New shot peening requirements are emerging which are driven by aircraft engine customers. These include the military services and commercial air framers. The interest is in enhanced life engine components produced through quantified, verifiable benefits obtained by controlled, repeatable shot peen processes. These new requirements have the potential to greatly change the way peening is defined, and used in aircraft engine applications.

Today, the typical benefit that peening provides the aircraft engine manufacturer is fatigue life improvement. Peening benefits low and high cycle fatigue and retards crack growth. However, these benefits are not quantified, and are seldom used directly in calculating the component life. Peening is also used today to inhibit stress corrosion cracking, reduce fretting of contact surfaces, and to minimize the effects of machining which are typically not quantified.

Aircraft engine repair and overhaul facilities use peening to restore the repaired hardware to overhaul requirements. These requirements are often the same requirements that the aircraft engine OEM places on the new components.

Shot peening has progressed from manual controls and indirect process measurements in the 1970's to robotic nozzle motions and micro-processor controls in the 1980's. Required for the 1990's are quantitative benefits to be achieved through process enhancements and direct process measurements.
Shot peening technology may be divided into three chronological phases as shown in Figure 1. Phase one was the typical practice of shot peening from the 1970's into the 1980's. In this phase, the benefits of peening are not quantified, and the equipment has manual controls. All the nozzle positioning is done manually, and the operator monitors the process. In Typical Practice peening, the application of the process is measured indirectly with an Almen strip for compressive stress profile, and visually for coverage.

The next state of peening development is state-of-the-art (SOA) peening which is in use but not universally in practice. The benefits are still qualitatively defined as they were in the Typical Practice peening, but today the equipment is NC or microprocessor controlled. The key parameters of shot flow and air pressure are controlled and monitored by the machine controller. In robotic machines a manipulator sets all the nozzle positions very accurately and repeatably. In other systems, nozzle fixture motions are microprocessor controlled but without NC feedback. The same indirect process verification techniques used in typical practical peening are used in today's SOA peening.

Robotic shot peening represents the best approach for the future in shot peening equipment. This equipment offers improved process control and consistency for emerging needs which may require more precise control of impingement angles and local area coverage.

State-of-the-art in peening verification does not include any effective non-destructive method for measuring compressive residual stress. X-ray diffraction measures compressive stress only on the outer surfaces. Stress profiles are only obtained by destructive sectioning.

The next phase of peening may be labelled Enhanced Peening. This is the next generation of peening for the 1990's and beyond. In this phase of peening the benefits will be quantified with component specific life testing. The same robotic and/or microprocessor controlled equipment will be used as in SOA, but there will be several processor enhancements added to raise the level of process assurance. Direct non-destructive process verification techniques will be used to measure compressive stresses, and coverage.
FIGURE 1: PHASES OF PEENING

- **70's**: Typical Practice
  - Quantitative Benefits
  - Robotic Controls
  - Microprocessor Controls
  - Indirect Measurement

- **80's**: State-of-the-Art
  - Quantitative Benefits
  - Robotic Controls
  - Microprocessor Controls
  - Direct Measurement

- **90's**: Enhanced
  - Quantitative Benefits
  - Robotic Controls
  - Process Enhancements
  - Direct Measurement

- **TIME**: 70's, 80's, 90's
- **REQUIREMENTS**: Typical Practice, State-of-the-Art, Enhanced

**FIGURE 1: PHASES OF PEENING**
In order to describe Enhanced Peening, some specifics about Typical Practice and SOA peening will be reviewed. The process controls used in Typical Practice peening are rather minimal. Manual open loop air pressure controls are used that may be very inaccurate and typically are not well monitored. The shot flow is fixed by an orifice plate, which is also unmonitored and uncontrolled. All nozzle orientation to the component peened is done manually. In Typical Practice peening, the operator is the key to process control, the more knowledgeable and alert the operator, the more controlled the peening process.

The requirements which are used in Typical Practice peening are still today used in the SOA peening. Typical requirements are:

- **Media Size & Type**: S110 Steel Shot
- **Almen Intensity**: 5-7 A
- **Number of nozzles**: 2
- **Nozzle Position and Angle**: 4-5" from part 45°
- **Air Pressure Range**: 45-65 psi

These requirements are very general, rather simplistic, and the tolerances are broad.

An Almen strip intensity is specified which indirectly represents the compressive stress profile of the component peened. The Almen strip is a piece of steel which is measured for flatness with an indicator, and then peened. The change in flatness is called the Almen arc height, or Almen intensity. The Almen strip is an indirect measure of the process since it is done under the same conditions as the part but at a different time.

Visual inspection for coverage is another verification technique used in Typical Practice and SOA peening. The visual inspection for coverage can be done on the actual component but it is limited to areas which are accessible. Visual inspection is also a subjective measurement, thus slightly different interpretations of coverage are probable.

The obvious difference between SOA Robotic and Typical Practice peening is in the equipment. SOA Robotic machines usually have one or two gantry robots with 4 or 5 degrees of freedom. Each robot manipulates one nozzle around the component peened. All of these nozzle movements are controlled by a CNC machine controller and a part program. Along with the robotic nozzle manipulation, the SOA
equipment has closed loop air pressure and shot flow controllers. These controllers set and monitor their respective parameters. When specified tolerance bands are exceeded, they trigger machine shutdowns.

This SOA robotic equipment has significant advantages over its predecessor, the Typical Practice machine. These advantages are:

- Reduced nozzle setup time since part programs store all the nozzle positions electronically

- Improved process consistency due to the nozzle positioning repeatability, and closed loop control of key parameters, and

- Lends itself to automation when coupled with the right material handling, part fixturing, and cell software.

SOA microprocessor controlled multi-nozzle machines also have distinct process control advantages over Typical Practice machines when coupled with dedicated nozzle and part fixturing and malfunction shutdowns

- Reduced setup time
- Improved process consistency
- Assurance of peening integrity via the malfunctioning shutdowns

Quantitative benefits through Enhanced shot peening will require advances in several areas. Direct verification of stress profiles and peening coverage will be required. Definition and control of peening damage is another requirement. Increased assurance and control of the process itself is a necessity also.

These new requirements have three implications for the shot peening process. First, the benefits of peening will need to be quantifiably defined. Component life testing will be required to determine the benefit that peening provides for each component. Secondly the result of the peening process will need to be measured non-destructively for both compressive stresses and coverage. Finally, the peening process needs to be better controlled and proven to repeatable to raise the level of quality assurance.

Enhanced peening processes needed to meet these new requirements will most likely utilize the current SOA robotic peening equipment,
with the addition of several process enhancements. All of these enhancements should integrate into current SOA equipment.

The first enhancement is the establishment of a shot velocity sensor. Shot velocity is a critical parameter which contributes directly into the compressive stress profile of the component peened. The shot velocity sensor would detect nozzle wear as well as incorrect air pressure or shot mass flow rate. This device is necessary to assure that the process is consistent and repeatable.

Another needed process enhancement is adaptive control technology for the key parameters of shot velocity and coverage. Adaptive control technology will eliminate the effects of outside influences on the outcome of the peening process, improving process consistency.

Process modelling is another process enhancement needed. Process modelling would incorporate the hardware geometry as well as the process parameters and allow for process simulation. The simulation would be run to assure that uniform compressive stress is achieved over the entire component, including difficult areas, such as bolt holes, and dovetail slots. Process modelling would add assurance that the component was peened uniformly and also aid in process development. Less time would be required to develop part programs with the help of a process model.

The final area which needs development before Enhanced Peening can be implemented is process verification. A non-destructive direct measurement system is needed for both compressive stress profile and coverage. These techniques must measure the hardware directly in all areas. A new NDE technique is needed to measure peening damage. However, before damage can be measured, it must first be defined. All of the NDE methods will need to quantify the peening applied to the component.

An important point to remember is that all of the process enhancements discussed should integrate directly into existing SOA peening equipment. Also the new Enhanced Peening process will offer additional opportunities to reduce costs and improve productivity over the current SOA equipment. These savings will result from improved verification techniques introduced. Almen intensity checks may no longer be required. This would eliminate the time required to make these checks which often takes as long as the component peening time to complete.
Improved quality shot is another imperative for Enhanced shot peening. Conditioned cut wire shot is probably the most likely candidate.

In summary, new shot peening requirements are emerging that are driven by interest in enhanced part life. Recent progress in process controls has heightened that interest. Primary areas for process development are in the areas of shot quality, shot delivery control and non-destructive evaluation.