From *SIAM News*, Volume 43, Number 7, September 2010

Obituaries: Paul R. Garabedian

Paul R. Garabedian, a leader in the field of computational science, passed away at his home in Manhattan on May 13, 2010, after a long battle with cancer. He was 82. In the course of a sixty-year career at Stanford and New York University, he maintained an active research program in computational fluid dynamics and magnetohydrodynamics, and was one of the premier applied mathematicians of his time.

Paul R. Garabedian, 1927–2010

Paul was born in Cincinnati, Ohio, on August 2, 1927. He was raised in an academic family and did not attend school before setting off for college; he began his formal education as a precocious undergraduate at Brown University, graduating in 1946 [1]. His graduate training was in pure mathematics at Harvard University, where he received his PhD in 1948 with a dissertation in complex analysis [2].

He spent a year teaching at the University of California, Berkeley, followed by nine years on the mathematics faculty at Stanford. During this time Paul made outstanding contributions to the theory of partial differential equations and to problems in the theory of functions of a complex variable. A highlight was his celebrated work on the Bieberbach conjecture: If $f(z) = a_1z + a_2z^2 + \ldots$ is a one-to-one analytic function defined in the unit circle, then $|a_n| \leq n$. In 1955, Paul and his colleague Max Schiffer proved that $|a_4| \leq 4$ [3] (the general problem remained open until 1985).

Paul also led Stanford's research program in hydrodynamic free boundary problems. A noteworthy example of that work is his analysis of the bow shock wave generated by a blunt body traveling at supersonic velocities [4]. The fluid passing through the shock undergoes substantial heating, and it is necessary to characterize the degree of heating to ensure that the body can sustain these extreme conditions without mechanical failure. Computing the geometry of the shock wave and fluid flow past a given body is an extremely challenging nonlinear problem in partial differential equations. Paul's ingenious solution was to prescribe the shape of the bow wave in advance and then, extending the solution into the complex plane, determine the shape of the body that generated the shock wave and flow field as an inverse problem. He was aided in this work by his first wife, Gladys, who programmed the numerical procedure.

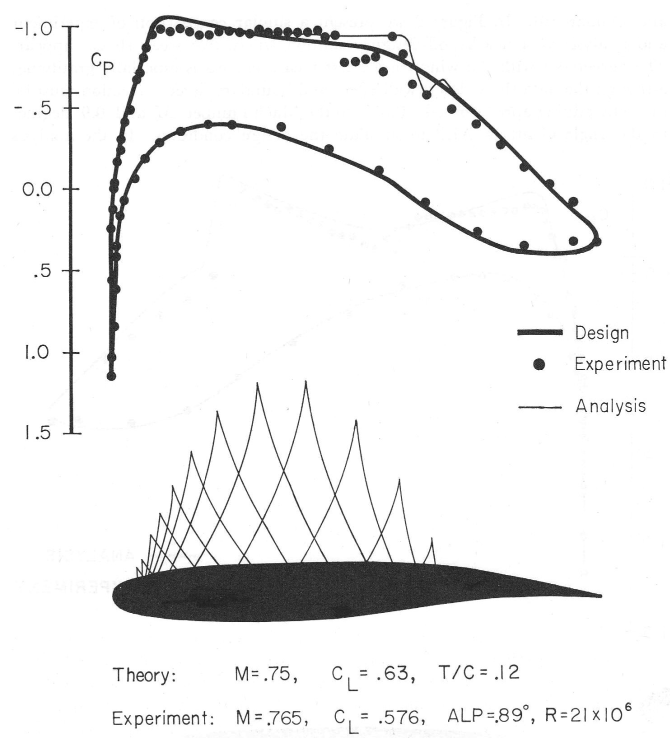

Figure 1. *The dimensionless pressure distribution C_P (thick solid curve) along the upper and lower surfaces, the airfoil shape, and characteristics ("Mach lines") in the supersonic region of flow for the Korn airfoil [7] under shockless design conditions: free-stream Mach number M = 0.75, lift coefficient C_L = 0.63, and thickness-to-chord ratio T/C = 0.12. An inviscid numerical simulation of the flow at a corresponding near-design condition (thin solid curve) exhibits a weak shock at the end of the supersonic zone, which is in good agreement with wind tunnel measurements (solid circles) for an angle of attack ALP = 0.89 degrees and Reynolds number R = 21 million. Reprinted with permission from* Communications on Pure and Applied Mathematics, *Vol. 24, No. 6, 1971.*

Paul joined the Courant Institute of Mathematical Sciences at New York University in 1959. His book *Partial Differential Equations* was first published a few years later [5]. A unique blend of pure and applied mathematics, the book includes extensive discussions of free boundary problems arising in fluid dynamics and plasma physics. Paul was director of the Division of Computational Fluid Dynamics at the Courant Institute for 32 years (1978–2010). In the course of his career he advised 27 doctoral students [6], in addition to a number of master's students and postdoctoral fellows.

During the 1960s and 1970s, with the advent of aircraft designed to fly efficiently near the speed of sound, Paul and his students and co-workers developed computer codes to study supercritical wing technology. In essence, they were able to reduce drag and suppress boundary layer separation by shifting the shock waves that occur toward the trailing edge of a wing and making them as weak as possible. Particularly striking was Paul's use of complex characteristics in the hodograph plane to design shockless airfoils that generate smooth transonic flows with given pressure distributions (see Figure 1). The resulting shapes increase lift, fuel efficiency, and speed, and the ideas that flowed from this work influence much of commercial aircraft design today. A NASA award and a NASA certificate of recognition acknowledged this research, which resulted in three books [8–10] with longtime collaborator Frances Bauer (whom he met during his undergraduate studies at Brown, while she was a graduate student), former PhD student David Korn, and colleague Antony Jameson.

Paul started working on problems related to fusion energy in the 1970s, using the techniques he had developed for problems in classical fluid dynamics and extending them to study the magnetic confinement problem. He worked first on free boundary models to understand plasma physics experiments carried out at Los Alamos National Laboratory and the Max Planck Institute for Plasma Physics in Germany. Over the years, the sophistication of the plasma modeling tools in Paul's research group grew steadily [11–13], resulting in a suite of computer codes used to study plasma equilibrium, transport, and stability. The codes have been used to design quasi-axisymmetric stellarators [14] as possible candidates for the DEMO experiments that may be performed on completion of the planned ITER experiments (see Figure 2). Paul's computations suggest that his quasi-axisymmetric designs have desirable transport properties, comparable to those in axisymmetric tokamaks, while enjoying the increased stability of stellarators that results from the absence of the large toroidal current used in tokamaks. In recognition of his many contributions to magnetohydrodynamics, Paul was elected a Fellow of the American Physical Society, Division of Plasma Physics, in 2004.

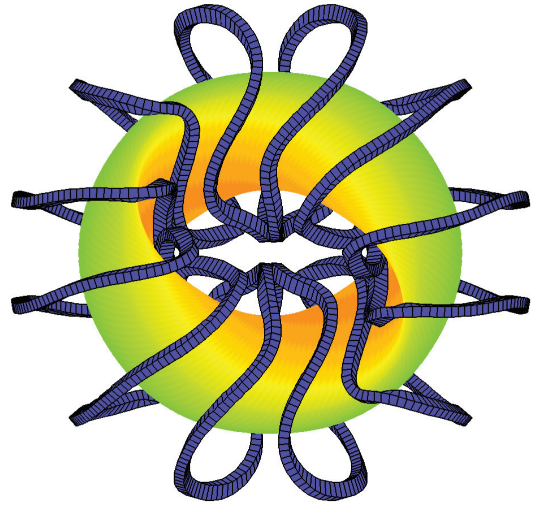

Figure 2. *A quasi-axisymmetric stellarator design with two field periods [15]. The shading of the plasma surface indicates magnetic field strength; the modular coils that generate the external magnetic field are shown in blue.*

Paul was actively pursuing his research at the time of his death. Among the many honors he received are the Birkhoff Prize (1983; awarded jointly by the American Mathematical Society and SIAM) for an outstanding contribution to "applied mathematics in the highest and broadest sense," SIAM's Theodore von Kármán Prize (1989), the National Academy of Sciences Award in Applied Mathematics and Numerical Analysis, and the Boris Pregal Award from the New York Academy of Sciences. He was a member of the National Academy of Sciences and the American Academy of Arts & Sciences. He was named a SIAM Fellow in the inaugural class of 2009; he was the recipient of a Sloan Foundation Fellowship and two Guggenheim Fellowships. Although only one-quarter Armenian, he was proud of his heritage, and a hero to the Armenian mathematical community. A scientific conference in his honor will be held at the Courant Institute in the fall of 2010.

Paul's marriage to Gladys Rappaport ended in divorce. He is survived by his wife, Lynnel; daughters, Emily and Cathy; two grandchildren; and a sister.—*Geoffrey McFadden, National Institute of Standards and Technology.*

Acknowledgments

Contributions from April Bacon, Frances Bauer, Leslie Greengard, Peter Lax, and Harold Weitzner are gratefully recognized.

References

1. An informative interview with Paul Garabedian can be found in the History of Numerical Analysis and Scientific Computing at the SIAM website (http://history.siam.org/oralhistories/garabedian.htm).
2. P.R. Garabedian, *Schwarz's lemma and the Szego kernel function*, Trans. Amer. Math. Soc., 67 (1949), 1–35.
3. P. Garabedian and M. Schiffer, *A proof of the Bieberbach conjecture for the fourth coefficient*, J. Rat. Mech. Anal., 4 (1955), 427–465.
4. P.R. Garabedian, *Numerical construction of detached shock waves*, J. Math. Phys., 36 (1957), 192–205.
5. P.R. Garabedian, *Partial Differential Equations*, Wiley, New York, 1964.
6. For a partial listing of Paul's doctoral students, see the Mathematics Genealogy Project at http://genealogy.math.ndsu.nodak.edu/id.php?id=8298&fChrono=1.
7. P.R. Garabedian and D.G. Korn, *Analysis of transonic airfoils*, Comm. Pure Appl. Math., 24 (1971), 841–851.
8. F. Bauer, P. Garabedian, and D. Korn, *A Theory of Supercritical Wing Sections, with Computer Programs and Examples*, Lecture Notes in Economics and Mathematical Systems, Volume 66, Springer-Verlag, New York, 1972.
9. F. Bauer, P. Garabedian, D. Korn, and A. Jameson, *Supercritical Wing Sections II,* Lecture Notes in Economics and Mathematical Systems, Volume 108, Springer-Verlag, New York, 1975.
10. F. Bauer, P. Garabedian, and D. Korn, *Supercritical Wing Sections III*, Lecture Notes in Economics and Mathematical Systems, Volume 150, Springer-Verlag, New York, 1977.
11. F. Bauer, O. Betancourt, and P. Garabedian, *A Computational Method in Plasma Physics*, Springer Series in Computational Physics, Springer-Verlag, New York, 1978.
12. F. Bauer, O. Betancourt, and P. Garabedian, *Magnetohydrodynamic Equilibrium and Stability of Stellarators*, Springer-Verlag, New York, 1984.
13. F. Bauer, O. Betancourt, P. Garabedian, and M. Wakatani, *The Beta Equilibrium, Stability and Transport Codes: Applications to the Design of Stellarators*, Academic Press, Boston, 1987.
14. P.R. Garabedian, *Stellarators with the magnetic symmetry of a tokamak*, Phys. of Plasmas, 3 (1996), 2483–2485.
15. P.R. Garabedian and G.B. McFadden, *Design of the DEMO fusion reactor following ITER*, J. Res. Natl. Inst. Stand. Technol., 114 (2009), 229–236.