Drexel University Improves the Performance of a New Design of Cryocoolers

THE CHALLENGE

Coupled flow and heat transport in the various components of a cryocooler is complex and unstable. Drexel research team had a challenge to study the work principles of a cryocooler and improve the product design while avoiding physical experiments. The simulation challenge included meshing a complicated geometry and solving complex system with moving boundaries and non-porous, porous zones.

THE BENEFITS

- Design an efficient and reliable cryocooler
- Reduce cost and production time by approximately 50%
- Improve performance of cryocooler and identified key parameters with simulation & sensitive analysis
- Generate high quality meshes reducing simulation time
- Benefit from great technical support provided by ESI's engineers

"While the application areas of cryocoolers are exciting, the underlying physics and computational tools required for simulating the systems are complex. The features available in ACE+ Suite allowed us to overcome the demands and develop realistic models for improving the performance of a novel design of cryocoolers."

Dr. Bakhtier Farouk, Professor of Mechanical Engineering, Drexel University

Cryocoolers are small refrigerating machines that are used to achieve and maintain very low temperatures, typically below 120 K (~ -153°C). Today, cryocoolers are used in various applications in the semiconductor, biotechnology, defense and aerospace industries. However, poor efficiency, low reliability, and high costs of the current cryogenics is limiting its widespread commercialization.

Professor Farouk's team at the Mechanical Engineering and Mechanics Department at Drexel University in Pennsylvania (supported by the US National Science Foundation) conducted extensive research to develop an efficient, reliable and cost effective Orifice Pulse Tube Refrigerator (OPTR), a thermoacoustic cryocooler that does not require any external cryogenic.

One of the key challenges was to better understand the complex cryogenic physics and come up with a prototype with minimum physical experiments. The Drexel research team decided to use ESI's ACE+ Suite to perform simulations and improve the product design at low costs.

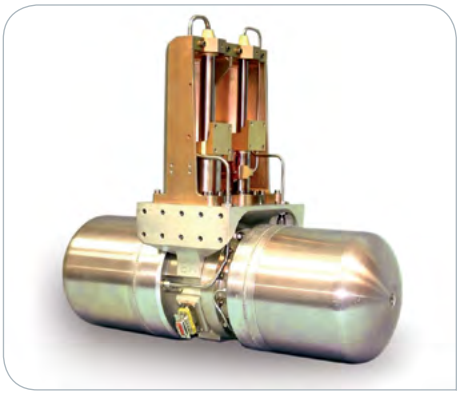
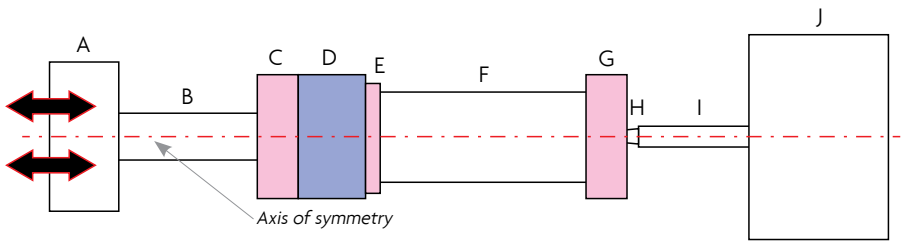


Figure 1 : Example of a Cryocooler
Courtesy of NASA

Design Optimization Using ACE+ Suite

To simulate the cryocoolers, Drexel research team had to first create a complicated 3D geometry that included various moving components as shown in Figure 2. The researchers were able to quickly create the geometry along with a high quality mesh using the hybrid mesher, CFD-GEOM. The coupled flow and heat transfer phenomena were then simulated using ACE+ solver, a CFD/Multiphysics solver available within the ACE+ Suite.



A : Compression Space (moving Piston)
B : Transfer Tube
C : Aftercooler
D : Regenerator
E : Cold Heat Exchanger
F : Pulse Tube
G : Hot Heat Exchanger
H : Orifice
I : Inertance Tube Section
J : Compliance / Buffer Volume

Figure 2: Model geometry of the Orifice Pulse Tube Refrigerator (OPTR).

The non-equilibrium porous-medium models along with the Transfinite Interpolation (TFI) mesh movement scheme were key to accurately simulate the cryocooler. After validating the ACE+ solver model with the experimental data, the research team simulated multiple design prototypes. ACE+ solver's functionality to dynamically change material properties and boundary conditions made it easy to determine the optimal operating parameters for each design.

The first set of simulations revealed interesting flow and thermal patterns in the 'pulse tube' component of the cryocooler. The fluid from the hot and cold ends was mixing, thereby reducing the effectiveness of the cryocooler. Based on the insights obtained, the team made design changes and was able to isolate the cold and hot ends of the pulse tube. This created a thermal buffer zone at the center of the pulse tube, improving the efficiency of the cryocooler.

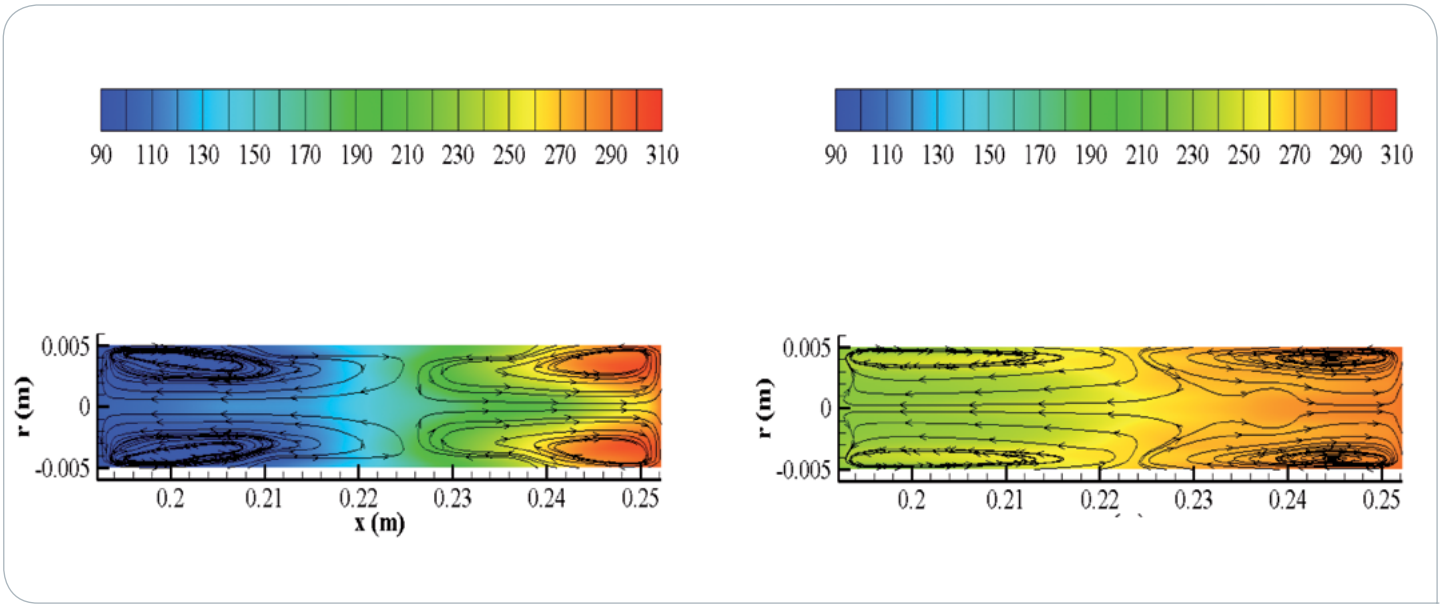


Figure 3: Flow and Temperature Profiles in "Pulse Tube" section of the cryocooler before (left) and after (right) the design changes.

Results and Conclusion

The Drexel research team succeeded in designing novel cryocoolers that are cheaper and more efficient. Moreover, the simulation reduced the design time by 50% and the product development cost by 40%. The new design will be used by government and commercial organizations. Drexel research team contributed in improving the commercial viability of cryocoolers significantly. The Drexel team continues to use ACE+ Suite for its research.

To find out more about ESI's solutions for multiphysics, please visit : www.esi-group.com/products/multiphysics

ABOUT DREXEL

Drexel University is a private research university founded in 1891 and located in Philadelphia, Pennsylvania, USA. Drexel offers 70 full-time undergraduate programs and accelerated degrees. Drexel is best known for its cooperative program (Co-op). The university has a large network of more than 1,600 corporate, governmental, and non-profit partners in 28 states and 25 international locations. The employers consist of top ranked international law firms, banks, corporations, and many Fortune 500 companies. Times Higher Education World University Rankings placed Drexel among the top 200 universities in the world.

ABOUT ESI GROUP

ESI is a pioneer and world-leading provider in Virtual Prototyping that takes into account the physics of materials. ESI boasts a unique know-how in Virtual Product Engineering, based on an integrated suite of coherent, industry-oriented applications. Addressing manufacturing industries, Virtual Product Engineering aims to replace physical prototypes by realistically simulating a product's behavior during testing, to fine-tune fabrication and assembly processes in accordance with desired product performance, and to evaluate the impact of product use under normal or accidental conditions. ESI's solutions fit into a single collaborative and open environment for End-to-End Virtual Prototyping. These solutions are delivered using the latest technologies, including immersive Virtual Reality, to bring products to life in 3D; helping customers make the right decisions throughout product development. The company employs about 900 high-level specialists worldwide covering more than 30 countries. ESI Group is listed in compartment C of NYSE Euronext Paris.

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