Curriculum Vitae of S. V. Tsynkov

April 2008

General Data

Full name	Semyon Victor Tsynkov
Date and place of birth	May 8, 1966, Moscow, Russia
Marital status	Married +1
Citizenship	Israeli since 1993; Russian; US permanent resident
Place of work	Department of Mathematics, North Carolina State University
Position held	Associate Professor
Highest degree obtained	Doctor of Science [Habilitation], 2004
General areas of expertise	Computational and Applied Mathematics, Numerical Analysis of PDEs
Languages	Russian, English, Hebrew
Addresses	Department of Mathematics North Carolina State University Box 8205 Raleigh, NC 27695 USA Phone: +1-919-515-1877 Fax: +1-919-515-3798 E-mail: `tsynkov@math.ncsu.edu` URL: `www.math.ncsu.edu/~stsynkov/`

Academic Degrees

June 1989	*MSc (with Honors) degree* [Diploma of Higher Education] in Engineering Physics from Moscow Institute for Physics and Technology (Moscow, Russia). Specialty: Aerodynamics and Thermodynamics.
May 1992	*PhD degree* [Candidate of Science] from Keldysh Institute for Applied Mathematics, Russian Academy of Sciences (Moscow, Russia). Specialty: Computational Mathematics; Advisor: Professor V. S. Ryaben'kii.
May 2004	*Doctor of Science degree* [Habilitation] from the Russian Academy of Sciences. Specialty: Computational Mathematics.

Education

1983 – 1989	Moscow Institute for Physics and Technology (Moscow, Russia), *College & Graduate Student* (Dept. of Control and Applied Mathematics).
1989 – 1991	Keldysh Institute for Applied Mathematics, Russian Academy of Sciences (Moscow, Russia), *PhD Candidate.*

Professional Background

July 1991 – – September 1992	National Institute for Mathematical Modeling, Russian Academy of Sciences (Moscow, Russia), *Research Scientist.*
October 1992 – – September 1994	Department of Applied Mathematics, Tel-Aviv University (Tel-Aviv, Israel), *Postdoctoral Fellow.*
October 1994 – – September 1997	NASA Langley Research Center (Hampton, VA, USA), *National Research Council Resident Research Associate* (Aerodynamic and Acoustic Methods Branch).
October 1997 – – September 2002	Department of Applied Mathematics, Tel-Aviv University (Tel-Aviv, Israel), *Senior Lecturer.*
October 1997 –	NASA Langley Research Center (Hampton, VA, USA),

– December 2002	*Consultant for ICASE.*
August 2000 – – present	Department of Mathematics, North Carolina State University (Raleigh, NC, USA), *Associate Professor.*

Awards

1994 — 1996	National Research Council Research Associateship Award (USA);
1996	Alexander von Humboldt Research Fellowship (Germany), later declined;
1997 — 2000	Alon Fellowship (young faculty award by the government of Israel — — an equivalent of the Presidential Young Investigator Award in the US);
2006 (June–July)	Sackler Visiting Chair, Tel Aviv University.

Research Grants

1998 — 2000	NASA Langley Research Center (USA) Director's Discretionary Fund, **PI** on the research grant for the project: *Global Boundary Conditions for Aerodynamic and Aeroacoustic Computations*;
2000	Israeli Department of Defense, **co-PI** on the research grant for the project: *Numerical Solution of the Unsteady Maxwell Equations.*
2000 — 2001	NASA Langley Research Center (USA) Creativity & Innovation Program, **PI** on the research grant for the project: *Active Shielding and Control of Environmental Noise*;
2001	North Carolina State University, Faculty Research and Professional Development Fund, **PI** on the research grant for the project: *Non-Deteriorating Numerical Algorithms for Wave Propagation Problems*;
2001 — 2004	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Non-Deteriorating Numerical Methods and Artificial Boundary Conditions for the Long-Term Integration of Maxwell's Equations*;
2001 — 2005	National Science Foundation, USA, **PI** on the research grant for the project: *Temporally Uniform Grid Convergence of Discrete Approximations and Numerical Simulations in the Problems of Wave Propagation over Unbounded Domains*;
2004 — 2007	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Lacunae-Based Methods for Problems in Electromagnetics*;
2005 — present	National Science Foundation, USA, **PI** on the research grant for the project: *High-Order Numerical Simulation of Focusing Nonlinear Waves in the Non-Paraxial Regime;*
2007 — present	US Air Force Office for Scientific Research, **PI** on the research grant for the project: *Determination of the Ionosphere Parameters by Analyzing the Propagation After-Effects.*

Research Topics, Collaborations & Groups

CFD	S. Abarbanel, E. Turkel, J. Nordström, V. Ryaben'kii, V. Vatsa. Sponsorship: NASA;
Electromagnetism, PML	S. Abarbanel, E. Kashdan (graduate student, 2003), E. Turkel, Sponsorship: Israeli DoD;
Acoustics, noise control	J. Lončaric, A. Peterson (graduate student, 2006) V. Ryaben'kii, S. Utyuzhnikov, Sponsorship: NASA;
Unsteady waves, lacunae, ionospheric propagation	H. Qasimov (graduate student), V. Ryaben'kii, V. Turchaninov, Sponsorship: AFOSR, NSF;
Nonlinear waves	G. Baruch (graduate student), G. Fibich, B. Ilan (graduate student, 2002), Sponsorship: NSF.

Editorial Board

2005 — present	Applied Numerical Mathematics (an Elsevier Journal).

Research Conferences (since 2000)

February 2000	Interior Noise Workshop, NASA Langley Research Center, Hampton, Virginia (contributed);
May 2000	2nd Joint Cyprus–Israel Mathematics Workshop, Tel Aviv University, Israel (invited);
July 2000	First International Conference on Computational Fluid Dynamics, Kyoto, Japan (contributed);
June 2001	International Conference on Spectral and High Order Methods, Uppsala, Sweden (1 invited & 1 contributed);
November 2001	South East Conference on Applied Mathematics, Raleigh, NC, USA (contributed);
January 2002	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
May 2002	SIAM Conference on Optimization, Toronto, Canada (contributed);
January 2003	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
February 2003	IPAM Conference on Emerging Applications of the Nonlinear Schrödinger Equations, Los Angeles, CA, USA (invited);
April 2003	AMS Spring Eastern Sectional Meeting, New York, NY, USA (invited);
May 2003	International Conference on Computational Science and its Applications, Montreal, Canada (invited);
June–July 2003	The Sixth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Jyväskylä, Finland (contributed);
January 2004	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
October 2004	SIAM Conference on Nonlinear Waves, Orlando, FL, USA (invited);
January 2005	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
June 2005	The Seventh International Conference on Mathematical and Numerical Aspects of Wave Propagation, Providence, RI, USA (contributed);
July 2005	SIAM Annual Meeting, New Orleans, LA (minisymposium organizer);
January 2006	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
February 2006	Workshop on Advances in Computational Scattering, Banff International Research Station (BIRS), Banff, Alberta, Canada (invited);
March 2006	Progress in Electromagnetics Research Symposium, Cambridge, MA, USA (invited);
April 2006	AMS Spring Central Sectional Meeting, Notre Dame, IN, USA (invited);
January 2007	AMS Joint Mathematics Meetings, New Orleans, LA, USA (invited);
January 2007	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);
June 2007	International Conference on Spectral and High Order Methods, (ICOSAHOM'07) Beijing, China (contributed);
July 2007	The Eighth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Reading, UK (two contributed);
September 2007	Nonlinear Photonics, Quebec City, Canada (invited);
January 2008	AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited).

Invited Seminars & Colloquia (since 2000)

February 2000	Department of Mathematics, University of California, Berkeley;
February 2000	Department of Aerospace Engineering, University of California, Davis;
February 2000	Department of Mathematics, University of Michigan, Ann Arbor;
April 2000	Department of Mathematics, The Hebrew University of Jerusalem;
February 2001	Department of Mathematics, UCLA;
February 2001	NASA Ames Research Center;

February 2001	Department of Aerospace Engineering, University of California, Davis;
February 2001	Department of Mathematics, Stanford University;
February 2002	Department of Applied Physics and Applied Mathematics, Columbia University;
February 2002	Courant Institute of Mathematical Sciences;
March 2002	Department of Engineering Sciences and Applied Mathematics, Northwestern University;
October 2002	Center for Scientific Computing and Applied Mathematics, University of Maryland;
February 2003	Department of Mathematics, University of Southern California;
February 2003	Department of Applied Mathematics, Illinois Institute of Technology;
February 2003	Department of Mathematical Sciences, Indiana University — Purdue University, Indianapolis;
May 2003	Department of Mathematics, University of North Carolina, Charlotte;
October 2003	Joint Colloquium of the Keldysh Institute for Applied Mathematics and Institute for Mathematical Modeling, Russian Academy of Sciences, Moscow, Russia;
February 2004	Public defense of the Doctor of Science Dissertation, Institute for Mathematical Modeling, Russian Academy of Sciences, Moscow, Russia;
March 2004	Department of Mathematics, Duke University;
March 2004	Department of Mathematics, University of Connecticut;
June 2004	Department of Mathematics, Stanford University;
October 2004	Department of Applied Mathematics, Caltech;
October 2004	Department of Mathematics, UCLA;
October 2004	Department of Applied Mathematics, Tel Aviv University, Israel;
November 2004	Courant Institute of Mathematical Sciences;
November 2004	Department of Mathematics, University of North Carolina, Charlotte;
February 2005	Center for Optoelectronics, University of North Carolina, Charlotte;
March 2005	NASA Langley Research Center;
March 2005	Department of Mathematics, University of California, Berkeley;
November 2005	Department of Applied Mathematics, Columbia University;
November 2005	Department of Mathematics, New Jersey Institute of Technology;
March 2006	Department of Mathematics, California State University, Northridge;
April 2006	ICES, University of Texas, Austin;
October 2006	Department of Mathematics, Georgia Institute of Technology;
January 2007	Department of Mathematics, Northeastern University;
February 2008	Department of Mathematics, University of Nevada, Reno.

List of Publications

Book

- V. S. Ryaben'kii and S. V. Tsynkov, *A Theoretical Introduction to Numerical Analysis,* Chapman & Hall/CRC, Boca Raton, 551 pages, November 2006.

Articles

[1] T. G. Elizarova, S. V. Tsynkov, and B. N. Chetverushkin, *Construction of Kinetical-Consistent Finite-Difference Schemes on Curvilinear Grids,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 8, Moscow, 1989. [Russian]

[2] T. G. Elizarova, S. V. Tsynkov, and B. N. Chetverushkin, *Derivation of Invariant Quasihydrodynamic Equations on the Basis of Kinetic Models,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 7, Moscow, 1990. [Russian]

[3] D. S. Kamenetsky and S. V. Tsynkov, *Numerical Generation of Conformal Grids in the Exterior of a Bounded Simply-Connected Domain Using Difference Potentials Method,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 61, Moscow, 1990. [Russian]

[4] S. V. Tsynkov, *Boundary Conditions at the External Boundary of the Computational Domain for Subsonic Problems in Computational Fluid Dynamics*, Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 108, Moscow, 1990. [Russian]

[5] D. S. Kamenetsky and S. V. Tsynkov, *Numerical Mappings of Simply-Connected Domains by the Solutions of Beltrami Equations,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 155, Moscow, 1990. [Russian]

[6] S. V. Tsynkov, *Exact Transfer of Boundary Conditions in Subsonic Problems of Computational Gas Dynamics,* in: Construction of Algorithms and Solution of Mathematical Physics Problems, A. V. Zabrodin and G. P. Voskresensky, eds., Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Moscow, 1991, pp. 194–198. [Russian]

[7] S. V. Tsynkov, *An Implementation of Potential Flow Model in Setting External Boundary Conditions for the Euler Equations. Part I*, Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 40, Moscow, 1991. [Russian]

[8] I. L. Sofronov and S. V. Tsynkov, *An Implementation of Potential Flow Model in Setting External Boundary Conditions for the Euler Equations. Part II*, Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 41, Moscow, 1991. [Russian]

[9] T. G. Elizarova, S. V. Tsynkov, and B. N. Chetverushkin, *Kinetic-Consistent Finite-Difference Schemes in Curvilinear Coordinate Systems,* Differential Equations, 27 (1991) No. 7, pp. 1161–1169 [Russian]; Differential Equations, Consultants Bureau, NY, 27, No. 7, pp. 813–820 [English].

[10] D. S. Kamenetsky, V. S. Ryaben'kii, and S. V. Tsynkov, *Boundary Equations with Projections on Composite Domains,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 112, Moscow, 1991. [Russian]

[11] D.S.Kamenetsky, V.S.Ryaben'kii, and S.V.Tsynkov, *Domain Decomposition Algorithms Based on the Boundary Equations with Projections,* Keldysh Inst. Appl. Math., U.S.S.R. Acad. Sci., Preprint No. 113, Moscow, 1991. [Russian]

[12] V. S. Ryaben'kii and S. V. Tsynkov, *Artificial Boundary Conditions for the Numerical Solution of External Viscous Flow Problems, Part I*, Keldysh Inst. Appl. Math., Russian Acad. Sci., Preprint No. 45, Moscow, 1993. [Russian]

[13] V. S. Ryaben'kii and S. V. Tsynkov, *Artificial Boundary Conditions for the Numerical Solution of External Viscous Flow Problems, Part II*, Keldysh Inst. Appl. Math., Russian Acad. Sci., Preprint No. 46, Moscow, 1993. [Russian]

[14] V. S. Ryaben'kii and S. V. Tsynkov, *Artificial Boundary Conditions for the Numerical Solution of External Viscous Flow Problems*, SIAM J. Numer. Anal., 32 (1995) pp. 1355–1389.

[15] S. V. Tsynkov, *An Application of Nonlocal External Conditions to Viscous Flow Computations*, J. Comput. Phys., 116 (1995) pp. 212–225.

[16] S. V. Tsynkov, E. Turkel, and S. Abarbanel, *External Flow Computations Using Global Boundary Conditions*, AIAA Journal, 34 (1996) pp. 700–706; also: AIAA Paper No. 95–0562, January 1995.

[17] S. V. Tsynkov, *Nonlocal Artificial Boundary Conditions for Computation of External Viscous Flows*, in: Computational Mechanics'95, S. N. Atluri, G. Yagawa, T. A. Cruse, eds., Springer-Verlag, Berlin, 1995, pp. 1065–1070.

[18] S. V. Tsynkov, *Nonlocal Artificial Boundary Conditions Based on the Difference Potentials Method*, in: Sixth International Symposium on Computational Fluid Dynamics, Collection of Technical Papers, Vol. IV, September 4–8, 1995, Lake Tahoe, Nevada, pp. 114–119.

[19] V. S. Ryaben'kii and S. V. Tsynkov, *An Effective Numerical Technique for Solving a Special Class of Ordinary Difference Equations*, Appl. Numer. Math., 18 (1995) pp. 489–501.

[20] S. V. Tsynkov, *Artificial Boundary Conditions for Computation of Oscillating External Flows*, SIAM J. Sci. Comput., 18 (1997) pp. 1612–1656.

[21] S. V. Tsynkov, *Construction of Artificial Boundary Conditions Using Difference Potentials Method*, Mathematical Modeling, 8, No. 9 (1996) pp. 118–128.

[22] S. V. Tsynkov, *Artificial Boundary Conditions Based on the Difference Potentials Method*, NASA Technical Memorandum No. 110265, Langley Research Center, July 1996.

[23] V. S. Ryaben'kii and S. V. Tsynkov, *An Application of the Difference Potentials Method to Solving External Problems in CFD*, Computational Fluid Dynamics Review 1998, Vol. 1, M. Hafez and K. Oshima, eds., World Scientific, Singapore, 1998, pp. 169–205.

[24] S. V. Tsynkov, *Nonlocal Artificial Boundary Conditions for Computation of External Viscous Flows*, in: Computational Fluid Dynamics'96, Proceedings of the Third ECCOMAS CFD Conference, September 9–13, 1996, Paris, France, J.-A. Desideri, C. Hirsch, P. Le Tallec, M. Pandolfi, and J. Périaux, eds., John Wiley & Sons, 1996, pp. 512–518.

[25] S. V. Tsynkov, *Artificial Boundary Conditions for Infinite-Domain Problems*, in Barriers and Challenges in Computational Fluid Dynamics, V. Venkatakrishnan, M. D. Salas, and S. R. Chakravarthy, eds., Kluwer Academic Publishers, 1998, pp. 119–138.

[26] S. V. Tsynkov and V. N. Vatsa, *An Improved Treatment of External Boundary for Three-Dimensional Flow Computations*, AIAA J., 36 (1998) pp. 1998–2004; also: AIAA Paper No. 97–2074, June 1997; also in: Absorbing Boundaries and Layers, Domain Decomposition Methods. Applications to Large Scale Computations, Loïc Tourrette and Lorance Halpern, eds., Nova Science Publishers, Inc., New York, 2001, pp. 181–200.

[27] S. V. Tsynkov, *External Boundary Conditions for Three-Dimensional Problems of Computational Aerodynamics*, SIAM J. Sci. Comp., 21 (1999) pp. 166–206.

[28] S. V. Tsynkov, *Numerical Solution of Problems on Unbounded Domains. A Review*, Appl. Numer. Math., 27 (1998) pp. 465–532.

[29] S. V. Tsynkov, *On the Combined Implementation of Global Boundary Conditions with Central-Difference Multigrid Flow Solvers*, in Proceedings of IUTAM Symposium on Computational Methods for Unbounded Domains, T. L. Geers, ed., Kluwer Academic Publishers, Dordrecht, 1998, pp. 285–294.

[30] S. V. Tsynkov, S. Abarbanel, J. Nordström, V. S. Ryaben'kii, and V. N. Vatsa, *Global Artificial Boundary Conditions for Computation of External Flow Problems with Propulsive Jets,* AIAA Paper No. 99–3351, in: 14th AIAA CFD Conference, Norfolk, VA, June–July 1999, A Collection of Technical Papers, Vol. 2, pp. 836–846.

[31] S. V. Tsynkov, S. Abarbanel, J. Nordström, V. S. Ryaben'kii, and V. N. Vatsa, *Global Artificial Boundary Conditions for Computation of External Flows with Jets,* AIAA J., 38 (2000) pp. 2014–2022.

[32] S. V. Tsynkov and E. Turkel, *A Cartesian Perfectly Matched Layer for the Helmholtz Equation*, in: Absorbing Boundaries and Layers, Domain Decomposition Methods. Applications to Large Scale Computations, Loïc Tourrette and Lorance Halpern, eds., Nova Science Publishers, Inc., New York, 2001, pp. 279–309.

[33] V. S. Ryaben'kii, V. I. Turchaninov, and S. V. Tsynkov, *On Lacunae-Based Algorithm for Numerical Solution of 3D Wave Equation for Arbitrarily Large Time,* Mathematical Modeling, 11, No. 12 (1999) pp. 113–127. [Russian]

[34] V. S. Ryaben'kii, V. I. Turchaninov, and S. V. Tsynkov, *Long-Time Numerical Integration of the Three-Dimensional Wave Equation in the Vicinity of a Moving Source*, ICASE Report No. 99–23, NASA/CR–1999–209350, Hampton, VA, January 1999.

[35] V. S. Ryaben'kii, V. I. Turchaninov, and S. V. Tsynkov, *Non-Reflecting Artificial Boundary Conditions for the Replacement of Truncated Equations with Lacunae,* Mathematical Modeling, 12, No. 12 (2000) pp. 108–127. [Russian]

[36] S. V. Tsynkov, *On the Results of Application of the Method of Difference Potentials to the Construction of Artificial Boundary Conditions for External Flow Computations,* in: V. S. Ryaben'kii, Method of Difference Potentials and its Applications, Springer-Verlag, Berlin, 2002, pp. 403–441.

[37] V. S. Ryaben'kii, S. V. Tsynkov, and V. I. Turchaninov, *Long-Time Numerical Computation of Wave-Type Solutions Driven by Moving Sources,* Appl. Numer. Math., 38 (2001) pp. 187–222.

[38] J. Lončarić, V. S. Ryaben'kii, and S. V. Tsynkov, *Active Shielding and Control of Noise,* SIAM J. Applied Math., 62 (2001) pp. 563–596.

[39] T. W. Roberts, D. Sidilkover, and S. V. Tsynkov, *On the Combined Performance of Non-Local Artificial Boundary Conditions with the New Generation of Advanced Multigrid Flow Solvers*, Computers and Fluids, 31 (2001) pp. 269–308.

[40] G. Fibich and S. V. Tsynkov, *High-Order Two-Way Artificial Boundary Conditions for Nonlinear Wave Propagation with Backscattering,* J. Comput. Phys., 171 (2001) pp. 632–677.

[41] V. S. Ryaben'kii, S. V. Tsynkov, and V. I. Turchaninov, *Global Discrete Artificial Boundary Conditions for Time-Dependent Wave Propagation*, J. Comput. Phys., 174 (2001) pp. 712–758.

[42] G. Fibich, B. Ilan, and S. Tsynkov, *Computation of Nonlinear Backscattering Using a High-Order Numerical Method,* J. Sci. Comput., 17 (2002) pp. 351–364.

[43] S. V. Tsynkov, *On the Definition of Surface Potentials for Finite-Difference Operators,* J. Sci. Comput., 18 (2003) pp. 155–189.

[44] J. Lončarić and S. V. Tsynkov, *Optimization of Acoustic Source Strength in the Problems of Active Noise Control*, SIAM J. Applied Math., 63 (2003) pp. 1141–1183.

[45] J. Lončarić and S. V. Tsynkov, *Quadratic Optimization in the Problems of Active Control of Sound*, Applied Numer. Math., 52 (2005) pp. 381–400.

[46] G. Fibich, B. Ilan, and S. Tsynkov, *Backscattering and Nonparaxiality Arrest Collapse of Damped Nonlinear Waves,* SIAM J. Applied Math., 63 (2003) pp. 1718–1736.

[47] S. V. Tsynkov, *Artificial Boundary Conditions for the Numerical Simulation of Unsteady Acoustic Waves*, J. Comput. Phys., 189 (2003) pp. 626–650.

[48] S. V. Tsynkov, *Artificial Boundary Conditions for the Numerical Simulation of Unsteady Electromagnetic Waves*, Center for Research in Scientific Computation, North Carolina State University, Tech. Report No. CRSC–TR03–19, Raleigh, NC, April 2003.

[49] J. Lončarić and S. V. Tsynkov, *Optimization of Power in the Problems of Active Control of Sound*, Mathematics and Computers in Simulation, 65, Issues 4–5 (2004) pp. 323–335.

[50] S. Abarbanel, S. Tsynkov, and E. Turkel, *A Future Role of Numerical and Applied Mathematics in Material Sciences*, ICASE Interim Report No. 40, NASA/CR–2002–211453, Hampton, VA, April 2002.

[51] J. Lončarić and S. V. Tsynkov, *Optimization in the Context of Active Control of Sound*, in: Computational Science and Its Applications — ICCSA 2003, Proceedings of the International Conference, Montreal, Canada, May 18–21, 2003, V. Kumar, M. L. Gavrilova, C. J. K. Tan, and P. L'Ecuyer, eds., Part II, Lecture Notes in Computer Science 2668, Springer, Berlin, 2003, pp. 801–810.

[52] S. V. Tsynkov, *Lacunae-Based Artificial Boundary Conditions for the Numerical Simulation of Unsteady Waves Governed by Vector Models*, in: Mathematical and Numerical Aspects of Wave Propagation WAVES 2003, Proceedings of the Sixth International Conference Held at Jyväskylä, Finland, June 30 – July 4, 2003, G. C. Cohen, E. Heikkola, P. Joly, and P. Neittaanmäki, eds., Springer, Berlin, 2003, pp. 103–108.

[53] S. V. Tsynkov, *On the Application of Lacunae-Based Methods to Maxwell's Equations*, J. Comput. Phys., 199 (2004) pp. 126–149.

[54] G. Fibich and S. V. Tsynkov, *Numerical Solution of the Nonlinear Helmholtz Equation Using Nonorthogonal Expansions*, J. Comput. Phys., 210 (2005) pp. 183-224.

[55] G. Fibich and S. V. Tsynkov, *Numerical Solution of the Nonlinear Helmholtz Equation Using Nonorthogonal Expansions*, in: Proceedings of the 7th International Conference on Mathematical and Numerical Aspects of Wave Propagation, WAVES 2005, Brown University, Providence, RI, June 20 – 24, 2005, pp. 379–381.

[56] V. S. Ryaben'kii, S. V. Utyuzhnikov, and S. V. Tsynkov, *The Problem of Active Shielding for Multiply Connected Regions,* Doklady Rossiiskoi Akademii Nauk (Transactions of the Russian Academy of Sciences), 411, No. 2 (2006) pp. 164–166 [Russian]

[57] A. Kurganov and S. Tsynkov, *On Spectral Accuracy of Quadrature Formulae Based on Piecewise Polynomial Interpolation*, Center for Research in Scientific Computation, North Carolina State University, Technical Report No. CRSC-TR07-11, 2007.

[58] G. Baruch, G. Fibich, and S. V. Tsynkov, *Numerical Solution of the Nonlinear Helmholtz Equation with Axial Symmetry*, Journal of Computational and Applied Mathematics, 204, No. 2 (2007) pp. 477–492.

[59] V. S. Ryaben'kii, S. V. Tsynkov, and S. V. Utyuzhnikov, *Inverse Source Problem and Active Shielding for Composite Domains,* Applied Mathematics Letters, 20, No. 5 (2007) pp. 511–515.

[60] G. Fibich and S. V. Tsynkov, *Numerical Solution of the Nonlinear Helmholtz Equation*, in: Effective Computational Methods in Wave Propagation, V. A. Dougalis, J. A. Ekaterinaris, and N. A. Kampanis, eds., CRC Press series: Numerical Insight, Volume 5, CRC Press, Boca Raton, February 2008, pages 37–62.

[61] S. V. Tsynkov, *Weak Lacunae of Electromagnetic Waves in Dilute Plasma*, SIAM J. Applied Math, 67, No. 6 (2007) pp. 1548–1581.

[62] A. W. Peterson and S. V. Tsynkov, *Active Control of Sound for Composite Regions*, SIAM J. Applied Math., 67, No. 6 (2007) pp. 1582–1609.

[63] G. Baruch, G. Fibich, and S. V. Tsynkov, *High-Order Numerical Method for the Nonlinear Helmholtz Equation with Material Discontinuities in One Space Dimension*, J. Comput. Phys., 227 (2007) pp. 820–850.

[64] G. Baruch, G. Fibich, and S. V. Tsynkov, *High-Order Numerical Method for the Nonlinear Helmholtz Equation with Material Discontinuities*, in: Proceedings of the 8th International Conference on Mathematical and Numerical Aspects of Wave Propagation, WAVES 2007, University of Reading, UK, July 23 – 27, 2007, pp. 455–457.

[65] H. Lim, S. V. Utyuzhnikov, Y. W. Lam, A. Turan, M. Avis, V. S. Ryaben'kii, and S. V. Tsynkov, *An Experimental Validation of the Noise Control Methodology Based on Difference Potentials,* submitted for publication to the AIAA Journal.

[66] H. Qasimov and S. Tsynkov, *Lacunae Based Stabilization of PMLs: Theoretical Foundations*, submitted for publication to the Journal of Computational Physics.

[67] H. Qasimov and S. Tsynkov, *Lacunae Based Stabilization of PMLs,* in: Proceedings of the 8th International Conference on Mathematical and Numerical Aspects of Wave Propagation, WAVES 2007, University of Reading, UK, July 23 – 27, 2007, pp. 298–300.

[68] S. V. Tsynkov, *On the Application of Lacunae-Based Methods to Maxwell's Equations: Part II*, in progress.

[69] G. Baruch, G. Fibich, S. V. Tsynkov, and E. Turkel, *Fourth Order Scheme for Wave-Like Equations in Frequency Space with Discontinuities in the Coefficients,* to appear in Communications in Computational Physics.

[70] S. Abarbanel, H. Qasimov, and S. Tsynkov, *Long-Time Performance of Unsplit PMLs with Explicit Second Order Schemes*, submitted to the Journal of Computational and Applied Mathematics.

[71] G. Baruch, G. Fibich, and S. V. Tsynkov, *Simulations of the Nonlinear Helmholtz Equation: Arrest of Beam Collapse, Nonparaxial Solitons, and Counter-Propagating Beams*, submitted for publication to Optics Express.

[72] S. V. Tsynkov, *On SAR Imaging through the Earth Ionosphere*, submitted for publication to SIAM Journal on Applied Mathematics.

Research Summary

My general research area is numerical analysis of PDEs, with applications to fluid flow, acoustics (including optimization and control), electrodynamics, nonlinear optics, and other fields. I was trained in Moscow, Russia, at the Moscow Institute for Physics and Technology and subsequently at the Russian Academy of Sciences, where I have completed my PhD in December 1991 under Professor V. Ryaben'kii. The subject of my PhD was development of numerical methods for solving fluid flow problems on the domains of irregular shape; and the thesis included the three key elements that pertain to every full-fledged algorithm designed for this purpose. These elements are the grid, the scheme, and the boundary conditions. As one part of the thesis work, I have developed and implemented (in collaboration with D. Kamenetsky) a collection of numerical algorithms for the generation of conformal [3] and quasi-conformal [5] two-dimensional grids around curvilinear shapes, like airfoils, etc. This was done by solving the Cauchy-Riemann and Beltrami equations, respectively, using the method of difference potentials by Ryaben'kii. The latter algorithm could also be used for gridding curvilinear surfaces and subsequently generating three-dimensional grids for computation of boundary layers. Another part of the thesis was devoted to building finite-difference schemes for the Euler and Navier-Stokes equations based on the kinetic models, see [1, 2, 9]. Such schemes often have better properties as far as capturing some "borderline" fluid physics phenomena, like those pertinent to rarefied gases (e.g., re-entry conditions). In this chapter of my dissertation, I devoted special attention to obtaining the schemes that would have the same boundary-layer limit near a curvilinear wall that the standard Navier-Stokes equations have. In the third part of my thesis, I developed highly-accurate nonlocal artificial boundary conditions (ABCs) for the numerical integration of external compressible inviscid flows, see [4, 6–8]. The ABCs is a general term currently adopted in the literature to identify a special group of numerical methods needed to implement the truncation and closure once the problem is originally formulated on an unbounded domain. Without the ABCs no finite-dimensional discretization can be obtained, and as such the problem simply cannot be solved on the computer. The issue of ABCs appears critical in many areas of scientific computing, e.g., in acoustics, electrodynamics, solid mechanics, and fluid dynamics. In my PhD thesis, I constructed global ABCs based on the assumption of linearized potential flow in the far field, and implemented these boundary conditions for integrating a variety of flow cases in the framework of the Euler's equations. The new ABCs provided for a very substantial reduction of the required computer resources through the shrinkage of the computational domain, while still guaranteeing high accuracy of the numerical solution.

The work [10, 11] done concurrently with the PhD but not as a part of the thesis addressed the construction of domain decomposition algorithms using the method of difference potentials. Unlike many traditional domain decomposition techniques based on the Schwartz algorithm, the approach we have developed in collaboration with D. Kamenetsky and V. Ryaben'kii did not require the overlap of subdomains for convergence.

Design of ABCs for the numerical integration of external flow problems was in the focus of my research for a number of years after the PhD. This work was supported by NASA. It is generally acknowledged that in computational fluid dynamics, where external problems represent a wide class of important formulations, the proper treatment of external boundaries may have a profound impact on the overall quality and performance of numerical algorithms and interpretation of the results. Most of the existing ABCs' techniques can basically be classified into two groups. The methods from the first group (global ABCs) usually provide high accuracy and robustness of the numerical procedure but often appear fairly cumbersome and computationally expensive. The methods from the second group (local ABCs) are, as a rule, algorithmically simple, numerically cheap, and geometrically universal; however, they usually lack accuracy of computations. In a series of papers written between 1993 and 2000 (partially with coauthors), see [12–27, 29–31], I developed a new ABCs' technique for computation of the steady-state compressible external viscous flows. This technique largely combines the advantages relevant to the two aforementioned groups of methods.

The approach of [12–27, 29–31] is based on application of the method of difference potentials. It allows one to obtain highly accurate ABCs in the form of certain nonlocal boundary operator equations. The operators involved are analogous to the pseudodifferential boundary projections first introduced by A. Calderon and then also studied by R. Seeley. In spite of the nonlocality, the new boundary conditions are geometrically universal, numerically inexpensive, and easy to implement along with the existing interior solvers. These ABCs allow one to drastically improve the treatment of external artificial boundaries for a variety of flow configurations and regimes. They have been constructed for both two and three space dimensions, and successfully implemented along with the NASA-developed production flow solver `TLNS3D`. The actual cases analyzed using the new ABCs include subsonic and transonic, laminar and turbulent, two- and three-dimensional flows. A case particularly interesting from the standpoint of flow physics involves jet exhaust, see [30, 31]. In all these cases, the new ABCs have systematically outperformed the standard existing methods; they have provided for a better accuracy and much smaller computational domains, which translated into very substantial savings of computer resources. Besides, the nonlocal ABCs could noticeably speed up the convergence of multigrid iterations, see [29].

Based on my deep involvement in the area of numerical methods for infinite-domain problems, I wrote a comprehensive survey article of the field that was solicited by Applied Numerical Mathematics and published in 1998, see [28]. This paper includes, among other things, a comparative assessment of different existing methods for constructing the ABCs. By now, it accumulated about 100 citations and has become a standard source of reference in the field. I also wrote a survey chapter on ABCs and the method of difference potentials for the research monograph by V. Ryaben'kii [36] (see Part V, Chapter 2).

As an extension of the work on ABCs for the steady-state external fluid flows, we developed and implemented (in collaboration with T. Roberts and D. Sidilkover), see [39], a unified flow solver that combines the advantages relevant to global far-field ABCs, as well as to another group of methods that has recently proven successful — the new factorizable schemes for the equations of hydrodynamics that facilitate the construction of optimally convergent multigrid algorithms. The key result obtained in [39] is the following. Global ABCs do not hamper the optimal (i.e., unimprovable) multigrid convergence rate pertinent to the solver. At the same time, contrary to the standard local ABCs, the solution accuracy provided by the global ABCs deteriorates very slightly or does not deteriorate at all when the computational domain shrinks, which clearly translates into most substantial savings of computer resources.

In the recent years, the focus of my research work has shifted more toward numerical methods for wave propagation problems, with applications primarily in acoustics, electrodynamics, and optics. This involves both time-harmonic (monochromatic) and genuine time-dependent (broad-band) wave fields. In [32], we consider (in collaboration with E. Turkel) the Helmholtz equation and study an alternative way of handling the external artificial boundary, by means of the so-called perfectly matched layer (PML) that damps the outgoing waves and prevents their reflection back into the computational domain. Using energy-type estimates and the separation of variables, we analyze the solvability, uniqueness, and limit properties (with respect to the thickness of the layer) of several PML models. We also consider numerical approximations, including those of high order, and discuss iterative methods and preconditioning for solving the Helmholtz equation with PML.

In a series of papers [33–35, 37, 41] we introduce (in collaboration with V. Ryaben'kii and V. Turchaninov) a special non-deteriorating algorithm for the long-term computation of wave-radiation solutions, and subsequently use it to construct global highly-accurate ABCs for the numerical simulation of genuinely unsteady waves on unbounded domains. This work is supported by NSF and AFOSR. The algorithm is based on the presence of lacunae, i.e., aft fronts of the waves, in wave-type solutions in odd-dimension spaces (a manifestation of the Huygens' principle). It is inherently three-dimensional and guarantees temporally uniform grid convergence of the solution driven by a continuously operating source on arbitrarily long time intervals. Moreover, the algorithm provides for a linear computational complexity with respect to the grid dimension. Note that the question of constructing the numerical schemes that would converge uniformly in time for unsteady problems has been an outstanding issue in numerical analysis of PDEs for many years, since the first studies on stability and convergence of discrete approximations have been conducted in the fifties.

The non-deteriorating numerical algorithm that we are discussing can, in fact, be built as a modification on top of any consistent and stable finite-difference scheme, making its grid convergence uniform in time and at the same time keeping the rate of convergence the same as that of the non-modified scheme. The corresponding lacunae-based ABCs are obtained directly for the discrete formulation of the problem; in so doing, neither a rational approximation of non-reflecting kernels, nor discretization of the continuous boundary conditions is required. The extent of temporal nonlocality of the new ABCs appears fixed and limited; in addition, the ABCs can handle artificial boundaries of irregular shape on regular grids with no fitting/adaptation needed and no accuracy loss induced. Moreover, the apparatus developed in [33–35,37,41] allows one to consider the most general formulation of the problem that involves radiation of waves by moving sources (e.,g., radiation of acoustic waves by a maneuvering aircraft).

The lacunae-based approach originally developed for the scalar wave equation can be extended to the cases of acoustics and electromagnetism, see [47,48,52,53,68]. Extension to electromagnetic waves is particularly non-trivial, as it requires that a special inverse problem be formulated and solved of reconstructing the auxiliary field sources in a prescribed form — zero charges and solenoidal currents — that would identically satisfy the continuity equation. The latest in the work on lacunae is their application to the stabilization of time-dependent PMLs [66,67] that are known to suffer from the long-time error buildup.

In addition to building the numerical algorithms, our work on the theory and computation of electromagnetic waves (under the sponsorship of the US Air Force) has diversified to encompass a variety of subjects that are not necessarily centered around numerics. It includes the study of the weakly dispersive propagation of electromagnetic waves in the ionosphere, with the goal of identifying the aft fronts of the waves in some approximate sense, and with the application to satellite communications. Most recently [61], we have shown that the "depth" of the weak lacunae in dilute plasma is proportional to the ratio of the Langmuir frequency to the driving frequency of the wave. Also in [61] we analyze the anisotropic case with gyrotropy and show that for the typical ionospheric conditions the additional effect on lacunae is small.

Our most recent project on the propagation of radio waves in the Earth ionosphere has to do with the analysis of how their dispersion affects the performance (image resolution) of spaceborne synthetic aperture radars (SARs). We employ the scalar model for transverse waves with weak anomalous dispersion due to the cold plasma. Random contributions to the refraction index are accounted for by the Kolmogorov model of ionospheric turbulence. The ionospheric phenomena, both deterministic and random, are shown to affect the azimuthal resolution of a SAR sensor stronger than the range resolution. We provide specific quantitative estimates for some typical values of the key parameters ad identify probing on two carrier frequencies as a possible venue for compensating for the ionospheric distortions [72].

In our work [38,43–45,49,51], we study (partially in collaboration with J. Lončarić and V. Ryaben'kii) the problem of active control of sound (time-harmonic wave fields), which is formulated mathematically as a particular type of the inverse source problem for elliptic PDEs. This work was supported by NASA. Unlike many existing methodologies, the approach of [38] provides for the exact volumetric cancellation of the unwanted noise on a given predetermined region of space, while leaving unaltered those components of the total acoustic field that are deemed as friendly. The key finding of this work is that for eliminating the unwanted component of the acoustic field in a given area, one needs to know relatively little; in particular, neither the locations nor structure nor strength of the exterior noise sources need to be known. Likewise, there is no need to know the volumetric properties of the supporting medium across which the acoustic signals propagate, except, maybe, in a narrow area of space near the perimeter of the protected region. The controls are built based solely on the measurements performed on the perimeter of the domain to be shielded; moreover, the controls themselves (i.e., additional sources) are concentrated also only on or near this perimeter. Perhaps as important, the measured quantities can refer to the total acoustic field rather than to its unwanted component only, and the methodology can automatically distinguish between the two. In [38], we constructed a general solution to the aforementioned noise control problem. The apparatus used for deriving this general solution is closely connected to the concepts of generalized potentials and boundary projections of Calderon's type. For a given total wave field, the application of a Calderon's projection allows one to definitively tell between its incoming and outgoing components with respect to a particular domain of interest, which may have arbitrary shape. Then, the controls are designed so that they suppress the incoming component for the domain to be shielded or alternatively, the outgoing component for the domain, which is complementary to the one to be shielded.

In [43] we construct special types of discrete surface control sources that correspond to the continuous densities of the single- and double-layer potentials. In [44,45,49,51] we focus on optimizing the control sources with respect to different criteria. We consider optimization in the sense of L_2, optimization of power, and optimization of acoustic strength. The L_2 norm of the control sources, although very easy to minimize, lacks clear physical interpretation. All power-based criteria involve interactions between the sources and the field, which may lead to certain types of degeneration, although some results are quite interesting and often counterintuitive. Optimization of acoustic strength mathematically translates into the minimization of complex-valued functions in the sense of L_1 with conical constraints, which are only "marginally" convex. The corresponding numerical optimization problem appears very challenging even for the most sophisticated state-of-the-art methodologies, and even when the grid dimensions are small and the waves are long. Our central result in [44] is that the global L_1-optimal solution can, in fact, be obtained without solving the numerical optimization problem. This solution is given by a special layer of monopole-type sources on the perimeter of the protected region. We provide a rigorous proof of the global L_1-minimality in the one-dimensional case. We also provide numerical evidence that corroborates our result in the two-dimensional case, when the protected domain is a cylinder. Even though we cannot prove it yet, we believe that the result is correct in general as well, i.e., for multi-dimensional settings that include domains of arbitrary shape. The most recent addition to this work is active control of sound for multiply connected regions [56,59,62]. Besides shielding the given multiply connected region from the exterior noise, the approach allows its different parts to selectively hear or not hear each other. Yet another resent extension is experimental verification and validation of the proposed noise control methodology, which is reported in [65].

In our work [40, 42, 46] we analyze (in collaboration with G. Fibich and partially with B. Ilan) the mathematical and numerical aspects of the propagation of electromagnetic waves (intense laser beams) in the nonlinear Kerr media. The work is supported by NSF. A standard model for describing this class of phenomena is the nonlinear Schrödinger equation (NLS). It is derived from the more comprehensive nonlinear Helmholtz equation (NLH) by employing the paraxial approximation and neglecting the backscattered waves. In [40] we use a high-order finite-difference method supplemented by the special two-way ABCs to solve the NLH as a true boundary value problem. The two-way ABCs is a key element of the algorithm. Because the propagation equation is nonlinear, the impinging and scattered waves cannot be separated (as typically done when solving linear scattering problems), and the problem has to be solved in its entirety. In particular, the boundary on which the incoming field values are prescribed, should transmit the given incoming waves in one direction and simultaneously be transparent to all the outgoing waves that travel in the opposite direction. In [40], the two-way ABCs are obtained in the framework of a fourth-order accurate discretization to the Helmholtz operator inside the computational domain. Our numerical methodology allows for a direct comparison of the NLH and NLS models and, apparently for the first time ever, for an accurate quantitative assessment of the backscattered signal in nonlinear self-focusing. In [42], we have been able to match the numerical predictions of nonlinear backscattering with the results of the asymptotic theory. In [46], we have introduced linear damping into the model and could show that the NLH requires less damping than the NLS to arrest the collapse. This is an indication that nonparaxiality and backscattering help suppress the singularity formation in the solution. In our subsequent paper on the subject [54] (see also [55,60]), we employ the Sommerfeld-type local radiation boundary conditions in the cross-range direction (lateral boundaries), instead of the previously used Dirichlet boundary conditions. Implementation of those requires evaluation of eigenvalues and eigenvectors for a non-Hermitian matrix; the eigenvectors subsequently render the separation of variables. The new algorithm offers considerable overall benefits, both from the standpoint of its numerical performance and the range of physical phenomena that it is capable of simulating. An extension of this approach to the case of cylindrical geometry is addressed in [58] (in collaboration with G. Baruch and G. Fibich). Most recently, a very considerable progress was made by constructing a new finite volume compact scheme for the analysis of material discontinuities, and by introducing a Newton-based nonlinear solver [63, 64]. Newton's linearization is nontrivial since the Kerr nonlinearity contains absolute values of the field and is Frechet non-differentiable for complex-valued solutions. Thus, the NLH has to be recast as a system of two real equations, in which case Newton's method converges rapidly and enables computations for very high levels of nonlinearity, beyond the actual threshold of material breakdown. An extension of this work in the general direction of direction of high-order schemes for the wave propagation problems with discontinuities is presented in [69]. The results of the most recent multi-dimensional simulations of the NLH using compact approximations and Newton's solver are summarized in [71].