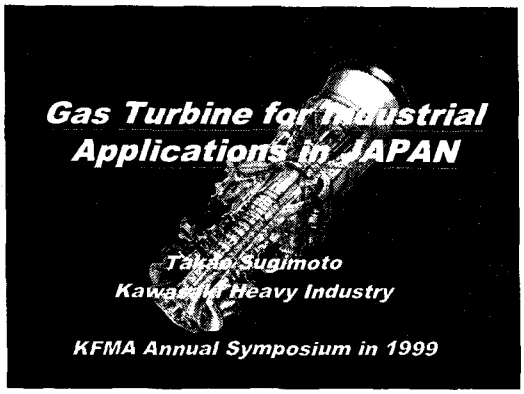
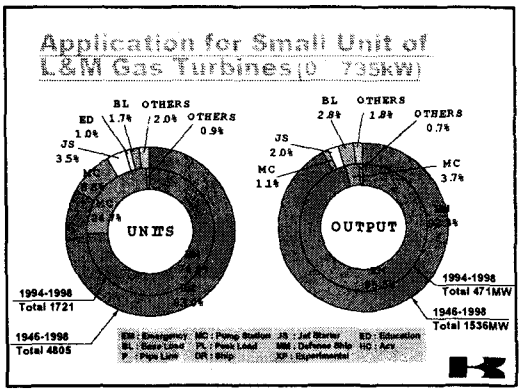
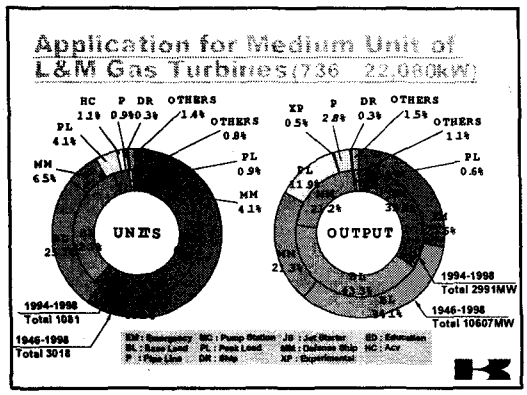
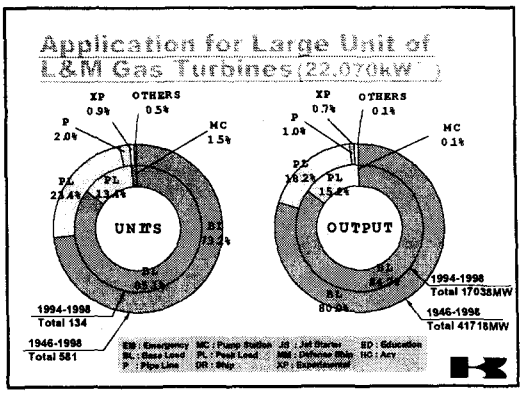
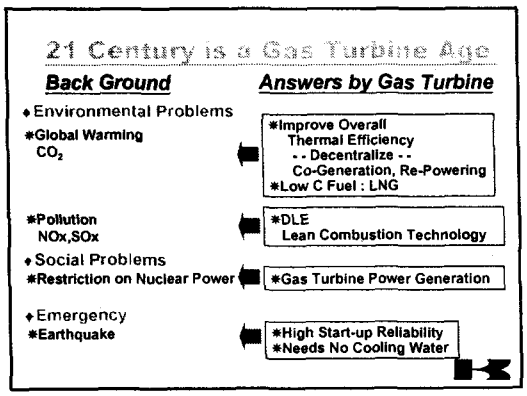
99 유체기계 연구개발 발표회 논문집 pp. 3-13
서울대학교 호암 컨벤션 센터 1999. 12. 3

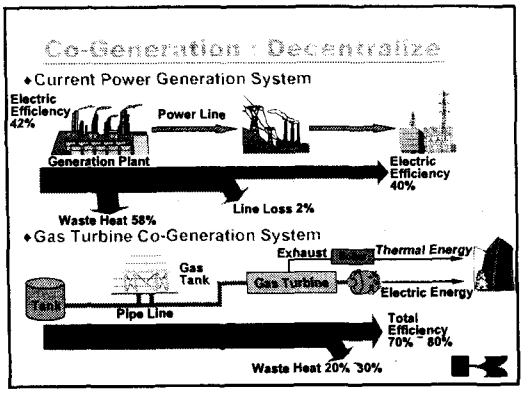












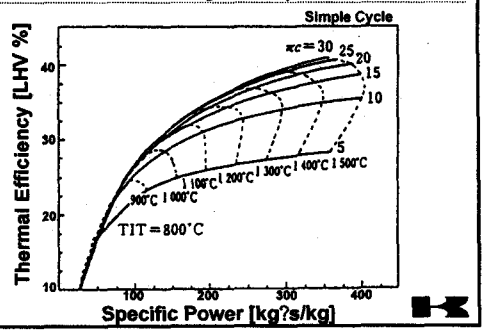
Technological Trend of Gas Turbine

* Improvements in Cycle
  - **Simple Cycle**
    Higher TIT up to 1500℃
  - **Regenerative Cycle**
    Recover Waste Heat by Heat Exchanger
  - **Re-Heat Cycle**
    Moderate TIT, High Efficiency by Sequential Combustor
* High Temperature Turbine
  - **Air Cooled Metal Turbine : FC / FC**
  - **Steam Cooled Metal Turbine: Saving Costly Cooling Air**
  - **Ceramic Turbine**

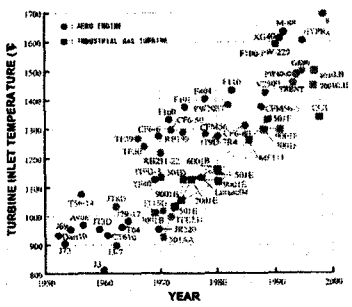
Technological Trend of Gas Turbine

* Low Emission Combustion
  - **Steam / Water Injection**
  - **Dry Low Emission**
* Aero Dynamics
  Three Dimensional Navier-Stokes Analysis Improves Aero Dynamic Design.
  - **Axial Compressor**
    - **Controlled Diffusion Aerofoil**
    - **3D Bowed Vane, End Bent Blade**
  - **Radial Compressor**
    - **High Backward Impeller**
    - **3D Arbitrary Impeller Blade**
  - **Axial Turbine**
    - **Bowed Nozzle Vane**
    - **Compound Leaned Vane**

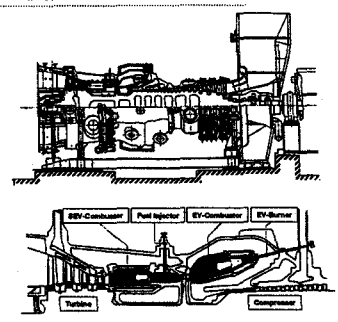
Thermal Efficiency vs Specific Power



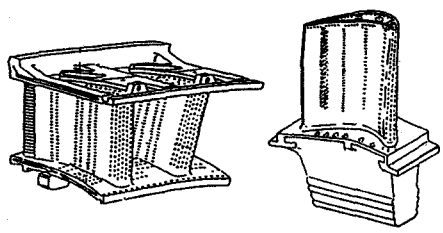
Trend of T.I.T.



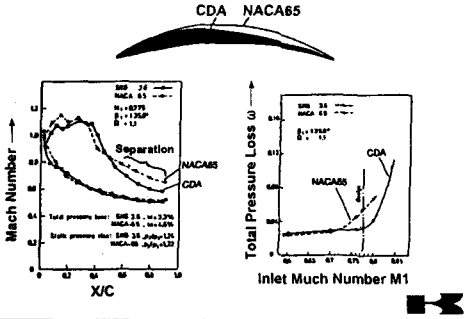
Re-Heat Gas Turbine

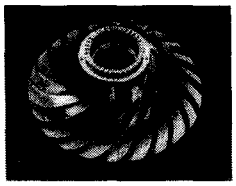


Full Coverage Film Cooled Vane & Blade



Effect of CDA

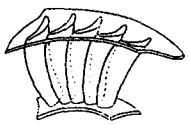




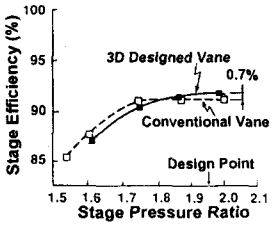
Axial Compressor Rotor

Radial Compressor Impeller

3D Bow Nozzle Vane

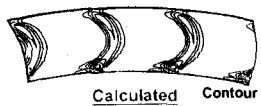


3D Designed Vane



3-D Viscous Flow Analysis (Vane)

Measured Contour Interval = 0.01



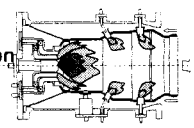
Calculated Contour Interval = 0.02

(Mesh 33X107X33)

$$\text{Pressure Ratio} = \frac{\text{Measured Total Pressure}}{\text{Upstream Total Pressure}}$$

DLE Design Concept

* Lean-Premixed Combustion
* Fuel Staging
* Supplemental Combustion
* Fully Retrofittable

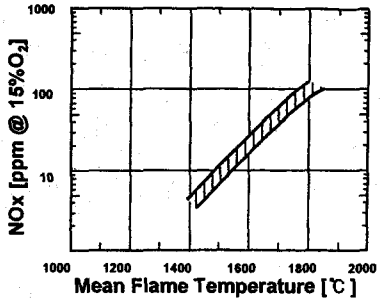


* Steam or Water Injection Pays The Penalty of Total Efficiency

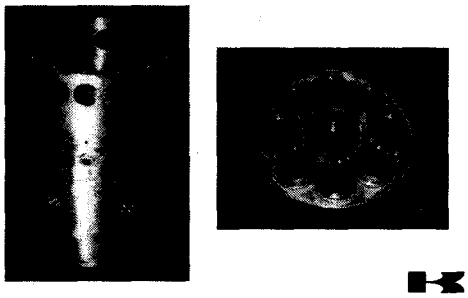
DLE Performance

* **NOx emissions less than 23ppm**
  - Japanese national regulation : less than 84ppm
  - Metropolitan area ordinance : less than 23ppm
* **CO emissions less than 50ppm**
* **Low emission from 75 to 100% power**

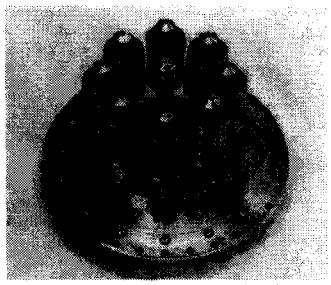
Flame Temperature vs NOx (NASA)

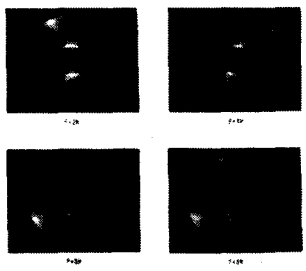


M1A-13D Combustor
(1500kW : multi burner type)

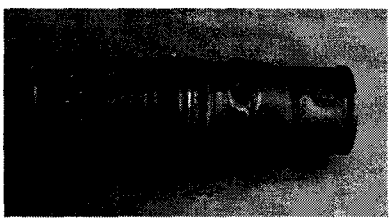


M1A-13D Burner Assembly

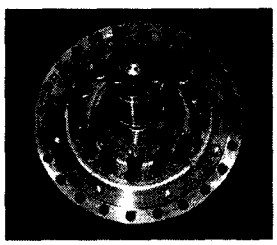




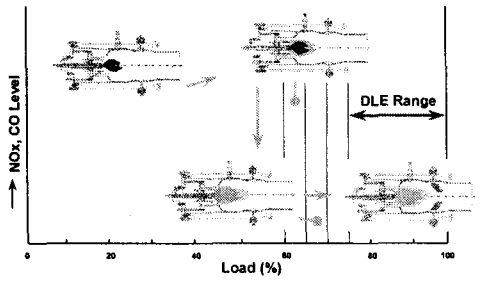
M7A DLE Combustor



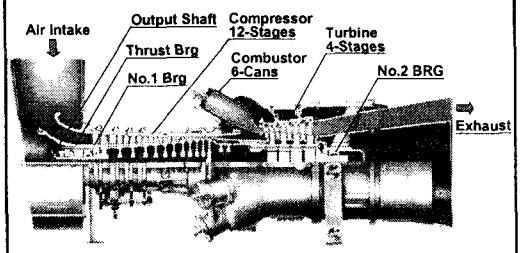
M7A DLE Burner Assembly



M7A DLE Fuel Staging



KAWASAKI M7A Gas Turbine



Performance

Power Output (1) (2)	6,150 kW
Efficiency (1) (2)	31.5 %
Turbine Inlet Temperature	1175 ℃
Exhaust Gas Temperature	555 ℃
Inlet Air Flow (1)	21.6 kg/s
Rated Speed	14,000 rpm
Pressure Ratio (1)	12.7

(1) ISO Condition, Natural Gas Fuel, No Duct Loss
(2) Gas Turbine Shaft End

High Efficiency Technology for M7A-01

*** High Turbine Inlet Temperature (1175℃)**

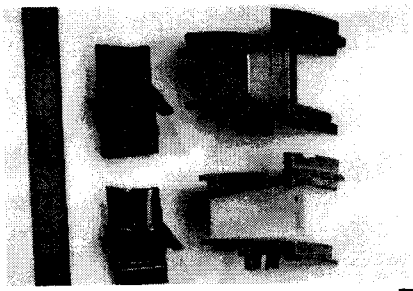
- New air cooled turbine blades & canes
- Thermal barrier coating for turbine nozzle vanes and combustor liner
- Double wall structure combustor liner

*** High Efficiency Compressor**

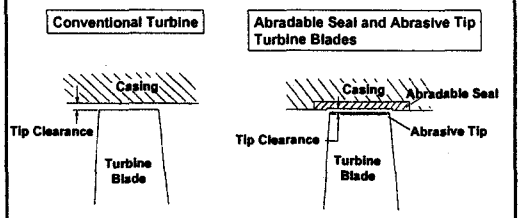
- Wide chord DCA airfoils
- Minimum blade tip clearance by abradable shroud

*** High Efficiency Turbine**

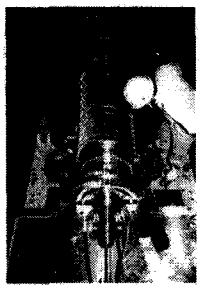
- Suitable vortex flow pattern
- Moderate aerodynamic loading
- Minimum blade tip clearance by abrasive tip-coating and abradable shroud



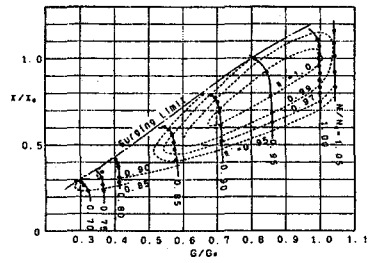
Abradable Seal and Abrasive Tip for Turbine Blades



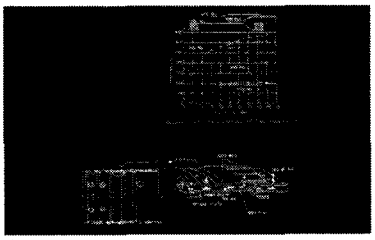
Axial Compressor Test Rig with Power Saving Turbine

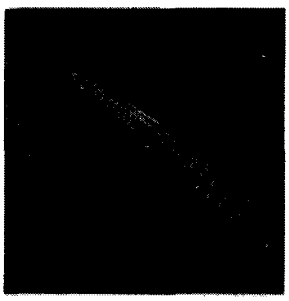


Measured Compressor Map

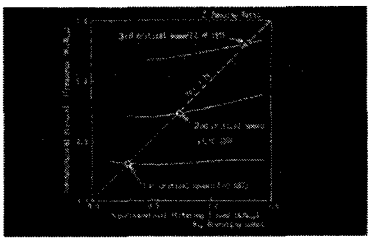


Double Wall Structure of the Combustor

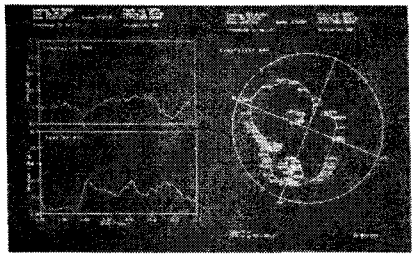


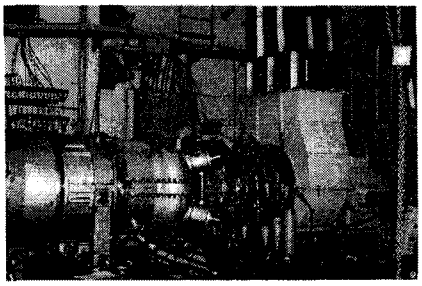


Calculation Result of Critical Speed



Measured Shaft Vibration

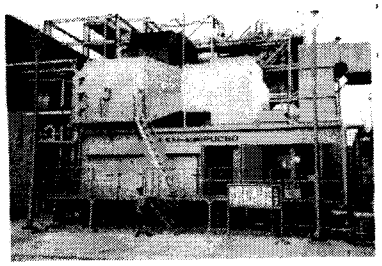


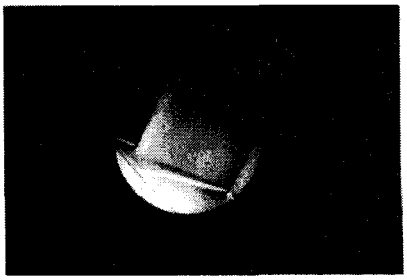


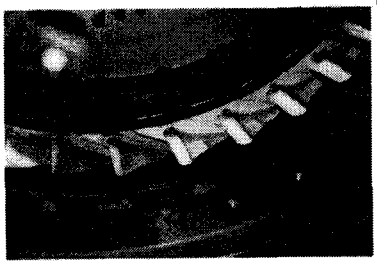
Shop Test Program

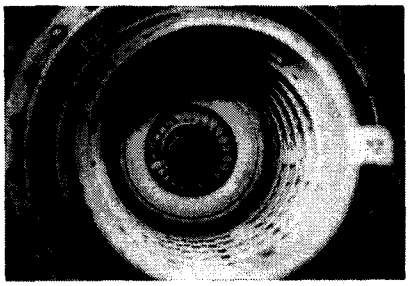
* Performance Test
* Rotor Dynamic Measurement
* Blade Resonance Evaluation
* Extra Severity Tests Over Speed, Overload, Over Temperature
* Cyclic Endurance

Kawasaki PUC60



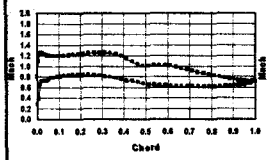




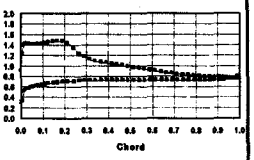


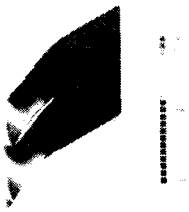
N-S Flow Analysis (Mean Radius)

MCA

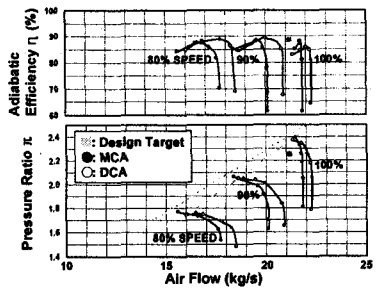


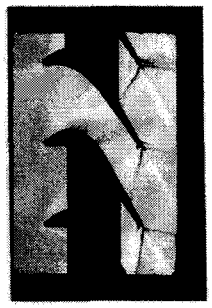
DCA



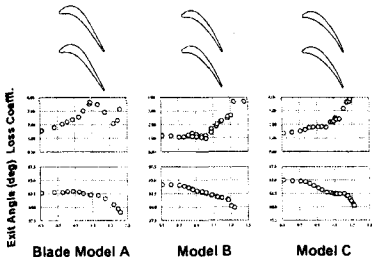


Supersonic Axial Compressor Teat Rig Performance

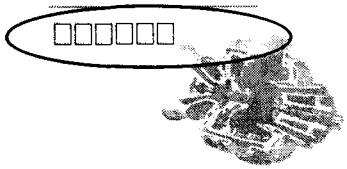




Transonic Turbine Cascade Model Test



Development Summary of the 300 kW Ceramic Gas Turbine



Why ceramics?

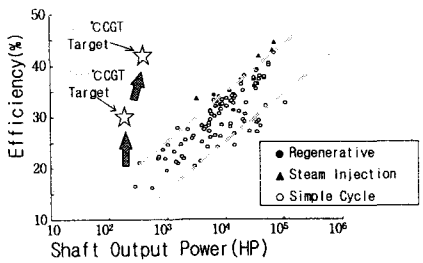
- **The** higher TIT, **the** better efficiency.
  - **But difficult to adopt cooling blades in** small GT **to get higher TIT**
- Cooling air **causes**
  - Efficiency loss
  - **Reduction of combustion air resulting** increase of NOx emission

- **Utilize high temperature resistant ceramics** to get higher TIT without cooling.

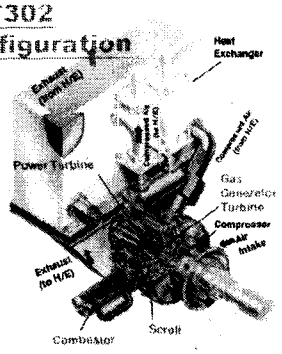
Development Target

	Target
Thermal Efficiency	42 %
Turbine Inlet temperature	1350℃
Output Power	300 kW class
Exhaust Emission	Satisfy the national regulation

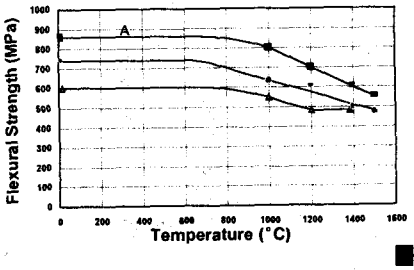
GT Efficiency vs. Output Power



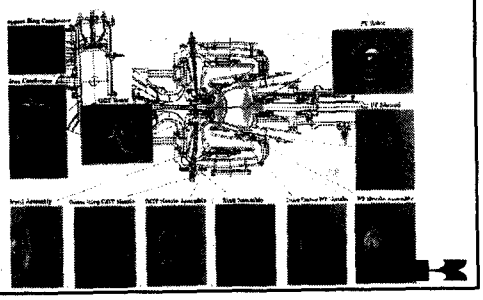
CGT302 Configuration



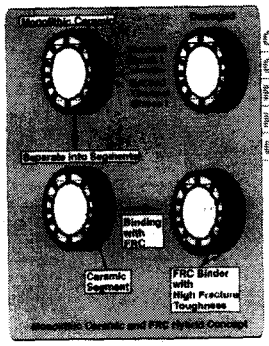
Flexural Strength of Silicon Nitride Material



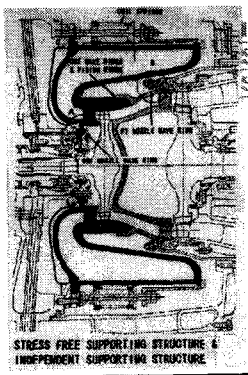
CGT302 Ceramic Components



Concept of Ceramic-FRC Hybrid Component

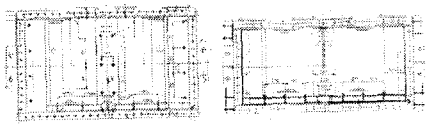


Independent Supporting Structure



Heat Exchanger

* **Improvement of efficiency**



Improve to Core 99 **Height** 650㎜

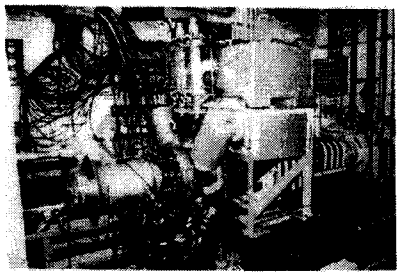
Achieved=85.5 %

Target=82%

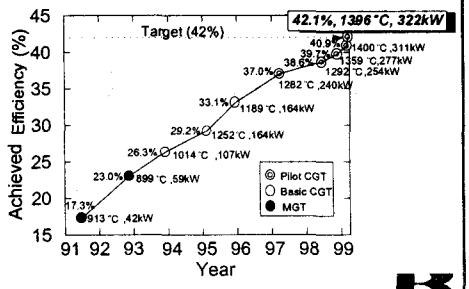
From Core 79 **height** 565㎜

Achieved=82%

CGT302 Test Cell



Achieved Efficiency Trend



Main Results

- **Confirmed the excellent efficiency 42.1%(1396 ℃) , 41.5%(1359℃)**
- **Confirmed 30 hours operation and low NOx emission 31.7ppm at 1350 ℃ .**
- **Confirmed over 2,100 Hrs accumulating operation time at 1200℃ to ensure reliability of ceramic components.**