EQUILIBAR® PRECISION FLUID CONTROL

For immediate release: July, 2023

Case study: brutal Antarctic conditions drive research and innovation for specialty pressure control systems

By Jeff Jennings, P.E

Background

McMurdo Station is an Antarctic research and logistics center run by the United States Antarctic Program, a branch of the National Science Foundation. Originally built in the 1950s as a naval air facility, it served as a center of operations for the International Geophysical Year and is now dedicated to supporting scientific research that relies on the unique atmospheric conditions found near the South Pole. Areas of investigation include astrophysics, earth sciences, glaciology, ecosystems, and ocean and atmospheric sciences. Weather conditions at the station are extreme, with all months having an average temperature below freezing as well as unique polar winds and ocean phenomena.

Dr. Ian Lowe is a postdoctoral research associate at the University of Arizona, where he is concentrating on spectral and polarization characteristics of interstellar dust, sub-Kelvin cryogenic detector systems, and stratospheric balloon instrumentation. Previously, as part of his doctoral work at the University of Pennsylvania, he participated in an international project called the next generation balloon-borne large aperture submillimeter telescope (BLAST-TNG).

Photo of BLAST-TNG, courtesy of Dr. Ian Lowe

The BLAST-TNG project's goal was to travel to McMurdo Station to launch a high-altitude balloon to carry a scientific module including a cryogenic instrument into the stratosphere. Antarctica was chosen because the balloon cannot safely fly over a populated area and Antarctica's circumpolar vortex keeps the balloon circling the South Pole without drifting away. The telescope, housed in a gondola, was designed to observe polarized thermal emission of interstellar dust and ultimately provide insight into how magnetic fields influence the formation of stars.

As with other complex, ambitious undertakings, the BLAST-TNG project required numerous control systems to be developed. Pressure control of the helium cryostat was just one of these, but it offers a valuable real-life illustration of the ways in which extreme conditions can drive technical innovation and contribute to scientific progress.

Pressure Control Details

A liquid helium cryostat played an important role in the BLAST-TNG experiment by keeping parts of the instrument close to absolute zero, which is necessary for the camera to operate correctly. Dr. Lowe needed to design a pressure control system to keep the helium supply tank for this cryostat at a constant pressure of 15 psia even as the barometric pressure dropped. Deviations in pressure would in turn cause temperature fluctuations or reduction in science time due to enhanced evaporative cooling.

Given the harsh weather conditions of Antarctica combined with the challenges of operating a telescope in the stratosphere, the BLAST-TNG experiment required that Dr. Lowe and other scientists planned for every contingency they could imagine.

"For flights like these, we aim to reduce the number of single points of failure as much as possible," Dr. Lowe said. "For example, we have redundant cameras and computers. If there is a problem with one, we have another on hand ready to go."

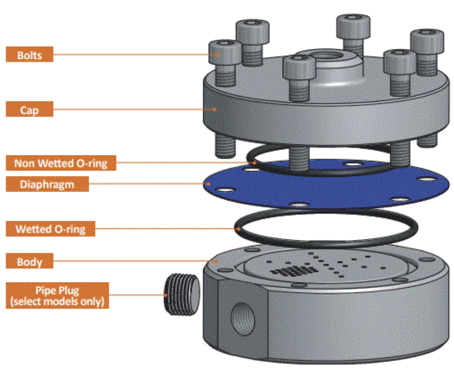
Not surprisingly, Dr. Lowe utilized multiple pressure control systems to prepare for as many scenarios as possible.

As described in his dissertation, the main pressure control device Dr. Lowe chose was a TAVCO valve. Developed for aerospace and defense many decades ago, TAVCO valves have a proven record of success in aerospace applications and are known as rugged psia pressure controllers.

According to Dr. Lowe, this valve works well and has been used for years in ballooning heritage including previous BLAST missions, making it a logical and familiar option to try first.

At the same time, Dr. Lowe believed that a higher precision device could ideally provide better results for the experiment. "We were really searching for something that could provide exquisitely accurate pressure control to get optimal results from our instruments," he explained. He began looking for a valve that provided exceptional precision and could control to 15 psia without leaking and outperform the +/- 1 psi range of the TAVCO. In addition, he preferred a valve from a company willing to develop custom solutions. As part of his search, he contacted Equilibar, a fluid control company in North Carolina that specializes in dome-loaded multi-orifice back pressure regulators.

Dome-loaded multi-orifice technology features a radically different design in which a thin and supple diaphragm covers a field of parallel orifices. As fluids flow through the unit, the diaphragm lifts off the orifices to release pressure. When flow is minimal, only a portion of one orifice opens to release the pressure. When flow is high, the diaphragm is pushed up to engage all the orifices. The simple design makes it easy to tailor materials of construction for demanding applications like cryogenic temperatures, which may use PTFE soft seals or PTFE/fluoropolymer jacketed spring-energized O-rings. Since they rely only on a force balance across a flexible diaphragm, these devices have no delay from a PID loop and external transducer setup as is often seen when using traditional control valves.



Laboratory Challenges

Unique challenges of the BLAST-TNG application included not only the extremely low temperature, but also the difficulties of working with helium, which is hard to control due to the ease of diffusion through membranes and seals.

Dr. Lowe collaborated with Equilibar application specialist Alan Black, a physicist who did undergraduate research on computational astrophysics and now specializes in aerospace and cryogenic applications. Black sent several diaphragm samples for Dr. Lowe to test to determine the best material.

In the laboratory, Dr. Lowe spent months building a test rig to qualify the Equilibar back pressure regulator (BPR) using a specialty polymer diaphragm. As is expected with complex experiments, certain modifications proved necessary. Equilibar valves precisely control their inlet port to be nearly equal to a reference port on top. To provide the needed stable reference pressure at 15 psia, Dr. Lowe provided a sealed gas container that was heat sunk to the gondola structure to provide thermal stability during instrument operation at altitude.

Final laboratory testing showed the Equilibar design provided excellent precision and response. The low-flow BPR performed reliably and maintained pressure closely to the desired setpoint through a wide flow range to ensure that pressure remained constant even when gas flow and differential pressure across the valve changed according to laboratory test conditions.

As a result, the BLAST-TNG team took the BPR to Antarctica as one of the qualified pressure control devices. As a third tier of pressure control coverage, the team also brought a motorized ball valve as a last resort measure.

On-Site Challenges

In Antarctica, an unanticipated challenge occurred to prevent the dome-loaded multi-orifice valve from being chosen for flight.

Temperature swings in the area around the McMurdo Station range from 35 C inside the laboratory building to -20 C outside. The extreme change in temperature caused a pressure differential across the polymer diaphragm, which allowed helium to quickly diffuse into the closed reference container, altering its pressure.

This new problem, which had not been observed during extensive testing in the laboratory, made the Equilibar BPR unreliable for flight despite its superior precision. The TAVCO valve was used in the scientific module instead.

The BLAST-TNG balloon was successfully inflated and launched on January 6, 2020. It reached cruising altitude of 120,000 feet and systems worked well as the team did initial tests and started to observe sources.

After nine hours, a sudden anomaly in the gondola caused an inability to point the telescope. The team spent hours trying to repair the system before deciding to terminate the flight to recover as much as possible to learn and plan for future attempts.

Inflated BLAST-TNG balloon, courtesy of Dr. Ian Lowe

Impact and Ongoing Improvements

The multinational effort of the BLAST-TNG project in general and the evolution of the pressure control system in particular provide a good example of how scientific progress occurs—with repeated, persistent attempts that build a body of knowledge and success over time. As the Apollo Mission and other bold endeavors have shown, these far-reaching scientific efforts eventually lead to diverse new technologies that benefit people and the planet in unexpected ways.

"In terms of the overall BLAST-TNG project, pressure control was a small detail, but it also illustrates the learning that can be gained from trying to meet aggressive goals," Black noted.

"Before Equilibar became involved in this experiment, the wide variety of diaphragm materials we have available to choose from had proven to be sufficient for most severe service conditions, even for cryogenic or supercritical applications. Now that we have a better understanding of the Antarctic challenges, we are setting up experiments in our laboratory to find the optimum material that will provide precise control while inhibiting the diffusion of helium during extreme temperature and pressure excursions.

"We have identified several exciting possibilities including some interesting metal coated polymers, and we're beginning to test prototypes. These are material combinations we would have never explored without this particular challenge, and I find that interesting and exciting. Past experience shows that breakthroughs we make for one application typically offer advantages for other applications as well. Helium is uniquely difficult to control and is used in many scientific applications, so I have no doubt an improved diaphragm will be an advantage for other projects as well."

At the University of Arizona, Dr. Lowe is building on his ballooning expertise in his new role with the Terahertz Intensity Mapper (TIM) experiment, which will use cryogenic camera systems to measure line emission tracers of star formations. The team is working on updating all controls, and Dr. Lowe is in discussions with Equilibar engineers regarding their attempt to configure and create an even more accurate and robust BPR for future flights.

The first flight of TIM is projected for 2025.

Contact Equilibar

Equilibar is a provider of unique and innovative pressure control solutions based near Asheville North Carolina. Equilibar's patented pressure regulator technology is used in a wide array of processes including catalyst, petrochemical, sanitary, supercritical and other industrial applications. For more information please contact an Equilibar applications engineer at inquiry@equilibar.com or 828-650-6590.

About the Authors

Jeff Jennings, PE, is founder of Equilibar, a manufacturer of dome-loaded multi-orifice valves and regulators for back pressure, vacuum, and flow control. His passion is inventing and developing fluid control technology that enables innovators to improve the world.

Dr. Ian Lowe conducts postdoctoral research at the University of Arizona's Steward Observatory. His experiments with the TIM project use sub-Kelvin detectors in the form of spectrometer banks to measure line emission tracers of star formation.