AEDC-TDR-63-20

63-2-4

BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS

By

P. L. Clemens and A. H. Cortner

von Kármán Gas Dynamics Facility
ARO, Inc.

TECHNICAL DOCUMENTARY REPORT NO. AEDC-TDR-63-20

February 1963

AFSC Program Area 750A, Project 8952, Task 895201

(Prepared under Contract No. AF 40(600)-1000 by ARO, Inc., contract operator of AEDC, Arnold Air Force Station, Tenn.)

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

NOTICES

BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS

By

P. L. Clemens and A. H. Cortner
von Kármán Gas Dynamics Facility
ARO, Inc.
a subsidiary of Sverdrup and Parcel, Inc.

February 1963
ARO Project No. VW2007

ABSTRACT

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

Donald R. Eastman, Jr.
DCS/Research

Jean A. Jack
Colonel, USAF
DCS/Test

CONTENTS

INTRODUCTION

The magnetic support of wind tunnel models is not a new art. A working magnetic model suspension system was first designed and constructed by l'Office National des Études et de Recherches Aéronautiques (ONERA) as early as 1955. Subsequent work by the ONERA improved the dynamic response characteristics of the system and enabled measurement of aerodynamic forces imposed upon the model as they are reflected in the electrical currents necessary to provide magnetic restraint.

Magnetic suspension of wind tunnel models is attractive because it allows close approach to the free-flight situation. The flow field surrounding the model is free of the aerodynamic effects ordinarily induced by the presence of a sting, struts, or other interfering structural supports. Support reactions are absent from the forces imposed upon the model. If heat-transfer studies are to be undertaken, no corrections need be made for heat conducted through support members. If dynamic stability measurements are of interest, magnetic suspension provides elastic restraint in five degrees of freedom. The elasticity of the restraint is adjustable to accommodate the conditions of the test, and either forced oscillation or free oscillation modes of testing may be used.

Although the magnetic support of wind tunnel models may be quite attractive, its value as a test technique can be no greater than will be permitted by the measurements which can be made through its use. As already mentioned, aerodynamic forces experienced by the magnetically suspended model have been measured. Accuracies of the measurements have fallen within one percent limits. Pressures have been measured by approaching the model with slender probes. Although this method has shown some success in the measurement of model base pressures, it is always questionable to what degree the probe has distorted the flow field. Also, the fact that the probe must be slender implies poor response to rapidly fluctuating pressures. Of course, this method is useless in the measurement of pressures near the model's stagnation region.

Recent attempts to exploit the magnetic suspension technique have sought to overcome such measurement system inadequacies through the use of both optical and radio telemeters contained within the model body. The exploitation has thus far been shallow. However, a number of

Manuscript received January 1963.

aerodynamic testing establishments* have undertaken to produce magnetic model suspension systems. It appears reasonable that with a greater number of magnetic suspension systems in operation, refined measurement methods will be forthcoming. Greater use of magnetic suspension in the production of aerodynamically interesting and useful data will be the natural consequence of greater sophistication in the applicable measurement methods.

An appreciable body of literature has been generated which bears upon the magnetic suspension of wind tunnel models. It is the purpose of this bibliography to compile the writings pertinent to this field of specialization. This is done in the hope that the entries which are listed may be of some value to the newcomer to the field, and in the certain knowledge that such a compilation will be useful to those engaging in the work.

The bibliography comprises four main parts: I. Magnetic Suspension for Aerodynamic Testing; II. Non-Aerodynamic Applications of Magnetic Suspension; III. Magnetic Circuits and Their Electronic Controls; IV. Telemetry from Magnetically Supported Aerodynamic Models. The order of listing of the items within each section is chronological, by date of publication. Where they were available, abstracts were made a part of each entry. In general, the abstract which accompanies an entry is that provided by the author or authors of the particular item entered.

---

*A listing of organizations planning to undertake, or now engaged in, work involving the magnetic suspension of wind tunnel models would include: the Massachusetts Institute of Technology (Aerophysics Laboratory); the University of Southampton; the University of Virginia; ONERA; and; the von Kármán Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command.

PART I

MAGNETIC SUSPENSION FOR AERODYNAMIC TESTING

1. Tournier, M., Dieulesaint, E., and Laurenceau, P. "Etude, Réalisation et Mise au Point d'une Suspension de Maquette Aérodynamique par Action Magnétique pour une Petite Soufflerie." (Design, Construction and Placing into Service of a Magnetic Suspension System for Aerodynamic Models in a Small Wind Tunnel). O. N. E. R. A. N. T. 1/1579 AP, Office National d'Études et de Recherches Aeronautiques, Chatillon-sous-Bagneux (Seine), Paris, France.

2. Laurenceau, P. "Etude, Réalisation et Mise au Point d'une Suspension de Maquette Aérodynamique par Action Magnétique pour une Petite Soufflerie." (Design, Construction and Placing into Service of a Magnetic Suspension System for Aerodynamic Models in a Small Wind Tunnel). O. N. E. R. A. N. T. 2/1579 AP, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France.

3. Laurenceau, P. "La Suspension Magnétique des Maquettes." (The Magnetic Suspension of Models). O. N. E. R. A. Discussion Technique OP, Office National d'Études et de Recherches Aeronautiques, Chatillon-sous-Bagneux (Seine), Paris, France, Juin 1956.

4. Tournier, M., and Laurenceau, P. "Perfectionnements à la Suspension Magnétique des Maquettes." (Improvements in the Magnetic Suspension of Models). O. N. E. R. A. N. T. 5/1579 AP, Office National d'Études Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France, Decembre 1956.

5. Laurenceau, P., and Desmet, E. "Adaptation de la Suspension Magnétique des Maquettes aux Souffleries S. 19 & S. 8 LCh." (Adaptation of the Magnetic Suspension of Models to Wind Tunnels S. 19 & S. 8). O. N. E. R. A. N. T. 7/1579 AP, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France, Janvier 1957.

6. Tournier, M., and Laurenceau, P. "Suspension Magnétique d'une Maquette en Soufflerie." (Magnetic Suspension of a Model in a Wind Tunnel). La Recherche Aéronautique, No. 59, p. 21, Office National d'Études et de Recherches Aéronautiques, Juillet-Aout 1957, Paris, France.

SOMMAIRE

Un procédé nouveau de suspension des maquettes a été elaboré et il a déjà subi dans diverses conditions de vitesse de veine, dès essais préparant l'utilisation que l'on peut en envisager dans l'avenir.

De premiers resultats obtenus sur des corps fuselés, dans cette phase préliminaire, sont présentés à titre d'exemple.

TRANSLATION:

ABSTRACT

A new procedure for the suspension of models has been developed and has been put to use under various conditions of flow velocity in preparation for its use in future tests.

Some early results obtained with several slender bodies, in this preliminary phase, are presented by way of example.

7. Nelson, Winston, Trachtenberg, Alfred, and Grundy, Albert, Jr. "An Apparatus for the Study of High Speed Air Flow Over a Freely Suspended Rotating Cylinder." WADC Technical Report 57-338, ASTIA Document No. AD 142127, Electronics Research Laboratories, Columbia University, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1957.

ABSTRACT

This report described an apparatus constructed for the study of air flow over high speed smooth surfaces. A steel and aluminum rotor, eight inches in diameter, is magnetically supported in a test chamber and is accelerated to speeds up to 21,000 rpm. Specific attention is given to the theory and design of the magnetic support and drive systems.

8. Tournier, M., Laurenceau, P., and Dubois, G. "La Suspension Magnétique O.N.E.R.A." (The ONERA Magnetic Suspension System). Conference on Premier Symposium International sur l'Aérodynamique et l'Aérothermique des Gas Raréfiés, Nice, France, 2-5 Juillet 1958. Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, Francis. Permagon Press, London.

SOMMAIRE

La suspension magnétique O. N. E. R. A. ne fait appel, pour maintenir une maquette dans une soufflerie, qu'à des électro-aimants situés hors de la veine. Elle évite donc les perturbations de l'écoulement et les fuites thermiques dues aux supports matériels.

Elle constitue d'autre part une balance qui peut être très sensible. Dès à présent elle a été employée avec succès pour la mesure de la résistance aérodynamique de crops fuselés.

On donne une brève description des installations existantes. Quelques résultats obtenus dans une petite soufflerie à rafales à des nombres de Mach de 3, 75 et 5, 4 et à des nombres de Reynolds de 130000 à 500000 (rapportés à la longueur de la maquette) sont présentés à titre de'exemple.

TRANSLATION:

ABSTRACT

The ONERA magnetic suspension system, in order to maintain a model within a wind tunnel, requires nothing other than electromagnets situated outside the test section. It circumvents, therefore, the flow disturbances and the heat losses attributable to structural supports.

It constitutes, on the other hand, a balance which can be very sensitive. To the present, it has been employed with success in the measurement of the aerodynamic resistance of slender bodies.

A brief description of the existing installation is given. Some results obtained within a small wind tunnel during runs at Mach numbers 3. 75 and 5. 4 and Reynolds numbers of 130, 000 to 500, 000 (referred to the model length) are presented by way of example.

9. Desmet, E., and Rosset. "Charactéristiques et Notice d'Emploi de la Suspension Magnétique Destinée aux Souffleries S. 19 et S. 8." (Characteristics and Review of the Use of the Magnetic Suspension System Intended for Wind Tunnels S. 19 and S. 8). O. N. E. R. A. N. T. 9/1579 AP, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France.

10. Desmet, E. "Suspension Magnetique O. N. E. R. A. - Essai d'Application à l'Étude des Oscillations de Lacet d'un Corps Fuselé." (The ONERA Magnetic Suspension System - Test of Application to the Study of Oscillations of a Body in Yaw). O. N. E. R. A. N. T. 10/1579 AP, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France.

11. Jenkins, A. W., Jr., and Parker, Herman M. "An Electromagnetic Support Arrangement with Three Dimensional Control, Part I - Theoretical." Report UVA/ORL-04-58 TR 1, Presented at 4th Conference on Magnetism and Magnetic Materials, Philadelphia, Pennsylvania, November 17-20, 1958.

ABSTRACT*

The original electromagnetic support developed in the late 1930's is a one dimensional system. Servoed control is obtained in one direction and, only inherent stability due to the field shape is obtained in the lateral directions. In this paper the more general problem of a three dimensionally controlled support is treated theoretically. By virtue of making certain assumptions which seem reasonably close to practical feasibility, two basic three dimensional support schemes have been devised in which, ideally, the three mutually perpendicular forces are uncoupled. The two arrangements are described, and the theory is applied to predict the amount of coupling to be expected due to the deviations from the ideal system.

---

12. Fosque, Hugh S., and Miller, Glenn H. "An Electromagnetic Support Arrangement with Three Dimensional Control, Part II - Experimental." Report UVA/ORL-04-58-TR3, Presented at 4th Conference on Magnetism and Magnetic Materials, Philadelphia, Pennsylvania, November 17-20, 1958.

ABSTRACT*

The first gradient coil configuration described in Part I of this paper has been constructed. In this system the axis of one pair of

---

*This work was supported jointly by the Office of Naval Research and the Air Force under Contract NOnr 474 (04).

gradient coils is parallel to the magnetizing field. The details of the magnetic, optical and electronic aspects of this implementation will be presented and discussed. It has been convenient in this case to use a Varian four inch electromagnet to produce the magnetizing field. The optical and gradient coil systems have been mounted on heavy aluminum plates attached to the magnet. In this way a rigid mounting is assured and adjustments in the optical systems are facilitated.

The performance of this system has been experimentally investigated. The method used in making measurements on overall performance will be presented and discussed. In particular, some of the properties examined are:

(1) The elastic constant associated with the restoring force due to the magnetic field gradient.

(2) The cross-coupling between the three forces produced by the three pairs of coils. This applies both to the case of displacement of the supported sample, as well as zero displacement.

(3) Steady state and transient force limits which the sample can withstand and still remain in support.

(4) The bandwidth of the overall system, i. e., the displacement resulting from an artificially inserted a. c. error signal.

The difficulties encountered in this system will be discussed and means for making improvements will be presented. Some of these improvements will be incorporated in the second system, which is presently under construction. In this system the gradient coils are symmetrically located relative to the magnetizing field. In both cases the greatest difficulty lies in the optical system used to sense the three components of sample position.

13. Chrisinger, John E. "An Investigation of the Engineering Aspects of a Wind Tunnel Magnetic Suspension System." MIT Thesis, MIT TR 460, ASTIA Document No. AD 221294, Massachusetts Institute of Technology, Cambridge, Massachusetts, May 1959.

ABSTRACT

The basic theory of a wind tunnel magnetic suspension system is presented. The design parameters to be used for developing any particular system are discussed. Methods of solution are noted

which may be used to determine the sizes of the system magnetic units required to produce the design forces. The experimental method is used as a basis for the design of the magnetic units to be employed with a particular small hypersonic wind tunnel. A detailed discussion is given of the design and fabrication of these units.

14. Matheson, L. R. "Some Considerations for Design and Utilization of Magnetic Suspension." Aerodynamics Fundamental Memo No. 84, General Electric Missile and Space Vehicle Department, Philadelphia, Pennsylvania, May 1959.

ABSTRACT

The use of magnetic force to support aerodynamic models in a wind tunnel is within the realm of practical possibilities. The techniques to accomplish this are all known in the present state of the art.

The models to be used using this support will be relatively inexpensive since they can be fabricated from solid bars of low carbon iron.

The use of this system is particularly well suited to long slender shapes. Data obtained will include drag forces, normal forces and pitching moments.

In view of the loads on the supporting coils, it appears desirable to introduce angles of attack in the horizontal direction. This will provide greater accuracy in measuring pitching (yaw) moments.

15. Mirande, J. "Mesure de la Résistance d'un Corps de Révolution, a $M_0 = 2.4$, au Moyen de la Suspension Magnétique O. N. E. R. A." (Measurement of the Drag of a Body of Revolution, at $M = 2.4$, by Means of the ONERA Magnetic Suspension System). No. 70, Office National d'Études et de Recherches Aéronautique; Mai-June 1959, p. 24.

16. Tilton, E. L., and Schwartz, S. "Static Tests on the Magnetic Suspension System." MIT AR Memo 399, Massachusetts Institute of Technology, Naval Supersonic Laboratory, Cambridge, Massachusetts, July 1959.

ABSTRACT

As a recent thesis project by Chrisinger, a magnetic suspension system for the N.S.L. hypersonic wind tunnel was designed and fabricated. The three magnet units (suspension and lateral units, drag solenoid) have now been statically tested and the results are presented in this memo.

The units were tested independently, and no attempt has yet been made to study the interactions caused by the three units in simultaneous operation. The model used in these tests was a cylindrical Alnico permanent magnet six inches in length and one-half inch in diameter.

17. Tilton, Edward Lee, III. "Design, Construction and Testing of an Automatic Control System for a Wind Tunnel Magnetic Suspension System." MIT Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, May 1960.

ABSTRACT

A discussion of the basic methods of controlling a model in magnetic suspension is presented. A detailed discussion is given on the analysis and design of an integral control system for the longitudinal degree of freedom of the model. Construction of the system is carried out and the results of the experimental verification of the system's performance are given.

18. Baron, L. A. "The Design and Construction of an Automatic Control System for a Wind-Tunnel Magnetic Suspension System." MIT Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, June 1960.

ABSTRACT

The design approach and analysis of an automatic control system for a wind tunnel magnetic suspension system is presented. The interpretation of the physical situation and its mathematical expression is discussed. The analytical design of the control system is developed in a step by step procedure, as is the physical realization of the analytical parameters involved. An attempt is made to give a physical explanation leading to the form of the control system, as well as for many of the analytical and graphical techniques involved in linear system design.

19. "Magnetic Suspension of Wind Tunnel Models." The Engineer, Vol. 210, No. 5463, October 7, 1960, pp. 607-608.

20. Scott, John E., Jr., and May, James E. "Laboratory Investigation of the Basic Nature of Low Density Gas Flow at High Speeds." Report No. AST-4435-109-61U, Research Laboratories for the Engineering Sciences, University of Virginia, Charlottesville, Virginia, January 1961.

21. "Magnetic Suspension Replaces Mechanical Support of Wind Tunnel Models." Electronic Design News, Vol. 6, No. 7, July 1961, pp. 13-15.

ABSTRACT

This article discusses the magnetic suspension control circuits developed by the Office National d'Études et de Recherches Aéronautiques in a 30 cm diameter wind tunnel test section at Chatillon-sous-Bagneux, France.

22. Scott, John E., Jr., and Kuhlthaw, A. R. "Laboratory Investigation of the Basic Nature of Low Density Gas Flow at High Speeds, Annual Progress Report for the Period 1 January to 31 December 1961." Report No. AST-4435-116-62U, University of Virginia, Charlottesville, Virginia, February 1962.

23. Parker, H. M., May, J. E., and Nurre, G. S. "An Electromagnetic Suspension System for the Measurement of Aerodynamic Characteristics." Report No. AST-4443-106-62U, University of Virginia, Charlottesville, Virginia, March 1962.

ABSTRACT

The design concepts are presented for a free electromagnetic suspension system functioning as force balance yielding simultaneous and independent measurements of force in three mutually perpendicular directions. The system is adapted to function as a wind tunnel balance which requires no physical attachment to the model under study. The concepts have been reduced to practice in a first-generation balance which is to be applied to the study of low-density sphere drags as a first demonstration of the unique capabilities of this balance system. The first model also is intended to serve as a test device to provide design information for a second-generation balance for the study of dynamic stability. The apparatus is described in detail and calibration procedures and future applications are discussed.

24. Chrisinger, J. E., Tilton, E. L., III, Parkin, W. J., Coffin, J. B. and Covert, E. E. "Magnetic Suspension and Balance System for Wind Tunnel Application." Massachusetts Institute of Technology, Aerophysics Laboratory, Cambridge, Massachusetts, April 1962.

PART II

NON-AERODYNAMIC APPLICATIONS OF MAGNETIC SUSPENSION

1. Holmes, F. T. "Axial Magnetic Suspension." The Review of Scientific Instruments, Vol. 8, December 1937, pp. 444-447. Rouss Physical Laboratory, University of Virginia, Charlottesville, Virginia.

ABSTRACT

A vertical ferromagnetic needle can be supported in macroscopic equilibrium by magnetic forces alone. One method using a variable magnetic field is described and shown to have considerable latitude in details of application. A 6 g rotor having a moment of inertia of about 0.8 g cm^2 was suspended in this manner. It was spun at about 1200 rev./sec., its behavior indicating that with suitable driving arrangements much higher speeds should be attainable. At 600 rev./sec. with driving torque zero it exhibited a deceleration of about 2×10^{-3} rev./$sec.^2$. A suspended element weighing about 3/4 g showed torsion constants, depending on adjustments, down to 7×10^{-6} dyne-cm./rad.

2. Beams, J. W., Young, J. R., III, and Moore, J. W. "The Production of High Centrifugal Fields."* Journal of Applied Physics, Vol. 17, November 1946, pp. 886-890. University of Virginia, Charlottesville, Virginia.

ABSTRACT

High centrifugal fields were produced by spinning small solid steel spherical rotors up to their bursting speeds. The rotors were supported magnetically in a vacuum by an improved method and spun by rotating magnetic fields. The peripheral velocities at which the rotors of various sizes, made of the same (flaw free) steel and having the same shapes, exploded, were roughly the same and of the order of 10^5 cm/sec. A centrifugal field of 2.4×10^8 times gravity was obtained with a 0.795-mm spherical rotor which was the smallest diameter tried. Calculations indicate that in some cases plastic flow probably occurred in small regions near the centers of the spherical rotors somewhat below their bursting speeds.

---

*The work described in this paper has been supported by the Bureau of Ordnance, U. S. Navy under Contract NOrd-7873.

3. Wroughton, D. M., Okress, E. C., Brace, P. H., Comenetz, G., and Kelly, J. C. R. "A Technique for Eliminating Crucibles in Heating and Melting of Metals." Journal of the Electromechanical Society, Vol. 99, No. 5, May 1952, p. 205.

ABSTRACT

An original method of heating and melting metals without a crucible, by suspension in space with an electromagnetic field, is described. The required field was generated by applying high frequency alternating current to two coaxial coils connected in series opposition. Stable levitation and heating of various metals in the solid state was obtained between the coils in the vicinity of the common axis, both in air and in a vacuum. Weights levitated ranges up to 550 grams. In air, some tens of grams of Al, Sn, and a brass were brought to melting and continued in levitation while in the liquid state. In a vacuum, 10 grams of Al was successfully levitated molten. On the other hand, several attempts to levitate molten Ag, Ti, and Zn in a vacuum failed.

4. Okress, E. C., Wroughton, D. M., Comenetz, G., Brace, P. H., and Kelly, J. C. R. "Electromagnetic Levitation of Solid and Molten Metals." Journal of Applied Physics, Vol. 23, No. 5, May 1952, p. 545.

ABSTRACT

The subject is an unconventional method of heating and melting metals without a crucible by suspension in space with an electromagnetic field. Operating conditions for certain cases are given. The results obtained by means of the new technique encourage the thought of melting, purifying, alloying, and agitating of inert and reactive metals without resort to crucibles, and thereby avoiding the contamination of reactive metals by crucible materials. Preliminary results with various forms and masses of metal are described. Considerations concerning the atmosphere in which levitation occurs are included.

5. Davisson, C. J., and Beams, J. W. "A New Variation of the Rotation-by-Magnetization Method of Measuring Gyromagnetic Ratios."* Reviews of Modern Physics, Vol. 25, No. 1, January 1953, pp. 246-252. University of Virginia, Charlottesville, Virginia.

---

*This work was supported by the Bureau of Ordnance, U. S. Navy Contract NOrd-7873 at the University of Virginia.

6. Beams, J. W. "Magnetic-Suspension Ultracentrifuge Circuits." Electronics, March 1954, pp. 152-155. **University of Virginia.**

ABSTRACT

This paper described a magnetic support for high-speed rotors which has been under development at the University of Virginia for more than a decade and a half and which has proven to be an almost ideal support bearing for a wide variety of high speed rotors. Essentially, the same support technique is employed in spinning the rotors used in a number of different problems.

7. Carpenter, Delma Rae, Jr. "A New Equilibrium Ultracentrifuge for Determination of Molecular Weights." A dissertation presented to the graduate faculty of the University of Virginia in candidacy for the degree of Doctor of Philosophy, June 1957. Available from University Microfilms, Inc., Ann Arbor, Michigan, 1960.

8. Breazeale, J. B., McIlwraith, C. G., and Dacus, E. N. "Factors Limiting a Magnetic Suspension System." Journal of Applied Physics, Vol. 29, No. 3, March 1958, pp. 414-415. Bill Jack Scientific Instrument Company, Solana Beach, California.

ABSTRACT

A magnetic suspension apparatus is reported which is capable of operating in any attitude in space, or under reasonable accelerations in any direction. The device may be used as a low-friction bearing or as a force-measuring balance. Limitations of both of these useful properties exist because of physical and magnetic properties of the materials used. These limitations are discussed and their order of magnitude reported for several common magnetic materials. As a low-friction bearing, hysteresis torques as low as 3×10^{-5} dyne-cm, and eddy current torques as low as 9×10^{-7} dyne-cm per radian/sec are reported. As a force-measuring balance hysteresis errors and deviations from linearity of as little as 0.1% of full-scale force may be obtained. The maximum force under which support can be maintained is above five times the weight of ferromagnetic material in the supported object. Displacement of the supported object under an applied force can be made as small as 10^{-6} cm/dyne.

9. McIlwraith, G. C., and Breazeale, J. B., and Dacus, E. N. "Improved Magnetic Suspension System." The Review of Scientific Instruments, Vol. 29, No. 11, November 1958, pp. 1029-1033. Bill Jack Scientific Instrument Company, Solana Beach, California.

ABSTRACT

A magnetic suspension apparatus is described which supports a ferro-magnetic object free from contact with its surroundings and which is capable of maintaining this support for any attitude or orientation in space of the apparatus as a whole. The apparatus and circuits are described and the conditions for stable support given. Features of the system of potential use in instrumentation are described.

10. Schreiber, H. "Photomagnetic Toy is True Servomechanism." Radio-Electronics, January 1962, pp. 79-80.

11. Gilpin, B. J., Neiman, D. F., Moss, F. E., Jr., Ging, L., and McVey, E. S. "Investigation of Magnetic and Electric Forces for Rotating Shaft Suspension." Report No. EMI-4441-117-62U, ASD-TDR-62-441, ASTIA Document No. AD-277202, Wright-Patterson Air Force Base, Ohio, Aeronautical Systems Division, Air Force Systems Command, May 1962. Research Laboratories for the Engineering Sciences, University of Virginia, Charlottesville, Virginia.

ABSTRACT

The initial efforts in the study of magnetic and electric journal bearings are given. These include: 1) the selection of magnetic systems rather than electric or super-conducting systems for the first study; 2) the selection of a magnetic system which uses static magnetic fields for the radial confinement; 3) construction details; 4) static test results; and 5) servo system design. Statically, the system has given a radial restoring force coefficient of 0.5 pounds per milli-inch, and simultaneously, an axial unbalance force coefficient of 5.4 pounds per milli-inch.

A servo system is proposed for the axial confinement. Theoretical designs are given for several types of compensation techniques to achieve stability. It is shown that the mass of the supported member and the axial stiffness required demand an electromagnet that can respond with large forces to frequencies as high as 1200 cps. Measurements on the actual components of the system point to the difficulty in achieving such a response.

12. Gilpin, B. J. "Research Investigation of Magnetic and Electric Forces for Rotating Shaft Suspension." Report No. EMI-4454-103-62U, ASTIA Document No. AD-277753, June 1962. Research Laboratories for the Engineering Sciences, University of Virginia, Charlottesville, Virginia.

PART III

MAGNETIC CIRCUITS AND THEIR ELECTRONIC CONTROLS

1. Anderson, H. L., Dunning, J. R., and Mitchell, D. P. "Regulator Systems for Electromagnets." The Review of Scientific Instruments, Vol. 8, December 1937, pp. 497-501. Pupin Physics Laboratories, Columbia University, New York, New York.

ABSTRACT

A regulator for maintaining constant, to better than 0.1 per cent over long periods, the magnetic field of large (100 kw) electromagnets is described. This consists of two basic components: (1) A vacuum tube voltage regulator which compensates for rapid changes in voltage and thus anticipates the change in current which would result. (2) A current actuated element arranged so as to alter the operating point of the voltage regulator in order to compensate for slow changes in current due to changes in the temperature of the windings. Very rapid regulator action is secured with no drift or hunting to the limit specified.

2. Electrical Engineering Staff of Massachusetts Institute of Technology. Magnetic Circuits and Transformers; A First Course for Power and Communications Engineers. John Wiley and Sons, New York, 1943. (718 pp.)

ABSTRACT

"Few basic textbooks reflect as representative a matching of practice with theory as this does. For that reason the rising engineer should find the treatment far more than a 'refreshener' book. Whether in design or performance objectives, the examples worked out are more practical and pertinent than any practicing engineer is likely to have had in no matter what course of his day - that penetrating, elucidative and current is the subject matter." ---Electrical World, June 12, 1943, p. 165.

3. Goodbar, L., and Uluant, C. A. "Investigation of the Magnetic Field Near a Round Cylindrical Coil Having a Short Axis." Massachusetts Institute of Technology, Master's Thesis, Course VI, 1945.

4. Bates, L. F. Modern Magnetism. Syndics of the Cambridge University Press, London, 1951. (506 p.) (Third Edition)

ABSTRACT

"Much fresh material is incorporated including new h.f. techniques developed during the last war and the very striking elaborations of the domain concept resulting from important work in America, England and France, and their bearing on the interpretation of the hysteresis cycle. Written from the experimental rather than the theoretical aspect the author has been eminently successful in this endeavor to present an account of modern magnetic theory that can be followed not only by students of physics but by more general readers." --- Electrician, October 19, 1951, p. 1207.

5. Slottow, H. Gene. "A High Stiffness Electromagnetic Weighing System." Report No. 805, U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, April 1952.

ABSTRACT

Following a discussion of performance requirements for wind tunnel balance systems, and an account of early electromagnetic balances, a new electrically controlled unit is described that has the following performance characteristics:

1) Range:	±40 pounds
2) Sensitivity:	0.0004 pounds per division on ±4 pound range 0.004 pounds per division on ±40 pound range
3) Accuracy:	to within 0.1 per cent of 0.4 pounds for forces up to 0.4 pound
	to within 0.1 per cent of actual load from 0.4 pound to 4 pounds
	to within 0.2 per cent of actual load from 4 pounds to 40 pounds
4) Deflection:	less than 0.0004 inch for 40 pounds (a stiffness of over 100,000 pounds per inch).
5) Response time:	less than 0.2 second for step function input.

The circuits of the device are described in detail, and a complete weighing system, because of tendencies towards oscillation, is analyzed from the standpoint of closed loop control theory. Experimental procedures are described and the results of performance tests are presented.

6. Smith, Turner L. "Balance System for the Aberdeen 13" x 15" Supersonic Wind Tunnel." BRL Report No. 802, U. S. Army Ordnance Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, January 1953.

ABSTRACT

A new design 6-component external balance system for a supersonic wind tunnel is described. The design contemplates use of Eastman electromagnetic weighing cells and considers such factors as building vibrations and temperature changes. Interactions and their elimination are discussed, including the method of alignment of parts.

7. Ahrendt, William R. Servomechanism Practice. McGraw-Hill Book Company, New York, 1954. (349 pp.)

ABSTRACT

"A comparatively simple treatment of servomechanism principles and elements. Simplicity has been achieved largely by emphasizing servo-mechanism components such as electronic amplifiers and hydraulic systems and by limiting the discussion of design to simple cases. The book offers the conscientious reader with practical interests a reliable explanation of the purpose of servomechanisms, how they work, what they consist of and gives him an insight into the design problems. Although developed in a formal college course and intended primarily for use as a text, it is suitable also for self-instruction". ---New Technical Books, Vol. 40, No. 1, January-February 1955, p. 17.

8. Burnett, James H. "Applying Thyratrons to Control - Part I." Control Engineering, January 1957, pp. 88-96.

ABSTRACT

Author Burnett presents a complete and up-to-date discussion of thyratron servos, which are turning in optimum performances in military and industrial applications. He describes the principles of their operation, shows how to control their output for motor and magnetic clutch loads, and details application procedures.

9. Burnett, James H. "Applying Thyratrons to Control - Part II." Control Engineering, February 1957, pp. 73-77.

ABSTRACT

In this article, the author illustrates five typical thyratron-servo applications, explains stabilization methods used for the various motors and power circuits, and concludes with an original contribution to control technology development of a nonlinear stabilization method for ideal kinetic-energy damping of thyratron servos.

10. Underhill, Earl M. (Editor). Permanent Magnet Handbook. Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh, Pennsylvania, 1957.

11. Savant, C. J., Jr. Basic Feedback Control System Design. McGraw-Hill Book Company, New York, 1958. (418 pp.)

ABSTRACT

"Attempts to teach the fundamentals of servodesign by means of practical examples and from the student's own point of view. The author makes several deviations from more conventional methods of presentation. One difference is in the use of the root-locus method as a basic tool for servodesign. Another is to present servotheory and practical servodesign without the requirement of an elaborate mathematical background. Problems are included at the end of each chapter."--Aero/Space Engineering, May 1958, p. 156.

12. Gibson, John E. and Tuteur, F. B. Control System Components. McGraw-Hill Book Company, New York, 1958. (493 pp.)

ABSTRACT

"As an analytical treatment of the components commonly used in servomechanisms and other feedback control systems, this book contains discussions on electronic, electric, mechanical, hydraulic, and pneumatic components. Discussed. . . is a theoretical approach to selection of control-system components. Included is information on work synthesis, system analysis of value-operated hydraulic systems, and relay amplifiers."--- Machine Design, September 18, 1958, p. 245.

13. Hayt, William H., Jr. Engineering Electromagnetics. McGraw-Hill Book Company, New York, 1958. (328 pp.)

ABSTRACT

"A clearly written, unusually teachable text for the modern junior-level introductory course in electric and magnetic fields. . . Introduces the electrical engineering student to electro-magnetic theory in a way that enables him to readily understand more advanced texts. . . Although the development follows that of several more advanced books, the treatment is simplified, expanded, and well illustrated with problems to help familiarize the undergraduate with this theoretical subject."----Midwest Engineer, July 1958, p. 26.

14. Grabbe, Eugene M., Ramo, Simon, and Wooldridge, Dean E. (Editors). Handbook of Automation Computation and Control, Volume 1. John Wiley and Sons, New York, 1958. (1020 pp.)

ABSTRACT

"This Handbook, pertaining to the field of automatic control, is designed to provide a source of definitions and descriptive material about new areas of technology in automation and to serve as a reference and as background material for understanding modern techniques of importance in the field. . . Preparation of the series is by a staff of specialists recruited from industry and the various universities."---Electronic Equipment Engineering, November 1958, p. 90.

15. Harrington, Rogers F. Introduction to Electromagnetic Engineering. McGraw-Hill Book Company, New York, 1958. (320 pp.)

ABSTRACT

"A very attractive book. . . Contains a thorough and well-organized introduction to electric and magnetic field problems, with the emphasis on the static case. . . Directed. . . towards engineering students at the junior, senior, and first-year graduate levels. Calculus and some circuit theory are presupposed. . . A dominant feature of the text is the quality of the writing. Ideas are clearly stated, and care is evident in the continuity from paragraph to paragraph, chapter to chapter. Problems and review questions are included. All in all, it is a good book, and should be teachable as well."---L. A. Manning in Proceedings of the IRE, September 1958, p. 1662.

16. Seely, Samuel. Introduction to Electromagnetic Fields. McGraw-Hill Book Company, New York, 1958. (308 pp.)

ABSTRACT

"In addition to providing a sound background in electricity and magnetism, this book also serves as the foundation on which to develop later work in field-operated devices, such as transducers and rotating electrical machinery, and the important problems of electromagnetic field theory. Important topics such as current flow fields, electrostatics, electromagnetism, and introductory electromagnetic field phenomena are covered."---Electrical Manufacturing, August 1958, p. 262.

17. Boast, Warren B. Principles of Electric and Magnetic Circuits. Harper and Brothers, New York, 1958. (369 pp.) (Second Edition)

ABSTRACT

"This second edition, like the first, is designed to give a full comprehension of electric and magnetic circuits. The text section dealing with electric energy sources has been brought up to date relative to improvements in solar sources; and, in Part IV, a presentation of the methods of electrical network analysis, sections have been reorganized and expanded to include discussion and further examples on situations involving pure-current or voltage sources in circuits where a direct application of basic principles would render the circuits interminable of solution."---National Engineer, January 1958, p. 37.

18. Gutzwiller, F. W. "Overcurrent Protection of Semiconductor Rectifiers." GE Report ECG-328, Semiconductor Products Department, General Electric Company, Clyde, New York, June 1958.

19. "Hall-Effect Devices." Electronics, Ronald K. Jurgen, Associate Editor, January 16, 1959, p. 63.

ABSTRACT

When a strip of metal is placed with its plane perpendicular to a magnetic field and an electric current flows longitudinally through the strip, a potential difference is developed between its two opposite edges. This Hall effect becomes more pronounced with semiconductor materials.

20. Agusta, Benjamin. "Dynamic Test of Choke Inductance." Electronics, January 23, 1959, p. 54. International Business Machines Corp., Poughkeepsie, New York.

21. Laurenceau, P. "Description et Reglage de l'Amplificateur - Correcteur Utilise sur les Suspensions Magnétiques." (Description and Performance of the Error Amplifier Used with the Magnetic Suspension System). O.N.E.R.A. N.T. 13/1579 AP, Office National d'Études et de Recherches Aéronautiques; Chatillon-sous-Bagneux (Seine), France. Avril 1959.

22. Brog, Kenneth C. "A Transistor Regulated Power Supply for a High Current Magnet." Office of Naval Research Technical Report No. 2; ASTIA Document No. AD-229365, Thesis, Case Institute of Technology, Cleveland, Ohio, August 1959.

ABSTRACT

Current regulation of a high current electromagnet utilizing power transistors in series was achieved.

A sampling voltage, obtained from a sensing resistor in series with the magnet, is compared with a reference voltage; the error signal is sufficiently amplified and fed back to the series transistors through a 2 stage transistor driver.

Magnetic fields from 845 gauss to 8550 gauss with field regulation of a few parts per million over this range were obtained.

23. Fano, R. M., Chu, L. J., and Adler, R. B. Electromagnetic Fields, Energy and Forces. John Wiley and Sons, Inc., New York, 1960. (520 pp.)

ABSTRACT

"Develops a consistent macroscopic theory of electromagnetism and discusses the relation between circuit theory and field theory. Special features cover the electromagnetism of moving bodies and the process of electromechanical energy conversion, introduces a power-series technique for analyzing quasi-stationary systems and presents the four-dimensional relativistic formulation of macroscopic electrodynamics recently developed by one of the authors."--- Design News, April 25, 1960, p. 101.

24. Giauque, W. F., and Lyon, D. N. "Design of a 100-Kilogauss 4-Inch Core Solenoid for Continuous Operation."* The Review of Scientific Instruments, Vol. 31, No. 4, April 1960, pp. 374-390. University of California, Berkeley, California.

ABSTRACT

The design of high field cylindrical solenoid magnets for continuous operation is discussed. Equations are given relating power input, allowable temperature rise, coolant rate, and pressure drop to give the detailed dimensions required for the electrical conductor and the cooling annuli. The stresses from electromagnetic forces acting upon conductors are discussed, equations are given, and some devices and factors concerned in resisting these forces are described. The properties of kerosene as a magnet coolant and safety precautions for its use are discussed. The details for a magnet with a 4-in. air core, constructed for good homogeneity, and 7.5 megawatts of power are given. A procedure for preparing laminated insulation in the form of a spiral is described and a method of squaring the magnet ends to improve heat transfer, reduce heat production, and facilitate support at the ends has been devised. Equations are given which enable the evaluation of the conductor temperature at any point along the coil by making use of the temperature coefficient of resistance for thermometric purposes. A graph of conductor and kerosene temperatures as a function of axial length has been prepared from data obtained from magnet operation. The particular magnet described here, which is the first of several to be built, gave a field of 99,500 gauss at 7.5 megawatts. Some suggested improvements based on experience with the present magnet have been included.

25. Adair, T. W., III, Squire, C. F., and Utley, H. B. "High Field Solenoid Magnet with Liquid Nitrogen Cooling." The Review of Scientific Instruments, Vol. 31, No. 4, April 1960, pp. 416-418. Rice Institute, Houston, Texas.

ABSTRACT

The high field solenoid described in this paper operates at liquid nitrogen temperature (78°K), and uses a relatively small dc power

---

*This work was supported in part by the Office of Naval Research, U. S. N., the U. S. Atomic Energy Commission, and the National Science Foundation.

source (100 KW). It has operated continuously and steadily at 36 K gauss and 62 KW under steady state conditions. This is done by forcing the liquid nitrogen coolant through the annuli between the electrical conductors with a circulation pump. The first magnet designed has a 4.6-cm diameter core and the length is such that the central portion of the solenoid gives an experimental "working space" 10 cm in length where the field is quite uniform. The cost is modest compared to comparable water-cooled solenoids both as to initial investment and operation.

26. Alexander Kusco, Inc., Consulting Engineers. "Precision Power Supply Design for Air-Core Magnet Loads." Cambridge, Massachusetts, ASTIA Document No. AD 237777, Prepared for Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts, April 1960.

ABSTRACT

This report includes a discussion of the problems and the methods of building rectifier power supplies for air-core research magnets, where the ripple and current regulation must be held to extremely low levels. The electrical behavior of a suitable saturable reactor system is derived and the parameters of the components are calculated for a 200-KW power supply.

27. Autler, S. H. "Superconducting Electromagnets." The Review of Scientific Instruments, Vol. 31, No. 4, April 1960, pp. 369-373. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts.

ABSTRACT

Experiments or devices requiring the joint use of liquid helium and magnetic fields can make use of superconducting electromagnets. Solenoids capable of producing up to 4300 gauss in large volumes are described. Higher fields, up to 14 kilogauss, have been produced by iron-core super-conducting magnets. A small power supply may be used to energize one of the magnets and then disconnected after a persistent current has been set up. A stable magnetic field is thus maintained for many hours if the magnet is kept cold.

28. Hunsicker, J. E. "An Electromagnetic Balance with Emphasis on Linear Polar Plots Directly Derivable from the Differential Equations of Motion." BRL Memorandum Report No. 1351, U. S. Army Ordnance Ballistic Research Laboratories, Aberdeen Proving Grounds, Maryland, June 1961.

ABSTRACT

This report considers the analysis of an electromagnetic balance consisting of a multiresonant mechanical structure driven by electromagnetic force transducers made by the Eastman Corporation. The electromagnetic properties of the "Eastman Pot" or force transducer are discussed in detail. Special emphasis has been placed on the analysis of relatively complicated systems through the derivation of linear polar plots* obtained directly from the linear differential equations describing the electromagnetic or electromechanical circuits.

29. Strnat, Dr. Karl, and Wolf, Robert A. "Construction and Calibration of a Hall-Effect Gaussmeter." ASD TR 61-273, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, November 1961.

ABSTRACT

A gaussmeter, based on the Hall-effect, was built for laboratory use. It permits easy and quick measurement of steady magnetic fields in ten ranges between 1 gauss and 30 kilogauss. The small indiumarsenide probes facilitate the mapping of non-uniform fields and provide access to the interior of small coils and into narrow gaps. The report describes the meter design and calibration.

30. Montgomery, D. Bruce, and Terrell, J. "Some Useful Information for the Design of Air-Core Solenoids." AFOSR-1525, National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, November 1961.

ABSTRACT

Relationships relating power, magnetic field, current density, and ampere turns in terms of certain dimensionless factors are summarized for many types of coil geometries and current distributions. A number of plots of these factors are presented.

The field homogeneity in magnet structures is presented in terms of a series expansion about the origin utilizing Legendre Polynomials. A number of tables to facilitate design of homogeneous fields are presented. A method of achieving homogeneity in long solenoid structures by use of determinants is discussed. Expressions for the axial field from uniform and radially varying current density coils are given.

*Nyquist Diagram

31. Montgomery, D. Bruce. "Some Useful Information for the Design of Iron Magnets." AFOSR-1526, National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, November 1961.

ABSTRACT

The calculation of gap fields in iron magnets by means of equivalent surface poles has been explored by several authors. This work is enlarged and the results compared with the performance of a wide range of commercial magnets. Magnet circuits can also be analyzed by a volume integral of dipoles. This removes the restriction of uniform magnetization and allows the optimum direction of magnetization to be explored. General results are given for iron cylinders, and a number of specific tapered poles are analyzed. The homogeneity of fields in the gaps of magnets is presented in the form of a Taylor series of error coefficients.

32. Morris, David E., and Kilgore, Robert A. "The Magnetic Field on the Axis of Circular Cylindrical Coils." NASA Technical Note D-1013, NASA, Langley Research Center, Langley Station, Hampton, Virginia, April 1962.

ABSTRACT

The magnetic-field intensity along the axis of circular cylindrical coils of finite winding thickness has been computed for a range of coil geometries. Nondimensional field plots are presented that facilitate coil design for a desired field intensity along the axis.

PART IV

TELEMETRY FROM MAGNETICALLY SUPPORTED AERODYNAMIC MODELS

1. Dubois, Georges, and Rogué, Charles. "Sur une Méthode de Mesure de la Pression de Culot." (On a Method for Measurement of Base Pressure; Measurement and Visualization on a Cone Cylinder Magnetically Suspended at M_O = 7.6).* La Recherche Aéronautique, No. 79, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France, Novembre-Decembre 1960.

SOMMAIRE

La présente note est relative à une méthode de mesure de la pression de culot d'un corps à symétrie axiale.

Cette méthode évite tout support materiel, la maquette étant maintenue dans l'axe de la veine d'expériences grâce à la suspension magnetique O. N. E. R. A. La pression de culot est alors mesurée, sans interaction, par un manomètre optique situé à l'intérieur de la maquette. Simultanément, il est possible de visualiser l'écoulement par strioscopie.

Cette note indique les conditions requises pour l'application de la methode, examine la précision des mesures, discute les résultats déterminés avec et sans dard et les compara à ceux obtenus antérieurement à des nombres de Mach plus faibles.

TRANSLATION:

ABSTRACT

The present note is relative to a method for the measurement of base pressure of an axisymmetric body.

The model is maintained on the test section axis by the ONERA magnetic suspension system; this method circumvents use of structural supports. The base pressure is then measured, without interaction, by an optical pressure transducer situated within the model. Simultaneously, it is possible to visualize the flow by a schlieren system.

---

*NOTE: This report has been translated from the French by R. N. Zapata of the University of Virginia and is available as ASTIA Document No. AD 260634.

This note indicates the conditions required for application of the method, examines the accuracy of measurement, discusses the results obtained with and without a sting, and compares them to those previously obtained at several lower Mach numbers.

2. Beaussier, Jacques. "Télémesure pour Maquette Suspendu Magnétiquement en Soufflerie." (Telemetry for a Model Magnetically Suspended in a Wind Tunnel). La Recherche Aéronautique, No. 82, Office National d'Études et de Recherches Aéronautiques, Chatillon-sous-Bagneux (Seine), Paris, France, Mai-Juin 1961, p. 49.

3. Clemens, P. L. "Radio Telemetry of Stagnation Pressures from a Wind Tunnel Model Magnetically Supported in Supersonic Flow." AIEE CP 62-1209, AEDC-TDR-62-141, AIEE Summer General Meeting, Denver, Colorado, June 17-22, 1962. Arnold Engineering Development Center, Air Force Systems Command.

ABSTRACT

During a set of aerodynamic tests in a Mach number 2.4 wind tunnel, it was proven feasible to telemeter stagnation pressure measurements from within a magnetically suspended, ferromagnetic model. State-of-the-art, f-m radio telemetry developed for hypervelocity range use was employed. Although data at the outset of each of three trials reflect errors of less than three per cent, frequency versus temperature interactions introduced intolerable shifts in telemeter center frequency as testing progressed. Several methods may be used to reduce these interactions. Magnetogasdynamic effects introduced by the magnetic model suspension technique are negligible in most wind tunnel testing.

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee
Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee
Rpt. No. AEDC-TDR-63-20. BIBLIOGRAPHY: THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS. February 1963. 34 p.

Unclassified Report

This is a selective bibliography of the literature on the magnetic suspension of wind tunnel models including a chronological arrangement of titles and abstracts under four main headings: Magnetic Suspension for Aerodynamic Testing, Non-Aerodynamic Applications of Magnetic Suspension, Magnetic Circuits and Their Electronic Controls, Telemetry from Magnetically Supported Aerodynamic Models. An introduction presents a resumé of the state-of-the-art of magnetic model suspension technology.

1. Wind tunnel models
2. Test methods
3. Magnetism
4. Suspension devices

I. AFSC Program Area 750A, Project 8952, Task 895201
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. P. L. Clemens and A. H. Cortner
V. Available from OTS
VI. In ASTIA Collection