A Radical View on the Improvement of Gas Turbine Technology and Future Direction

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Integrated Design Tool

1D Cooling Flow Rate Sizing

Standard Convection Model

Throughflow Code includes leakage flows

2D Cooling Design

Stationary Tests

- Turbine Cooling Passage

Rotating Tests

- 1.5 stage Turbine Generic Test Rig
Contents

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Product Development Trend

Industrial Gas Turbine - Efficiency vs. Pressure Ratio

Product Development Trend
Aero Gas Turbine

Overall Gas Turbine Engine Efficiency as a Function of Core Thermal Efficiency, Propulsive and Transmission Efficiencies (Hathaway, Rosario, & Madavan, 2013)
Product Development Trend
Aero Gas Turbine

Specific Core Power as a Function of Turbine Inlet Temperature (Hathaway, Rosario, & Madavan, 2013)
Product Development Trend
Aero Gas Turbine

SFC as a Function of Propulsive and Thermal Efficiency (Haselbach and Parker, 2011)
Gas Turbine - at the limit of high pressure

- Compress air to higher pressure
- Temperature also increases
- Demand more work to reach target pressure
- Increase in associated losses
Gas Turbine - at the limit of high temperature

- Target higher temperature
- Demand more cooling
- Increase blockage
- Change in rotor incidence
- Reduced rotor work
- Decrease in efficiency

Sunwoo Hwang, 2015
Gas Turbine - push to zero emission

- Change the RTDF/OTDF to flatter profile
- Upper and lower endwalls get hotter
- Requires additional cooling
- Increase associated losses
Evolutionary vs. Revolutionary

- **Design:** 1~ 3D vs. 3D Approach
- **Manufacturing:** Casting vs. ALM
- **Operation:** Design vs. Off-design
- **Service:** Diagnostics vs. Prognostics
Evolutionary vs. Revolutionary

Effectiveness ($\varepsilon$) vs. $m^*$

Case 0 (Conventional Multi-pass)
Case 1 (Triangular Impingement)
Case 2 (Twin Multi-pass)
Case 3 (Wall Cooling)
Case 4 (Mixed Multi-pass)

Gas Turbine Lab., Pusan Nat’l Univ, 2017
Evolutionary vs. Revolutionary

Topology optimization: Gas turbine rotor heat shield

- Results: density distribution after topology optimization.

- Results: blue area (low density) means removable material.

The weight loss of this component after optimization is ca. 15%.

Alstom Image
Evolutionary vs. Revolutionary

Deep Learning Generative Design

Dassault Systems Image

Pusan Nat’l Univ Image
Radical Thinking on Turbine Design

Concept of Topology

- By stretching and deforming, it is possible to turn a doughnut into a cup.
- They are all topologically equivalent.
Radical Thinking on Turbine Design

Topology Optimization

Local control of density $\rho > 0$ (void) and 1 (solid)

Minimize $F(\rho)$
Subject to $R(\rho) = 0$, $\rho_{min}$

Allow density design variables to vary continuously for gradient-based optimization
Radical Thinking on Turbine Design
A Trial on Internal Structure

Gas Turbine Lab., Pusan Nat’l Univ, 2014
Radical Thinking on Turbine Design
A Trial on a Airfoil Shape

vf: volume fraction

Shinyoung Jeon, 2016
Radical Thinking on Turbine Design

Why starts with U-bend?

Standard Blade Model (Chauvin, 1969)
Cooling efficiency is primarily determined by the cooling system geometry.

\[ \eta_c = 1 - \exp \left( -4St \frac{l_c}{d_H} \right), \text{ Where } St = \frac{h_c A_c}{m_c C_{p,c}} \]

For larger \( l_c/d_H \), increase the number of small holes or use multiple passages

Radical Thinking on Turbine Design
A Trial on Fluid Domain (2D)

U-bend (2D) results (Re_{in} = 100k)
Number of cells = 65748
Computational resource: CPU@3.20GHz, 48GB memory
Calculation time (per 100 iteration) 2D model = 25.32 [s]
3D model = 3825.18 [s]
Radical Thinking on Turbine Design

Additional Features (2D)

Added features to meet min p-loss

Optimized Shape for U-Bend  Velocity Distribution

Changhee Kim, 2016
Radical Thinking on Turbine Design
Optimum U-bend Shape (3D)

[Ref]
Namgoong H., Ireland P., Son C., et al., 2015, "Optimization of a 180 Degree U-Shaped Bend Shape for a Turbine Blade Cooling Passage Leading to a Pressure Loss Coefficient of Approximately 0.6," Journal of Aerospace Engineering US8662825, Ireland et al., Cooled Aerofoil Blade or Vane
Radical Thinking on Turbine Design
Finally, bring it back to CAD

Final Topology → Point Cloud Data/Extraction → Triangulate → Model Translation in CAD

Changhee Kim, 2016
What Next?
Summary

- Follow Trends? vs. Radical Thinking!
- Global network becomes more important
- Grow people and share infrastructure
“One of nicest things about life is the way we must regularly stop whatever it is we are doing and devote our attention to eating.”

Luciano Pavarotti