

REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-98-

0263

FORM 298

Public reporting burden for this collection of information is estimated to average 1 hour per response, including gathering and maintaining the data needed, and completing and reviewing the collection of information. Send collection of information, including suggestions for reducing this burden, to Washington Headquarters Service, Paperwork Project, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Project, Suite 1204, Arlington, VA 22202-4302.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 25 February 1998	3. REPORT TYPE AND DATES COVERED Final Technical Report, 5/1/97-12/31/97
----------------------------------	------------------------------------	---

4. TITLE AND SUBTITLE Godunov's Method for Gas Dynamics: Current Applications and Future Development. A Symposium in Honor of S. K. Godunov	5. FUNDING NUMBERS F49620-97-1-0309
--	--

6. AUTHOR(S)

Bram van Leer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
W. M. Keck Foundtion Laboratory for Computational Fluid Dynamics
Department of Aerospace Engineering
University of Michigan
Ann Arbor, MI 48109-2140

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
Major Scott Schreck, Program Manager
Computational Mathematics
Directorate of Mathematics and Computer Sciences
Bolling AFB DC

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

On May 1 and 2, 1997, an international symposium was held at the University of Michigan in honor of Sergei K. Godunov (Novosibirsk, Russia), one of the founding fathers of Computational Fluid Dynamics (CFD). Symposium chair was Bram van Leer (Aerospace Engineering). Support for the Symposium came largely from the Air Force and the National Science Foundation.

The Godunov Symposium brought together 107 CFD experts of all ages from 13 countries, including 50 students and postdocs. Three sessions of half-hour presentations by fourteen invited speakers gave an overview of the ways in which Prof. Godunov's groundbreaking work of the fifties has permeated the methodology of computing fluid flows. The subjects ranged from semiconductor modeling to the simulation of relativistic jets emitted by active galaxies. The high point of the conference was a nostalgic lecture by Prof. Godunov himself, "Recollections about Difference Schemes."

14. SUBJECT TERMS
Computational fluid dynamics
Godunov-type methods

15. NUMBER OF PAGES
11

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
unclassified

20. LIMITATION OF ABSTRACT
UL

19980331 030

Godunov's Method for Gas Dynamics: Current Applications and Future Developments

A Symposium in Honor of S. K. Godunov

Final technical report to AFOSR

regarding AFOSR Grant No. F49620-97-1-0309

Bram van Leer

W. M. Keck Laboratory for Computational Fluid Dynamics

Department of Aerospace Engineering

The University of Michigan

1 General information

This is the final technical report on the international symposium "Godunov's Method for Gas Dynamics: Current Applications and Future Developments," further referred to as the "Godunov Symposium," organized at the University of Michigan in honor of S. K. Godunov, with support from ASOFR, NSF, Journal of Computational Physics (Academic Press) and various units of the University of Michigan. The support by AFOSR was under Air Force Grant No. F49620-97-1-0309, for the period May 1 - December 31, 1997.

2 Occasion of the Symposium

On May 3, 1997, the Russian numerical/applied mathematician S. K. Godunov (Institute of Mathematics, Russian Academy of Sciences, Novosibirsk, Russia) received an honorary degree from the University of Michigan, for his fundamental contributions to the field of computational fluid dynamics and applied mathematics. To amplify this festive event, an international symposium was held on May 1-2, on the subject of Godunov-type numerical methods, used world-wide to compute continuum processes dominated by wave propagation. The venue of the Symposium was the François-Xavier Bagnoud (FXB) Building, home of the Department of Aerospace Engineering; Symposium Chair was Bram van Leer, from the same department.

Godunov's work of the 1950's and 1960's in the field of hyperbolic partial differential equations and their numerical approximation has had an profound effect on computational fluid dynamics. Many of today's state-of-the-art codes for simulating compressible flow, used in fields as diverse as civil aeronautics, industrial process modeling, nuclear-reactor safety, weapons research, meso-scale meteorology, planetary space physics and astrophysics, have their roots in a single paper by Godunov (1959) based on his Ph.D. thesis. In this paper the use of the solution to Riemann's initial-

value problem appears as a building block for a monotone finite-volume method for compressible flow. In extensions by later authors this concept is combined with that of non-oscillatory initial-value reconstruction, in order to achieve higher accuracy.

3 Purpose of the Symposium

The purpose of the Symposium was to give an overview of the current state of development and use of Godunov-type methods in science and engineering, and to offer a perspective of their future development and use. In the context of the symposium, Godunov-type methods were loosely defined as non-oscillatory finite-volume schemes that incorporate the solution (exact or approximate) to Riemann's initial-value problem, or a generalization of it. "Generalization" meant that, for example, multidimensional fluctuation splitting was included.

The symposium was technique- rather than discipline-oriented; it freely crossed interdisciplinary boundaries by demonstrating the similarity in numerical treatment of a wide range of continuum-modeling problems.

4 Scientific program

The scientific program of the symposium started with a full-length lecture by Phil Roe (University of Michigan) titled "Physical Reasoning in Computational Fluid Dynamics," underscoring the fundamental importance of Godunov's work in applied and numerical mathematics. In the following three sessions of half-hour lectures, invited speakers from diverse disciplines linked his work to powerful methodologies currently in use in Computational Fluid Dynamics (CFD) and other computational fields.

The material presented in turn served as the basis for three end-of-session panel discussions on "Current and Future Directions in Computational Science," lending a workshop character to the meeting.

In addition, a poster exhibit was set up for the duration of the conference.

The high point of the Symposium was a full-length lecture by Godunov himself titled "Recollections about difference schemes," an account of the earliest development of CFD in Russia, in which Godunov was personally involved. Godunov further gave lengthy comments during the panel discussions, and closed the Symposium with a thankword, in which he contrasted the present recognition of his work with the lack of appreciation he experienced throughout his career.

After the last session, tours of facilities in the College of Engineering were offered, specifically, the brand-new Media Union, home of the Center for Parallel Computing and the Visualization/Virtual Reality Lab; furthermore, the still new François-Xavier Bagnoud Building.

5 Participation

The symposium brought together 107 computational scientists in all stages of their career, from 13 countries. Among these were 50 students and postdoctoral researchers, of which about half were from the University of Michigan. 12 travel grants were awarded to students and postdocs from within and outside the USA, 4 to more senior scientists (including 3 Russians who otherwise would not have been able to attend). The Russian consul for science and technology in San Francisco was present and spoke during the first luncheon about US-Russian S&T relations. Worth mentioning is also the presence of two national program directors in computational mathematics: Scott Schreck, AFOSR, and Steve Davis, ARO.

6 Scientific impact

There was general agreement that the meeting was one of historic importance. Particularly impressive were (a) the presence of Godunov himself, one of the founding fathers of CFD, actively participating, (b) his lecture, disclosing never-heard details about the early days of CFD in Russia, and (c) the atmosphere of celebration, because of the attached honorary-degree ceremony. Add to this a sequence of invited presentations by top-notch researchers, covering the whole spectrum of computational modeling from semiconductor devices to radio galaxies, unified by a common numerical approach. Participants to the Symposium came away with a strong sense of the generality and uniform applicability of Godunov-type methods, although the limitations of the approach were also discussed, notably during the last panel discussion.

The handsome book of abstracts documents the power of Godunov-type methods and has contributed to the scientific impact of the Symposium. The book is now a collector's item; all spare copies were sold after the Symposium. Godunov's lecture, translated in English, and some more Symposium material, will appear in the *Journal of Computational Physics*.

7 Educational impact

Students and postdocs that were fortunate enough to attend the Symposium clearly understood they were part of a historic event. Moreover, they were presented with a top-notch scientific program which demonstrated that one computational approach can cross all discipline boundaries. This is an empowering and motivating experience: the student of computational science learns that he/she needs not feel restricted to any particular field of applications, making him/her more "marketable."

Students and postdocs were also actively involved in the program. Two graduate students and one postdoc gave half-hour presentations; in addition, one student who defended the day before the Symposium, with Godunov joining the thesis committee,

took part in the last panel discussion. There also were student contributions to the poster display.

8 Use of AFOSR's financial support

The financial support by AFOSR served largely to cover the travel expenses of the invited speakers and panelists; the remainder was used to pay in part for the full-color book of abstracts.

9 The Symposium program

Thursday 1 May

8.00-8.30am	Breakfast	
8.30-8.45	Welcoming address	Bram van Leer (UMi)
Session 1	Basic algorithms	Chair Bram van Leer (UMi)
8.45-9.30	Overview lecture	Phil Roe (UMi)
9.30-10.00	PPM & applications	Paul Woodward (UMn)
10.00-10.30	MUSCL & applications	Harland Glaz (UMd)
10.30-10.45	Break	
10.45-11.15	ENO & semiconductor modeling	Chi-Wang Shu (Brown)
11.15-11.45	Multi-D upwinding	Herman Deconinck (VKI, BE)
11.45-12.30pm	Algorithm development I	Panel of speakers + Rolf Jeltsch (ETHZ, CH) Rémi Abgrall (UBordeaux, FR) Paul Arminjon (U Montreal, CA)
12.30-1.30	Luncheon offered by CoE USA-Russia science relations	Valery Semin (Russian S&T Consul)

Session 2	Applications	Chair Ken Powell (UMi)
1.30-2.00pm	Modeling of heliosphere	Timur Linde (UMi)
2.00-2.30	Incompressible flow	John Bell (LLL)
2.30-3.00	Extended hydrodynamics	Clinton Groth (UMi)
3.00-3.15	Break	
3.15-3.45	CFL3D & applications	Chris Rumsey (NASA LaRC)
3.45-4.15	Astrophysics	Phil Hughes (UMi)
4.15-4.45	Moving boundaries	Sami Bayyuk (CFDRC & UMi)
4.45-5.30	Algorithm development II	Panel of speakers + Barry Koren (CWI NL) Smadar Karni (Temple)
5.30-6.30	Break/Poster viewing	
7.30-8.00	Reception hosted by CoE	

Thursday 2 May

8.00-8.30am	Breakfast	
Session 3	Hardware/software issues	Dave Darmofal (TxA&M)
8.30-10.00am	Recollections about Difference schemes	Sergei Godunov
10.00-10.30	Break	
10.30-11.00	GASP/GUST	Bob Walters (AeroSoft)
11.00-11.30	Validation/internal flows	Charles Hirsch (VU Brussels)
11.30-12.00pm	CLAWPACK/AMRCLAW	Randy LeVeque (UWa)
12.00-12.30	Amrita & multi-fluid modeling	James Quirk (Caltech)
12.30-2.00	Luncheon offered by JCP/AP JCP-Godunov connection	Bram van Leer (UMi)
2.00-3.00	Computer architecture/software	Panel of speakers + Alain Dervieux (INRIA, FR) Tim Barth (NASA ARC) Eric Charlton (UMi)
3.00-3.10	Closing remarks	Bram van Leer (UMi)
3.10-3.30	Thankword	Sergei Godunov
3.30-4.00	Lurie carillon Recital	Ray McLellan
3.30-5.00	Tours of CoE facilities: Center for Parallel Computing & Visualization Lab Aerospace Engineering Bldg	Hal Marshall (UMi) Luis Bernal (UMi)

10 List of participants

Abgrall, Rémi
Université de Bordeaux
abgrall@math.u-bordeaux.fr

Abouziarov, Mikle
University of Nizhni Novgorod, RU
abouziar@dk.mech.unn.runnet.ru

Agarwal, Ramesh
Wichita State University
agarwal@shocker.ee.twsu.edu

Agresar, Grenmarie
University of Michigan
agresar@engin.umich.edu

Anderson, William
University of Michigan
billa@umich.edu

Arminjon, Paul
University of Montreal
arminjon@CRM.UMontreal.CA

Aslan, Necdet
Marmara University, TR
necdet@nem.nukleer.gov.tr

Bahram, Taheri
University of Michigan
mohammad@umich.edu

Bale, Derek S.
University of Washington
dbale@amath.washington.edu

Barth, Tim
NASA Ames Research Center
barth@nas.nasa.gov

Bayyuk, Sami
CFD Research Corporation
sab@neptune.cfdrc.com

Bell, John
Lawrence Berkeley National
Laboratory
jbell@lbl.gov

Benko, Jeffrey
University of Michigan
jbenko@engin.umich.edu

Bombach, Paul
University of Michigan
pbombach@umich.edu

Bunner, Bernard
University of Michigan
bunner@engin.umich.edu

Charlton, Eric
University of Michigan
charlton@umich.edu

Che, Judy
University of Michigan
judyche@engin.umich.edu

Cheolwan, Kim
University of Michigan
cheolwan@engin.umich.edu

Chernyshev, Sergei
TsAGI
tsagiint@aol.com

Clark, Marlon
Purdue University
marlon@purdue.edu

Dai, Wenlong
University of Minnesota
wenlong@lcse.umn.edu

Darmofal, David L.
Texas A&M University
darmofal@chianti.tam.u.edu

Davis, Stephen
U. S. Army Research Office
sdavis@aro.ncren.net

de Palma, Pietro
Politecnico di Bari
depalma@poliba.it

De Zeeuw, Darren
University of Michigan
darrens@umich.edu

Deconinck, Herman
Von Kármán Institute ,BE
deconinck@vki.ac.be

DeMore, Dan
Purdue University
demore@ecn.purdue.edu

Dervieux, Alain
INRIA - Sophia Antipolis,FR
dervieux@sophia.inria.fr

DesJardin, Paul
Purdue University
desjardi@ecn.purdue.edu

Gentile, Nick
Lawrence Livermore National Lab
gentile1@llnl.gov

Ghidaglia, Jean-Michel
École Normale Supérieure de Cachan,
FR
jmg@cmla.ens-cachan.fr

Girodroux, Francis
Safety Consulting Engineers Inc.
cneuman@comshare.com

Glascoe, Lee
University of Michigan
glascoe@engin.umich.edu

Glaz, Harland M
University of Maryland
hmg@math.umd.edu

Godunov, Sergei
Sobolev Institute of Mathematics, RU
godunov@books.nsu.ru

Gombosi, Tamas
University of Michigan
tamas@umich.edu

Gottlieb, Sigal
Brown University
sg@cfm.brown.edu

Ding, Zhong
Florida State University
ding@scri.fsu.edu

Dinge, Dennis
University of Minnesota
dennis@lcse.umn.edu

Donat, Rosa Beneito
University of Valencia, ES
donat@rocafort.matapl.uv.es

Duncan, Comer
Bowling Green State University
gcd@chandra.bgsu.edu

Ebrat, Omid
University of Michigan
ebrat@engin.umich.edu

Groth, Clinton
University of Michigan
groth@umich.edu

Hagerty, Patrick
University of Michigan

Harabetian, Eduard
University of Michigan
eduard@math.lsa.umich.edu

Hirsch, Ch.
Vrije Universiteit Brussel, BE
hirsch@stro10.vub.ac.be

Hittinger, Jeffrey
University of Michigan
jhitt@engin.umich.edu

Hughes, Philip
University of Michigan
hughes@astro.lsa.umich.edu

Huynh, Hung
NASA Lewis Research Center
tohung@freya.lerc.nasa.gov

Jeltsch, Rolf
ETH Zürich, CH
jeltsch@sam.math.ethz.ch

Kabin, Konstantin
University of Michigan
kabin@engin.umich.edu

Karni, Smadar
Temple University & New York
University
karni@cims.nyu.edu

Kauffman, C. William
University of Michigan
cwkauff@engin.umich.edu

Kinsey, Dawn
University of Michigan
kinsey@geom.umn.edu

Kleb, William
NASA Langley Research Center
kleb@ab00.larc.nasa.gov

Koren, Barry
Centrum voor Wiskunde en
Informatica, NL
barry@cw.nl

Krasny, Robert
University of Michigan
krasny@math.lsa.umich.edu

Krispin, Jacob
Krispin Technologies, Inc
jmk@math.umd.edu

Langseth, Jan Olav
Forsvarets Forskningsinstitut, NO
jol@ffi.no

Lee, Dohyung
University of Michigan
dohyung@engin.umich.edu

Lee, Wen-Tzong
J.P. Industrial Inc.
wtlee@jpi-cae.com

LeVeque, Randall J.
University of Washington
rjl@amath.washington.edu

Linde, Timur
University of Michigan
linde@engin.umich.edu

Lindsay, Keith
University of Michigan
klindsay@umich.edu

Lynn, John
Ford Motor Co.
jlynn1@ford.com

Madrane, Aziz
University of Montreal, CA
madrane@crm.umontreal.ca

Marshall, Hal
University of Michigan
idaho@engin.umich.edu

Martin, William
University of Michigan
wrm@umich.edu

Mathiesen, Ben
University of Michigan
bfm@umich.edu

Menshov, Igor
Keldysh Institute of Applied
Mathematics, RU
menshov@kiam.ru

Mesaros, Lisa
Automated Analysis Corp.
lisamesaros@mindspring.com

Mott, David R.
University of Michigan
mott@engin.umich.edu

Myong, Rho Shin
NASA Goddard Space Flight Center
myong@cesdis1.gsfc.nasa.gov

Nguyen, Brian
University of Minnesota
nguyen@ima.umn.edu

Nishikawa, Hiroaki
University of Michigan
hiroakin@engin.umich.edu

Ohlandt, Jeffrey
University of Michigan
chadjo@umich.edu

Ostapenko, Prof Vladimir
Lavrent'ev Institute of
Hydrodynamics, RU
pukh@hydro.nsc.ru

Pascasio, Giuseppe
Politecnico di Bari
pascasio@poliba.it

Patch, Sarah
Stanford University
patch@cartan.Stanford.EDU

Powell, Ken
University of Michigan
powell@engin.umich.edu

Pukalo, Boyd R.
University of Michigan
bluebook@engin.umich.edu

Quirk, James
California Institute of Technology
jjq@galci.caltech.edu

Rad, Mani
University of Michigan
mrad@engin.umich.edu

Rider, William
Los Alamos National Laboratory
wjr@lanl.gov

Roe, Phil
University of Michigan
philroe@engin.umich.edu

Rumsey, Christopher L
NASA Langley Research Center
c.l.rumsey@larc.nasa.gov

Sanders, Brett
University of Michigan
bfs@engin.umich.edu

Semin, Valery
Russian Consulate, San Francisco

Schreck, Maj. Scott
AFOSR/NM
scott.schreck@afosr.af.mil

Short, Edward C
State University of New York at
Buffalo
short@eng.buffalo.edu

Shu, Chi-Wang
Brown University
shu@cfm.brown.edu

Sichel, Martin
University of Michigan
sichel@engin.umich.edu

Smereka, Peter
University of Michigan
psmereka@umich.edu

Somfai, Ellak
University of Michigan
ellak@umich.edu

Subramani, Anil K.
University of Michigan
aks@engin.umich.edu

Tai, Chang-Hsien
Chung Cheng Institute of Technology,
TW
chtai@cc04.ccit.edu.tw

Tauber, Warren
University of Michigan
wtauber@engin.umich.edu

Toro, Eleuterio
Univeristy of Manchester, UK
e.f.toro@mmu.ac.uk

Tryggvason, Grétar
University of Michigan
gretar@engin.umich.edu

van Leer, Bram
University of Michigan
bram@engin.umich.edu

Walters, Robert
Aerosoft, Inc.
r.walters@aerosft.com

Wang, Bei
University of Maryland
bei@math.umd.edu

Washabaugh, Peter
University of Michigan
pete@umich.edu

Weekes, Suzanne
Texas A&M University
Suzanne.Weekes@math.tamu.edu

Wierzbicki, Edmund A.
University of Michigan
edmundw@engin.umich.edu

Woodward, Paul R.
University of Minnesota
paul@lcse.umn.edu

Zhukov, Viktor
Keldysh Institute of Applied
Mathematics, RU
zhukov@kiam.ru