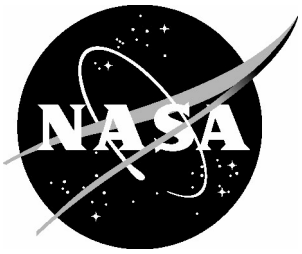
NASA/TM-2004-213268



Water-Based Pressure Sensitive Paint

Donald M. Oglesby and JoAnne L. Ingram
Swales Aerospace

Jeffrey D. Jordan, A. Neal Watkins, and Bradley D. Leighty
Langley Research Center, Hampton, Virginia

October 2004

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

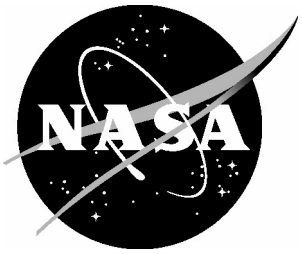
- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2004-213268



Water-Based Pressure Sensitive Paint

Donald M. Oglesby and JoAnne L. Ingram
Swales Aerospace

Jeffrey D. Jordan, A. Neal Watkins, and Bradley D. Leighty
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

October 2004

The use of trademarks or names of manufacturers in the report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Abstract

Preparation and performance of a water-based pressure sensitive paint (PSP) is described. A water emulsion of an oxygen permeable polymer and a platinum porphyrin type luminescent compound were dispersed in a water matrix to produce a PSP that performs well without the use of volatile, toxic solvents. The primary advantages of this PSP are reduced contamination of wind tunnels in which it is used, lower health risk to its users, and easier cleanup and disposal. This also represents a cost reduction by eliminating the need for elaborate ventilation and user protection during application. The water-based PSP described has all the characteristics associated with water-based paints (low toxicity, very low volatile organic chemicals, and easy water cleanup) but also has high performance as a global pressure sensor for PSP measurements in wind tunnels. The use of a water-based PSP virtually eliminates the toxic fumes associated with the application of PSPs to a model in wind tunnels.

Introduction

PSP measurements provide a means for the recovery of global surface pressure distributions on aerodynamic test articles of interest. The PSP is applied by spray application to the model. Most often this is done in the test section of the wind tunnel. This requires the implementation of temporary exhaust ventilation, cleanup with toxic organic solvents, and respiratory protection from organic vapors. Because wind tunnel test sections are not designed for easy removal of toxic vapors, the levels of such materials in both the test section and the wind tunnel building can exceed allowed Occupational Safety and Health Administration (OSHA) levels, even with temporary exhaust fans. The use of water as the primary paint solvent drastically reduces the presence of these volatile organic chemicals (VOCs). For this reason water-based paints are being used wherever possible, both in consumer and industrial applications. The need for a water-based PSP was the basis for work presented here.

PSPs all contain a luminescent compound that is quenched by oxygen (luminescence is reduced by the presence of oxygen), an oxygen permeable binder (polymer), and solvents. Under the appropriate illumination, the intensity of the luminescence emission from the PSP is inversely proportional to the oxygen concentration, and hence pressure at the surface. The interested reader is directed to several excellent reviews (refs. 1–7) for a more detailed description of the measurement science. In general, PSP measurements require a paint, illumination (i.e., excitation) source(s), scientific-grade CCD camera(s), and optical filters for spectral discrimination between excitation and emission light. Images are captured by a PC and image processing is typically performed on a separate platform. In operation, luminescence intensity data can be acquired in either time-averaged or time-resolved mode. In the more widely employed "intensity method," images of the painted surface acquired prior to (or immediately following) wind tunnel operation (wind off) are aligned and ratioed with images acquired at run conditions (wind on). The resulting intensity-ratio images are converted into pressure using either a priori calibration data (determined using a pressure/temperature-controlled apparatus in the laboratory), or by applying an in situ calibration using a small population of pressure taps to compensate for PSP temperature sensitivity and photodegradation (refs. 8–19).

Because the polymers used in water-based paints are emulsion polymers (polymers dispersed in water), an oxygen permeable, emulsion polymer had to be synthesized. The resulting emulsion polymer, combined with pigment, water, and other components, leads to a high performance, water-based PSP.

Materials and Method

In order to prepare a water-based PSP it was necessary to produce a water-dispersed emulsion of a polymer that has good oxygen permeability. The polymer chosen was poly-1,1,1-trifluoroethylmethacrylate-co-isobutylmethacrylate at a 1:1 mole ratio (FEM). The emulsion polymer of FEM was then used in the preparation of a water-based PSP.

Synthesis of Polymer Emulsion (Latex)

Materials

- deionized water
- sodium lauryl sulfate
- 1,1,1-trifluoroethylmethacrylate
- isobutylmethacrylate (IBM)
- nitrogen for purging the reaction mixture and maintaining an inert atmosphere during polymerization
- ferrous sulfate heptahydrate solution (0.3 g/200 ml)
- sodium persulfate
- sodium metabisulfite (0.20 g)
- 70-percent tertiary butyl hydroperoxide
- hydroquinone

Procedure

The apparatus shown in figure 1 was assembled and 43 g of water was placed in the 250 ml 3-neck flask. To allow purge nitrogen to escape, a small strip of paper was placed between the stopper and the ground glass fitting of the reaction vessel side arm opening. The long needle for purging the reaction flask was adjusted so that it was below the water level, and the water was purged with nitrogen for at least 10 min. Mixed and added to the separatory funnel were 23.0 g trifluoroethylmethacrylate and 19.4 g isobutylmethacrylate. The monomers were purged with nitrogen for at least 5 min. Sodium lauryl sulfate (0.4 g) was added to the water in the reaction flask and the purge needle was raised above the surface of the liquid. The stirring speed was adjusted to a level just below that which caused bubbles to rise into the side arms. After purging the monomer mixture for at least 5 min, about half the monomer mixture was added dropwise to the reaction mixture. The temperature of the reaction flask was adjusted to 90 °C. Ferrous sulfate solution (0.8 g) was added to the reaction mixture and sodium persulfate (0.2 g) was added to the solution. When making additions to the reaction mixture, the component was rinsed into the reaction flask using a small stream of deionized water from a wash bottle. Sodium metabisulfite (0.2 g) was added and rinsed down, then 2 drops of tert-butyl hydroperoxide were added. Dropwise addition of the monomer mixture was continued until it had all been added to the reaction vessel. The addition of the second half of the monomer took about 10 min. The nitrogen purge of the separatory funnel was discontinued. The nitrogen purge of the headspace above the reaction mixture was continued. The mixture was allowed to react with vigorous stirring at 90 °C for 30 min. It was necessary to adjust the rate of stirring during the reaction to prevent the contents of the flask from being forced up into the flask necks. The temperature controller was reset to 25 °C and the flask was removed from the heating mantle. It was allowed to cool to below 40 °C. The latex was filtered through a #140 (106 μm) wire mesh filter. It was then transferred to a glass jar, a few crystals of hydroquinone were added, and the jar was sealed tightly.

Preparation of Water-Based PSP

Materials

- propylene glycol
- Dowanol
- Byk 346
- DuPont TriPure R-706 TiO_2
- Lubrizol 2062
- latex of poly-1,1,1-trifluoroethylmethacrylate-co-isobutylmethacrylate

- water (6.00 g)
- N-methylpyrrolidone (NMP)
- platinum tetra(pentafluorophenyl)porphyrin (PtTFPP)
- glassware
- overhead power blender with appropriate Cowles blade

Procedure

Weighed into a tared container of the appropriate size were 3.00 g Dowanol, 1.85 g propylene glycol, and 0.60 g Byk. The mixture was stirred, then TiO_2 was added and blended at low speed (grind) for 25 min using a Cowles blade. Dowanol (6.00 g) and Lubrizol (0.60 g) were weighed into a separate beaker. FEM latex (60.0 g) and water (6.00 g) were weighed into another beaker. NMP (6.0 g) was weighed into a third beaker. PtTFPP (90.8 mg) was weighed and dissolved in the NMP. The NMP/PtTFPP solution was slowly added to the Dowanol/Lubrizol mixture with stirring. This mixture was then added to the FEM latex/water mixture. The latex mixture was added to the grind mixture and blended at moderate speed for 5 min or until thorough blending occurred.

The final paint mixture was filtered through a 106 μm wire screen and transferred to a container and sealed.

Application of Paint to a Model

Paint performance was evaluated in a low speed wind tunnel. The paint was applied using a Paasche Type UT air brush and 40 psi air pressure in a paint spray booth. The model taps were continuously purged with air to prevent clogging. The test article was a "Lockman Wing," 15.2-cm semispan, 10.2-cm chord, NACA-0012 airfoil with a sweep angle of 20°. The model was equipped with 41 pressure taps in three chordwise rows. The paint was air cured for 10 minutes and then gently heated with a hot air gun to anneal the polymer. This annealing procedure gave better adhesion and made cracking of the cured paint less likely. The model was then allowed to air cure for 24 hr. The paint was wet sanded with 1500 grit paper before installing in the test section. The average roughness was 5 μin.

Tunnel Test Conditions

The wind tunnel was a low speed (maximum speed 160 mph), closed-cycle with a 10-in. by 12-in. test section. For this test the wind speed was 160 mph and the angle of attack was 20°.

Results

The water-based paint is easily applied by spraying. When properly applied, the cured paint was smooth without tack. When applied on aluminum surfaces no primer was required; however, adhesion to stainless steel was poor and the use of a self-etching primer was necessary for acceptable adhesion. It was found that the water-based PSP was very sensitive to surface contamination of the test object. The slightest presence of oil or silicone caused the paint to not coalesce or to "fisheye." It was found that the best cleaning procedure was wet sanding (2000 grit paper) with a detergent solution. Water-based paints typically are slow to cure and this one is no exception. It required 24 hr at room temperature to sufficiently cure for testing. Although curing of water-based paints continues for several weeks, no change in the performance of the paint was observed during the test period. The paint may be wet sanded to remove any rough spots caused by dust particles, or to achieve a desired smoothness. After wet sanding with 1500 grit paper it had a typical roughness of less than 5 μin.

Performance of the water-based PSP (WBPSP) was essentially the same as that for a solvent-based PSP using FEM/IBM as the binder. A typical response or calibration curve is shown in figure 2. A typical pressure sensitivity at atmospheric pressure is 6.2 percent/psia, or a slope of 0.91 for a plot of I_o/I versus P/P_o. The temperature sensitivity is typically −1.4 percent/°C. Although there is a slight

bending over of the Stern-Volmer plot, response over a typical wind tunnel pressure test range is essentially linear.

Global pressure images of the test model are shown in figures 3(a) and (b), and the correlations between the taps and the pressure as measured from the PSP are shown in figures 4(a) and (b).

Concluding Remarks

The combination of an oxygen permeable polymer and a platinum porphyrin-type luminescent compound in a water matrix to give a PSP that performs well without the use of volatile, toxic solvents represents an important contribution to PSP paint options. The primary advantages of a water-based PSP are reduced contamination of wind tunnels in which it is used, lower health risk to its users, and easier cleanup and disposal. This also represents a cost reduction by eliminating the need for elaborate ventilation and user protection during application.

References

1. Peterson, J. I; and Fitzgerald, V. F.: New Technique of Surface Flow Visualization Based on Oxygen Quenching of Fluorescence. *Rev. Sci. Instrum.*, vol. 51, no. 5, May 1980, pp. 133–136.

2. Crites, B. C.: Measurement Techniques—Pressure Sensitive Paint Technique. Lecture Series 1993-05, von Karman Institute for Fluid Dynamics, 1993.

3. McLachlan, B. G.; and Bell, J. H.: Pressure-Sensitive Paint in Aerodynamic Testing. *Experimental Thermal and Fluid Science*, vol. 10, 1995a, pp. 470–485.

4. McLachlan, B. G.; Kavandi, J. L.; Callis, J. B.; Gouterman, M.; Green, E.; and Khalil, G.: Surface Pressure Field Mapping Using Luminescent Coatings. *Experiments in Fluids*, vol. 14, 1993a, pp. 33–41.

5. Kavandi, J.; Callis, J. B.; Gouterman, M. P.; Khalil, G.; Wright, D.; Green, E.; Burns, D.; and McLachlan, B.: Luminescent Barometry in Wind Tunnels. *Rev. Sci. Instrum.*, vol. 61, no. 11, 1990, pp. 3340–3347.

6. Morris, M. J.: Aerodynamic Applications of Pressure Sensitive Paint. AIAA J., 31 (3), March 1993, pp. 419–421.

7. Liu, T.; Campbell, B.; Burns, S.; and Sullivan, J.: Temperature- and Pressure-Sensitive Luminescent Paints in Aerodynamics. *Appl. Mech. Rev.*, vol. 50, no. 4, 1997a, pp. 227–246.

8. Donovan, J. F.; Morris, M. J.; Pal, A.; Benne, M. E.; and Crites, R. C.: Data Analysis Techniques for Pressure- and Temperature-Sensitive Paint. AIAA Paper 93-0176, 1993.

9. Abdel-Aziz, Y. I.; and Karara, H. M.: Direct Linear Transformation From Comparator Coordinates Into Object Space Coordinates in Close-Range Photogrammetry. Paper presented at Close Range Photography Symposium (Urbana, Illinois), Jan. 1971, pp. 1–18.

10. Le Sant, Y.; Deleglise, B.; and Mebarki, Y.: An Automatic Image Alignment Method Applied to Pressure Sensitive Paint Measurements. ONERA, TP No. 1997-162, ICIASF ’97 B International Congress on Instrumentation in Aerospace Simulation Facilities, 17th, Pacific Grove, CA, Sept. 29–Oct. 2, 1997, Record; Piscataway, NJ, Institute of Electrical and Electronics Engineers, Inc., 1997, pp. 57–65.

11. Shanmugasundaram, R.; and Samareh-Abolhassani, J.: Pressure Sensitive Paint Image Registration Using Modified Scatter Data Interpolation. Flow Visualization VII; Proceedings of the 7th International Symposium on Flow Visualization, Seattle, WA, Sept. 11–14, 1995; New York, Begell House, Inc., 1995, pp. 812–817.

12. Weaver, W. L.; Jordan, J. D.; Dale, G. A.; and Navarra, K. R.: Data Analysis Methods for the Development and Deployment of Pressure Sensitive Paints. AIAA Paper 99-0565, 1999.

13. Ardasheva, M. M.; Nevsky, L. B.; and Pervushin, G. E.: Method of Pressure Distribution Measurement With the Indicating Coating. *J. App. Mech. & Tech. Phys.*, vol. 26, no. 4, 1985, pp. 469–474.

14. Andreev, A.; Bukov, A.; Ipatov, M.; Kabin, S.; Nushtaev, P.; Orlov, A.; Mosharov, V.; Radchenko, V.; Pestsly, V.; and Fonov, S.: Pressure Field Investigation by LPS Technology on the Aerospacecraft Model Buran in the TsAGI Wind Tunnel T-112. Preprint No. 75, TsAGI, Moscow, 1993.

15. Andreev, A. O.; Bykov, A. P.; Ipatov, W. M.; Kabin, S. V.; Nushtaev, P. D.; Orlov, A. A.; Mosharov, P. E.; Radchenko, V. N.; Pesetsky, V. A.; and Fonov, S. D.: Pressure Fields Investigation by LPS Technology on the Aerospacecraft Model. J. Phys. III France 4 (1994), pp. 2317–2337.

16. Bell, J. H.; and McLachlan, B. G.: Image Registration for Pressure-Sensitive Paint Applications. *Experiments in Fluids*, vol. 22, no. 1, Nov. 1996, pp. 78–86.

17. Bell, J. H.; and McLachlan, B. G.: Image Registration for Luminescent Paint Sensors. AIAA Paper 93-0178, 1993.

18. Bosnyakov, S.; Bykov, A.; Coulech, V.; Fonov, S.; Morozov, A.; Moskalik, V.; Moskalik, L.; Orlov, A.; Radchenko, V.; and Tarassov, N.: Blade Deformation and PSP Measurements on a Large Scale Rotor by Video-Metric System. Proceedings of 17th International Congress on Instrumentation in Aerospace Simulation Facilities (ICIASF), Monterey, CA, 1997.

19. Ruyten, W.: Toward an Integrated Optical Data System for Wind Tunnel Testing. AIAA Paper 99-0181, AIAA, Aerospace Sciences Meeting and Exhibit, 37th, Reno, NV, Jan. 11–14, 1999.

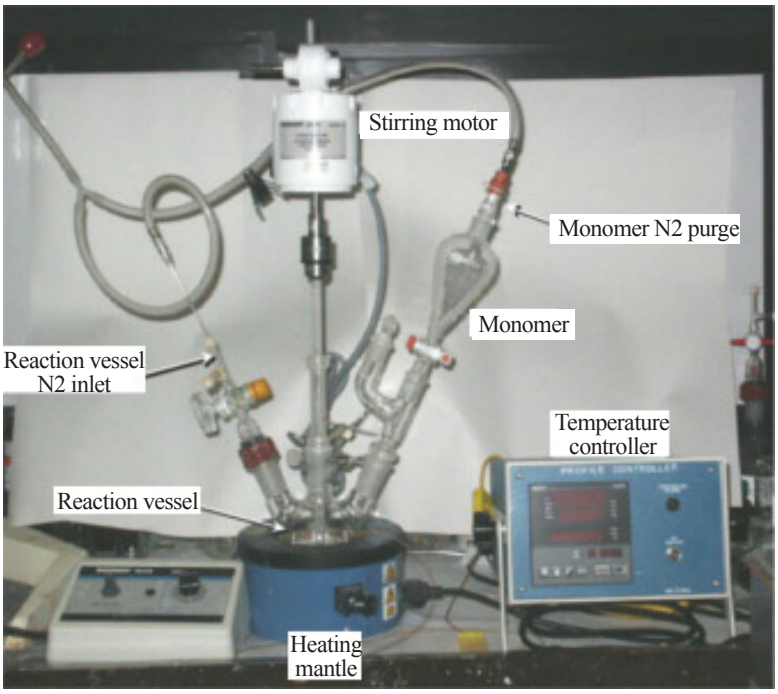


Figure 1. Apparatus for synthesizing FEM emulsion polymer.

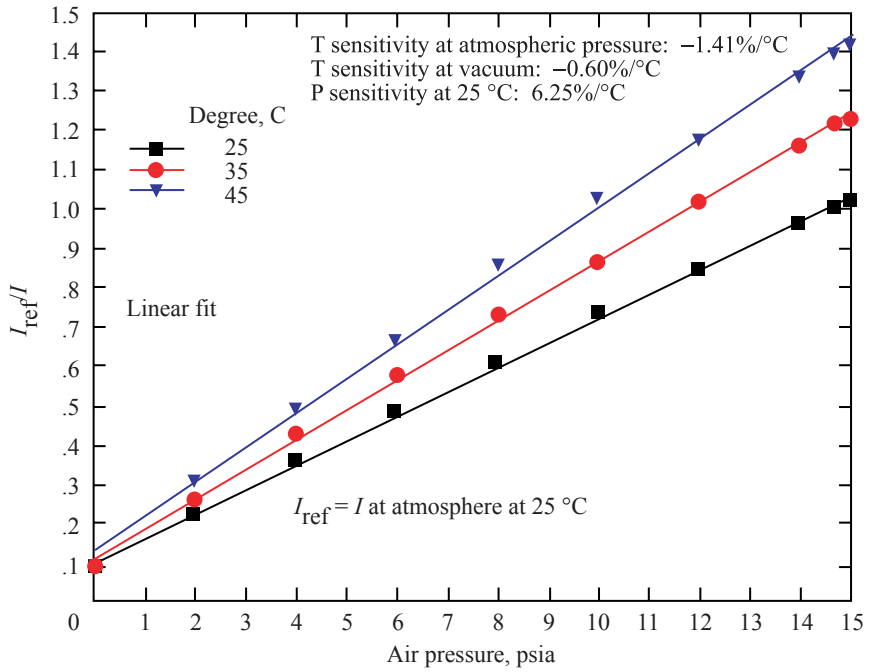
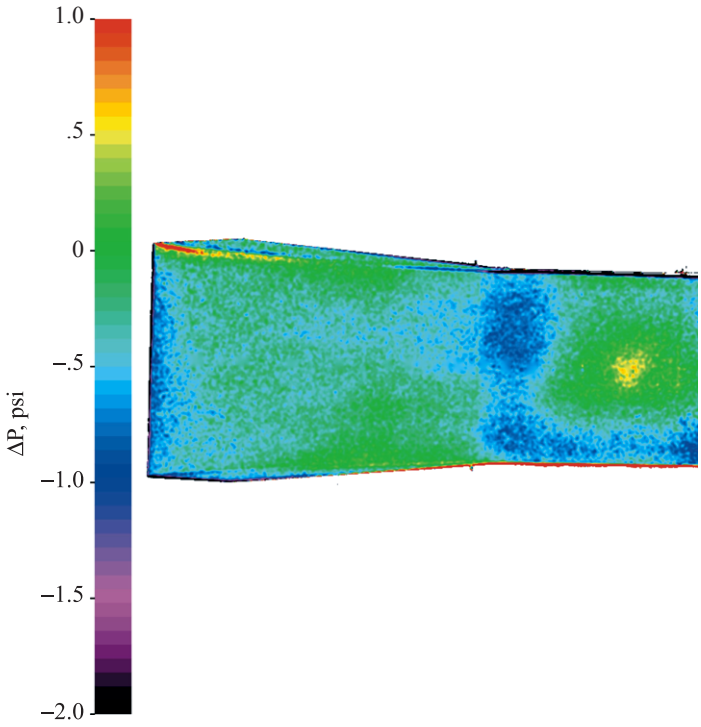
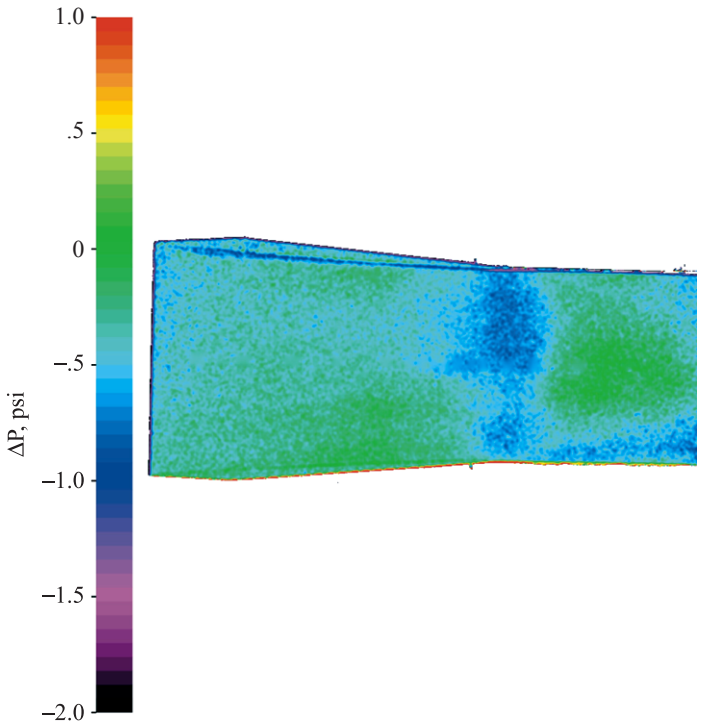


Figure 2. Pressure (P) response curves at different temperatures (T) for water-based PSP.

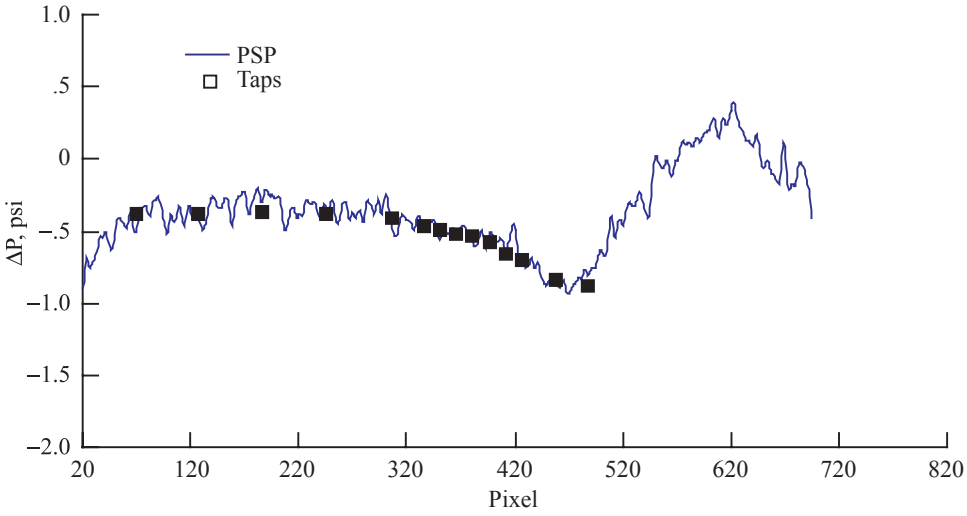


(a) Ratio of run image to pre–wind-off image.

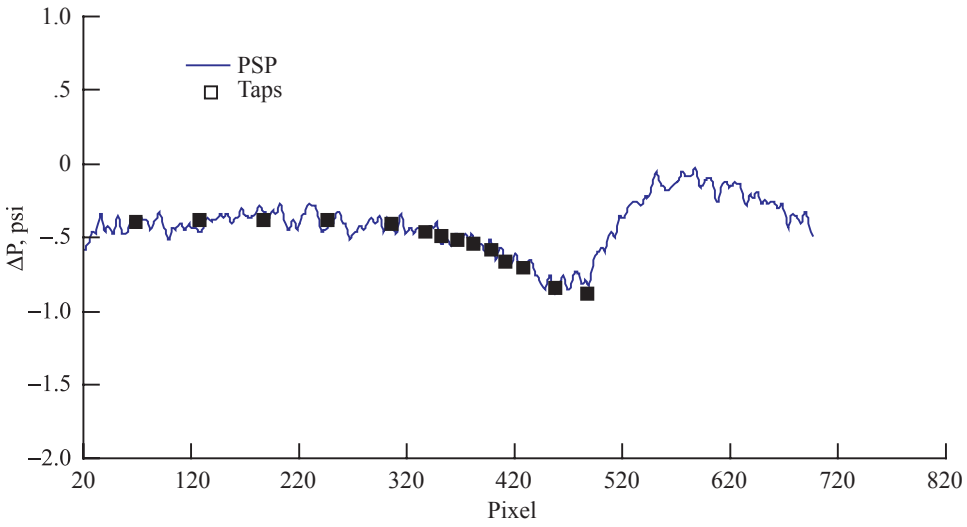


(b) Ratio of run image to post–wind-off image.

Figure 3. Global pressure distribution.



(a) Image ratio based on using pre–wind-off image.



(b) Image ratio based on using post–wind-off image.

Figure 4. Correlation between taps and PSP pressure data.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01- 10 - 2004	Technical Memorandum	

4. TITLE AND SUBTITLE
Water-Based Pressure Sensitive Paint

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Oglesby, Donald M.; Ingram, JoAnne L.; Jordan, Jeffrey D.;
Watkins A. Neal; and Leighty, Bradley D.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
23-090-80-40

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-18349

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2004-213268

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 35
Availability: NASA CASI (301) 621-0390 Distribution: Standard

13. SUPPLEMENTARY NOTES
Oglesby and Ingram, Swales Aerospace. Jordan, Watkins, and Leighty, Langley Research Center.
An electronic version can be found at http://techreports.larc.nasa.gov/ltrs/ or http://ntrs.nasa.gov

14. ABSTRACT

Preparation and performance of a water-based pressure sensitive paint (PSP) is described. A water emulsion of an oxygen permeable polymer and a platinum porphyrin type luminescent compound were dispersed in a water matrix to produce a PSP that performs well without the use of volatile, toxic solvents. The primary advantages of this PSP are reduced contamination of wind tunnels in which it is used, lower health risk to its users, and easier cleanup and disposal. This also represents a cost reduction by eliminating the need for elaborate ventilation and user protection during application. The water-based PSP described has all the characteristics associated with water-based paints (low toxicity, very low volatile organic chemicals, and easy water cleanup) but also has high performance as a global pressure sensor for PSP measurements in wind tunnels. The use of a water-based PSP virtually eliminates the toxic fumes associated with the application of PSPs to a model in wind tunnels.

15. SUBJECT TERMS
Pressure sensitive paint; Polymer emulsification; Optical pressure measurements; Water-based paints

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	13	(301) 621-0390