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Turbo Air Supply and Power Generation System for Fuel Cell

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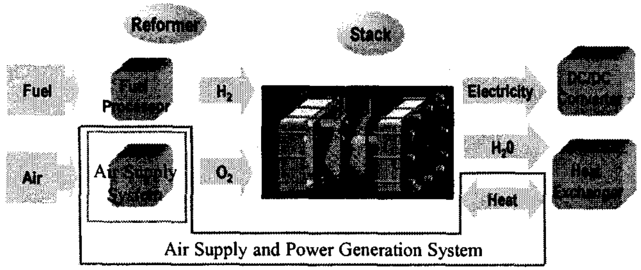
Overview of Air Supply System for Fuel Cell

❑ **Block Diagram of FC System**

- Stack : Produce Electricity, H_2O, and Heat by the Exothermic Reaction of H_2 and O_2
- BOP : Fuel Supply System, Air Supply System, Power Electronics, Heat recovery System



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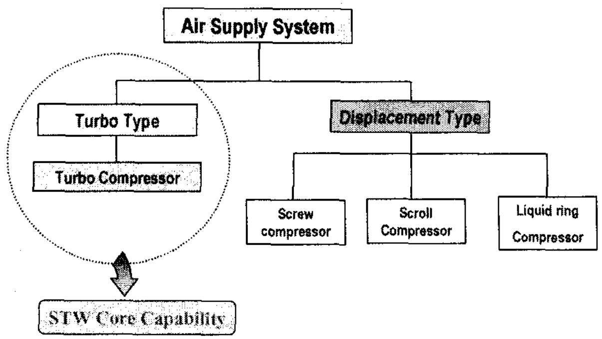
Overview of Air Supply System for Fuel Cell

❑ **Air Supply Systems for Pressurized Type FC Systems**



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Overview of Air Supply System for Fuel Cell

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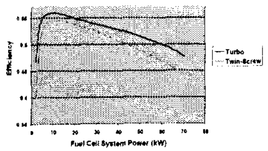
❑ Comparison of Air Supply Systems

	Turbo Compressor	Screw/Scroll Compressor
Layout		
Size	Compact	△
Maintainability	Better	△
System Efficiency		

Reference: Dr. Galen Kulp, "Comparison of a twin screw and a turbocompressor for a fuel cell system", Virginia Tech.

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Turbo Air Supply and Power Generation System

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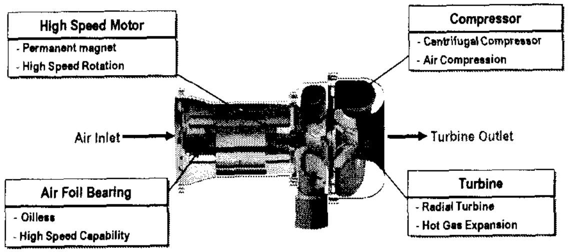
❑ Devised for efficiency improvement of FC Power generation System

- No Electric Power is Used for Air Supply Except for Startup: Self Sustainable
- Additional Electric Power Generation by HSM: Efficiency Improvement
- Pressurized Operation : Higher Stack Electrical Efficiency



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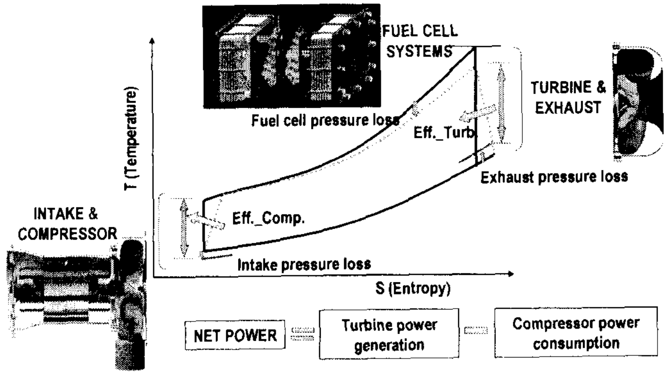
❑ Cycle Overview of Fuel Cell-Gas Turbine Hybrid System



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Turbo Air Supply and Power Generation System

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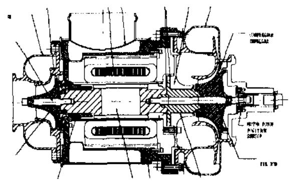
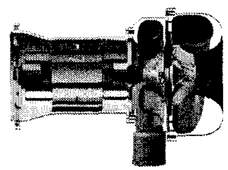
❑ Configurations of ASPGS depending on the Operation Temperature



Low Turbine Inlet Temp



High Turbine Inlet Temp

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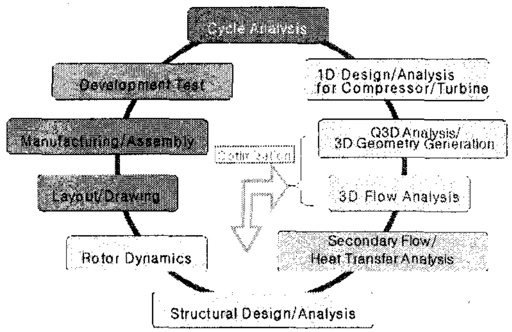
STW's Turbo ASPGS Development

❑ Air Supply and Power Genetation System (ASPGS) Development Process



STW's Turbo ASPGS Development

❑ Design Requirement

- High Efficiency : low power consumption or high power generation
- Long life, low cost, maintenance free system

❑ Design Strategy

Optimize to Fuel Cell System
- Pressure ratio(Pr), Flow rate, turbine inlet temperature(TIT)

Design
- Reduce the Pressure Losses : inlet and exhaust
- Increase the Efficiencies : compressor, turbine and motor/generator

Compromise
- Performance and Cost : efficiency, life and cost

❑ Technology

- Components design/manufacturing technology
  - intake, compressor, turbine, exhaust, HSM, AFB, PCU
- Components integration and matching
  - Power matching, rotor dynamic, hot section cooling, life design
- Test and evaluation

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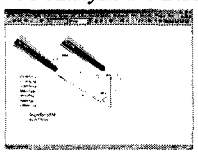
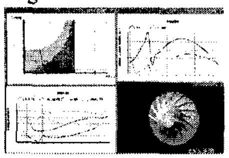
❑ Turbo Compressor

- Rotating dynamic machine to increase pressure with energy transfer due to changes of angular momentum

❑ Aerodynamic Design

- Mean streamline 1D analysis to determine the compressor size
  - Loss modeling, Slip factor modeling
  - Design/Off-design performance prediction
- Quasi-3D Analysis and Blade Profiling


Velocity Triangles


Q3D Analysis

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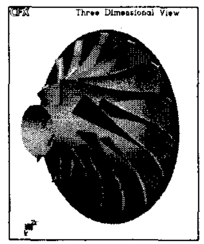
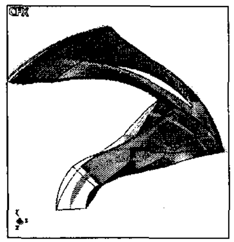
❑ 3D Flow Analysis

- Three-dimensional flow analysis for the compressor and diffuser with Navier-Stokes equations solver
- Turbulence Modeling : k-ε Model, etc
- Boundary Conditions : Inflow boundary, Outflow boundary, Periodic boundary, Solid wall boundary



Static pressure on the Impellor


Velocity Vectors and Static Pressure

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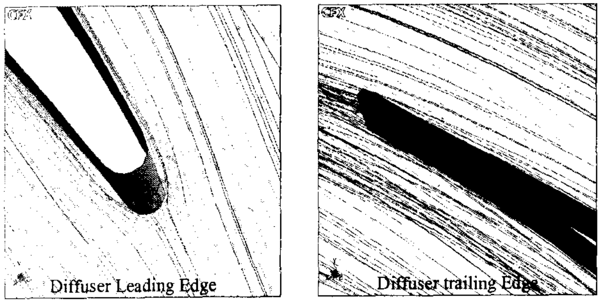

Velocity Vectors and Stream Lines (Design Point)

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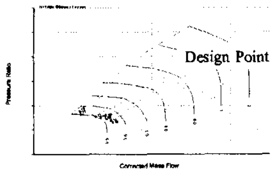
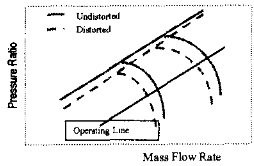
❑ Typical Compressor Map





❑ Key Points to Develop Compressors

- Off-Design Performances as well as Design Performance
- Surge Margin and Distortion
- Impeller Tip Clearance
- Multi-Disciplinary Optimization

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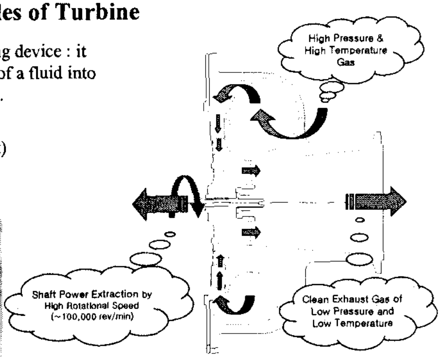
❑ Fundamental Principles of Turbine

- A turbine is a work-producing device : it converts the internal energy of a fluid into the energy of a rotating shaft.

$W_{out}=h^0(inlet)-h^0(outlet)$



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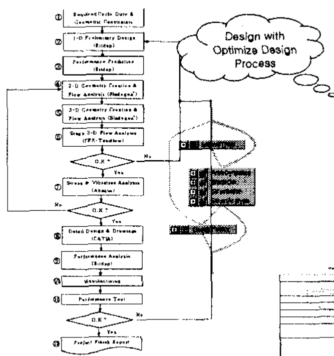
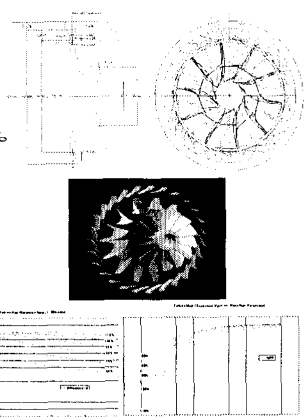
❑ Turbine Design and Analysis





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❑ Flow Network Analysis for the Secondary Flow Design

- Annulus Duct
- Sudden Expansion/Contraction Flow Passage
- Disk (Rotating/Stationary)

❑ Heat Transfer Analysis

- Prediction of the Onset of Transition
- Local Heat Transfer Coefficient Calculation

❑ Finite Element Heat Transfer Analysis

- Temperature Distribution Calculation of Components
- Linked to Flow Network Analysis Code
- Transient Analysis of Stator and Rotor

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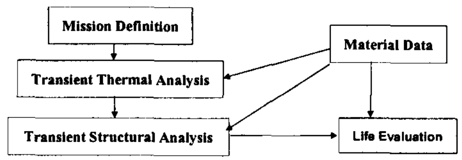
❑ Life Evaluation Procedure

- **Life Design**
  - Safe life design → Crack Initiation Life
  - Damage tolerance → Crack Initiation Life + Crack Propagation Life
- **Life Calculation**
  - Crack Initiation Life → Solid Mechanics Approach (Creep or LCF) (Total strain amplitude,von-mises stress)
  - Crack Propagation Life → Fracture Mechanics Approach (K value, Major stress)
- ***Life Evaluation Procedure***



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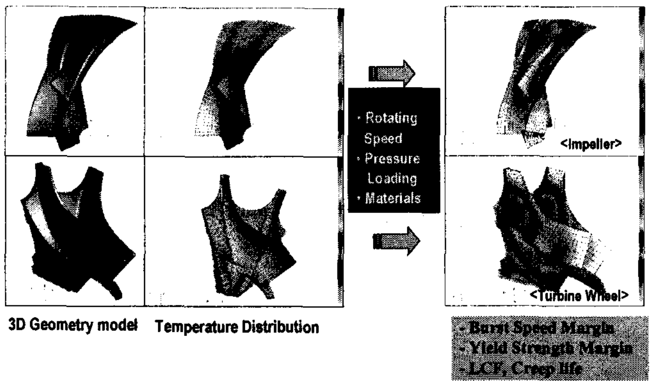
❑ Structural Design Criteria



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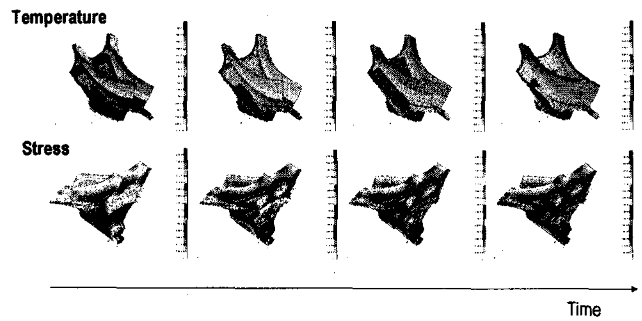
❑ Transient Stress & Temperature Plots of Turbine Rotor



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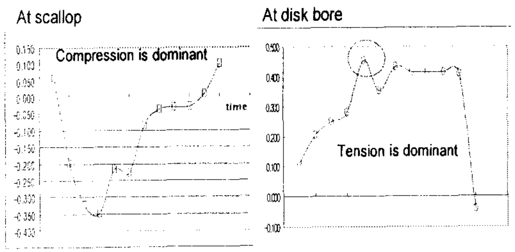
❑ Strain Evolution Curve at Critical Zone



Strain Results

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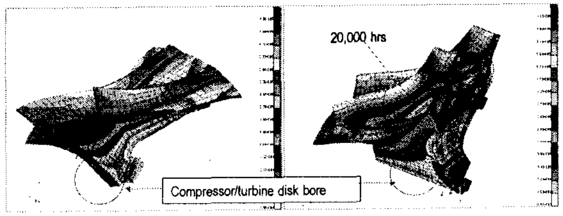
❑ Turbine Wheel Life Evaluation Results



- LCF life of Compressor and Turbine Disk bore will be more than 4,000 cycles
- LCF life of scallop is more than 4,000 cycles
- Creep rupture life is estimated to be more than 20,000 hrs

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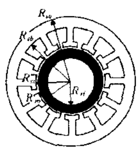
❑ High Speed Motor

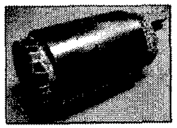
- Permanent magnet synchronous motor (2 pole 3 phase)
- High speed(line speed : ~300m/s)
  - retaining ring type
  - Small size and light weight
- Direct Coupled to the rotor of turbomachinery

❑ Power Control Unit

- Speed control by PWM (Employed sensorless vector control)
- Motoring and power generation mode control



Cross Section of HSM

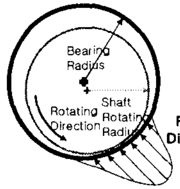


Stator

STW's Turbo ASPGS Development

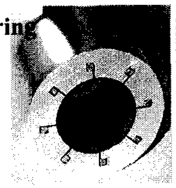
❑ Principles of Airfoil Bearing

- Shaft is lifted by dynamically generated air pressure within the bearing due to high rotation speed.
- Once the Shaft is lift off, it rotates without contacting with the bearing

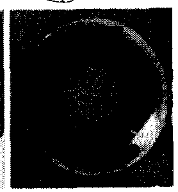


❑ Advantages of Airfoil Bearing

- Oil Free & Maintenance Free
- Simple Construction & Low Weight
- Low Wear & Long Life



Radial Bearing



Thrust Bearing

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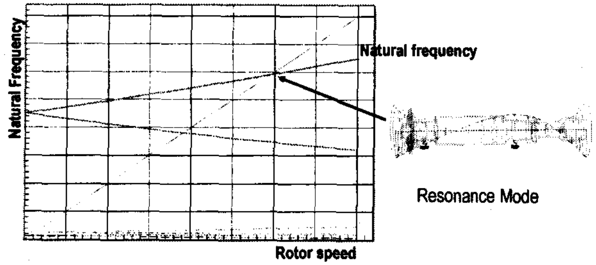
❑ Rotor Dynamics: Critical Speed Analysis

- Main goal of rotor dynamics is to get enough critical speed margin from the critical speed.
- Critical speed is a resonance RPM of the rotor which is defined by the intersection of rotor speed and natural frequency.



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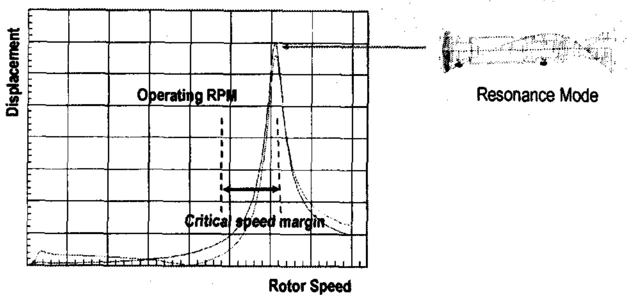
❑ Rotor Dynamics: Bearing Displacement Analysis

- Rotor has enough critical speed margin more than 25%.



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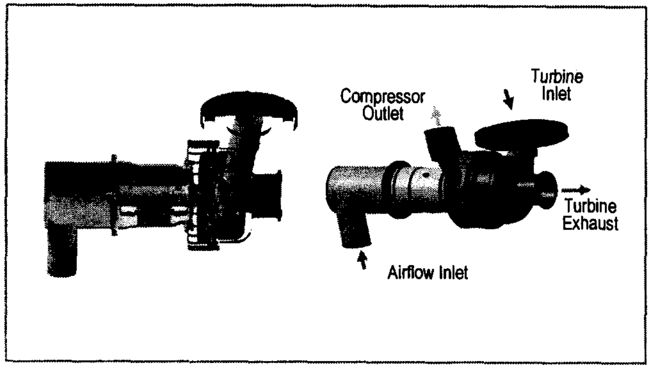
❑ 3-Dimensional Solid Modeling



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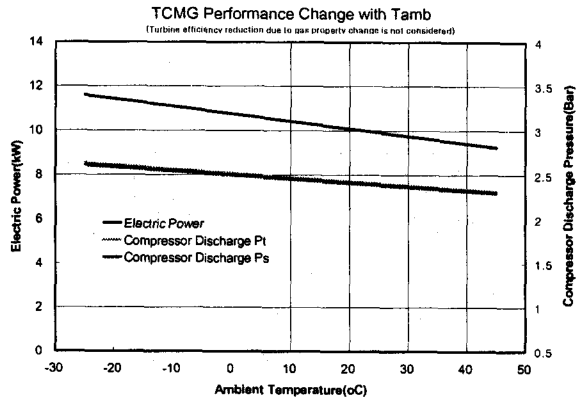

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Conclusion

- Development **of a high performance ASPG System for Fuel Cells** is underway
  - The first prototype was assembled in July, 2004
  - Validation Test will be completed by December, 2004

- STW's ASPG System is expected to have **the high efficiency, compactness, long life.**
  - ASPG System can supply air to FC and also generate power
    (Compressor Eff. 70%, Turbine Eff. 80%, Output Power of 9.2kW)
  - ASPG System employed a HSM and AFB reduces the volume and weight
    (188mmD x 289mmL, 26kg)
  - Life estimation results show the design life of 20,000hrs and 4,000cycles

- STW's ASPG System can be used as a BOP in pressurized-type **fuel cells for automobile and power generations application**