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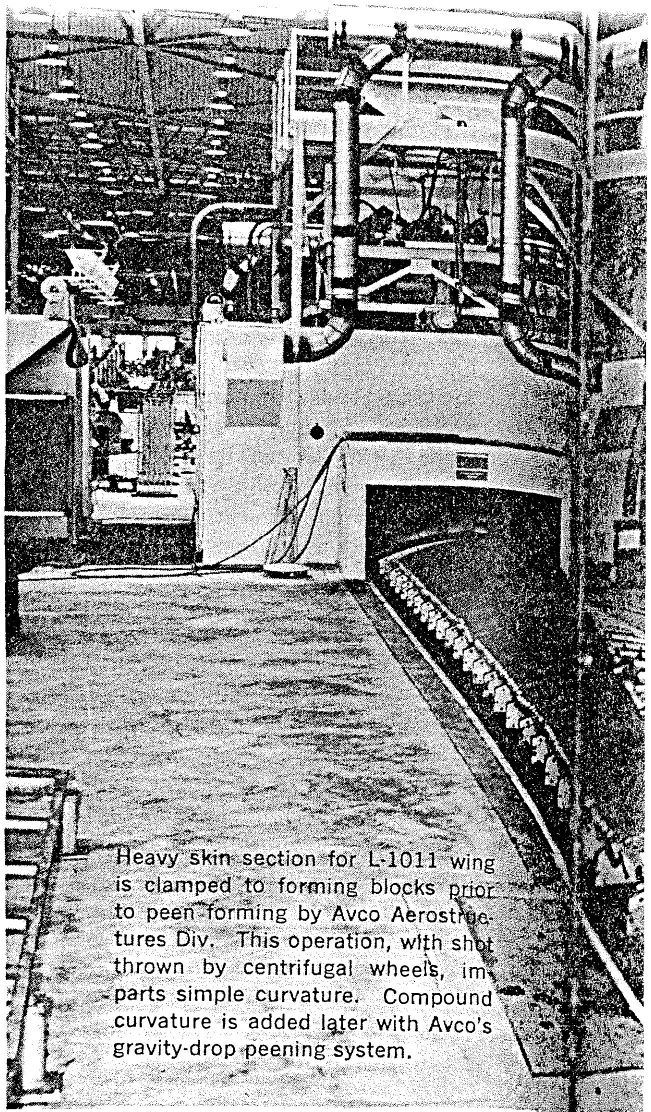
Peen Forming

Expensive dies and a costly press are usually needed to form metal sheet or plate into useful shapes. Now there is a new and simpler option: Just blast the metal with steel shot until it curls into shape all by itself.



Heavy skin section for L-1011 wing is clamped to forming blocks prior to peen forming by Avco Aerostructures Div. This operation, with shot thrown by centrifugal wheels, imparts simple curvature. Compound curvature is added later with Avco's gravity-drop peening system.

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SHOT PEENING, the well-known process for improving the fatigue life of metal parts, is now emerging as an important method for forming metal into complex shapes.

In conventional shot peening, where a torrent of steel balls is hurled against a metal surface, the numerous small impacts produce a uniform layer of surface compressive stress. This stress then minimizes the chance that residual tensile stress will promote premature fatigue failure.

Under certain conditions, the compressive stresses also make the workpiece curl or warp out of shape. Peen forming, or shot forming as it is also called, harnesses this effect for a useful purpose. The metal shot is applied selectively in an appropriate pattern so that the metal curves to some desired contour.

The process was first used some 20 years ago to form the wing skins for large aircraft. It has since been used from time to time for that one specialized purpose, and the wing skins for the Lockheed 1011 and Douglas DC-10 are currently formed by this process.

Because most engineers felt that peen forming was inherently limited to thin sheet in soft metals such as aluminum, there was never much inducement to develop machinery or technology to apply the process to other types of forming. However, forming problems encountered with the massive wing skins of the L-1011 forced some new thinking about the prospects for forming thicker and harder materials. Development work then proved that the process can indeed form thick plate, and in steel as well as aluminum.

Segments for large structures such as tank cars, tank trucks, and water towers probably could be formed with less cost and trouble by peen forming. Truck, bus, and railroad car bodies are other

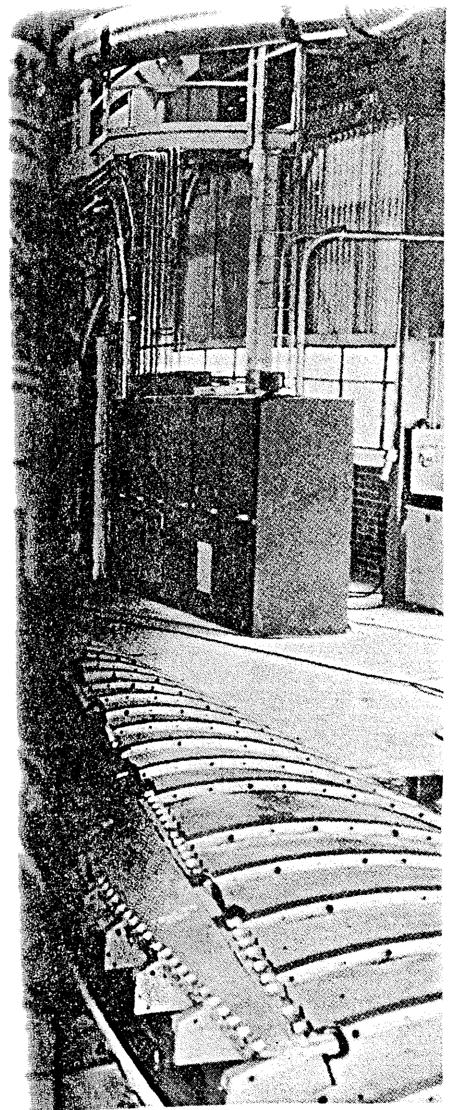
It Started with Connie

The first application of shot forming was in the forming of wing planks for the Lockheed Constellation, a large piston-powered transport built during the early 1950s. Portions of the Constellation wing were designed so that skin and stiffeners were extruded as one piece instead of being separate pieces riveted together. These extrusions had to be curved slightly across the width to conform to an airfoil contour. But the stiffeners interfered with any attempt to produce this curvature by roll or press forming, so Lockheed developed a method for producing the curvature by peen forming.

Also during this period, designers began to use more dihedral breaks in wings. These breaks have both span-wise and chord-wise curvature that create compound curvature or "saddle backs" in the skin.

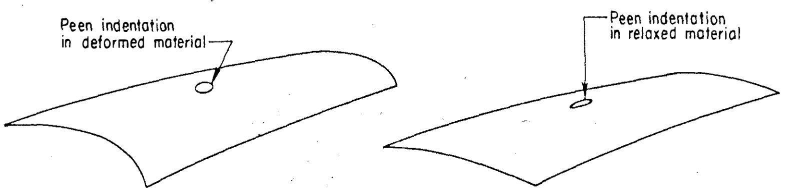
This compound curvature was generally produced by stretch forming. But stretch forming requires large expensive dies and massive presses, and there is a rather severe limit on the maximum size of skin that can be formed. On large parts this limitation makes it necessary to use skin splices that add weight.

In 1966, Grumman Aircraft & Engineering Corp. launched a program in conjunction with Metal Im-

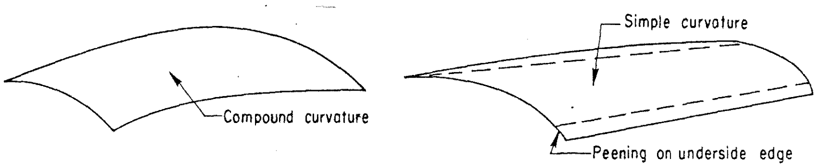


Peening for Simple Curvature

A uniformly peened surface tends to assume a hemispherical shape of compound curvature. Sometimes only simple, two-dimensional curvature is desired, and there are two commonly used techniques for producing this type of shape.



One method is to deform the material beyond the final desired curvature (but still within the elastic limit of the metal) by clamping over simple form blocks during peening. Each impact of shot then makes a round indentation causing equal radial stretching in all directions. Upon release of the material, these indentations become slightly elliptical, leaving higher induced compressive stresses in the direction of the bend. This imbalance of induced stress creates the desired simple curvature with minimum tendency to form a hemispherical or compound contour.



Another method to produce simple curvature is to peen the entire part in the free state on the side that is to be convex. This operation produces a compound curve. Next, two opposite edges of the back (concave) side are peened to expand the effective length of these edges and remove one of the degrees of curvature. Peening of these edges on the convex side also may be necessary.

provement Corp. to develop a peening method for producing compound curvature . Grumman then used this technique to form wing skins for the Gulfstream II business jet.

As aircraft grew larger, designers turned to wings where an increasingly greater share of the stresses are carried by the skin rather than by the supporting spars within the wing. Since this makes the skin a primary structural element, it is necessary to taper the skin along the span to accommodate the span-wise variation in air loads. Tapered skins cannot be stretch formed because the highest stresses and major portion of the plastic flow occur in the thinnest regions, and it is virtually impossible to make allowance for this fact in the design of the die.

When Lockheed designed the L-1011 transport, the engineers wanted long skin sections to avoid the structural inefficiencies of splices. But they had to contend with two dihedral breaks in each wing. Since the skins were both large and tapered, stretch forming was just about out of the question. Thus, attention focused on peen forming.

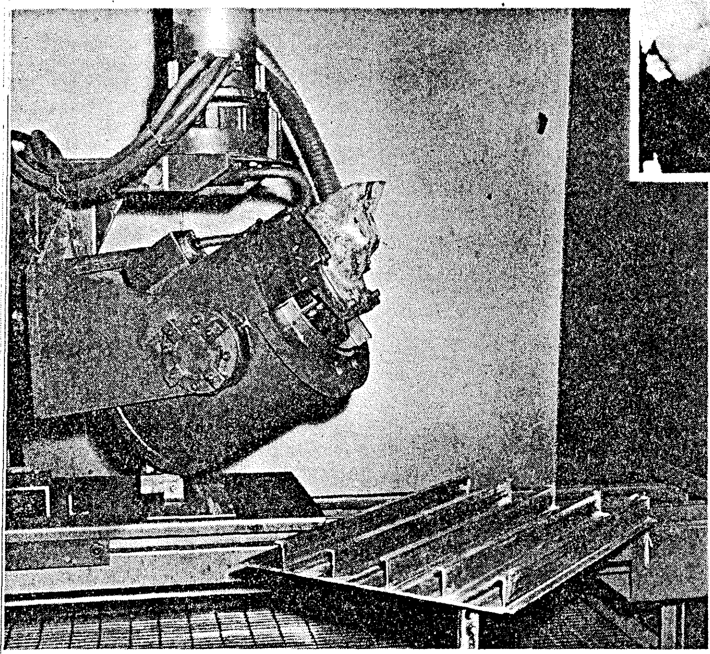
Virtually all prior shot forming had been done with air nozzles, where the shot is fed to a nozzle through pneumatic hose and propelled toward the workpiece by high pressure air. It became clear that air-nozzle systems—which tend to be slow and inefficient—would not be suitable for forming the massive L-1011 parts.

Avco Aerostructures Div., a subcontractor commissioned to build the L-1011 wings, began working on the problem in conjunction with Pangborn Div. of the Carborundum Co. Pangborn had recently developed a centrifugal wheel for throwing large quantities of shot in highly controllable patterns, and the engineers finally decided that the skins could be formed by this wheel throwing S-660 shot, a size at that time considered to be quite large.

But the skins are coated with a soft layer of corrosion-resistant aluminum alloy, and this coating was dimpled or roughened too much during the forming process. The rough surface could have been avoided by a change to larger shot size, but S-660 was the largest size that could be thrown by existing centrifugal wheels. So Avco came up with a system whereby large shot is simply dropped by gravity onto the skin. The system proved successful, and the L-1011 wings are now partially formed by this process.

Pangborn, meanwhile, approached the problem on a different tack and developed a centrifugal wheel that could throw extremely large shot up to 1/4 in. diameter. And it is this capability to throw large shot at high velocities that has now opened commercial possibilities for peen forming.

A downpour of steel shot falls at Avco Aerostructures Div., where the gravity-fall process was developed so that exceptionally large shot could be used to avoid a tendency for surface roughness on soft workpieces.



Centrifugal wheel for throwing shot is positioned above a section of integrally stiffened wing plank in a development test. Planks such as this, difficult to form in presses, spurred initial development of peening forming.

potential applications, as are large radar antennae now commonly made by spin forming.

In general, peen forming is a potentially cheaper way to form sheet and plate where the required part is large and where only gentle curvatures are needed. Moreover, peen forming easily produces compound curvature, which is often quite difficult to produce with press forming.

The main attraction of peen forming is that no dies or presses are required. The workpiece is simply placed on a table or suspended from a support and then blasted with shot. Occasionally it may be clamped to help it assume the desired contour, but such tooling is not nearly as expensive as that needed by conventional forming methods.

What's more, the forming process actually enhances the fatigue properties and corrosion resistance of the metal in contrast to the degradation that may accompany other methods. And the material can be formed in the hard temper. There is no need for a post-forming heat treatment.

Finally, the process permits design changes without the expense associated with reworking dies or tooling fixtures. A simple change in spray pattern and intensity changes the shape of the part.

What Peening Can Do

The limits of the process are still being investigated, but some interesting capabilities have already been demonstrated. For example, a flat steel disc of 6-ft diameter and ¼-in. thickness can be peened to about a 6-in. hemispherical or parabolic rise (10-ft radius) with S-660 (0.066 in.) shot.

Shaped discs such as this are used for end plates for truck tanks in which a liquid is subjected to a good deal of sloshing. The curved shape prevents "oil-canning" of the plate as the fluid hits the end of the tank. Currently, such tank sections are hammered into shape from heated blanks between massive dies, or are made by explosive forming or other techniques requiring forming dies. Peen forming offers a simpler alternative.

The toroidal-like shapes often used for water tanks are other likely prospects for the process. Parabolic radar dishes, some as large as 15 ft in diameter are now spun-formed on large lathes in a rather cumbersome and expensive operation. Peen forming could produce the same part more simply and at less cost.

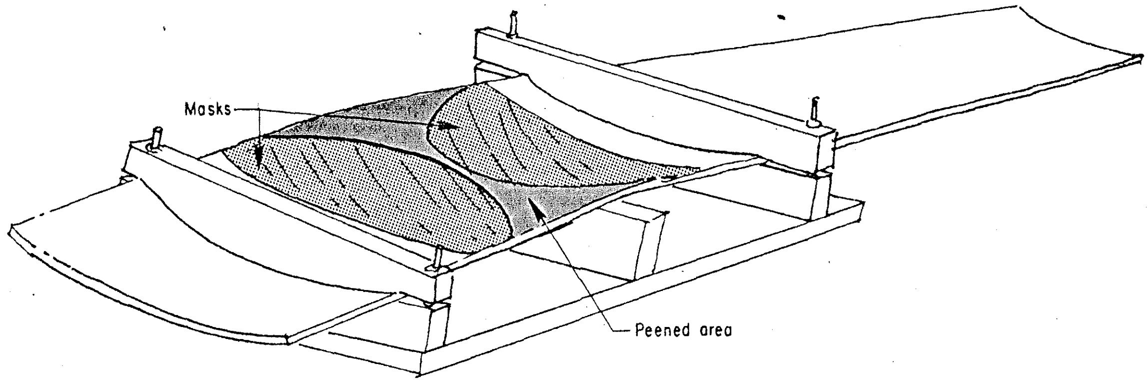
Tests indicate that about the largest plate thickness that can be formed with S-660 shot is $\frac{3}{16}$-in. Tests are being made with shot of ⅛ through ¼-in. diameter. These sizes will permit more severe curvature; the ¼-in. shot, for example, may permit the forming of steel plate as thick as ½-in.

The Technology of Peening

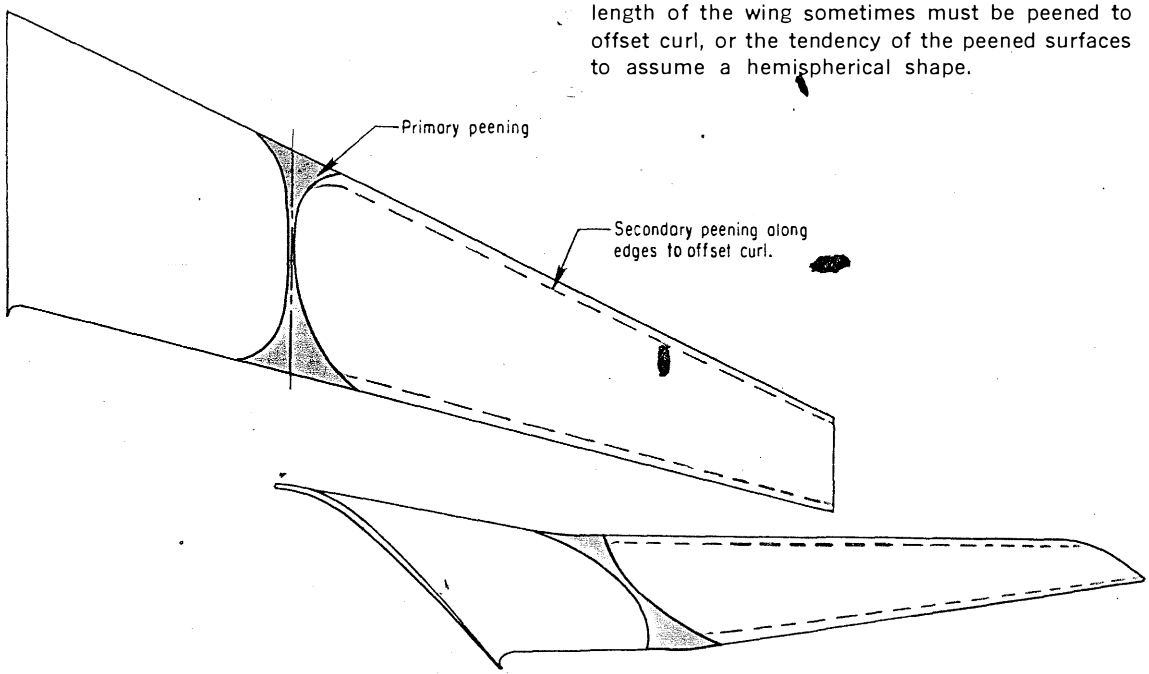
There are two primary limiting factors in peen forming. First, the process should be set up so

Some Tricks of the Trade

Some of the considerations involved in peening complex shapes are illustrated by the techniques used to produce a dihedral break in an airplane wing skin. The skin shown represents either a bottom panel with dihedral break down, or a top panel with dihedral break up.



The skin is first cut to a flat shape, and an airfoil contour is induced by peening the convex side. Then the skin is clamped in a fixture, which need not actually deform the skin, but which simply helps maintain the airfoil curvature already applied while stressing the piece slightly in the direction of the desire dihedral break. Masks, usually made of rubber, are applied to outline a carefully predetermined area to be peened. If the break is severe or if the workpiece is thick, the tool may be designed to permit peening from both sides. The shape of the area peened depends on the severity of airfoil curvature, skin thickness, and angle of the break. Thin strips along the complete length of the wing sometimes must be peened to offset curl, or the tendency of the peened surfaces to assume a hemispherical shape.



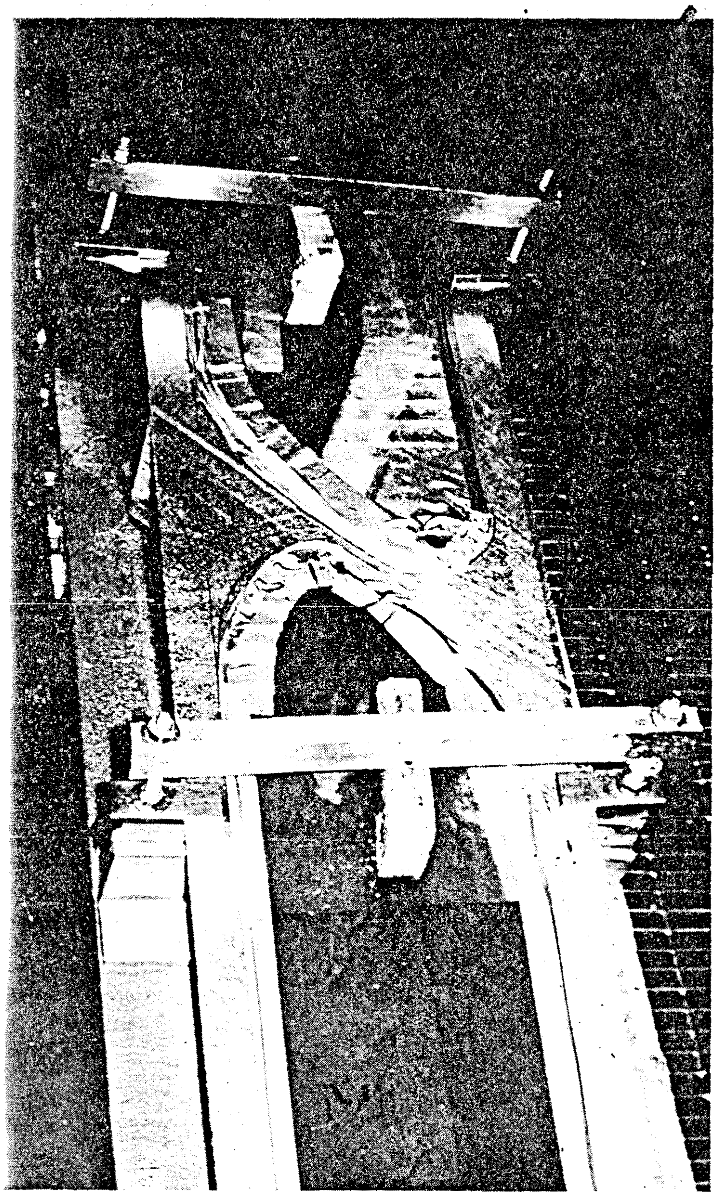
that the desired curvature is produced at less than 100 percent coverage, referred to as saturation peening. The reason is that the only available way to control or evaluate peening coverage is by a visual inspection of the peened surface. The amount or intensity of peening is then related to the percentage of the surface that has been struck by shot. Once 100 percent of the surface has been struck, there is a decline in the amount of additional compressive stress that can be induced by further peening. Anything in excess of saturation peening is thus outside the normal bounds of precise engineering control. Furthermore, peening in excess of saturation reduces the possibilities for making minor corrections in the forming operation.

The second primary limitation concerns the depth of the layer of induced compressive stress as a ratio of total part thickness. When this ratio exceeds a certain value—which varies with specific applications—the sheet or plate warps in an unpredictable and uncontrolled manner.

The value of this ratio also determines the extent of contouring possible in a material of given thickness. Since small shot or shot thrown at low velocities cannot produce a deep layer of compressive stress, large shot thrown at high velocity is necessary to form thick materials.

The objective in peen forming is to balance these two considerations by selecting shot sizes and shot velocities that provide the desired curvature at less than 100 percent coverage. If 100 percent coverage is reached without achieving the desired curve, it usually is necessary to change to larger shot or higher velocities if the workpiece thickness permits.

In practical terms, this means selecting a shot size that is acceptable insofar as indentation or surface roughness is concerned (larger shot makes less indentation), and then selecting a shot velocity that produces the desired curvature with less than 100 percent coverage. In trial applications to date, 50 percent coverage is often adequate to produce appreciable curvature.



View of test rig used in process development shows simulated wing skin with clamps and masking in place for peen forming. Dihedral break crosses the wing at 45 degree angle to conform to airflow across a swept wing.

Getting the Shape You Want

One of the key factors in peening technology is that various shapes can be produced by carefully masking the part so that selective regions are peened while other remained unpeened. This masking must be tailored very carefully for the peening to produce exactly the shape desired.

Uniform peening of flat sheet or plate ordinarily urges the metal toward compound curvature. Uniform peening over a square or round plate tends to produce hemispherical curvature, for example. Likewise, uniform peening over a rectangle tends to produce somewhat of an ellipsoid form. But suppose you do not want these types of curvatures. Or suppose you want only simple (two-dimensional) curvature. What can peening do then?

Early work in peening did not encounter this problem because the workpieces generally had integral stiffening ribs running along one axis of the part. Deformation from the peening stresses were thus constrained to simple curvature. But this same type of simple curvature can be produced on unstiffened sheet merely by applying the peening in narrow bands. Moreover, the degree of curvature can be controlled by varying the width of the bands of peened metal. Thus it is possible to produce ellipses, parabolas, or whatever is required by adjusting the masking so that the amount of exposed metal along the curve is proportional to the desired curvature at that point.

Clamping the workpiece in some desired shape (usually against simple form blocks) promotes deformation toward the bent configuration. For example, clamps might be applied to a sheet fore and aft to promote deformation into the airfoil curvature, while other clamps on the sides would urge the metal into a dihedral break.

The process cannot produce severe contours. However, interesting effects can be produced by adroit masking. An oblong shape can be made with curves at the ends and a straight section in the middle. Or another shape might have simple curvature in the middle with hemispherical ends. And one of these hemispheres can be made larger than the other.

In all, the future for the process looks promising. Although there may be some forming work done with air nozzles, most forming will probably be done with centrifugal wheels and by a newly developed gravity drop process (see IT STARTED WITH CONNIE) since these two can easily handle the great amounts of large shot needed for massive structures, thick materials, and high production rates.

Preliminary studies indicate that peen forming can be applied to titanium, thus offering the possibility of the process being used on exotic aerodynamic shapes for supersonic aircraft. And as work progresses on thick plate in the common industrial metals, the method undoubtedly will find uses outside the aerospace industry.