# DEVELOPMENT AND VALIDATION OF A NEW TEST PLATFORM FOR CLEANING PROCESS DEVELOPMENT
# PHASE I

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**ABSTRACT**

Innovative electronic assembly designs strive to increase functionality over smaller surface areas. Highly dense circuit assembly designs increase the cleaning challenge. Understanding the balance between static chemical and mechanical driving forces is fundamental to predicting and optimizing process variables.

The objective of this research is to improve the science of cleaning under low standoff components. The research will encompass three designed experiments to study nozzle designs, test simulations, and verification in industry standard cleaning equipment. Phase I of this research studies nozzle design cleaning effects for penetrating and removing flux residue under low standoff components. The nozzle cleaning effects were studied using a Cleaning Analyzer Recording Lab that provides video evidence of six different nozzle types.

In this study, two industry suppliers with the cooperation of industry experts at Lockheed Martin seek to understand impingement and fluid flow effects for penetrating and removing flux residue under low standoff components. The testing was done on glass substrates that were bumped using anisotropic epoxy. Glass die were placed over the die. High solids flux residue was dispensed and reflowed using a ramp to spike Pb-free profile. The test simulations were videoed to learn the fluid flow characteristics required to penetrate and remove flux residue under low standoff components.

Key words: Cleaning process, Cleaning, Cleaner

**BACKGROUND**

For many years the electronic assembly industry needed a cleaning test platform to measure improvements in the cleaning process. Until now, engineers caravan from cleaning equipment and chemistry supplier's application labs to test various options to understand what it takes to clean their most challenging assemblies. Application testing labs are an excellent resource, but may be limiting since it is difficult to test a wide range process variables that influence the process cleaning rate. Equipment designs have different spray patterns, wash section lengths, pump configurations, and pressure differentials.

The objective of spray-in-air batch and in-line cleaning systems is to reduce time by engineering fluid displacement that maximizes the physical energy delivered at the surface to be cleaned. An optimized cleaning system delivers the necessary chemistry and energy to clean the most difficult and sensitive areas, at a rate that will meet the process time requirements using minimal chemical energy and floor space consumption.

The research design provides customers with a platform for understanding the influence of process variables. Which nozzle configuration works best at removing residues under low standoff components? Is it a combination of flow and high pressure or will some other nozzle configuration work better? What is the best cleaning fluid and concentration required? How long does the part need to be positioned in the wash section? What influence does fixtures have on part cleaning? What is the temperature range required? What influence does upstream processing have on the cleanability of the assembly? Many variables influence the process cleaning rate. Accurately testing and simulating the optimal parameters allows customers to accurately specify equipment design and options. Additionally, the platform allows customers to evaluate cleaning fluids to select the material that best meets their needs.

**UNMET CUSTOMER NEED**

Difficult cleaning challenges, such as leadless chip carriers (LCCs), flush mounted chip caps, and area array components, are difficult to clean due to size, spacing, and standoff height of the components.[1] Leadless chip carriers and chip caps are placed flush mounted to the circuit board. The capillary action and surface tension of flux residue at peak reflow fills the underside of the component with flux residues (Figure 1).

The average spacing under one of these devices is approximately 2-4 mils, provided by the height of the solder pad and solder fillet on the pad.[1] Compounding the problem is the use of solder mask on bare copper under these components which further reduces the space under the LCC's and chip caps down to approximately 2 mils. Flux residue fills the underside of the component, thus forming a flux dam that prevents flow. To clean under these components, the static and dynamic cleaning rates must break the flux dam, create flow under the part, and dissolve all flux residues.

**Figure 1**: Flux residue trapped under component

Drivers for removing all flux residues under component include time in the wash section, nozzle type, pressure, cleaning fluid, and temperature. The limiting factor is time. Data findings from designed experiments indicate 5-15 minutes is required in the wash section to remove all flux residues under low standoff component.

The time required to clean under flush mounted components creates a bottle-neck. Customers are requesting optimized cleaning processes that reduce the time require to clean under these components. To open the process window and satisfy this unmet need, incremental innovations are needed from both dynamic and static sources.

## PURPOSE STATEMENT

The timing and sequence of events in a cleaning process are critical. Each section or step in the process requires careful thought and understanding. The pre-wash should thoroughly wet the parts with the wash solution chemistry and provide sufficient flow and contact time to bring the assembly to wash temperature. The time between pre-wash and wash requires an optimum soaking time. Both can be optimized to facilitate the full static cleaning in the power wash. In the wash zone, the part should see several high impingement scourgings, punctuated by brief soak periods. What is the minimum number of passes required under the manifolds? How is this affected by change in impingement pressure, nozzle design, manifold pressure, and so on?

Today, engineers are constantly being challenged with new cleaning opportunities. The difficulty lies in developing the process before you purchase the machine/chemistry combination required to do the job. Development of this programmable and process flexible test platform will help solve this problem by allowing a specific process recipe to be tested and compared to other process recipes. By changing one variable at a time, a ranking order can be established. Each top ranking variable can then be tested for process limits required to produce acceptable results given machine and assembly limitations. This allows a cleaning recipe to be fully tested before the equipment is purchased and loaded with cleaning chemistry for production. It also serves as a development tool to improve cleaning efficiency for existing production machines

Initial studies[2,3,4] developed a cleaning rate theory to empirically refined our process cleaning rate equations based on ($R_p=R_s+R_d$) where $R_p$ represents the process cleaning rate, $R_s$ represents the static cleaning rate, and $R_d$ represents the dynamic cleaning rate. It has been shown that the energy applied to the surface of the part to do work speeds the cleaning rate.

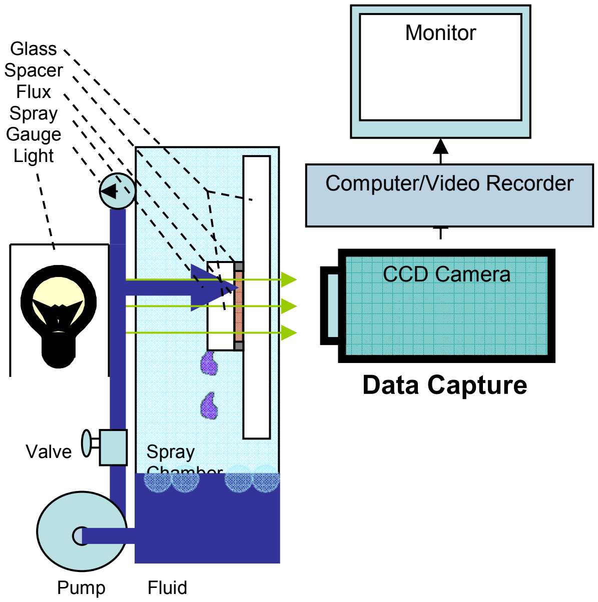
The design and layout of the nozzles becomes important if the cleaning system is to be truly optimized. This research paper is the first of three designed experiments to evaluate nozzle types for penetrating under low standoffs; manifold placement and time under the manifold to clean under low standoffs; and optimization of different nozzles to facilitate cleaning under low standoffs. The research team hypothesizes that the findings from the three designed experiments will help customers characterize and optimize process parameters needed to clean under tightly spaced components. After completion of the nozzle design experiments the same level of testing can be applied to cleaning fluids and other process variables of interest. For the nozzle designed experiments, other process variables such as wash temperature, cleaning chemistry and concentration will be held constant

## TEST PROTOCOL

The test protocol represents a three part series of designed experiments. Phase 1, which will represent the data reported in this paper, tests nozzle and pressure variations. Phase 2, which will be reported in a follow up technical submission, will validate the nozzle and cleaning fluid simulations using the test platform design illustrated in Figure 2. Phase 3, which will be reported in a follow up technical submission, will validate the findings from Phase 2 in an inline aqueous cleaning machine.

Figure 2 shows a system diagram of the test apparatus design we referred by the acronym "CARL" Cleaning Analysis Recording Laboratory. This system allows the filming and recording of real time cleaning on transparent assemblies/coupons. The capture rate of the video is 30 frames/second (33 milliseconds between captures).

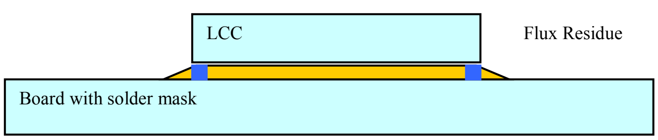
**Figure 2**: Diagram of Cleaning Analyzer Recorder Lab (CARL)




## PHASE I TEST VEHICLE

The test device allowed for nozzle, wash temperature, wash time, pressure, chemistry and movement variations. Figure 3 shows a test slide mounted in the viewing window. A solvent rich zone in the center of the slide is visually detectable. The arrows indicate several out-gassing channel exit points in the flux mass. These out-gassing tracks remaining from the solder reflow heat cycle leave weak areas which allow cleaning fluid channels to initiate.

**Figure 3**: Test Vehicle




## PHASE 2 TEST VEHICLES

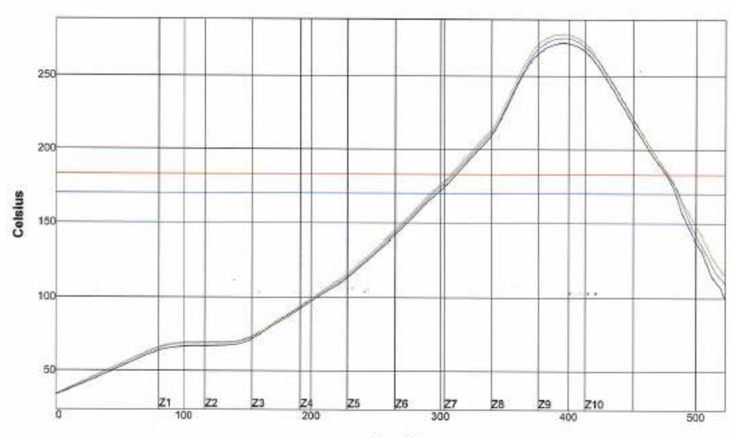
Verification testing will be done using a populated circuit assembly using leadless chip carriers flux mounted to the board (Figure 4). The components selected for this study are multi-resistor arrays and leadless ceramic chip carriers (LCC's) mounted on solder mask. Removal of high solids rosin flux residue under leadless chip carriers has been shown to be extremely difficult. The gap is 2 mils or less and the area is relatively large.

**Figure 4**: Leadless Chip Carrier Example

## PREPARTION OF PHASE I TEST SAMPLES

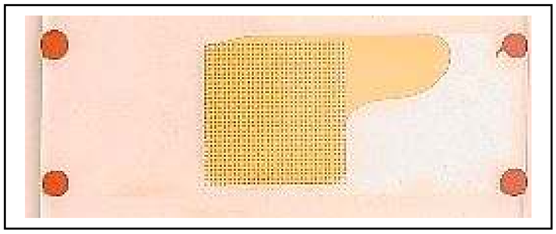
Test coupons will be assembled using glass slides to characterize nozzle types. The slides were bumped with epoxy using 75mm pitch, 900 I/O. The die size tested was 25mm x 25mm (Figure 6). Samples were assembled and pre-cleaned to remove all assembly residues prior to testing. All gaps to be tested were pre-fluxed with sufficient volume of liquid RMA (Alpha 615-50) flux to fill the gap. The test coupons were reflowed in a convection oven using a Pb-free ramp to spike standard profile that achieves a peak temperature of 270$^{\pm}$5C (Figure 5). The selection of 50% solids rosin flux and high peak reflow created a very challenging flux residue to clean. This allowed for differentiation in the cleaning rates. The coupons then cooled to room temperature and aged for the appropriate time before running the cleaning test.

**Figure 5**: Reflow Profile




| PWI= 606% | Max Rising Slope | | Soak Time 150-170C | | Reflow Time /183C | | Peak Temp | |
|---|---|---|---|---|---|---|---|---|
| 3 | 1.8 | 152% | 22.1 | -26% | 168.5 | 362% | 276.2 | 582% |
| 4 | 1.8 | 161% | 21.9 | -27% | 170.6 | 369% | 278.6 | 606% |
| 5 | 1.8 | 152% | 23.1 | -23% | 164.9 | 350% | 272.8 | 548% |
| Delta | 0.0 | | 1.1 | | 5.7 | | 5.8 | |

**Figure 6**: Completed Test Coupon Cross Section



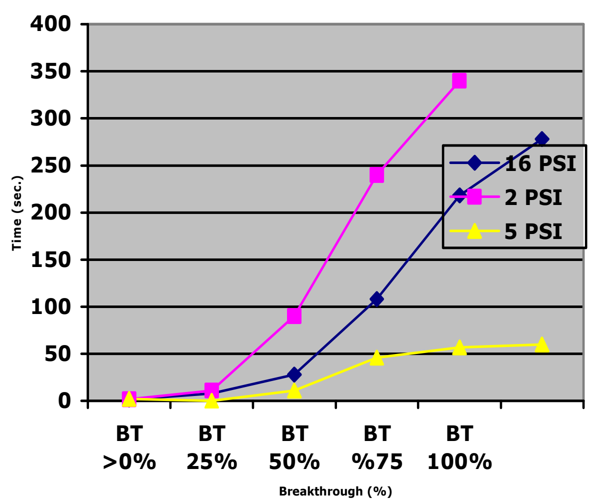
## PHASE I RESEARCH HYPOTHESIS

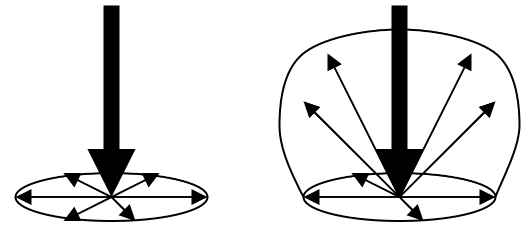
The research hypothesis infers that turning up the pressure does not necessarily help improve the cleaning rate. In fact, data in graph #1 indicates that there is an optimal impingement pressure for a given cleaning result. In this case, hardened high solids rosin flux residue was reflow using a Pb-free profile with a peak temperature of 278ºC to create a challenging cleaning task that shows differentiation in cleaning.

Previous testing indicates higher pressures do not always produce the best result. Video analysis indicates a possible reason. In comparing a 5psi impingement jet to a 15psi impingement jet, the 5psi jet splashed much less than the 15psi jet. This resulted in a much more even spreading of the cleaning fluid on the glass surface. In the higher pressure jet, the fluid tended to "bounce' off the surface.

The 3-dimentional aspects of a high pressure jet leaves less fluid mass on the board's surface spreading to clean areas adjacent to the impact area. Figure 7 illustrates this point.

**Graph #1**: Illustrates the effects of jet bounce in Jets with too high pressure.



Optimum pressure impact spreads 2-D     Too high a pressure impact spreads 3-D

**Figure 7**: Observed effect of to high pressure jet spreading in 3-D pattern verses 2-D surface spread on lower pressure jet

## FACTORIAL DESIGN

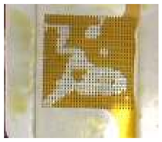
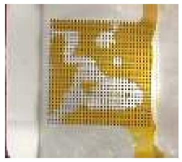
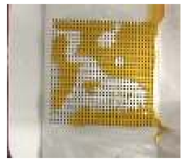
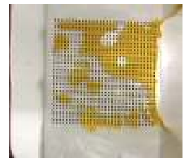
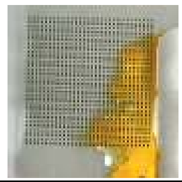
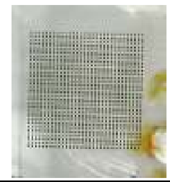
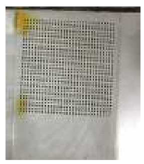
To arrive at an optimal machine design, a range of process variables must be considered. Spray manifolds vary based on 1) nozzle type, 2) nozzle spacing and 3) nozzle arrangement. Aqueous engineered cleaning fluids vary based on solvency, reactivity, wetting, and compatibility. The concentration of the cleaning fluid varies the static cleaning rate. Wash temperature varies the dissolution rate. Impingement energy varies the force and velocity applied to the surface area. Movement varies the time the force sees the part and soaking interactions.

To understand the process cleaning rate, many variables must interact seamlessly to optimize the process. The variables studied included six nozzle designs. The engineered cleaning fluid used is the material currently used by Lockheed Martin. For each nozzle type there were two test simulations. Test 1 held the nozzle at a fixed position at the leading edge of the die using pressure #1. Test 2 held the nozzle at a fixed position at the leading edge of the die using pressure #2. The factorial experimental design variables tested in Phase 1 are illustrated in Table 1.

**Table 1**: Factorial Experimental Design

| Nozzle | Pressure | Wash Temperature | Visual Image Before Cleaning | Time in seconds | Time in seconds | Time in seconds | Time in seconds |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 1 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 2 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 2 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 3 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 3 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 4 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 4 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 5 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 5 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 6 | 1 | 150ºF | BC | 15 | 30 | 45 | 60 |
| 6 | 2 | 150ºF | BC | 15 | 30 | 45 | 60 |

**Figure 8:** Data Findings

| Nozzle | Before Cleaning | 15 seconds | 30 seconds | 45 seconds | 1 minute |
|---|---|---|---|---|---|
| **Nozzle 1** **Pressure 1** |  |  |  |  |  |
| **Nozzle 1** **Pressure 2** |  |  |  |  |  |
| **Nozzle 6** **Pressure 2** |  |  |  |  |  |

## DATA FINDINGS

The data findings point to three variables that influence the dynamic cleaning rate: nozzle selection, flow, and pressure. The video images conclusively indicate differences in cleaning performance. Nozzle 5&6 provided the best cleaning performance. These nozzles provided two important characteristics. First they delivered higher fluid flow at the leading edge of the die and second they provided the highest pressure at the leading edge of the die.

The cleaning fluid and temperature selected were highly effective at dissolving rosin flux residue. To move this residue from under the die required flow and pressure. The focal point (center) of the nozzle jet provides the highest pressure from the point of contact. Diameters closely aligned to the focal point clean at a faster rate. The greater the distance from the focal point, cleaning drops off even when flow is greater. The data finds that higher flow with pressure decreases cleaning time and high flow without pressure increases the time to remove all residues.

## RECOMMENDATIONS

Dynamic cleaning rates reduce time and improve the process cleaning rate. To optimize the cleaning process, the data infers that jets designed to overlap the focal point with high flow improve the process cleaning rate. The data from this research indicates that the cleaning equipment design is highly important to performance. The nozzle jets need to be properly aligned and spaced. The jet must create an applied force upon contact to move the cleaning liquid into the tight space to move and free the residue.

The rate of dissolution is a function of the cleaning fluid design. Selecting a cleaning fluid that exhibits a high static cleaning rate for the soil matrix and combining this with the appropriate mechanical design improves the process cleaning rate. To optimize the cleaning process, the mechanical and cleaning fluid designs must work hand in hand. A properly designed machine is ineffective without the right cleaning fluid. Conversely, the right cleaning fluid is ineffective removing residues under tight spacing's without the applied mechanical energy.

## FOLLOW ON RESEARCH
## MACHINE DESIGN

Phase II will use a new machine design that consists of many standard features found in an inline cleaner with one big difference. The standard wire mesh conveyor belt was replaced with a programmable lead screw. This change not only allows bi-directional motion of the conveyor but also facilitates programmable speed control in each step of the cleaning process through computer/PLC control. Reducing the number of spray bars reduces the size of the reservoir and amount of chemistry needed.

This design affords the control of the following process variables in the washing process

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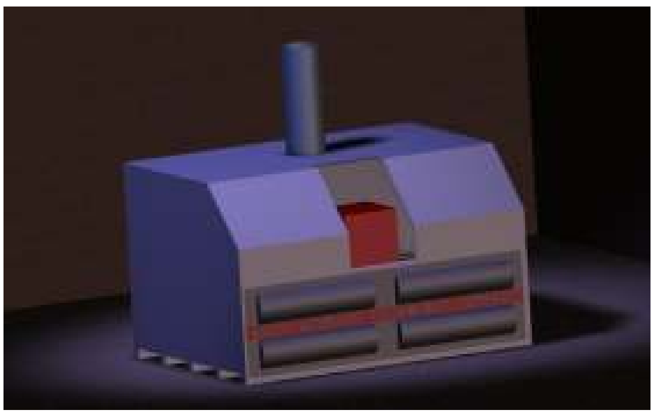
1. Pre-wash spray time
2. Pre-wash soak time
3. Wash pressure
4. Wash temperature
5. Number of passes under wash manifold
6. Speed of travel in the wash
7. Wash manifold height
8. Angle of the spray
9. Wash nozzle type
10. Wash nozzle spacing/configuration
11. Type of cleaning chemistry
12. Concentration of cleaning chemistry

Similarly these rinsing process variables can be controlled.

1. Application of rinse aid (optional)
2. Rinse aid soak time
3. Rinse pressure
4. Power rinse temperature
5. Number of passes under rinse manifold
6. Speed of travel in the rinse
7. Rinse manifold height
8. Angle of the spray
9. Rinse nozzle type
10. Rinse nozzle spacing/configuration

The important variables for the chemical isolation and dryer sections are time and number of passes. Age of the flux is another variable previously shown to have influence on the cleaning rate.

**Figure 9**: Diagram of the Test Platform

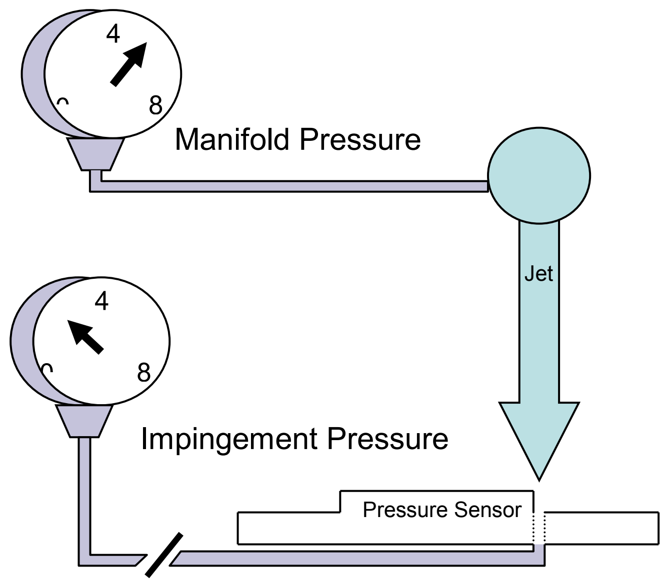


The test platform is designed to be front loading with two wet chambers. The chamber to the left is the wash chamber. The middle zone is for loading and unloading. The middle zone also serves as the chemical isolation blow off and the final dryer. Chemistry is thus, effectively separated from the rinse on the right hand side by the isolation blower. Stripped chemistry is returned to the wash sump saving chemistry and minimizing environmental streams and DI load. Front windows with interior lighting provide easy access for manifold adjustments and process viewing

**VALIDATION METHODOLOGY**

The old premise that increasing the manifold pressure with a bigger pump is being challenged. Fluid mechanics suggests that the energy delivered to the surface is equal to the mass times the velocity squared. Designers of cleaning equipment have historically correlated cleaning efficiency with manifold pressure. Impingement pressure at the cleaning surface is very dependent on the nozzle type and distance from the nozzle manifolds to the surface to be cleaned. Prior measurements of different nozzle types have shown typical pressure drops of 50% for fan nozzles, 75% for conical nozzles, and 25% for coherent nozzles for each inch traveled. A removable impact pressure sensor will be inserted in the fluid jet to measure the impact pressure at the board's surface independent of the manifold pressure. A key feature of the sensor is that the sensor head reproduce the spacing and surrounding components of the assembly to be cleaned.

**Figure 10:** Manifold Pressure Sensor




The manifold pressure sensor will be setup to differentiate manifold pressure from impingement pressure. Note; size the opening of the pressure sensor to match as closely as possible the true gap dimensions of the component.

**Conclusion**

Removing flux residue from low standoff components requires an optimized cleaning process. Dynamic forces require the interaction of pressure and flow. The research findings conclusively point to nozzle jets that provide the greatest force and flow at the leading edge of the component. With the right nozzle selection defined, manifolds must be built to provide over lapping coverage at a preset distance from the focal point.

Cleaning fluid selection requires a material that exhibits a static cleaning rate for the soil. The proper mechanical force removes a residue that is dissolved in a constricted space. Without proper dissolution, the mechanical force fails to provide the needed result. Optimization requires a hand in hand interaction of the dynamic and cleaning rates.

## REFERENCES


Woody, L. (no date). Cleaning under LCC's: An evaluation of semi-aqueous and aqueous cleaning processes. Ocala, FL: Lockheed Martin Electronics and Missiles Systems.

Stach, S., & Bixenman, M. (2004, Sep). Optimizing cleaning energy in batch and inline spray systems. SMTAI Technical Forum, Rosemont, IL: Donald Stephens Convention Center.

Stach, S., & Bixenman, M. (2005, Sep). Optimizing cleaning energy in electronic assembly spray in air systems: Phase II. SMTAI Technical Forum, Rosemont, IL, Donald Stephens Convention Center.

Bixenman, M., & Stach, S., (2006, Sep). Optimized static and dynamic driving forces for removing flux residue under flush mounted chip caps. SMTAI Technical Forum, Rosemont, IL, Donald Stephens Convention Center.