

**Turbomachinery Laboratory, Texas A&M University
Mechanical Engineering Department**

MICRO TURBOMACHINERY Applications

August 2020

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<http://rotorlab.tamu.edu>

MICROTURBOMACHINERY

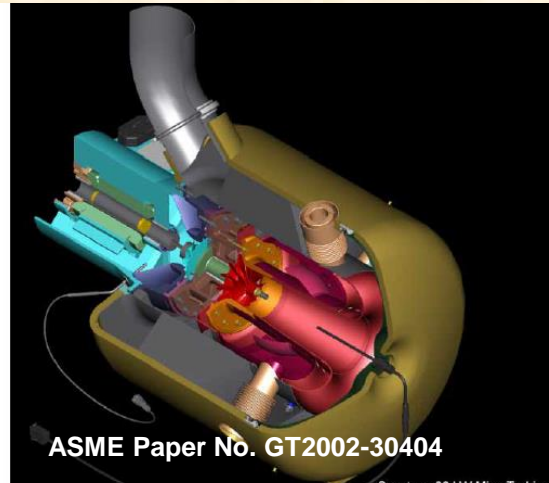
Justification

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



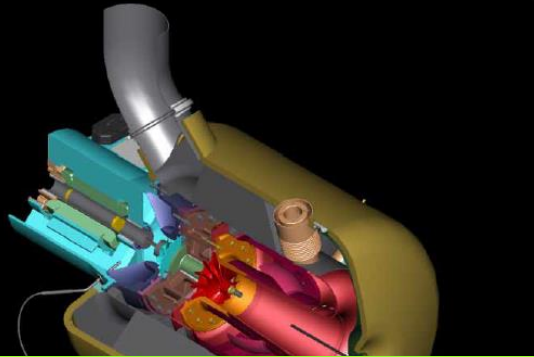
Distributed power
(Hybrid Gas
turbine & Fuel Cell),
Hybrid vehicles

Automotive
turbochargers,
turbo expanders,
compressors,

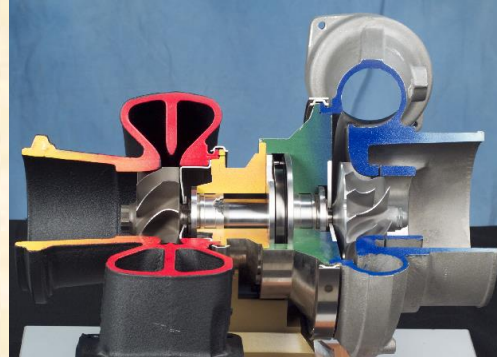
Max. Power ~
250 kWatt

POWER RANGE

< 400 kW

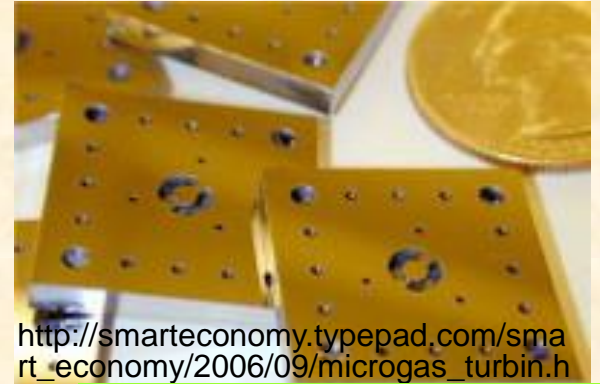


**Distribute power
(Gas turbine & Fuel
Cell Hybrid)**



**Auto engine and
part / Industrial
compressor**

< 100 W



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

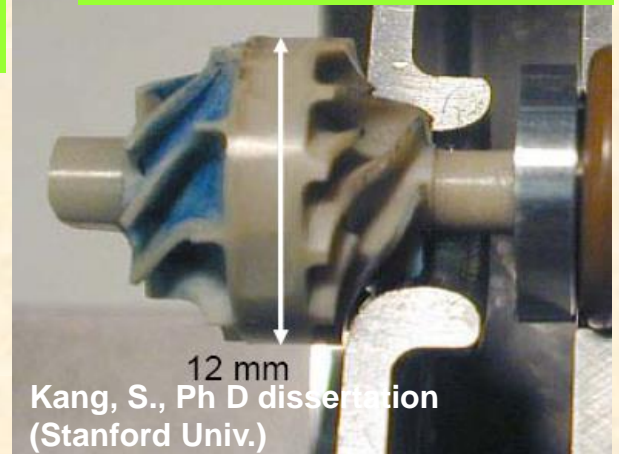
**Portable Electronic
Devices**



Honeywell, Hydrogen and Fuel Cells
Merit Review



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



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

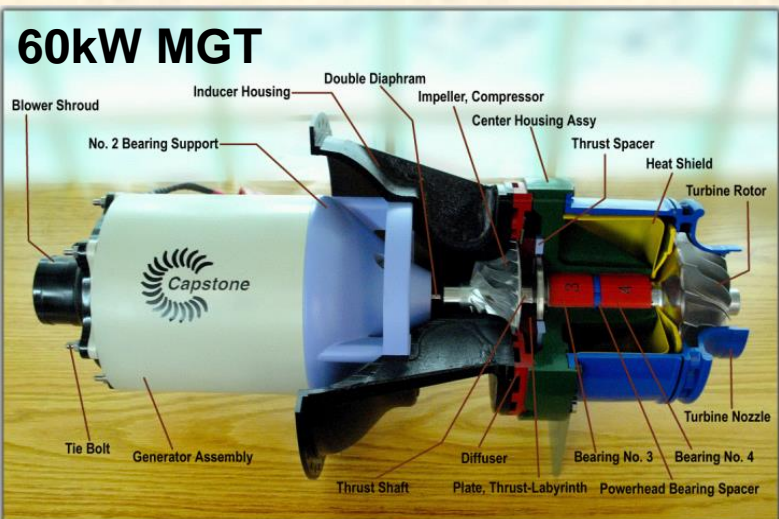
MICRO GAS TURBINES

Cogeneration systems with high efficiency

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

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

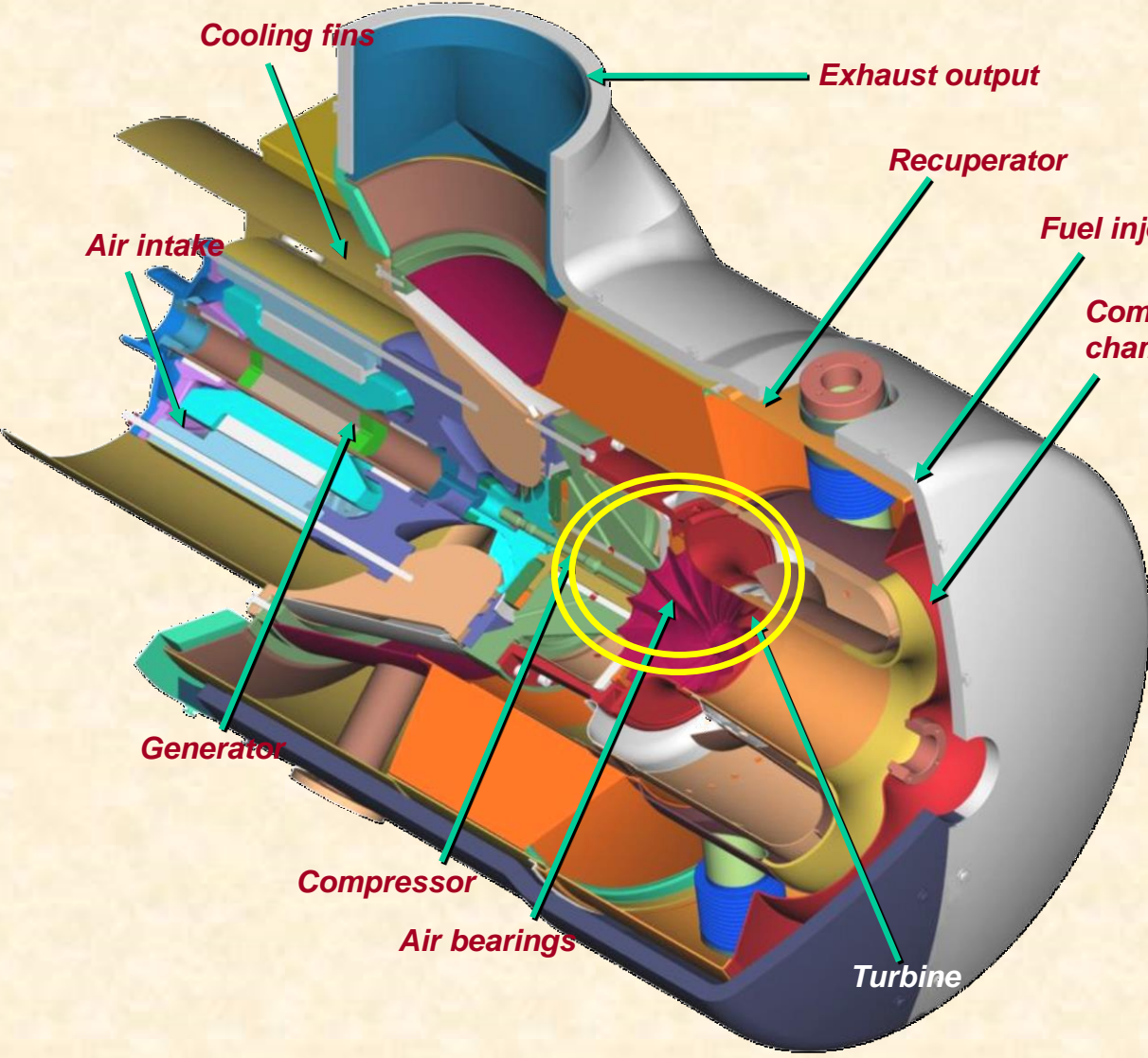


Hybrid System: MGT with Fuel Cell can reach efficiency > 60%

Ideal to replace reciprocating engines. Low footprint desirable

source: Dan Lubell, 2006 IJTC, Capstone Turbine Corporation

Capstone MicroTurbine™



No gearbox or other mechanicals

Low scheduled maintenance

Only one moving part

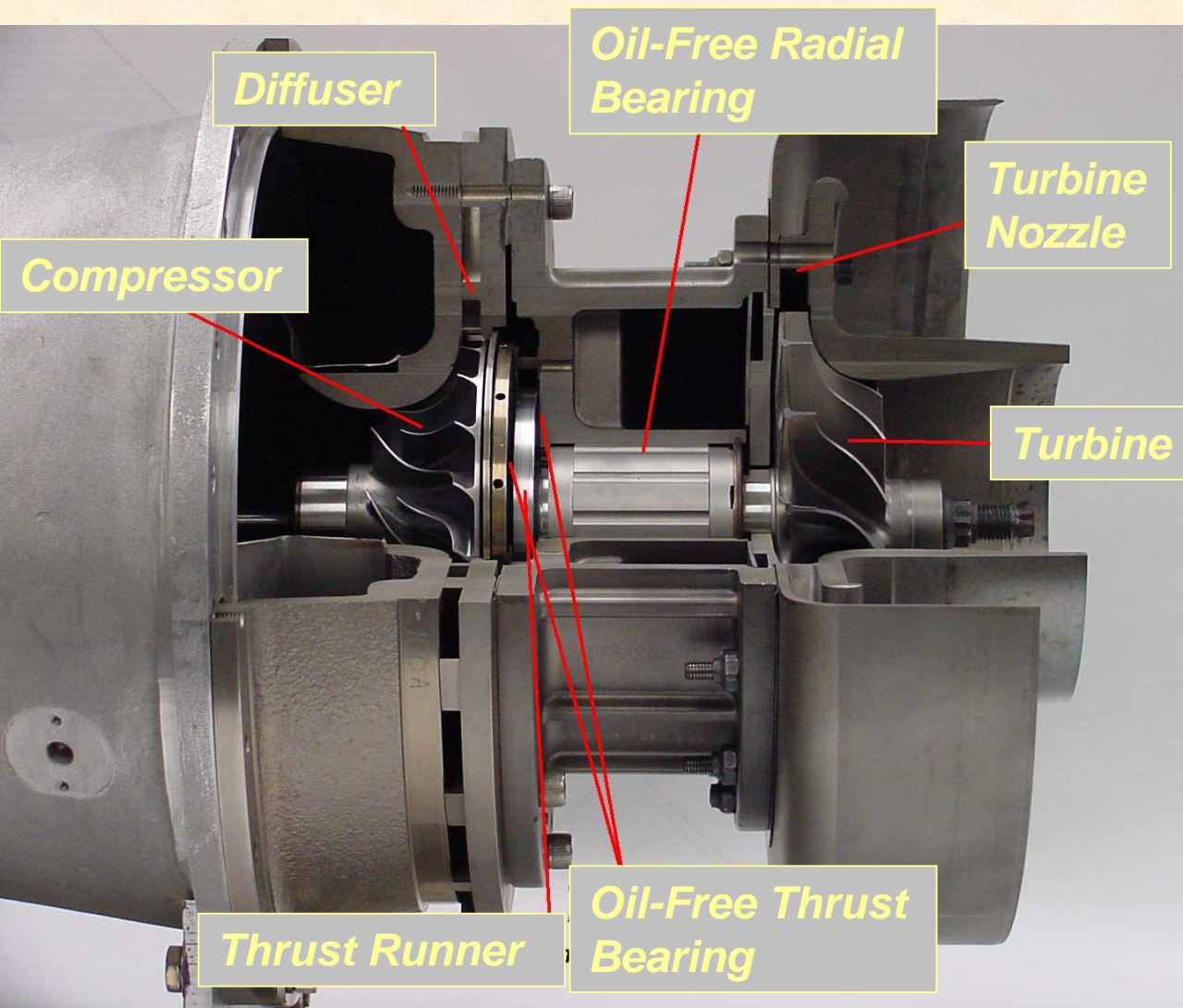
No coolants or lubricants

Contaminant-free exhaust

Compact and lightweight

Super-low CO & NO_x

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

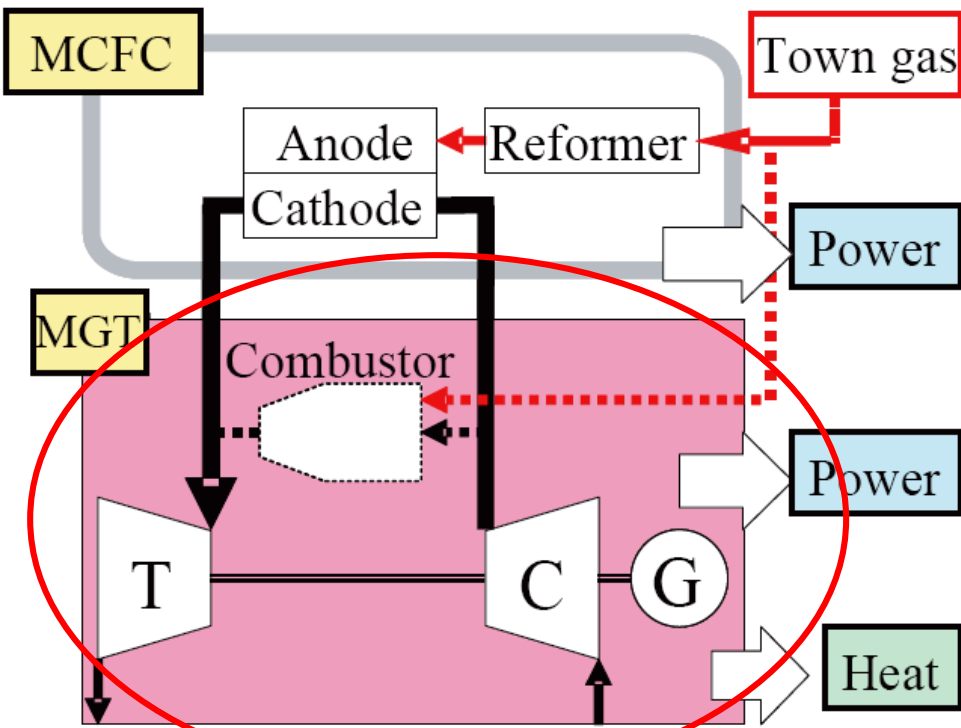
Mhrs field life

Expectations & Requirements

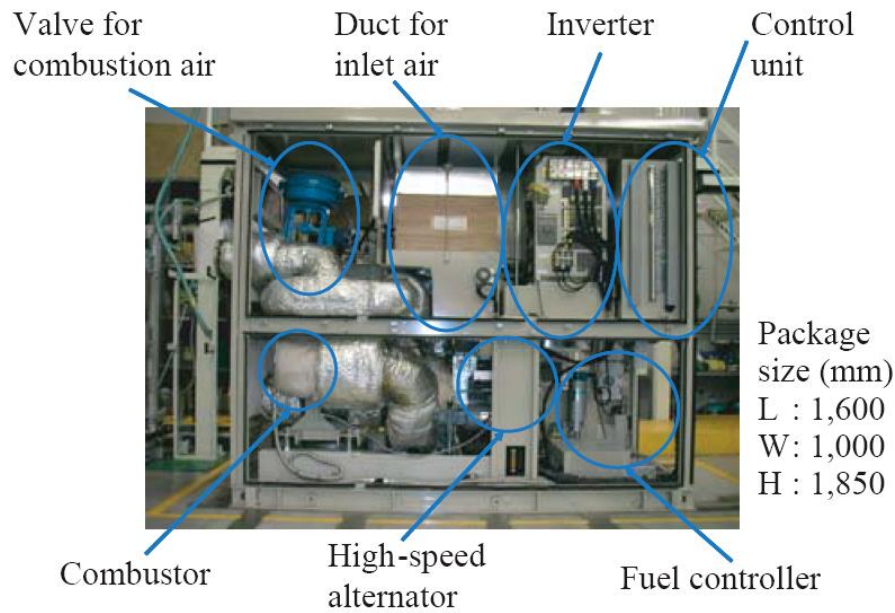
- **Low cost** – driven by materials
- **Low maintenance** – driven by design
- **Long life** – defined by the bearings and materials
- **Efficient** – driven by design
- **Fully integrated solutions** – system design

HYBRID GENERATION SYSTEMS

MCRC (molten carbonate fuel cell) MT generator



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

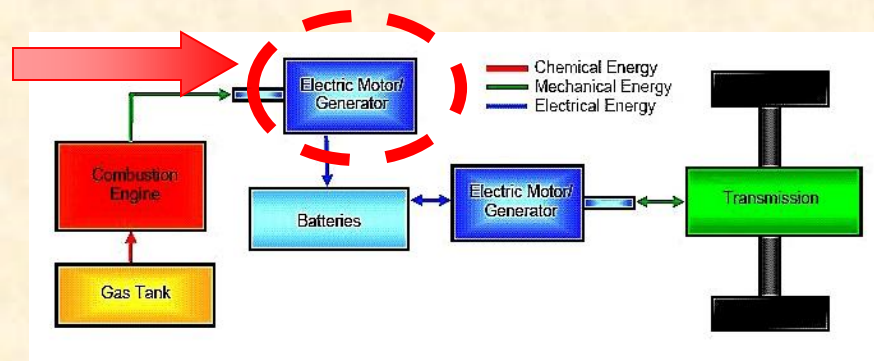
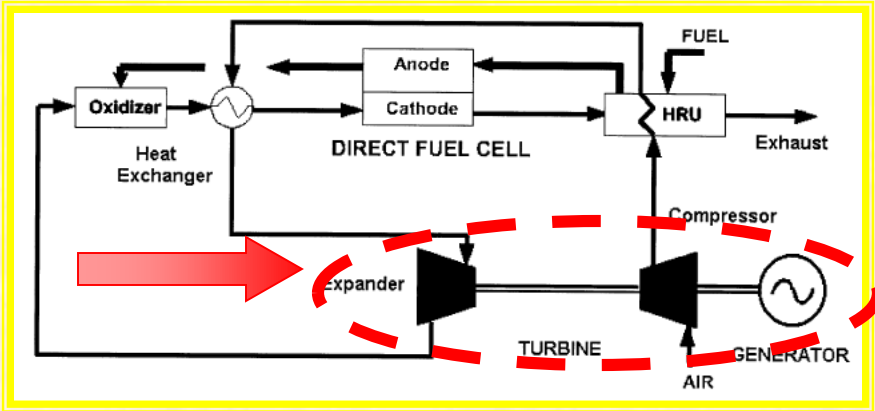
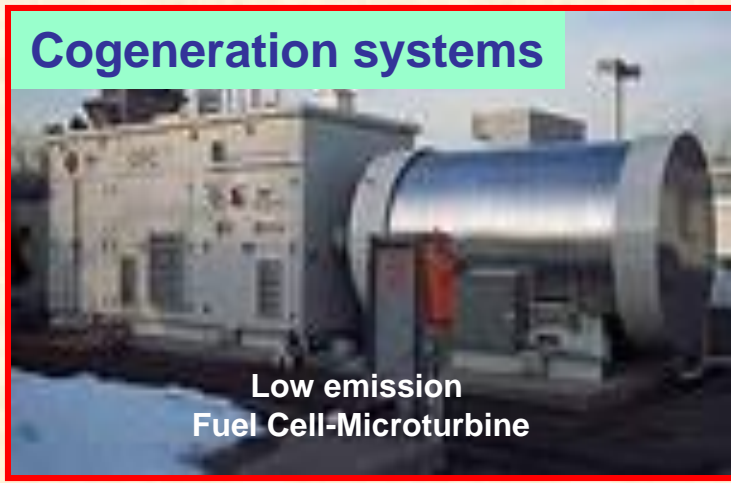


R&D Review of Toyota CRDL, 41

Single-shaft gas turbine (max. 80 krpm)

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.**



Turbo blower packages (50-300 Hp)

20-40% more
efficient

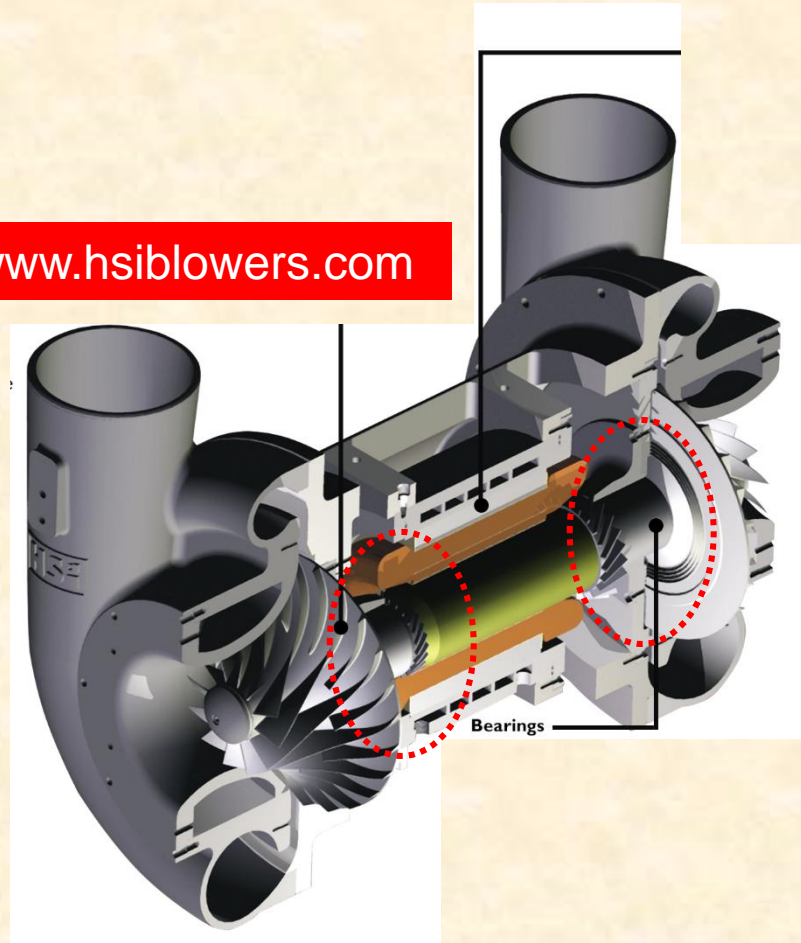
Low maintenance

Low noise

Small footprint

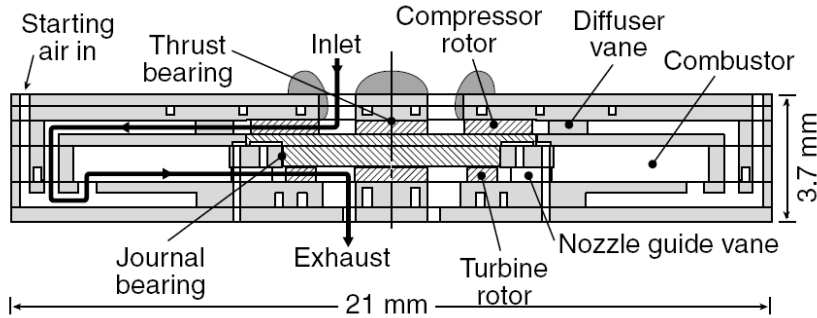
See also www.neuros.com
for R&D and products in Korea

www.hsiblowers.com



ULTRA MICROTURBOMACHINERY

MEMS MTM

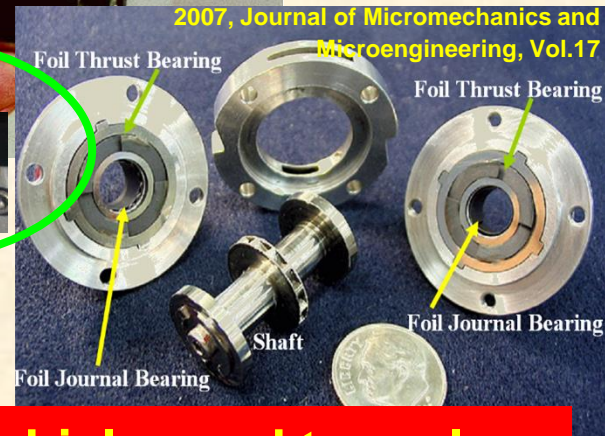


GT-2003-38866

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

Meso-scale MTM

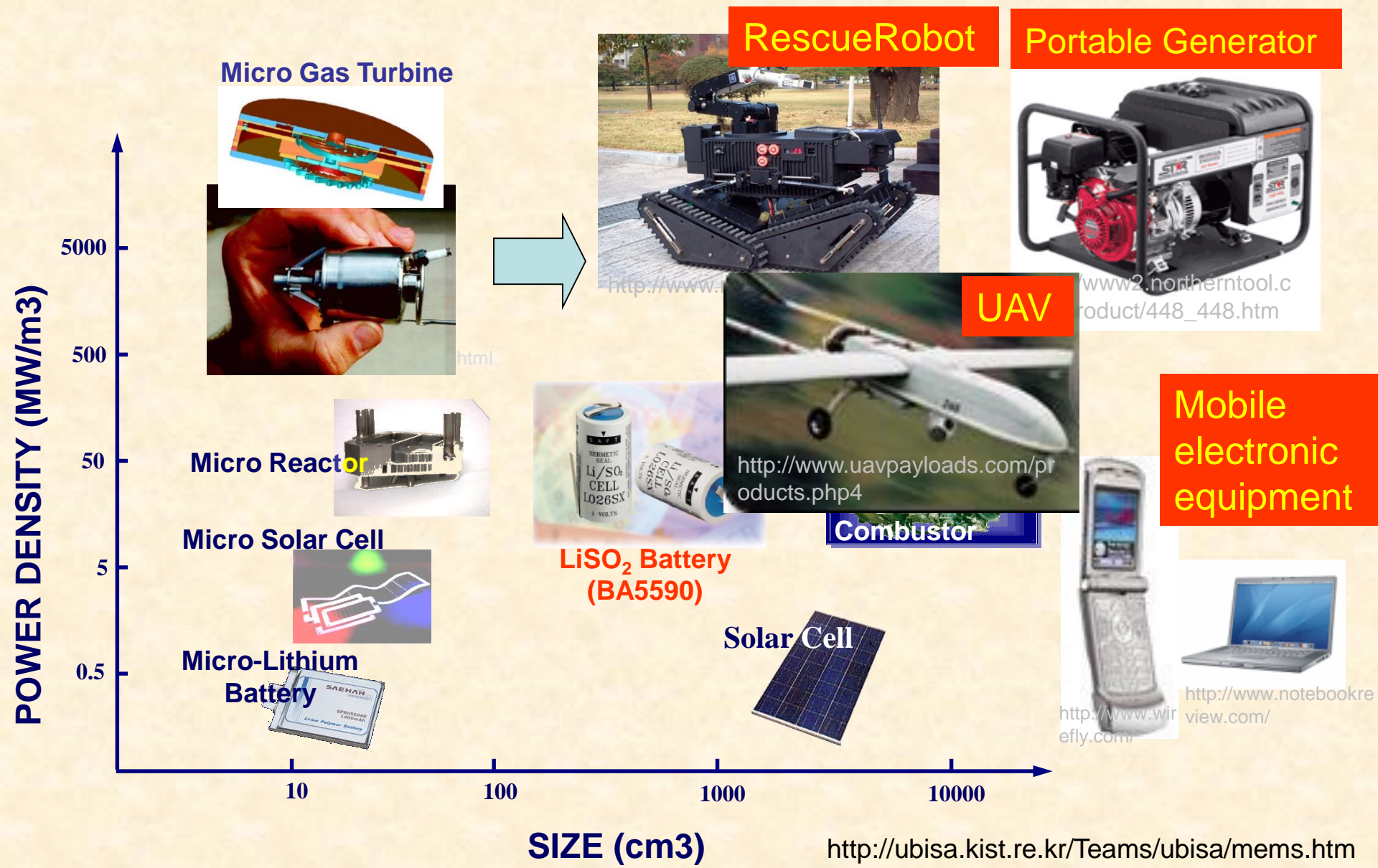
- Palm-size power source
- Brayton cycle
- Gas foil bearings



100 Watt & less

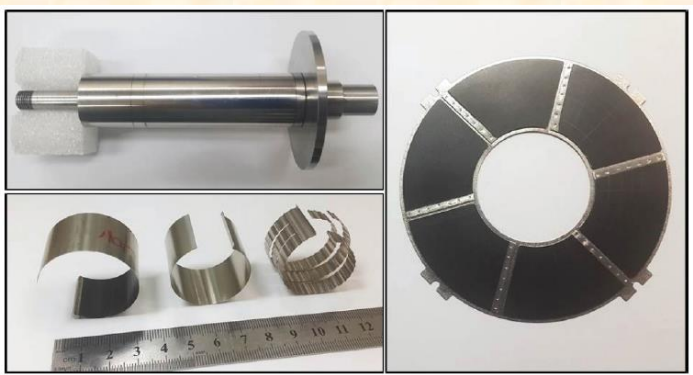
Small unmanned vehicles and to replace batteries in portable electronic devices

Application of Meso/MEMS MTM

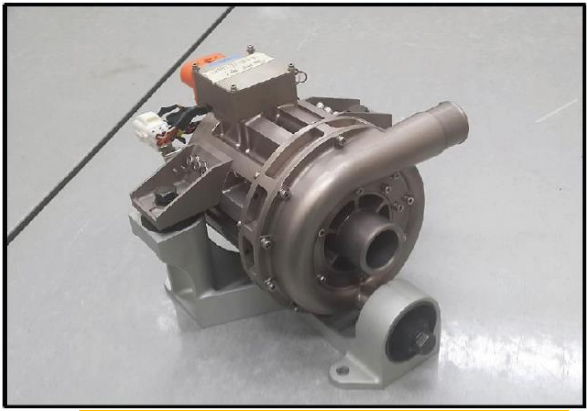


GFBs for Fuel Cell Electrical Vehicles

A Gas Foil Bearing system offers higher efficiency & power density.

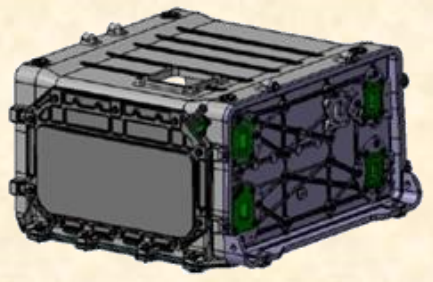


Rotor and GFBs



Air compressor

Compressed air
blows into FC stack



Fuel cell stack



Efficient FCEV!!

*Photos from SAE Int. J. Alt. Power 2016 and EHEC 2018

MEMS MTM at MIT

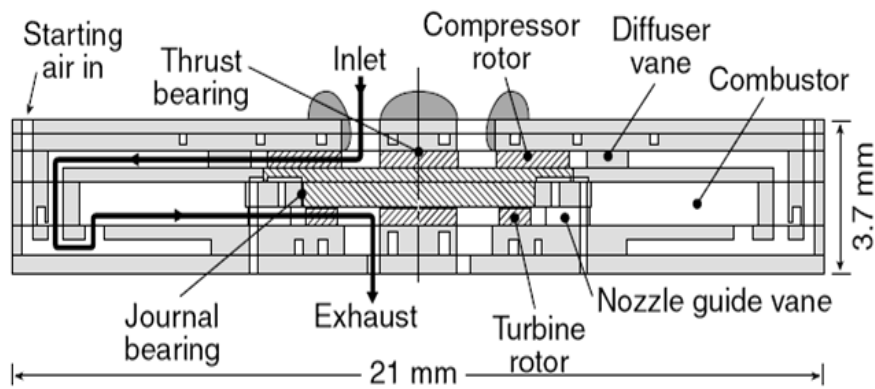


Figure 3: H₂ demo engine with conduction-cooled turbine constructed from six silicon wafers.



Figure 10: A 500 m/s tip speed, 8 m compressor

Thrust: 11g (17 W)

**Turbine inlet temp
: 1600 K**

Fuel burn: 16 gram/hr

Rotor Speed: 1.2 M rpm

Weight: 2 gram

**Exhaust gas temp
: 1243 K**

**Never worked to
date (2020)**

Mesoscale MTM at Stanford

~1997: DARPA – M-Dot project

Palm size gas turbine engine (thrust type)

ϕ 25 mm turbine, 400k rpm

All metal components

Ran a few minutes.

Turbine blades melted!

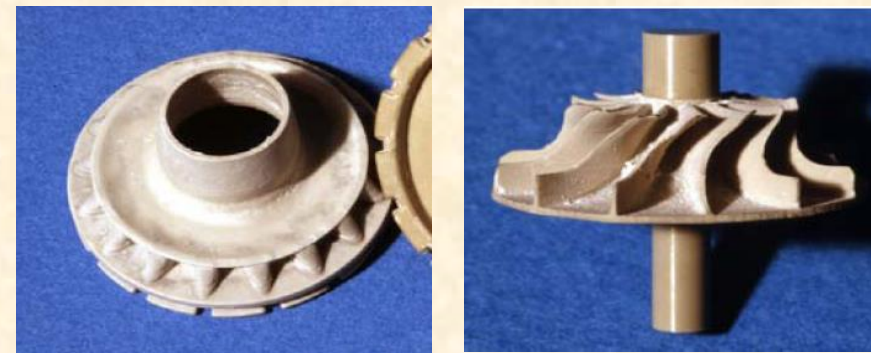


M-DOT micro-turbine engine

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.



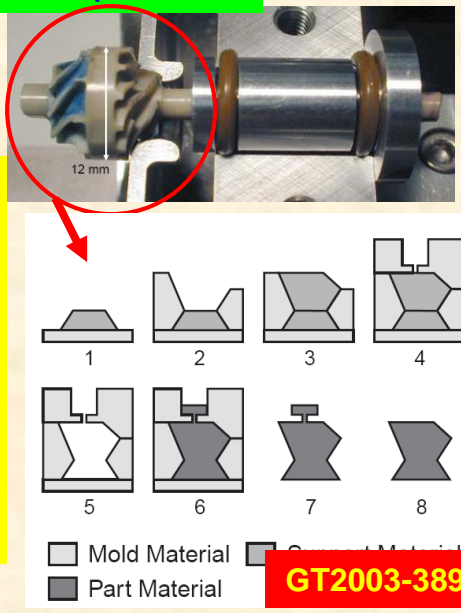
Silicon nitride inlet nozzle and turbine

MTM materials & fabrication

Fabrication

- Mold SDM
- Precision 3D Milling
- MEMS
- ADDITIVE MANUFACTURING

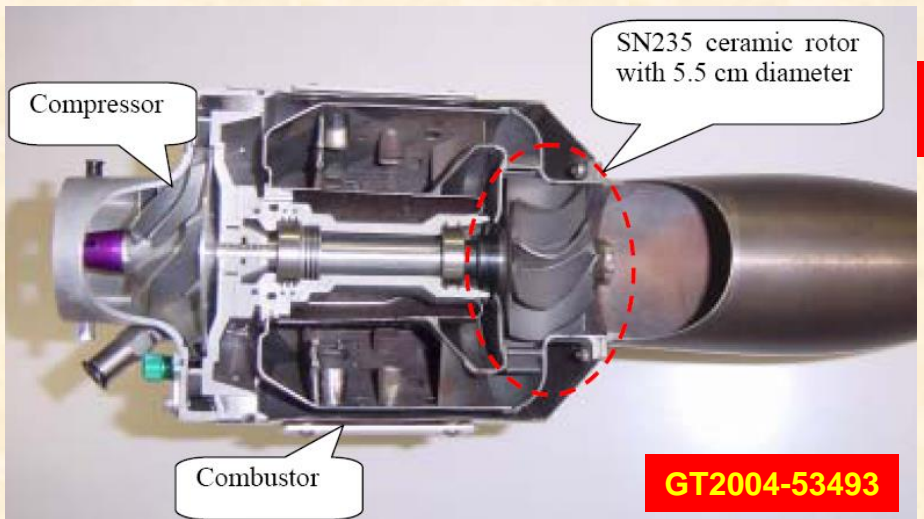
Mold SDM process



3D Milling



DRIE process



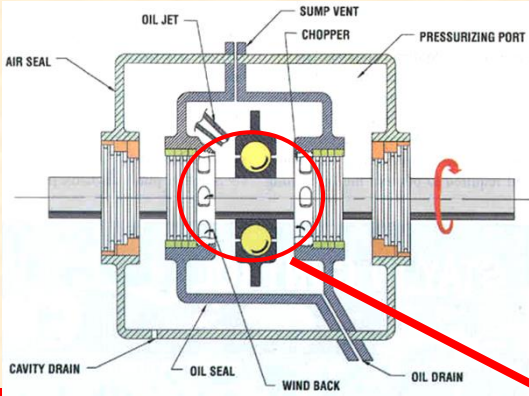
Materials & Reliability

- High temperature durability
- Light weight

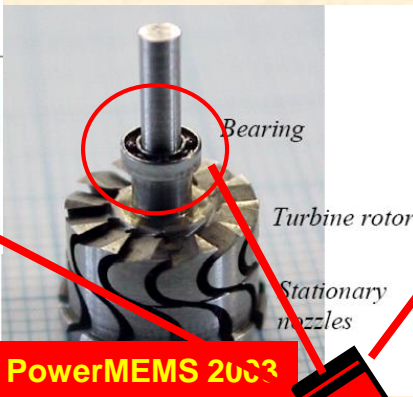
Available Bearing Technologies

Rolling element bearings

- Low temperatures
- Low DN limit ($< 2 \text{ M}$)
- 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

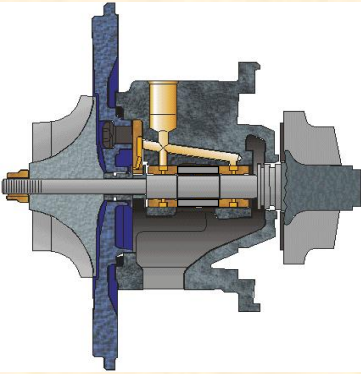
Flexure Pivot Bearing



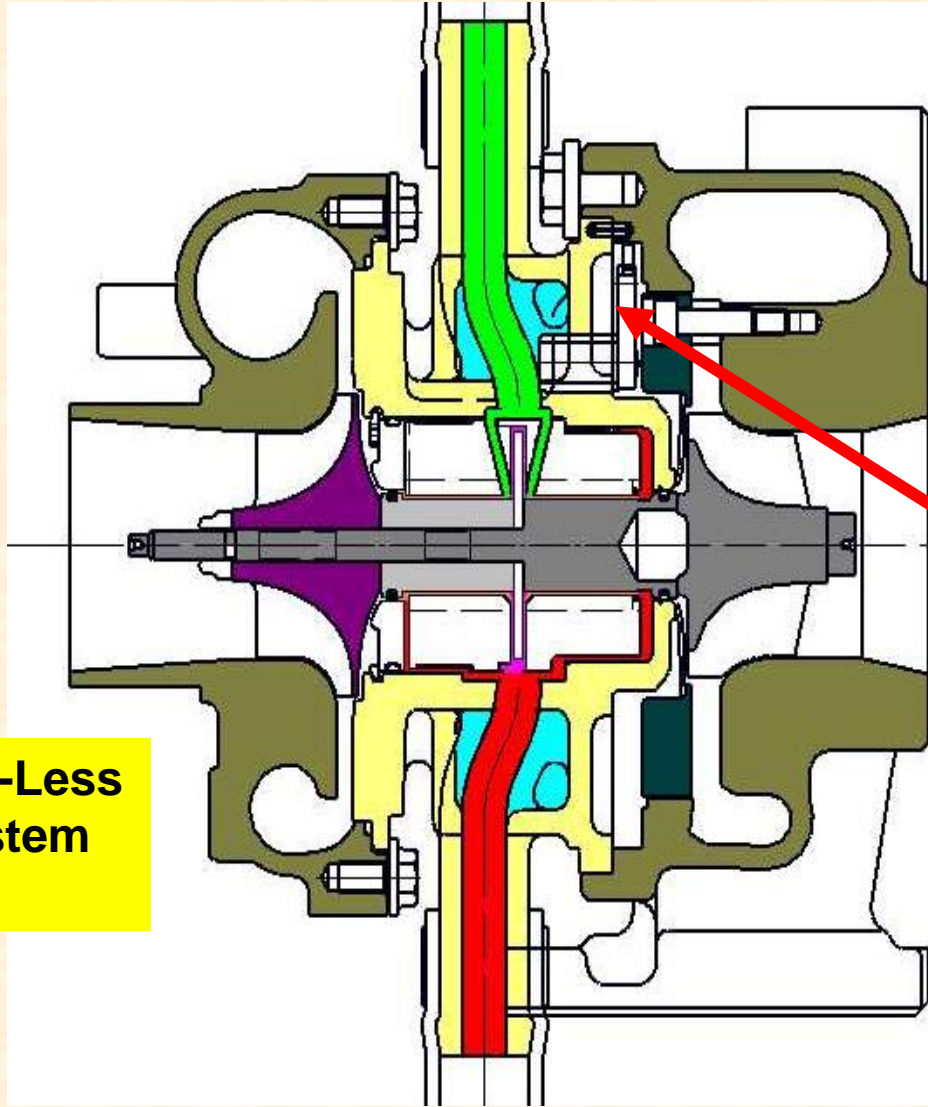
GT 2004-53621

PV turbocharger system

A challenge!

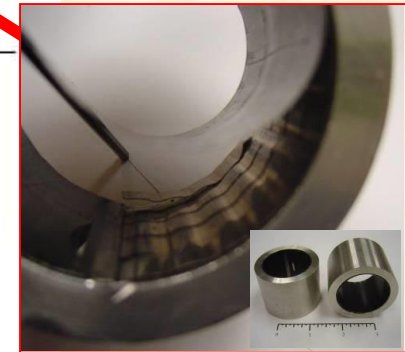


conventional
Oil-Bearing



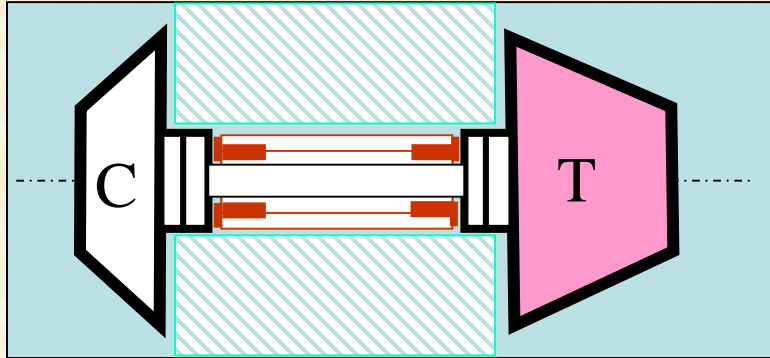
**Honeywell Oil-Less
Bearing System
(2007)**

**Foil Bearings
chosen**



PV turbocharger

Max. 240 krpm



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

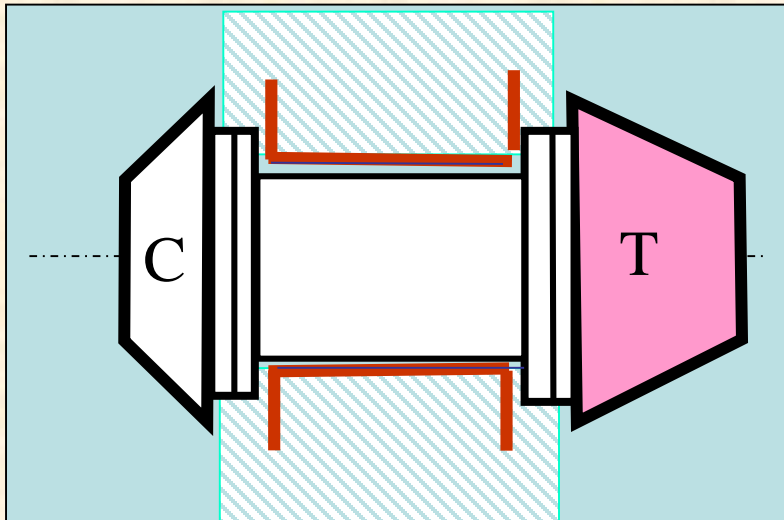
Engine oil TC

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)



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)

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/>