Turbomachinery Laboratory, Texas A&M University
Mechanical Engineering Department

MICRO TURBOMACHINERY Applications

August 2014

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http://rotorlab.tamu.edu

MICROTURBOMACHINERY

Justification

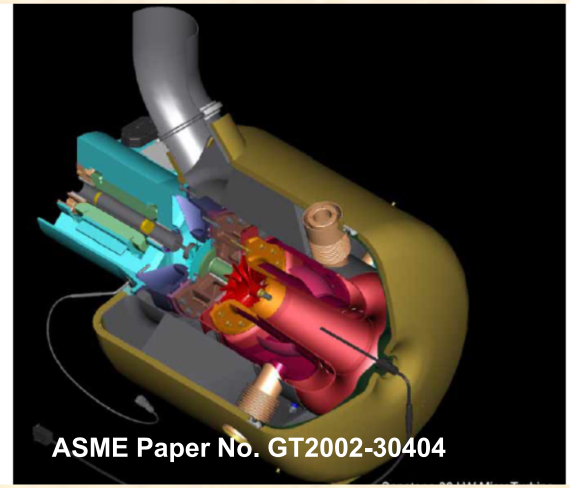
DOE, DARPA, NASA interests range from applications as portable fuel cells (< 60 kW) in microengines to midsize gas turbines (< 400 kW) for distributed power and hybrid vehicles.

Meso-scale or MEMS turbomachinery (< 100 W) for Next Generation Land Warriors, Micro vehicles & robots, Portable electronic devices and systems, Smart munitions

MICROTURBOMACHINERY as per IGTI

Drivers:

deregulation in distributed power, environmental needs, increased reliability & efficiency



Distributed power (Hybrid Gas turbine & Fuel Cell), Hybrid vehicles

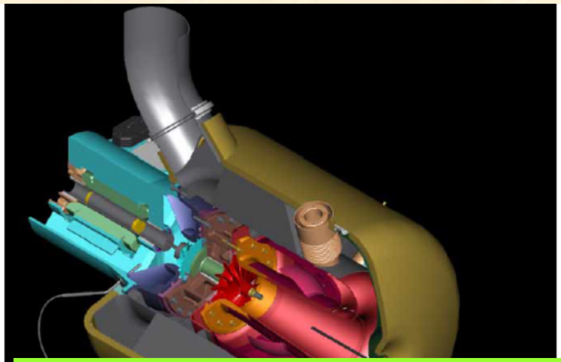
Automotive turbochargers, turbo expanders, compressors,

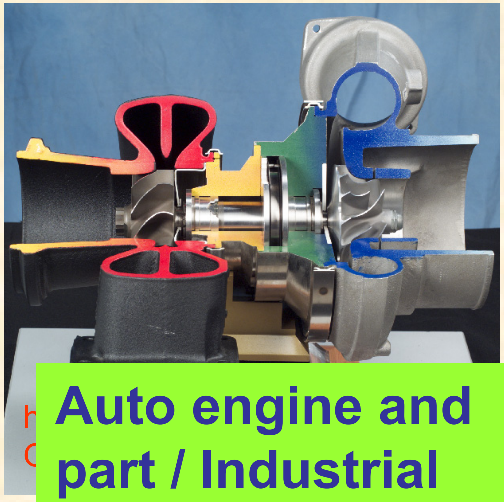
Max. Power ~ 250 kWatt

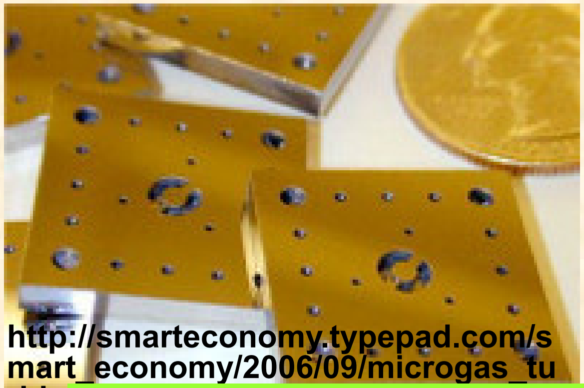
POWER RANGE

< 400 kW

< 100 W







http://smarteconomy.typepad.com/smart_economy/2006/09/microgas_turbin

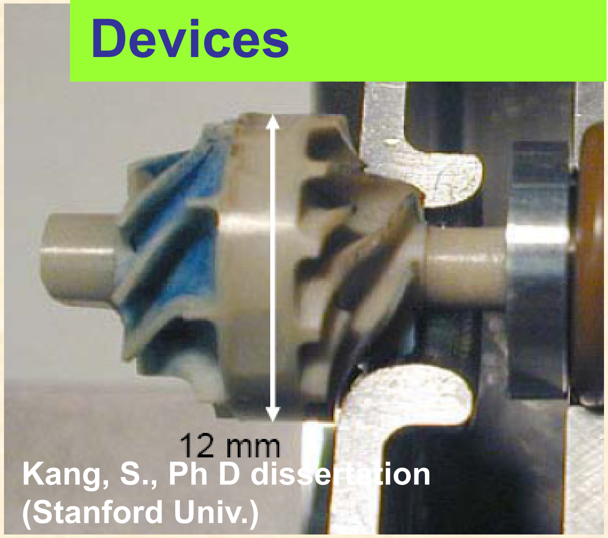
Distribute power (Gas turbine &Fuel Cell Hybrid)

Auto engine and part / Industrial compressor

Portable Electronic Devices

Honeywell, Hydrogen and Fuel Cells Merit Review

http://www.miti.cc/newsletters/150hpcompressozr.pdf



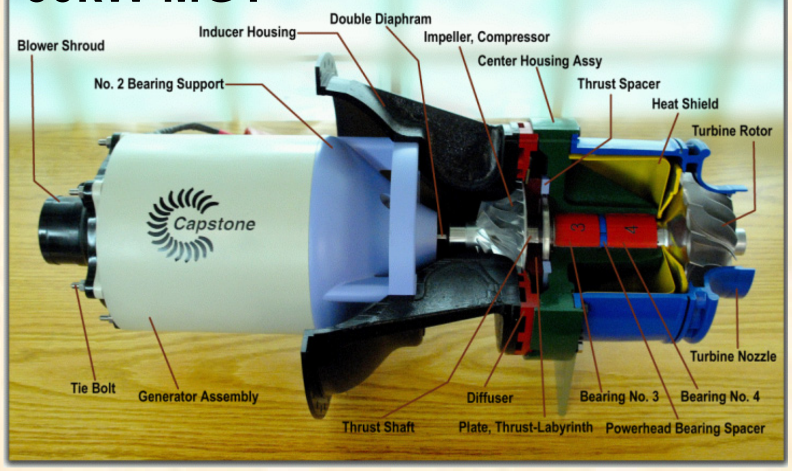
Kang, S., Ph D dissertation (Stanford Univ.)

MICRO GAS TURBINES

Cogeneration systems with high efficiency

- Multiple fuels (best if free)
- 99.99X% Reliability
- Low emissions
- Reduced maintenance
- Lower lifecycle cost

60kW MGT



source: Dan Lubell, 2006 IJTC, Capstone Turbine Corportation

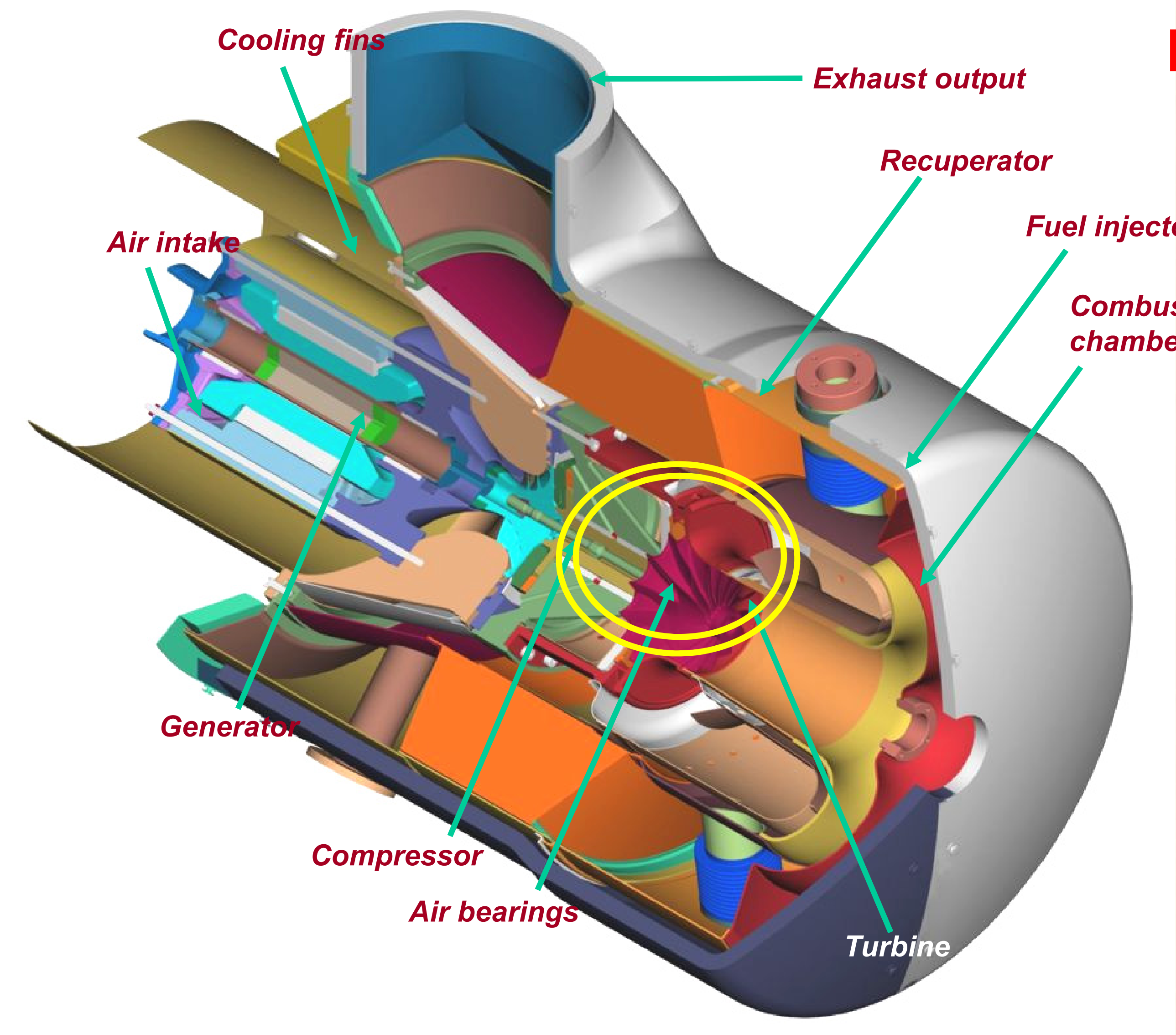
Microturbine Power Conversion Technology Review, ORNL/TM-2003/74.

MANUFACTURER	OUTPUT POWER (kW)
Bowman	25, 80
Capstone	30, 60, 200
Elliott Energy Systems	35, 60, 80, 150
General Electric	175
Ingersoll Rand	70, 250
Turbec, ABB & Volvo	100

Hybrid System: MGT with Fuel Cell can reach efficiency > 60%

Ideal to replace reciprocating engines. Low footprint desirable

Capstone MicroTurbine™



No gearbox or other mechanicals

Low scheduled maintenance

Only one moving part

No coolants or lubricants

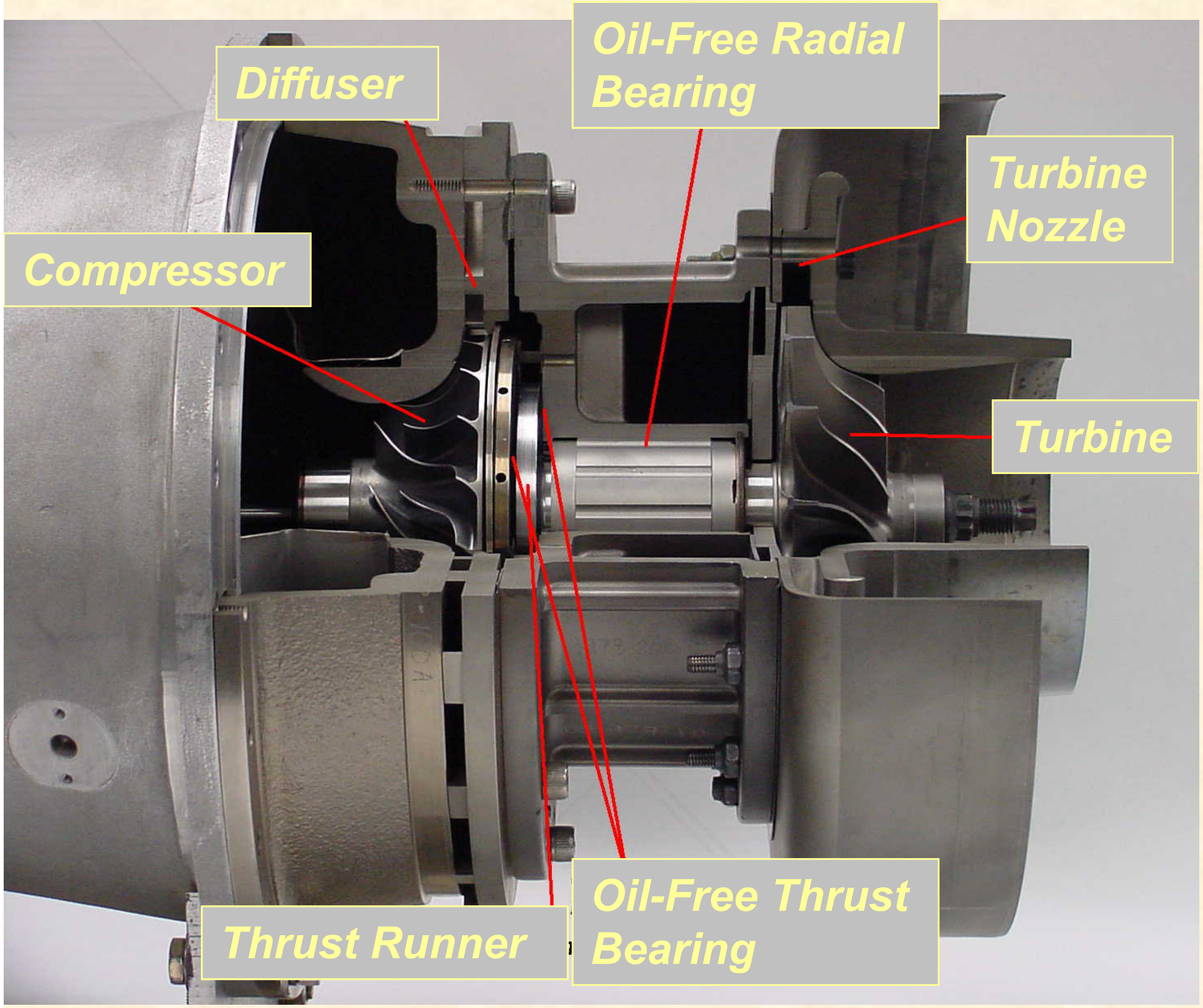
Contaminant-free exhaust

Compact and lightweight

Super-low CO & NO_X

source: Dan Lubell, 2006 IJTC, Capstone Turbine Corportation

Capstone's C30 Engine



Oil-Free Foil Bearings:

>500°C

Proprietary bearing design and coating

Thin Dense Chrome journals

1.4 MDN (idle)

3.1 MDN (full speed)

~1.5 L/D

1.6 psi static load

Demonstrated Life: >40k hours; >6k cycles and over 11 Mhrs field life

source: Dan Lubell, 2006 IJTC, Capstone Turbine Corportation

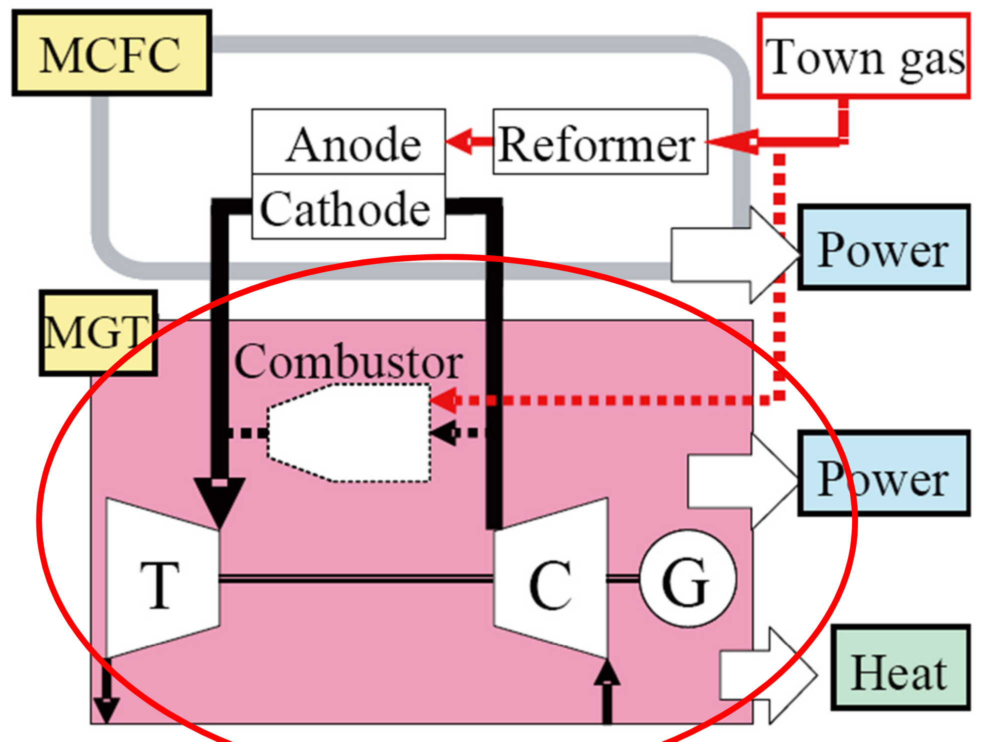
Expectation & Requirement

- Low cost – driven by materials
- Low maintenance – driven by design
- Long life – defined by the bearings and materials
- Efficient – driven by design
- Fully integrated solutions – system design

source: Dan Lubell, 2006 IJTC, Capstone Turbine Corportation

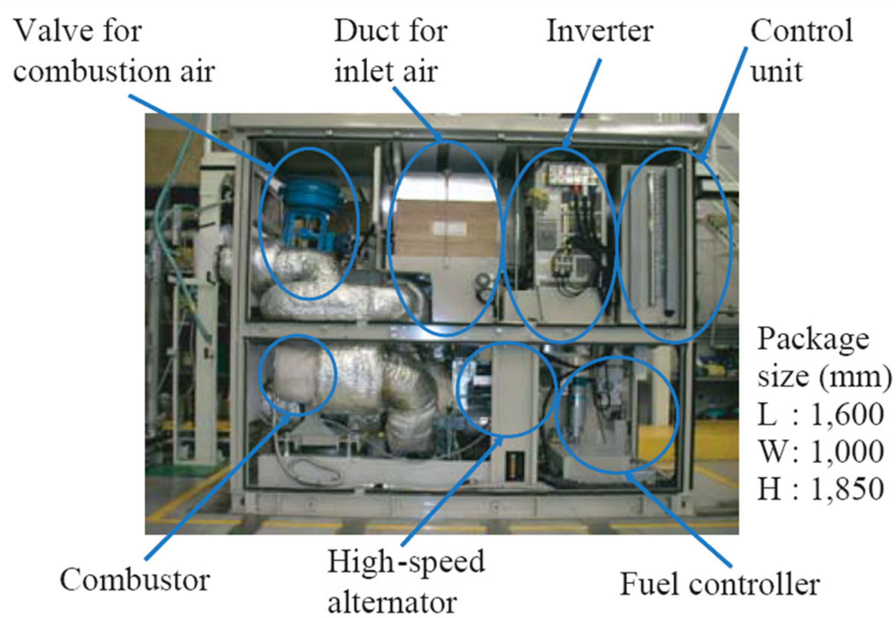
HYBRID GENERATION SYSTEM

MCRC (molten carbonate fuel cell) MT generator



R&D Review of Toyota CRDL, 41

Pressured, and Powered by reformed fuel and air supplied by compressor of MGT

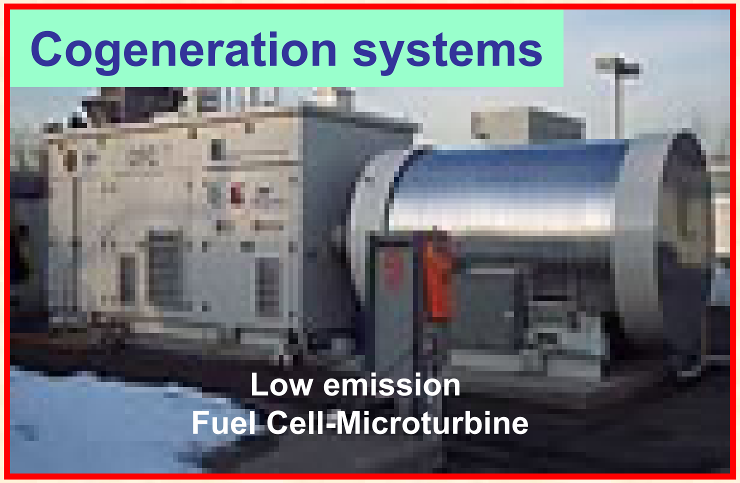


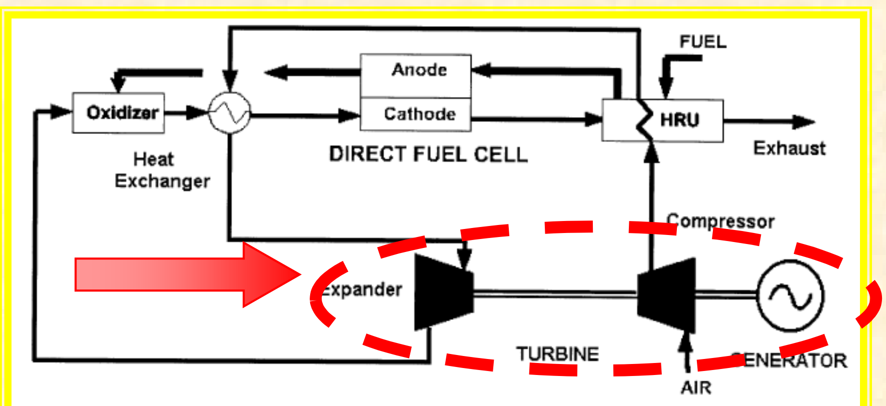
Single-shaft gas turbine (max. 80 krpm)

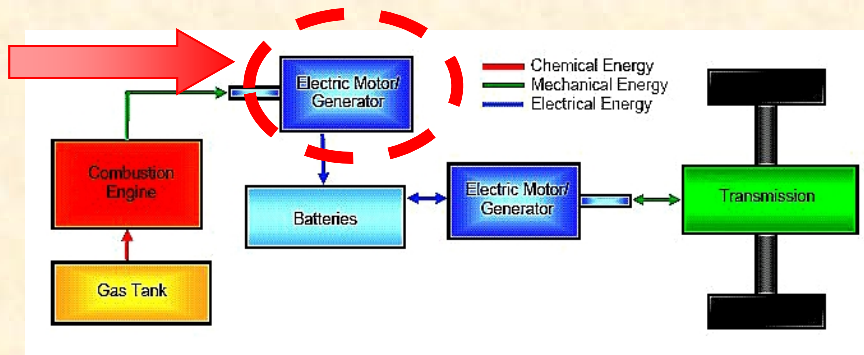
R&D Review of Toyota CRDL, 41

MTM in your neighborhood

Microturbine Power Conversion Technology Review, ORNL/TM-2003/74.







Hybrid System : MGT with Fuel Cell can reach efficiency > 60%
Electricity-Heat total efficiency ~ 90%.

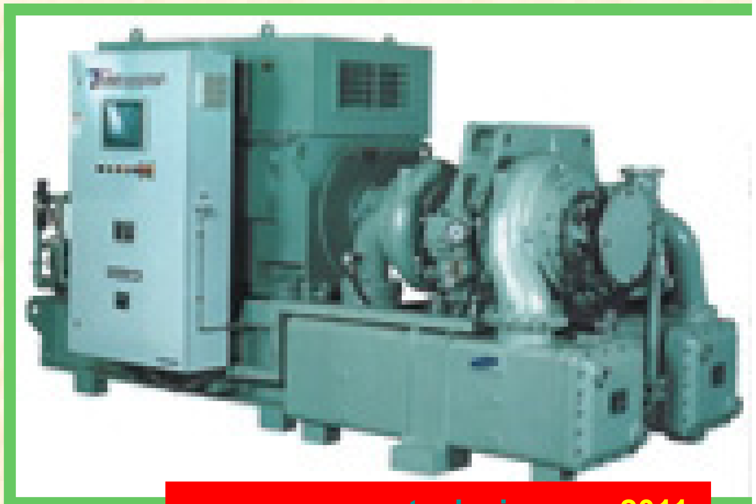
Reduces emissions of Carbon & other air pollutants
Supports renewable energy goals

Compressor industrial applications

Samsung Micro Turbo Master compressors feature gas foil bearings

- **Pressures to 130 psig, power to 0.13 MW**

- **Samsung line Turbo Master has pressure to 300 psig and power to 2.4 MW. Runs on oil TPBs.**



www.samsungtechwin.com, 2011

HSI Turbo blower packages (50-300 Hp)

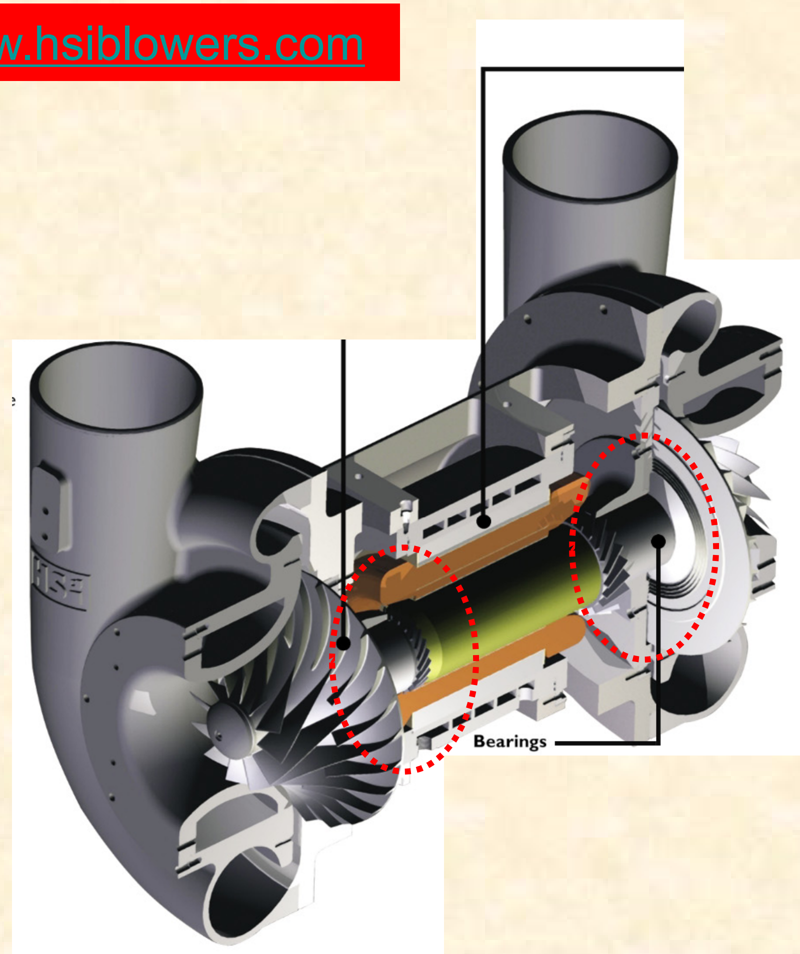
20-40% more efficient

Low maintenance

Low noise

Small footprint

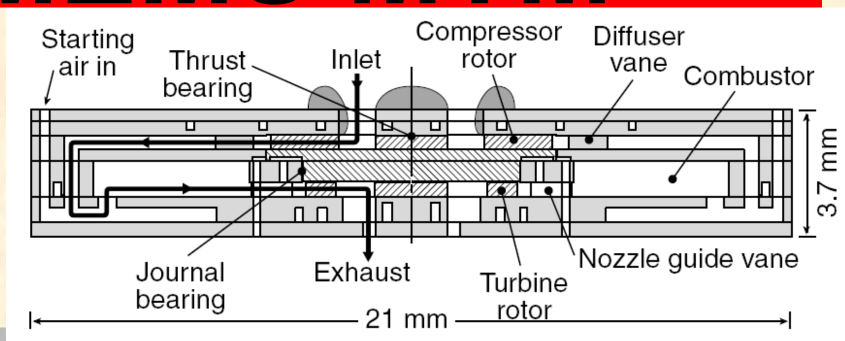
www.hsiblowers.com

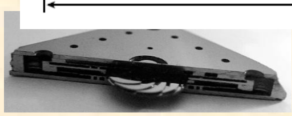


See also www.neuros.com
for R&D and products in Korea

ULTRA MICROTURBOMACHINERY

MEMS MTM



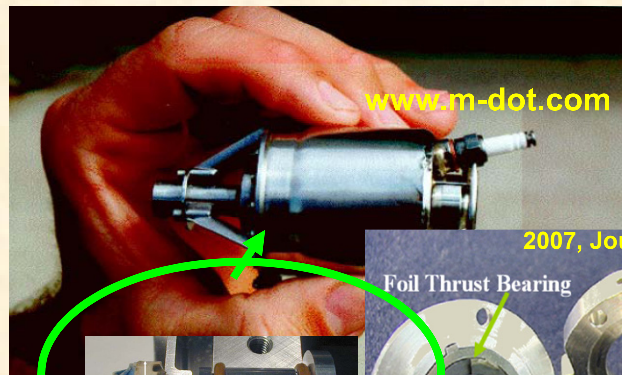


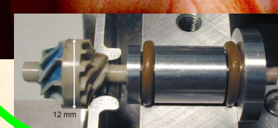
GT-2003-38866

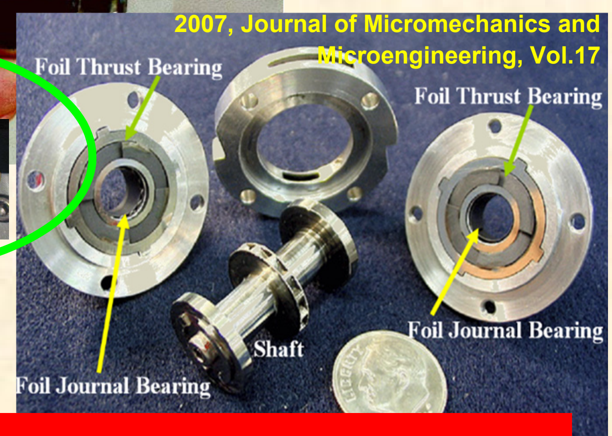
- Silicon wafer
- 1.2 Million rpm
- Thrust 0.1 N
- Spiral groove and hydrostatic gas bearings

Meso-scale MTM

- Palm-size power source
- Brayton cycle
- Gas foil bearings



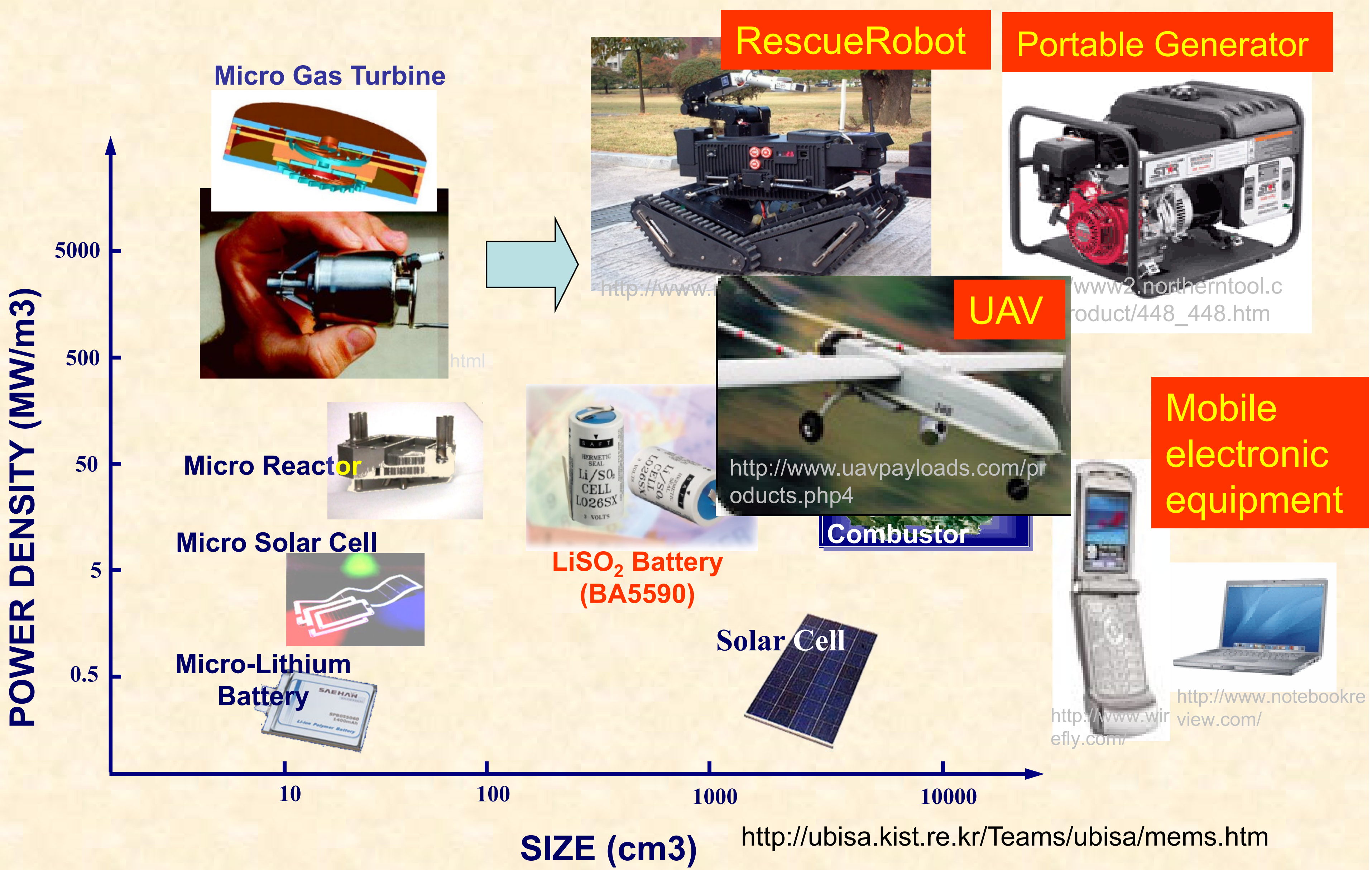




100 Watt & less

Small unmanned vehicles and to replace batteries in portable electronic devices

Application of Meso/MEMS MTM



MEMS MTM at MIT

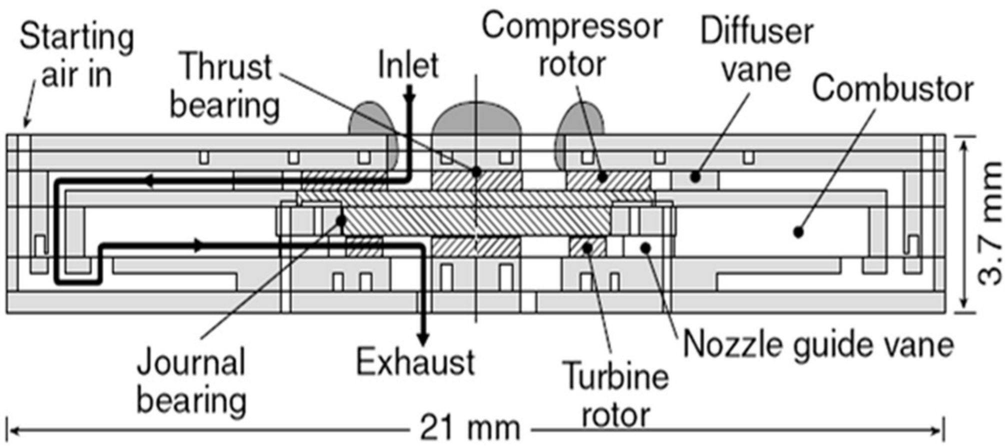


Figure 3: H_2 demo engine with conduction-cooled turbine constructed from six silicon wafers.

Figure 10: A 500 m/s tip speed, 8 mm dia centrifugal engine compressor.

Thrust: 11g (17 watts)

Turbine inlet temp : 1600 K

Fuel burn: 16 gram/hr

Rotor Speed: 1.2 M rpm

Weight: 2 grams

Exhaust gas temp : 1243 K

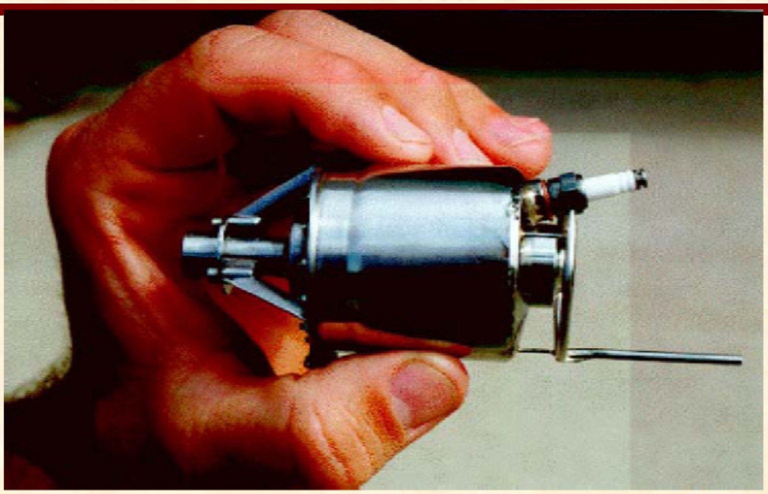
Source: GT2003-38866

Mesoscale MTM at Stanford

~1997: DARPA – M-Dot project

Palm size gas turbine engine (thrust type)

φ25 mm turbine, 400k rpm
All metal components
Ran a few minutes.
Turbine blades melted!

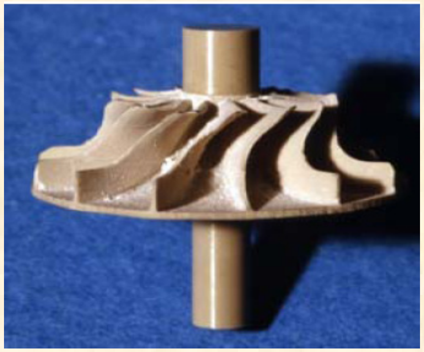


M-DOT micro-turbine engine

1998: DARPA – M-Dot – Stanford – Carnegie Mellon project

Replace the inlet nozzle to improve specific thrust density.

· Inlet nozzle: major ceramic part. Tested in 1,250°C gas
· 7% performance (thrust/weight) improvement expected
· Ceramic turbine built but not tested.



Silicon nitride inlet nozzle and turbine

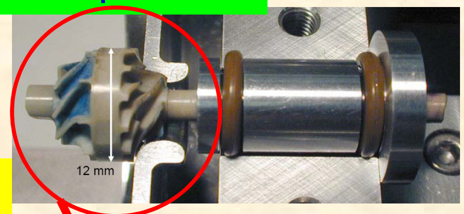
Figures and text: Kang, S.,2001, Ph.D dissertation, Stanford Univ. & Personal communication with Kang, S.

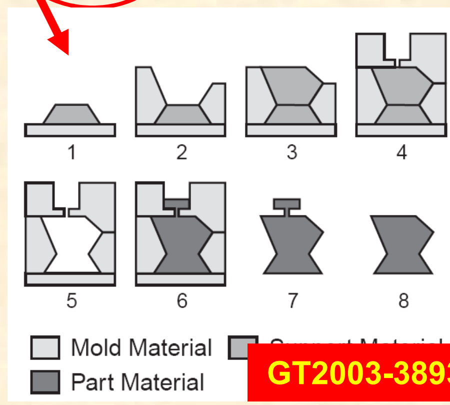
MTM materials & fabrication

Fabrication

- Mold SDM
- Precision 3D Milling
- MEMS

Mold SDM process





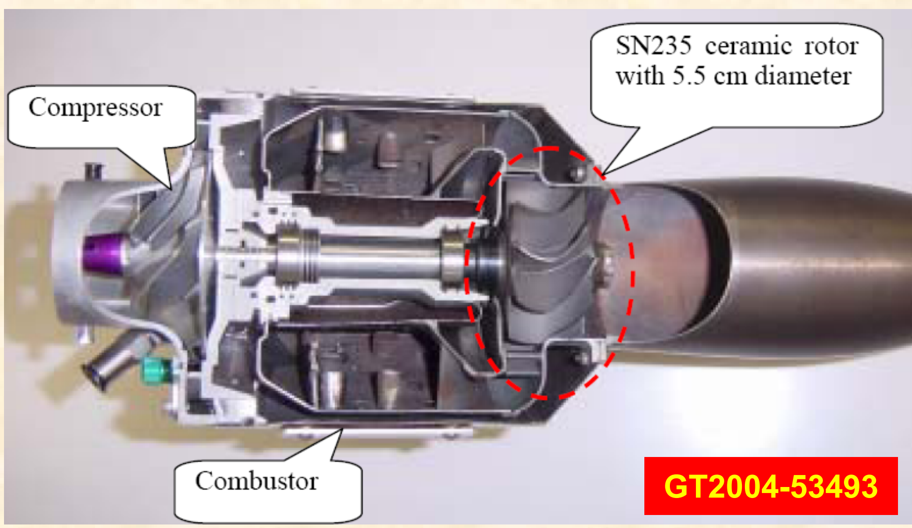
GT2003-38933

3D Milling

GT2003- 38151

DRIE process

GT2003-38866



GT2004-53493

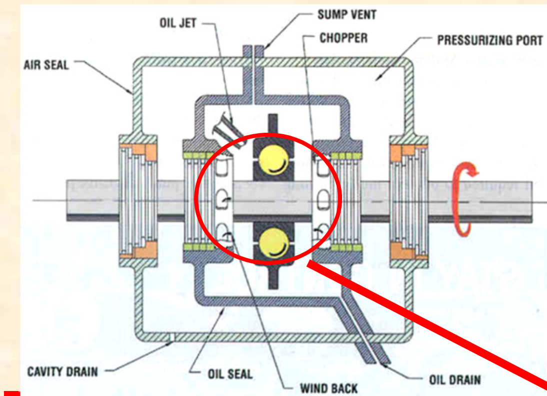
Materials & Reliability

- High temperature durability
- Light weight

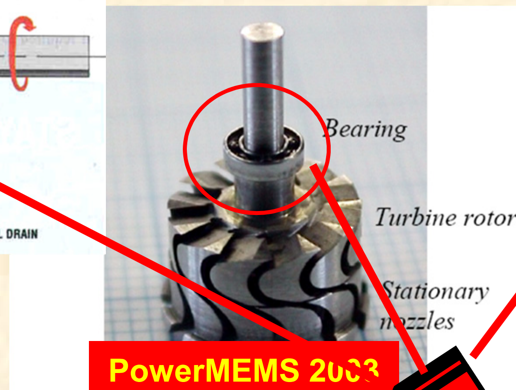
Available Bearing Technologies

Rolling element bearings

- Low temperatures
- Low DN limit (< 2 M)
- Need lubrication system



AIAA 2004-4189



PowerMEMS 2003

Herringbone grooved bearing

NICH Center,
Tohoku University

- Precision fabrication process
- Low load capacity and stiffness and little damping

GAS BEARINGS

- Oil-Free
- NO DN limit
- Low friction and power loss
- Thermal management

Gas Foil Bearing

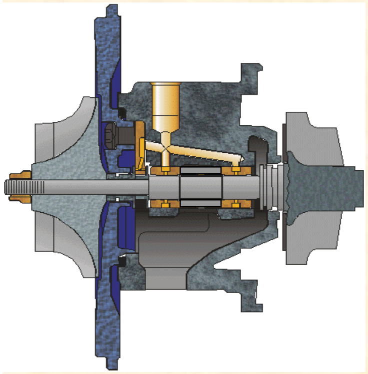
AIAA-2004-5720-984

Flexure Pivot Bearing

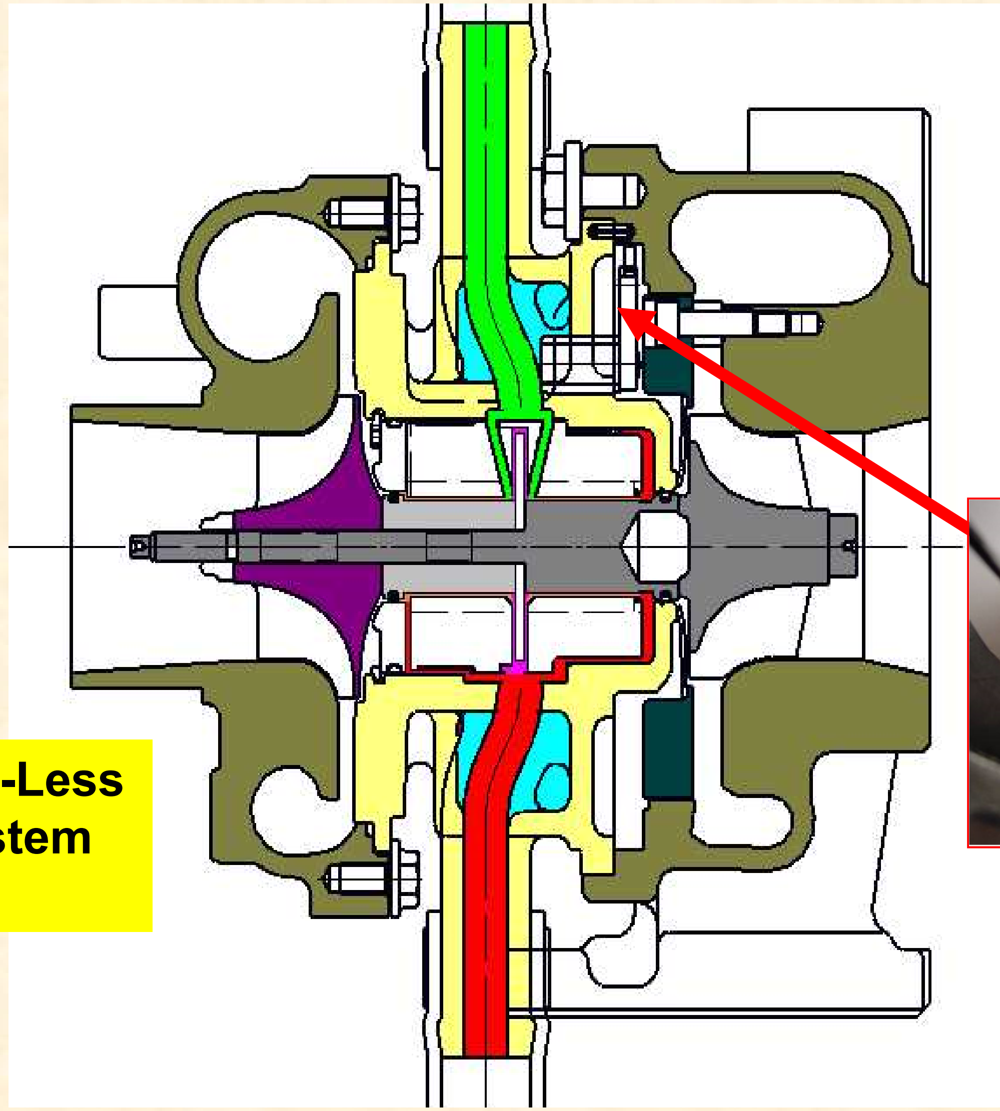
GT 2004-53621

PV turbocharger system

A challenge!

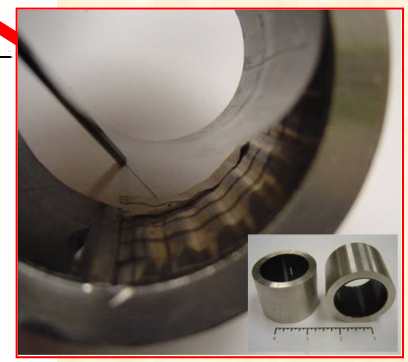


conventional Oil-Bearing



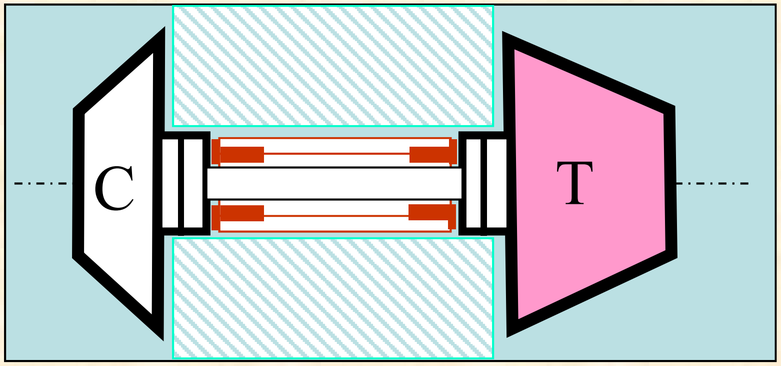
Honeywell Oil-Less Bearing System (2007)

Foil Bearings chosen



PV turbocharger

Max. 240 krpm



Engine oil TC

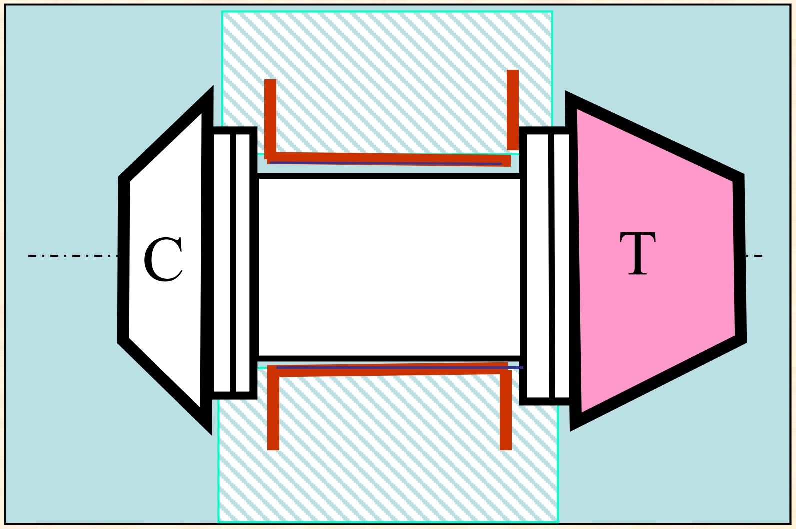
W=100 gram

Bearings 5W-30 oil lubricated

T=150 C, 1.2 cPoise

(d=6 mm, l=4 mm, c=0.012 mm, 78.5 m/s)

L=109 mm, D=45 mm, tip speed=589 m/s



Gas bearing TC

W~230 gram

air lubricated bearings

T=150 C, 0.0239 cPoise

(d=25 mm, l=40 mm c=0.007 mm, 412 m/s)

MTM – Needs, Hurdles & Issues

Largest power to weight ratio,
Compact & low # of parts

Reliability and efficiency,
Low maintenance

Extreme temperature and pressure

Environmentally safe (low emissions)

Lower lifecycle cost ($ kW)

High speed

Rotordynamics &
(Oil-free) Bearings & Sealing

Materials

Coatings: surface conditioning for low friction and wear
Ceramic rotors and components

Manufacturing

Automated agile processes
Cost & number

Processes & Cycles

Low-NOx combustors for liquid & gas fuels
TH scaling (low Reynolds #)

Fuels

Best if free (bio-fuels)

Pressing challenges for gas bearing technology

intermittent contact and damaging wear at startup & shut down, and temporary rubs during normal operating conditions

Current research focuses on coatings (materials), rotordynamics (stability) & high temperature (thermal management)

Need a low cost & long life solution!

Useful websites

NASA Oil-Free Turbomachinery Program

http://www.grc.nasa.gov/WWW/Oilfree/

DOE

http://www.eere.energy.gov/de/microturbines/

Capstone micro turbine

http://www.capstoneturbine.com/

Mohawk Innovative Technology, Inc.

http://www.miti.cc/

MIT Gas Turbine Lab.

http://web.mit.edu/aeroastro/www/labs/GTL/