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A STUDY OF FLUID DYNAMICS OF GASEOUS NUCLEAR ROCKETS

A comprehensive review of the state of knowledge of vortex flows and how such flows may or may not be used for fluid dynamic containment of a gaseous nuclear fuel has been initiated. The first step has been the compilation of the attached bibliography of articles concerned with confined vortex flows. This list includes the results of research sponsored by NASA, USAF, and private companies on various proposed concepts of fluid dynamic containment which involve vortex flow in one form or another. It also includes articles motivated by a wide variety of other problems which involve vortex flows bounded in some way by either a solid boundary or a closed streamline. A continuing search of the literature is being made for other pertinent references. If the reader knows of an article that has been overlooked this information would be appreciated. The next step of the study involves assimilation of the useful information from these articles.

A graduate student, William H. Newton, is working with experimental data available in the references to obtain some empirical correlations of various vortex parameters. Several different approaches are being used in this attempt. One approach is similar to that introduced by Keyes(1960). It involves determining the turbulent eddy viscosity that is needed to make experimentally obtained velocity profiles approximately agree with predictions based on laminar flow theory. The laminar flow theory chosen for use in this comparison is that by Rosenzweig, Lewellen and Ross (1964) which is quite similar to that of Anderson (1961). Another more straight-forward approach is to correlate the velocity ratio between the vortex periphery and center exhaust with variations in the experimentally prescribed parameters. No conclusions have yet been reached from this investigation, but a large amount of data has been retrieved from the literature to be used in determining the most appropriate correlations.

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BIBLIOGRAPHY

Anderson, O. L. (1961), Theoretical solutions for the secondary flow on the end wall of a vortex tube, UARL Report R-2494-1 (November).

Anderson, O. L. (1963), Theoretical effect of Mach number and temperature gradient on primary and secondary flow in a jet-driven vortex, Air Force Systems Command Report RTD-TDR-63-1095 (November).

Anderson, O. L. (1966), Numerical solutions of the compressible boundary layer equations for axisymmetric flows, UARL Report E110266-1 (October).

Barber, Edde (1960), Vortex tubes, Jet Propulsion Laboratory, Vortex Literature Search No. 56 (October).

Bell, A. C. (1965), Optimization of a vortex valve, S.M. Thesis, Dept. of Mechanical Engineering, M.I.T. (December).

Benjamin, T. Brooke, and Barnard, B. J. S. (1964), A study of the motion of a cavity in a rotating liquid, J. Fluid Mech. 19, Part 2 (June).

Binnie, A. M. and Harris, D. P. (1950), The application of boundary-layer theory to swirling liquid flow through a nozzle, Quart. J. Mech. and Applied Math. III, Part 1.

Burgers, J. M. (1956), The effect of stretching of a vortex core, Univ. of Maryland, Tech. Note BN-80 (August).

Chanaud, Robert C. (1965), Observations of oscillatory motion in certain swirling flows, J. Fluid Mech. 21, Part 1, 111-127. Printed in Great Britain.

Chang, C. C., Chi, S. W. and Chen, C. M. (1967), Gas-core nuclear rocket fluid mechanics experiments at Catholic University, AIAA Paper No. 67-502 (July).

Chang, T. S. (1965), Hydromagnetic stabilization of nondissipative vortex flow, Developments in Theoretical and Applied Mechanics II, Pergamon Press, 261-276.

Chang, T. S. (1965), Exact criterion of hydromagnetic stability of inviscid vortex flow with finite conductivity, AIAA J. 3, 2050 (November).

Chang, T. S. and Sartory, W. K. (1965), Hydromagnetic stability of dissipative vortex flow, The Physics of Fluids 8, 235-241 (February).

Chang, T. S. and Sartory, W. K. (1965), Hydromagnetic stability of dissipative flow between rotating permeable cylinders, J. Fluid Mech. 27, 65-79.

Clark, J. W., Johnson, B. U., Kendall, J. S., Mensing, A. E., and Travers, A. (1967), Summary of gaseous nuclear rocket fluid mechanics research at United Aircraft, AIAA Paper No. 67-500.

Collins, J. C. and Stubbs, T. F. (1964), Qualitative experimental investigations on various vortex tube configurations, University of California, Lawrence Radiation Laboratory, UCRL 12045.

Cooper, Ralph S., Editor (1965), Proceedings of an Advanced Nuclear Propulsion Symposium, Los Alamos Scientific Laboratory, LA-3229-MS (January).

Cooper, Ralph S. (1965), Advanced nuclear propulsion concepts, AIAA Paper No. 65-531, AIAA Second Annual Meeting, San Francisco, California (July).

Deissler, Robert G. (1965), Unsteady viscous vortex with flow toward the center, NASA TN D-3026 (September).

Donaldson, Coleman DuP. (1956), Solutions of the Navier-Stokes equations for two and three-dimensional vortices, Ph.D. Dissertation, Princeton University (December).

Donaldson, Coleman DuP. and Snedeker, R. S. (1962), Experimental investigation of the structure of vortices in simple cylindrical vortex chambers, ARAP Report 47.

Donaldson, Coleman DuP. and Sullivan, Roger D. (1960), Examination of the solutions of the Navier-Stokes equations for a class of three-dimensional vortices, Aeronautical Res. Associates of Princeton, Inc., AFOSR TN 60-1227 (October).

Donaldson, Coleman DuP. and Williamson, G. G. (1964), An experimental study of turbulence in a driven vortex, ARAP Tech. Memo 64-2.

Easton, C. R. and Johnson, K. P. (1963), Fluid mechanical studies of fuel containment in a gaseous core reactor, Douglas Aircraft Co. Report SM-44886 (November).

Einstein, H. Albert and Huon Li (1958), Steady vortex flow in a real fluid, Proceedings of the 1958 Heat Transfer and Fluid Mechanics Institute.

Eisler, T. J. (1966), Taylor instability in a stratified flow, NASA CR-569 (October).

Evvard, J. C. (1965), Wheel-flow gaseous-core reactor concept, NASA TN D-2951 (November).

Fax, David H., Daskin, Walter, et al. (1953), Hydrodynamic analysis of flow through spherical vessels, The Johns Hopkins University, Baltimore, Maryland (June).

Fletcher, E. C., Gyarmathy, G. and Hasinger, S. (1966), Separation of submicron condensate particles in a vortex chamber, Aerospace Research Laboratories Report 66-0218 (November).

Foley, W. M. (1965), Comparison of simulated and required flow characteristics for vortex-stabilized gaseous nuclear rocket engine, UARL Report UAR-D46A (May).

Gartshore, I. S. (1962), Recent work in swirling incompressible flow, National Aeronautical Establishment, AR-LR-343, Ottawa (June).

Gebben, U. D. (1967), Vortex valve performance power index, Advances in Fluidics, A.S.M.E.

Gol'dshtik, M.A. (1960), A paradoxical solution of the Navier-Stokes equations, PMM 24, No. 4, 610-621.

Gol'dshtik, M.A., Leontov, A. K., and Paleev, I. I. (1960), Aerodynamics of a vortex chamber, Leningrad Polytechnic Institute.

Greenspan, H. P. (1965), On the general theory of contained rotating fluid motions, J. Fluid Mech. 22, Part 3, 449-462.

Grey, J. (1959), A gaseous-core nuclear rocket utilizing hydrodynamic containment of fissionable material, ARS Paper No. 848-59 (June).

Gross, R. A. and Kessey, K. O. (1964), Magnetohydrodynamic species separation in a gaseous nuclear rocket, AIAA J. 2, 295 (February).

Gyarmathy, G. (1967), Optical measurements of radial density distribution in a high-speed confined air vortex, ARL 67-0234 (December).

Gyarmathy, G. (1968), Optical measurements in a high-speed confined gaseous vortex, AIAA Paper No. 68-694.

Hall, M. G. (1966), The structure of concentrated vortex cores, Progress in Aeronautical Sciences 7, Pergamon Press,

Hartnett, J. P. and Eckert, E. R. G. (1957), Experimental study of the velocity and temperature distribution in a high-velocity vortex-type flow, Transactions of the A.S.M.E. (May).

Harvey, J. K. (1962), Some observations of the vortex breakdown phenomenon, J. Fluid Mech. 14, 585.

Hester, J. A. (1966), The effects of L/D and mass flow rate on the strength of a confined vortex, S.M. Thesis, M.I.T. Dept. of Aeronautics and Astronautics (June).

Johnson, B. U. (1965), Analytical study of propellant flow requirements for reducing heat transfer to the end walls of vortex-stabilized gaseous nuclear rocket engines, UARL Report D-910091-6 (September).

Johnson, B. U. (1967), Exploratory flow and containment experiments in a directed-wall jet vortex tube with radial outflow and moderate superimposed axial flows, UARL Report F-910091-11 (May). NASA Report CR-992 (February 1968).

Johnson, B. U. (1965), Analysis of secondary-flow control methods for confined vortex flows, NASA Report CR-276.

Johnson, B. U. and Travers, A. (1965), Application of flow control to a confined vortex, UARL Report UAR-D 50 (March).

Johnson, B. U. and Travers, A. (1965), Analytical and experimental investigation of flow control in a vortex tube by end-wall suction and injection, UARL Report D-910091-8 (September).

Johnson, B. U., Travers, A. and Hale, R. W. (1963), Measurements of flow patterns in a jet-driven vortex, Air Force Systems Command Report RTD-TDR-63-1094 (November).

Johnson, Kurt P. (1966), A plasma core nuclear rocket utilizing a magneto-hydrodynamically-driven vortex, AIAA J. 4, 635 (April).

Kao, T. W. (1966), Concentration profile establishment of binary gas mixture in swirl and dust flows, NASA Report CR-399 (March). The Physics of Fluids 9, 1216 (1966).

Kao, T. W. (1967), Baro-diffusion effect on diffusion time, The Physics of Fluids 10, 1814 (August).

Kelsall, D. G. (1952), A study of the motion of solid particles in a hydraulic cyclone, Trans. Instn. Chem. Engrs. 30, 87-108.

Kendall, James M., Jr. (1962), Experimental study of a compressible viscous vortex, J.P.L. Tech. Report No. 32-290 (June).

Kendall, J. S. and Mensing, A. E. (1966), Experimental investigation of the effect of heavy-to-light-gas density ratio on vortex containment characteristics, UARL Report UAR-E54 (April).

Kendall, J. S., Mensing, A. E. and Johnson, B. U. (1967), Containment experiments in vortex tubes with radial outflow and large superimposed axial flows, UARL Report F-910091-12 (May).

Kerrebrock, J. L. and Meghreblian, R. U. (1961), Vortex containment for the gaseous fission rocket, J. of the Aerospace Sci. 28, 710-724.

Keyes, J. J., Jr. (1960), An experimental study of gas dynamics in high velocity vortex flow, Proc. of the 1960 Heat Transfer and Fluid Dynamics Institute, Stanford University Press.

Keyes, J. J., Jr. (1961), An experimental study of flow and separation in vortex tubes with application to gaseous fission heating, ARS J. 31, 1204.

Keyes, J. J., Jr.,Chang, T. S., and Sartory, W. K. (1967), Hydromagnetic stabilization of jet-driven vortex flow, Oak Ridge National Laboratory Report TM-1896 (October).

Keyes, J. J., Jr. and Dial, R. E. (1960), An experimental study of vortex flow for application to gas-phase fission heating, Oak Ridge National Laboratory Report 2837.

Kidd, G. J., Jr. (1966), Confined vortex flow near a stationary disk; theory and experiment, Oak Ridge National Laboratory, ORNL-TM 1387 (April).

Kidd, G. J., Jr. and Farris, G. J. (1968), Potential vortex flow adjacent to a stationary surface, ASME Paper No. 68-APM-15 (June).

King, W. S. (1963), Momentum-integral solutions for the laminar boundary layer on a finite disk in a rotating flow, Aerospace Corp. Report No. ATM-63(9227)-3 (June). ASME Paper No. 64-FE-14 (1963).

King, W. S. (1967), A theoretical investigation of swirling flows through a nozzle, Ph.D. Thesis, U.C.L.A.

King, W. S. and Lewellen, W. S. (1963), Boundary-layer similarity solutions for rotating flows with and without magnetic interaction, Aerospace Corp., ATN-63(9227)-6 (July). Physics of Fluids 7, 1674 (October 1964).

Kinney, R. B. (1966), Theoretical effect of seed opacity and turbulence on temperature distributions in the propellant region of a vortex-stabilized gaseous nuclear rocket, UARL Report E-910092-8 (September). NASA Report CR-694

Kirkpatrick, D. L. I. (1964), Experimental investigation of the breakdown of a vortex in a tube, Great Britain Royal Aircraft Estb. AD 449 461 TN AERO 2963 (May).

Knapp, D. E. (1965), Lecture notes on advanced fluid core nuclear propulsion concepts, Douglas Missile & Space Systems Division, Douglas Paper No. 3169 (March).

Krueger, E. R. and Di Prima, R. C. (1964), The stability of a viscous fluid between rotating cylinders with an axial flow, J. of Fluid Mech. 19, 528.

Kuchemann, D. (1965), Report on the I.U.T.A.M. Symposium on Concentrated Vortex Motions in Fluids, J. Fluid Mech. 21, Part 1, 1-20.

Kurzweg, U. H. (1967), Criteria for the stability of heterogeneous swirling flows, UARL Report UAR-F96 (May).

Kwok, C. C. K. (1966), Vortex flow in a thin cylindrical chamber and its application in fluid amplifier technology, McGill University (Montreal) Department of Mech. Eng. Report 66-8.

Lance, G. N. and Rogers, M. H. (1962), The axially symmetric flow of a viscous fluid between two infinite rotating disks, Proc. Royal Society, Sec. A, 226, 109-121.

Lavan, Z. (1965), Luminescence in supersonic swirling flows, Illinois Institute of Technology, J. Fluid Mech. 23, Part 1, 173-183.

Lay, J. E. (1959), An experimental and analytical study of vortex-flow temperature separation by superposition of spiral and axial flows, Part 1, Transactions of the ASME (August).

Lay, J. E. (1959), Ibid. Part 2. J. of Heat Transfer, 213-221 (August).

Leibovich, S. (1968), Axially-symmetric eddies embedded in a rotational stream, J. Fluid Mech. 32, 529.

Lewellen, W. S. (1960), Magnetohydrodynamically driven vortices, Proceedings of the Heat Transfer and Fluid Mechanics Institute, Stanford University Press, 1-15.

Lewellen, W. S. (1962), A solution for three-dimensional vortex flows with strong circulation, J. of Fluid Mech. 14, 420 (November).

Lewellen, W. S. (1965), Linearized vortex flows, AIAA J. 3, 91 (January).

Lewellen, W. S. (1964), Three-dimensional viscous vortices in incompressible flow, Ph.D. Thesis, U.C.L.A.

Lewellen, W. S., Burns, W. J. and Strickland, H. J. (1968), Transonic swirling flow, AIAA Paper No. 68-693 (June).

Lewellen, W. S. and King, W. S. (1965), The boundary layer of a conducting vortex flow over a disk with an axial magnetic field, Developments in Mechanics (Proceedings of the Eighth Midwestern Mechanics Conference held April 1963 in Cleveland, Ohio) Pergamon Press, 108-127.

Lewellen, W. S., Ross, D. H. and Rosenzweig, M. L. (1966), Binary diffusion in a confined vortex, AIAA J. 4, 396-405 (March).

Long, Robert R. (1956), Sources and sinks at the axis of a rotating liquid, Quart. J. of Mechanics and Applied Math. IX, Part 4 (December).

Long, Robert R. (1953), Steady motion around a symmetrical obstacle moving along the axis of a rotating liquid, J. of Meteorology, 10, No. 3, 197-203 (June).

Long, Robert R. (1952), The flow of a liquid past a barrier in a rotating spherical shell, J. of Meteorology 9, No. 3, 187-199 (June).

Long, Robert R. (1961), A vortex in an infinite viscous fluid, The Johns Hopkins Univ., Dept. of Mech., 11 (December).

Ludwieg, H. (1960), Stability of flow in an annular space, Zeitschrift für Flugwissenschaften 8, 135-140.

Ludwieg, H. (1961), Extension of the work on the stability of flow in an annular space, Zeitschrift für Flugwissenschaften 9, 359-361.

Lugt, Hans J., and Schwiderski, Ernst W. (1965), On the birth and decay of vortices, U.S. Naval Weapons Laboratory, Dahlgren, Virginia, NWL Report No. 1972 (April).

Mack, Leslie M. (1960), The compressible viscous heat-conducting vortex, J. Fluid Mech. 8, 284.

Mack, Leslie M. (1962), Laminar boundary layer on a disk of finite radius in a rotating flow, Part I, JPL Report TR-32-224.

Mager, Artur (1960), Approximate solution of isentropic swirling flow through a nozzle, ARS 1517-60 (December).

Marxman, G. A. and Kerrebrock, J. L. (1960), Heat transfer in a two-dimensional vortex flow of a dissociating gas, STL TR 60-0000-09061 (February).

Mayer, E. A. (1967), "Large-signal vortex valve analysis", Advances in Fluidics, ASME.

McFarlin, D. J. (1965), Experimental investigation of the effect of peripheral wall injection technique on turbulence in an air vortex tube, UARL Report D-910091-5 (September). NASA Report CR-68867.

McLafferty, G. H. (1963), Summary of investigations of a vortex-stabilized gaseous nuclear rocket concept, Air Force Systems Command Report RTD-TDR-63-1097 (November).

McLafferty, G. H. (1965), Analytical study of the performance characteristics of vortex-stabilized gaseous nuclear rocket engines, UARL D-910093-20 (September).

McLafferty, G. H. (1967), Survey of advanced concepts in nuclear propulsion, AIAA Paper No. 67-783 (October).

McLafferty, G. H. and Anderson, G. E. (1963), Analytical investigation of diffusive loss rates of gaseous iodine from a helium vortex, Air Force Systems Command Report RTD-TDR-63-1095 (November).

McLafferty, G. H., Bauer, H. E. and Sheldon, D. E. (1966), Preliminary conceptual design study of a specific vortex-stabilized gaseous nuclear rocket engine, UARL Report E-910093-29 (September).

Mensing, A. E. and Kendall, J. S. (1964), Experimental investigation of containment of a heavy gas in a jet-driven light-gas vortex, UARL Report C-910091-3 (September).

Mensing, A. E. and Kendall, J. S. (1965), Experimental investigation of the containment of a heavy gas in a light-gas vortex, UARL Report UAR-D45 (March).

Mensing, A. E. and Kendall, J. S. (1965), Experimental investigation of the effect of heavy-to-light-gas density ratio on two-component vortex tube containment characteristics, UARL Report D-910091-9 (September).

Mensing, A. E. and Kendall, J. S. (1963), Experimental investigation of containment of gaseous iodine in a jet-driven vortex, Air Force Systems Command Report RTD-TDR-63-1093, prepared by UARL (November).

Nakamura, T. (1966), Experimental study of a confined vortex flow, S.M. Thesis, Dept. of Aeronautics and Astronautics, M.I.T. (January).

Nanda, R. S. (1961), Revolving flow of an incompressible fluid past a porous flat plate, Kharagpur 5, 1 (January).

Ohrenberger, J. T. (1967), Boundary layers in rotating flow with heat transfer, Ph.D. Thesis, U.C.L.A.

Ostrach, Simon and Loper, David E. (1966), An analysis of confined vortex flows, AIAA Paper No. 66-88.

Owen, F. S., Hale, R. W., Johnson, B. U. and Travers, A. (1961), Experimental investigation of characteristics of confined jet-driven vortex flows, UARL Report R-2494-2 (November).

Owen, F. S. and Mensing, A. E. (1961), Heat transfer to confined vortex flow by means of a radio frequency gas discharge, UARL R-2494-3 (November).

Pearson, Carl E. (1965), Numerical solutions for the time-dependent viscous flow between two rotating coaxial disks, Sperry Rand Research Center, J. Fluid Mech. 21, Part 4, 623-633.

Pengelley, C. Desmond (1957), Flow in a viscous vortex, J. of Applied Physics 28, 1 (January).

Pinchak, Alfred C. and Poplawski, Robert (1965), On the attainment of extremely high rotational velocities in a confined vortex flow, AIAA Paper No. 65-400 (July).

Pivirotto, T. J. (1966), Mass-retention measurements in a binary compressible vortex flow, JPL Report No. 32-864 (June).

Pivirotto, T. J. (1967), Radial static pressure distributions in confined compressible vortex flow fields, JPL Report No. 32-1076.

Poplawski, R. and Pinchak, A. C. (1965), Aerodynamic performance of reversed flow vortex chambers, Aerospace Research Laboratories Report ARL-65-219, Wright-Patterson Air Force Base (October).

Prager, Stephen (1964), Spiral flow in a stationary porous pipe, The Physics of Fluids 7, 6 (June).

Ragsdale, Robert G. (1961), A mixing length correlation of turbulent vortex data, ASME Paper No. 61-WA-244 (August).

Ragsdale, Robert G. (1960), NASA Research on the hydrodynamics of the gaseous vortex reactor, NASA TN D-288.

Ragsdale, Robert G. (1963), Outlook for gas-core nuclear rockets, Astronautics and Aerospace Engineering 1, 88 (August).

Reynolds, Alan J. (1961), Energy flows in a vortex tube, ZAMP, XII.

Reynolds, Alan J. (1961), On the dynamics of turbulent vortical flow, ZAMP, XII.

Riley, N. (1962), Radial jets with swirl, Part I. Incompressible flow, Quart. J. Mech. and Applied Math. XV, Part 4.

Riley, N. (1962), Radial jets with swirl, Part II. Compressible flow, Quart. J. Mech. and Applied Math. XV, Part 4.

Ringleb, Friedrich (1963), Vortex motion, Aerophysics, Mississippi State University Research Report 47 (October).

Romero, Jacob B. (1964), Fuel containment in the gaseous-core nuclear rocket by MHD driven vortices, AIAA J. 2, 1092 (June).

Roschke, E. J. (1966), Experimental investigation of a confined, jet-driven water vortex, JPL Report 32-982.

Roschke, E. J. (1966), Flow-visualization studies of a confined, jet-driven water vortex , JPL Report 32-1004.

Roschke, E. J. and Pivirotto, T. J. (1965), Similarity in confined vortex flows, JPL TR No. 32-789 (August).

Rosenzweig, M. L. (1961), The vortex matrix approach to gaseous nuclear propulsion, Aerospace Corp., American Rocket Society Paper No. 1735-61 (May).

Rosenzweig, M. L., Lewellen, W. S. and Kerrebrock, J. L. (1961), Feasibility of turbulent vortex containment in the gaseous fission rocket, ARS J. 31, 873 (July).

Rosenzweig, M. L., Lewellen, W. S. and Ross, D. H. (1964), Confined vortex flows with boundary layer interaction, AIAA J. 2, 2127 (December).

Rosenzweig, M. L., Ross, D. H. and Lewellen, W. S. (1962), On secondary flows in jet-driven vortex tubes, J. Aerospace Sci. 29, 1142 (September).

Ross, D. H. (1964), An experimental study of secondary flow in jet-driven vortex chambers, Aerospace Corp. Report No. ATN-64(9227)-1 (January).

Ross, D. H. (1964), An experimental study of turbulence levels in jet-driven vortex chambers, Aerospace Corp. ATN-64(9227)-5 (October).

Rott, Nicholas (1958), On the viscous core of a line vortex, J. of Applied Math. and Physics, ZAMP , IXb, Fax. 5/6, 543-553.

Rott, Nicholas (1959), On the viscous core of a line vortex, II, J. of Applied Math. and Physics ZAMP, X, Fasc. 1, 73-81.

Rott, Nicholas (1962), Turbulent boundary layer development on the end wall of a vortex chamber, Aerospace Corp. ATN-62(9202)-1.

Rott, N. and Lewellen, W. S. (1966), Boundary layers in rotating flows, Proceedings of the Eleventh International Congress of Applied Mechanics held September 1964 in Munich, Germany, Springer-Verlag Press, 1030-1036.

Rott, N. and Lewellen, W. S. (1965), Some examples of rotating boundary layers, Recent Developments in Boundary Layer Research, AGARDograph 97 (May).

Rott, N. and Lewellen, W. S. (1966), Boundary layers and their interactions in rotating flows, Progress in Aeronautical Sciences,7, Pergamon Press, 111-144.

Savino, Joseph M. and Keshock, Edward G. (1965), Experimental profiles of velocity components and radial pressure distributions in a vortex contained in a short cylindrical chamber, NASA TN D-3072 (October).

Savino, J. M. and Ragsdale, R. G. (1960), Some temperature and pressure measurements in confined vortex fields, ASME Paper No. 60-SA-4, Summer-Annual Meeting, Dallas, Texas, June.

Sarpkaya, T., Goto, J. M. and Kirshner, J. M. (1967), A theoretical and experimental study of vortex rate gyro, Advances in Fluidics, ASME.

Schwiderski, Ernst W. and Lugt, Hans J. (1964), Rotating flows of von Karman and Bodewadt, The Physics of Fluids 7, 6 (June).

Smith, J. L., Jr. (1962), An analysis of the vortex flow in the cyclone separator, ASME J. Basic Engr. 84, 602.

Smith, J. L., Jr. (1962), An experimental study of the vortex in the cyclone separator, ASME J. Basic Engr. 84, 609.

Steiger, Martin H. and Bloom, Martin H. (1962), Axially symmetric laminar free mixing with large swirl, Transactions of the ASME, 370 (November).

Stewartson, K. (1957), On rotating laminar boundary layers, Boundary Layer Research, Symposium Freiburg, Springer-Verlag, Berlin, 59-71 (1958).

Stewartson, K. (1957), On almost rigid rotations, J. Fluid Mech. 3, 1 (October).

Taylor, G. I. (1950), The boundary layer in the converging nozzle of a swirl atomizer, Quart. J. Mech. and Applied Math. 3, 129-139 (June).

Ter Linden, A. J. (1953), Cyclone dust collectors for boilers, Transactions of the ASME, 75, No. 1, 433-440.

Thompson, Joe Floyd, Jr. (1963), The structure of free and confined turbulent vortices, Miss. State Univ., Research Note No. 44 (May).

Talbot, L. (1954), Laminar swirling pipe flow, J. of Applied Mechanics 21, No. 1, 1-7.

Toomre, J. (1963), Highly swirling flows through a converging-diverging nozzle, S.M. Thesis, M.I.T. Dept. of Aero. and Astro. (June).

Travers, A. (1967), Experimental investigation of flow patterns in radial-outflow vortexes using a rotating peripheral-wall water vortex tube, UARL Report F-910091-10 (May).

Travers, A. and Johnson, B.U. (1966), Measurements of flow characteristics in a basic vortex tube, NASA CR-278 (January).

Travers, A. and Johnson, B. U. (1965), Measurements of flow characteristics in an axial-flow vortex tube, NASA CR-277 (August).

Travers, A. and Clark, J. W. (1968), Experimental investigation of flow stability and flow patterns in radial-outflow vortexes, AIAA Paper No. 68-695 (June).

Turner, J. S. (1965), The constraints imposed on a class of strong vortices by an axial boundary, J. of Fluid Mech. 25, Part 2, 377-400.

Weske, J. R. and Rankin, T. M. (1963), On the generation of secondary motions in the field of a vortex, Univ. of Maryland Tech. Note BN-313 (March).

Williamson, G. G. and McCune, J. E. (1961), A preliminary study of the structure of turbulent vortices, ARAP Report No. 32.

Wormley, D. N. (1967), An analytical and experimental investigation of vortex-type fluid modulators, Ph.D. Thesis, M.I.T. Dept. of Mech. Eng.

Yeh, Hsuan (1957), Boundary layer along annular walls in a swirling flow, Transactions of the ASME, Semi-Annual Meeting, San Francisco, Calif. (June).