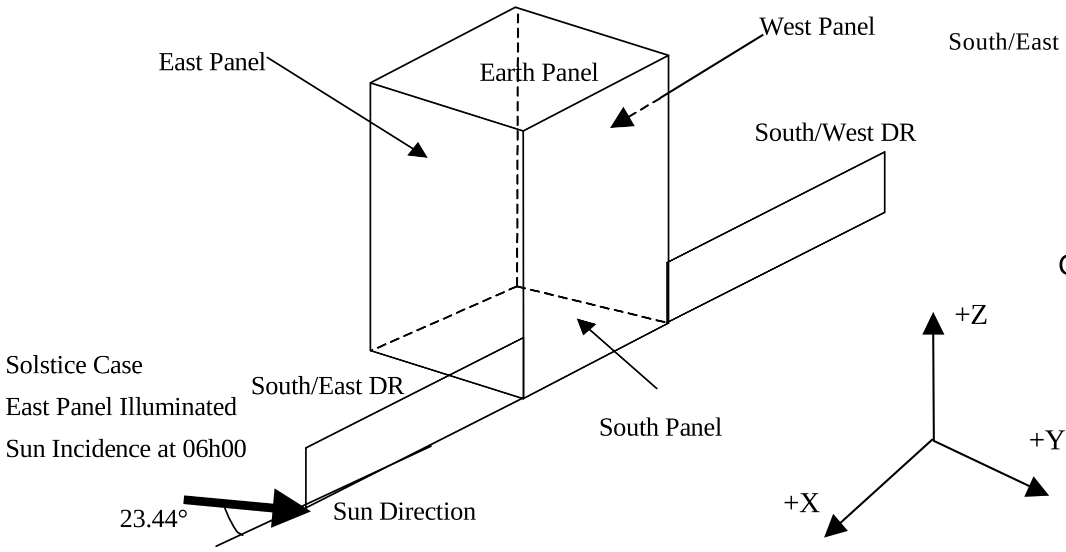
	Calculation				
	Operating Temperature (°C)		Non Operating Temperature (°C)		Cold Start Up (°C)
	Min	Max	Min	Max	
TWT	+10	+70	-20	+70	-20
OMUX	+35	+75	-20	+75	-20

	TWTA	OMUXA	TWTB	OMUXB
m (kg)	0,80	0,90	0,80	0,15
mCp (J/K)	720	810	720	135

Environmental conditions (1/2)



Cold environmental condition



Hot environmental condition

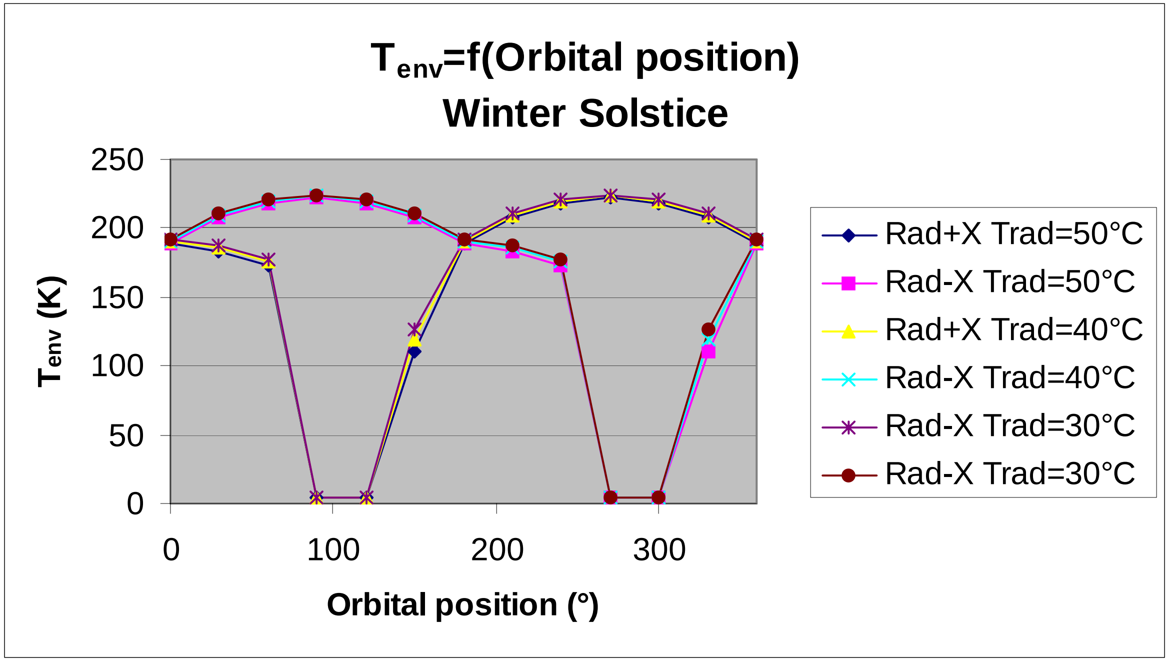
Environmental conditions (2/2)

$$\left(1+F_{rad-space}\right)\varepsilon_{OSR}\sigma S_{rad}\left(T^4_{rad+X}-T^4_{env+X}\right)=Q_{MPL+X}$$

$$\left(1+F_{rad-space}\right)\varepsilon_{OSR}\sigma S_{rad}\left(T^4_{rad-X}-T^4_{env-X}\right)=Q_{MPL-X}$$

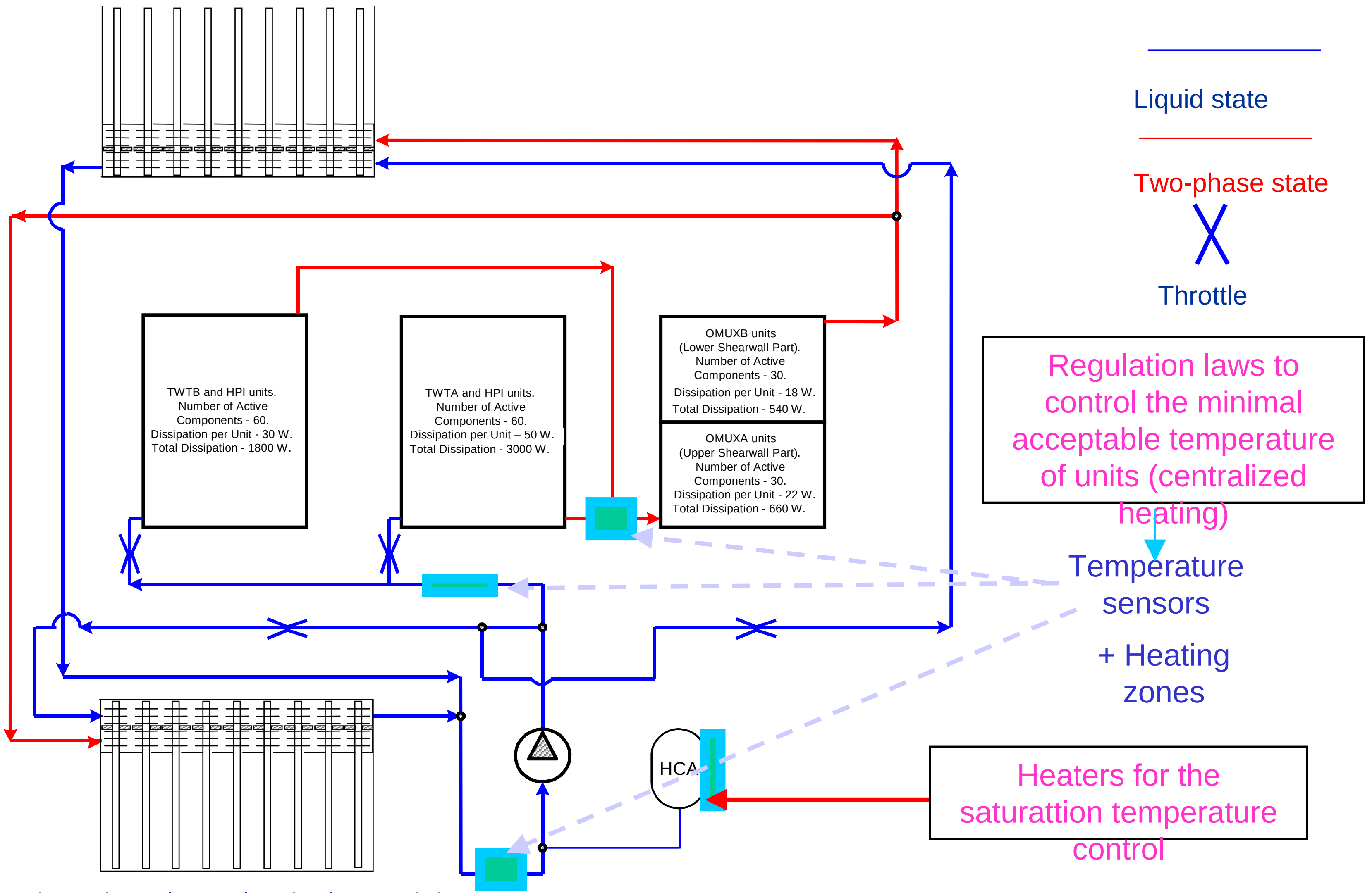
$$Q_{MPL\_tot}=Q_{MPL+X}+Q_{MPL-X}$$

S_{rad} (m^2)	$F_{rad-space}$
5	0,86
4,5	0,85
4	0,83
3,5	0,82
3	0,80
2,5	0,77



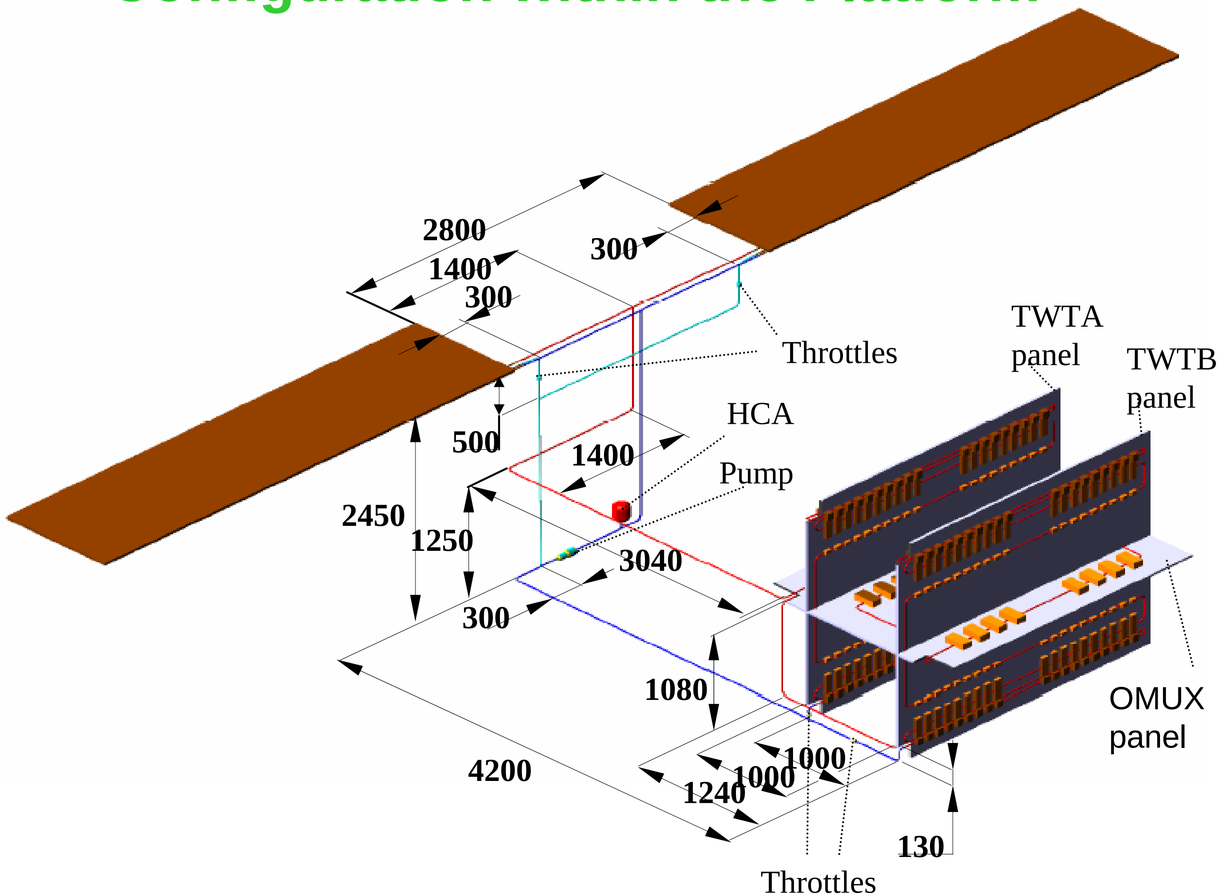
Environmental temperatures variation the deployable radiators for different orbital positions in winter solstice S_{rad}=5m²

2φ MPL Hydraulic Scheme (1/2)



2φ MPL Hydraulic Scheme (2/2)

Configuration within the Platform



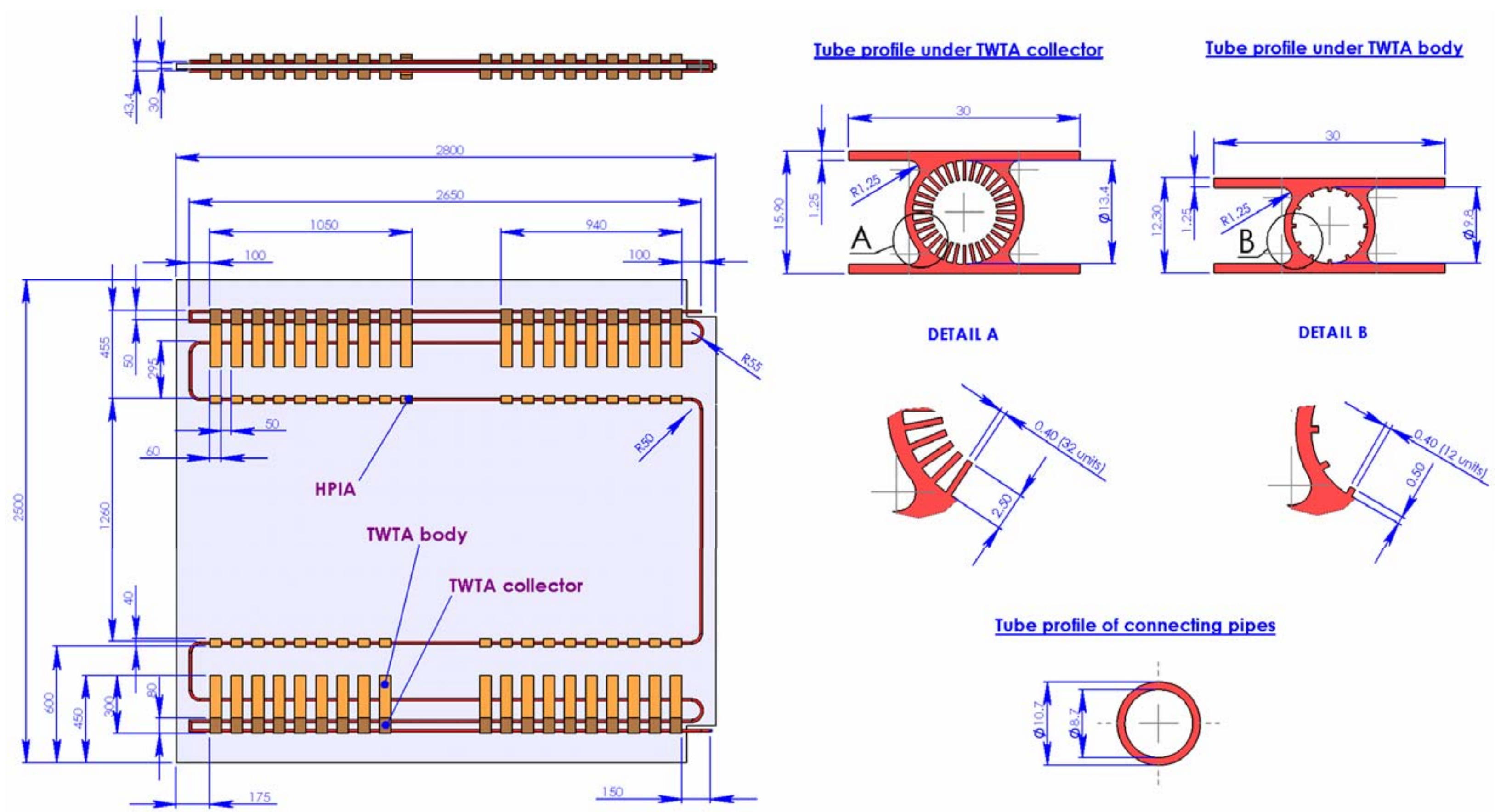
2φ MPL Components (1/5)

- Evaporator tubing
- Pump
- Heat-controlled accumulator (HCA)
- Radiators with embedded heat pipes
- Condenser/subcooler components
- Throttles
- Heaters

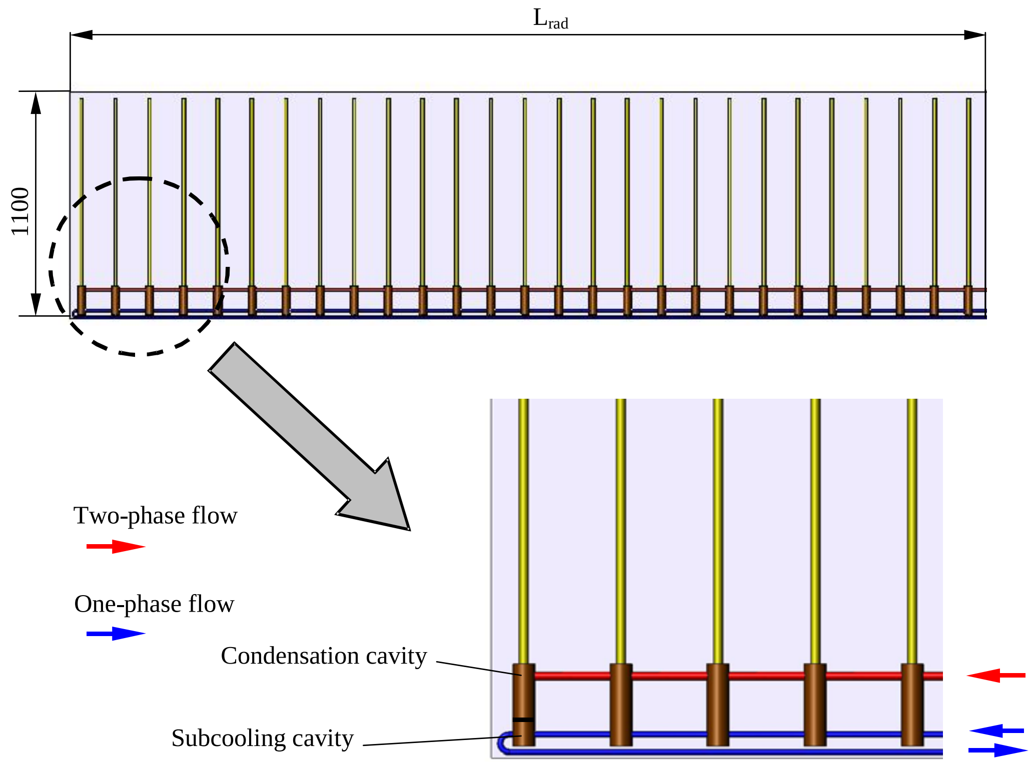
Optimization of the components design to minimize the overall system mass :

$$M_{MPL} = \left(M_{tube} + M_{fluid} + M_{pump} + M_{power} + M_{rad}\right) \rightarrow \min$$

Evaporators tubing



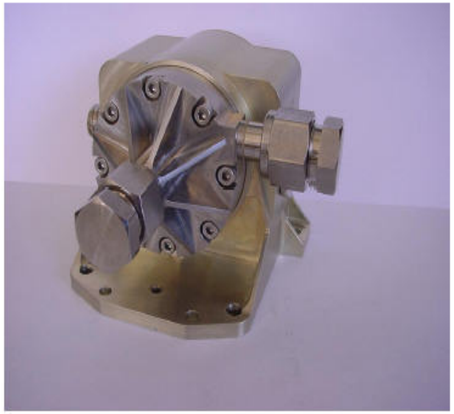
Condenser/subcooler components in the radiators

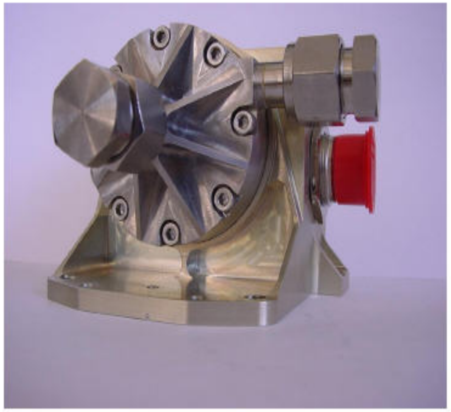


2φ MPL Components (4/5)

NACPA II Pump Opportunity (1/2)

- ✓ In 2005-2006, ThAS has been invited by ESA to follow NACPA project that has consisted in Realtechnologie AG review of the NACPA centrifugal pump package (documentation + hardware, performance tests included) developed by ESA/ETEL in the 90's



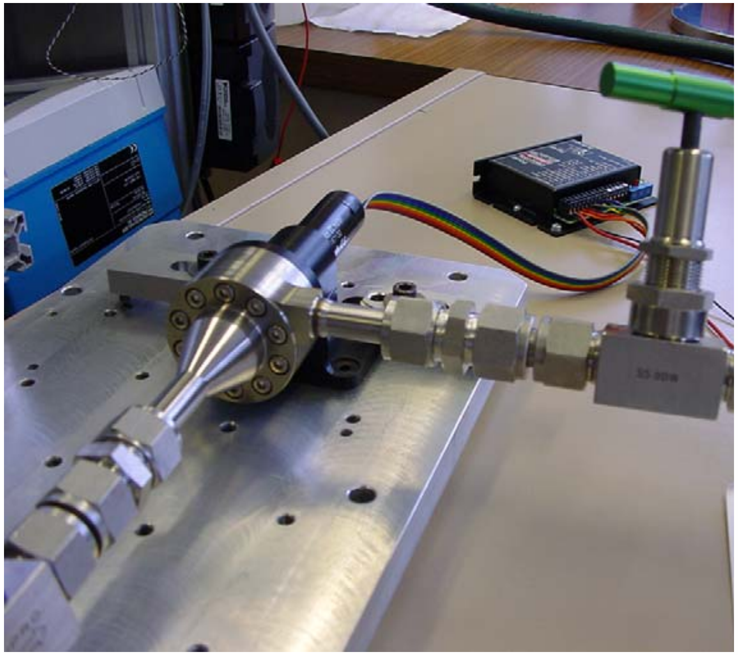


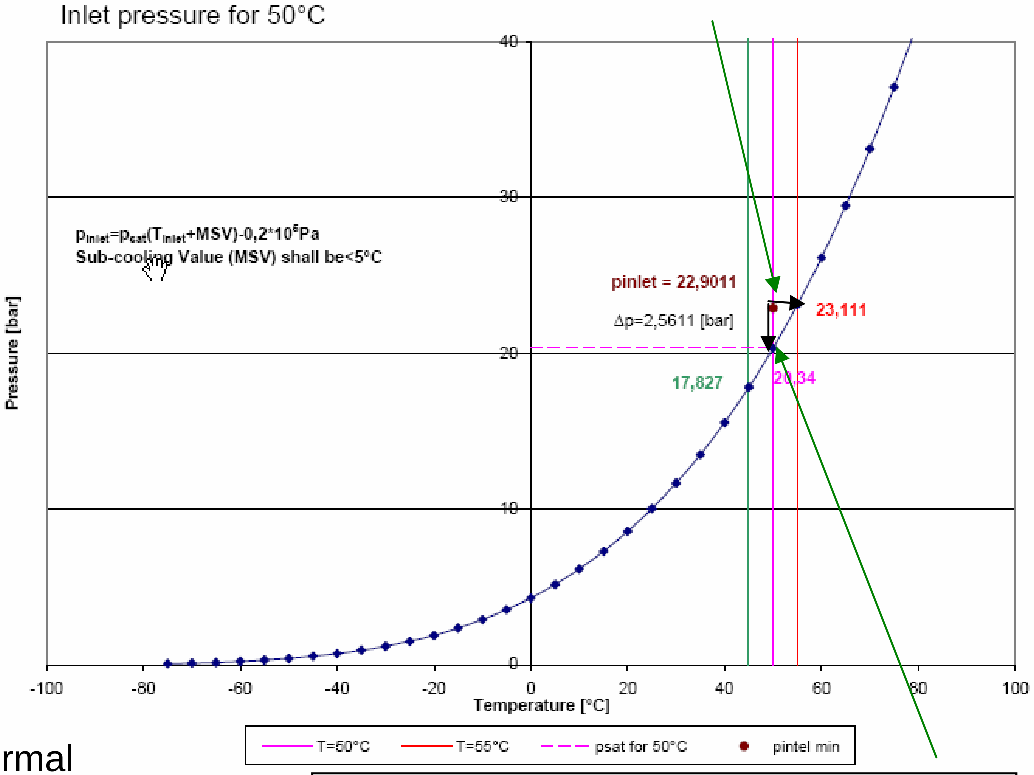
- ✓ Between 2006 and 2008, ThAS collaborates for the ESA/Realtechnologie AG development of a new NH_3 pump/motor engineering model and of a prototype of the associated driver motor electronic unit (NACPA II project)

2φ MPL Components (5/5)

NACPA II Pump Opportunity (2/2)

Temperature reserve : maximum allowable local temperature increase in the pump

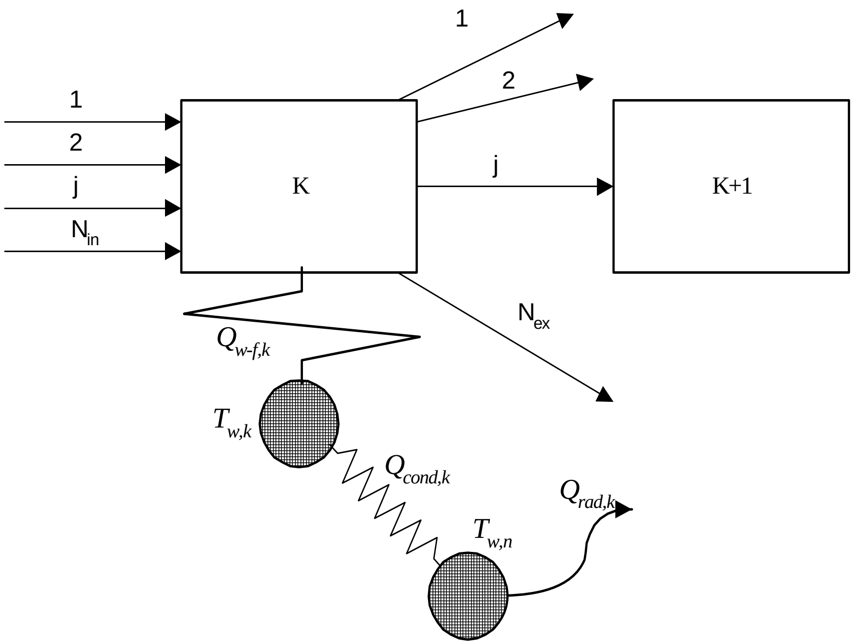




- ThAS is responsible for the thermal analysis of the NACPA II pump
- Cavitation issue in the pump can be critical at low temperature

Pressure reserve : maximum allowable local pressure drop inside the pump (only 0.44bar at –10°C)

Mathematical Modeling (1/2)



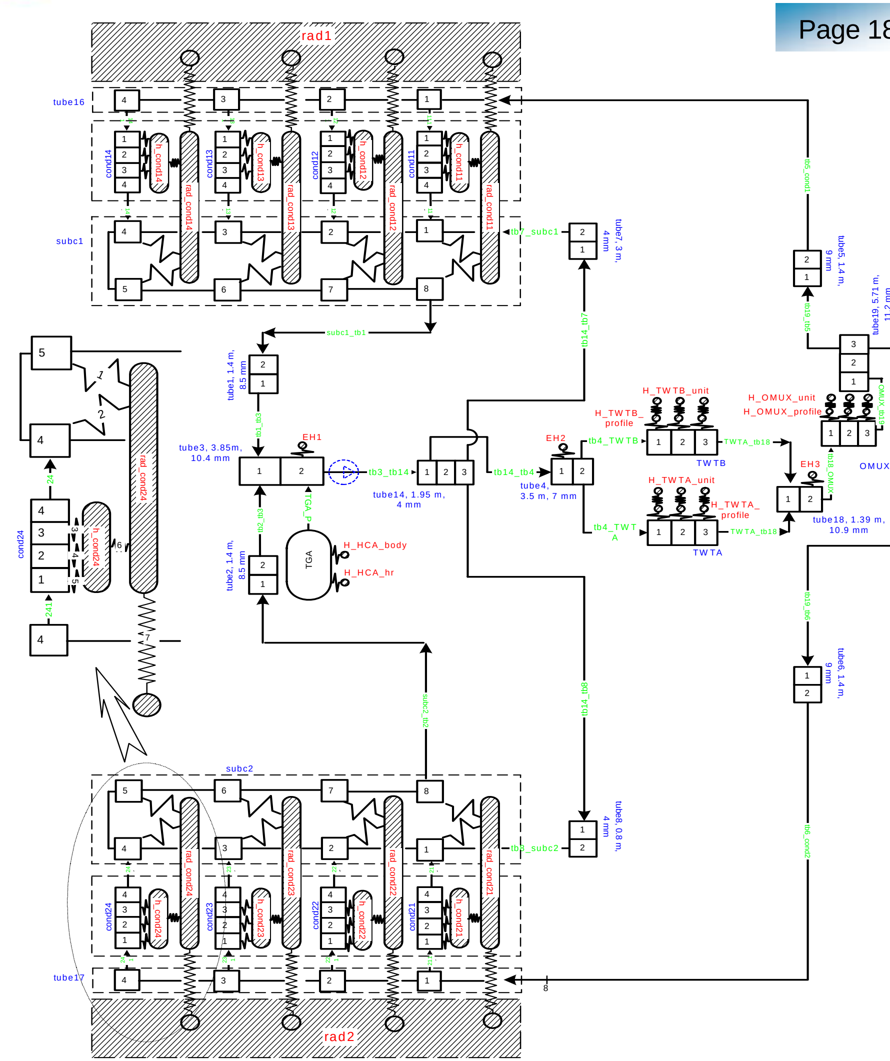
- control volume;

- branch (junction)

- convective heat conductor;

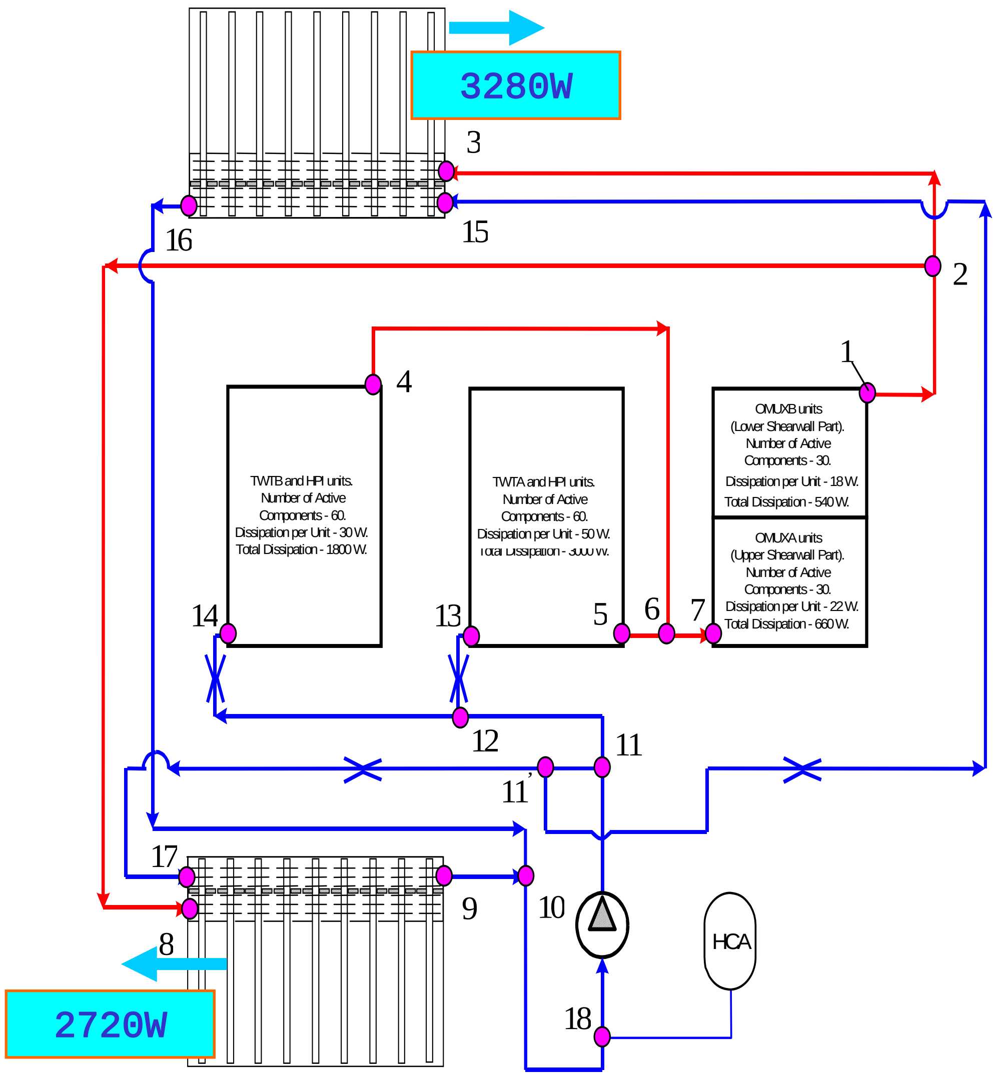
- conductive heat conductor;

- radiative heat conductor.



Nodalisation of flight 2ΦMPL

Mathematical Modeling (2/2)

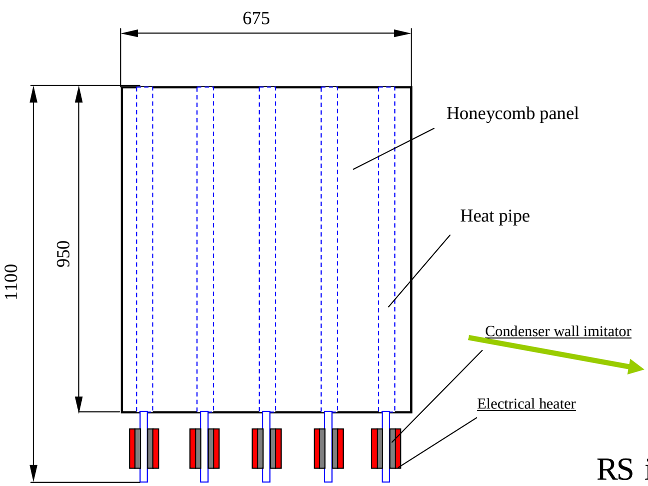


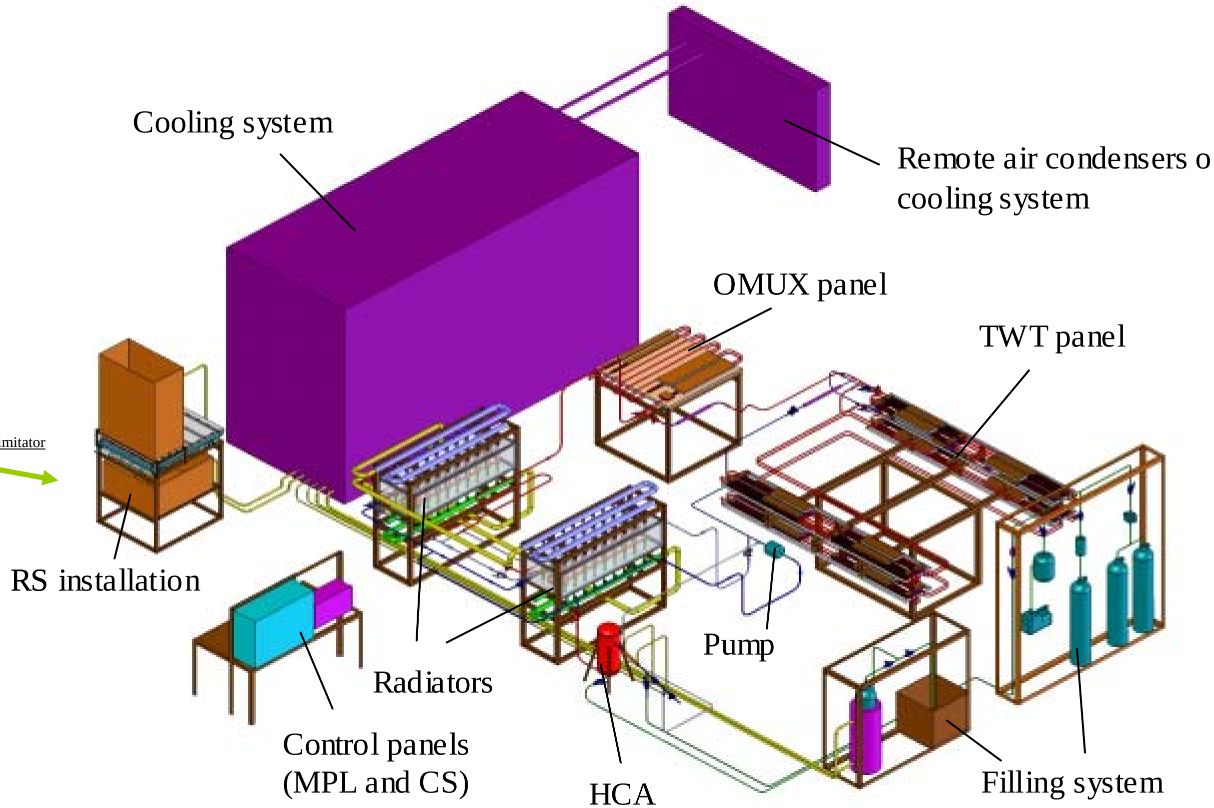
	P, MPa	T, °C	x	m, g/s
1	2.3918	56.392	0.90412	6.3116
2	2.3912	56.384	0.90411	6.3116
3	2.3911	56.382	0.90411	3.4308
4	2.3946	56.441	0.71332	2.3988
5	2.3946	56.441	0.72941	3.9128
6	2.3946	56.441	0.72330	6.3116
7	2.3945	56.439	0.72330	6.3116
8	2.3912	56.382	0.90411	2.8808
9	2.3804	51.887	0.0	11.337
10	2.3803	51.559	0.0	23.045
11	2.4557	51.479	0.0	23.045
11'	2.4476	51.478	0.0	16.734
12	2.4555	51.479	0.0	6.3116
13	2.3970	51.900	0.0	3.9128
14	2.3995	51.900	0.0	2.3988
15	2.3821	51.546	0.0	8.2778
16	2.3804	51.220	0.0	11.708
17	2.3802	51.546	0.0	8.4586
18	2.3800	51.560	0.0	23.045

Overall Mass Budget

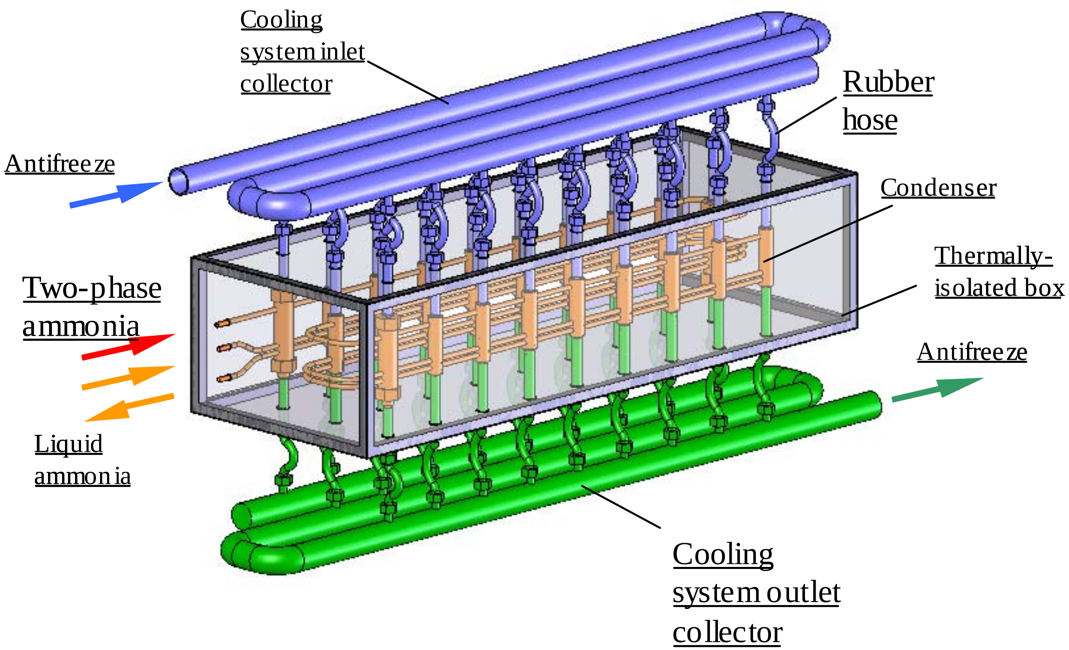
MPL components	Mass, kg	Comments
Mass of radiators + tubes + HCA	104	Surface area of one side of radiator is equal to **4.3 m^2** calculated based on conservative hot heat removal conditions corresponding to 270^0 with the same environmental conditions of both radiators. Thermal gradient of MPL between TWT unit and radiator skin is equal to **22.2 K** : **9.5K** between TWT and evaporator fluid (two-phase thermal exchange calculation) and **12.7K** between condenser fluid and radiator => Global conductance>**120W/K** and Heat Rejection Capacity>**650W/m^2**
Ammonia	8	
Pump unit (redunded, with electronics)	8	Operating point of pump corresponds to 1.17 bar and 44×10^{-6} m^3/s at 50°C temperature of ammonia. Required power of pump is less than 50 W.
Total	**120**	**20 kg/kW** but without the shielding against micrometeorits =>**25kg/kW** is nevertheless reachable (P=0.998 for 15 years)

General view of the prototype

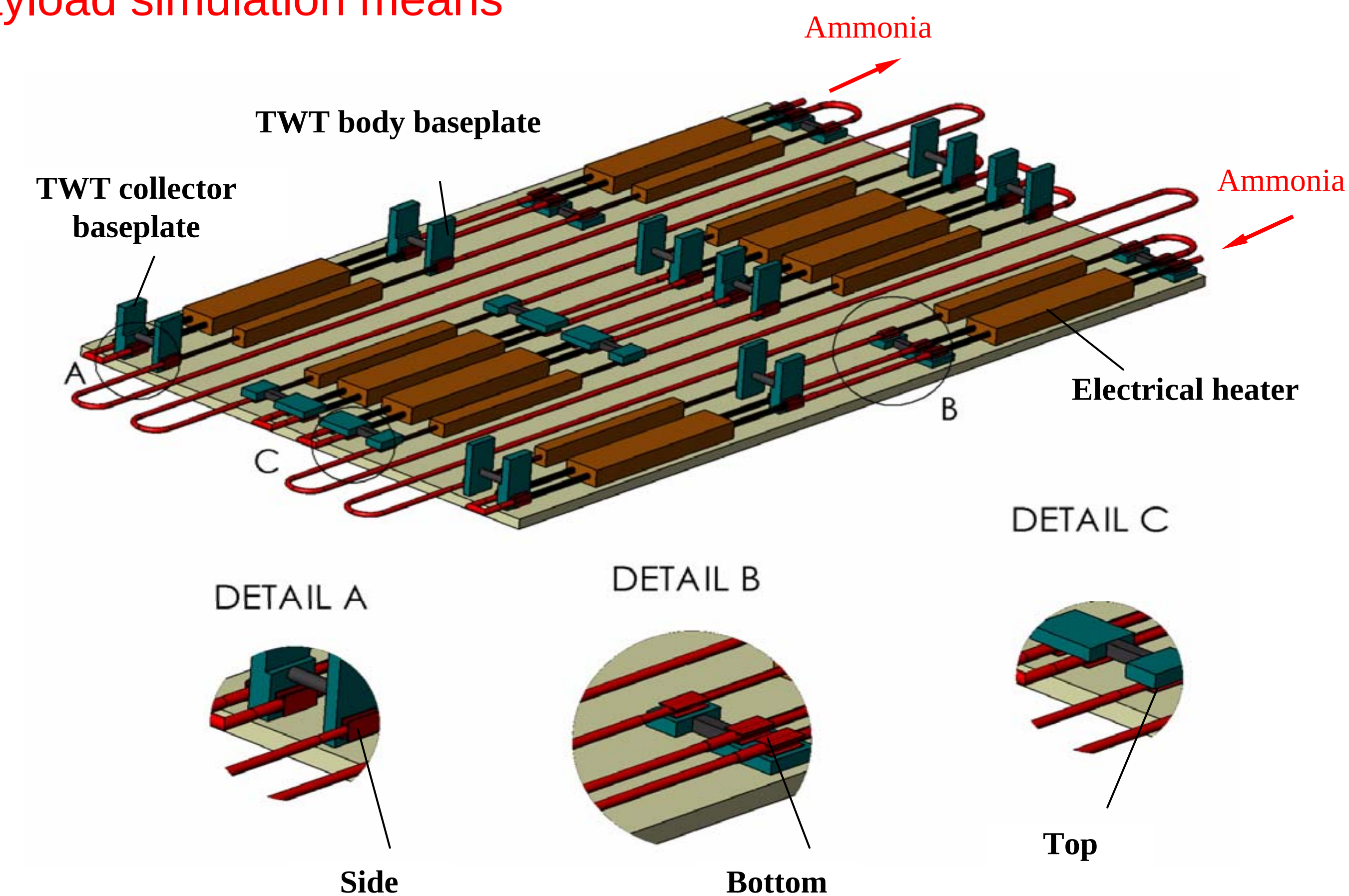




Condenser and cooling fluid circulation



Payload simulation means



Positions of heat transfer surface between unit and tube

- The prototype partly assembled

2008 perspectives

MPL Prototype Functional Testing

- The proof, leak and filling phases are foreseen for the end of May
- During the second semester of 2008
  - ✓ Both steady-state (hot and cold cases) and transient (hot to cold and cold to hot) will be tested
  - ✓ The regulation concept using HCA heating and centralized heating will be investigated
  - ✓ Start-up issue of the system will be investigated too

NACPA Pump

- The pump BBM shall be successfully tested for performances (including cavitation test) for the end of May
- The pump+motor DM and the DME BBM shall be assembled/tested for the end of 2008