Radioisotope Thermoacoustic Power Generation for Space Missions

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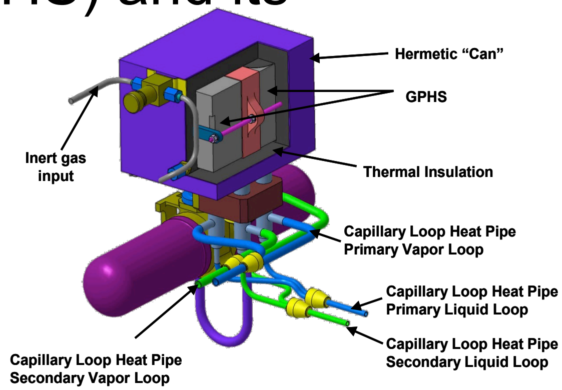
Background

- In this presentation we will describe the Thermoacoustic Power Converter (TAPC), its performance as a space power generator when powered by the radioisotope General Purpose Heat Source (GPHS) and its integration onto a spacecraft.



- Operates on the Stirling thermodynamic cycle
- High reliability and efficiency
- Reliability results from their mechanical simplicity
  - No moving part thermoacoustic (Stirling) heat engine coupled to
  - balanced linear alternator derived from the non-wearing and proven TRL 9 NGAS thermoacoustic pulse tube cryocooler compressors
  - Low complexity electronic control
- Ease of integration of TAPC onto spacecraft results from the mechanical and thermal interfaces incorporated into the device
- Low exported vibration to the spacecraft and sensitive science payloads has been flight proven with the NGAS pulse tube cryocoolers in use with very sensitive space telescopes.

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Replacing Stirling heat engine with thermoacoustic heat engine makes TAPC reliable and producible

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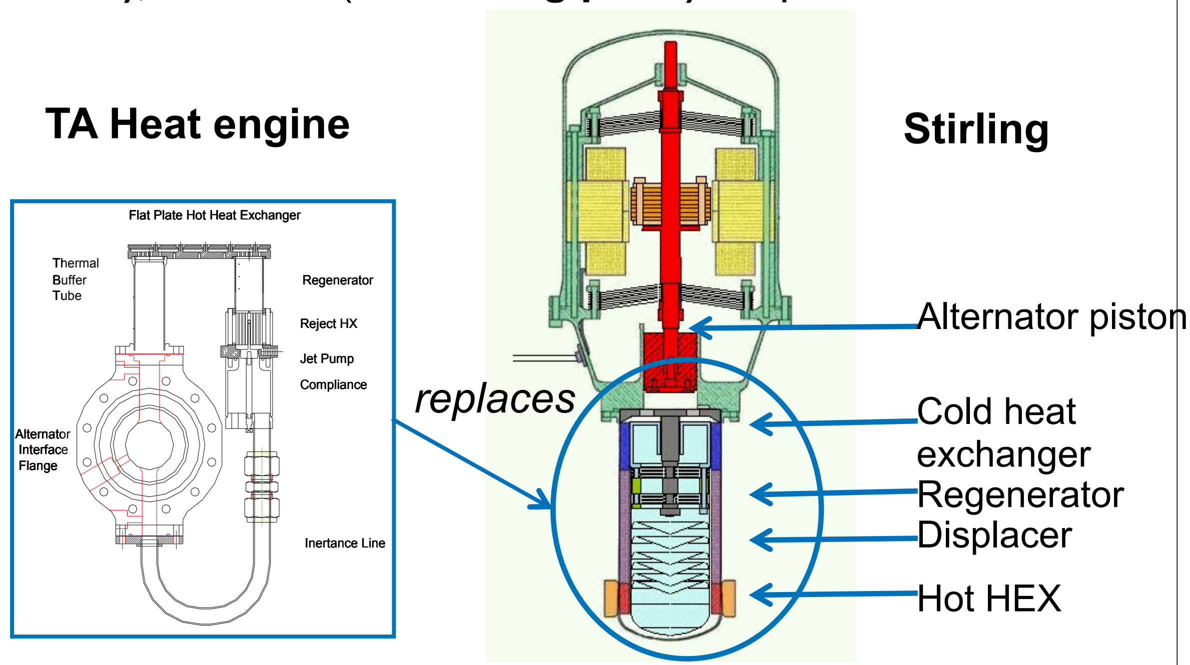
Free Piston Stirling Engines Versus Thermoacoustic Heat Engines

- In the **free piston Stirling** converter oscillating gas is heated at the hot heat exchanger and cooled at the cold heat exchanger.
- **Regenerator** gas motion is amplified to oscillate ~1/3 the regenerator length by the resonant moving displacer (a big piston with a large axial temperature gradient and close piston/cylinder tolerances)
- The displacer motion and the alternator piston motions are both powered by the “thermo-acoustic” oscillation produced in the regenerator
- In the **Thermo acoustic heat engine (TASHE),** resonant (**no moving parts)** lumped element components replace the displacer

Alternator for Stirling and TA Engines

- In both converters, the coupled oscillating pressure drives the resonant alternator piston to produce the electrical output
- The alternators differ chiefly in the piston size because the extra volume of the TAHE results in a lower Δp than in the Stirling unit



The ThermoAcoustic Power Converter operates on the Stirling cycle with the highest reliability because of low complexity relative to other Stirling heat engines

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TAPC:
Thermoacoustic (Stirling) Power Converter

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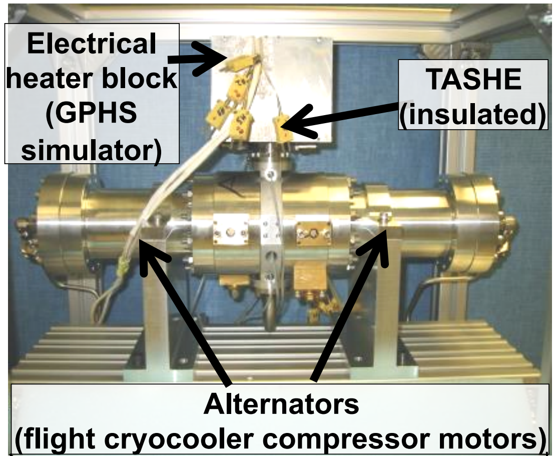
1st Unit demonstrated

- No moving parts thermal to acoustic power conversion in the hot heat engine component
- Demonstrated 18% efficiency on first try
- Demonstrated a simple and efficient heat exchanger interface directly to GPHS units
- Demonstrated the use of a highly reliable alternator using a modified TRL 9 cryocooler compressor
- Demonstrated self-starting
- Demonstrated the simplicity of the electronic control system

Recent Tests

- Demonstrated efficiency increase of 7% in recent heat engine component tests



NGAS designed, built and tested the first ever Thermoacoustic Power Converter that converted heat to electricity in 2003

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Thermoacoustic Power Converter System Components

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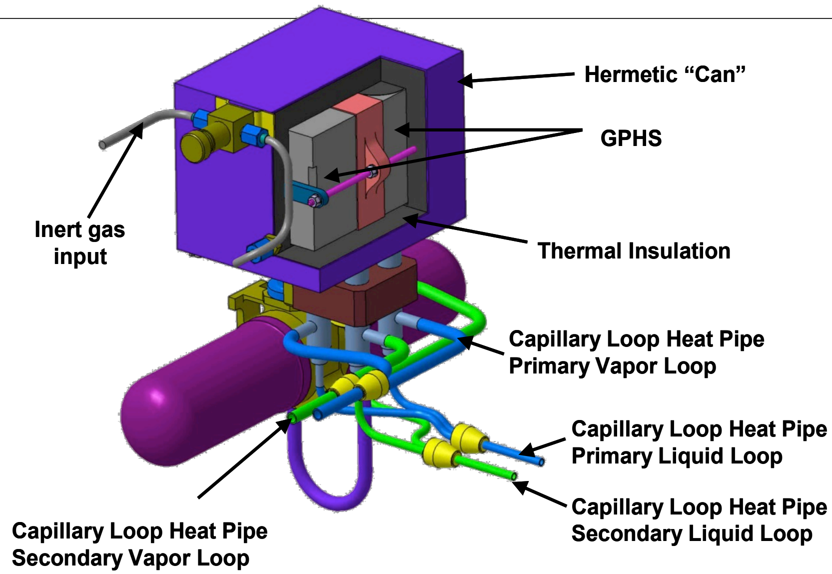
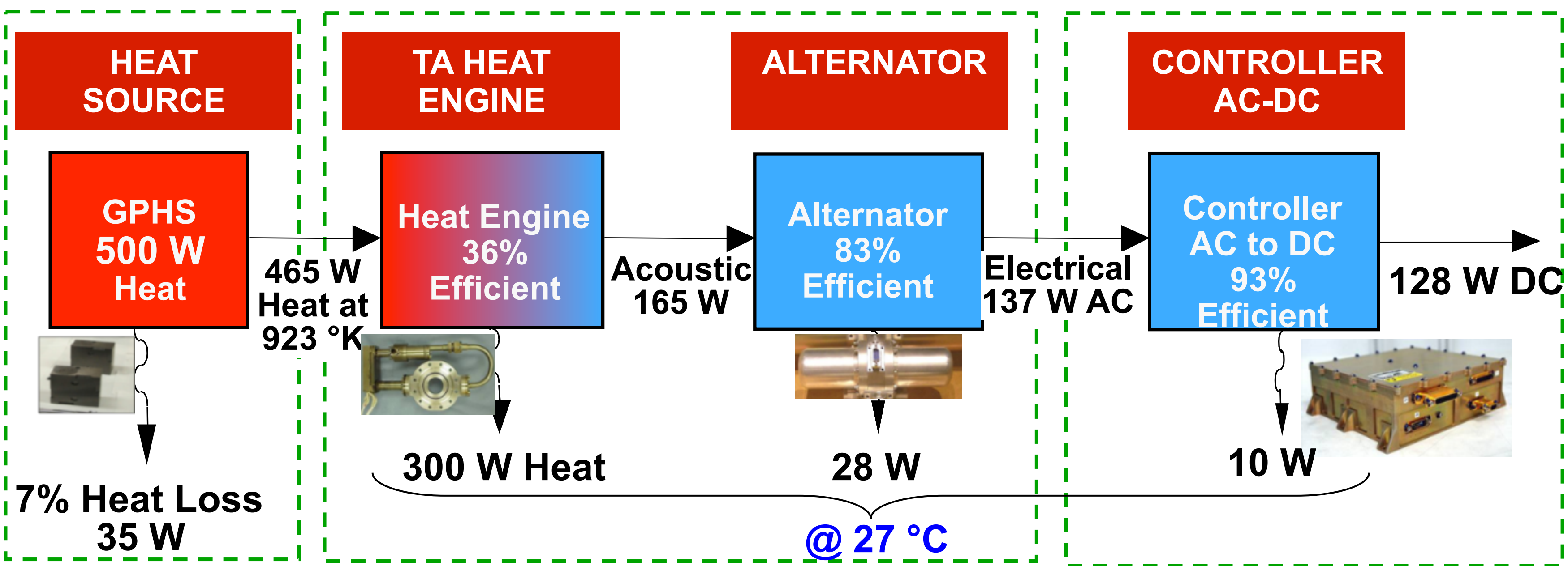


- Silent, low vibration
- Space design: Use heat provided by TRL 9 GPHS (General Purpose Heat Source – ^{238}Pu)
- Using no moving parts, thermoacoustic heat engine converts heat to acoustic travelling wave
- Acoustic travelling wave drives an oscillating pair of resonant opposed pistons in an alternator similar to TRL 9 cryocooler compressor
- Pistons are connected to "voice" coils that produce alternating current (AC) power when oscillating in magnetic circuit
- AC is rectified to DC (direct current) by electronic power converter



Reliable, efficient conversion of heat to DC

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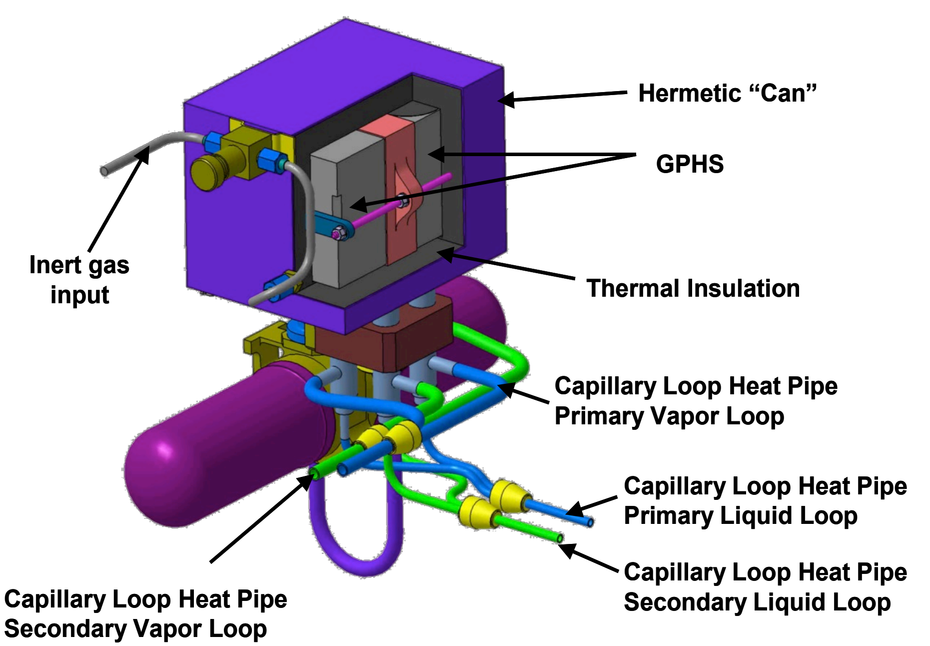
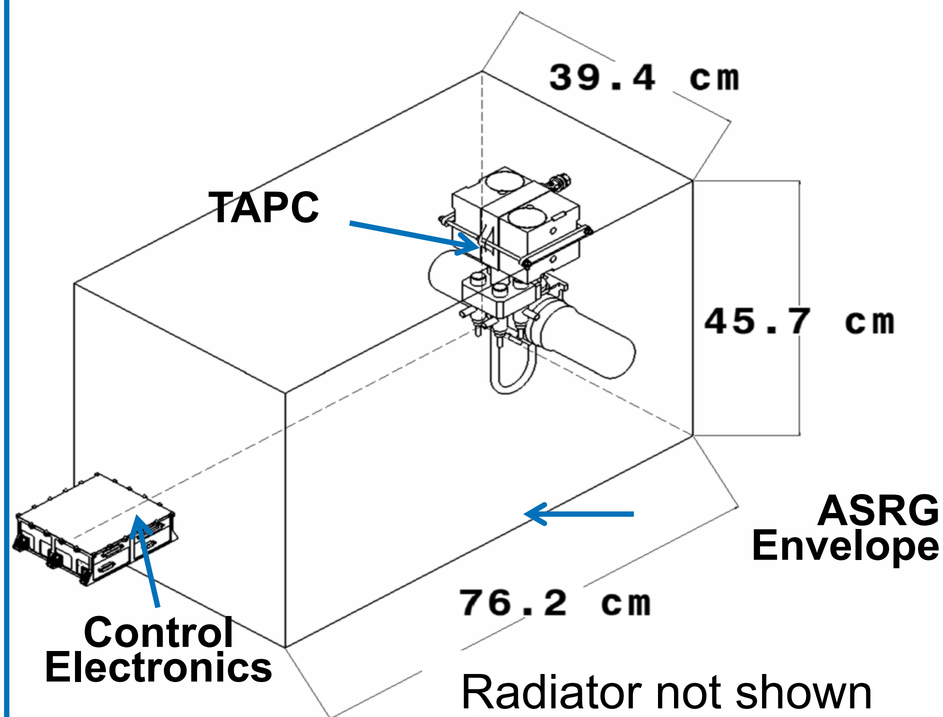
TAPC Integration Features

TAPC with integration components



TAPC compared to ASRG Envelope



- Efficient, small volume, low mass
- Integrated system can be bolted to radiator
- Vibrationally balanced alternator pair

Incorporating spacecraft mechanical and thermal interfaces into TAPC eases integration into a variety of spacecraft

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Spacecraft Systems Design and Integration Example Using TAPC Space Power Generation

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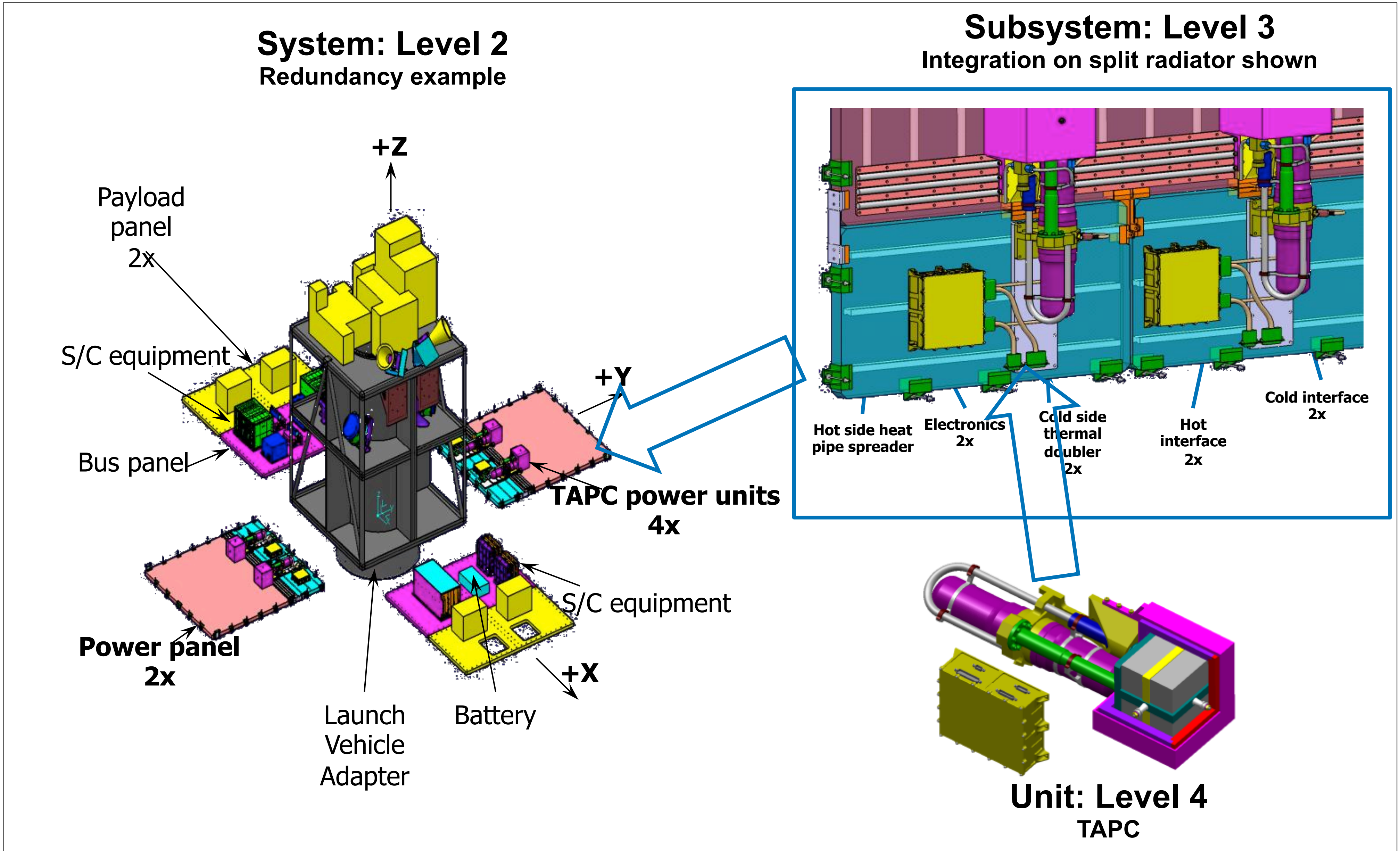

NGAS understands TAPC's spacecraft thermal, mechanical and electrical interfaces

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TAPC Outer Planets Capabilities

- **Mechanical simplicity makes TAPC reliable in extreme low temperature environments**
  - Flexure bearing supported piston in alternator
  - No moving part heat engine
- **1/4 the ^{238}Pu of the (e)MMRTG**
- **1/3 the mass of the (e)MMRTG**
- **More power at EOL than (e)MMRTG**
- **Low vibration - very similar NG cryocoolers flying with .005N exported vibration in 3 axes**
- **50% more power at Titan because of low reject temperature**

	MMRTG	eMMRTG	ASRG	TAPC	
	Cruise phase			Cruise phase	at Titan
Technology	PbTe/TAGS	SKD	Stirling	TA Stirling	TA Stirling
Status	Current Technology	In development	Canceled (TRL 5-6)	TRL 4-5	TRL 4
Pu^{238} mass (Kg)	4.8	4.8	1.2	1.2	1.2
# GPHS Modules	8	8	2	2	2
Hot Temperature (°C)	530	600	850	650	650
Cold Temperature (°C)	200	200	Unstated	25	-143
BOL Power (W)	110	145	130	129	200
EOL (17 yrs) Power (W)	60	90	102	101	156
Mass (Kg)	43	43	32	15	15
BOL Specific Power (We/kg)	2.6	3.4	4.1	8.6	13.3
EOL Specific Power (We/kg)	1.4	2.1	3.2	6.7	10.4
Exported Vibration (N)	0	0	~2	<0.2	<0.2

TAPC provides high reliability, high specific power, low mass, low vibration

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Summary

- Northrop Grumman is developing thermoacoustic power converters for use in radioisotope power systems for space applications
- Efficiencies appear comparable to conventional Stirling systems
- Less complexity promises higher reliability and manufacturability

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