NASA Technical Memorandum 84661

Magnetic Suspension and Balance Systems

A Selected, Annotated Bibliography

Marie H. Tuttle, Robert A. Kilgore,
and Richmond P. Boyden

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Magnetic Suspension and Balance Systems

A Selected, Annotated Bibliography

Marie H. Tuttle
Kentron International, Inc.
Hampton, Virginia

Robert A. Kilgore and Richmond P. Boyden
Langley Research Center
Hampton, Virginia

National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

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INTRODUCTION

This publication, containing 206 entries, supersedes an earlier bibliography, NASA TM-80225 (April 1980). Citations for 18 documents have been added in this updated version.

The purpose of this selected bibliography is to list available publications that might be helpful to persons interested in magnetic suspension and balance systems for use in wind tunnels. Some historical material has been included, and the arrangement is generally chronological by date of publication. However, papers presented at conferences or meetings are placed under dates of presentation. Therefore, the collection also serves as a "history" of the development of this type of equipment.

The numbers assigned to many of the citations have been changed from those used in the previous bibliography. This has been done in order to allow outdated citations to be removed and some recently discovered older works to be included in their proper chronological order.

An effort has been made to include the relevant literature. However, some important papers may have been inadvertently omitted. It is hoped that omissions of this type will be called to the attention of the compilers so that possible subsequent updated versions may be more nearly complete and, therefore, more useful. Some early French reports are omitted, as attempts to secure copies have thus far been unsuccessful.

Corporate source, author, and subject indexes, by citation number, are included for the convenience of the users. In many cases, abstracts used are from the NASA announcement bulletins "Scientific and Technical Aerospace Reports" (STAR) and "International Aerospace Abstracts" (IAA). In other cases, authors' abstracts were used. License was taken to modify or shorten abstracts. Abstracts are usually not included for documents having limited distribution. The information included about the authors is that existing when the papers were written and may not have remained the same. If it is known that a paper has appeared in several forms, mention is made of this fact.

Identifying information, including accession and report numbers when known, is included in the citations in order to facilitate filling requests for specific items. When requesting material from a library or other source, it is advisable to include the complete citation; the abstract may be omitted.

Availability of journal articles, books, and other open literature has not always been included, as this type of material is available at many libraries or may be secured through interlibrary loan.

Availability sources of the different types of materials are given on the following page.

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NXX-XXXXX Example: N67-37604	Report literature having no distribution limitation	National Technical Information Service (NTIS) 5285 Port Royal Road Springfield, VA 22161
XXX-XXXXX Example: X72-76040	Report literature having distribution limitation of some type	NASA Scientific and Technical Information Facility (STIF) P. O. Box 8757 B.W.I. Airport, MD 21240
AD Numbers	Report literature with or without distribution limitation	Defense Technical Information Center Cameron Station Alexandria, VA 22314
Order number (when given)	Theses	University Microfilms A Xerox Company 300 North Zeeb Road Ann Arbor, MI 48106
No acquisition number	MIT theses	Mass. Inst. of Technology Room 14-0551 Photoduplication Service Cambridge, MA 02139

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A "#" after an acquisition number indicates that the document is also available in microfiche form.

MAGNETIC SUSPENSION AND BALANCE SYSTEMS

U.S.A.	Degrees of freedom	Size, cm	Mach number	Use	Description (see citation numbers)
1. AEDC/NASA Langley	5	33.0	8/0 to 0.5	Wake studies/R&D	45, 80, 105
2. MIT/NASA Langley	5	15.2 octag.	0 to 0.5	Static and Magnus	98, 143
		7.6 × 10.2	4.2	Static and dynamic	98, 113
3. MIT	5	10.2 × 10.2	4.8	Static and dynamic	26, 27
4. NASA Langley	1	12.7	----------	R&D tool	56
5. Princeton Univ.	3	15.2	16	Wake studies	35, 53
6. Univ. of Michigan	1	5.1	Subsonic	Low Reynolds number sphere drag	82, 92
7. Univ. of Virginia (A)	3	10.2	7.6	Cone and sphere drag	22
(B) Superconducting	3	15.2	3	Dynamic stability/R&D	149, 158
Foreign					
1. ONERA (A)	5	8.5 × 8.5	1 to 3	Drag, base pressure	6, 9, 59
		6.0	7	Drag, base pressure	59
2. ONERA (B)	5	30.0	7	Base pressure and heat transfer	59
3. Oxford Univ.	3	7.6 × 7.6	Supersonic	Low density sphere drag	151, 180
4. Univ. of Southampton (A)	6	18.0 octag.	0 to 1.8	Static and dynamic	83
5. RAE/Univ. of Southampton (B)	5	17.8 × 17.8	8.6	Sting and Magnus effects	54, 64, 87

BIBLIOGRAPHY

1 *Holmes, F. T.: **Axial Magnetic Suspensions.** Review of Scientific Instruments, vol. 8, Nov. 1937, pp. 444–447.

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 ¾ g showed torsion constants, depending on adjustments, down to 7×10^{-6} dy cm/rad.

*Univ. of Virginia, Charlottesville, Va. 22901

2 *Beams, J. W.: **Magnetic Suspension Balance.** Physical Review, vol. 78, no. 4, May 15, 1950, pp. 471–472.

Magnetic suspension balances, in which the material to be weighed is freely suspended, have been designed and operated successfully by Holmes and by Clark, but these balances lacked the sensitivity and stability necessary for some types of measurement. In a recent paper a magnetic suspension for high speed rotors was described which also proved to be an excellent magnetic suspension balance. This magnetic balance has now been modified and improved to a point where its sensitivity is limited only by the natural fluctuations or "Brownian motion" of the system, and may be used in almost any experiment where small changes in mass or force are to be determined. It is especially suited to experiments where the weighing must be carried out in an evacuated or enclosed chamber, under a transparent liquid, etc., where no mechanical connections to the outside are possible. Also the same apparatus may be used to support and weigh over a wide range of masses or forces. The apparatus is described in this report.

*Univ. of Virginia, Charlottesville, Va. 22901

Contract No. NOrd-7873

3 *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, pp. 545–552. For a comment on and corrections to this article see: Journal of Applied Physics, vol. 23, no. 12, Dec. 1952, p. 1413.

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.

*Westinghouse Electric Corp., Bloomfield, NJ

Note by compilers: The a.c. levitation discussed in this paper has no direct application to the magnetic suspension of models in wind tunnels. The paper is included in this bibliography, however, for its historic interest as an example of the early work on a.c. levitation which, through misinterpretation, led many to believe that all schemes of levitation by magnetic fields would result in melted models.

4 *Beams, J. W.: **Magnetic-Suspension Ultracentrifuge Circuits.** Electronics, vol. 27, no. 3, March 1954, pp. 152–155.

This paper describes 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. A high-speed rotor, surrounded by a vacuum, is held in alignment by an electronically controlled solenoid to give a frictionless bearing that permits speeds up to 50,000,000 rpm, measured by comparing phototube output with WWV signals.

*Univ. of Virginia, Charlottesville, Va. 22901

5 Boerdijk, A. H.: **Technical Aspects of Levitation.** Phillips Research Rep. 11, pp. 45–56, 1956. R-284. (Available STIF).

Levitation of a body is here defined as a state of either stable or indifferent equilibrium relative to the earth in which material contact between the body and its environment is not essential. The possibilities and limitations of levitation by auxiliary gravitational forces, by reaction forces and by forces in electromagnetic fields are investigated. Levitation by gravitational forces or by radiation pressure is not feasible in practice, whilst levitation by forces in electrostatic fields is theoretically impossible. Under certain conditions levitation may be achieved by reaction forces and by forces in magnetostatic, stationary and quasi-stationary electromagnetic fields. Published applications comprise balances, centrifuges, and a method for melting metals in vacuo without a crucible.

6 *Tournier, Marcel; and *Laurenceau, P.: **Suspension Magnetique d'une Maquette en Soufflerie. (Magnetic Suspension of a Model in a Wind Tunnel.)** La Recherche Aeronautique, no. 59, July–Aug. 1957, pp. 21–27.

N80-71571 (In English)

A new method of suspending models has been worked out and has been subjected to varying conditions of speed of flow in tests demonstrating the future use for which it was conceived. This paper provides a rapid review of methods utilized up to now to "support" the body in wind-tunnel tests which shows that no real material supports possess all the qualities which are required of them. These considerations led the O.N.E.R.A. (National Office of Aeronautical Studies and Research) to seek a means of supporting a model in a position determined by immaterial bonds in order that the fluid flow around the body be disturbed by neither the sides of the test cell (the consequences of whose perturbation creates the object of particular studies) nor by the supports. Several solutions have

been imagined: the first consists of suspending a permanent magnet intended to support the model and to balance the resultant aerodynamical forces. The others utilize one or more iron electromagnets acting astride a bar of soft iron which constitutes the body of the model.

*ONERA, 92320, Châtillon, France

7 *Nelson, W. L.; and *Alaia, C. M.: **Aerodynamic Noise and Drag Measurements on a High-Speed Magnetically Suspended Rotor.** WADC-TR-57-339, Jan. 1958, 52 pp.

AD-142153 N80-71540#

This report describes measurements of aerodynamic noise, drag torque, and temperature effects produced at the surface of a magnetically suspended cylindrical rotor spinning in air at high speed. The primary objective of this investigation has been the measurement of aerodynamic noise. This has led to the development of apparatus and instrumentation for controlled measurement, within the laboratory, of the noise, drag, and thermal effects encountered in high speed flight in the atmosphere. The results of this study indicate that with certain improvements recommended in this report, this apparatus can be developed as a fruitful method for the investigation of boundary layer phenomena.

*Columbia Univ., New York, N.Y.

Contract No. AF 33(616)2331

8 *Kuhlthau, A. R.: **Applications of a Free Magnetic Support.** In: Proceedings of the Fourth U.S. Navy Symposium on Aeroballistics, Sponsored by the Bureau of Ordnance, NAVORD Rep. No. 5904; NPG Rep. No. 1599, Vol. 1, Paper No. 29, Chapter 5, pp. 8–16. May 1958.

N-49028, Vol. 1

This paper gives some possible applications of the free electromagnetic support developed by the Univ. of Virginia. Described are methods for measuring rotating cylinder drag, measurement of molecular reflection parameters and use as a wind tunnel balance for measurement of Magnus forces and aerodynamics of various body shapes.

*Univ. of Virginia, Director, Ordnance Res. Lab., Charlottesville, Va. 22901

9 *Tournier, M.; *Laurenceau, P.; and *Dubois, G.: **La Suspension Magnetique O.N.E.R.A.** Paper presented at the First International Symposium on Rarefied Gas Dynamics, Nice, France, 2–5 July 1958. International Series on Aeronautical Sciences and Space Flight, Division IX: Symposia, Vol. 3, Rarefied Gas Dynamics, pp. 80–99. Pergamon Press, 1960. (In French).

N80-71561# (In English)

Electromagnets are situated outside the flow, avoiding disturbances in the flow and heat losses due to support materials. It is being used with success for the measurement of drag of tapered bodies. A brief description of the existing installations is given. Some results are presented which were obtained in small wind tunnels with speeds up to M of 3.75 and 5.4 and RN from 130,000 to 500,000.

*ONERA (Office National d'Etudes et de Recherches Aérospatiales) 92320 Châtillon, France

10 *Rebuffet, Pierre: **Effets de supports sur l'ecoulement a l'arriere d'un corps. (Effect of Supports on the Flow at the Rear of a Body.)** AGARD Rep. no. 302, Presented at AGARD Wind Tunnel Tests and Models Working Group, March 1959, 31 pp. (In French, English summary).

N80-71569#

With a view to determining the effects of supports on models with a flat base, two cases are examined in a supersonic flow with a turbulent boundary layer. The first concerns the effect of various obstacles situated upstream of the two-dimensional base, at Mach 2. The second relates to a body of revolution passing through the throat of the jet from upstream to downstream. The interference of obstacles simulating supporting masts is examined for the base, both bare and with a sting, at Mach 1.94. Without any support, the drag of a conical-cylindrical body of revolution was measured by means of the ONERA magnetic suspension. The interference of various stings was studied at Mach 2.4, with a laminar boundary layer and with a separated turbulent boundary layer. The mechanism of the interference of a sting, progressively approached axially to the base, was determined.

*Directeur Scientifique Adjoint de l'Aerodynamique a' l'O.N.E.R.A. 92320 Châtillon, France

11 *Jenkins, A. W.; and *Parker, Hermon, M.: **Electromagnetic Support Arrangement With Three-Dimensional Control. Part I, Theoretical.** Journal of Applied Physics, Supplement to vol. 30, no. 4, April 1959, pp. 238S–241S.

AD-207140

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 support performance and to predict the amount of coupling to be expected due to deviations from the ideal system.

*Ordnance Research Lab., Univ. of Va., Charlottesville, Va. 22901

Contract No. NONR-474(04)

12 *Fosque, Hugh S.; and *Miller, Glenn: **Electromagnetic Support Arrangement With Three-Dimensional Control. Part II, Experimental.** Journal of Applied Physics, Supplement to vol. 30, no. 4, April 1959, pp. 240S–241S.

The first gradient coil configuration described in Part I of this paper has been constructed. In this system the axis of one pair of gradient coils is parallel to the magnetizing field. The details of the mechanical, magnetic, optical, and electronic aspects of this implementation are presented and discussed.

*Ordnance Research Lab., Univ. of Va., Charlottesville, Va. 22901

Contract No. NONR-474(04)

13 *Mirande, J.: **Mesure de la Résistance d'un Corps de Révolution à 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_0 = 2, 4, using the O.N.E.R.A. Magnetic Suspension.)** Brève Information, La Recherche Aéronautique, No. 70, May–June 1959, pp. 24–25. (In French).

The drag and base pressure of a cone-cylinder are measured at supersonic speed using a magnetic suspension and balance system. (The information contained in this note is also included in AGARD Rept. no. 302 which is item no. 10 in this bibliography.)

*ONERA, 92320 Châtillon, France

14 *Matheson, L. R.: **Some Considerations for Design and Utilization of Magnetic Suspension.** General Electric Co. Aerodynamics Fundamental Memo No. 84. May 1959, 10 pp.

N80-71562#

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 tested 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 relatively 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.

*General Electric Company, U.S.A.

15 *Tilton, Lee; and *Schwartz, Stuart: **Static Tests on the Magnetic Suspension System.** MIT, Naval Supersonic Lab. AR Memo 399, July 20, 1959, 18 pp.

N80-71555#

As a thesis project by Chrisinger, a magnetic suspension system for the NSL 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, no attempt has yet been made to study the interactions caused by the three units in simultaneous operation. The model used in the tests was a cylindrical Alnico permanent magnet six inches in length and one half inch in diameter.

*M.I.T., Naval Supersonic Lab., Cambridge, Mass. 02139

16 *Tilton, Edward Lee, III: **Design, Construction and Testing of an Automatic Control System for a Wind Tunnel Magnetic Suspension System.** M.I.T. Thesis for B.S. degree, May 21, 1960, 49 pp. (Available from MIT).

N80-71556#

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.

*M.I.T., graduate student

17 *Baron, Larry A.: **The Design and Construction of an Automatic Control System for a Wind-Tunnel Magnetic Suspension System.** MIT Thesis for B.S. degree, June, 1960. (Available from M.I.T.).

N80-71557#

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.

*M.I.T., graduate student

18 *Dubois, George; and *Rougé, Charles: **Sur une Méthode de Mesure de la Pression de Culot-Mesure et Visualisation sur une Maquette Cylindro-Conique Suspendue Magnétiquement à $M_0 \simeq 7.6$.** La Recherche Aéronautique, No. 79, pp. 35–44, Nov.–Dec. 1960. (In French).

N80-71567# (In French)

English translation by **R. N. Zapata, **On a Method for Measuring the Base Pressure: Measurement and Visualization on a Cone Cylinder Magnetically Suspended at $M_0 \cong 7.6$.** Rep. AFOSR-1020; AST-4443-102-61U, May 1961, 38 pp.

N80-71541# (In English)

The present paper is concerned with a method for measuring the base pressure of an axially symmetrical body. This method avoids material supports through the use of the O.N.E.R.A. magnetic suspension for keeping the model on the axis of the stream at the test section. Thus, the base pressure is measured, with no interactions, by means of an optical manometer located inside the model. At the same time, the flow can be visualized by a schlieren system. This paper specifies the conditions required for the applicability of the method, analyzes the precision of the measurements, discusses the results obtained with and without sting, and compares them to those previously obtained at lower Mach numbers.

* ONERA, 92320 Châtillon, France
** Univ. of Virginia, Charlottesville, Va. 22901

19 *Beaussier, Jacques: **Télémesure Pour Maquette Suspendue Magnétiquement en Soufflerie. (Telemetry for a Model Magnetically Suspended in a Wind Tunnel).** La Recherche Aéronautique, May–June 1961, no. 82, p. 49. (In French).

This brief note discusses the use of high frequency telemetry in recording pressures on a model magnetically suspended in a wind tunnel.

*O.N.E.R.A., 92320 Châtillon, France

20 *Gilpin, B. J.; *Moss, F. E.; *Nieman, D. F.; and *Osborne, W. F., Jr.: **A Survey of the Literature Relating to Electromagnetic Suspension Systems.** Univ. of Virginia Rep. no. EMI-4441-105A-61U, May 1961, 67 pp.

N67-85274#

The material is grouped under five headings: (1) MAGNETIC SYSTEMS (INCLUDING EDDY CURRENT AND CRYOGENICS), pp. 3–17; (2) TOPICS RELATED TO MAGNETIC SYSTEMS, pp. 18–46; (3) ELECTROSTATIC SYSTEMS, p. 47; (4) TOPICS RELATED TO ELECTROSTATIC SYSTEMS, pp. 48–55; and (5) SUBJECTS RELATED TO OTHER ASPECTS OF THE ENTIRE PROGRAM, pp. 56–67.

*Univ. of Virginia, Charlottesville, Va. 22901

Contract No. AF 33(616)-7864

21 *Dubois, Georges: **Trainees de Maquettes de Soufflerie Comportant des Ogives de Formes Variées en Suspension Magnétique. (Drag of Wind Tunnel Models of Various Ogival Forms Suspended Magnetically.)** La Recherche Aéronautique no. 87, March–April 1962, pp. 47–54. (In French.)

This paper is concerned with the experimental determination of minimum drag of ogives at supersonic and hypersonic speeds using the ONERA magnetic suspension. Two families of models are tested, (1) ogives with a profile N^n, and (2) AGARD B, of which the ogives were blunted according to a given law. The results obtained with the first family were comparable to those calculated by the approximation of Cole and Newton; also to the tests done by Kubota. The work was done at ONERA in a small hypersonic wind tunnel. The magnetic suspension allowed precise drag measurements of the bodies of revolution. Magnetic suspension permits such measurements of C_X at these higher Mach numbers (M = 3.75 and 6.3) with a greater range of Reynolds numbers; and simultaneous measurement of base pressure by telemetry, an indispensable measurement for a complete analysis of the tests.

*ONERA, Chief Engineer of the Research Group, 92320 Châtillon, France

22 *Parker, H. M.; *May, J. E.; and *Nurre, G. S.: **An Electromagnetic Suspension System for the Measurement of Aerodynamic Characteristics.** Rep. Nos. AFOSR-2294; AST-4443-106-62U, 40 pp., March 1962.

N62-10806#

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 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.

*Univ. of Virginia, Charlottesville, Va. 22901

Contract No. AF 49(638)-1022.

23 *LaGraff, John Erwin: **Some Calibrations and Measurements on Models Magnetically Suspended in a Hypersonic Tunnel.** MIT, B.S. Thesis, May 1962, 36 pp. (Available from MIT).

N80-70406#

A study was made of model configurations, calibration, and testing of a magnetic suspension system for a M = 4.8 wind tunnel. Some tests were conducted and the results compared to theoretical results. Various afterbody shapes were tested.

*MIT, graduate student

24 *Clemens, P. L.: **Radio Telemetry of Stagnation Pressure from a Wind Tunnel Model Magnetically Supported in Supersonic Flow.** Rep. no. AEDC-TDR-62-141, July 1962, 25 pp. Presented at the AIEE Summer General Meeting, Denver, Colo., June 18–22, 1962.

N62-13831

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 percent, inordinate frequency vs temperature interactions introduced intolerable shifts in telemeter center frequency as testing progressed. Several methods may be used to reduce these interactions. Magnetogasdynamic effects arising from the use of the magnetic model suspension technique are discussed in an appendix, and are shown to be negligible in most wind tunnel testing. (Tests made in the ONERA tunnel).

*von Karman Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tenn. 37389

Contract No. AF 40(600)-1000

25 *Lawton, Michael Phelps: **Design and Calibration of a Finned Model Magnetically Suspended in a Hypersonic Tunnel.** MIT Thesis for B.S., June 1962, 47 pp. (Available from MIT).

N80-70421#

The problem of roll stability in a five-degree of-freedom magnetic suspension system in a hypersonic wind tunnel is investigated. A finned model provides torsional stiffness and eddy-current damping. Calibration and prediction of wind tunnel performance are included.

*MIT, graduate student

26 *Tilton, Edward Lee, III; *Parkin, William J.; *Covert, Eugene E.; *Coffin, James B.; and *Chrisinger, John E.: **The Design and Initial Operation of a Magnetic Model Suspension and Force Measurement System.** Rep. No. MIT-TR-22, Aug. 1962. ARL-63-16, Jan. 1963. Covers period Feb. 1960–May 1962.

N63-16372#

The design, construction and proof tests of a magnetic model suspension system capable of use in a M = 4.8 wind

tunnel is described. The results indicate that the model can be suspended magnetically during the wind tunnel starting conditions, that the model can be angulated and lift and drag forces measured with the model at angle of attack.

*MIT, Cambridge, Mass. 02139

Contract No. AF 33(616)7023.

27 *Tilton, E. L.: **Dynamic Stability Testing With a Wind Tunnel Magnetic Model Suspension System.** MIT, M.S. Thesis, Jan. 1963, 48 pp. (Available from MIT).

N80-70419#

An investigation of the possibilities of using a wind tunnel magnetic balance system to measure longitudinal dynamic stability derivatives is presented. A discussion is given on the design and setup of measuring equipment. The results from a wind tunnel experiment are given and the data which was obtained is analyzed.

*MIT, graduate student

28 *Clemens, P. L.; and *Cortner, A. H.: **Bibliography: The Magnetic Suspension of Wind Tunnel Models.** Rep. no. AEDC-TDR-63-20; Feb. 1963.

N63-12750#

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 resume of the state-of-the-art of magnetic model suspension technology.

*von Kármán Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tenn. 37389.

Contract No. AF 40(600)-1000

29 *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.** Journal of the Royal Aeronautical Society (London), vol. 67, no. 635, Nov. 1963, pp. 717–724.

A64-11303

In this article a magnetic suspension and balance system suitable for wind tunnel application is discussed. General considerations are presented that illustrate the nature of the problems to be solved as well as one solution of these problems. Finally some initial wind tunnel data are presented.

*MIT, Cambridge, Mass. 02139

30 *Covert, Eugene E.; and *Tilton, Edward Lee, III: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels. (Part I) Interim Tech. Rep., Aug. 1961–Aug. 1962.** Rep. No. ARL-63-235, Dec. 1963, 31 pp.

AD-437265 N64-24384

This report presents a discussion of the studies related to the development of a magnetic model suspension system. It includes a description of an initial calibration procedure and a procedure for controlling the roll degree of freedom of the model. Particular attention is given to the discussion of low density, high temperature limits of the system. A discussion of schlieren optical systems is also presented.

*MIT, Cambridge, Mass. 02139

Contract No. AF 33(616)-7023

For Part II of this series, see no. 33 of this bibliography, Part III, no. 42, and Part IV, no. 67.

31 *Covert, Eugene E.; and *Tilton, Edward Lee, III: **Further Evaluation of a Magnetic Suspension and Balance System for Application to Wind Tunnels.** Rep. no. ARL-63-226, Dec. 1963, 73 pp.

AD-427 810 N64-14659

The application of a magnetic suspension and balance system to static and dynamic wind tunnel testing is discussed. The equipment and experiments are described and an analysis of the performance of the system is given.

*MIT, Cambridge, Mass. 02139

Contract No. AF 33(616)-7023

32 *Parker, H. M.; and *Kuhlthau, A. R.: **A Magnetic Wind Tunnel Balance.** Rep. no. AFOSR-64-0567; AST-3420-105-64U; Feb. 1964, 19 pp.

AD-434844 N64-18916

A preliminary model of a 3-D wind tunnel balance, which has been constructed and operated in low speed continuum flow for the purpose of demonstrating the feasibility of the approach, is described in this report.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. AFOSR 62-92

33 *Covert, Eugene E.; *Copeland, Alan B.; *Stephens, Timothy; and *Tilton, Edward Lee, III: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels. (Part II). Covers period Aug. 1962–Aug. 1963.** Rep. No. ARL-64-36, March 1964, 37 pp.

N64-20446

This report presents a discussion of the recent development work on a magnetic model suspension and balance system. System equipment additions and modifications are described. A summary of calibration procedures and wind tunnel tests is given. Studies on methods of roll control, magnetic field distribution, and a new digital model position indicator are discussed.

*MIT, Cambridge, Mass. 02139

Contract No. AF 33(616)-7023

For Part I of this series see no. 30 in this bibliography, Part III, no. 42, and Part IV, no. 67.

34 *Hensel, Rudolph W.: **Recent Developments in Wind-Tunnel Testing Techniques at Transonic and Supersonic Speeds.** Journal of Spacecraft and Rockets, vol. 1, no. 5, Sept.–Oct. 1964, pp. 449–463. This journal article consists of pp. 47–52 from the proceedings of the AIAA Aerodynamic Testing Conference, Washington, D.C., March 10, 1964, and published as AEDC-TR-65-75, AD-465023, June 1965, 86 pp. (The conference volume is available to U.S. Gov't Agencies and their Contractors Only.)

AD-465023 X65-17570 or A64-14530 } Entire Conference
A64-26570# (Journal Article)

These pages consist of a discussion of basic principles, measurements, and limitations of magnetic suspension and balance systems.

*ABO, Inc., Arnold Air Force Station, Tenn. 37389

Contract No. AF 40(600)-1000

35 *Stephens, Timothy: **Determination of Nonlinear Aerodynamic Damping Effects With a Wind Tunnel Model Suspension System.** MIT, M.S. Thesis, June 1964, 50 pp. (Available from MIT).
N80-70412#

A technique is developed to describe the dynamic behavior of a flight vehicle. The forces experienced by a body are characterized by general nonlinear functions of the kinematics of the body, referred to wind tunnel axes. A statistical method for measuring the parameters in these nonlinear functions, using a wind tunnel magnetic balance system, is developed. The experimental procedure using a particular magnetic balance system is described and data is analyzed.

*MIT, graduate student

Contract No. AF 33(615)-1470

36 *Dukes, T. A.; and *Zapata, R. N.: **An Electromagnetic Suspension System for Spherical Models in a Hypersonic Wind Tunnel.** Princeton Univ. Rep. 682, July 1964, 83 pp.
AD-605846 N65-14569#

The design and operation of an electromagnetic balance for suspending spherical models in a hypersonic wind tunnel is described. An orthogonal force system, together with compensated optical sensors in three stabilizing automatic feedback loops, provides inherently uncoupled control in three degrees of freedom. The major parts of the report contain the designs of the electromagnetic coil configuration and of the feedback loops.

*Princeton Univ., Princeton, N.J. 08540

Contract No. Nonr-1858(37)

37 *Dukes, Theodor A.; and *Zapata, Ricardo N.: **A Wind Tunnel Magnetic Suspension With Minimum Coupling Effects.** Presented as Paper no. 13 at the 1st International Congress on Instrumentation in Aerospace Simulation Facilities, Paris, France, Sept. 1964, pp. 13–1 to 13–15. This paper is also in IEEE Transactions on Aerospace and Electronic Systems, vol. AES-1, no. 1, Aug. 1965, pp. 20–28.
A65-35219 Aug. 1965 N65-13935 or A64-28117 } Sept. 1964

In a multidegree-of-freedom suspension system coupling effects are undesirable because they make the calibration difficult and they can cause deterioration of the dynamic stability of the system. This paper presents an analysis of the coupling problem leading to the design of a particular system configuration. The support of spherical models by means of a three-degree-of-freedom magnetic suspension system is analyzed in terms of the forces acting on a magnetized point. It is shown that long axisymmetrical bodies can also be supported by the same system. This is made possible by decoupling the angular and the translational degrees of freedom. The magnetic suspension system capable of supporting models in M = 16 flow is described.

*Princeton Univ., Princeton, N.J. 08540

Contract No. Nonr-1858(37)

38 *Geary, P. J.: **Magnetic and Electric Suspensions. A Survey of Their Design, Contraction, and Use.** British Scientific Instrument Research Association—A Survey of Instrument Parts, No. 6, 1964. SIRA Research Rep. R-314, 162 pp. QC753.64

This survey, carried out by the British Scientific Instrument Research Association, reviews methods of supporting and levitating solid members (such as rotors) and molten metals in magnetic and electric fields. An attempt was made to assemble all relevant material published in periodicals, books, and reports which is likely to be of use to designers and constructors of instruments and precision apparatus, but systematic searches for patents in the subject have only been undertaken selectively.

* Geary, P. J., M. Sc. (Eng.), British Scientific Instrument Research Association, South Hill, Chislehurst, Kent, England

39 *Vas, Irwin E.; *Murman, Earll M.; and *Bogdonoff, Seymour M.: **Studies of the Wakes of Support-Free Spheres at M = 16 in Helium.** AIAA Journal, vol. 3, no. 7, July 1965, pp. 1237–1244. Presented at the AIAA 2nd Aerospace Sciences Meeting, New York, N.Y., Jan. 25–27, 1965.
AIAA Paper 65-51 A65-28207# or A65-14802#

A detailed investigation of the flow field behind spheres magnetically suspended in a Mach 16 helium stream has been initiated. Pitot pressure and constant-current hot-wire measurements have been employed to investigate a region from 1 to 50 body diameters downstream of two sphere diameters, 0.75 and 0.375 in., and several body Reynolds numbers from 45,400 to 109,000. Previous data reported in the literature indicated that transition to turbulence should occur within the region of investigation, but hot-wire voltage measurements lead to the conclusion that the wake is probably laminar. Detailed radial and axial pitot pressure distributions are presented and compared with two-dimensional cylinder data at the same Mach number, ballistic-range data, and two theories. The measured rms hot-wire fluctuation voltage was constant at a very low value along the wake axis but showed peaks at the wake edge.

*Princeton Univ., Princeton, N.J. 08540

Contract Nos. Nonr-1858(37); and AF 33(615)-1079

40 *Copeland, Alan B.; and *Tilton, Edward Lee, III: **The Design of Magnetic Models for Use in a Magnetic Suspension and Balance System for Wind Tunnels.** Rep. no. ARL-65-113, June 1965.
AD-619271 N65-34865#

This report discusses the design of the magnetic portion or core of a model for use in a magnetic suspension system for wind tunnels. The calculation of the forces obtainable with a given suspension system and model, and the optimization of model core geometry and material are

discussed. An example of the design of a model core for use in the M.I.T. Aerophysics Laboratory magnetic suspension is presented.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470.

41 *Copeland, Alan B.: **Measurement of Damping in Roll of a Finned Body Using a Magnetic Wind Tunnel Model Suspension System.** MIT, M.S. Thesis, June 1965. 38 pp. (Available from M.I.T.).

N80-71538#

An experimental investigation of the damping torque in roll of a three-finned missile configuration (Iroquois sounding rocket) as a function of angle of attack using a magnetic wind tunnel model suspension system is presented. Damping data was obtained at three angles of attack, 0°, 2.45°, and 4.88°.

*M.I.T., graduate student

Sponsored by the Air Force.

42 *Copeland, Alan B.; *Covert, Eugene E.; and *Stephens, Timothy: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels, Part III. Annual Summary, Sept. 1963–Sept. 1964.** ARL-65-114, June 1965, 52 pp.

AD-619174 N66-29811#

This report presents a discussion of the recent development work on a magnetic model suspension and balance system. System equipment additions and modifications are described. Wind tunnel test data is presented. A summary of work done on dynamic stability testing with the magnetic balance is given. Studies on roll control, a digital position measuring system, and magnetic model configuration are discussed. A summary of the design of a magnetic suspension and balance system for the Aerospace Research Laboratory twenty-inch hypersonic tunnel is included.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

For Part I of this series see no. 30 in this bibliography, Part II, no. 33, and Part IV, no. 67.

43 *Covert, Eugene E.: **Remarks on the Design of Magnetic Balance and Suspension Systems with Particular Reference to the ARL 20-Inch Hypersonic Tunnel.** MIT-TN-113, July 1965, 26 pp.

N80-71552#

A list of aerodynamic studies is given that are made easier, or even possible, by the use of magnetic suspension and balance systems. This list is not meant to be exhaustive but rather is typical of the ideas which have occurred to a single group of experimenters. Discussed are design conditions, magnetic system design, tunnel equipment design, calibration and assorted systems, operational goals, critical items, and general considerations.

*M.I.T., Cambridge, Mass. 02139

Contract AF 33(615)-1470

44 *Stephens, Timothy: **Methods of Controlling the Roll Degree of Freedom in a Wind Tunnel Magnetic Balance. Part I: Production of Rolling Moments.** MIT-TR-78, July 1965; ARL-65-242; Dec. 1965, 49 pp. Covers period Jan. 1964–Mar. 1965.

AD-628570 N66-21466#

This report presents a discussion of methods of producing rolling moments by magnetic fields on a model suspended in a magnetic wind tunnel balance system. Two methods are described and compared: one involving the interaction of steady nonuniform fields with a nonuniformly magnetized body, and the other involving the interaction of an alternating uniform magnetic field with a closed loop of conducting material. The two alternative methods are translated into magnet configurations designed to satisfy the objective of a completely integrated six degree of freedom balance system.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

45 *Crain, C. D.; *Brown, M. D.; and *Cortner, A. H.: **Design and Initial Calibration of a Magnetic Suspension System for Wind Tunnel Models.** Rep. AEDC-TR-65-187. Sept. 1965. 70 pp. An abbreviated form of this paper is included in "Summary of ARL Symposium on Magnetic Wind Tunnel Model Suspension and Balance Systems," which is no. 52 in this bibliography.

AD-470147 N65-34335

The design, construction, and initial calibration of a prototype magnetic suspension system capable of supporting models in a wind tunnel are described. Magnetically supported models allow measurements free from the interferences produced by mechanical model supports. The described system is of the "V"-type configuration and is compared to other types of configurations. Initial force calibration data are given, and it is concluded that quantitative force data would be difficult to obtain from the prototype suspension system because of the many interactions involved. This system was, for the most part, designed in 1959 and does not represent the state-of-the-art insofar as magnetic suspension systems are concerned. Recommendations for future magnetic suspension system designs are included as well as a discussion of the types of aerodynamic testing where the use of such a system might be beneficial.

*ARO, Inc., Arnold Air Force Station, Tenn. 37389

Contract No. AF 40(600)-1200

46 *Copeland, Alan B.; *Covert, E. E.; and *Tilton, E. L., III: **Measured Aerodynamic Characteristics of a Cone-Cylinder-Cone Model with Base Separation at M = 4.8.** Journal of Spacecraft and Rockets, vol. 2, no. 6, Nov.–Dec. 1965, pp. 998–1000.

A66-12773#

This note presents some measurements of the aerodynamic characteristics on a body with a pointed base, with the use of the magnetic balance. These data show an improvement in accuracy that has resulted from further experience with this kind of balance system. The tests were conducted in the 4-in. continuous flow wind tunnel of the Massachusetts Institute of Technology (MIT) Naval Supersonic Facility.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

47 *Covert, Eugene E.; *Copeland, Alan; and *Stephens, Timothy: **Dynamic Stability Testing With Magnetic Balance**

Systems. 1965. Paper #4 in Arnold Eng. Develop. Center Trans. of the 2nd Tech. Workshop on Dyn. Stability Testing, Vol. II, 1965, 35 pp.

AD-472298 X66-11730

Magnetic suspension and balance systems can be used in the measurement of dynamic stability parameters when there is rigid control over the position of the model, and the two extremes of sinusoidal motion and random motion have been found to be very useful in accomplishing this control. Three techniques have been tried for handling the resultant data: forced oscillation, random excitation, and damping in roll. By applying a forced motion to the model, damping can be measured by a phase change in motion. A technique based upon the ideas of system identification has been applied to determining aerodynamic characteristics of several different shapes, and can be used with both linear and nonlinear systems. Damping in roll is accomplished by forcing the model to roll at a known rate, and, after turning off the roll forcing function, recording the roll velocity as function of time.

*M.I.T., Cambridge, Mass. 02139

Contract AF 33(615)-1470

48 *Basmajian, V. V.; *Copeland, A. B.; and *Stephens, T.: **Studies Related to the Design of a Magnetic Suspension and Balance System.** Covers period Dec. 1964—Jan. 1966. MIT-TR-128, Feb. 1966, 231 pp. NASA-CR-66233.

N67-11322#

The basic design principles of a relatively interaction-free five-component magnetic suspension and balance system are described. The performance of the various subsystems is described in detail. Several recent innovations in subsystem design are outlined. The results of the study are applied to a proposed design of a complete magnetic suspension and balance system to be compatible with the NASA-Langley fifteen-inch (Mach 10) hypersonic flow apparatus.

*M.I.T., Cambridge, Mass. 02139

Contract No. NAS1-4421

49 *Goodyer, M. J.: **The Theoretical Rolling Moment Capacity of Magnetically Suspended Shaped Cores.** Southampton Univ. Rep. ISAV-140, Feb. 1966, 34 pp.

N67-10575#

In order to control the rolling motions of magnetically suspended wind tunnel models, shaped magnetic cores were used within the model to generate rolling moments under the action of the magnetic fields generated by the controlled electromagnets comprising the suspension system. The theoretical moment generating performance of some shaped cores is given. The effect of the design of the cross section of the core is discussed, and an optimum cross sectional shape is proposed.

*Southampton Univ., Southampton SO95NH, England

50 *Wilson, A.; and *Luff, B. F.: **Magnetic Suspension for Wind Tunnels.** Electronic Engineering, vol. 38, no. 456, pp. 72—76, Feb. 1966.

A66-20664

A magnetic suspension system for aerodynamic wind tunnel models is described. The system is designed to hold axisymmetrical models in a Mach 8 airstream. The models, which may be flown at small degrees of incidence, are controlled in five degrees of freedom, and aerodynamic forces may be measured under conditions more nearly approaching those of free flight.

*Royal Aircraft Establishment, Farnborough, England

51 *Parker, H. M.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic-Stability Research in Wind Tunnels.** Semiannual Status Rep. May 31, 1965—Feb. 28, 1966, 47 pp. NASA-CR-71422; AST-4030-102-66U, Mar. 1966.

N67-81180

A series of basic magnetic field calculations have been made and design charts have been prepared which enable designs of tan $^{-1}\sqrt{2}$ and tan $^{-1}\sqrt{8}$ magnetic balances as well as drag augmented tan $^{-1}\sqrt{8}$ systems. While the coil cross sections are optimized in a certain sense and as a result may not be suitable for actual coil shapes, they are considered to be close enough to practical shapes for design purposes. The basic geometries have been worked out and while at first sight the geometrical relationships seem to be complicated, experience has shown that one is able to visualize them quite quickly.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-029

52 *Daum, Fred L.: **Summary of ARL Symposium on Magnetic Wind Tunnel Model Suspension and Balance Systems.** Dayton Univ., Ohio, Fluid Dynamics Facilities Lab., Rep. No. ARL-66-0135, July 1966, 461 pp. Symp. held at Wright-Patterson AFB, Ohio, 13—14 Apr. 1966.

AD-637208 N67-13581

Thirteen papers were presented at this symposium which has been called the "First International Conference on Electromagnetic Suspension." The last section of the volume consists of discussion which followed the presentation of the papers. Citations for eleven of the papers follow in this bibliography.

*Fluid Dynamics Research Lab., Aerospace Research Laboratories, WPAFB, Ohio 45433.

Contract No. AF33(615)-3626

53 *Zapata, R. N.; and *Dukes, T. A.: **The Princeton University Electromagnetic Suspension System and Its Use as a Force Balance.** In Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 1—26.

N67-13582#

A three-degree-of-freedom electromagnetic suspension system which is being used to support models in a hypersonic wind tunnel for the primary purpose of studying wake characteristics is described. A high degree of decoupling between the three force axes has been achieved by making appropriate use of the symmetry of the problem. Although the system was originally designed for spherical models, it can be used to support aerodynamically stable axisymmetric bodies under certain conditions. Examples of suspension of spheres and cones in a Mach number 16 helium stream are

shown. Also force calibration procedure and results are presented and discussed.

*Princeton Univ., Princeton, N.J. 08540

Contract No. Nonr-1858(37)

54 *Wilson, A.; and *Luff, B.: **The Development, Design and Construction of a Magnetic Suspension System for the R.A.E. 7"x7" (18x18 cm) Hypersonic Wind Tunnel.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 27–79. Also RAE-TR-66248, Aug. 1966, 47 pp.

N67-13583#, Apr. 1966
N67-14195#, Aug. 1966

A magnetic suspension system for aerodynamic wind tunnel models is described. The system is designed to hold axisymmetrical models in a Mach 8 airstream. The models, which may be flown at small degrees of incidence, are controlled in five degrees of freedom. Aerodynamic forces on a model may be measured under conditions more nearly approaching those of free flight. The system is being engineered into the Royal Aircraft Establishment 18 cm hypersonic wind tunnel, and has been used to measure drag forces on a conical model. No great difficulties have been encountered in launching or recovering the model.

*Royal Aircraft Establishment, Farnborough, Hampshire GU 14 6TD, U.K.

55 *Stephens, T.: **The General Features of a Six-Component Magnetic Suspension and Balance System.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems. Apr. 1966, pp. 81–108

N67-13584#

The general arrangement of a six-component magnetic suspension and balance system has been defined. The design of the model-position-measuring system, the suspension feedback control system, and the force and moment readout system are in the process of development and refinement. Efforts have also been directed toward the design of the magnet system and the requirements of a completely integrated six-component suspension. The design of a relatively interaction-free six-component suspension depends to a large degree upon the magnet system arrangement. Symmetrical magnet systems have been devised which allow relatively independent control of the force and moment components. Such arrangements generally provide uniform and independent magnetization fields and field gradients at the center of the test section. Symmetrical arrangements provide the additional advantages of linear current-force relations and relatively efficient use of controlled power. Two stages in the evolution of the design of a six-component magnetic suspension employing a symmetrical magnet array have been accomplished, and the design of a compact and flexible magnet system, compatible with the operations of a wind tunnel, appears to be feasible.

*M.I.T., Cambridge, Mass. 02139
Contract No. AF 33(615)-1470
Contract NAS1-4421

56 *Hamlet, I. L.; and *Kilgore, R. A.: **Some Aspects of an Air-Core Single-Coil Magnetic Suspension System.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems. Apr. 1966, pp. 109–135

N67-13585#

Technical aspects in the development of an air-core, dual-wound single-coil, magnetic-suspension system with one-dimensional control are reviewed. Overall electrical system design features and techniques are discussed in addition to the problems of control and stability. Special treatment is given to the operation of a dual-wound, high-current support coil which provides the bias field and a superimposed modulated field. Other design features include a six-phase, solid-state power stage for modulation of the relatively large magnitude control current, and an associated six-phase trigger circuit.

*NASA, Langley Research Center, Hampton, Va. 23665

57 *Parker, H. M.: **Principles, Typical Configurations and Characteristics of the University of Virginia Magnetic Balance.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 137–157.

N67-13586#

The theory of the magnetic balance is developed from first principles through design charts for particular configurations. The general areas of types of application and problems encountered are discussed and the manner in which balance weight, power required, and force capacity scales with size is summarized. Current prospects for the practical application of the balance to the study of the dynamic stability of aerodynamic configurations are emphasized.

*Univ. of Virginia, Charlottesville, Va. 22901

AFOSR Grant No. AF-AFOSR-1046-66
NASA Grant No. NGR-47-005-029

58 *Goodyer, M. J.: **Some Force and Moment Measurements Using Magnetically Suspended Models in a Low Speed Wind Tunnel.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 159–197

N67-13587#

The utilization of a four-component magnetic suspension system as a drag balance for models at zero incidence is discussed. The balance utilizes the lift and lateral electro-magnets only of an $\perp$ type suspension system, with a wind tunnel having a horizontal working section. Two possible drag measuring techniques are proposed, and one of these has been chosen for experimental investigation. This technique is suitable for use in circumstances where the drag of the model is less than about 10% of its weight. The drag force calibration is given and factors affecting its repeatability are discussed. Some drag measurements on a blunt-based body of revolution illustrate the quality of results obtainable. At a drag force level of 0.012 lb., it is claimed that the force can be measured to an accuracy of $\pm 2\%$. The same four-component balance has been used for the measurement of a roll derivative for a model fitted with thin cropped delta wings. The technique adopted was to spin the model about the roll axis and to monitor the free-body rate of decay of the rolling motion. The roll angular velocity measuring equipment is described, the accuracy assessed, and the suitability of the technique for measurements at high tunnel air speeds discussed.

*Univ. of Southampton, SO95NH, England

59 *Moreau, Roland: **Use of Magnetic Suspension System in O.N.E.R.A. Wind Tunnel.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 199–245.

N67-13588#

Initial research on magnetic suspension systems is reviewed. The present state of these systems is described and some of the difficulties found in the course of their development and adaptation of hypersonic wind tunnels are revealed as well as their solutions. Some results are presented and the future of such systems is discussed.

*O.N.E.R.A., 92320 Châtillon, France

60 *Phillips, W. M.: **The Measurement of Low Density Sphere Drag With a University of Virginia Magnetic Balance.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 247–260

N67-13589#

Measurements of sphere drag at high Mach number and in the range of about 0.4 to 5.0 for Knudsen number have been made with a magnetic balance of a special design which is described. Drag results are presented and compared with other available data. At low Knudsen numbers, the drag coefficient agrees with existing data. An apparent lack of agreement with free molecule calculations is discussed and an outline of future work is presented.

*Univ. of Virginia, Charlottesville, Va. 22901

61 *Copeland, A.: **Some Limitations of the Magnetic Suspension System When Used for Dynamic Stability Testing.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966.

N67-13590#

The reduced frequency and amplitude of motions obtainable in a magnetic suspension system are functions of the mass and moments of inertia of the test model, the demagnetizing factors of the test model, the field and field gradient obtainable, the dynamics of the field producing system (magnets and power supplies), and the aerodynamics of the test model. The limitations on both reduced frequency and amplitude for several typical test models as functions of the above parameters are presented and discussed with regard to the testing methods which might be employed. The expected accuracy of measurements of dynamic stability characteristics for several typical cases is discussed.

*M.I.T., Cambridge, Mass. 02139
Contract No. AF 33(615)-1470

62 *Goodyer, M. J.: **The Theoretical and Experimental Performance of Roll Control Elements in the Six Component Magnetic Wind Tunnel Balance.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 313–347

N67-13592#

Two fundamentally different roll control systems have been developed for the magnetic wind tunnel balance at Southampton University. Each provides positive stiffness and near critical damping, and, within a roll angle range of $\pm 10^{o}$ about the mean, allows the selection of the roll attitude of the model. The first roll control system, making use of a magnetic "shaped core" within the model, was demonstrated and installed in a low speed wind tunnel, controlling the roll attitude of a winged model. The theoretical moment and force producing capability of such shaped cores is discussed, and the experimental performance presented. The second roll control system consists of battery energized coils mounted in suitable locations on the model, which are acted upon by magnetic fields generated by electromagnets around the wind tunnel. Two modes of operation are proposed, and experimental data are presented. The more promising mode is further developed and its roll oscillation damping performance is demonstrated. Details of the rolling motion optical and stabilization systems are given and possible lines of further development are discussed.

*Southampton Univ., Southampton, SO95NH, England

63 *Judd, M.; and *Goodyer, M. J.: **Some Factors in the Design of Magnetic Suspension Systems for Dynamic Testing.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 349–385

N67-13593#

Some general characteristics, difficulties and limitations of dynamic testing with magnetically suspended models are discussed together with possible improvements. Parallels are drawn between mechanical and magnetic support test techniques and the problem of large acceleration loads emphasized. It is suggested that great reductions of power requirements are possible if the model is constructed so that its outside inflexible shape is spring connected with an inner magnetic mass. The mass-spring-mass system can be tuned for a desired natural frequency. The effect on the overall feedback characteristics and some practical considerations are discussed.

*Southampton Univ., Southampton, SO95NH, England

64 *Crane, J. F. W.: **Preliminary Wind Tunnel Tests of the R.A.E. Magnetic Suspension System and a Discussion of Some Drag Measurements Obtained for a 20^{o} Cone.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, Apr. 1966, pp. 433–461

N67-13594#

This paper briefly describes the initial tests made in the 7"x 7" hypersonic wind tunnel using the newly installed magnetic model suspension and balance system. Drag measurements were made at zero degrees incidence on a 20^{o} cone model at a Mach number of 8.57. A mechanical method of launching the model at the start of the test and recapturing it at the end proved satisfactory.

*Royal Aircraft Establishment, Farnborough, England.

65 *Goodyer, M. J.: **Some Experimental Investigations into the Drag Effects of Modifications to the Blunt Base of a Body of Revolution.** Rep. no. ISAV-150, July 1966, 35 pp.

N67-22502#

This is a report on a series of experiments originally begun to find the effects of changes of base-design on the zero incidence drag of a blunt-based body of revolution. The investigations were to cover drag measurements of a long body of revolution with a simple blunt base, a skirted base

with and without slits, and a blunt base with aft mounted disc, the measurements being made with both laminar and turbulent boundary layers over a magnetically suspended model. However, some interesting transition wire effects were found, and the scope of the tests was broadened to include a more comprehensive study of the effects of this wire, and to include some measurements of base pressure.

*Southampton Univ., Southampton, SO9 5NH, England

66 *Browand, F. K.; *Finston, M.; and *McLaughlin, D. K.: **Some Preliminary Measurements Behind Cones Magnetically Suspended in a Mach number 4.3 Stream.** MIT-TR-132; AFOSR-66-2510; Oct. 1966, 40 pp.
AD-644824 N67-20357#

Preliminary results of pitot pressure measurements behind 7 degree half angle cones are presented. The cones are at recovery temperature. Pitot pressure data is presented for three Reynolds numbers, and an accurate map of the near wake is obtained. In particular the bounds of the recirculation region, the rapid corner expansion, and the lip shock locations are clearly evident. The length of the recirculation region (about 3 base diameters) is consistent with schlieren observations of the suspended model, and also with ballistic range photographs for similar test conditions. At the lowest Reynolds number the wake bifurcates. This cause is not understood at present.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 49(638)-1328.

67 *Bousman, William; *Copeland, Alan; *Covert, Eugene; and *Stephens, Timothy: **Recent Advances in Magnetic Balance Systems, Part IV, Scientific Interim Rep., Jan.—Nov. 1965.** Rep. No. ARL-66-0200, Oct. 1966, 106 pp.
AD-649243 N67-28186#

The results of continued studies on several aspects of magnetic balance systems are presented. The aspects studied include: (1) detailed studies of several classes of optical model position sensors; (2) development and proof testing of an automatic model injection and retrieval system, and (3) detailed study of methods of producing roll torque including compatibility with existing and future magnetic balance systems and experimental verification of the design on bench tests. It is concluded that two of the classes of optical position sensing systems can meet the desired sensitivity but that these systems are somewhat geometry dependant. A recommendation for a system that seems to overcome these difficulties is made.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

For Part I of this series see No. 30 in this bibliography; Part II, No. 33; and Part III, No. 42.

68 Dancy, William H. Jr.; and *Towler, William R.: **Three Dimensional Magnetically Supported Wind Tunnel Balance.** The Review of Scientific Instruments, vol. 37, no. 12, December 1966, pp. 1643—1648.
A67-16461

A three component, wind tunnel balance capable of magnetically suspending a test model in the center of a 25 cm diameter, high velocity, low density gas stream without the use of mechanical supports has been developed. Reaction forces experienced by the model are resolved into three mutually orthogonal components with one of these components being aligned with the axis of the tunnel. A complete description of the magnetic and electrical components of the balance is presented.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. AF-AFOSR-62-92

69 *Copeland, Alan B.: **Wind Tunnel Measurements of the Roll Aerodynamics of the Iroquois Sounding Rocket and the Basic Finner Using a Magnetic Model Suspension System.** Final Report, Covers period Feb. 7, 1966—Feb. 7, 1967. MIT-TR-137, Feb. 1967, 68 pp.
N80-71535#

Wind tunnel data on roll damping moment and roll moment due to fin cant at a Mach number of 4.25 is presented for the Basic Finner configuration for angles of attack from zero to ten degrees and for the Iroquois sounding rocket from zero to seven and one-half degrees. Roll "lock-in" was observed in the wind tunnel and data taken on this phenomenon is presented. Modifications made to the Aerophysics Laboratory magnetic suspension system in order to complete these tests are discussed.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 19(628)-5815

70 *Goodyer, M. J.: **Roll Control Techniques on Magnetic Suspension Systems.** Aeronautical Quarterly, vol. 18, Feb. 1967, Pt. 1, pp. 22—42.
A67-23471

The various methods which are available for controlling the rolling motions of a model suspended in an electromagnet system are discussed. Data on the moment capability and damping achieved with some of the possible control techniques are presented, together with details of the roll control system adopted for the six-component magnetic balance which has been developed at Southampton University for an 8x 6 in. supersonic wind tunnel.

*Southampton Univ., Southampton, SO9-5NH, England

Sponsored by the Science Research Council

71 *Parker, H. M.; *Smoak, R.; and *Zapata, R. N.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic-Stability Research in Wind Tunnels. Status Report Mar. 1, 1966—Mar. 1, 1967.** NASA-CR-66,344, Apr. 1967, 50 pp.; AST-4030-103-67U.
N67-83546

This summarizes the work already accomplished and provides a base on which the decisions relative to the prototype cold balance were to be made. The four sections of the report are: (1) Coil Configuration Design, (2) Control System, (3) Low Temperature Magnets, and (4) Stability Analysis Application.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-029

72 *Judd, M.: **The Effect of Wind Tunnel Size on the Power and Voltage Requirements of Magnetic Suspension Systems.** Southampton Univ. Rep. No. A.A.S.U.-269, May 1967, 16 pp.
N68-14366

A method has been developed for the rapid estimation of the effect of tunnel scale on the power and voltage requirements of magnetic suspension systems. It is used in conjunction with values obtained from existing equipment. The method covers such loads as weight, inertia, steady and unsteady aerodynamic forces and moments but does not give an optimum design.

*Southampton Univ., Southampton, England, SO95NH

73 *Sirieix, Maurice; and *Delery, Jean: **Analyse Experimentale du Proche Sillage d'un Corps Elance Libre de Tout Support Lateral. (Experimental Analysis of the Near-Wake of a Slender Body with no Lateral Support).** *Presented at the AGARD meeting on Plasmas Occurring in* Wakes, Fort Collins, Colo., May 10–12, 1967, 45 pp. (In French). This report is Paper no. 4 in AGARD "Fluid Physics of Hypersonic Wakes," Vol. 1, May 1967.

A67-29379#ONERA-TP-454
N67-33336#ONERA-TP-454
N67-37605#AGARD CP-19, Vol. 1

Testing conditions without any parasite interaction for studying experimentally the near-wake of axisymmetric bodies were studied. Hence, either streamlined supports fixed upstream of the throat of Mach 1.92 and Mach 4 nozzles designed to study cylindrical afterbodies in turbulent flow were used or a magnetic suspension for the blunt and slender model (HB1) which was tested at Mach 5 in laminar flow. The results obtained include a detailed analysis of the flow at the base and are compared with some existing theoretical elements. At the same time, a hot-wire transition investigation, in the case of wake of a cylinder normal to the flow, was carried out at Mach 2.3 and provided an experimental criterion for transition.

*ONERA, 92320 Châtillon, France

74 *Murman, E. M.; *Peterson, C. W.; and *Bogdonoff, S. M.: **Diagnostic Studies of Laminar Hypersonic Cone Wakes.** In: AGARD Fluid Physics of Hypersonic Wakes, vol. 1, May 1967, paper no. 2, 36 pp.

N67-37603#

Laminar hypersonic wakes behind conical bodies were *studied in a conventional wind* tunnel at Mach number 16 and in a free stream Reynolds number of 120,000/inch. A magnetic suspension system capable of supporting axisymmetric bodies was used, and helium at a stagnation temperature of 525°R was the test gas. Pitot pressure probes, hot-wire anemometry, and conventional static pressure probes were used. For the pitot pressure probes, the viscous wake behind the body was actually larger than the body base diameter, and no throat was present. This extensive spread of the wake is attributed to the expansion of the highly vortical boundary layer upon separation from the body.

*Princeton Univ., Gas Dynamics Lab, Princeton, N.J. 08540

Contract No. Nonr-1858(37).

75 *Browand, F. K.; *Finston, M.; and *McLaughlin, D. K.: **Wake Measurements Behind a Cone Suspended Magnetically in a Mach Number 4.3 Stream.** In: AGARD Fluid Physics of Hypersonic Wakes, vol. 1, May 1967, paper no. 3, 43 pp., MIT-TR-143, AFOSR-68-1565;

N67-37604#
or
N68-87554 (thesis)

AD-671965

Continuous pitot pressure is described behind a 7° half-angle cone at zero angle of attack and at recovery temperature. The pitot pressure surveys extend from the base to a distance of about 6 diameters downstream and are sufficiently detailed to accurately indicate the complete geometry of the near wake region including the corner expansion, lip shock, free shear layer, and wake recompression. Reynolds number dependence of the near wake characteristics and on body size effects is considered. These data are supported by Schlieren photographs of the near wake, although the photographs are of poorer quality than those usually obtained in ballistic ranges. Similar results are presented for the 7° cone at small angles of attack, which forcefully illustrate the sensitivity of the wake flow to this variable. The magnetic suspension system and the data acquisition techniques are described.

*M.I.T., Cambridge, Mass. 02139

Contract Nos. AF49(638)-1328; AF33(616)-7023; AF33(615)-1470

76 *Petersen, Robert A.: **Calibration Study for a Six-Degree-of-Freedom Magnetic Balance and Suspension System.** MIT, M.S. Thesis, June 1967, 53 pp.

(Available from MIT). N80-70420#

This thesis presents the background and design of a six component calibration system to be used to calibrate a six degree of freedom magnetic balance and suspension system. The development and use of a three component modified calibration system is discussed. In particular drag, lift, and pitching moment coefficients are measured for the Iroquois and Basic Finner test models at Mach 4.28, and are presented as functions of angle of attack. Recommendations are made towards the eventual automation of the calibration system. Both models are cone-cylinder configurations with flat bases and a symmetrical arrangement of fins. A study to determine the feasibility of basing the calibration system on a pneumatic balance is presented in the appendix.

*M.I.T., Graduate student

AF 33(615)-1470

77 *Daum, Fred L.: **Magnetic Wind-Tunnel-Model Suspension and Balance Systems.** Research Review, Office of Aerospace Research, vol. 6, no. 6, June 1967, pp. 1–4.

N80-71568#

Reviews progress made during the ten years since feasibility of wind tunnel model magnetic suspension was first demonstrated in 1957 by the French organization, ONERA.

*Fluid Dynamics Facilities Research Lab., Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio 45433.

78 *Parker, H. M.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic Stability Research in Wind Tunnels.** Semiannual Status Report, Mar. 1, 1967–Aug. 31, 1967. NASA-CR-91513, Dec. 1967, 8 pp.; AST-4030-104-67U,

N68-81306

This report consists of brief summaries of the status of the various pertinent items involved in the project: (1) Philosophy, (2) Cryogenic and Coil Systems, (3) Model Motion Degrees of Freedom, (4) Aerodynamic Data Systems,

(5) Sphere Position Sensor, (6) Gradient Coil Power Supplies, (7) The Control Problem, and (8) General Theoretical Studies.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-029

79 *Copeland, Alan; *Covert, Eugene; *Petersen, Robert; and *Stephens, Timothy: **Contribution to the Knowledge of Magnetic Balance and Suspension Systems. Scientific Interim Rep., Nov. 1965—May 1967.** MIT-TR-139; ARL-67-0283; Dec. 1967, 58 pp.

AD-666668 N68-23580#

The report separates, for the purpose of discussion, into three distinct parts: comments on design studies for the ARL large scale balance system; experimental studies of problems relating to the multiple use of an advanced configuration of coils for roll, pitch and yaw; and studies of a calibration system capable of automatic operation. The first part is a brief discussion of the philosophy behind the design. The nature of the compromises is included as well as a discussion of the performance goals for the design. The second part describes studies conducted to determine whether or not the pitching and yawing moment coil can also be used to generate rolling moments. In particular the problem of isolating the roll power supplies from the pitch and yaw power supplies, while loading the coils simultaneously, was studied in detail. It was found that this problem can be solved simply and that primary problems associated with multiple use of the coils include selection of the conductor, maximum potential and cooling. The third part contains a description of a multiple purpose calibration system. This system can either be used in the classical sense of applying the several loads and measuring the output from the data readout, or in the inverse sense that entails fixing currents in the magnetic balance and, by using the calibration system as a mechanical balance, determine the forces and moments on the model. While the latter use is unconventional it offers the promise of a fully automatic procedure.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

80 *Langford, J. M.: **Tunnel E With Magnetic Model Support System: Basic Concept and Initial Design.** Interim Report, 1 Mar.—31 Oct. 1967. Jan. 1968. AEDC-TR-67-268, 26 pp. (Available to U.S. Gov't Agencies and their Contractors Only). Unclassified report.

AD-826303 X68-13504#

*ARO, Inc., Arnold Air Force Station, Tenn.

Contract No. AF 40(600)-1200

81 *Matthews, G. B.; *Parker, H. M.; and *Zapata, R. N.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic-Stability Research in Wind Tunnels.** Technical Annual Status Report, Mar. 1, 1967—Mar. 1, 1968. NASA-CR-94440, Mar. 1968, 130 pp.; AST-4030-105-68U.

N68-85749

During this report period significant modifications in the balance design and operation modes were made and current thoughts on longer range plans and projects were outlined. The complete system is described: which includes the aerodynamic facility, coils, cryogenic system, power amplifier, controls, aerodynamics and models, aerodynamic data acquisition, and scaling considerations. An appendix is entitled "General Design Requirements for Three Channel Power-Amplifier."

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-029

82 *Sivier, Kenneth R.: **A One-Component, Magnetic Support-and-Balance System for Wind Tunnel Models.** AIAA paper 68-401 presented at the 3rd AIAA Aerodynamic Testing Conference, San Francisco, Apr. 8—10, 1968. Also published in Journal of Aircraft, Sept.—Oct., vol. 6, 1969, pp. 398—404.

A68-25374#

AIAA Paper 68-401 A69-43714#

A one-component, magnetic support-and-balance system was designed and built as part of a wind-tunnel investigation of sphere drag at subsonic Mach numbers and Reynolds numbers in the range from about 25 to several thousand. This experimental approach has two important advantages: (1) the tests are free of the effects of model support interference, and (2) the balance sensitivity increases as the model size is decreased to obtain lower Reynolds numbers. The magnetic system was used with a vertical wind tunnel, permitting the alignment of the drag and gravity force and the use of a true one-component support. The magnetic configuration included two separate coil pairs--a water-cooled Helmholtz pair providing a steady, uniform magnetic field to magnetize the ferromagnetic spheres and a small coil pair producing enough field gradient to support the magnetized model. Vertical control of the model position was provided by a feedback control system using an optical model position detector. Radial position stability was provided automatically by the basic model/magnet configuration. The use of the system proved to be simple and effective under those flow conditions--i.e., low free-stream turbulence and Re $<$ 300--for which negligible lateral aerodynamic forces exist. With 1/16-in.-diam. spheres, drag measurements were made at values of Re down to about 25; the corresponding drag force was about 4 mg. Under flow conditions where substantial unsteady, lateral forces exist, the radial magnetic restraint was insufficient to prevent significant lateral motion of the model. In spite of this motion, it was possible to obtain good drag data at Reynolds numbers up to about 4000.

*Illinois Univ., Urbana, ILL. 61801
(Work done at Mich. Univ. Ann Arbor Mich. 48109).
NASA Grant No. NsG-86-60

83 *Goodyer, M. J.: **The Magnetic Suspension of Wind Tunnel Models for Dynamic Testing.** Univ. of Southampton, Dept. of Aeronautics and Astronautics—Ph.D. Thesis, April 1968.

N78-78589, Chapt. 1-8
N78-78218, Chapt. 9-14

The purpose of the work described was to investigate practically the feasibility of magnetic suspension for dynamic tests and to develop suitable measuring techniques. Existing magnetic suspension systems incorporated control of model position in five rigid body degrees of freedom, leaving roll motions free. For measurements on non-axisymmetric models, it is necessary to control all six degrees of freedom. A satisfactory low speed roll control system was developed

for models having wings and fins. The suspension system may be used directly as a force and moment balance. The drag forces produced by bodies of revolution were measured at subsonic Mach numbers. Dynamic tests included roll damping and pitch stability derivative measurements on delta planform models. Difficulties involved in the separation of unsteady aerodynamic loads from relatively large inertia forces led to the concept of a tuned model in which, at the resonant frequency, inertia forces are balanced by internal spring forces. Aerodynamic damping forces then dominate and can be measured accurately. The tuned model was difficult to suspend with adequate stability margin until special feedback control characteristics were incorporated. It has been demonstrated that steady load measurements can be made to an accuracy of 2% and dynamic loads to 10%. The system has been proved for subsonic operation; it is anticipated that problems associated with supersonic speeds can be overcome.

*Southampton Univ., Southampton SO95NH, England

84 *Copeland, Alan B.; *Petersen, Robert A.; and *Covert, Eugene E.: **Wind-Tunnel Measurement at M = 4.28 of Some Static and Dynamic Aerodynamic Characteristics of Finned Missiles Suspended Magnetically.** Journal of Spacecraft and Rockets, Vol. 5, July 1968, pp. 838-842.

A68-34110#

The lift, drag, pitching moment, and rolling moment due to roll velocity have been measured at M = 4.28 for two slender finned missile models by means of a magnetic suspension and balance system. Comparisons of the results with data measured by conventional balances show substantial agreement. The trend for damping in roll (due to roll velocity) to increase gradually with increasing angle of attack is more clearly shown than in earlier data because the scatter in the data is reduced by a factor of 1/2.

*M.I.T., Cambridge, Mass. 02139

Contracts AF 33(615)-1470; AF 19(628)-5815

85 . *Phillips, Winfred M.; and *Kuhlthau, A. R.: **Drag Measurements on Magnetically Supported Spheres in Low Density High Speed Flow.** Proceedings of the 6th Int. Symposium on Rarefied Gas Dynamics, MIT, Cambridge, Mass., July 22–26, 1968, Vol. I. Advances in Applied Mechanics, Supplement 5, 1969, pp. 711-721.

A70-18373

Extensive and accurate measurements of sphere drag have been made in hypersonic transition and near-free molecule flow. Small spheres were electromagnetically supported in a free-jet flow field. The results are in general agreement with those of other experimenters where comparable, and also in reasonable agreement with the theoretical predictions of Willis using a modified Krook solution. The free-molecule limit based on diffuse reflection is approached smoothly throughout the transition regime.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant no. AF AFOSR 1046-67.

86 *Beaussier, J.; and *Zakneim, J.: **Telemetrie Multivoies pour Maquettes en Suspension Magnetique. (Multichannel Telemetering Device for Magnetically Suspended Models.)** Presented at the Colloq. on the Properties and the Behavior of the Electronic Components and Assemblies Submitted to Strong Accelerations, Saint-Louis, France, 18 pp., Oct. 1968. (In French, English summary.) ONERA-TP-643.

A69-11623#
N69-32427#

A telemetering device is described that ensures the simultaneous transmission of six channels, this equipment is small and sturdy enough to be used in wind tunnel models that are magnetically suspended and/or released in free flight in the tunnel. It uses three types of strain-gage short response time pick-ups for accelerations and thermal flux measurements. The auxiliary circuits, the commutation process, the transmitters and receivers are described.

*ONERA, 92320 Châtillon, France

87 *Crane, J. F. W.: **Performance Aspects of the RAE Magnetic Suspension System for Wind Tunnel Models.** Nov. 1968. RAE-TR-68274. 44 pp. (This report is marked "Unclassified-UK in Confidence." Reports so marked are not necessarily available to the general public. Requests for this report may be made directly to the Royal Aeronautical Establishment, Farnborough, England.) (Available to U.S. Gov't Agencies and their Contractors Only). Unclassified report.

X69-15721#

The performance of the L-type magnetic suspension system operating in the 7 in. x 7 in. hypersonic wind tunnel is reviewed critically and the limitations of the system are outlined. Some particular aspects of the system discussed are operational techniques, some causes of model instability, model design, scaling factors, safety, and diffuser performance. Axisymmetric models 6 inches long may be flown at incidences of up to about 5 degrees and provision is made for probing the flow field. Use of the system as a 3-component balance is feasible but this aspect has not been fully assessed. Asymmetric shapes cannot as yet be flown because of the lack of roll control in the system. A tentative scheme for achieving stabilization is proposed which might allow asymmetric shapes to be flown.

*RAE, Farnborough, Hampshire GU 14 6TD, U.K.

88 *Vlajinac, Milan: **Wind Tunnel Measurements of the Aerodynamic Characteristics of the 2.75 Wrap Around Fin Rocket Using a Magnetic Suspension System. Final Tech. Rep. 15 May 1967–15 Dec. 1968.** MIT-TR-150, Dec. 1968, 61 pp. (Available to U.S. Gov't Agencies and their Contractors Only). Unclassified report. This is also paper #30 in the Naval Weapons Center Proceedings of the 8th Navy Symp. on Aeroballistics, vol. 3, June 1969, pp. 717-749.

AD-851832
or
AD-857475, Paper #30

X69-16514#
or
X70-12190#, Paper #30

Wind tunnel data on damping in roll, damping in pitch, as well as lift, drag and pitching moment coefficients at a Mach number of 4.25 are presented for the 2.75 wrap-around fin configuration for angles of attack from zero to nine degrees. Force and moment data were obtained using a pneumatic calibration technique developed for magnetic suspension systems. Recommendations for future dynamic stability testing using magnetic suspension systems are discussed.

*M.I.T., Cambridge, Mass. 02139

Contract Nos. AF 33(616)-7023; AF 33(615)-1470; and N60530-68-C-1016

89 *McLaughlin, D. K.; **Carter, J. E.; and *Finston, M.: **Experimental Investigation of the Near Wake of a Magnetically Suspended Cone at $M_\infty = 4.3$.** Presented at the 7th AIAA Aerospace Sciences Meeting, New York City, Jan. 20–22, 1969.

AIAA Paper 69–186 A69-18068#

The results of mean flow measurements in the near wake of a 7° half-angle cone at Mach number 4.3 are presented. The cone was supported by a five-degree-of-freedom magnetic suspension system in a continuous-flow hypersonic wind tunnel. Hot-wire fluctuation measurements established that transition to turbulence occurred downstream of the region of measurement. Measurements were made of pitot pressure, static pressure (using both cone and cone-cylinder static pressure probes), and recovery temperature (using a hot-film anemometer). An important finding was the establishment of the rear stagnation point to be about 2.5 diameters downstream of the base.

*M.I.T., Cambridge, Mass.
**V.P.I. Graduate student

Contract AF 49(638)-1328

90 *Stephens, Timothy: **Summary of the Design of a Magnet Suspension and Balance System for the Aerospace Research Laboratories.** Wright-Patterson AFB, Ohio, Rep. no. ARL-69-0019, MIT–TR-140, Jan. 1969, 61 pp. (Supersedes MIT-TR-101).

AD-687867 N69-34441#

The design of a six-component magnetic suspension and balance system for use in wind tunnels is summarized. The general features of the magnet system, model-position sensing system, compensation system, and power amplifiers are described. The auxiliary equipment required for magnet cooling and safe operation of the balance is outlined.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470.

91 *Covert, Eugene E.; and **Daum, Fred L.: **The Magnetic Wind-Tunnel-Model Suspension and Balance System.** Pages K1–K19 of Proceedings of the OAR Research Applications Conference, Mar. 13, 1969, Vol. 1, Annual Scientific Report, OAR-69-0011-Vol. 1, June 1969.

AD-692500, pp. K1–K19 N70-22327#, pp. K1–K19

The magnetic wind-tunnel-model suspension and balance system is a unique aerodynamic testing tool which affords a method for obtaining test data which is absolutely free of model support interference effects. The suspension system is comprised of multiple pairs of electromagnets which surround the test section and provide the magnetic forces required for balancing the aerodynamic and gravitational loads acting on the model. Control of the magnets is accomplished through feedback control loops which receive signals from a set of model position sensors which may employ either optical or electromagnetic principles. The magnetic forces generated are proportional to the coil currents required; a measure of these currents provides an indication of the model forces. By inserting artificial position sensor signals into the control feedback loops, the magnetic fields may be controlled so as to force the model into various motions and oscillatory modes such as pitching, plunging, or rolling. Thus, the magnetic balance system is adaptable to dynamic, as well as static, testing situations. No longer merely a laboratory curiosity, the magnetic suspension and balance system has been born as a useful aerodynamic wind tunnel test instrument.

*M.I.T., Cambridge, Mass. 02139

**Aerospace Research Labs., OAR, Wright-Patterson AFB, Ohio 45433

92 *Sivier, K. R.; and *Henderson, M.: **One Component, Magnetic, Support and Balance System for Wind Tunnel Models.** NASA-CR-1353, May 1969, 83 pp.

N69-25343#

Sphere drag at subsonic Mach numbers and Reynolds numbers from about 25 to 4000 was measured by the instrumentation. The system was used with a vertical wind tunnel and incorporated a simple error-rate type of feedback control system to hold the model vertically. The natural radial stability of the system was used to hold the model on or near the axes of the solenoids and the wind tunnel. The system performed well, especially at Reynolds numbers where unsteady lateral aerodynamic forces were absent or very small.

*Univ. of Michigan, Ann Arbor, Mich. 48109

Grant No. NGR-23-005-003

93 *Sivier, K. R.: **Magnetic Field Properties Related to the Design of a One-Component Magnetic Support and Balance System.** NASA-CR-1352, May 1969, 50 pp.

N69-24089#

Calculations have been made of the magnetic performance characteristics of air-cored solenoids applied to a one-component magnetic support-and-balance system. These characteristics include field strength, field gradients, static stability derivatives for a ferromagnetic body in the solenoid field, and the solenoid power required to produce given field strengths and to levitate a magnetic body. These characteristics were calculated only in the vicinity of the solenoid axis and are shown to be related simply to four fundamental, shape dependent, dimensionless parameters (and to several ratios of these parameters).

*Univ. of Michigan, Ann Arbor, Mich. 48109

Grant No. NGR-23-005-003

94 *Judd, M.: **The Magnetic Suspension System as a Wind Tunnel Dynamic Balance.** Presented at the 3rd International Congress on Instrumentation in Aerospace Simulation Facilities, Poly. Inst. of Brooklyn, Farmingdale, N.Y., May 1969 (ICIASF'69), IEEE publication 69C 19-AES, pp. 198–206

A69-35738

The design and principles of operation of a magnetic suspension system are outlined together with the features and problems associated with its use as a dynamic balance. A

technique developed to improve resolution of measurement is described. Results are presented for delta wing models chosen because of the availability (for comparison) of other theoretical and experimental data.

*M.I.T., Cambridge, Mass. 02139

Research supported by MIT and NASA

95 *Parker, Hermon M.; and *Zapata, Ricardo N.: **The University of Virginia Cold Magnetic Wind Tunnel Balance.** Paper No. 29 in Naval Weapons Center Proc. of the 8th Navy Symp. on Aeroballistics, vol. 3, June 1969, pp. 695–716.

AD-857 475, Paper #29 X70-12189#

A three degrees of freedom electromagnetic balance, using stabilized superconductor coil systems, is discussed. The major potential of the system is considered to be the investigation, with reasonable and improved accuracy, of the dynamic stability characteristics of a model.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-029

96 *Sivier, Kenneth R.; and *Nicholls, J. A.: **Subsonic Sphere Drag Measurements at Intermediate Reynolds Numbers.** NASA-CR-1392, July 1969.

N69-30609#

The drag of spheres, at subsonic Mach numbers and Reynolds numbers from 25 to 4000, was studied in a continuous wind tunnel using a one-component, magnetic support-and-balance system. The low turbulence incompressible results verified this experimental approach, especially at Reynolds numbers below 300 where the spherical models were not disturbed by unsteady lateral forces. Measurements were also made to evaluate the effects of compressibility, slip flow (Knudsen numbers up to 0.04), sphere surface roughness, and free-stream turbulence (intensities up to 8%).

*Univ. of Michigan, Ann Arbor, Mich. 48109

97 *Murman, Earll M.: **Experimental Studies of a Laminar Hypersonic Cone Wake.** AIAA Journal, vol. 7, no. 9, Sept. 1969, pp. 1724–1730.

A69-43576#

An experiment has been conducted to investigate the fluid mechanical structure of a laminar hypersonic wake behind a sharp, circular cone. The flowfield was surveyed from zero to fifteen diameters downstream of a 10° half-angle cone at zero angle of attack and at the adiabatic wall temperature. The model was magnetically suspended in the freestream of a M = 16 helium wind tunnel. Pitot pressure and static pressure probes were the principle diagnostic tools. Axial and radial profiles of density, velocity, Mach number, and pressure were obtained from the measurements. Some important findings include: 1) the measurement of a maximum axial static pressure in the near wake significantly greater than P_∞, 2) a base pressure equal to 1.58 P_∞ which correlates with published data, 3) a velocity defect of about 20% in the laminar viscous far wake, 4) a density defect greater than an order of magnitude in the viscous far wake, and 5) verification of the validity of the boundary-layer assumptions to treat the far wake.

*Princeton Univ., Princeton, N.J. 08540 (NASA trainee.)

Contract Nonr 1858(37); AF33(615)-67-C-1065

98 *Stephens, Timothy: **Design, Construction, and Evaluation of a Magnetic Suspension and Balance System for Wind Tunnels.** Tech. Rep. Feb. 1966–Nov. 1969. Rep. no. MIT-DSR-75396. MIT-TR-136; NASA-CR-66903, Nov. 1969. 187 pp.

N70-28734#

The basic design principles of a relatively interaction-free six component magnetic suspension and balance system are defined. The construction of a particular magnet configuration is described. The performance of the magnet configuration is evaluated. The evaluation is based upon parameters measured on the assembled and operating system. The evaluation is extended to a range of system sizes, by use of scaling laws. Design and construction of the required feedback compensation electronics system is described. Design of a five-component model position remote transducer is described. Magnet power supplies and control amplifiers are described, and the performance requirements are related to system size, model configuration, and test conditions.

*M.I.T., Cambridge, Mass. 02139

Contract NAS1-4421

99 *Goodyer, M. J.: **The Roll Control of Magnetically Suspended Wind Tunnel Models by Transverse Magnets.** Southampton Univ. Rep. no. AASU-291 (1969).

N69-39330#

A wind tunnel magnetic suspension system has been developed at Southampton University. The equipment is used for the suspension of models in a wind tunnel, free from support interference, and to measure dynamic stability derivatives of wing-body combinations. For this purpose electro-magnets suspend the model and provide position control in six degrees of freedom, including roll. Roll control was necessary in order to orientate the model properly with respect to suspension electro-magnets, and to counteract any aerodynamic rolling moment. The original roll control system utilized the capacity of a specially shaped magnetic core in the model to generate rolling moments under the action of the suspension electro-magnets. The roll control system has proved adequate for the suspension and control of models at low dynamic head, but available evidence suggested that the moment capacity would be inadequate for control at projected increased values of dynamic head. This report describes the evaluation of a novel technique for generating a rolling moment using magnetic fields. The technique should enable models to be constructed having up to five times the moment capacity that previously could be incorporated.

*Southampton Univ., Southampton SO9 5NH, England

100 *McLaughlin, Dennis K.: **Experimental Investigation of the Mean Flow and Stability of the Laminar Supersonic Cone Wake.** MIT-TR-164; AFOSR-70-0072 TR; Nov. 1969, 144 pp. (Available MIT)

N80-71536#

The mean flow and stability of the near wake of a cone at Mach number 4.3 were studied experimentally. The cone was supported by a five-degree-of-freedom magnetic model suspension system. Free stream Reynolds numbers varied from 40,600 to 94,300. The cone had a 7 degree half angle, a sharp nose, and a wall temperature very close to recovery temperature. Mean measurements were made of pitot

pressure, static pressure (using both cone and cone-cylinder static pressure probes) and recovery temperature of a hot-film probe. The entire near wake flow field, except for reverse flow regions, was mapped for the fully laminar Reynolds number of 40,600 and the Reynolds number 94,300 case where the flow downstream of the recirculation region is in transition to turbulence. Important differences between the measured supersonic wake and other investigators' measurements in hypersonic cone wakes are found. The recirculation region was shown to be two or three times longer at the lower Mach numbers, and the pressure overshoot peculiar to the hypersonic cone wake was not found in the present measurements. In the instability investigation, hot-wire fluctuation measurements were made for a range of Reynolds numbers. These measurements indicated a completely stable near wake at $Re_{\infty} = 51{,}600$ and large amplifications of small disturbances at $Re_{\infty} = 61{,}900$. The amplified waves were highly concentrated with respect to frequency, with a number of pronounced harmonics being present. Amplitude and phase measurements of the spectral components indicated that the instability process fits within the framework of linear stability theory as formulated by Gold, with each mode having a wavefront shaped like a circular helix. It appears that each succeeding mode has an additional thread in the helical wavefront. The instability waves are characterized by long wavelengths and high growth rates. In addition, weak nonlinear interactions were observed, which grow stronger with downstream position.

*MIT, Cambridge, Mass. 02139

Contract No. F44620-69-C-0013

101 *Vlajinac, Milan: **A Pneumatic Calibration Rig for Use With a Magnetic Suspension and Balance System.** Tech. Rep., Nov. 1967—Aug. 1969. Wright-Patterson AFB Rep. ARL-70-0016, MIT-TR-159, Jan. 1970, 41 pp.

AD-707858 N70-40056#

The preliminary investigation and design of a prototype pneumatic calibration rig for use with a magnetic suspension system is described. Results and performance of the pneumatic calibration rig are shown. Previous calibration techniques and advantages of this new technique are discussed.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

102 *Crane, J. F. W.: **Interference Effects at M = 8.5 of Wires and Probes on the Wake of a Magnetically Suspended Rounded Base Cone.** London, Aeron. Res. Council Rep. ARC-CP-1133, Feb. 1970, 25 pp. (Supersedes RAE-TR-70023; ARC-32287).

N71-20848#

Transverse and axial probes and wires in the wake produce two types of interference with the wake. With transverse probes and wires the effect is to narrow the wake shock diameter and move its source downstream. With axial probes and wires there is an opposite effect. The former is apparent when the probe is within three base diameters of the model, and the latter is apparent when the edge of the viscous core is approached from within. The Schlieren method of flow visualization was used.

*Royal Aircraft Establishment, Farnborough, Hampshire, GU14 6TD, U.K.

103 *Vlajinac, Milan; and *Gilliam, George D.: **Aerodynamic Testing on Conical Configurations Using a Magnetic Suspension System.** Final Rept. June 1—Oct. 30, 1969. Wright-Patterson AFB Rep. ARL-70-0067, April 1970. MIT-TR-162, 81 pp.

AD-709197 N70-41721#

Tests were conducted at the M.I.T. Aerophysics Laboratory to obtain the pitch plane static force and moment coefficients on conical models at subsonic speeds using a prototype magnetic suspension system. Similar tests were also conducted on a 10° half angle cone at Mach 4.25. The static data obtained is presented and comparison of the supersonic data with results obtained elsewhere is shown. Tests were conducted to obtain the damping in pitch coefficients at both subsonic and supersonic speeds. Although the results of these tests were inconclusive, a discussion of the technique used and recommendations for future testing are presented.

*M.I.T., Cambridge, Mass. 02139

Contract No. AF 33(615)-1470

104 *Phillips, W. M.; *Keel, A. G., Jr.; and *Kuhlthau, A. R.: **The Measurement of Sphere Drag in Rarefied Gas Using a Magnetic Wind Tunnel Balance. Final Report.** April 1970, 70 pp. AFOSR-70-1588TR. AEEP-3435-115-70U.

AD-712741 N71-14891#

Drag measurements on spheres in high speed transition regime flow are presented. The spheres are suspended electromagnetically in the low density flow field from a jet expanding freely from a small sonic nozzle into a vacuum. This arrangement provides sting-free measurements under hypersonic conditions. The current in the control coil of the electromagnetic balance is proportional to the applied force and provides a sensitive determination of the small forces encountered. Data were taken using nitrogen and argon gases. A number of nozzle and sphere sizes were employed covering a Knudsen number range of 0.05 to 5. The results exhibit a smooth increase in the transition regime drag coefficient toward the free molecular limit for diffuse reflection and complete thermal accommodation. Comparison is made with the available experimental results of other techniques. Improved repeatability and an extension of range of flow parameters is obtained with the present methods. The data are compared with current near-free molecular flow theories and the modified Krook solution of Willis is found to give the best agreement with the experimental results.

* Univ. of Virginia, Charlottesville, Va. 22901

Contract No. AF-AFOSR-1046-67.

105 *Matthews, R. K.; *Brown, M. D.; and *Langford, J. M.: **Description and Initial Operation of the AEDC Magnetic Model Suspension Facility Hypersonic Wind Tunnel (E). Final Report, Sept. 1967—Jan. 1970.** AEDC-TR-70-80, May 1970, 50 pp. (U.S. Gov't. Agencies and their Contractors Only).

AD-869,634 X70-17092#

*ARO, Inc., Arnold Air Force Station, Tenn. 37389

Contract No. F40600-69-C-0001

106 *Gilliam, George D.: **Data Reduction Techniques for Use With a Wind Tunnel Magnetic Suspension and Balance System. Interim Technical Rept., Nov. 1968—June 1970.**

MIT-TR-167; NASA-CR-111844, June 1970, 70 pp.

N71-23122#

The equations relating the forces and moments exerted on a body by the magnetic fields produced by the MIT NASA prototype magnetic balance are presented. A computer program which will derive the aerodynamic coefficients for a body using these relations is listed along with a sample output. A preliminary procedure for aligning the axis of the magnetic suspension system with a reference axis is detailed. A procedure for determining dynamic-stability derivatives is outlined.

*M.I.T., Cambridge, Mass. 02139

Contract No. NAS1-8658

107 *Zarin, Neil A.: **Measurement of Non-Continuum and Turbulence Effects on Subsonic Sphere Drag.** NASA-CR-1585, June 1970, 137 pp.

N70-31869#

The drag of spheres, at Mach numbers from 0.10 to 0.57, Reynolds numbers ranging from 40 to 5000, Knudsen numbers as high as 0.060, and turbulence intensities up to 13% were measured in a continuous wind tunnel utilizing a magnetic suspension system. Stainless steel ball bearings having diameters of from 1 mm to 1/4 in. were used as models. The effects of free-stream turbulence, compressibility, and gas rarefaction were observed and compared with existing data wherever possible.

*Michigan Univ., Ann Arbor, Mich. 48109

Grant No. NGR-23-005-003

108 *Zapata, R. N.; *Parker, H. M.; *Moss, F. E.; **Hamlet, I. L.; and **Kilgore, R. A.: **University of Virginia Superconducting Wind-Tunnel Balance.** Applied Superconductivity Conference, Boulder, Colo., June 1970. Journal of Applied Physics, vol. 42, no. 1, Jan. 1971, pp. 3–5. Also published as NASA TM-X-72184.

A71-20151#

N75-70783

The design of an electromagnetic balance using superconducting coils is reported. Both dc and ac coils are used to support aerodynamic models in a supersonic (Mach 3) wind tunnel and to simultaneously measure the forces acting on them along 3 orthogonal axes. Major design characteristics include: adoption of symmetrical coil arrangement to provide maximum space for the wind tunnel; 3 gradient-coil pairs capable of being driven between 0 and 350 A at a frequency of 30 Hz by specially designed power supplies; a vertical wind tunnel with a 6-in. test section located in the axial room-temperature access of a 250-liter liquid-helium Dewar. Results on ac losses for prototype gradient coils wound of three different superconducting materials are reported.

*Univ. of Virginia, Charlottesville, Va. 22901

**NASA, Langley Research Center, Hampton, Va. 23665

NSF supported Grant No. NGR-47-005-029.

109 *File, J.; *Martin, G. D.; *Mills, R. G.; and *Wakefield, K. E.: **Operation of a Levitated Superconducting Ring in a Plasma Physics Experimental Device.** Nat. Bur. Stds, U.S. Navy, Amer. Physical Soc., IEEE, and Univ. of Colorado Applied Superconductivity Conference, Boulder, Colo., June 15–17, 1970, 4 pp. Also, Journal of Applied Physics, vol. 42, no. 1, pp. 6–9, Jan. 1971.

A71-20152#

An isolated, isochoric Dewar and superconducting ring, operable up to 130 000 ampere turns, has been installed in the Princeton Spherator, and plasma physics experiments have been performed with the ring levitated and stabilized by means of a system similar to that discussed previously. The evolution of this device has progressed through three stages. Initially the poloidal field coil was a conventional copper conductor ring within a vacuum jacket supported within the reaction chamber from top and bottom by four thin bars. In its second stage of development, the conventional coil was replaced by a superconducting coil and Dewar, supported by thin wire-like hangars. The present mode eliminates the need for mechanical supports of any sort.

*Princeton University, Plasma Physics Lab., Princeton, N. J. 08540

AEC supported research

110 *Vlajinac, Milan: **Summary of the Design and Initial Operation of a Transonic Wind Tunnel for Use With a Magnetic Suspension System.** Covers work performed July 1968–July 1970. MIT-TR-170, July 1970.

N80-71558

A summary of the construction and initial operation of a transonic wind tunnel facility for use with magnetic suspension and balance system is presented. Initial tests indicate a tunnel operating range from low subsonic to Mach 1.42. The tunnel is 4"x4" and is located at the M.I.T. Aerophysics Laboratory.

*M.I.T., Cambridge, Mass. 02139

Contract No. N00123-67-C-1598

111 *Vlajinac, Milan; *Stephens, Timothy; *Gilliam, George D.; *Pertsas, Nicholas V.; and *Covert, Eugene E.: **Subsonic Static Characteristics of Slender Wing Configurations Using a Magnetic Suspension and Balance System.** MIT-TR-168, July 1970, 25 pp. NASA-CR-1796, July 1971.

N71-29775#

Wind tunnel investigations of the static aerodynamic characteristics of three sharp-edged, slender wings were conducted at subsonic speeds using a magnetic suspension and balance system. Measurements of lift, drag, and pitching moment coefficients were made at angles of attack from 2^{o} to 30^{o} at a Reynolds number of the order of 1×10^{5} and a Mach number of approximately 0.05. The results were expected to be relatively free from Reynolds number effects due to the sharp leading and trailing edges of these wing planforms, and therefore in agreement with larger scale data. Comparison of the present results is made with previously published experimental data, as well as with a theoretical model using the leading-edge suction analogy. The agreement of the present results with data obtained at test Reynolds numbers an order of magnitude larger is considered good, thereby validating the small scale tests.

*M.I.T., Cambridge, Mass. 02139

Contract No. NAS1-8658

112 *Bogdonoff, Seymour M.: **Hypersonic Wake Studies. Final Report, 15 Jan. 1962—15 Jan. 1970.** July 1970, 18 pp.

AD-708757 N70-40162#

The development of the magnetic suspension system was one of the key achievements of the early part of the program. Major work on the balance was completed in 1965 and only small modifications were made after that. The magnetic suspension system very satisfactorily supported spheres of 3/8 and 3/4 inch diameter and 10° cones of 3/4 inch to 1 1/2 inch diameter. The suspension system was of a rather unique geometry. By mounting the tunnel vertically, the suspension system was made symmetric. The magnetic geometry chosen uncoupled the magnetic forces of the drag components from the stabilization forces. Studies of the wakes of spheres, the first body tested using the magnetic suspension system, were carried out to the point where full analysis of the results showed that far wake results could not be obtained and since the purpose of the program was to study both near and far wakes, the work on spheres was discontinued and the primary emphasis was then placed on conical bodies. Studies of the wake of a sharp 10° cone were completed. The subsequent study of the effect of bluntness on the same cone varying the configuration from a sharp cone to one with a nose radius 20% of the base radius also was completed. A hemispherical base was used to evaluate base geometry effects. One cone had a fluted surface. Most of the experiments were carried out at M = 16 and RN ≈ 120,000/in.

*Princeton Univ., Princeton, New Jersey 08540

Contract No. Nonr-1858(37)

113 *Vlajinac, M.; *Stephens, T.; *Gilliam, G.; and *Pertsas, N.: **Subsonic and Supersonic Static Aerodynamic Characteristics of a Family of Bulbous Base Cones Measured With a Magnetic Suspension and Balance System.** MIT-TR-166, Nov. 1970, NASA-CR-1932, Jan. 1972, 63 pp.

N72-14984#

Results of subsonic and supersonic wind-tunnel tests with a magnetic balance and suspension system on a family of bulbous based cone configurations are presented. At subsonic speeds the base flow and separation characteristics of these configurations are shown to have a pronounced effect on the static data. Results obtained with the presence of a dummy sting are compared with support interference free data. Support interference is shown to have a substantial effect on the measured aerodynamic coefficient.

*M.I.T., Cambridge, Mass. 02139

Contract No. NAS1-8658

114 *Keel, A. G., Jr.; *Kraige, L. G.; *Passmore, R. D.; and *Zapata, R. N.: **Hypersonic Low Density Cone Drag.** 9th AIAA Aerospace Sciences Meeting, New York City, Jan. 25—27, 1971.

AIAA Paper 71—133. A71-18577#

Highly accurate and precise cone drag measurements in the transition regime of low density hypersonic flow have been made using a method that combines the experimental advantages of a free jet and a wind tunnel electromagnetic balance. After the effects of the free jet axial flow gradients are deleted from the data by means of an empirical correction technique, direct comparison with experimental results obtained by more conventional methods is afforded. In all experiments reported in this paper the following conditions are fixed: zero angle-of-attack, 9° cone semi-vertex angle, $T_W/T_O = 1$, nitrogen test gas, steady state measurements. Single parameter studies on the effects of bluntness ratio and Mach number were conducted over a wide range of rarefaction parameters including the region where blunt cones produce less drag than sharp cones. First results of a quantitative study of the sting interference effects of conventional mechanical wind tunnel balances are included. A comparison of experimental results for a sharp cone with predictions of transition and near free-molecule theories yields satisfactory agreement.

*Univ. of Virginia, Charlottesville, Va. 22901

115 *Crane, J. F. W.: **Air Condensation Effects at M = 8.5 Measured on the Drag and the Wake of a Magnetically Suspended 20 Deg. Cone.** Aeron. Res. Council ARC-CP-1177, Feb. 1971, 17 pp. (Supersedes RAE-TR-70022 and ARC-32346.)

N72-11014#

Schlieren pictures of the near wake of a 20 deg cone and drag measured by magnetic balance both show effects of air condensation at temperatures below that predicted. Above this level, supersaturated air may be used by hypersonic testing with complete absence of effects due to air condensation.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

116 *McLaughlin, Dennis K.; **Carter, James E.; ***Finston, Morton; and ****Forney, J. Alan: **Experimental Investigation of the Mean Flow of the Laminar Supersonic Cone Wake.** AIAA Journal, vol. 9, no. 3, March 1971, pp. 479—484.

A71-22091#

This paper presents results of an experimental study of the mean flow of the near wake of a sharp, 7 deg half-angle, adiabatic cone at Mach number 4.3 and freestream Reynolds numbers of 40,600 and 94,300. The cone was supported by a five-degree-of-freedom magnetic model suspension system. Measurements were made of pitot pressure, static pressure (using both cone and cone-cylinder static pressure probes), and recovery temperature of a hot-film probe in the near-wake region between the model and six model diameters downstream. This enabled the flow regions to be mapped and a complete determination to be made of the flowfield properties at the measurement stations excluding the interior region of the recirculation bubble. The near wake was fully laminar at a Reynolds number of 40,600, and at the higher Reynolds number of 94,300 the flow downstream of the recirculation region underwent transition to turbulence. When compared with hypersonic cone wake measurements, it was shown that the recirculation region was two or three times longer at the lower Mach number, and the pressure overshoot peculiar to the hypersonic cone wake was not found in the present measurements.

*Oklahoma State Univ., Stillwater, Okla. 74074
**NASA, Langley Research Center, Hampton, VA 23665
***M.I.T., Cambridge, Mass. 02139
****NASA, Marshall Space Flight Center, Huntsville, Alabama 35812

Contract No. AF 44(620)-69-C-0013

117 *McLaughlin, Dennis K.: **Experimental Investigation of the Stability of the Laminar Supersonic Cone Wake.** AIAA Journal, vol. 9, no. 4, April 1971, pp. 696–702.

A71-25475#

This paper presents the results of an investigation of the instability occurring in the wake of a 7 deg half-angle, sharp cone suspended magnetically. Hot-wire fluctuation measurements were made in the wake for a range of Reynolds numbers and at a Mach number of 4.3. These measurements indicated a completely stable near wake at a freestream Reynolds number of 51,600 and large amplification of small disturbances at a freestream Reynolds number of 61,900. The amplified waves were highly concentrated with respect to frequency, with a number of pronounced harmonics being present. Amplitude and phase measurements of the spectral components indicated that the instability process fits within the framework of linear stability theory as formulated by Gold, with each mode having a wavefront shaped like a circular helix. It appears that each succeeding mode has an additional thread in the helical wavefront. However, the measured fundamental oscillation has a larger amplification rate and a much lower frequency than predicted by Gold's theory. In addition, weak nonlinear interactions were observed, which grow stronger with downstream position.

*M.I.T. (graduate student), Cambridge, Mass. 02139

Contract No. AF (620)-C-0013

118 *Willard, J. W.; *File, J.; and *Martin, G. D.: **Levitated Ring in FM-1.** Rept. no. MATT-842, CONF-710418-19, presented at the 4th Symposium on Engineering Problems of Fusion Research, Washington, D.C., Apr. 20, 1971, 9 pp.

N72-14275#

The ring was successfully levitated in the slide unstable mode in the FM-1 Machine: The magnet, wound of 4221 turns of 90 mil RCA NB3Sn ribbon, has a current capacity of 375,000 ampere turns. The coil is charged inductively or by external power supply, and is housed in a seven inch-minor-diameter toroidal Dewar with external connections for filling, venting, and charging under high vacuum. Test results of quench temperature vs. current for isochoric life of the ring at full current is approximately one hour. This corresponds to 10.7 K at 25 atmospheres.

*Princeton University, Plasma Physics Lab., Princeton, N. J. 08540

Contract AT(30-1)-1238

119 *Judd, M.; **Vlajinac, M.; and **Covert, E. E.: **Sting-free Drag Measurements on Ellipsoidal Cylinders at Transition Reynolds Numbers.** Journal of Fluid Mechanics, vol. 48, part 2, 1971, pp. 353–364.

A71-36037

The drag coefficient for a family of axially symmetric ellipses of fineness ratio 4, 5, and 8 was measured using magnetically suspended models. The Reynolds number ranged up to 10^6. Thus, only the blockage interference is present, which may be partially allowed for by classical wind tunnel procedures. It is expected that the drag values presented here are accurate to 1%.

*Southampton Univ. (England) SO9 5NH
**M.I.T., Cambridge, Mass. 02139

120 *Crane, J. F. W.; *Woodley, J. G.; and *Thompson, J. P.: **Use of the RAE Magnetic Suspension System as a Force Balance.** RAE-TR-71140, 31 pp., July 1971. (This report is marked "Unclassified–UK in Confidence." Reports so marked are not necessarily available to the general public. Requests for this report may be made directly to the Royal Aircraft Establishment, Farnborough, England.) (Available to U.S. Gov't Agencies and their Contractors Only).

AD-894178 X72-76040

*Royal Aircraft Establishment, Farnborough, England

121 *Phillips, Winfred M.; and **Kuhlthau, A. R.: **Transition Regime Sphere Drag Near the Free Molecule Limit.** AIAA Journal, vol. 9, no. 7, July 1971, pp. 1434–1435.

A71-32124#

Measurements were made in hypersonic flow from a freejet using a magnetic suspension system to obtain sting-free data. The results obtained, which are assumed as representative of a warm wall condition, indicate no tendency of sphere drag to overshoot the free molecular limit, at least for Reynolds number of order of unity.

*Pennsylvania State Univ., University Park, Pa. 16802
**Univ. of Virginia, Charlottesville, Va. 22901

NSF Grant No. CK 5559; Grant No. AF AFOSR-1046-67

122 2nd International Symposium on Electro-Magnetic Suspension. University of Southampton, Southampton, England, July 12–14, 1971, Proceedings. 343 pp.

A72-24756-A72-24776#

Topics discussed during the symposium include the use of superconductivity in magnetic suspension design, losses in superconducting magnets, an automatic suspension using tuned LCR circuits, an electromagnetic model position sensing system for wind tunnels, electro-optical detectors for magnetic suspension, an optical scanning detection system for low-density drag measurements, data acquisition and reduction for a superconducting magnetic suspension and balance facility, a dc power supply for a magnetic suspension system, wind-tunnel tests of conical and winged model configurations using a magnetic suspension and balance system, the use of an electromagnetic balance in rarefied gas research, an electromagnetic position sensor for a magnetically supported model, and the simulation of gravity in wind tunnels with the aid of magnetic fields.

123 *Beams, J. W.: **Some Remarks on Servo-Controlled Magnetic Suspensions at the University of Virginia.** In the 2nd Int. Symp. on Electro-magnetic Suspension, July 12–14, 1971, pp. 3–7.

A72-24756 pp. 3–7

This introductory paper by Professor Beams was read at the Symposium by Professor H. M. Parker. The paper discusses the part that the University of Virginia had in the early development of magnetic suspension.

*Professor at Univ. of Virginia, Charlottesville, Va. 22901

124 *Zapata, R. N.: **The University of Virginia Superconducting Magnetic Suspension and Balance Facility.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings, pp. A.1–A.22; Discussion pp. A.23, A.24. (This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies".

A72-24757# or N73-24272#

This paper describes a prototype facility comprising a superconducting magnetic suspension and balance and a supersonic wind tunnel. This facility was developed with the objectives of establishing the feasibility of applying the three-component magnetic balance concept to dynamic stability studies, and investigating design concepts and parameters that are critical for extrapolation to large-scale systems. Many important design and operational aspects, as well as safety considerations, are dictated by the cryogenic nature of the advanced-technology facility. Results of initial tests demonstrate that superconductors can be utilized safely and efficiently for wind-tunnel magnetic suspensions. At the present stage of development of this facility, controlled one-dimensional support of a spherical model has been achieved.

*Univ. of Virginia, Charlottesville, Va. 22901

Grants No. NGR-47-005-029; No. NGR-47-005-110; and No. NGR-47-005-112

125 *Cornish, D. N.: **A Report on the Culham Superconducting Levitron.** 2nd Int. symp. on Electro-Magnetic Suspension, July 12–14, 1971. Proceedings, pp. B.1–B.11. Discussion p. B.12.

A72-24758#

This machine is being built to study the stability and confinement of a hot plasma trapped in the magnetic field around a levitated superconducting ring carrying half a million ampere-turns. Superconducting coils up to 1.2 metres mean diameter and using the latest techniques are incorporated in the vacuum system to provide the vertical field. A brief description of this equipment, concentrating on the superconducting aspects, is presented together with performance data for the coils.

*Culham Laboratory, Abingdon, Berks., England

126 *Moss, F. E.: **The Use of Superconductivity in Magnetic Balance Design.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971. Proceedings. pp. C.1–C.15. (This paper is also contained in "Development of a Superconducting Electromagnetic Syspension and Balance System for Dynamic Stability Studies").

A72-24759# or A73-24273#

This paper contains a summary of the magnetic field and field gradient requirements for magnetic suspension in a Mach 3, 6-in. diam. wind tunnel, along with the power requirements for gradient coil pairs wound of copper operating at room temperature or of aluminum cooled to 20° K. The power dissipated is large enough so that the use of superconductivity in the coil design becomes an attractive alternative. The problems of stability and ac losses are outlined along with the properties of stabilized superconductors. A brief review of a simplified version of Bean's (1964) critical state model is presented, and the problems involved in calculations of the ac losses in superconducting coils are outlined. A summary of ac loss data taken at Brookhaven National Laboratories (BNL) on pancake coils wound of commercially available Nb3Sn partially stabilized tape is presented and shown as leading to the University of Virginia gradient coil design. The actual coil performance is compared with predictions based on the BNL results. Finally, some remarks are presented concerning scaling of the ac losses to larger magnetic suspension systems as well as prospects for improved performance using newer multifilament superconductors.

*Univ. of Virginia, Charlottesville, Va. 22901

NASA Grants NGR-47-005-029; NGR 47-005-110, and NGR 47-005-112

127 *Stephens, T.: **An Electromagnetic Remote Model Position Sensing System for Wind Tunnels With Particular Application to Magnetic Suspension Systems.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971. Proceedings, pp. G.1–G.17; Discussion, pp. G18, G19.

A72-24762#

This paper describes a versatile electromagnetic model position sensing system which is capable of accommodating a wide range of model geometry with minor adjustment. This system is based upon differential transformer action, and initially was designed to measure the components of model displacement relative to the wind tunnel axes. By minor modification to the system electronics and model core, independent sensitivity to roll attitude has been provided.

*M.I.T., Cambridge, Mass. 02139

128 *Moreau, R.; *Besson, J.; and *Hoarau, R.: **Electro-Optical Detectors for Magnetic Suspension and the Study of the Free Motion of Models.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971. Proceedings, pp. H.1–H.14; Discussion, p. H.15.

A-72-24763#

This paper describes the development of a remote position sensor based on scanning analysis of optical contrasts directly applied to a model magnetically suspended in a wind tunnel. Following a brief enumeration of its requirements and a general definition, the design, operation, and expected performance of the position-sensing system are described. It is felt that the main advantage of this system as applied to magnetic suspension is that it leaves the inner space of the coil assembly entirely clear, thus permitting a reduction to be made both in the inner diameter and in the power requirement without loss of performance.

*ONERA, Châtillon-sous-Bagneux, Hauts-de-Seine, France

129 *Altmann, H.: **An Optical Scanning Detection System and its Use with a Magnetic Suspension System for Low Density Sphere Drag Measurements.** In the 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings, pp. I.1–I.15; Discussion pp. I.16, I.17.

A72-24764#

This paper describes an optical model position detecting system that uses the television principle of scanning an image with a raster of lines. The system has been developed for use in a low-density wind tunnel for the purpose of measuring the aerodynamic drag on small spheres. The instantaneous position signals that are available call for a sampled data control system to stabilize the model position. The resulting algorithm for the digital controller requires a combination of present, previous, and twice previous signals. An outline is given of the electronic system used to provide the control signal.

*Oxford Univ., Dept. of Engineering Science, Parks Rd., Oxford, OX1 3PJ England

130 *Gilliam, G. D.: **Determination of Forces and Moments with a Magnetic Wind Tunnel Balance System.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings, pp. J.1–J.17; Discussion, p. J.18.

A72-24765#

The aerodynamic forces and moments experienced by a model in a wind tunnel may be deduced from the magnetic forces and moments required to balance them. The derivation of the equations presently used to determine the forces and moments exerted on a body by the magnetic fields produced by the M.I.T.-N.A.S.A. Prototype Magnetic Balance is presented. In addition, a procedure for determining the parameter in the equations for a particular model is outlined.

*M.I.T., Cambridge, Mass. 02139

131 *Jacobson, I. D.; *Junkins, J. L.; and *Jancaitis, J. R.: **Data Acquisition and Reduction for the U. Va. Superconducting Magnetic Suspension and Balance Facility.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings. pp. K.1–K.12; Discussion p. K.13, K.14. (NASA-CR-112186). (This paper is also contained in "Development of a Superconducting Electromagnetic Syspension and Balance System for Dynamic Stability Studies").

A72-24766#
N73-10276#
or
N73-24274#

The problems associated with data acquisition and reduction in the University of Virginia superconducting magnetic suspension and balance facility are similar to those in free-flight ranges (or tunnels). The model undergoes a "Quasi-six-degree-of-freedom" motion which must be monitored both in position and angular orientation from which the aerodynamics must be inferred. The data acquisition problem is made more difficult because geometric constraints prevent direct visual access to the model in the Mach 3 wind tunnel. The methods, accuracies and problems associated with the acquisition of data are discussed.

*Univ. of Virginia, Charlottesville, Va. 22901

Grants NGR-47-005-029; NGR-47-005-149; NGR-47-005-112).

132 *Jaysinghani, N. D.: **Power Supply for a Magnetic Suspension System.** In the 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings, pp. L.1–L.16; Discussion, p. L.17.

A72-24767#

This paper describes a special dc power supply which has practically no time delay and by means of which a high rate of change of current can be achieved at relatively low working voltages. This power supply consists mainly of an input rectifier, whose output is maintained at a constant voltage, and a dc power amplifier. The choice of the dc voltage is a function of the magnet inductance and the desired rate of change of current. The load thyristors of the power amplifier can be fired or turned off with forced commutation without delay, so as to maintain a load current which does not deviate more than plus or minus 5% from its mean value of 175 A. To achieve this, the current feedback is used to actuate two chains of logic circuits which cause the firing or turning off of either one or both the load thyristors, depending on the amplitude and polarity of the error signal. Three modes of current flow result. The switching frequency of the thyristors is limited by means of certain timing interlocks in the logic circuit which keep the losses low. These interlocks are also necessary to avoid short circuits. During operation at maximum switching frequency the run time of power supply is limited to about 15 min followed by a rest period of 30 min.

*Brown, Boveri et Cie. AG, Zurich, Switzerland

133 *Goodyer, M. J.: **Improvements Related to Model Position Control.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings. pp. M.18–M.22; Discussion, p. M.23.

A72-24768#

This paper describes some of the design features of wind tunnel model position sensing and controlling systems. Means are reviewed for reducing drift in model position when the magnetic suspension system is used as a force and moment balance. The physical properties are examined of two permanent magnet materials (platinum-cobalt and samarium-cobalt alloys) whose insertion into model wings helps generate rolling moments about the X–X axis of the model.

*Univ. of Southampton, Southampton SO9 5NH, England

134 *Vlajinac, M.: **Aerodynamic Characteristics of Axisymmetric and Winged Model Configurations Using a Magnetic Suspension and Balance System.** In the 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12–14, 1971, pp. N.1–N.12; Discussion, p. N.13.

A72-24769#

Results of subsonic and supersonic wind tunnel tests with a magnetic balance and suspension system on a family of bulbous-based cone models are presented. At subsonic speeds the base flow and separation characteristic of these models is shown to produce anomalous behavior of the static force and moment coefficients with angle of attack. Comparison of data obtained with a dummy sting is made with support interference free results. The static aerodynamic characteristics of three sharp-edged, slender wings at subsonic speeds is presented. Comparison of the present results with tests at Reynolds numbers an order of magnitude higher is considered good, thereby validating the small scale tests.

*M.I.T., Cambridge, Mass. 02139

135 *Abdel-Kawi, S.; *Diab, T.; *Goodyer, M. J.; *Henderson, R. I.; and *Judd, M.: **Aerodynamic Data Acquisition with the University of Southampton Magnetic Balance.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12–14, 1971, pp. 0.1–0.17; Discussion, p. 0.18, 0.19.

A72-24770#

A brief description of the Southampton magnetic balance is presented first with particular emphasis on the methods for extracting steady and unsteady wind tunnel data. New acquisition and analysis methods are then described. Steady lift, drag and pitching moment measurements have been made on a body of revolution and on wing-body combinations of delta and AGARD G wing planform. Roll-damping for the wing-body combination is also presented.

*Southampton Univ., Southampton, SO9 5NH, England

136 *Zapata, R. N.; *Kuhlthau, A. R.; and *Fisher, S. S.: **Research in Rarefied Gas Dynamics Using an Electromagnetic Wind-Tunnel Balance.** 2nd Int. Symp. on Electro-Magnetic Suspension, July 12–14, 1971, Proceedings, pp. P.1–P.16; Discussion, p. P.17, P.18.

A72-24771#

Aerodynamic forces on spheres and slender cones in hypersonic, low-density flows have been measured with a 3-component magnetic balance of improved capabilities. Improvements in the experimental techniques permitting measurements of increased accuracy, precision, and resolution have made possible interesting studies of slender-cone aerodynamics. Preliminary results of an investigation of sting effects are reported. Current and future research plans are discussed from the point of view of facility development.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. AF-AFOSR-69-1798

137 *Covert, E. E.; and *Vlajinac, M.: **Sphere Drag in Laminar Flow.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12–14, 1971, pp. Q.1–Q.2; Discussion, p. Q.3.

A72-24772#

Drag coefficient data on spheres in laminar flow taken from the early study by Wieselsberger done in Germany from 1920 to 1926 are compared with those from recent experimental studies performed by Roos and Will (1971), Bailey and Hyatt (1971), and Covert and Vlajinac at MIT (1971). In the latter study, one sphere had two small flat spots that were observed not to matter as long as the surface irregularity they caused was less than the boundary layer thickness.

*M.I.T., Cambridge, Mass. 02139

138 *Towler, W. R.: **Electromagnetic Position Sensor for a Magnetically Supported Model in a Wind Tunnel.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings. July 12–14, 1971, pp. Q.4–Q.7; Discussion, p. Q.8. (This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies.")

A72-24773#
N73-24276#

This paper describes the design, principle of operation, and performance characteristics and problems of an electromagnetic position sensor for a magnetically supported model in a wind tunnel. The sensor is based upon the principle of a differential transformer, and it is hoped that the problems encountered in its operation will be solved eventually.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant no. NGR-47-005-112

139 *Zapata, R. N.: **Safety Aspects of Superconducting Magnetic Suspension Systems.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12–14, 1971, pp. Q.9-Q.14. (This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies.")

A72-24774
or
N73-24277#

Various forms of failure are discussed that any designer or builder of a superconducting magnetic suspension system should thoroughly consider in order to make sure that the system is safe. The major protective devices and techniques used to this end are reviewed. For additional progress under NGR-47-005-112 which is directly relevant to the main questions left unanswered in this paper see the final section of N73-24271 which is citation no. 149 in this bibliography.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-112

140 *Parker, H. M.; and *Jancaitis, J. R.: **The Use of Iron and Extended Applications of the University of Virginia Cold Balance Wind Tunnel System.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12–14, 1971, pp. S.1–S.10. (This paper is also included in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies.")

A72-24776#
N73-24275#

The prototype design of the University of Virginia Cold Magnetic Balance Wind Tunnel System, primarily for assured performance, is based on the use of ferrites for the magnetic support element and for the case of spinning missile configurations in supersonic flow. The extension of applicability to noncontinuously spinning airplane configurations and to subsonic flow regimes would be highly desirable. The problems involved in these extensions are discussed. The possible use of iron for the magnetic support element, or some material reasonably equivalent, is found to be crucial. The existing theoretical evidence that iron may be used without penalty is summarized.

*Univ. of Virginia, Charlottesville, Va. 22901

Grants No. NGR-47-005-029; No. NGR-47-005-112

141 *Zarin, Neil A.; and **Nicholls, J. Arthur: **Sphere Drag in Solid Rockets--Non-continuum and Turbulence Effects.** Combustion and Science Technology, vol. 3, Aug. 1971, pp. 273–285.

A71-40861

This paper presents the results of an experimental study concerning the momentum transfer between the gas and condensed phase in metalized solid propellant rocket motors. Noncontinuum and turbulence effects on sphere drag have been measured in a small, vertical, subsonic wind tunnel incorporating a magnetic suspension system. Drag data have been obtained at Reynolds numbers (Re) ranging from 40 to 5000, Mach numbers (M) from 0.10 to 0.57, Knudsen numbers (Kn) as high as 0.060, and turbulence intensities up to 13%. Sphere drag measurements taken with moderate (0.4 to 3.3%) levels of turbulence show that turbulence of these levels produces significant drag increases for Reynolds numbers between 200 and 800. The data indicate that, for a given turbulence level, the percentage drag rise due to turbulence decreases with decreasing Re; the drag coefficient increase approaches zero for Re less than or equal to 100. For sphere drag data obtained at turbulence levels from 3 to 13% and Reynolds numbers from 600 to 5000, a very pronounced effect of sphere diameter is evident. At a given Re, the drag coefficient increases monotonically with inverse sphere diameter. Present data for Re ranging from 40 to 200 and M ranging from 0.17 to 0.57 exhibit pronounced noncontinuum and compressibility effects. These data are compared with empirical relations and other experimental data found in the literature.

*Cornell Aeron. Lab. Inc. Buffalo, N.Y. 14850
**Michigan Univ., Ann Arbor, Mich. 48109

Grants No. NsG-86-60; No. NGR-23-005-003

142 *Stevens, T.; *Vlajinac, M.; and *Covert, E. E.: **Recent Development and Application of a Wind Tunnel Magnetic Suspension and Balance System.** Final Tech. Report, Apr.–Oct. 1971. NASA-CR-127,390, Oct. 1971, 6 pp.

N72-73800

The effort of this report period was devoted to two items: A. Measurement of Subsonic Sphere Drag and B. Development of a Roll Attitude Sensor. An aerodynamic investigation was conducted to determine the laminar flow drag coefficient of spheres of various sizes in a subsonic wind tunnel. The tests were conducted using the M.I.T.--N.A.S.A. prototype magnetic suspension and balance system. The absence of model support interference in these tests implies the effect of tunnel wall interference on the measurement of drag of different sized spheres can be deduced. The present results indicate the conventional wind tunnel correction does not completely account for the effects of model size and wall interference. That is, the corrected drag coefficient data for the different sphere sizes differs somewhat in the region of Reynolds number overlap.

*M.I.T., Cambridge, Mass. 02139

143 *Stephens, T.; *Covert, E. E.; *Vlajinac, M.; and *Gilliam, G. D.: **Recent Developments in a Wind Tunnel Magnetic Balance.** 10th AIAA Aerospace Sciences Meeting, San Diego, Calif., Jan. 17–19, 1972.

AIAA Paper 72–164 A72-16829#

A functional description of a prototype six component magnetic balance system for wind tunnel application is presented. The relationship of forces and moments on a ferromagnetic body to applied magnetic fields and gradients is shown. The method of producing the required fields in the prototype balance, its magnet arrangement and its performance are discussed. Aerodynamic data obtained with this balance on several model geometries are presented and compared with wind tunnel and ballistic range results.

*M.I.T., Cambridge, Mass. 02139

NASA-USAF-supported research

144 *Day, Lawrence Eric: **Wind Tunnel Wall Effects on Cones With Bulbous Bases.** MIT, M.S. Thesis, Jan. 1972, 52 pp. (Available from MIT).

N80-71537

In an attempt to deduce wind tunnel wall interference effects, a series of tests were performed using geometrically similar 6 degree half angle cones with bulbous bases. The lift and drag coefficients versus Reynolds number for a variety of positions in the wind tunnel were determined. The effects of model size and model position with respect to the tunnel centerline on the lift and drag coefficients are shown. A magnetic balance and suspension system was used.

*M.I.T., Graduate student

145 *Vlajinac, M.; and *Covert, E. E.: **Sting-Free Measurements of Sphere Drag in Laminar Flow.** Journal of Fluid Mechanics, vol. 54, Part 3, Aug. 8, 1972, pp. 385–392.

A72-40110

An aerodynamic investigation was conducted to determine the laminar-flow drag coefficient of spheres of various sizes in a subsonic wind tunnel. The tests were conducted using the MIT-NASA prototype magnetic-balance system. By measuring the drag of different sized spheres without model support interference the tunnel wall effect can be deduced. The present results indicate that the classical wind tunnel correction does not completely account for the effects of model size and wall interference. That is, the corrected drag coefficient data for the different sphere sizes differ among themselves in the region of Reynolds number overlap. An analysis of the estimated error in the present data indicates the primary source to be measurement of the wind tunnel parameters rather than errors resulting from the balance system.

*M.I.T., Cambridge, Mass. 02139

146 *Raghunath, Boray S.; and *Parker, Hermon M.: **Evaluation of Aerodynamic Derivatives From a Magnetic Balance System.** NASA-CR-112305 (1972).

N73-20279#

The dynamic testing of a model in the University of Virginia cold magnetic balance wind-tunnel facility is expected to consist of measurements of the balance forces and moments, and the observation of the essentially six degree of freedom motion of the model. The aerodynamic derivatives of the model are to be evaluated from these observations. The basic feasibility of extracting aerodynamic information from the observation of a model which is executing transient, complex, multidegree-of-freedom motion is demonstrated. It is considered significant that, though the problem treated here involves only linear aerodynamics, the methods used are capable of handling a very large class of aerodynamic nonlinearities. The basic considerations include the effect of noise in the data on the accuracy of the

extracted information. Relationships between noise level and the accuracy of the evaluated aerodynamic derivatives are presented.

*Univ. of Virginia, Charlottesville, Va. 22901

NASA Grant No. NGR 47-005-029

147 *Coffin, James B.; and *Haldeman, Charles W.: **Design and Initial Operation of a 3-Degree of Freedom Magnus Rotor in a Magnetic Balance System.** Picatinny Arsenal Rep. no. PA-TM-2069. Jan. 1973.

AD-755108 N73-20001#

Progress is reported on an experimental program to determine the Magnus forces on the center of gravity and the rotational startup response of a self-spinning rotor in a subsonic air stream. Development of a new type of model for the magnetic balance system was required in order to provide rotational freedom about all three axes. The design, construction and initial testing of this model at low subsonic speeds are discussed. The results indicate that models with three degrees of rotational freedom can be suspended with the magnetic balance system and tested in a subsonic air stream. Because of the force limits of the present balance system, the maximum operating dynamic pressure for this model is low.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAAA21-72-C-0254

148 *Bharathan, D.; and *Fisher, S. S.: **Measured Axial and Normal Force Coefficients for 9° Cones in Rarefied Hypersonic Flow.** 11th AIAA Aerospace Sciences Meeting, Wash. D.C., Jan. 10–12, 1973.

AIAA Paper 73–154 A73-16902#

Axial and normal force coefficients for slender cones in the transitional regime of low-density, hypersonic flow have been measured. The flow fields are freely expanding jets emerging from sharp-edged orifices. Models are supported in a three-dimensional electromagnetic suspension system in which the aerodynamic forces are measured by monitoring the currents in various electromagnetic coils. In the experiments, the following conditions are fixed: models of 9° semivertex angle, free-stream Mach number 8.2 at model mid-chord point, nitrogen test gas, ratio of model wall temperature to gas stagnation temperature unity. For all tests, care is taken to avoid the identifiable extraneous influences of a) finite static pressure outside the free-jet Mach bottle and b) variation of free-stream properties over the extent of the submerged model. Angle of attack is varied from 0 to 18°. Model Reynolds number, based on free-stream density, free-stream velocity, model length, and viscosity at the model wall temperature, varies from 4 to 60. Comparisons to theoretical predictions at low and high Reynolds numbers and to available experimental data are discussed.

*Univ. of Virginia, Charlottesville, Va. 22901

AFOSR Grant 69-1798

149 *Zapata, Ricardo N.: **Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies.** Final Tech. Report. Univ. Va. Rep. no. ESS-4009-101-73U. NASA-CR-132255, Feb. 1973. 76 pp. N73-24271#

A prototype facility comprising a superconducting magnetic suspension and balance and a supersonic wind tunnel was developed with the objectives of (1) establishing the feasibility of applying the 3-component magnetic balance concept to dynamic stability studies, and (2) investigating design concepts and parameters that are critical for extrapolation to large scale systems. Many important design and operational aspects are dictated by the cryogenic nature of this advanced technology facility. Results of initial tests demonstrate that superconductors can be utilized safely and efficiently for wind tunnel magnetic suspensions. Controlled one-dimensional support of a spherical model was achieved. The individual titles of the six papers are: 1. "The University of Virginia Superconducting Suspension and Balance Facility," R. N. Zapata (N73-24272); 2. "The Use of Superconductivity in Magnetic Balance Design," F. E. Moss (N73-24273); 3. "Data Acquisition and Reduction for the UVA Superconducting Magnetic Suspension and Balance Facility," I. D. Jacobson, et al. (N73-24274); 4. "The Use of Iron and Extended Applications of the U. Va. Cold Balance Wind Tunnel System," H. M. Parker, J. R. Jancaitis (N73-24275); 5. "Electromagnetic Position Sensor for a Magnetically Supported Model in a Wind Tunnel," W. R. Towler (N73-24276); and 6. "Safety Aspects of Superconducting Magnetic Suspension Systems," R. N. Zapata (N73-24277). These papers are copies of papers contributed by the Univ. of Va. research group at the 2nd Int. Symp. on Electro-Magnetic Suspension held at the Univ. of Southampton, July 1971. For abstracts of these papers see nos. 124, 126, 131, 140, 138, and 139 in this compilation.

*Univ. of Va., Charlottesville, Va. 22901

NASA Grant NGR-47-005-029

150 *Blankson, Isaiah, M.: **Experimental Study of the Mean Flow in a Laminar Axisymmetric Cone Near-Wake at M_∞ = 6.3 Using Magnetic Model Suspension. Final Report, June 1973.** AFOSR-TR-74-1516; MIT-TR-185; 144 pages.

AD-787883 N75-73717

Measurements of the Pitot pressure and the recovery temperature of a cylindrical hot-film probe in the laminar near-wake of sharp and spherically-blunted, 7° half-angle, adiabatic-wall cones, at M_∞ = 6.32 and free-stream Reynolds numbers from 88,000/in., to 117,000/in., are presented. The extent of the region of measurements was from the model base to five base diameters downstream. The cones were supported with a 5-degree-of-freedom magnetic model suspension system. The present study establishes several important effects of hypersonic Mach number on the structure of the axisymmetric cone near wake when compared with the results of a previous laminar supersonic (M_∞ = 4.3) near-wake investigation of the same model geometry at identical Reynolds numbers. An important finding, among others, is a confirmation of the phenomenon of decreasing length of the recirculation region with increasing Mach number. Dramatic changes in the wake structure are most pronounced in the orientation and development of the lip and wake compression shock waves. At M_∞ = 6.32 the viscous region was found to extend beyond the wake shock wave whereas at the supersonic Mach number, as far back as six base diameters, there was only a gradual, compressive turning of the outer inviscid flow, with the fully developed wake shock appearing further

downstream. The axial static pressure overshoot characteristic of hypersonic cone wakes was not observed in the present investigation. (This report contains the same information as in the author's SCD thesis.)

*M.I.T., Cambridge, Mass. 02139

Contract No. AF-F44620-69-C-0013

151 *Altmann, H.: **A Magnetic Suspension System for the Measurement of Sphere Drag in Low Density Supersonic Flow.** Oxford Univ., Dept. of Engineering Science Rept-1062/73, June 1973, 78 pp.

N74-15949#

A magnetic suspension system was developed for measuring sphere drag in the transition and near-free molecular regimes when used with a low density hypersonic wind tunnel. The restrictions that the tunnel placed upon the suspension system design are discussed, together with the methods used to accommodate them. The overall design is compared with that of other systems. The advantages and disadvantages of both linear and scanned optical detection methods are discussed, and their relevant control system theories are developed. The realization of these systems together with the method of controlling the electromagnets and measuring the forces on a suspended body are described.

*Oxford Univ., Engineering Laboratory, Parks Road, Oxford OX1 3PJ England.

152 *Fajen, Jay D.; and *Smoak, Robert A.: **A Proposed Method of Analog Identification System for Models in a Magnetic Suspension Wind Tunnel.** American Soc. for Engineering Education, Computers in Education Division, Transactions, vol. 5, no. 8, Aug. 1973, pp. 123–128.

N80-71564#

A magnetic wind tunnel balance is under development at the University of Virginia in which a model can be suspended in a magnetic field. This paper presents a method which translates position information from the tunnel into explicit aerodynamic data. The translation method to be used is the identification procedure of Hoberock and Kohr and it is currently being implemented on an analog computer. Further, magnitude scaling can be done while the program is running. This research differs from that done by Hoberock and Kohr mainly in that input data of much higher frequencies is being used and that the analog scaling is done during the run. In a conventional wind tunnel, the model being tested needs to be held in a fixed position and this is done by means of a physical support called a sting. A model held in such a fixed position does not allow investigations into the dynamics of free-flying models and there is always the possibility that the sting has an effect on the airflow which will affect the accuracy of the aerodynamic data to be obtained. The University of Virginia magnetic wind tunnel balance will hopefully solve these two problems.

*Univ. of Virginia, Charlottesville, Va. 22901

153 *Haldeman, Charles W.; *Coffin, James B.; *Birtwell, Edwin; and **Vlajinac, Milan: **Improvements in the Magnetic Balance System Required for Magnus Testing.** In ICIASF '73; 5th Int. Congress on Instrumentation in Aerospace Simulation Facilities, Pasadena, CA, Sept. 10–12, 1973, Record.

A74-26476, pp. 24–30
or A74-26478

Recent improvements in the magnetic balance system at the MIT Aerophysics Laboratory are described. Improvement in the balance, which holds wind tunnel models magnetically without physical supports, was required in order to obtain measurements of the aerodynamic Magnus side force on spinning bodies of revolution at angles of attack up to 10 degrees. Improvements described include a laser position system with an angular holding capability of .02 degrees, a data acquisition system, and model construction techniques using copper-iron composite structures. Typical aerodynamic data is presented for a 5:1 ogive cylinder at M = .27 (Re = 7.7 x 10^5) to .43 (Re = 1.3 x 10^6), magnetically obtained Magnus side force data is presented which exhibits a scatter of less than 0.005 in side force coefficient.

*M.I.T., Cambridge, Mass. 02139

**M.I.T., Lexington, Mass.

U. S. Army supported research

154 *Hadjmichalis, K. S.: **A Study of Sphere Drag in the Transition from Continuum to Free Molecular Flow.** Univ. of Oxford, Department of Engineering Science, Rep. 1073/73, Oct. 1973, 145 pp.

N74-18660#

An experimental investigation of the effect of wall temperature on the drag of a sphere in the transition from continuum to free molecular flow was conducted. An electromagnetic suspension system was used both to suspend the model and to measure the drag force exerted by the flow. The experiments were conducted in a low density wind tunnel in a flow produced by a freely expanding jet of air. Measurements were obtained for various wall to stagnation temperature ratios, ranging from 0.25 to 1. A stagnation chamber heater was used to heat the gas. The models were cooled by liquid nitrogen in a cooling box before they were introduced to the flow. The free stream Mach number was varied from 6 to 12. The Reynolds number based on conditions behind the normal shock was between $0.195 < Re_2 < 81.73$ ($16.36 > Rn_\infty > 0.036$). The measurements showed a reduction in the drag coefficient as the value of Tw/To was reduced. It was also found that the drag coefficient was independent of the body temperature and free stream Mach number. It depended only on the wall to stagnation temperature ratio. No overshooting of the free molecular limit of the drag coefficient was observed. A theoretical prediction of the drag coefficient for various wall to stagnation temperature ratios is presented.

*Oxford Univ., Engineering Lab, Parks Road, Oxford, OX1 3PJ, England

Contract No. AT/2057/042

155 *Covert, E. E.; *Finston, M.; *Vlajinac, M.; and Stephens, T.: **Magnetic Balance and Suspension Systems for Use with Wind Tunnels.** In Progress in Aerospace Sciences, vol. 14. Oxford and New York, Pergamon Press, 1973.

A74-12203, pp. 27–107
or A74-12204

This paper describes the principles of operation and design features of magnetic balance and suspension systems

used to provide interference-free support of models in wind-tunnel tests. The term balance is applied to cases where the suspension is used for direct measurement, e.g., unknown aerodynamic forces and torques applied to a model by the relative velocity of the wind are balanced by (1) known gravitational and inertial forces and torques and (2) magnetic forces and torques given in terms of electric currents. Attention is given to elementary magnetic concepts, generation of forces and torques, system analysis procedures, magnetic field configurations, materials employed, power supplies, cooling techniques, control systems, and scaling laws.

*M.I.T., Cambridge, Mass. 02139

156 *Birtwell, Edwin P.: **Magnus Forces and Sting Interference on Magnetically-Suspended Ogive Cylinders.** MIT, M.S. Thesis, May 1974, 94 pp. (Available from MIT).

N80-71560#

Subsonic Magnus testing was conducted on a spinning ogive nosed cylinder suspended with a magnetic suspension and balance system. At low angles of attack and Reynolds numbers, an unanticipated reversal in Magnus coefficient was observed. Further testing was done to determine the influences of sting interference and transition to turbulence on this effect. The results showed that a considerable dependence exists on the sting and transition and suggested a possible explanation for the reversal effect.

M.I.T., Graduate student, Cambridge, Mass., 02139
U.S.A. DAAD-05-72-C-0181

157 *Haldeman, Charles W.; *Coffin, James B.; *Birtwell, Edwin P.; and *Vlajinac, Milan: **Magnus Measurements With the Magnetic Balance System.** Final Tech. Rep., 6 Mar. 1972—30 Dec. 1973. Ballistics Research Labs. Rep. BRL-CR-153, May 1974, 57 pp.

AD-782753 N75-13236#

Recent wind tunnel tests in the Magnetic Balance System at the M.I.T. Aerophysics Laboratory are described. Improvement in the balance, which holds wind tunnel models magnetically without physical supports, was required in order to obtain measurements of the aerodynamic Magnus side force on spinning bodies of revolution at angles of attack up to 10 degrees and spinning ring airfoils at angles of attack up to 3.5°. Improvements described include a laser position system with an angular holding capability of .02 degrees, a data acquisition system, and model construction techniques using copper-iron composite structures. Typical aerodynamic data is presented for a 5-1 ogive cylinder at M = .27 (Re = 7.7 x 10^5) to .43 (Re = 1.3 x 10^6). Magnetically obtained Magnus side force data is presented which exhibits a scatter of less than 0.005 in side force coefficient. Data is also presented, which shows that in this Reynolds number range the effect of a sting can be large.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAAD05-72-C-0181

158 *Zapata, Ricardo N.; *Humphris, Robert R., and *Henderson, Karl C.: **Experimental Feasibility Study of the Application of Magnetic Suspension Techniques to Large-Scale Aerodynamic Test Facilities.** 8th AIAA Aerodynamic Testing Conference, Bethesda, Md., July 8—10, 1974. NASA-CR-146,761, Jan. 1975, 10 pp.

AIAA Paper 74-615 A74-35383# or N80-11102#

Based on the premises that (1) magnetic suspension techniques can play a useful role in large-scale aerodynamic testing and (2) superconductor technology offers the only practical hope for building large-scale magnetic suspensions, an all-superconductor three-component magnetic suspension and balance facility was built as a prototype and was tested successfully. Quantitative extrapolations of design and performance characteristics of this prototype system to larger systems compatible with existing and planned high Reynolds number facilities have been made and show that this experimental technique should be particularly attractive when used in conjunction with large cryogenic wind tunnels.

*Univ. of Va., Charlottesville, Va. 22901

Grants No. NGR-47-005-029; NGR-47-005-110; NGR-47-005-112; NSG-1010

159 *Humphris, R. R.; *Zapata, R. N.; and *Bankard, C. H.: **Performance Characteristics of the U. Va. Superconducting Wind Tunnel Balance.** In the Applied Superconductivity Conference, Argonne & Batavia, Ill., Sept. 30—Oct. 2, 1974. IEEE Transactions on Magnetics, vol. MAG-11, no. 2, Mar. 1975, pp. 598—601. A75-25833

Initial operational characteristics of a wind tunnel electromagnetic balance utilizing superconducting coils are reported. Both d.c. and a.c. superconducting coils are used for balancing and measuring 3-component aerodynamic forces on simple models in Mach 3, room temperature flow. Liquid helium boil-off measurements corresponding to a wide range of operating conditions are presented together with results of systematic a.c. losses scaling experiments using various pancake coils wound with superconducting tape. This unique prototype facility is primarily for studying the practical feasibility of using superconducting magnetic suspension techniques for aerodynamic testing and accumulating the knowledge and expertise required for extrapolating these techniques to large-scale facilities.

*Univ. of Virginia, Charlottesville, Va. 22901

Grants NGR-47-005-029; NGR-47-005-110; NGR-47-005-112; NSG-1010

160 *Bisplinghoff, R. L.; *Coffin, J. B.; *Covert, E. E.; *Finn, D. M.; *Haldeman, C. W.: **The Measurement of Aerodynamic Forces on a Short Body at High Angles of Attack With the Magnetic Balance System. Final Rep. 31 Mar.—31 Dec. 1974.** MIT-TR-190; PA-TR-4806, Dec. 1974, 68 pp.

AD-A012071 N76-16048#

Aerodynamic lift coefficient, drag coefficient and pitching moment coefficient are reported for a short finned body at angles of attack from -20 to +20 degrees as measured with the magnetic balance system at M = .18 and .37. Re sub d = 100,000 and 200,000. Also reported are modifications made to the magnetic balance system in order to extend the angle of attack range. A new controllable D.C. power supply was constructed using 300 ampere, 30 volt D.C. aircraft

generators. The steady state and transient response characteristics of this power supply are reported.

*M.I.T., Cambridge, Mass. 02139

Contract DAAA21-74-C-0304

161 *Zapata, R. N.; *Humphris, R. R.; and *Henderson, K. C.: **Development of Superconductor Magnetic Suspension and Balance Prototype Facility for Studying the Feasibility of Applying this Technique to Large Scale Aerodynamic Testing, Final Rep. 1 Sept. 1969–30 Sept. 1974.** Univ. Va. ESS-4009-102-75, NASA-CR-141284, 59 pp., Jan. 1975. Also NASA-CR-2565, July 1975, 64 pp.

N75-28025#

The unique design and operational characteristics of a prototype magnetic suspension and balance facility which utilizes superconductor technology are described and discussed from the point of view of scalability to large sizes. The successful experimental demonstration of the feasibility of this new magnetic suspension concept of the University of Virginia, together with the success of the cryogenic wind-tunnel concept developed at Langley Research Center, appear to have finally opened the way to clean-tunnel, high-Re aerodynamic testing. Results of calculations corresponding to a two-step design extrapolation from the observed performance of the prototype magnetic suspension system to a system compatible with the projected cryogenic transonic research tunnel are presented to give an order-of-magnitude estimate of expected performance characteristics. Research areas where progress should lead to improved design and performance of large facilities are discussed.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. NGR-47-005-112

162 *Goodyer, M. J.; *Henderson, R. I.; and *Judd, M.: **The Measurement of Magnus Force and Moment Using a Magnetically Suspended Wind Tunnel Model.** 13th Int. Magnetics Conference, London, England, Apr. 14–17, 1975. IEEE Transactions on Magnetics, vol. MAG-11, Sept. 1975, pp. 1514–1516.

A75-43713

The magnetic suspension system makes an ideal facility for the measurement of the aerodynamic Magnus force acting on a wind tunnel model which is spinning about an axis inclined at an angle to the air flow. The Southampton University system was modified to allow the suspended model freedom to spin whilst retaining control of the other rigid body degrees of freedom. Force and moment readout was obtained from calibration of the suspension electromagnet currents. The model was spun up using air jets and the mechanism retracted leaving the model rotating and free from flow interference. The Magnus force signals were recorded on magnetic tape during the gradual decay of spin rate for subsequent digital analysis. Typical test data is presented showing a strong influence of tail region geometry on Magnus force. This indicates that a mechanical support at the tail should be avoided and illustrates the usefulness of magnetic suspension in aerodynamic testing.

*Univ. of Southampton, Southampton SO95NH, England

163 *Ahmadi, Ali Reza; and *Finston, M.: **Wall Temperature Effects on Laminar Wakes. Final Tech. Rep. 1 Nov. 1973–30 June 1975.** MIT Rep. TR-191, AFOSR-75-1634TR, July 1975. 68 pp.

AD-A019530 N76-24517#

An experimental investigation was made of the effects of cold wall conditions on the structure of the laminar near wake of a 7 degree half-angle right circular cone with a sharp nose at zero pitch and yaw. Free stream Mach number and Reynolds number were M = 6.3 and Re = 112,500 per inch. The cone was supported by a five-degree-of-freedom magnetic model suspension system. Measurements of pitot pressure and the recovery temperature of a cylindrical hot film were made in the region extending from the model base to five base diameters downstream. A time-dependent method was used in which the data were taken while an initially cold model slowly warmed up to adiabatic condition.

*M.I.T., Cambridge, Mass. 02139

Contract No. F44620-74-C-0025

164 *Blankson, Isaiah M.; and *Finston, Morton: **Measurements in the Laminar Near-Wake of Magnetically Suspended Cones at M = 6.3.** AIAA Journal, vol. 13, no. 12, Dec. 1975, pp. 1562–1567.

Measurements of the Pitot pressure and the recovery temperature of a cylindrical hot-film probe in the laminar near-wake of sharp, 7° half-angle, adiabatic-wall cones, at M_∞ = 6.32 and freestream Reynolds numbers based on model base diameter from 62,000 to 86,000 are presented. The extent of the region of measurements was from the model base to five base diameters downstream. The cones were supported with a five-degree-of-freedom magnetic model suspension system. The present study establishes several important effects of hypersonic Mach number on the structure of the axisymmetric cone near-wake when compared with the results of a previous laminar supersonic (M_∞ = 4.3) near-wake investigation of the same model geometry at similar Reynolds numbers. An important finding, among others, is a confirmation of the phenomenon of decreasing length of the recirculation region with increasing Mach number. Dramatic changes in the wake structure are most pronounced in the orientation and development of lip and wake recompression shock waves. At M_∞ = 6.32 the viscous region was found to extend beyond the wake shock wave, whereas at the supersonic Mach number, as far back as six base diameters, there was only a gradual compressive turning of the outer inviscid flow, with the fully developed wake shock appearing farther downstream. The axial static pressure overshoot characteristics of hypersonic cone wakes were not observed in this investigation.

*M.I.T., Cambridge, Mass. 02139

For comments on this paper see: (1) *Crane, R. I.: **Comment on "Measurements in the Laminar Near-Wake of Magnetically Suspended Cones at M = 6.3."** AIAA Journal, vol. 15, no. 6, Dec. 1977, pp. 891; and (2) Blankson, Isaiah M.; and Finston, Morton; **Reply of Authors to R. I. Crane.** AIAA Journal, vol. 15, no. 6, Dec. 1977, p. 892.

*Imperial College of Science & Technology, London, U.K.

165 *Zapata, Ricardo N.: **Magnetic Suspension Techniques for Large Scale Aerodynamic Testing.** In: "Wind Tunnel Design and Testing Techniques," AGARD-CP-174, pp. 39–1 through 39–14, Mar. 1976. For comments on this paper see no. 169 in this bibliography.

N76-25213# Paper no. 39
or N76-25250#

The potential utility of magnetic suspension techniques is discussed in the context of current efforts towards realistic aerodynamic simulation in wind tunnels. Design parameters are defined and problems of constructing large size facilities identified. A three stage strategy towards realizing a truly large scale magnetic suspension and balance with full research capability is outlined. Stage one, consisting of building and testing a prototype superconductor coil system to establish the feasibility of the concept has been completed successfully and its principal results are briefly described. This proven feasibility of using superconductors for magnetic suspensions, together with the successful demonstration of the cryogenic wind tunnel concept, appear to have opened the way to clean tunnel, high-Re aerodynamic testing. Results of a comparative analysis of scaling of several coil technologies for a specific magnetic suspension configuration, from the prototype size to a size compatible with the projected high Reynolds number cryogenic wind tunnel facility, are discussed in some detail.

*Univ. of Virginia, Charlottesville, Va. 22901
Grant No. NSG-1010

166 *Bisplinghoff, Ross L.: **Advanced Calibration Techniques for the M.I.T. Magnetic Suspension and Balance System.** MIT, M.S. Thesis, May 1976. (Available from MIT).

N80-71559#

Procedures were developed for calibrating models for spin and angle of attack effects in the M.I.T. magnetic suspension and balance system. The construction and use of a calibration load cage is discussed as an aid to more accurate calibration. Measurements of calibration coefficients were conducted with tangent ogive cylinder models and the data reduced using a computer calibration program. Finally, suggestions are presented for calibrating a spinning and coning model; and a computer program for calculating the oscillatory terms in the force equations is discussed for this case.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAHC04-75-C-0001

167 *Zapata, R. N.: **Development of the Design Concept for a Medium-Scale Wind Tunnel Magnetic Suspension System.** Semiannual Status Report, 1 Oct. 1975–31 Mar. 1976. June 15, 1976. 3 pp.

N76-90227

A brief report is given on the research during this period which was carried out through five major activities: (1) participation in the 1975 AGARD symposium on Windtunnel Design and Testing Techniques, (2) phasing out of work with the prototype facility, (3) analysis of a new electromagnetic position sensor concept, (4) ac losses measurements in state-of-the-art superconductors, and (5) design of support coils for the transonic pilot tunnel facility.

*Univ. of Virginia, Charlottesville, Va. 22901

NASA Grant No. NSG1010

168 *Diab, Talat A. G.: **Improved Wind Tunnel Testing and Data Reduction Methods Using a Magnetic Suspension System.** Southampton Univ. Ph.D. Thesis, July 1976. 369 pp.

N78-78588

Improved techniques and data reduction methods for aerodynamic force measurements were proposed and tested using the magnetic suspension and balance of Southampton Univ. Quasi-static and dynamic forces and moments were measured at low speed. A simple relationship between the maximum ramp rate, the aerodynamic flow response time and the required data smoothing was obtained and verified experimentally. Aerodynamic forces on several slender models were measured and the effect of ramp rate on various aerodynamic characteristics was studied using the AGARD-G model. Results compared well with published work. Drag force was found to exhibit very slow response and needed correction even at the lowest ramp rate. Ramp testing shows finer details than conventional point-by-point method. Data points for a single test are very consistent and have the potential for reducing costs. A method of digital covariance zero crossing for accurate determination of the frequency response of linear dynamic systems is proposed which is very useful for low frequency sinusoidal signals distorted by heavy superimposed noise. A relationship between the signal-to-noise ratios, minimum record length and required accuracy is obtained. The method has been applied to, or considered for: (1) measurement of roll damping derivative at constant incidence, (2) measurement of roll damping derivative with ramped incidence, and (3) multi-degree of freedom systems for measurement of combined pitch and heave derivatives.

*Southampton Univ., Southampton, SO9 5NH, England

169 *Goethert, Bernhard H.: **Technical Evaluation Report on Windtunnel Design and Testing Techniques.** AGARD-AR-97, Aug. 1976, 22 pp.

N76-30236#

This Advisory Report reviews and evaluates the Fluid Dynamics Panel Symposium and establishes recommendations for future research activities. It is observed that recent advanced design concepts, technologies, techniques and instrumentation have emerged which offer great potential for the development of highly sophisticated transonic windtunnel systems as well as upgrading of existing facilities. Future advanced transonic windtunnel systems will be able to incorporate such concepts and technologies as: cryogenic condition of the windtunnel gas; adjustable walls or adjustable crossflow through partially opened walls; magnetic suspension and force-and-moment measuring systems; and remote measuring and scanning systems. Additional research is required to realize the full potential of each technology area, however, sufficient knowledge is available today to initiate construction of advanced technology windtunnels with designs that will accommodate the future expected advances in test section wall technology, mounting systems, instrumentation, etc.

*AGARD, 7 rue Ancelle, 92200 Neuilly sur Seine, France

170 *Pierce, T. V., Jr.; and *Zapata, R. N.: **Superconductor Coil Geometry and AC Losses.** Journal of Applied Physics, vol. 47, Aug. 1976, pp. 3745–3746.

A76-40080

An empirical relation is presented which allows simple computation of volume averaged winding fields from central fields for coils of small rectangular cross sections. This relation suggests that, in certain applications, ac loss minimization can be accomplished by use of low winding densities, provided that hysteresis losses are independent of winding density. AC loss measurements on coils wound of twisted multifilamentary composite superconductor show no significant dependence of ac losses on winding density, thus permitting the use of winding density as an independent design parameter in loss minimization.

*University of Virginia, Charlottesville, Va. 22901
NSG-1010

171 *Bisplinghoff, R. L.; *Coffin, J. B.; and *Haldeman, C. W.: **Support Free Measurements of Aerodynamic Characteristics of a Spinning 2-1/8 Inch Diameter Ring Airfoil Using the Magnetic Balance.** BLR-CR-317; MIT-TR-194. Sept. 1976. 55 pp. (Available to U.S. Government Agencies Only).

AD-B015079L X77-72845

Aerodynamic forces are measured on a magnetically-suspended ring airfoil at a Mach number of 0.22. Lift, drag, pitching moment, side force, and yawing moment are reported at spin rates PD/2V = 0 to .45, at M = .22 and Re = 2.6×10^5 and angles of attack from -3^o to $+5^o$. Drag coefficient is also reported as a function of Reynolds number for a non-spinning model at zero angle of attack and is found to depend strongly on Reynolds number dropping from 0.2 at Re = 1.5×10^5 to 0.06 at Re = 2×10^5. The effect of artificial roughness on the drag-Reynolds number dependence is also reported at Re = $.7 \times 10^5$ to 3×10^5. A brief study of the characteristic sound emitted by the model is also reported. Maximum sound intensity was observed at a Strouhal number (ft/V) = .35 based on wind velocity, sound frequency, and ring radial thickness.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAAD05-74-C-0735

172 *Bharathan, Desikan; *Fisher, Sam S.; and *Zapata, Ricardo N.: **Aerodynamic Stability Testing With Magnetically Suspended Models.** Final Report, Mar. 1, 1974–Aug. 31, 1976. Sept. 1976. 135 pp. AFOSR-76-0036TR; UVA/525603/ESS76/101.

AD-A031473 N77-22048#

The practicality of measuring aerodynamic stability derivatives using models suspended in the University of Virginia water-cooled electromagnetic suspension facility is examined. Two non-spinning models are tested in pitch and heave oscillations in a subsonic flow, and both static and dynamic derivatives are determined from the measurements. The two models are 7-caliber and 5-caliber cone cylinders. For the tests, M = 0.071 and Re_d = 13,000. Pitch and heave oscillatory motions are induced by forcing the model laterally with its center of mass displaced from its center of magnetization. Each model's response is measured in a frequency range near pitch resonance.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. AFOSR 74-2705

173 *Bharathan, Desikan: **Aerodynamic Stability Testing With Magnetically Suspended Models.** Univ. of Virginia Ph. D. Thesis, 1977. 130 pp. (Available from **University Microfilms).

Order No. 7812113 N78-32108

The practicality of measuring aerodynamic stability derivatives using models suspended in a water-cooled electromagnetic suspension facility is examined. Two non-spinning models are tested in pitch and heave oscillation in a subsonic flow and both static and dynamic aerodynamic derivatives are determined from the measurements. The two models are 7 caliber and 5 caliber cone cylinders. Important factors in aerodynamic derivative measurements such as magnetic damping, position sensing, and position-control stability are discussed and a comprehensive description of the apparatus is presented.

*Univ. of Virginia, Charlottesville, Va. 22901
**University Microfilms, A Xerox Company, 300 North Zeeb Road, Ann Arbor, Michigan 48106
AFOSR-74-2705

174 *Bharathan, D.; and *Fisher, S. S.: **Stability Derivative Measurements with Magnetically Suspended Cone-Cylinder Models.** AIAA paper 77–79, 15th Aerospace Sciences Meeting, Los Angeles, Calif., Jan. 24–26, 1977. Also "Journal of Spacecraft and Rockets," vol. 14, no. 12, Dec. 1977, pp. 719–723.

A77-19813#

In an initial feasibility study, the stability derivatives, C_{m_α}, $C_{m_{\dot\alpha}} + C_{m_q}$ C_{z_α} and $C_{z_{\dot\alpha}} + C_{z_q}$ for 5- and 7-caliber cone-cylinder models have been measured at M = 0.071 and Re = 1.3×10^4 by suspending each model electromagnetically in a small subsonic wind tunnel, forcing it in periodic, combined pitching/heaving motion at frequencies near pitch resonance, and comparing its frequency response with flow to that without flow. Drag coefficients are measured as well. The apparatus and techniques employed are described, the analytical model used to extract the derivatives from the response data is outlined, typical response data are shown, comparisons are made with conventionally obtained, similar data from other facilities, and a general assessment of the technique is made.

*Univ. of Virginia, Charlottesville, Va. 22901

Grant No. AFOSR-74-2705

175 *Birtwell, E. P.; *Coffin, J. B.; *Covert, E. E.; and *Haldeman, C. W.: **Some Measurements of the Magnus Characteristics on a Magnetically-Suspended 5-Caliber Ogive Cylinder. Final Report.** MIT-TR-193; BRL Rep. 328, Jan. 1977. 71 pp. (For a condensed and corrected version of the more extensive material in the above report see "Reverse Magnus Force on a Magnetically-Suspended Ogive Cylinder at

Subsonic Speeds" (No. 179 in this bibliography), AIAA Journal, Feb. 1978, by the same authors).

AD-A035861 N77-82310
or A78-23186#

The Magnus side force and yawing moment on a spinning 5-caliber ogive cylinder have been measured using the magnetic suspension and balance system at the MIT Aerophysics Laboratory. Data are reported at M = .27 to .43 and Re = 1 x 10^5 to 1.2 x 10^6 at non-dimensional spin rate, PD/2V between 0 and 0.14. The Magnus side force is found to undergo reversal from its classical direction at angles of attack below 5^o and Re = .77 x 10^6. Above 7^o angle of attack the side force is in the classical direction and in agreement with the data in the literature. The reverse Magnus force is a maximum at $\alpha = 2^o$. The peak value is reduced by increase in Reynolds number, by artificially induced boundary layer transition and by the presence of a support sting. At angles of 7^o and 9^o both artificial roughness and a support sting increase the size of the classical Magnus force. Results are compared with other reported data.

*M.I.T., Cambridge, Mass. 02139

Contract DAADO5-74-C-0735

176 *Finn, Douglas M.; *Haldeman, Charles W.; and *Covert, Eugene E.: **Wake Measurements Behind a Magnetically-Suspended Spinning and Non-Spinning Ogive Cylinder at Angles of Attack. Final Report.** MIT TR-195; BRL-CR-331. Feb. 1977, 77 pp.

AD-A037836 N77-27077#

Total pressure measurements were performed in the wake of a magnetically-suspended ogive nosed cylinder immersed in a subsonic flow. Profile drag was computed by the momentum defect method and compared to magnetic balance measurements. Impact pressure wake profiles were then recorded to investigate the effects of varying Reynolds number, angle of attack, spin rate, and transition wake characteristics. Fully turbulent boundary layer conditions served to attenuate this reverse Magnus force and promote a linear relationship between the induced sidewash angle and spin rate. Interpretation of the pressure surveys enabled a qualitative assessment of flow conditions about the body to be made, leading to suggestions as to a possible source of the observed phenomena. (The bulk of this material was part of the MS thesis by D. M. Finn dated Feb. 1976.)

*M.I.T., Cambridge, Mass. 02139

Contract DAADO5-74-C-0735

177 *Covert, Eugene E.; *Haldeman, Charles W.; and *Ziph, Benjamin: **Increasing the Force Limits of the Magnetic Balance System. Final Report, April 15, 1976—Sept. 30, 1977.** MIT-TR-199; ARO-13897.1-EX; Nov. 1977, 27 pp.

AD-A050746 N78-22121#

The construction and testing of new motor generator power supplies and filter inductors for use with the magnetic balance system were described. Motor generator output is plus or minus 380 volts with a current limit of plus or minus 300 amps and a power limit of 50 hp. Connected to the lift and drag circuits the supplies were tested up to 144 amperes in drag and 244 amperes in lift. Calculations of the performance of the 200 ampere 1.6 mh inductors as coupling networks were also presented as well as Q = (omega)(L/R) vs frequency measured for the coils. Measured Q at 20 KC was 660.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAAG29-76-C-0028

178 *Luh, Peter B.; *Covert, Eugene E.; *Whitaker, H. Phillip; and *Haldeman, Charles W.: **Application of Digital Control to a Magnetic Model Suspension and Balance System. Final Report, Apr. 1, 1976—Nov. 30, 1977.** MIT-TR-198, Dec. 1977, 120 pp. (This report was also published as NASA-CR-145316, Jan. 1978.)

N78-14060#
N78-20145#

The feasibility of using a digital computer for performing the automatic control functions for a magnetic suspension and balance system (MSBS) for use with wind tunnel models was investigated. Modeling was done using both a prototype MSBS and a one dimensional magnetic balance. A microcomputer using the Intel 8080 microprocessor is described and results are given using this microprocessor to control the one dimensional balance. Hybrid simulations for one degree of freedom of the MSBS were also performed and are reported. It is concluded that use of a digital computer to control the MSBS is eminently feasible and should extend both the accuracy and utility of the system. (This is a version of Luh's M.S. thesis.)

*M.I.T., Cambridge, Mass. 02139

Grant No. NsG-1292

179 *Birtwell, E. P.; *Coffin, J. B.; *Covert, E. E.; and *Haldeman, C. W.: **Reverse Magnus Force on a Magnetically Suspended Ogive Cylinder at Subsonic Speeds.** AIAA Journal, vol. 16, Feb. 1978, pp. 111—116. (This is a condensed and corrected version by the same authors, no. 175 in this bibliography.)

A78-23186#
or N77-82310

Data are presented showing an additional domain of reversed sign Magnus force coefficient. This phenomenon was found in essentially incompressible flow in a length Reynolds number range of at least 0.77 to 1.1 million and for an angle of attack range of 0 to ±4.5 deg. Furthermore the location of the center of pressure is independent of the sign of the Magnus force coefficient. Finally, the presence of a dummy sting support system and an artificially induced turbulent boundary layer causes the reversed sign region to vanish for all practical purposes.

*M.I.T., Cambridge, Mass. 02139

Grant Nos. DAAD05-74-C-0735; DAHC04-75-C-0001

180 *Haslam-Jones, T. F.: **Measurement of the Drag of Slender Cones in Hypersonic Flow at Low Reynolds Numbers Using a Magnetic Suspension and Balance.** Oxford Univ., Rep. No. OUEL-1235/78, March 1978, 119 pp.

N79-23938#

In order to carry out a comprehensive experimental survey of aerodynamic force on slender axisymmetric bodies in rarefied hypersonic flow, an electromagnetic jig and balance was built for use with the Oxford University low density tunnel. The design of this apparatus was based on the magnetic jig for spheres built in the same laboratory. The drag force measurements on sharp cones are given for freestream Reynolds numbers, based on cone diameter of 120 to 1200 at free stream Mach numbers between 5 and 9. These data were obtained by using a contoured nozzle and free jets. The results from the two types of flow devices overlapped and afforded direct comparisons between them. Comparisons are made with other experimental results and the general correlation of all relevant data is discussed.

*Oxford Univ., Engineering Laboratory, Parks Road, Oxford, OX1 3PJ, England

Min.-Def./PE-AT/2057/042

181 *Covert, E. E.; and *Haldeman, C. W.: **Initial Wind Tunnel Tests of a Magnetically-Suspended Spinning and Coning Ogive Cylinder. Final Rep., 1 Sept. 1974–31 Dec. 1977.** MIT-TR-201; Aero-12209.3-E, March 1978, 24 pp.

AD-A053758 N78-27090#

Research extending magnetic balance techniques to produce simultaneous spinning and coning motion of a magnetically-suspended wind tunnel model is reported. Initial measurements of the time varying normal force and side force on a model spinning at 100 rps while coning at 2 Hz are reported for coning angles up to 7 degrees and velocities up to 300 ft/sec. Analysis of initial data indicates that improvements in model position sensor stability, balance servo compensation, and data channel filtering will be required to produce data of desired quality.

*M.I.T., Cambridge, Mass. 02139

Contract No. DAAG29-75-C-0001

182 *Britcher, C. P.: **The Magnetic Suspension and Balance System in the Cryogenic Wind Tunnel.** Southampton Univ. B.Sc. Honours Project Report, April 1978, 95 pp.

N80-71565#

A fully developed magnetic suspension and balance system may in the future offer a test facility capable of rapid and accurate measurements of the overall aerodynamic characteristics, particularly all the aerodynamic derivatives, of aircraft models. It has been shown that high Reynolds Number capabilities are essential for much aerodynamic work, particularly at transonic speeds and where local or large scale flow separation occurs. It is shown in this report that for highest economy in balance system coil size and ampere turn and power requirements, high Reynolds Numbers are best achieved by cryogenic operation. Nitrogen, neon, and helium are identified as the most attractive test gases. Other advantages and the fundamental difficulties of the use of a cryotunnel with a magnetic suspension and balance system are identified. Suitable modifications, including construction of a new test section leg, allowed the installation of the Southampton University 0.1 m low speed cryogenic tunnel in the University's 6-component magnetic suspension and balance system. Tunnel temperatures in the range +92.8 C to -181.6 C have been achieved with a model in steady suspension. Drag coefficient measurements of a 7-calibre AN spinner model, over a very wide range of Reynolds Number are presented. Operational difficulties, so far encountered, can be overcome by suitable detail modifications.

*Southampton Univ., Southampton SO9 5NH, England

183 *Haslam-Jones, T. F.; and *Brundin, C. L.: **Vertex Angle and Flow Uniformity Effects on Rarefied Hypersonic Cone Drag.** In "Rarefield Gas Dynamics," Proceedings of the 11th International Symposium, Cannes, France, July 3–8, 1978, Vol I., (A80-34876), pp. 303-310.

A80-34897

Accurate experimental results, obtained with a new magnetic suspension and balance, present data on the drag of very slender cones in comparable free jet and uniform flow fields in low density hypersonic flow. Cones of semi-apex angles of 3, 5, 10, and 15 deg were tested at Mach numbers between 5.1 and 9 and base-diameter free-stream Reynolds numbers between 110 and 1200. The less slender cones were tested in free jets as well as in uniform flow, and a simple correction for flow gradient correlated the results so that the experiments were self-consistent. The very slender cone results display amplifications of rarefied viscous flow effects. The results agree with existing magnetic suspension data. Most available experimental data on sharp cone drag have been assembled and their correlation is discussed.

*Oxford Univ., Dept. of Engineering Science, Parks Road, Oxford OX1 3PJ, England

Ministry of Defence Contract AT/2057/042

184 *Kraemer, Richard A.: **Low A.C. Loss Superconducting Coils for a Wind Tunnel Magnetic Suspension and Balance System,** M. S. Thesis, MIT., NASA-CR-164289, Sept. 1978, 119 pp.

N81-74545

Superconducting theory and application, as obtained from the current literature, is analyzed and tested to determine that superconducting coil technology can be applied to magnetic suspension systems. It is determined from theory and proven by experiment that multifilament copper matrix composite superconductors cannot be used in coils for dynamic suspension of wind tunnel models. Single core copper composites are shown to be more efficient than the multifilament composite conductors for this application. A scheme for calculating the overall loss of an isolated superconducting coil subjected to an A.C. current is devised and shown to be accurate within twenty percent of measured losses.

*Graduate student, M.I.T., Cambridge, Mass. 02139

Grant no. NSG-1356

185 *Haldeman, Charles W.; **Kraemer, Richard A.; and *Way, Peter: **Developments at M.I.T. Related to Magnetic Model Suspension and Balance Systems for Large Scale**

Facilities. Paper no. 9, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, U.K., April 3–5, 1979.

A80-24087#

Magnetic model suspension and balance systems for wind tunnel use have been designed, tested and used at M.I.T.'s Aerophysics Laboratory for over eighteen years. Despite this experience, which demonstrates the utility and durability of the magnetic model suspension and balance systems, no large-scale system has yet been constructed for use anywhere in the world. This appears to be principally due to the large capital cost of such a facility. This paper presents several attributes of magnetic balance systems which make them attractive for use in large-scale cryogenic facilities and reports on recent developments in model roll control and superconducting coil construction, which enhance system versatility and reduce the electrical power requirements.

*M.I.T., Cambridge, Mass. 02139
**Arizona State Univ., Tempe, Arizona, 85281

186 *Britcher, C. P.; and *Goodyer, M. J.: **The Southampton University Magnetic Suspension/Cryogenic Wind Tunnel Facility.** Paper no. 10, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, U.K., Apr. 3–5, 1979.

Scaling laws relating design parameters of magnetic suspension and balance systems to wind tunnel test conditions are identified. Reduction of test temperature is found to be the most attractive and powerful technique of reducing the cost of a magnetic suspension facility for specific test Reynolds Number and Mach Number requirements. Details of the adaption of a small, low-speed, fan driven cryogenic wind tunnel for use with a magnetic suspension and balance system are given. Aerodynamic data has been acquired from a model suspended in the new facility over a wide range of tunnel conditions. Temperature is shown to have a small effect on the magnetization of the model magnetic cores. Studies of the effect have begun.

*Southampton Univ., Southampton SO9 5NH, England

187 *Chan, Y. M.: **Sensitivity Adaptive Control of a Magnetic Suspension System.** Rept. No. UILU-ENG-78-2236 DC-25. Illinois University at Urbana-Champaign, MS Thesis, May 1979, 97 pp.

AD-A077148 N80-21052#

This project is concerned with the study of the behavior of a particular stochastic system, the magnetic suspension system, under the application of the Sensitivity Adaptive Feedback with Estimation Redistribution (SAFER) Control Algorithm. Matrix factorization techniques are used in the controller and estimator design for the system. Simulation results indicate that the magnetic suspension system can operate satisfactorily under the SAFER control method: and factorization techniques indeed enhance the numerical stability of computations. However, due to the complex structure of the SAFER control method, real time application of the algorithm may require faster computing device or simplified mathematical model. Its application will be most pertinent to system with slow time constants.

*Illinois University, Urbana-Champaign, Decision & Control Lab., Urbana, Illinois 61801

Contracts DAAG29-78-C-0016; NSF ENG-74-20091; AF-AFOSR-3633-78; NSF INT-77-2069

188 *Way, Peter: **A Roll Control System for a Magnetic Wind Tunnel Balance and Model Suspension System.** MIT M.S. Thesis, June 1979, 80 pp. NASA-CR-162640

N80-71553#

A system for controlling the roll degree of freedom in a magnetic wind tunnel balance is designed, constructed, and evaluated. The capabilities of the electromagnetic position sensor in use with the five degree of freedom system are extended to include roll position sensing. An analog drive circuit is devised to apply magnetic rolling moments to the model with a single phase transverse A.C. field. General improvements for the existing compensation and position sensing systems are discussed. Torque versus field and position sensor data for a prototype roll model are given.

*M.I.T., Graduate student, Cambridge, Mass. 02139

189 *Solomon, M.; *Finston, M.; and *Haldeman, C. W.: **Wake Studies Related to Reentrant Pyramids. Final Rep., 1 Jan. 1976–30 Nov. 1978.** MIT-TR-205, Aug. 1979, 82 pp. AFOSR-79-0984TR.

AD-A073825 N80-12105#

The original objectives of this project were to completely map the reentrant pyramid near wake with pitot pressure and recovery temperature probes in order to study the axial development of the wake's azimuthal asymmetry. Although only a modest amount of data has been collected, compared to our original goal, sufficient information is available to identify most features of the pyramid's wake and to make a comparison to the axisymmetric cone wake.

*M.I.T., Cambridge, Mass. 02139
Contract No. F44620-76-C-0049

190 *Goodyer, M. J.: **Cryogenic Wind Tunnel Activities at the University of Southampton.** NASA-CR-159,144, Sept. 1979, 9 pp.

N80-10231#

The cryogenic wind tunnel was born as a result of research into the magnetic suspension of wind tunnel models, and as the University had a cryogenic tunnel and a 6-component balance it seemed appropriate to link them. Modification of the tunnel has continued to refine the test technique. The refinements include the addition of automatic data acquisition equipment with on line reduction and real time reduced data displays for the operators. An outline of the circuit is given showing the locations of the magnet system and some of the key features of the tunnel. The test procedure comprises launching the model by hand at room temperature using the hatch, closing up the tunnel, acquiring a good set of wind-off tunnel and balance data, then running the tunnel while cooling down. Wind-on data is acquired, reduced and displayed continuously, but data taken during speed or temperature changes is rejected. Typical data is shown which was taken in the temperature band 100 K to 360 K. With more experience we would expect to reduce the scatter, but the work has already served to show that the combination of magnetic suspension with cryogenic wind

tunnel does not raise insuperable technological problems. Further, this is one force balance which is relatively immune to the cryogenic environment.

*Univ. of Southampton, Southampton, SO9 5NH, England

NASA Grant NSG-7523

191 *Prey, Scott W.: **A. C. Losses in Interacting Superconducting Magnet Coils.** MIT, M.S. Thesis, Sept. 1979, 75 pp. NASA-CR-162580

N80-71702#

Theory of type II superconductivity is discussed as it applies to magnetic suspension systems. A scheme to predict losses in pairs of adjacent coils is developed and the results compared with data obtained by experiment. Problems to be faced in future work are discussed.

*M.I.T., Graduate student, Cambridge, Mass. 02139

NASA Grant 1356

192 *Haldeman, Charles W.; and *Covert, Eugene E.: **New Techniques for Production of Combined Spinning and Coning Motion with Magnetically-Suspended Wind Tunnel Models.** Presented at the 8th Int. Congress on Instrumentation in Aerospace Simulation Facilities. Sept. 24–26, 1979. Naval Postgraduate School, Monterey, Calif.

A80-29476, pp. 194–200
or N80-71554#

In recent years the magnetic balance and suspension system has been developed as a useful laboratory tool for conducting wind tunnel tests of high accuracy without model support interference. In addition to removing support interference the magnetic balance offers the capability of producing complex model motion. This paper describes techniques which have been recently developed to produce combined spinning and coning motion of a magnetically-suspended ogive cylinder. These techniques include use of a multichannel system for forcing all degrees of freedom to produce the desired motion, development of an analogue compensator to reduce gyroscopic model responses, and new methods of data acquisition from the moving model.

*M.I.T., Cambridge, Mass. 02139

Research supported by U.S. Army Research Office, Durham, North Carolina

193 *Britcher, C. P.; *Fortescue, P. W.; *Allcock, G. A.; and *Goodyer, M. J.: **Investigation of Design Philosophies and Features Applicable to Large Magnetic Suspension and Balance Systems.** NASA-CR-162433, Nov. 1979, 35 pp.

N80-11104#

The technology which is required to allow the principles of magnetic suspension and balance systems (MSBS) to be applied to the high Reynolds number transonic testing of aircraft models is examined. A test facility is presented as comprising a pressurized transonic cryogenic wind tunnel, with the MSBS providing full six degree of freedom control. The electro-magnets which are superconducting and fed from quiet, bipolar power supplies are examined. A model control system having some self-adaptive characteristics is discussed.

*Southampton Univ., Southampton SO9 5NH. England

Grant No. NSG-7525

194 *Alishahi, Mohammad M.: **Preliminary Design of a Superconducting Coil Array for NASA Prototype Magnetic Balance.** M.S. Thesis. NASA CR-164027, May 1980, 67 pp.

N81-18064#

Using a computer program a partly optimized configuration for a superconducting version of side and lift coil system of NASA-MIT prototype is presented. Cable size for the mentioned coils and also for superconducting drag and magnetizing coils regarding the overall computed field was determined.

*Graduate student, MIT, Dept. of Aeronautics and Astronautics, Cambridge, MA 02139

Grant NsG-1356

195 *Haldeman, C. W.; *Kraemer, R. A.; *Prey, S. W.; *Alishahi, M. M.; and *Covert, E. E.: **Application of Superconducting Coils to the NASA Prototype Magnetic Balance.** Final Rept. Jan. 1, 1977 – Aug. 31, 1980. MIT TR-207, Nov. 1980; NASA CR-165660, 142 pp.

N81-20086#

Application of superconducting coils to a general purpose magnetic balance is studied. Under the conditions of operation with fields of 1 or 2 teslas and frequencies of 20-40 Hz as well as D.C., the most suitable currently available superconducting cable for coils appears to be a bundle of many fine wires which are transposed and are mechanically confined. Sample coils were constructed and tested using such a cable of 220 strands of varnish-insulated, 0.064 mm O.D., copper-stabilized Nb-Ti superconductor and cables of the same superconducting area, but fifty-five 0.122 mm diameter strands. Sample coils were tested at central A.C. fields up to 0.5 tesla, slewing rates up to 53 tesla/sec and frequencies up to 30 Hz. A.C. losses were measured from helium boil-off and were approximately 20 percent higher than those calculated. Losses were dominated by hysteresis and a model for loss calculation which appears suitable for design purposes is presented along with the computer listings. Combinations of two coils were also tested and interaction losses are reported. Again, the proposed loss models appear adequate at high currents for which design calculations would be carried out. Two feasible geometries are presented for a version of the NASA-MIT prototype magnetic balance using superconductors.

*Mass. Inst. of Technology, Aerophysics Lab., Cambridge, Mass. 02139

Grant NSG1356

196 *Covert, E. E.; *Eberhardt, D. S.; and *Haldeman, C. W.: **Further Studies on Magnus Phenomena on Spinning and Coning Bodies. Final Rept., 25 Oct. 1978 – 24 Oct., 1980.** Rept. No. MIT-TR-209; ARO-15813.3-E. Dec. 1980, 17 pp.

AD-A095193 N81-20032#

Further research on adapting the magnetic balance system for dynamic testing is reported. System improvements are discussed and initial data on a magnetically-suspended ogive cylinder plunging at 2 Hz are reported. Results of a simplified theoretical model for the Magnus force on a spinning body of revolution are also reported.

*Massachusetts Inst. of Tech., Aerophysics Lab., Cambridge, Mass. 02139

Contract DAAG29-79-C-0002

197 *Tuttle, Marie H.; and *Gloss, Blair B.: **Support Interference of Wind Tunnel Models: A Selective Annotated Bibliography.** NASA-TM-81909, March 1981, 36 pp.

N81-20084#

This bibliography, with abstracts, consists of 143 citations arranged in chronological order by dates of publication. Selection of the citations was made for their relevance to the problems involved in understanding or avoiding support interference in wind tunnel testing throughout the Mach number range. An author index is included.

*NASA, Langley Research Center, Hampton, Va. 23665

198 *Fortescue, P. W.; and *Bouchalis, C.: **Digital Controllers for the Vertical Channels of a Magnetic Suspension System.** NASA-CR-165,684, May 1981, 33 pp. (Period covered Nov. 1, 1979 – Nov. 1, 1980)

N81-26159#

The Southampton University Magnetic Suspension System has an analog controller which is being replaced by a digital filter. The report covers the first stage of conversion in which two of the six degrees of freedom, viz vertical heave and pitch, have been fitted with a digital version of the analog filters. Direct replacements for the analog phase advance filters were used and performance comparisons were made. In addition, a mathematical model of the magnetic coils and suspended model was developed for future small angle use.

*Univ. of Southampton, Dept. of Aeronautics & Astronautics, Southampton S09 5NH, England

Grant NSG-7523

199 *Britcher, C. P.: **Electromagnet Configurations for Extreme Attitude Testing in Magnetic Suspension and Balance Systems.** Semiannual Progress Rept., period ending Dec. 1980. NASA-CR-163862, May 1981, 22 pp.

N81-15008#

A preliminary examination is made of the impact on conventional wind tunnel magnetic suspension and balance system configurations of a requirement to suspend models over a wide range of attitudes relative to the balance system. The problem of gross changes in the system's magnetic couplings is addressed. Computations concerning a 10 electromagnet system in the classical "+" arrangement, representative of the system under construction at Southampton University, indicate that a permanent magnet model could usefully be suspended to approximately 45^{o} angle of attack in the vertical plane. The study continues towards the exploration of higher angles of attack.

*Univ. of Southampton, Dept. of Aeronautics and Astronautics, Southampton S09 5NH, England

Grant NSG-7523

200 *Britcher, C. P.: **An Assessment of the Performance of the Spanwise Iron Magnet Rolling Moment Generating System for Magnetic Suspension and Balance Systems, Using the Finite Element Computer Program "GFUN."** NASA-CR-165888, April 1982, 60 pp.

N83-18747#

Development of a powerful method of magnetic roll torque generation is essential before construction of a Large Magnetic Suspension and Balance System (LMSBS) can be undertaken. Some preliminary computed data is presented concerning a relatively new D.C. scheme, referred to as the Spanwise Iron Magnet scheme. Computations have been made using the finite element computer program 'GFUN' and indicate that adequate torque is available for at least a first generation LMSBS. Torque capability appears limited principally by current electromagnet technology.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton S09 5NH, England

Grant NSG-7523

201 *Bloom, H. L.: **Design Concepts and Cost Studies for Magnetic Suspension and Balance Systems, Final Rept. Nov. 1980 – Mar. 1981.** NASA-CR-165917, July 1982, 346 pp.

N82-33404#

This report presents the final results of a study of the application of superconducting magnets for suspension and balance of wind tunnel models. Conceptual designs are presented for Magnetic Suspension and Balance System (MSBS) configurations compatible with three high Reynolds number cases representing specified combinations of test section conditions and model sizes. Concepts, in general, met initially specified performance requirements such as duty cycle, force and moment levels, model angular displacement and positioning accuracy with nominal design requirements for support subsystems. Other performance requirements, such as forced model sinusoidal oscillations, and control force magnitude and frequency, were modified to alleviate the magnitude of magnet, power, and cryogenic design requirements.

*General Electric Company, Energy Systems Programs Dept., Schenectady, N.Y. 12345

NAS1-16000

Prepared for Kentron International, Inc., Hampton, Va. 23666

202 *Britcher, C. P.: **Some Aspects of Wind Tunnel Magnetic Suspension Systems With Special Application at Large Physical Scales.** Univ. of Southampton Ph.D. Thesis, July 1982, 320 pp., 66 refs. (To be published as a NASA-CR.)

Wind tunnel magnetic suspension and balance systems (MSBSs) have so far failed to find application at the large physical scales necessary for the majority of aerodynamic testing. Three areas of new technology relevant to such application are investigated. Two variants of the new Spanwise Magnet roll torque generation scheme are studied. Spanwise Permanent Magnets are shown to be practical and are experimentally demonstrated using the Southampton University MSBS. Extensive computations of the performance of the Spanwise Iron Magnet scheme indicate powerful capability, limited principally by electromagnet technology. Aerodynamic testing at extreme attitudes is shown to be practical in relatively conventional MSBSs. Preliminary operation of the Southampton MSBS over a wide range of angles of attack is demonstrated. The impact of a requirement for highly reliable operation on the overall

architecture of Large MSBSs is studied and it is concluded that system cost and complexity need not be seriously increased.

*University of Southampton, Dept. of Aeronautics and Astronautics, Southampton S09 5NH, England

NSG-7523 (Partial support)

203 *Wu, Yu Yuan: **Design of a Horizontal Liquid Helium Cryostat for Refrigerating a Flying Superconducting Magnet in a Wind Tunnel.** NASA-CR-165980, Progress Rept. June 1981 – April 1982, Aug. 1982, 65 pp.

N83-10081#

Note: This report consists of a Master of Science Thesis by Y. Y. Wu dated December 1981 with appendix by **Dr. R. G. Scurlock dated March 24, 1982.

The design of a horizontal liquid helium cryostat for refrigerating a flying superconducting magnet in a wind tunnel is presented. The basic principles of magnetic suspension theory are described and theoretical calculations of the superconducting magnet are provided. The experimental results of the boil-off of liquid nitrogen and liquid helium in the cryostat are reported.

*University of Southampton, Dept. of Aeronautics and Astronautics, Southampton SO9 5NH, England
**University of Southampton, Institute of Cryogenics, Southampton S09 5NH, England

NSG-7523

204 *Covert, E. E.; *Haldeman, C. W.; *Ramohalli, G.; and *Way, Peter: **Development of Closed Loop Roll Control for Magnetic Balance Systems. Final Rept. Feb. 1978 to Feb. 1982.** NASA-CR-166017, Oct. 1982, 87 pp.

N83-13122#

This research was undertaken with the goal of demonstrating closed loop control of the roll degree of freedom on the NASA prototype magnetic suspension and balance system at the MIT Aerophysics Laboratory, thus, showing feasibility for a roll control system for any large magnetic balance system which might be built in the future. During the research under this grant, study was directed toward the several areas of torque generation, position sensing, model construction and control system design. These effects were then integrated to produce successful closed loop operation of the analogue roll control system. This experience indicated the desirability of microprocessor control for the angular degrees of freedom.

*Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Cambridge, Massachusetts 02139

NSG-1502

205 *Humphris, R. R., and *Zapata, R. N.: **Development of the Design Concepts for a Medium-Scale Wind Tunnel Magnetic Suspension System.** Final Rept., Feb. 1977 to Sept. 1982, UVA/643078/MAE82/111; NASA-CR-166042, Dec. 1982, 38 pp.

N83-15320#

These results show a direct determination of the magnitude of AC losses from a superconducting coil of a size required for operation of larger magnetic suspension systems, and the design of such a suspension facility should now be carried out with a much greater confidence. This test of a 50 cm diameter superconducting coil strongly indicates that the predicated scaling laws are valid. Evidently, the stainless steel bands around the test coil were the source of additional helium boil-off due to a transformer action and, hence, caused erroneously high AC loss measurements in the first run. However, removal of these bands for the second run produced data which are consistent with previous results on small-scale multifilamentary superconducting coils.

An Appendix consists of a paper by *T. V. Pierce, Jr. and *R. N. Zapata entitled **Superconductor Coil Geometry and AC Losses**, and which was published in the Journal of Applied Physics, vol. 47, no. 8, August 1976, pp. 3745-3746.

*University of Virginia, Department of Mechanical and Aerospace Engineering, Charlottesville, Va. 22901

NSG-1010

206 *Dahlen, G. A.; and *Brundin, C. L.: **Wall Temperature Effects on Rarefied Hypersonic Cone Drag.** Presented at the 13th International Symposium on Rarefied Gas Dynamics held July 5 – 9, 1982, at Novosibirsk, U.S.S.R., and will appear in the Proceedings of the conference.

An experimental study has been made of wall temperature effects on hypersonic zero-incidence cone drag in the near-continuum to transition regimes using a magnetic suspension and balance. Cone wall-to-stagnation temperature ratios (T_w/T_o) were systematically reduced for models with semi-vertex angles (θ_c) of 3, 6, 10 and 15 degrees. The resulting data indicate a consistent reduction in drag as the ratio T_w/T_o is decreased from 1.0 to 0.18. For the present range of flow conditions, the effect of wall temperature increases with a reduction in cone angle.

*Oxford University, Dept. of Engineering Science, Parks Road, Oxford, OX1 3PJ, England

Research supported by Ministry of Defence

CORPORATE SOURCE INDEX
(Affiliation of Authors)

AUTHOR INDEX

SUBJECT INDEX

NOTE: The following index, although in no way complete, might be useful by giving an indication of where some material on definite subject areas may be found. Generally, surveys and summaries are not indexed in depth.

(c.) Comprehensive — Surveys

29, 38, 43, 83, 151, 155, 182, 183, 193, 201, 202, 203, 204, 205

(d.) Comprehensive — Summaries

22, 26, 30, 33, 42, 50, 53, 54, 55, 68, 71, 79, 81, 87, 90, 94, 98, 105, 108, 112, 165, 172, 173, 190

4. Control Techniques (See also Roll Control)

11, 12, 16, 17, 68, 70, 79, 82, 83, 90, 95, 98, 124, 129, 133, 143, 151, 155, 158, 160, 172, 173, 174, 178, 187, 193, 198, 202, 204

5. Data Acquisition and Reduction

(a.) General

75, 81, 83, 84, 94, 106, 130, 131, 135, 146, 152, 153, 155, 157, 166, 168, 174, 181, 196

(b.) Telemetry

19, 21, 24, 59, 73, 86

6. Design and Fabrication

6, 11, 12, 14, 15, 16, 18, 26, 33, 35, 36, 37, 41, 43, 45, 48, 50, 51, 53, 54, 55, 59, 63, 68, 71, 76, 79, 80, 81, 83, 90, 93, 95, 98, 105, 124, 125, 126, 128, 133, 138, 139, 140, 143, 151, 155, 165, 167, 177, 180, 182, 186, 188, 193, 201, 203, 204, 205

7. (a.) Electromagnets — Conventional

6, 9, 11, 12, 26, 29, 31, 33, 36, 37, 40, 45, 47, 50, 54, 56, 63, 90, 92, 98, 143, 155, 199

(b.) Electromagnets — Supercooled

11, 12, 51, 71, 78

(c.) Electromagnets — Superconducting

32, 71, 78, 81, 94, 98, 108, 109, 118, 124, 125, 126, 139, 140, 149, 158, 159, 161, 165, 167, 169, 170, 182, 184, 185, 191, 193, 194, 195, 201, 202, 203, 205

8. Flow — Visualization

18, 29, 30, 80, 102, 105, 171

9. Historic

1, 2, 3, 4, 6, 7, 26, 59, 77, 123, 155

10. Magnetic Fields

12, 32, 33, 36, 44, 51, 68, 92, 95, 106, 109, 118, 125, 126, 130, 143, 155, 170, 182, 194, 202

11. Models

(a.) General

23, 25, 40, 41, 65, 69, 70, 76, 84, 88, 111, 134, 135, 153, 157, 196, 204

(b.) Superconducting Cores

109, 118, 125, 203

12. Operational Procedures or Techniques

33, 34, 37, 41, 43, 46, 49, 56, 58, 61, 62, 63, 64, 65, 67, 70, 87, 88, 90, 93, 98, 103, 106, 109, 115, 118, 120, 124, 131, 138, 139, 140, 142, 155, 158, 159, 165, 170, 171, 172, 173, 174, 181, 186, 190, 192, 198, 200, 201, 202

13. Position Sensing

11, 12, 33, 42, 44, 67, 69, 70, 80, 90, 95, 98, 105, 127, 128, 129, 133, 138, 142, 152, 153, 157, 167, 169, 172, 173, 181, 188, 204

14. Power Supplies

56, 63, 68, 72, 78, 79, 81, 83, 90, 95, 98, 108, 124, 126, 132, 155, 160, 161, 177, 182, 185, 193

15. Roll Control

25, 30, 33, 42, 44, 49, 50, 62, 67, 70, 79, 83, 99, 127, 133, 142, 185, 188, 200, 202, 204

16. Safety

64, 67, 87, 90, 124, 139, 149

17. Scaling

72, 78, 81, 87, 98, 126, 152, 155, 158, 159, 161, 165, 186

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16. Abstract

This publication, containing 206 entries, supersedes an earlier bibliography, NASA TM-80225 (April 1980). Citations for 18 documents have been added in this updated version. Most of the additions report results of recent studies aimed at increasing the research capabilities of magnetic suspension and balance systems, e.g., increasing force and torque capability, increasing angle of attack capability, and increasing overall system reliability. Some of the additions address the problem of scaling from the relatively small size of existing systems to much larger sizes. The purpose of this bibliography is to provide an up-to-date list of publications that might be helpful to persons interested in magnetic suspension and balance systems for use in wind tunnels. The arrangement is generally chronological by date of publication. However, papers presented at conferences or meetings are placed under dates of presentation. The numbers assigned to many of the citations have been changed from those used in the previous bibliography. This has been done in order to allow outdated citations to be removed and some recently discovered older works to be included in their proper chronological order.

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