

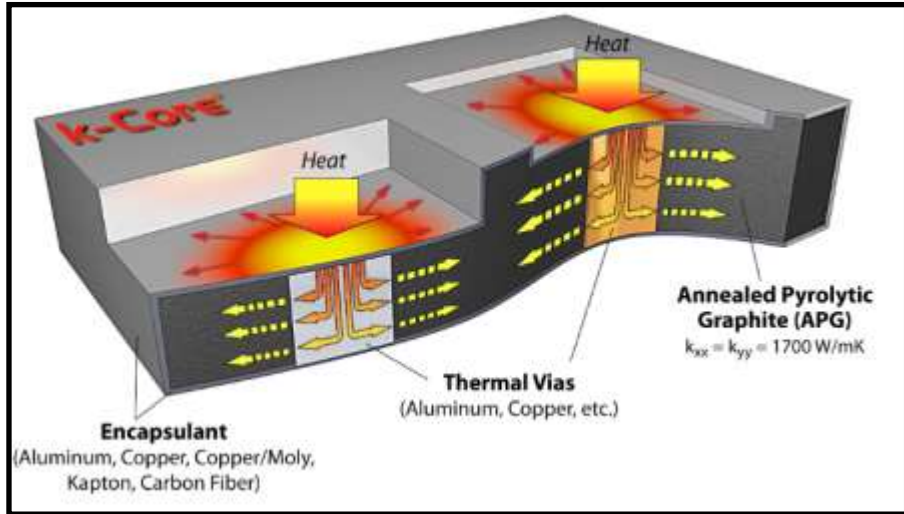


BOYD
TRUSTED INNOVATION

Enhanced Graphite Thermal Solutions

Boyd Confidential

k-Core® Annealed Pyrolytic Graphite (APG)



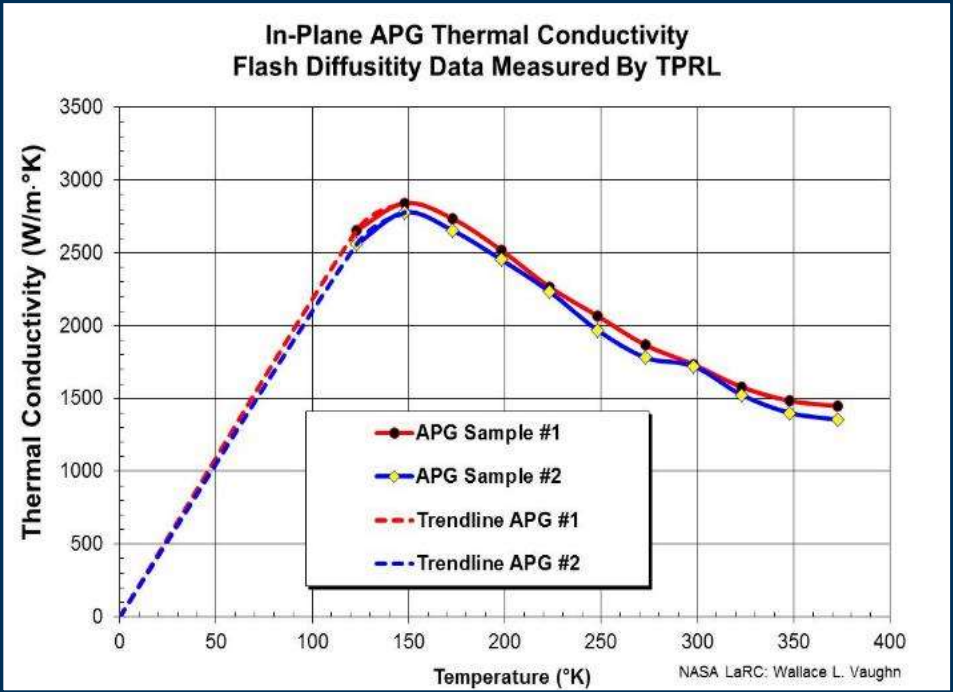
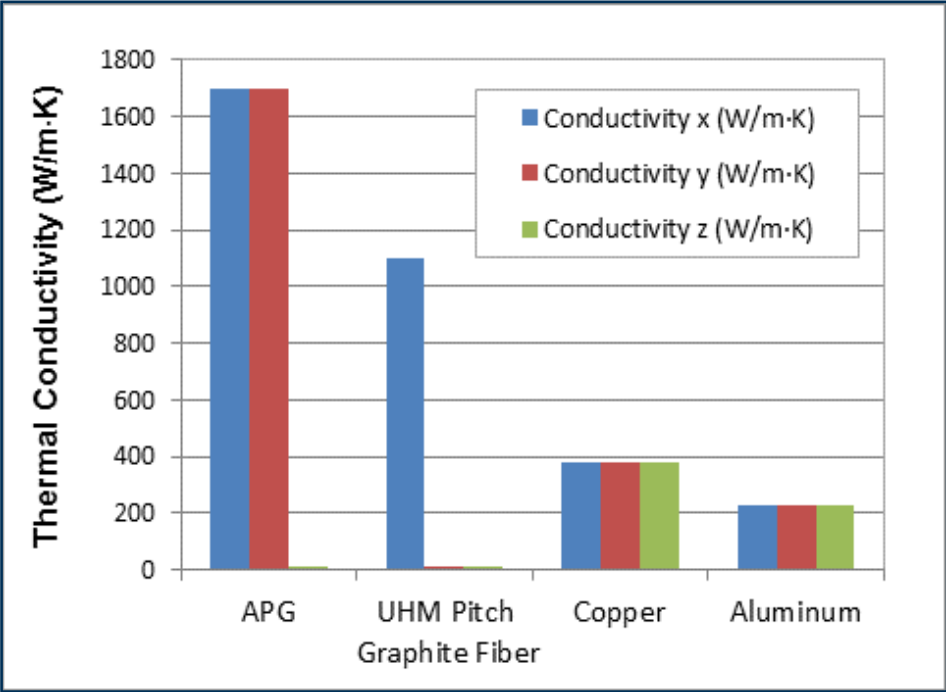
A propriety product featuring K-Core APG, a highly ordered crystalline material with a thermal conductivity of $>1000 \text{ W/m-K}$, within an aluminium parent material.

- High planar conductivity
- Operational temp limited to encapsulant material
- Gravity independent operation
- Solid Conduction – Passive Solution
- Pyrolytic structure conforms to encapsulant CTE



K-Core APG is a macro-composite which is fully encapsulated by an outer material than can vary In thickness depending upon application requirements

k-Core® Annealed Pyrolytic Graphite (APG)



Mechanical

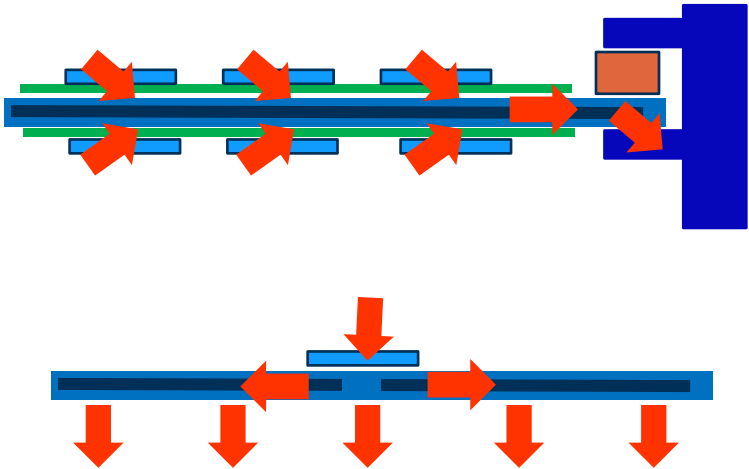
Modulus (psi)			Poisson's Ratio			Shear Modulus (psi)			CTE (PPM/K)		
E1	E2	E3	v12	v13	v23	G12	G13	G23	a1	a2	a3
8.00E+07	8.00E+07	5.00E+05	0.3	0.002	0.002	3.07E+07	2.00E+05	2.00E+05	-6.00E-07	-6.00E-07	2.57E-05

Thermal, 25 °C

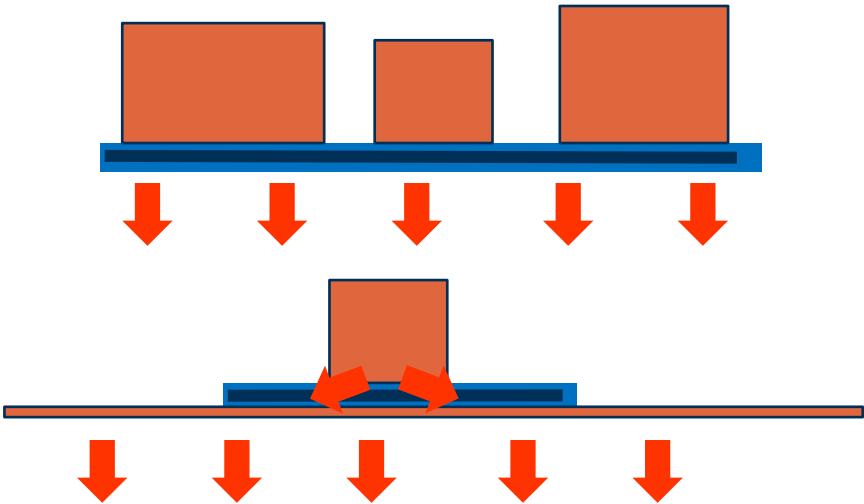
Conductivity (W/mK)			Diffusivity (cm2/K)			Specific Heat (W/gK)	Density (g/cm3)
k1	k2	k3	v1	v2	v3	Cp	d
1700.0	1700.0	10.0	1071.5	1071.5	6.3	0.702	2.26

k-Core® Annealed Pyrolytic Graphite (APG)

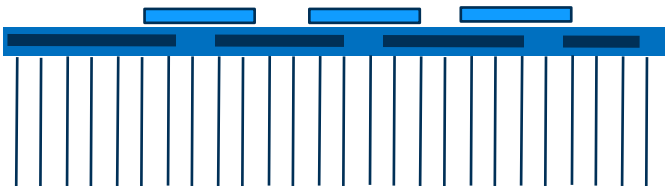
Thermal Cores and Heat Spreaders



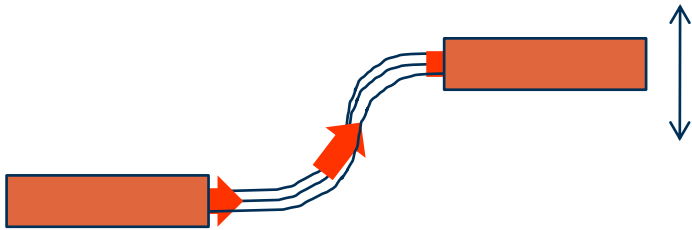
Radiators and Doublers



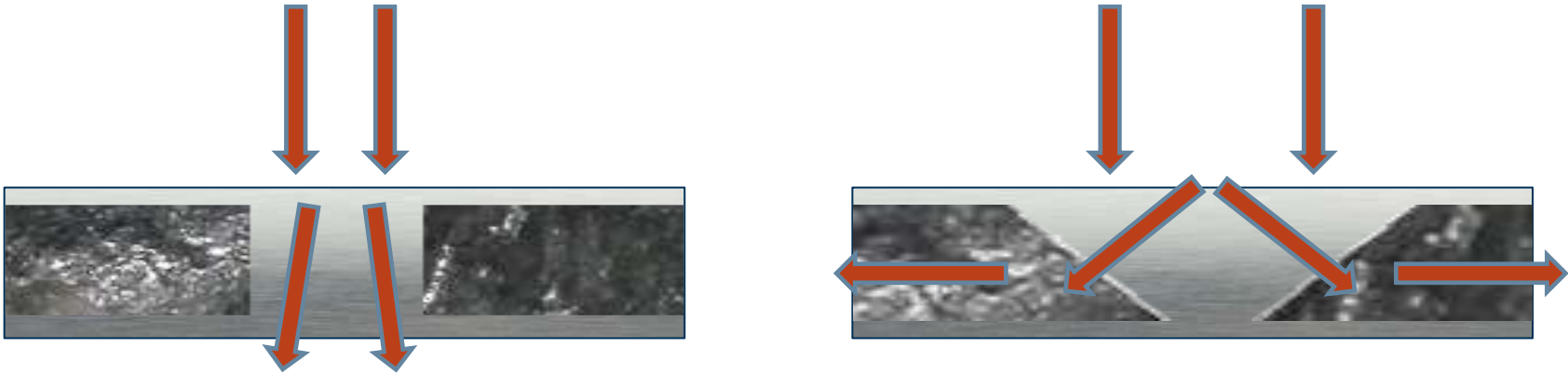
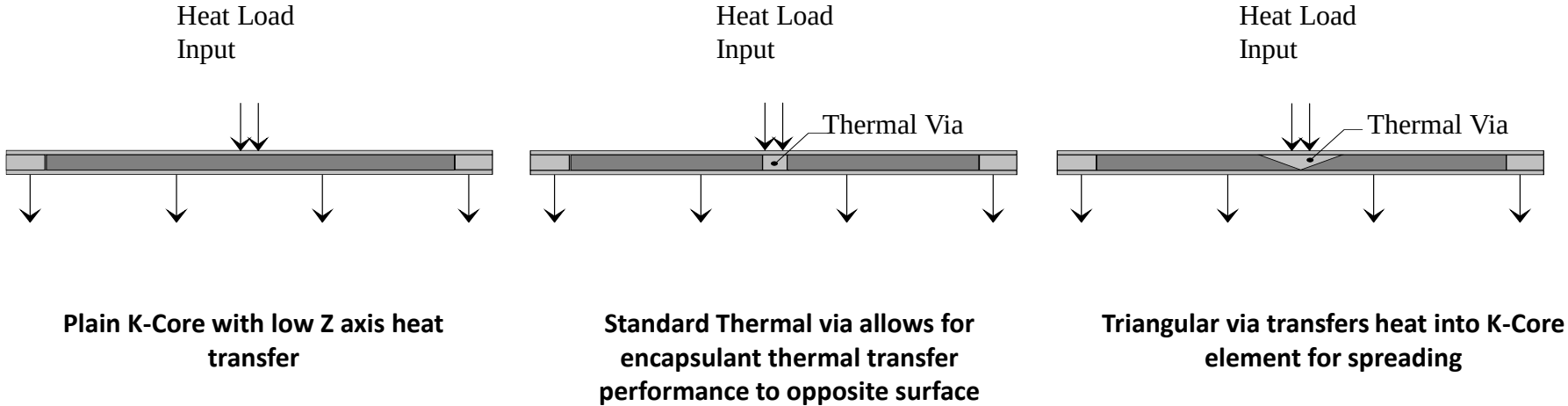
Chassis and Heat Exchangers



Thermal Straps and Assemblies



k-Core® Annealed Pyrolytic Graphite (APG)



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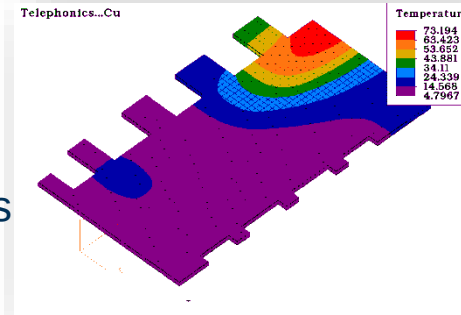
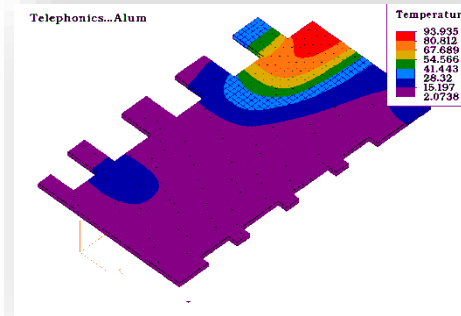
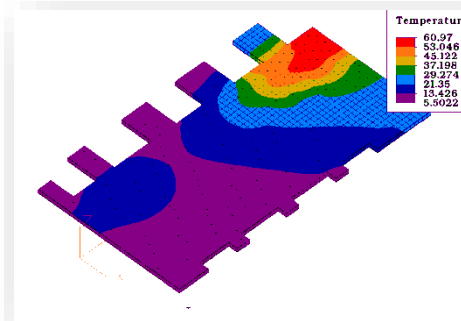


- Cold Plate, Heat Spreader
- 1000 W Heat Dissipation
- Aluminum Encapsulation

APG core
 $\Delta T_{\max} = 55\text{ }^{\circ}\text{C}^*$
Weight = 2.9 lbs

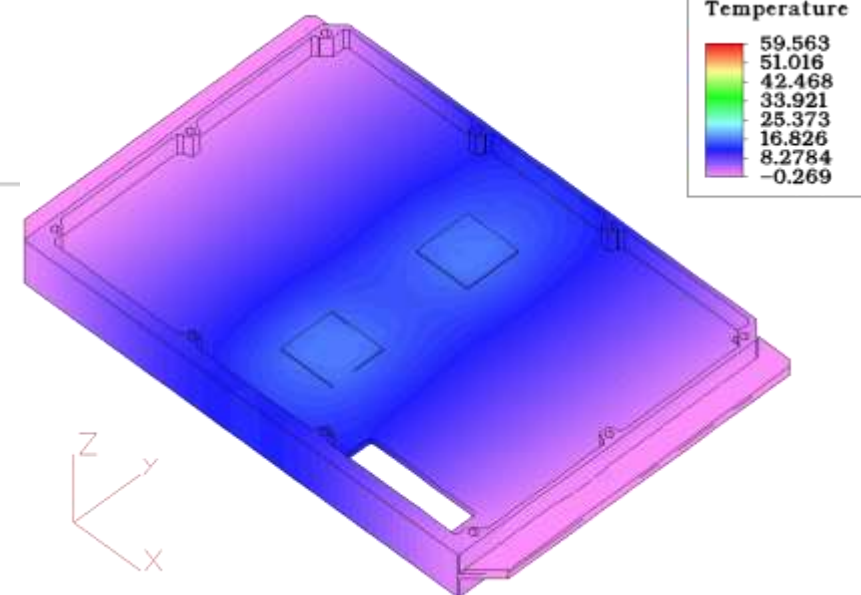
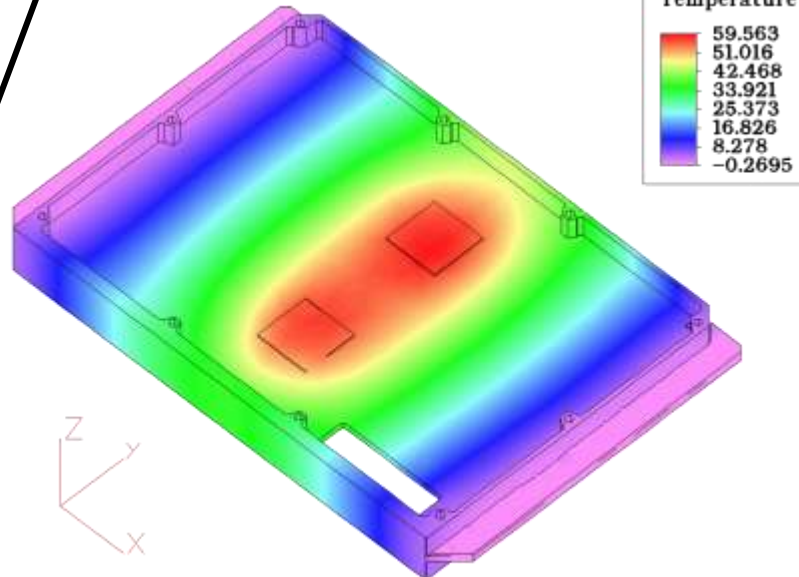
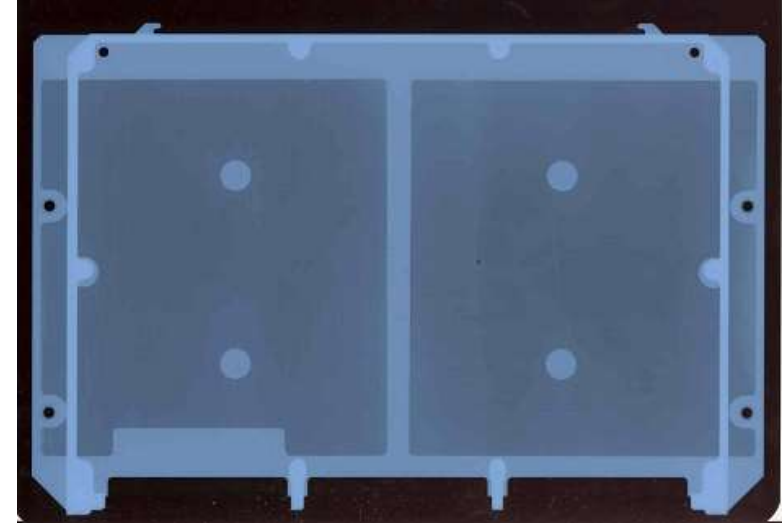
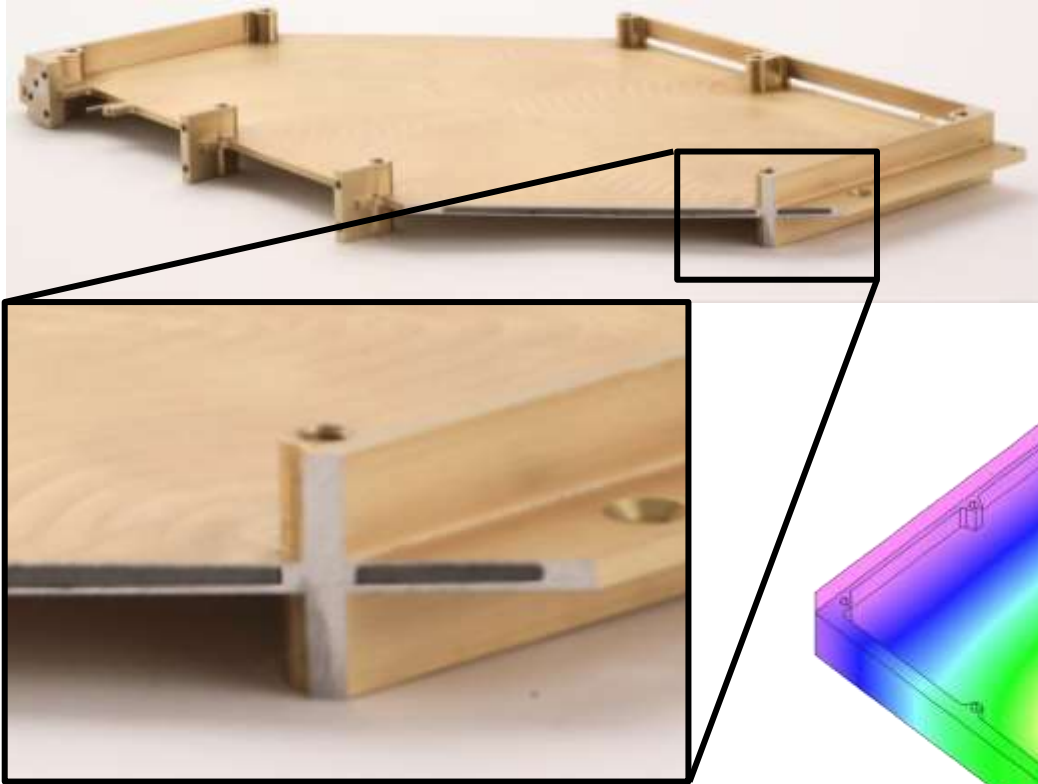
Aluminum
 $\Delta T_{\max} = 91\text{ }^{\circ}\text{C}^*$
Weight = 3.2 lbs

Copper
 $\Delta T_{\max} = 68\text{ }^{\circ}\text{C}^*$
Weight = 10.9 lbs

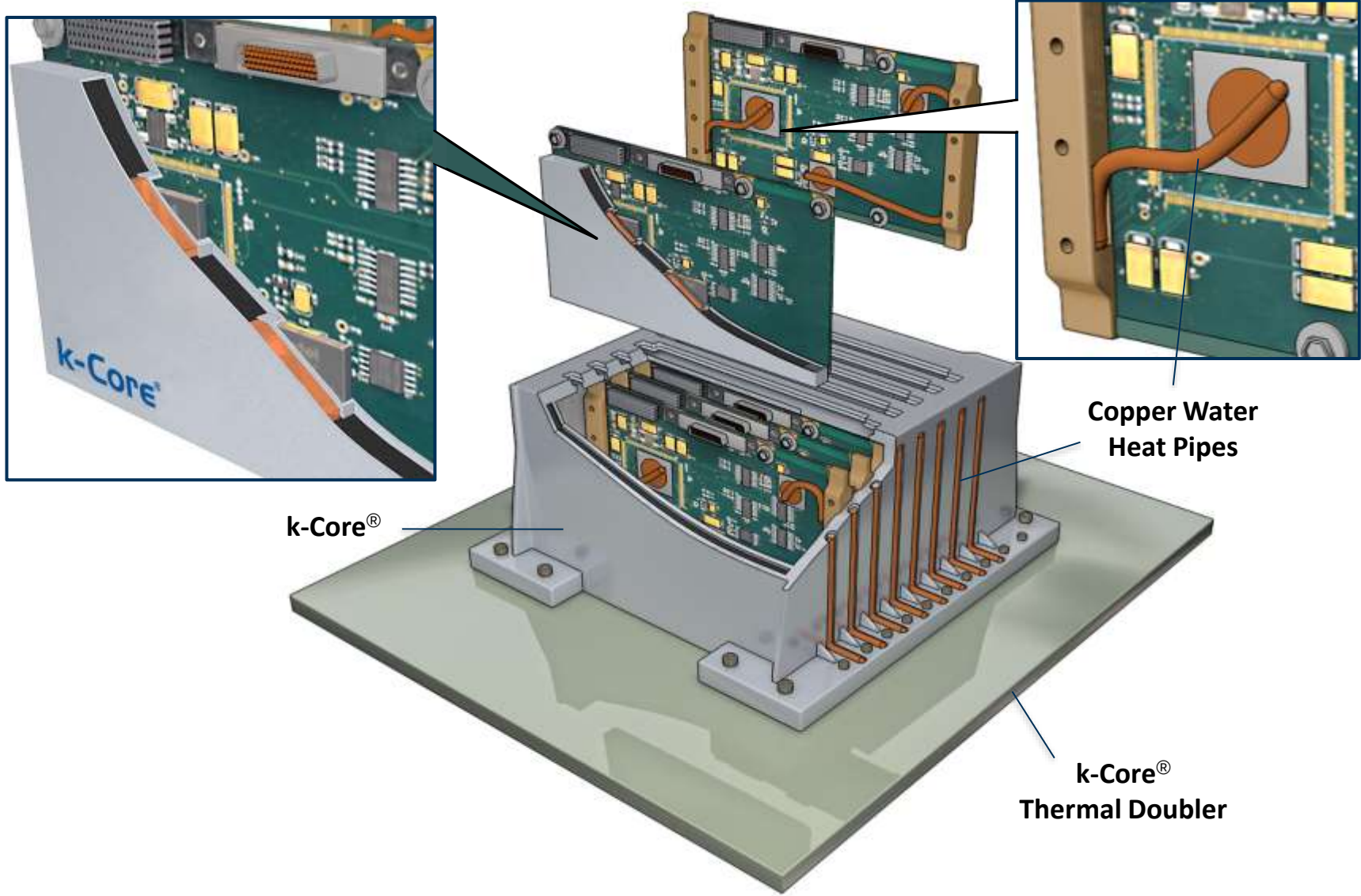


k-Core® Annealed Pyrolytic Graphite (APG)

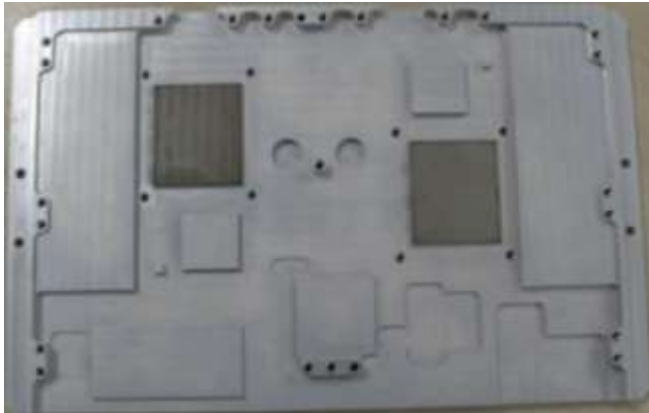
- High Gravitational Acceleration Fast Jet Application
- ΔT reduced from 59 °C to 19 °C ($Q = 250$ W)



k-Core® Annealed Pyrolytic Graphite (APG)



K-Core APG Applications

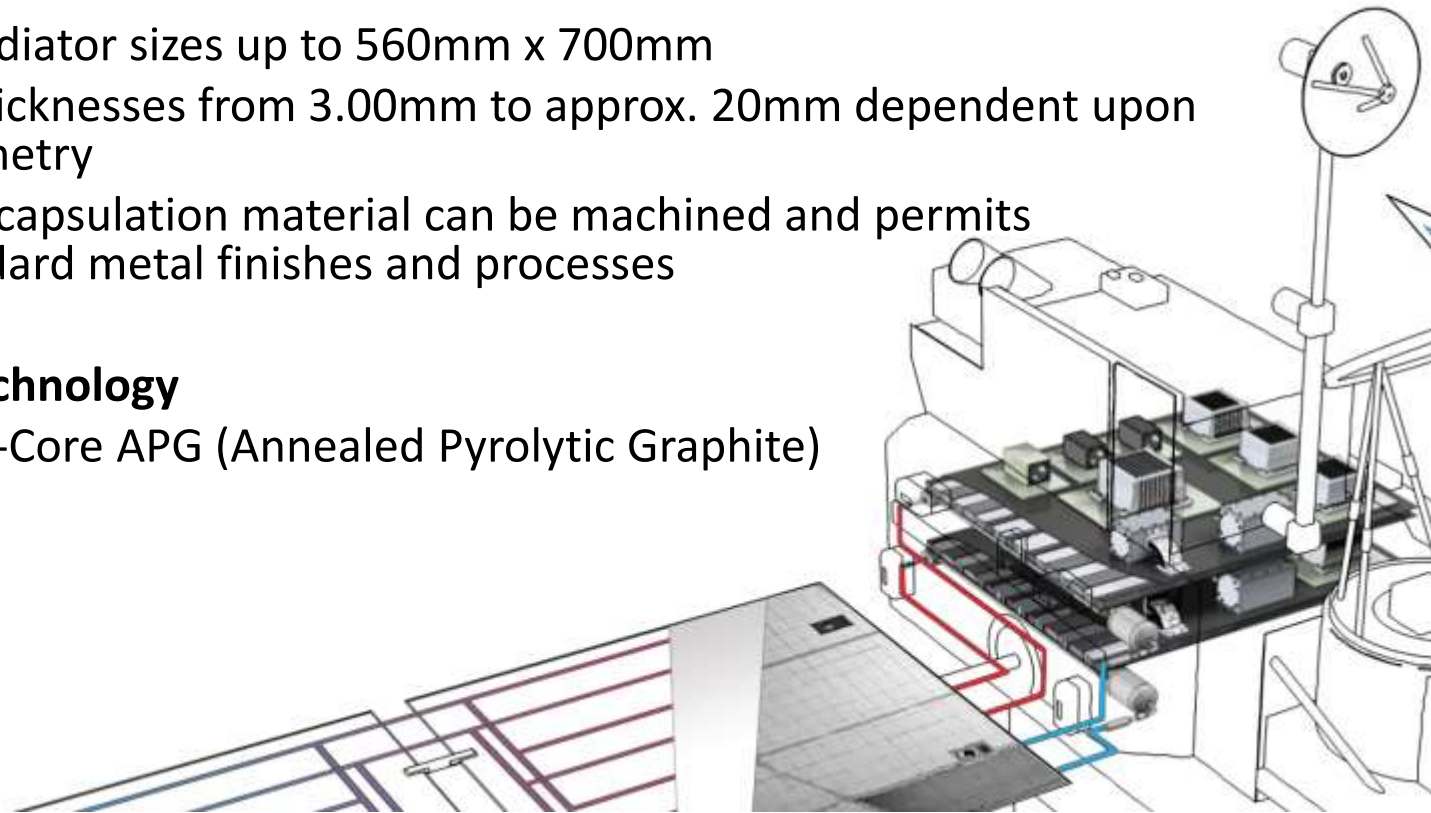


- **Solid Conduction Cooling**
 - Can support commercial off-the-shelf (COTS) packaging formats.
 - Cold plate technology which meets the most recent VME64x/VPX standards can offer a K-Core APG equivalent to an aluminium option.
- High Gravitational Acceleration Fast Jet Application
- **Technology**
 - K-Core APG (Annealed Pyrolytic Graphite)

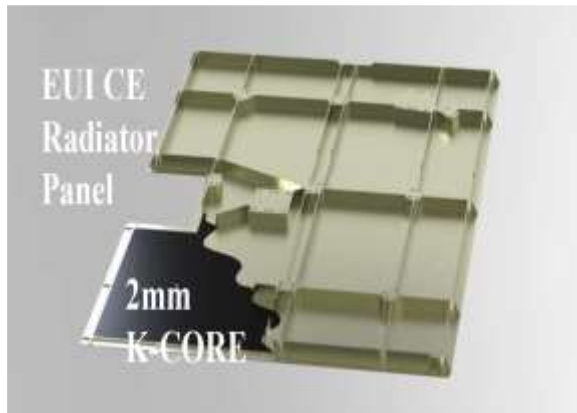
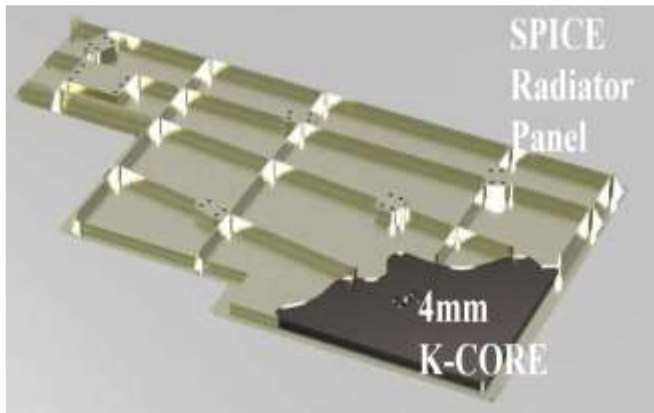
k-Core® - APG Multi-Segment Space Radiators



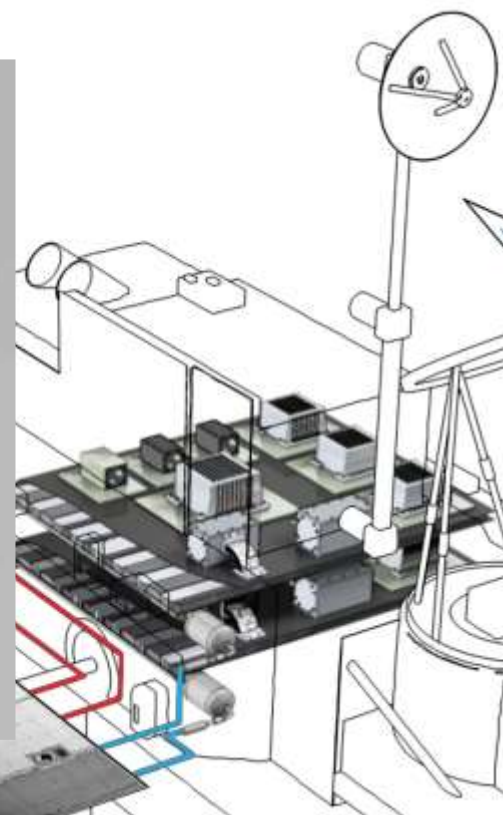
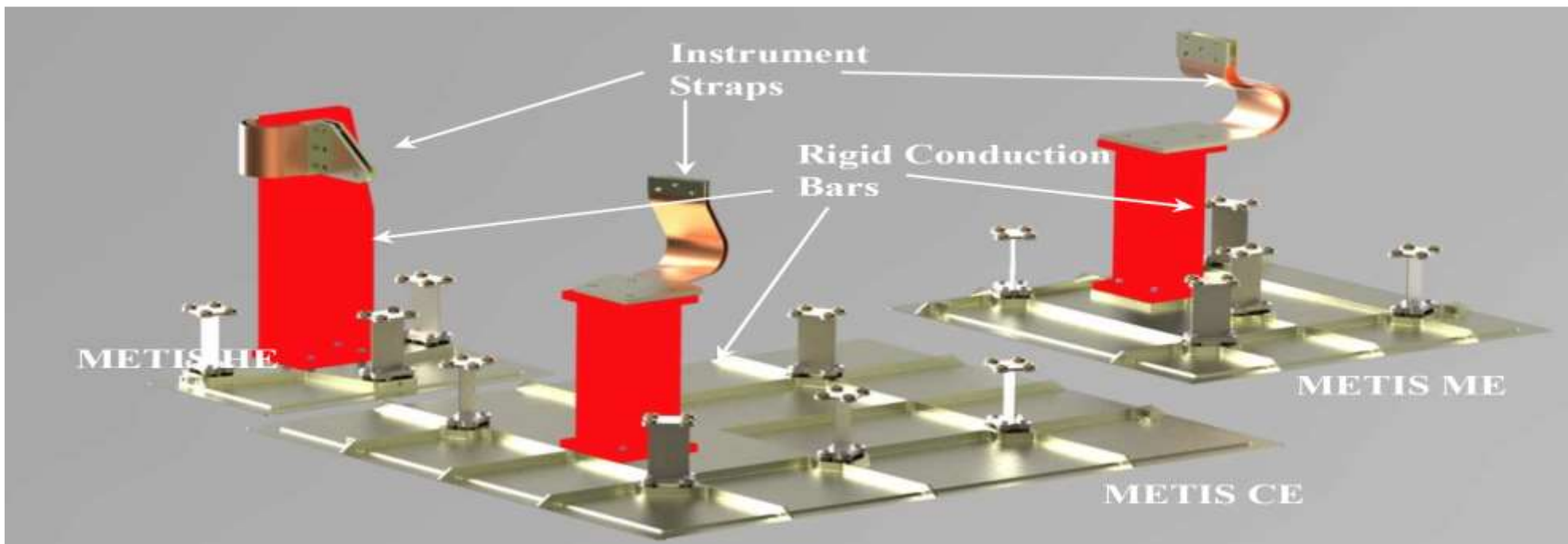
- **Solid Conduction Cooling**
 - Mass slightly lower than solid aluminium and drop in replacement for many all-metal designs
 - Made up of several APG segments and ribs machined into the radiator to improve both mechanical and structural performance
 - Radiator sizes up to 560mm x 700mm
 - Thicknesses from 3.00mm to approx. 20mm dependent upon geometry
 - Encapsulation material can be machined and permits standard metal finishes and processes
- **Technology**
 - K-Core APG (Annealed Pyrolytic Graphite)



k-Core® - APG Multi-Segment Space Radiators



Boyd Technologies' background at European level is the implementation of the K-core APG within the remote-sensing instrument payload for three of the measurement systems of the European Space Agency's Solar Orbiter Mission.

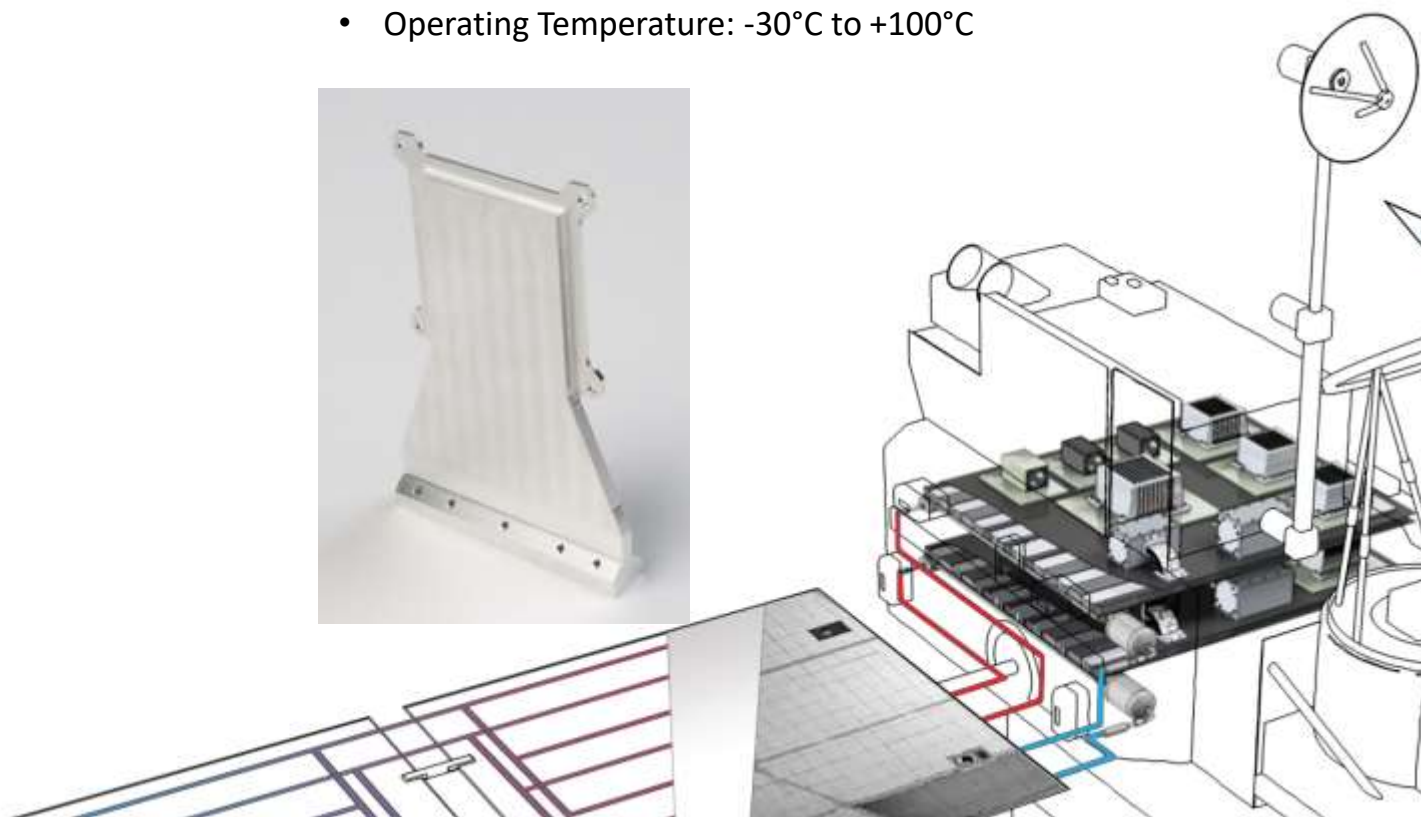


k-Core® - APG Payload Components



- K-Core Spreader
- Used in commercial satellites
- Solid Conduction - Encapsulated Annealed Pyrolytic Graphite
- 120mm x 75mm x 13mm (Approx. Overall Dimensions)
- Power: 10W Min.
- Allowable ΔT : 10°C
- Operating Temperature: -30°C to +100°C

- k-Core Cover
- Used in commercial satellites
- Multiple source power collection
- Solid Conduction - Encapsulated Annealed Pyrolytic Graphite
- 300mm x 300mm x 10mm (Approx. Overall Dimensions)
- Power: 22W (Total)
- Allowable ΔT : 12°C Max.
- Operating Temperature: -35°C to +70°C

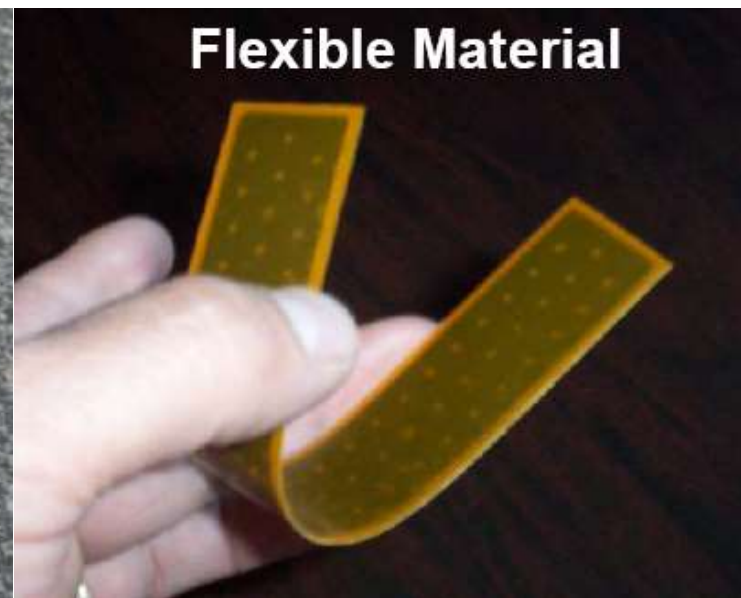


k-Core® - APG Thermal Straps

- **Solid Conduction Cooling**
- Diffusion bonded & soldered configurations available
- Low bending stiffness – flexible material
- Multi-Layer strap designed to suit thermal performance requirements
- High dielectric breakdown strength (Kapton) material

- **Technology**

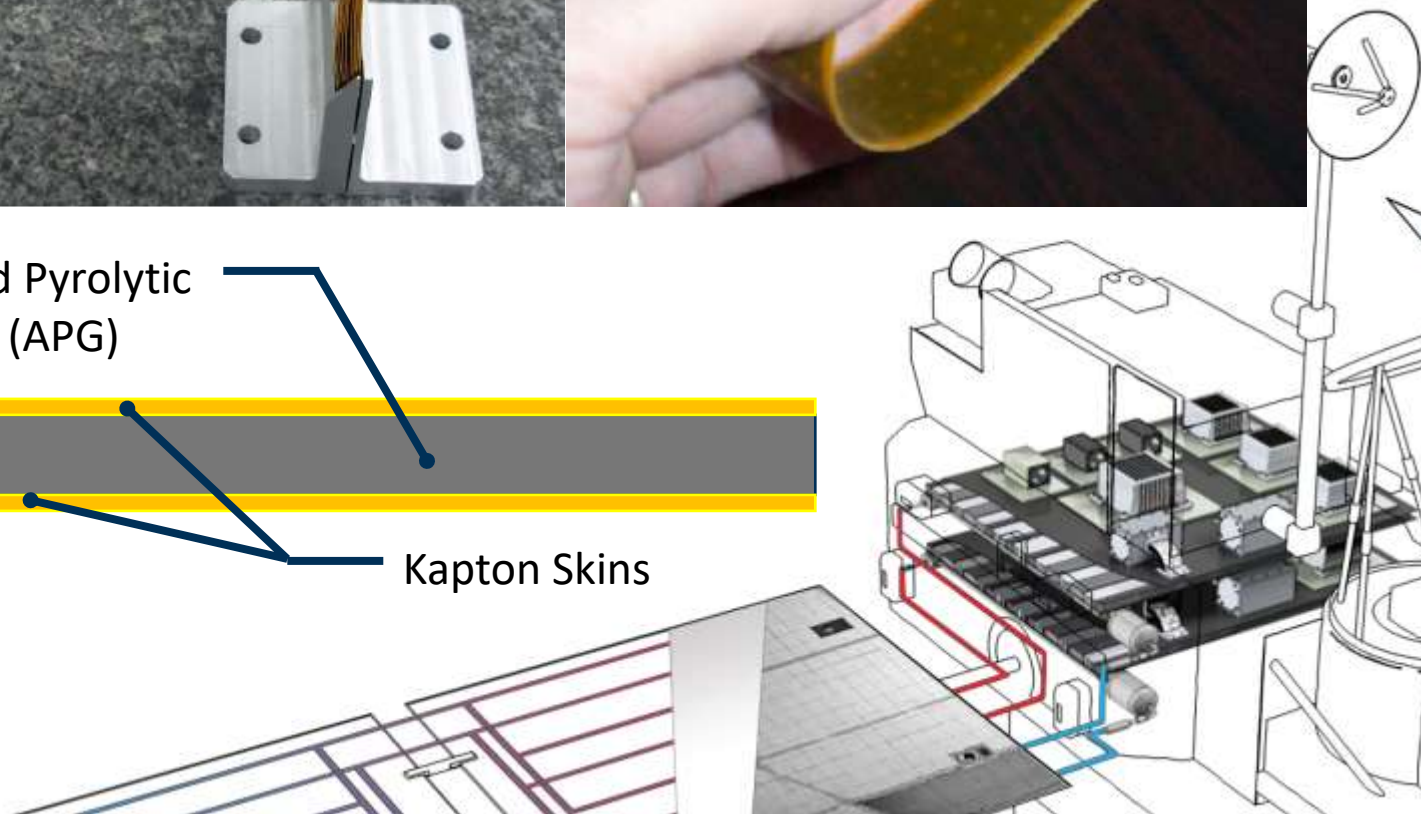
- K-Core APG (Annealed Pyrolytic Graphite)



Annealed Pyrolytic Graphite (APG)



Kapton Skins



k-Core® - Annealed Pyrolytic Graphite (APG) - Overview

Specification

- Aluminium 6061 T6
- Heat load – dependent upon geometry ~ 5W up to ~ 500W
- In plane thermal conductivity > 1000W/mK
- Size: Max ~ 680mm x 500mm, down to ~ 100mm x 50mm. Thickness ~ 2mm up to 100mm
- Operating and storage temperature range of -150°C to +180°C
- Resistant to Space launch qualification Shock and vibration tests
- Withstands without damage, a steady state acceleration of 3g in any direction.

Pricing

- Pricing are dependent upon geometry and volume
- Pricing become more competitive as volume increases

Features & Benefits

- Not affected by gravitational forces
- Can be a drop-in replacement for equivalent all aluminium or copper heat spreader
- Can be incorporated into a heat sink with integral fins
- Mass: Approximately 4% lighter than an equivalent all aluminium part. Through re-design, mass can be reduced further
- Most surface treatments can be applied as normal
- Technology can be incorporated into structural parts of a system
- High thermal conductivity

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