



Novel Thermal Powered Technology for UUV Persistent Surveillance



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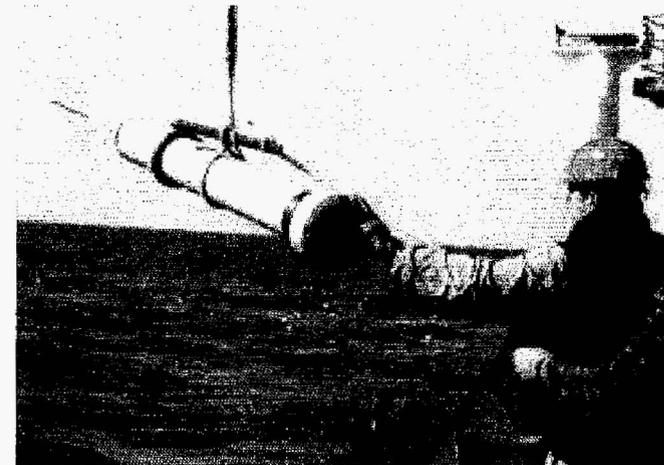
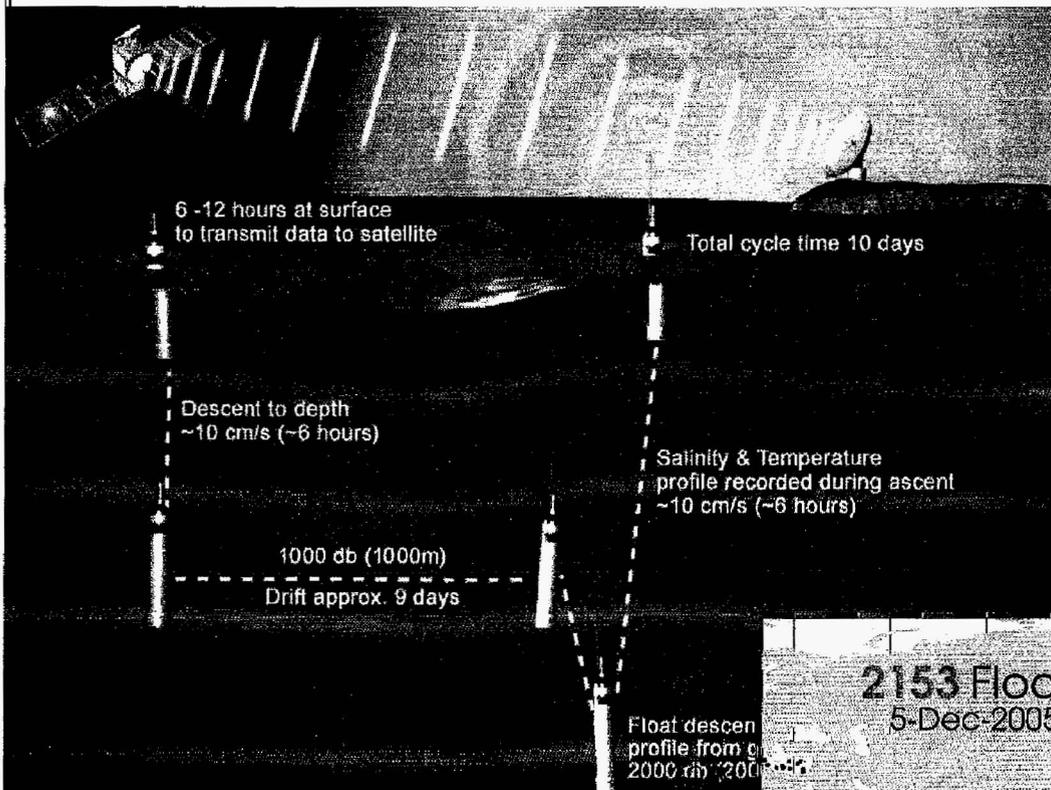
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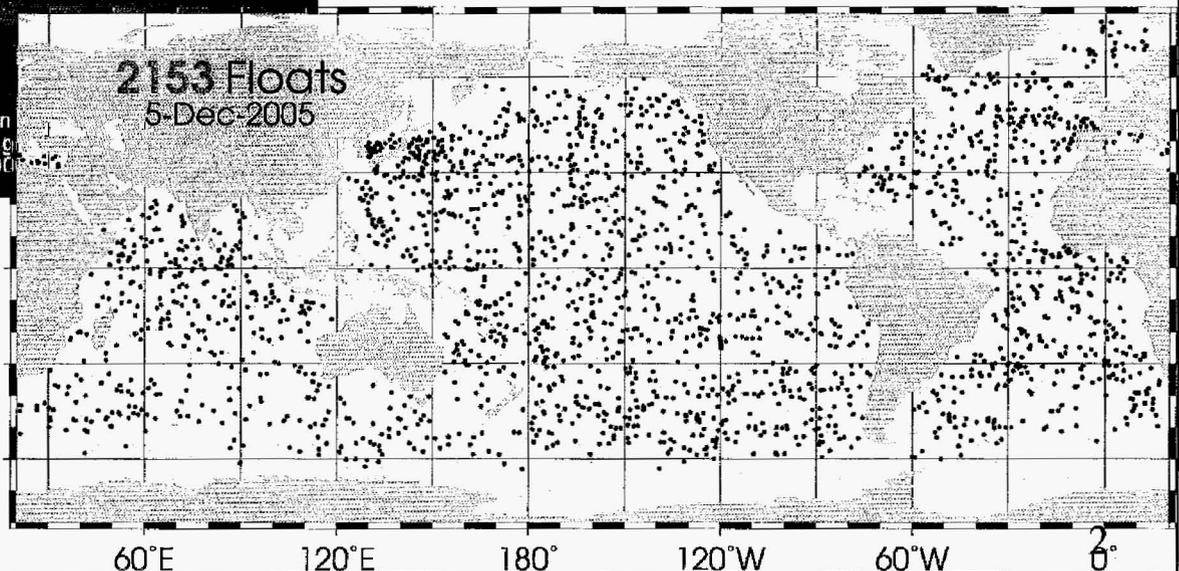


Long-Term Ocean Presence with UUVs: Large-Scale (1000s km)



Argo Floats:

- \$20,000
- Free-drifting
- 100 dives (10day, 3yr)



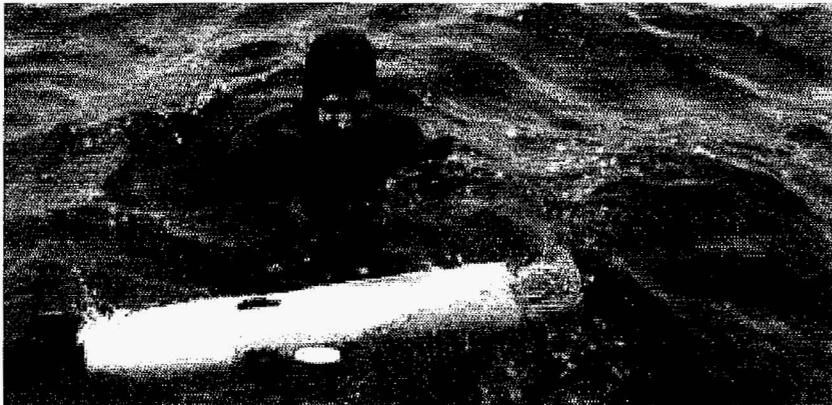


Long-Term Ocean Presence with UUVs and AUVs



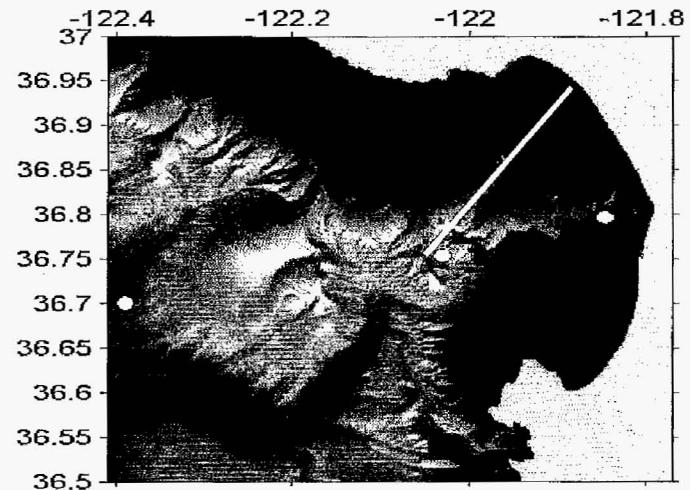
Gliders:

- ~ \$100,000
- 0.5~2 hour, 2~5 weeks
- 1 knot



Remus AUV:

- \$1M
- 1-day @ 5 knots





PHASE CHANGE THERMAL COMPRESSOR



There have been numerous attempts to harness the energy from temperature differences between the warm ocean surface and the colder ocean depths.

Buoyancy Generation: Various technology attempts include melting a wax, which pushes directly against a piston (U.S. Patent 5,291,847) or against a bladder (Webb Research), using ammonia or Freon 21 (U.S. Patent 5,303,552), and using solar heat to expand an oil (www.space.com, April, 10, 2002). All these heat-activated buoyancy control designs have thus far proved impractical and have ultimately failed during repeated cycling in ocean testing. JPL has demonstrated fully reversible 10°C encapsulated wax phase change, which can be used to change buoyancy without electrical hydraulic pumps. This technique has greatly improved heat transfer and much better reversibility than previous designs.

Power Generation: Ocean Thermal Energy Conversion (OTEC) systems have been designed that transfer deep, cold sea water to the surface to generate electricity using turbine cycles with ammonia or water as the working fluid. JPL has designed several UUV systems:

- Using a propeller water turbine to generate power on a gliding submersible
- Employing a compact CO₂ turbine cycle powered by moving through thermoclines
- Using melted wax to directly produce power through a piston-gear generator.



Novel Thermal Powered UUVs (Float/Glider/AUVs)

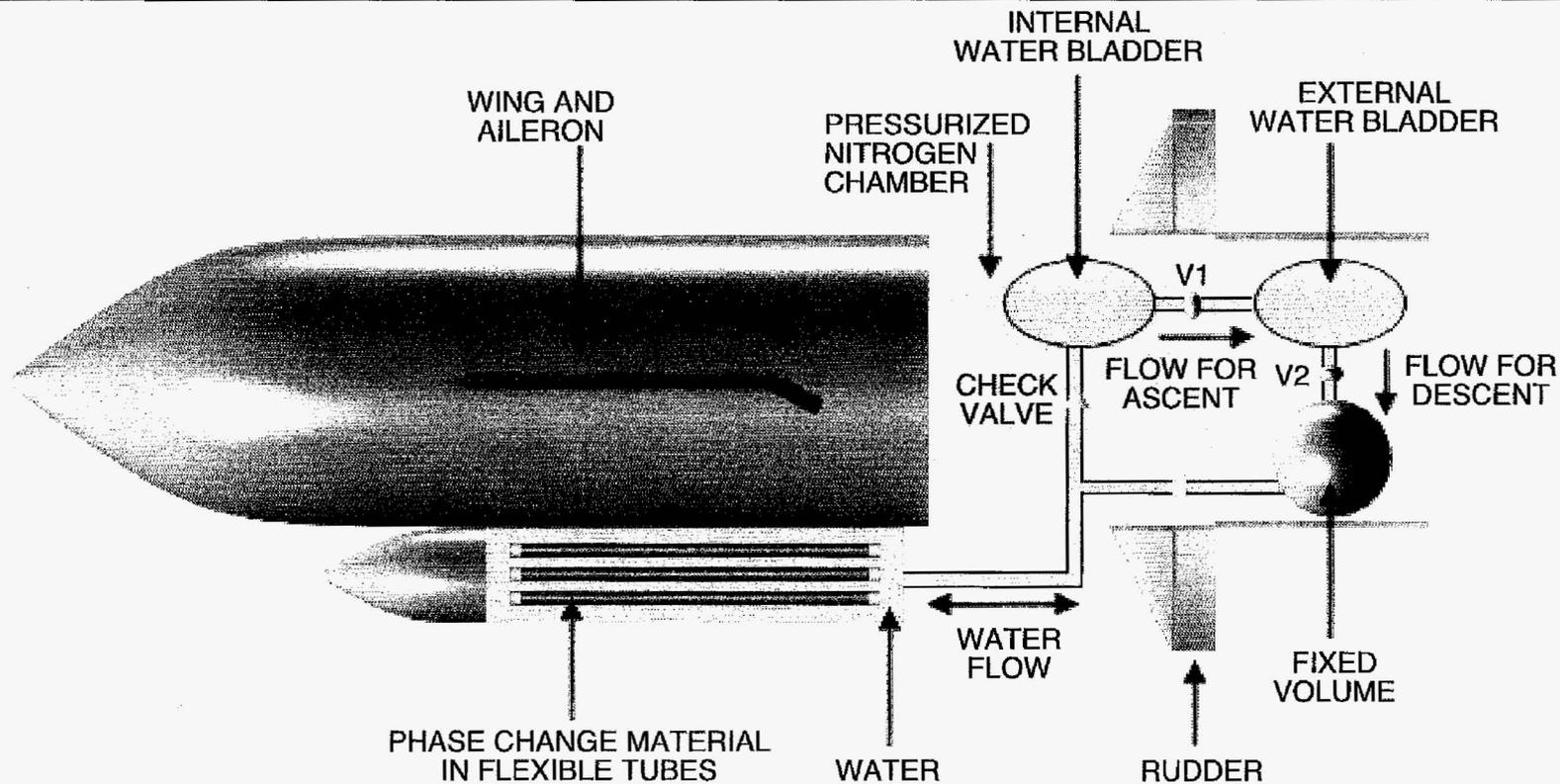
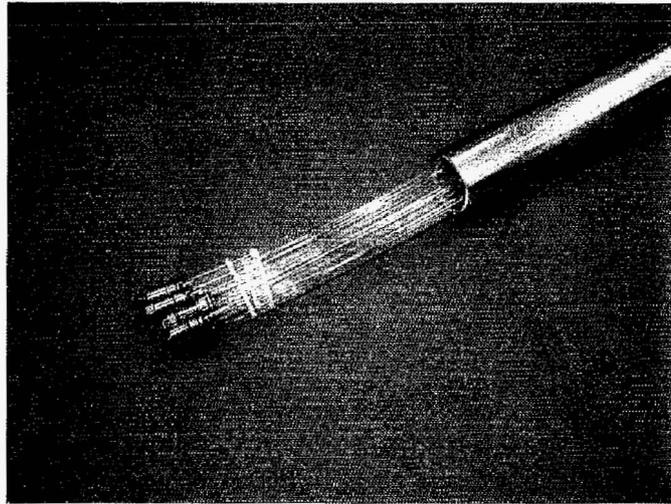


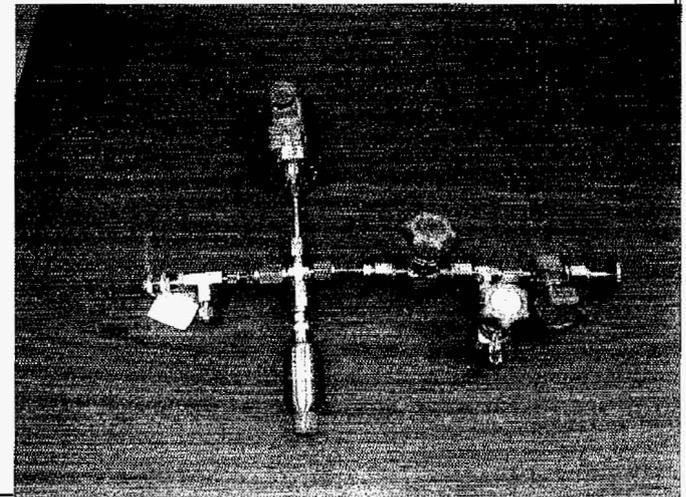
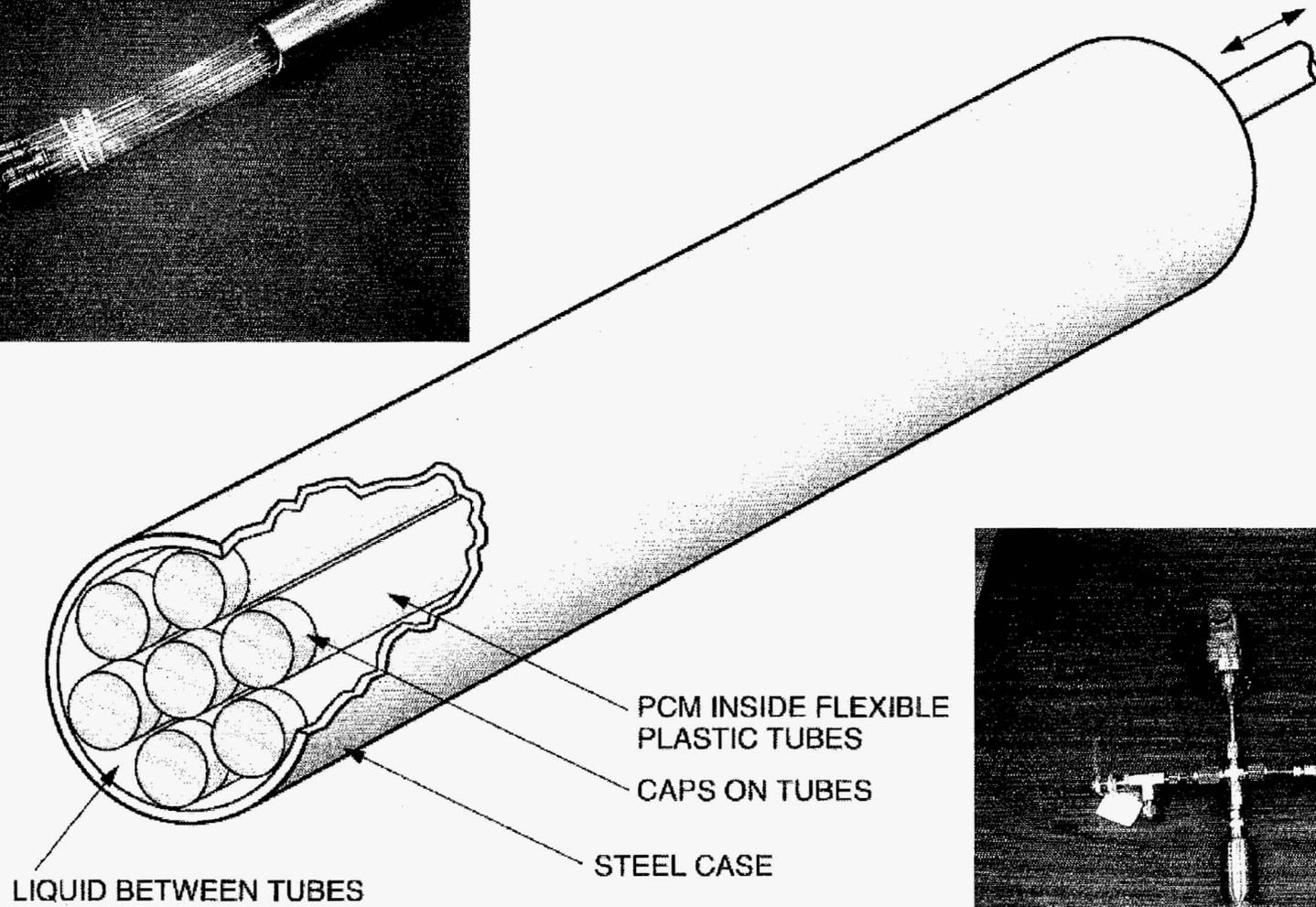
Figure. Ocean Buoyancy Operation: When the vessel ascends to warm water, the encapsulated phase change material (PCM) wax melts, expands, and fills an internal bladder with water. When descent is desired, opening valve V2 drains water from an external bladder, thus decreasing total displaced volume of the glider. Upon reaching colder depths, this water is pulled into the lower PCM canister when the wax freezes and contracts. When ascent is desired, valve V1 is opened, and the internal nitrogen pressure forces water from the internal bladder to the external bladder, thus completing the cycle.



PHASE CHANGE THERMAL COMPRESSOR: Design



LIQUID FLOW RESULTING
FROM PCM FREEZE/THAW
VOLUME CHANGES



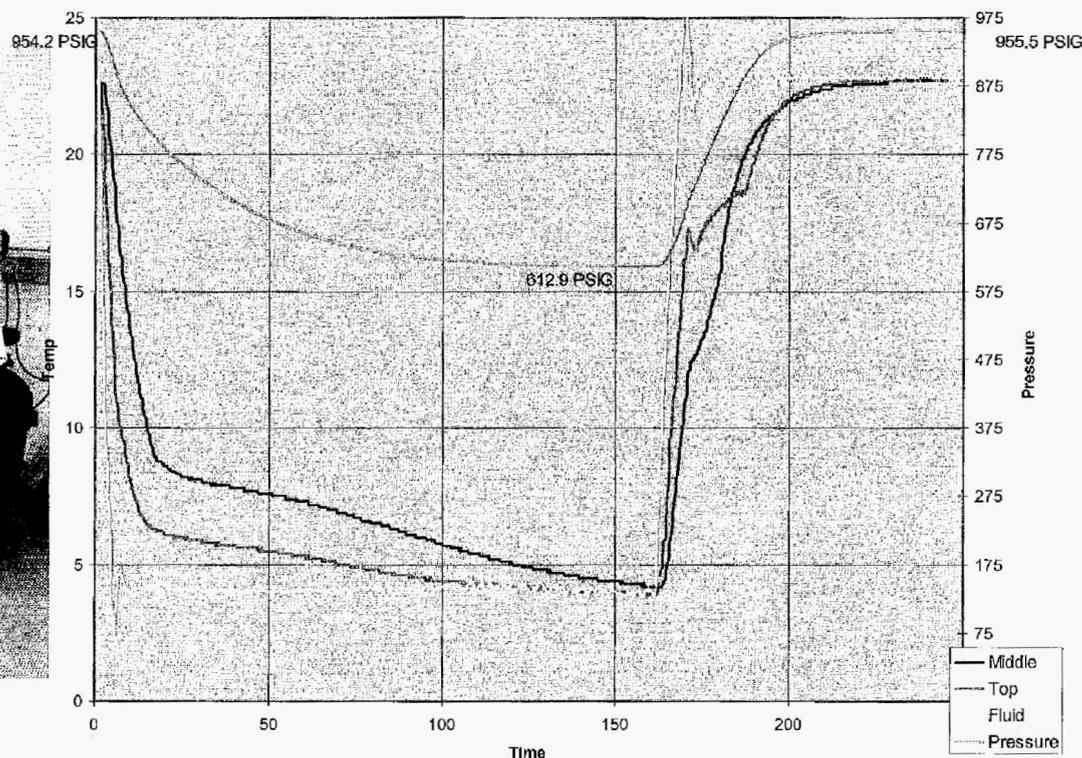
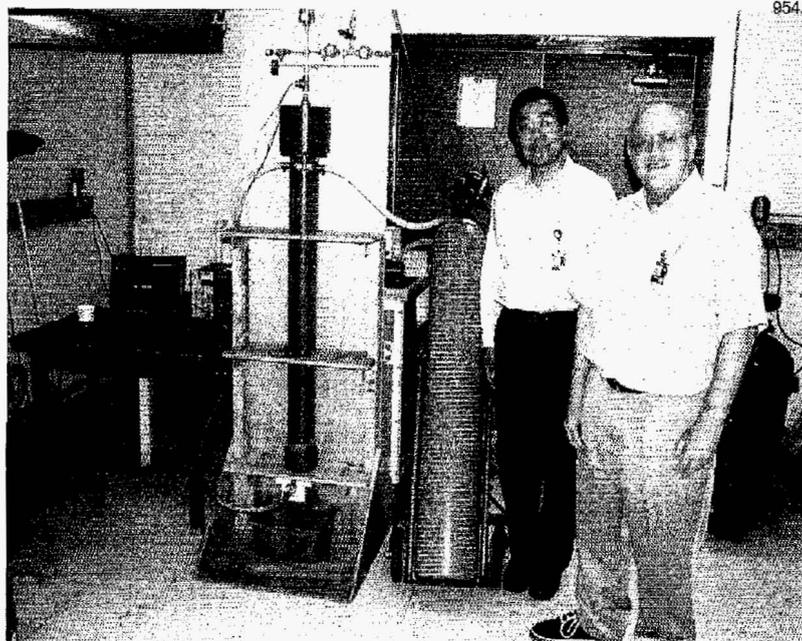


PHASE CHANGE THERMAL COMPRESSOR: Laboratory Testing and Preliminary Results



The PCM Compressor shows relatively fast response times with about 7% phase change volume.

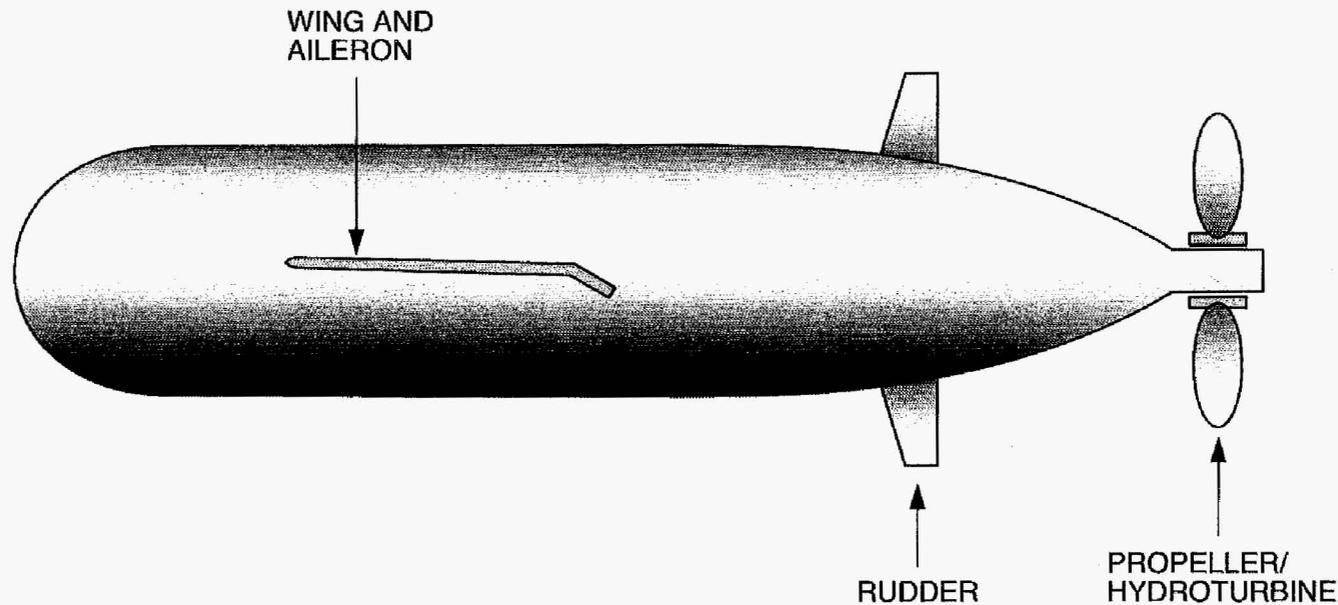
Phase Change Thermal Compressor



A pressure vessel is heated by a liquid coolant annular flow. The encapsulated phase change material (PCM) then melts and generates a pressure of 70 bars (or higher) in the constant volume vapor space above the pressure vessel. Cooling the PCM then causes the phase change material to freeze with resulting lowering of the pressure. This pressure shift can be used to generate power or to change buoyancy of a submersible vessel.



SUBMERSIBLE POWER GENERATION WITH A PROPELLER HYDROTURBINE

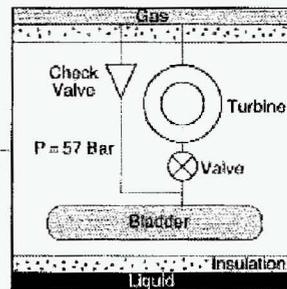


Hybrid glider design with three modes of operations:

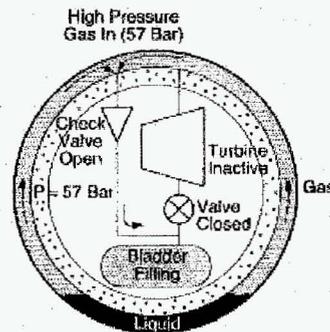
- Neutral mode (i.e., float drifting with current)
- Power generation & battery recharging mode (i.e., glider moving @ 1 knot)
- Powered-up propelled mode (i.e., AUVs moving @ 5 knots)



SUBMERSIBLE POWER GENERATION WITH CO₂ TURBINE POWER CYCLE

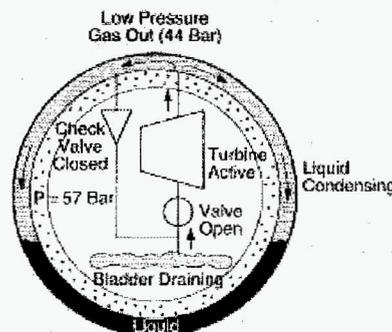


SIDE VIEW



FRONT VIEW AT SEA LEVEL

In these upper submersible section views, liquid CO₂ is boiled in the warmer surface ocean water, and the vapor is stored in a pressurized bladder.

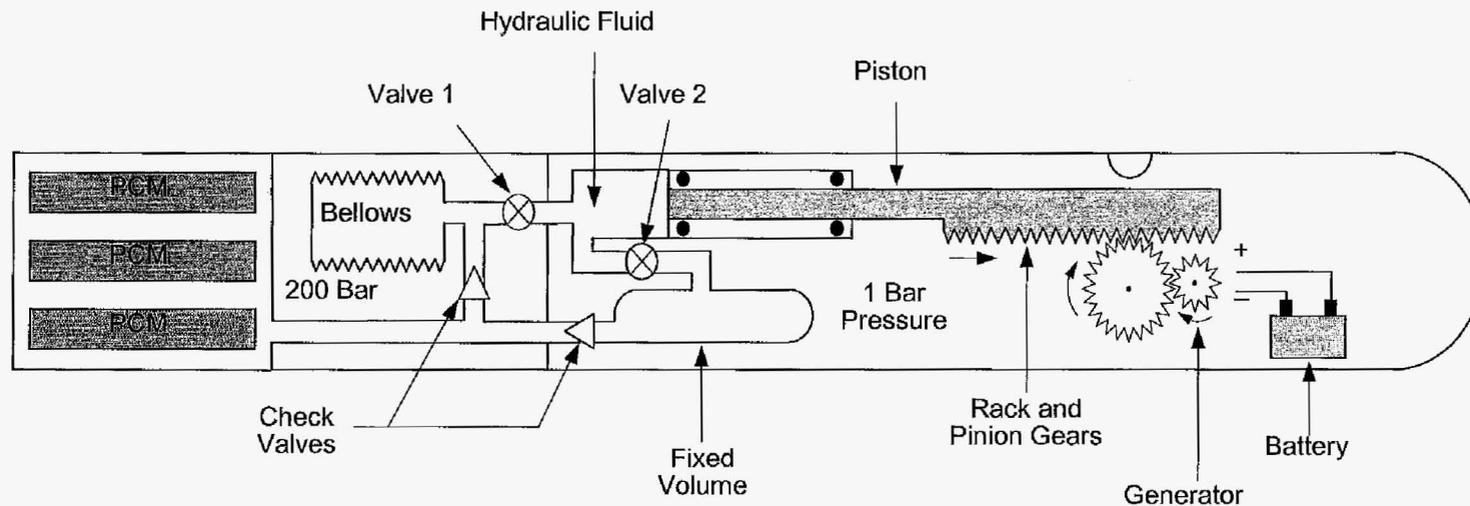


FRONT VIEW AT DEPTH

In this lower view in colder water, the high pressure gas that was stored in the bladder is allowed to flow through a turbine, generating power, and is then condensed at lower pressure on the outside surface of the submersible.



Small Temperature Changes Generate Power With a PCM Piston-Powered Generator



- In this sketch, the PCM tubes (green) are submerged in hydraulic fluid (yellow). When heated above 10°C , the PCM melts (expands) and pushes hydraulic fluid into a bellows, which is inside a pressurized chamber (~ 200 bar).
- Valve #1 is opened to a piston chamber, and allows the hydraulic fluid to push a rack and pinion gear system. The gears spin a generator, which charges a battery.
- Valve #2 is then opened, which allows the fluid to drain to a fixed volume container.
- The PCM is then cooled below 10°C , which causes freezing and shrinking, and the hydraulic fluid is pulled back into the left chamber, thus completing the circuit.



SUMMARY AND CONCLUSIONS



- As a lead NASA center for satellite oceanography, JPL has strong interests in developing submersible in situ technology.
- We have demonstrated that phase change materials (PCMs) can be used to control the buoyancy of submersibles. Unlike previous attempts at submersible PCM buoyancy control, JPL's system is fully reversible and is not subject to "frozen pipe failure syndrome", since the PCM canisters are inside flexible tubes.
- JPL has also designed a number of energy generation systems for submersibles:
 1. Using a propeller water turbine to generate power on gliding submersibles
 2. Employing a compact CO₂ turbine cycle powered by moving through thermoclines
 3. Using melted wax to directly produce power through a piston-gear generator.
- We are interested in applying these technologies to several areas:
 1. Demonstrating our PCM buoyancy technology on an existing floater UUV
 2. Demonstrating a PCM-powered piston power generator
 3. Demonstrating both our PCM buoyancy technology and our PCM power generation system on an existing glider UUV