Demonstration of Enabling Spar-Shell Cooling Technology in Gas Turbines

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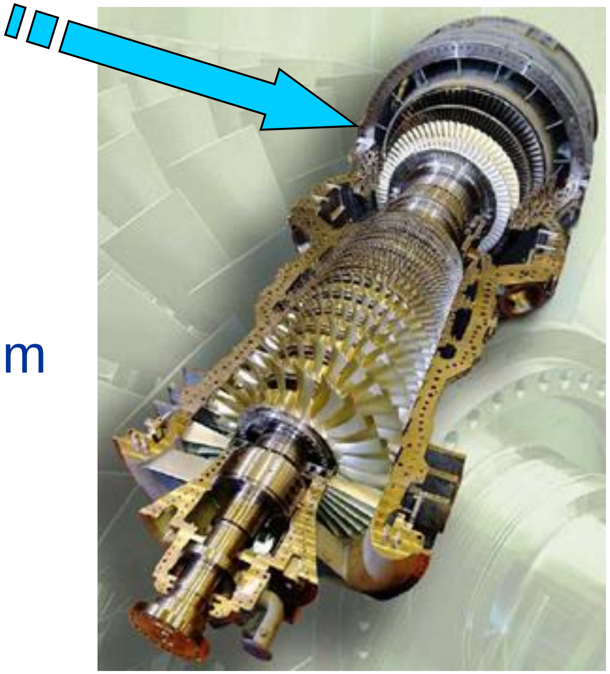
Overview

- Why spar-shell?
- Demonstration of enabling spar-shell cooling technology in gas turbines

Why Spar-Shell?

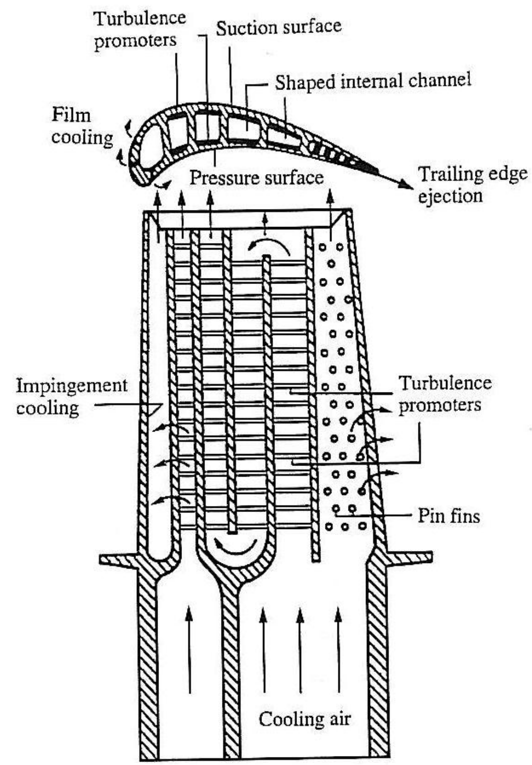
Background – Current state-of-the-art

- Turbine cooling technologies permit temperature of environment to exceed material capability (including melt) by wide margin
  - Front turbine stages characterized with extensive use of film cooling
  - Aft turbine stages characterized highly efficient convective cooling designs – No film cooling
  - Thermal barrier coatings used extensively throughout the turbine



Why Spar-Shell?

Background – Current state-of-the-art



Turbine components produced In monolithic structure

- Materials: Advanced nickel-based alloys
- Casting: Directional solidification & single crystal
- Good <u>compromise</u> of thermal and structural capabilities

Advanced internal convection and film cooling

Ref: Han, J. C., Dutta, S. & Ekkad, S.V., *Gas Turbine Heat Transfer and Cooling Technology*., page 20, Taylor & Francis, 2000.

Why Spar-Shell?

Future turbine systems require increased efficiency

- Address well-known problems of global energy usage & emissions
  - CO_2 production increasingly accepted as global warming cause/contributor
- Requires increased turbine inlet temperature & pressure
  - Increased heat load
- Possible shift of working fluid
  - Reduced nitrogen, increased steam & CO_2

→ Explore innovative cooling system design approaches to increase turbine efficiency by reducing required cooling flows

Why Spar-Shell?

Alternative to existing state-of-the-art

- Enabler for advanced cooling
- Provides path for implementation of next generation materials
- Optimized thermal/structural arrangement allows increased firing temperatures and improved efficiency

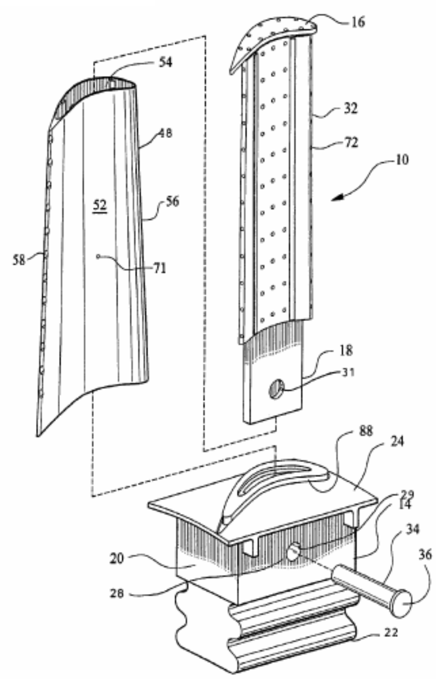


FIG. 1

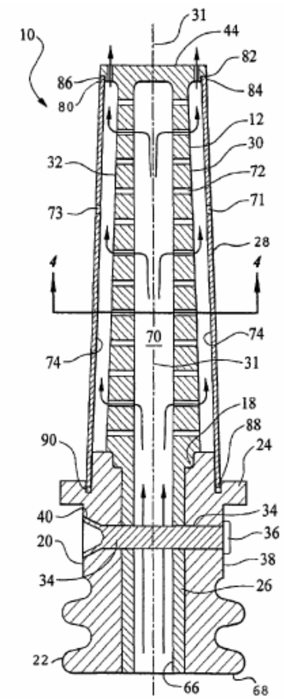


FIG. 3

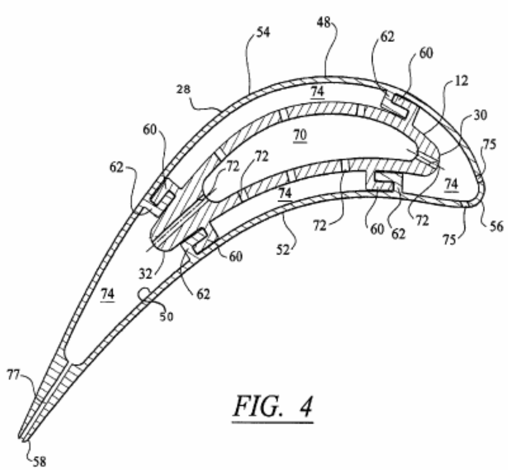
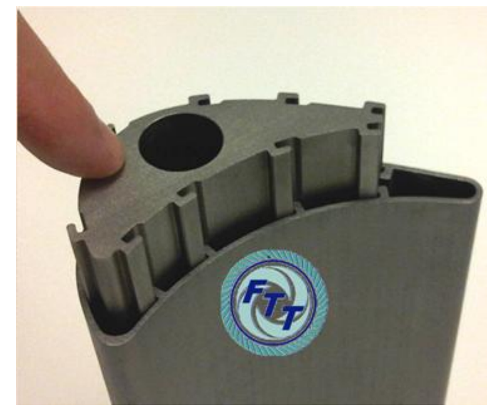


FIG. 4



Ref: U.S. Patent #7080971, "Cooled Turbine Spar Shell Blade Construction, J. W. Wilson and W. Brown, July 25, 2006.

Why Spar-Shell?

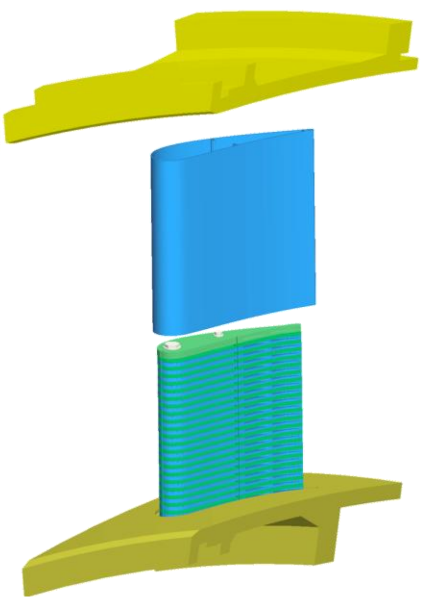
Global benefits of spar-shell technology:

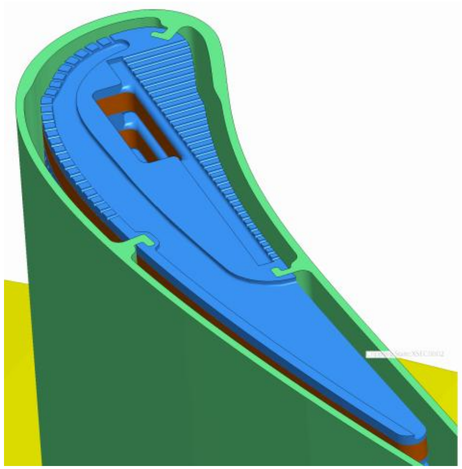
- Can be Applied to 500GW of Installed Power Generation Capacity
  - 14% of Worldwide Capacity
- Curb Emissions
  - Reduce CO_2 Emissions by 25 Million Tons/Year
- Reduce Dependence on Foreign Oil
  - Natural Gas Savings of 480 Trillion Btu/Year
  - Equivalent Oil Savings of 84 Million Barrels of Oil (4 Days of U.S. Consumption/Year)

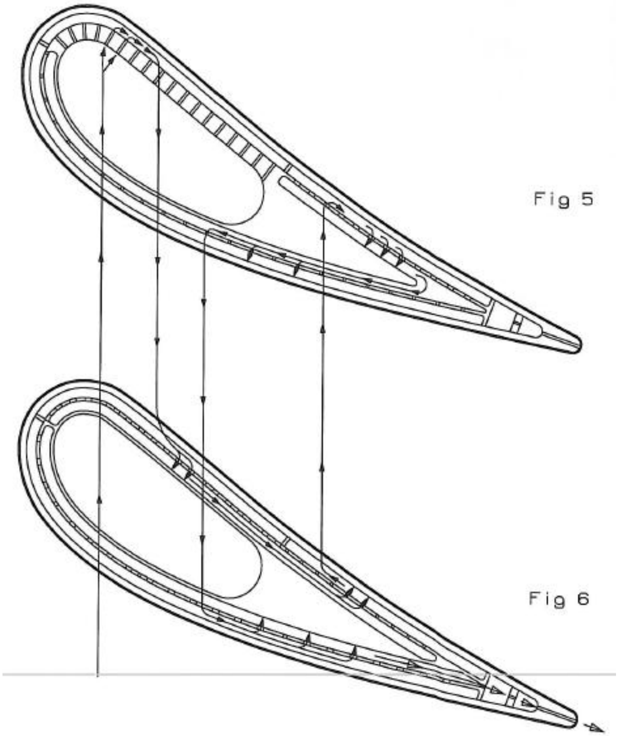
Spar-Shell Technology – What Is It?

Innovative design that enables 40% cooling flow reduction

- FTT sequential-impingement cooling scheme based on new insert design improves cooling (reduces cooling flow)
- Introduction of flexible, multi-piece design reduces thermal/structural fight for improved durability
- Enabler for the use of alternative, high temperature material systems







FTT Invention Disclosure F650R

Commercialization Plan

Developing opportunities in the marketplace

Near-Term: Retrofit Into Existing GT's

- First commercial product (1st stage turbine vane): Enhance durability of hot section components
  - 40% cooling flow reduction
  - Reduced combustion temperatures (average and hot streak)

Mid-Term: Extend Technology to Other Turbine Components

- Enables turbine rotor inlet temperature to be increased for increased power and efficiency

Future Plan: Enabler for Advanced GT's

- Enables use of high temperature materials in the shell to address increasing firing temperatures

Development Funding Opportunities

SBIR programs*: Government-funded avenue to accomplish specific objectives within small business

Phase I – Development of a concept, fundamental research

- Development of innovative cooling approaches for robust design (DE-SC0002713)

Phase II – Detailed design/development, manufacture of prototypes

Phase III - Commercialization

- Demonstration of enabling spar-shell cooling technology in gas turbines (DE-FE0006696)

* Small Business Innovative Research (Program/Grant)

Enabling Spar-Shell Cooling Technology

Program goals and objectives

- Develop and test – commercial prototype:
  - First-stage turbine airfoils requiring significantly less cooling flow than the current state-of-the-art
- Proposed cooling approach:
  - Addresses durability concerns associated with turbine inlet pressure and temperature increases desired for future gas turbines
- Open door to commercialization:
  - Both F-frame and other highly cooled turbine airfoil applications

→ Enabling technology for future gas turbine-based power systems

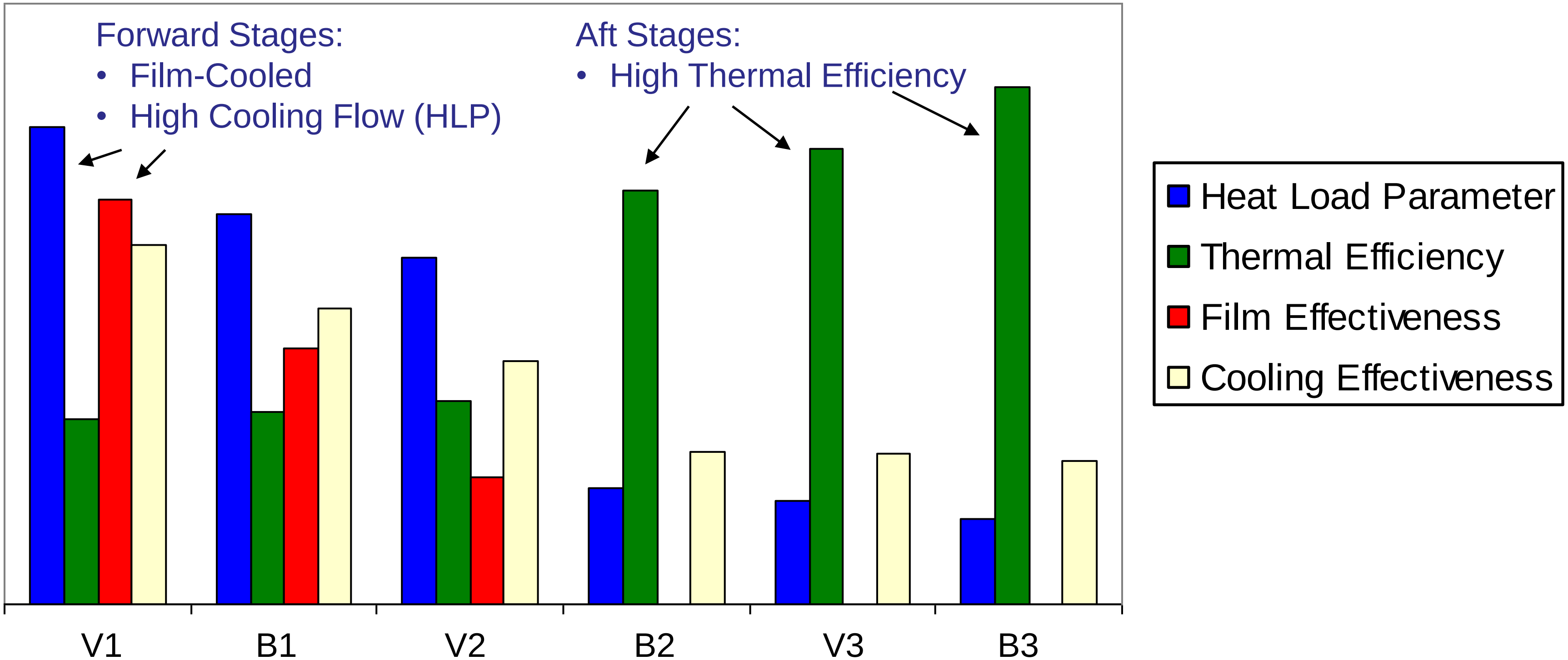
- DOE Office of Fossil Energy-sponsored hydrogen and oxy-fueled turbomachinery programs

Enabling Spar-Shell Cooling Technology

Low-risk approach to commercialization

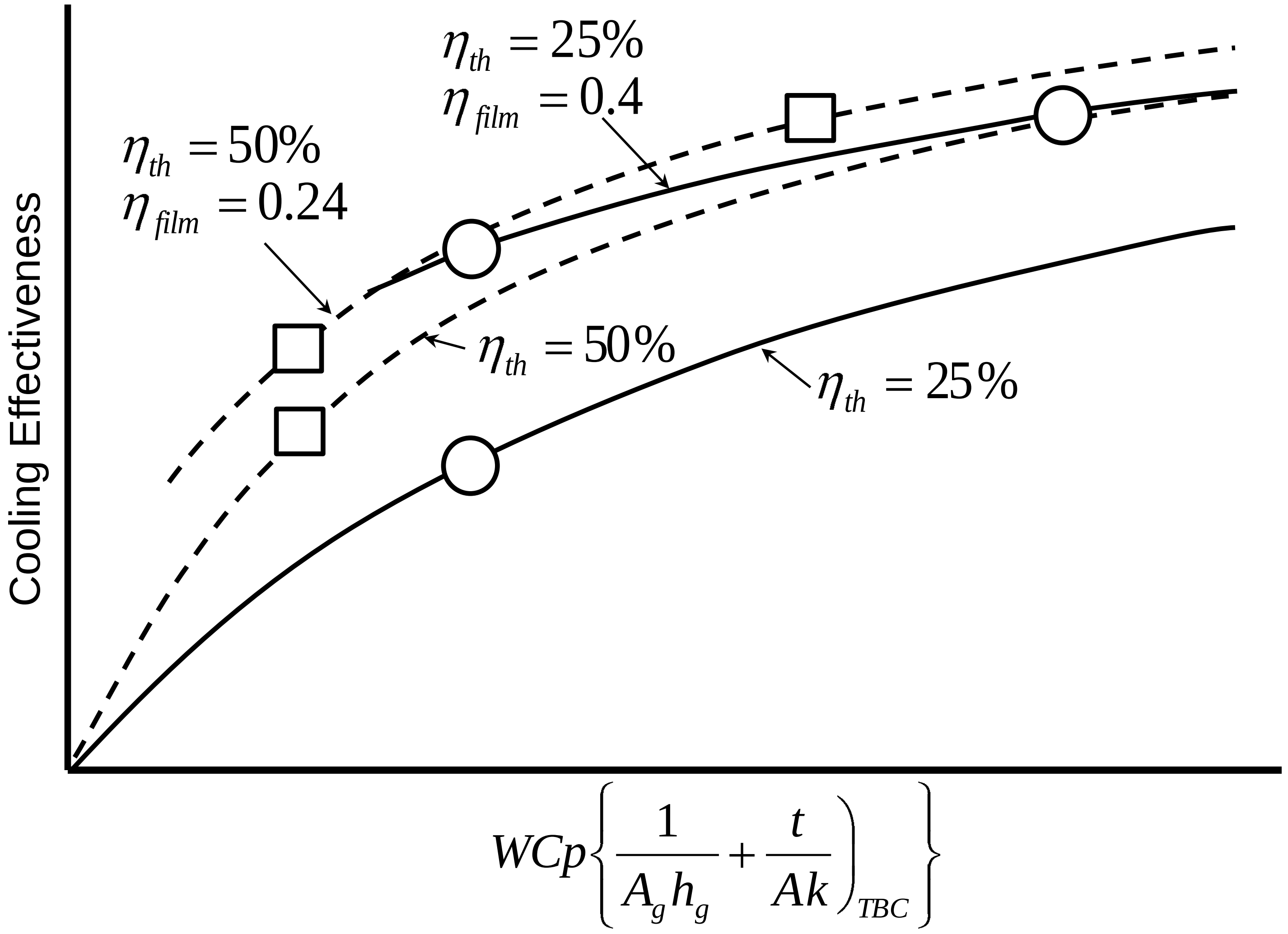
- 1st stage turbine vane is a stationary component – no rotating mass concerns
- Use existing (proven) vane casting as the shell
- Sequential-impingement cooling provided by FTT spar insert
  - Low risk due to cold environment
- Basic cooling flow and heat transfer performance can be evaluated via experimental test prior to engine installation
- Health can be monitored during engine test to assure product integrity
  - Demonstration will install 6-8 parts in a rainbow arrangement with bill-of-material parts
  - Frequent borescope (visual) inspection
  - On-line health monitoring instrumentation (IR & thermocouples)

Application of specific cooling methods depends on local environment



- Material limits routinely approached – Natural consequence of need to minimize cooling flows to optimize the power and performance of the machine
- Cooled turbine components placed in position of inherent risk
  - Coolant system breakdown may cause material limits to be exceeded, resulting in premature distress, or failure of the component

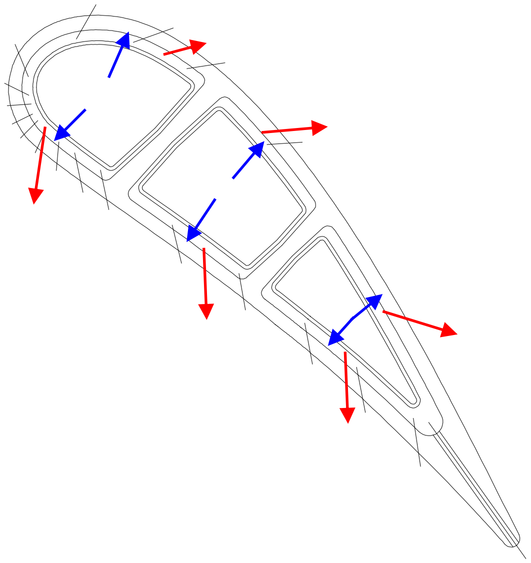
Approach to reduce cooling flow requirement

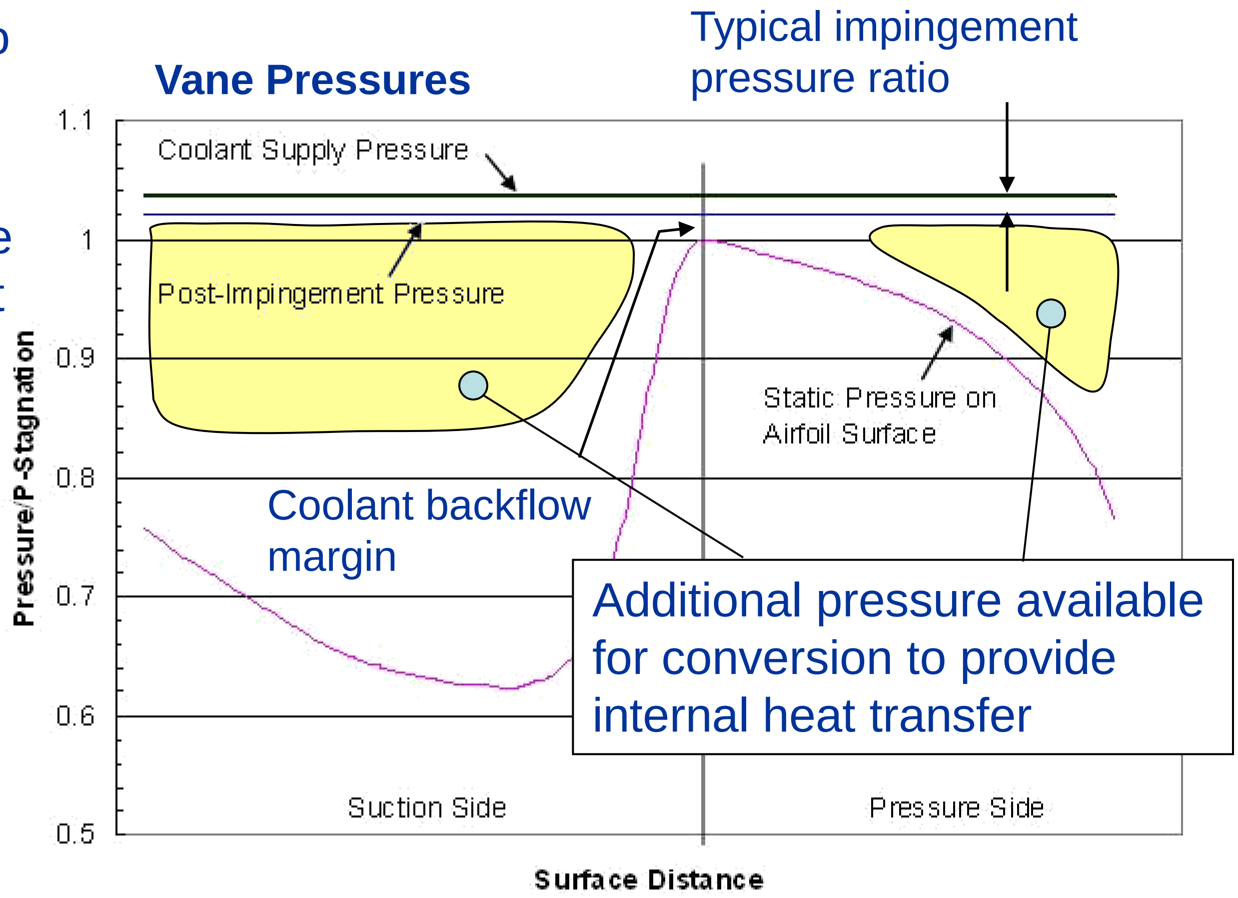


Conventional cooling design

→ Philosophy/practice limits cooling potential

- Impingement pressure ratio typically near constant around airfoil
- Post-impingement pressure set high enough for coolant outflow to leading edge

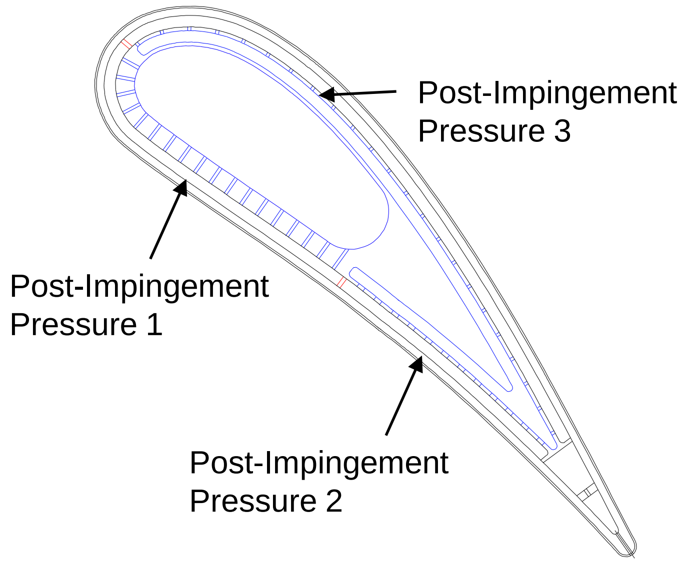




Enabling Spar-Shell Cooling Technology

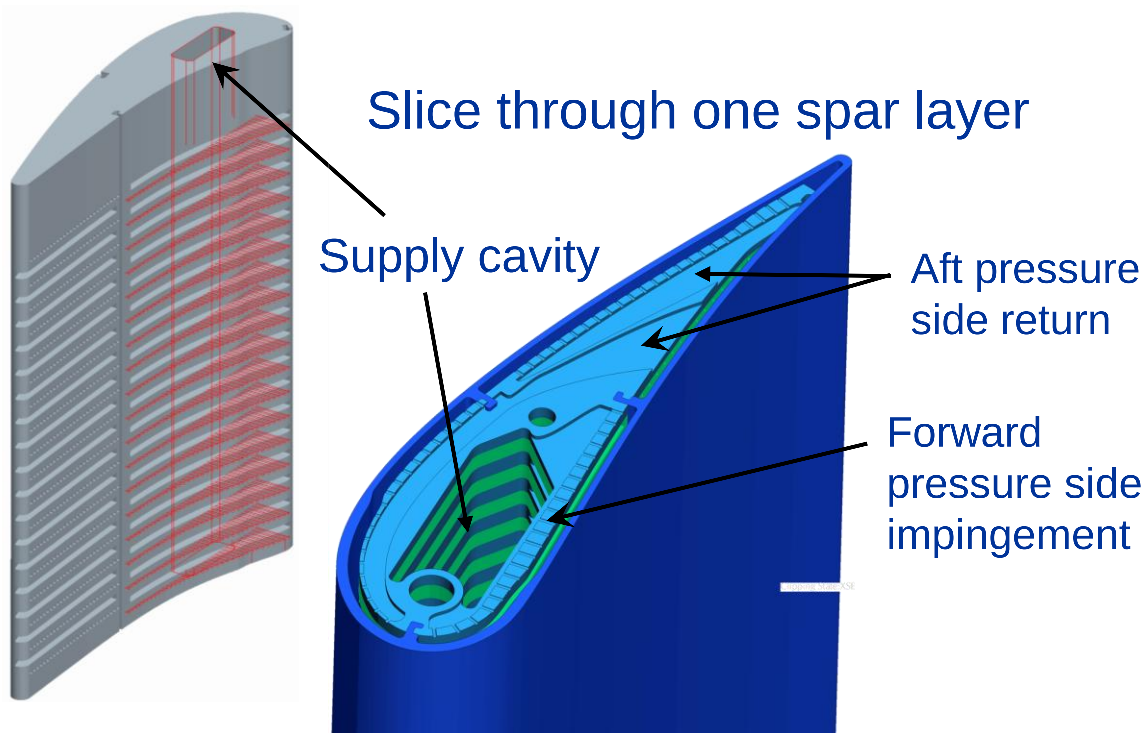
Sequential impingement cooling: Makes use of available pressure to increase heat transfer

- Re-use of coolant through multiple, sequential impingement
- Post-impingement pressure set high enough for coolant outflow to all regions of airfoil



Enabling Spar-Shell Cooling Technology

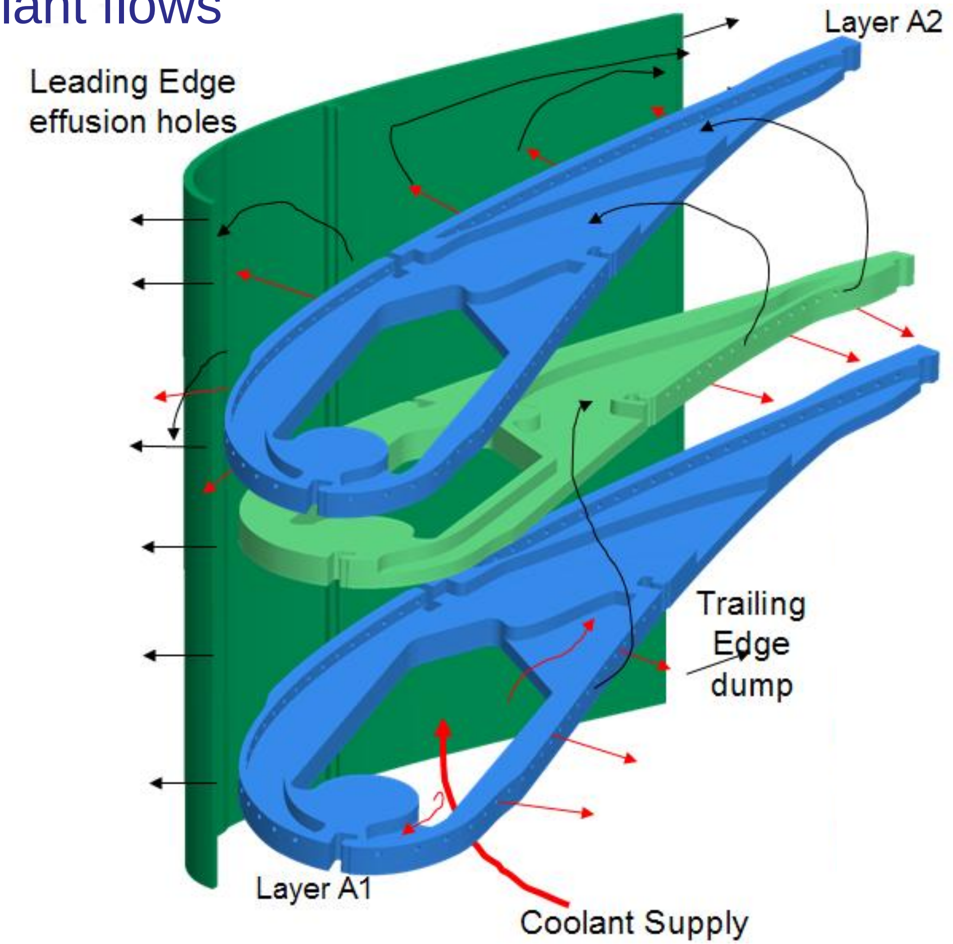
Advanced cooling technology design



Enabling Spar-Shell Cooling Technology

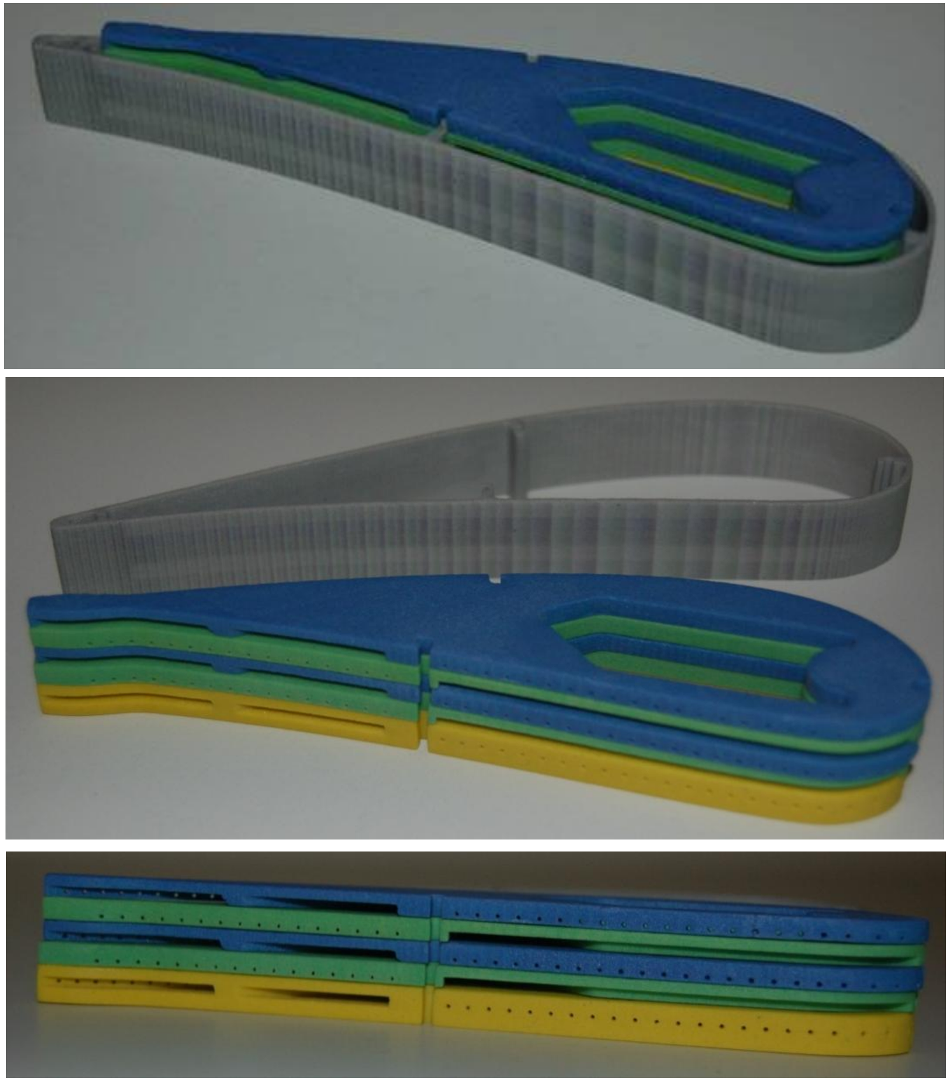
Advanced cooling technology geometry

→ Layered spar satisfies sequential impingement system needs for routing of coolant flows



Enabling Spar-Shell Cooling Technology

Rapid prototype of spar-shell vane



Summary

- FTT is executing a program to accelerate demonstration and validation of Spar-Shell turbine components in a commercial prototype scale
- The program includes design, procurement and instrumentation of hardware, test planning and support during engine assembly and test, and post-test data reduction
- Target test vehicle and windows of opportunity have been identified – design of hardware is in progress

Acknowledgements

Department of Energy

National Energy Technology Laboratory

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Enabling Spar-Shell Cooling Technology

Thank You

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Questions?