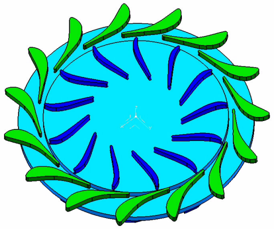
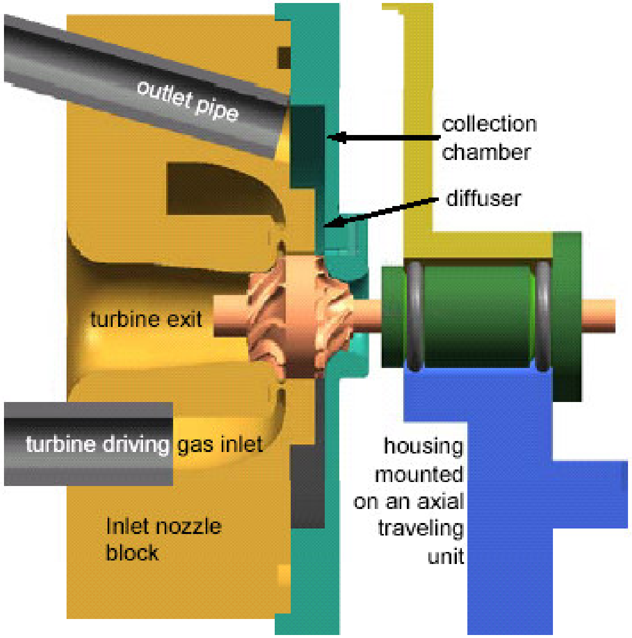
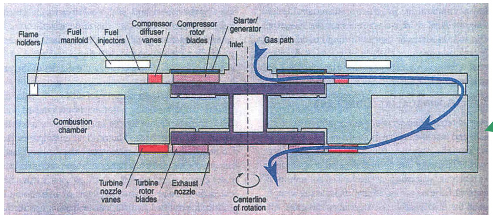


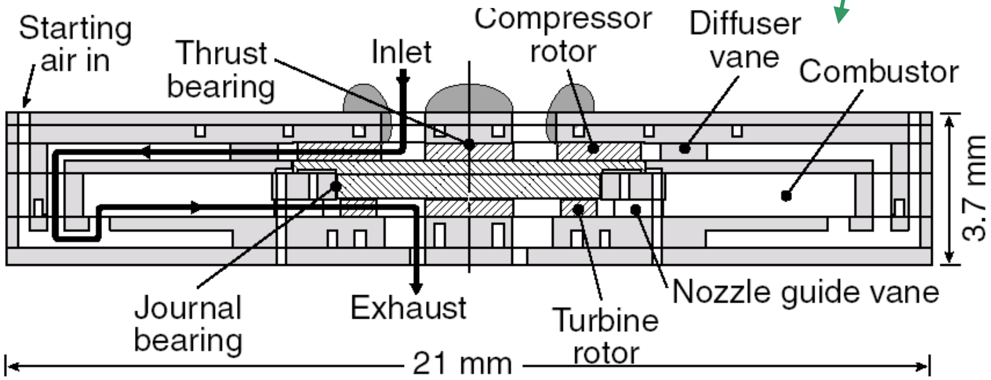
OVERALL THERMODYNAMIC MODEL OF AN ULTRA MICROTURBINE

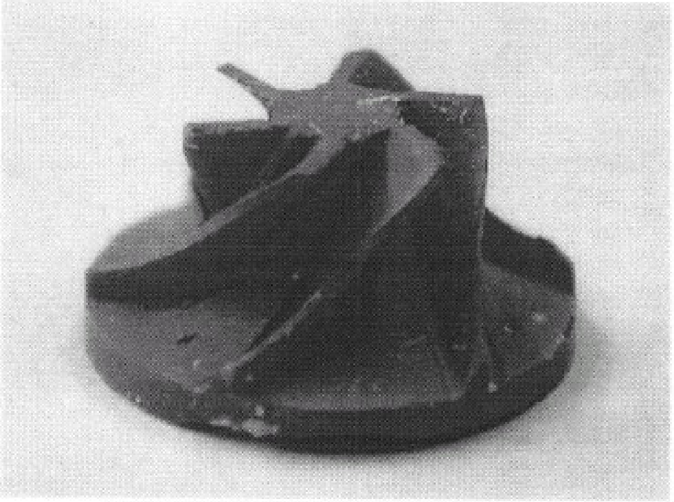
- µturbine description
- separation between aero and heat losses
- « hot button » energetic model
- main results
- future research directions





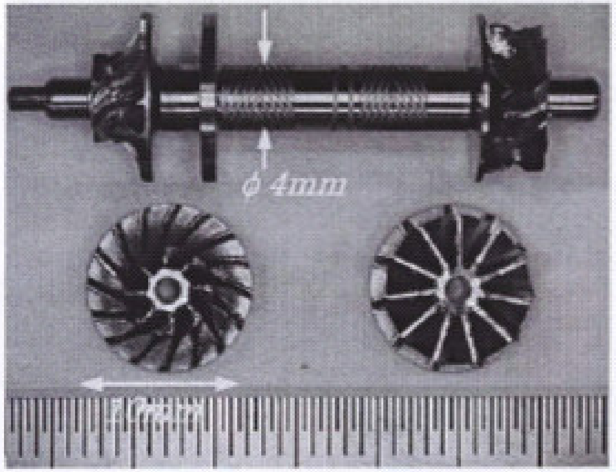
MIT





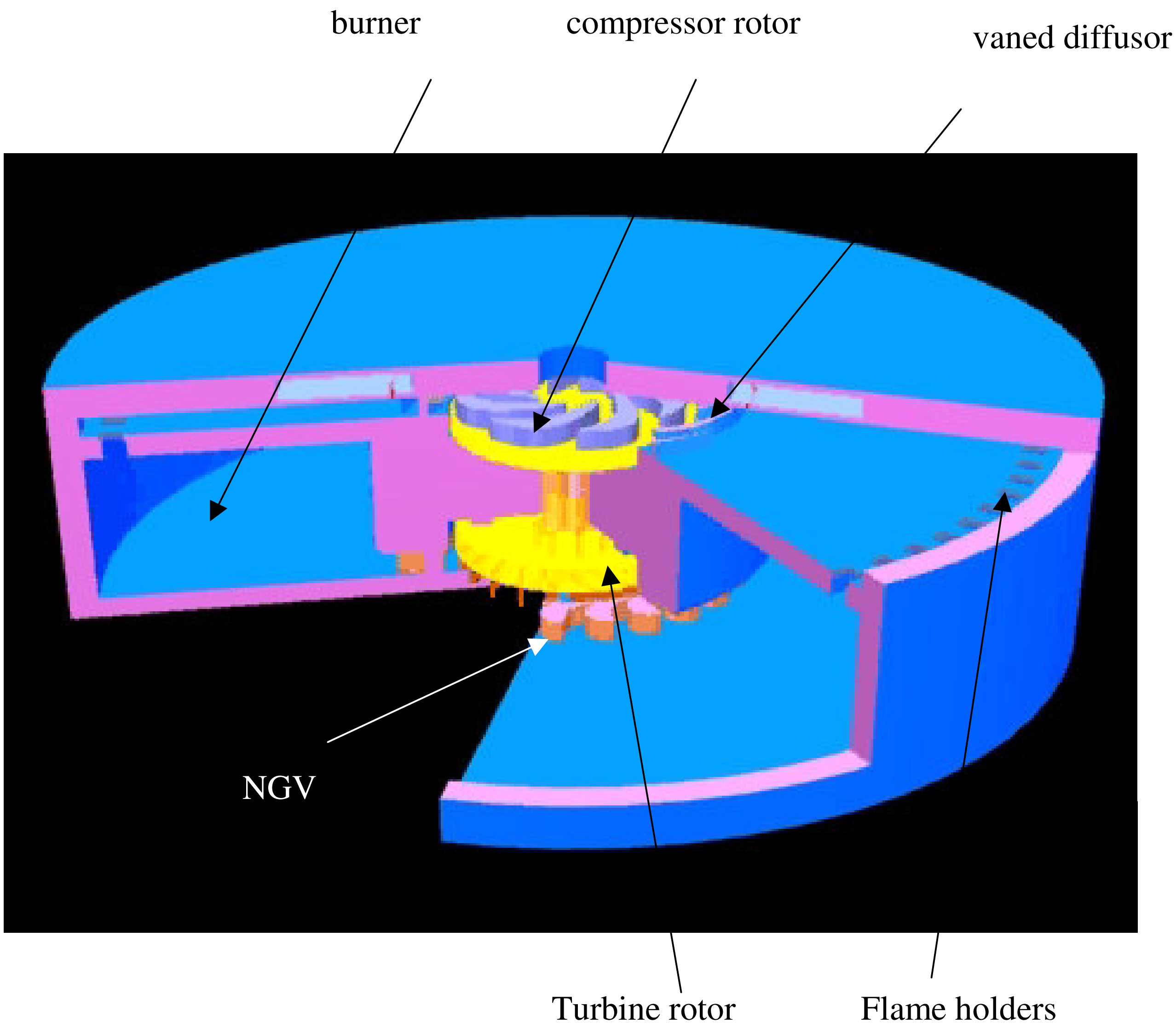
3-dimensional Si_3N_4 micro-turbine rotor with a diameter of 9 mm

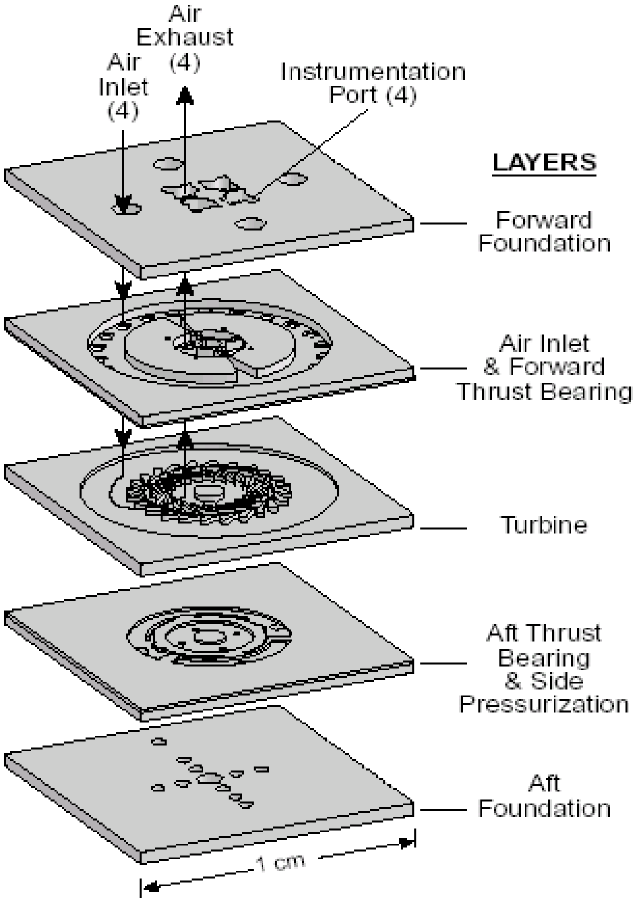
Stanford University



Cross sectional photo of rotor

IHI, Sendaï, University





MIT first model

1cm × 3mm, 3 gr

Power : 10 - 50 W, 7 gr/h fuel

M air = 0.1g/s

N = 2.4 10^6 rpm

Tit = 1600 K

Π ~ 3, pressure ratio

« Hot button » thermodynamic model

- In tiny engines ⇑ heat transfer by internal forced convection, conduction in the material, radiation, external free convection.
- The compressor becomes a heat exchanger/compressor
- The turbine becomes a heat exchanger /turbine
- convection internal heat transfer :
- to compare with mechanical power

$$\frac{\alpha_{(Re)}*(Tw - Tg)* S_{heat}}{\rho.S_{inlet}V.\Delta H_i}$$

- α ⇑ for low Re, (Tw - Tg) important, S too important , Ns non optimal.
- With SiC, the Biot number , of the order of 0.1 : $Bi = \alpha\ L/\lambda_w$

Aerodynamic polytropic efficiency

Compressor case

$Q = 0$ aerodynamic losses : $dP_{comp}.(1-\eta_p) = \delta f^+$

$Q \neq 0$

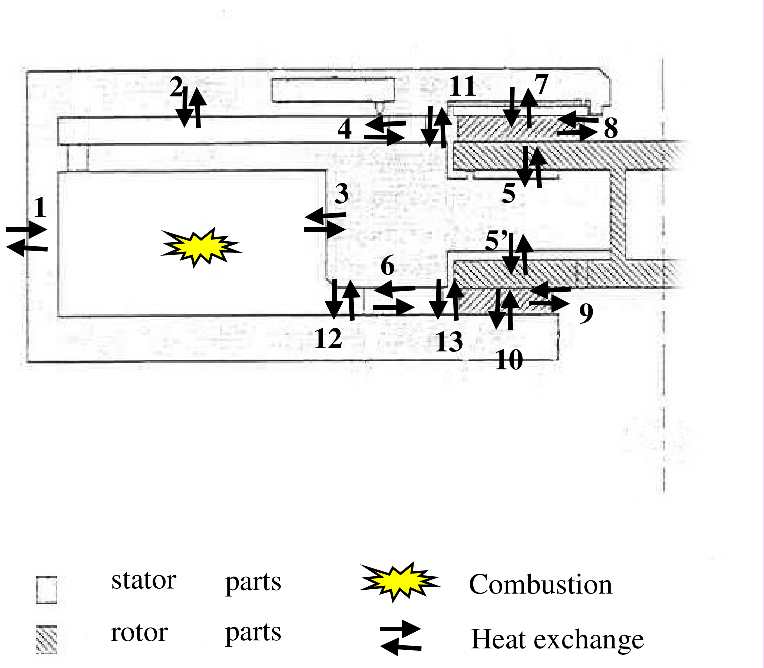
η_p by definition is the aerodynamic polytropic efficiency

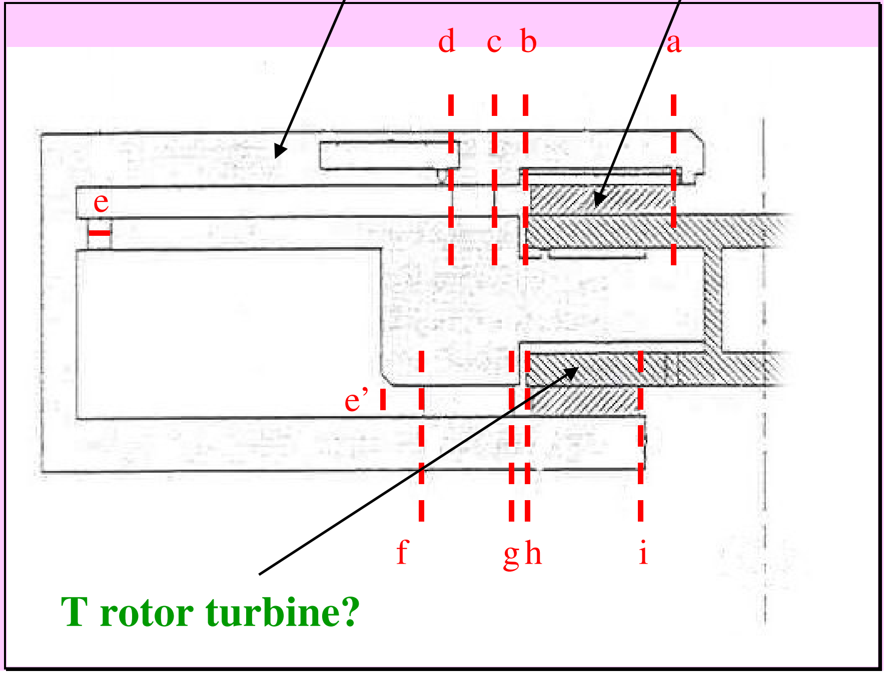
heat transfer calibration : $\lambda = Q\ /\ P_{comp}$

$$\frac{Ti_2}{Ti_1} = \left(\frac{Pi_2}{Pi_1}\right)^{\left(\frac{\gamma - 1}{\gamma.\eta_{pol}}\right)} \quad \Rightarrow \quad \frac{Ti_2}{Ti_1} = \left(\frac{Pi_2}{Pi_1}\right)^{\left(\frac{\gamma - 1}{\gamma.\eta_{pol}(1+\lambda)}\right)}$$

Heat transfer scheme and main calculation sections

- Balance in the stator
- Balance in the rotor(s), option : conduction in the shaft
- Conservation equations in the fluid volumes :
    - in the compressor rotor
    - in the vaneless diffusor
    - in the vaned diffusor
    - in the premixing region
    - in the burner
    - upstram the NGV
    - in the NGV
    - in the vaneless space between the NGV and the turbine rotor
    - in the turbine rotor
    - in the rotor/stator cavities





AERO and THERMODYNAMIC CALCULATIONS

Input :

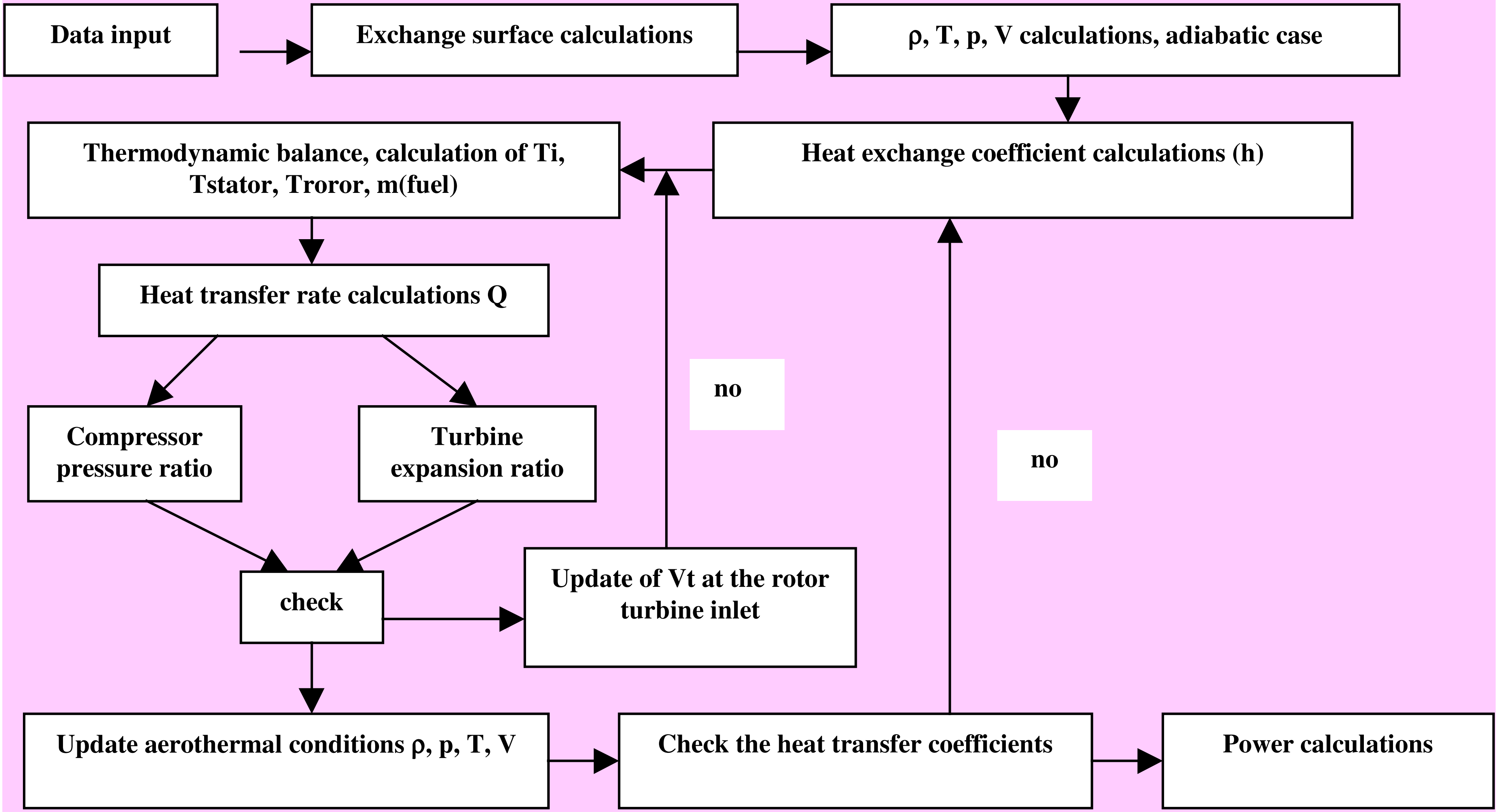
- air mass flow rate m_{air},
- angular speed ω,
- aerodynamic polytropic efficiencies:

$$\eta_{pc} * \eta_{pt} = 0.42$$

- compressor rotor work factor $\mu' \sim 0.8 = v_{tb} / \omega r_b$
- T max. in the combustion chamber
- $T_{combustor} = T_{e'} \sim 1600K$ for SiC.
- Microturbine geometry.
- Type of fuel : H_2, kerosene, methane, propane

Thermodynamic model

and organigram



Data input

Exchange surface calculations

ρ, T, p, V calculations, adiabatic case

Heat exchange coefficient calculations (h)

Thermodynamic balance, calculation of Ti, Tstator, Troror, m(fuel)

Heat transfer rate calculations Q

Compressor pressure ratio

Turbine expansion ratio

check

Update of Vt at the rotor turbine inlet

no

no

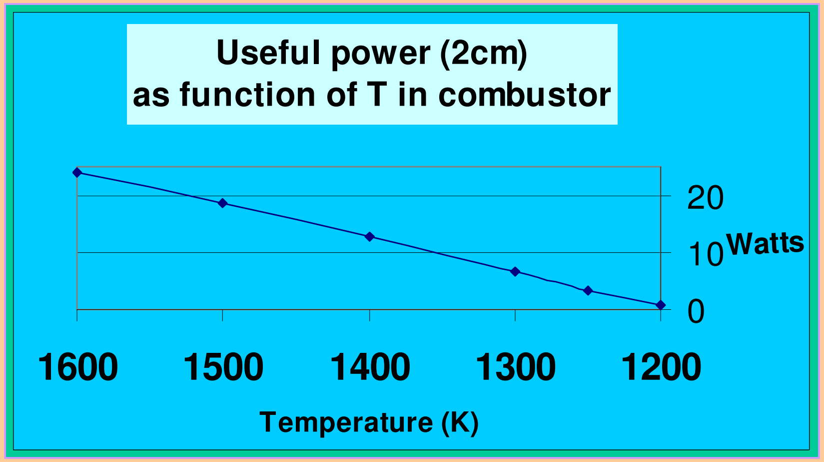
Update aerothermal conditions ρ, p, T, V

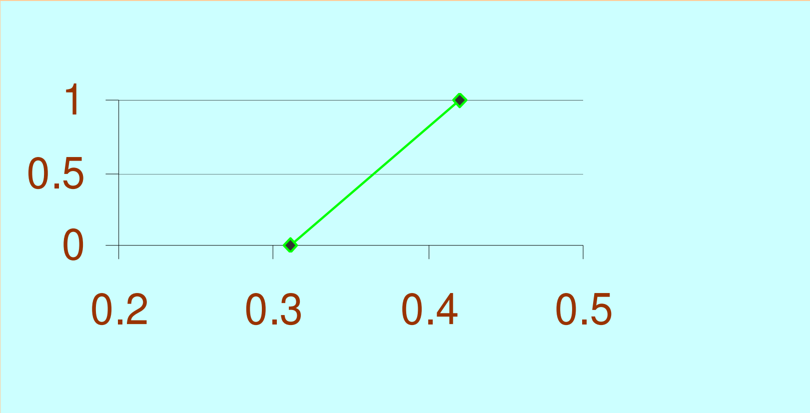
Check the heat transfer coefficients

Power calculations

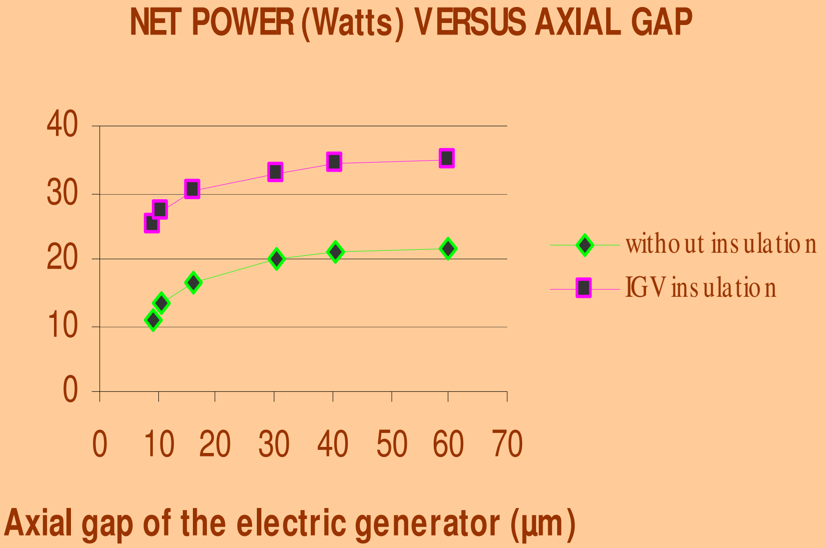
Calculation gains

Useful Power (W)	Microturbine 1cm diameter	Microturbine 2 cm diameter
Adiabatic	14	54
Non-adiabatic	4	24
Non-adiabatic + disc friction	1.7	17

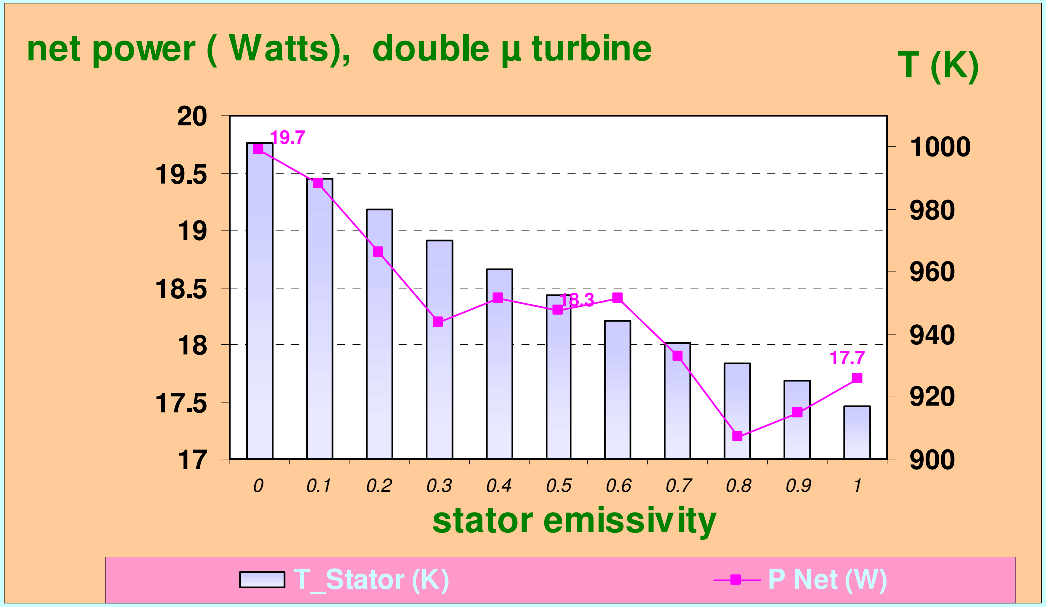




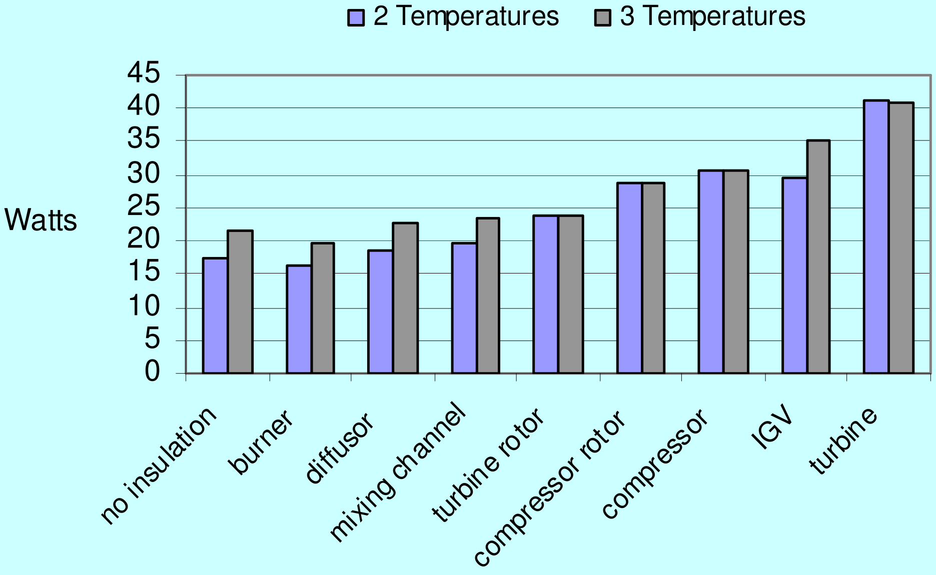
Useful power as function of the product of the aero. efficiencies of the turbomachines



Results (following)



Net power for partial thermal insulation



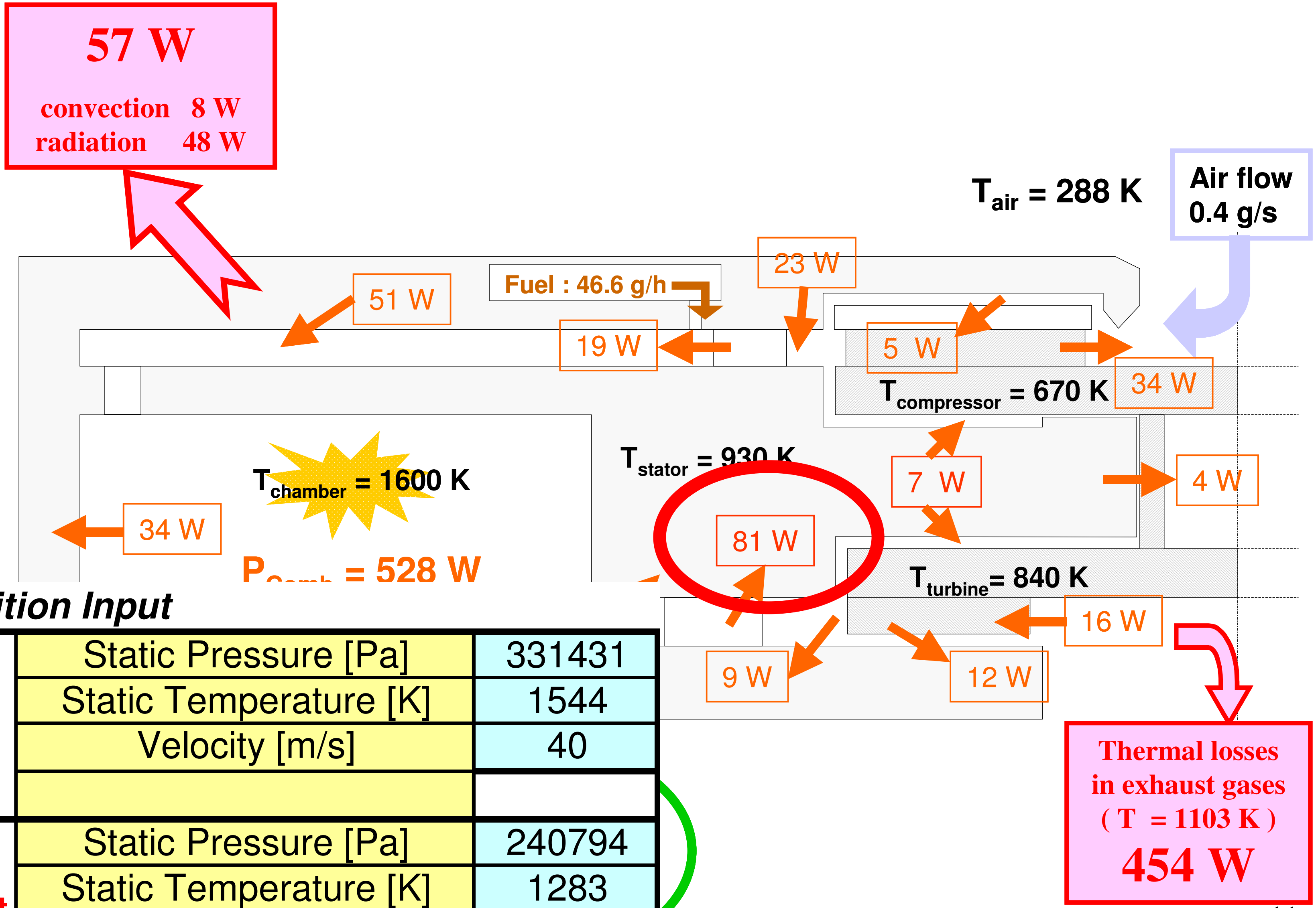
Net Power (W)	28.45
Net Power with considering disk friction (W)	21.63
Thermal Efficiency (%)	3.87
Fuel Mass Flow Rate (kg/s)	4.66E-06

Hydrogen

Net Power (W)	25.27
Net Power with considering disk friction (W)	18.46
Thermal Efficiency (%)	3.22
Fuel Mass Flow Rate (kg/s)	1.24E-05

Propane

Microturbine MEMS, 2cm



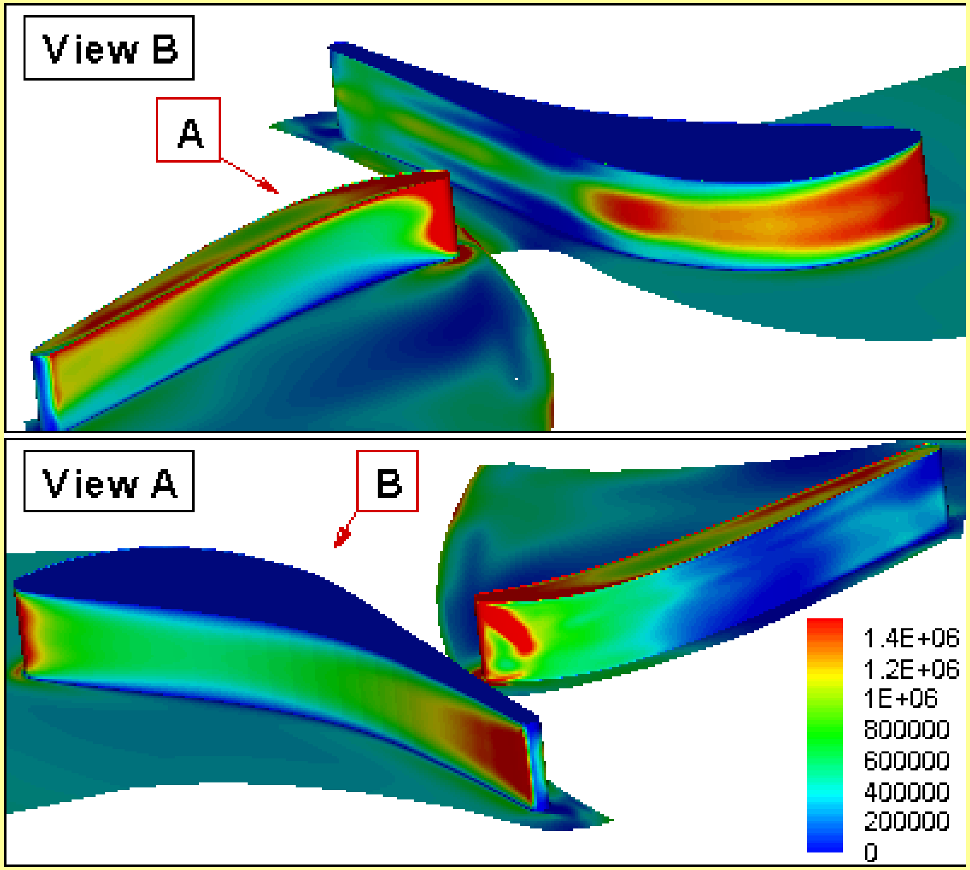
Condition Input

Inlet	Static Pressure [Pa]	331431
	Static Temperature [K]	1544
	Velocity [m/s]	40
Outlet	Static Pressure [Pa]	240794
	Static Temperature [K]	1283
	Velocity [m/s]	512

Heat flux in the NGV for isothermal wall temperature T = 921K

Tatsuo ONISHI ASME RENO 05

COUSTEIX model		**79 W**
Conventional model		**88W**
average		
Conventional model		**72W**
local		
K. OKAMOTO model		**112W**
CFD by T. ONISHI		**75 W**



CONCLUSION

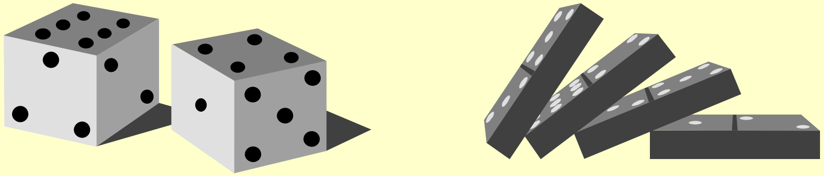
Is the MEMS concept valid from an energetic point of view?

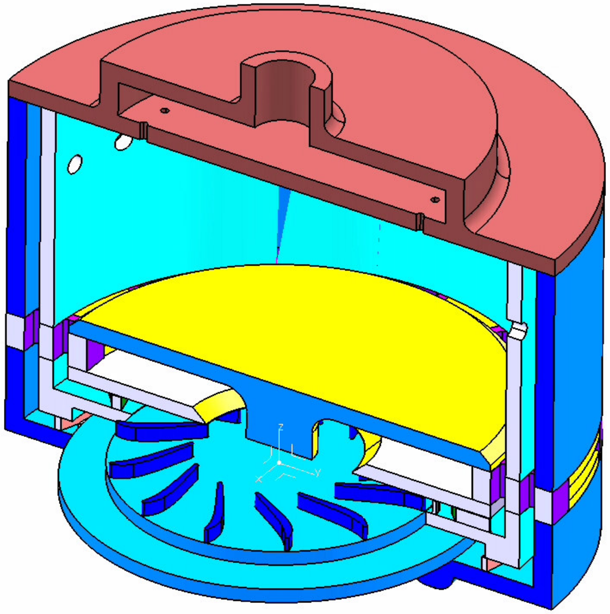
- Uncertainty about the aerodynamic compressor efficiency
- etching depth ? Depth variation with radius?
- Possibility of the NGV thermal insulation?
- Electric generator efficiency and thermal integration?
- Efficient minimum volume for the combustion chamber
- Gas bearings, : stability, lost power and stiffness

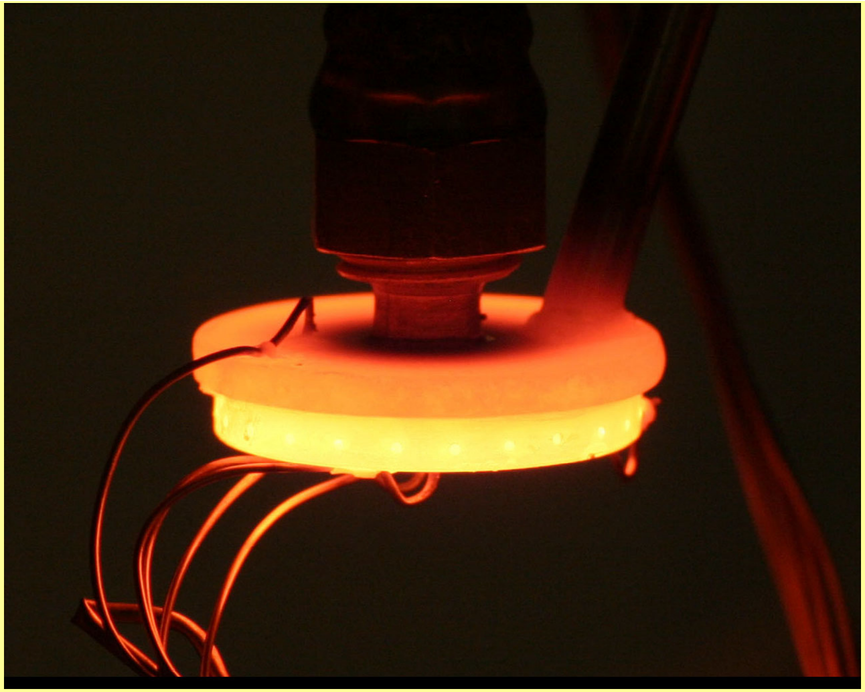
- new direction :

bulk machining µturbine, more than one material

« the die is better than the chip »







Three technological bricks