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EFFECT OF CHARGE TRANSPORT ON LIQUID JETS AND LIQUID DROPS

FINAL TECHNICAL REPORT

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Rocketdyne
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A technical summary of all work accomplished under the subject contract is presented. Topics included in this summary are: the empirical examination of electrified-jet instabilities and breakup employing high-speed photographic techniques; development of a generalized theory of electrified-jet instabilities using Lagrangian techniques; drop-size reduction achieved with electrified jets; examination of charge accumulation in complex, high-velocity flow systems; a broad study of charged-drop instabilities, multiple disintegrations, heat transfer anomalies, and evaporative behavior; and the applicability of the high collection efficiency of charged drops to fog dispersal. Indices of (1) technical reports issued during the course of the contract and (2) all publications resulting from the contract are included.

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ON
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Final Technical Report

30 June 1972

Contract N00014-67-C-0474

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FOREWORD

The effort described in this report was sponsored by the Office of Naval Research under Contract No. N00014-67-C-0474, Identification No. 094-358/2-2-67 (Code 429) and was performed by Rocketdyne division of North American Rockwell Corporation during the period 1 June 1967 to 31 May 1972.

ABSTRACT

A technical summary of all work accomplished under the subject contract is presented. Topics included in this summary are: the empirical examination of electrified-jet instabilities and breakup employing high-speed photographic techniques; development of a generalized theory of electrified-jet instabilities using Lagrangian techniques; drop-size reduction achieved with electrified jets; examination of charge accumulation in complex, high-velocity flow systems; a broad study of charged-drop instabilities, multiple disintegrations, heat transfer anomalies, and evaporative behavior; and the applicability of the high collection efficiency of charged drops to fog dispersal. Indices of (1) technical reports issued during the course of the contract and (2) all publications resulting from the contract are included.

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SUMMARY OF WORK ACCOMPLISHED

Phenomena associated with the disintegration of charged liquid jets have been investigated since the last century. It has been established that the breakup of the jet and the dynamic behavior of the drops formed is of a completely different pattern for charged jets than for the uncharged case. However, investigations of this subject, which is of considerable importance in modern technology (e.g., the dependence of combustion phenomena on liquid jet disintegration and droplet breakup), have been fragmentary, and fundamental understanding of the distinction between charged and uncharged liquid jet disintegration has been limited.

Some of the recent contributions to this understanding have been accomplished at Rocketdyne under this Office of Naval Research (ONR)-sponsored study. The overall objective was to acquire a basic knowledge of electrified-jet processes (instabilities, disintegration, droplet dynamics) suitable to their control and technological utilization. Initially, high-speed photographic techniques were used to determine the effect of charging on the disintegration of cylindrical jets, the size distribution of the drops formed, and the velocities of the drops (Ref. 1). Several liquids were employed so that a range of electrical and flow properties could be spanned. In addition, liquid jet dimensions and levels of electrifiction were varied over wide limits. Throughout much of this period, experiment was allowed to lead theory.

A major effort was devoted subsequently to development of a comprehensive theory of electrically charged liquid jet instabilities. Small-perturbation analysis was used to develop a theory exhibiting the stabilizing or destabilizing influence of surface tension and electric effects for both axisymmetric and nonaxisymmetric instabilities. The results of this analysis were in good agreement, in the appropriate limit, with the more limited results of previous investigators (Ref. 2). This theory of electrified jet instabilities was later extended to include a quantitative description of the sizes of drops formed upon jet breakup. The method which Rayleigh applied in the case of unelectrified jets was re-derived to yield drop diameter in terms of jet diameter, physical properties of the jet liquid, level of electrification, and the mode of instability dominating the breakup process (Ref. 3).

The comprehensive theory of electrified jets has been compared with data obtained using the original laboratory apparatus developed for charged-jet studies. A second apparatus was designed to reflect the full development of the theory of jet electriciation, modeling the idealized geometry of the theory more closely than did the original apparatus. Critical comparison between the theory and test data obtained from the two modifications of the experimental apparatus has afforded important design information for the application of electrified jets in nonlaboratory situations (Ref. 3).

The disintegration patterns of jets of isopropyl alcohol differ from those of water at applied potentials above (nominally) 15 kv in that the former exhibit (1) extensive formation of secondary jets and (2) the development of a fan configuration. This fan configuration represents a previously unreported mode of jet instability which does not particularize from the small-perturbation analysis indicated above. As yet, no complete theoretical explanation of this new instability has been developed, though a semiquantitative description in terms of surface free energy has been given (Ref. 4). This description treats the fan instability as an alternative manifestation of surface growth.

The results obtained with electrified jets of isoproprylalcohol stimulated further investigation. Jets of three freon blends were examined to provide further information on breakup of electrified jets of low surface tension liquids of varying electrical conductivity and, in particular, on development of the fan configuration (Ref. 5). This work supports the hypothesis that this configuration is an alternative manifestation of surface growth.

Other tasks accomplished using charged liquids have included: (1) examination of the interaction of two electrified jets and of the interaction of drops formed from two electrified jets, using both high and low surface tension liquids;

(2) evaluation of the influence of jet/collector polarity combinations; and (3) study of charge accumulation in complex, high-velocity flow systems. The results of these studies are presented in Ref. 2.

A second major area of study during the program concerned examination of several aspects of charged-drop behavior particularly instabilities and multiple disintegrations and, to a lesser extent, heat transfer anomalies and evaporative behavior. Examination of the literature on charged drops showed it to be very extensive, widely scattered, and deserving of a comprehensive and critical analysis. Completion of this analysis, in turn, indicated the need for development of a comprehensive model of charged drop behavior. A model was developed which includes the influences of the charge on the drop, of external electric fields applied to the drop, of surface tension, and hydrodynamical influences. The influence of corona discharge, heat transfer, and evaporation were considered and related to the dynamics of charged-drop behavior. This work has been reported in Ref. 3, 5, and 6. In addition, a review paper on the subject of charged-drop instabilities is being prepared for submittal to The Physics of Fluids.

The information developed concerning disintegration of charged jets and formation of charged drops had application to a fog-dispersal program being conducted at the Naval Weapons Center (NWC), China Lake. One technique of fog dispersal involves injection of small, charged water drops at the top of the fog bank. These drops have a very high collection efficiency for the removal of liquid water from clouds and fog. Consultation was provided to the Earth and Atmospheric Sciences Branch of NWC concerning methods of producing drops of optimum size and maximum charge, subject to the demanding condition that injection ultimately be accomplishable from an aircraft. In tests in which a balloon supported the apparatus for production of charged drops, drops of the desired size bearing a reasonable quantity of charge were produced. Field demonstration of this method of fog dispersal was not accomplished because of the failure of sufficient fog to develop at the demonstration site (Arcata, California). A report covering this program in detail is being prepared at NWC.

INDEX OF TECHNICAL REPORTS

The following technical reports were issued during the course of the contract period.

1. R-7487, <u>The Effect of Charge Transport on the Disintegration of Liquid Jets</u>, by A. L. Huebner, Rocketdyne, a division of North American Rockwell Corporation, Canoga Park, California, 31 May 1968.
2. R-7880, <u>The Effect of Charge Transport on the Disintegration of Liquid Jets</u>, Interim Technical Report, by A. L. Huebner, Rocketdyne, a division of North American Rockwell Corporation, Canoga Park, California, 31 May 1969.
3. R-8240, <u>The Effect of Charge Transport on the Disintegration of Liquid Jets</u>, Interim Technical Report, by A. L. Huebner, Rocketdyne, a division of North American Rockwell Corporation, Canoga Park, California, 31 May 1970.
4. R-8731, <u>The Effect of Charge Transport on Liquid Jets and Liquid Drops</u>, by A. L. Huebner, Rocketdyne, a division of North American Rockwell Corporation, Canoga Park, California, 27 May 1971.

INDEX OF PUBLICATIONS AND PRESENTATIONS

The following is an index of all publications resulting from the subject contract. Where actual publication has not yet occurred, appropriate additional information is included in the citation.

1. Huebner, A. L.: "Disintegration of Charged Liquid Jets," Journal of Fluid Mechanics, Vol. 38, pp 679-688, 6 October 1969.

2. Huebner, A. L.: "Disintegration of Charged Liquid Jets: Results with Isopropyl Alcohol," Science, Vol. 168, pp 118-119, 3 April 1970.

3. Huebner, A. L. and H. N. Chu: "Instability and Breakup of Charged Liquid Jets," Bulletin of the American Physical Society, Series II, Vol. 15, No. 11, 1 November 1970.

4. Huebner, A. L. and H. N. Chu: "Instability and Breakup of Charged Liquid Jets," Journal of Fluid Mechanics, Vol. 49, pp 361-372, 9 September 1971.

5. Huebner, A. L.: "Disintegration of Charged Liquid Jets: Results with Freons," Science (to be published).

6. Huebner, A. L.: "The Physics of Charged-Drop Instability," (in preparation).

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1. Huebner, A. L.: "Disintegration of Charged Liquid Jets," Journal of Fluid Mechanics, Vol. 38, pp 679-688, 6 October 1961.

2. R-8240, The Effect of Charge Transport on the Disintegration of Liquid Jets, Interim Technical Report, by A. L. Huebner, Rocketdyne, a division of North American Rockwell Corporation, Canoga Park, California, 31 May 1970.

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