

Curriculum Vitae of S. V. Tsynkov

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General Data

Full name	Semyon Victor Tsynkov
Date and place of birth	May 8, 1966, Moscow, Russia
Marital status	Married +2
Citizenship	United States, Israel, Russia
Degrees	MSc (1989), PhD (1992), DSc (2004)
General areas of expertise	Applied and Computational Mathematics, Numerical Analysis of PDEs
Place of work	Department of Mathematics, North Carolina State University
Position held	Professor
Languages	Russian, English, Hebrew
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Academic Credentials

June 1989	<i>MSc (with Honors)</i> [Diploma of Higher Education] in Engineering Physics from Moscow Institute for Physics and Technology (Moscow, Russia). Specialty: Aerodynamics and Thermodynamics.
May 1992	<i>PhD</i> [Candidate of Science] from Keldysh Institute for Applied Mathematics, Russian Academy of Sciences (Moscow, Russia). Specialty: Computational Mathematics; Advisor: Professor V. S. Ryaben'kii. Thesis: <i>Computational methods for external flows</i> , Moscow, 98 pages.
May 2004	<i>Doctor of Science</i> [Habilitation, an advanced post-PhD degree] from the Russian Academy of Sciences. Specialty: Computational Mathematics. Thesis: <i>Nonlocal artificial boundary conditions for the numerical solution of problems on unbounded domains</i> , Moscow, 217 pages.

Education

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

Professional Background

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

October 1997 – – September 2002	Department of Applied Mathematics, Tel-Aviv University (Tel-Aviv, Israel), <i>Senior Lecturer.</i>
October 1997 – – December 2002	NASA Langley Research Center (Hampton, VA, USA), <i>Consultant</i> for ICASE.
August 2000 – – present	Department of Mathematics, North Carolina State University (Raleigh, NC, USA), <i>Associate Professor (until 2009), Professor (since 2009)</i> ;
March 2008 – – August 2011	<i>Consultant</i> for Computational Sciences, LLC, Huntsville, AL.

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;
June 2008	Best student paper by G. Baruch (advisee) at the international conference on Nonlinear Waves — Theory and Applications, Beijing, China;
2008 — 2010	Invited Project Director for the research project <i>Methods, Algorithms, and Software for Computing the Diffraction of Waves in Heterogeneous Media on Multiprocessor Computer Platforms</i> , Russian Academy of Sciences.

Research Grants

1998 — 2000	NASA Langley Research Center (USA) Director's Discretionary Fund, PI on the research grant for the project: <i>Global Boundary Conditions for Aerodynamic and Aeroacoustic Computations</i> ;
2000	Israeli Department of Defense, co-PI on the research grant for the project: <i>Numerical Solution of the Unsteady Maxwell Equations</i> .
2000 — 2001	NASA Langley Research Center (USA) Creativity & Innovation Program, PI on the research grant for the project: <i>Active Shielding and Control of Environmental Noise</i> ;
2001	North Carolina State University, Faculty Research and Professional Development Fund, PI on the research grant for the project: <i>Non-Deterio- rating Numerical Algorithms for Wave Propagation Problems</i> ;
2001 — 2004	US Air Force Office for Scientific Research, PI on the research grant for the project: <i>Non-Deteriorating Numerical Methods and Artificial Boundary Conditions for the Long-Term Integration of Maxwell's Equations</i> ;
2001 — 2005	National Science Foundation, USA, PI on the research grant for the project: <i>Temporally Uniform Grid Convergence of Discrete Approximations and Numerical Simulations in the Problems of Wave Propagation over Unbounded Domains</i> ;
2004 — 2007	US Air Force Office for Scientific Research, PI on the research grant for the project: <i>Lacunae-Based Methods for Problems in Electromagnetics</i> ;
2005 — 2008	National Science Foundation, USA, PI on the research grant for the project: <i>High-Order Numerical Simulation of Focusing Nonlinear Waves in the Non-Paraxial Regime</i> ;
2007 — 2010	US Air Force Office for Scientific Research, PI on the research grant for the project: <i>Determination of the Ionosphere Parameters by Analyzing the Propagation After-Effects</i> ;
2008 — 2011 (current)	National Science Foundation, USA, PI on the research grant for the project: <i>High-Order Numerical Solution of Wave-Type Equations with Discontinuous Coefficients</i> ;
2008 — 2011 (current)	US Air Force Research Laboratory/Computational Sciences, LLC, co-PI on SBIR Phase I and II research grants: <i>Accurate and Efficient Computation</i>

2009 — 2013 (current)	<i>of Electromagnetic Fields and Waves over Unbounded Regions in 3D</i> ; US–Israel Binational Science Foundation (BSF), American co-PI (jointly with Professor E. Turkel of Tel Aviv University) on the research grant for the project: <i>Numerical Simulation of Waves in Piecewise Continuous Media with High Order Accuracy</i> ;
2010 — 2013 (current)	US Air Force Office for Scientific Research, PI on the research grant for the project: <i>SAR Imaging through the Earth’s Ionosphere</i> ;
2011 — 2014 (current)	US Army Research Office, PI on the research grant for the project: <i>Singularity-free high order boundary methods for heterogeneous wave problems</i> ;
2011 — 2012 (current)	US Army Research Office/Computational Sciences, LLC, co-PI on the STTR Phase I research grant for the project: <i>A Priori Error-Controlled Simulations of Electromagnetic Phenomena for HPC</i> .

Research Topics & Collaborations

CFD	S. Abarbanel, J. Nordström, V. Ryaben’kii, E. Turkel, V. Vatsa, D. Sidilkover, T. Roberts. Support: NASA.
Electromagnetism, PML	S. Abarbanel, E. Kashdan, E. Turkel, H. Qasimov, S. Petropavlovsky, I. Tsukerman. Support: Israeli DoD, AFOSR, ARO.
Acoustics, noise control	J. Lončarić, A. Peterson, V. Ryaben’kii, S. Utyuzhnikov. Support: NASA.
Unsteady waves, lacunae, non-deteriorating methods	H. Qasimov, V. Ryaben’kii, V. Turchaninov, S. Petropavlovsky, E. Kansa, I. Tsukerman. Support: AFOSR, NSF, ARO.
Nonlinear waves	G. Baruch, G. Fibich, B. Ilan. Support: NSF.
Waves in discontinuous media	E. Turkel, G. Fibich, G. Baruch, S. Britt, M. Medvisny, I. Tsukerman. Support: NSF, BSF, ARO.
Synthetic aperture radar (SAR) and the ionosphere	E. Smith, M. Gilman. Support: AFOSR.
Numerical simulation of FRC plasmas	E. Kansa, U. Shumlak, I. Tsukerman. Support: AFRL.

Research Leadership Experience

1997 — 2002	Research group leader at ICASE, NASA Langley Research Center, Hampton, VA;
2008 — 2010	Research group leader (invited foreign project director) at the Russian Academy of Sciences, Moscow, Russia.

Supervision of Students

B. Ilan	co-advised, PhD 2002;
D. Warren	senior undergraduate, 2005–2006;
L. Bilbro	senior undergraduate, 2006;
A. Peterson	MSc 2006;
H. Qasimov	PhD 2008;
G. Baruch	co-advised, PhD 2010;
M. Medvinsky	co-advised, PhD expected in 2012;
E. Smith	PhD expected in 2013;
S. Britt	PhD expected in 2013.

Supervision of Postdocs

Mark Hoefer
Michael Gilman

NSF Postdoc during the Academic Year 2009–2010;
Postdoc supported by AFOSR.

Editorial Board

2005 — present

Applied Numerical Mathematics (an Elsevier Journal).

Research Conferences (since 2001)

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);

June 2008 Nonlinear Waves — Theory and Applications, Beijing, China (minisymposium organizer);

September 2008 Numerical Methods for Aeroacoustics, Svetlogorsk, Russia (invited);

January 2009 AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);

March 2009 The 6th IMACS International Conference on Nonlinear Evolution Equations and Wave Phenomena: Computation and Theory, Athens, GA, USA (invited);

June 2009 The Ninth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Pau, France (two contributed);

June 2009 International Conference on Spectral and High Order Methods, (ICOSAHOM'09) Trondheim, Norway (2 invited);

July 2009 International Conference in Honor of Professor Godunov's 80th Birthday, Novosibirsk, Russia (invited);

September 2009 Air Force workshop "Radar and the Ionosphere," Wright-Patterson Air Force Base, Dayton, OH (invited);

January 2010 AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);

January 2010 Air Force Orbital Resources Ionosphere (ORION) Conference, Dayton, OH, USA (invited);

June 2010 Second International Conference on Nonlinear Waves — Theory and Applications, Beijing, China (minisymposium organizer & invited talk);

November 2010 AMS Fall Central Sectional Meeting, Notre Dame, IN, USA (invited);

January 2011 AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);

June 2011 International Conference in Honor of Prof. Saul Abarbanel's 80th Birthday, Tel-Aviv, Israel (invited);

July 2011 The Tenth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Vancouver, Canada (contributed);

January 2012 AFOSR Electromagnetics Workshop, San Antonio, TX, USA (invited);

February 2012 IPAM Workshop on Challenges in Synthetic Aperture Radar, Los Angeles, CA, USA (invited).

Invited Seminars & Colloquia (since 2001)

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 Univ.;

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 Acad. Sci., 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;
June 2008	Mathematical Institute, Oxford University, UK;
January 2009	Department of Mathematics, the University of Sussex, UK;
February 2009	Keldysh Institute for Applied Mathematics, Moscow, Russia;
March 2009	Institute for Mathematical Modeling, Moscow, Russia;
March 2009	Naval Research Laboratory, Washington, DC;
May 2010	Department of Applied Mathematics, Northwestern University.

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, 2007.

Articles

- [1] T. G. ELIZAROVA, S. V. TSYNKOV, AND B. N. CHETVERUSHKIN, *Construction of Kinetic-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. KAMENETSKII 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. KAMENETSKII 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. KAMENETSKII, 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.KAMENETSKII, 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 Tournette and Lorraine 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, *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.

- [29] 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.
- [30] S. V. TSYNKOV, *Numerical Solution of Problems on Unbounded Domains. A Review*, Appl. Numer. Math., 27 (1998) pp. 465–532.
- [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 Turrette and Lorraine 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.
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Extended Research Summary

My general research area is applied mathematics, with the emphasis on numerical analysis of PDEs and scientific computation, and with applications to fluid flow, acoustics (including optimization and control), electrodynamics, nonlinear optics, plasma, 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 difference scheme, and the boundary conditions. As a part of the PhD, I have developed and implemented (in collaboration with D. Kamenetskii) 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. Another part of the thesis was devoted to building the Euler and Navier-Stokes schemes based on kinetic models [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 doing so, special attention was paid to obtaining the schemes with the same boundary-layer limit as that of the standard Navier-Stokes equations. 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 [4, 6–8]. The ABCs help truncate the problem originally formulated on an unbounded domain. They provide a closure for the truncated formulation that enables construction of a finite-dimensional discretization so that the problem can 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 have constructed global ABCs under the assumption of a linearized potential flow in the far field, and implemented these boundary conditions for simulating a variety of compressible Euler flows. 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.

In work [10, 11] (done in collaboration with D. Kamenetskii and V. Ryaben’kii) we have used the method of difference potentials to build a class of domain decomposition algorithms that did not require the overlap of subdomains for convergence (unlike many traditional techniques based on the Schwartz algorithm).

Design of the ABCs for the numerical solution 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. External problems represent a wide class of important formulations in computational fluid dynamics, and the proper treatment of external boundaries may have a profound impact on the quality and performance of numerical algorithms and interpretation of the results. Existing ABCs’ techniques can basically be classified into two groups. Global ABCs usually provide high accuracy and robustness of the numerical procedure but often appear fairly cumbersome and computationally expensive. Local ABCs are algorithmically simple, numerically inexpensive, and geometrically universal; however, they usually lack the accuracy of computations. In a series of papers written between 1993 and 2000 (partially with coauthors), see [12–29, 31], I have developed new ABCs for the steady-state compressible viscous flows that combine the advantages of local and global methods.

The approach of [12–29, 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 their nonlocal nature, 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 of particular interest from the standpoint of flow physics involves the jet exhaust, see [29, 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 [28].

Based on my deep involvement in the area of numerical methods for unbounded domains, I wrote a

comprehensive survey article on the subject that was solicited by Applied Numerical Mathematics and published in 1998, see [30]. This paper includes, among other things, a comparative assessment of different existing methods for constructing the ABCs. By now, it has accumulated over 300 citations (Google Scholar) 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, Part V, Chapter 2].

As an extension of the work on ABCs for the steady-state external fluid flows, we have developed and implemented (in collaboration with T. Roberts and D. Sidilkover), see [39], a unified flow solver that combines the advantages of the global far-field ABCs with those of the so-called factorizable schemes for hydrodynamics; these schemes facilitate the construction of optimally convergent multigrid algorithms. Global ABCs do not hamper the optimal multigrid convergence of 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 enables substantial savings of computer resources.

The latest development on ABCs based on Calderon’s operators is the work done under the AFRL Phase I and II SBIR grants with Computational Sciences, LLC, on computing the exterior magnetic fields for the field reversed configurations (FRC) is plasma (considered a promising approach to fusion), see [86].

More recently, the focus of my research work has shifted toward numerical methods for wave propagation problems, with applications primarily in acoustics, electromagnetism, and optics. This involves both time-harmonic (monochromatic) and time-dependent (broad-band) 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 PMLs. We also consider numerical approximations, including those of high order accuracy, and discuss iterative methods and preconditioning for solving the Helmholtz equation with a PML.

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

The non-deteriorating numerical algorithm of [33–35,37,41] 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 and do not require a discretization of the continuous boundary conditions. The extent of temporal nonlocality of the new ABCs is fixed and limited. In addition, the ABCs can handle artificial boundaries of irregular shape on regular grids with no loss of accuracy. Moreover, the approach of [33–35,37,41] allows one to consider the radiation of waves by moving sources (e.,g., radiation/scattering by a maneuvering aircraft).

The lacunae-based approach originally developed for the scalar wave equation can be extended to the systems of equations of acoustics and electromagnetism, see [47, 48, 52, 53]. Extension to electromagnetic waves is particularly non-trivial because of the additional constraints due to the continuity equation for currents and charges. An important application of the work on lacunae is the stabilization of time-dependent PMLs [66, 67] known to suffer from the long-time error buildup. A recent extension involves the concept of quasi-lacunae [82, 83] that generalize the notion of classical lacunae for Maxwell’s equations, and allow for a non-zero electrostatic solution behind aft fronts of the propagating waves. Quasi-lacunae facilitate the development of a universal algorithm for long-time electromagnetic simulations (stabilization of any ABC or PML); this project is currently underway, supported by the US Army Phase I STTR.

My work on lacunae also involves 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. In [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 have analyzed the anisotropic case with gyrotropy and shown that for the typical ionospheric conditions the additional effect on lacunae was small.

My most recent project on the propagation of radio waves in the Earth ionosphere (supported by AFOSR) has to do with the analysis of how their dispersion affects the performance of spaceborne synthetic aperture radars (SAR). We employ the scalar model for transverse waves with weak 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 and identify probing on two carrier frequencies as a possible venue for compensating for the ionospheric distortions [71]. Another paper on the subject of SAR imaging is [74], where we analyze the effect of a commonly used approximation, known as the start-stop approximation, on the quality of the image in the case of a spaceborne radar that moves considerably faster than an airborne radar. In the recent paper [80], we show that if the matched filter of a spaceborne SAR sensor is corrected using dual carrier probing, as suggested in [71], then the performance of the radar indeed improves, i.e., the distortions of the image due to the ionosphere are reduced. Subsequent work includes some aspects of polarimetric imaging (vector fields) [87], as well as the algorithm with improved robustness [85].

In our work [38, 43–45, 49, 51], we study (in partial collaboration with J. Lončarić and V. Ryaben’kii) the problem of active control of sound (time-harmonic wave fields), formulated as a special 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 friendly. It turns out that for eliminating the noise one needs to know nothing about either its sources or the properties of the medium across which it propagates. The controls are built based solely on the measurements performed at the boundary of the domain to be shielded. 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 have constructed the general solution to this noise control problem using the concepts of generalized potentials and boundary projections of Calderon’s type. For a given 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. 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 have constructed 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: L_2 , power, and acoustic strength. Optimization of acoustic source strength, in particular, translates into a challenging numerical problem of the constrained L_1 minimization of complex-valued functions. Our central result in [44] is that the global L_1 -optimal solution can, in fact, be obtained without solving the numerical optimization problem; it is rather by a special layer of monopoles on the boundary of the protected region. The most recent addition to this work is active control of sound for multiply connected regions [56, 59, 62] and active control of sound with variable degree of cancellation [73, 75]. 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 recent extension is experimental verification and validation of the proposed noise control methodology, which is reported in [65].

In our work [40, 42, 46] we have analyzed (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 nonlinear Kerr media. This work was 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 nonlocal two-way ABCs to solve the NLH as a true boundary value problem. As the propagation equation is nonlinear, the impinging and scattered waves cannot be separated, and the problem has to be solved in its entirety. In doing so, the boundary should transmit the given incoming waves in one direction and simultaneously be transparent to all the outgoing waves that travel in the opposite direction. The two-way ABCs in [40] are obtained directly for the fourth order accurate scheme that we use to approximate the NLH. 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 prevent the blow-up of the solution for high input powers. This is an indication that nonparaxiality and backscattering can help suppress the formation of the singularity. In our subsequent papers on the subject [54, 55, 60], we employ the Sommerfeld-type local radiation boundary conditions in the cross-range direction, instead of the previously used Dirichlet boundary conditions. The modified algorithm offers a considerable improvement as far as 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). In [63, 64], a major 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. Newton's linearization is nontrivial since the Kerr nonlinearity 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 context of high order accurate schemes for wave propagation problems with discontinuities is presented in [68]. The results of the recent multi-dimensional simulations of the NLH using compact approximations and Newton's solver are summarized in [70, 72].

The subject of my most recent numerical project is the design of high order accurate methods for PDEs with discontinuous coefficients. This work is supported by NSF, the US-Israel Binational Science Foundation (BSF — jointly with Prof. E. Turkel of Tel Aviv University), and by ARO. Examples include the propagation of waves through the media with sharply varying material characteristics, such as the speed of sound undergoing jumps in acoustics or the index of refraction undergoing jumps in electromagnetism/optics. The key objective is to develop a methodology that would not lose its high order accuracy because of those discontinuities, and at the same time would be capable of handling the interfaces of arbitrary shape. In [76, 81], we have proposed a family of compact high order accurate finite difference schemes for the case of variable yet smooth coefficients. Their important advantage is that because of the compact stencils they do not need any additional boundary conditions beyond those required by the differential equation itself. They have also proven to be a very economical way of attaining high order accuracy, because the number of degrees of freedom is the same as that for the standard second order schemes. The material discontinuities are addressed by combining these schemes with discrete Calderon's operators and the method of difference potentials [84, 88]. A key advantage of this approach is that it allows to build the discretization on a regular structured grid and at the same time to take care of the non-conforming interfaces with no loss of accuracy. Compared to the methods based on the boundary integral equations, discrete Calderon's operators do not involve singular integrals and handle variable coefficients with the same ease as constant coefficients (in the regions of smoothness). They also offer a considerably more straightforward computational procedure than the high order methods based on weak formulations, such as isoparametric finite elements.