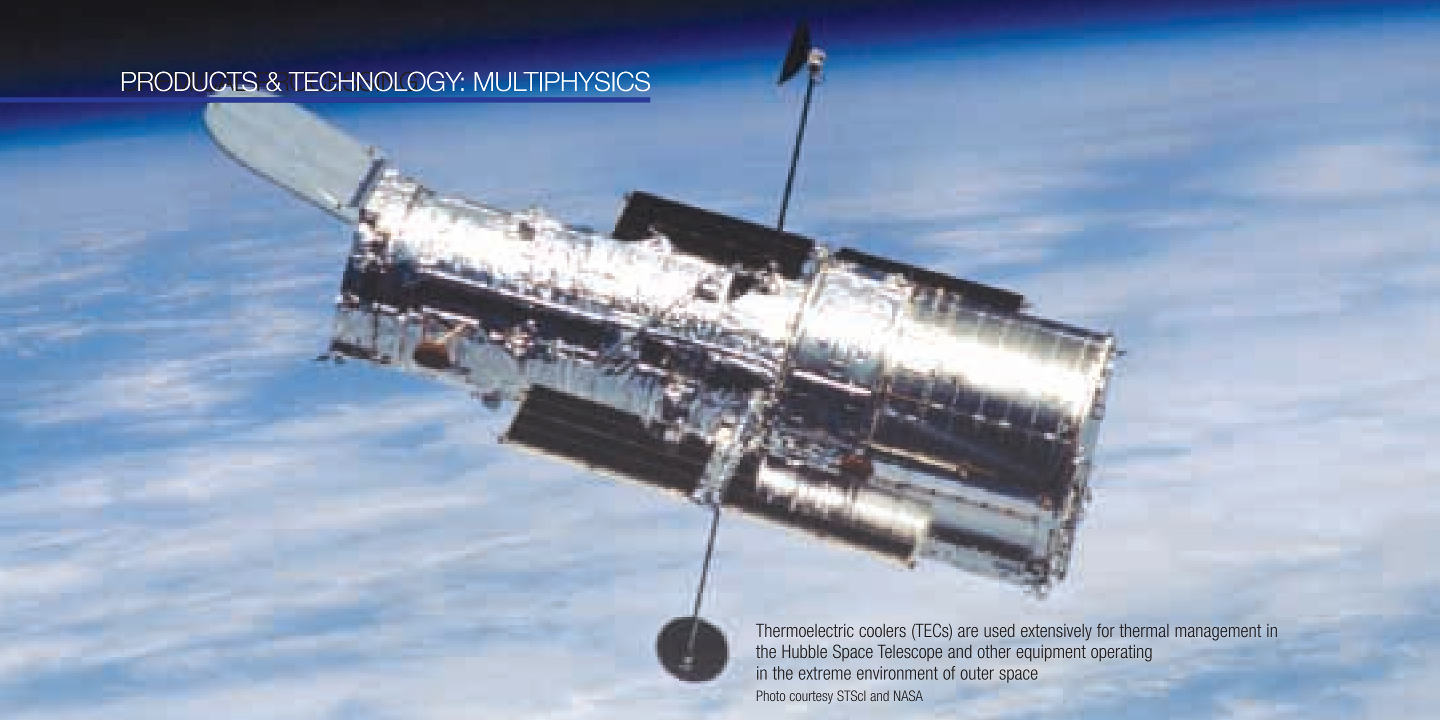

Thermoelectric coolers (TECs) are used extensively for thermal management in the Hubble Space Telescope and other equipment operating in the extreme environment of outer space
Photo courtesy STScI and NASA

High Performance from **Multiphysics Coupled Simulation**

Engineers use ANSYS Multiphysics to study the mechanical strength and thermal performance of an innovative thermoelectric cooler design.

By Robin McCarty, Senior Engineer for Product and Process R&D,
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Thermoelectric coolers (TECs) serve as small heat pumps, utilizing semiconductors for the cooling action in an enclosed package without any moving parts. Because of their quiet operation and small size, the devices are used extensively for spot-cooling electronics in aerospace, defense, medical, commercial, industrial and telecommunications equipment. In the extreme environments found in satellites and space telescopes applications, TECs often are stacked on top of one another to achieve the required cold-side temperatures. The traditional multistage configuration is pyramidal in shape, with the unavoidably tall profile posing packaging problems in applications with limited vertical space.

To address these issues, Marlow Industries developed an innovative new planar multistage TEC (patent pending) that reduces overall device height by arranging the thermoelectric elements side-by-side in a single plane, instead of stacking them. Because this configuration radically changed the structure, engineers used ANSYS Multiphysics software in evaluating the thermoelectric (TE) performance and thermomechanical stresses of the device, enabling the company to meet critical deadlines for launching the new product in a competitive market.

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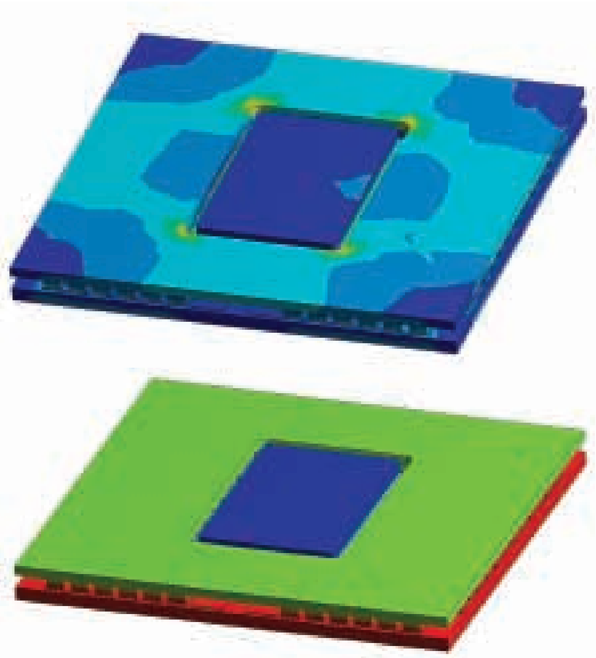
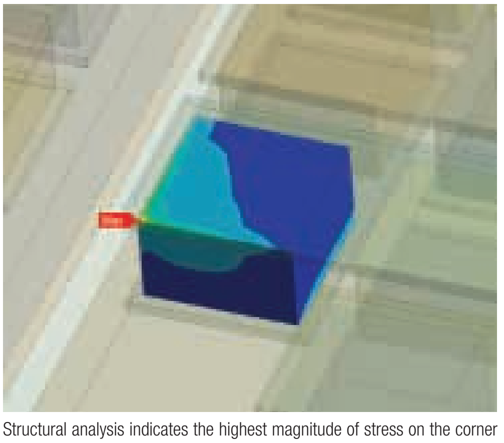


Coupled-physics simulation determined the temperature distribution throughout the device (top). These results were applied to the TEC assembly to perform a static structural analysis of the structure (bottom).

The company selected the ANSYS Multiphysics product because it is recognized as the only commercial finite element analysis package with the capability to model 3-D thermoelectric effects with the required level of accuracy. Given the multiphysics capabilities of the software, a fully coupled thermoelectric simulation could be performed, calculating the current densities and temperatures in the TEC considering both Joule heating and the Peltier effect. Marlow engineers used the calculated temperatures from the thermoelectric analysis of the TECs to perform a static structural analysis, which then was used to predict thermal stresses in the thermoelectric materials due to temperature differences in the TEC assembly.



Structural analysis indicates the highest magnitude of stress on the corner of the thermoelectric element where Marlow has historically seen cracking.

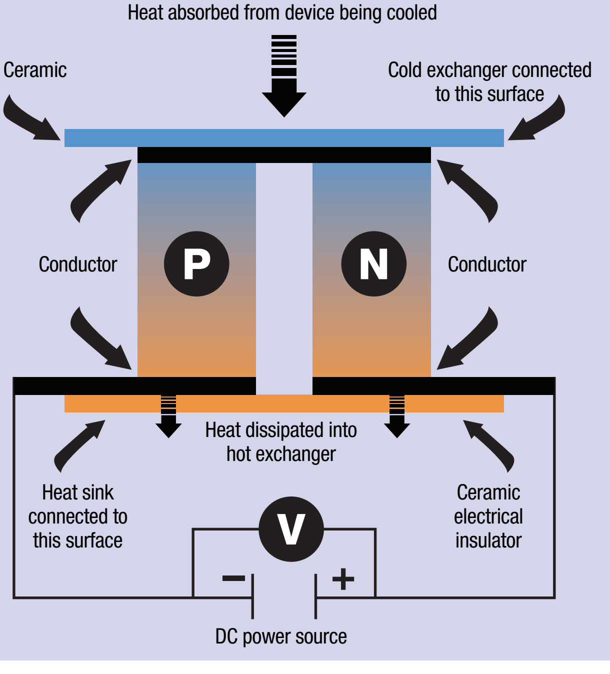
The objective of the thermoelectric simulation was to determine temperature distribution throughout the device. For creating the analysis model, a constant temperature condition was applied to the bottom of the mounting solder, and a radiation boundary condition was applied to the cold-side ceramic. A heat load (simulating the heat-producing device to be cooled) was applied to the cold side of the TEC, and a DC current was applied to the TEC's electrical terminals to drive the thermoelectric cooling. From this coupled-physics simulation, the minimum cold-side temperature, temperature uniformity of the top stage, voltage drop and electrical resistance of the TEC were determined.

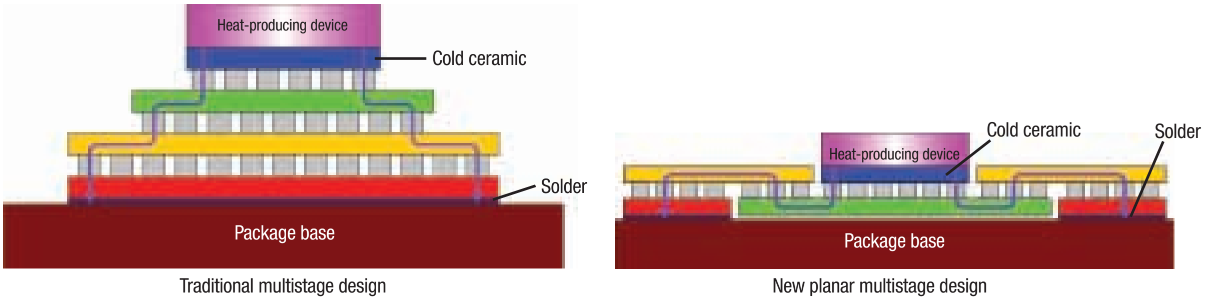
Once the temperature distribution of the TEC assembly was calculated from the thermoelectric model, it was applied to the TEC assembly in a static structural analysis. To mimic the TEC's mounting conditions, the solder on the

How a Thermoelectric Cooler Works

A thermoelectric cooler operates based on a principle known as the Peltier effect, in which cooling occurs when a small electric current passes through the junction of two dissimilar thermoelectric materials: a "p-type" positive semiconductor with a scarcity of electrons in its atoms and an "n-type" negative semiconductor with an abundance of electrons. Current is carried by conductors connected to the semiconductors, with heat exchanged through a set of ceramic plates that sandwich the materials together.

When a small positive DC voltage is applied to the n-type thermo element, electrons pass from the p- to the n-type material, and the cold-side temperature decreases as heat is absorbed. The heat absorption (cooling) is proportional to the current and the number of thermoelectric couples. This heat is transferred to the hot side of the cooler, at which point it is dissipated into the heat sink and surrounding environment.





In contrast to traditional multistage thermoelectric coolers with elements stacked in a pyramid shape (left), the new Marlow flat configuration (right, patent pending) arranges stages side by side. The new design reduces the height of the device and also changes heat flow through the ceramic material (denoted by the purple arrow).

hot side of the device was fixed on the bottom surface. Maximum principal stress was used to evaluate and compare the TEC designs because it can be directly related to the failure of a brittle material, such as bismuth telluride.

The testing team identified the thermoelectric element with the maximum stress and then refined the finite element mesh in that area to ensure that stress convergence had been obtained for the structural simulation. Using a plot of maximum principal stress distribution in a typical TE element, the engineering team found that the maximum stress occurs on the corner of the TE element, which correlated to where Marlow historically had seen cracking in thermoelectric elements that resulted in device failure.

To validate the new planar multistage designs, Marlow evaluated the mechanical stress levels for a thermoelectrically equivalent traditional multistage device and a planar multistage device. Each device consisted of three stages equivalent with thermoelectric element dimensions and thermoelectric element count per stage. In the model, three different currents were evaluated, and the maximum principal stress located in the most highly stressed thermoelectric element was noted.

Through these analyses, Marlow configured planar designs with maximum principal stress levels comparable to the traditional multistage devices. Thermal performance also was nearly equivalent. The correlation between the stress results for the traditional multistage and planar multistage devices provided confidence in the new planar multistage design concepts. This type of evaluation would not have been possible without the multiphysics simulation capabilities available in software from ANSYS. ■