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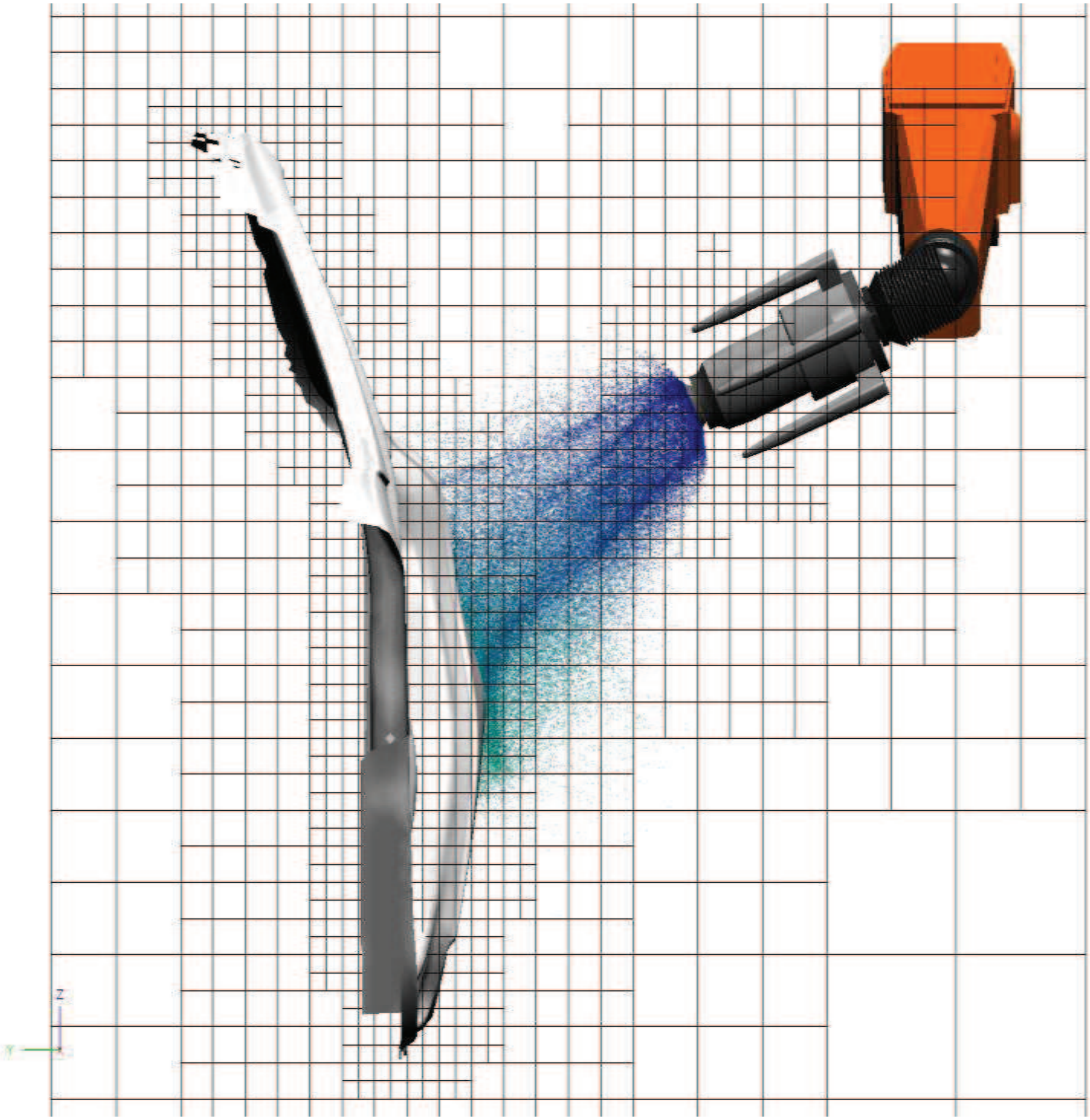
SETTING SCIENCE AGENDAS FOR EUROPE

FORWARD LOOK

Mathematics and Industry Success Stories - DRAFT



European Mathematical Society

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Foreword

This brochure shows via several success stories the crucial contribution of mathematics to the industrial creation of value and the key position of mathematics in the handling of complex systems, amplifying innovation.

Each story describes the challenge that led to the industrial cooperation, how the challenge was approached and how the solutions were achieved and implemented, and when brought together, they illustrate the versatile European landscape of projects in almost all areas of applied mathematics and across all business sectors.

Today models are used everywhere to describe real world processes in the language of mathematics. The art of modelling is to focus on the important relationships to make the model as useful as possible to the user, and modelling therefore needs support from domain specialists. Indeed, close collaboration between industry experts and academia is both highly valued by all parties and highly valuable to successful projects.

The next step after creating the mathematical model is the analysis or numerical simulation, to validate the model in comparison with experimental data and to investigate the robustness and sensitivity of the model. Once a mathematical model has been validated, then this model can be used to improve, optimize or control the process described. Model based control and optimization is a crucial element of automation in all areas of industry, often reducing the cost and time of product, process and service development and innovation.

All of this is unthinkable without the existence of modern computers and information technology. However, the progress in computer technology is not alone sufficient for the future development of high technology innovation. Many of the success also rely to a large extent on the progress in the development of mathematical algorithms and tools.

Although this brochure only describes a snapshot of all the European activities in industrial mathematics, it demonstrates that the level of cooperation between academia and industry is not equally well established throughout Europe and that there exists great opportunity for more industrial challenges to be addressed with the powerful ideas and tools at the disposal of mathematicians. The impact achieved in industrial mathematics is through a wide variety of timescales and engagement mechanisms, from PhD studentships and post-doctoral research contracts to shorter-term Internships, Study Groups and consultancy contracts.

> “In view of concrete economic and social challenges, Mathematics plays a central role. Mathematics enables innovations in the industrial and service sectors that lead to more jobs and an increasing competitiveness.”
>
> Dr. Annette Schavan
> German Federal Minister
> of Education and Research

Predicting climate change

Executive summary

Increasing global temperatures, rising sea levels and the disruption of fragile ecosystems: climate change is one of the greatest challenges humanity has ever faced, and could potentially affect billions of lives in the coming century. Scientists around the world are working to tackle the problem with detailed models of our changing climate, and mathematicians are at the heart of these models, solving the difficult equations that no one else can. Researchers in meteorology, physics, geography and a host of other fields all contribute their expertise, but mathematics is the unifying language that enables this diverse group of people to implement their ideas in climate models.

Challenge overview

At the centre of all climate models are the Navier-Stokes equations, which describe the movement of liquids and gases such as the atmosphere and ocean. Translating the Navier-Stokes equations into computational code is undertaken by Paul Williams, a Royal Society Research Fellow at the University of Reading, who aims to improve the time-stepping calculation, making it more accurate without losing computational efficiency.

The problem

As a linked set of four nonlinear partial differential equations the Navier-Stokes equations are impossible to solve analytically in all but a few trivial cases, hence the need for numerical approximation methods. These methods allow us to apply the Navier-Stokes equations to a range of practical situations.

There are a variety of time-stepping methods, each with their own strengths and weaknesses, but because climate modelling is so complex, the different methods don't always produce results that agree. Determining which method to use can be beneficial as it allows climate scientists to investigate uncertainties.

Other aspects of the climate aren't captured by the Navier-Stokes equations, and some atmospheric phenomena lack fundamental mathematical theory behind them. Clouds are the leading source of uncertainty in climate modeling because they occupy a scale much smaller than the 100 km grids currently in use in climate models, so the full details of their behaviour are lost.

These unanswered questions show that while current climate models have served us well, demonstrating that increased carbon dioxide levels lead to a rise in temperature, we must still gain a deeper understanding of all the mechanisms within our atmosphere and ocean if we are to effectively fight global warming.

Climate scientists use many different varieties of time-stepping methods to power their models, and the choice of method can influence the resulting predictions. The most widely used is the "leapfrog" method, so-called because the function and its derivative get from the previous time to the future time by "leaping" over the current time.

Results and achievements

The method's success is due to its ease of use and low computational complexity, but its jumping nature can lead to discrepancies between even and odd steps. This can be solved by using the Robert-Asselin filter to smooth the discontinuities, but at the cost of a loss in accuracy. Williams' research modifies the filter in a way that counteracts this loss, producing better models with no noticeable reduction in calculation speed.

University of Reading

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Institute of mathematics & its applications

http://www.met.reading.ac.uk/~williams/
p.d.williams@reading.ac.uk

Editorial Board

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

1 quai Lezay-Marnésia • BP 90015
67080 Strasbourg cedex • France
Tel: +33 (0)3 88 76 71 00 • Fax: +33 (0)3 88 37 05 32
www.esf.org