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Interview Bruno Stoufflet, Chief Technology Officer at Dassault Aviation

"Mathematics is quite easy if you understand it, I taught my daughters"

On 4 April 2018, the second day of NMC 2018, Barry Koren and Robbert Fokkink interviewed Bruno Stoufflet, the main industrial speaker at NMC 2018.

Short biography

Spring 1958, to give birth to her son, Bruno Stoufflet's mother went from Paris to the place where her parents lived, Verdun, Bruno's single residence out of the Paris area so far. Bruno grew up and went to schools in Paris, among which the gymnasium, where he passed the scientific final exam and the contest to enter École Polytechnique. He studied mathematics at École Polytechnique, Palaiseau and Université de Paris-Sud, did his PhD research at the Rocquencourt site of INRIA (the French sister institute of CWI), and obtained his PhD degree in applied mathematics from Université de Pierre et Marie Curie in 1984. Since that year until now he is employed by Dassault Aviation, where he currently is Chief Technology Officer.

Mathematics

Mathematics was Bruno's favorite study. He liked it very much, more than physics and other studies. He particularly liked the logic in mathematics and the fact that you don't need to rely so much on memory when studying it; Bruno: "If you have the reasoning, you can retrieve the results." Later, he taught his three daughters: "Mathematics is quite easy if you understand it."

At École Polytechnique he remained fond of mathematics and — important for his career — he discovered applied mathematics, through Jacques-Louis Lions (renowned mathematician and father of 1994 Fields Medal winner Pierre-Louis Lions). In Jacques-Louis Lions' large-class cours-

Bruno Stoufflet, lecturing as main industrial speaker at NMC 2018

Photo: Martijn Anthonissen

es, Bruno learned finite-element methods, the variational formulation, optimization, and — more generally — how to tackle practical problems by mathematics. In small-scale courses with deepening, Bruno met mathematics lecturer Roland Glowinski. Glowinski advised Bruno to start PhD research in applied mathematics. To be able to do so, he first obtained the Diplôme d'Études Approfondies de Mathématiques Appliquées, from Université de Paris-Sud in Orsay. In the following two-and-half years only, at INRIA Rocquencourt, he succeeded to complete his PhD research, on a thesis entitled *Résolution numérique des équations d'Euler des fluides parfaits compressibles par des schémas implicites en éléments finis*.

During his PhD research, Bruno came into contact with mathematicians working at Dassault Aviation. He was recruited by Dassault, directly after he had obtained his PhD degree; no postdoc position abroad. Bruno: "As opposed to today, travelling and partly doing your research abroad was not very common those days in France."

Hermes

In 1984, upon request by the European Space Agency, Dassault Aviation started the development of a European reusable spacecraft, Hermes (messenger of the gods), as an alternative to the American Space Shuttle.

As opposed to the Space Shuttle, Hermes was to be mounted on top of, instead of alongside, the main launching rocket, Ariane V, implying a smaller frontal area and hence lower aerodynamic drag. Hermes never entered the manufacturing stage though. During the Hermes design phase, it became clear that Ariane V was not capable to carry Hermes during launch. The design of a new rocket that was suited to do so was beyond budget. Policy makers decided to stop the Hermes program therefore. On the positive side: the many computations in the Hermes program had offered several years of challenging research work to tens of applied mathematicians throughout Europe, with Dassault Aviation in the leading role.

Artist impression of Hermes space plane

Dassault

At Dassault, Bruno continued to do the kind of work that he had already done during his PhD research: to develop and implement new numerical methods for the Euler equations of fluid dynamics, but now directed towards real engineering problems, of Dassault's space plane Hermes and fighter aircraft Rafale. Computational design, finding optimal shapes of aircraft designs by computational means (inverse computing) was arising. About 20 mathematicians were working at Dassault Aviation those days, among others on methods for computational design. Today, this number is still the same. Dassault keeps a keen eye on having good mathematicians as employees. Bruno: "We put emphasis on having design capacity at the top level. There is an understanding at Dassault that this is really critical for the quality of our products."

Computers

Those days, it must have been hard to model so much by computer, because computers were not yet that powerful.

"Yes. When I was at École Polytechnique, only a few years before my start at Dassault, the only goal of the only computer-science course given there was to learn Fortran, and we only had punch cards to make our software and other input readable to computers. It was awful. In future, I will never be using computers, I thought. But when I arrived at INRIA and at Dassault, there were computer screens linked to mainframes, still not very user-friendly, but the improvement was enormous. There was a huge discrepancy between punch cards and what I could suddenly use when arriving at INRIA and Dassault."

Was the design of aircraft mainly done through wind tunnels these days?

"No, engineers did use simple computational methods to direct the design, like the method of characteristics and potential-flow methods. These methods have a lot of limitations though, for instance with respect to positions of shock waves and the presence and strengths of vortices. You are very far from a realistic description of an air flow with these methods. Wind tunnels were still used a lot that time. The design of the engine air inlets of Rafale, for instance, has taken thousands of wind-tunnel hours."

Civil versus military aircraft

Dassault fills a unique niche within the European aircraft manufacturing industry with its Falcon family of small civil aircraft, its Rafale family of military aircraft and its very innovative unmanned military aircraft nEUROn. Dassault is complementary to Airbus, which designs and manufactures large civil aircraft only.

"Yes. Airbus and Dassault have a full range of cooperation on the research side."

Is designing military aircraft mathematically more challenging than designing civil aircraft?

"Yes, with military aircraft you have a larger spectrum of configurations, depending on the different systems attached to the aircraft. Moreover, the stealth aspects are there; to make the aircraft invisible for radar. nEUROn is a stealth aircraft, it is a huge step forward in stealth properties, really a breakthrough as compared to Rafale. Designing military aircraft is particularly more demanding in computational efficiency."

Are the stealth aspects exclusive for military aircraft, are they no issue at all for civil aircraft?

"In principle, the computational methods developed for simulating stealth aspects (methods using the Maxwell equations) are for military aircraft only. Yet, sometimes, we also apply these methods to antenna-integration problems on civil aircraft."

Research partners

How important is ONERA (Office National d'Études et Recherche Aerospatiale, the French sister institute of the American NASA and the Dutch NLR) for mathematics used at Dassault?

"We are not working very much with ONERA on mathematical problems. For mathematics, we rely on INRIA and university groups. But this does not mean that we have no relations with ONERA. For the de-

Dassault aircraft, left: a Falcon; right: a Rafale and a nEUROn

velopment of turbulence models and other mathematical-physical models relevant for aircraft design, such as icing models and lightning models, we cooperate with ONERA, and for materials research and wind-tunnel experiments we even heavily rely on ONERA. A very special international wind tunnel being used by Dassault is the European Transonic Wind Tunnel (ETW) in Köln, a cryogenic wind tunnel, using nitrogen flows at very low temperatures in order to have the same viscous effects as in real flight.”

Wind tunnel experiments versus computer simulations

What is more accurate nowadays, the computer or the wind tunnel; if they give different results, which of both do you trust?
“In ETW you can have the same viscous effects as in real flight, the so-called Reynolds number in an ETW experiment can be the same as in real flight, but of course on wind-tunnel models for ETW you will still miss geometrical details of the real, full-scale aircraft. So, you will still have discrepancies. In computer simulation you can be very accurate in all aspects. An important source of discrepancies in computer simulations though, still today, is the mathematical-physical model used for turbulence. In engineering practice we cannot compute Navier–Stokes-flow solutions to the smallest physical scale of turbulence, the Kolmogorov microscale; turbulence models have to be applied therefore. A second source of computational discrepancies is formed by numerical errors. So, in both wind-tunnel experiments and computer simulations, we have sources of discrepancies with real flight. A new approach being followed by Dassault to understand the discrepancies between real flight on the one hand and wind-tunnel experiments and computations on the other hand, are large-scale, detailed measurements on real aircraft. It is not wise to strive for a tool which gives you the truth, because you will never get this. However, having a tool of which you fully know and understand the discrepancies, in order to take the proper margins in your design, is very relevant for engineering practice. A difficult source of discrepancies is the deformation of the aircraft in flight, due to the aerodynamic forces exerted on it. Another one is turbulence.

Finally, an important difference between wind-tunnel experiments and computer simulation is that computer simulation gives you the unique capacity to perform a design loop, which you do not have with a wind-tunnel model. Once you have built a scale model of an aircraft to be investigated in a wind tunnel, you cannot change it during the experiment. A computational model of an aircraft can be changed though during the computation; through a single computation you can explore a wide range of potential configurations.”

So that’s why they do not yet have the Joint Strike Fighter; they are still in a computational design loop?
“No [laughing], to my knowledge, the F35 [editor: Joint Strike Fighter] has no aerodynamic design issues. It is more an issue of system integration and maintenance capacity, because of the complexity of the F35, with its 360 degrees vision system for the pilot and alike.”

Academic contacts

Is it possible to publish in the open literature at Dassault?
“In the past, it was quite easy to publish. In the Hermes program for instance, there was no issue of confidentiality, because it was a European project with a lot of visibility. Now it is more difficult, but people still continue to publish. Of course, you need a clearance of your management, but it is still possible. At Dassault we want to be close to the scientific community and we want to actively participate in scientific conferences. Therefore, we also have to publish from time to time, to be part of the scientific community. We have some groups with experts, who have extra opportunities to publish. Dassault also has in-house PhD students; France has industrial PhD students, PhD students working in industry with a fellowship from the government. [editor: NWO started the same recently.] The students are in connection with a professor at the university. The limitation at Dassault is that candidates for these positions must have the French nationality.”

Do they get a background check?
“Yes, they do. Further, Dassault still has external PhD students in connection with its research teams, who they may recruit afterwards, as in my case. And we have some people who give courses in engineering schools or are part-time professor at a university. One of Dassault’s research engineers, a specialist in stochastic methods, is part-time professor in the group of Jean-François Le Gall, one of the other keynote speakers at NMC 2018. Das-


Évariste Galois

sault facilitates academic careers for its employees who are capable and willing to do so."

French mathematics

France has a very rich history in mathematics, until today. Are you proud of something in French mathematics, do you have a hero in French mathematics?
"Well,... there is a French mathematician, a romantic one, who died very young but had very important contributions to mathematics nevertheless, Galois. He died in a duel, a pistol fight, at the age of 20 only."

The entire night before the duel, Galois wrote about mathematics. If he had not done so and would have slept well instead, he might have won.
"[Laughing] Yes..."

Developments since arrival at Dassault

Has mathematics at Dassault changed a lot over the years, since you came to Dassault?
"Well, the need to improve the accuracy of numerical methods is not that high anymore as it was when I arrived at Dassault. We have reached a rather satisfactory accuracy level. Challenges are now more in the development and incorporation of new models and in obtaining numerical solutions as efficiently as possible. We do more development work now in modelling and on solvers. This may change in future though."

Is it almost perfect now?
"No, it's not perfect yet."
Close to perfect?
"No. We also have new competition, from meshless methods, like smoothed particle hydrodynamics, often being offered in commercial packages."

Meshless methods are very well-suited for complex geometries.
"Yes, but we are requiring a level of accuracy that meshless methods do not yet offer, but they improve. It is a new competition that is coming."

Is it possible to put a helicopter in a computer simulation now, a body of which parts are moving relatively with respect to each other, the helicopter rotor blades with respect to the helicopter fuselage for instance?
"Yes, ONERA is doing it, but I don't know at which accuracy. It's very complex in terms of implementation and data management."

Immersed boundary methods can handle geometries 'swimming' through a fixed computational grid. Are immersed boundary methods considered at Dassault?
"No, they are not considered because we don't have that many applications with bodies moving relatively with respect to each other. I know that ONERA is developing immersed boundary methods, but these methods are also very difficult in terms of data management."

Immersed boundary methods are also rather crude with respect to boundary-layer resolution, isn't it?
"Oh, yes. We prefer to generate unstructured boundary-fitted grids around our aircraft geometries, and we prefer to regenerate the grid in case of relative motions of body parts".

Future of mathematics at Dassault

What is important future mathematics at Dassault?
"An important future mathematics topic is the emergence of data analytics. There was shortage of time to speak about this in my presentation at NMC 2018. We will need mathematics to make use of the increasing

Meshless methods
Commonly used equations to describe fluid flows are the Navier–Stokes equations, partial differential equations which, for flows around aircraft, cannot be solved analytically. Numerical methods are used instead.

Most numerical methods discretize the computational domain as a grid of fixed points or cells: the mesh. On the mesh, numerical formulae are defined to locally approximate derivatives and integrals, occurring in (differential and integral forms of) the Navier–Stokes equations. Examples of families of such numerical methods are finite-difference methods (using meshes of fixed points), and finite-volume and finite-element methods (using meshes of fixed cells).

The use of a mesh becomes difficult in case of flow bodies that are very complex in geometry, that are deforming, or that have relative motions with respect to each other. In these cases, methods describing fluid flows by moving mathematical particles, may be used as an alternative; particles that may exchange momentum and energy. An example of such a particle method is smoothed particle hydrodynamics.

The particles in this method do not directly model real physical particles, such as the molecules or atoms of the fluid considered. The mathematical particles may be much larger than real physical particles, but they do have physical properties such as location, velocity and mass, and they do obey proper physical laws when colliding with each other or with other bodies in the flow. A pleasant property of a particle method as smoothed particle hydrodynamics is that it does not need a mesh; it is meshless. The mathematical particles can move throughout the entire computational domain; they can have any position inside or at the boundary of the domain, as long as they do not coincide with the position of another particle.


Photo: Martijn Anthonissen

Bruno Stoufflet, answering questions after his lecture at NMC 2018

amount of data that is becoming available. Another topic for the future is stochastic modelling. We have to qualify and quantify more and more risks taken by decisions in our designs. We have to learn people what stochastic modelling means and what it can bring to have a more robust design.”

Is the safety factor put on the design of aircraft structures, to account for uncertainties, still 1.5? Or has this old, crude approach been replaced meanwhile by computer simulations with uncertainty quantification; by probabilistic designing and engineering?
“The safety-factor approach may be way too crude indeed, but aircraft certification — the law — still requires the safety-factor approach. It is very hard to get rid of regulations prescribed by law. And if we would try to get rid of them, after all, it might very well appear to be a huge effort for an alternative which is not very valuable.”

Future of aircraft from Dassault

Concerning future aircraft to be designed and manufactured by Dassault, would the rapidly growing drone market be interesting for Dassault?
“The engineering difficulties of a drone are not limited to getting it flying; aerodynamics and flight mechanics are not the only major issues for drones. Designing a drone is also about what information you want to obtain and provide. Drone design is a data-acquisition problem; a problem of designing the sensor, electronics and data-handling systems. Dassault has to acquire the skills to do this. From a scientific perspective, drone engineering also has to encompass artificial intelligence and information theory. Drone technology is interesting for Dassault. There are a lot of developments in drone technology that may be applied in Dassault’s future aerospace systems.”

Own research

You probably have no time for research now, but you are strongly involved in high-tech developments. Would a university position be something for you?
“Yes, but not for having a position, not just for myself. When you have taken distance from research as I have done, it is very difficult to come back and to be relevant.”

You could combine it with your industrial knowledge and experience, and carry these over to students?
“Yes perhaps in terms of industrial experience, but not in terms of research. I have lost research competence, I have no longer the skills to be an efficient researcher. I can understand mathematics research very well, but I can no longer practice it myself as efficiently as young researchers can.”

Maybe your grandchildren can do so in future.
“Yes, maybe,... not my daughters.”

What are your daughters doing?
“The eldest one is physiotherapist. The second one is an artist, she is living from painting. The third one is in neuro-science, she is working on the brains of mice.”

Oh, beautiful!

Bruno, we thank you very much for the very nice interview.