VOICE COIL
THE PERIODICAL FOR THE LOUDSPEAKER INDUSTRY

*Article prepared for www.audioXpress.com*

# Metal Sandwich Composite Cones For Pro Drivers

*By Steve Mowry*

Metal cones and/or diaphragms have been utilized in professional loudspeakers for many years. The typical diaphragm is a solid homogeneous material of aluminum, magnesium, titanium, or an alloy of the same. Metal cones and diaphragms perform quite well within their respective piston bandwidths; however, at the onset of the modes of vibration there is a characteristic of energy storage and high Q release, breakup. It is not uncommon to measure a 10dB or more peak in the frequency response around the first mode, *f1* with subsequent peaks and dips related to *f2*, *f3* . . . *fn,* for transducers utilizing metal diaphragm assemblies. If the metal cone design is not robust, fatigue and the resultant cracking of the cone can occur over time. These characteristics along with the higher densities of metals versus paper has resulted in paper becoming the cone material of choice for the last several decades. I have investigated a new very high-performance sandwich composite cone as an alternative to the traditional paper cone.

## INTRODUCTION

Having visited paper cone manufacturing facilities within the US, Europe, Mexico, and Asia, I have observed that the manufacturing processes are extensive and difficult to control. Paper cones start out as a soup-like mixture of pulp, fibers, and chemicals in water called the slurry. Subsequently there are forming processes, on screens, and there are drying and treating processes. The resultant paper cone can change properties very quickly if a supplier of the paper pulp is changed.

I am quite certain that most transducer professionals have had to deal with this problem at some time. Furthermore, both during production and in the field, the properties of a paper cone can change with the environment and particularly relative humidity. The paper cone is not a stable material and it is difficult to control the inherent variability, whereas metals and polymers are typically very stable leaving only the manufacturing processes to control.

When companies began to add carbon and/or aramid fibers to the paper pulp/slurry, the term composite also began to appear. These processes resulted in increased stiffness and improved damping. A search of the US Patent Office website indicated that most of the patents have expired and the process of adding carbon and/or Kevlar® fibers to paper cones has become commonplace within the industry for paper cone manufacturers. Paper cone manufacturing techniques have improved the performance of paper cones but variability issues simply cannot be overcome.

The speed of sound in the paper-based material is much lower than in most metals. The speed of sound in a material is related to the square root of the ratio of stiffness to mass of that material, $c_m = \sqrt{\frac{E}{\rho}}\left(ms^{-1}\right)$, where **E** is the Modulus of Elasticity (Pa) and $\rho$ is the mass density (kg $m^{-3}$). However, paper has the characteristic of inner loss that is much higher than metals. This loss property relates to the Q of the modes of vibration more commonly referred to as resonances. The higher the inner loss of the cone, the lower the Q of the modes or resonances.

I have investigated an alternative to paper and metal

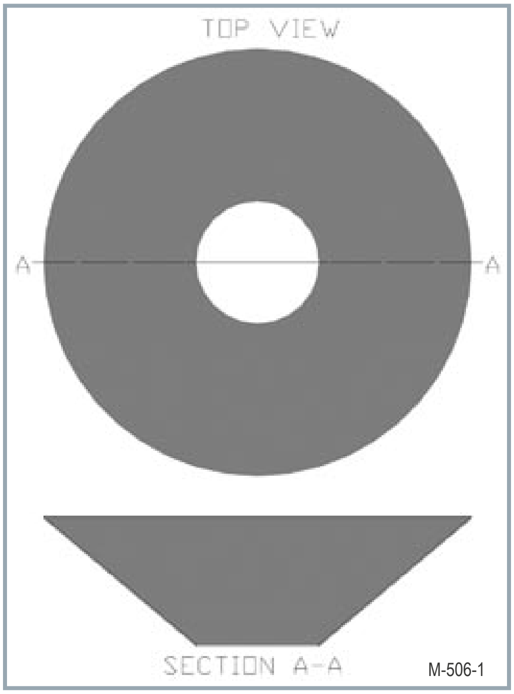

**FIGURE 1:** The treated paper cone drawing.

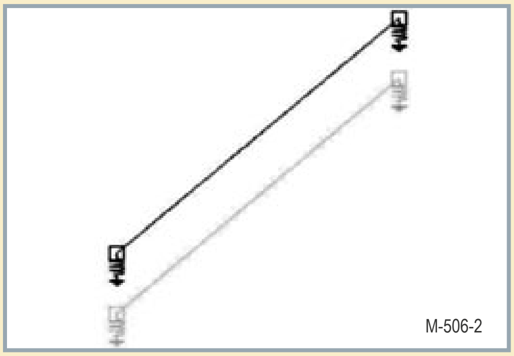

**FIGURE 2:** Paper cone mode shape at $f_0$ = 30Hz, cone mass = 25g, total effective mechanical moving mass = 49g, cone thickness = 0.8mm.

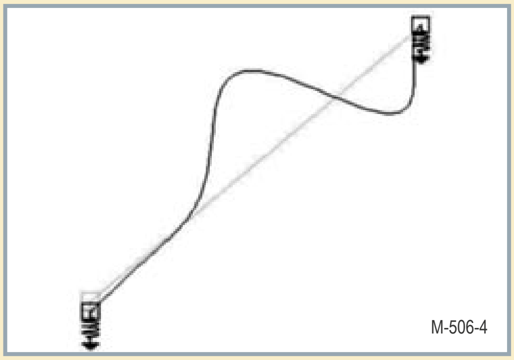

**FIGURE 4:** Paper cone mode shape at $f_2$ = 1.12kHz, modal damping = 0.019.

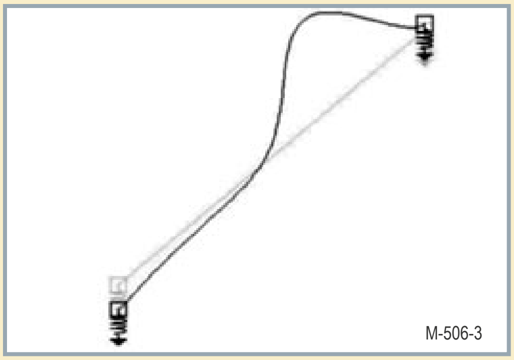

**FIGURE 3:** Paper cone mode shape at f1 = 934Hz, modal damping = 0.016.

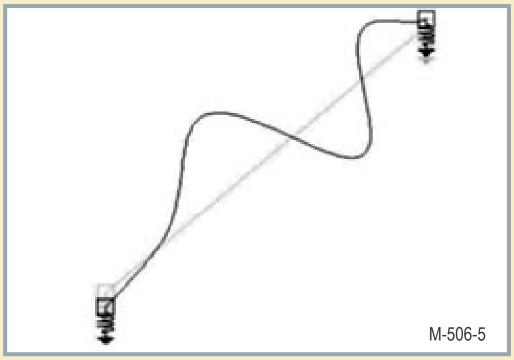

**FIGURE 5:** Paper cone mode shape at $f_3$ = 1.27kHz, modal damping = 0.018.

cones—the true "Sandwich Composite" (SC). This is quite common in applications for boats, airplanes, aerospace, bicycles, automotive, and even tennis rackets. The typical configuration is a molded sandwich of carbon fiber/polymer foam/carbon fiber; however, for transducer diaphragm applications, the sandwich can also be metal/polymer foam/metal. I will show that although the sandwich composite is costly (in low quantities and manufactured in the US), it has the potential for a very high performance cone with simple and controllable/repeatable manufacturing processes.

There are at least two famous loudspeaker manufacturers who have implemented the sandwich composite cones. The first makes the following claims: "W Sandwich®, the latest development in the sandwich concept uses a glass–glass structure based around a structural foam core, (Patent No 2,615,345) and the Poly-K sandwich structure comprising two sheets of Kevlar® on both sides of a core comprised of tiny hollow beads is a unique solution in the production of membranes, featuring an optimal weight—rigidity—damping balance, (Patent No 2,731,579)."

Unfortunately, after extensive searching within the US and World Patent and Trademark Office databases, I could not find these patents. The patent numbers correspond to unrelated inventions dating back to the mid 1950s. I also searched for the trademark "W Sandwich"; however, no records could be found in the USPTO database. These claims can be found at www.focal-fr.com/gb/societe/tek.htm.

The second manufacturer describes the sandwich composite cone in detail; however, this company makes no claim as to propriety of their cone material or topology. This cone is a true molded sandwich composite of epoxy impregnated carbon fiber/Rohacell/epoxy impregnated carbon fiber. A white paper on the topic of the development of this company's new "Flagship Loudspeaker" including their composite cone is available for download at www.bwspeakers.com/downloadFile/technicalFeature/800_Development_Paper.pdf.

Note that other metals and materials such as aluminum, carbon fiber, aramid fiber, or fiberglass are potential substi-

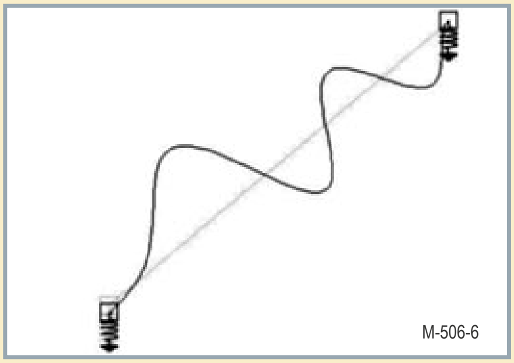

**FIGURE 6:** Paper cone mode shape at $f_4$ = 1.49kHz, modal damping = 0.019.

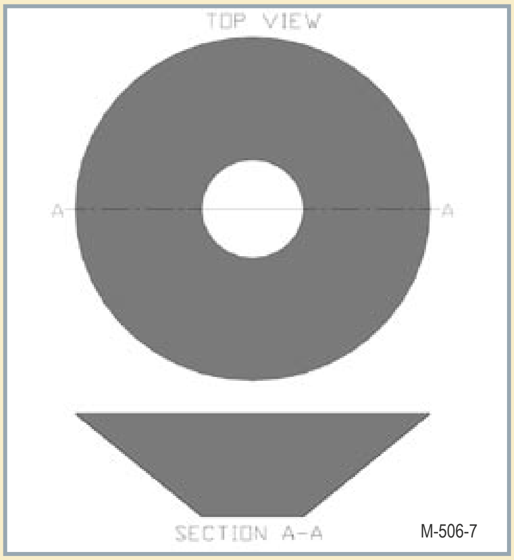

**FIGURE 7:** The anodized magnesium cone drawing.

tutes for the magnesium material used within the following models. However, I believe that magnesium has the most cost effective/performance material properties and is the most appropriate material for the metal and sandwich cone applications discussed here.

The cone requirements for system application are as follows: A 12″ low frequency transducer to be utilized in line array systems and other compact two-way ported box loudspeakers from 30Hz to 1.5kHz.

## SIMULATIONS

I will use proprietary axisymmetric 1° of freedom linear finite element analysis to compare and contrast a high quality paper cone, a magnesium cone, and a sandwich composite cone as described below. In all the following simulations, cone angle, cone inside diameter, cone outside diameter, and boundary conditions and cone mass will remain constant. Only the materials will be changed to represent cone and thus the thickness changes from cone to cone.

**FIGURE 8:** Anodized magnesium cone mode shape at $f_0$ = 30Hz, cone mass = 25g, total effective mechanical moving mass = 49g, cone thickness = 0.3mm.

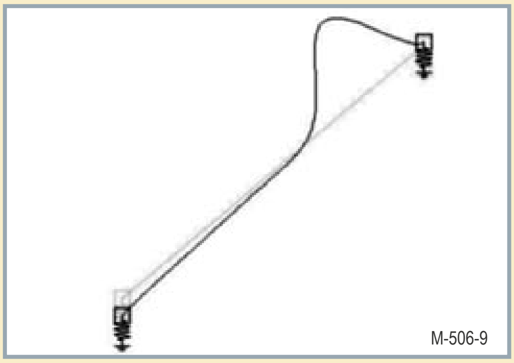

**FIGURE 9:** Anodized magnesium cone mode shape at $f_1$ = 1.56kHz, modal damping = 0.004.

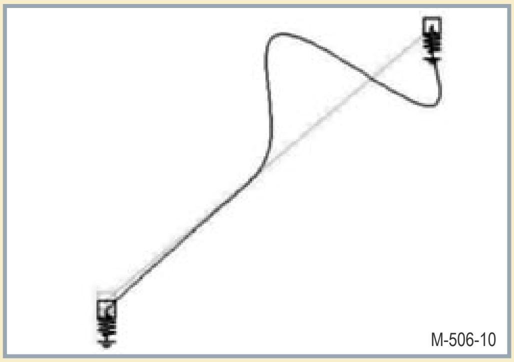

**FIGURE 10:** Anodized magnesium cone mode shape at $f_2$ = 1.76kHz, modal damping = 0.005.

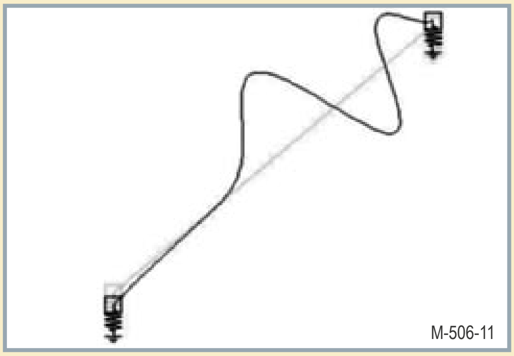

**FIGURE 11:** Anodized magnesium cone mode shape at $f_3$ = 1.93kHz, modal damping = 0.005.

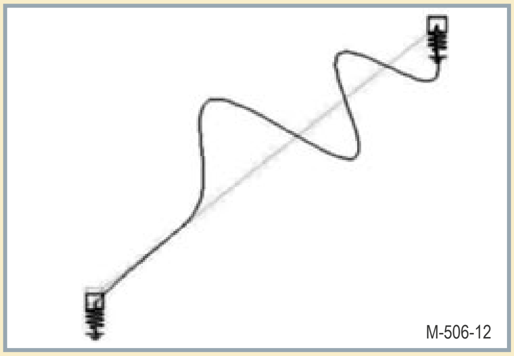

**FIGURE 12:** Anodized magnesium cone mode shape at $f_4$ = 2.15kHz, modal damping = 0.005.

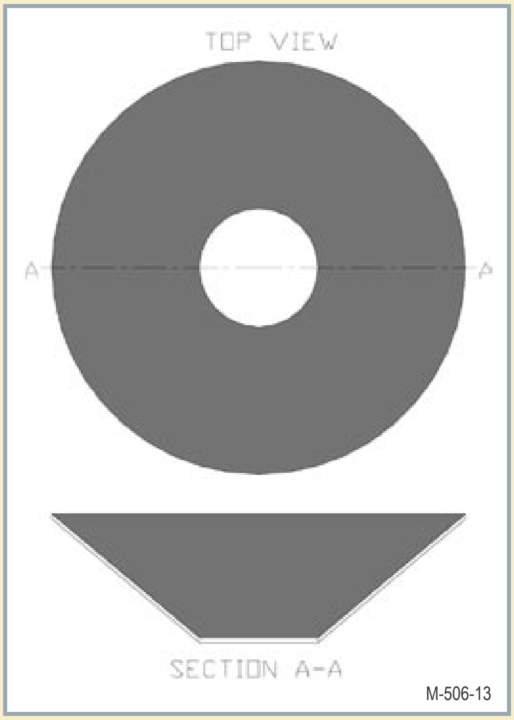

**FIGURE 13:** The magnesium sandwich composite cone drawing.

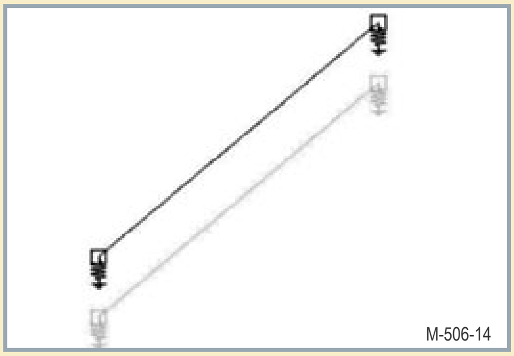

**FIGURE 14:** Composite cone mode shape at $f_0$ = 30Hz, cone mass = 25g, total effective mechanical moving mass = 49g, cone thickness = 2.2mm.

## Material Properties:

CONE # 1: Treated Paper (top secret formula)
Modulus of Elasticity, $E_E = 6.00 \times 10^9$ Pa
Mass Density, $\rho E = 0.683$ g $cm^{-3}$
Poisson's Number = 0.33 Unit-less
Inner Loss, $\tan\delta = 0.02$ Unit-less

CONE # 2: Anodize/Mg/Anodize
Anodizing (Ceramic):
Modulus of Elasticity, $E_C = 2.75 \times 10^{11}$ Pa
Mass Density, $\rho C = 3.58$ g $cm^{-3}$
Poisson's Number = 0.33 Unit-less
Inner Loss, $\tan\delta = 0.007$ Unit-less
Magnesium (Mg):
Modulus of Elasticity, $E_M = 4.40 \times 10^{10}$ Pa
Mass Density, $\rho M = 1.84$ g $cm^{-3}$
Poisson's Number = 0.33 Unit-less
Inner Loss, tan = 0.005 Unit-less

CONE # 3: Anodize/Mg/Anodize/Epoxy/Foam/Epoxy/Anodize/Mg/Anodize
Structural Poly-foam (Rohacell®):
Modulus of Elasticity, $E_P = 6.90 \times 10^7$ Pa
Mass Density, $\rho P = 0.052$ g $cm^{-3}$
Poisson's Number = 0.40 Unit-less
Inner Loss, $\tan\delta = 0.1$ Unit-less
Thermosetting Polymer (Epoxy):
Modulus of Elasticity, $E_E = 3.00 \times 10^9$ Pa
Mass Density, $\rho E = 1.50$ g $cm^{-3}$
Poisson's Number = 0.33 Unit-less
Inner Loss, $\tan\delta = 0.02$ Unit-less

***Figures 2–6*** show the first five modes of vibration of the treated paper cone, while ***Figs. 8–12*** illustrate the first five modes of vibration of the anodized magnesium cone.

If the cones in ***Figs. 1, 7***, and ***13*** look the same, that's because they are very similar in size and weight, while only the thickness varies. However, the simulations look very different. ***Figures 14–18*** display the first five modes of vibration of the sandwich composite cone.

In principle a sandwich consists of two skins or facings with a core material in between. The skins take up normal stresses and give the structure a hardwearing surface. The core material absorbs the shear stresses generated by loads, distributing them over a larger area. This configuration has the I-beam analogy in a two-dimensional sense. The load in sandwich composites is distributed over the entire structure.

Compared to single skin laminates, the sandwich concept offers substantial improvements in both flexural rigidity and flexural strength. By doubling the thickness of the core, the improvements are even greater yet the weight increase is almost negligible.

The inherent material losses or damping is also significantly improved by a phenomenon referred to as composite modal (modes of vibration) damping. This seems intuitive in comparing the sandwich to the single laminate and is essentially due to the foam core construction.

With much of the development of the SC materials being for defense and aerospace application, the costs tend to be high for loudspeaker cones. Development of these technologies within Asia is critical to controlling the piece part pricing. Sandwich Composite technology also has potential applications in loudspeaker enclosures and waveguides as well as diaphragms. You can obtain more information on the general topic of composite materials at www.composite.about.com.

**FIGURE 15:** Composite cone mode shape at $f_1$ = 1.75kHz, modal damping = 0.018.

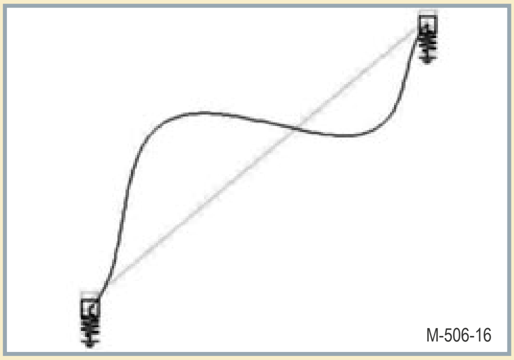

**FIGURE 16:** Composite cone mode shape at $f_2$ = 2.53kHz, modal damping = 0.025.

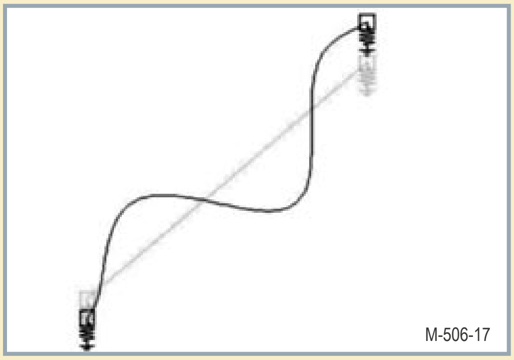

**FIGURE 17:** Composite cone mode shape at $f_3$ = 3.10kHz, modal damping = 0.020.

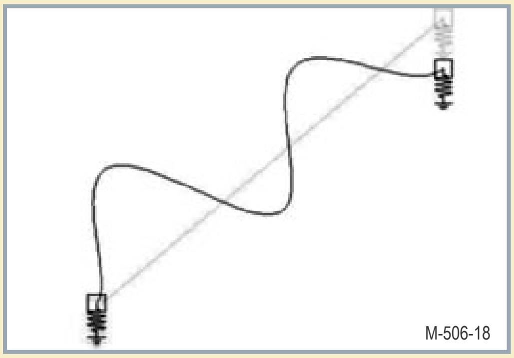

**FIGURE 18:** Composite cone mode shape at $f_4$ = 4.00kHz, modal damping = 0.024.

***Figures 19***, ***20***, and ***21*** illustrate the results from nonlinear buckling analysis of the paper, magnesium, and composite cones, respectively. In this analysis, the outside diameter is constrained for all 3° of freedom, while the inside diameter is left free to move in the axial direction. An incrementally increasing pressure is then applied to the surface of the cone until the structure deforms. The sandwich composite is an extremely robust design and it is again illustrated that the composite cone bends as a structure, while the paper cone bends locally at the outside diameter.

## CONCLUSION

Although the bandwidth requirement of 30Hz to 1.5kHz seemed reasonable, I was unable to design a paper cone that would work at 1.5kHz with bending occurring below 1.0kHz. The magnesium cone did not bend until just above 1.5kHz. The simulations indicate that the magnesium cone could be implemented in a system from 30Hz to 1.5kHz and is a high-performance cone in its own right; however, the modal damping is very low. Crossover design would require high order low pass and some equalization with the magnesium cone, while the composite cone simulations indicate that the sandwich cone works well at 1.5kHz and above. All bending is out of band for the sandwich composite cone.

Perhaps more important is that the bending is well controlled and damped. The composite cone outperforms the treated paper and the anodized magnesium cones in every category except cost; however, this is the opportunity to manufacture and market sandwich composite cones at a cost below high quality (magic) paper cones.

The few grams of anodized magnesium, Rohacell, and epoxy required to manufacture this sandwich composite cone should be of a low raw material cost. The floor space, equipment, and capital investment required to implement a suitable manufacturing process for sandwich composite cones is elegantly simple and downscaled in both size and cost as compared to a paper cone manufacturing facility. Simple processes that can be consistently performed and repeated are beautiful things. ***VC***

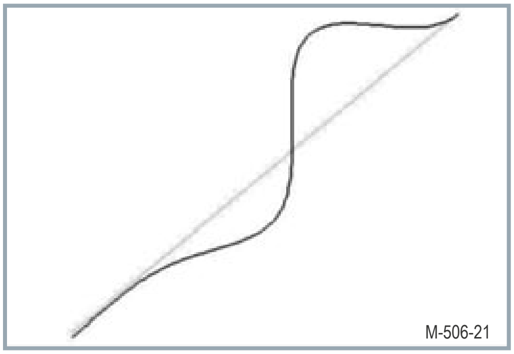

**FIGURE 21: Buckling mode shape of composite cone at 745 PSI!**

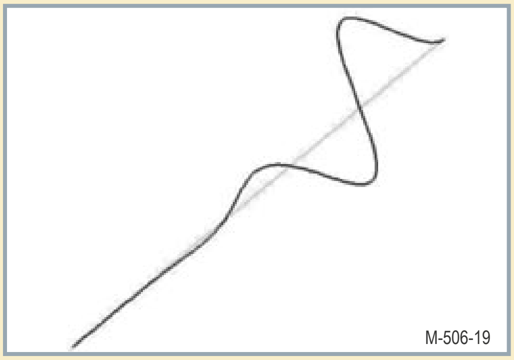

**FIGURE 19: Buckling mode shape of paper cone at 45 PSI.**

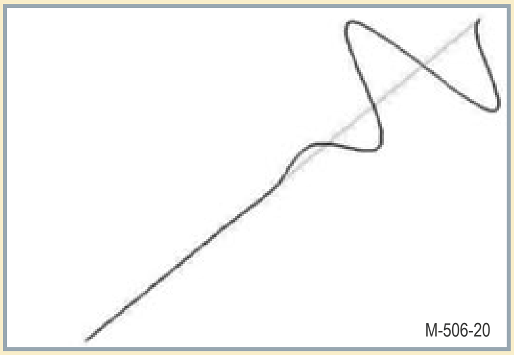

**FIGURE 20: Buckling mode shape of anodized magnesium cone at 48 PSI.**