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WAVEFIELD INVERSION

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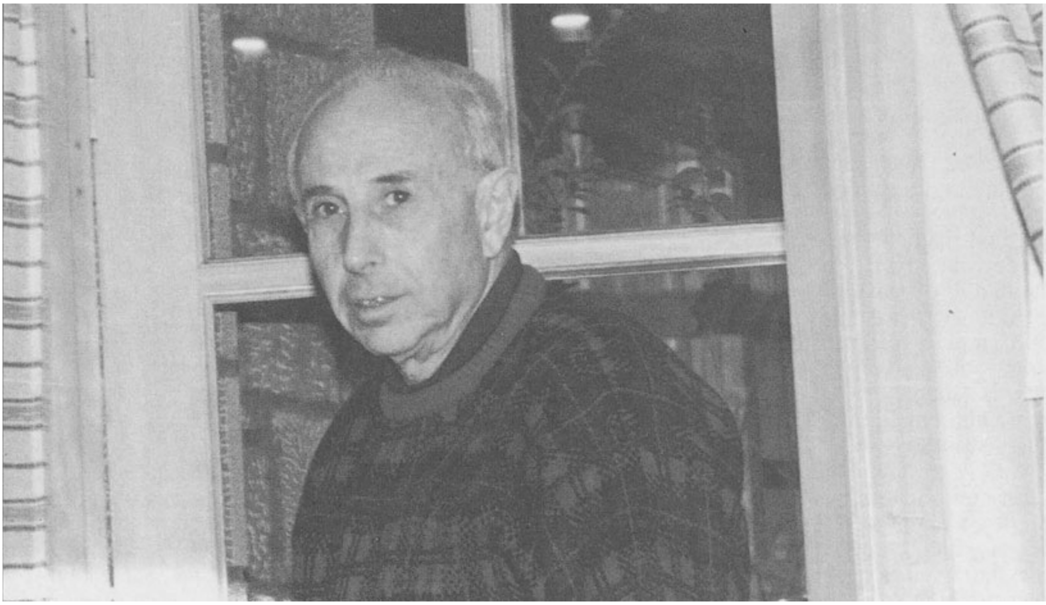

DEDICATION

This book is dedicated to the memory of Ralph E. KLEINMAN, who suddenly passed away in February 1998, a few months before his scheduled participation in the CISM lectures collected herein.

I invited Ralph to be one of the lecturers of the course because he was a friend, a fine man, and one of the pioneers and most eminent researchers on inverse scattering theory.

Much of Ralph's later work in this field was conducted with Peter M. van den Berg, so that it was natural to ask Peter to deliver the course in place of Ralph. Peter accepted this delicate task and we are all very grateful to him for this gesture.

Ralph was born on July 27, 1929 in New York City. He did his undergraduate studies (B.A. in 1950) in mathematics at New York University, his graduate studies (M.A. in 1951) at the University of Michigan and got his Ph.D. (in 1961) from Delft University of Technology. He was a research assistant (1951-53), research associate (1955-59), associate research mathematician (1959-62), and research mathematician (1959~62) at the Radiation Laboratory of U. Michigan. In the last period of his career he was an associate professor (1968-72) and then professor (1972- 98) in the department of mathematics of the University of Delaware, where he founded the Center for the Mathematics of Waves (CMW).

I first met Ralph in 1966 at Delft during the URSI Symposium on Electromagnetic Waves on which occasion he delivered his memorable talk entitled "Low frequency solution of electromagnetic scattering problems". My second encounter with Ralph was at the Progress in Electromagnetics Research Symposium at Cambridge MA in 1991 where Ralph spoke on "Profile inversion for two dimensional scatterers" (co-authored by Peter) before a fascinated audience in a packed lecture room. This lecture prompted Dominique Lesselier, W. Tabbara (well-known French researchers who had already delved into the field of inverse scattering) and myself (who had hardly been involved with inverse problems until then) to invite Ralph to become a visiting professor in Paris. He accepted and stayed in Paris for six months in 1993-94 during which time I got to know and became friends with Ralph and his wife Vicky. This period was all-important for the persons who had the privilege of coming in contact with Ralph and hearing his illuminating lectures (about a dozen in all) on the mathematics and numerics of inverse scattering of acoustic and electromagnetic waves. After going back to the States, the ties between the two French teams (Lesselier's and mine) and the CMW (Ralph, Tom Angell and Fadil Santosa) developed steadily (contracts, visits, etc.) so that Ralph's death was not only the loss of a friend, but that of a close collaborator and mentor.

Lest it be forgotten, Ralph Kleinman was one of the major figures in the field of applied mathematics engaged in what started out during World War II as the battle of waves (radar, microwave circuits, antennas) and continued during the post-war (cold war) period as the battle of waves (same or better devices, plus more sophisticated signal processing). Much of this work was carried out at the Michigan Radiation Laboratory and concerned propagation in complex media, radar detection of planes, ballistic missiles and satellites, etc. Ralph's contribution to this effort was to determine the speed of rotation, rise- or drop-rate and size of various spatial vessels in the phase of ascension or descent (atmospheric re-entry) by means of computations employing measured radar scattering cross sections. This probably kindled his interest in inverse scattering problems.

Although the wavelengths employed in radar were often of the order of the characteristic dimensions of the target, Ralph thought it useful to rely on low-frequency approximations of the scattering to get at least a rough description of the characteristics of the target which he often modeled by bodies of canonical shape (cones, spheroids, etc.) for which the static solution is available. Not content with this trial solution, he generalized Stevenson's (perturbation) scheme for iterative improvement of the static solution so as to include dynamic effects (this was the subject of his talk in Delft in 1966). With the increasing availability and speed of computers it became feasible to resolve scattering problems by means of boundary integral equations and this prompted Ralph, in the eighties, to develop techniques for appropriately modifying the Green's function so as to reduce the condition number of the linear systems arising from the discretized form of the integral equation for exterior domain scattering problems near the frequencies of internal resonance. At the same time, he became interested in the optimization of the scattering pattern of an antenna by modifying the structure of the latter. A few years later, he studied forward and inverse problems of floating bodies by integral equation methods similar to those he had previously employed in the electromagnetic wave scattering context. An important contribution of his in this genera] area had to do with iterative schemes for resolving both boundary and domain integral equations.

All this led quite naturally to a heavy involvement in the area of shape and composition identification of 2 and 3D bodies by inversion of scattered wavefields. I believe he was one of the first to attempt to treat this as an optimization problem, incorporating a simultaneous resolution of both the state and observation equations, the former being treated either on the same footing as the latter, or as a regularization agent. Once again, he searched for appropriate field representations and first recognized the simplicity of complete family of functions (e.g., Rayleigh or equivalent sources) expansions, and then the power and generality of the Lippmann-Schwinger domain integral representation. His ambition was to retain as much of the physics of the wave-body interaction as possible via the field representation even if this meant being faced with a coupling equation that is non-linear in terms of the to-be identified parameters. The first shape identification (of 2D impenetrable bodies) results, were obtained (in this manner) and published by Ralph and his colleagues in 1989. He then developed the domain integral equation approach for shape and composition identification by again relying on iterative techniques for solving the two integral (state and observation) equations and doing the inversion by successive over-relaxation and minimization of the residual error at each stage. This evolved into the so-called modified gradient method by means of which Ralph and Peter obtained the first convincing blind identification of objects from real measured data.

Ralph Kleinman's research and teaching activities were exceptionally diverse and high-quality. He was a man who had the talent of bringing people together to enjoy the good things of life as well as to get (tough) things done. The community of applied mathematicians, physicists, and engineers involved in wave scattering has lost one of its finest and most dedicated representatives.

PREFACE

Waves of acoustic, elastic and electromagnetic nature are often employed to probe the interior of the earth, the natural environment, biological media and man-made materials and structures. The purpose is generally to either partially or exactly locate, characterize the composition, identify the size, shape and orientation of, some anomalous feature in its surroundings and/or the surroundings itself. The main fields of application are: remote sensing of the environment, seismic tomography of the earth, medical diagnostics, material characterization in connection with process and quality control, non-destructive testing and evaluation of materials and structures. These applications are all of considerable scientific and socio-economic interest.

The purpose of the Lectures, entitled "Identification of Media and Structures by Inversion of Mechanical Wave Propagation", given at the CISM, Udine, Italy, 13-17 July 1998, was to provide an up-to-date presentation of a broad range of contemporary problems in the field of inverse scattering, the latter constituting the scientific framework underlying the above-mentioned applications. Four broad topics were discussed : 1) data acquisition, 2) theory of data inversion, 3) numerics of data inversion, 4) comparison, evaluation and possible evolution of available techniques.

These lectures have evolved, during the past few months, into a series of articles compiled in the present monograph whose title is slightly different than that of the course: "Wavefield Inversion for Probing and Characterizing Complex Media". These articles are (the underlined author being the lecturer): "Energy functionals in scattering theory and inversion of low frequency moments" by G. Dassios (University of Patras, Greece), "Inverse scattering with acoustic, electromagnetic, and elastic waves as applied in nondestructive evaluation", by K.J. Langenberg, M. Brandfass, R. Hannemann, C. Hofmann, T. Kaczorowski, J. Kostka, R. Marklein, K. Mayer and A. Pitsch (University of Kassel, Germany), "Inverse problems in geophysics", by R. Snieder and J. Trampert (Utrecht University, The Netherlands), "Reconstruction of media posed as an optimization problem", by P.M. van den Berg (Delft University of Technology, The Netherlands) and "Some quasi-analytic and numerical methods for acoustical imaging of complex media" by A. Wirgin (LMA/CNRS, France).

It is a pleasure to thank the lecturers, authors and 26 attendees who came from about 11 countries. The efficient help and organization of the staff of CISM is also gratefully acknowledged.

Armand Wirgin

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