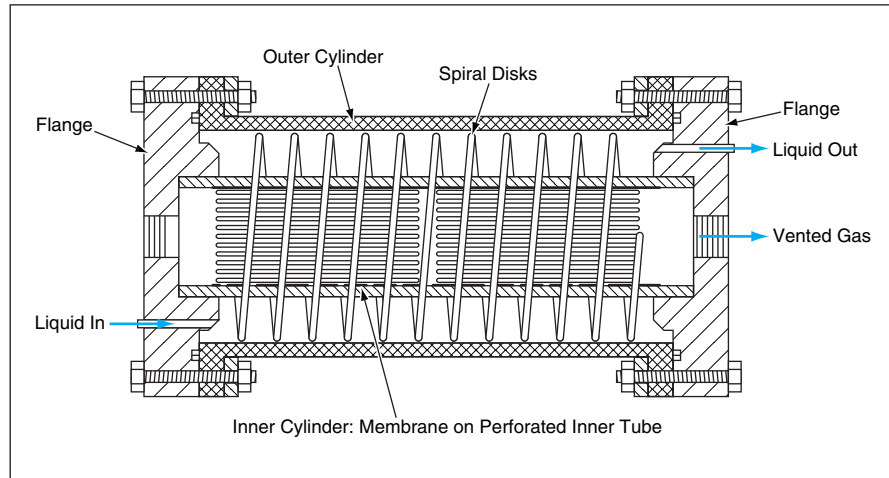# ✛ Bubble Eliminator Based on Centrifugal Flow

This device contains no moving parts.

Lyndon B. Johnson Space Center, Houston, Texas

The fluid bubble eliminator (FBE) is a device that removes gas bubbles from a flowing liquid. The FBE contains no moving parts and does not require any power input beyond that needed to pump the liquid. In the FBE, the buoyant force for separating the gas from the liquid is provided by a radial pressure gradient associated with a centrifugal flow of the liquid and any entrained bubbles. A device based on a similar principle is described in "Centrifugal Adsorption Cartridge System" (MSC-22863), which appears on page 48 of this issue. The FBE was originally intended for use in filtering bubbles out of a liquid flowing relatively slowly in a bioreactor system in microgravity. Versions that operate in normal Earth gravitation at greater flow speeds may also be feasible.

The FBE (see figure) is constructed as a cartridge that includes two concentric cylinders with flanges at the ends. The outer cylinder is an impermeable housing; the inner cylinder comprises a gas-permeable, liquid-impermeable membrane covering a perforated inner tube. Multiple spiral disks that collectively constitute a spiral ramp are mounted in the space between the inner and outer cylinders.

The liquid enters the FBE through an end flange, flows in the annular space between the cylinders, and leaves through the opposite end flange. The spiral disks channel the liquid into a spiral flow, the circumferential component of which gives rise to the desired centrifugal effect. The resulting radial pressure gradient forces the bubbles radially inward; that is,

The **Spiral Disks Channel the Liquid** into a spiral flow, which gives rise to a pressure gradient that drives bubbles toward the inner cylinder.

toward the inner cylinder. At the inner cylinder, the gas-permeable, liquid-impermeable membrane allows the bubbles to enter the perforated inner tube while keeping the liquid in the space between the inner and outer cylinders. The gas thus collected can be vented via an end-flange connection to the inner tube.

The centripetal acceleration (and thus the radial pressure gradient) is approximately proportional to the square of the flow speed and approximately inversely proportional to an effective radius of the annular space. For a given FBE geometry, one could increase the maximum rate at which gas could be removed by increasing the rate of flow to obtain more centripetal acceleration. In experiments and calculations oriented toward the original micro-

gravitational application, centripetal accelerations between 0.001 and 0.012 g [where $g \equiv$ normal Earth gravitation (≈ 9.8 m/s^2)] were considered. For operation in normal Earth gravitation, it would likely be necessary to choose the FBE geometry and the rate of flow to obtain centripetal acceleration comparable to or greater than g.

✛ Inflatable Emergency Atmospheric-Entry Vehicles

Ballutes would act as inexpensive, lightweight atmospheric decelerator "lifeboats."
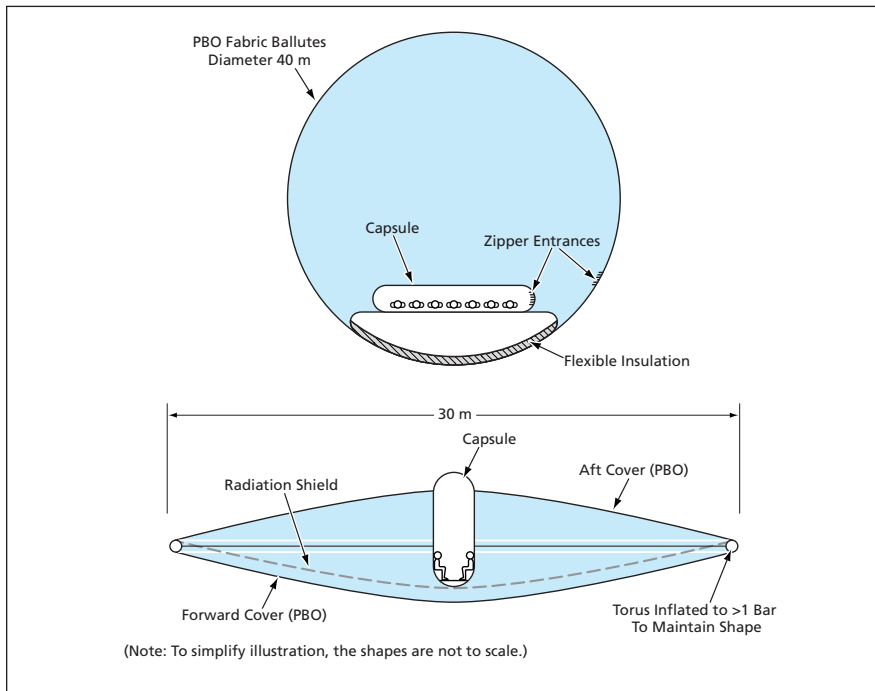
NASA's Jet Propulsion Laboratory, Pasadena, California

In response to the loss of seven astronauts in the Space Shuttle Columbia disaster, large, lightweight, inflatable atmospheric-entry vehicles have been proposed as means of emergency descent and landing for persons who must abandon a

spacecraft that is about to reenter the atmosphere and has been determined to be unable to land safely. Such a vehicle would act as an atmospheric decelerator at supersonic speed in the upper atmosphere, and a smaller, central astronaut

pod could then separate at lower altitudes and parachute separately to Earth.

Astronaut-rescue systems that have been considered previously have been massive, and the cost of designing them has exceeded the cost of fabrication of a

A **Spherical Ballute** (upper) **and a Lens-Shaped Ballute** (lower) have been considered for inflatable emergency atmospheric-entry vehicles.

space shuttle. In contrast, an inflatable emergency-landing vehicle according to the proposal would have a mass between 100 and 200 kg, could be stored in a volume of approximately 0.2 to 0.4 m^3, and could likely be designed and built much less expensively.

When fully inflated, the escape vehicle behaves as a large balloon parachute, or ballute. Due to very low mass-per-surface area, a large radius, and a large coefficient of drag, ballutes decelerate at much higher altitudes and with much lower heating rates than the space shuttle. Although the space shuttle atmospheric reentry results in surface temperatures of about 1,600 ^{o}C, ballutes can be designed for maximum temperatures below 600 ^{o}C. This allows ballutes to be fabricated with lightweight ZYLON$^®$, or polybenzoxazole (PBO), or equivalent.

Two preliminary cocoon ballute "lifeboat" concepts are shown in the figures. The cocoon portion of the vehicle would be, more specifically, a capsule pressurized to 1 bar (0.1 MPa — approximately 1 standard atmosphere). Crewmembers would enter the cocoon pod and then zip it shut. The spacecraft would be placed on a reentry trajectory, and the inflated cocoon with deflated ballute would be ejected.

Once the vehicle was safely away from the spacecraft, the entire ballute would be inflated. For this inflation at high altitude, the ballute would be pressurized to about 0.01 bar (1 kPa). As low as this pressure is, it is at least ten times the expected dynamic pressure on the vehicle during the heating portion of very high atmospheric reentry, and hence it is sufficient to enable the ballute to retain its shape. From thermal reentry heating analyses performed at JPL, the diameter of the inflated ballute would be made large enough (30 to 40 m) to limit the maximum temperature to about 500 ^{o}C — safely below the 600 ^{o}C limit for PBO, or equivalent.

The spherical ballute shown in the upper figure would have a mass of about 200 kg for a seven-astronaut rescue mission, while the lens-shaped ballute in the lower figure has been further improved by reducing the overall mass required and increasing the coefficient of drag. To maintain stability, the center of mass of both concepts must be kept low, and spin stabilization may be necessary.

Lightweight Deployable Mirrors With Tensegrity Supports
Extremely lightweight, deployable structures could be made by assembling tensegrity modules.

Marshall Space Flight Center, Alabama

The upper part of Figure 1 shows a small-scale prototype of a developmental class of lightweight, deployable structures that would support panels in precise alignments. In this case, the panel is hexagonal and supports disks that represent segments of a primary mirror of a large telescope. The lower part of Figure 1 shows a complete conceptual structure containing multiple hexagonal panels that hold mirror segments.

The structures of this class are of the tensegrity type, which was invented five decades ago by artist Kenneth Snelson. A tensegrity structure consists of moment-free compression members (struts) and tension members (cables). The structures of this particular developmental class are intended primarily as means to erect large segmented primary mirrors of astronomical telescopes or large radio antennas in outer space. Other classes of tensegrity structures could also be designed for terrestrial use as towers, masts, and supports for general structural panels.

An important product of the present development effort is the engineering practice of building a lightweight, deployable structure as an assembly of tensegrity modules like the one shown in Figure 2. This module comprises two octahedral tensegrity subunits that are mirror images of each other joined at their plane of mirror symmetry. In this case, the plane of mirror symmetry is both the upper plane of the lower subunit and the lower plane of the upper subunit, and is delineated by the mid-height triangle in Figure 2. In the configuration assumed by the module to balance static forces under mild loading, the upper and lower planes of each sub-