

Rarefied Gas Dynamics

By F. M. Devienne



Shown above is a session in progress at the Symposium on Rarefied Gas Dynamics, held last July at the Centre Universitaire Méditerranéen in Nice, France. Nearly forty percent of the participants were Americans.

THE first international symposium on rarefied gas dynamics was held from the 2nd to the 5th of July under the chairmanship of J. Pérès, dean of the Paris Faculty of Science. This symposium took place in Nice, a town of whose charm it is hardly necessary to boast, and the participants enjoyed magnificent weather. Fourteen countries were represented. The American delegation was particularly important for it included not only representatives from the Berkeley and Moffett Field groups but also numerous American university professors who have worked both experimentally and theoretically in the field of rarefied gases.

The inaugural session, which was attended by numerous personalities, was presided over by Edouard Ramonet, French Minister of Industry, who warmly thanked all the participants who had come from far-off places and in particular the Americans who were so numerous (35 out of 91 participants).

The symposium was divided into six sessions which were devoted respectively to: (1) a broad survey of wind tunnels and other equipment, (2) techniques of measurement and flow visualization, (3) theoretical work on the kinetic theory of gases, (4) experimental work on the kinetic theory of gases: Couette flow, (5) aerodynamics of rarefied gases, and (6) aerothermodynamics of rarefied gases.

The first lecture was given by J. R. Stalder of the NACA Ames Laboratory, Moffett Field, who is one of the first to have carried out experimental researches in the field of rarefied gas dynamics. In his talk he described four wind tunnels presently in operation at the University of California at Berkeley, Ames Laboratory at Moffett Field, The Institute of Aerophysics in Toronto, and the Mediterranean Laboratory of Thermodynamic Research in Nice. He pointed out that in the near future there would be an increasing number of low-density wind tunnels and also that the diameter of the nozzle exit would be larger. Following this lecture R. N. Cox presented a paper by W. Clayden on a new low-density wind tunnel at the Armament Research and Development Establishment, Fort Halstead, England, which is not yet in full operation.

The afternoon session, with Professor Ferrari of the University of Turin presiding, began with lectures by I. Estermann (Office of Naval Research) and F. C. Hurlbut (University of California) on techniques of measurement and flow visualization. These lectures showed that it was impossible to use most of the gas

techniques in the continuum regime. In particular, Professor Estermann showed that there was a possibility of using molecular beams which have the advantage of providing information on the interaction between molecules of a gas and a surface. Following these lectures various papers were presented by B. M. Leadon (Convaire) on the design of a density probe, by H. M. Parker, A. R. Kuhlthau, R. Zapata, and J. Scott, Jr. on the application of supersonic molecular-beam sources to low-density, high-velocity experimentation, and finally by Professor Siestrunk, who presented a paper by Messrs. Tournier, Laurenceau, and Dubois from the French National Office of Aeronautical Research on the ONERA magnetic suspension which enables samples to be maintained in the wind tunnel without any material support; this represents considerable advantages, particularly in the rarefied gas techniques. A lively discussion followed in which Professor Estermann, Dr. Devienne, and Professor Luncz took part.

A reception in honor of the participants was given by the Municipality of Nice at the Villa Messéna. Professor Lepine, one-time dean of the Faculty of Medicine in Lyon and First Assistant to the Mayor of Nice, gave a welcoming speech to the participants and thanked them for having come to Nice.

On the following day the morning session was presided over by Professor Schultz-Grunow from the Lehrstuhl für Mechanik, Aachen, Germany. It began with a lecture by Professor Gross of Brandeis University who summarized the lecture which was to have been given by Professor Grad from New York University. Professor Grad had been taken ill and was unable to attend the symposium. The aim of this lecture was the theoretical study of transport phenomena in rarefied gases. Professor Gross ended by giving his ideas on the boundary value problems and the linearized Boltzmann equation. This was followed by papers given by Toyoki Koga (Nagoya University, Japan) on the Boltzmann-Maxwell equation as the fundamental equation of gas dynamics, and by Professor Pekeris (Weizmann Institute of Science, Israel) on the solution of the Boltzmann-Hilbert integral equation.

Professor Luncz of the Polish Academy of Science presided over the afternoon session, which began with a paper by F. S. Sherman (Office of Naval Research, Washington) and L. Talbot (University of California). This lecture was given by Dr. Sherman, as Professor



Members of the symposium took time out to visit the nearby Mediterranean Laboratory of Thermodynamic Research, whose director, F. M. Devienne, was in charge of organizing the meeting.



Dr. Devienne, who conducted the symposium participants on a guided tour through the laboratory, is shown above explaining the characteristics of the low-density wind tunnel used in thermodynamic research at Nice.

Talbot was unable to attend the symposium. Professor Sherman showed how partial solutions of the Boltzmann equation can be more or less verified by means of three types of phenomena which are particularly important: the shock wave structure, ultrasonic wave propagation, and finally the Couette flow, i.e., a flow which occurs between two concentric cylinders, one of which is driven at a certain speed. A number of papers succeeded this lecture: that of Professor Kuhlthau (University of Virginia) on recent low-density experiments using rotating cylinder techniques, H. T. Yang and L. Lees (University of Maryland) on Rayleigh's problem at low Reynolds number according to the kinetic theory of gases, and finally two more papers by V. C. Liu (University of Michigan) and D. R. Willis (Princeton University).

In the evening a banquet attended by 70 persons took place at the Chateau de la Chèvre d'Or at Eze Village, from which vantage point the participants were able to enjoy a magnificent bird's-eye view of part of the Côte d'Azur. The dinner was held in an atmosphere of great cordiality and gaiety and it enabled a number of Europeans and Americans to establish bonds of friendship.

On Friday morning most of the participants visited the Mediterranean Laboratory of Thermodynamic Research. The visit was carried out under the guidance of the writer, who described the principal researches carried out at the Laboratory by means of the revolving arm method and the low-density wind tunnel. Visitors were also able to see new apparatus being built or set up, such as the helium liquefier and a new apparatus destined to form molecular beams at very high speeds.

W. P. Jones from the National Physical Laboratory, Teddington, England, presided over the Friday afternoon session. The lecture by R. F. Probst (Brown University, Providence) on the aerodynamics of rarefied gases showed the complexity of the problems in this field of science; he distinguished in particular six possible regimes following the interaction between a boundary layer and the shock wave. This distinction, of course, only concerns the supersonic regime. Other papers were given by Professor Street (University of Washington), Dr. Laurmann (University of California), Professor Welander (University of Stockholm), Messrs. Langelo and Lengyel (General Electric Co., Philadelphia), Pro-

fessor Krzywoblocki (University of Illinois), and by Professor Luncz (Polish Academy of Science).

The Saturday morning session, with Professor Estermann presiding, began with a lecture by Edmond A. Brun (Paris Faculty of Science) on the aerothermodynamics of rarefied gases, which was followed by a short outline by Dr. Devienne on the precautions taken for the application of formulae in the kinetic theory of gases in the free molecular flow regime and on the fact that it is difficult to apply laws of similitude in this regime on account of the variation of the accommodation coefficient. A paper by Dr. Crave (Mediterranean Laboratory of Thermodynamic Research) dealt with the establishment of the different flow regimes in rarefied gases by means of the revolving arm method. Some papers were then presented by Ingénieur General Vernotte of the French Air Ministry, Mr. Griffiths of the Lockheed Aircraft Corporation, and Professors Luncz and Lubonski of the Polish Academy of Science; a paper was also given by Professor Lykoudis (Purdue University) on magnetic boundary layers, with boundary conditions assimilating combustion blowing or sublimation at the wall. Finally Shi I. Pai (University of Maryland) gave a paper on plasma dynamics from the gas dynamic point of view. The session ended with an announcement by the secretary of the symposium concerning the setting up of an international committee and indicating that the second symposium would take place in Berkeley.

Professor Estermann closed the symposium by thanking the organizers, Professor Pérès, dean of the Paris Faculty of Science, and Professors Brun and Devienne.

In brief this symposium has allowed an over-all survey to be made on the work at present being carried out in the field of rarefied gas dynamics. It has also shown the advantages to be gained by developing experimental research, particularly in the field of highly rarefied gases, in order to obtain a more accurate knowledge of the laws of interaction of molecules with a solid surface. One of the principal results of the symposium is that it has encouraged contacts between Americans and Europeans and the creation, outside the Nice group, of several other groups in Europe. These motives should also permit the development of exchange of scientists between the different research groups who work or will work in an important field whose rapid extension within the next few years may be envisaged.