Summary for Oral Presentation/Viewgraphs:

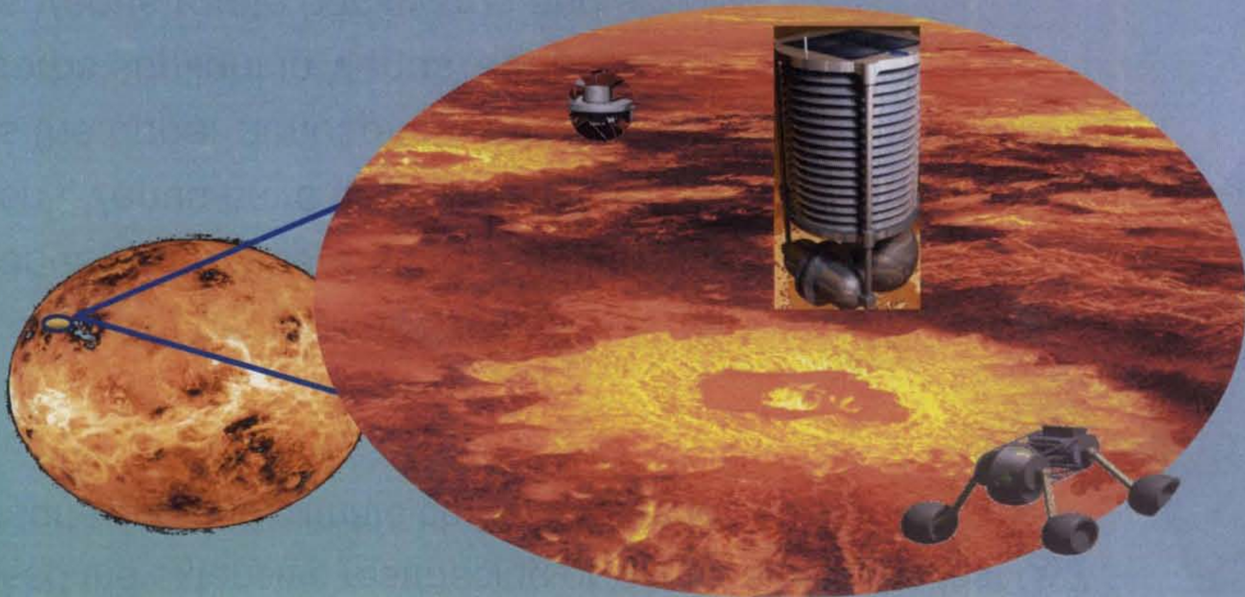
Surprisingly little is known about Venus, our neighboring sister planet in the solar system, due to the challenges of operating in its extremely hot, corrosive, and dense environment. For example, after over two dozen missions to the planet, the longest-lived lander was the Soviet Venera 13, and it only survived two hours on the surface. Several conceptual Venus mission studies have been formulated in the past two decades proposing lander architectures that potentially extend lander lifetime. Most recently, the Venus Science and Technology Definition Team (STDT) was commissioned by NASA to study a Venus Flagship Mission potentially launching in the 2020-2025 time-frame; the reference lander of this study is designed to survive for only a few hours more than Venera 13 launched back in 1981!

Since Cytherean mission planners lack a viable approach to a long-lived surface architecture, specific scieutific objectives outlined in the National Science Foundation Decadel Survey and Venus Exploration Advisory Group final report cannot be completed. These include: mapping the mineralogy and composition of the surface on a planetary scalej determining the age of various rock samples on Venus, searching for evidence of changes in interior dynamics (seismometry) and its impact on climatej and many other key observations that benefit with time scales of at least a full Venus day (Le. daylight/night cycle).

This report reviews those studies and recommends a hybrid lander architecture that can survive for at least one Venus day (243 Earth days) by incorporating selective Stirling multi-stage active cooling and hybrid thermoacoustic power.

Long-Lived Venus Lander Conceptual Design:

How To Keep It Cool



Rodger W. Dyson, Paul C. Schmitz,
L. Barry Penswick, Geoffrey A. Bruder
NASA Glenn Research Center
Cleveland, OH

Aug. 5, 2009

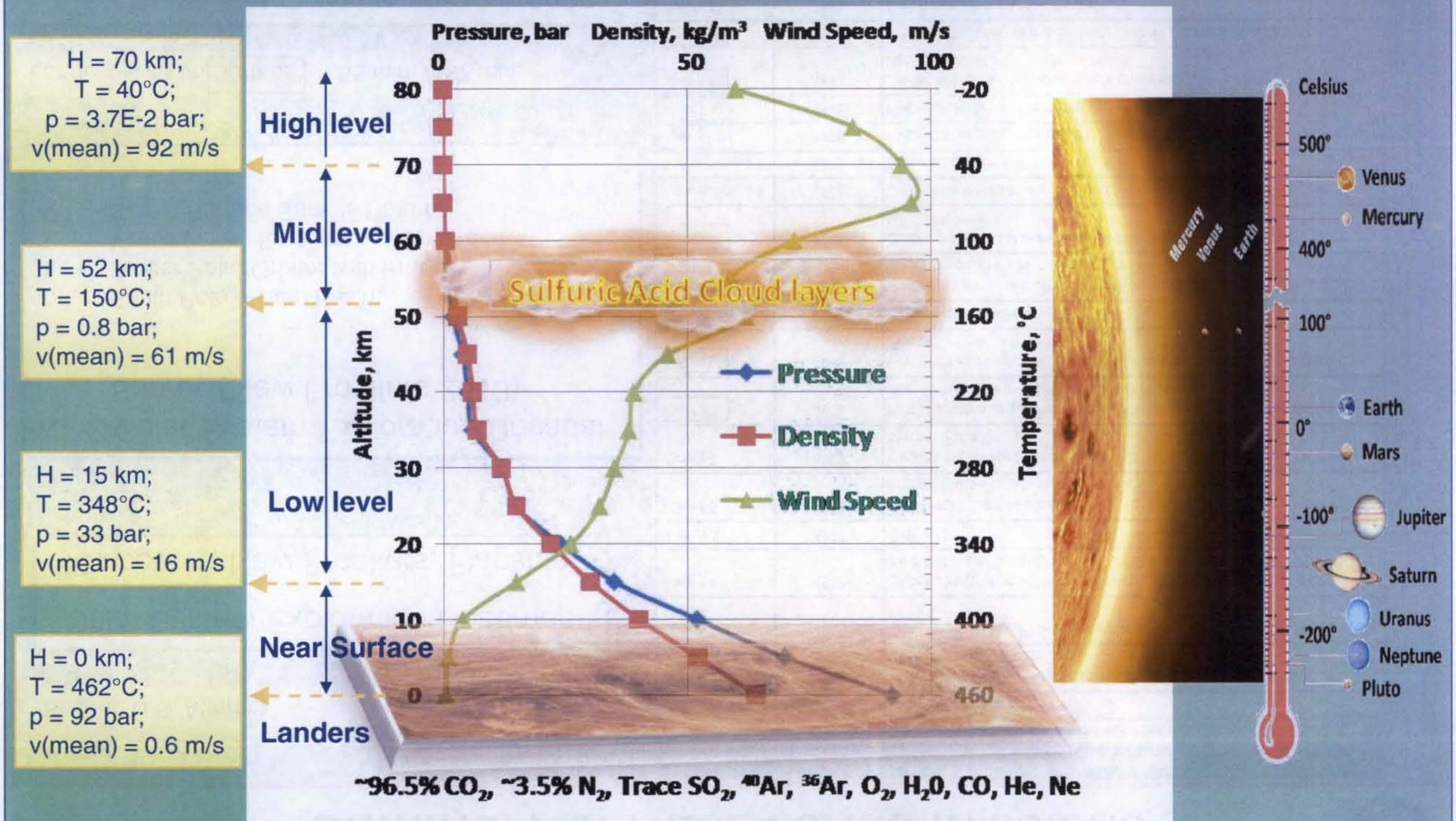
IECEC 2009 / Session 30-EC-7 / AIAA-2009-4631
Thermal Energy Conversion Technology and Applications

The Outstanding Mysteries of Venus

- The Evolution of Venus
  - Why did Venus evolve so differently from Earth?
  - Was there ever an ocean on Venus, and if so, when did it exist and how did it disappear?
  - Did conditions for life or life in some form ever exist on Venus?
  - Did Venus lose an early atmosphere to catastrophic loss?
  - Did Venus ever have plate tectonics?
  - What caused the extensive resurfacing of Venus during the last Gy?
  - Are the resurfacing and climate change somehow related?

- Venus Today
  - Is Venus currently geologically active?
  - Why is Venus' atmosphere super-rotating?
  - Why doesn't Venus have a magnetic field?
  - How does the upper atmosphere interact with space environment?
  - What absorbs sunlight in Venus' atmosphere?
  - Why does Venus rotate backwards and slowly?
  - How do the surface and atmosphere interact chemically?

GRC Environments Encountered by In-Situ Elements



Summary of Past Venus Missions

Second U.S. Attempt → Mariner 2

Solar System Exploration Roadmap

Discovery, New Frontiers, Flagship

NRC Solar System Exploration Decadal Survey (New Frontiers 2013)

1. South Pole–Aitken Basin;
2. Jupiter Polar Orbiter with Probes;
3. Venus In Situ Explorer (2015); and
4. Comet Surface Sample Return

Longest-lived on Surface -- 55 min. /127 min. → Venera 13

Next Proposed Flagship Mission 2020

Venus Mobility Explorer – Several Months

(Air Mobility vs. Rover)

Search for granitic and sedimentary rocks, in-situ analysis of the crust, measurements of oxidation/mineralogic state of iron

Spacecraft	Launch Date	Type of Mission
Venera 1	1961	Impactor; Spacecraft sealed and pressurized with nitrogen
Mariner 2	1962	Flyby; first to fly by Venus (US)
Zond 1	1964	Probe and main bus; Entry capsule designed to withstand 60 to 80°C, and 2 to 5 bars
Venera 2 & 3	1965	Probe and main bus; Entered the atmosphere of Venus; Designed for up to 80 °C / 5 bar
Venera 4	1967	Stopped transmitting at 25 km; 93 minutes descent; first to descend through the atmosphere; Designed for 300 °C / 20 bar (Russia)
Mariner 5	1967	Flyby (US)
Venera 5	1969	Hard-lander; Stopped transmitting at ~20 km (320 °C / 27 bar); 53 minutes descent (Russia)
Venera 6	1969	Hard-lander; Stopped transmitting at ~20 km (320 °C / 27 bar); 51 minutes descent (Russia)
Venera 7	1970	First to soft land on surface; Parachute failure, rough landing, landed on the side; 55 min descent / 23 min on surface (Russia)
Venera 8	1972	Performed as designed; Soft-lander; 55 min descent / 50 min on surface (Russia)
Mariner 10	1973	Flyby en route to Mercury (US)
Venera 9	1975	Orbiter (moves out of radio range); soft-lander; first to return photos of surface; 20+55 min descent / 53 min on surface (Russia)
Venera 10	1975	Orbiter (moves out of radio range); soft-lander; 20+55 min descent / 65 min on surface (Russia)
Pioneer-Venus 1	1978	Orbiter with radar altimeter; first detailed radar mapping of surface (US)
Pioneer-Venus 2	1978	Four hard-landers (US)
Venera 11	1978	Flyby, soft-lander; 60 min descent / 95 min on surface (Russia)
Venera 12	1978	Flyby, soft-lander; 60 min descent / 110 min on surface (Russia)
Venera 13	1981	Orbiter, soft-lander; first color images of surface; 55 min descent / 127 min on surface (Russia)
Venera 14	1981	Orbiter, soft-lander; 55 min descent / 57 min on surface (Russia)
Venera 15	1983	Orbiter with radar mapper (Russia)
Venera 16	1983	Orbiter with radar mapper (Russia)
Vega 1	1984	Flyby, atmospheric balloon probe (Russia / International)
Vega 2	1984	Flyby, atmospheric balloon probe (Russia / International)
Magellan	1989	Orbiter with radar mapper (mapped 98% of the surface); first high-resolution global map of Venus (US)
Venus Express	2005	Orbiter – Ongoing mission (ESA)
Planet-C	2010	Venus Climate Orbiter – In development (JAXA)

Summary of Enabling Technologies

Telecom
- Satellite Communication
- High temperature motor for antenna gimbal

Mobility Technologies
- Metallic bellows/balloon
- High temperature motor for rover and sample acquisition

Venus Environment Facility
- Launch, transit, entry, descent, land, extended surface operations
- Components & Systems
- GRC & ARC provide all mission phases except near surface

Materials and Joining Technologies
- High temperature, pressure, and corrosion resistant
- Enable higher power conversion efficiencies
- Pressure Vessel Insulation
- Lander mass reduction

Aeroshell Transit and Entry
- Thermal Protection Shell
- Minimize deceleration forces/temperature
- Heat pipe/radiator integration

Thermal Management
- Passive Cooling-1 day
- Active Cooling-1 year
- Hybrid for redundancy and minimal duty cycle
- Aerogel, Mutli-layer Insulation

Component Hardening
- Enables warmer coldbay
- High temperature electronics
- Imagers/Optics at interface
- External components/sensors

Power and Storage
- Solar – High Altitude
- Stirling – Low Altitude
- High temperature battery for redundancy and minimal duty cycle

GRC GLENN RESEARCH CENTER at Lewis Field

Summary of Venus Mission Testing Facilities

Mission Phase	Facility/Center	Size (feet)	Pressure (bar)	Temp. (°C)	Simulates
Launch	SDL/GRC	10x10	1	20	Vibration
Transit	SPF/GRC	100x122	1.3e-9	-195	Solar Radiation
Entry	IHF/ARC	Coupon	1	1649	Viscous Heating
Entry	HTF/GRC	25x20	.143 thru 1	1893	High Velocity
Entry	20g Centrifuge/ARC	7.6x5.9	1	20	Deceleration
Descent	Wind Tunnel/ARC	80x120	1	20	Full Vehicle
Surface	Proposed/GRC	6x10	100	510.2	Pressure & Temp.

Location	Size	Pressure (bar)	Temp. (°C)	Gas Environment
Georgia Institute of Technology	12"x12"	100	343	Variable
University of Iowa	5"x12"	90	500	CO_2
Jet Propulsion Lab	4"x54"	92	500	CO_2, N_2, trace
Massachusettes Institute of Technology	1"x48"	200	700	CO_2
Massachusettes Institute of Technology	0.5"x12"	200	700	CO_2

Most larger facilities are available at GRC for each mission phase, except surface. Small Venus facilities at universities NASA needs a large facility, recent study completed indicates feasibility at GRC

Power and Cooling Options

Approach	Efficiency, % $\frac{T_{hot}}{T_{cold}} - \frac{1123\ K}{773\ K}$	Properties
Free-piston Stirling	17	Alternator cooling required, forms a pneumatic duplex
Free-displacer Stirling	15	Alternator cooling required, forms a pneumatic duplex
Thermoacoustic Stirling	13	Alternator cooling required, forms a pneumatic duplex
Brayton/Rankine	11	High speed rotation gear reduction required for cooling
Thermoelecitrc (Segmented)	3-4	Difficult to couple with efficient dynamic cooling
Solar Array	< 1	Additional development required for high temperature
Beamed Power	< 1	Energy dissipates in atmosphere, requires development
Thermionic	< 1	Difficult to couple with efficient dynamic cooling
Battery	-	Limited mission duration or requires repeated charging

Approach	Efficiency % of Carnot	Properties
Free-piston Stirling	28	Space operations heritage, forms a pneumatic duplex
Free-displacer Stirling	24	Less bearings required, forms a pneumatic duplex
Thermo-Acoustic/Pulse Tube	20	Few moving parts, forms a pneumatic duplex
Brayton/Rankine	18	Gear reduction required from power takeoff
Thermionic	15	Electrons carry heat across vacuum, requires development
Thermoelectric (Segmented)	1	Peltier Cooling, Useful for localized cooling
Mixed Refrigerant	-	High temperature Venus applications not developed yet
Phase Change	-	Limited mission duration, can complement active cooling

Stirling power and cooling offers most potential when combined into duplex

Principles of Stirling Convertor Operation

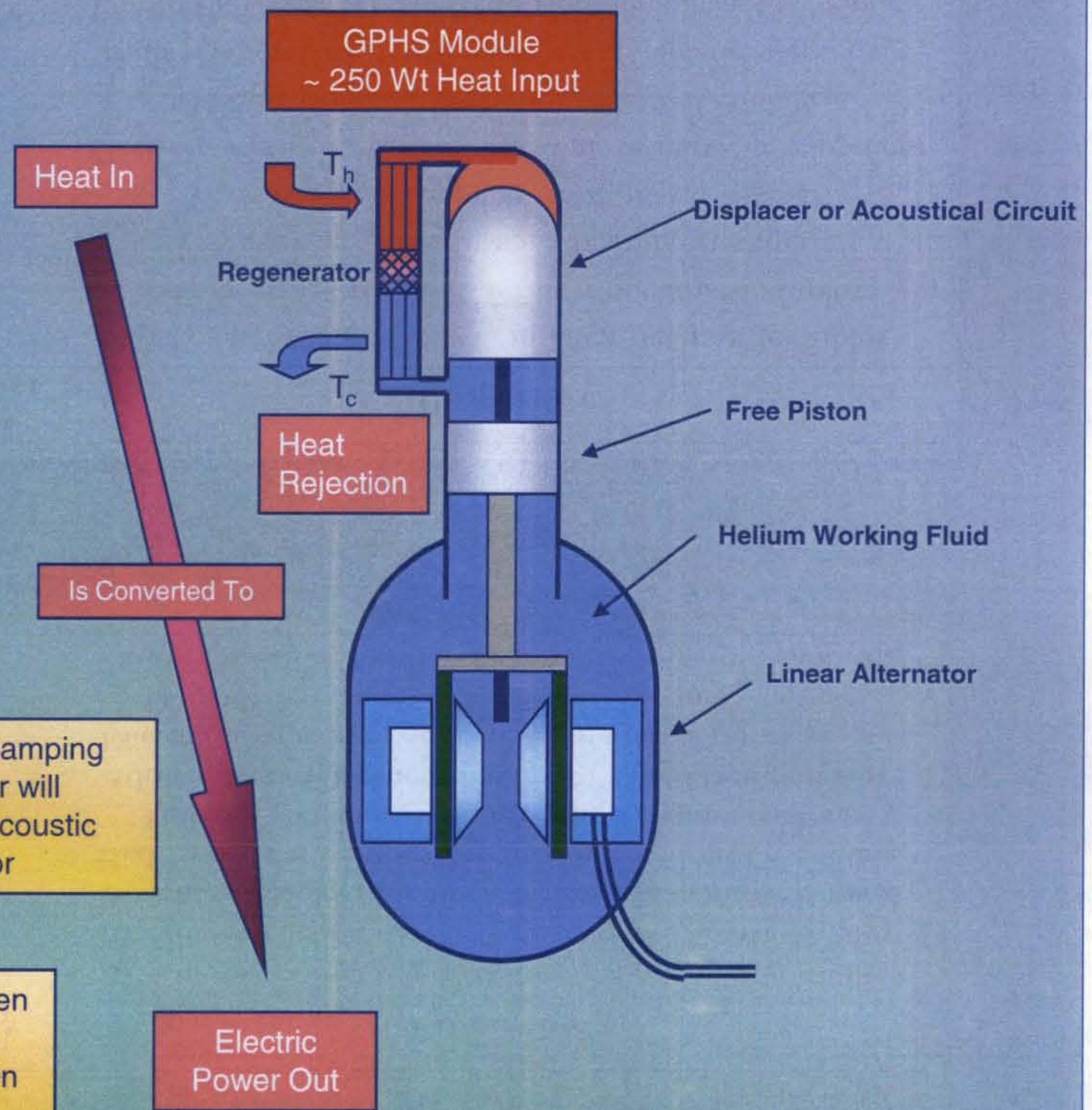
Sunpower Advanced Stirling Convertor

Northrop Grumman Thermo-Acoustic Convertor

The Stirling cycle engine, when integrated with a linear alternator, becomes a Stirling cycle power convertor

With proper masses, spring rates and damping (dynamic/acoustic tuning), the convertor will resonate as a Free-Piston or Thermo-Acoustic Stirling Thermodynamic Cycle Convertor

- All Wear Mechanisms Have Been Eliminated By Design
- Long Life Operation Is Based On Non-Contacting Operation



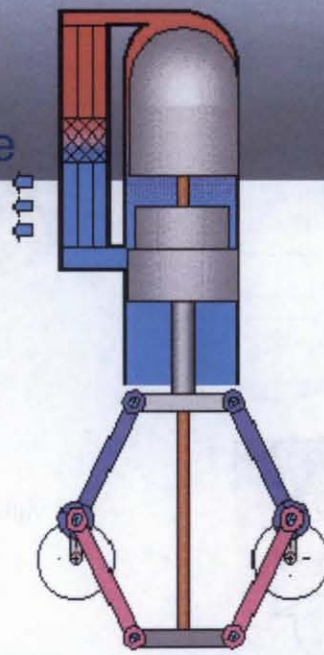
What are the Life Limiting Mechanisms?

Potential life limiting mechanisms
- Wear
- Fatigue
- Creep
- Permeation
- Radiation

Motion does not limit the life

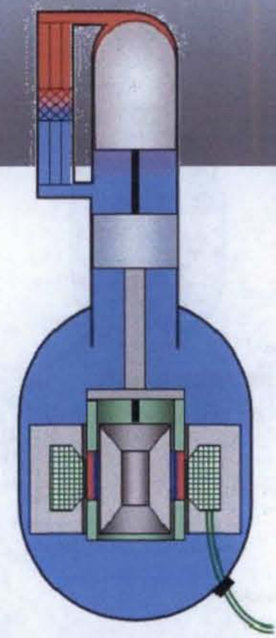
- Wear mechanisms have been eliminated
- Based on non-contacting operation

Kinematic



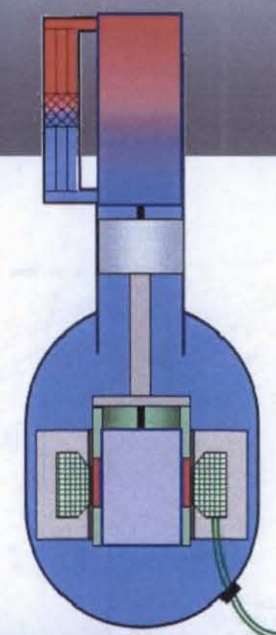
Sliding seals
Rolling element bearings

Free Piston



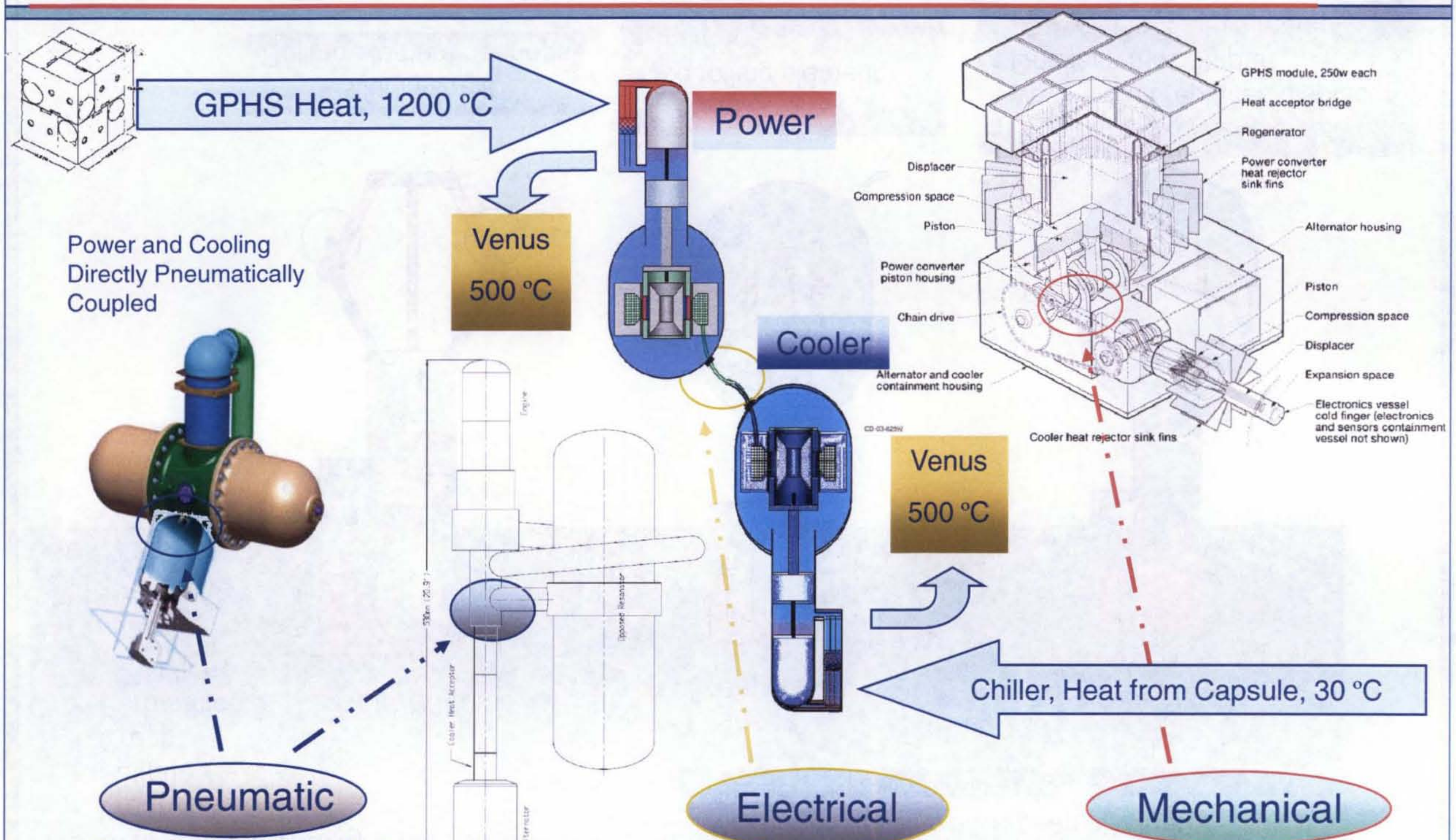
- No sliding seals
- No rolling element bearings

Free-Piston Thermo-Acoustic



- High amplitude acoustical wave circuit replaces displacer
- One less moving part
- Less efficient, but simpler

Stirling Duplex Principle of Operation

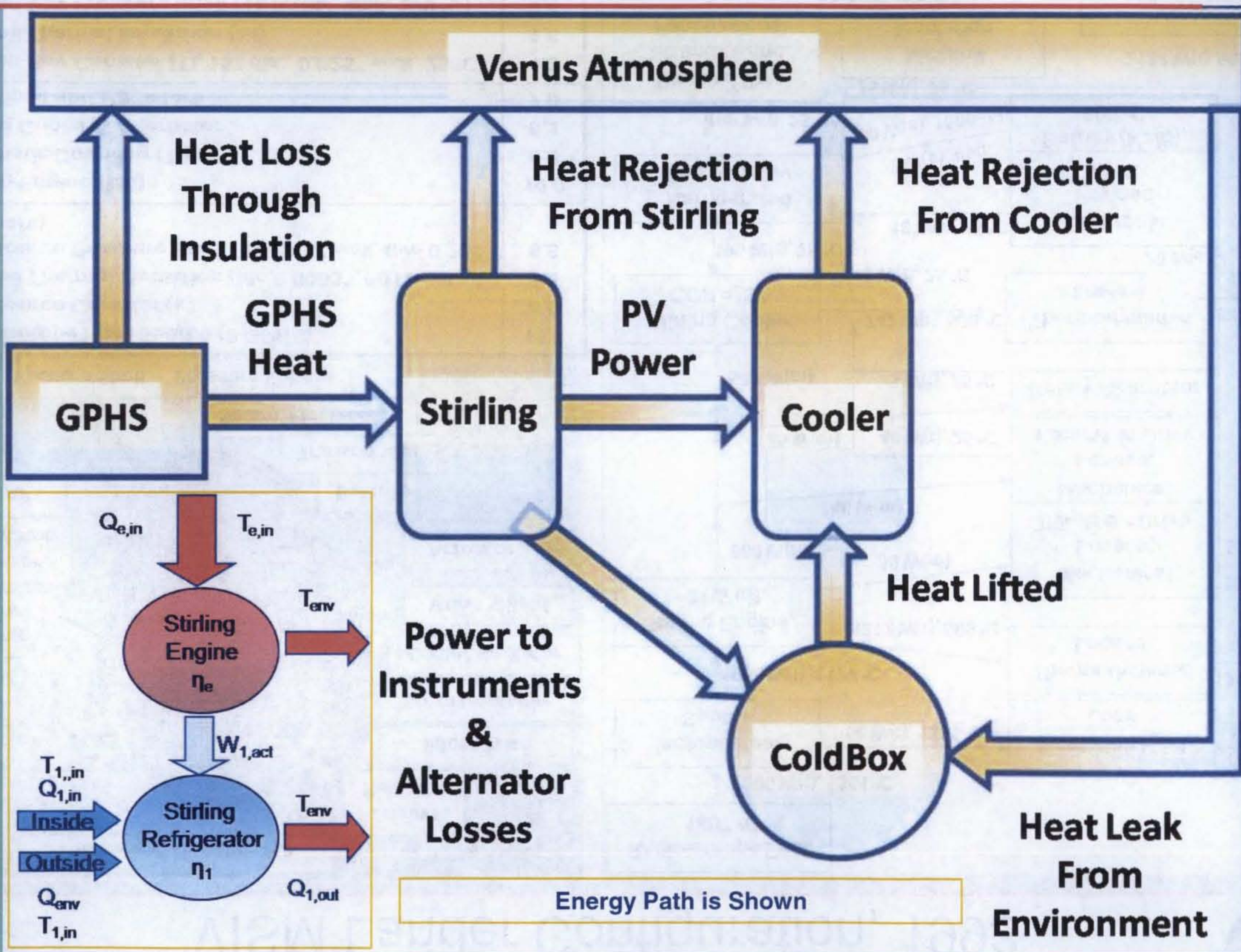


Pneumatic: Most efficient method of connecting power with active cooling

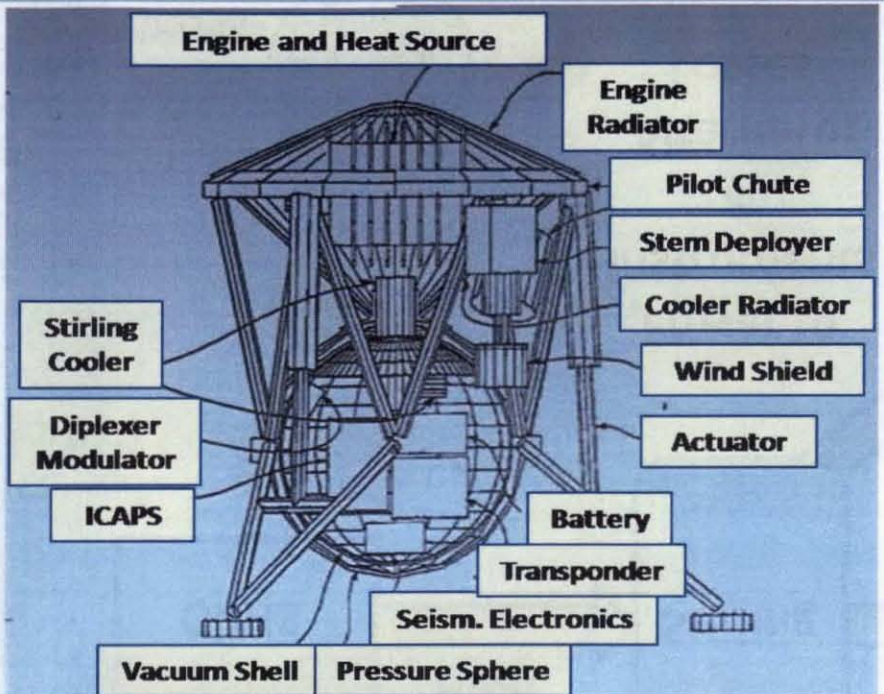
Electrical: Linear alternator losses, 94% efficient

Mechanical:
- Mechanisms impact reliability
- Lubrication required

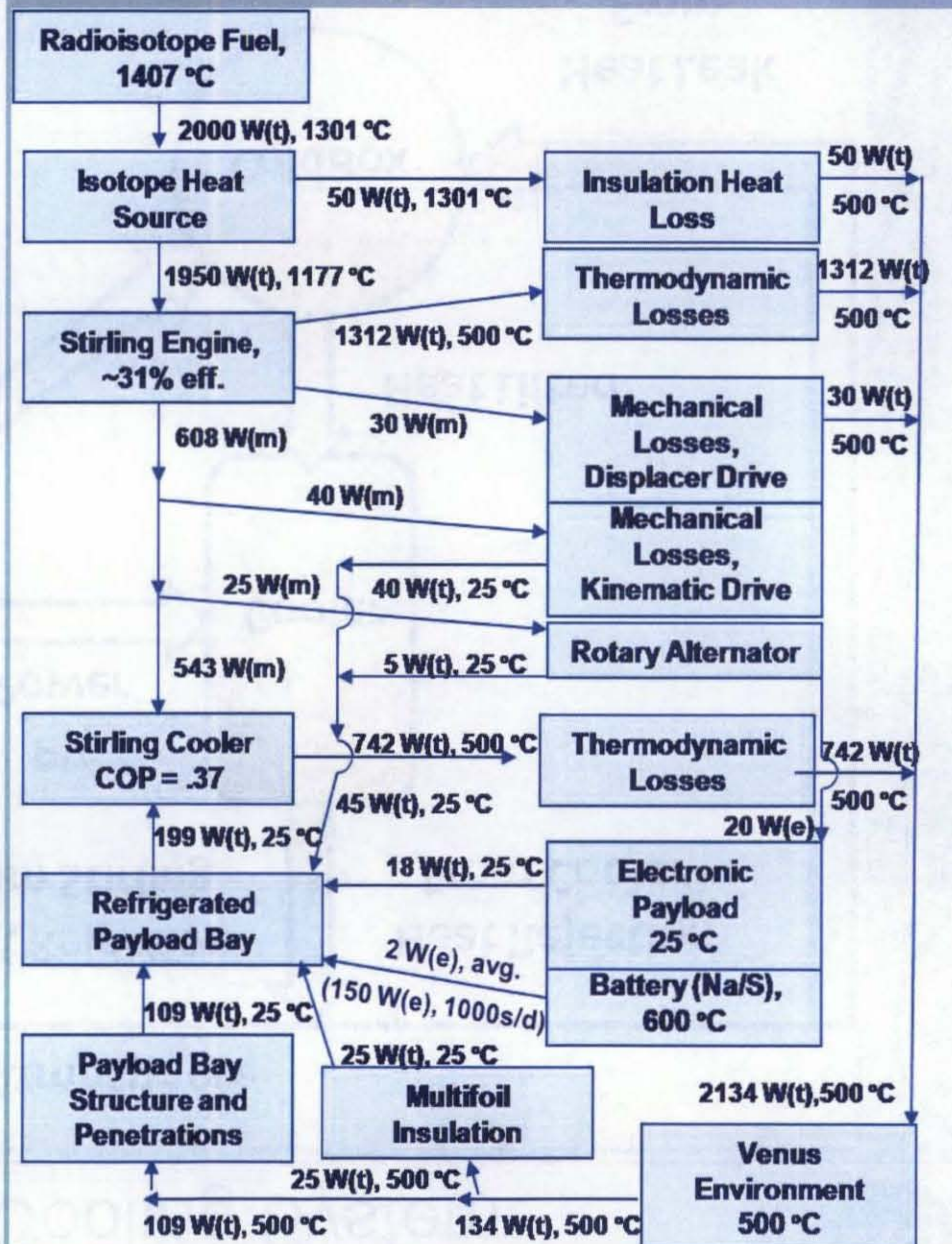
Single-Stage Cooling System



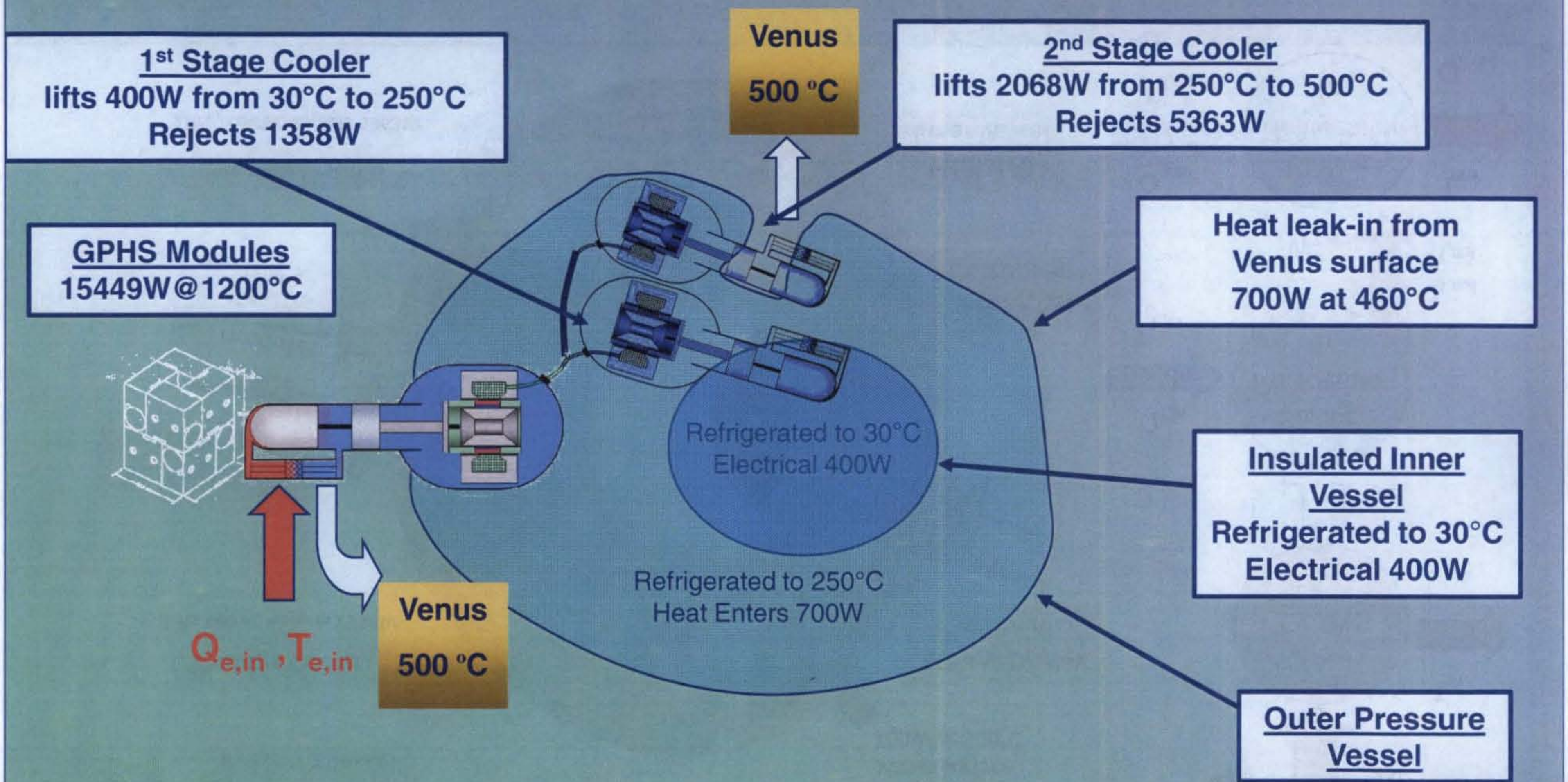
VISM Lander Configuration, 1993



Radioisotope Heat Source (8 GPHS)	11.6
Heat Source Canister (Ir)	4.0
Multifoil Thermal Insulation (Mo,0.0003", 60 layer)	1.5
Heat Source Pressure Shelf (Ti, 0.25" wall, five 0.20" stiffeners)	9.6
Stirling Engine (Mo)	10.0
Pneumatic Coupling (Ti)	0.5
Stirling Cooler & Alternator	9.1
Heat Pipes and Radiators	7.0
Payload Bay Canister (Ti, 15" dia., 0.025" wall, 25 °C)	1.3
Multifoil Thermal Insulation (Ni)	1.8
Payload Bay Pressure Shell (Ti, 0.165" wall, 500 °C)	9.4
TOTAL Mass (kg)	*65.8*



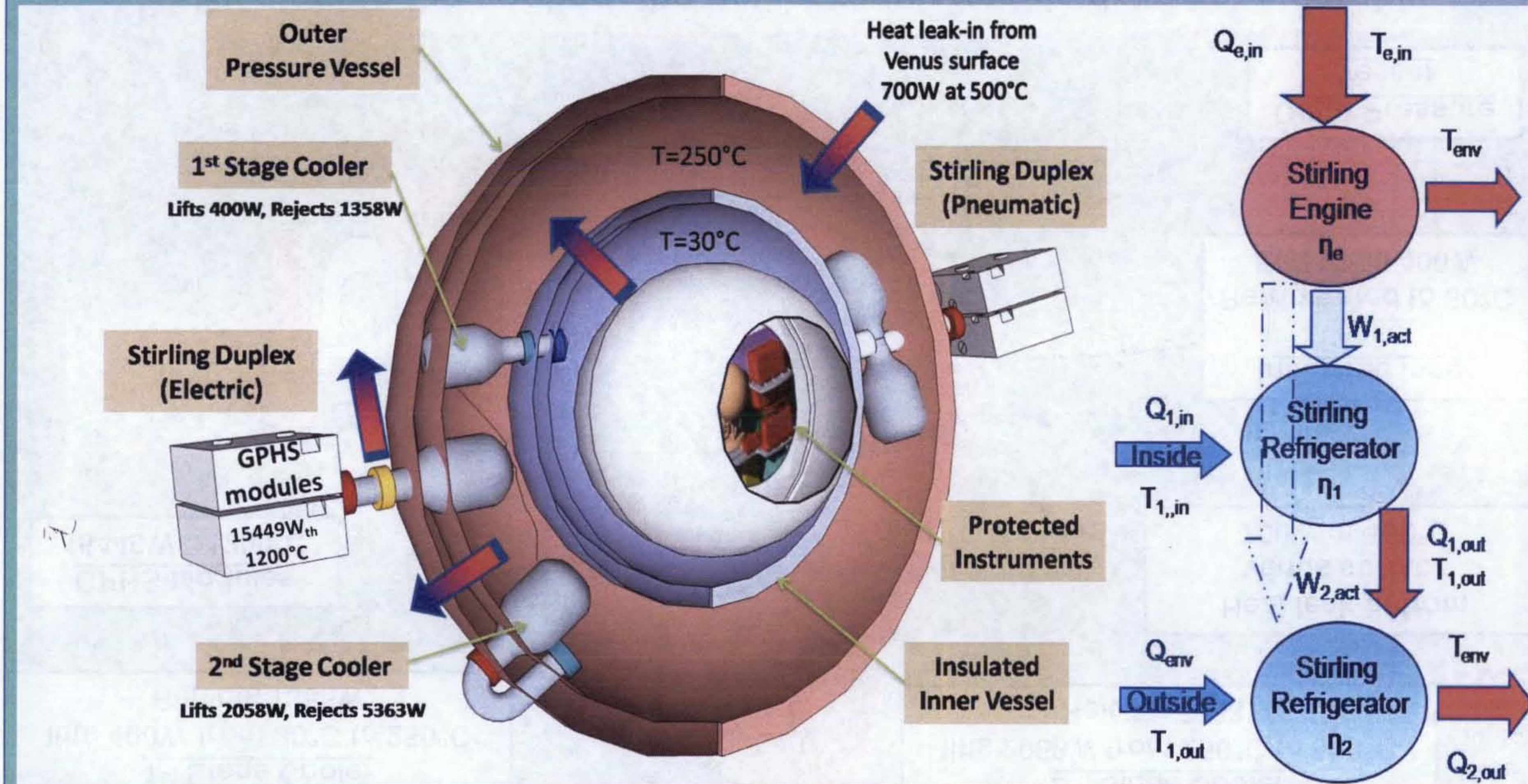
Thermodynamic Two Stage System



By staging the cooling, the power requirements drop considerably

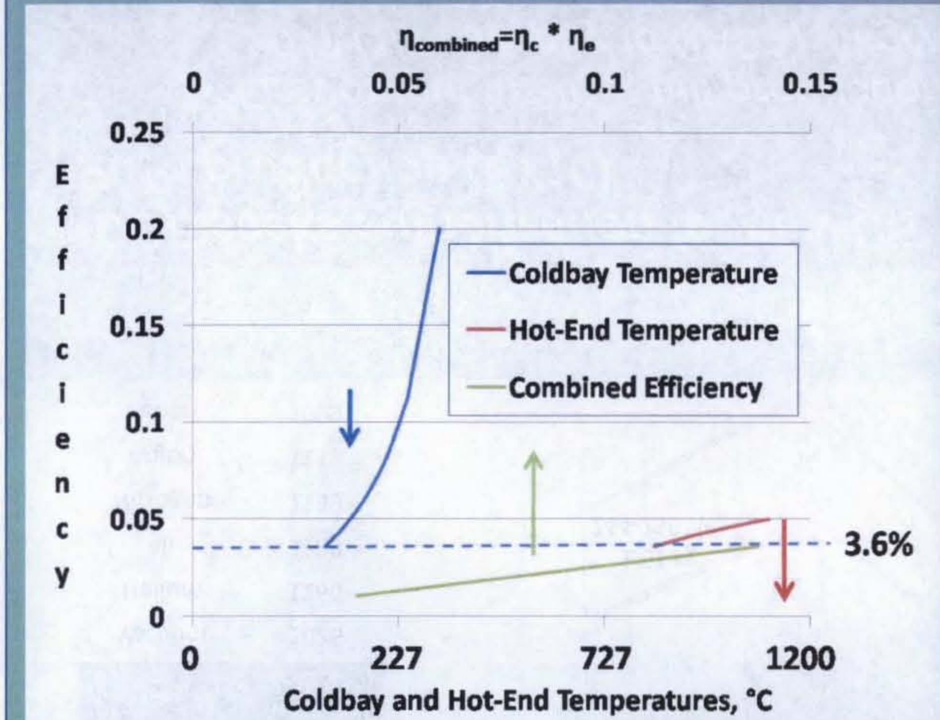
Shown here are two stages, one additional stage would be optimal

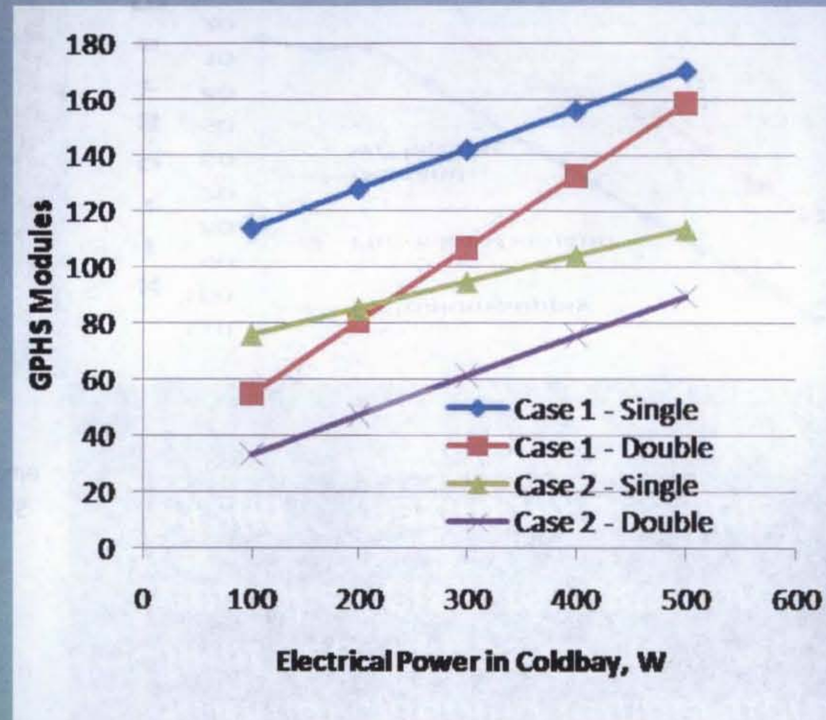
Two-Stage Cooler Integration



Multistage Duplex Electrically Connected & Pneumatically Connected

GPHS Requirements & Availability





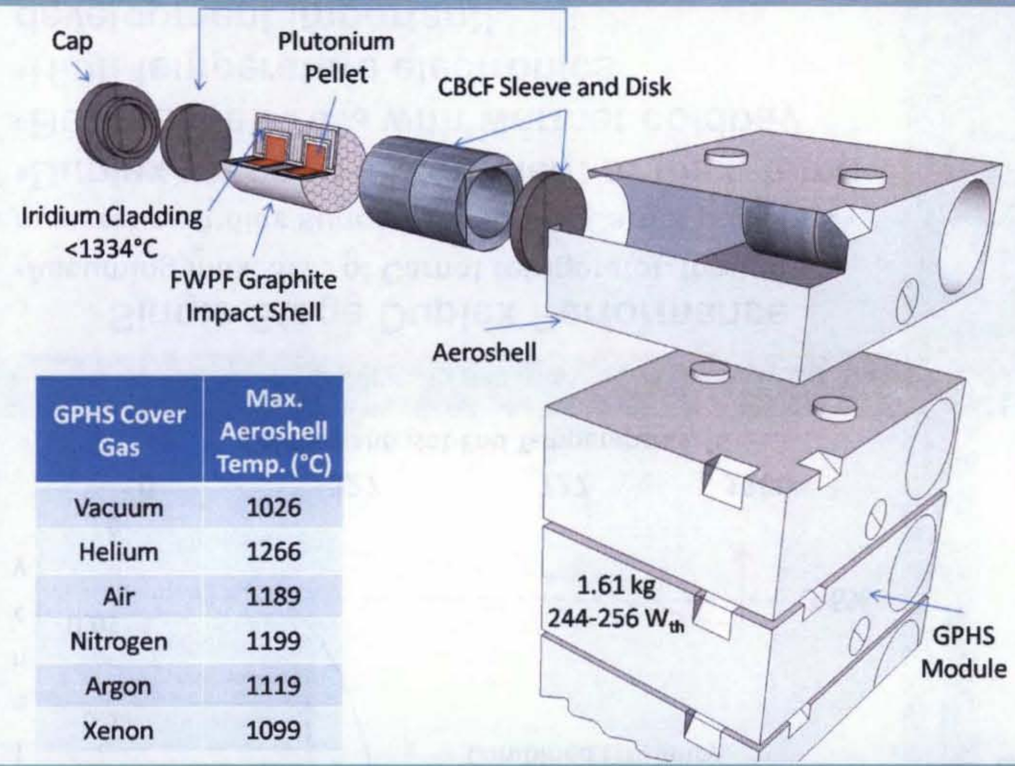
Single-Stage Duplex Performance

- Assuming max. 30% of Carnot refrigerator, though numerous studies suggest 55-60% of Carnot possible.
- **Duplex reaches 5% efficient at max. temp**
- **But reaches 20% with warmer coldbay**
- **High temperature electronics development important!**

Multistage vs. Single Stage Cooling Function of electrical power requirements

700 W heat leak in
1200°C Hot-end
250°C Buffer
30°C Coldbay
55% of Carnot Convertor
Case 1 = 20 % of Carnot cooler
Case 2 = 30% of Carnot cooler

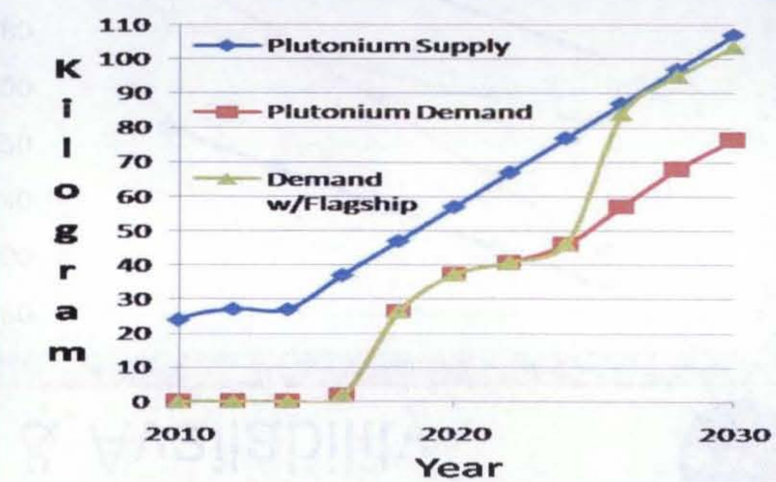
GPHS Design Limits



GPHS Cover Gas	Max. Aeroshell Temp. (°C)
Vacuum	1026
Helium	1266
Air	1189
Nitrogen	1199
Argon	1119
Xenon	1099

- ***Fabric Weave Pierced Fabric Graphite Impact Shells vendor unavailable***
- ***Carbon bonded Carbon Fiber Thermal Insulation Sleeve***
- ***Iridium cladding temperature limit determines GPHS aeroshell max. temperature***
- ***1266°C maximum possible***

- ***DOE seeks authorization for new US Pu^{238} production (FY10)***
  - ✓ ***First output in 2015, full production by 2017 (1/2 capacity to NASA), 5kg/yr, <u>~5/.6=8 GPHS/year</u>***



High Temperature Materials

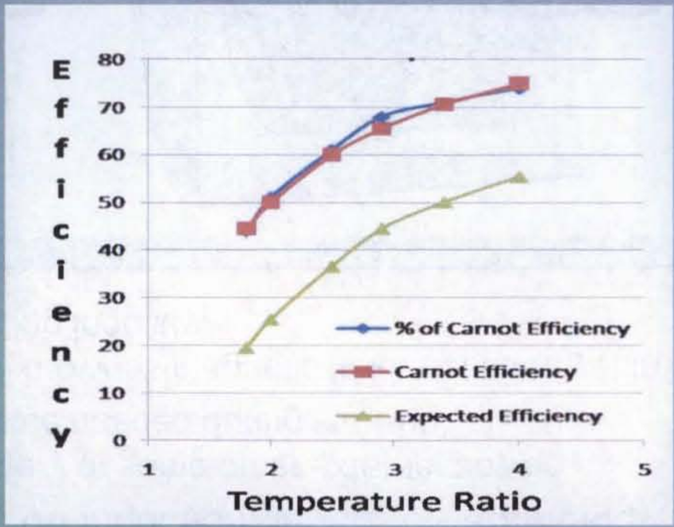
Nickel base superalloy

- Current Stirling hot-end material (MarM-247) is being developed in the ASC/ASRG project to operate for **17 years** at 850 °C
- For Venus missions of less than 1 year, MarM-247 needs to be evaluated for potential use at temperatures up to 1000 °C.
- The use-temperature may be able to be raised to as high as 1100 °C

MarM-247 heater head

Refractory

- For higher temperatures, a different class of material would be required
- GRC conducted initial development of advanced materials (refractory metal alloys and ceramics) specifically for high-temperature Stirling applications



Although not fully mature at the present time, these advanced materials have the capability of operating at temperatures as high as 1200 °C.

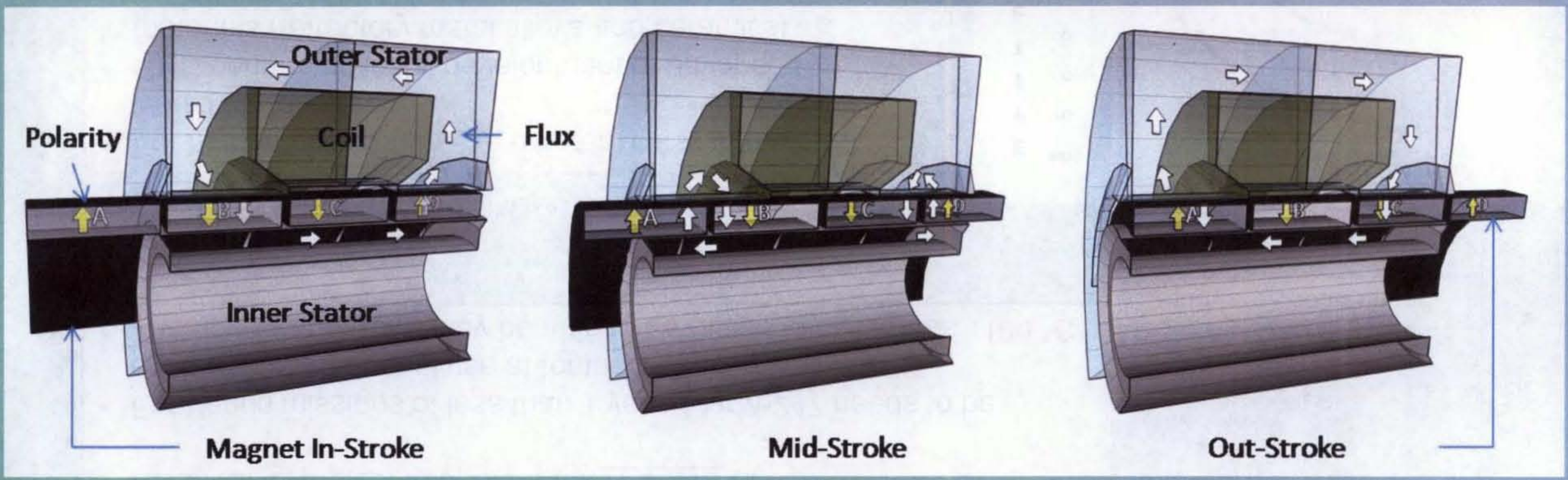
Higher hot-end temperatures increases efficiency

Refractory metal casting for heater head fabrication

Ref. R. Bowman

High Temperature Alternator Development

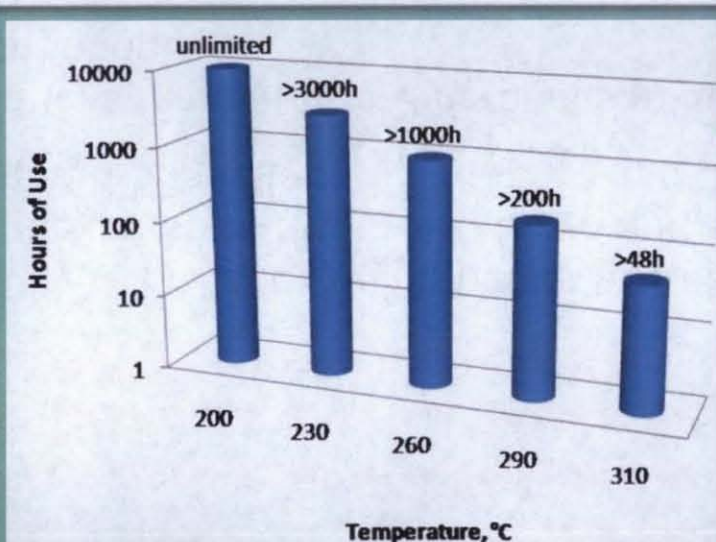
- Option 1: Permanent Magnet Type
  - Venus ambient temperature ≈ 460 °C
  - Known SmCo type magnets may be used potentially up to 300 °C
    - Magnet Remanence declines with increasing temperatures
- Option 2: Electromagnet Type
  - Based on induction generator technology
    - Battery or some other external power source needed during start-up
    - Coil provides magnetic field, not used yet in Stirling industry.



GRC has an existing laboratory for the evaluation and development of high-temperature linear alternators. Wire insulation is primary limiting component, but ceramics could be considered. Fortunately, duplex design can refrigerate itself!

Organics Maximum Operating Temperature

Organic Compounds	Use/Function	Temp. °C
Viton(FKM)	Gasket Seal	200
Silicon	O-ring	300
Hysol EA9394	Adhesive Potting	177
Loctite 2422	Thread Locker	343
Nomex Paper	Coil Backing	220
Polyamide	Coil Insulation	240
Polythermalize	FLDT Coil Insulation	200
Teflon	Wire lead insulation	260
Tra-bond	FLDT Coil Potting	190
Xylan	Bearing lubricant	260
Matrimid 5218	Adhesive	250



remove or make general no location specifics

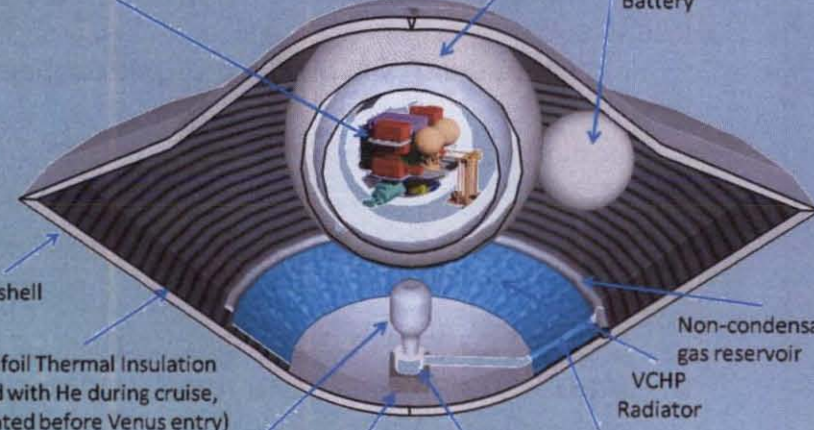
- ASC is being developed for 17 years of ASRG operation and ~130 °C maximum alternator temperature
- Fission Surface Power convertor is being developed for ~150 °C alternator temperature with similar materials as ASC
- CTPC was developed, as part of the SP-100 program, for ~273 °C alternator temperature for a 60,000-hour life
  - Short-term tests completed at temperature
  - Still needed long-life, ceramic-coated coil development
- Tradeoffs of maximum operating temperature vs. required development and risk need to be investigated in terms of:
  - Long-term thermal stability
  - Outgassing
  - Synergistic effects, e.g., radiation + temperature + aging time
  - Selection and validation of high temperature alternatives, especially for ~ 177 °C or higher alternator

Note that higher temperatures permitted for shorter missions, Maximum use temperatures assume unlimited duration.

Ref. E. Shin

Variable Conductance Heat Pipe

- ***Allows option of commanded stop and restart of Stirling for GPHS installation and taking sensitive science data with zero vibration and minimal EMI***



- **Ability to protect Stirling heater head in event of unexpected Stirling shutdown and allow restart if possible**
- **Reduces temperature differences in hot-end components**
- **Minimal mass or performance impacts, 1000 °C operation**

VCHP off during normal operation (NCG covers condenser) – when convertor stops, temperature and alkali-metal vapor pressure increase to uncover condenser and remove GPHS heat

- Designed to turn on with ~30 °C temperature rise to not risk normal operation and minimize effect on convertor life when convertor off

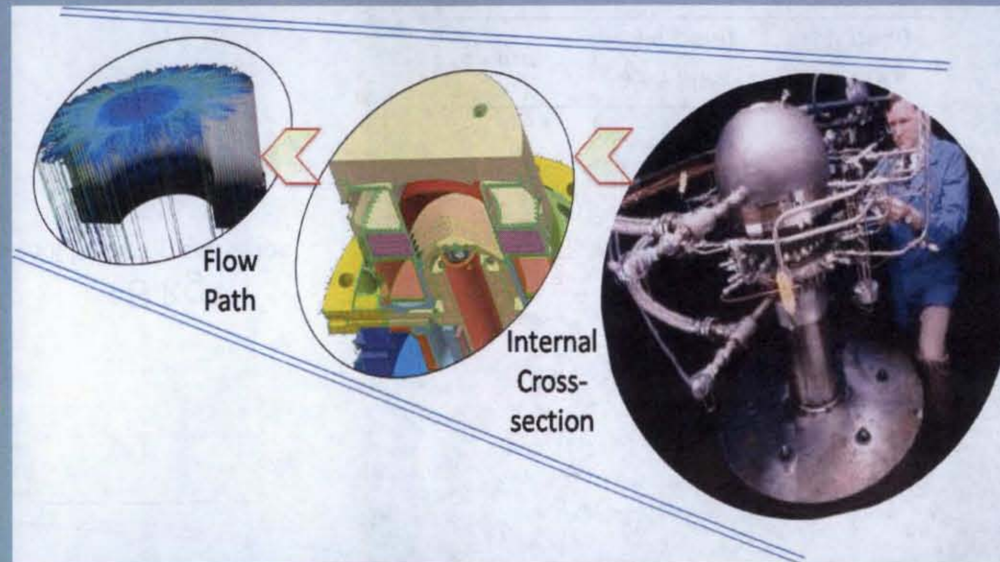
When coupled with currently available energy storage technology, enables quiet seismometer and magnetic field measurements.

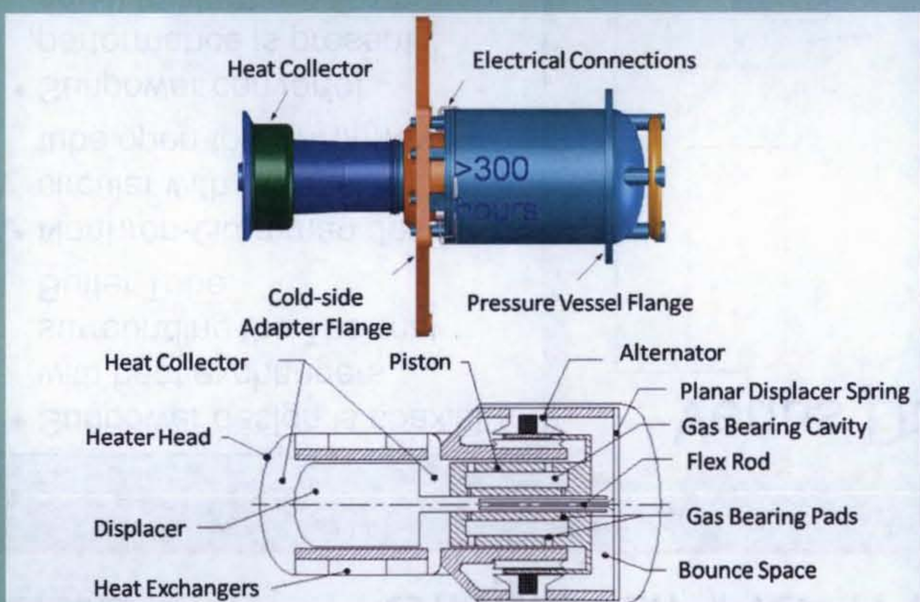
Ref. Advanced Cooling Technolgies, Inc., W. Anderson & L. Thieme

Existing High-Temperature Convertors

CTPC Operated at:

777 °C hot-end,
252 °C cold-end,
3-4 hours at max. temp.
1500 hours total testing (527/127 °C)
70Hz, 15.0 MPa, 12 kWe, Nov. 1992





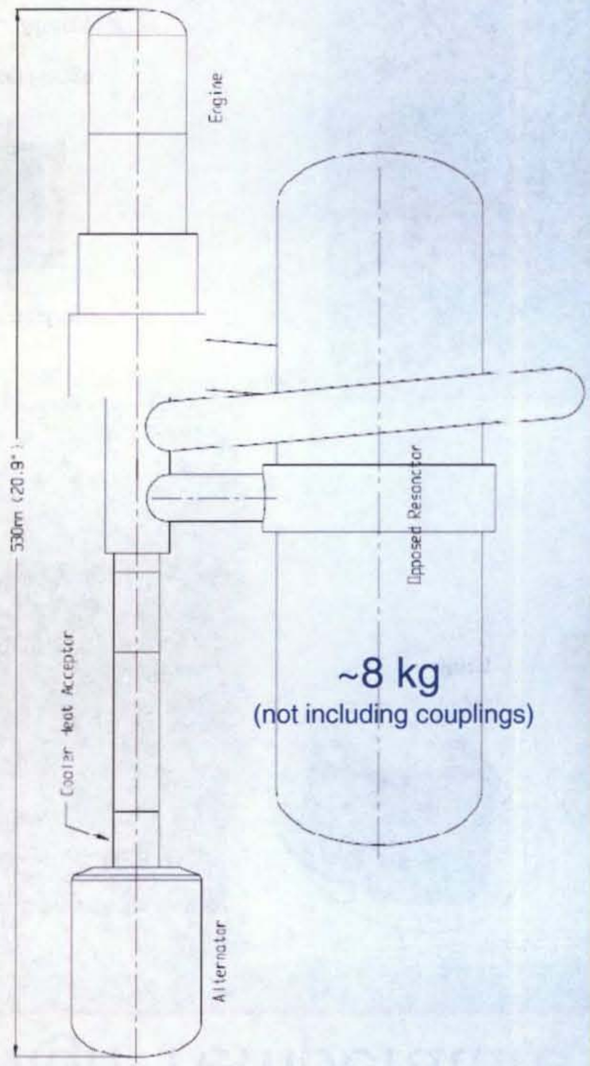
ASC-1 and ASC-1HS

Single Convertor Operating over 300 hours
Total hours on all convertors: 1257
850 °C hot-end
90 °C cold-end
38% efficient, 1.3 kg, 102 Hz,
~3.6MPa,
88 W up to 114 W, 2005

Single GPHS TASHE, 2003-2008

- Sunpower design is coaxial with heat exchangers surrounding the Thermal Buffer Tube
- Northrop-Grumman design is circular with thermal buffer tube open to environment
- Sunpower convertor performance is presently equal to Northrop Grumman

Venus Duplex

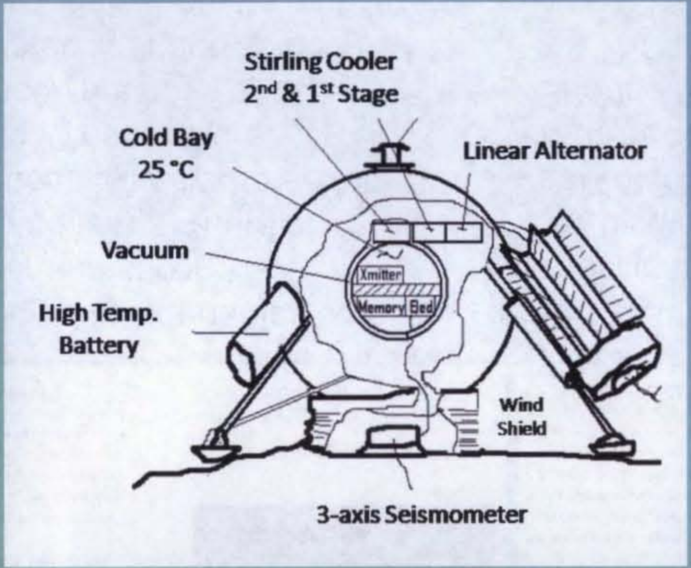


Comparison of Northrop Grumman & Sunpower Technology

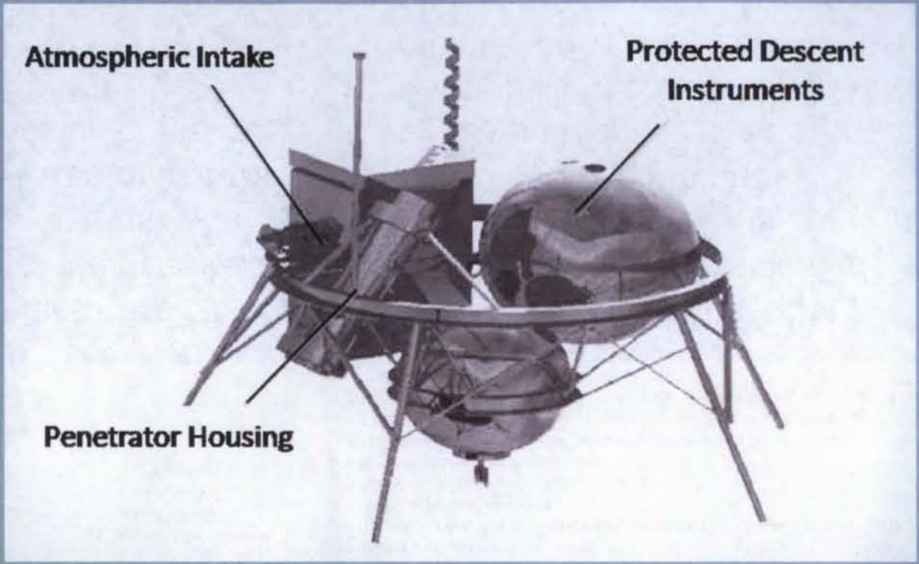
	Sunpower	Northrop Grumman
Pressure	3.65 MPa (530 psia)	5.28 MPa (765 psia)
Frequency	100 Hz.	125 Hz.

Ref. G. Wood & M. Tward

Lander Concepts

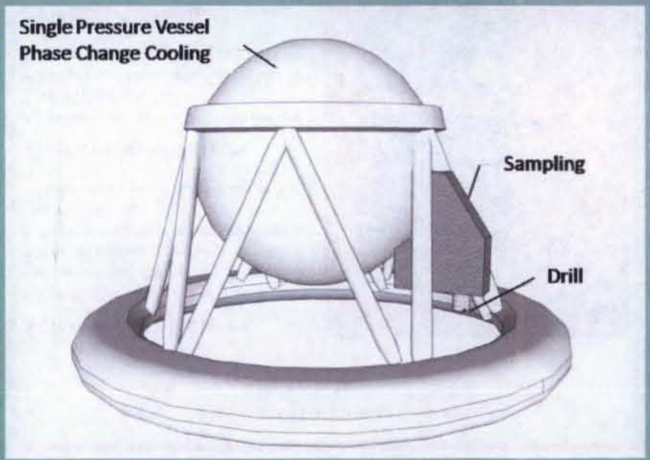


Multistage Cooling/ Hybrid Power/Storage



Multistage Cooling/ Hybrid Power/Storage/Cooling

Hybrid cooling provides:
- redundancy,
- potential mass savings,
- lower duty cycle,
- longer-lived than passive



Single-stage Passive Cooling/ Storage

Hybrid power provides:
- redundancy,
- potential mass savings,
- higher peak power,
- longer-lived than passive

Mission Capability Summary

Flagship Class Mission Concept
Venus Geophysical Network

Scientific Objectives
- Determine the internal structure and seismic activity of the planet
- Monitor the circulation of the atmosphere

Exploration Metrics
- At least three stations on the surface of Venus
- Operate for at least one Earth year

Science Payload
- Camera, descent imager
- Seismometer network
- Meteorology station with pressure, temperature and wind velocity sensors

Technology & Heritage
- Extreme-environments technologies (pressure vessel, thermal management, corrosion)
- High-temperature electronics for telecom / high-data volume
- Radioisotope power system w/ active cooling
- Long-duration operations in situ
- Passive insulation and survival technology from VISE

Mission & LV Class
- Flagship Class Mission
- Launch Vehicle(s): TBD

Flagship Class Mission Concept
Venus Mobile Explorer

Scientific Objectives
- Composition and isotopic measurements of surface and atmosphere
- Near IR descent images
- Acquire and characterize core samples at multiple sites
- Demonstrate key technologies for VSSR

Exploration Metrics
- Operate in Venus surface environment for 90 days+
- Range and altitude if aerial vehicle TBD
- Range across surface if rover TBD

Science Payload
- Neutral-mass spectrometer with enrichment cell
- Instruments to measure elements and mineralogy of surface materials
- Imaging microscope

Technology & Heritage
- Extreme-environments technologies (pressure vessel, thermal management, corrosion)
- High-temperature electronics
- Sample acquisition and handling in Venus near-surface environment
- Air-mobility system (e.g., metallic bellows)
- Radioisotope power system w/ active cooling
- Long-duration operations in situ

Mission & LV Class
- Flagship Class Mission
- Launch Vehicle:
  - Delta-IV-H
  - Atlas V

Flagship Class Mission Concept
Venus Surface Sample Return

Scientific Objectives
- Measure isotopic composition of oxygen in surface rocks
- Measure isotopic composition of trace elements to characterize core-and-mantle formation
- Determine the age of returned rocks

Exploration Metrics
- Return samples of Venus rock soil and atmosphere for analysis on Earth
- Mission duration: TBD
- Time on surface: TBD (short lived)

Science Payload
- Camera and Descent imager
- Sample identification as needed
- Sample-acquisition system
- In-situ instrumentation

Technology & Heritage
- Extreme-environments technologies (pressure vessel, thermal management, corrosion)
- High-temperature electronics
- Sample acquisition and handling in Venus near-surface environment
- Multi-stage ascent air-mobility system to lift sample to launch altitude
- Rendezvous and sample-return systems inherited from Mars Sample Return
- Heritage from prior Venus missions: e.g., VISE, Venus Geophysical Network, VME

Mission & LV Class
- Flagship Class Mission
- Launch Vehicle: TBD

- Stirling duplex enables both power and cooling.
- Hot-end temperature of 850 °C has been demonstrated for 300 hours without failure.
- Cryocoolers have successfully operated in space since 1971 for thousands of hours at similar to Venus temperature ratios

VEXAG flagship class missions specifically suggest the use of a radioisotope power system with active cooling for **three out of the four concepts,** including Venus Surface Sample Return.

- Numerous studies over the past 15 years have indicated the need for duplex Stirling power/cooling on Venus.
- GRC and Industry partnered to develop flight convertors for the radioisotope generator and are primed to begin development for the Venus application.

Ref. VEXAG report

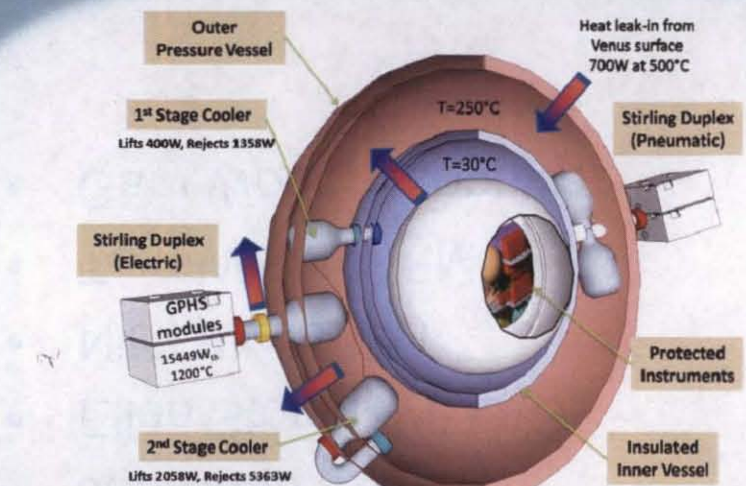
Remaining Technical Challenges

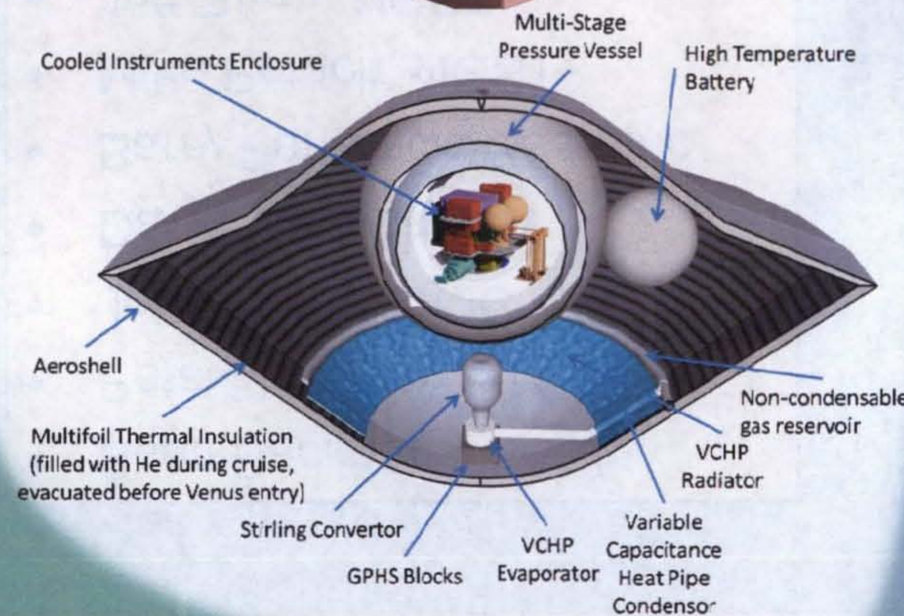
To combine a Stirling heat engine and refrigerator into a long-lived duplex machine with at least two cooling stages.

To achieve a high thermodynamic efficiency that will keep the GPHS module requirements manageable.

To create a complete system design with the multi-stage refrigerator integrated into the Venus platform.

To mitigate potential electromagnetic or mechanical vibration effects.





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NASA GLENN RESEARCH CENTER
OFFICIAL BULLETIN BOARD GUIDELINES

Custodian Duties: Custodians are required to post official bulletins in a timely manner. Custodians receive bulletins via GRC inter-lab mail service. Custodians are responsible for monitoring and displaying current and approved bulletins.

Official Bulletin Board System: The official bulletin board system is a resource used to display approved official bulletins only. Bulletin board sizes and types may vary. They are open air and glass enclosed. Though not required, some enclosed board types include a lock feature.

Official Bulletins: Bulletins are distributed under the A35 distribution list resource. Unique information generated from the A35 database is printed on each bulletin including the custodian's name (recorded as an e-mail address), their mail stop, the board location, and the assigned bulletin board number.

Bulletin Board Database: The mailroom personnel manage the official bulletin board data base. Please call 216-433-2251/2247 with any inquiries.

A35–GRC Official Bulletin Board List: The A35 listing is a GRC database that includes all information unique to the official bulletin board posting network. The mailroom staff controls and updates the A35 database. The mailroom is located in building 21 annex, room 8, and can be reached by phone at 216–433–2247/2251. The A35 listing is a shared resource used by the GRC print shop for distribution purposes only.

Custodian Change: In the event a new custodian is appointed please – contact the mailroom at extension 3–2247 or 3–2251 (GRC facility custodians). Off-center contact is possible by calling 216–433–2247 or 216–433–2251. Please have ready the following information at the time of your call:

1. Bulletin board number
2. Former custodian's name
3. New custodian's name
4. New custodian's phone number
5. New custodian's mail stop
6. New custodian's room number

Display Time of Official Postings:

Events: Remove the day after the event occurs.

Posters: Remove the day after the event occurs or display the poster for a period of 3 months and remove dated posters when available display space is in demand.

Safety infraction notices: These notices are posted by GRC Building Managers and are required to remain on display until the safety infraction is remedied. Contact your building manager with any questions or concerns.

Form NASA–570a: Display time is continuous.

Other postings: Custodian discretion is advised on all other postings. Please contact the mailroom for questionable matters of display time. The mailroom personnel are located in building 21 annex, room 8, and can be reached at 216–433–2247/2251.