SECTION N — Discussion: Flow Dynamics

Note: A participant's full name and address are given with the first contribution to the Discussion. Authors' full names and addresses are given with the title of each paper. For subsequent entries the addresses are omitted.

Paper N-1: High-Speed Photography Applied to High-Speed Aerodynamic Research at the National Physical Laboratory, *R. J. North*, National Physical Laboratory, Teddington, Middlesex, England.

Wallace H. Allan (Naval Ordnance Test Station, China Lake, California): How do you use a tricolor filter in your color schlieren? I am familiar with using a two-color filter, a yellow and blue, with the image of the source focused on the parting line between the two filters, thereby obtaining three colors — yellow, green and blue.

R. J. North: There are three strips of color filter — tricolor blue, green and red. The light source is focused on the central green filter, and this image of the light source is just wider than the width of the green filter, so that your background color is green. Any deviation of the light in the test section of the wind tunnel results in a change of color.

W. H. Allan: Could you not achieve the same effect, leaving the middle filter out?

R. J. North: No. With two filters you can only get a restricted color range; e.g. yellow, green and blue, as you described above. With three filters, you can extend this range into the red.

W. H. Allan: What are the filters made of? Are they glass or gelatin?

R. J. North: Both gelatin and glass filters have been used. The glass ones are preferable since they are robust and permanent.

Lincoln L. Endelman (The Martin Company, Cocoa Beach, Florida): What is the frequency, or recycle time, of the multiple spark system?

R. J. North: It is intended to be a single-shot device; but it may be fired a few times per second when setting up, or for other purposes.

L. L. Endelman: What is the total light output, or intensity, o the light emitted from the argon jet spark source?

R. J. North: The total integrated light output has not been measured; but it is ample for the intended applications, even for color schlieren or interferometer applications.

Paper N-2: High-Speed Photography of Rapid Air Currents and Shockwaves by Means of High-Frequency, High-Voltage Sparks, *H. G. Patzke, Walter Thorwart and Frank Früngel*, Dr.-Ing. Frank Früngel GmbH., Sülldorfer Landstrasse 400, Hamburg-Rissen (24a), Germany.

Jean St. Thomas (RCA Atlantic Missile Range, Eau Gallie, Florida): On the slides shown at the beginning of the paper what is the time resolution between individual spark traces?

Dr. Früngel: Each spark has a light emission of a little less than 1 μsec. Where there were, say, 50,000 sparks/sec, there would be 1-μsec light emission and 19-μsec pause; i.e. the period would be exactly 20 μsec. The spark lines are precisely iso-time lines (i.e. constant-time lines). We might compare the record with a wind tunnel interferogram, where the fringes are constant-pressure lines.

The method allows the time and velocity analysis of all aerodynamic phenomena of steady, transient or sinusoidal character, and can also be used to study shock waves. For example, the short operating time in a vacuum-driven wind tunnel can be used over the full range of air speeds. It is possible to gate the triggering; e.g. 10 sparks at 50 kc/sec, then 100 μsec pause, a further 10 sparks, and so on.

Professor P. Santorini (The University, Athens, Greece): Was reversal color film used, or negative color film? In the latter case, any color could be obtained in the print by the incorrect choice of the copying filter. Was a test color chart or a gray scale used?

Dr. Früngel: The exact colors are not important; only the distances along and between the spark lines. It is possible to mark coordinate positions by producing color changes by injection of other gases into the air stream. Sodium and argon are useful; sodium because of the pronounced color effect, argon because its density is similar to that of air.

Professor John R. Weske (University of Maryland, College Park, Maryland): The spark method can be valuable in the investigation of three-dimensional flow about turbine rotor blades. There is a study now in progress at the University of Maryland.

Dr. Früngel: Several slides were shown of sparks traveling along the surface of turbine blades in the trans-sonic and hypersonic ranges. For clear evaluation, the number of sparks of each series must be low, normally less than 10. The method has been used with good results for the last two years in many aerodynamic research problems. With a moving turbine rotor, the pulses may be gated so that a series of sparks may be started at any particular phase of the rotation.

Dr. Werner G. Braun (U.S. Air Force Research Division, Wright Field, Ohio): Are the self-magnetic forces on the spark channel actually insignificant? Have tests been made in gases at rest? These should show no movement of the arc channel (i.e. no kink instability), if the self-magnetic forces are indeed negligible in this method.

Dr. Früngel: We have made experiments of the kind you suggest. It is possible to maintain a stable spark path. The danger of introducing a mechanical disturbance of the spark channel is negligible. The impulsive influence between a current line and a magnetic field varies as $I^2\Delta t$. Δt lies in the region of 10^{-6} sec; I lies between 10 and 100 amp. Especially because of the short time for which the current flows, the influence is extremely small; but, of course, it does exist.

It may be more dangerous to use longer spark times; but it is easy to avoid trouble by using short pulses from a high-tension pulse transformer, as described. In any case, to avoid thermal disturbance of the air current, the spark energy must be as weak as possible, while still sufficient, of course, for getting pictures. This, too, reduces the danger mentioned above.

Heinz Fischer (U.S.A.F., Research Division, Hanscom Field, Bedford, Massachusetts): I think that Dr. Früngel stated that magnetic kink instabilities do not occur at times shorter than about 10^{-6} sec. However, we observed instabilities in arc channels at times as short as 10^{-9} sec.

Dr. Früngel: First, sparks several inches long, as here desired, need a much longer time for forming the plasma than do small point sparks. The time required is several tenths of a μsec. Second, in the case of sparks for illuminating purposes, the current must lie in the kiloampere range. For the sparks that we use in aerodynamic research, the current must be as weak as possible — just high enough to allow us to make a photographic record of the spark-channels themselves. We must avoid all unnecessary heating. Third, suppose that the stray capacity of our lead wires is 100 μμf and that it must be charged to 100 kv in 10^{-7} sec. We need a mean power $N = (1/2\ CU^2)/t = 5 \times 10^6$ w. Now, suppose instead (though in fact we do not desire it) that the charging time was only 10^{-9} sec. The power needed would be 100 times higher, that is 5×10^8 w. Such a high-power pulse generator would be perhaps 30 times more expensive than a device for 5×10^6 w, which is expensive enough anyway.

Paper N-3: High-Speed Photography of Liquid/Solid Impact, *J. H. Brunton*, PCS Laboratory, Department of Physics, University of Cambridge, England.

Dr. David C. Oakley (University of California, Lawrence Radiation Laboratory, Livermore, California): How did you synchronize the Model 189 Beckman & Whitley camera with your gun? This is one thing that I did not think was possible.

J. Brunton: No exact synchronization is possible. The method of operation involved running the camera up to a predetermined speed in a darkened room with the shutter open. The rotor speed was arranged such that the time for one revolution was rather more than the effective duration of the light source. The light source was turned on by triggering at the beginning of the event. Several runs were necessary to produce a series of runs completely covering the interval during which the event was illuminated.

Dr. D. C. Oakley: Do you mean that you take, say, eight shots, and one of them may have a sequence of photographs on it?

J. Brunton: All the shots have information on them, as the impacts last for a considerable time; but we might have to take eight or ten shots if we were looking particularly for the initial part of the impact.

Dr. D. C. Oakley: Was there any evidence to show that the liquid jet was hollow at the nose?

J. Brunton: Several hundred photographs have been taken of liquid jets produced by this method and no evidence has been found which suggests that they are hollow. The fact that the jets produce smooth saucer-shaped depressions in metal targets supports this view.

Winston O. S. Johnson (E. I. du Pont de Nemours and Company, Mechanical Research Laboratory, Wilmington, Delaware): What sort of driving bullet was used in the experiment?

J. Brunton: The choice of bullet is not critical. In the present work, .22 air-gun slugs and .22 rifle bullets were used.

W. O. S. Johnson: Did you use liquids other than water?

J. Brunton: Most of the work was carried out with water jets. Some experiments were carried out with water/glycerol mixtures in order to study the effect of liquid viscosity on the deformation. In such cases, it was found that the surface shear damage increased with viscosity.

Paper N-4: A Study of the Structure and the Ultrasonic Emission of a High-Speed Air Jet by High-Speed Schlieren and Shadowgraph Techniques, *F. Canac and Mlle. M. Merle*, Centre de Recherches Scientifiques, Industrielles et Maritimes de Marseille, France.

Dr. Hubert Schardin (Institut Franco-Allemand de Recherche, St. Louis, France, and Rosenstrasse 10, Weil am Rhein, Germany): Most of the pictures presented by Mlle. Merle were of periodic phenomena, recorded with the aid of a multiple-spark camera. The sparks could be triggered at short intervals so that the whole sequence of pictures could be recorded within one (or a few) period(s) of the phenomenon. For phenomena that are strictly periodic, it would be possible to use a stroboscopic arrangement when one wished to record over a longer period. If the phenomena are not exactly periodic, then the new camera that I have described* would be of considerable value, as it allows photography at short enough intervals so that each period may be studied, and over a long enough sequence so that many successive periods may be studied.

Mlle. M. Merle: In our work, the frequencies are not well determined, and a camera of the kind you described would be of value. It would not usually be possible to take stroboscopic records.

Paper N-5: Photographic Investigation of a Pulsating Air Jet Impinging on a Heated Plate, *G. F. Cochrane, Jr., and R. G. Nevins*, Department of Mechanical Engineering, Kansas State University, Manhattan, Kansas.

Dr. M. El-Wakil (Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin): At the University of Wisconsin, we have developed a *two*-wavelength interferometer in which *both* temperature and concentration gradients in boundary layers can be measured simultaneously. This should be useful in two-component systems, such as vapor and air, or two gases, etc. The work is described in more detail in "Progress in Astronautics and Rocketry," Volume 2, *Liquid Rockets and Propellants*, Academic Press, New York, 1960; "A Two Wavelength Interferometric Technique for the Study of Vaporization and Combustion of Fuels" by P. A. Ross & M. El-Wakil, pages 265–298.

Paper N-7: Photography and Analysis of Time Variation in Drop Size Distribution of a Liquid Spray, *Marcus F. Heidmann*, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio.

David A. Cahlander (Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts): Do your droplets ever multiply in number, or fragment, as they travel down the stream?

M. F. Heidmann: Sometimes we notice something of this nature, especially under accelerating flow. Under our usual air conditions, it doesn't occur.

D. A. Cahlander: Have you also noticed any coalescence phenomena, where two droplets join together?

M. F. Heidmann: It appears so on some of our films; although if there's one droplet behind the other, it's a little bit hard to determine. There is some coalescence.

W. O. S. Johnson: I might mention to D. A. Cahlander that in my work no breakup of particles ever occurred, but that coalescence did. There was never further breakup once the main film had broken into droplets.

W. C. Griffin (U. S. Naval Ordnance Test Station, China Lake, California): What is the smallest drop size that you have been able to photograph by your method?

M. F. Heidmann: Well, I hadn't really tried to extend it to the smallest drop sizes. We're interested primarily in large droplets because they affect our combustion and determine the performance to the greatest extent. I use unity magnification. If we took photomicrographs, we could record much smaller drops. Our particle analyzer only counts drops down to an image diameter of 200 microns on the film.

R. Jackson (British Coal Utilisation Research Association, Leatherhead, Surrey, England): What was the range of droplet sizes measured?

M. F. Heidmann: Two hundred to two thousand microns in diameter.

R. Jackson: Was the 2% error, estimated for 12,000 drops in each case, believed to be a real accuracy or merely a statistical levelling out? Measurements of size, by different observers or by machines, often vary by more than 10% on the same sample. The particle sizer that we have developed gives reproducible results, but the difficulty is to confirm the absolute accuracy of the sizes measured.

M. F. Heidmann: Two percent consistency; the absolute accuracy was probably lower.

R. Jackson: Have the bimodal distributions been plotted on a log basis? If so, do they give a mainly linear relation similar to the Rosin-Ranmiler law?

M. F. Heidmann: We have not investigated this.

Paper N-8: High-Speed Photography of Hypersonic Phenomena by a Schliereninterferometric Method, *H. Oertel*, Institut Franco-Allemand de Recherches, St.-Louis, France.

W. O. S. Johnson: What was the size of the field of view of the pictures which were shown?

Dr. H. Oertel: The field of view was 5 cm across.

W. O. S. Johnson: Can your technique be used at atmospheric pressure, as well as at very reduced pressure?

Dr. H. Oertel: It is a good method for reduced density. If you have atmospheric density and intense shocks, you will see the shocks, but you will not be able to measure the fringe shift.

W. O. S. Johnson: In other words, at normal atmospheric pressure, you could measure extremely minute changes?

Dr. H. Oertel: Yes. The sensitivity is the same as the sensitivity of a Mach interferometer.

R. J. North: I would like to congratulate Dr. Oertel on his excellent photographs. In answer to the previous question, I would point out that yesterday I showed some photographs taken with a similar system to that used by Dr. Oertel, but at pressures near 1 atm in a high-speed wind tunnel. For weak disturbances, the method is useful for measurement and visualization. If measurement of the shift is not important, the method may still be useful for visualization of strong disturbances.

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* "The multiple-spark camera in studies requiring highly detailed photography," published in these Proceedings.