

# Clean then Assemble versus Assemble then Clean: Several Comparisons

By

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## Abstract

Cleanliness of manufactured parts and assemblies is a significant issue in many industries including disk drives, semiconductors, aerospace, and medical devices. Clean manufacturing requires cleanroom floor space and cleaning technology that are both expensive to own and expensive to operate. Strategies to reduce these costs are an important consideration. One strategy shown to be effective at reducing costs is to assemble parts into subassemblies and then clean the subassembly, rather than clean the individual parts first and then assemble them. One advantage is that assembly outside of the cleanroom reduces the amount of cleanroom floor space and its associated operating cost premium. A second advantage is that this strategy reduces the number of individual parts that must be cleaned prior to assembly, reducing the number of cleaning baskets, handling and, possibly, reducing the number of cleaners. The assemble then clean strategy also results in a part that is significantly cleaner because contamination generated during the assembly steps are more effectively removed than normally can be achieved by hand wiping after assembly in the cleanroom.

## Introduction

When developing a strategy for achieving cleanliness of parts and assemblies, many factors must be considered. Among the factors that must be considered are those associated with quantitative measures of cleanliness, including particle contamination, ionic contamination, volatile organic contamination, and viable contamination. Particle contamination is the result of casting machine coating and handling processes.

Fortunately, the quantitative measurement and specification of contamination is a fairly mature area of applied technology. There are a number of methods that can be used to quantitatively estimate cleanliness of parts. Among the most mature of these is the International Disk Drive Equipment and Materials Association (IDEMA) standard procedure for particles [1]. The validity of this approach to measurement of particle cleanliness has been repeatedly demonstrated [2, 3, 4]. Similarly, there are generally accepted IDEMA methods for quantification of extractable anions [5] and cations [6], which are adaptations of widely used ASTM [7] and EPA methods [8, 9]. In the disk drive industry, nonvolatile residues are measured using an IDEMA technique [10] based on well-accepted and widely used ASTM standards [11, 12, 13]. In general, the selection of methods and controls used in the disk drive industry are based on a military standard [14] that

has withstood the test of time. Most tests for viable microorganisms are modeled after a well-accepted ASTM test method. [15]

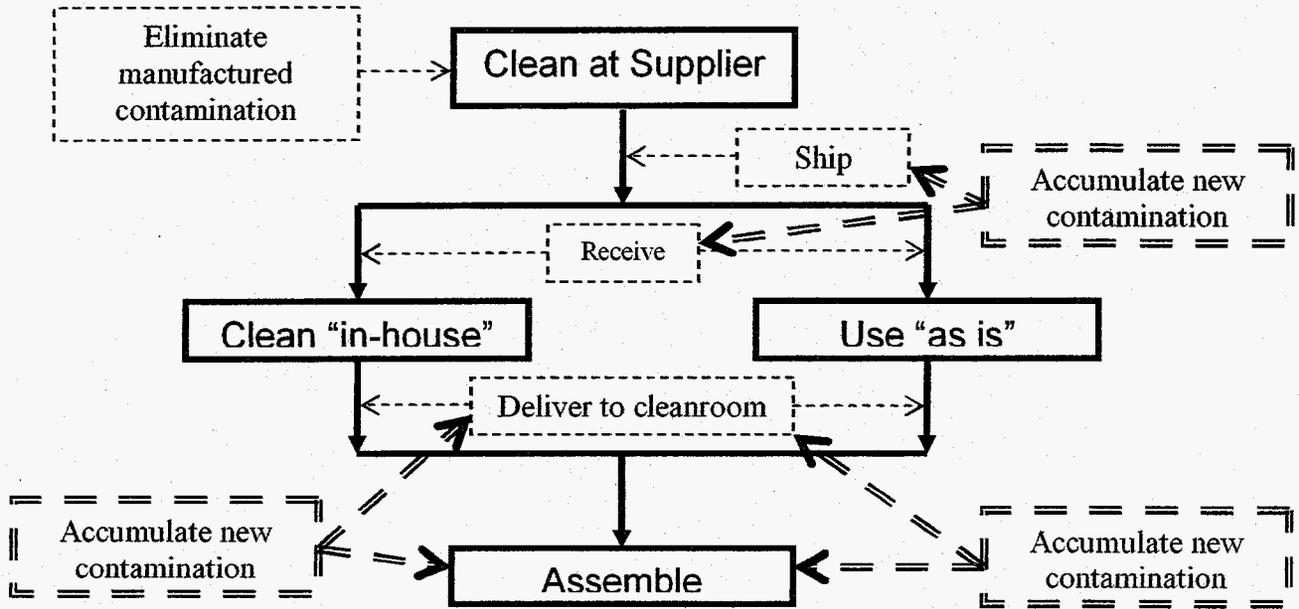
Another factor that must be considered is the overall risk of recontamination of parts after they are cleaned in-house. In general, the risk of recontamination by ionic or organic contamination during transportation and assembly is quite low. This is due to several factors, the most important of which is the careful process used to qualify materials used to make the product (coatings, adhesives, etc. [16, 17]) and the materials these parts come in contact with during assembly (gloves, for example, [18]). Moreover, the migration of many industries to aqueous based cleaning has provided a great deal of protection from corrosion due to the high relative solubility in water of most contaminants promoting corrosion, i.e., ionic contamination. The use of aqueous cleaning chemistries has driven the elimination of cutting fluids and other materials which previously required the use of solvents for cleaning [19, 20]. As a consequence, organic residues that are not readily soluble in aqueous detergent cleaning have been largely eliminated. This has driven down the amount of non-volatile residue. Most precision parts that must be free of bacterial contamination (spacecraft, medical devices) are designed so that the product can be sterilized after assembly [21, 22] using validated processes.

### Cleaning Strategies

Two different strategies may be considered: clean then assemble versus assemble then clean.

The clean then assemble strategy is illustrated in Figure 1.

Figure 1. The clean then assemble strategy and its contamination consequences.



In this strategy, the responsibility for achievement of the ultimate cleanliness of parts rests with suppliers. This strategy is adopted recognizing that the supplier produces a relatively small

number of parts, whereas the customer receives all parts. The supplier is better able to supply a process customized to the individual piece parts than is the customer.

Parts are shipped by the supplier and received by the customer. Two categories of parts may be described: parts that may be cleaned 'in-house' and parts which must be used 'as is'. During the shipping and receiving process all of these parts may accumulate new contamination due to packaging and handling. For parts which can be cleaned in-house the packaging and handling debris can be removed. For parts that must be used "as is", this accumulated new packaging and handling contamination pass through to the cleanroom. Parts emerging from the 'in-house cleaner' are also delivered to the cleaner. Any additional packaging and handling debris are then passed through to the assembly process. Finally parts are subject to assembly. Here additional contamination is likely to be generated.

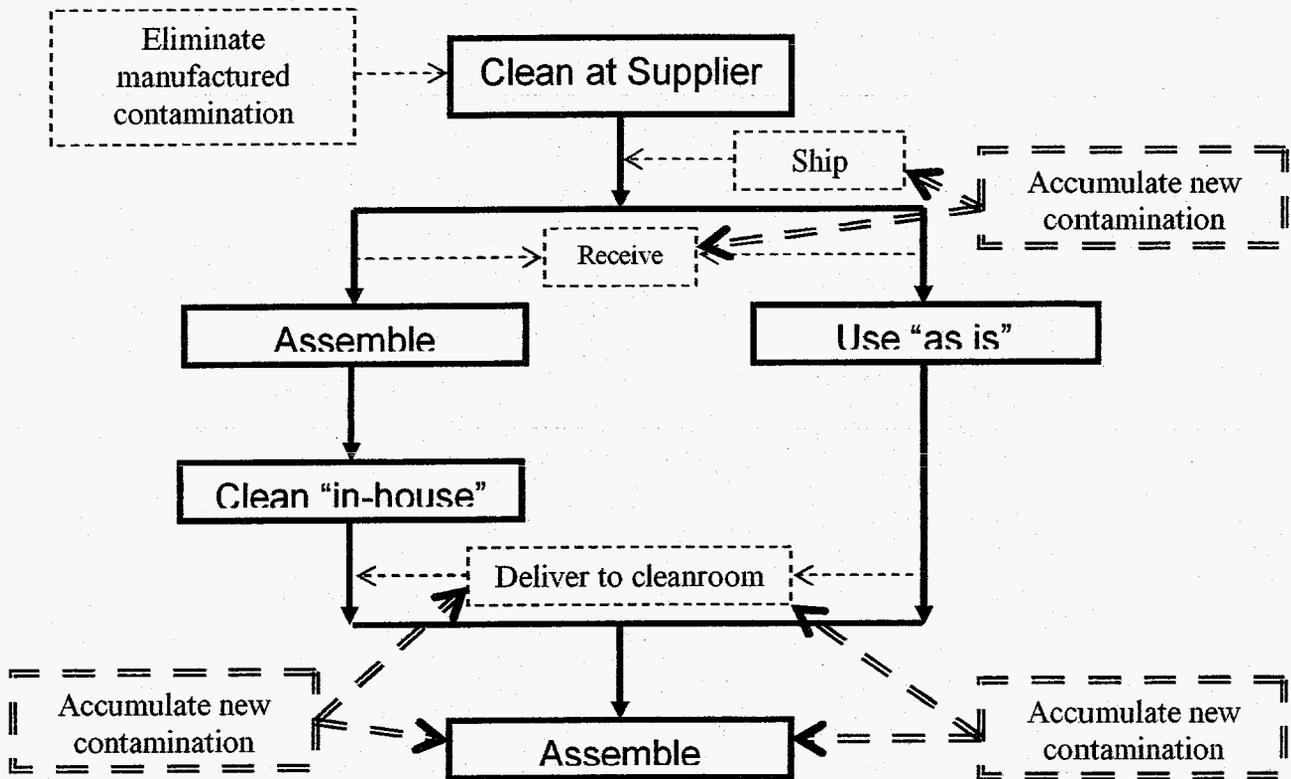
As can be seen from this illustration three pathways for accumulation of new contamination exist in the clean then assemble strategy that are not mitigated by the clean then assemble strategy. These are:

- Accumulated by parts to be used "as is" parts during shipping and handling.
- Accumulation by parts cleaned "in house" and parts to be used "as is" in the subsequent handling and movement within the cleanroom.
- Accumulation by parts due to the assembly process.

Looking at this strategy, it is obvious that some parts, like motors and bearing which contain lubricants, cannot be cleaned by conventional 'in house' cleaning processes which usually involve immersion in a bath of liquid. However, there are sets of parts that could possibly be assembled outside the cleanroom that then could be cleaned prior to delivery to the cleanroom for further assembly. This can be referred to as the assemble then clean strategy. Figure 2 illustrates one possible application of the assemble then clean strategy.

The degree to which an assemble then clean strategy benefits an overall assembly process depends on the relative proportion of the subassemblies that are to be cleaned 'in house' versus parts that must be used "as is" and the relative improvement in cleanliness achieved. In a process where all parts must be used 'as is', there is no benefit to be derived because it cannot be implemented. Conversely, where none of the received parts must be used 'as is', the maximum benefit can be derived, depending on the ability to qualify the process. In most real world situations, some portion of the parts can fall into the assemble then clean strategy.

Figure 2. One possible application of the assemble then clean and its contamination consequences.



In the assemble then clean strategy, the process is analyzed to identify those subassemblies which could be assembled outside the cleanroom and subsequently cleaned, eliminating the handling and assembly contamination generated by those steps previously performed in the cleanroom after "in-house" cleaning.

### Methods

In the course of the study several different methods have been employed. Cleaning of assemblies can introduce new failure modes of other than cleanliness or dryness degradation. In each case to be reported careful consideration has been given to the various failure modes that might be introduced by the cleaning process:

- The breakaway torque of all mechanical fasteners was measured.
- The shear strength of all in use of bonds was measured.
- Critical dimensional positions of all components were measured.
- Ionic contamination levels were measured by deionized water extraction and ion chromatography chromatography.
- Volatile organic contamination was measured using witness plates and combination FTIR GC/MS.

- Particle cleanliness was measured using liquid particle count following one of two extraction methods: ultrasonic immersion extraction and a detergent DI water solution or needle spray extraction with pure DI water.

The breakaway torque of all mechanical fasteners was made using instruments capable of measuring the torque, whose gauge capability has been shown to be able to measure to the degree specified on the drawing. The pull-strength and shear-strength of all adhesive bonds were measured using Instron mechanical testers, again with gauges demonstrated to be capable for the measurement required. Critical dimensional properties were measured using the receiving inspection's coordinate measurement machines. Ionic contamination levels were measured using standard extraction and measurement techniques. Volatile organic contamination was measured by either extracting the part using a suitable solvent or by placing the part in the chamber containing an absorbent cartridge and subsequently measuring the volatile component using Fourier transform infrared (FTIR) spectroscopy or gas chromatography/mass spectrophotometry (GC/MS). All of these measurements were made either using the instruments used for materials qualification of receiving inspection of the parts.

The most important measurement for these studies was the particle content of the parts after assembling part. Particle cleanliness was measured in ultrasonic immersion extraction in a 200 ppm solution of Triton X-100 detergent in the ionized water, one minute extraction, and 40 kHz in a Branson DHA 1000 tank, with a one inch coupling fluid depth. Particles measured by spray extraction, using pure DI water (no detergent), at  $50 \pm 5$  PS IG, with approximately 0.7 mm diameter needle jets. Particle concentrations in the spray extracts were measured after ultrasonic pulse degassing. All using extinction particle count instruments with either 5 micrometer ( $\mu\text{m}$ ) or 2  $\mu\text{m}$  lower detection and light scattering optical particle counters with 0.5  $\mu\text{m}$  lower detection limit.

### **Case studies**

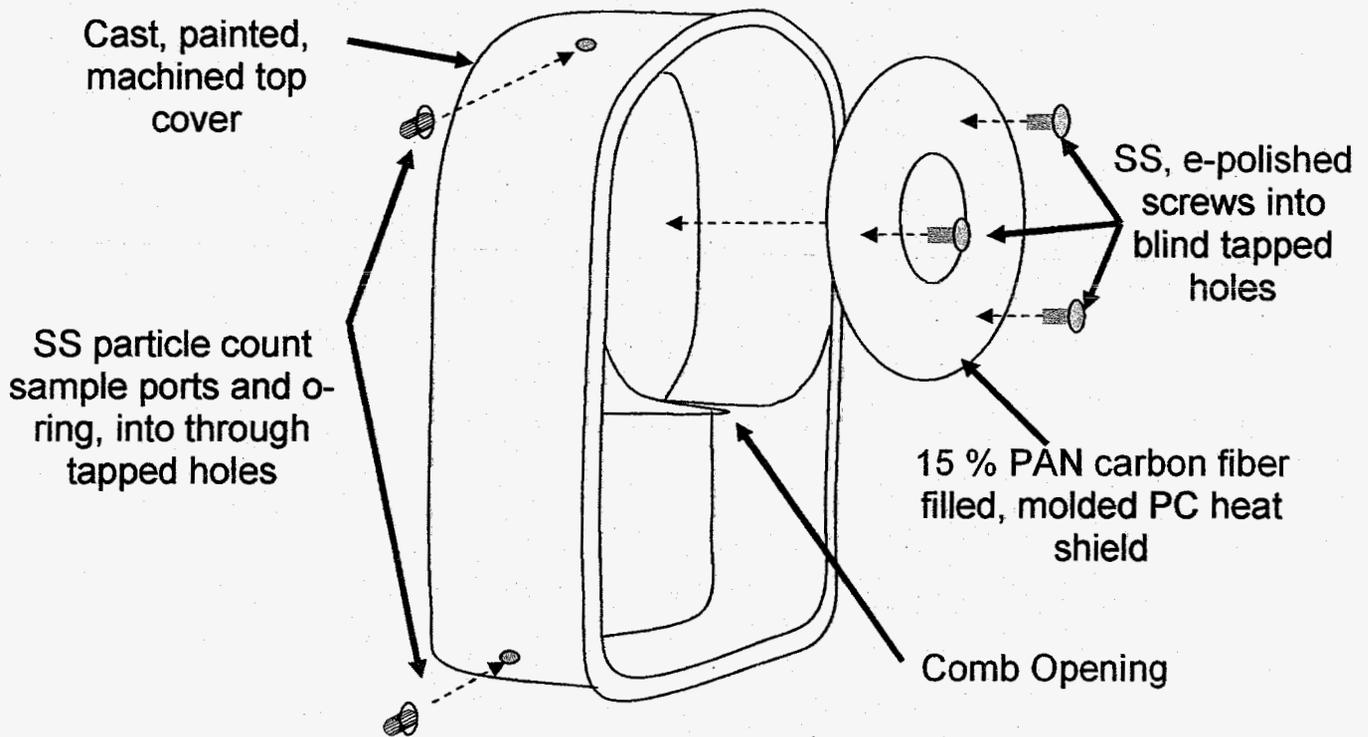
Four case studies are explored in this paper. A top cover assembly, a comb seal assembly, a voice coil motor permanent magnet assembly and an actuator assembly. This succession represents parts in increasing order of complexity and cleaning challenge. In every one of these evaluations, the ionic contamination and organic contamination were well within specified limits.

#### ***Case Study 1: Top Cover Assembly:***

The top cover assembly is illustrated in Figure 3. The top cover assembly is a very large casting that has relatively few machine features. Unfortunately during assembly every one of the machine features is used. Two stainless steel particle count sampling ports are driven into their aluminum through holes in the top cover. A heat shield is fastened to the inside of the top cover assembly using three stainless steel, electropolished screws. The heat shield is molded from a highly friable material: 15 percent polyacrylonitrile carbon fiber filled polycarbonate.

The heat shield is a great concern for this qualification: experimental tests to select the optimum cleaning process had previously shown that ultrasonic immersion cleaning resulted in significant particle generation and thus was not a suitable cleaning technique. The "in-house" cleaner proposed for the top cover assembly used ultrasonic immersion cleaning. There was the concern the in-house cleaning of an assembly containing the heat shield would result in a dirtier part.

Figure 3. Top cover assembly.



The challenge is then to determine does ultrasonic immersion clean after assemble adversely affect:

- torque of the screws used to attach the top heat shield or the particle count sample ports to the cover
- air leakage through the particle count sampling port seals
- retention of water in any of the fastening holes (dryness achieved by the forced hot air drying process)
- increase of detergent drag out due to an adequate rinsing oven assembly that contains an obstruction that prevents rinse water from directly spraying on a portion of the part.
- Erosion of particles from the carbon filled heat shield

#### Top Cover Assembly Results:

- Screw torque for the top cover heat shield and particle count sampling ports were unaffected.
- No increase in air leakage around the particle count sample ports was measureable.

- The existent forced hot air dryer for the top cover part using the original cleaner basket was acceptable for drying the top cover assembly.
- No detergent drag-out increase using existent top-cover cleaner basket.
- Particle cleanliness (50 psig needle jet spray extraction w/DI water, followed by liquidborne particle count) is significantly improved by the assemble then clean versus the clean then assemble strategy. See Table 1

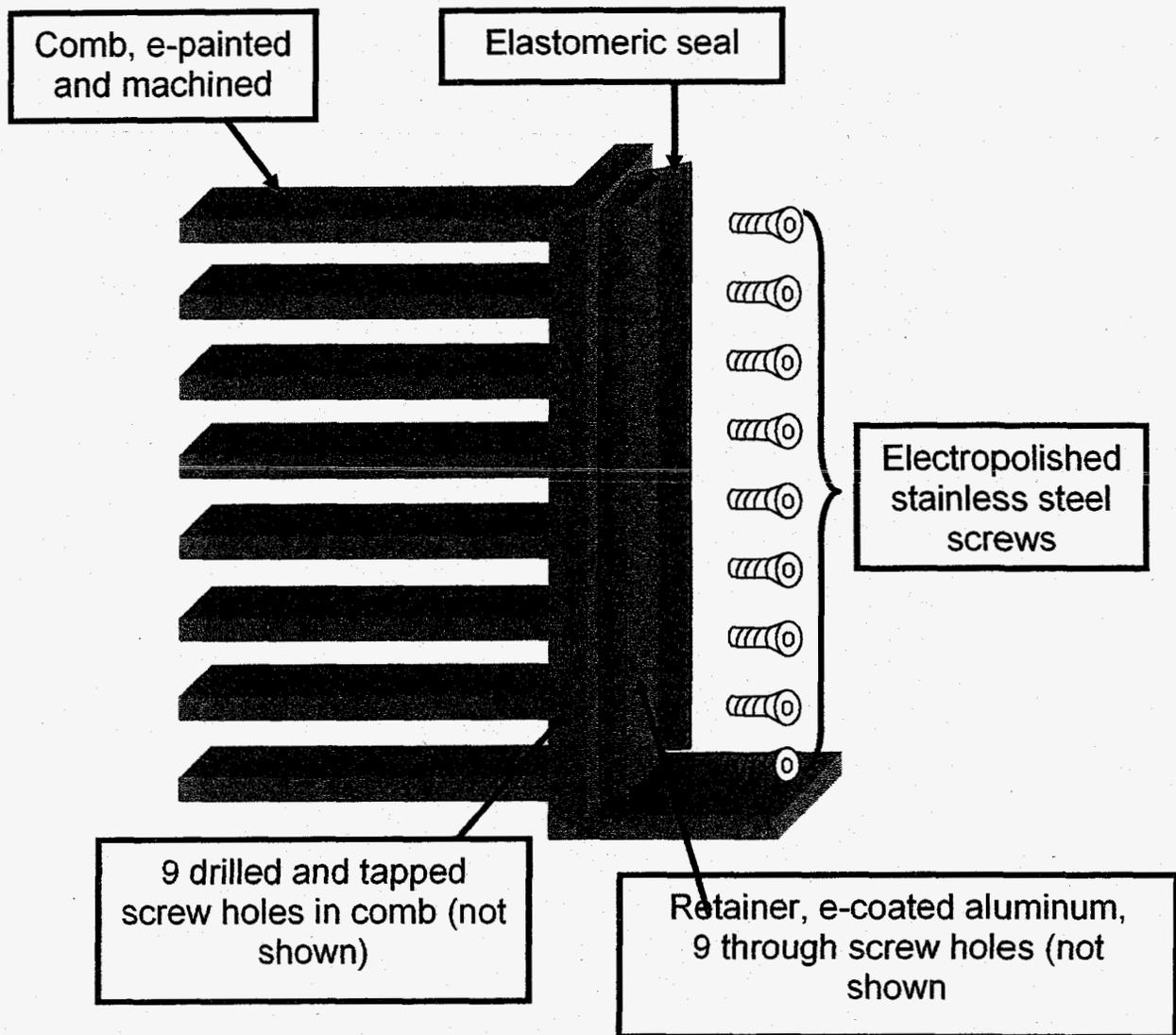
Table 1. Liquidborne particle counts after spray extraction of top cover assemblies using two different cleaning strategies.

Size, $\mu\text{m}$	Clean, then Assemble	Assemble, then Clean
$\geq 5$	8497	2775
$\geq 9$	5214	1620
$\geq 15$	2402	956
$\geq 25$	961	238
$\geq 50$	117	25

### **Case Study 2: Comb Assembly**

A second case study is a comb assembling that fit into an opening in the top cover assembly. All of the components had been previously shown to be acceptable for ultrasonic immersion cleaning. In addition, the finished part could be ultrasonic immersion extracted. Figure 2 shows an illustration of the comb assembly. The comb assembly consists of a partially machined electrophoretically painted aluminum casting. This to this is mounted an elastomeric seal, held in place by an e-coated aluminum part using nine screws. The screws are electropolished stainless steel. Because of the thickness of the part, the screw holes are not blind holes. Assembly debris generated by driving the screws into the holes into the comb could become a significant contaminant.

Figure 4. The comb assembly.



The challenge:

The challenge for the comb assembly includes:

- There are many screws. The torque of each of the screws must be measured individually because their position on the assembly may render them susceptible to ultrasonic energy that reduces their fastening strength needed for their position.
- A large portion of the elastomeric seal that is unsupported (more than 1 cm by 20 cm) is subject to deformation.
- Dryness of the subassembly, where a layer of elastomeric seal is sandwiched between two layers of electrophoretic painted a concern.
- Detergent drag out is critical because this part will end up assembled in the final disk drive within one hour after cleaning.

- Particle cleanliness

Comb Assembly Results:

- Screw torque was unaffected
- Elastomeric seal not distorted
- Force hot air drying effective, existent cleaner basket acceptable
- Particle cleanliness (40 kHz, ultrasonic immersion extraction in 200 ppm detergent/DI water, followed by liquidborne particle count) is improved. See Table 2.

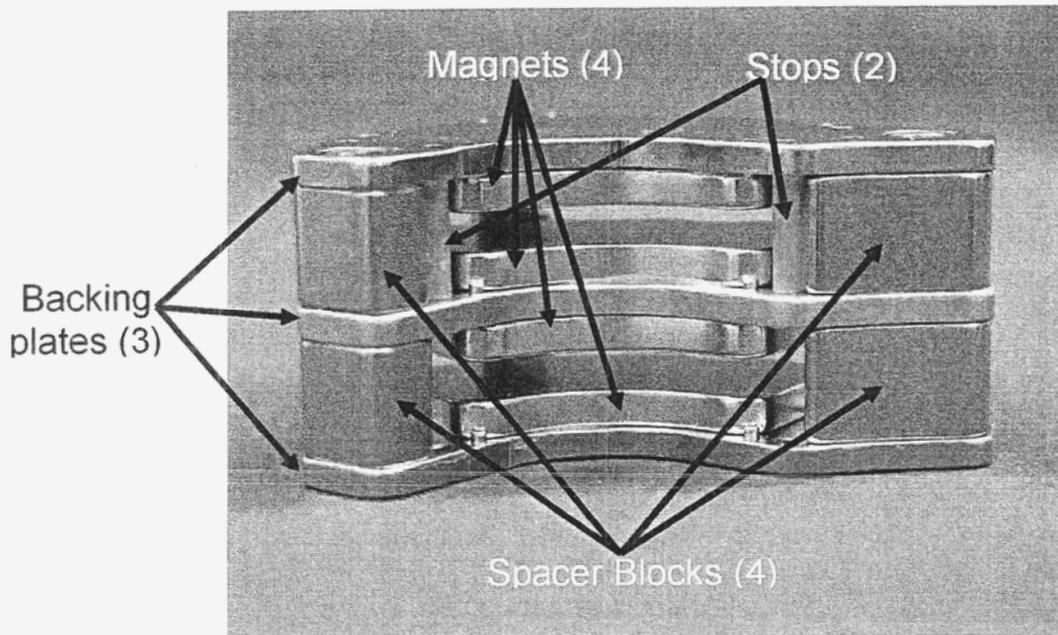
Table 2. LPC particle cleanliness of the Comb Assembly:

Size, $\mu\text{m}$	Clean, then Assemble	Assemble, then Clean
$\geq 5$	2541	1192
$\geq 9$	980	624
$\geq 15$	402	285
$\geq 25$	61	38
$\geq 50$	7	5

**Case Study 3: Voice Coil Motor Magnet Assembly**

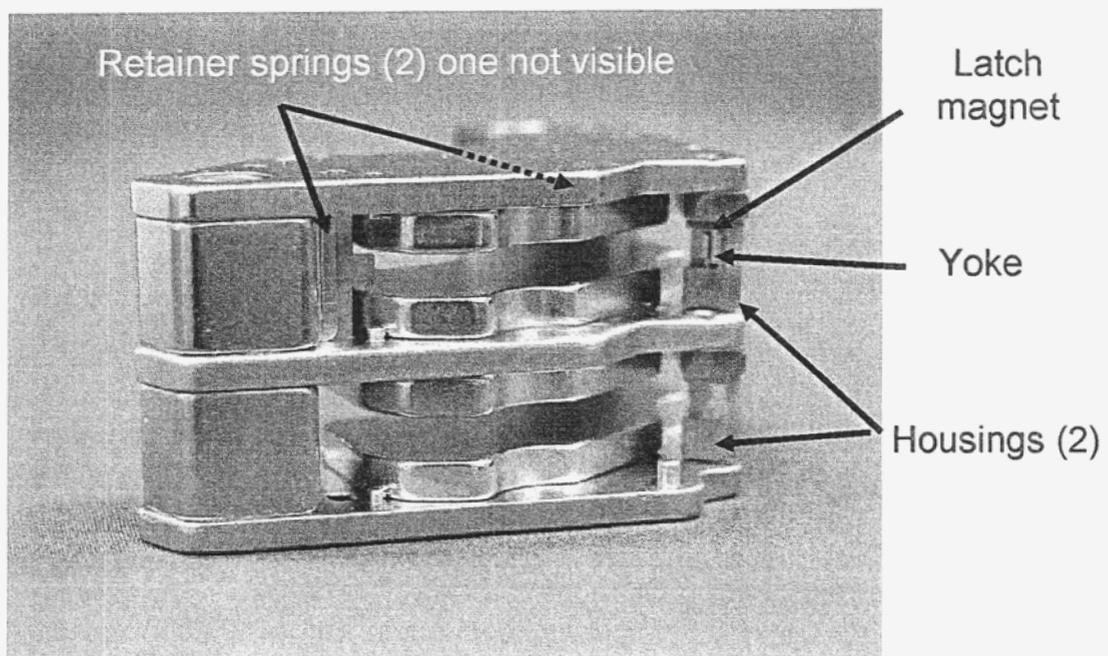
A more challenging assembly to qualify using the assemble then clean strategy is the voice coil motor magnet assembly. This consists of a large number of parts assembled using adhesives but no screwed fasteners. Voids in the adhesives could result in pockets that retained either moisture or detergent. The voice coil motor assembly contains magnetic materials, adhesives, the elastomeric materials, electroless nickel coated parts, magnetic material, springs that must maintain tension, molded plastic parts that must maintain position, and magnets that must retain their magnetic force (after forced hot air drying). And, similar to all the other parts, this subassembly must be clearable using an existing cleaning process to minimize capital equipment cost. Figures 5, 6, 7 and 8 illustrate the complexity of the voice coil motor magnet assembly.

Figure 5. Front view of the voice coil motor magnet assembly showing 4 nickel coated magnets, 4 nickel coated spacers, 3 nickel plated backing plates and 2 molded polyimide stops.



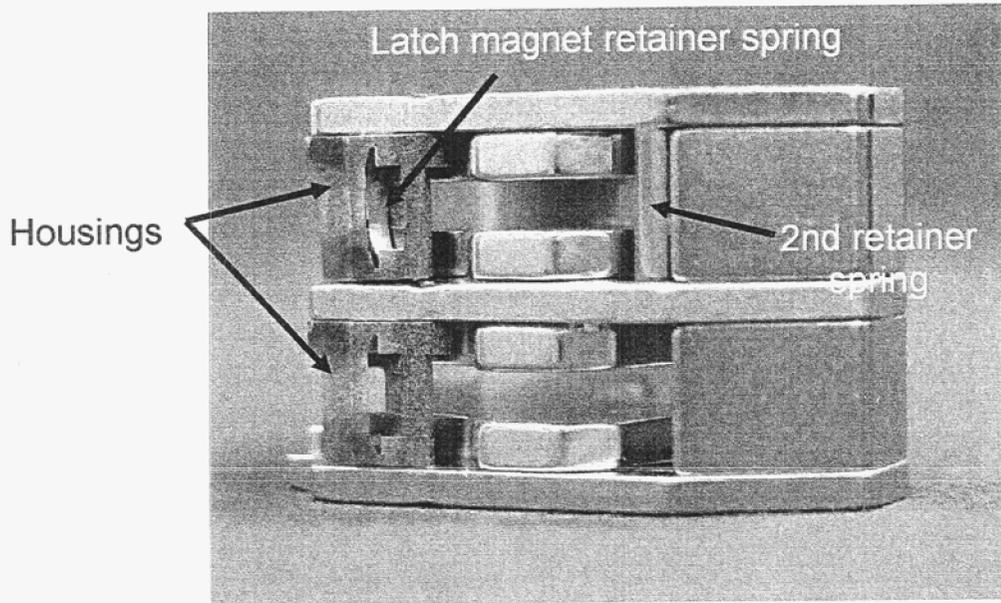
Courtesy of JPL/Caltech

Figure 6. Partial rear view of the voice coil motor magnet assembly showing 2 nickel coated springs, the latch magnet and yoke and two molded polyimide housings.



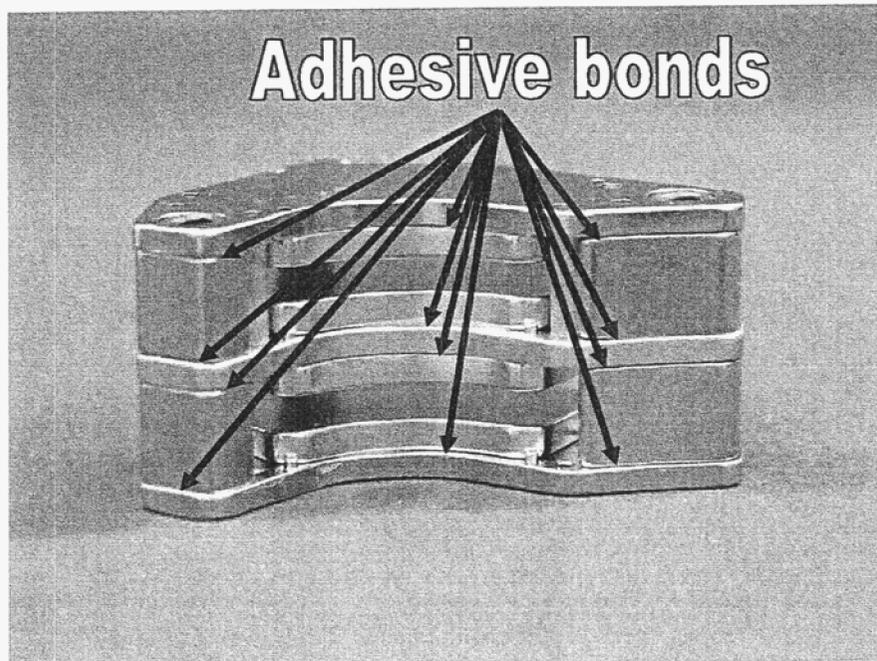
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Figure 7. Partial rear view of the voice coil motor magnet. The second retainer spring and the bare steel latch magnet retainer spring. The two housings are those shown in Figure 6.



Courtesy of JPL/Caltech

Figure 8. Front view of the voice coil motor magnet, showing the locations of the 12 adhesive bonds fastening the spacer blocks, magnets and backing plates. All other components are press-fit.



Courtesy of JPL/Caltech

- Particle cleanliness

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- Force hot air drying effective, existent cleaner basket acceptable
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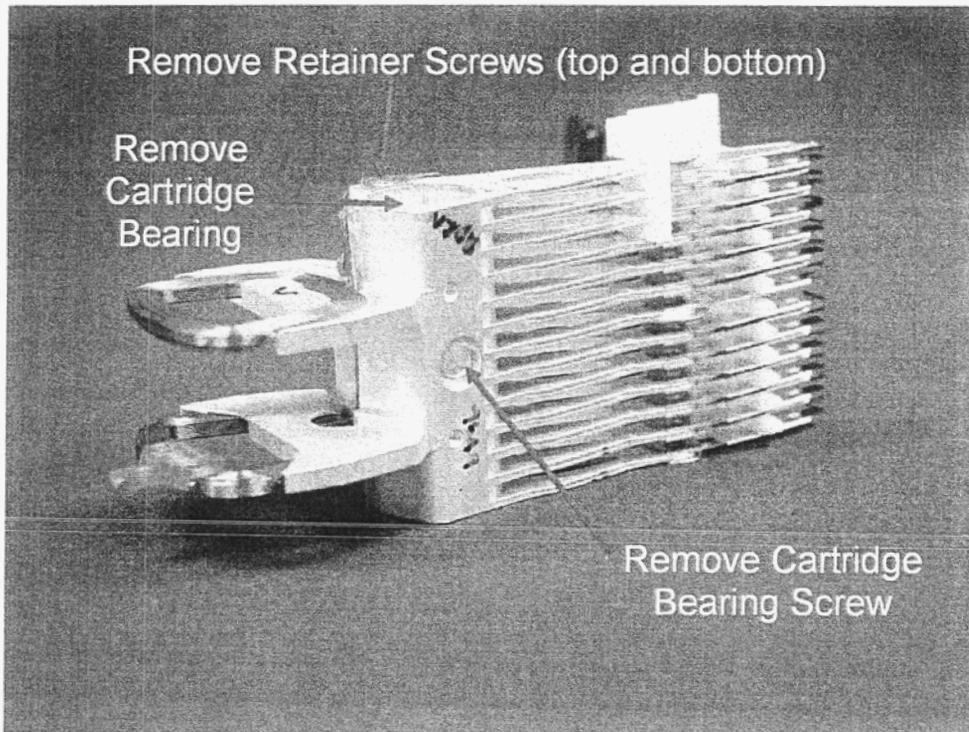
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Figure 9. First portion of head stack assembly rework operations.



Courtesy of JPL/Caltech

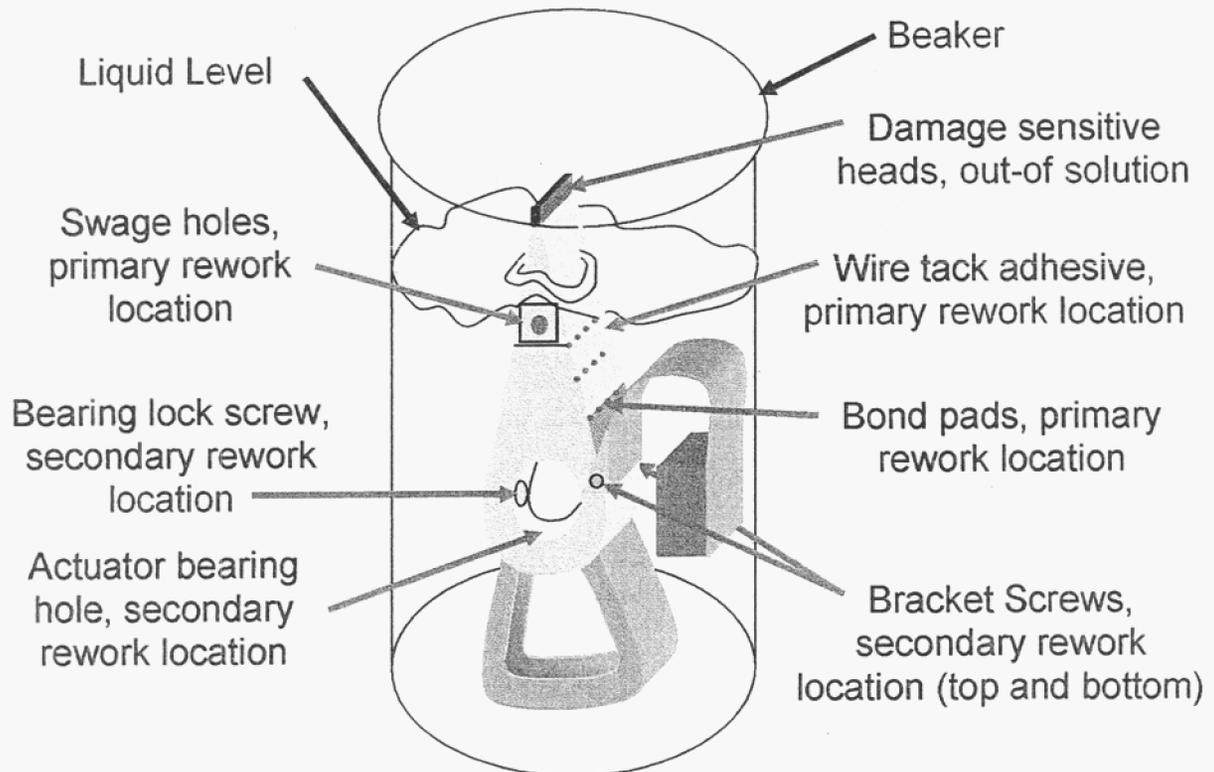
Figure 10. Second portion of head stack assembly rework operations.



Courtesy of JPL/Caltech

Figure 10 shows the arrangement of the head stack assembly in the measurement beaker for ultrasonic particle extraction. It is known that 40 kHz ultrasonic cleaning can damage the delicate flexure assembly, head attachment adhesive and wire bonds for the magnetic recording heads. However, this portion of the head suspension is not touched during rework. Thus, the liquid level in the beaker is adjusted to immerse up to and including the swage hole and all other portions of the actuator assembly touched during rework.

Figure 10. Diagram of extraction for actuator assemblies.



Head Stack Assembly Results:

- Screw torque unaffected
- Adhesives and coating unaffected
- Force hot air/vacuum drying effective, existent cleaner basket acceptable
- Particle cleanliness (40 kHz, ultrasonic immersion extraction in 200 ppm detergent/DI water, followed by liquidborne particle count) significantly improved. See Table 4.

Table 4. LPC of actuator assembly.

Size, $\mu\text{m}$	Assemble (Rework)		Assemble (Rework) then Clean	
	Mean	Mean + 4.5 $\sigma$	Mean	Mean + 4.5 $\sigma$
$\geq 0.5$	116,900	489,500	23,040	54,600
$\geq 2$	35,630	122,400	11,020	23,400
$\geq 5$	21,120	89,230	8,056	19,120
$\geq 10$	10,220	34,450	3,045	7,776
$\geq 15$	3,455	11,209	1,122	2,307
$\geq 25$	823	1,650	433	745

## Results and Discussion.

All four of the case studies shown here demonstrate the viability of the cleaning strategy assemble then clean. In the cases of the top cover assembly and the comb assembly, only the mean value of the qualification trials are shown. The reliability of disk drives and other precision mechanical and electromechanical components is a statistical phenomenon. To the extent that cleanliness affects reliability, it is perhaps more important to know about the variability of cleanliness of parts. For this reason, the mean plus 4.5 times sigma cleanliness data is included for the voice coil motor magnet assembly and the actuator assembly.

The overall improvement in cleanliness afforded by the assemble then clean strategy versus the clean than assemble strategy may be estimated by dividing the cumulative concentration at each size for the clean then assemble approach by the corresponding result for the assemble than clean approach, as is summarized in Table 5.

Table 5. Particle cleanliness improvement factor afforded by assemble then clean strategy versus clean than assemble strategy

Size, $\mu\text{m}$	Cover	Comb	VCMA		Actuator	
	Mean	Mean	Mean	Mean + 4.5 $\sigma$	Mean	Mean + 4.5 $\sigma$
$\geq 0.5$					5.1	9.0
$\geq 2$			3.2	4.0	3.2	5.2
$\geq 5$	3.1	2.1	3.0	4.4	2.6	4.7
$\geq 9$	3.2	1.6				
$\geq 10$			2.7	3.6	3.4	4.4
$\geq 15$	2.5	1.4	4.3	5.5	3.1	4.9
$\geq 25$	4.0	1.6	3.6	6.0	1.9	2.2
$\geq 50$	4.7	1.4	3.9	4.4		

The data in Table 5 shows that there is a significant improvement in mean particle cleanliness for all particle size ranges over all of the four types of assemblies examined. For the VCMA and actuator assemblies, there is an even greater improvement in statistical cleanliness over all size ranges, based on the higher improvement ratio for the mean plus 4.5 standard deviation versus the mean value improvement ratio.

The implications for the manufacturing processes are significant. The benefits include reduction in the square footage of cleanroom floor space. In most precision assembly cleanrooms, floor space costs from \$300 to \$500 per square foot more for acquisition than factory floor space. Operating costs for cleanrooms range from \$30 to \$50 per square foot per year for class 100 clean space (ISO14644 Class 5).

Looking at each individual sub assembly reveals cost savings associated with handling and cleaning.

1. Top Cover Assembly

Cleaning the individual pieces required one basket per top cover, one small basket for PC ports, one small basket for seals, one large basket for heat shields, and one small basket for screws. Elimination of cleaner baskets for the smaller parts resulted in a fractional reduction in the number of baskets going through the cleaner. It did result in much less material handling, resulting in significant labor savings. Cleaning baskets could be eliminated, since the top cover assembly could be effectively cleaned and dried using the existent top cover cleaner basket and cleaning machine.

2. Comb Assembly

Cleaning the individual parts required one basket for combs, one small basket for seals, one small basket for retainers and one small basket for screws. Cleaning the assembly reduced the number of baskets going through the cleaner by half and eliminated labor cost and handling damage. The existent cleaner basket for the cob could be effectively used for cleaning the comb assembly.

3. Voice coil motor permanent magnet assembly

There was an increased cost because a new cleaner basket had to be designed for the VCMA assemblies. However, there were offsetting costs due to reduction in the number of individual parts going through the cleaner. For each basket containing VCMA assemblies there had previously been approximately three times as many baskets to clean the 20 individual parts cleaned previously. The major savings was in reduction in labor cost and handling.

4. Actuator Assembly

There were no significant savings by implementation of the rework cleaner. The improvement in particle cleanliness of the reworked actuators was seen as a benefit that drove decisions about the process.

## Conclusions:

Cleaning after assembly can be accomplished using conventional DI water cleaners

In most cases, no new cleaner baskets must be designed, fewer individual parts are handled, fewer numbers of cleaner baskets are required. This results in an effective increase in the capacity of the cleaners. Dryness is acceptable using existent process equipment/times

Dimensions and locations of parts were unaffected. Screw torque, adhesive bonds unaffected. Cleanroom floorspace and operating costs are reduced. Finally, the finished assemblies parts come out cleaner from a particle perspective than in the clean, then assemble approach

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# Clean then Assemble versus Assemble then Clean: Several Comparisons

By

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## Abstract

Cleanliness of manufactured parts and assemblies is a significant issue in many industries including disk drives, semiconductors, aerospace, and medical devices. Clean manufacturing requires cleanroom floor space and cleaning technology that are both expensive to own and expensive to operate. Strategies to reduce these costs are an important consideration. One strategy shown to be effective at reducing costs is to assemble parts into subassemblies and then clean the subassembly, rather than clean the individual parts first and then assemble them. One advantage is that assembly outside of the cleanroom reduces the amount of cleanroom floor space and its associated operating cost premium. A second advantage is that this strategy reduces the number of individual parts that must be cleaned prior to assembly, reducing the number of cleaning baskets, handling and, possibly, reducing the number of cleaners. The assemble then clean strategy also results in a part that is significantly cleaner because contamination generated during the assembly steps are more effectively removed than normally can be achieved by hand wiping after assembly in the cleanroom.

## Introduction

When developing a strategy for achieving cleanliness of parts and assemblies, many factors must be considered. Among the factors that must be considered are those associated with quantitative measures of cleanliness, including particle contamination, ionic contamination, volatile organic contamination, and viable contamination particle contamination is the result of casting machine coating and handling processes.

Fortunately, the quantitative measurement and specification of contamination is a fairly mature area of applied technology. There are a number of methods that can be used to quantitatively estimate cleanliness of parts. Among the most mature of these is the International Disk Drive Equipment and Materials Association (IDEMA) standard procedure for particles [1]. The validity of this approach to measurement of particle cleanliness has been repeatedly demonstrated [2, 3, 4]. Similarly, there are generally accepted IDEMA methods for quantification of extractable anions [5] and cations [6], which are adaptations of widely used ASTM [7] and EPA methods [8, 9]. In the disk drive industry, nonvolatile residues are measured using an IDEMA technique [10] based on well-accepted and widely used ASTM standards [11, 12, 13]. In general, the selection of methods and controls used in the disk drive industry are based on a military standard [14] that

has withstood the test of time. Most tests for viable microorganisms are modeled after a well-accepted ASTM test method. [15]

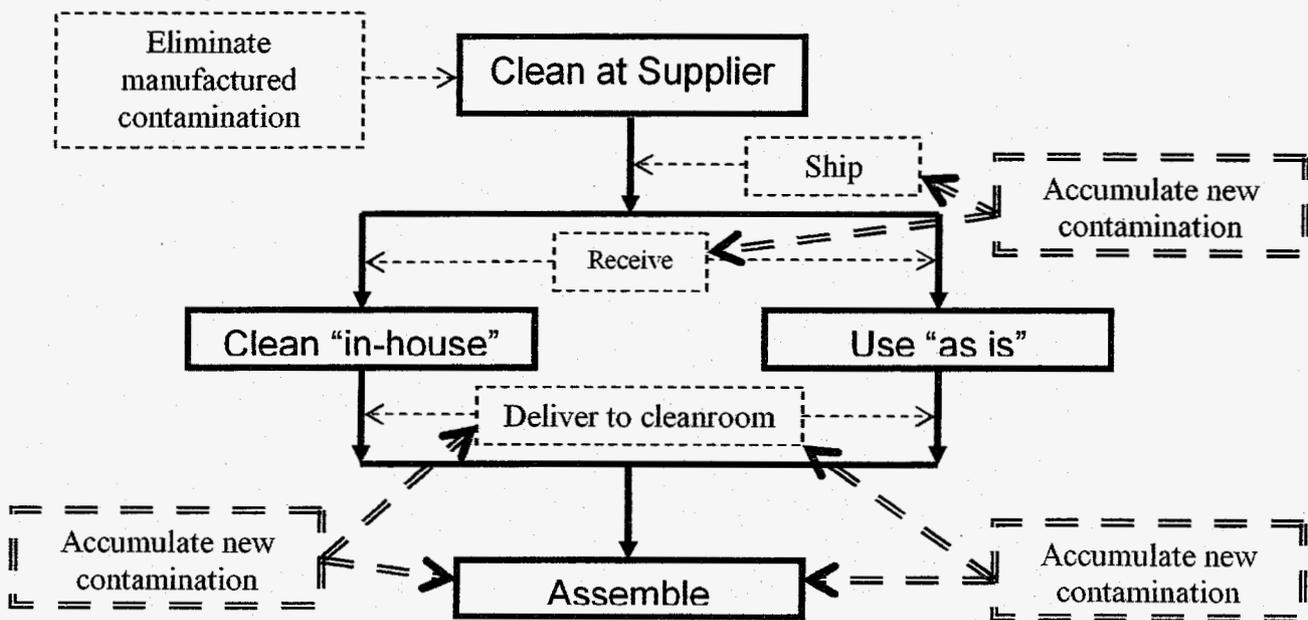
Another factor that must be considered is the overall risk of recontamination of parts after they are cleaned in-house. In general, the risk of recontamination by ionic or organic contamination during transportation and assembly is quite low. This is due to several factors, the most important of which is the careful process used to qualify materials used to make the product (coatings, adhesives, etc. [16, 17]) and the materials these parts come in contact with during assembly (gloves, for example, [18]). Moreover, the migration of many industries to aqueous based cleaning has provided a great deal of protection from corrosion due to the high relative solubility in water of most contaminants promoting corrosion, i.e., ionic contamination. The use of aqueous cleaning chemistries has driven the elimination of cutting fluids and other materials which previously required the use of solvents for cleaning [19, 20]. As a consequence, organic residues that are not readily soluble in aqueous detergent cleaning have been largely eliminated. This has driven down the amount of non-volatile residue. Most precision parts that must be free of bacterial contamination (spacecraft, medical devices) are designed so that the product can be sterilized after assembly [21, 22] using validated processes.

### Cleaning Strategies

Two different strategies may be considered: clean then assemble versus assemble then clean.

The clean then assemble strategy is illustrated in Figure 1.

Figure 1. The clean then assemble strategy and its contamination consequences.



In this strategy, the responsibility for achievement of the ultimate cleanliness of parts rests with suppliers. This strategy is adopted recognizing that the supplier produces a relatively small

number of parts, whereas the customer receives all parts. The supplier is better able to supply a process customized to the individual piece parts than is the customer.

Parts are shipped by the supplier and received by the customer. Two categories of parts may be described: parts that may be cleaned 'in-house' and parts which must be used 'as is'. During the shipping and receiving process all of these parts may accumulate new contamination due to packaging and handling. For parts which can be cleaned in-house the packaging and handling debris can be removed. For parts that must be used "as is", this accumulated new packaging and handling contamination pass through to the cleanroom. Parts emerging from the 'in-house cleaner' are also delivered to the cleaner. Any additional packaging and handling debris are then passed through to the assembly process. Finally parts are subject to assembly. Here additional contamination is likely to be generated.

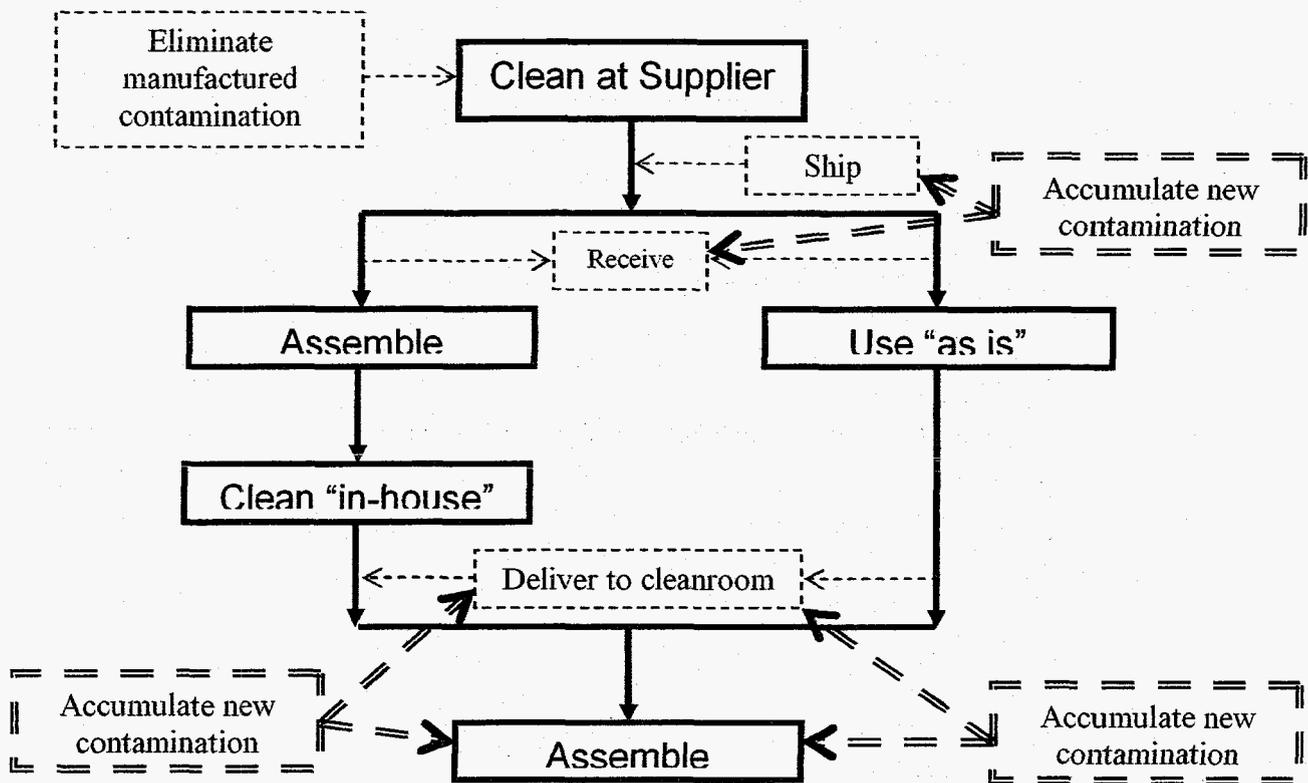
As can be seen from this illustration three pathways for accumulation of new contamination exist in the clean then assemble strategy that are not mitigated by the clean then assemble strategy. These are:

- Accumulated by parts to be used "as is" parts during shipping and handling.
- Accumulation by parts cleaned "in house" and parts to be used "as is" in the subsequent handling and movement within the cleanroom.
- Accumulation by parts due to the assembly process.

Looking at this strategy, it is obvious that some parts, like motors and bearing which contain lubricants, cannot be cleaned by conventional 'in house' cleaning processes which usually involve immersion in a bath of liquid. However, there are sets of parts that could possibly be assembled outside the cleanroom that then could be cleaned prior to delivery to the cleanroom for further assembly. This can be referred to as the assemble then clean strategy. Figure 2 illustrates one possible application of the assemble then clean strategy.

The degree to which an assemble then clean strategy benefits an overall assembly process depends on the relative proportion of the subassemblies that are to be cleaned 'in house' versus parts that must be used "as is" and the relative improvement in cleanliness achieved. In a process where all parts must be used 'as is', there is no benefit to be derived because it cannot be implemented. Conversely, where none of the received parts must be used 'as is', the maximum benefit can be derived, depending on the ability to qualify the process. In most real world situations, some portion of the parts can fall into the assemble then clean strategy.

Figure 2. One possible application of the assemble then clean and its contamination consequences.



In the assemble then clean strategy, the process is analyzed to identify those subassemblies which could be assembled outside the cleanroom and subsequently cleaned, eliminating the handling and assembly contamination generated by those steps previously performed in the cleanroom after "in-house" cleaning.

### Methods

In the course of the study several different methods have been employed. Cleaning of assemblies can introduce new failure modes of other than cleanliness or dryness degradation. In each case to be reported careful consideration has been given to the various failure modes that might be introduced by the cleaning process:

- The breakaway torque of all mechanical fasteners was measured.
- The sheer strength of all in use of bonds was measured.
- Critical dimensional positions of all components were measured.
- Ionic contamination levels were measured by deionized water extraction and ion chromatography chromatography.
- Volatile organic contamination was measured using witness plates and combination FTIR GC/MS.

- Particle cleanliness was measured using liquid particle count following one of two extraction methods: ultrasonic immersion extraction and a detergent DI water solution or needle spray extraction with pure DI water.

The breakaway torque of all mechanical fasteners was made using instruments capable of measuring the torque, whose gauge capability has been shown to be able to measure to the degree specified on the drawing. The pull-strength and shear-strength of all adhesive bonds were measured using Instron mechanical testers, again with gauges demonstrated to be capable for the measurement required. Critical dimensional properties were measured using the receiving inspection's coordinate measurement machines. Ionic contamination levels were measured using standard extraction and measurement techniques. Volatile organic contamination was measured by either extracting the part using a suitable solvent or by placing the part in the chamber containing an absorbent cartridge and subsequently measuring the volatile component using Fourier transform infrared (FTIR) spectroscopy or gas chromatography/mass spectrophotometry (GC/MS). All of these measurements were made either using the instruments used for materials qualification of receiving inspection of the parts.

The most important measurement for these studies was the particle content of the parts after assembling part. Particle cleanliness was measured in ultrasonic immersion extraction in a 200 ppm solution of Triton X-100 detergent in the ionized water, one minute extraction, and 40 kHz in a Branson DHA 1000 tank, with a one inch coupling fluid depth. Particles measured by spray extraction, using pure DI water (no detergent), at  $50 \pm 5$  PS IG, with approximately 0.7 mm diameter needle jets. Particle concentrations in the spray extracts were measured after ultrasonic pulse degassing. All using extinction particle count instruments with either 5 micrometer ( $\mu\text{m}$ ) or 2  $\mu\text{m}$  lower detection and light scattering optical particle counters with 0.5  $\mu\text{m}$  lower detection limit.

### **Case studies**

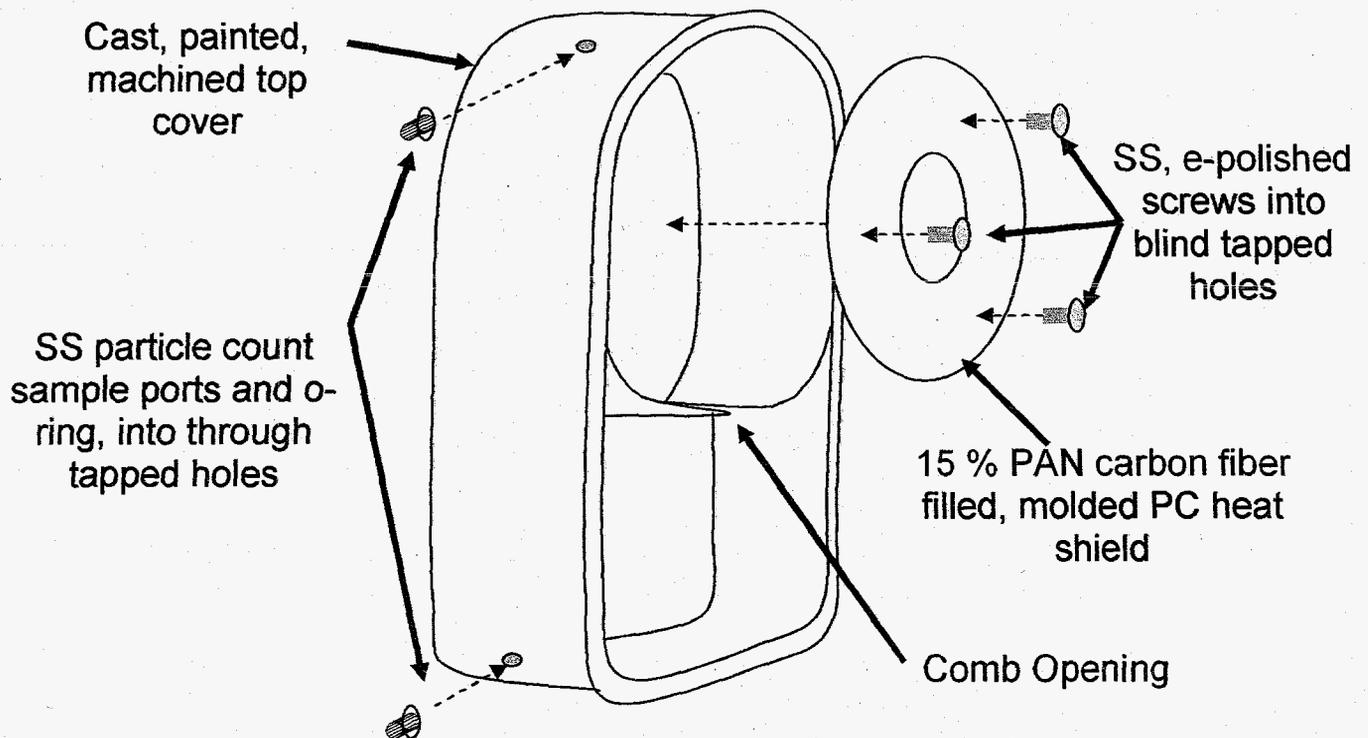
Four case studies are explored in this paper. A top cover assembly, a comb seal assembly, a voice coil motor permanent magnet assembly and an actuator assembly. This succession represents parts in increasing order of complexity and cleaning challenge. In every one of these evaluations, the ionic contamination and organic contamination were well within specified limits.

#### **Case Study 1: Top Cover Assembly:**

The top cover assembly is illustrated in Figure 3. The top cover assembly is a very large casting that has relatively few machine features. Unfortunately during assembly every one of the machine features is used. Two stainless steel particle count sampling ports are driven into their aluminum through holes in the top cover. A heat shield is fastened to the inside of the top cover assembly using three stainless steel, electropolished screws. The heat shield is molded from a highly friable material: 15 percent polyacrylonitrile carbon fiber filled polycarbonate.

The heat shield is a great concern for this qualification: experimental tests to select the optimum cleaning process had previously shown that ultrasonic immersion cleaning resulted in significant particle generation and thus was not a suitable cleaning technique. The "in-house" cleaner proposed for the top cover assembly used ultrasonic immersion cleaning. There was the concern the in-house cleaning of an assembly containing the heat shield would result in a dirtier part.

Figure 3. Top cover assembly.



The challenge is then to determine does ultrasonic immersion clean after assemble adversely affect:

- torque of the screws used to attach the top heat shield or the particle count sample ports to the cover
- air leakage through the particle count sampling port seals
- retention of water in any of the fastening holes (dryness achieved by the forced hot air drying process)
- increase of detergent drag out due to an adequate rinsing oven assembly that contains an obstruction that prevents rinse water from directly spraying on a portion of the part.
- Erosion of particles from the carbon filled heat shield

Top Cover Assembly Results:

- Screw torque for the top cover heat shield and particle count sampling ports were unaffected.
- No increase in air leakage around the particle count sample ports was measureable.

- The existent forced hot air dryer for the top cover part using the original cleaner basket was acceptable for drying the top cover assembly.
- No detergent drag-out increase using existent top-cover cleaner basket.
- Particle cleanliness (50 psig needle jet spray extraction w/DI water, followed by liquidborne particle count) is significantly improved by the assemble then clean versus the clean then assemble strategy. See Table 1

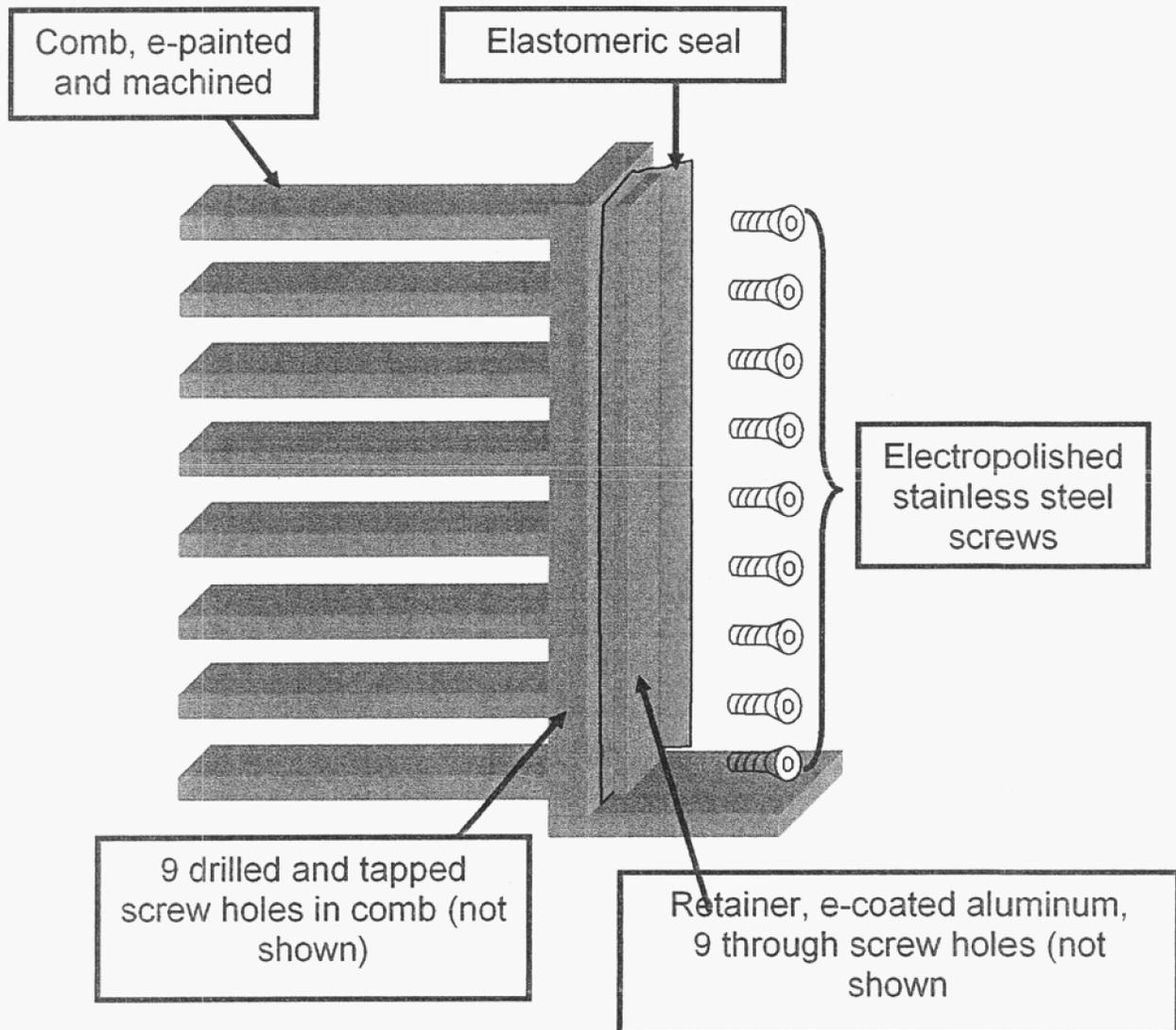
Table 1. Liquidborne particle counts after spray extraction of top cover assemblies using two different cleaning strategies.

Size, $\mu\text{m}$	Clean, then Assemble	Assemble, then Clean
$\geq 5$	8497	2775
$\geq 9$	5214	1620
$\geq 15$	2402	956
$\geq 25$	961	238
$\geq 50$	117	25

### **Case Study 2: Comb Assembly**

A second case study is a comb assembling that fit into an opening in the top cover assembly. All of the components had been previously shown to be acceptable for ultrasonic immersion cleaning. In addition, the finished part could be ultrasonic immersion extracted. Figure 2 shows an illustration of the comb assembly. The comb assembly consists of a partially machined electrophoretically painted aluminum casting. This to this is mounted an elastomeric seal, held in place by an e-coated aluminum part using nine screws. The screws are electropolished stainless steel. Because of the thickness of the part, the screw holes are not blind holes. Assembly debris generated by driving the screws into the holes into the comb could become a significant contaminant.

Figure 4. The comb assembly.



The challenge:

The challenge for the comb assembly includes:

- There are many screws. The torque of each of the screws must be measured individually because their position on the assembly may render them susceptible to ultrasonic energy that reduces their fastening strength needed for their position.
- A large portion of the elastomeric seal that is unsupported (more than 1 cm by 20 cm) is subject to deformation.
- Dryness of the subassembly, where a layer of elastomeric seal is sandwiched between two layers of electrophoretic painted a concern.
- Detergent drag out is critical because this part will end up assembled in the final disk drive within one hour after cleaning.

- Particle cleanliness

Comb Assembly Results:

- Screw torque was unaffected
- Elastomeric seal not distorted
- Force hot air drying effective, existent cleaner basket acceptable
- Particle cleanliness (40 kHz, ultrasonic immersion extraction in 200 ppm detergent/DI water, followed by liquidborne particle count) is improved. See Table 2.

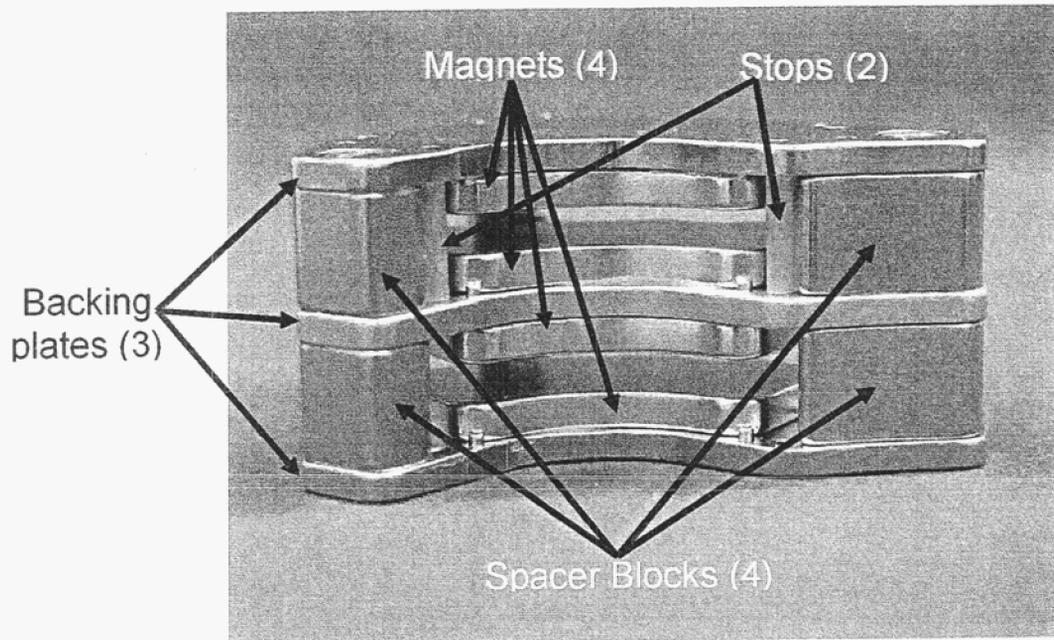
Table 2. LPC particle cleanliness of the Comb Assembly:

Size, $\mu\text{m}$	Clean, then Assemble	Assemble, then Clean
$\geq 5$	2541	1192
$\geq 9$	980	624
$\geq 15$	402	285
$\geq 25$	61	38
$\geq 50$	7	5

**Case Study 3: Voice Coil Motor Magnet Assembly**

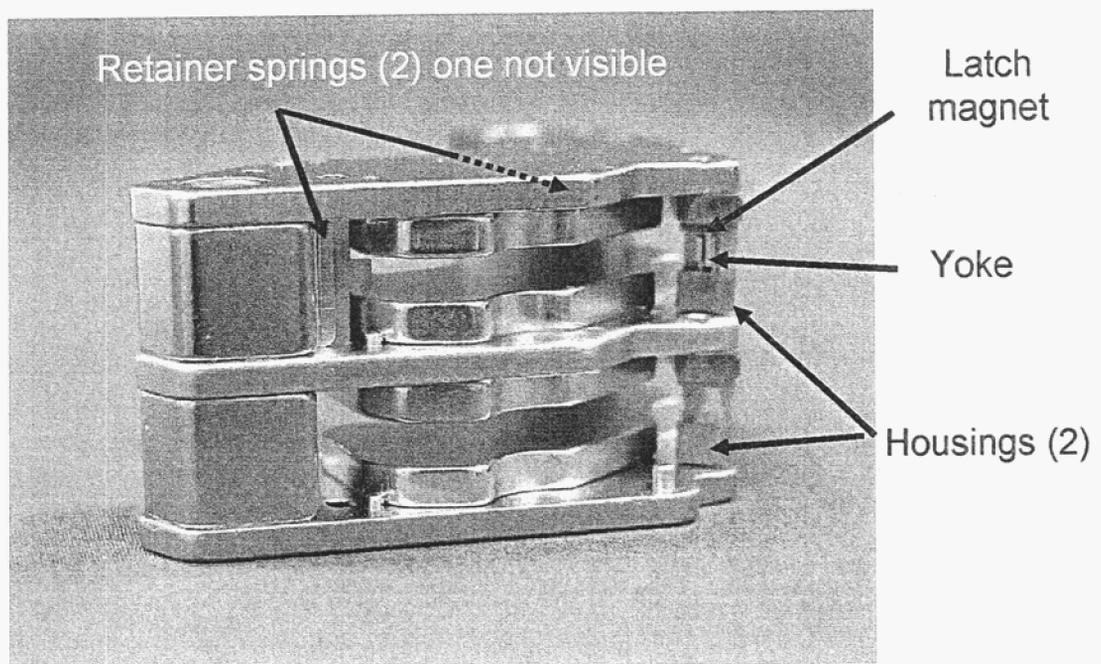
A more challenging assembly to qualify using the assemble then clean strategy is the voice coil motor magnet assembly. This consists of a large number of parts assembled using adhesives but no screwed fasteners. Voids in the adhesives could result in pockets that retained either moisture or detergent. The voice coil motor assembly contains magnetic materials, adhesives, the elastomeric materials, electroless nickel coated parts, magnetic material, springs that must maintain tension, molded plastic parts that must maintain position, and magnets that must retain their magnetic force (after forced hot air drying). And, similar to all the other parts, this subassembly must be clearable using an existing cleaning process to minimize capital equipment cost. Figures 5, 6, 7 and 8 illustrate the complexity of the voice coil motor magnet assembly.

Figure 5. Front view of the voice coil motor magnet assembly showing 4 nickel coated magnets, 4 nickel coated spacers, 3 nickel plated backing plates and 2 molded polyimide stops.



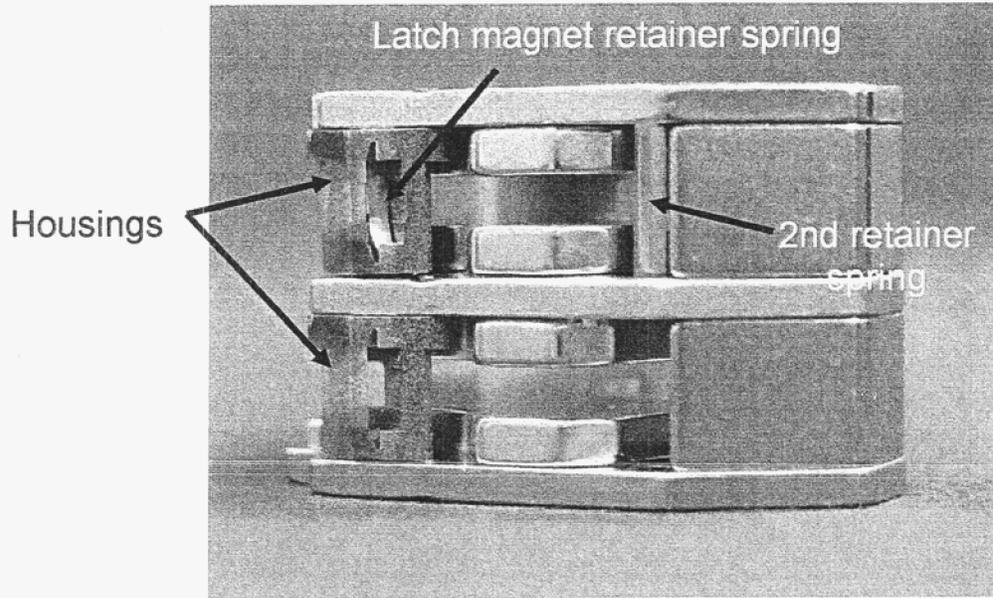
Courtesy of JPL/Caltech

Figure 6. Partial rear view of the voice coil motor magnet assembly showing 2 nickel coated springs, the latch magnet and yoke and two molded polyimide housings.



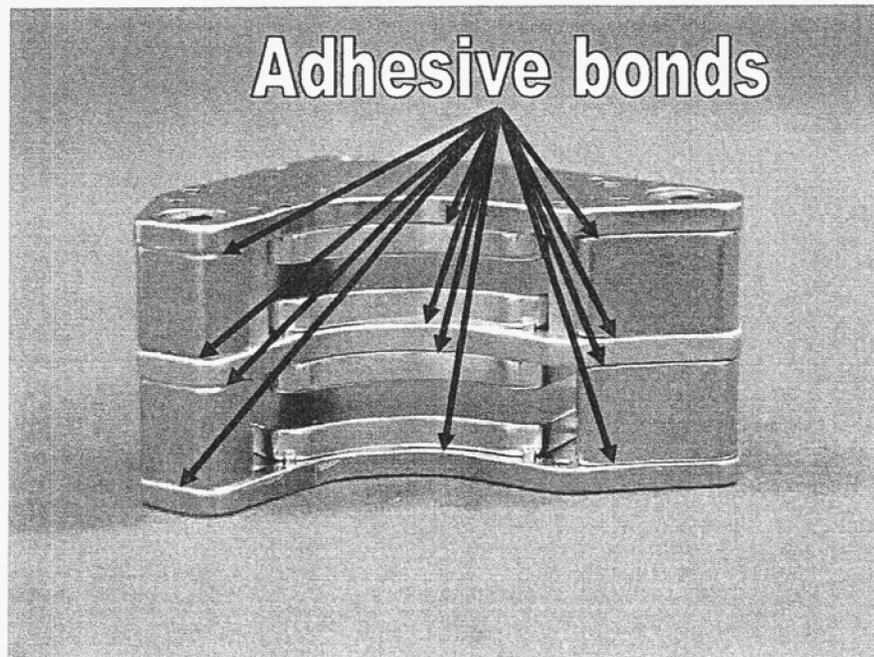
Courtesy of JPL/Caltech

Figure 7. Partial rear view of the voice coil motor magnet. The second retainer spring and the bare steel latch magnet retainer spring. The two housings are those shown in Figure 6.



Courtesy of JPL/Caltech

Figure 8. Front view of the voice coil motor magnet, showing the locations of the 12 adhesive bonds fastening the spacer blocks, magnets and backing plates. All other components are press-fit.



Courtesy of JPL/Caltech

#### VCMA Results:

- Adhesive bonds unaffected
- Position of press-fit components unaffected
- Force hot air drying effective, existent cleaner basket acceptable
- Particle cleanliness (40 kHz, ultrasonic immersion extraction in 200 ppm detergent/DI water, followed by liquidborne particle count) is improved. See Table 3.

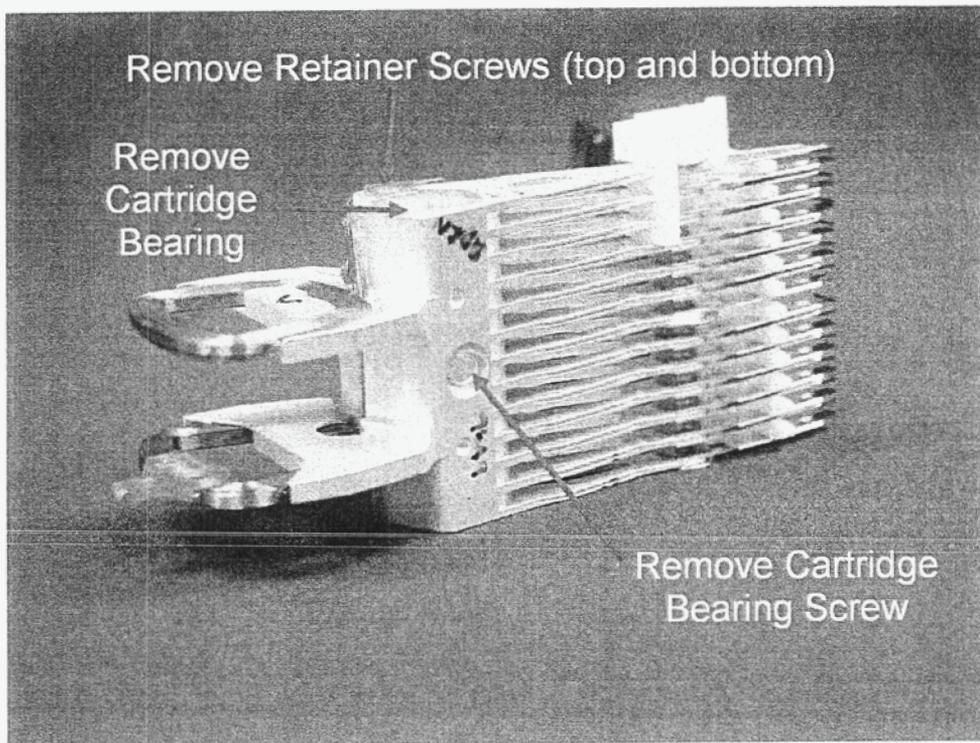
Table 3. LPC of voice coil motor magnet assembly.

Size, $\mu\text{m}$	Clean then Assemble		Assemble then Clean	
	Mean	Mean + 4.5 $\sigma$	Mean	Mean + 4.5 $\sigma$
$\geq 2$	39827	101354	12345	25478
$\geq 5$	24506	67819	8223	16454
$\geq 10$	12344	43000	4530	12003
$\geq 15$	4845	12704	1121	2311
$\geq 25$	1230	3425	345	569
$\geq 50$	355	1067	92	245

#### ***Case Study 4: Head Stack Assembly***

The head stack assembly is the most complicated part tested in this study. The motive for testing is to determine the effect of cleaning after rework, which may be thought of as an assemble then clean process. For this comparison, reworked but not cleaned assemblies were compared to reworked then cleaned assemblies. Figures 9 and 10 show the complexity of the head stack assembly. In these figures emphasis is on the rework operations, as opposed to a detailed list of the many materials present.

Figure 9. First portion of head stack assembly rework operations.



Courtesy of JPL/Caltech

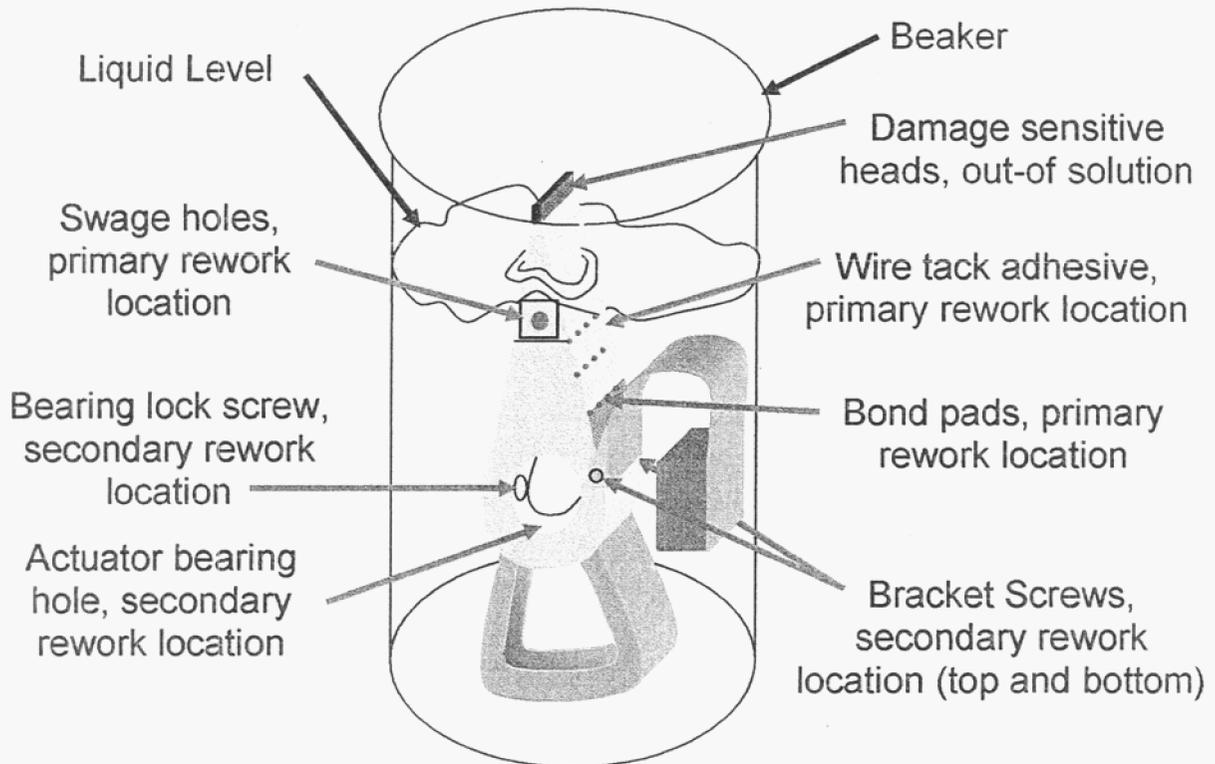
Figure 10. Second portion of head stack assembly rework operations.



Courtesy of JPL/Caltech

Figure 10 shows the arrangement of the head stack assembly in the measurement beaker for ultrasonic particle extraction. It is known that 40 kHz ultrasonic cleaning can damage the delicate flexure assembly, head attachment adhesive and wire bonds for the magnetic recording heads. However, this portion of the head suspension is not touched during rework. Thus, the liquid level in the beaker is adjusted to immerse up to and including the swage hole and all other portions of the actuator assembly touched during rework.

Figure 10. Diagram of extraction for actuator assemblies.



Head Stack Assembly Results:

- Screw torque unaffected
- Adhesives and coating unaffected
- Force hot air/vacuum drying effective, existent cleaner basket acceptable
- Particle cleanliness (40 kHz, ultrasonic immersion extraction in 200 ppm detergent/DI water, followed by liquidborne particle count) significantly improved. See Table 4.

Table 4. LPC of actuator assembly.

Size, $\mu\text{m}$	Assemble (Rework)		Assemble (Rework) then Clean	
	Mean	Mean + 4.5 $\sigma$	Mean	Mean + 4.5 $\sigma$
$\geq 0.5$	116,900	489,500	23,040	54,600
$\geq 2$	35,630	122,400	11,020	23,400
$\geq 5$	21,120	89,230	8,056	19,120
$\geq 10$	10,220	34,450	3,045	7,776
$\geq 15$	3,455	11,209	1,122	2,307
$\geq 25$	823	1,650	433	745

## Results and Discussion.

All four of the case studies shown here demonstrate the viability of the cleaning strategy assemble then clean. In the cases of the top cover assembly and the comb assembly, only the mean value of the qualification trials are shown. The reliability of disk drives and other precision mechanical and electromechanical components is a statistical phenomenon. To the extent that cleanliness affects reliability, it is perhaps more important to know about the variability of cleanliness of parts. For this reason, the mean plus 4.5 times sigma cleanliness data is included for the voice coil motor magnet assembly and the actuator assembly.

The overall improvement in cleanliness afforded by the assemble then clean strategy versus the clean than assemble strategy may be estimated by dividing the cumulative concentration at each size for the clean then assemble approach by the corresponding result for the assemble then clean approach, as is summarized in Table 5.

Table 5. Particle cleanliness improvement factor afforded by assemble then clean strategy versus clean than assemble strategy

Size, $\mu\text{m}$	Cover	Comb	VCMA		Actuator	
	Mean	Mean	Mean	Mean + 4.5 $\sigma$	Mean	Mean + 4.5 $\sigma$
$\geq 0.5$					5.1	9.0
$\geq 2$			3.2	4.0	3.2	5.2
$\geq 5$	3.1	2.1	3.0	4.4	2.6	4.7
$\geq 9$	3.2	1.6				
$\geq 10$			2.7	3.6	3.4	4.4
$\geq 15$	2.5	1.4	4.3	5.5	3.1	4.9
$\geq 25$	4.0	1.6	3.6	6.0	1.9	2.2
$\geq 50$	4.7	1.4	3.9	4.4		

The data in Table 5 shows that there is a significant improvement in mean particle cleanliness for all particle size ranges over all of the four types of assemblies examined. For the VCMA and actuator assemblies, there is an even greater improvement in statistical cleanliness over all size ranges, based on the higher improvement ratio for the mean plus 4.5 standard deviation versus the mean value improvement ratio.

The implications for the manufacturing processes are significant. The benefits include reduction in the square footage of cleanroom floor space. In most precision assembly cleanrooms, floor space costs from \$300 to \$500 per square foot more for acquisition than factory floor space. Operating costs for cleanrooms range from \$30 to \$50 per square foot per year for class 100 clean space (ISO14644 Class 5).

Looking at each individual sub assembly reveals cost savings associated with handling and cleaning.

1. Top Cover Assembly

Cleaning the individual pieces required one basket per top cover, one small basket for PC ports, one small basket for seals, one large basket for heat shields, and one small basket for screws. Elimination of cleaner baskets for the smaller parts resulted in a fractional reduction in the number of baskets going through the cleaner. It did result in much less material handling, resulting in significant labor savings. Cleaning baskets could be eliminated, since the top cover assembly could be effectively cleaned and dried using the existent top cover cleaner basket and cleaning machine.

2. Comb Assembly

Cleaning the individual parts required one basket for combs, one small basket for seals, one small basket for retainers and one small basket for screws. Cleaning the assembly reduced the number of baskets going through the cleaner by half and eliminated labor cost and handling damage. The existent cleaner basket for the cob could be effectively used for cleaning the comb assembly.

3. Voice coil motor permanent magnet assembly

There was an increased cost because a new cleaner basket had to be designed for the VCMA assemblies. However, there were offsetting costs due to reduction in the number of individual parts going through the cleaner. For each basket containing VCMA assemblies there had previously been approximately three times as many baskets to clean the 20 individual parts cleaned previously. The major savings was in reduction in labor cost and handling.

4. Actuator Assembly

There were no significant savings by implementation of the rework cleaner. The improvement in particle cleanliness of the reworked actuators was seen as a benefit that drove decisions about the process.

## **Conclusions:**

Cleaning after assembly can be accomplished using conventional DI water cleaners

In most cases, no new cleaner baskets must be designed, fewer individual parts are handled, fewer numbers of cleaner baskets are required. This results in an effective increase in the capacity of the cleaners. Dryness is acceptable using existent process equipment/times

Dimensions and locations of parts were unaffected. Screw torque, adhesive bonds unaffected. Cleanroom floorspace and operating costs are reduced. Finally, the finished assemblies parts come out cleaner from a particle perspective than in the clean, then assemble approach

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