EPIC - Staves Prototype Simulation and Testing

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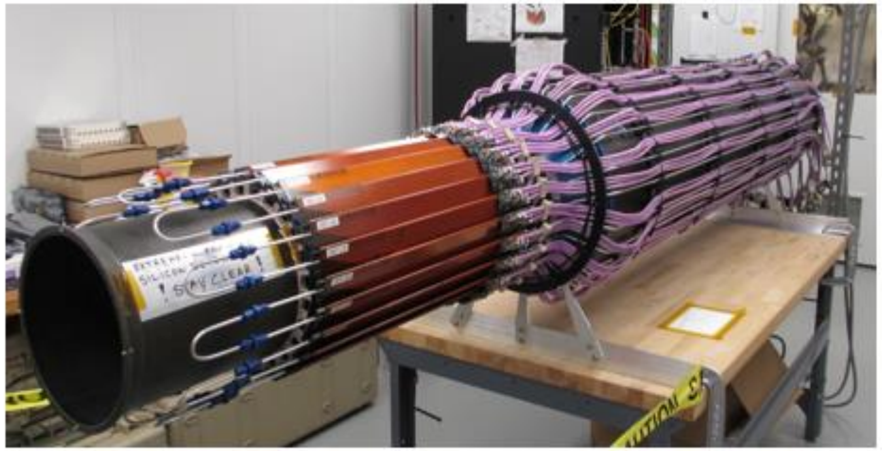
NCKU-AS-Purdue Team

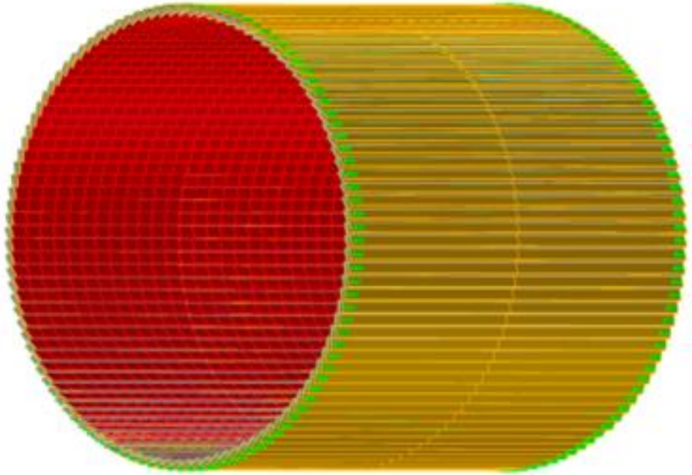
- Yi Yang (NCKU), Wen-Chen Chang (AS) & Po-Ju Lin (NCU)
  - Experiences with the AMS-02 UTTPS radiator and lead the project of the mechanical structure of STAR FST
  - Excellent machine shop

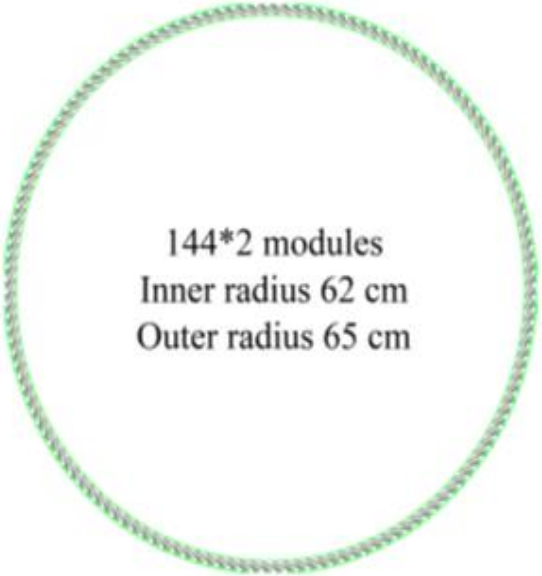


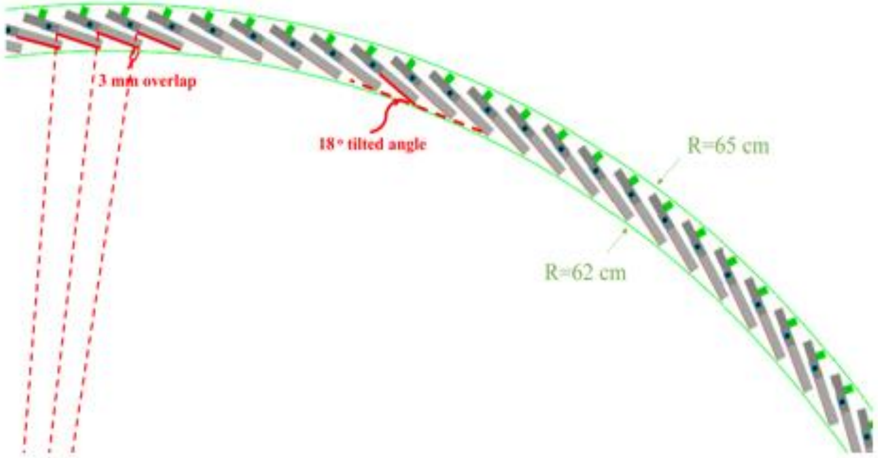
- Andreas Jung (Purdue)
  - Experienced in R&D for low mass support structures.
  - Working on the light-weight composite tracker support structures for CMS.

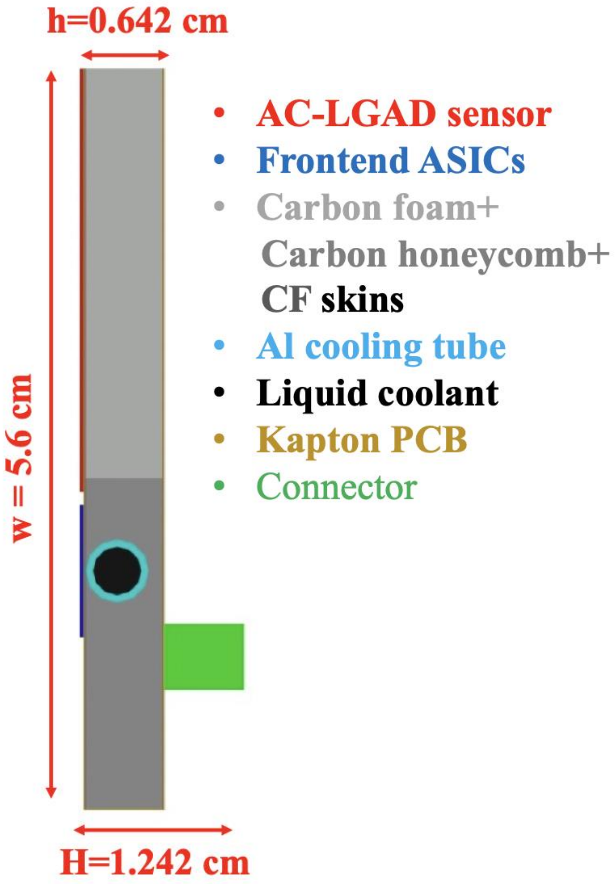
Similar concept of STAR IST







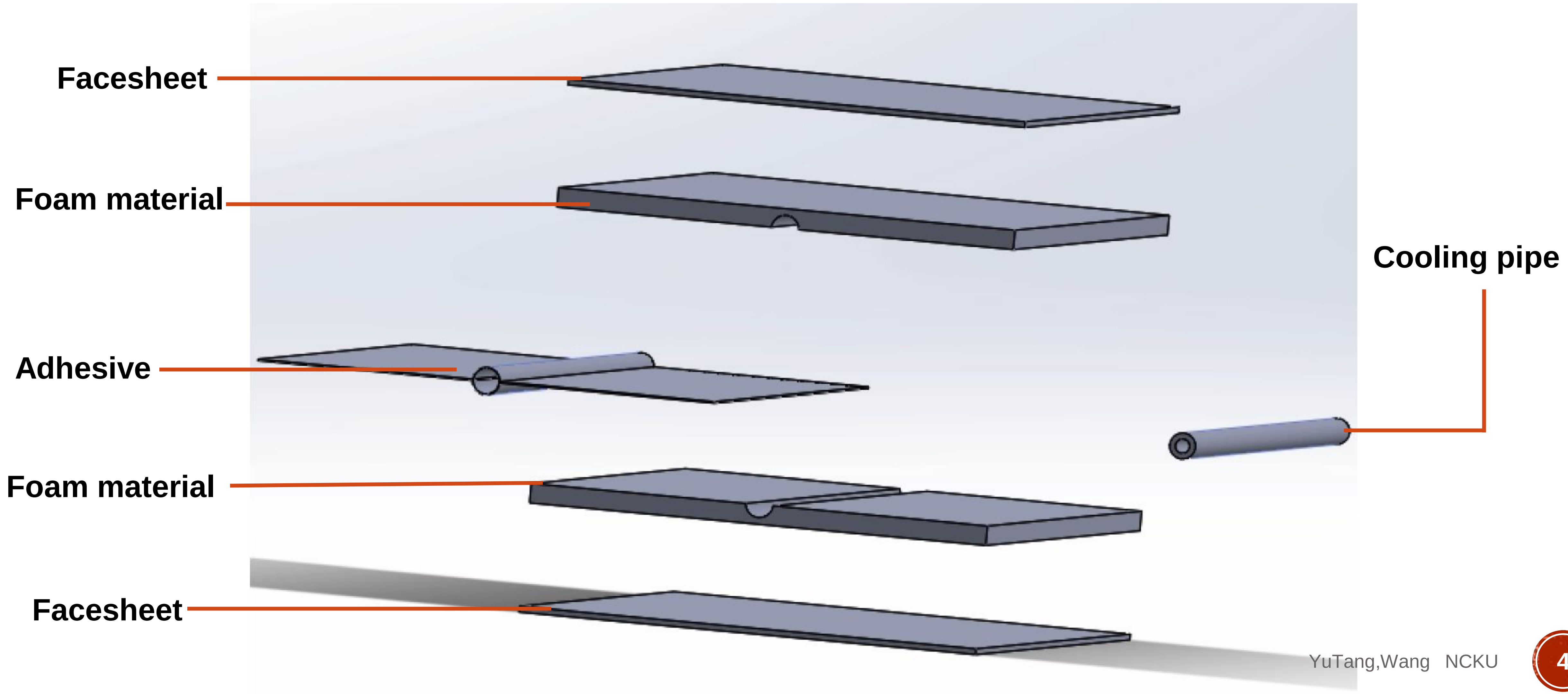




From Zhenyu's talk
https://indico.bnl.gov/event/16765/

Structure of Prototype

- Bases on the concept of STAR IST

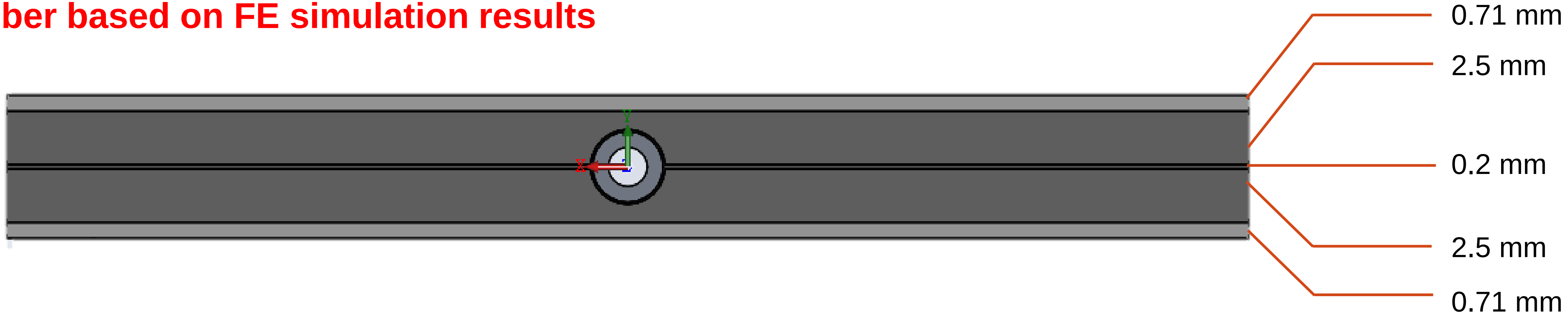


Preliminary design of Prototype From Purdue (Professor Jung Andreas and Sushrut Karmarkar)

- Design based on the STAR IST staves
  - – Deviates from the STAR IST stave design by making it symmetric
- Dimensions as follows – **total thickness is 6.42 mm**

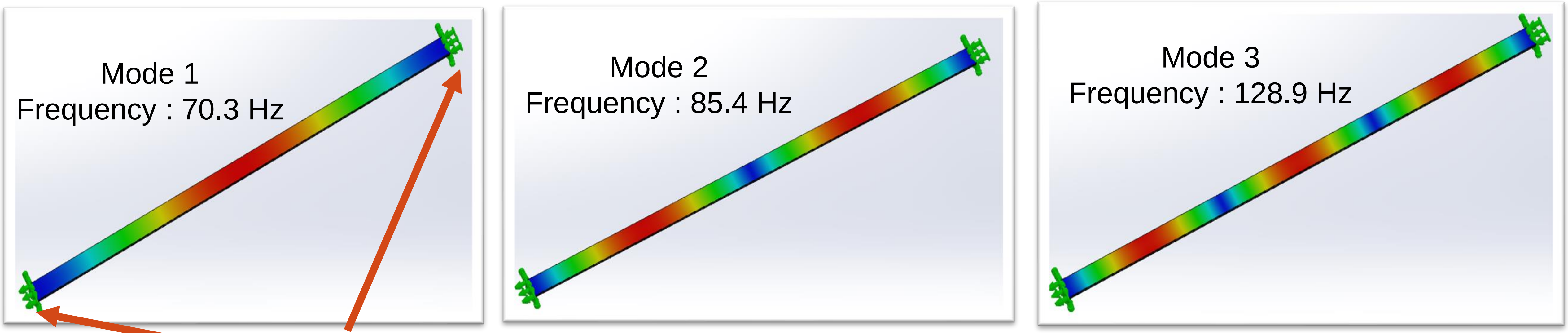
  (0.71 mm facesheet [0/90/0/90/0/90/0] – assumed to be EX1515-K13D2U 120 gsm

  + 2.5 mm foam + 0.2 mm adhesive thickness + 2.5 mm foam + 0.71 mm facesheet)
- Foam material used – CFOAM 35 HTC
- Facesheet – Toray EX1515 – K13D2U – 120 gsm – UD prepreg EHM32 / T700 – 250 F cure – UD prepreg – layup [0/90/0]
  - ➢ **Final material of choice will be radiation hard cyanate ester prepreg with choice of fiber based on FE simulation results**



Preliminary setup of frequency analysis

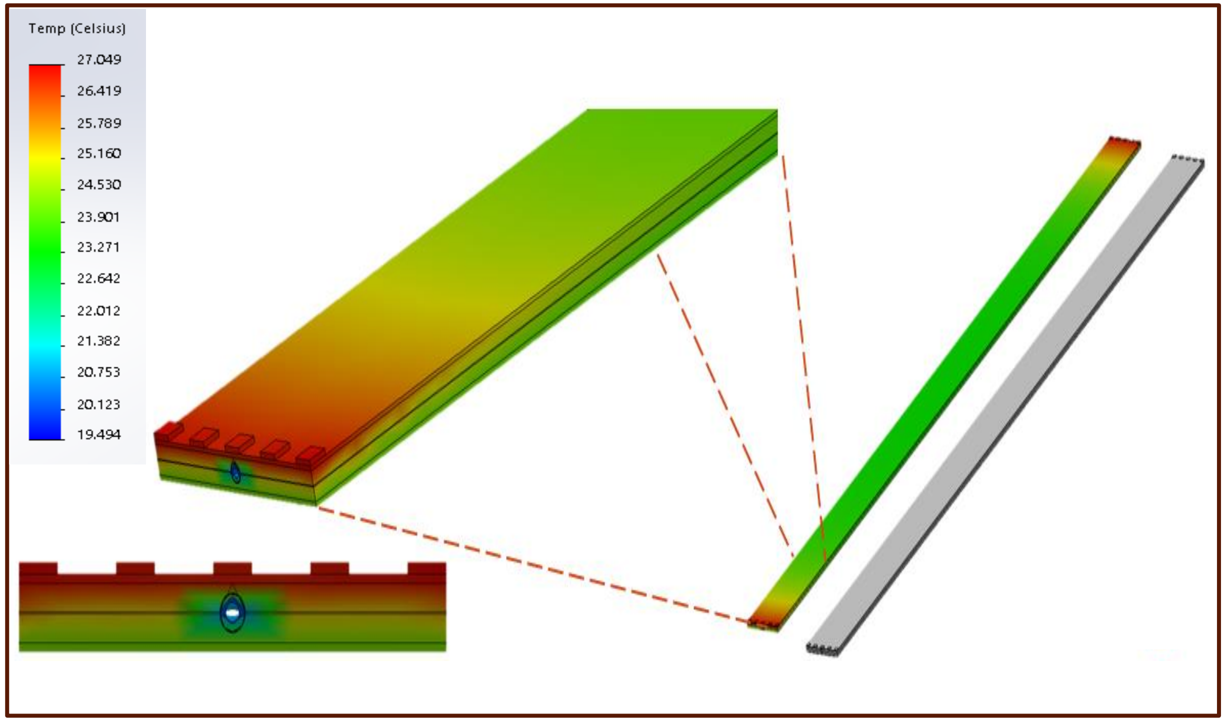
- Make sure the structure won't be damage because of resonance
- Decide the position of extra support if necessary
- Building up the simulation environment, **materials are not the final materials**

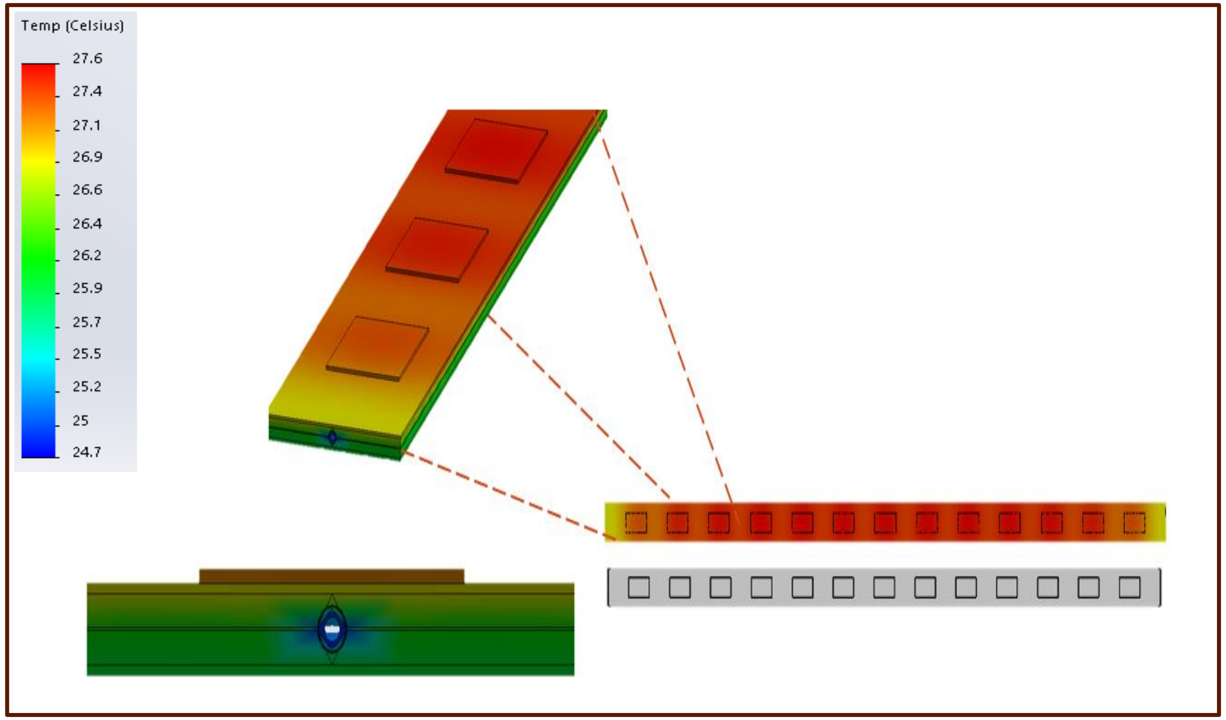


Fixed point

Preliminary setup of thermal analysis

- Estimate the efficiency of cooling system
- Simulate the temperature profile of different configuration
- Building up the simulation environment, **materials are not the final materials**



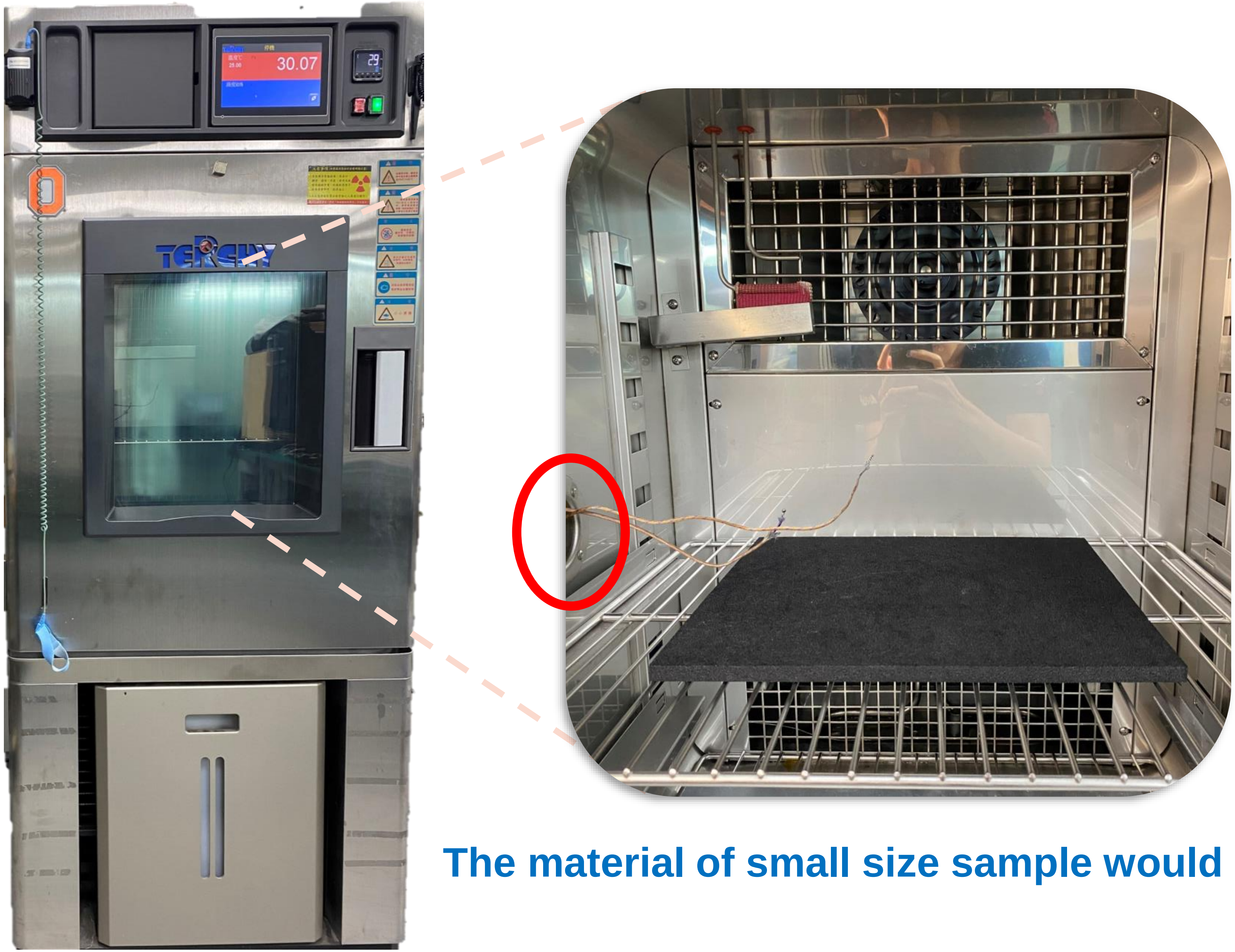


Material properties used in simulation

	Facesheet (K13D2U)	facesheet (K13C2U)	Foam material (CFoam 20)	Cooling pipe (Aluminum alloy 6061)	adhesive (EC2216)	chip
Tensile modulus (N/m^2)	9.3E+11	9.0E+11	4.14E+08	6.90E+10	0.1	4.10E+11
Poisson ratio	0.073			0.33	0	0.3
Shear modulus (N/m2)	from K13C2U	3.9E+09		2.60E+10	3.42E+08	
Density (kg/m^3)	2200	2200	320.37	2700	1330	1250
Tensile strength (N/m2)	3.7E+09	3.8E+09	2.31E+06	1.24E+08		
Thermal expansion coefficient (1/K)			5E-06	2.40E-05	2.59E-06	1E-06
Thermal Conductivity (W/m*K)	800	620		170	0.3947	130
Specific heat (J/kg*K)	0		600	1300	0	670

Preparation for thermal testing

For small sample : Thermal and humidity chamber



- Dimensions :
  - 40 x 50 x 60 (cm^3)
- Temperature
  - Range : -40 °C ~ 100 °C
  - Stability : ± 0.2 °C
- Humidity
  - Range : 10% ~ 98%
  - Stability : ± 2.5%

The material of small size sample would be closed to real design

For large sample : Thermal isolated alumunum tank

- Dimensions：
  - 220 x 15 x 15 (cm^3)
- Used in the thermal testing of AMS

Styrofoam

Thermal testing of AMS

Thermocouple and DAQ Systems

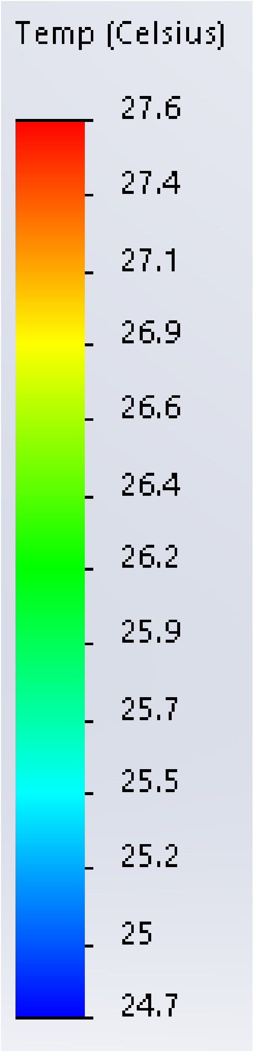
- Thermocouple
  - Type E (Chromel-Constantan)
  - Temperature range : -250°C ~ 900°C
- DAQ (NI)
  - 16 thermocouple channels
  - Temperature Measurement Accuracy
    - High-resolution mode : <0.02 °C
    - High-speed mode : <0.25 °C

NEXT STEP

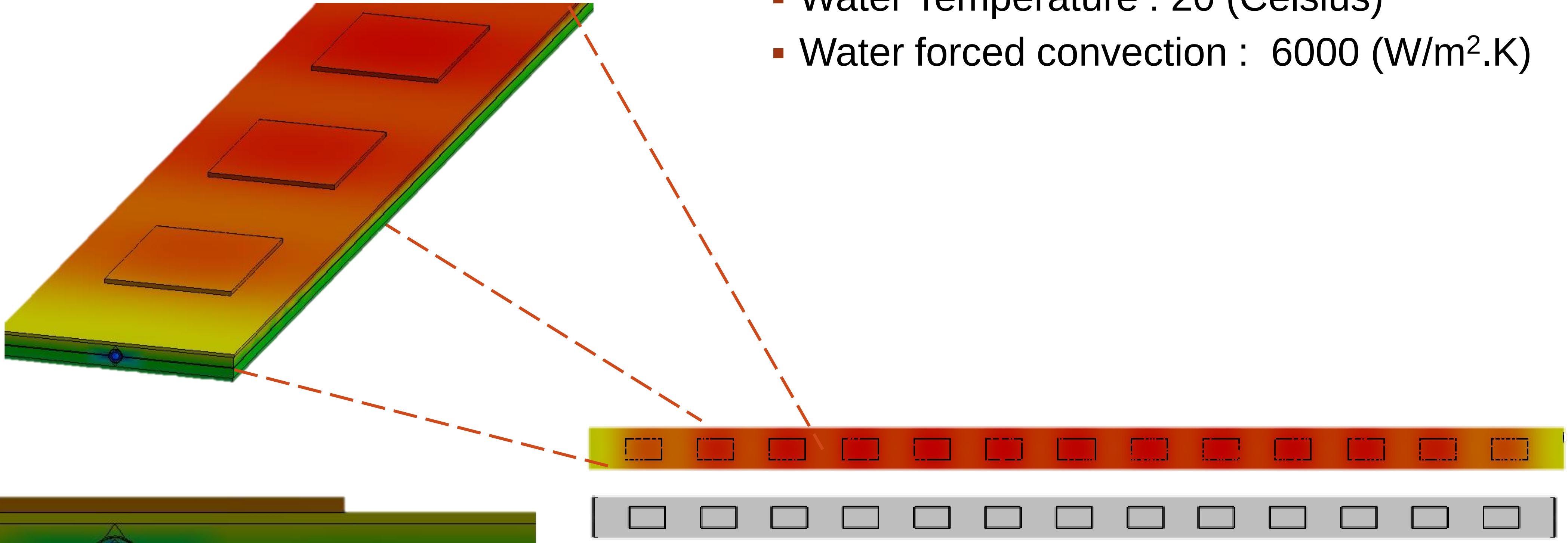
- Calibrating the thermocouple
- Performing thermal testing on the prototype
- Compare the result between simulation and thermal testing

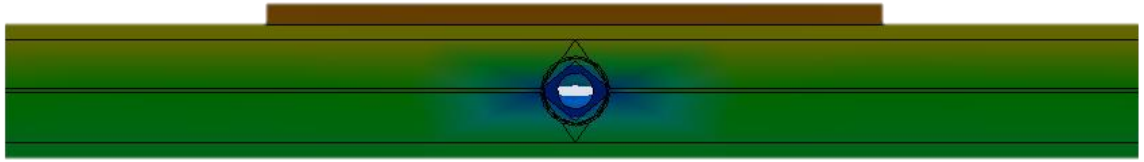
BACK UP

Thermal analysis 1



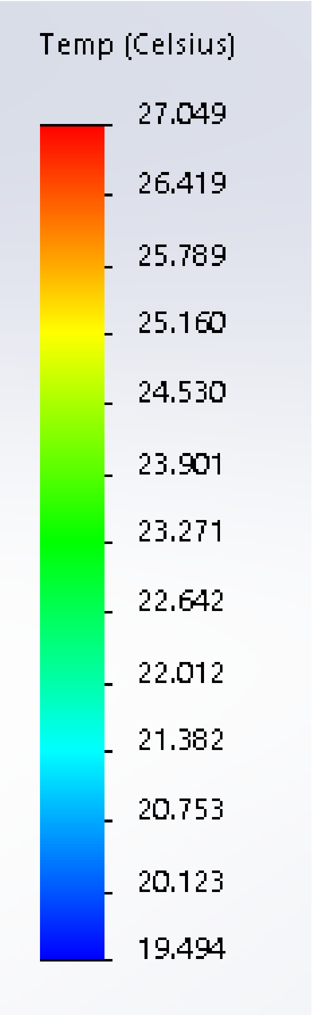
- Chip
  - Size : 3 * 5 * 0.1 (cm^3)
  - Power : 0.25 * 4 (W)
- Heat Transfer Coefficient
  - Room Temperature : 25 (Celsius)
  - Air nature convection : 25 ($W/m^2.K$)
  - Water Temperature : 20 (Celsius)
  - Water forced convection : 6000 ($W/m^2.K$)

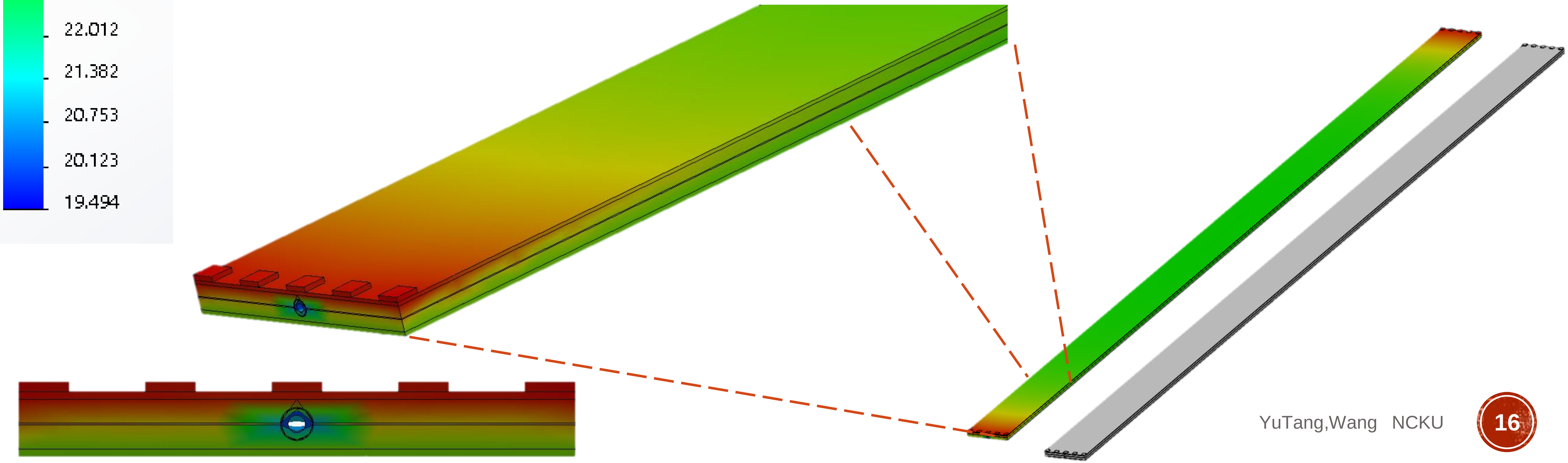




Thermal analysis 2

- Chip
  - Size : 0.5 * 0.5 * 0.1 (cm^3)
  - Power : 0.25 (W)
- Heat Transfer Coefficient
  - Room Temperature : 25 (Celsius)
  - Air nature convection : 25 ($W/m^2.K$)
  - Water Temperature : 20 (Celsius)
  - Water forced convection : 6000 ($W/m^2.K$)





- Material Properties in Simulation

Elastic Modulus	Elastic Modulus in the global X, Y, and Z directions. For a linear elastic material, the elastic modulus in a certain direction is defined as the stress value in that direction that causes a unit strain in the same direction. Also, it is equal to the ratio between the stress and the associated strain in that direction. Elastic Moduli are used in static, nonlinear, frequency, dynamic, and buckling analyses. The modulus of elasticity was first introduced by Young and is often called Young's Modulus.
Shear Modulus	The shear modulus, also called modulus of rigidity, is the ratio between the shearing stress in a plane divided by the associated shearing strain. Shear Moduli are used in static, nonlinear, frequency, dynamic and buckling analyses.
Poisson's Ratio	Extension of the material in the longitudinal direction is accompanied by contractions in the lateral directions. If a body is subjected to a tensile stress in the X-direction, then Poisson's Ratio is defined as the ratio of lateral contraction in the Y-direction divided by the longitudinal strain in the X-direction. Poisson's ratios are dimensionless quantities. For isotropic materials, the Poisson's ratios in all planes are equal. Poisson ratios are used in static, nonlinear, frequency, dynamic and buckling analyses.
Coefficient of Thermal Expansion	The Coefficient of Thermal Expansion is defined as the change in length per unit length per one degree change in temperature (change in normal strain per unit temperature). You specify the average coefficient of thermal expansion that is based on the reference temperature (T_0) associated with the stress-free condition: $a = \frac{1}{L}\frac{L_T - L_{T_0}}{T - T_0}$ Coefficients of thermal expansion are used in static, frequency, and buckling analyses if thermal loading is used. Frequency analysis uses this property only if you consider the effect of loads on the frequencies (in-plane loading).
Thermal Conductivity	The Thermal Conductivity indicates the effectiveness of a material in transferring heat energy by conduction. It is defined as the rate of heat transfer through a unit thickness of the material per unit temperature difference. The units of thermal conductivity are Btu/in sec °F in the English system and W/m K in the SI system. Thermal conductivity is used in steady state and transient thermal analyses.
Density	The Density is mass per unit volume. Density units are lb/in^3 in the English system, and kg/m^3 in the SI system. Density is used in static, nonlinear, frequency, dynamic, buckling, and thermal analyses. Static and buckling analyses use this property only if you define body forces (gravity and/or centrifugal).
Specific Heat	The Specific Heat of a material is the quantity of heat needed to raise the temperature of a unit mass of the material by one degree of temperature. The units of specific heat are Btu in/lbf °F in English system and J/kg K in the SI system. This property is used in transient thermal analysis only.
Material Damping Ratio	The material damping ratio allows the definition of damping as a material property. This property is used in dynamic analysis to calculate equivalent modal damping ratios.

- Specific heat for CFOAM 20

CFOAM25 specific heat capacity was measured using three different samples and one sample crushed into powder form. Results shown in Figure 3 indicated that maximum upper and lower data values vary by 9.7% and 10.2%, respectively.

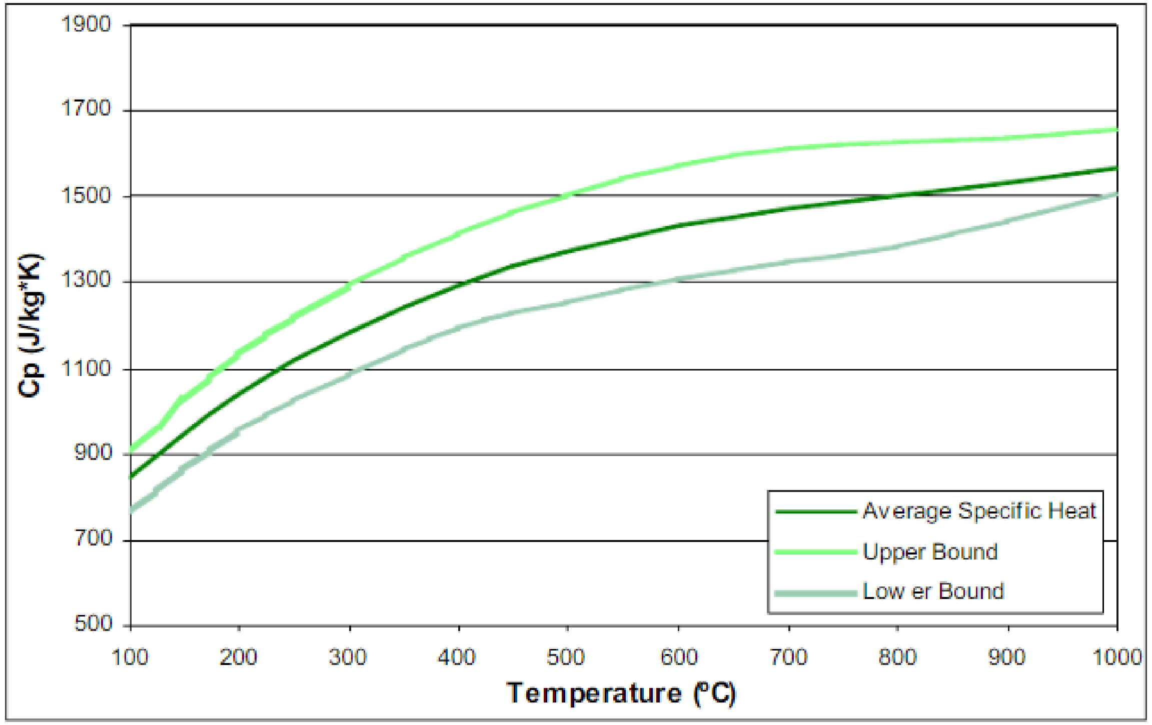


Figure 3. CFOAM® average specific heat, C_p, vs. temperature with upper and lower bounds

- Shear modulus of adhesive (EC2216)

A. Typical Shear Properties on Etched Aluminum

ASTM D 1002

Cure: 2 hours @ 150 ± 5°F (66°C ± 2°C), 2 psi pressure

Test Temperature	Overlap Shear (psi)	
	3M™ Scotch-Weld™ Epoxy Adhesive	
	EC-2216 B/A Gray	EC-2216 B/A Translucent
-423°F (-253°C)	2440	—
-320°F (-196°C)	2740	—
-100°F (-73°C)	3000	—
-67°F (-53°C)	3000	3000
75°F (24°C)	3200	1700
180°F (82°C)	400	140

—No value present.

Test Temperature	Shear Modulus (Torsion Pendulum Method)
-148°F (-100°C)	398,000 psi (2745 MPa)
-76°F (-60°C)	318,855 psi (2199 MPa)
-40°F (-40°C)	282,315 psi (1947 MPa)
32°F (0°C)	218,805 psi (1500 MPa)
75°F (24°C)	49,580 psi (342 MPa)

- Density of adhesive (EC2216)

Specifications

Adhesive Type	Epoxy
Applications	Composite Bonding , Erosion Protection , Metal Bonding , Metal to Composite Bonding , Structural Bonding
Brand	Scotch-Weld™
Chemical Base	Epoxy
Color	White/Gray
Container Size	1 Pint , 1 Quart , 1.6 Liter , 2 Ounce , 43 ml , 50 ml , 6 Ounce
Cure Rate	7 Days
Cure Temperature	Room Temperature
Density	1.3 g/cc , 1.3 Gram Per Litre
Percent Volatile	0.06 Percent
Product Form	Kit(set)
Shelf Life	24 Month
Storage Environment	Room Temperature
Time to Handling Strength	8-12 Hours
Worklife	100 grams: 90 minutes @ 75 F (24 C)

3M® Scotch-Weld™ EC-2216 Gray Adhesive 62221654403 1 pt 021200-65202

3M Aerospace

Part # **021200-65202=32** Mfr. Part # **62221654403** UPC # **21200652028**

3M™ Scotch-Weld™ EC-2216 structural epoxy adhesive is a flexible, two-part formula, effectively replaces mechanical fasteners, screws, rivets and spot welds. The 3M™ EPX™ applicator system of a cartridge containing adhesive, ensures minimal waste and professional results. Gray colored part-A liquid of epoxy adhesive has a very mild pungent odor and a 1.26 specific gravity. The off-white colored part-B liquid of epoxy adhesive has a slight epoxy odor and a 1.33 specific gravity. It has a boiling point greater than or equal to 306 degrees F for part-A and greater than or equal to 500 degrees F for part-B. Flash point of this high-performance adhesive is greater than or equal to 305 degrees F for part-A and 480 degrees F for part-B. The vibration-resistant epoxy adhesive has a density of 1.33 grams per milliliter for part-B. It comes with a vapor pressure rating less than or equal to 27 psia at 131 degrees F for part-A/B. This product has a viscosity of 40,000 to 80,000 centipoises for part-A and 75,000 to 150,000 centipoises for part-B. It takes a curing time of 7 days at 24 degrees C, 2 hours at 66 degrees C and 30 minutes at 93 degrees C. The adhesive provides an application time of 90 minutes. It has a peeling strength of 25 piw at 75 degrees F and a shear strength of 2440 psi at -423 degrees F. This product offers an area of coverage up to 320 square feet per gallon. This adhesive comes in a 1-pint duo-pak cartridge and is rated at 60 to 80 degrees F for safe storage.

Safety Data Sheets

- Heat Transfer Coefficient

Medium	**Heat Transfer Coefficient h ($W/m^2.K$)**
Air (natural convection)	5-25
Air/superheated steam (forced convection)	20-300
Oil (forced convection)	60-1800
Water (forced convection)	300-6000
Water (boiling)	3000-60,000
Steam (condensing)	6000-120,000

- Thermal properties of adhesive (EC2216)

Typical Cured Thermal Properties

Product	3M™ Scotch-Weld™ Epoxy Adhesive	
	EC-2216 B/A Gray	EC-2216 B/A Translucent
Thermal Conductivity	0.228 Btu-ft/ft^{2}h°F	0.114 Btu-ft/ft^{2}h°F
Coefficient of Thermal Expansion	102 x 10^{-6} in/in/°C between 0-40°C 134 x 10^{-6} in/in/°C between 40-80°C	81 x 10^{-6} in/in/°C between -50-0°C 207 x 10^{-6} in/in/°C between 60-150°C