D.O.E.

High efficiency Thermoelectrics

A novel thermoelectrically driven engine for air and ground vehicles

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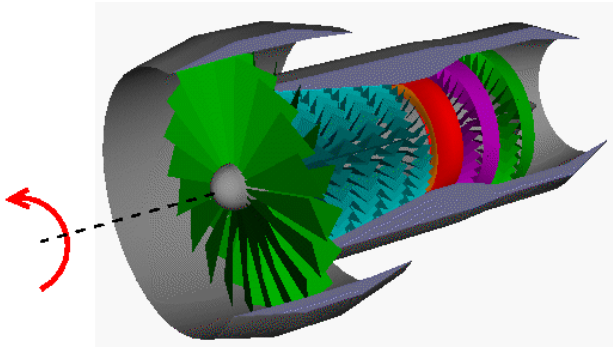
San Diego 2004

Engines use macroscopic motion of components



Power is lost due to friction, slippage and heat

↓

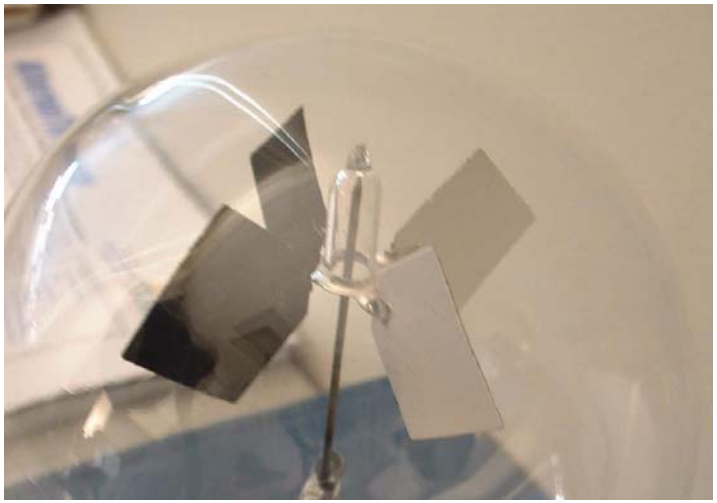
High power demand

↓

Combustion is necessary

→ **Noise** → **Emissions**

Crookes Radiometer: a no-moving-parts engine



Black surface is hot

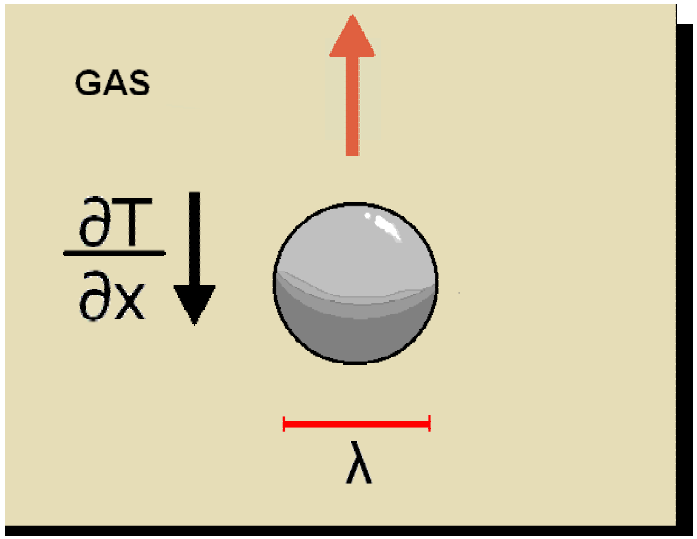
White surface is cold

$\Delta T \approx 0.1$ K

Thrust is generated by unequal bombardment of gas molecules

Force $\approx 10^{-6}$ N

RADIOMETRIC FORCES

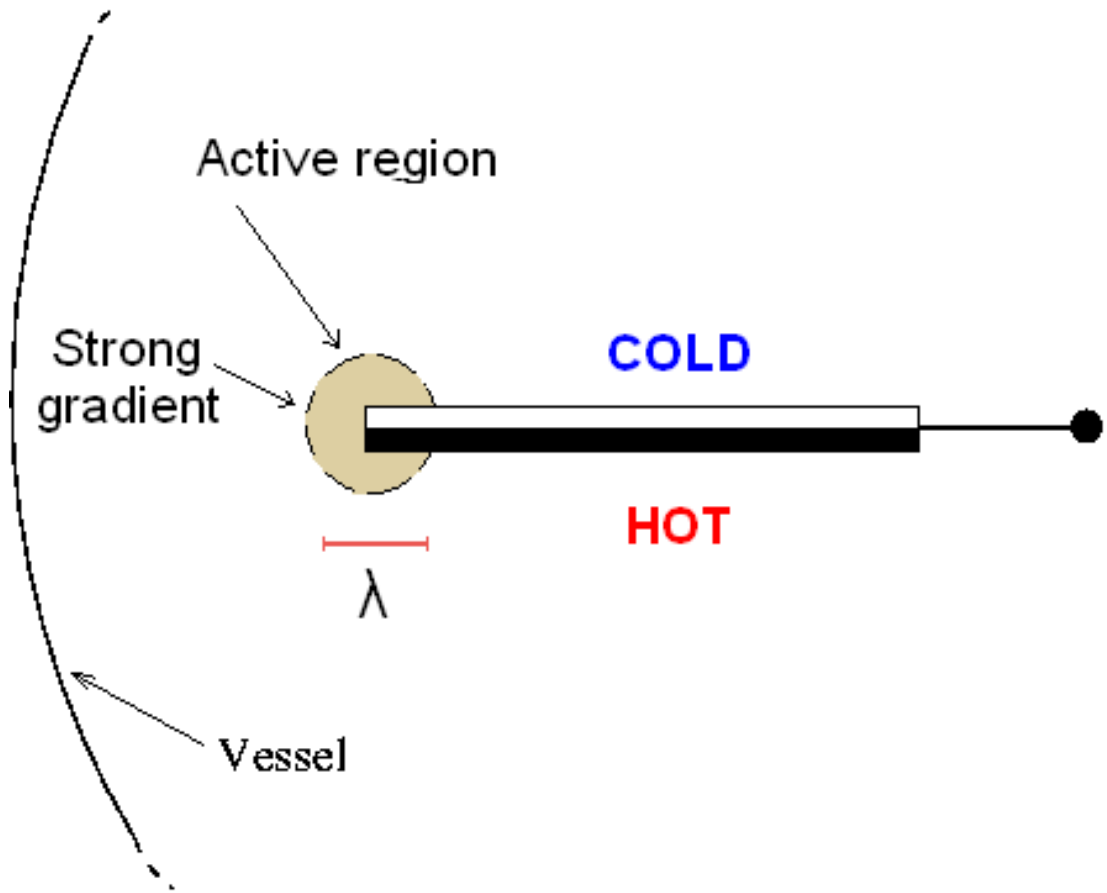


1. **Forces arise in presence of a T- gradient .**
2. **Forces act on small bodies ≈ λ**
3. **Forces point the cold side**

$\lambda = 1 / (n \pi \sqrt{2} \sigma^2)$; **n= gas density ; σ =molecule diameter**

- For a large body only a portion ≈ λ is active
- In air at atmospheric pressure λ=70nm

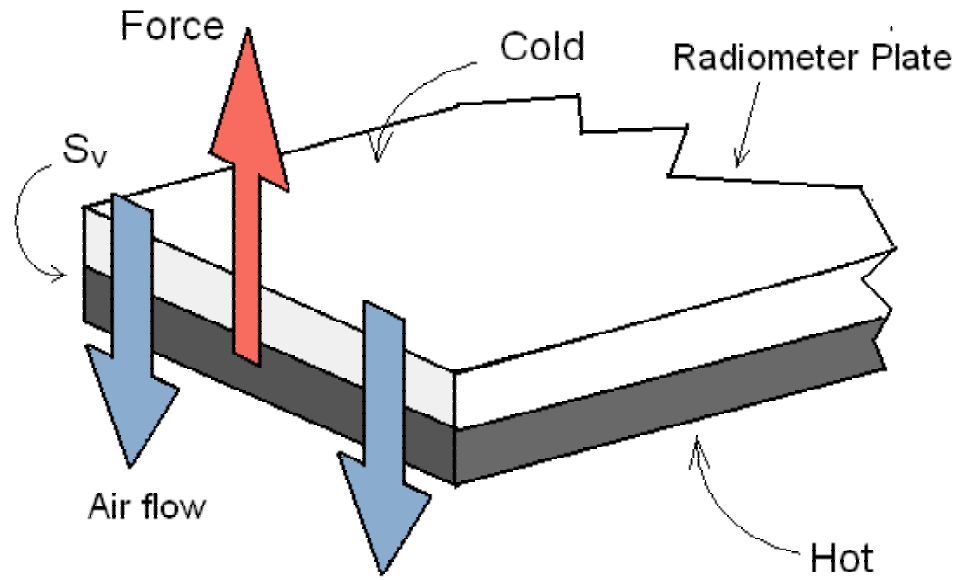
Inside Crookes Radiometer



MECHANISM OF ACTION

Creep Effect:

- Air flows along plate edge
- Reaction Force toward cold side



- **Creep force depends on edge surface S_v**

$$F_{creep} = -\frac{3}{4\sqrt{2}\pi^2}\frac{k}{\sigma^2}\frac{\Delta T}{L}S_v$$

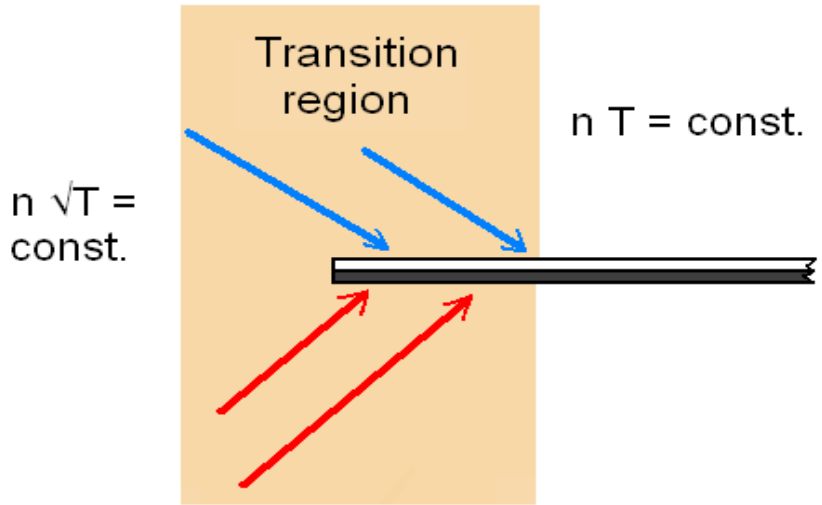
L = thickness

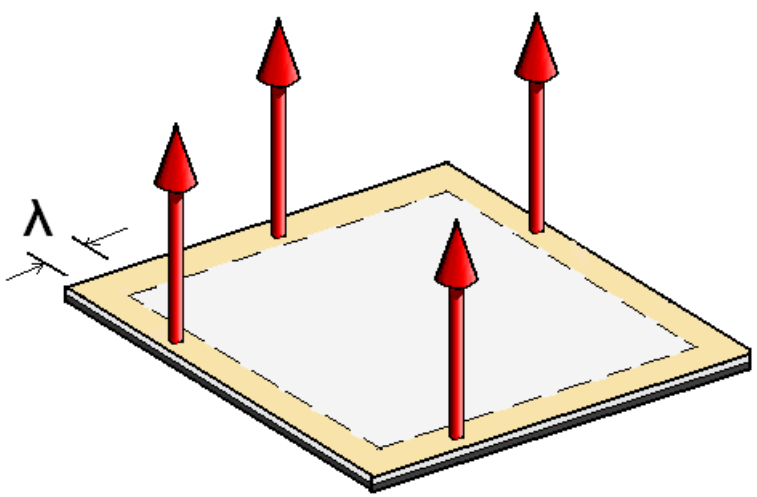
MECHANISM OF ACTION

Einstein Effect:

- Constant pressure does not hold near edge

- Tiny strip ≈ **λ** along perimeter suffers force





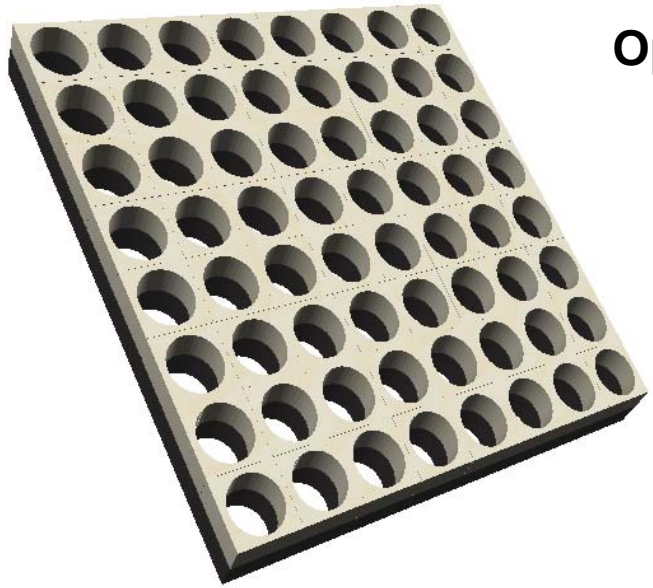
Einstein Force depends on perimeter ℓ

$$F_E = n\,k\,\Delta T \lambda\,\ell$$

Plate thickness ⟶ λ

ENHANCING RADIOMETRIC FORCES

- Forces depend on perimeter, not on area
  - increase perimeter to enhance forces

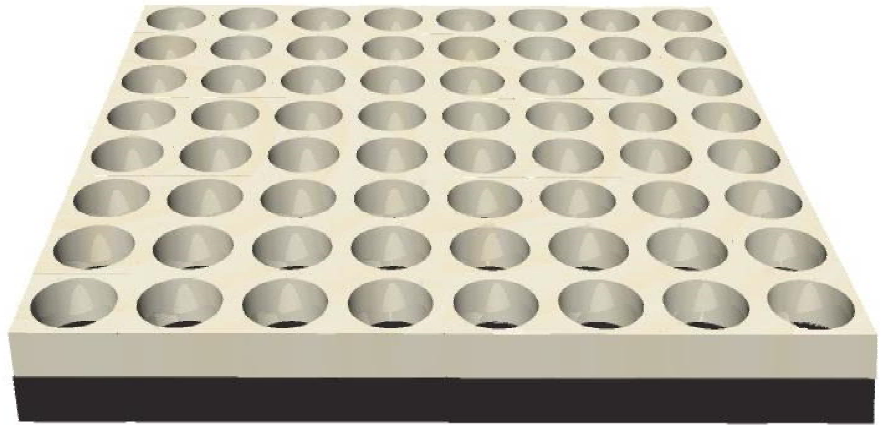


Open area 50%

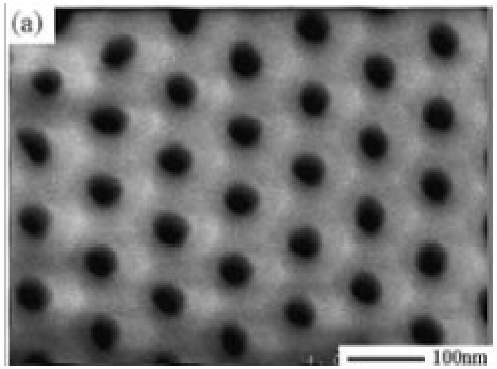
λ

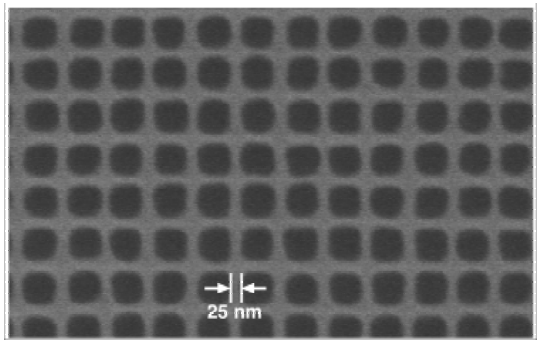
OPERATION AT ATMOSPHERIC PRESSURE

Shrink the scale of the device → λ = 70 nm

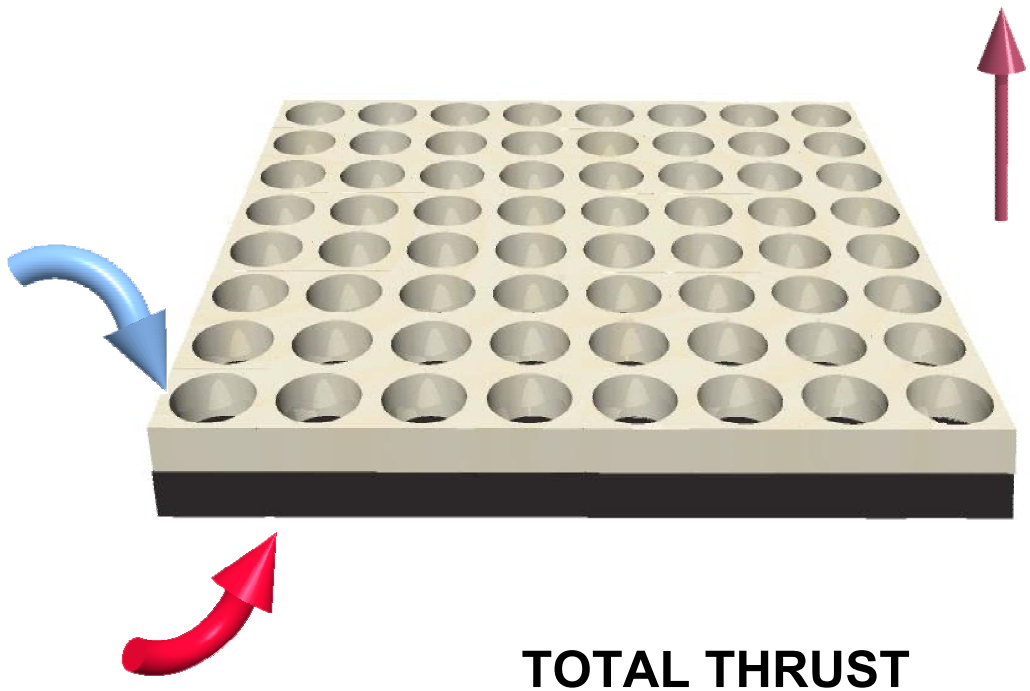


- **Plate side can be macroscopic**





USING RADIOMETRIC FORCES FOR PROPULSION



TOTAL THRUST

$$F = \left(\frac{1}{2} + \frac{3}{4\pi}\frac{\lambda}{R}\right) n\, k\, \Delta T$$

R=channel radius

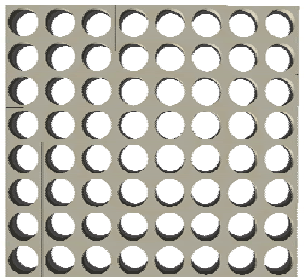
= 340 N/m² /K

- **Large enough for vehicle propulsion**

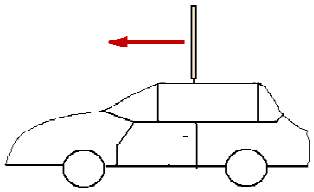
USING RADIOMETRIC FORCES FOR PROPULSION

TOTAL THRUST

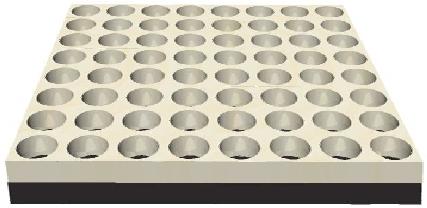
Want 1000 N/m^2 $\longrightarrow$ $\Delta T = 2.9$ K



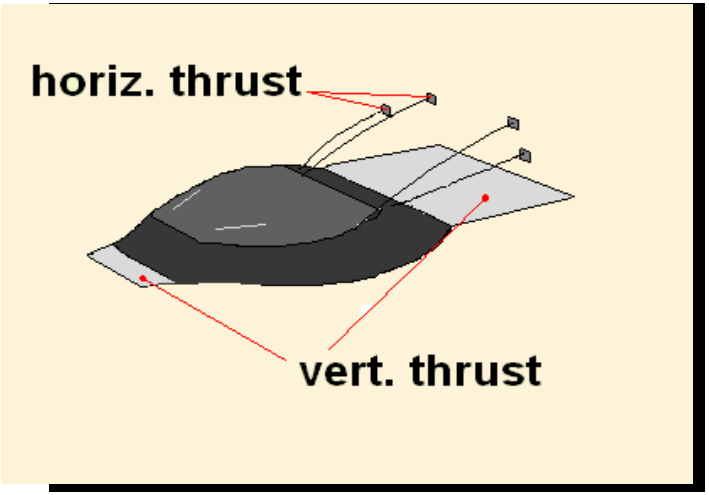
$F = 340\ N / m^2 / K$



Vertical plate gives translatory thrust



Horizontal Plate gives levitational force



Absolute temperature is irrelevant

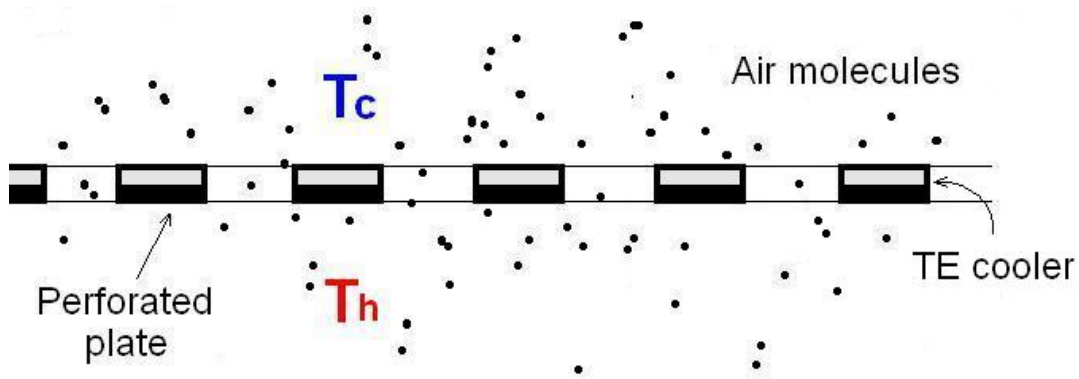
Only Δ**T** appears in master equation

ADVANTAGES OF RADIOMETRIC PROPULSION

- **No moving parts**
- **Only ≈ 1 K above room temperature**
- **No operational noise**
- **Power efficient (stay tuned for more)**

MAINTENANCE OF THE ΔT

Want a zero emission device: use a TE heat pump



At **λ**-scale heat is transported ballistically

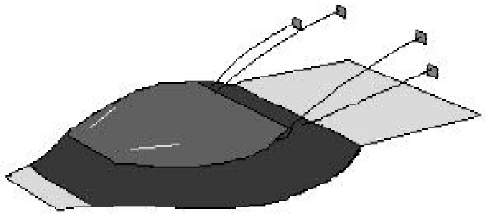
$$W_{air} = \frac{3}{2}\, p \sqrt{\frac{k}{2\pi m}}\, \left(\sqrt{T_h} - \sqrt{T_c}\right)\, A$$

p= atm. pressure;
A=plate area;
m=molecule mass

(W_{air} must be pumped by TE cooler)

Power consumption = W_{air} (COP – 1)$^{-1}$

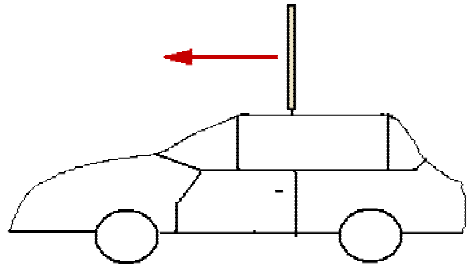
A RADIOMETRIC ARICRAFT



- **Need to lift an aircraft weighing 1000 Kg**
- **Use a 10 m^2 radiometric plate with ΔT=3K,**
- **W_{air}=430 k W**
- **Use Sb_2Te_3/Bi_2Te_3 superlattice microcoolers**
- **COP= 29.3 (ZT=2.4, *Venkatasubramanian)***
- **W=15kW**

Conventional helicopter consumes: 1MW

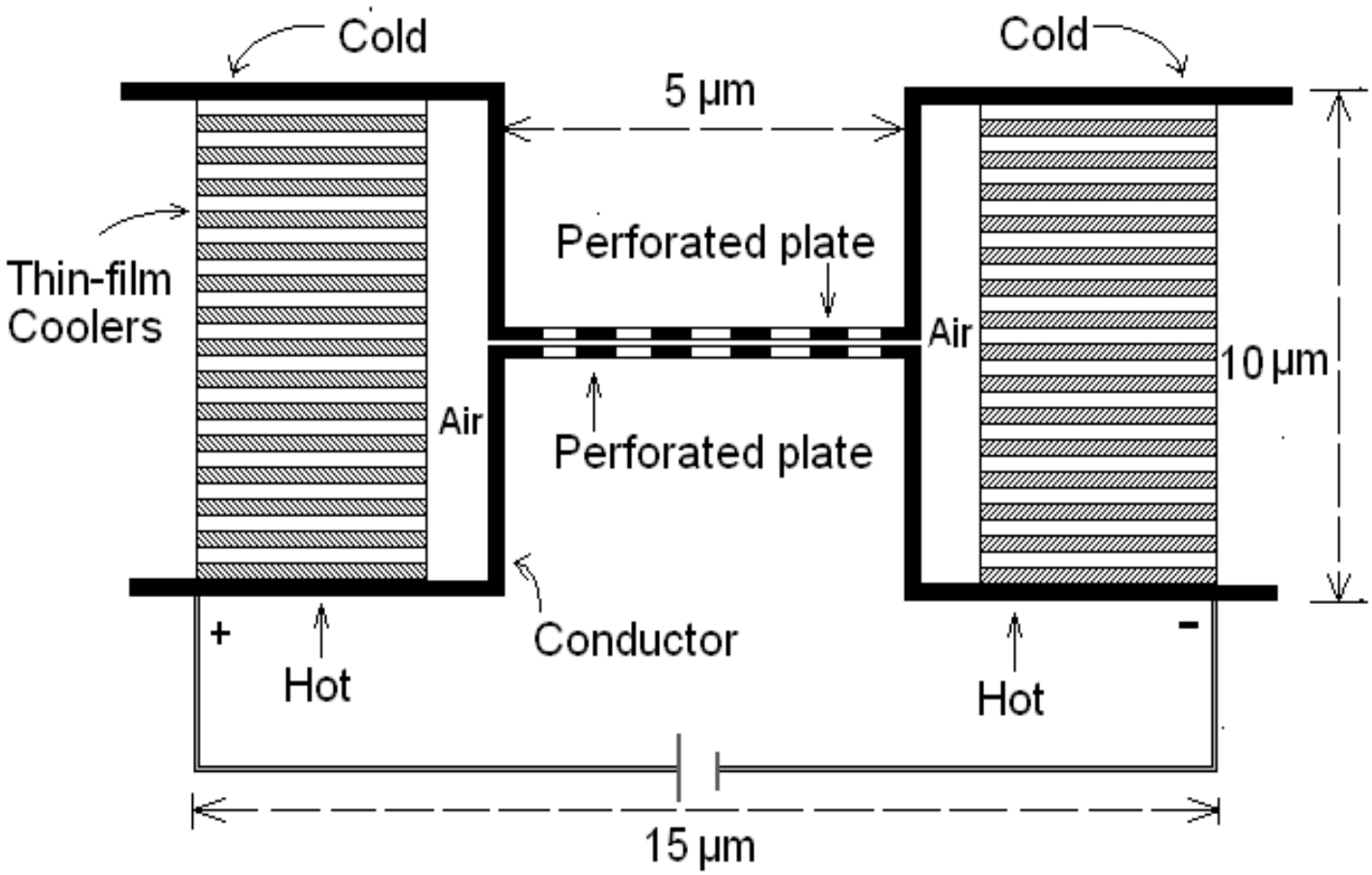
A RADIOMETRIC AUTOMOBILE



- **Need ≈ 4000 N thrust**
- **Use a 1 m^2 radiometric plate with ΔT=3K,**
- **W_{air}=172 k W**
- **Use Sb_2Te_3/Bi_2Te_3 superlattice microcoolers**
- **COP= 29.3 (ZT=2.4, *Venkatasubramanian)***
- **W=6kW**

Conventional car consumes: 50kW

DEVICE SPECIFICATION



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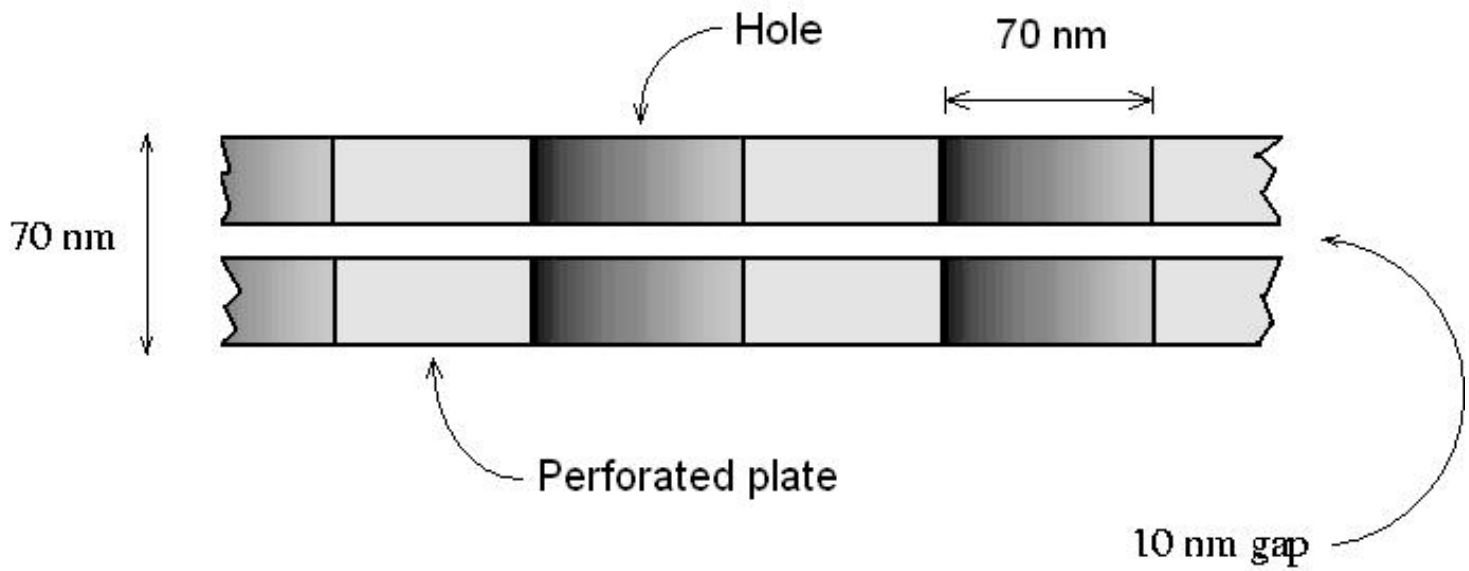
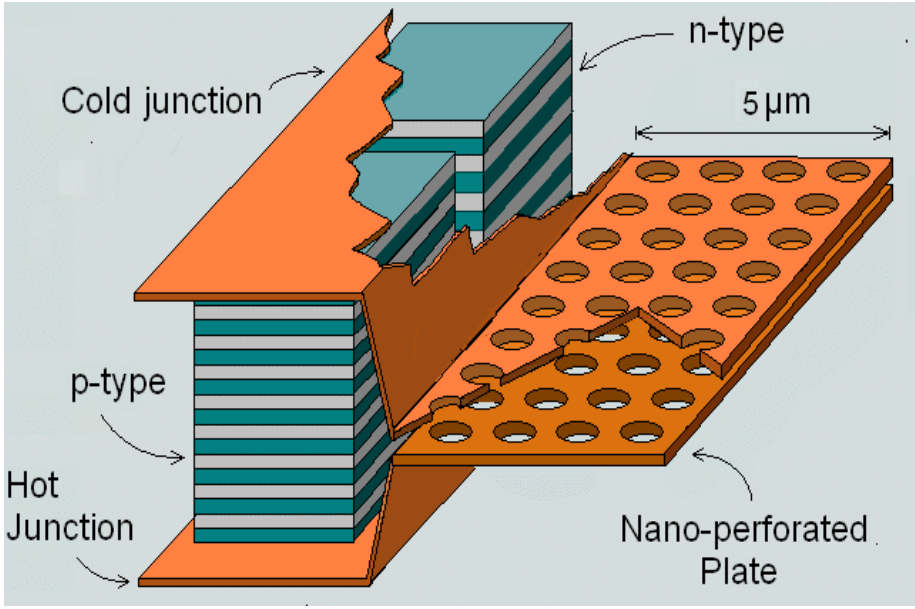
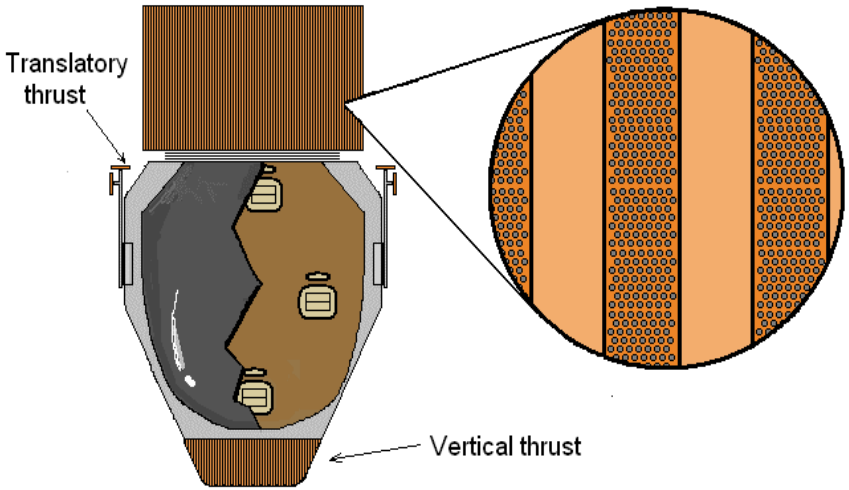


Thermal insulation of hot and cold regions

DEVICE SPECIFICATION





Engine's thrust/weight ratio ≈ 1000

Lightest engine ever made!

CONCLUSIONS

- The Radiometric propulsion system powered by TE coolers is a safer, quieter and more ecological way of providing thrust to vehicles
- It is a propulsion system without combustion.
- Without dangerous moving blades or wheels
- Operating at room temperature.