RJA

FINAL REPORT ON THE DEVELOPMENT OF A STANDARDIZED TEST PROTOCOL FOR DETERMINING THE RELATIVE TRANSFER EFFICIENCY OF SPRAY GUNS

Submitted to:

California Air Resources Board
South Coast Air Quality Management District

Submitted by:
Ron Joseph
Ron Joseph & Associates, Inc.
12514 Scully Ave.
Saratoga, CA 95070
(408) 446-9736

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RON JOSEPH & ASSOCIATES, INC.
COATING CONSULTANTS
12514 Scully Ave.
Saratoga, CA 95070
(408) 446-9736

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Marla Mueller (RD), Project Manager, California Air Resource Board, (CARB)
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John Lappin, Testing Engineer, Customer Technology Application Center (CTAC) of the Southern California Edison Company, (SCE)
Michael Lo, Testing Engineer, CTAC
Kenneth Pascual, Technician RJA
Sharod Vaughn, Technician RJA
Joseph Hoang, Technician, RJA
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<u>California Air Resources Board (ARB)</u>	
Marla Mueller (RD)	(916) 323-1529
Mike Jaczola, (SSD)	(916) 327-1515
Manjit Ahuja (R&D)	(916) 323-1511
Cindy Castronovo (MLD)	(916) 323-0301
<u>South Coast Air Quality Management District (SCAQMD)</u>	
Glenn Kasai, Project Manager	(909) 396-2271
John Higuchi (AST)	(909) 396-2267
Fred Lettice (SB&CP)	(909) 396-2576
<u>US EPA (RTP)</u>	
Charles Darvin	(919) 541-7633
<u>US EPA Region IX</u>	
Duane James	(415) 744-1191

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Bay Area Air Quality Management District
Douglas Tolar (415) 749-5118

San Diego Air Quality Management District
Natalie Zlotin (619) 694-3312

Graco Inc.
Glenn Muir (612) 623-6316

Binks Manufacturing
Kent Anderson (310) 691-1900

Infratech Corp
William Petro (818) 331-9400

Edison International
Paul Delaney (310) 463-3122

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2 Introduction

This is the final report summarizing all of the work performed under Contract No. R-C94104 - *Development of a Standardized Test Protocol for Determining the Relative Transfer Efficiency of Spray Guns"*. The deliverables for the project are:

- **Volume 1**: Standardized Test Protocol for Determining the Relative Transfer Efficiency of Spray Guns.
- **Volume 2**: Final Report Highlighting the Results, Conclusions and Recommendations of Tasks #1, #2, #3 and #4.
- **Volume 3**: Raw data of all tests conducted during the project. The results are contained on both hard copy and 3½" computer disks. Spreadsheets are formatted in Microsoft Excel 5.0, and documents in WordPerfect 6.1. A "readme.txt" file is provided that explains where to find specific spreadhseets and documents.

3 Glossary of Terms

All of the terms used in this report are defined in the *"Glossary of Terms"*, which can be found in Appendix 1.

4 History of the Project.

Several rules of South Coast Air Quality Management Districts regulate the emissions of VOCs from spray coating operations. One aspect common to all these control regulations is the concept of transfer efficiency. Transfer efficiency is defined as the ratio of the mass of solid coating that remains on the target to the total amount of coating solids sprayed. Typically, air quality rules deem certain coating application techniques, such as electrostatic attraction, HVLP (high volume low pressure), flow or dip coating as high transfer efficiency equipment. Any other non-specified coating process or application equipment must demonstrate a minimum transfer efficiency of 65%. However, no standardized test method currently exists that accurately, precisely and reproducibly determines the transfer efficiency of spray equipment.

The United States Environment Protection Agency (EPA) sponsored a contract with Centec Applied Technologies to address this problem in the early 1980's[1]. This work was used as the basis for a subsequent contract between Ron Joseph & Associates and the South Coast Air Quality Management District (RJA-SCAQMD)

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1 This project was coordinated by Mr. Charles Darvin of the USEPA who was subsequently invited to participate on the Advisory Committee of this project.

FINAL REPORT ON THE DEVELOPMENT OF A STANDARDIZED TEST PROTOCOL FOR DETERMINING THE RELATIVE TRANSFER EFFICIENCY OF SPRAY GUNS

1 Executive Summary

A Transfer Efficiency Test Protocol has been developed to evaluate the efficiency of a manual or automatic spray gun in comparison with a spray gun that the South Coast Air Quality Management District (SCAQMD) will select as its standard or baseline.

In developing the protocol it was first necessary to understand the sensitivity of transfer efficiency to various parameters, a comprehensive list of which is provided in Table 1.

Because transfer efficiency is directly or indirectly affected by more than 15 parameters, it was necessary to focus this study on those that were considered to have the most effect. They were:

- Panel size
- Coating rheology (solvent-borne coatings)
- Spray gun type
- Distance between the spay gun tip and the targets (flat panels)
- Spray gun design
- Water-borne coating

The research demonstrated that the protocol will yield repeatable results, and can be sufficiently sensitive to differentiate between spray guns of different types and designs. Except with guns for which the efficiency differences are not significant, the work showed that the relative ranking of spray guns, when compared against each other, is preserved even when panel size and coating formulation are changed.

Based on the results of the sensitivity studies, the Draft Protocol was modified to (a) identify a specific panel size, (b) standardize on a coating that can be used to evaluate all existing and future spray gun types, (c) specify parameters and their ranges that will need to be defined during a spray gun evaluation.

It is expected that the protocol can be used by the SCAQMD, industry, and other agencies to identify spray guns that are at least as efficient as a reference spray gun (yet to be chosen) which meets regulatory transfer efficiency requirements. The protocol will also permit the agency to identify spray guns that do not meet a minimum standard of efficiency.

The report provides recommendations for additional work that will further refine the protocol in the areas of (a) the possible use of a pressure pot as the coating reservoir in the fluid delivery system, (b) the effect of ambient humidity on the electrostatic application of the coating, (c) the effect of different solvent blends in the coating formulation on its electrostatic properties, (d) water-borne coatings, (e) the effect of air flow in the booth on transfer efficiency.

The project comprised six tasks:

Task #1 - Draft Test Protocol
Task #2 - Test Protocol Development
Task #3 - Laboratory Test Protocol
Task #4 - Intra-Laboratory Validation
Task #5 - Inter-Laboratory Validation
Task #6 - Final Report

Details of each task provide the body of this report.

6 Transfer Efficiency

6.1 Explanation of Transfer Efficiency.

Transfer efficiency of a coating application is calculated by the ratio of the weight[4] of **solid** coating deposited on a substrate, to the weight of **solid** coating used in the application. In the case of spray applications, the amount of coating used is the weight of solid coating fed to the spray gun which is then atomized toward the substrate.

$$\text{Transfer Efficiency (\%)} = \frac{\text{Wt. of Solid Coating Deposited (g)} \times 100}{\text{Wt. of Solid Coating Used (g)}} \quad \ldots\ldots\ldots \quad (1)$$

To calculate the denominator of Equation (1) the technician measures the volume of **liquid** coating used during a transfer efficiency test. By analyzing a sample of the coating to determine its density, one can calculate the weight of liquid coating used. ASTM D-2369 test method is followed to determine the percent weight of **solid** coating present in the **liquid** sample. From this it is a simple matter to calculate the weight of solid coating used during the application.

$$\text{Weight of solid coating used (g)} = \text{Volume of liquid coating used (cc)} \times \text{Density of Coating (g/cc)} \times \text{\% Weight solids} \quad \ldots\ldots\ldots (2)$$

To calculate the numerator of Equation (1), the panels are weighed before the coating is applied and again after the coating has been applied and cured in an oven. The weight of **solid** coating deposited is the difference between the "before" and "after" weighings.

4 While transfer efficiency in this protocol is calculated by weight, it is also possible to perform the calculation on the basis of volume.

in 1989/90. The goal of the RJA-SCAQMD study was to determine the feasibility of developing a standardized test protocol for evaluating the transfer efficiencies of spray guns under simulated production conditions[2]. The study was successful in demonstrating statistical reproducibility using two different sized targets and three application methods.

5 Objectives

The objectives of this study were to develop a standardized test protocol for a laboratory environment to measure the transfer efficiency of paint spray gun, and to validate the protocol's reproducibility both within and between laboratories.

The specific objectives were as follows:

Develop a standardized test protocol for measuring transfer efficiency, such that any qualified analytical laboratory and most spray guns manufacturers may acquire and set up the protocol-specified apparatus, and perform testing to certify spray guns submitted by equipment manufacturers.

The protocol must be independent of any specific spray guns type, and should allow for the testing of most currently available spray guns as well as future spray-gun developments.

Development of this protocol will utilize the work completed earlier in RJA-SCAQMD study[3] and must consider and propose solutions to the problems identified in that study. In addition, the protocol must also incorporate the effects of the following variables on transfer efficiency:

a. Size of panels
b. Coating rheology
c. Spray guns types
d. Spray gun-target distance
e. Same spray gun type from different manufacturers
f. Water-borne vs. solvent-borne coating

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2 The phrase implies that the spray gun moves both horizontally and vertically across the face of a panel. Triggering allows for leading and trailing edges, and for overlap on the first and last strokes. This is exactly what a spray painter would do to coat a similar panel.

3 Ron Joseph, <u>Transfer Efficiency Test Protocol Development and Validation in Custom Coating Facility</u>, 1989, SCAQMD.

- Steel panels are relatively inexpensive and can be cut from standard 4' x 8' sheets of metal resulting in minimal, if any scrap.

- Flat panels are easy to work with. They can be stacked and stored and require minimum space.

- Much of what is painted in industry is flat metal.

- Panels of 20 gage are not too thin to cause buckling and deformation[6], yet are not too heavy to handle.

- The medium-sized panels represent typical medium-sized products that are fabricated in the general metals industry, while the small panels represent items such as name plates, brackets, etc.

- Discussions took place to justify the use of flat panels versus ones with bends, cut-outs, etc. The conclusion was that while it would be nice to have more complicated shapes and sizes included in the project, the material and labor costs for testing would be significantly higher. Since this protocol provides for the comparison of transfer efficiency between guns, one would expect the **relative ranking** to remain the same.

- Project funding did not allow for a sensitivity study to evaluate different shapes or geometries.

7.3 Simulated Production Conditions

Discussions took place among members of the Advisory Committee regarding the manner in which the panels would be coated.

- One suggestion was that the spray gun should remain stationary and that the technician would briefly apply a spray fan pattern onto the panel by triggering the gun for approximately 0.5 sec.. The argument was that transfer efficiency was only a function of particulate bounce back rather than gun movement.

- Another suggestion was that the gun should move horizontally across the face of the panel, and at the end of the stroke move down for the next stroke. Each stroke would overlap the previous one by 50% thus ensuring uniform coating coverage on the panel. Therefore, the movement of the gun would replicate typical painting practices, with the exception that the entire spray envelope would be contained on the panel.

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6 After the panels are coated the cured coating can be removed by grit or sand blasting. If the steel is too thin the panels will deform.

6.2 Parameters Which Affect Transfer Efficiency.

The development of a standard test protocol to measure the efficiency of a spray gun is complicated by many parameters that affect the measurement.

Table1 lists parameters which affect transfer efficiency. Some, such as panel size and gun-target distance can easily be measured and controlled all of the time. Most, however, are either difficult to control all of the time, or are affected by the operator's experience in setting up the gun so that it can consistently apply a finish with an acceptable appearance[5]. Because of the extensive list of parameters only the most important could be evaluated in this project. They are listed on page 3.

7 Task #1 - Draft Test Protocol

7.1 Objectives

The objectives were to:

- write a draft test protocol based on the results of the earlier RJA-SCAQMD study .
- address concerns raised during the previous RJA-SCAQMD study.
- set up the spray application equipment and fluid delivery system so that a coating could be applied to metal panels. Two sizes were to be used; medium panels 16" x 20" x 16 gage, and small panels 6" x 4" x 16 gage.
- calibrate the instruments and confirm that the experimental design was adequate to proceed to the testing phase.
- select a coating that could be used to commence the project. It was understood that final coating selection could only take place after transfer efficiency testing had been conducted.
- select the spray guns which would be used.

7.2 Panels Used

Two panel sizes were used; medium 16" x 20" x 20 gage, and small 6" x 4"x 20 gage were used for the following reasons:

5 Acceptable appearance comprises three separate tests; gloss, Distinctness of Image (DOI) and dry film thickness.

Throughout Tasks #1 and #2 only one coating, Cardinal High Solids Polyester Baking Enamel, Gray #16440, was used.

The Cardinal coating was selected because it met all the above criteria, and it was convenient that Cardinal Industries[9] is located within a few miles of the CTAC laboratory.

Although it appeared to meet all of the requirements listed above, the coating proved to be very difficult to use (as will be further explained in the results sections of Task #2). The viscosity of the coating was too high to be spray applied at ambient temperature; however, when heated to ~105°F using an in-line heater, the application met the "appearance" criteria. The primary problem was that the coating had a very sensitive viscosity/temperature relationship. To better understand the coating, a viscosity/temperature curve was plotted by measuring the viscosity on a Krebbs-modified Stormer viscometer. The result is shown in Figure . Two curves are presented. The first is based on the actual measurements; the second was created from a regression analysis. To measure the viscosity the coating was placed in a quart container which was immersed in a beaker of ice water so that the first measurements would be below ambient temperature. By adding warm water to the beaker the temperature gradually increased and viscosity measurements were taken at 0.5 - 2.5°F increments[10]. This procedure was terminated at ~122°F . A detailed description of the procedure to measure viscosity is provided in Section 12.4 of the Test Protocol.

The steepness of the curve is an indication of the sensitivity of the viscosity to temperature. While this was not fully appreciated until much later in the project, it was later shown to be the primary cause of poor repeatability, calculated as Coefficient of Variation (COV).

7.5 Spray Guns

The spray guns to be evaluated were:

*	(CONV)	DeVilbiss-Ransberg conventional air atomizing Type MBC
*	(HVLP1)	Binks Mach #1 HVLP gun (pressure regulated)
*	(ELEC)	Graco Pro 3500 SC electrostatic
*	(AAA)	Graco 200 HS air-assisted airless
	(HVLP2)	Accuspray HVLP
	(HVLP3)	Graco HVLP Optimizer M-1265
	(TURBINE#1)	Accuspray HVLP Turbine
	(TURBINE#2)	Apollo HVLP Turbine

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9 Cardinal Industries, (213) 283-9335, FAX (818) 444-0382

10 The temperature was measured whenever the Krebbs Unit changed on the Brookfield viscometer.

- A third suggestion was that the gun should move as described in the previous paragraph, but that the spray gun should start triggering 1.0" to the left of the left edge[7] of the panel, and stop triggering 1.0" to the right of the right edge of the panel. Also, the first stroke of the gun would allow one half of the spray fan to be above the top edge of the panel, while the last stroke would allow one half the fan width to be below the bottom edge of the panel. Each stroke would overlap by 50% thus ensuring uniform coating coverage on the panel. This scenario would replicate typical industrial painting practices, and take into account poor fan pattern definition.

While all three scenarios have merit, the last one was selected as the method for applying coating to the panels. In fact, the results showed that some guns produced better fan pattern definition than others, but unfortunately the scope of the project did not allow for a sensitivity study to be conducted.

7.4 Coatings Used in the Project

The criteria for selecting a coating were as follows:

a. A coating was required that would meet the VOC requirements of the SCAQMD, namely 420 g/L (3.5 lbs/gal) for a high gloss air dry coating,[8] or 275 g/L (2.3 lbs/gal) for a baking coating.

b. The coating was to be commercially available to metal fabricators and have proven application performance within the industry.

c. All spray gun types were to be able to atomize the coating.

d. The coating was to have the capability to be dried and cured within one or two hours after application so that the results of a transfer efficiency test set could be evaluated on the same day that testing took place.

e. The formulation should <u>not</u> vary from one batch to the next, and should not be specifically formulated for this project.

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7 The initial distance through which the spray gun triggers before reaching the edge of the panel is known as the "Leading" edge, while the final distance before the gun stops triggering is the "Trailing" edge. In Task #2 these were 1.0", but they were later changed to 1.75" because it was difficult to reliably achieve a 1.0" distance with all guns.

8 Control of Surface Coatings for Miscellaneous Metal Parts, Rule 1107, South Coat Air Quality Management Rule 1107.

7.6 Measurement of Coating Usage by Volume

A digital readout volumetric fluid[12] flow meter placed in the fluid line, was used throughout the project[13], to measure liquid coating usage. The following data was recorded:

the digital reading on the flow meter immediately after the gun had been purged. This was considered to be the initial reading.

the reading immediately after the coating had been applied. This was the "final" reading.

in some cases the flow meter moved backwards (recorded as "Rev" for reverse) after triggering had ceased, and represented a negative flow.

The meter is a mechanical device which comprises two inter-locking gears through which the coating passes. The flow meter does not directly record the volume of coating passing through. Instead, it records the number of gear cogs, that rotate, or "pulses". Volume usage is computed as follows:

Measured Flow (pulses) = FM[14] Final Reading (pulses) - FM Initial Reading (pulses) - FM Rev Reading (pulses) . . . . *(3)*

The vendor of the meter provides the calibration from pulses to cubic centimeters (cc). In this case 0.126 cc of coating was transferred through the meter for every pulse, or cog rotation.

It was necessary to calibrate the flow meter to confirm that the measured volume was equivalent to the actual volume, and this procedure is detailed in Appendix II, Section 3 of the Test Protocol. The calibration resulted in a Conversion Factor (K). Therefore:

FM Measured Flow Volume (cc) = Measured Flow (pulses) x Calibration Factor (cc/pulse) . . . . *(4)*

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12 Whenever the word "fluid" is used in this report, it refers to the liquid coating.

13 The flow meter was used in each of the tasks with the exception of Task #4 - 2nd Test Series. In that series the flow meter was not used when a pressure pot fed the coating to the spray gun.

14 FM = Flow Meter

The spray guns marked with an asterisk were used throughout most of the project. Those unmarked were used in only one instance; to evaluate the sensitivity of the protocol to different gun designs of the same gun type, in this case HVLP.

The abbreviations (CONV), etc., are used in some of the tables to identify the individual guns.

In Task #2 only three guns were used; HVLP1, electrostatic and air-assisted airless.

HVLP was selected because (a) it is one of the methods of application approved for use in most of California's VOC regulations, and (b) it has become one of the most commonly used guns in industry. Two distinct designs of HVLP guns are available. The first and most common, takes shop compressed air entering the gun at approximately 60-80 psig, and reduces it to an outlet pressure less than 10 psig. The second design uses a high speed turbine to generate high volume, low pressure air, where the maximum allowable exit pressure is also 10 psig. These two designs are described in more detail in Appendix 1, Glossary of Terms. Of the two, it was decided to use the pressure regulated design for all but one of the test series in this project[11].

An electrostatic gun was selected because it is also on the list of approved application devices in the California regulations. The Graco Pro 3500 was used because the CTAC facility had recently purchased it, and it was available for the project. This gun generates an electrostatic charge by means of an air-driven turbine located within the body of the spray gun. This design is not to be confused with the turbine-generated HVLP gun.

Although air-assisted airless guns are not on the approved lists of most of the California regulations, this gun type is still being extensively used in the wood furniture industry, and VOC regulations for this industry have not yet barred them from use.

In Task #3 a conventional air atomizing gun was added to the three guns, because the Advisory Committee deemed it valuable to have this gun serve as a baseline. Outside of California, this gun is still being used in many industries.

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11 The only test series in which the turbine design was evaluated was in Task #3, Paragraph 9.6 where the two gun designs were compared.

gun was moved horizontally across a medium-sized panel, and coating was applied as the gun moved from right to left, starting 1.0" to the right of the right edge of the panel and ending 1.0" to the left of the left edge. After the coating had cured, three pencil lines were scribed perpendicularly across the pattern. The first was near the left edge, the second was in the middle and the third was near the right edge. Each line was marked off in ¾" increments, starting well below the bottom edge of the fan pattern and extending well above the top edge. Dry film thickness measurements were taken at each point along each of the three lines. The results are plotted in the Figure. From the legend the reader can identify which graph corresponds to which of the three lines. The heavy black graph represents the average readings at each point. The coating was heaviest between the 4th and 10th increments. Below the 4th and above the 10th increments the fan pattern became more diffuse, until almost no coating was deposited on the panel. Three observers visually estimated the fan width to be approximately 5.5". From the graph one might have estimated the width at approximately (10-4)*0.75" = 4.5". Due to the inconsistency in film thicknesses even across a single stroke, this type of measurement was found to be more confounding than useful.

Measurement of dry film thickness became so time consuming that it was given subordinate priority to the transfer efficiency tests.

7.9 Envelope Size

It was recognized that when a panel is coated the overspray passing on the sides of the panel constitute an inefficiency in coating application. For instance, the wider the leading and trailing edges, the lower will be the transfer efficiency, TE_m. To account for this it was intended to make a correction to TE_m for envelope size, but it was found that its measurement was too dependent on the technician. The boundaries of the envelope are often diffuse, and the measurement of envelope size required a subjective interpretation of where the boundaries start and end. Therefore, the decision was made to scrap the concept of correcting for this parameter. The Test Protocol now places narrow controls on the leading and trailing edges, thus minimizing the effect of envelope size. For purposes of quality control, measurement of envelope size is still required, but the values are not incorporated into any calculations. The method is described in Appendix II, Section 6 of the Test Protocol.

7.10 Measuring Fan Pattern

When a spray gun is pointed toward a flat panel and the trigger is pulled for ~0.5 seconds, the coating which is applied takes on the shape of the fan pattern, which in most cases is elliptical. Unfortunately, the edges of the pattern can be so diffuse that it is often not possible to accurately measure where the pattern starts and ends. The Advisory Committee discussed various methods for determining these dimensions;

Corrected Volume (cc) =
FM Measured Volume Flow (cc) x Conversion Factor (K) . . . . (5)

To convert the corrected volume to weight:

*Weight **Liquid** Coating Used (g) =*
Corrected Volume (cc) x Coating Density (g/cc) . . . . (6)

The coating density was determined by following the procedures detailed in Appendix II, Section 1 of the protocol.

7.7 Acceptable Appearance Criteria

One of the criteria that was to be non-negotiable during the testing program concerned the appearance of the coated panels. It was important that the results of any transfer efficiency would only be valid if the coating appearance met specified minimum criteria. These specifications were developed in Task #3 and are reported in Paragraph 9.7.4 on Page 38.

7.8 Coating Dry Film Thickness

The transfer efficiency value as defined in Equation 1, does not take the coating's dry film thickness into account. For instance, two coating applications can yield similar transfer efficiency values, yet the one application can have a low coating film build while the other can be considerably higher. To account for coating thickness in the transfer efficiency equation it was proposed to measure dry film thickness of selected panels within each test set. The intent was to correct the measured transfer efficiency (TE_m) for film thickness, thus yielding a new transfer efficiency value, (TE_d), but this concept was scrapped when it was found that dry film thickness values were not constant across the face of a coated panel and TE_d values were not meaningful. A representative of the SCAQMD and the RJA technicians who were working on the project spent many hours measuring film thickness on the small and medium panels. The results were baffling, and some of the observations were:

film thickness, especially with the HVLP gun, was not constant across any one stroke.

film thicknesses at the overlaps were different from those in the non-overlapping areas.

As an example, Figure 2 illustrates the variability in dry film thickness for a single stroke of the HVLP spray gun using the Cardinal High Solids Polyester Baking Enamel. In this example the spray gun fan pattern was approximately 4-6". The

- The original design of the fluid delivery system was overly sophisticated and called for too many pressure and temperature gages, transducers, and other nice-to-have equipment and instrumentation. This made the system vulnerable to malfunctions. On account of the many pressure gages, valves, transducers and bends in the fluid line, the pressure drop from the pump to the spray gun was so high that it was not possible to achieve a reasonable fluid flow rate of 7-8 Fluid ounces/min[15].

  It is suggested that anyone wanting to perform transfer efficiency testing should design the fluid delivery system as simply as possible to avoid unnecessary pressure drops. The Test Protocol has been written to provide for only as many valves and gages as are required to apply the coating and record the data.

- The fluid hose should be as short as possible, preferably less than 25 ft.

- The equipment was designed with the intention to automatically computerize all data entry. This was to be carried out by having the pressure and temperature transducers feed data directly into spreadsheets. It was soon found that manual data gathering was more practical. The data forms which form part of the Test Protocol were printed out so that the technicians could enter data on the fly. At the end of a transfer efficiency test they entered the data into a computer spreadsheet, designed to automatically perform the necessary calculations.

- Because the coating's viscosity was so sensitive to temperature, small fluctuations affected the ability to get repeatable results. Therefore, the protocol requires that the temperature be controlled within ± 3°F. Because this can be problematic for a laboratory that is not temperature controlled, the protocol requires a heater in the coating line.

- Fluid pressure must remain constant at all times. The protocol specifies the use of an hydraulic pump fitted with a back pressure regulator. It is suggested that anyone wanting to perform these tests should pay special attention to the elimination of pressure changes when the pump gets to the end of a stroke and starts the next one.

8 Task #2 - Test Protocol Development

8.1 Objectives

Three spray gun types were used in this task; High Volume Low Pressure (HVLP), electrostatic conventional air atomizing and air-assisted airless. Throughout the task the protocol was to be refined to meet the following objectives:

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15 This is approximately the flow rate that is required in the Test Protocol.

(a) subjective visual observations, (b) measuring coating dry film thickness at small increments across the length of the fan pattern and (c) measuring gloss levels at small increments across the pattern.

Method (a) was evaluated by first spraying one stripe of coating along the width of a steel panel. Several observers were asked to use a pencil to indicate where they thought the pattern started and ended. They were asked to measure fan width near the left edge, middle and right edge of the stroke. The variability between observers was unacceptable, in some cases varying by more than 1" or 10%.

Method (b) was explained in Section 7.8 where it was shown that film thickness varied so extensively from one point to the next , that the method was abandoned.

Method (c) was similar to (b), but instead of measuring dry film thickness, gloss was measured using a specular gloss meter. This method proved to provide the most reliable results, and it was incorporated into Appendix II, Section 4 of the Test Protocol.

Since the coating must be fully cured before either dry film thickness or gloss measurements can be taken, the protocol allows the technician performing a transfer efficiency test to initially set up the fan width by visual observation.

7.11 Numbering of Jobs and Test Panels

All tests, regardless of their purpose, were assigned a Job Number. For instance, in Task #2 the numbers started with #1001 and progressed to #1033.

Test panels were not used for all of the Job Numbers, particularly at the beginning of the Task when several tests were conducted to either resolve equipment problems that had been identified, or to better understand the coating's application characteristics.

Some Job Numbers were initiated, but scrapped when it was found that no meaningful data would be derived. When panels were used, each was assigned an ID number. For instance, the panels used in Job #1004 were assigned the designations AB1 - AB12, and also AC1 - AC12. There was no significance to the panel numbers, except to allow the operator to identify one panel from another.

Some of the Job Numbers only comprised one set of panels, particularly when the purpose of the test was to establish something other than transfer efficiency.

7.12 Problems and Solutions Encountered in Task #1

This section is intended to provide guidance for anyone wanting to set up a laboratory to perform spray gun transfer efficiency evaluations.

of the panel[17]. Upon triggering, the gun moved horizontally at a constant speed[18] from right to left in front of the face of the panel to a position 1.75" from the left edge[19] of the panel to Position #2. While still applying coating, the gun retraced its movements back to Position #1. Two passes had been made. The program caused the gun to stop triggering, but moved it vertically down a predefined distance[20] to Position #3 where the second stroke was about to commence. Triggering of the gun was repeated while coating was applied over the next strip of panel. When the gun got to the end of its stroke, at Position #4, 1.75" beyond the left edge of the panel, it again retraced its movements until it arrived back at Position #3. Once again the program caused the gun to move downward by the same distance as before. The triggering procedure was repeated several times until the entire panel was coated.

The gun then moved to the second panel on the rack, as shown in Figure 4. When the panels were completely coated the rack was moved to the outside of the oven, and a second rack was suspended from the hooks in the spray booth. The coating procedure was repeated for the third and fourth panels, and then again for the fifth and sixth panels, thus making a total of six[21] coated panels per test set. Only after all panels within a set had been coated were they transported to the oven where they were dried and cured for 30 minutes at 250°F.

8.3.2 Revised Procedure

As will be discussed later in this report, numerous problems were encountered concerning poor repeatability of transfer efficiency values. Even when two panels were coated side by side, as described in the previous paragraphs, repeatability was unsatisfactory. At the end of Task #2 the procedure was changed so that only one panel was placed on the rack in the position of Panel #1 in Figure 4.

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17 In Task #3 the leading and trailing edges were increased to 1.75" because it was too difficult to maintain the narrow 1.0" distance. Note that Figure 5 shows only the 1.75" distance.

18 The speed was 250 mm/sec for the HVLP and electrostatic guns and 508 mm/sec for air-assisted airless guns.

19 Like the Leading Edge this was changed to 1.75" in Task #3.

20 Usually 1/2 the width of the spray fan pattern, which in most cases was 5.0". The fan width was 10".

21 During Task #2 the first few tests with medium-sized panels were conducted with six panels per test set. When the repeatability of the results was shown to be poor, eight panels were used because it was hoped that the larger number would make it easier to identify experimental problems. In Task #3 the repeatability was shown to be excellent, and a test set once again comprised six panels.

(a) The Coefficient of Variation (COV) of repeated tests was to be less than 2.5%.

$$\textit{Where COV (\%)} = \frac{\textit{Standard Deviation x 100}}{\textit{Mean}} \quad \ldots\ldots\ldots\ldots \quad (7)$$

(b) The efficiency of the protocol was to be improved so that the set-up time between tests could be minimized.

(c) The cost for testing was to be minimized.

(d) The number of tests which can be conducted per day were to be maximized without impairing the quality of the results.

8.2 Methodology for Coating Panels

Figure 3 shows the basic equipment set-up which was used at the CTAC facility.

To eliminate the variability introduced by individual spray painters, it was decided to use a computer-driven robot to move and trigger the gun according to predefined programs which were developed by the technical staff.

8.3 Medium-sized Panels

8.3.1 Initial Procedure

Two medium-sized panels were placed on a coating rack, as shown in Figure 4. Because of the manner in which the robot was programmed, the first panel to be coated was on the right of the second. There was no significance to this, nor did it have an effect on the transfer efficiency results. In addition, Panel #1 was placed slightly higher than Panel #2, and this too had no significance. The rack design made the staggered positions more convenient, but the transfer efficiency results were not affected.

To initiate spraying of the first medium-sized panel, the operator commenced a computer program which caused the robot arm[16] to move the spray gun into a predefined position relative the upper right corner of the panel. This is Position #1 in Figure 5. The gun was aimed away from the panel and automatically triggered for approximately 3 seconds to purge coating in the fluid hose. The program then caused the gun to face toward the spray booth, so that it was perpendicular to the plane of the panel. It was still in Position #1 which was 1.75" from the right edge

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16 Refer to label "L" in Figure 3.

etc., none of the input measurements was providing acceptable repeatability[22] from one panel to the next.

The Mean TE_m values for each test set did not correlate well with the TE_m values of the other two sets, (38.79%, 28.37%, 49.84% and 56.97%).

An analysis of Job #1019 provided a clearer understanding of the dynamics of the coating application. In Table 3 an analysis was made for each of the 12 small panels. The results clearly show why the coefficient of variance's were so high for "Weight of Coating Deposited" and "Wt. of Solid Coating Used". The graph accompanying the table shows the variation in "Weight of Coating Deposited" as the spray gun moved from the first panel to the last. Note that the first panel to be coated in the set, Panel #1 was located at the top of the first column on the coating rack. (See Figure 6). This panel had the lowest coating weight in the column. More coating was deposited on Panel #2, and so on until the spray gun had coated Panel #4, which was the last panel in the first column. Panel #5 was the topmost panel in the second column and had the lowest coating weight within its column. This increased steadily with Panels #6, #7 and #8, respectively. The trend repeated itself yet again in the last column. Interestingly, there was better correlation between the panels in the same horizontal plane (such as Panels #1, #5, and #9, or #2, #6 and #10, etc.), than for the four panels in a column.

One idea which was postulated was that perhaps the flow meter itself was contributing to the problem. Clearly, there might be a significant experimental error if one records volume by the number of cog pulses (rotations), particularly if the small volume of coating contained between two adjacent cogs is large relative to the amount of coating required to coat a small panel. In this case the volume between the cogs was 0.126 cc, while the volume of coating applied to each small panel was approximately 1.55 cc. Therefore, each flow meter *increment* represented approximately 8.1% of the total amount of coating used per panel, (0.126*100/1.55 = 8.1%). This could result in a high potential for error. While this argument seemed plausible the results did not verify the hypothesis.

To resolve the problem of poor panel-to-panel correlation, several additional tests were conducted in which each of the following strategies were separately tried:

> the flow meter was cleaned approximately once per week to insure that no contaminants had built up between the gears and thus affect the readings,

> the meter was calibrated at the beginning of each test series,

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22 Acceptable repeatability was for COV <2.5%

After the panel was coated, the operator removed it from the rack and placed it on a back-up rack where it awaited drying and curing in the oven. The second panel was then placed on the same rack and in the same position as the first. This procedure was repeated until all six or eight panels of the test set had been coated. Only then were all three racks sent through the large commercial oven where the coating was dried and cured.

8.4 Small Panels

8.4.1 Initial Procedure

A test set comprised 12 small panels which were placed on the coating rack as shown in Figure 6.

The coating procedure was the same as described for the medium panels, except that the spray gun remained in the same horizontal plane. It made one stroke but two passes as illustrated in Figure 7.

Exact dimensions of the rack and panel positions are not shown in Figures 4 and 6, because toward the end of the task a decision was made that only one panel would be on the rack at any time.

8.4.2 Revised Procedure

The revised procedure was the same as mentioned in Paragraph 8.3.2, except that each of 12 panels was coated individually on the coating rack, and then transferred one at a time to a back-up rack. Only when all the panels of a test set had been coated were the racks transferred into the oven.

8.5 Results: HVLP Gun - Small Panels

Despite the many tests which were conducted using small panels, only a few provided valuable information concerning the ability of the equipment to produce repeatable results.

Table 2 summarizes the results of three selected test sets, Jobs #1004, #1006, #1018 and #1019.

It will be seen that the COVs for Mean Weight of Coating Deposited, (Column 6), Mean Weight of Solid Coating Used, (Column 9) and Mean Transfer Efficiency (TE_m) , (Column 12) were all extremely high - in most cases greater than 10. This indicated that of the 12 small panels which made up a test set, such as AB, AC, Mean Weight of Coating Deposited, COV (%) (Column 7), were in the range 3.3 - 6.4%

Mean Weight of Solid Coating Used, COV (%) (Column 10) were in the range 0.92 - 2.91%

Mean TE_m , COV (%) (Column 13) were in the range 2.3 - 6.2%

Although the coefficient of variances were for the most part higher than the project goal of 2.5%, they were close to meeting the goal.

When the mean results of the five Job Numbers, #1007, #1009, #1014, #1019 and #1024 were compared, the COV for the TE_m was only 1.48% (see the last value at the bottom of Column 11). This correlation was considered to be excellent and met the goal of the project, <2.5%. However, the COV values for the Mean Weight of Coating Deposited and Mean Weight of Coating Used (last values in Columns 5 and 8, respectively) were poor, 13.48% and 13.87% respectively.

After the coating was changed in Task #3 even these COVs were brought within the goal of the project.

8.7 Results: Electrostatic Spray Gun - Medium Sized Panels

The electrostatic spray gun used in this series of tests was Graco's Pro 3500 SC.

The test protocol for these tests was the same as for the HVLP gun, except that the rack was grounded to insure that the coating could wrap the panels.

The results in Table 5 demonstrate exceptionally good repeatability. The standard deviation for TE_m was slightly less than 1%, and the COV 1.308%. (Refer to the last two values in Column 11.)

Once again, it should be noted that for the "Weight of Solid Coating Deposited" and the "Weight of Solid Coating Used", the COV were relatively high, 8.62% and 5.936%, respectively. (Refer to Columns 5 and 8.)

In Task #3 this issue was resolved when the equipment was improved and the coating was changed.

the robot was reprogrammed to insure that the coordinates of the panels, as originally entered into the computer, were in fact correct,

a better attempt was made to control and maintain the temperature of the coating at the spray gun by allowing for a longer purge time when the gun was first triggered at the beginning of a test set. The fluid delivery system did not have a recirculation loop.

in case the racks were not absolutely identical with regard to the position of the magnets, only one rack was used onto which the panels were placed. The remaining two racks were not to be used in the coating process. Their only function was to hold the already coated panels, and transfer them to the drying and curing oven.

Despite the many tests which were conducted with small panels, none of the above strategies lead to the project goal; namely, a COV <2.5%. The temperature changes which occurred each time the gun stopped triggering and moved to the next panel, (especially when it traveled from the bottom of one column to the top of the next), were sufficient to affect the transfer efficiency measurements. The problem was satisfactorily solved only in Task #3 when the new air dry high solids coating was used.

At the conclusion of Task #2, the Advisory Committee met to discuss the results of this work. During that meeting it was suggested that significant changes be made to the entire equipment set-up. This included providing for new pumping, replacing the fluid flow meter with one of greater precision, and better control of the coating temperature by providing for a recirculation loop in the fluid line. In addition, only one small panel placed in Position #6 on the rack was to be coated. Thereafter, it would be transferred to one of the back-up racks and await entry into the drying and curing oven. This was described in Paragraphs 8.3.2 and 8.4.2.

8.6 Results: HVLP Gun - Medium Panels

Table 4 provides the results for this sub-task.

Several transfer efficiency tests were initiated using medium sized panels, but the results for only Jobs #1007, #1009, #1014, #1019 and #1024 were considered to be similar to each other and valid for comparison. Additional tests (represented as job numbers) were conducted, but most were intended to resolve some of the equipment problems.

Repeatability for medium sized panels was considerably better than was experienced with the small panels. Salient observations were:

At the conclusion of Task #2 the California Air Resources Board recommended that the test plan for Task #3 and the subsequent results be reviewed by an independent statistician. It was suggested that the work be performed by the Statistics Department at the University of California, at Davis. A statistician was subsequently retained.

The statistician found that transfer efficiency is affected by so many direct and indirect variables, such as shown in Table 1, that many more sensitivity studies would be required than could be reasonably conducted within the scope of this project. He was appraised of the anticipated importance of each variable, and then was told of the sensitivity studies which had been selected for Task #3. Bearing in mind the need to restrict the number of variables for which a sensitivity study could be conducted, he was satisfied that the test plan as presented for Task #3 was sound. He agreed that for each test series a minimum of three tests should be conducted with each spray gun and he suggested that no two consecutive tests should be conducted with the same gun. For instance, if the first test was to be conducted with an HVLP gun, the next would be conducted with a conventional air atomizing gun, followed by the electrostatic gun, followed by the HVLP gun for the second time, and so on until each gun had been evaluated three times. While this was a plausible suggestion, it was found that so much time was required to set up each gun on the robot and ready it for a transfer efficiency test, that it would not be possible to complete Task #3 testing within the available time. As a compromise, the following procedure was developed. After the first test series, the gun was cleaned, and fluid and air controls were fully opened. The technician then re-adjusted the settings until the coating application produced an acceptable appearance. After the second test series, the settings were again re-adjusted.

In Task #2 there were occasions on which a coated panel fell to the floor or the coating was damaged before it had time to cure. The results for these panels were not included in the subsequent calculations for TE_m . In addition, there were seven occasions on which outliers were detected and eliminated from the calculations following the *Dixon Criteria for Testing Extreme Observation*. Details of Dixon Criteria can be found in Table 1, *5% Level of Significance*, in Appendix 4. Of the seven instances, three outliers were erroneously identified in that their values were below the Criteria's Ratio value,"r". (See the Appendix for details of the calculations). The correct values for two of the three instances; namely Jobs #3011 and #3023 have now been correctly incorporated into the results. The results for the third instance, Job #3035, are not used in any of the analyses, therefore the results have no bearing on the outcome of Task #2.

8.8 Results: Air-Assisted Airless Gun - Medium Sized Panels

Whenever one changes from a low-pressure spray gun[23] to a high pressure gun[24], it is necessary to change some of the components in the fluid line. In Task #2 this required a change of hydraulic pump, the fluid regulator and fluid flow meter which could handle the higher pressure[25].

In terms of TE_m, Table 6 demonstrates excellent repeatability between Jobs #1032 and #1033. Because only two meaningful tests were carried out[26], no standard deviation or COV was reported. The Mean TE_m COV for Job #1033 was still too high, (8.5%), but it was sufficiently encouraging to allow the project to proceed to Task #3.

This concluded the testing in Task #2.

8.9 Other Considerations in Task #2

8.9.1 Gun-Target Distance

The gun-target distance was not the same for all tests. While the Test Protocol now standardizes on this, it was necessary in Task #2 to use whatever distances would produce coated panels with an acceptable finish, and transfer efficiency values which were repeatable.

In this task the gun-target distances were as follows:

HVLP	4 inches
Electrostatic	6 inches
Air-assisted airless	9 inches

Because of the different distances the reader is cautioned not to compare the transfer efficiency results for the different guns.

8.9.2 Statistics for Task #2

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23 Conventional air atomizing, electrostatic conventional air atomizing, or HVLP.

24 Air-assisted airless and airless guns are high pressure. In this project only the air-assisted airless gun was used.

25 "Low pressure" usually denotes less than 100 psig, whereas "high pressure" systems usually operate above 250 psig.

26 The tests for Jobs #1029, #1030 and #1031 were not carried out using the correct pressure settings, and therefore the results were not used.

9 Task #3

9.1 Objectives

It was still necessary to meet the project goal of Mean Transfer Efficiency (TE_m) COV <2.5%

The primary objectives were to better define the fixed and variable parameters, and specify the tolerances which would be permitted in the protocol.

The most important findings of each sub-task are summarized in this section.

9.2 Evaluate Modified Spray Robot/Spray Gun Equipment, Small Panels.

9.2.1 Objectives

This test series was to demonstrate that repeatability could be achieved on the newly retrofitted equipment when the Cardinal High Solids Polyester Baking Enamel was applied to one rack equivalent of small panels using an HVLP spray gun.

9.2.2 Methodology

The procedure was to follow the Test Protocol as developed by the end of Task #2.

In Job #3001, the only test set in this sub-task, one rack equivalent of small panels was applied in one stroke and two passes.

9.2.3 Results

The results are provided in Table 7.

9.2.4 Discussion of Results

A COV for Mean Transfer Efficiency (TE_m) of 2.79% was achieved. While this was above the 2.5% goal of the contract, it was nevertheless a marked improvement on results which had been achieved in Task #2 where COVs for small panels were in the range 11.6 - 43.9%.

At the end of Job #3001, every effort was made to fine tune the equipment to lower the COV. It was felt that this was the best that could be achieved for small panels, and the decision was made to proceed to the next sub-task. The decision was supported by the expectation that if the COV was 2.79% it would be <2.5% when medium-sized panels were used.

8.9.3 Other Coating-Related Issues

Throughout Task #2 the COV often far exceeded the project goal of 2.5%. Even at the elevated temperatures of 105°F, it was extremely difficult to pump the coating through the fluid line. This caused the gun to be starved of coating, especially when the trigger was pulled for several seconds. The problem was resolved when the fluid hose was shortened and in Task #3 the baking enamel was substituted with a lower viscosity air drying enamel.

Another problem encountered concerned two consecutive batches of the same coating formulation. It was found that there were slight differences in color and rheological properties, and these could have contributed to some of the poor repeatability in Task #2. Clearly, it is critical that the coating formulation must always be the same. While this has been taken into account in the Test Protocol, the reader should be mindful of this requirement.

8.10 Recommendations

- It was suggested that a comprehensive review be performed of the entire fluid delivery system, including the pumps, (low and high pressure), fluid flow meter, and associated accessories. The low pressure pump is capable of delivering coating at 125 psig, and the high pressure pump >2,000 psig.

- The fluid hose was to recirculate heated coating back to the in-line heater. In Task #2 the dead-end system allowed for too great a temperature fluctuation when the gun was triggered.

- Due to poor repeatability encountered when panels were placed in different positions on the coating rack, it was recommended that only one panel at a time be coated, always in the same position and on the same rack. This was discussed in Paragraphs 8.3.2 and 8.4.2. An advantage of the revised procedure is that the coating rack need not be designed with precision. When programming the robot, the operator simply places a panel on the rack and uses its coordinates as the base-line.

Therefore, during the course of this test series it was necessary to interrupt the program and perform a series of tests to determine the lowest viscosity that could be achieved without exceeding the SCAQMDs VOC limit of 3.5 lbs/gal., (420 g/L).

As-packaged, the viscosity of the air dry coating at ambient temperature (~75°F) was 32 seconds measured on a Zahn #3 cup. It was found that by adding methylpropylketone (MPK) to the coating, the lowest viscosity for which the VOC content remained in regulatory compliance was 15 secs., or 55 KU on a Krebbs-Modified Stormer viscometer. The volume of MPK to be added varied depending on the batch of coating supplied. From an analysis of the coating density and percent weight solids of the diluted sample, one can determine if the VOC limit had been exceeded[29].

MPK was selected because it was the solvent that had been used in the CTAC laboratory for other coatings.

When an **electrostatic** spray gun is used to apply a coating, transfer efficiency will depend on the conductivity of the coating. Generally, one can assume that within a narrow range of conductivities[30] of **solvent-based** coatings the transfer efficiency will increase, because the paint particles will more easily pick up an electrostatic charge from corona surrounding the charged electrode of the spray gun. The high potential difference between the charged particles and the grounded work piece (in this project panels were used), causes the particles to be attracted to the work piece; hence, improved transfer efficiency. When the conductivity exceeds this range the charges on the paint particles can bleed back through the spray gun to ground, thus nullifying the advantage of electrostatics. Therefore, it is expected that small changes in conductivity of the coatings used in this project could have afected the results; however, a sensitivity study was not conducted on account of time constraints. Table 22, which was derived by a technician at Cardinal illustrates how sensitive conductivity can be when small amounts of MPK are added.

9.3.3 Methodology

The following four guns were used to evaluate transfer efficiency:

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29 Section 1 of Appendix II in the Test Protocol outlines the procedure to measure coating density. Section 2 describes the method to determine percent weight solids. A spreadsheet which inputs data from the Sections 1 and 2 analyses automatically computes VOC content.

30 The range of conductivities varies from one gun design to another and is usually specified by the spray gun manufacturer.

9.3 Effect of Coating Rheology- Medium Panels

9.3.1 Objectives

The purpose of this test series was to determine if the optimum coating was being used.

The three most important considerations were:

Ease of atomization
COV for Mean Transfer Efficiency (TE_m) $<2.5\%$
Acceptable appearance

All of the conditions (a) through (e) discussed in Section 7.4 were still to apply.

9.3.2 Coating Related Issues

In this sub-task a Cardinal High Solids Air Dry Enamel, Gray #14880-16440 was evaluated. This coating also met the requirements listed in (a) through (e) of Paragraph 7.4, although "through hardness"[27] could not be achieved during the prescribed 30 minute, 250°F drying schedule in the oven. This did not hinder the testing procedures, because it was possible to weigh the panels after they emerged from the oven and had cooled to ambient temperature. It was also possible to wait 24 hours or more for the coating to achieve sufficient hardness to allow for measurement of dry film thickness, gloss and DOI all of which contribute to the final appearance of the finish.

Not only did the air dry coating have a more favorable viscosity at ambient temperature, but when compared with the baking enamel it's viscosity was not as sensitive to temperature changes. Despite its **relative** insensitivity (compared with the baking enamel), tight temperature control was nevertheless required[28].

The Test Protocol now takes this into account and restricts temperature differences to ±3°F.

During the evaluation of Coating Rheology in Task #3, it was discovered that the coating was not being used at its lowest, and therefore most favorable viscosity.

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27 Through hardness occurs when the coating achieves its maximum hardness, from the coating/air interface down to the coating/substrate surface.

28 A viscosity/temperature curve was not generated for the air dry enamel.

coating deposited and weight of coating used were well below the project goal of 2.5%.

- If in the future a laboratory does not have a constant temperature laboratory environment, the fluid delivery system will need to be fitted with a heater that can maintain a constant coating temperature at all times. The fluid lines between the heater and the spray gun will need to be particularly well heat insulated. The final Test Protocol requires a tolerance of ± 3°F for the coating.

9.4 Evaluating Gun-Target Distance - Medium Panels

9.4.1 Objectives

The objective of this task was to determine the optimum gun-target distance for each gun. Three distances were to be evaluated; 8", 10" and 12". In discussions with two equipment vendors[31] it was agreed that distances less than 8" and greater than 12" were probably not realistic for most industry spray applications.

9.4.2 Background

Prior to commencing this test series a discussion took place between RJA, CTAC, and a representative of Graco, regarding the parameters that should be standardized and those which could be varied. Correspondence on this topic can be found in Appendix 3.

In summary, it was decided that all transfer efficiency tests must produce an acceptable appearance. This implies that the specified limits for gloss, DOI and dry film thickness must be met.

Unless testing showed otherwise, the following parameters would be held constant:

Coating viscosity, (implying also coating temperature)
Speed of gun travel
Gun-target distance
Fan size

It was tentatively agreed that the following parameters would be allowed to vary, depending on the constraints of a particular gun type.

Number of strokes
Fluid flow rate (mL/min)
Atomizing air pressure
Orifice size

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31 Binks and Graco

(CONV)	DeVilbiss-Ransberg conventional air atomizing Type MBC
(HVLP1)	Binks Mach #1 HVLP gun (pressure regulated)
(ELEC)	Graco Pro 3500 SC electrostatic
(AAA)	Graco 200 HS air-assisted airless

The coating was changed to the new Cardinal High Solids Air Dry Enamel, Gray #4880-16440.

The first three test sets, Jobs # 3002, #3003 and #3004 were conducted at the coating's package viscosity. For Jobs #3002 and #3003 an HVLP gun was used, while for Job #3004 a conventional air atomizing gun was employed. It was then discovered that the coating viscosity could be reduced to 15 seconds using MPK solvent, without exceeding the regulatory VOC content. Therefore, Jobs #3006 and #3007 were conducted at the lower viscosity and using electrostatic and air-assisted airless guns, respectively.

9.3.4 Results

A summary of the results is provided in Table 8.

9.3.5 Discussion of Results

Despite the higher viscosity for the first three jobs, the results of COV were most encouraging as they were all well below the project goal of 2.5%, and demonstrated an improvement over tests conducted in Task #2 with the High Solids Polyester coating. The last two tests, #3006 and #3007 were equally impressive, and appearance of the panels had improved.

There was no need to repeat the tests with the HVLP and conventional guns at the lower viscosity, since it could be reasonably assumed that if one could achieve the project goals at the higher viscosity, even better results could be expected at the lower viscosity.

9.3.6 Conclusions

Several conclusions could be made as a consequence of the this test series:

- In Task #2 a heater was used to control the viscosity of the coating. When the new Cardinal air dry coating was implemented in Task #3 the heater was eliminated from the fluid delivery system. Instead, coating was recirculated back to the coating reservoir. Due to the friction generated in the hydraulic pump, the coating temperature rose above ambient and stabilized at approximately 84°F. The temperature remained sufficiently constant so that the COVs for transfer efficiency, weight of immediately available locally. In Task #4 - 1st Test Series an orifice designed for a wider fan pattern was used, and the problem was resolved.

Coating temperature proved to be very difficult to control. The laboratory temperature had a latitude of ±5°F, and this could not be tightened during the project. Since consistency of coating viscosity is critical, the coating was hereafter allowed to condition at room temperature, after which the viscosity was adjusted to 15 secs. Due to the friction within the hydraulic pump the temperature of the coating increased to approximately 84°F.

As this test series progressed every effort was made to keep the spray gun parameters constant, particularly the number of strokes and passes. Unfortunately, this proved to be impossible. Prior testing had shown that acceptable appearance could be accomplished with five strokes and one pass. However, with the air-assisted airless gun the only way the operator could achieve an acceptable appearance was to reduce the strokes to three, increase the passes to two, and set the spray gun speed to 508 mm/sec.

An additional air-assisted airless test was performed on 11/8/95 (Panel ID BAA, Job #3500-4) in which the medium panel was coated with five strokes and two passes. Results confirmed that the number of strokes do have an affect on transfer efficiency.

Throughout the remainder of the project it was necessary to increase the gun speed for the air-assisted airless gun to 508 mm/sec to meet the appearance criteria. The protocol now makes allowance for this.

It is important to note that when a specific gun was being evaluated, the number of strokes and passes were kept constant for all three gun target distances, 8", 10" and 12"[34]. Therefore it is fair to compare the results for the <u>same</u> gun at all three distances.

Repeatability of results in terms of <u>Mean TE_m COV (%)</u> were excellent for all tests, with the exception of Job #3011 for which the value was 14.56%. This was due to a high value for the Mean Weight Solids Coating Deposited COV of 14.80%. No reasonable explanation could be found for this high value.

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34 With the air-assisted airless gun three strokes and two passes were used for all three gun-target distances, with the exception of Job #3007 (10" distance) for which five strokes and one pass were used. For all other guns five strokes and one pass were used. Therefore, it is still possible to compare the results at the three gun-target distances for the air-assisted airless gun, but one should not compare the results of the air-assisted airless gun with those for the other guns.

9.4.6 Conclusions

- This test series confirmed that for most of the guns transfer efficiency improves as gun-target distance decreases.

- It had been speculated that the electrostatic gun would perform better at a longer distance[35], but the results showed otherwise. Refer to Figure 8.

- Although transfer efficiency improved at the closer distances, <u>appearance</u> (as observed by the operators) was better at the 10" distance. For the HVLP gun appearance was better at 8".

- After lengthy discussion, it was decided to proceed with the protocol development by standardizing on the 10" gun-target distance, primarily because of the improved appearance. However, the protocol makes allowance for HVLP guns to be evaluated at 8".

- To the extent possible, the protocol standardizes on five strokes and one pass. Exceptions are only allowed if the technician cannot achieve an acceptable finish when setting the gun to the specified parameters.

9.5 Effect of Selected Gun Target Distance on Small Panels

9.5.1 Objectives

The goal of this series of tests was to demonstrate (a) that the same gun settings could be used to coat small panels, and (b) that the protocol could yield repeatable results.

At the outset it was understood that in the real world paint operators usually shorten gun-target distance to accommodate small targets. Therefore, in these tests transfer efficiencies could be expected to be lower than one might experience in the real world.

9.5.2 Methodology

At the conclusion of the tests for evaluating gun-target distance with medium panels, the spray gun settings were not altered. The only differences in the protocol were that:

(a) small panels replaced medium panels on the coating rack.

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35 It was thought that at the longer distances the electrostatic wrap would improve.

(b) one stroke and two passes were used for all four spray guns.

9.5.3 Results

A summary of the results is provided in Table 11.

9.5.4 Discussion of Results

For Jobs #3028 and #3031 the small COVs for Mean Wt. Coating Deposited and Mean Wt. Coating Used were particularly encouraging. This was in strong contrast to the high COVs obtained in Task #2 where values in many cases were well over 10%.

Job #3030 did not fare as well because the COV for TE_m was 5.45%. Nevertheless, even this value, which is > 2.5%, is well below the COVs obtained in Task #2.

Job #3029 produced unacceptably high COVs for "Mean Wt. Solid Coating Deposited" and "Mean Wt. Solid Coating Used" and the only possible explanation is that throughout this project it had been difficult to get consistently repeatable results with the HVLP gun.

As was mentioned in the previous sub-task, it was necessary to set the fan width for the electrostatic gun to 6", measured at a 10" gun-target distance, and also to adjust the spray gun speeds for all guns to achieve acceptable appearance.

9.5.5 Conclusions

The results for the small panels, specifically the COVs, were considerably lower, and therefore more favorable than had been possible in Task #2.

Setting spray fan widths to the 10"[36] standard can be extremely difficult and instances will occur when one cannot achieve this goal, because fan width depends on the spray gun orifice dimensions or tip size and design. For some guns the most appropriate orifice might not be manufactured, or might not be available in inventory. Therefore, one might need to settle for the next best alternative size. Small differences in spray fan width can significantly affect transfer efficiency results particularly on small panels, where a significant portion of the fan overlaps the edges. While the same is true for medium-size panels, the overall effect on the transfer efficiency value will be less significant.

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36 Measured at a gun-target distance of 10"

An SCAQMD engineer developed equations to attempt to correct for deviations from the 10" fan width requirement, but he found that they would be too complex and would not necessarily make a marked improvement on the accuracy of the transfer efficiency results.
For these reasons it was recommended that the small panels be dropped from the Test Protocol, and that only medium-sized panels should be used.

Finally, it should be noted that when a similar test was conducted in Task #2 using the High Solids Baking Enamel, the results showed a cyclical nature, (Refer to Table 3). It is clear that as a result of the changes made to the equipment and the coating, the previous problems had been resolved. Figure 9 illustrates this for Jobs #3028, #3029, #3030 and #3031.

9.6 Evaluating Different Gun Manufacturers Within One Spray Gun Type (HVLP) - Medium Panels

9.6.1 Objectives

In this task five spray guns, all of the same <u>type</u>, namely HVLP, were to be evaluated.

<u>Pressure Regulated Design</u>

(HVLP1) Binks Mach #1 HVLP gun
(HVLP2) Accuspray HVLP
(HVLP3) Graco HVLP Optimizer M-1265

<u>Turbine Design</u>

(TURBINE#1) Accuspray HVLP Turbine
(TURBINE#2) Apollo HVLP Turbine

The first three were of the pressure regulated design. Incoming air to the gun is at shop pressure, (often as high as 80-90 psig) but a baffle or other form of restrictor in the gun body regulates the pressure to 10 psig. For the two remaining guns high speed turbines were used to generate the high volume of air. The resulting air pressure emerging from the cap of the gun is usually well below 10 psig., which is the upper limit stipulated in SCAQMD and other California rules. It is not unusual for a turbine operated gun to effectively atomize coatings with pressures of 3 - 5 psig.

It was hoped that the Test Protocol would be able to distinguish between the two gun designs.

The two turbine guns were to be from different manufacturers, as were the three pressure regulated guns.

9.6.2 Methodology

The same protocol was used as for the previous tests with medium-sized panels.

Between each test set the guns were cleaned and reset, but they were not dismantled from the gun holder on the robot arm. After making these adjustments, they were moved further from or closer to the target such as 8", 10", 12".

9.6.3 Results

A summary of the results for this test series can be found in Tables 12, 13 and 14. Because HVLP Gun #1 had already been previously evaluated in Table 10 the results were simply transferred into these tables.

9.6.4 Discussion of Results

These results, more than any other in the entire project, demonstrated the repeatability of the Test Protocol.

There was a remarkable closeness between the Mean TE_m (%) values for the two turbine guns, versus the values for the pressure regulated guns. Although the differences appear to be small, (~56% and ~52%, respectively at the 10" gun-target distance) they do confirm what had been previously reported in the literature[37], namely that the turbine operated guns are more transfer efficient than the pressure regulated ones.

It is also remarkable that as a group the three pressure regulated guns, HVLP #1, #2 and #3 had such close correlation, despite the fact that they were manufactured by different equipment companies. This is another indication that the Test Protocol is able to produce repeatable results.

In all three Tables 12, 13 and 14 transfer efficiency decreased as gun-target distance increased as expected, and the ranking between the two types of HVLP guns was preserved.

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37 Stephen A. Ewert, et. al. Low-Cost Transfer-Efficient Paint Spray Equipment, Metal Finishing, Vol. 91, No 8, P59.

9.6.5 Conclusions

The protocol provides repeatable results when different guns of the same type are evaluated, (e.g. HVLP).

The protocol is sensitive to the performance of different gun designs within the same gun type, (e.g. turbine versus pressure regulated).

Although the HVLP gun favors a shorter gun-target distance, such as 8", the ranking between the guns remains essentially the same. Figure 10 demonstrates this.

9.7 Evaluation of Water-Borne Coating - Medium Panels

9.7.1 Objective

The project required that at least one test series comprise a water-borne coating to determine if the protocol can be used for coating technologies other than the Cardinal High Solids Air Dry Enamel, Gray #14880-16440.

It was fully understood that one test series alone would not be adequate to standardize the protocol for water-borne coatings, but limited funding precluded additional tests.

In this sub-task a water-borne coating[38] was used. Selection of the coating was based solely on CTAC's prior experience with a specific water-borne formulation; namely, Trail Chemical Water-borne High Solids Baking Enamel, #08347-18815.

9.7.2 Methodology

In this test series the following guns were used:

(CONV) DeVilbiss-Ransberg conventional air atomizing Type MBC
(HVLP1) Binks Mach #1 HVLP gun (pressure regulated)
(AAA) Graco 200 HS air-assisted airless

The electrostatic gun was not used because that would have required extensive modifications to the fluid delivery system to cater to the high conductivity of water.

38 This is covered in Section 9.7

Before the water-borne coating, described in Paragraph 7.4 could be used, it was first necessary to thoroughly flush out the fluid lines, coating reservoir, etc. that had carried the high solids, solvent-borne coating.

Determination of percent weight solids was carried out in the same manner as for solvent-borne coatings; namely by following Appendix II, Section 2 of the Test Protocol.

Because the solvent-borne coating had been used for many months, the fluid flow meter, valves, fittings and other components in the fluid delivery system had to be disassembled and cleaned, piece by piece. This was a very time-consuming procedure.

After the equipment had been readied for the water-borne series the protocol was essentially the same as had been followed for the solvent-borne test series.

To achieve an acceptable finish, the pressure settings and spray gun speed had to be changed.

9.7.3 Results

Table 15 provides a summary of the results.

9.7.4 Discussion of Results

Surprisingly, the Test Protocol held up very well for this new, previously untested coating. Before the first transfer efficiency test set could be run, it was necessary to go through a learning curve to determine the spraying characteristics of the coating. This predominantly involved fluid and air pressure settings, trying a different number of strokes and passes, and adjusting the spray gun speed.

The viscosity of the water-borne coating was considerably higher than for the solvent-borne coating. Therefore, it was not practical to measure viscosity on a Zahn #3 cup[39]. Only the Krebbs-modified Stormer viscometer was used. The viscosity on this instrument was 73 KU, whereas for the solvent-borne high solids coating it had been ~55 KU. The difference between the two is significant.

A limiting factor was that the coating vendor recommended the addition of approximately 2% water to lower viscosity. Had it been possible to add more water without compromising the quality of the finish, spray application would have been easier.

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39 When viscosities are high, and particularly when the coating is thixotropic, (non-Newtonian behavior), efflux viscometers do not provide meaningful data.

It must be noted that for both the conventional air atomizing and the HVLP guns, the spray gun **speed** had to be reduced to 75 mm/sec. This must be contrasted with 255-300 mm/sec for the previously used solvent-borne coating. However, when using the air-assisted airless gun and a speed of 250 mm/sec it was possible to achieve an acceptable appearance. (When the air-assisted airless gun was used to apply the solvent-borne coating earlier in this task, it was necessary to increase its speed to 508 mm/sec.)

It is also notable that in this test series the HVLP gun performed significantly better than either of the other two guns, (62.79% for HVLP, versus 48.68% for conventional air atomizing, and 31.69% for air-assisted airless). While this is an interesting observation, it should be pointed out that due to insufficient testing experience with this water-borne coating, one should not assume that these results are necessarily indicative of all water-borne coatings.

It is noteworthy that the **relative ranking** of the guns was retained, regardless of the coating types tested. In fact, one might consider the water-borne tests to be an extension of the rheology sensitivity test. This is demonstrated in Figure 11. The results provide some evidence that relative ranking (not absolute transfer efficiency values) is not affected by the coating type. HVLP and electrostatic had the highest transfer efficiencies, followed by conventional air atomizing and air-assisted airless.

The reader is urged not to quote these results in any literature or advertising, since too little information is available to validate the numbers.

9.8 Large Panel Tests - Solvent-Based Coating

9.8.1 Background

Representatives from two spray gun companies[40] commented on the especially low transfer efficiency results throughout Task #3 for the air-assisted airless gun when compared to other guns. Even after reviewing the raw data, they could not identify the potential problem. It was suggested that because air-assisted airless guns perform better with larger targets than with smaller ones, (such as the 16" x 20" panels that were being used in the test protocol), additional tests should be run comparing the transfer efficiencies of all guns when the panel size was 42" x 42", and allowing the entire spray envelope to be contained within the face of the panel. The Advisory Committee agreed to conduct additional test series to further pursue this.

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40 Binks Manufacturing and Graco Inc.

9.8.2 Objectives

To determine if the gun ranking in terms of transfer efficiency was preserved, especially as it concerned the air-assisted airless gun.

To establish why the transfer efficiency result for air-assisted airless in the previous sub-tasks were so much lower than would have been expected from real world experience.

9.8.3 Methodology

This series of tests required two transfer efficiency tests to be conducted with each of the four guns; HVLP, electrostatic, conventional air atomizing, and air-assisted airless.

The protocol was followed as before, but the following deviations were made:

> The entire spray envelope was contained within the face of a panel. This meant that the vertical, top and bottom edges of the envelope were approximately 3" within the outer edges of the panel.
>
> The protocol calls for each spray gun to make 5 strokes and one pass on the 16" x 20" panels. For the large panels, this was increased to 6 strokes and one pass for all guns. Only if necessary to achieve an acceptable appearance as defined in the Protocol was the technician allowed to apply the coating in two passes.

9.8.4 Results

The results are summarized in Table 17. Transfer efficiency of the large panels are compared with those for the medium panels which had been evaluated earlier in Task #3. This is illustrated in Figure 12.

Details of the large panel tests are recorded in Table 18.

All of the transfer efficiency values for the large panel tests increased when compared with those achieved when medium panels were used. This was no surprise, because unlike the medium panels tests the entire spray envelope was contained within the face of the large panel.

The gun rankings remained essentially the same, with HVLP and electrostatic being the most efficient, (refer to Columns 2 and 3 in Table 17). The transfer efficiency values for these two guns were also similar. The next in ranking was the conventional gun, apparently followed by the air-assisted[41] gun.

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41 It was later shown that the air pressure used to set the airless gun in all of Task #3 was too high. The air pressure was approximately 80 psig, whereas it should have been approximately 20 psig. The lowering of the air pressure would have increased the transfer efficiency values considerably, as was later shown in Task #4, 2nd. Set.

9.8.5 Conclusions

The large panel tests demonstrated that the gun ranking remained the same regardless of the panel size, or the incorporation of the entire spray envelope within the face of the panels.

9.9 Statistics for Task #3

After the results of Task #3 had been finalized, they were sent to the statistician for his review. His report of September 21, 1995 can be found in Appendix 2.

In summary, the statistician suggested that when a new spray gun is tested, the protocol should require that the gun be evaluated at three gun-target distances. One of these will be a distance for which the gun has shown itself to be well suited. The other two will be a distance two inches shorter and a distance two inches longer than the middle value. In addition, three test sets will be run per target distance, and the spray gun will be taken apart for cleaning after each test. The air and fluid pressure settings will be reset as if the gun had not been previously tested. Therefore, a total of nine test sets will be conducted for each spray gun which is submitted for certification testing.

It was suggested that the results might be more valuable if the test sets and gun-target distances could be randomly chosen, as shown below, but the time and cost to perform a spray gun certification on this basis might become prohibitive.

Example of Testing Program:

Test set #1	*10" gun-target distance*
Test set #2	*8 "*
Test set #3	*12"*
Test set #4	*8"*
Test set #5	*10"*
And so on.	

Throughout the project six medium-sized panels were used within a test set. Repeatability of results between panels was so good that the statistician questioned the need for six panels, and suggested that the number can be reduced to four. However, it was decided to retain six panels per set in the protocol, because occasionally one or two panels are accidentally dropped from the coating rack or are partially damaged as the rack passes through the curing oven. Such accidents will still allow the technicians to obtain meaningful results from the remaining four panels. Moreover, the time taken to coat six panels rather than four is insignificantly longer.

Unlike the results in Task #2, no outliers were reported in Task #3.

9.10 Dry Film Thickness

A thorough analysis of dry film thickness measurements across the length and width of the medium panels was too complicated to be included into the scope of this project, but transfer efficiency results in Task #3 demonstrated that despite film thickness variations it was possible to achieve the desired repeatability[42] between tests. In finalizing the Test Protocol, it was decided to specify an average film thickness range (1.0 - 1.5 mils[43]). This range was chosen because all of the spray guns were able to achieve an acceptable finish within these limits. Therefore, the protocol now requires the measurement of dry film thickness, but this is for purposes of quality control rather than to make a correction to TE_m.

Before the testing program could commence it was necessary to set basic criteria that would not be negotiable. The most important of these was the appearance of the coating finish. It was agreed that coated panels would only be acceptable if the finish met the expectations of the general metals industry. Each industry has its own standards. The Automotive Industry generally has the highest finishing standards, whereas building steel supplies is at the low end, and the general metals industry[44] is somewhere in the middle. Moreover, this industry probably accounts for the largest share of the metals fabrication market.

To be acceptable, five observers at the CTAC laboratory, all of whom had experience in the Paints and Coatings industry, were asked to evaluate several coated panels that had appearances ranging from clearly unacceptable to excellent. The observers selected those that they subjectively believed would pass quality control in most metals fabrication companies. Three tests, gloss, Distinctness of Image (DOI) and coating dry film thickness were then conducted to determine what the values were for each of the "acceptable" panels. It was found that all had a gloss >85% when measured on a 60° specular gloss meter. Distinctness of Image was > 40 measured on a DOI meter[45], and dry film thickness was in the range 1.0 - 1.5 mils. Table 16 provides the results of the measurements which were taken from eight coated panels. There was agreement among all five observers that panels ABA-3, ABH-6, ABI-3 and ABJ-6 had too poor a quality visual appearance to be acceptable in most painting operations. Equally, there was agreement that the appearance of panels ABO-4, ABP-1, ABS-4 and ABT-2 would pass in most commercial operations.

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42 COV < 2.5%

43 Note that 1 mil = 0.001" = 0.0254 mm

44 This industry fabricates items such as steel cabinets, tool boxes, gas cylinders, hand and machine tools, sports equipment, agricultural harvesters, street sweepers, etc.

45 There is no standard method, such as ASTM for measuring DOI; therefore, a test method and scoring procedure was written for the protocol.

9.11 Summary of Conclusions for Task #3

The most important conclusions resulting from this task are as follows:

The protocol meets the goals of the project in that it is possible to get acceptable repeatability, where COV 2.5, when medium panels are used.

Repeatability for small panels can be <2.5%; however, one cannot have any assurance that this will be so as it makes the protocol more vulnerable to experimental errors. Therefore, it is recommended that small panels not form part of the Test Protocol.

The Cardinal High Solids Polyester Baking Enamel was found to be overly sensitive to temperature changes, as evidenced by changes in its viscosity with small fluctuations in temperature. For this reason, the coating was not adequately suitable.

The Cardinal High Solids Air Dry Enamel, Gray #4880-16440 can be used as a standard coating when conducting transfer efficiency tests.

Testing in this task has shown that it is not always possible to implement exactly the same spray gun set-up parameters, unless one is willing to compromise appearance. Therefore, the protocol will allow the spray gun vendor for whom a transfer efficiency test might be conducted, to have some input. For the most part the vendor can suggest the air and fluid pressure settings, and it may also be necessary to have some flexibility with regard to the gun speed of travel, number of strokes and number of passes[46].

The Test Protocol can be used with water-borne coatings, but additional work will be required to establish the most suitable water-borne coating and appropriate spray gun parameters.

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46 The number of passes has little influence of transfer efficiency, whereas the number of strokes has a significant influence.

9.12 Recommendations from Task #3

It was recommended that the project now proceed to Task #4. This required that two independent technicians, representing two companies, neither of whom had actively participated in the protocol development, would evaluate the protocol for intra-laboratory repeatability.

Since the water-borne coatings market is rapidly gaining acceptance in the coatings industry, it is suggested that more work be done to include this type of technology in the Test Protocol.

10 Task #4 - 1st Test Series

10.1 Objectives

Two technicians[47] from a spray equipment company were asked to repeat some of the Task #3 tests in the CTAC laboratory by exactly following the Test Protocol as refined after completing Task #3.

The objectives were:

to determine if the protocol followed a logical sequence

to identify any omissions or incorrect procedures

to recommend improvements that would make the protocol easier to follow, provide more repeatable results, and economize on testing time and materials

validate the test results by comparing those from Task #3 (work done by CTAC technicians) with those of Task #4, 1st Test Series.

10.2 Methodology

A test plan for Task #4 was written and sent together with the protocol to the technicians. They were to study the sequence of events that were to take place before commencing their tests.

They were discouraged from following their own instincts, and were asked to make a note of any corrections or comments that would clarify and improve the protocol.

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47 Binks Manufacturing volunteered to provide two technicians who were well versed with the use of spray guns.

Representatives from RJA and CTAC monitored the ability of the technicians to correctly interpret the protocol. They answered questions only when required. Some of the technicians' questions related to logistics of the CTAC facility and had nothing to do with the protocol per se. If they were confused about an instruction in the protocol, they were given an explanation, and the protocol was promptly annotated so that a clearer explanation could be provided.

After familiarizing themselves with the protocol and test plan the technicians performed the following tasks:

- familiarized themselves with the equipment and fluid delivery system
- prepared the coating and equipment for the first series of tests
- weighed the test panels
- determined the coating viscosity
- calibrated the fluid flow meter
- determined the coating density and percent weight solids
- evaluated the transfer efficiency of three spray gun types; HVLP, electrostatic conventional air atomizing and air-assisted airless.
- reviewed the results and made recommendations for improvements to the protocol.

The technicians were not required to program the robot because any laboratory which might want to use the protocol will in any case need to train its staff to operate the robot and instrumentation. In addition, (a) training will be specific to the make and design of the equipment used, and (b) the protocol provides the specifications to which the robot must be set so that a technician who is able to program the robot will be able to easily mimic the CTAC spraying conditions.

After the technicians had performed a laboratory calibration once[48], they were not required to go through the procedure again. Instead, a CTAC technician performed these routine tasks. The rationale was (a) testing time was limited and had to be completed within a working week, (b) the main reason for having the technicians

48 Calibrations included here were for obtaining the viscosity/temperature characteristics of the coating, measuring coating density and percent weight solids, calibrating the fluid flow meter. In addition, they only once followed the procedures for confirming that the coated panels had an "acceptable appearance".

go through the process once, was to ensure that the protocol was readable and complete.

10.3 Results

A summary of the results are provided in Table 19.

Details of tests conducted in Task #4 - 1st Test Series are provided in Table 20[49].

10.4 Discussion of Results

From Table 19 and Figure 13 it can be seen that in Task #3 the HVLP gun performed better than the electrostatic gun, (54.77% vs 50.05%) which in turn performed better than the air-assisted airless gun (31.76%). The results for Task #4 - 1st Test Series demonstrated the same ranking, but the transfer efficiency values were higher for the HVLP gun (66.14%) and electrostatic gun (59.12%), but was essentially the same for the air-assisted airless gun, (29.68%).

In reviewing the results it must be mentioned that when the air-assisted airless gun was tested in Task #3, the technician set the **air pressure** too high. With these guns the air pressure is only intended to shape the fan, but not atomize the paint. Pressures of approximately 20 psig usually suffice. The technician, however, set the pressure as high as 86 psig, thus not only shaping the fan, but also atomizing the paint. Therefore, in Table 19 the low transfer efficiency reported for the air-assisted airless gun (31.76%) in the Task #3 column is unrealistically low. This error was only noticed when the tests were being conducted by the technicians in Task #4. To provide valid comparisons they conducted two sets of tests with the air-assisted airless gun; one in which the air pressure was set at approximately 80 psig, (transfer efficiency 29.68%) the other in which the pressure was set to 20 psig, (transfer efficiency 46.87%). The results show a marked increase when the air pressure was appropriately set.

The electrostatic spray gun used in this project was Graco's Pro 3500 SC. As was stated earlier the electrostatic charge is generated by a turbine which is driven by the atomizing air passing through the gun. According to Graco[50], the tip-voltage remains constant only when the atomizing pressure is above 40 psig. In the tests conducted in Task #3 the air pressure was 30 psig and in Task #4 - 1st. Test Series it was 20 psig. This would indicate that the tip-voltage might have been different in the two tests. Because this finding was made after the tests had been

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49 Table 19 also provides comparative results for Task #4 - 2nd Test Series, and will be discussed in the section dealing with the Section 11.

50 Telephone discussion with Glen Muir of Graco.

concluded, it was not possible to verify this experimentally.

10.5 Conclusions

The results demonstrated consistent gun ranking, even though the transfer efficiency values had increased.

When the air pressure to the air-assisted airless was lowered to the vendor-recommended 20 psig the transfer efficiency values were in line with real-world expectations for this gun type.

The technicians found that the current data forms onto which they were required to manually enter data were cumbersome, and they suggested that the forms be revised to be more user-friendly.

They found that the hydraulic pump system was somewhat cumbersome due to the need to regularly calibrate the fluid flow meter. It was suggested that if a pressure pot system were used to replace the hydraulic pump when testing **low pressure** guns, one could altogether eliminate the fluid flow meter and perform the coating usage measurements by directly weighing the pressure pot before and after applying coating to each panel, respectively. This would eliminate the need for the fluid flow meter. In addition, the measurement of coating density could be eliminated, as this procedure is carried out solely to calibrate the fluid flow meter.

They observed that on account of friction losses the hydraulic pump tends to heat up the coating as it passes through, thus elevating the coating temperature from ambient of ~75°F to ~84°F. It was difficult to maintain a truly constant temperature at the gun, because this was dependant on the extent to which the coating was being recirculated through the pump.

The hydraulic pump system coating was recirculated to a covered[51], but not sealed reservoir, and a small amount of solvent could constantly evaporate. To maintain a constant viscosity MPK solvent was added when appropriate. Consequently, it was postulated that the solvent balance in the coating was constantly changing. With a pressure pot scenario, the fluid delivery system is completely closed, and no solvent should be able to escape. Thus, one can expect the solvent balance in the entire fluid line to remain constant.

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51 The setup required that a large syphon tube lead from the reservoir to the hydraulic pump. To accomplish this the tube was lowered into the 5-gallon pail.

If a pressure pot were used coating temperature could be expected to remain at ambient throughout the testing period, because there are no friction losses as with the hydraulic pump.

The pressure pot alternative is less costly, requires fewer valves and fittings, and does not require a fluid flow meter to measure coating usage.

The technicians realized that with the pressure pot system only low pressure spray guns can be evaluated. Therefore, when testing a high pressure spray gun, such as air-assisted airless, the fluid delivery system must be changed to the hydraulic pump and accessories. This poses a problem when performing a comparison between high and low pressure guns, such as air-assisted airless vs HVLP. If only the hydraulic pump is employed, the same fluid delivery system can be used for both gun types.

10.6 Recommendations

It was suggested that a second series of tests be conducted to determine if a pressure pot system used with low pressure guns would duplicate the results obtained by using the hydraulic pump.

The data spreadsheets were to be completely revamped to eliminate redundancy and provide for more user friendly data entry forms, a copy of which can be found in Appendix 5.

11 Task #4 - 2nd Test Series

11.1 Objectives

To confirm that the pressure pot system can be used in place of the hydraulic pump when testing low pressure spray guns.

To evaluate the new data entry forms and spreadsheets.

11.2 Methodology

The same two technicians once again volunteered to repeat the test sequence. Prior to commencing, they modified the fluid delivery system as shown in Figure 14.

A two-gallon pressure pot was placed directly onto an electronic balance capable of an accuracy of ± 0.5 g. The capacity of the balance was 20 Kg.

A Plexiglass™ box was specially made to be placed over the pressure pot and scale to prevent drafts from affecting the weight readings.

Flexible fluid and air hoses connected the pressure pot directly to the spray gun, thus avoiding the need for a fluid flow meter. For the sake of convenience, hose fittings were fixed into the top of the Plexiglass™ box to allow the two hoses to connect first from the pressure pot to the fittings, and then from the fittings to the spray gun. Low pressure air gages and fluid pressure gages have a 100 psig range and an accuracy of ± 1 psig. The gages were installed in their respective air and fluid lines between the box and the gun.

The newly designed data entry forms and spreadsheets were used.

In Task #4 - 2nd Test Series, the technicians tested the air-assisted airless gun with the air pressure set at 20 psig. They did not repeat the test at 80 psig.

The hydraulic pump was used only for the air-assisted airless gun, while the pressure pot was used to feed coating to the low pressure guns (HVLP and electrostatic).

When using the pressure pot the coating was at ambient temperature, but when the hydraulic pump was used, the coating was recirculated as in Task #4 - 1st. Test Series.

The technicians noticed that by the end of Task #4 - 1st Test Series, the orifice of the air-assisted airless gun produced an uneven pattern. Therefore, a new orifice was inserted into the gun for the 2nd Test Series.

11.3 Results

A summary of the results is presented in Table 19.

Details of the tests are provided in Table 21.

In this test series, there was a dramatic reduction in the transfer efficiency value for the HVLP spray gun. When tested with the hydraulic pump system in the 1st Test Series the result was 66.14%, but when the pressure pot was used the transfer efficiency value dropped to 53.87%. For this gun one might conclude that the hydraulic pump setup and the pressure pot setup did not provide equivalent transfer efficiency results.

The electrostatic gun maintained essentially the same transfer efficiency value as for the 1st Test Series; namely 59.52%. Thus one might conclude that for this spray gun the hydraulic system and pressure pot system yielded essentially the same results.

The air-assisted airless gun, which was evaluated with the hydraulic pump system similar to the setup in the 1st Test Series, yielded a relatively similar value; namely 52.61% versus 46.87%.

11.4 Discussion of Results

Extensive discussions took place between the participants in the project to try to explain the dramatic change in the transfer efficiency value for the HVLP gun, but no convincing answer could be found. A repeat of the test series would have been required to determine if the reversal was valid, or due to an unapparent change in one or more of the testing parameters. Since the project could not be further extended it was not possible to repeat these tests.

The protocol requires that the coating be reduced to a viscosity of 16±1 seconds as measured with a Zahn #3 viscosity cup. The technicians found that they required more solvent to reduce the coating to this viscosity when using the pressure pot (at ~75°F) than to thin the coating when using the hydraulic pump (at ~84°F)[52]. This change in conditions would have affected the transfer efficiency results. From Table 22 on can see that the electrostatic properties can change dramatically as the solvent balance in the coating changes. This can be expected to affect TE_m when electrostatic guns are used. This could also have had an effect on the results of Task #4, 2nd test series. In addition, the increase in solvent used resulted in a VOC content in the range 453.56 - 467.22 g/L. These values are greater than the regulated 420 g/L.

The CTAC laboratory was not controlled for constant humidity. It is possible that humidity changes which occurred during Task #4 (51-62% during the 1st Set, and 31% during the 2nd Set) had an affect on the transfer efficiency results of the electrostatic gun. No data was available to better understand the gun's sensitivity to humidity.

11.5 Conclusions

For the HVLP gun the results for Task #4 - 1st Test Series were different from those of Task #4 - 2nd Series, demonstrating that for this gun the conditions between these two sets were sufficiently different to preclude the conclusion that the hydraulic pump setup and pressure pot setup were equivalent.

After completing the second test program, the results were studied and sent to the Advisory Committee for review.

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52 Coating viscosity is higher at lower temperatures, therefore the need for additional thinning.

A meeting of the Committee was convened via teleconference on March 18, 1996 to discuss the final recommendations for the Test Protocol. It was decided that since the hydraulic pump setup in Tasks #3 and Task #4 - 1st Test Series had produced consistent gun rankings, the pressure pot setup would not be included in the protocol until additional data was available to justify its inclusion.

The revised data forms which were used by the technicians in conducting Task #4 - 2nd Test Series, were said to be practical and acceptable. They have therefore been included in the protocol.

12 Task #5 - Inter-Laboratory Reproducibility

12.1 Objectives

This task was intended to validate the protocol in two additional laboratories using a portable spray fixture. However, at the end of Task #3, the Advisory Committee for this project decided to eliminate the task because a portable fixture having similar performance specifications to the CTAC setup would have been required. The cost would have been in excess of $50,000 and it was felt that the market for performing transfer efficiency tests is too small for a conventional analytical laboratory to justify such an expense. Moreover, such tests will most likely be conducted by spray gun vendors who will want to evaluate their spray guns. These companies generally have access to the sophisticated type of equipment, such as was used at CTAC.

13 Cost to Run a Transfer Efficiency Test

Based on the experiences encountered in this project it is possible to estimate the total time required to evaluate a subject, or canditate spray gun and compare it with standard gun which the SCAQMD selects for baseline purposes. The protocol requires that the standard gun be evaluated each time a subject gun is to be tested.

Following a few basic assumtions, provided in Table 23, the total cost to evalute a gun is $3,772 - $6,470. The following paragraphs explain the findings that allowed for to bottom-line costs to be calculated.

The two technicians who conducted the transfer efficiency tests were asked to keep track of the time it took to prepare for and carry out the tests. After they had gone through the learning curve and were thoroughly familiar with the procedures, Table 24 was compiled. This provides a detailed account of the time taken to conduct all of the steps necessary to evaluate a single spray gun at three gun-target distances (GTD). Altogether nine tests sets, each comprising 6 medium-sized panels are required; three at the first GTD, three at a distance 2" closer, and three at a distance 2" further. For most guns the distances are 10", 8" and 12".

Using Table 24 as a guide, it is suggested that a minimum of 16 labor hours, split between two technicians should be budgeted. When properly acquainted with the procedure, a single gun can be evaluated within an 8 hour shift. This assumes that there are no glitches or equipment failures. If everything goes according to plan it is possible to evaluate three or possibly four guns in one working week.

In addition to the time required to conduct the tests, approximately 40 hours labor are required prior to commencing the testing program to do the following:

- review the Transfer Efficiency Test Protocol
- procure the coating to be used
- insure cleanliness of lab and test equipment
- if necessary calibrate the laboratory instruments, such as the gloss meter, dry film thickness gage, scales, etc.[53]
- procure panels, unless there are sufficient in inventory
- already used panels can be grit or shot blasted to remove old cured coating
- confirm that computer system and robot are in good working order
- clean out the fluid delivery system and if necessary disassemble and clean the hydraulic pump
- disassemble the fluid flow meter and thoroughly clean it
- confirm that the in-line heater works and can maintain the coating temperature at ±3°F.
- procure the spray guns that will be used, and insure that the orifices or tips will provide a 10" fan pattern at a gun-target distance of 10". This might require preliminary spray tests, unless the vendor can confirm that the correct orifices are being used.
- print out the necessary data entry forms, insuring that sufficient copies are made

Based on the work performed in this research project it was evident that after the tests had been conducted one technician required approximately 8 hours **per gun** to complete data entry and print the data forms.

At least 8-16 hours were necessary to clean up the laboratory and equipment at the conclusion of a testing program.

Labor cost to perform a transfer efficiency test program can be calculated based on the hourly rate of the technicians.

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53 The Test Protocol provides a full list of the equipment required to perform a transfer efficiency test, and guidelines are given as to how often they should be calibrated.

At least 36 medium-sized panels are required to evaluate one spray gun. Allowance must also be made for scrap panels that will be used to set up the gun, adjust for fan pattern, leading and trailing edges, pressure settings, etc. Unless the technicians are experienced at this, it is suggested that one should budget for at least 10 additional panels per gun. However, most can be reused either by washing with solvent (if the coating is still wet), or by blast cleaning. Typical cost for a new 16" x 20" x 20 gage panel is $1.50 - $2.00.

The current cost of the coating is approximately $43.00 per gallon, packaged in gallon containers, or $34.00 per gallon packaged in a 5-gallon pail, plus tax and shipping if applicable. One can expect to use approximately 0.25 - 0.50 gallon to fill the fluid system (depending on the length of the fluid hose and size of the pump), and approximately 0.25 - 0.50 gallons to evaluate a single gun.

14 Conclusions for Transfer Efficiency Project

- The Transfer Efficiency Test Protocol demonstrated that when three transfer efficiency tests are conducted using the same spray gun, coating, laboratory and technician it is possible to get repeatable results, with COV ≤2.5%.
- The protocol can be used for both low- and high- pressure spray guns.
- It is expected that the protocol can be used to evaluate future designs of spray guns.
- When different spray gun types are evaluated under similar conditions, the protocol can provide a ranking of the guns that corresponds with real world experience. This was demonstrated in most of the tables, but specifically in Table 19.
- The protocol was sufficiently sensitive to differentiate between guns of the same type but different design. Refer to Table 12, 13 and 14 and Figure 10. More tests would be required to demonstrate this statistically, but from **visual** evaluation of the graphs, it appears so.
- If more than one technician conducts a test using the same guns and coating, the relative ranking of TE_m is preserved. However the Mean TE_m for each of the tests might be different.
- Preliminary results showed that the Test Protocol can be used to evaluate relative gun rankings when a water-borne coating is used; however, more research is required to evaluate the parameters that would need to be standardized.

- Transfer efficiency is strongly affected by panel size. This can be seen by comparing the transfer efficiency values in Tables 9, 10 and 11.

- Transfer efficiency is sensitive to coating rheology; namely the coating resin type, and coating viscosity. This was demonstrated by the inability to work with the high solids polyester baking enamel in comparison to the ease of working with the air dry enamel. In addition, small fluctuations of temperature[54] affected the viscosity of the baking enamel more than they affected the air dry enamel.

- Tables 9 and 10 and Figure 8 demonstrated the sensitivity of transfer efficiency to gun-target distance. The closer the gun-target distance the higher TE_m.

- The project was not successful in providing for reasonably inexpensive portable equipment to be used, so that any analytical laboratory can conduct the tests. On the contrary, the protocol requires sophisticated equipment and should be conducted by a coatings laboratory, such as at CTAC or similar laboratories[55] where a reciprocator or robot is available. Most spray equipment companies already have most, if not all of such equipment.

- The protocol has not been evaluated with electrostatic bells and discs[56], and it is possible that modifications would first need to be made before such guns could be evaluated. More research would be required before such modifications could be made.

- The tests showed that dry film thickness varied when measured at different locations on a coated panel. The variance was affected by the spray gun design. It appeared that the HVLP gun used in this project yielded greater variation than the other guns.

15 Recommendations for Future Work

- Additional tests will need to be conducted before the pressure pot alternative can be demonstrated to be equivalent to the hydraulic pump set-up.

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54 Fluctuations in temperature have a direct impact on a coating's viscosity, which in turn affects transfer efficiency.

55 A few laboratories in the mid-west and on the east coast already have the type of equipment required to perform the tests.

56 These are high speed rotary devices that atomize coatings by centrifugal force rather than by air and fluid pressures.

the paint. Although this solvent was used throughout the project (since Task #2), it is possible that MPK is not the most appropriate for this coating. Ketones have polar properties and are expected to have an effect on transfer efficiency because of improved electrostatic "wrap". Additional testing should be considered using different solvents or solvent blends, to establish the sensitivity of electrostatic guns to these different formulations.

- The atomizing pressures for spray guns must be within the range recommended by the gun vendors.

- If a pressure pot set-up is to be demonstrated again in the future, it will be important to re-establish one or more of the following:

  the most appropriate coating viscosity at which all guns will be expected to atomize the coating, ensuring that when the coating is reduced to that viscosity, the VOC content will not exceed the regulatory limit.

  a temperature ±3°F at which the coating must be maintained throughout testing.

- If the laboratory is not controlled for humidity, it will be necessary to conduct a sensitivity study in which electrostatic "wrap" is evaluated against changing ambient humidity.

- Any laboratory intending to conduct transfer efficiency evaluations must first study the air flow in their spray booth and ensure that it is laminar. It is expected that turbulent flow will affect the results for all guns. It seems likely that HVLP guns will suffer most, because the low energy of the paint particles projected toward the target may not adequately be able to overcome the turbulence in the spray booth air.

- If the protocol is to be used to evaluate spray guns with water-borne coatings, additional research will be required. The most important tasks that should be addressed concern the coating itself, which will need to be selected and characterized. Because water-borne coatings are inherently thixotropic[57] it will be necessary to perform several sensitivity studies while using different spray guns. Apparent application viscosity will be affected by the atomizing pressures, and this will be most evident when high pressure guns, such as air-assisted airless and airless are evaluated.

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57 Viscosity is affected by shear rate. Typically, viscosity decreases as shear rate increases.

TABLES

Table 1
Parameters which Affect Transfer Efficiency

Panel size

<u>Coating related parameters:</u>

Coating rheology:
- coating resin
- coating ingredients

Coating viscosity
- coating temperature
- concentration of solvent blends in formulation
- composition of solvent blend

<u>Spray gun related parameters</u>:

Gun-target distance[58]
Spray gun type[59]
Spray gun design
Spray gun orifice diameter
Spray fan size
Speed of gun travel
Width of leading and trailing edges
Pressure of atomizing air (if applicable[60])
Pressure of fluid delivery

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58 Gun-target distance is the distance between the cap of the spray gun and the steel panel.

59 For the differentiation between the "spray gun type" and the "spray gun design" refer to the Glossary of Terms.

60 Airless and air-assisted airless spray guns do not require air to atomize the paint particles. In the case of the air-assisted airless gun, air is used to shape the fan pattern. All other guns require air for atomization.

Table 1 (Cont)
Parameters which Affect Transfer Efficiency

For electrostatic guns, all of the above, plus:

Gun tip voltage
Need for target panel to be properly grounded
Coating conductivity (or resistivity)
- Concentration of solvents
- Polarity of ingredients, particularly solvents
- Ambient humidity[61]

61 It is believed that the efficiency of electrostatic "wrap" is affected by either high (>90%) or low (<20%) ambient relative humidity. In the middle humidity range wrap apparently does not change significantly. These relationships were not tested in this project. Source: Glen Muir, Graco, private communication. For a definition of" wrap" see Glossary of Terms.

TABLE 2
SUMMARY RESULTS
FOR SMALL SIZED PANELS USING HVLP GUN
The Flow Measurement for Each Panel on Rack was Measured

1	2	3	4	5	6	7	8	9	10	11	12
JOB NUMBER	DATE	PANEL ID	MEAN WT. COATING DEPOSITED (g)	MEAN WT. COATING DEPOSITED STDEV	MEAN WT. COATING DEPOSITED COV %	MEAN WT. SOLID COATING USED (g)	MEAN WT. SOLID COATING USED STDEV	MEAN WT. SOLID COATING USED COV %	MEAN TE(m) (%)	MEAN TE(m) STDEV	TE(m) COV %
1004	7/27/94	AB	0.790	0.107	13.5	2.137	0.194	9.078	37.12	5.16	13.9
1004	7/27/94	AC	0.754	0.120	15.9	1.928	0.287	14.886	40.46	11.55	28.5
MEAN			0.772			2.033			38.792		
1006	8/3/94	AD	0.614	0.084	13.7	2.603	0.125	4.802	23.60	3.14	13.3
1006	8/3/94	AE	0.658	0.301	45.7	2.233	0.316	14.151	29.77	13.08	43.9
1006	8/3/94	AF	0.674	0.218	32.3	2.552	0.230	9.013	26.97	10.52	39.0
MEAN			0.649			2.393			28.369		
1018	9/14/94	AX	0.656	0.070	10.7	1.388	0.191	13.761	47.97	7.58	15.8
1018	9/14/94	AY	1.021	0.095	9.3	1.988	0.201	10.111	51.71	6.01	11.6
MEAN			0.775			1.688			49.840		
1019	9//20/94	AZ	0.914	0.132	14.4	1.623	0.155	9.550	56.97	11.19	19.6
		MEAN	0.777			1.934			43.494		
		STD DEV	0.108			0.355			12.555		
		COV (%)	13.9			18.3			28.9		

TABLE 3
SUMMARY OF RESULTS
FOR TEST 1019 - SMALL PANELS
HVLP GUN

JOB NUMBER	PANEL REF. ID	PANEL ID	WT. SOLID COATING DEPOSITED (g)	WT. SOLID COATING USED (g)	TE(m) (%)
1019	AZ	1	0.876	1.862	47.05
1019	AZ	2	0.880	1.861	47.29
1019	AZ	3	1.068	1.613	66.21
1019	AZ	4	1.148	1.488	77.15
1019	AZ	5	0.768	1.613	47.61
1019	AZ	6	0.858	1.738	49.37
1019	AZ	7	0.960	1.489	64.47
1019	AZ	8	1.009	1.613	62.55
1019	AZ	9	0.710	1.613	44.02
1019	AZ	10	0.755	1.484	50.88
1019	AZ	11	0.947	1.742	54.36
1019	AZ	12	0.992	1.364	72.73
Mean			0.91	1.62	56.97
Std . Dev.			0.13	0.15	11.19
COV (%)			14.40	9.55	19.64

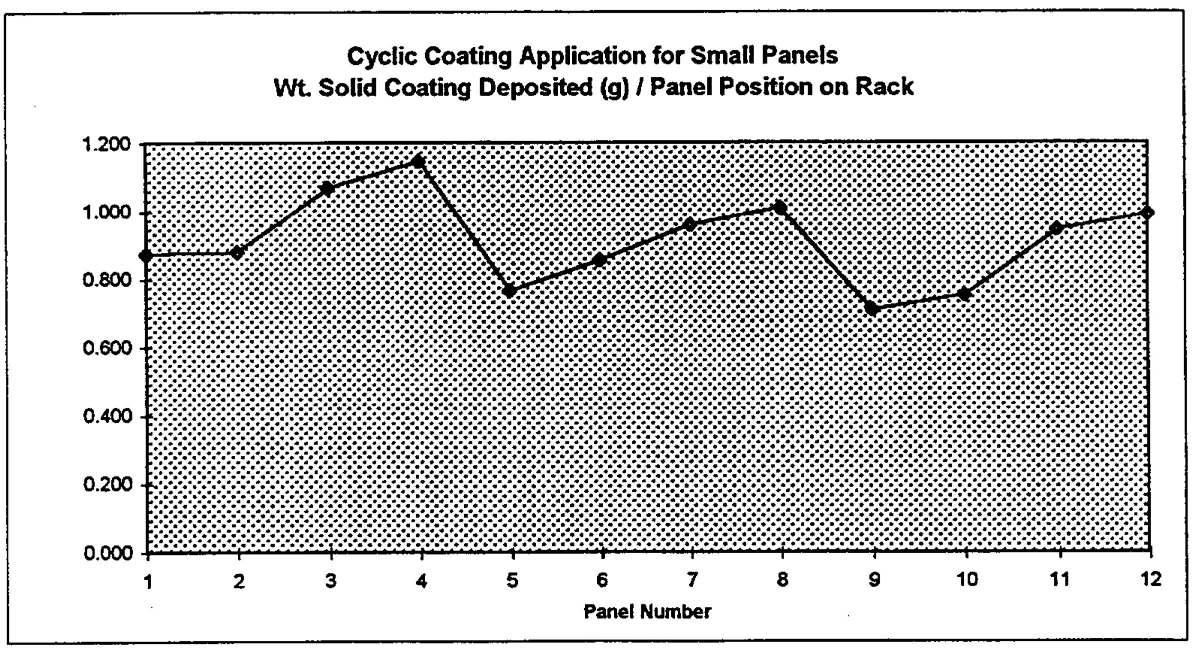


TABLE 4
SUMMARY OF RESULTS
FOR MEDIUM SIZED PANELS AND HVLP GUN

	1	2	3	4	5	6	7	8	9	10	11	12	13
	JOB NUMBER	DATE	PANEL SET	PANEL NUMBER PER SET	MEAN WT. COATING DEPOSITED (g)	MEAN WT. COATING DEPOSITED STDEV	MEAN WT. COATING DEPOSITED COV %	MEAN WT. SOLID COATING USED (g)	MEAN WT. SOLID COATING USED STDEV	MEAN WT. SOLID COATING USED COV (%)	MEAN TE(m) (%)	MEAN TE(m) STDEV	MEAN TE(m) COV %
1	1007	8/10/94	AG	6	14.933	0.956	6.4	19.673	0.225	1.144	75.90	4.71	6.2
2	1009	8/11//94	AH	6	14.817	0.719	4.9	18.918	0.514	2.717	78.32	3.04	3.9
3	1014	8/29/94	AN	8	14.050	0.489	3.5	17.792	0.228	1.281	78.97	2.67	3.4
4	1014	8/29/94	AO	8	13.100	0.632	4.8	17.613	0.389	2.209	74.38	3.10	4.2
5	MEANS				13.575			17.703			76.7		
6	1019	9//20/94	AS	8	11.767	0.476	4.0	15.075	0.358	2.375	78.04	2.16	2.8
7	1019	9//20/94	AT	8	11.417	0.431	3.8	14.454	0.420	2.906	78.98	1.82	2.3
8	MEANS				11.59	0.45	3.91	14.765	0.389	2.640	78.51		
9	1024	9/28/94	BE	8	11.117	0.371	3.3	14.493	0.133	0.918	76.70	2.16	2.8
10			MEAN		13.207			17.110			77.221		
11			STD DEV		1.781			2.374			1.139		
12			COV (%)		13.483			13.873			1.475		

Notes:

1. The Mean in Column 5, Row 10 is for the Means in Rows 1, 2, 5, 8 and 9.
2. The Standard Deviations in Column 5, Row 11 is for the Means in Rows 1, 2, 5, 8 and 9
3. The COV (%) in Column 5, Row 12 = 1.781*100/13.207
4. The Mean, Standard Deviation and COV (%) in Column 8 and 11 , Rows 10, 11 and 12 are calculated in the same manner as Notes 1, 2, and 3 above.

TABLE 5
SUMMARY OF RESULTS
TEST RESULTS FOR MEDIUM SIZED PANELS AND ELECTROSTATIC GUN

1	2	3	4	5	6	7	8	9	10	11	12	13
TEST	DATE	PANEL SET	PANEL SIZE	MEAN WT. COATING DEPOSITED (g)	MEAN WT. COATING DEPOSITED STDEV	MEAN WT. COATING DEPOSITED COV %	MEAN WT. SOLID COATING USED (g)	MEAN WT. SOLID COATING USED STDV	MEAN WT. SOLID COATING USED COV (%)	MEAN TE(m) (%)	MEAN TE(m) STDV	MEAN TE(m) COV %
1025	10/5/94	BF	8	10.717	0.194	1.8	14.814	0.266	1.796	72.36	1.67	2.3
1026	TEST ABORTED											
1026	10/6/94	BH	8	12.733	0.493	3.9	16.659	0.062	0.372	76.44	2.94	3.8
1027	10/7/94	BI	8	11.65	1.194	10.2	15.531	1.445	9.304	75.04	4.03	5.4
		MEAN		11.700			15.668			75.736		
		STD DEV		1.009			0.930			0.991		
		COV (%)		8.623			5.936			1.308		

TABLE 6
SUMMARY OF RESULTS
FOR MEDIUM SIZED PANELS
AND AIR-ASSISTED AIRLESS

1	2	3	4	5	6	7	8	9	10	11	12	13
JOB NUMBER	DATE	PANEL SET	NUMBER OF PANELS PER SET	MEAN WT. COATING DEPOSITED (g)	MEAN WT. COATING DEPOSITED STDEV	MEAN WT. COATING DEPOSITED COV %	MEAN WT. SOLID COATING USED (g)	MEAN WT. SOLID COATING USED STDEV	MEAN WT. SOLID COATING USED COV (%)	MEAN TE(m) (%)	MEAN TE(m) STDEV	MEAN TE(m) COV %
1029	10/20/94	BJ	8	7.300	0.200	2.8	16.100	0.000	0.000	45.00	1.30	2.8
1030	10/21/94	BK	8	6.500	0.100	1.8	14.800	0.400	2.703	43.70	1.60	3.6
1031	10/21/94	BL	8	6.500	0.300	4.4	14.800	0.400	2.500	43.90	2.20	5.1
1032	11/1/94	BM	8	19.300	0.400	2.1	39.800	1.000	2.513	48.40	1.10	2.3
1033	11/2/94	BN		20.800	1.000	4.8	39.6	4.300	10.8	52.80	4.50	8.5
		MEAN		20.050			39.700			50.600		
		STD DEV		N/A			N/A			N/A		
		COV (%)		N/A			N/A			N/A		

Notes:

1. The tests which are shaded were not carried out with satisfactory pressure settings. Only Job Numbers 1032 and 1033 should be considered.
2. Standard deviation and Coefficient of Variance are not relevant for two measurements

TABLE 7

RESULTS OF TESTS TO EVALUATE REPEATABILITY OF ROBOT/SPRAY GUN USING SMALL PANELS

Date	Job Number	Panel ID	Gun Type	Gun-Target Distance (inches)	Fan Size (inches)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)	Strokes	Passes	Gun Speed (mm/sec)
1/30/95	3001	AAB	HVLP 1	10	6	0.80	0.00	5.41	6.30	0.30	4.08	13.26	0.37	2.79	1	2	300

TABLE 8
RESULTS OF TESTS TO EVALUATE COATING RHEOLOGY USING MEDIUM PANELS

Date	Job Number	Panel ID	Gun Type	Gun-Target Distance (inches)	Fan Size (inches)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)	Strokes	Passes	Gun Speed (mm/sec)
2/23/95	3002	AAC	HVLP1	10	6	10.60	0.20	2.10	20.20	0.50	2.70	52.61	0.85	1.62	5	1	250
2/23/95	3002	AAD	HVLP1	10	6	10.20	0.40	4.30	19.40	0.60	3.40	52.61	0.90	1.70	5	1	250
2/24/95	3003	AAE	HVLP1	10	6	10.10	0.20	1.90	18.90	0.50	2.50	53.23	0.86	1.62	5	1	250
						MEAN	0.27		19.50			52.82					
						STDEV	0.12		0.66			0.36					
						COV (%)	43.30		3.36			0.68					
3/3/95	3004	AAF	CONV	10	10	10.90	0.71	6.51	20.24	1.05	5.20	53.83	0.93	1.73	5	2	250
3/27/95	3006	AAG	ELEC	10	6	6.40	0.10	2.10	13.40	0.20	1.40	47.79	0.98	2.04	6	1	400
3/29/95	3007	AAH	AAA	10	8	11.00	0.10	1.30	30.30	0.20	0.80	36.30	0.45	1.24	5	1	325

TABLE 9
RESULTS OF TESTS
TO EVALUATE GUN-TARGET DISTANCE
USING MEDIUM-SIZED PANELS
AIR-ASSISTED AIRLESS AND CONVENTIONAL GUNS

Date	Job Number	Panel ID	Gun Type	Gun-Target Distance (inches)	Fan Size (inches)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)	Strokes	Passes	Gun Speed (mm/sec)
3/29/95	3007	AAH	AAA	10	8	11.00	0.10	1.30	30.30	0.20	0.80	36.30	0.45	1.24	5	1	325
4/5/95	3008	AAI	AAA	10	10	7.10	0.10	2.10	26.10	0.10	0.50	27.21	0.45	1.65	3	2	508
					MEAN	9.05			28.20			31.76					
4/5/95	3009	AAJ	AAA	8	10	7.70	0.10	1.30	26.20	0.20	0.76	29.54	0.58	1.97	3	2	508
4/5/95	3010	AAK	AAA	8	10	7.80	0.20	2.00	26.30	0.20	0.60	29.75	0.53	1.78	3	2	508
4/5/95	3011	AAL	AAA	8	10	7.92	1.17	14.80	26.17	0.31	1.20	30.25	4.40	14.56	3	2	508
					MEAN	7.81			26.22			29.85					
					STDEV	0.11			0.07			0.36					
					COV (%)	1.41			0.26			1.22					
4/10/95	3012	AAM	AAA	12	10	15.00	0.10	0.67	52.00	0.40	0.77	28.90	0.20	0.71	3	2	200
4/10/95	3013	AAN	AAA	12	10	14.20	0.20	1.30	51.80	0.40	0.77	27.40	0.40	1.42	3	2	200
4/10/95	3014	AAO	AAA	12	10	14.80	0.40	2.50	52.10	0.30	0.58	28.40	0.80	2.84	3	2	200
					MEAN	14.67			51.97			28.23					
					STDEV	0.42			0.15			0.76					
					COV (%)	2.84			0.29			2.71					
4/19/95	3015	AAP	CONV	10	10	19.20	0.40	1.80	39.10	1.30	3.40	49.11	1.20	2.44	5	1	250
4/19/95	3015	AAQ	CONV	10	10	16.80	0.80	4.76	40.90	0.90	2.30	41.11	2.31	5.61	5	1	250
4/19/95	3015	AAR	CONV	10	10	16.50	0.39	2.35	39.20	0.60	1.44	42.20	0.90	2.13	5	1	250
					MEAN	17.50			39.73			44.14					
					STDEV	1.48			1.01			4.34					
					COV (%)	8.46			2.55			9.83					
4/24/95	3017	AAS	CONV	8	10	15.70	0.40	2.55	34.00	0.90	2.65	46.13	0.67	1.45	5	1	250
4/24/95	3017	AAT	CONV	8	10	15.50	0.20	1.29	32.20	0.50	1.55	48.00	0.40	0.83	5	1	250
4/24/95	3017	AAU	CONV	8	10	17.00	0.50	2.94	35.10	1.10	3.13	48.50	0.60	1.24	5	1	250
					MEAN	16.07			33.77			47.54					
					STDEV	0.81			1.46			1.25					
					COV (%)	5.07			4.34			2.63					
4/24/95	3018	AAV	CONV	12	10	15.00	0.40	2.67	36.50	0.70	1.92	41.10	0.45	1.09	5	1	250
4/24/95	3018	AAW	CONV	12	10	14.20	0.20	1.41	34.30	0.70	2.04	41.34	0.53	1.28	5	1	250
4/24/95	3018	AAX	CONV	12	10	14.60	0.26	1.77	34.90	0.70	2.14	41.70	0.52	1.25	5	1	250
					MEAN	14.60			35.23			41.38					
					STDEV	0.40			1.14			0.30					
					COV (%)	2.74			3.23			0.73					

N/A = NOT APPLICABLE
N/M = NOT MEASURED

TABLE 10
RESULTS OF TESTS TO EVALUATE GUN-TARGET DISTANCE USING MEDIUM-SIZED PANELS HVLP AND ELECTROSTATIC GUNS

Date	Job Number	Panel ID	Gun Type	Gun-Target Distance (Inches)	Fan Size (Inches)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)	Strokes	Passes	Gun Speed (mm/sec)
5/5/95	3019	ABA	HVLP1	10	10	14.80	0.20	1.35	27.50	0.20	0.73	53.74	0.72	1.34	5	1	250
5/5/95	3019	ABB	HVLP1	10	10	15.00	0.10	0.67	28.80	0.40	1.39	52.18	0.49	0.94	5	1	250
5/5/95	3019	ABC	HVLP1	10	10	15.10	0.37	2.48	29.00	0.60	2.20	52.04	0.78	1.50	5	1	250
					MEAN	14.97			28.43			52.65					
					STDEV	0.16			0.81			0.94					
					COV (%)	1.02			2.86			1.79					
5/8/95	3020	ABD	HVLP1	8	10	15.70	0.20	1.27	28.60	0.50	1.75	55.02	1.01	1.84	5	1	250
5/8/95	3020	ABE	HVLP1	8	10	15.30	0.20	1.40	27.30	0.40	1.30	55.84	0.52	0.93	5	1	250
5/8/95	3020	ABF	HVLP1	8	10	15.95	0.21	1.30	28.80	0.24	0.83	55.46	0.82	1.47	5	1	250
5/15/95	3024	ABK	HVLP1	8	10	15.00	0.40	2.50	28.30	0.20	0.80	53.02	1.67	3.14	5	1	250
					MEAN	15.42			28.13			54.77					
					STDEV	0.49			0.76			1.53					
					COV (%)	3.15			2.71			2.79					
5/11/95	3021	ABG	HVLP1	12	10	21.20	0.30	1.42	47.80	0.40	0.84	44.41	0.54	1.21	5	1	250
5/12/95	3022	ABH	HVLP1	12	10	15.10	0.30	1.80	31.20	0.60	1.80	48.33	1.29	2.68	5	1	250
5/12/95	3022	ABI	HVLP1	12	10	13.80	0.40	2.80	30.60	0.80	2.70	45.08	1.00	2.22	5	1	250
5/15/95	3023	ABJ	HVLP1	12	10	13.65	0.42	3.10	28.89	0.31	1.06	47.26	1.95	4.14	5	1	250
					MEAN	14.18			30.23			46.89					
					STDEV	0.80			1.20			1.66					
					COV (%)	5.62			3.97			3.53					
5/19/95	3025	ABL	ELEC	10	6	13.60	0.20	1.70	26.20	0.20	0.76	51.77	1.06	2.05	5	1	250
5/19/95	3025	ABM	ELEC	10	6	11.40	0.10	1.30	23.10	0.20	0.80	49.21	0.91	1.85	5	1	250
5/19/95	3025	ABN	ELEC	10	6	11.60	0.17	1.44	23.60	0.20	0.80	49.16	0.71	1.45	5	1	250
					MEAN	12.20			24.30			50.05					
					STDEV	1.22			1.66			1.49					
					COV (%)	9.97			6.85			2.98					
5/19/95	3026	ABO	ELEC	8	6	11.90	0.30	2.70	22.30	0.50	2.10	53.58	1.27	2.37	5	1	250
5/19/95	3026	ABP	ELEC	8	6	10.70	0.20	1.60	20.10	0.30	1.49	53.08	0.56	1.06	5	1	250
5/19/95	3026	ABQ	ELEC	8	6	10.30	0.20	2.30	19.30	0.30	1.55	53.02	1.05	1.98	5	1	250
					MEAN	10.97			20.67			53.23					
					STDEV	0.83			1.55			0.31					
					COV (%)	7.59			7.55			0.58					
5/24/95	3027	ABR	ELEC	12	6	11.10	0.30	2.90	23.70	0.60	2.53	47.05	0.32	0.68	5	1	250
5/24/95	3027	ABS	ELEC	12	6	12.90	0.20	1.90	26.90	0.40	1.49	48.10	0.78	1.63	5	1	250
5/24/95	3027	ABT	ELEC	12	6	12.00	0.30	2.50	24.90	0.20	1.00	48.24	0.76	1.57	5	1	250
					MEAN	12.00			25.17			47.80					
					STDEV	0.90			1.62			0.65					
					COV (%)	7.50			6.42			1.36					

N/A = NOT APPLICABLE
N/M = NOT MEASURED

SCAQMD\TASK#3\SUM-TSK3\SUM-TSK3.XLS\EXTRACTS

TABLE 11
RESULTS OF TESTS TO VERIFY GUN-TARGET DISTANCE USING SMALL PANELS

Date	Job Number	Panel ID	Gun Type	Gun-Target Distance (inches)	Fan Size (inches)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)	Strokes	Passes	Gun Speed (mm/sec)
5/31/95	3028	ACA	ELEC	10	6	0.88	0.02	2.71	5.73	0.12	2.11	15.39	0.43	2.76	1	2	300
6/7/95	3029	ACB	HVLP1	10	10@10	0.99	0.11	11.16	7.05	0.81	11.51	14.09	0.31	2.18	1	2	800
6/7/95	3030	ACC	CONV	10	10	0.66	0.02	3.58	6.01	0.30	4.99	11.04	0.60	5.45	1	2	250
6/14/95	3031	ACD	AAA	10	10	0.48	0.01	2.23	3.76	0.10	2.57	12.82	0.42	3.25	1	2	500

TABLE 12

Summary of Results
Evaluating Different Gun Manufacturers
Using Turbine and Pressure Regulated HVLP Guns
Medium Panels, Gun-Target Distance = 10 inches

Job #	Gun Design	Gun-Target Distance (inches)	Mean TE_m (%)
3032	Turbine #1	10	55.60
3035	Turbine #2	10	56.10
3019	HVLP #1	10	52.65
3038	HVLP #2	10	52.02
3041	HVLP #3	10	53.43

Notes:

1. The turbine operated guns use a high speed turbine to generate the high volume of air.
2. An HVLP gun as shown in the above table refers to a pressure-regulated gun in which a restrictor of some form, usually placed in the gun body, acts as a venturi that throttles the pressure to <10 psig.
3. The values for HVLP #1 is the mean of three separate test sets and were taken from Table 10.

TABLE 13
Summary of Results
Evaluating Different Gun Manufacturers
Using Turbine and Pressure Regulated HVLP Guns
Medium Panels, Gun-Target Distance = 8 inches

Job #	Gun Design	Gun-Target Distance (inches)	Mean TE_m (%)
3033	Turbine #1	8	59.23
3036	Turbine #2	8	59.64
3020/3024	HVLP #1	8	54.77
3039	HVLP #2	8	56.11
3042	HVLP #3	8	58.93

Notes:
1. The turbine operated guns use a high speed turbine to generate the high volume of air.
2. An HVLP gun as shown in the above table refers to a pressure-regulated gun in which a restrictor of some form, usually placed in the gun body, acts as a venturi that throttles the pressure to <10 psig.
3. The values for HVLP #1 is the mean of four separate test sets and were taken from Table 10.

TABLE 14

Summary of Results
Evaluating Different Gun Manufacturers
Using Turbine and Pressure Regulated HVLP Guns
Medium Panels, Gun-Target Distance = 12 inches

Job #	Gun Design	Gun-Target Distance (inches)	Mean TE_m (%)
3034	Turbine #1	12	54.29
3037	Turbine #2	12	54.52
3021/3022/3023	HVLP #1	12	46.89
3040	HVLP #2	12	46.76
3043	HVLP #3	12	50.04

Notes:

1. The turbine operated guns use a high speed turbine to generate the high volume of air.
2. An HVLP gun as shown in the above table refers to a pressure-regulated gun in which a restrictor of some form, usually placed in the gun body, acts as a venturi that throttles the pressure to <10 psig.
3. The values for HVLP #1 is the mean of four separate test sets and taken from Table 10.

TABLE 15
Results of Transfer Efficiency Tests
Using Trail Chemical Water-Borne
High Solids Baking Enamel
#08347-18815
Medium Sized Panels

Job #	Spray Gun Type	Gun-Target Distance (inches)	Mean TE_m (%)
3045	Conventional air atomizing	10	48.94
3045	Conventional air atomizing	10	47.32
3045	Conventional air atomizing	10	49.77
Grand Mean TE_m			**48.68**
3046	HVLP	8	61.50
3046	HVLP	8	63.90
3046	HVLP	8	62.97
Grand Mean TE_m			**62.79**
3047	Air-assisted airless	10	32.18
3047	Air-assisted airless	10	30.61
3047	Air-assisted airless	10	32.29
Grand Mean TE_m			**31.69**

Note 1: Each test set comprised six medium sized panels.

Note 2: The spray gun speed for Job #3045 and #3046 was only 75 mm/sec. This was considerably slower than for all other transfer efficiency tests conducted in this project. Most other tests were conducted at 250 mm/sec or higher.

Note 3: For tests #3045 and #3046 the panels were coated in 5 strokes and 1 pass. For Job #3047, the panels were coated in 3 strokes and 1 pass.

Note 4: The spray gun speed for Job #3047 was 250 mm/sec.

TABLE 16
Results of Measurable Parameters
for Determining "Acceptable Appearance"

Panel ID	Visual Pass/Fail	DOI [1]	Ave. 20° Gloss	Ave. 60° Gloss	Ave. DFT (mils) [2]
ABA-3	FAIL	25	85.7	96	1.35
ABH-6	FAIL	25	72.7	95	1.90
ABI-3	FAIL	15	77.3	94	1.55
ABJ-6	FAIL	<10	79.3	97	1.50
ABO-4	PASS	40	93.3	97	1.10
ABP-1	PASS	40	86.7	96	0.90
ABS-4	PASS	55	96.0	96	1.30
ABT-2	PASS	55	92.7	94	1.20

1. DOI = Distinctness of Image and the measurement is based on being able to recognize the the open letter "C" reflected from a light source onto the coating.

2. DFT = Dry film thickness of the coating measured in mils, where 1.0 mil = 0.001 inches.

Parameters for Acceptable Appearance
DOI ≥40
Gloss > 85 on a 60° gloss meter
DFT < 1.5 mils

Table 17

Comparison of Transfer Efficiency Values (TE_m) (%) for Medium and Large Panels

Spray Guns	Panels 16" x 20" Solvent-borne Coating	Large Panels 42" x 42" Solvent-borne Coating	Panels 16" x 20" Water-borne Coating[5]
HVLP	54.77[1]	81.1	62.79
Electrostatic	50.05[2]	84.4	N/M
Air-assisted airless	31.76[3]	63.0	31.69
Conventional	44.14[4]	71.0	48.68

Notes:

N/M Not measured
1. Taken from Table 10, 8" gun-target distance
2. Taken from Table 10, 10" gun-target distance
3. Taken from Table 9, 10" gun-target distance
4. Taken from Table 9, 10" gun-target distance
5. Taken from Table 15

Table 18

Detailed Results for the Large Panel Tests

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 1

					Basic Preliminary Coating Details					Coating Analyses				
Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Coating ID	Coating Batch Number	Coating Temp (oF)	Viscosity (secs) (Zahn 3) / Temp oF	Solvent (S) or Water (W)Added (Y/N)	Coating Conduc-tivity (uA)	Percent Wt. Solids (%)	Coating Density (lbs/gal)	Coating VOC (g/L)	In Comp-liance with Regs? (Y/N)
400B-4	11/28/95	AAA	BBA	3	4408-16440	3.06	73	17	Y	N/A	65.196	10.307	430.0	N
4001B-4	11/28/95	AAA	BBB	3	4408-16440	3.06	73	17	Y	N/A	65.196	10.307	430.0	N
4002-4	11/29/95	HVLP	BBC	3	4408-16440	3.06	82	16	N	N/A	66.074	10.389	420.0	Y
4004-4	11/29/95	HVLP	BBD	3	4408-16440	3.06	82	16	N	N/A	66.074	10.389	420.0	Y
4004-4	12/1/95	ELEC	BBE	3	4408-16440	3.06	81	16	N	N/M	66.686	10.437	416.7	Y
4005-4	12/1/95	ELEC	BBF	3	4408-16440	3.06	81	16	N	N/M	66.686	10.437	416.7	Y
4006-4	12/1/95	CONV	BBG	3	4408-16440	3.06	81	16	N	N/M	66.686	10.437	416.7	Y
4007-4	12/1/95	CONV	BBH	3	4408-16440	3.06	81	16	N	N/M	66.686	10.437	416.7	Y

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 2

Job Number	Date	Spray Gun Type	Panel ID	Spray Gun Details and Settings														
				Gun Vendor	Spray Gun Type	Spray Gun Model Name	Gun Tip Size	Gun Orifice Size (in.)	Gun Cap Size (inches)	Gun Needle Size (mm)	Gun-Target Distance (inches)	Leading Edge (inches)	Trailing Edge (inches)	Fan Size (inches)	Spray Gun Speed (mm/sec)	Strokes	Passes
400B-4	11/28/95	AAA	BBA	Graco	AAA	2000 HS	513	13 mils	N/A	N/A	10	0	0	8	508	6	2
4001B-4	11/28/95	AAA	BBB	Graco	AAA	2000 HS	513	13 mils	N/A	N/A	10	0	0	8	508	6	2
4002-4	11/29/95	HVLP	BBC	BINKS	HVLP	Mach 1	97P	0.07	97P	97P	10	0	0	10	250	6	1
4004-4	11/29/95	HVLP	BBD	BINKS	HVLP	Mach 1	97P	0.07	97P	97P	10	0	0	10	250	6	1
4004-4	12/1/95	ELEC	BBE	GRACO	ELEC	PRO 3500 SC	1.5	N/A	0.033	0.5 mm	10	0	0	10	250	6	1
4005-4	12/1/95	ELEC	BBF	GRACO	ELEC	PRO 3500 SC	1.5	N/A	0.033	0.5 mm	10	0	0	10	250	6	1
4006-4	12/1/95	CONV	BBG	DEVILBISS	CONV	TYPE MBC	N/A	0.07	N/A	0.07	10	0	0	10	250	6	1
4007-4	12/1/95	CONV	BBH	DEVILBISS	CONV	TYPE MBC	N/A	0.07	N/A	0.07	10	0	0	10	250	6	1

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 3

				Air Flow Through Spray Gun						Fluid Pressure to Spray Gun					
Job Number	Date	Spray Gun Type	Panel ID	Air Flow Through Gun (cfm)	Air Temp At Gun (°F)	Air Pressure To Gun (psig)	Air Pressure At Cap Gun (psig)	Air to Pressure Pot (If applicable) (psig)	Air Valve Opening (screw turns)	High or Low Pressure Fluid Delivery System (H/L)	Pump Ratio (If applicable)	Fluid Pressure At Gun (psig)	Fluid Valve Opening (screw turns)	Electro-static Voltage at Tip (KV)	Computer Set-up: Name of File
400B-4	11/28/95	AAA	BBA	N/A	76	86	N/A	N/A	1	H	30:1	400	N/A	N/A	TE4LRG1
4001B-4	11/28/95	AAA	BBB	N/A	76	86	N/A	N/A	1	H	30:1	400	N/A	N/A	TE4LRG1
4002-4	11/29/95	HVLP	BBC	N/M	76	85	FULL	N/A	1/2	H	30:1	92	5/8	N/A	TE4LRG2
4004-4	11/29/95	HVLP	BBD	N/M	76	85	FULL	N/A	1/2	H	30:1	92	5/8	N/A	TE4LRG2
4004-4	12/1/95	ELEC	BBE	N/A	76	80	N/M	N/A	1/2	H	30:1	40	6	N/M	TE4LRG3
4005-4	12/1/95	ELEC	BBF	N/A	76	80	N/M	N/A	1/2	H	30:1	40	6	N/M	TE4LRG3
4006-4	12/1/95	CONV	BBG	N/A	76	100	N/A	N/A	5/8	H	30:1	40	1 1/2	N/A	TE4LRG4
4007-4	12/1/95	CONV	BBH	N/M	76	100	N/A	N/A	5/8	H	30:1	40	1 1/2	N/A	TE4LRG4

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 4

				Environmental Conditions			Acceptable Appearance				
Job Number	Date	Spray Gun Type	Panel ID	Ambient Temp. (oF)	Ambient Relative Humidity (%)	Spray Booth Air Velocity (fpm)	DOI "C" Recog-nition (%)	Gloss 60*	Coating DFT (mils)	Pass/Fail (F/P)	Mean Area of Spray Envelope (cm2)
400B-4	11/28/95	AAA	BBA	75	N/M	N/M	N/M	N/M	0.66	N/M	N/M
4001B-4	11/28/95	AAA	BBB	75	N/M	N/M	N/M	N/M	0.80	N/M	N/M
4002-4	11/29/95	HVLP	BBC	76	N/M	N/M	N/M	N/M	0.80	N/M	N/M
4004-4	11/29/95	HVLP	BBD	76	N/M	N/M	N/M	N/M	0.84	N/M	N/M
4004-4	12/1/95	ELEC	BBE	76	N/M	N/M	N/M	N/M	1.15	N/M	N/M
4005-4	12/1/95	ELEC	BBF	76	N/M	N/M	N/M	N/M	1.59	N/M	N/M
4006-4	12/1/95	CONV	BBG	76	N/M	N/M	N/M	N/M	0.88	N/M	N/M
4007-4	12/1/95	CONV	BBH	76	N/M	N/M	N/M	N/M	0.88	N/M	N/M

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 4

				Environmental Conditions			Acceptable Appearance				
Job Number	Date	Spray Gun Type	Panel ID	Ambient Temp. (oF)	Ambient Relative Humidity (%)	Spray Booth Air Velocity (fpm)	DOI "C" Recog-nition (%)	Gloss 60*	Coating DFT (mils)	Pass/Fail (F/P)	Mean Area of Spray Envelope (cm2)
400B-4	11/28/95	AAA	BBA	75	N/M	N/M	N/M	N/M	0.66	N/M	N/M
4001B-4	11/28/95	AAA	BBB	75	N/M	N/M	N/M	N/M	0.80	N/M	N/M
4002-4	11/29/95	HVLP	BBC	76	N/M	N/M	N/M	N/M	0.80	N/M	N/M
4004-4	11/29/95	HVLP	BBD	76	N/M	N/M	N/M	N/M	0.84	N/M	N/M
4004-4	12/1/95	ELEC	BBE	76	N/M	N/M	N/M	N/M	1.15	N/M	N/M
4005-4	12/1/95	ELEC	BBF	76	N/M	N/M	N/M	N/M	1.59	N/M	N/M
4006-4	12/1/95	CONV	BBG	76	N/M	N/M	N/M	N/M	0.88	N/M	N/M
4007-4	12/1/95	CONV	BBH	76	N/M	N/M	N/M	N/M	0.88	N/M	N/M

TABLE 18
SUMMARY OF RESULTS FOR LARGE PANEL TESTS

SHEET 5

				Flow Meter and Transfer Efficiency Measurements									
Job Number	Date	Spray Gun Type	Panel ID	Flow Meter Conver-sion Factor (K)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)
400B-4	11/28/95	AAA	BBA	0.942	20.8	0.6	3.1	33.7	0.3	0.8	61.9	1.7	2.7
4001B-4	11/28/95	AAA	BBB	0.942	27.8	1.2	4.5	43.5	0.1	0.3	64.0	3.0	4.7
										MEAN	63.0		
4002-4	11/29/95	HVLP	BBC	1.001	27.7	0.4	1.4	34.0	0.4	1.1	81.4	0.4	0.5
4004-4	11/29/95	HVLP	BBD	1.001	30.2	0.6	2.0	37.5	0.5	1.3	80.7	2.1	2.6
										MEAN	81.1		
4004-4	12/1/95	ELEC	BBE	0.999	49.0	4.6	9.4	58.2	4.7	8.0	84.1	1.1	1.3
4005-4	12/1/95	ELEC	BBF	0.999	51.0	12.2	24.0	60.0	13.0	21.7	84.6	2.3	2.7
										MEAN	84.4		
4006-4	12/1/95	CONV	BBG	0.999	34.5	2.0	5.8	48.9	1.3	2.6	70.6	2.3	3.3
4007-4	12/1/95	CONV	BBH	0.999	32.0	0.1	0.2	44.8	0.2	0.3	71.4	0.1	0.2
										MEAN	71.0		

TABLE 19

Comparison of Transfer Efficiency Values (TE_m) (%) for Task #3 Medium Panels, and for Task #4, 1st and 2nd Test Series

Spray Guns	Task #3	Task #4 1st. Test Series	Task #4 2nd. Test Series
HVLP [1, 2, 3]	54.77	66.14	53.87
Electrostatic[4, 5, 6]	50.05	59.12	59.52
Air-assisted airless (#1) [7, 8]	N/M	46.87	52.61
Air-assisted airless (#2) [9, 10, 11]	31.76	29.68	N/M

Notes:

N/M Not measured
1. Results for HVLP taken from Table 10, 8" gun-target distance in Task #3.
2. Results for HVLP in Task #4 - 1st Test Series were measured with the **high** pressure fluid delivery system.
3. Results for HVLP in Task #4 - 2nd Test Series were measured with the **low** pressure fluid delivery system.
4. Results for Electrostatic were taken from Table 10, 10" gun-target distance in Task #3.
5. Results for Electrostatic in Task #4 - 1st Test Series were measured with the **high** pressure fluid delivery system.
6. Results for Electrostatic in Task #4 - 2nd Test Series were measured with the **low** pressure fluid delivery system.
7. In both tests, the technician set the air pressure to the gun at approximately 20 psig.
8. The values for Task #4 - 2nd Test Series were for panels AAA, AAB and AAC
9. In both tests, the technician set the air pressure to the gun at approximately 86 psig, which is too high for this type of gun.
10. The values for Task #4 - 1st Test Series were for panels AA, AB and AC where the technician deliberately set the air pressure to the gun at approximately 80 psig to duplicate the work performed in Task #3.
11. After demonstrating the repeatability between Tasks #3 and Task #4 - 1st Test Series, there was no need to repeat the high air pressure setting of 80 psig in Task #4 - 2nd Test Series

Table 20

Detailed Results for

Task #4 - 1st Test Series

TABLE 20
TASK #4 - 1ST TEST SERIES

SHEET 1

					Basic Preliminary Coating Details								Coating Analyses			
Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Coating Manufac-turer	Coating Name	Coating ID	Coating Batch Number	Coating Temp (oF)	Viscosity (secs) (Zahn 3) / Temp oF	Solvent (S) or Water (W)Added (Y/N)	Coating Conduc-tivity (uA)	Percent Wt. Solids (%)	Coating Density (lbs/gal)	Coating VOC (g/L)	In Comp-liance with Regs? (Y/N)
TSK4G1B	12/12/95	HVLP	BA	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/82	S/Y	N/A	66.97	10.45	413.53	Yes
TSK4G1B	12/12/95	HVLP	BB	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/82	S/Y	N/A	66.97	10.45	413.53	Yes
TSK4G1B	12/12/95	HVLP	BC	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/82	S/Y	N/A	66.97	10.45	413.53	Yes
TSK4G2A	12/12/96	Electrostatic	EA	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16.5/82	S/Y	N/M	66.97	10.45	413.43	Yes
TSK4G2B	12/13/96	Electrostatic	EB	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/86	S/Y	N/M	67.50	10.46	407.40	Yes
TSK4G2B	12/13/96	Electrostatic	EC	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/86	S/Y	N/M	67.50	10.46	407.40	Yes
TSK4G3B	12/14/95	Air-Assisted Airless	AAD	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/85	S/Y	N/A	66.611	10.394	415.901	Yes
TSK4G3B	12/14/95	Air-Assisted Airless	AAE	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/85	S/Y	N/A	66.611	10.394	415.901	Yes
TSK4G3B	12/14/95	Air-Assisted Airless	AAF	6	Cardinal	Air Dry High Solids	4408-16440	3.06	85	16/85	S/Y	N/A	66.611	10.394	415.901	Yes

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 20
TASK #4 - 1ST TEST SERIES

SHEET 2

					Spray Gun Details and Settings														
Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Gun Vendor	Spray Gun Type	Spray Gun Model Name	Spray Gun Model #	Gun Tip Size	Gun Orifice Size (in.)	Gun Cap Size (Inches)	Gun Needle Size (mm)	Gun-Target Distance (Inches)	Leading Edge (Inches)	Trailing Edge (Inches)	Fan Size (Inches)	Spray Gun Speed (mm/sec)	Strokes	Passes
TSK4G1B	12/12/95	**HVLP**	BA	6	Binks	HVLP	Mach 1	N/A	97P	0.07	97P	97P	10	1.75	1.75	10	250	5	1
TSK4G1B	12/12/95	**HVLP**	BB	6	Binks	HVLP	Mach 1	N/A	97P	0.07	97P	97P	10	1.75	1.75	10	250	5	1
TSK4G1B	12/12/95	**HVLP**	BC	6	Binks	HVLP	Mach 1	N/A	97P	0.07	97P	97P	10	1.75	1.75	10	250		
TSK4G2A	12/12/96	**Electrostatic**	EA	6	Graco	Electro-static	Pro 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
TSK4G2B	12/13/96	**Electrostatic**	EB	6	Graco	Electro-static	Pro 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
TSK4G2B	12/13/96	**Electrostatic**	EC	6	Graco	Electro-static	Pro 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
TSK4G3B	12/14/95	**Air-Assisted Airless**	AAD	6	Graco	Air-Assisted Airless	AA 200 HS	N/A	413	0.013	N/A	N/A	10	1.75	1.75	10	250	5	1
TSK4G3B	12/14/95	**Air-Assisted Airless**	AAE	6	Graco	Air-Assisted Airless	AA 200 HS	N/A	413	0.013	N/A	N/A	10	1.75	1.75	10	250	5	1
TSK4G3B	12/14/95	**Air-Assisted Airless**	AAF	6	Graco	Air-Assisted Airless	AA 200 HS	N/A	413	0.013	N/A	N/A	10	1.75	1.75	10	250	5	1

TABLE 20
TASK #4 - 1ST TEST SERIES

SHEET 3

Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Air Flow Through Spray Gun: Air Flow Through Gun (cfm)	Air Temp At Gun (°F)	Air Pressure To Gun (psig)	Air Pressure At Cap Gun (psig)	Air to Pressure Pot (if applicable) (psig)	Air Valve Opening (screw turns)	Fluid Pressure to Spray Gun: High or Low Pressure Fluid Delivery System (H/L)	Pump Ratio (if applicable)	Fluid Pressure At Gun (psig)	Fluid Valve Opening (screw turns)	Electro-static Voltage at Tip (KV)	Robot Program Setup: Name of File
TSK4G1B	12/12/95	HVLP	BA	6	N/M	72	20	N/M	N/A	Full Open	H	15:1	65	Full open	N/A	TASK4B
TSK4G1B	12/12/95	HVLP	BB	6	N/M	72	20	N/M	N/A	Full Open	H	15:1	65	Full open	N/A	TASK4B
TSK4G1B	12/12/95	HVLP	BC	6	N/M	72	20	N/M	N/A	Full Open	H	15:1	65	Full open	N/A	TASK4B
TSK4G2A	12/12/96	Electrostatic	EA	6	N/A	72	20	N/A	N/A	Full Open	H	15:1	62	Full open	N/M (1)	TASK4C
TSK4G2B	12/13/96	Electrostatic	EB	6	N/A	72	20	N/A	N/A	Full Open	H	15:1	45	Full open	N/M (1)	TASK4C
TSK4G2B	12/13/96	Electrostatic	EC	6	N/A	72	20	N/A	N/A	Full Open	H	15:1	45	Full open	N/M (1)	TASK4C
TSK4G3B	12/14/95	Air-Assisted Airless	AAD	6	N/A	76.6	20	N/A	N/A	Full Open	H	15:1	375	Full open	N/A	TASK4E
TSK4G3B	12/14/95	Air-Assisted Airless	AAE	6	N/A	76.6	20	N/A	N/A	Full Open	H	15:1	375	Full open	N/A	TASK4E
TSK4G3B	12/14/95	Air-Assisted Airless	AAF	6	N/A	76.6	20	N/A	N/A	Full Open	H	15:1	375	Full open	N/A	TASK4E

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 20
TASK #4 - 1ST TEST SERIES

SHEET 4

					Environmental Conditions			Acceptable Appearance				
Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Ambient Temp. (oF)	Ambient Relative Humidity (%)	Spray Booth Air Velocity (fpm)	DOI "C" Recog-nition (%)	Gloss 60*	Coating DFT (mils)	Pass/Fail (F/P)	Mean Area of Spray Envelope (cm2)
TSK4G1B	12/12/95	HVLP	BA	6	72	55	77	N/M	N/M	N/M	N/M	N/M
TSK4G1B	12/12/95	HVLP	BB	6	72	55	77	N/M	N/M	N/M	N/M	N/M
TSK4G1B	12/12/95	HVLP	BC	6	72	55	77	N/M	N/M	N/M	N/M	N/M
TSK4G2A	12/12/96	Electrostatic	EA	6	72	51	77	N/M	N/M	N/M	N/M	N/M
TSK4G2B	12/13/96	Electrostatic	EB	6	72	62	77	N/M	N/M	N/M	N/M	N/M
TSK4G2B	12/13/96	Electrostatic	EC	6	72	62	77	N/M	N/M	N/M	N/M	N/M
TSK4G3B	12/14/95	Air-Assisted Airless	AAD	6	76.6	41	77	45	92	N/M	Pass	N/M
TSK4G3B	12/14/95	Air-Assisted Airless	AAE	6	76.6	41	77	45	92	N/M	Pass	N/M
TSK4G3B	12/14/95	Air-Assisted Airless	AAF	6	76.6	41	77	45	92	N/M	Pass	N/M

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 20
TASK #4 - 1ST TEST SERIES

					Flow Meter and Transfer Efficiency Measurements									
Job Number	Date	Spray Gun Type	Panel ID	Number Panels In Set	Flow Meter Conver-sion Factor (K)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)
TSK4G1B	12/12/95	HVLP	BA	6	0.992	18.57	0.46	2.47	27.72	0.19	0.69	66.97	1.48	2.20
TSK4G1B	12/12/95	HVLP	BB	6	0.992	17.87	0.19	1.04	26.88	0.27	1.00	66.47	0.85	1.27
TSK4G1B	12/12/95	HVLP	BC	6	0.992	16.90	0.30	1.79	26.01	0.25	0.95	64.98	1.06	1.62
										MEAN TEm		66.14		
										STD. DEV		1.04		
										COV (%)		1.57		
TSK4G2A	12/12/96	Electrostatic	EA	6	0.992	19.42	0.52	2.67	31.05	0.95	3.05	62.56	1.68	2.68
TSK4G2B	12/13/96	Electrostatic	EB	6	0.987	12.00	0.27	2.11	20.97	0.28	1.35	60.57	0.93	1.54
TSK4G2B	12/13/96	Electrostatic	EC	6	0.987	11.30	0.90	8.24	20.75	0.34	1.63	54.23	4.58	8.45
										MEAN TEm		59.12		
										STD. DEV		4.35		
										COV (%)		7.36		
TSK4G3B	12/14/95	Air-Assisted Airless	AAD	6	0.98	11.12	0.52	4.66	23.47	0.38	1.62	47.58	2.01	4.22
TSK4G3B	12/14/95	Air-Assisted Airless	AAE	6	0.98	10.62	0.35	3.34	23.34	0.37	1.60	45.49	1.25	2.76
TSK4G3B	12/14/95	Air-Assisted Airless	AAF	6	0.98	11.10	0.40	3.71	23.42	0.40	1.72	47.53	1.45	3.06
										MEAN TEm		46.87		
										STD. DEV		1.19		
										COV (%)		2.54		

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

Table 21

Detailed Results for

Task #4 - 2nd Test Series

TABLE 21
TASK #4 - 2ND TEST SERIES

					Basic Preliminary Coating Details								Coating Analyses			
Job Number	Date	Spray Gun Type	Panel ID	Number Panel in Set	Coating Manufac-turer	Coating Name	Coating ID	Coating Batch Number	Coating Temp (oF)	Viscosity (secs) (Zahn 3) / Temp oF	Solvent (S) or Water (W)Added (Y/N)	Coating Conduc-tivity (uA)	Percent Wt. Solids (%)	Coating Density (lbs/gal)	Coating VOC (g/L)	In Comp-liance with Regs? (Y/N)
BW2G1S	2/27/96	Electrostatic	EA	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.5	S/Y	N/M	60.16	9.787	467.22	N
BW2G1S	2/27/96	Electrostatic	EB	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.5	S/Y	N/M	60.16	9.787	467.22	N
BW2G1S	2/27/96	Electrostatic	EC	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.5	S/Y	N/M	60.16	9.787	467.22	N
BW2G2S	2/27/96	HVLP	HA	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.0	S/Y	N/A	61.56	9.848	453.56	N
BW2G2S	2/27/96	HVLP	HB	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.0	S/Y	N/A	61.56	9.848	453.56	N
BW2G2S	2/27/96	HVLP	HC	6	Cardinal	Air Dry High Solids	4408-16440	3.07	75	16.0	S/Y	N/A	61.56	9.848	453.56	N
BW2G3S	2/28/96	Air Assisted Airless	AAA	6	Cardinal	Air Dry High Solids	4408-16440	3.07	77	16.1	S/Y	N/A	62.89	10.028	445.78	N
BW2G3S	2/28/96	Air Assisted Airless	AAB	6	Cardinal	Air Dry High Solids	4408-16440	3.07	77	16.1	S/Y	N/A	62.89	10.028	445.78	N
BW2G3S	2/28/96	Air Assisted Airless	AAC	6	Cardinal	Air Dry High Solids	4408-16440	3.07	77	16.1	S/Y	N/A	62.89	10.028	445.78	N

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 21
TASK #4 - 2ND TEST SERIES

					Spray Gun Details and Settings													
Job Number	Date	Spray Gun Type	Panel ID	Number Panel in Set	Gun Vendor	Spray Gun Model Name	Spray Gun Model #	Gun Tip Size	Gun Orifice Size (in.)	Gun Cap Size (inches)	Gun Needle Size (mm)	Gun-Target Distance (inches)	Leading Edge (inches)	Trailing Edge (inches)	Fan Size (inches)	Spray Gun Speed (mm/sec)	Strokes	Passes
BW2G1S	2/27/96	**Electrostatic**	EA	6	Graco	PRO 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
BW2G1S	2/27/96	**Electrostatic**	EB	6	Graco	PRO 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
BW2G1S	2/27/96	**Electrostatic**	EC	6	Graco	PRO 3500 SC	222-300	1.5	N/A	0.033	0.5	10	1.75	1.75	10	250	5	1
BW2G2S	2/27/96	**HVLP**	HA	6	Binks	Mach 1	N/A	97P	0.070	97P	97P	10	1.75	1.75	8	250	5	1
BW2G2S	2/27/96	**HVLP**	HB	6	Binks	Mach 1	N/A	97P	0.070	97P	97P	10	1.75	1.75	8	250	5	1
BW2G2S	2/27/96	**HVLP**	HC	6	Binks	Mach 1	N/A	97P	0.070	97P	97P	10	1.75	1.75	8	250	5	1
BW2G3S	2/28/96	**Air Assisted Airless**	AAA	6	Graco	AA 200 HS	N/A	413	13	N/A	N/A	10	1.75	1.75	8	508	5	1
BW2G3S	2/28/96	**Air Assisted Airless**	AAB	6	Graco	AA 200 HS	N/A	413	13	N/A	N/A	10	1.75	1.75	8	508	5	1
BW2G3S	2/28/96	**Air Assisted Airless**	AAC	6	Graco	AA 200 HS	N/A	413	13	N/A	N/A	10	1.75	1.75	8	508	5	1

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 21
TASK #4 - 2ND TEST SERIES

SHEET 3

Job Number	Date	Spray Gun Type	Panel ID	Number Panel In Set	Air Flow Through Spray Gun: Air Flow Through Gun (cfm)	Air Temp At Gun (°F)	Air Pressure To Gun (psig)	Air Pressure At Cap Gun (psig)	Air to Pressure Pot (If applicable) (psig)	Air Valve Opening (screw turns)	Fluid Pressure to Spray Gun: High or Low Pressure Fluid Delivery System (H/L)	Pump Ratio (If applicable)	Fluid Pressure At Gun (psig)	Fluid Valve Opening (screw turns)	Electro-static Voltage at Tip (KV)	Robot Program Setup: Name of File
BW2G10	2/26/96	Electrostatic	AA	6	N/M	74	20	N/A	N/M	Full Open	L	N/A	24	Full Open	N/M	TASK4C1
BW2G1S	2/27/96	Electrostatic	EA	6	N/M	75	30	N/A	N/M	Full Open	L	N/A	27	Full Open	N/M	TASK4C1
BW2G1S	2/27/96	Electrostatic	EB	6	N/M	75	30	N/A	N/M	Full Open	L	N/A	27	Full Open	N/M	TASK4C1
BW2G1S	2/27/96	Electrostatic	EC	6	N/M	75	30	N/A	N/M	Full Open	L	N/A	27	Full Open	N/M	TASK4C1
BW2G2S	2/27/96	HVLP	HA	6	N/M	74	Not Measured	N/M	N/M	Full Open	L	N/A	18	Full Open	N/A	TASK4B1
BW2G2S	2/27/96	HVLP	HB	6	N/M	74	Not Measured	N/M	N/M	Full Open	L	N/A	18	Full Open	N/A	TASK4B1
BW2G2S	2/27/96	HVLP	HC	6	N/M	74	Not Measured	N/M	N/M	Full Open	L	N/A	18	Full Open	N/A	TASK4B1
BW2G3S	2/28/96	Air Assisted Airless	AAA	6	N/M	77	20	N/A	N/A	Full Open	H	15:1	385	Full Open	N/A	TASK4D
BW2G3S	2/28/96	Air Assisted Airless	AAB	6	N/M	77	20	N/A	N/A	Full Open	H	15:1	385	Full Open	N/A	TASK4D
BW2G3S	2/28/96	Air Assisted Airless	AAC	6	N/M	77	20	N/A	N/A	Full Open	H	15:1	385	Full Open	N/A	TASK4D

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 21
TASK #4 - 2ND TEST SERIES

SHEET 4

				Environmental Conditions			Acceptable Appearance				
Job Number	Date	Spray Gun Type	Panel ID	Ambient Temp. (oF)	Ambient Relative Humidity (%)	Spray Booth Air Velocity (fpm)	DOI "C" Recog-nition (%)	Gloss 60*	Coating DFT (mils)	Pass/Fail (F/P)	Mean Area of Spray Envelope (cm2)
BW2G1S	2/27/96	Electrostatic	EA	74	31	77-120	N/M	N/M	N/M	N/M	N/M
BW2G1S	2/27/96	Electrostatic	EB	74	31	77-120	N/M	N/M	N/M	N/M	N/M
BW2G1S	2/27/96	Electrostatic	EC	74	31	77-120	N/M	N/M	N/M	N/M	N/M
BW2G2S	2/27/96	HVLP	HA	75	44	77-120	N/M	N/M	N/M	N/M	N/M
BW2G2S	2/27/96	HVLP	HB	75	44	77-120	N/M	N/M	N/M	N/M	N/M
BW2G2S	2/27/96	HVLP	HC	75	44	77-120	N/M	N/M	N/M	N/M	N/M
BW2G3S	2/28/96	Air-Assisted Airless	AAA	77	33	77-120	N/M	N/M	N/M	N/M	N/M
BW2G3S	2/28/96	Air-Assisted Airless	AAB	77	33	77-120	N/M	N/M	N/M	N/M	N/M
BW2G3S	2/28/96	Air-Assisted Airless	AAC	77	33	77-120	N/M	N/M	N/M	N/M	N/M

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

TABLE 21
TASK #4 - 2ND TEST SERIES

SHEET 5

Job Number	Date	Spray Gun Type	Panel ID	Flow Meter and Transfer Efficiency Measurements: Flow Meter Conversion Factor (K)	Mean Wt. Solid Coating Depos. (g)	Mean Wt. Solid Coating Depos. Std. Dev. (g)	Mean Wt. Solid Coating Depos. COV (%)	Mean Wt. Solid Coating Used (g)	Mean Wt. Solid Coating Used Std. Dev. (g)	Mean Wt. Solid Coating Used COV (%)	Mean TEm (%)	Mean TEm Std. Dev.	Mean TEm COV (%)
BW2G1S	2/27/96	Electrostatic	EA	N/A	12.85	0.14	1.07	21.42	0.27	1.24	60.00	0.30	0.50
BW2G1S	2/27/96	Electrostatic	EB	N/A	13.55	0.180	1.300	22.79	0.17	0.74	59.62	0.76	1.28
BW2G1S	2/27/96	Electrostatic	EC	N/A	13.6	0.200	1.100	23.13	0.13	0.56	58.94	0.49	0.84
									MEAN TEm		59.52		
									STD. DEV		0.54		
									COV (%)		0.90		
BW2G2S	2/27/96	HVLP	HA	N/A	11.67	0.48	4.12	22.02	0.65	2.95	52.99	1.59	3.00
BW2G2S	2/27/96	HVLP	HB	N/A	11.85	0.10	0.89	22.39	0.20	0.90	52.93	0.43	0.81
BW2G2S	2/27/96	HVLP	HC	N/A	11.70	0.40	3.24	21.17	2.12	10.01	55.68	5.00	8.99
									MEAN TEm		53.87		
									STD. DEV		1.57		
									COV (%)		2.92		
BW2G3S	2/28/96	Air-Assisted Airless	AAA	0.992	11.58	0.29	2.47	22.39	0.19	0.84	51.98	1.37	2.63
BW2G3S	2/28/96	Air-Assisted Airless	AAB	0.992	11.83	0.14	1.15	22.14	0.15	0.67	53.46	0.50	0.93
BW2G3S	2/28/96	Air-Assisted Airless	AAC	0.992	11.60	0.30	2.83	22.04	0.11	0.50	52.39	1.48	2.82
									MEAN TEm		52.61		
									STD. DEV		0.76		
									COV (%)		1.45		

Note (1). The Graco electrostatic gun operates with an air turbine. The electrostatic tip voltage could not be measured.
N/M = Not Measured
N/A = Not applicable to this particular spray gun

Table 22
Conductivity of Cardinal High Solids Air Dry Enamel[1], Gray #14880-16440 with Additions of MPK Solvent

Volume of MPK Added (%) (2)	Megohms	Microamps
0	0.37	18
5	0.18	28
10	0.11	38
20	0.05	52

1. This table was derived by a technician at Cardinal Industrial Finishes.
2. Volume was measured as a percentage of the original coating content.

TABLE 24

TEST DAY 4/24/95
ESTIMATED COSTS TO RUN A TRANSFER TEST SERIES

JOBS # 3017 & 3018
3 SETS OF 6 PANELS FOR CONVENTIONAL GUN AT 8" GUN TARGET DISTANCE (GTD), AND 3 SETS FOR 12" GTD

TASK	COMMENTS	TIME MIN.	START	FINISH	TECHNICIAN #1	TECHNICIAN #2	WAIT TIME (MINS)	NUMBER OF PEOPLE PERFORMING TASK	TOTAL MINUTES
INITIALIZE COMPUTER SYSTEMS	SET UP ROBOT CONTROLLER, DATA ACQUISITION (DAQ) TERMINALS, DATAFORMS COMPUTER	0:20	8:00	8:20	1			1	0:20
SUITING UP / GEAR UP	BRING OUT LABCOAT, GAS MASKS, RUBBER GLOVES, ETC.	0:10	8:20	8:30	1			1	0:10
SET UP PAINT DELIVERY SYSTEM	OPEN PAINT CONTAINER, MIX PAINT, ACTIVATE PUMP/AIR, CIRCULATE PAINT	0:15	8:30	8:45	1			1	0:15
SPRAY BOOTH MAINTENANCE	REPLACE FILTERS / MASK SPRAY BOOTH	0:45	9:00	9:45	1			1	0:45
SUITING UP / GEAR UP	BRING OUT LABCOAT, GAS MASKS, RUBBER GLOVES, ETC.	0:10	9:30	9:40		1		1	0:10
BLAST MATERIAL BEFORE TESTING	BLAST PAINT RACK/MAGNETS, AND ALGINMENT ROD	0:40	9:40	10:20		1		1	0:40
TAKE VISCOSITY READINGS	TAKE ZAHN #3 CUP READINGS, RECORD TEMPERATURE, TAKE KREBBS UNITS	0:15	9:45	10:00	1			1	0:15
PREPARE FOR % WT SOLIDS SAMPLE AND TESTING	WEIGH EMPTY AND FULL DISHES W/ SYRINGE	0:30	10:00	10:30	1			1	0:30
DATA ENTRY	ENTER COLLECTED DATA INTO COMPUTER	0:10	10:20	10:30		1		1	0:10
BAKE % WT SOLIDS DISHES	BAKE IN OVEN FOR 30 MIN @ 250°F	0:30	10:30	11:00			0:30	0	0:00
TEST DENSITY SAMPLE	WEIGH DENSITY CUPS EMPTY AND FILLED WITH COATING	0:15	10:30	10:45	1			1	0:15
BLAST CLEANING	BLAST LARGE PANELS FOR ENVELOPE SIZE	0:30	10:30	11:00		1		1	0:30
CLEAN UP	WASH DENSITY/VISCOSITY CUPS DISPOSE SYRINGE AND PAPER ETC.	0:10	10:45	10:55	1			1	0:10
PREPARE PLASTIC BAGS FOR FLOW METER CALIBRATION	WEIGH AND MARK 10 PLASTIC BAGS FOR FLOWMETER CALIBRATION	0:20	10:55	11:15	1	1		2	0:40
DATA ENTRY	ENTER COLLECTED DATA INTO COMPUTER	0:15	11:00	11:15		1		1	0:15
CALIBRATE FLOW METER	ACTIVATE DAQ, SPRAY INTO BAGS, RECORD DATA,	0:20	11:15	11:35	1	1		2	0:40
WEIGH PLASTIC BAGS AFTER FLOW METER CALIBRATION / DATA ENTRY	WEIGH AND DISPOSE AFTER DATA ENTRY	0:25	11:35	12:00	1	1		2	0:50
LUNCH TIME		1:00	12:00	13:00			1:00	0	0:00

Table 24

Estimated Costs to Run a Transfer Efficiency Test

TABLE 24

TEST DAY 4/24/95
ESTIMATED COSTS TO RUN A TRANSFER TEST SERIES

COMPLETE SHUT DOWN	STORE PANELS FOR EVALUATION	0:15	6:15	6:30	1	1		2	0:30
TOTALS		15:30					4:30		15:00

TABLE 24

TEST DAY 4/24/95
ESTIMATED COSTS TO RUN A TRANSFER TEST SERIES

	WEIGH, MARK PANELS AND PRINT FORMS FOR THREE SETS OF 6 PANELS FOR 8" GTD	0:30	1:00	1:30	1			1	0:30
SET UP FOR TESTING	ACTIVATE LARGE OVEN / POSITION BAKING RACKS / OPEN AIR LINES FOR PAINT SYSTEM	0:30	1:00	1:30		1		1	0:30
RUN 1ST SET (1-6) MEDIUM @ 8" GTD	ACTIVATE DAQ, SPRAY PANELS, LOAD RACK, SPRAY ENVELOPE SIZE ON LARGE PANEL	0:15	1:30	1:45	1	1		2	0:30
BAKE 1ST SET OF PANELS		0:30	1:45	2:15			0:30	0	0:00
DISASSEMBLE GUN, REASSEMBLE, AND RUN SET 2ND SET (1-6) MEDIUM @ 8" G-T DISTANCE	ACTIVATE DAQ, SPRAY PANELS, LOAD RACK , SPRAY ENVELOPE SIZE ON LARGE PANEL	0:25	1:45	2:10	1	1		2	0:50
PREPARE PANELS / PRINT DATA FORMS FOR 2ND SERIES OF 3 TEST SETS WITH 6 PANELS EACH	MARK PANELS AND PRINT FORMS FOR THREE SETS OF 6 PANELS FOR 12" GTD	0:20	2:10	2:30	1	1		2	0:40
BAKE 2ND SET OF PANELS		0:30	2:30	3:00			0:30	0	0:00
DATA ENTRY FOR 1ST SET OF PANELS	LET COOL DOWN	0:30	2:30	3:00	1	1		2	1:00
POSITION BAKING RACKS		0:05	3:00	3:05		1		1	0:05
PREPARE FOR NEXT TEST SET	LOAD PANEL ON RACK READY TO SPRAY / STAND BY	0:10	3:05	3:15		1		1	0:10
PROGRAM ROBOT	EDIT COMPUTER PROGRAM TE3MED11 FOR TE3MED12	0:10	3:05	3:15	1			1	0:10
DISASSEMBLE GUN, REASSEMBLE, RUN 3RD SET (1-6) MEDIUM @ 8" GTD	ACTIVATE DAQ, SPRAY PANELS, LOAD RACK , SPRAY ENVELOPE SIZE ON LARGE PANEL	0:15	3:15	3:30	1	1		2	0:30
BAKE 3RD SET OF PANELS		0:30	3:30	4:00			0:30	0	0:00
PREPARE FOR 2ND TEST SERIES	LOAD PANEL TO SPRAY / STAND BY	0:05	3:30	3:35		1		1	0:05
PRINT DATA FORMS FOR 3 SETS OF PANELS FOR 2ND SERIES		0:05	3:30	3:35	1			1	0:05
RUN SET 1ST SET OF (1-6) MEDIUM @ 12" GTD	ACTIVATE DAQ, SPRAY 1 PASS FOR FAN WIDTH SPRAY PANELS, LOAD RACK, HOLD, SPRAY ENVELOPE SIZE ON LARGE PANEL	0:25	3:35	4:00	1	1		2	0:50
DISASSEMBLE GUN, REASSEMBLE, RUN 2ND SET (1-6) MEDIUM @ 12" GTD	ACTIVATE DAQ, SPRAY 1 PASS FOR FAN WIDTH SPRAY PANELS, LOAD RACK, SPRAY ENVELOPE SIZE ON LARGE PANEL	0:15	4:00	4:15	1	1		2	0:30
BAKE 1ST SET OF PANELS		0:30	4:15	4:45			0:30	0	0:00
DISASSEMBLE GUN, ASSEMBLE, RUN 3RD SET (1-6) MEDIUM @ 12" GTD	ACTIVATE DAQ, SPRAY 1 PASS FOR FAN WIDTH SPRAY PANELS, LOAD RACK , SPRAY ENVELOPE SIZE ON LARGE PANEL	0:15	4:45	5:00	1	1		2	0:30
BAKE 2ND SET OF PANELS	NO MORE TESTS RUN AFTER LAST TEST SET (SHUT DOWN)	0:30	5:00	5:30			0:30	0	0:00
SHUT DOWN FLUID DELIVERY SYSTEM	SHUT OFF AIR LINES, SEAL PAINT CAN, GENERAL CLEAN UP	0:30	5:00	5:30		1		1	0:30
SHUT DOWN COMPUTER DAQ SYSTEM / ROBOT	SHUT DOWN ROBOT, DAQ, GENERAL CLEAN UP	0:30	5:00	5:30	1			1	0:30
BAKE 3RD SET OF PANELS		0:30	5:45	6:15			0:30	0	0:00

TABLE 23

CALCULATION OF COSTS TO EVALUATE A SUBJECT SPRAY GUN VS. A STANDARD GUN

	Low	High
Labor required to set up equipment prior to test	40	40
Time to perform Transfer Efficiency Tests (hrs/gun)	16	16
Complete data entry (hrs/gun)	8	8
Clean up equipment at end of tests (hrs)	8	16
Number of medium panels per gun	36	36
Number of panels for setting up gun	10	10
Cost of panels ($/panel)	$1.50	$2.00
Cost of coating ($/gal)	$34.00	$43.00
Gals required to fill fluid system (gal)	0.25	0.50
Gals required to perform test (gals/gun)	0.25	0.50
Time required to rent laboratory to evaluate two guns(hrs	16	16
Rental cost of laboratory ($/day)	$600.00	$1,000.00
Labor rate for technicians ($/hr)	$15.00	$25.00

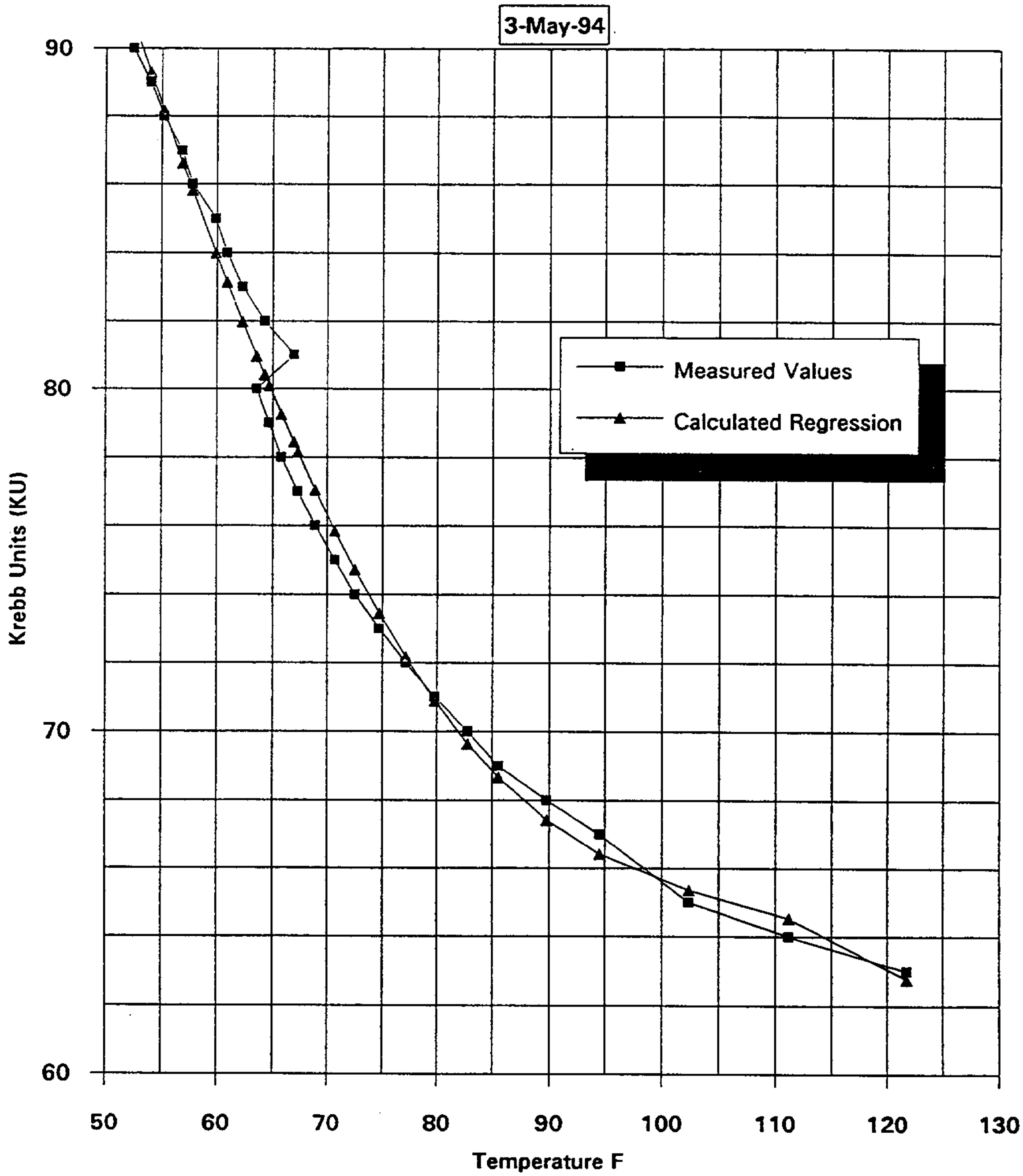
CALCULATION OF COSTS TO EVALUATE ONE SUBJECT GUN AND ONE STANDARD GUN

	Low	High
Labor to set up laboratory	$600.00	$1,000.00
Cost to perform Transfer Efficiency Tests on two guns	$240.00	$400.00
Cost to complete data entry forms for two guns	$240.00	$400.00
Cost to clean up equipment at the end of the tests	$120.00	$400.00
Cost of panels to evaluate two guns	$138.00	$184.00
Cost of the coating for two guns	$34.00	$86.00
Cost to rent laboratory only during testing phase	$2,400.00	$4,000.00
TOTAL CSOT RANGE TO EVALUATE TWO GUNS	**$3,772.00**	**$6,470.00**

FIGURES

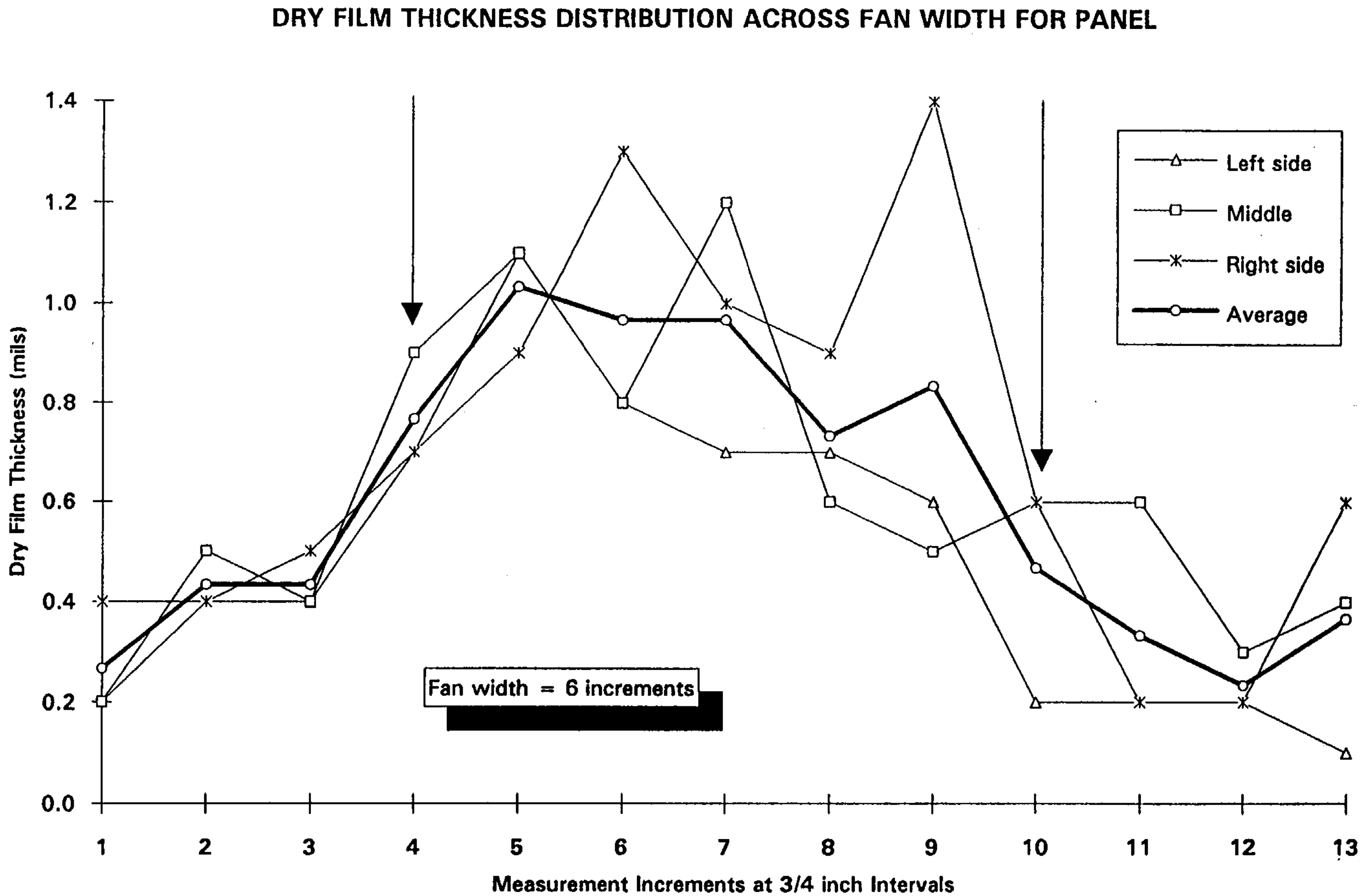
FIGURE 1

VISCOSITY/TEMPERATURE CURVE FOR CARDINAL HIGH SOLIDS POLYESTER BAKING ENAMEL LIGHT GRAY, #16440



232-5-1.XLC

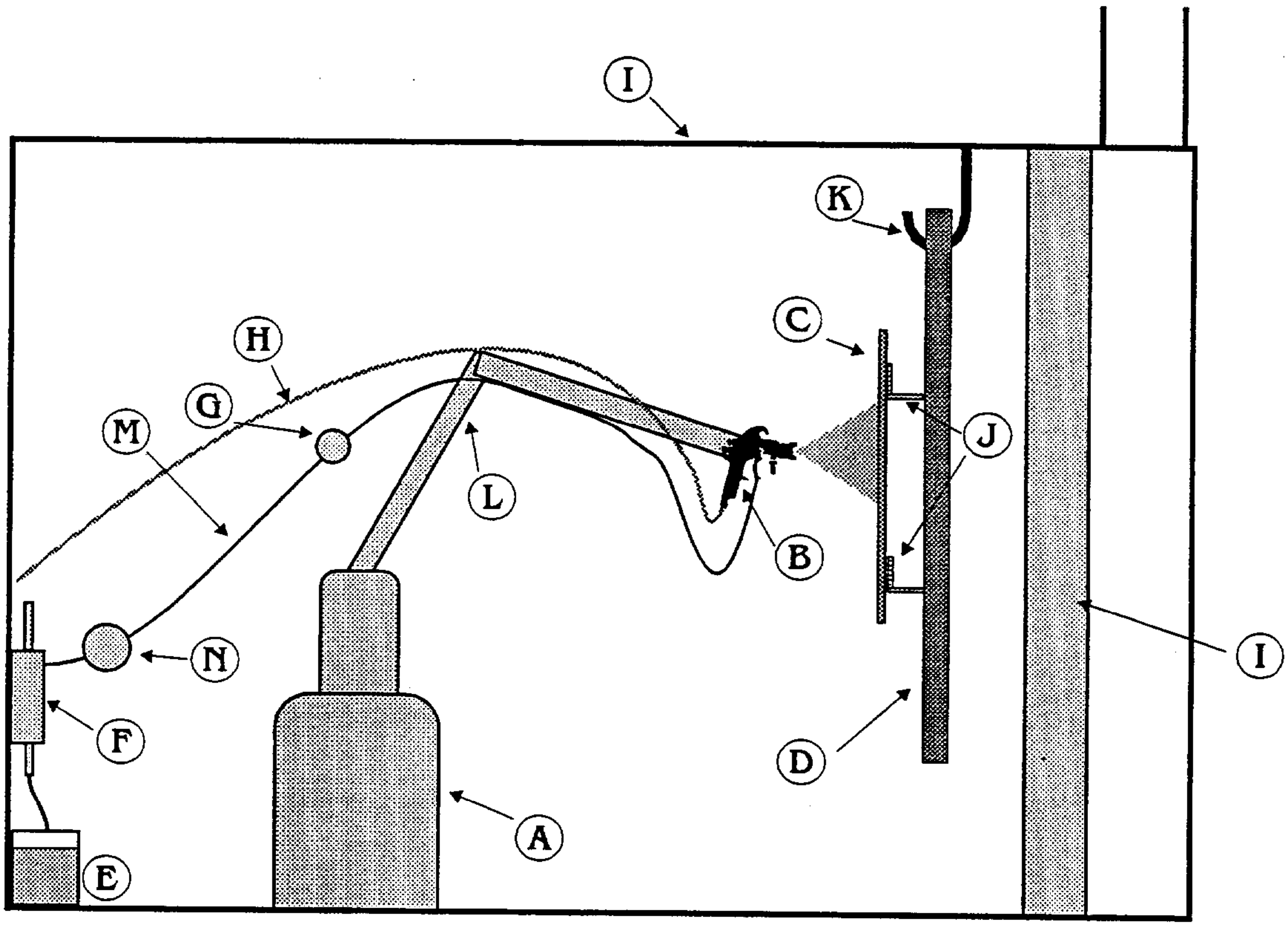
FIGURE 2



232-2-1.XLC

FIGURE 3

SCHEMATIC OF SPRAY EQUIPMENT SET-UP

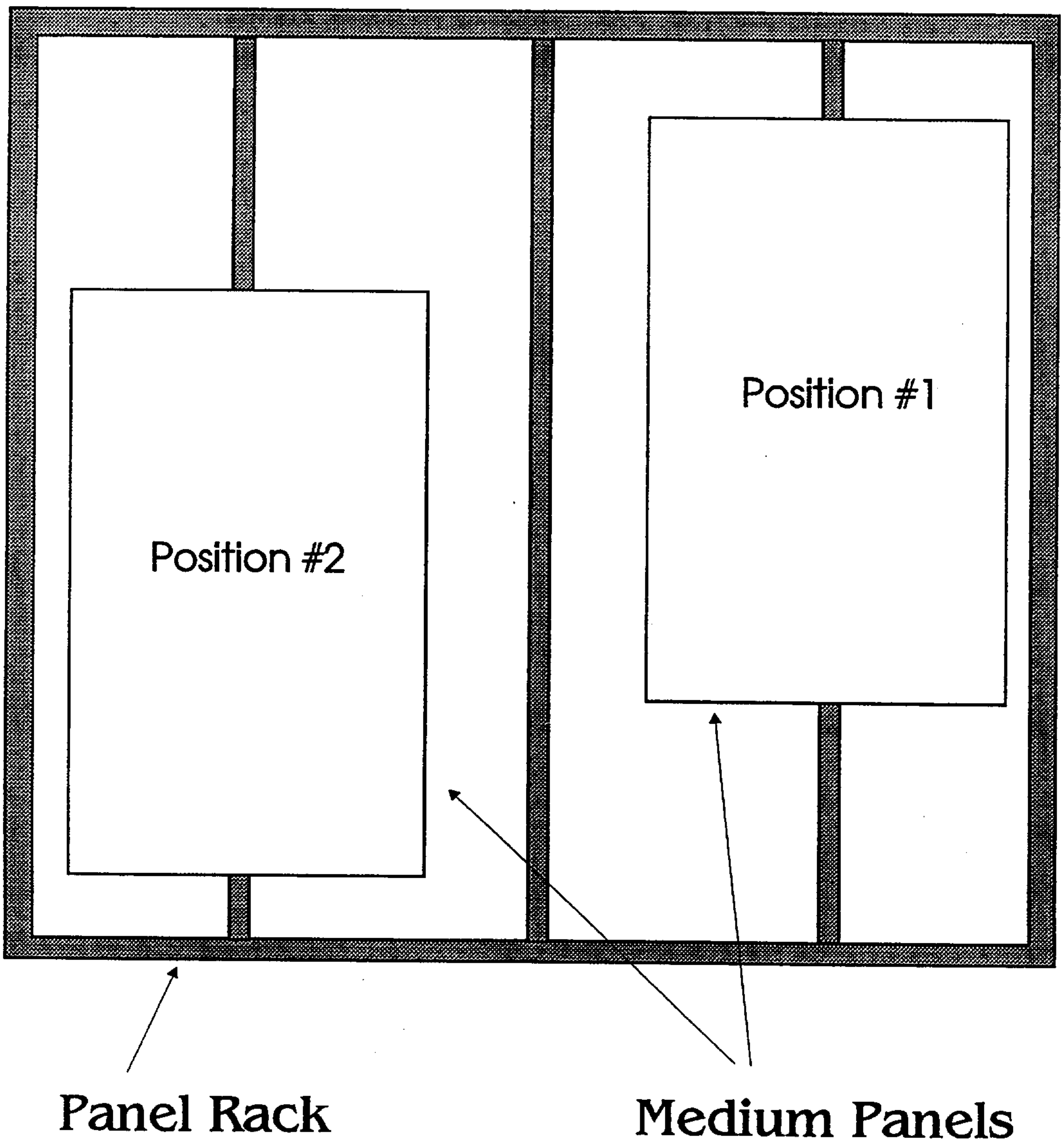


A = Robot	H = Air Supply Hose
B = Spray Gun	I = Spray Booth
C = Steel Panel (Target)	J = Magnets to hold Panel
D = Panel Rack	K = Hook
E = Coating Reservoir	L = Robot Arm
F = Pump	M = Fluid Hose
G = Fluid Flow Meter	N = In-Line Heater

FIGURE 4

Layout of Medium Panels (16" x 20") on Rack

(Not to Scale)



Note: Spacing between panels is not relevant.
See text for explanation.

FIGURE 5

Coordinates for Spraying Panels 16"W x 20"H x 20G Based on 1.75" Leading and Trailing Edges

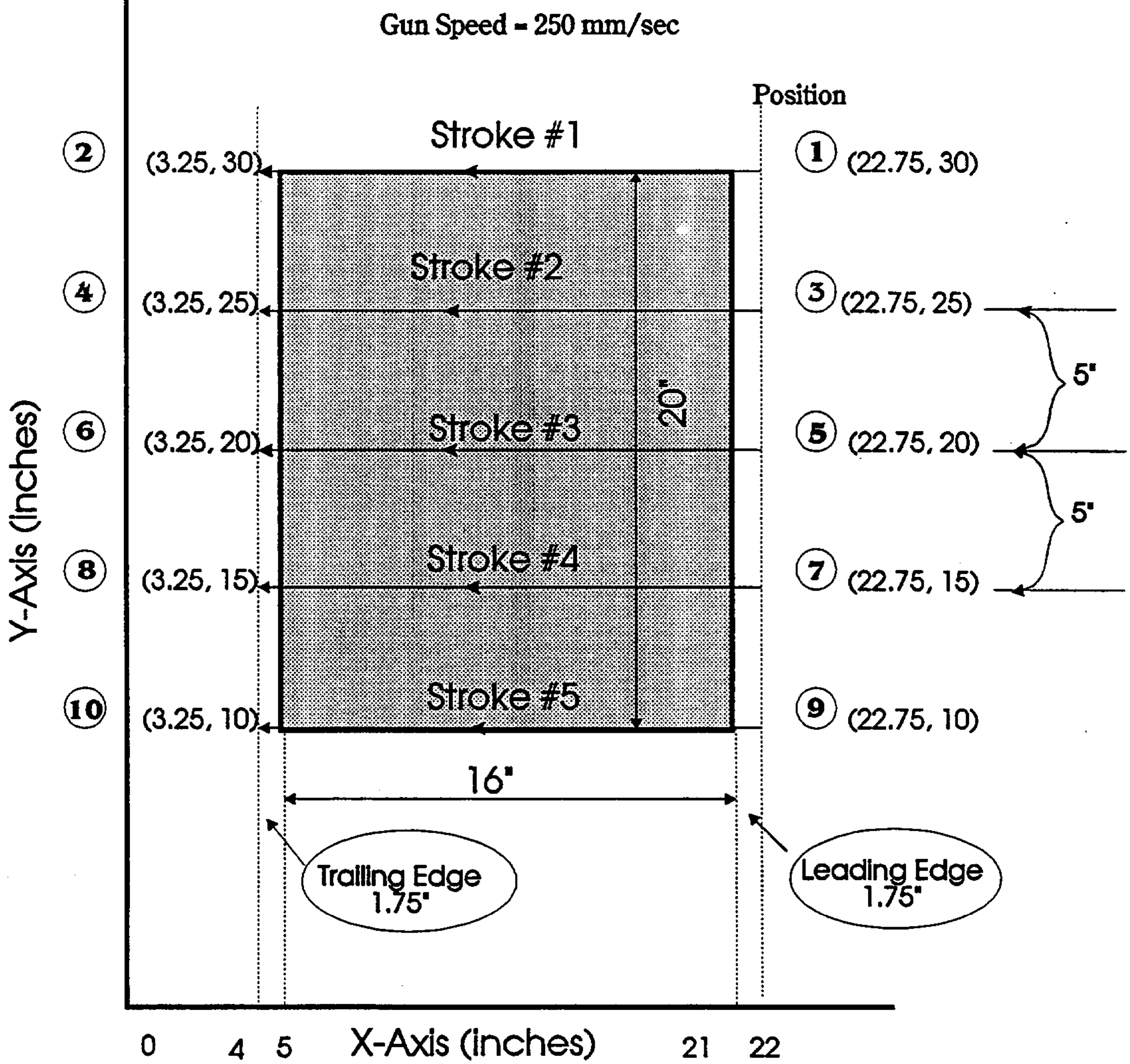
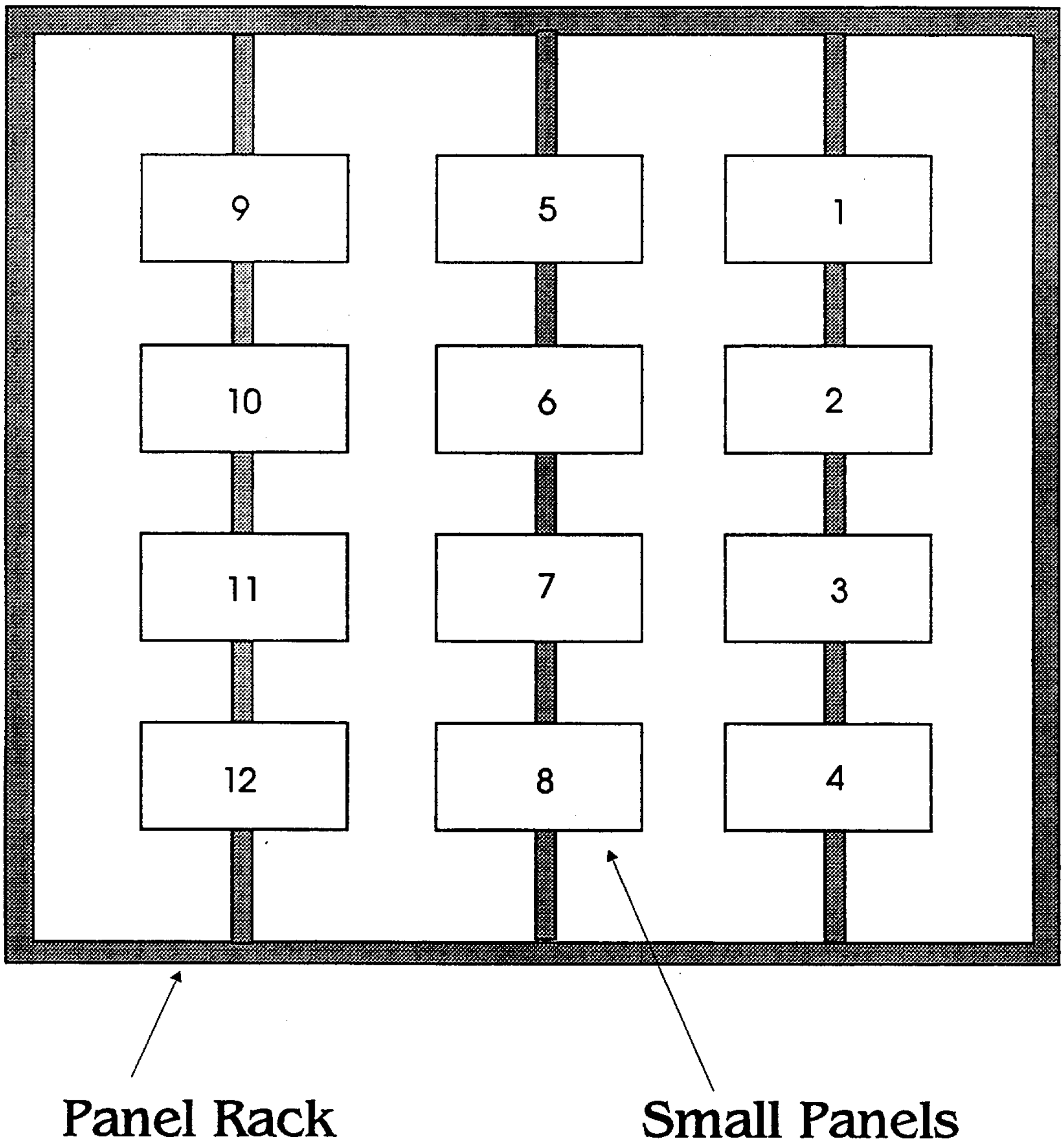


FIGURE 6

Layout of Small Panels (6" x 4") on Rack

(Not to Scale)



Note: Spacing between the brackets is not relevant. See text for explanation.

232-5

FIGURE 7

Coordinates for Spraying Small-Sized Panels Based on a 1.75" Leading and Trailing Edge

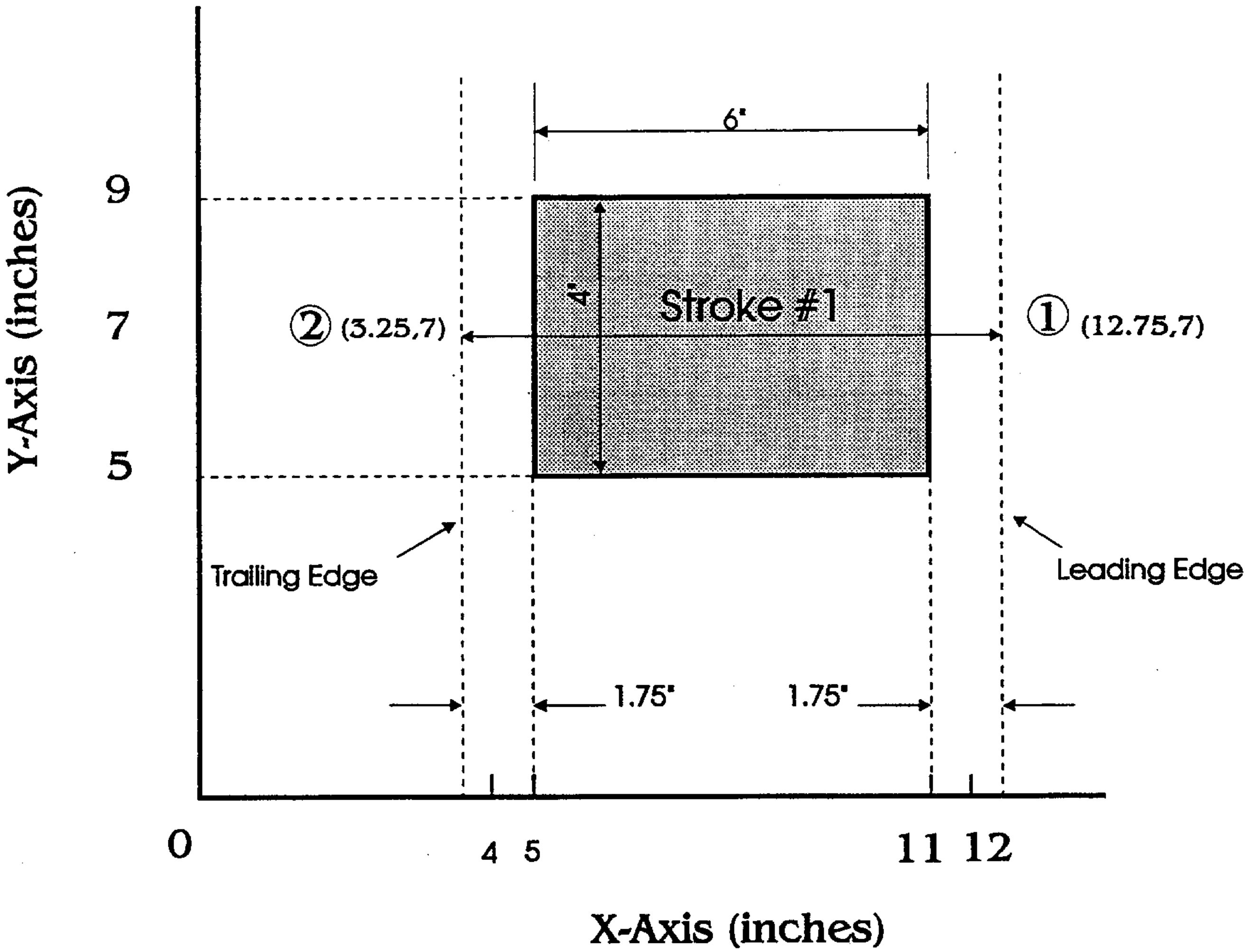


FIGURE 8

Transfer Efficiency vs. Gun-Target Distance Evaluated By Gun Type

Based on Tables #10 and #11

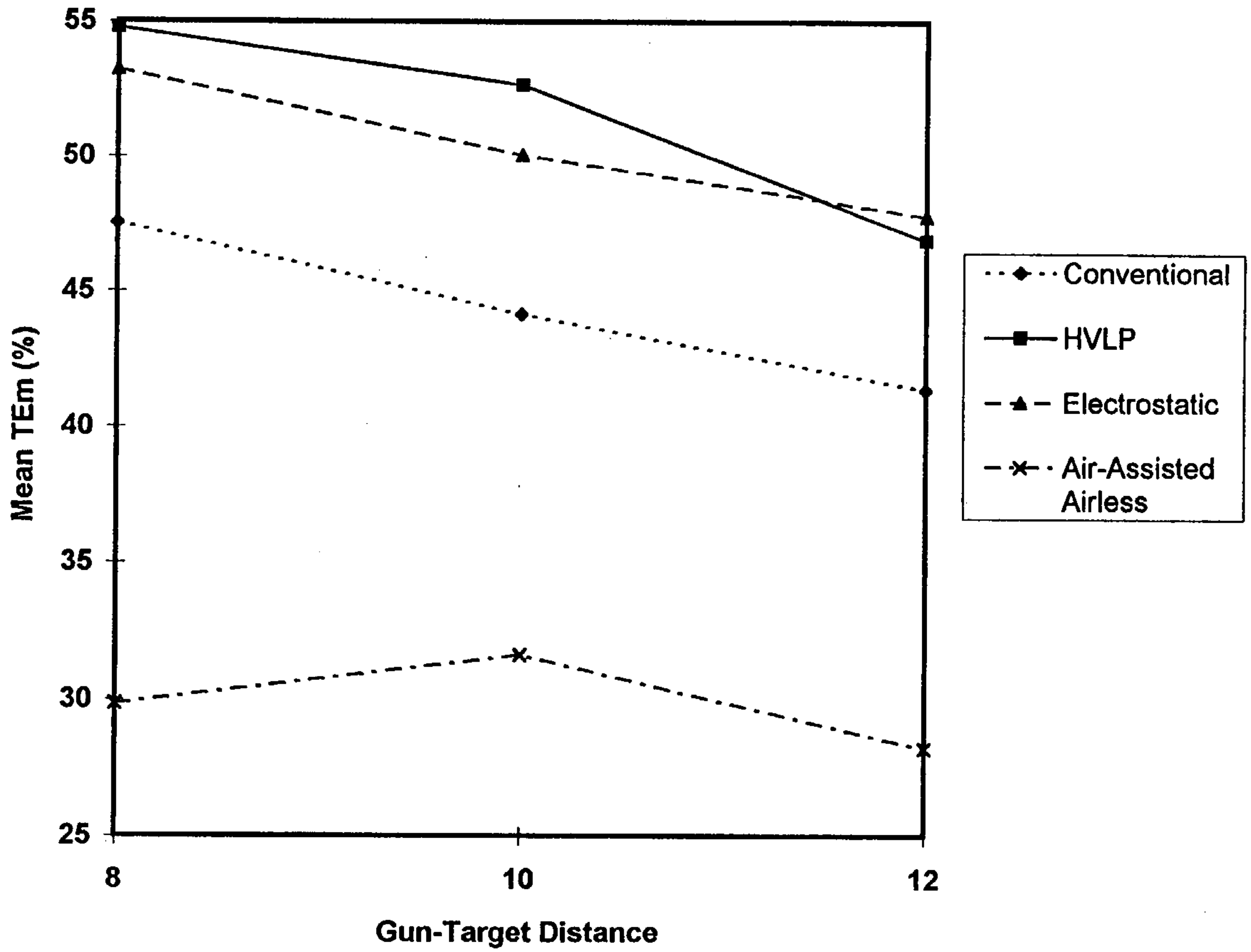


FIGURE 9

Wt. of Solid Coating Deposited on Small Panels vs. Panel Number

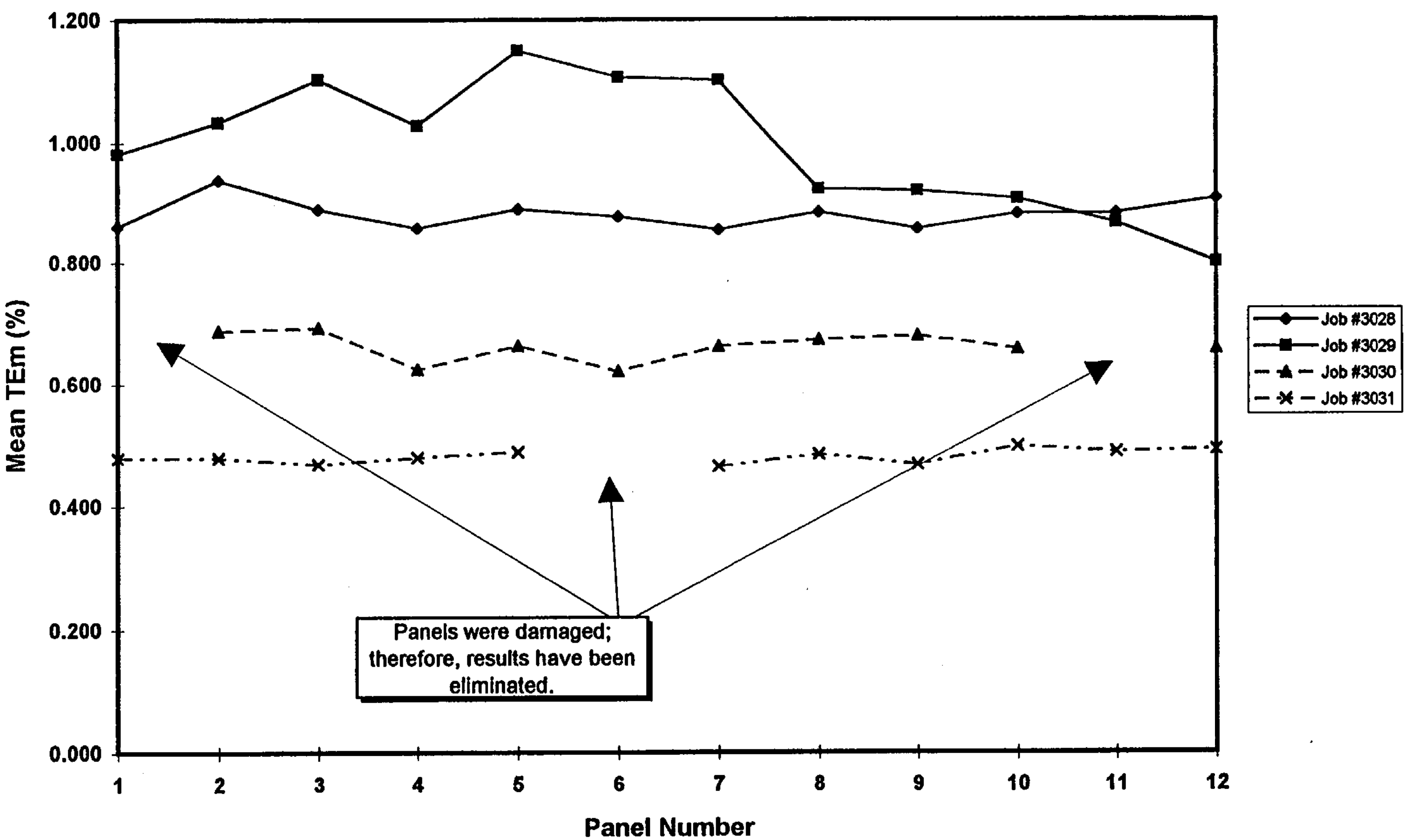


FIGURE 10

Sensitivity of Test Protocol to Spray Gun Design

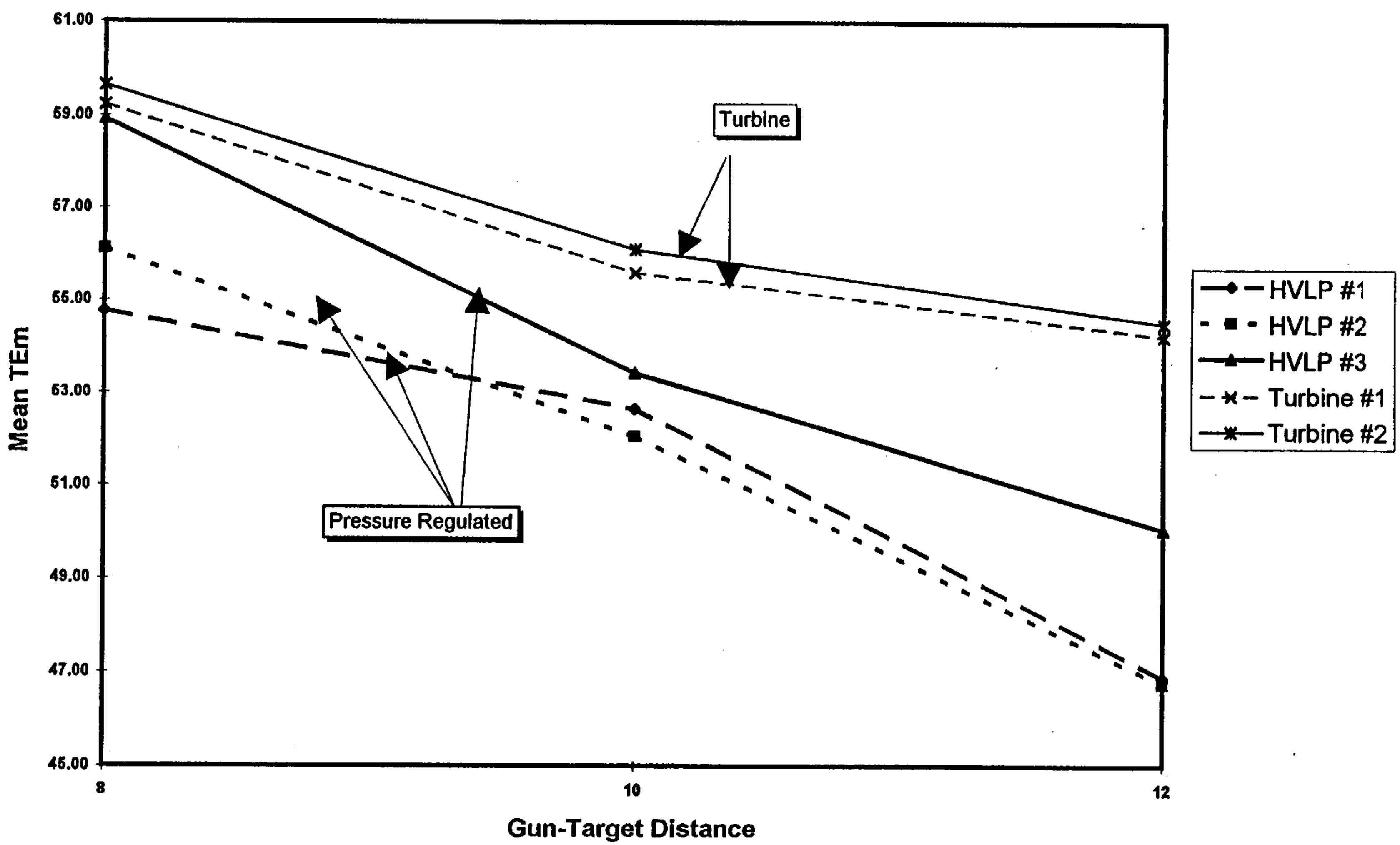


FIGURE 11

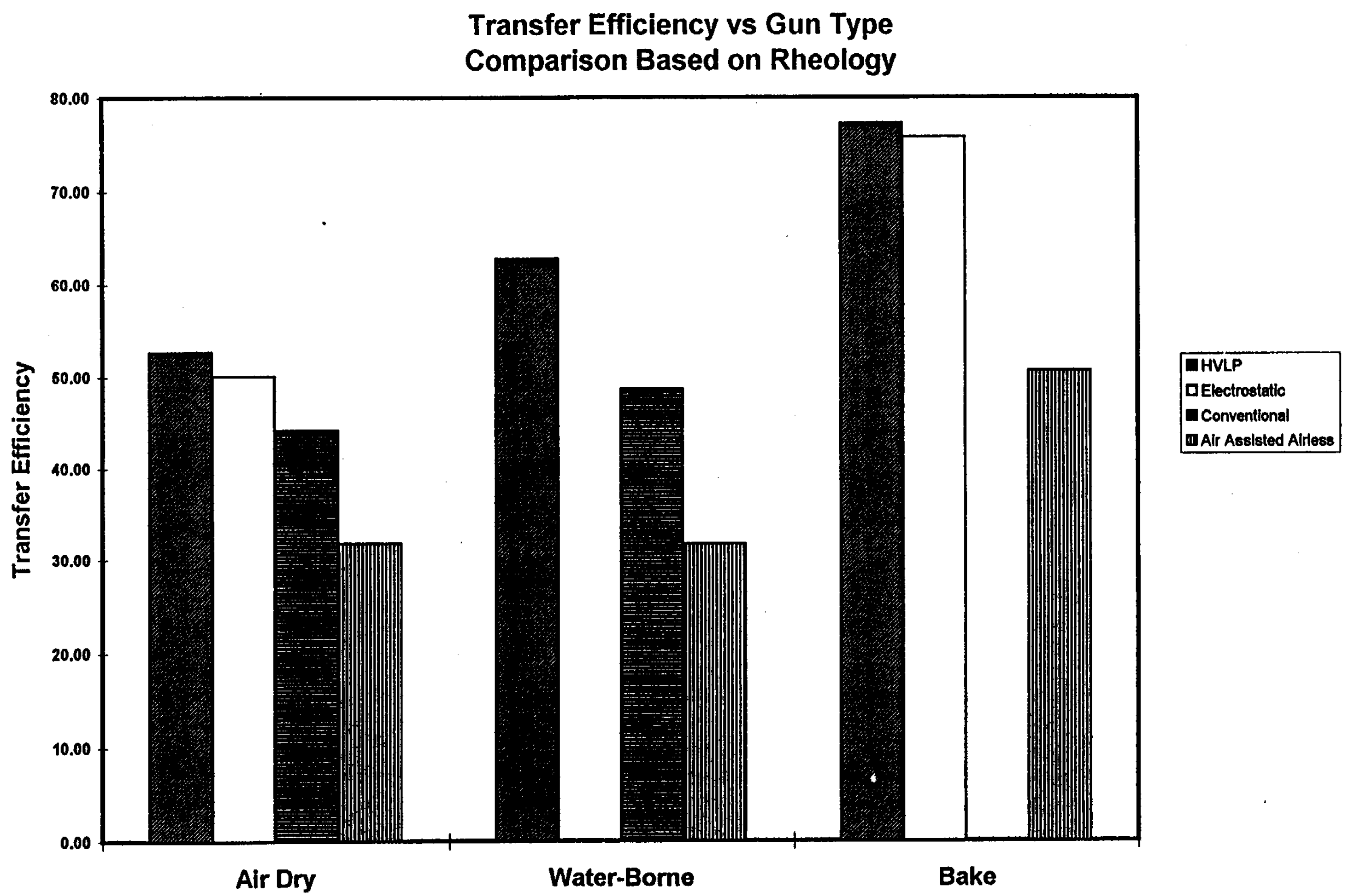

Transfer Efficiency vs Gun Type
Comparison Based on Rheology
Transfer Efficiency
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Air Dry
Water-Borne
Bake
HVLP
Electrostatic
Conventional
Air Assisted Airless

FIGURE 12

Comparison of Gun Ranking When Using Solvent-Borne and Water-Borne Coatings. (Based on Table 17)

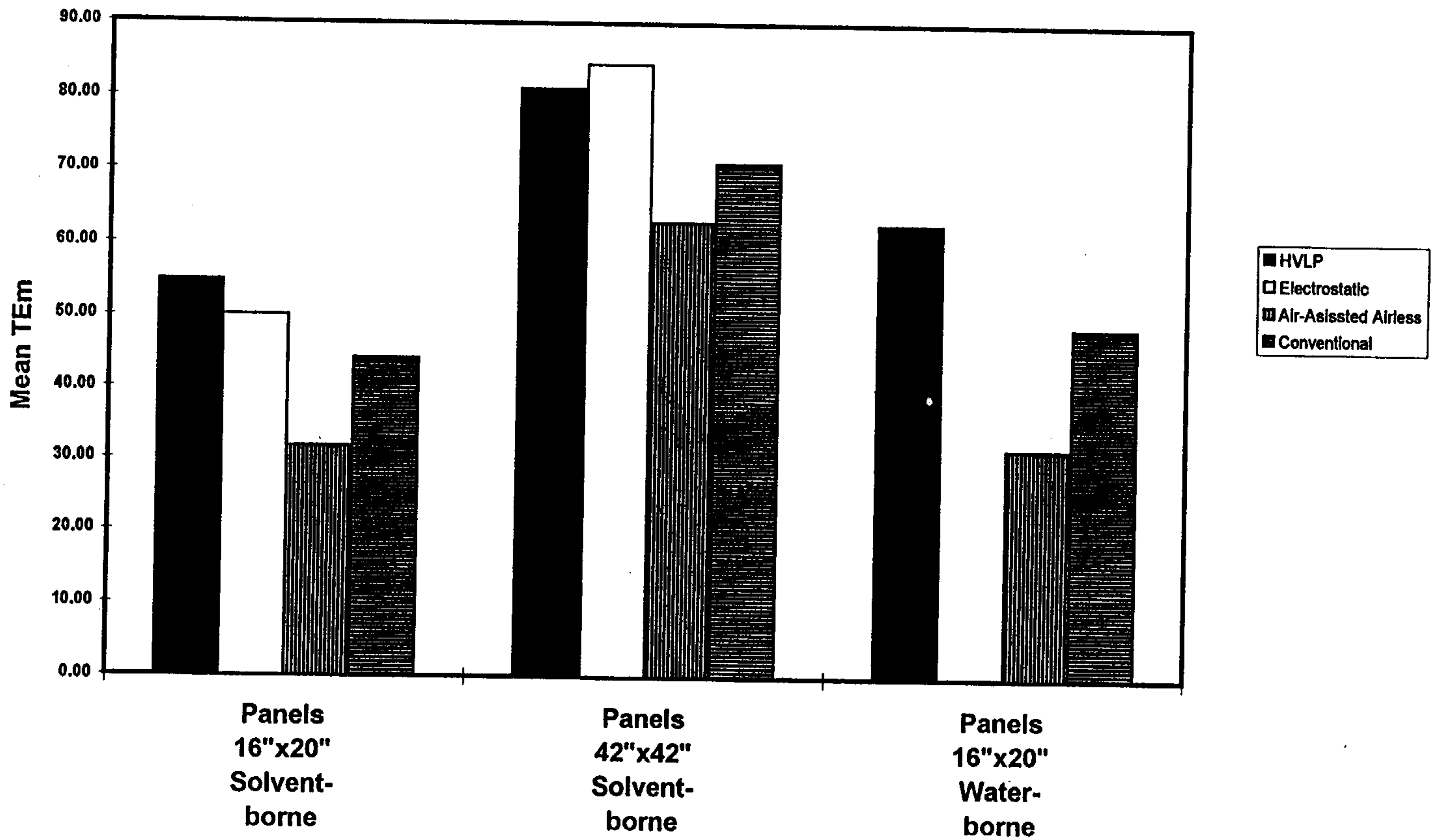


FIGURE 13

Comparison of TE Between Medium Panels in Task #3 and Medium Panel in Task #4

Based on Table 19

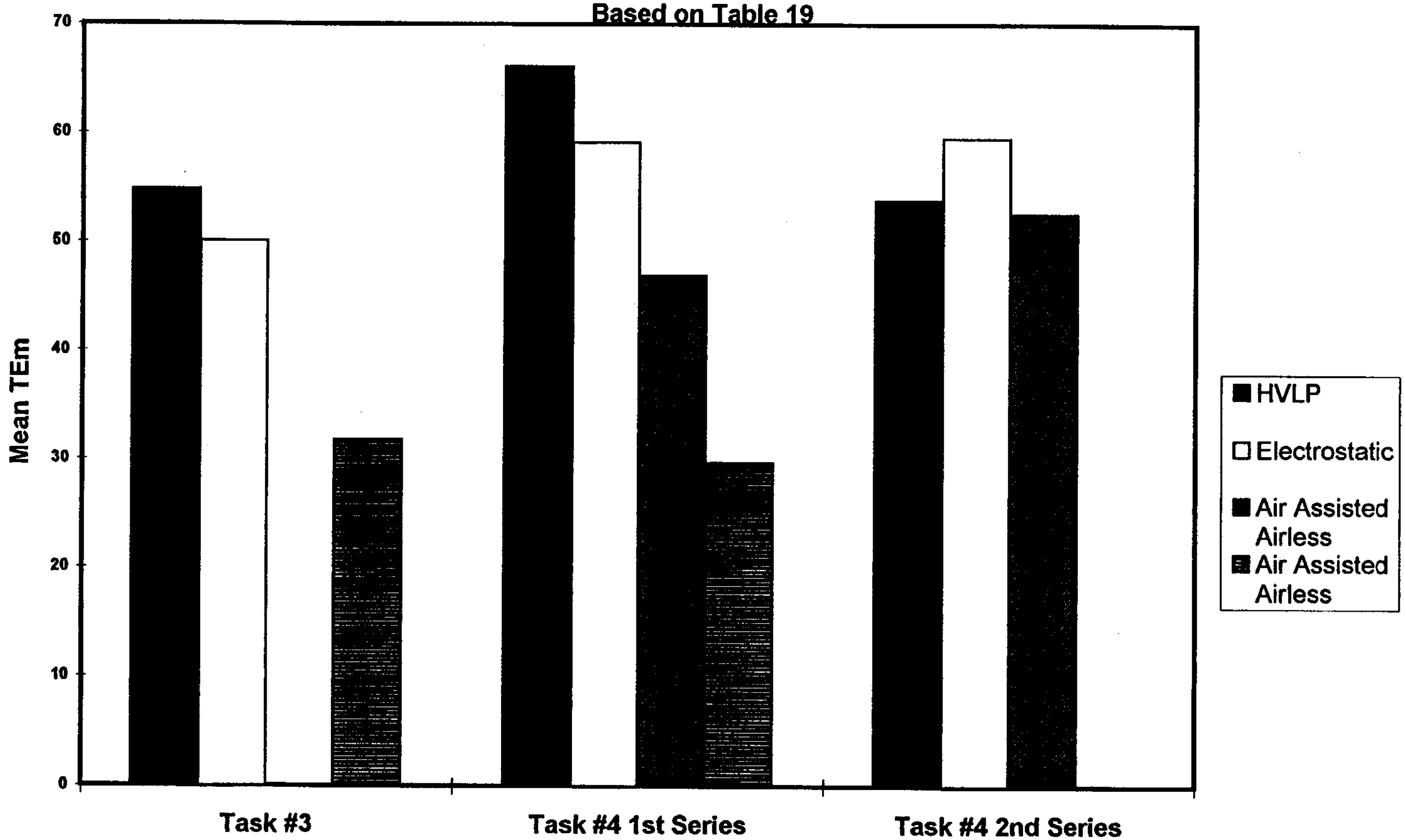


FIGURE 14

FLUID DELIVERY SYSTEM FOR LOW PRESSURE SPRAY GUNS (OPTIONAL)