MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

T a g u n g s b e r i c h t 33/1988

Hyperbolic Systems of Conservation Laws

24.7. bis 30.7.1988

The conference was organized by C. Dafermos (Brown Universi
Providence, R.I.) and W. von Wahl (Bayreuth). It was cente1
around the following subjects:

Compensated Compactness and Applications,

Untypical Riemann-Problems,

Rich Systems of Conservation Laws,

Gas-Dynamics,

Functional-Analytic Treatment of Nonlinear
Wave Equations,

Periodic Solutions of Nonlinear Wave Equations,

Elasticity.

Vortragsauszüge

H.-D. ALBER:

The asymptotic behavior of non-isentropic flow at large times

The asymptotic behavior of solutions to the system of conservation laws describing one-dimensional, compressible flow is discussed. Such results are known for systems consisting of not more than two equations. The system under consideration consists of three equations, and the methods used can be generalized to treat systems with m equations.

P. BRENNER:

Regularity of solutions of certain nonlinear hyperbolic equations

First a short review of some recent progress and the present state of art concerning the solutions to the hyperbolic problem

$$(*)\quad u_{tt} + P(x,D)u + f(u) = 0,\ x \in \mathbb{R}^n,\ t \in \mathbb{R}_+$$
$$\text{data at } t=0 \text{ in } H^1 \times H^0$$

where

$P \sim -\Delta$ for x large
P 2nd order smooth elliptic positive operator (hyperbolic problem) and f(u) is of power growth at ∞.

The discussion was mainly "limited" to the case of "large" initial data, and only touched on the works of Klainerman, Hörmander and John in the case of small initial data.

Finally a recent result by the author was presented: Strong solutions (Brenner, -88. To appear in Math. Z.). Let

(*) $u_{tt} + P(x,D)u + f(u) = 0$, $x \in \mathbb{R}^n$, $t \in \mathbb{R}_+$

with

data at $t = 0$ in $H^2 \times H^1$.

We then have the following result:

THM. There exist a unique global solution u to (*) in $C^2(\mathbb{R}_+) \times L_2(\mathbb{R}^n) \cap C(\mathbb{R}_+) \times H^2(\mathbb{R}^n)$, provided $|f(u)| \le C|u|^p$, $p < (n+2)/(n-2)$, $n > 2$.

H. ENGLER:

Singular kernels in nonlinear viscoelasticity of integral type

The description of finite shear deformations for viscoelastic liquids and solids leads to systems of two conservation laws, one with a memory term, in one or more space dimensions. If the memory term contains an integral with a singular kernel, then global weak solutions of this nonlinear system can be found that satisfy a physically meaningful entropy inequality. My work is concerned with consequences and variants of this entropy property and with results on the properties of the weak solutions.

H. FREISTÜHLER:

Rotational degeneracy of hyperbolic systems of conservation laws

Rotational symmetry of the flux function induces a loss of strict hyperbolicity at each invariant point in the system's state space, which makes the pattern of elementary waves delicate. Nevertheless, near any such point, if certain genericity assumptions are satisfied, Riemann's initial value problem has a unique stable solution, depending continuously on the data.

The results can be applied to interesting cases from continuum mechanics, where the invariance property is a consequence of isotropy.

J. M. GREENBERG:

Continuum limits of descrete gases or surges in glacial flows - An example of conservation laws with limit cycle oscillations

We look at motions of discrete particles moving on the line. The particles are free streaming and interact elastically. Limit flows are characterized (as the mass of each particle and the initial particle spacing tend to zero) and we show that in certain cases the limit fields satisfy the usual gasdynamics equation with a $p = S\rho^3$ law. The limit motions are characterized without solving the limiting pde's directly.

E. HORST:

Symmetric solutions of the Vlasov-Maxwell system revisited

The Vlasov-Maxwell system describes the evolution of a plasma in $\mathbb{R}^3$ (consisting of ions and electrons) that moves under the influence of the electric field E and the magnetic field B that it generates itself.

If the initial data are symmetric in the sense that they are invariant under all rotations of $\mathbb{R}^3$, the global existence of unique classical solutions was shown by R. Glassen and J. Schaeffer in 1985. In this case B vanishes identically.

Recent work of Schaeffer suggests that one can expect global classical solutions also for data that are near symmetric data, provided the symmetric solution satisfies a decay estimate like $\|E(t)\|_\infty \leq \text{const.} \cdot t^{-2}$. We give a necessary and a sufficient condition for the validity of such an estimate.

C. KLINGENBERG:

<u>On hyperbolic conservation laws in two space dimensions</u>

After being able to explicitly construct the solution to Cauchy problems

$$u_t + f(u)_x + g(u)_y = 0, \quad u(x,y,t) \in \mathbb{R}$$

$$u(0,x,y) = u_0$$

which are invariant under the transformation

$$(x,y,t) \to (\alpha x, \alpha y, \alpha t), \quad \alpha > 0$$

for generic cases, we constructed a numerical algorithm which finds the solution to these two dimensional Riemann problems. These were used as part of numerical schemes which solve the Cauchy problem, namely a front tracking code and a two dimensional Glimm scheme.

D. KRÖNER:

Numerical schemes for the Euler equations in 2-D without dimensional splitting

We consider a numerical scheme for the nonlinear Euler equations of gasdynamics in 2-D. The algorithm doesn't use any dimensional splitting. It is a generalization of a scheme developed by Roe for the linearized Euler equations. In 1-D perturbation can propagate only in two directions but in 2-D there are infinitely many directions of propagation. Therefore the algorithm should be able to select the most important directions and to ensure that the scheme takes this fact into account. In this lecture we shall describe some details of this algorithm and we shall present some numerical results in 1-D and 2-D. Furthermore we shall compare our scheme with some Godunov-type schemes of first order.

N. A. LAR'KIN:

Hyperbolic equations in the theory of transonic flows

Initial-boundary value problems for nonlinear equations

$$u_{xt} + u_x u_{xx} - u_{yy} = 0$$

modelling nonsteady 3-D transonic gas flows near a slender body are considered. Local in time existence and uniqueness of classical solutions are proved.

M. MEIER:

Harmonic maps on Minkowski space and related nonlinear wave equations

We consider harmonic maps from (n+1)-dimensional Minkowski space-time with values in a Riemannian manifold M. Such maps arise, for instance, in SU(2)-gauge theory and in general relativity. We survey the conserved quantities of the system and some theorems concerning the local existence for the Cauchy problem and the global existence in case of small initial data. The latter result is compared to a perturbed nonlinear wave equation where blow-up of classical solutions always occurs in 2 and 3 space dimensions. I. Shatah has given an example of a self-similar rotationally symmetric harmonic map in 3 space dimensions with values in S^3, thus showing that harmonic maps with large Cauchy data may develop singularities in finite time. We present a number of sufficient conditions in terms of geometric properties of the target manifold M which exclude the existence of self-similar solutions. Nonexistence is proved, e.g., when $n \leq 3$ and M has non-positive sectional curvature. For rotationally symmetric harmonic maps, a nonexistence result is obtained for $n \leq 7$ and special target manifolds including hyperbolic space.

G. NAKAMURA:

An inverse problem for a stratified elastic medium

Let $\Omega = \{x = (x_1, x_2, x_3);\ x_3 > 0\}$ be a stratified elastic medium with free boundary. Denote its density, Lamé parameter functions by $\rho(x_3), \lambda(x_3), \mu(x_3) > 0$. Now put an impulse (eg. a dynamite) at a boundary point x^0 at a time $t = 0$. Then it generates an elastic wave for $t > 0$.

We have an affirmative answer to the following problem: Can you globally determine $p(x_3)$, $\lambda(x_3)$, $\mu(x_3)$ by observing certain components of the o-th and first order velocity moments of the elastic wave.

H. PECHER:

Some remarks on the scattering theory for nonlinear wave equations

Consider as a model the Cauchy problem for semilinear wave equations with power type nonlinearities

$$u_{tt}-\Delta u = |u|^p,\ u=u(x,t),\ x\in\mathbb{R}^3,\ t\in\mathbb{R}^+.$$

It is well known that global classical solutions do not exist for any nontrivial smooth data with compact support in the range $1<p<1+\sqrt{2}$ (F. John 1979). So especially a scattering theory does not exist in these cases. On the other hand we are able to show that for $p>1+\sqrt{2}$ the scattering operator which belongs to the pair of equations $u_{tt}-\Delta u = |u|^p$ and $u_{o_{tt}}-\Delta u_o = 0$ exists in the sense of energy norms for smooth and small data if they decay sufficiently rapidly at ∞. The proof requires the use of space-time weighted L^∞-norms and is completely elementary. The idea of using norms like these goes back to F. John who already proved a global existence result in the above case for small data in $C_o^\infty(\mathbb{R}^3)$.

B. PERTHAME:

Numerical approximation of gas dynamics using Boltzmann equations

Boltzmann schemes for solving gas dynamics equations have been used for a few years by several authors. They can be related rigorously to Boltzmann equations and they provide schemes which have remarkable properties: Unconditional stability, the entropy condition is satisfied ... etc. ...

We generalize the class of Boltzmann schemes used in the literature, analyse the above properties and perform numerical computations - It turns out that the class of Boltzmann schemes contains many "classical" schemes: Steger & Warming, Osher & Engquist, Lax & Friedrichs ...

It gives also a way to build entropies for gas dynamics equations.

R. RACKE:

Global existence resp. blow-up phenomena for solutions to the equations of 3-d-thermoelasticity

In the first part we discuss the Cauchy problem for the hyperbolic-parabolic system of 3-d nonlinear thermoelasticity. The assumption that the nonlinear coefficients differ from those of the initial constant state by terms of at least order two for small values of the variables leads to cubic but also to some quadratic nonlinearities in the final setting. (The latter results from the parabolic part.) Global smooth solutions are shown to exist if the initial data are small in special Sobolev norms. We also point out that in the genuinely nonlinear case blow-up phenomena have to be expected.

In the second part we prove L^p-L^q-estimates for the solution to a special linear initial boundary value problem in an exterior domain, proposing a method using generalized eigenfunction expansions.

M. RASCLE:

Hyperbolic systems of conservation laws and compensated compactness

We study the extension of previous works by R. Di Perna, M. Rascle, D. Serre, as well as V. Roytburd and M. Slemrod, on the applications of the compensated compactness method to study the structure of oscillating solutions (or approximate solutions) to some nonlinear hyperbolic systems of conservation laws:

$$u_t^\varepsilon + f(u^\varepsilon)_x \simeq 0$$

with initial data

$$u^\varepsilon(x,0) = u_0(x).$$

B. SCARPELLINI:

Periodische und fastperiodische Lösungen in der Nähe von Gleichgewichtslösungen der nichtlinearen Wellengleichung $u_{tt} = u_{xx} - g(u)$ auf der Halbgeraden

Wir betrachten die Wellengleichung (*) $u_{tt} = u_{xx} - g(u)$ auf $R_+ = \{x \geq c\}$, $t \in \mathbb{R}$, wo $g(u) = m^2 + \tilde{g}(u)$ ist und $\tilde{g}(u) = Au^2 + \ldots$ eine ganze Funktion. Sei u_0 eine Gleichgewichtslösung von (*), d.h. $u_{0xx} = g(u)$, für welche $\lim\limits_{x\to\infty}(|u_0(x)| + |u_{0x}(x)|) = 0$ gilt. Wir suchen Lösungen $u(x,t)$ von (*), die folgendes erfüllen:

(1) $u(x,t)$ ist periodisch oder fastperiodisch in t, $(\forall x \geq c)$

(2) $\Delta(x) := \sup\limits_{t\in\mathbb{R}} \{|u(x,t) - u_0(x,t)| + |u_x(x,t) - u_{0x}(x,t)|\}$

strebt in einem zu präzisierenden Sinne gegen Null,

(3) $\sup_{x \geq 0} |\Delta(x)|$ ist klein.

Familien von Lösungen solcher Art werden konstruiert mit Hilfe einer Technik, die von A. Weinstein für den 2π-periodischen Fall und $u_o \equiv 0$ und die von Scarpellini-Vuillermot auf den fastperiodischen Fall und $u_o \equiv 0$ ausgedehnt wurde.

M. SCHATZMAN:

Post-processing of dispersive numerical schemes

Dispersive approximations of the transport equation $u_t+u_x = 0$, such as the leap-frog scheme, or particle discretisation with non-characteristic speed can be summarized in the following model problem:

(1) $u_t^\varepsilon+\zeta^\varepsilon * u_x = 0$

where $\zeta^\varepsilon(x) = \varepsilon^{-1}\zeta(x/\varepsilon)$, $\zeta \in S(\mathbb{R})$, $\zeta(x) = \zeta(-x)$, $\forall x \in \mathbb{R}$, $\int \zeta(x)x^2\, dx \neq 0$. Eqn. (1) is stable in $L^2(\mathbb{R})$, but not in any other L^p space. If ρ is an arbitrary kernel, $\rho \in S$, and $\rho_\alpha = \alpha^{-1}\rho(./\alpha)$, the solution of (1) is postprocessed by convolution with ρ_α, and the following holds: if $\kappa = \varepsilon^{2/3}/\alpha$ is bounded from above by K, there exists a constant $C(t,\rho,K)$ such that for all initial data u_o,

$$|u^\varepsilon(.,t)*\rho_\alpha|_1 \leq C(t,\rho,K)|u_o|_1.$$

Moreover, if $\kappa \to 0$, $u^\varepsilon(.,t)*\rho_\alpha - u(.,t) \to 0$ in L^1. The critical exponent $\frac{2}{3}$ is optimal, if ζ has more vanishing moments ($\int x^p\zeta(x)dx = 0$, $1 \leq p \leq 2n-1$), then the same result holds for critical exponent $\frac{2n}{2n+1}$.

D. SERRE:

Rich hyperbolic systems of first order

In order to understand the complexity of hyperbolic systems of the first order, one may start to characterize which ones are endowed with a rich structure: Diagonalization, a large set of entropies. We shall describe what they are, how to construct them and how to find the entropies. For such systems, the compensated compactness goes on as for the 2×2 systems. Finally, we shall show an example of such a rich system. It is provided by the zero-dispersion limit of the Korteweg de Vries equation, as given by Lax and Levermore.

M. SHEARER:

Nonstrictly hyperbolic systems of conservation laws (with S. Schecter)

It is shown how to solve the Riemann problem for the 2×2 system

(1) $U_t + dC(U)_x = 0$,

where $U = (u,v)$, $C(U) = au^3/3 + bu^2v + uv^2$, with $a < 3b^2/4$. The solution involves undercompressive shocks, which are characterized using a result of Chicone on quadratic gradient vector fields in the plane. Perturbing the flux in (1) by cubic and higher order terms leads to a bifurcation problem which is solved using Melnikov's method.

Y. SHIBATA:

<u>The local and global existence theorem of solutions to Neumann problem for some quasilinear hyperbolic operators</u>

It is considered the local and global existence theorems of classical solutions to the following mixed problem:

$$\partial_t^2 u - \partial_i (\partial_i u/\sqrt{1+|\nabla u|^2}) = 0 \text{ in } (0,T)\times\Omega;$$

$$\nu_i (\partial_i u/\sqrt{1+|\nabla u|^2}) + b(u,\partial_t u) = 0 \text{ on } (0,T)\times\Gamma;$$

$$u = u_0 \text{ and } \partial_t u = u_1 \text{ at } t=0 \text{ in } \Omega.$$

Here, the summation convention is understood; Ω is a domain in $\mathbb{R}^n$, its boundary Γ being a C^∞ and compact hypersurface; $\nu = (\nu_1,\ldots,\nu_n)$ is the unit outer normal to Γ; $\nabla u = (\partial_1 u,\ldots,\partial_n u)$ $(\partial_j = \partial/\partial x_j)$.

Furthermore, the local existence theorem is extended to the case where the operators are some quasilinear hyperbolic system of 2nd order with fully nonlinear boundary condition. And, as an application, it is proved a local existence theorem of classical solutions to some nonlinear elastodynamics equations with some applied surface force which is not dead load.

T. C. SIDERIS:

<u>Long time behavior of solutions to the three-dimensional compressible Euler equations</u>

We show that the life space $T(\varepsilon)$ of classical solutions to the three-dimensional, compressible, isentropic Euler equations, with initial data that is a C_0^∞ perturbation of a constant state of amplitude ε, satisfies the lower bound $T(\varepsilon) > \exp(c/\varepsilon)$.

M. SLEMROD:

Weak decay of a nonlinear wave equation

In this talk I will explain how some of the ideas expressed by Luc Tartar in the use of Young measures for proving existence of solutions in hyperbolic conservation laws may be used for describing asymptotic behavior as $t \to \infty$ for a nonlinear wave equation. In particular I show that for the equation $u_{tt} - \Delta u = -a(x)g(u_t)$, $x \in \Omega$ (bounded smooth domain in $\mathbb{R}^N$), $u = 0$ on $\partial\Omega$, $a(x) \geq 0$, $a \in C^\infty(\Omega)$, meas$\{x;\ a(x) > 0\} > 0$, $\xi q(\xi) \geq 0$, ker $q \subseteq [0,\infty)$ or ker $q(-\infty,0]$, we have weak $\lim_{t\to\infty}(u,u_t) = (0,0)$ in $H_0^1(\Omega) \times L_2(\Omega)$.

S. J. SPECTOR:

Nonuniqueness for a hyperbolic system: Cavitation in nonlinear elastodynamics

We let $\Omega \subset \mathbb{R}^n$, $n \geq 3$, and consider the problem: Find $u: \Omega \times [0,T] \to \mathbb{R}^n$ that satisfies

$$\operatorname{div} S(\nabla u) = u_{tt} \text{ in } \Omega \times [0,T],$$

$$u(x,t) = \lambda x \text{ für } x \in \partial\Omega \text{ and } t \in [0,T],$$

$$u(x,0) = \lambda x \text{ for } x \in \Omega,$$

$$u_t(x,0) = 0 \text{ for } x \in \Omega,$$

where

$$S(F) := F + h'(\det F) \operatorname{adj} F$$

with $h'' > 0$, $h''' < 0$, $h'(v) \to -\infty$ as $v \to 0^+$, and $h'(v) \to +\infty$ as $v \to +\infty$.

We prove that there are $\lambda_i \to +\infty$ such that the above problem, with $\lambda = \lambda_i$, has multiple solutions. Moreover we show that each such solution is admissible according to the standard entropy criterion. The solutions that we construct are superpositions of special cavitation similarity solutions; that is, solutions of the form

$$u(x,t) := \frac{\varphi(s)}{s}(x-x_o), \quad s := |x-x_o|/(t-t_o),$$

for $t \geq t_o$, where φ is continuous, piecewise C^2 and satisfies

$$\varphi(0) > 0, \quad \varphi(s) = \lambda s \text{ for } s \geq \sigma,$$

for some $\sigma > 0$. Thus each such solution is discontinuous, opening a hole in the region Ω.

L. TARTAR:

Compensated compactness

A new concept, generalizing the now classical theory of compensated compactness, will be presented. It involves the description of some measures (called H-measures) which are associated to any (sub)sequence of a sequence converging to 0 weakly in L^2 and is indexed by (x,ξ) with $x \in \Omega$ and $\xi \in S^{N-1}$. It permits to solve exactly some questions of homogenization of lower order or small amplitude; it sees the complete characteristic set given by the balance equations and allows some description of propagation of oscillations and concentration effects. The case of a scalar linear equation with variable coefficients and of the wave equation shows its ability to describe the propagation of energy along bicharacteristic rays; nothing on the phase can be seen by these measures. The basic formula involves a limit of $\int_{\mathbb{R}^N} F(\varphi_1 U_i^\varepsilon)\overline{F(\varphi_2 U_j^\varepsilon)}\,\psi(\xi/|\xi|)\,d\xi$.

T. C. T. TING:

The Riemann problem and the generalized Riemann problem for elastic-plastic waves

For wave propagation in solids, the Riemann problem prescribes the initial condition $U(x,0)$, $x>0$ and the boundary condition $\sigma(0,t)$, $t>0$; both are constant. U contains the velocity vector v and the stress vector σ. The solution to the Riemann problem, when it exists, is valid for the entire region $x>0$, $t>0$. The generalized Riemann problem prescribes the initial condition $U(x,0)$, $x>0$ which is a constant but the boundary condition is given by $\sigma(0,T) = \sigma(0,0^+) + \dot{\sigma}(0,0^+)t$, $t>0$. If $\dot{\sigma}(0,0^+) = 0$ we have the Riemann problem. For $\dot{\sigma}(0,0^+) \neq 0$, we are interested in the solution near the origin $x=0$, $t=0$. We want to know how much the solution differs from the solution to the Riemann problem. The tension-torsion of a thin-walled tube of elastic-plastic materials is used as an example to illustrate how one can find the solution to the generalized Riemann problem. The differential equations are a 4×4 non-strictly hyperbolic system with one umbilic point.

A. E. TZAVARAS:

Weak solutions for a nonlinear system in viscoelasticity

We consider a one-dimensional model problem for the motion of a viscoelastic material with fading memory governed by a quasilinear hyperbolic system of integrodifferential equations of Volterra type. For given Cauchy data in $L^{\infty} \cap L^2$, we use the method of vanishing viscosity and techniques of compensated compactness to obtain the existence of weak solutions (in the class of bounded measurable functions) in a special case.

P. A. VUILLERMOT:

Smooth manifolds for certain dynamical systems on tori: Quasiperiodic soliton solutions to nonlinear Klein-Gordon equations on $\mathbb{R}^2$

Invoking the theory of stable and unstable manifolds for infinite-dimensional dynamical systems, we present new theorems concerning the existence and the regularity of certain real solutions to a class of semilinear wave equations in $\mathbb{R}^2$. Those solutions are Bohr almost periodic in time and converge exponentially rapidly to a constant equilibrium solution as the spatial variable goes to plus or minus infinity.

Berichterstatter: W. von Wahl

Tagungsteilnehmer

Dr. H.-D. Alber
Mathematisches Institut A
der Universität Stuttgart
Pfaffenwaldring 57

7000 Stuttgart 80

Dr. H. Freistühler
Lehrstuhl für Mathematik und
Institut für Mathematik
der RWTH Aachen
Templergraben 55

5100 Aachen

Prof. Dr. P. Brenner
Dept. of Mathematics
Chalmers University of Technology
and University of Göteborg
Sven Hultins gata 6

S-412 96 Göteborg

Prof. Dr. J. M. Greenberg
Department of Mathematics
University of Maryland
Baltimore County

Catonsville , MD 21228
USA

Prof. Dr. C. M. Dafermos
Division of Applied Mathematics
Brown Univerity
Box F

Providence , RI 02912
USA

Dr. E. Horst
Fachbereich 17 - Mathematik
Universität/GHS Paderborn
Warburger Str. 100

4790 Paderborn

Prof. Dr. H. Engler
Department of Mathematics
Georgetown University

Washington , DC 20057
USA

Prof. Dr. W. Jäger
Institut für Angewandte Mathematik
der Universität Heidelberg
Im Neuenheimer Feld 294

6900 Heidelberg 1

Dr. B. Fiedler
Institut für Angewandte Mathematik
der Universität Heidelberg
Im Neuenheimer Feld 294

6900 Heidelberg 1

Dr. C. Klingenberg
Institut für Angewandte Mathematik
der Universität Heidelberg
Im Neuenheimer Feld 294

6900 Heidelberg 1

Dr. D. Kröner
Institut für Angewandte Mathematik
der Universität Heidelberg
Im Neuenheimer Feld 294

6900 Heidelberg 1

Prof. Dr. G. Nakamura
Department of Mathematics
Josai University
1-1, Keyakidai Sakado

Saitama 350-02
JAPAN

Prof. Dr. P. Kumlin
Dept. of Mathematics
Chalmers University of Technology
and University of Göteborg
Sven Hultins gata 6

S-412 96 Göteborg

Prof. Dr. H. Pecher
Fachbereich 7: Mathematik
der Universität/Gesamthochschule
Wuppertal, Gaußstr. 20
Postfach 10 01 27

5600 Wuppertal 1

Prof. Dr. N. A. Lar'kin
Institute of Theoretical
and Applied Mechanics

630090 Novosibirsk 90
USSR

Prof. Dr. B. Perthame
Centre de Mathematiques
Ecole Normale Superieure
45, rue d'Ulm

F-75230 Paris Cedex 05

Prof.Dr.Dr.h.c. R. Leis
Institut für Angewandte Mathematik
der Universität Bonn
Wegelerstr. 10

5300 Bonn 1

Dr. R. Racke
Institut für Angewandte Mathematik
der Universität Bonn
Wegelerstr. 10

5300 Bonn 1

Dr. M. Meier
Mathematisches Institut
der Universität Bonn
Beringstr. 4

5300 Bonn 1

Prof. Dr. M. Rascle
Laboratoire de Mathematiques
Universite de Nice
Parc Valrose

F-06034 Nice Cedex

Prof. Dr. B. Scarpellini
Mathematisches Institut
Universität Basel
Rheinsprung 21

CH-4051 Basel

Prof. Dr. T. C. Sideris
Dept. of Mathematics
University of California

Santa Barbara , CA 93106
USA

Prof. Dr. M. Schatzman
Dept. de Mathematiques
Universite Claude Bernard de Lyon I
43, Bd. du 11 Novembre 1918

F-69622 Villeurbanne Cedex

Prof. Dr. M. Slemrod
Dept. of Mathematics
University of Wisconsin-Madison
721 Val Vleck Hall Math.
1210, West Dayton Street

Madison , WI 53706
USA

Prof. Dr. D. Serre
ENS de Lyon
46, Allee d'Italie

F-69364 Lyon CEdex 07

Prof. Dr. S. J. Spector
Dept. of Mathematics
Southern Illinois University

Carbondale , IL 62901-4408
USA

Prof. Dr. M. Shearer
Dept. of Mathematics
North Carolina State University

Raleigh , NC 27695
USA

Prof. Dr. L. Tartar
Dept. of Mathematics
Carnegie-Mellon University

Pittsburgh , PA 15213-3890
USA

Prof. Dr. Y. Shibata
Department of Mathematics
University of Tsukuba
Tsukuba-shi

Ibaraki 305
JAPAN

Prof. Dr. T. C. T. Ting
Department of Civil Engineering
University of Illinois
Box 4348

Chicago , IL 60680
USA

Prof. Dr. A. Tzavaras
Dept. of Mathematics
University of Wisconsin-Madison
721, Van Vleck Hall Math.
610, Walnut Street

Madison , WI 53706
USA

Prof. Dr. P. A. Vuillermot
Mathematikdepartment
ETH-Zürich
Rämistrasse 101

CH-8092 Zürich

Prof. Dr. W. von Wahl
Lehrstuhl für Angewandte Mathematik
Universität Bayreuth
Postfach 10 12 51

8580 Bayreuth

Dr. P. Weidemaier
Lehrstuhl für Mathematik
Universität Bayreuth
Postfach 10 12 51

8580 Bayreuth

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