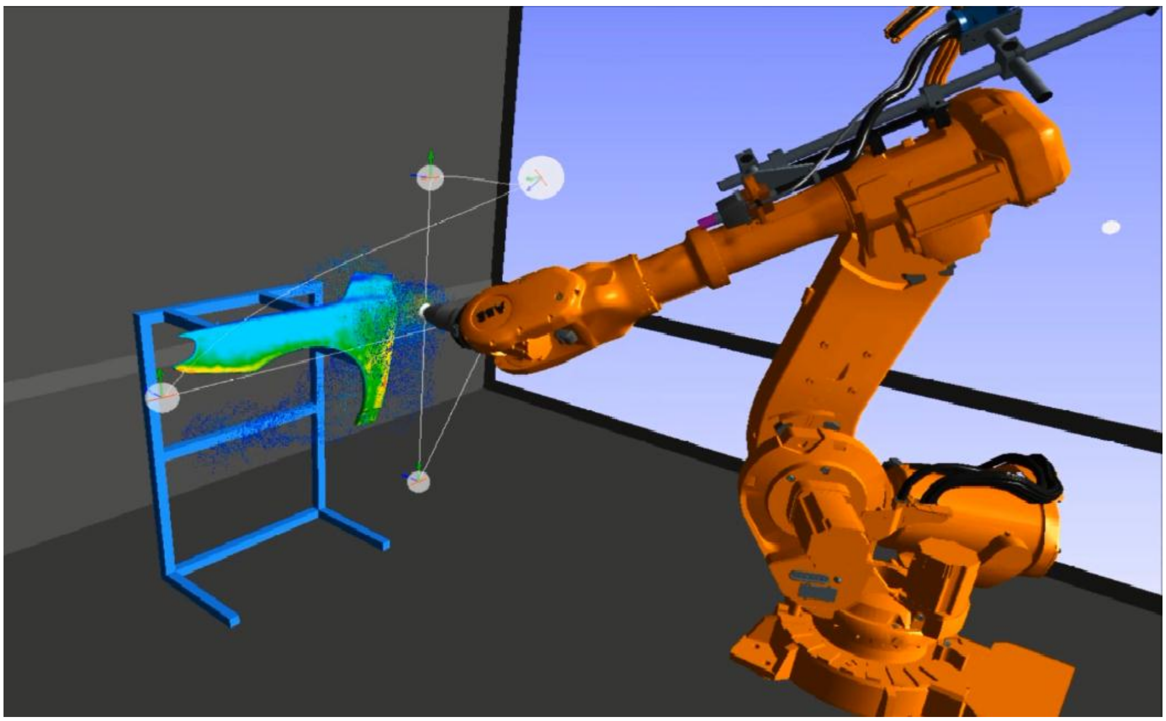
# The Virtual Paint Shop



Project within FFI-Sustainable Production Technology

Authors: Johan S. Carlson, Fredrik Edelvik, Henrik Söröd, Jörg Wohner

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# Content





# 1. Executive summary

The surface treatment is the process in an automotive factory that consumes most energy, water and chemicals, and produces most waste and pollution. Approximately 36 percent of the energy for OEM operations in automotive manufacturing is consumed in the paint shops. Furthermore, even though virtual tools are frequently used to support an effective product and production realization in other parts of the automotive factory that is not the case in the paint shop. In the paint shop the product preparation, when robot paths and process parameters are fine-tuned, is a slow and costly trial-and-error procedure, where a large number of prototypes are painted, washed and painted again etc. Therefore, the paint shop not only has a large environmental impact it is also a bottleneck in production.

Today, the margins of automotive manufacturers are moderate and competition is fierce. To support sustainable production and an efficient product development new virtual tools for simulation and optimization are necessary and can give a competitive advantage. The overall objective of the project is to develop unique math-based methods and tools for simulation of the key paint and surface treatment process in automotive paint shops. In particular, by enabling detailed simulations of current and future paint and surface treatment processes these processes can be further developed and optimized

- to be more environmental friendly,
- to be more energy efficient,
- to be more cost efficient,
- to give a higher product quality result.

The main goals are

- Methods and tools for accurate prediction of paint thickness on a complex car part in just a few hours on a standard LapTop.
- Methods for simulation of the break-up of paint into droplets to reduce the need for advanced near-bell measurements of size distributions and velocities.
- Methods and tools for accurate prediction of sealing material laydown and automatic generation of robot paths.
- Methods and prototype tools for simulation of fluid access and drainage in a complete car geometry.
- Methods and prototype tools that integrate scanning and path planning for automatic generation of robot paths for spray painting of low-volume products.

This project covers essentially all the key paint and surface treatment processes in automotive paint shops. The first seven work packages focus on the modeling and simulation of the different processes and the remaining three concerns the validation, software demonstrators and management. The general approach in the first work packages is to develop and implement models in a general form and continuously compare simulations to experiments, initially on simplified test cases that still retain the relevant physics, and later on full scale problems. Only when the full model compares well to experiments, model simplifications to speed-up the simulations are initiated. The results are continuously implemented in the IPS software demonstrator that is available to the project partners.

The project has been carried out in the following ten work packages:

- WP1: Modeling and simulation of near bell paint droplet break-up in electro static painting,
- WP2: Modeling and simulation of cavity wax and sealing application,

- WP3: Modeling and simulation of fluid access and drainage of paint fluids and E-coat film build,
- WP4: Automatic generation of robot paths thru 3D scanning technology,
- WP5: Modeling and simulation of oven curing in paint ovens,
- WP6: Optimization of process holes for surface treatment of vehicle bodies,
- WP7: Thermal spraying,
- WP8: Measurements and validation,
- WP9: Surface treatment demonstrator,
- WP10: Project management.

The project results show that it is possible to accurately simulate spray painting of a complex car part in only a few hours on a standard computer. This is an extreme improvement compared to earlier approaches that require weeks of simulation time. Unique algorithms for coupled simulations of air flows, electrostatic fields and charged paint particles have made this possible. Several successful measurements campaigns have been performed with very good results. A similar break-through in simulation performance has also been achieved for the sealing application. The methods and algorithms are integrated in the CAE-tool IPS and are thus ready for industrial implementation. By integrating and further develop the available technologies of path planning, 3D scanning and spray painting simulation a first approach to automatically generate optimized paths for paint robots from an analysis of the component's surface has been developed. For the electro dipping application the results show a great potential for accurate analysis of the fluid access and drainage far beyond the capabilities of the current tools. The long term funding from Vinnova has made it possible to build-up a world-leading research team for paint and surface treatment processes with expertise in modeling and simulation, advanced measurement and validation, and industrial process knowledge.

# 2. Background

The surface treatment is the process in an automotive factory that consumes most energy, water and chemicals, and produces most waste and pollution. Approximately 36 percent of the energy for OEM operations for automotive manufacturing is consumed in the paint shops. Furthermore, today's product preparation when robot paths and process parameters are fine-tuned is a slow and costly trial-and-error procedure, where a large number of prototypes are painted, washed and painted again etc. The result depends heavily on how well the plant people have succeeded with the task of setting the different process parameters. The setting is complicated by the fact that every combination of product specification, material specification, product design and equipment design is unique and a small deviation can give large effects on the final result. Discovering defects at the end of the production line, or even worse by the costumer, can be extremely costly.

There is therefore a great need to improve the product preparation process and this is absolutely necessary to meet the future demands on fast adaption and tailored solutions for new material combinations and products. The possibility to perform systematic simulations is then essential and would contribute to sustainable production by reducing the number of prototypes that needs to be painted, and by making it possible to optimize the processes with respect to quality, cost and environmental impact.

However, the spray painting and surface treatment processes pose great challenges for mathematical modelling and simulation, and are characterized by multi-phase and free surface flows, multi-physics, multi-scale phenomena, and large moving geometries. On the market today such software is therefore not available or has very limited performance.

# 3. Objective

The objective of the project is to develop unique math-based methods and tools for simulation of the key paint and surface treatment process in automotive paint shops and integrate them in a user-friendly software demonstrator. In particular, by enabling detailed simulations of current and future paint and surface treatment processes these processes can be further developed and optimized

- to be more environmental friendly,
- to be more energy efficient,
- to be more cost efficient,
- to give a higher product quality result.

The main goals are

- Methods and tools for accurate prediction of paint thickness on a complex car part in just a few hours on a standard LapTop.
- Methods for simulation of the break-up of paint into droplets to reduce the need for advanced near-bell measurements of size distributions and velocities.
- Methods and tools for accurate prediction of sealing material laydown and automatic generation of robot paths.
- Methods and prototype tools for simulation of fluid access and drainage in a complete car geometry.
- Methods and prototype tools that integrate scanning and path planning for automatic generation of robot paths for spray painting of low-volume products.

# 4. Project realization

This project covers essentially all the key paint and surface treatment processes in automotive paint shops and the first seven work packages each address different modeling and simulation aspects of these processes. The general approach is to develop and implement models in a general form and continuously compare simulations to experiments, initially on simplified test cases that still retain the relevant physics, and later on full scale problems. Only when the full model compares well to experiments, model simplifications to speed-up the simulations are initiated. The results are continuously implemented in the IPS software demonstrator that is available to the project partners.

## 4.1 Workpackages

**WP1: Modeling and simulation of near bell paint droplet break-up**

This work package has mainly been conducted as a PhD project. The student Björn Andersson is employed at FCC and has been supervised by researchers at FCC and two professors at the fluid dynamics division at Chalmers. The PhD defence is planned for early fall 2013. The ultimate goal of the work is to model and simulate the break-up of the paint liquid into droplets in the near bell region, to reduce the need for costly measurements of droplet size distributions, and droplet and air velocities, which currently are used as input for the paint thickness prediction simulations. Models for the secondary break-up have been developed and validated, and detailed simulations of the primary break-up of water drops have also been accomplished. A major focus has been the automatic generation of input data for the paint thickness simulation from detailed simulations of the near bell region.

The spray paint demonstrator has been made ready for production use and extensively validated against measurements at Swerea IVF, Fraunhofer IPA and GM.

**WP2: Modeling and simulation of cavity wax and sealing application**

The vehicle body consists of many sheets joined together by welding and other joining technologies. It is unavoidable that the final design of floor, doors, hood and trunk lid contains cavities that need to be sealed to prevent corrosion problems. In this work package the focus has been to develop and implement mathematical algorithms for process simulation of the sealing material laydown. To verify the simulations the resulting width, thickness and shape of applied material on test plates as a function of time and spraying distance have been compared to experiments. Much effort has been spent on the implementation to make it possible to include detailed simulations in the production preparation process and off-line programming of the sealing robots.

**WP3: Modeling and simulation of fluid access and drainage and E-coat film build**

To protect the vehicle from corrosion it is dipped into a bath with an electrolyte liquid. Through an electrochemical process a protecting layer is build up on the exposed surfaces. It is crucial that the process and product are designed in such a manner that no air pockets occur when the body is dipped into the bath and that all the fluid is drained from the cavities when the body is leaving the bath. A dynamic simulation of a moving vehicle in the bath puts extreme challenges on the simulation methods and algorithms involving two-phase flow and multi-scale phenomena. The focus in this work package has been on modeling and simulation of the access and drainage of water and neglecting the electrochemical effects. A novel volume of fluids (VOF) method has been developed for the two-phase flow. Validation of the simulation on a test cube has been carried out and the dipping of a full car has been demonstrated.

**WP4: Automatic generation of robot paths thru 3D scanning technology**

This work package targets painting of complex components in low volume series, which have until today been painted manually due to the lead time of programming a paint robot to perform the same operation. By integrating and further develop the available technologies of path planning, 3D scanning and spray painting simulation the aim is to automatically generate optimized paths for paint robots from an analysis of the component's surface. Benefits would then include an increased automation of the spray painting process and a more uniform quality level.

The work has included the development of algorithms for automatic generation of curves for coverage of complex surfaces. Also the collision free curve following algorithms have been further developed in this WP to multiple TCP and flat brush options and can be used to automatically generate the robot paths including (i) task planning to find promising configurations and motions that can follow each stroke/curve, (ii) sequence optimization and motion planning to select one solution for each stroke/curve and connect them by efficient motions and in a sequence minimizing the cycle time. The path planner has also been extended to work on hybrid models with a mixture of triangles and scanned point clouds.

**WP5: Modeling and simulation of oven curing in paint ovens**

This work package relied on a stand-alone oven curing project at Volvo Cars that was not started. Despite this fact some work has been done on developing methods and algorithms for simulation of convective and IR ovens. A future research project would benefit from these results.

**WP6: Optimization of process holes for surface treatment of vehicle bodies**

The design and location of process holes are important for the fluid access and drainage during the dipping process treated in WP3. The delivery from this work package included a visualization in the demonstrator to support a manual optimization of the location of process holes.

**WP7: Thermal spraying**

In this work package the models and simulation techniques developed in the previous spray painting project have been applied to thermal spraying to estimate the amount of work required to extend the available tools to that application. Thermal spraying is commonly used in manufacturing of for instance airplane engines and turbines. The work package was performed as a Master thesis project in co-operation with Volvo Aero. The coating thickness on a test geometry has been compared to measurements.

**WP8: Measurements and validation**

In this work package the required measurement methodology has been developed and measurements have been carried out to ensure a successful implementation of the methods and algorithms in WP1 to WP7.

**WP9: Surface treatment demonstrator**

The deliveries from this work package have been demonstrators on the IPS platform that integrate the methods and algorithms developed in WP1 to WP6.

# 5. Results and deliverables

Unique methods and tools have been developed that for the first time make it possible to accurately simulate spray painting and bodywork seam sealing in just a few hours on a standard computer. The only other tool on the market ends up with simulation times in the order of weeks for similar simulations. The methods and tools have been extensively validated on real industrial cases with very good agreement between simulation results and measurements. The fast simulation times make it possible to use detailed simulations during the product preparation phase and offline programming of the paint and sealing robots. The new methods for droplet break-up significantly reduce the need for costly measurements of the particle size distributions and velocities close to the bell. This fact makes the spray painting software easier to use and is also important for the later dissemination of the tools to other companies.

From research on numerical methods the novel volume of fluids method for two-phase flows is a distinct highlight from the project. Several alternatives are available in the literature but they typically need to apply an under relaxation of the time step and severe constraints on the mesh. Our solution is fully stable and an adaptive mesh can be used at and along the interface. Both WP2 and WP3 have benefited a lot from this new method.

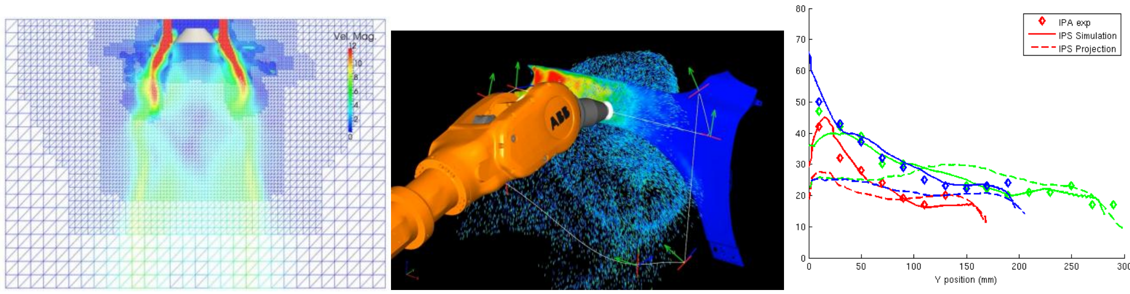


Figure 1. Snapshot from a near bell simulation (left). A robot painting a car fender in IPS Virtual Paint (middle). A validation of the paint thickness on a painted car fender (right).

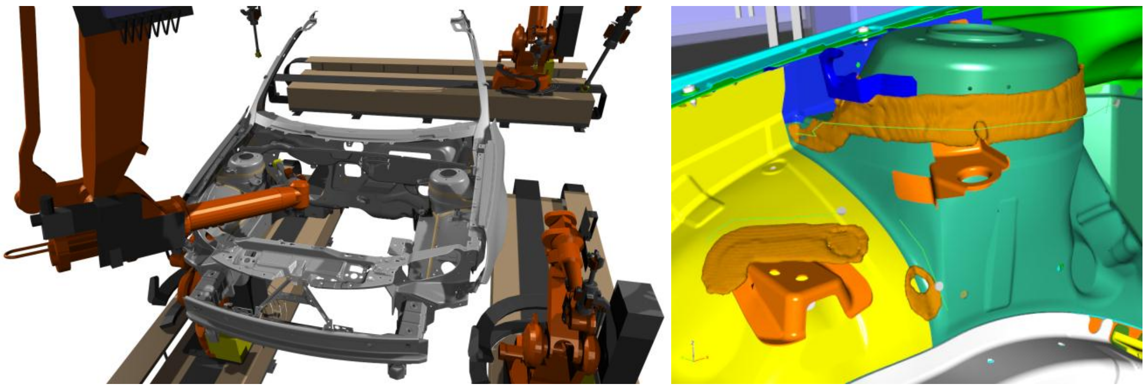

Figure 2. A robot is applying sealing material to a seam on the front damper in IPS Virtual Sealing (left) and an example of simulated sealing beads (right).

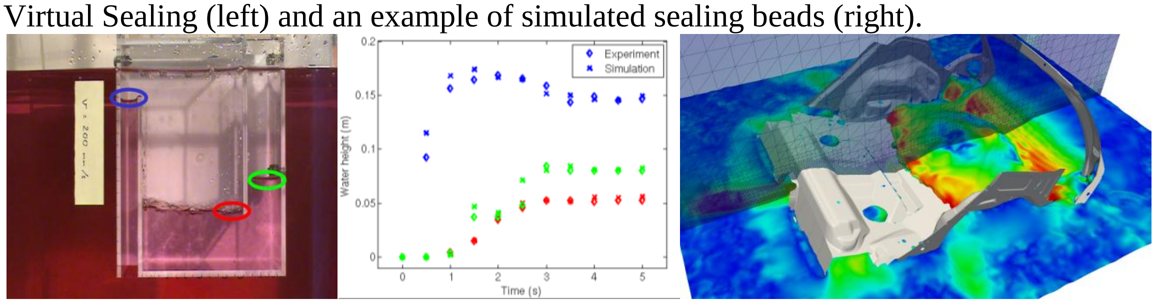


Figure 3. Comparison of the water height at three different locations of the test cube (left, middle). Part of a Volvo V60 dipped in a water bath - note how the water enters through the small holes (right).

A first program for automatic generation of painting robot paths for a general geometry was developed as a Master thesis at Swerea IVF. The idea is to generate a "first guess", which can be evaluated in simulations rather than by painting real products. The program takes as input a CAD or scanned 3D-geometry. The operator specifies a number of input parameters and a series of geometric evaluations are used to calculate the shortest possible path that covers the entire object, and by parallel IPS simulations it is possible to quickly get a good idea on how to setup the painting process. The automatic generation of paths have been tested for implementation in a robot controller (ABB RobotStudio) and generated great interest from the industry.

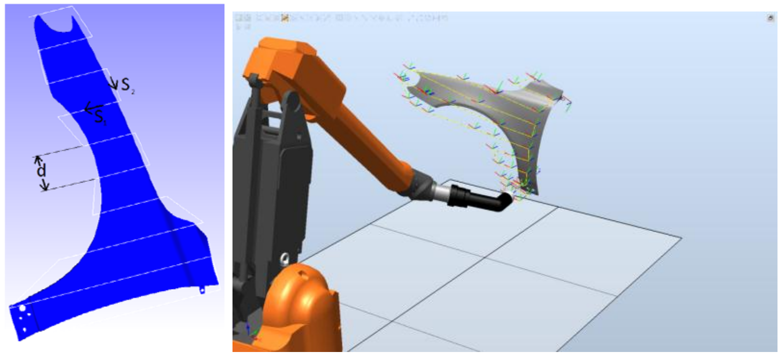

Figure 4. Example of an automatically generated path ran in RobotStudio.

A second and more general approach for automatic generation of curves is ongoing. This approach is based on three independent steps (i) create start segment, (ii) find displacement distance between segments/strokes, and (iii) velocity tuning along the segments. The start segment is chosen to minimize the total number of turns and the risk for segment crossing. This is done by finding a close to geodesic curve in the middle of the surface. The displacement is calculated by minimizing the thickness variation orthogonal to the segment. Velocity tuning is formulated as a semi-definite optimization problem with the objective function "thickness variation along the segment". This work will be further developed and validated during 2013.

Given the enormous complexity of the surface treatment processes the focus in most of the work packages has been to enable a detailed simulation. However, the ultimate goal is to automatically determine the process parameters that produce the best possible result. In Figure 5 a snapshot from a prototype decision support system based on multi-criteria optimization is shown. The engineer can interactively use such a system to choose a solution which is a good compromise between quality, cost and stability of the oven curing process.

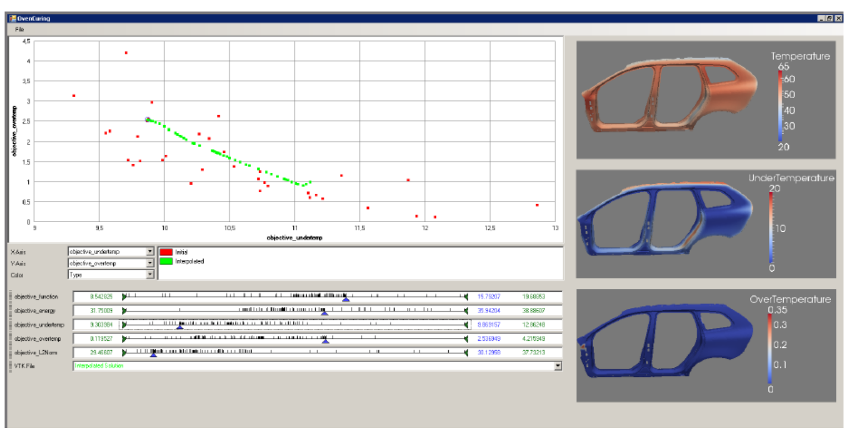


Figure 5. Snapshot from a decision support system based on multi-criteria optimization of oven curing. To the right the investigated geometry is shown, with the colors representing end surface temperature for a specific oven setting. To the left is the outcome of different trials plotted as two of the target functions versus each other.

The tools are being tested by several of the companies involved in the project and the spray painting and sealing modules are expected to be commercially released during 2013. The work has resulted in six journal publications, nine conference papers, three master theses, one bachelor thesis and one licentiate thesis. The project will result in a PhD thesis in fluid dynamics at Chalmers during 2013.

Related detailed technical result highlights from the project are:

- A novel volume of fluid method for robust multiphase flow simulations.
- A published second-order accurate immersed boundary method that can handle thin objects.
- A published immersed boundary method for flow with heat transfer.
- An implicit solver for the momentum equation leading to 10-100 times longer time-steps in smooth particle hydrodynamics (SPH).
- An MPI parallelization of the fluid flow solver IBOFlow.
- Acceleration of the simulation by solving the linear systems of equations on the graphics card.
- The break-up of a small bubble simulated using the VOF method.
- A novel algorithm for optimizing the robot paths on a semi-complex object.
- A statistically based diffusion density method for paint thickness integration.

## 5.1 Delivery to FFI-goals

- The project has developed methods, algorithms and software tool that contribute to sustainable production by substantially increasing the productivity in the preparation process since significantly less prototypes needs to be painted. Furthermore, the cycle time can be reduced by optimizing the robot paths and load balance the paint robots work. The environmental impact can be reduced by choosing paint paths and process conditions that maximize the transfer efficiency.
- By enabling more of the product preparation to be done offline new products can be introduced with shorter lead time.
- By offering an efficient software for simulation of the surface treatment more companies will be able to take the step from manual to robotized spray painting with large benefits in efficiency, product quality and reduced human exposure to un-healthy paint substances.
- The project has further strengthened the world-leading research team in simulation of paint and surface treatment processes that contributes to a vehicle industry in Sweden that continues to be globally competitive.
- The math based approach in this project is a key to meet the challenge of increased complexity in the paint shops due to an increased number of product and material variants.
- Increases the use and the understanding of advanced mathematics in production development.
- Increases the collaboration between industry and research institutes.

- The project resulted during 2012 in a licentiate thesis and will during 2013 result in PhD at Chalmers in fluid dynamics.
- The project has further strengthened Sweden's competitiveness as advanced user and developer of digital tools in the border line of product and production.
- The research group of Geometry and Motions Planning at FCC which is part of the environment for innovation and collaboration; Wingquist excellence centre at Chalmers for efficient product realization, has been further strengthened growing from 9 (2009) to 17 researchers.
- The research group of Computational Engineering and Design at FCC has been further strengthened growing from 6 (2009) to 11 researchers.
- The software platform IPS for math based virtual product realization has been further developed and will continue to secure comprehensive and fast implementation of research results, as well as to facilitate technology exchange between the industrial partners.

# 6. Dissemination and publications

## 6.1 Knowledge and results dissemination

This project has resulted in an increased interest to simulate the paint and surface treatment processes to be able to reduce the time required for introduction of new products, reduce the cycle-time, reduce the environmental impact and increase quality. During 2013, Volvo Cars will perform an implementation project to take full advantage of the project results on spray painting. General Motors have performed several measurement campaigns during the project and will perform a validation on a full car painted in production during 2013. Scania has chosen IPS as a key platform for simulation of paint and surface treatment processes. AB Volvo has an ongoing project with FCC where a prototype system for manual spray painting is being developed partly based on the project results. The results have also attracted considerable international interest and will for example be presented to the German surface treatment community in Potsdam, in May 2013.

Scania, AB Volvo, Volvo Cars, and Swerea IVF are together with companies from FkG involved in the current project "The Virtual Paint Shop – Powder and Externally Charged Wet Paint" that will further develop and extend the methods and tools to the surface treatment processes used by the heavy vehicle industry and other industrial sectors.

The project results and demonstrator have continuously been disseminated during company visits, seminars and educations, including e.g.:

- Mötesplats för framtidens framgångsrika verkstäder, Katrineholm, May 2010.
- Wingquist Laboratory International Seminar, Göteborg, December, 2010.
- Mötesplats för framtidens framgångsrika verkstäder, Katrineholm, May 2011

- Scanautomatic fair in October at Stockholmsmässan, October 2011.
- Mötesplats för framtidens framgångsrika verkstäder, Katrineholm, May 2012
- Wingquist Laboratory International Seminar, Göteborg, December 2011.
- ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012.
- 12th Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany, September 2012.
- ABB workshop on spray painting, November 2012.
- Swedish Production Symposium SPS12, Linköping, November 2012.
- Wingquist Laboratory International Seminar, Göteborg, December 2012.
- Volvo Cars Manufacturing Research & Advanced Engineering Seminar, February 2013.
- Deutsche Forschungsgesellschaft für Oberflächenbehandlung, May 2013.

## 6.2 Publications


1. B. Andersson, V. Golovitchev, S. Jakobsson, A. Mark, F. Edelvik, L. Davidson, J.S. Carlson, "Modified TAB Model for Viscous Fluids applied to Breakup in Rotary Bell Spray Painting", submitted to Journal of MultiPhase Flows, 2013.
2. A. Mark, B. Andersson, S. Tafuri, K. Engström, H. Söröd, F. Edelvik, J. S. Carlson, "Simulation of Electrostatic Rotary Bell Spray Painting in Automotive Paint Shops", submitted to Automization and Sprays, 2012.
3. A. Mark, E. Svenning, F. Edelvik, "An Immersed Boundary Method for Simulation of Flow with Heat Transfer", International Journal of Heat and Mass Transfer, 56:424-435, 2013.
4. A. Mark, R. Rundqvist, F. Edelvik, "Comparison Between Different Immersed Boundary Conditions for Simulation of Complex Fluid Flows", Fluid Dynamics & Materials Processing, 7(3):241-258, 2011.
5. R. Rundqvist, A. Mark, F. Edelvik, J. S. Carlson "Modeling and simulation of viscoelastic fluids using Smoothed Particle Hydrodynamics", Fluid Dynamics & Materials Processing, 7(3):259-278, 2011.
6. Robert Rundqvist, Andreas Mark, Björn Andersson, Anders Ålund, Fredrik Edelvik, Sebastian Tafuri, and Johan S Carlson, "Simulation of Spray Painting in Automotive Industry", In G. Kreiss et al. (eds.), Numerical Mathematics and Advanced Applications 2009, pp. 769-777, Springer-Verlag Berlin Heidelberg 2010.
7. H. Söröd, R. Ingemarsson, A. Mark, R. Bohlin, D. Segerdahl, F. Edelvik, J.S. Carlson, "3D Scanning and Automatic Path Planning of Paint Process in General Coating Industry", Swedish Production Symposium SPS12, Linköping, November 2012.
8. A. Mark, R. Bohlin, D. Segerdahl, F. Edelvik, J. S. Carlson, "Optimization of Robotized Sealing Stations in Paint Shops by Process Simulation and Automatic Path Planning", Swedish Production Symposium SPS12, Linköping, November 2012.
9. S. Tafuri, F. Ekstedt, J. S. Carlson, A. Mark, F. Edelvik, "Improved Spray Paint Thickness Calculation From Simulated Droplets Using Density Estimation", Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012, Chicago, IL, USA
10. B. Andersson, V. Golovitchev, S. Jakobsson, A. Mark, F. Edelvik, L. Davidson, J.S. Carlson, "Modified TAB Model for Viscous Fluids applied to Breakup in Rotary Bell Spray Painting", Proc. 12th Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany, 2012.
11. A. Mark, B. Andersson, S. Tafuri, K. Engström, H. Söröd, F. Edelvik, J. S. Carlson, "Simulation of Electrostatic Rotary Bell Spray Painting in Automotive Paint Shops", Proc. 12th Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany, 2012.
12. M. Pieper, P. Klein, K-H Küfer, A. Mark, F. Edelvik, "Multi-objective Optimization of Oven Curing in Automotive Paint Shops", In The 21st International Conference on Multiple Criteria Decision Making, Jyväskylä, Finland, June 2011.

13. Björn Andersson, Stefan Jakobsson, Andreas Mark, Fredrik Edelvik, Lars Davidson, "Modeling Surface Tension in SPH by Interface Reconstruction using Radial Basis Functions", In proceedings of the 5th International SPHERIC Workshop, pp. 7-14, Manchester, U.K., June 2010.
14. A. Mark, R. Rundqvist, F. Edelvik, "Comparison Between Different Immersed Boundary Conditions for Simulation of Complex Fluid Flows", 7th International Conference on Multiphase Flow (ICMF), Tampa, FL, USA, June 2010.
15. R. Rundqvist, A. Mark, F. Edelvik, J. S. Carlson "Modeling and simulation of viscoelastic fluids using Smoothed Particle Hydrodynamics", 7th International Conference on Multiphase Flow (ICMF), Tampa, FL, USA, June 2010.
16. B. Andersson, "Droplet Breakup in Automotive Spray Painting", Lic. thesis at FCC, Chalmers University of Technology, January 2012.
17. A. Berce, "Simulation of Thermal Spraying in IPS Virtual Paint", MSc thesis at FCC, Chalmers University of Technology, June 2011.
18. L. A. Martinez, "Near-bell simulations", MSc thesis at FCC, Chalmers University of Technology, June 2012.
19. R. Ingemarsson, "Virtual paint - scanning and path planning", BSc thesis at Swerea IVF, May 2012.
20. L. Quan, M. Pourghahreman, "Sealing simulations in IPS Virtual Sealing", MSc thesis at Volvo Cars, Chalmers University of Technology, June 2012.

# 7. Conclusions and future research

The project results show that it is possible to accurately simulate spray painting of a complex car part in only a few hours on a standard computer. This is an extreme improvement compared to earlier approaches that required weeks of simulation time. Unique algorithms for coupled simulations of air flows, electrostatic fields and charged paint particles have made this possible. Several successful measurements campaigns have been performed with very good results. A similar break-through in simulation performance for the sealing application has also been achieved. The methods are implemented in the CAE-tool IPS and are thus ready for industrial implementation. The long term funding from Vinnova has made it possible to build-up a world-leading research group in modeling and simulation of paint and surface treatment processes. By integrating and further develop the available technologies of path planning, 3D scanning and spray painting simulation a first approach to automatically generate optimized paths for paint robots from an analysis of the component's surface has been developed. For the electro dipping and oven curing applications this project has resulted in new methods and the first version of the demonstrators. However, another research project is needed in both cases to reach an industrial implementation level.

In the ongoing Vinnova project (Dnr 2012-02148) the spray painting methods and tools are extended to powder and externally charged wet paint. After completing that project all spray painting technologies used by the automotive industry is included and technology dissemination to other branches can be made. Powder coating is for example a large industry in Sweden with a consumption of roughly 9000 tons/year. Around 400 companies coat hundreds of products such as furniture, household appliances, and windows to name just a few. The major challenges are the modeling of the corona discharge at the electrode tip and the charging of the paint particles as they pass through the Corona region.

The longer term vision with the research on the virtual paint shop is to radically rationalize the surface treatment in Swedish industry by developing simulation tools that makes it possible to completely automate the product preparation process in the paint factory. With a geometry description and available brushes as input, optimal robot paths and process conditions that guarantee a certain coverage and visual results such as gloss and color match, should be automatically calculated. This is obviously an extremely complex problem but the research group has a unique platform to take on this challenge. If successful it would dramatically improve the productivity and reduce the environmental impact during product preparation as well as in production.

# 8. Participating parties and contact persons

This has been a collaboration project with the industrial partners Volvo Car Corporation, SAAB Automobile, AB Volvo, Scania CV and Konga Bruk, and the research partners Fraunhofer-Chalmers Research Center (FCC) and Swerea IVF. A steering group with one representative from each partner has been appointed for the management of the project. It has been responsible for the project control, economy and reporting to VINNOVA. The daily operations of project management have been handled by Jörg Wohner, Volvo Car Corporation (Industrial project leader) and Johan S. Carlson, FCC (Academic project leader). Volvo Car Corporation took over the lead of the project after the bankruptcy of SAAB Automobile. General Motors joined the project through a collaboration agreement and provided expert knowledge and financial support that extended the scope of the project.

| **Name** | **Role** | **Organisation** | **E-mail and Phone** |
|---|---|---|---|
| Jörg Wohner | Project leader, Industrial partner | Volvo Cars | jorg.wohner@volvocars.com +46-31-3257760 |
| Christer Bodén | Industrial partner | Scania CV | christer.boden@scania.com +46-8-55381646 |
| Henrik Kloo | Industrial partner | AB Volvo | henrik.kloo@volvo.com +46-31-3227099 |
| Robert Tilow | Industrial partner | General Motors | robert.tilow@gm.com |
| Henrik Söröd | Research partner | Swerea IVF | henrik.sorod@swerea.se +46-31-3226932 |
| Johan S. Carlson | Research leader | Fraunhofer-Chalmers Centre | johan.carlson@fcc.chalmers.se +46-31-7724289 |