Navy Fighter Pilots Tolerate Higher-G Maneuvers Thanks to Oxygen Regulator Bellows

Low Spring-Rate Sensor Applies Positive Pressure Breathing for G with Quick, Consistent Response
MISSION CRITICAL ELECTRODEPOSITED NICKEL BELLOWS

Maneuvering for position in air-to-air combat, fighter pilots able to pull more G (the force of gravity) without losing consciousness have a powerful advantage. A leading manufacturer of pneumatic components and oxygen systems found a way to increase that advantage and save the U.S. Navy money. Engineers at Carleton Technologies Inc., in Orchard Park, New York, designed an aircrew oxygen regulator that automatically applies positive pressure for breathing under G. With fewer parts than previous devices performing similar functions, the regulator costs about one-fourth as much as its predecessors and has proven reliable in service. At the heart of the responsive, lightweight regulator design is a low spring-rate electrodeposited nickel bellows from Servometer® - PMG, LLC, in Cedar Grove, New Jersey.

The CRU-103 chest-mounted regulator is worn on the parachute harnesses of U.S. Navy pilots and Naval Flight Officers flying tactical jets. The 13-ounce device routes breathing oxygen under pressure to the wearer’s oxygen mask and to an upper-body G-vest in response to aircraft maneuvers. The more G the pilot pulls, the greater the oxygen pressure applied to mask and vest.

Between the G-sensing air supply valve on the aircraft and the pressure valve in the regulator is a highly flexible metal bellows. As the bellows fill with air and expand, they close the regulator valve and increase the pressure of oxygen going to the pilot. Carleton Design Engineer Jim Talty explained, “We could have used a piston or some other arrangement, but the bellows gave us the most mechanically efficient solution. Thin-walled electrodeposited nickel bellows provided exceptionally low spring rates for a quick, consistent response. It provided a reliable mechanical solution that was lighter and smaller than the alternatives.”

“...the bellows gave us the most mechanically efficient solution...”
Banking and turning an aircraft at high speed increases G loads on pilots to several times the normal force of gravity in the vertical axis. Today’s agile fighters can very rapidly attain nine Gs or more. As blood drains from the head to the lower body, cerebral perfusion pressure in the brain falls, and nerve cells denied oxygen shut down. The vision of the pilot turns gray, then black. With sustained or rapidly increased G force, G Loss Of Consciousness (G-LOC) can totally disable the pilot for up to 40 seconds. Full recovery from G-LOC may take up to three minutes. In a high performance aircraft maneuvering near the ground or in a sky full of enemies, even momentary loss of consciousness can be fatal.

Positive pressure breathing for G delays the onset of gray-out and G-LOC, and makes the anti-G straining exercises commonly performed by maneuvering pilots less tiring. Increasing the partial pressure of oxygen in the blood compensates for the reduced blood pressure in the brain. Boosting intra-thoracic pressure through breathing oxygen and a counter-pressure vest can hike G-tolerance of pilots by approximately 2 G’s. However, the positive pressure must be matched to increasing G by an automatic regulator with a quick response.

Until recently, U.S. Navy pilots used three different oxygen regulators with their life support equipment. The least expensive cost only $300, but it varied breathing oxygen pressure only in response to altitude, not G. The inexpensive regulator could not provide sufficient oxygen to meet peak demand and would cause pilots breathing discomfort when they needed oxygen most. Despite its simplicity, the aneroid regulator also proved unreliable and costly to maintain. Two more sophisticated regulators could adjust their output pressures to both altitude and G, but they cost around $4,000 each.

The U.S. Navy sponsored development of the CRU-103 regulator as part of an Advanced Tactical Life Support System. “They were seeking to reduce cost while improving functionality over the three existing units they were using,” Mr. Talty said.
Carleton is a leading designer and manufacturer of high pressure pneumatic components and systems for aerospace and defense applications. The company’s Life Support Group makes atmosphere control systems and breathing regulators. To meet Navy requirements, engineers in the Life Support Group looked for a reliable pressure translating device that could reduce parts count.

RESPONSIVE REGULATOR

After evaluating pistons and springs, the manufacturer partnered with Servometer on a solution based upon a precision metal bellows. “We use bellows in hundreds of our designs,” noted Mr. Talty. “We contacted Servometer to help us because they had a good track record in previous projects with our company.”

Servometer engineers helped analyze the regulator requirements including travel distance with pressure change. Most of Carleton’s products used hydroformed brass bellows. Servometer offered custom-designed electrodeposited nickel bellows with far lower spring rates to minimize resistance. Bellows spring rate is a function of inside diameter, outside diameter, number of convolutions, material and wall thickness.

Electrodeposition routinely produces walls one quarter the thickness made by mechanical hydroforming. Electrodeposited nickel bellows typically provide one fifth to one-tenth the spring rate of hydroformed brass bellows of the same size. Mr. Talty explained, “When they expand, the amount of force you lose stretching the bellows is very low. The force also stays consistent from regulator to regulator.”

The bellows assembly used in Carleton’s oxygen regulators is a .153 inch (3.89 mm) long cylinder with walls .0015 inch (.038 mm) thick and has an outside diameter of .375 inch (9.53 mm).
The convolution pitch of the bellows is .032 inch (.81 mm) with a depth of .025 inch (.64 mm). The assembled regulator measures 3 inches (76.2 mm) high by 4 inches (101.6 mm) wide by 2 inches (50.8 mm) deep.

Electrodeposited nickel bellows are widely used as the sensing elements in pneumatic regulators, switches, gauges, actuators, and pressure compensators. Compared with brass and other bellows materials, nickel combines high yield strength (110,000 psi minimum) and high tensile strength (125,000 psi minimum). The electrodeposition process maintains high chemical purity, and retains the mechanical properties of the metal. The bellows in the CRU-103 oxygen regulator have a projected service life greater than 100,000 cycles.

In operation, the bellows are typically triggered at 3.5 G’s, releasing oxygen under pressure at 0.1 psi. Supply pressure increases gradually to 1.0 psi at 9 G’s. Thanks to the regulator, pilots get exactly the oxygen they need without waste. Pressure to the mask and the compression vest is kept the same to maintain equilibrium inside and outside the pilot’s chest.

The valve-actuating end cap soldered on the bellows makes it easy for life support technicians to adjust the regulator. An easy-to-install maintenance kit includes a replacement bellows, diaphragm, and o-ring.

**BROADER ACCEPTANCE**

Initially, the Navy issued the CRU-103 regulator only to the crews of the highest-performance fighters and attack aircraft. However, at $1,100 each, the lower cost of the regulator with its sensitive bellows has led to the CRU-103 being used on all U.S. Navy aircraft. Regulator production is ramping up from 1,000 to 3,000 regulators a year. Fleet experience has been excellent. “Our primary measure of success is the unit’s reliability,” said Mr. Talty. “With our design, the Navy has had far fewer regulators return for repairs than with any of the previous designs.”
Building on the regulator success, Carleton has found other applications for Servometer’s electro-deposited nickel bellows. The company now uses 20 different bellows in pneumatic systems on commercial and military aircraft, and in products controlling oxygen, nitrogen, air, and other gases.

Fighter pilots routinely push the edge of aircraft performance envelopes and their own physical limits. With thoughtful engineering and a Servometer electrodeposited nickel bellows, they now have an extra edge.

**CONCLUSION**

Thanks to their unique manufacturing technology Servometer engineers were able to design a highly sensitive and responsive electrodeposited bellows assembly for a leading designer and manufacturer of high pressure pneumatic components and systems for aerospace and defense applications. This new oxygen regulator is critical in improving G tolerance for US Navy fighter pilots and has proven to be more responsive and less expensive than alternate mechanical solutions.
ABOUT SERVOMETER AND BELLOWSTECH

Making the Impossible Possible

Servometer, the pioneer of electrodeposited miniature metal bellows, bellows assemblies, contact springs, flexible shaft couplings and rigid electroforms offers over 50 years of engineering and manufacturing experience servicing the aerospace, defense, medical, test, semiconductor, UHV, solar and oil and gas industries. Servometer is ISO 9001:2008 certified. In 2007, Servometer acquired BellowsTech of Ormond Beach, Florida, a premiere manufacturer of edge welded bellows and bellows assemblies encompassing a wide array of alloys and dimensional configurations for oil and gas, semiconductor and vacuum technology industries. BellowsTech is AS9100-C compliant.