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Technical Memorandum 4318

...netic Suspension and ...nce Systems

...mprehensive, Annotated Bibliography

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NASA Technical Memorandum 4318

Magnetic Suspension and Balance Systems

A Comprehensive, Annotated Bibliography

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NASA

National Aeronautics and
Space Administration

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Contents

Magnetic Suspension and Balance Systems

Organization	Degrees of freedom*	Size, cm	Mach number	Use	Approximate dates of operation
ONERA	5	8.5 x 8.5	1 to 3	Drag, base pressure	1957–58
ONERA	5	6.0	7	Drag, base pressure	1958–62
Mass. Inst. of Tech. (MIT)	5	10.2 x 10.2	4.8	Static & dynamic	1962–71
ONERA	6	30.0	7	Base pressure & heat transfer	1962–71
University of Southampton	5 / 6	15.2 x 20.3	0 to 1.8	Static & dynamic	1962–present
NASA Langley	1	12.1	Low speed	Research & development	1964–65
Princeton University	3	15.2	16	Wake studies	1964–70
University of Virginia	5	10.2	7.6	Cone & sphere drag	1964–77
AEDC / NASA Langley 13-inch MSBS	5	27.2 x 31.9	8 / 0 to 0.5	Wake studies / R & D	1965–70 / 1979–present
RAE / U. of Southampton	5	17.8 x 17.8	8.6	Sting effect & magnus	1966–77
University of Michigan	1	5.1	Subsonic	Low Rn sphere drag	1968–71
MIT / NASA Langley 6-inch MSBS	5 / 6	15.2 octag.	0 to 0.5	Aero. testing / R & D	1969–82 / 1984–present
Oxford University	2	14	5 and 9	Low density sphere & cone drag	1971–75
University of Virginia	3	15.2	3 / Subsonic	Dynamic stability R & D	1973–82
Oxford University	3	12 x 12	Hypersonic	Low density sphere & cone drag	1975–present
MAI / TsAGI (U.S.S.R.)	5	40 x 60	Subsonic	Aerodynamic research	1983–present
NAL (Japan)	5 / 6	10 x 10	Transonic	Research & development	1987–present
MAI (U.S.S.R.)	6	30 x 40	Subsonic	Research & development	1989–present
NAL (Japan)	6	60 x 60	Subsonic	Research & development	Under Construction

RAK 6/91

* degrees of active control

Presently active systems.

INTRODUCTION

This bibliography contains 301 entries. It updates and supersedes earlier NASA bibliographies on Magnetic Suspension and Balance Systems (TM-80225, April 1980, and TM-84661, July 1983). Many of the additions report results of studies aimed at increasing the research capabilities of magnetic suspension and balance systems. For example, 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 list unclassified publications that might be useful to anyone interested in designing, building, and using magnetic suspension and balance systems (MSBSs) for wind tunnels. Also included are some publications of historical interest which relate to key events in the evolution of magnetic suspension and balance systems. 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 MSBS. This arrangement also aids in locating specific papers.

The numbers assigned to many of the citations have been changed from those used in the previous bibliography. We did this so we could include some recently discovered older works in their proper chronological order. We have noted those items which were published in several forms.

We have included author, source, and subject indexes in order to increase the usefulness of this compilation.

Usually, we used abstracts from the NASA announcement bulletins *Scientific and Technical Aerospace Reports (STAR)* and *International Aerospace Abstracts (IAA)*. In other cases, we used abstracts supplied by the authors. We modified or shortened some abstracts, using only parts pertinent to MSBS. The information included about the authors' affiliation was correct at the time the paper was written.

We include accession numbers, report numbers, and other identifying information in the citation to make it easier for the libraries to fill requests for specific items. When requesting material, it is best to include the complete citation; the abstract may be omitted.

Listed on the next page is information to help when requesting the different types of materials.

ORDERING INFORMATION

Ordering sources for the different types of materials are given below:

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N??-????? Example: N77-12345	Report literature having no distribution limitations.	NASA Center for AeroSpace Information (CASI) P. O. Box 8757 B.W.I. Airport, MD 21240
X??-????? Example: X66-12345	Report literature having some distribution limitation.	NASA Center for AeroSpace Information (CASI) P. O. Box 8757 B.W.I. Airport, MD 21240
N-????? Example: N-12345	Pre-1962 reports and papers.	NASA libraries
Example: TL123 C66	Books	Libraries

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ISSN is an acronym for International Standard Serial Number, an internationally accepted code for the identification of serial publications; it is precise, concise, unique, and unambiguous.

ISBN is an acronym for International Standard Book Number, a number which is given to every book or edition of a book before publication to identify the publisher, the title, the edition, and volume number.

BIBLIOGRAPHY

1. *Holmes, F. T.: **Axial Magnetic Suspensions.** Review of Scientific Instruments, vol. 8, November 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 $g \cdot cm^2$ was suspended in this manner. It was spun at about 1200 r/s, its behavior indicating that with suitable driving arrangements much higher speeds should be attainable. At 600 r/s, with driving torque zero, it exhibited a deceleration of about 2×10^{-3} r/s^2. A suspended element weighing about 0.75 g showed torsion constants, depending on adjustments, down to 7×10^{-6} dy·c-m/rad.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

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; it 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
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, December 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, 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 07003 U.S.A.

Note by compilers: The ac levitation discussed in this paper has no direct application to the magnetic suspension of models in wind tunnels. However, the paper is included in this bibliography for its historic interest as an example of the early work on ac 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

5. Boerdijk, A. H.: **Technical Aspects of Levitation.** Phillips Research Rep. No. 284, vol. 11, 1956, pp. 45-56.

N80-71570#

Levitation of a body is defined here 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, reaction forces, and forces in electromagnetic fields are studied. Levitation by gravitational forces or by radiation pressure is not feasible in practice, while levitation by forces in electrostatic fields is theoretically impossible. Under certain conditions, levitation may be achieved by reaction forces and forces in magnetostatic, stationary, and quasi-stationary electromagnetic fields. Published applications comprise balances, centrifuges, and a method for melting metals in a vacuum without a crucible.

6. *Tournier, M.; 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-August 1957, pp. 21-27.

N80-71571 (In English)

A new method of suspending models has been worked out and 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 used 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 National Office of Aeronautical Studies and Research (ONERA) to seek a means of supporting a model in a position determined by immaterial bonds so that the fluid flow around the body is not disturbed either by the sides of the test cell (the consequences of whose perturbation creates the object of particular studies) or 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 use one or more iron-core electromagnets acting astride a bar of soft iron which constitutes the body of the model.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, 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, January 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 study 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 studying boundary layer phenomena.

*Columbia University, New York, NY 10128 U.S.A.
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, May 1958, pp. 8-16.

NASA Langley Library No. N-49028, Vol. 1

This paper gives some possible uses of the free electromagnetic support developed by the University 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

9. *Tournier, M.; *Laurenceau, P.; and *Dubois, G.: **La Suspension Magnetique ONERA.** Paper presented at the First International Symposium on Rarefied Gas Dynamics, Nice, France, July 2-5, 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. They are 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 Mach numbers of 3.75 and 5.4 and Reynolds numbers from 130,000 to 500,000.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

10. *Rebuffet, P.: **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#

Note: For an English translation see citation no. 218 in this bibliography.

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 National Office of Aeronautical Studies and Research (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.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

11. *Jenkins, A. W.; and *Parker, H. 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 NASA Langley Technical Library No. N-79503

The original electromagnetic support developed in the late 1930s 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 the amount of coupling to be expected due to deviations from the ideal system.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Contract No. NONR-474(04)

12. *Fosque, H. S.; and *Miller, G.: **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 built. 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Contract No. NONR-474(04)

13. *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 made 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 Co., Cincinnati, OH 45215 U.S.A.

14. *Mirande, J.: **Mesure de la Résistance d'un Corps de Révolution à M_∞ = 2.4, au Moyen de la Suspension Magnétique ONERA (Measurement of the Drag of a Body of Revolution at M_∞ = 2.4, using the ONERA 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 Rep. No. 302 which is citation no. 10 in this bibliography.)

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

15. *Tilton, E. L., III; and *Schwartz, S.: **Static Tests on the Magnetic Suspension System.** M.I.T., Naval Supersonic Laboratory, AR Memo 399, July 20, 1959, 18 pp.

N80-71555#

As a thesis project by Chrisinger, a magnetic suspension system for the Naval Supersonic Lab (NSL) Hypersonic Wind Tunnel was designed and built. 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 6 inches long and 1/2 inch in diameter.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

16. *Tilton, E. L., 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.

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 performance of the system are given.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

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

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 are 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

18. *Cole, R. A.: **Magnetic Suspension Holds Wind-Tunnel Models.** In: Aircraft and Missiles, vol. 3, No. 10, October 1960, pp. 37-38.

A system developed in France eliminates model support structures and greatly reduces interference problems in data acquisition. World interest was stimulated by initial success with a 12-inch National Office of Aeronautical Studies and Research (ONERA) tunnel. The results of a limited number of tests, mainly with the drag values of a body of revolution, have been considered very satisfactory and worthy of further development. These tests were carried out in two tunnels and covered the speed range up to Mach 1.15.

*European Member, Editorial Board

19. *Dubois, G.; and *Rougé, C.: **Sur une Méthode de Mesure de la Pression de Culot-Mesure et Visualisation sur une Maquette Cylindro-Conique Suspendue Magnétiquement à $M_\infty \simeq 7.6$** La Recherche Aéronautique, no. 79, November-December 1960, pp. 35-44. (In French).

N80-71567# (In French)

English translation by **Zapata, R. N., **On a Method for Measuring the Base Pressure: Measurement and Visualization on a Cone Cylinder Magnetically Suspended at $M_\infty \simeq 7.6$.** 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 National Office of Aeronautical Studies and Research (ONERA) magnetic suspension for keeping the model on the axis of 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, B.P. 72, F-92322 Châtillon Cedex, France
**University of Virginia, Charlottesville, VA 22901 U.S.A.

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.** University 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
5. Subjects related to other aspects of the entire program, pp. 56-67

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Contract No. AF 33(616)-7864

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

A69-11623

Note: Translation into English is NASA-TT-20277 (X88-10285#), June 1988, available to U.S. Government Agencies and their contractors only. For an ONERA publication on this topic see citation no. 89 in this bibliography.

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

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

22. *Judd, M.: **Feasibility Study of Magnetic Suspension for Derivative Measurement.** Progress Report, August 1961, DCAF F003662, University of Southampton Rep. No. AASU-191, 15 pp.

N87-70634#

Topics discussed in this paper include the following: Outline of steady-force calculations; Stabilization of the Support System; Oscillatory Force Calculations; Method of Measurement; Coil Design; Proposed Layout; and Conclusions and Future Work. The feasibility study has been carried out under a D.S.I.R. contract which also covers a study of a possible method of derivative measurement using a random exciting force.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

23. *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, March 1962, 40 pp.

N62-10806#

The design concepts are presented for a free electromagnetic suspension system functioning as a 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 the 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 uses are discussed.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Contract No. AF 49(638)-1022

24. *Dubois, G.: **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.)

Note: For an English translation, see citation no. 220 in this bibliography.

This paper is concerned with the experimental determination of minimum drag of ogives at supersonic and hypersonic speeds using the National Office of Aeronautical Studies and Research (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 and 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, B.P. 72, F-92322 Châtillon Cedex, France

25. *LaGraff, J. E.: **Some Calibrations and Measurements on Models Magnetically Suspended in a Hypersonic Tunnel.** M.I.T., Thesis for B. S. degree, May 1962, 36 pp.

N80-70406#

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

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

26. *Lawton, M. P.: **Design and Calibration of a Finned Model Magnetically Suspended in a Hypersonic Tunnel.** M.I.T., Thesis for B.S. degree, June 1962, 47 pp.

N80-70421#

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

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

27. *Clemens, P. L.: **Radio Telemetry of Stagnation Pressure from a Wind Tunnel Model Magnetically Supported in Super-**

sonic 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 used. 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 Kárman Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. AF 40(600)-1000

28. *Tilton, E. L., III; *Parkin, W. J.; *Covert, E. E.; *Coffin, J. B.; and *Chrisinger, J. E.: **The Design and Initial Operation of a Magnetic Model Suspension and Force Measurement System.** Rep. No. MIT-TR-22, August 1962. ARL-63-16, January 1963. Covers period February 1960 - May 1962.

N63-16372#

The design, construction, and proof tests of a magnetic model suspension system capable of use in an M = 4.8 wind tunnel is described. The results indicate the model can be suspended magnetically during the wind tunnel starting conditions, that the model can be positioned at different angles, and lift and drag forces measured with the model at angle of attack.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33 (616)7023.

29. *Tilton, E. L., III: **Dynamic Stability Testing With a Wind Tunnel Magnetic Model Suspension System.** M.I.T., Thesis for M.S. degree, January 1963, 48 pp.

N80-70419#

A study 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

30. *Clemens, P. L.; and *Cortner, A. H.: **Bibliography: The Magnetic Suspension of Wind Tunnel Models.** Rep. No. AEDC-TDR-63-20; February 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 Kárman Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. AF 40(600)-1000

31. *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, November 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. Some initial wind tunnel data are presented.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

32. *Covert, E. E.; and *Tilton, E. L., III: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels. (Part I) Interim Tech. Rep. August 1961-August 1962.** Rep. No. ARL-63-235, December 1963, 31 pp.

AD-437265 N64-24384

Note: For Part II of this series, see citation no. 36, Part III, no. 44, and Part IV, no. 69 in this bibliography.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(616)-7023

33. *Covert, E. E.; and *Tilton, E. L., III: **Further Evaluation of a Magnetic Suspension and Balance System for Application to Wind Tunnels.** Rep. No. ARL-63-226, December 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(616)-7023

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

AD-434844 N64-18916

This report describes a preliminary model of a 3-D wind tunnel balance, which has been built and operated in low speed continuum flow for the purpose of demonstrating the feasibility of the approach. The ultimate goal is to provide a technique of studying dynamic stability of an aerodynamic configuration in a wind tunnel under conditions of no motion, or small controlled motion, of the center of gravity of the model and essentially complete rotational freedom. An intermediate goal is to measure sphere drag in the transition region, adequate experimental determination of which has not yet been made.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. AFOSR 62-92

35. *Hensel, R. W.: **Recent Developments in Wind-Tunnel Testing Techniques at Transonic and Supersonic Speeds.** Journal of Spacecraft and Rockets, vol. 1, no. 5, September-October 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.

A64-26570#

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

*von Kármán Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. AF 40(600)-1000

36. *Covert, E. E.; *Copeland, A. B.; *Stephens, T. and *Tilton, E. L., III: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels. (Part II). Covers period August 1962-August 1963.** Rep. No. ARL-64-36, March 1964, 37 pp.

N64-20446

Note: For Part I of this series see citation no. 32, Part III, no. 44, and Part IV, no. 69 in this bibliography.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(616)-7023

37. *Stephens, T.: **Determination of Nonlinear Aerodynamic Damping Effects With a Wind Tunnel Model Suspension System.** M.I.T., Thesis for M.S. degree, June 1964, 50 pp.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

38. *Dukes, T. A.; and *Zapata, R. N.: **An Electromagnetic Suspension System for Spherical Models in a Hypersonic Wind Tunnel.** Princeton University Rep. 682, July 1964, 83 pp.

AD-605846 N65-14569#

This paper describes the design and operation of an electromagnetic balance for suspending spherical models in a hypersonic wind tunnel. 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 University, Princeton, NJ 08540 U.S.A.
Contract No. Nonr-1858(37)

39. *Dukes, T. A.; and *Zapata, R. 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, September 1964, pp. 13-1 to 13-15. This paper is also in IEEE Transactions on Aerospace and Electronic Systems, vol. AES-1, no. 1, August 1965, pp. 20-28.

A65-35219 August 1965 — N65-13935 or A64-28117 — September 1964

In a multi-degree-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 University, Princeton, NJ 08540 U.S.A.
Contract No. Nonr-1858(37)

40. *Geary, P. J.: **Magnetic and Electric Suspensions. A Survey of Their Design, Construction, 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.

*British Scientific Instrument Research Association, South Hill, Chislehurst, Kent, England

41. *Vas, I. E.; *Murman, E. M.; and *Bogdonoff, S. 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., January 25-27, 1965.

AIAA Paper 65-51 A65-28207# or A65-14802#

A detailed study 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 used to study 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 study, 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 University, Princeton, NJ 08540 U.S.A.
Contract Nos. Nonr-1858(37); and AF 33(615)-1079

42. *Copeland, A. B.; and *Tilton, E. L., 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470.

43. *Copeland, A. B.: **Measurement of Damping in Roll of a Finned Body Using a Magnetic Wind Tunnel Model Suspension System.** M.I.T., Thesis for M.S. degree, June 1965, 38 pp.

N80-71538#

An experimental study 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°.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Sponsored by the Air Force.

44. *Copeland, A. B.; *Covert, E. E.; and *Stephens, T.: **Recent Advances in the Development of a Magnetic Suspension and Balance System for Wind Tunnels, Part III. Annual Summary, September 1963 - September 1964.** ARL-65-114, June 1965, 52 pp.

AD-619174 N66-29811#

Note: For Part I of this series see citation no. 32, Part II, no. 36, and Part IV, no. 69 in this bibliography.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

45. *Covert, E. 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract AF 33(615)-1470

46. *Stephens, T. **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; December 1965, 49 pp. Covers period January 1964 - March 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue,

Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

47. *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, September 1965, 70 pp.

Note: An abbreviated form of this paper is included in "Summary of ARL Symposium on Magnetic Wind Tunnel Model Suspension and Balance Systems", which is citation no. 66 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.

*von Kárman Gas Dynamics Facility, ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. AF 40(600)-1200

48. *Copeland, A. 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, November-December 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 made in the 4-inch continuous flow wind tunnel of the Massachusetts Institute of Technology (M.I.T.) Naval Supersonic Facility.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

49. *Covert, E. E. *Copeland, A. B.; and *Stephens, T.: **Dynamic Stability Testing With Magnetic Balance Systems.** 1965, Paper #4 in Arnold Eng. Develop. Center Trans. of the 2nd Tech. Workshop on Dynamic Stability Testing, Vol. II, 1965, 35 pp.

AD-472298 N80-72451
Paper No. 4

Magnetic suspension and balance systems can be used to measure 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract AF 33(615)-1470

50. *Basmajian, V. V.; *Copeland, A. B.; and *Stephens, T.: **Studies Related to the Design of a Magnetic Suspension and Balance System.** Covers period December 1964-January 1966. MIT-TR-128, February 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. NAS1-4421

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

N67-10575#

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

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

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 Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

53. *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-February 28, 1966, NASA CR-71422; AST-4030-102-66U, March 1966, 47 pp.

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 it is easy to visualize them quite quickly.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-029

54. *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, April 13-14, 1966, pp. 1-26, 6 refs.

N67-13582#

This paper describes a three-degree-of-freedom electro-magnetic suspension system which is being used to support models in a hypersonic wind tunnel for the primary purpose of studying the wake characteristics. 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 University, Princeton, NJ 08540 U.S.A.
Contract No. Nonr-1858(37)

55. *Wilson, A.; and *Luff, B. F.: **The Development, Design and Construction of a Magnetic Suspension System for the R.A.E. 7" × 7" (18 × 18 cm) Hypersonic Wind Tunnel.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, April 13-14, 1966, pp. 27-79, 5 refs. Also RAE-TR-66248, August 1966, 47 pp.

N67-13583#, April 1966
N67-14195#, August 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 Aerospace 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 Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

56. *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. April 13-14, 1966, pp. 81-108, 7 refs.

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 using 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470
Contract NAS1-4421

57. *Hamlet, I. L.; and *Kilgore, R. A.: **Some Aspects of an Air-Coil Single-Coil Magnetic Suspension System.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, April 13-14, 1966, pp. 109-135, 2 refs.

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 control current, and an associated six-phase trigger circuit.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

58. *Parker, H. M.: **Principles, Typical Configurations and Characteristics of the University of Virginia Magnetic Balance.** In: Sum. of ARL Symp. of Magnetic Wind Tunnel Model Suspension and Balance Systems, April 13-14, 1966, pp. 137-157, 6 refs.

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. Prospects for the practical use of the balance to the study of the dynamic stability of aerodynamic configurations are emphasized.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
AFOSR Grant No. AF-AFOSR-1046-66
NASA Grant No. NGR-47-005-029

59. *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, April 13-14, 1966, pp. 159-197, 2 refs.

N67-13587#

The use of a four-component magnetic suspension system as a drag balance for models at zero incidence is discussed. The balance uses the lift and lateral electro-magnets only of an ⊥ 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 study. This technique is suitable for use 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 pounds, it is claimed that the force can be measured to an accuracy of ±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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

60. *Moreau, R.: **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 System, April 13-14, 1966, pp. 199-245, 7 refs.

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.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

61. *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, April 13-14, 1966, pp. 247-260, 5 refs.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

62. *Copeland, A. B.: **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, April 13-14, 1966, pp. 261-281, 4 refs.

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 used. The expected accuracy of measurements of dynamic stability characteristics for several typical cases is discussed.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

63. *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, April 13-14, 1966, pp. 313-347, 3 refs.

N67-13592#

Two fundamentally different roll control systems have been developed for the magnetic wind tunnel balance at University of Southampton. Each provides positive stiffness and near critical damping, and, within a roll angle range of ±10° 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

64. *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, April 13-14, 1966, pp. 349-385, 11 refs.

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

65. *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° Cone.** In: Sum. of ARL Symp. on Magnetic Wind Tunnel Model Suspension and Balance Systems, April 13-14, 1966, pp. 433-443.

N67-13594#

This paper briefly describes the initial tests made in the 7" × 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° 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 Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

66. *Daum, F. L.: **Summary of ARL Symposium on Magnetic Wind Tunnel Model Suspension and Balance Systems.** Dayton University, Ohio, Fluid Dynamics Facilities Laboratory, Rep. No. ARL-66-0135, July 1966, 461 pp. Symposium held at Wright-Patterson AFB, Dayton, Ohio, April 13-14, 1966.

AD-637208 N67-13581

Note: For individual papers presented at this symposium see citation nos. 54 through 65 in this bibliography.

This report is comprised of a series of technical papers which were presented at the ARL Magnetic Wind Tunnel Model Suspension and Balance Symposium, and a summary of the concomitant discussion. The Symposium was held at Wright-Patterson Air Force Base. It resulted in an international symposium with participants from the United States, England, France, and Canada. General chairman of the symposium was *Mr. Fred L. Daum.

*Fluid Dynamics Facilities Research Laboratory, Aerospace Research Laboratories, Wright-Patterson AFB, Dayton, OH 45433 U.S.A.
Contract No. AF33(615)-3626

67. *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., 8 refs.

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 studies 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

68. *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; October 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. The cause of this is not understood at present.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 49(638)-1328.

69. *Bousman, W.; *Copeland, A. B.; *Covert, E. E.; and *Stephens, T.: **Recent Advances in Magnetic Balance Systems, Part IV, Scientific Interim Rep., January-November 1965.** Rep. No. ARL-66-0200, October 1966, 106 pp.

AD-649243 N67-28186#

Note: For Part I of this series see citation no. 32; Part II, citation no. 36; and Part III, citation no. 44 in this bibliography.

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 dependent. A recommendation for a system that seems to overcome these difficulties is made.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

70. *Dancy, W. H., Jr.; and *Towler, W. R.: **Three Dimensional Magnetically Supported Wind Tunnel Balance.** The Review of Scientific Instruments, vol. 37, no. 12, December 1966, pp. 1643-1648, 9 refs.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. AF-AFOSR-62-92

71. *Rebùffet, P.: **Aerodynamique Experimentale**, Vol. 2, Dunod, Paris, 1966, 823 pp., in French.

TL570.R37,V.2
67V11410

Pages 96 and 97 contain the following on MSBS: Section 2.7.3.2 A model can be held in a wind tunnel test section, without any visible support, by the means of a magnetic field. This particularly neat method has been developed by ONERA. The electronic devices which maintain the model in position allow the measurement of the forces applied. The drag of a cylindrical body at zero incidence has been determined by this method in supersonic flow. Magnetic suspension proves to be particularly well adapted to the study of afterbody flow phenomena in hypersonic flow (pressures and fluxes) and to the study of wakes.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

72. *Copeland, A. 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 February 7, 1966 - February 7, 1967. MIT-TR-137, February 1967, 68 pp., 9 refs.

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 0° to 10° and for the Iroquois sounding rocket from 0° to 7.5°. 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 to complete these tests are discussed.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 19(628)-5815

73. *Goodyer, M. J.: **Roll Control Techniques on Magnetic Suspension Systems.** Aeronautical Quarterly, vol. 18, Pt. 1, February 1967, pp. 22-42, 6 refs.

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 University of Southampton for an 8 × 6 inch supersonic wind tunnel.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Sponsored by the Science Research Council

74. *Parker, H. M.; *Smoak, R. A.; and *Zapata, R. N.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic-Stability Research in Wind Tunnels. Status Report March 1, 1966 - March 1, 1967.** NASA CR-66,344, April 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-029

75. *Sirieix, M.; and *Delery, J.: **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., 21 refs., in French. This report is Paper No. 4 in AGARD "Fluid Physics of Hypersonic Wakes", Vol. 1, May 1967.

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

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 study, 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, B.P. 72, F-92322 Châtillon Cedex, France

76. *Judd, M.: **The Effect of Wind Tunnel Size on the Power and Voltage Requirements of Magnetic Suspension Systems.** University of Southampton Rep. No. A.A.S.U.-269, May 1967, 16 pp., 6 refs.

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

77. *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, (N67-37601), paper No. 2, May 1967, 36 pp., 16 refs.

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 University, Princeton, NJ 08540 U.S.A.
Contract No. Nonr-1858(37).

78. *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, paper No. 3, May 1967, 43 pp., 11 refs., MIT-TR-143, AFOSR-68-1565.

AD-671965

N67-37604#
or
N68-87554 (thesis)

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract Nos. AF49(638)-1328; AF33(616)-7023; AF33 (615)-1470

79. *Petersen, R. A.: **Calibration Study for a Six-Degree-of-Freedom Magnetic Balance and Suspension System.** M.I.T., Thesis for M.S. degree, June 1967, 53 pp., 6 refs.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
AF 33(615)-1470

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

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 Laboratory, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Dayton, OH 45433 U.S.A.

81. *Parker, H. M.: **Theoretical and Experimental Investigation of a Three-Dimensional Magnetic-Suspension Balance for Dynamic Stability Research in Wind Tunnels.** Semiannual Status Report, March 1, 1967 - August 31, 1967. NASA CR-91513, December 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-029

82. *Copeland, A. B.; *Covert, E. E.; *Petersen, R. A.; and *Stephens, T.: **Contribution to the Knowledge of Magnetic Balance and Suspension Systems. Scientific Interim Rep., November 1965 - May 1967.** MIT-TR-139; ARL-67-0283; December 1967, 58 pp., 15 refs.

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 made to determine if 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

83. *Langford, J. M.: **Tunnel E With Magnetic Model Support System: Basic Concept and Initial Design.** Interim Report, March 1-October 31, 1967. Magnetic Model Suspension System for Hypersonic Wind Tunnel. AEDC-TR-67-268, January 1968, 26 pp., 7 refs., (U.S. Government and their Contractors Only.)

AD-826303 X68-13504#

This report discusses the addition of the existing magnetic model suspension system to the 12- by 12-inch hypersonic Tunnel E at Arnold Engineering Development Center. The addition requires an unusually long test section for studying undisturbed model wake. With the magnetic suspension system, the model can be positioned in any axial direction, and the model angle of incidence can be changed in either positive or negative direction. The proposed model positioning sensor system will consist of a gamma or X-ray source and ion detectors that will allow the model position to be controlled without need for optical ports in the tunnel wall. The instrumentation for and overall test capabilities with this magnetic suspension system in Tunnel E are discussed, and proposals for future improvements in the capabilities of the system are made.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. 40(600)-1200

84. *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, March 1, 1967-March 1, 1968. NASA CR-94440, March 1968, 130 pp., 20 refs., 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 wind tunnel, 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."

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-029

85. *Sivier, K. 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, April 8-10, 1968. Also published in Journal of Aircraft, September-October 1969, vol. 6, pp. 398-404, 9 refs.

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 study of sphere drag at subsonic speeds 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, that is, low free-stream turbulence and Re < 300–for which negligible lateral aerodynamic forces exist. With 1/16 inch diameter 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.

*University of Illinois, Urbana-Champaign, Urbana, IL 61801 U.S.A.
(Work done at University of Michigan, Ann Arbor, MI 48109 U.S.A.).
NASA Grant No. NsG-86-60

86. *Goodyer, M. J.: **The Magnetic Suspension of Wind Tunnel Models for Dynamic Testing.** University of Southampton, Department of Aeronautics and Astronautics-Ph.D. Thesis, April 1968, 17 refs.

N78-78589, Chapters 1-8
N78-78218, Chapters 9-14

The purpose of the work described was to study the feasibility of magnetic suspension for dynamic tests and to develop suitable measuring techniques. Existing magnetic suspension systems control 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 speeds. 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 used. 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

87. *Phillips, W. 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, M.I.T., Boston, Mass., July 22-26, 1968, Vol. I. Advances in Applied Mechanics, Supplement 5, 1969, pp. 711-721, 17 refs.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. AF AFOSR 1046-67.

88. *Copeland, A. B.; *Petersen, R. A.; and *Covert, E. E.: **Wind-Tunnel Measurements 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, 13 refs.

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 using 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contracts AF 33(615)-1470; AF 19(618)-5815

89. *Beaussier, J.; and *Zakheim, 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, October 7-10, 1968, 18 pp., 2 refs. (In French, English summary.) ONERA-TP-643.

N69-32427#
or A69-11623#

Note: Translation into English is NASA TT-20277, (X88-10285#), June 1988, available to U.S. Government Agencies and their contractors only.

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, B.P. 72, F-92322 Châtillon Cedex, France

90. *Crane, J. F. W.: **Performance Aspects of the RAE Magnetic Suspension System for Wind Tunnel Models.** RAE-TR-68274, November 1968, 44 pp. (Unclassified and unlimited as of February 20, 1990.)

N90-70529

The performance of the L-type magnetic suspension system operating in the 7 in. × 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.

*Royal Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

91. *Vlajinac, M.: **Wind Tunnel Measurements of the Aerodynamic Characteristics of the 2.75 Wrap Around Fin Rocket Using a Magnetic Suspension System. Final Tech. Rep. May 15, 1967-December 15, 1968.** MIT-TR-150, December 1968, 61 pp. This is paper #30 in the Naval Weapons Center Proceedings of the 8th Navy Symp. on Aeroballistics, vol. 3, June 1969.

N80-72444
pp. 717-749

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract Nos. AF 33(616)-7023; AF 33(615)-1470; and N60530-68-C-1016

92. *McLaughlin, D. K.; **Carter, J. E.; and *Finston, M.: **Experimental Investigation of the Near Wake of a Magnetically Suspended Cone at M_∞ = 4.3.** Presented at the 7th AIAA Aerospace Sciences Meeting, New York City, January 20-22, 1969, 12 pp., 17 refs.

AIAA Paper 69-186 A69-18068#

Note: Also in the AIAA Journal vol. 9, No. 3, March 1971, pp. 479-484.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
**Virginia Polytechnic Institute, Blacksburg, VA 24061 U.S.A.

Contract AF 49(638)-1328

93. *Stephens, T.: **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, January 1969, 61 pp., 11 refs. (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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470.

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

AD-692500 N70-22327#, pp. K1-K19, 11 refs.

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 free of model support interference effects. The suspension system consists 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 use 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
**Aerospace Research Laboratories., OAR, Wright-Patterson Air Force Base, Dayton, OH 45433 U.S.A.

95. *Sivier, K. R.; and *Henderson, M.: **One Component, Magnetic, Support and Balance System for Wind Tunnel Models.** NASA CR-1353, May 1969, 83 pp., 29 refs.

N69-25343#

Sphere drag at subsonic speeds and Reynolds numbers from about 25 to 4,000 was measured by the instrumentation. The system was used with a vertical wind tunnel and used 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.

*University of Michigan, Ann Arbor, MI 48109 U.S.A.
Grant No. NGR-23-005-003

96. *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., 10 refs.

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).

*University of Michigan, Ann Arbor, MI 48109 U.S.A.
Grant No. NGR-23-005-003

97. *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., (ICIASF '69), IEEE publication 69C 19-AES, (A69-35714), May 1969, 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Research supported by M.I.T. and NASA

98. *Peterson, C. W.; and *Bogdonoff, S. M.: **An Experimental Study of Laminar Hypersonic Blunt Cone Wakes.** Presented at the AIAA Fluid and Plasma Dynamics Conference held at San Francisco, Calif., June 16-18, 1969, 10 pp., 16 refs.

AIAA Paper 69-714 A69-33500#

This paper describes an experiment made to provide detailed flow information about the high Mach number-low Reynolds number wake behind spherically blunted cones. A complete set of surface and wake flow-field data was obtained behind two cones with bluntness ratios of 10 and 20%. The 10% blunt cone was selected because its drag was slightly lower than the sharp cone drag, and the 20% blunt cone was chosen because its drag was significantly higher. All other parameters associated with the cone geometry and the test environment were the same as for the sharp cone experiment by Murman (1967) using a MSBS. By tracing the effects of bluntness from the initial conditions on the surface into the wake flowfield, it was possible to propose a flow model which describes the near wake pressure field. The large pressure gradients observed in the recirculation region are apparently balanced by viscous stresses, giving rise to a Stokes-like flow. The axial static pressure distribution downstream of the rear stagnation point may be strongly dependent on the reflected wave system emanating from the cone shoulder. The data indicate that these mechanisms are equally valid for sharp and blunt cones. The effects of tip bluntness on the wake flowfield are most apparent in the radial-wake profiles and in the near-wake centerline static pressure distributions. In both regions, the observed perturbations caused by bluntness may be attributed to corresponding perturbations in the cone shoulder flowfields. Differences among sharp and blunt cone radial wake profiles at the wake edge and in the inviscid wake will undoubtedly persist far downstream. Conversely, several viscous wake centerline flow parameters become insensitive to bluntness ratio once the axial pressure gradients die out.

*Princeton University, Princeton, NJ 08540 U.S.A.
ARPA-USAF-supported research.

99. *Parker, H. M.; and *Zapata, R. 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, 2 refs.

AD-857 475 N80-72444
Paper #29 pp. 695-716

This paper describes a three-degree-of-freedom electromagnetic balance using stabilized superconductor coil systems. The major potential of the system is considered to be the study, with reasonable and improved accuracy, of the dynamic-stability characteristics of a model.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-029

100. *Sivier, K. 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 speeds 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%).

*University of Michigan, Ann Arbor, MI 48109 U.S.A.

101. *Murman, E. M.: **Experimental Studies of a Laminar Hypersonic Cone Wake.** AIAA Journal, vol. 7, no. 9, September 1969, pp. 1724-1730, 35 refs.

A69-43576#

An experiment has been made to study the fluid mechanical structure of a laminar hypersonic wake behind a sharp, circular cone. The flow field 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 an 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 University, Princeton, NJ 08540 U.S.A.
Contract No. 1858(37); AF33(615)-67-C-1065

102. *Stephens, T.: **Design, Construction, and Evaluation of a Magnetic Suspension and Balance System for Wind Tunnels.** Tech. Rep. February 1966-November 1969. Rep. No. MIT-DSR-75396. MIT-TR-136; NASA CR-66903, November 1969, 187 pp., 16 refs.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. NAS1-4421

103. *McLaughlin, D. K.: **Experimental Investigation of the Mean Flow and Stability of the Laminar Supersonic Cone Wake.** MIT-TR-164; AFOSR-70-0072-TR; November 1969, 144 pp., 66 refs.

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° 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 are found between the measured supersonic wake and the measurements of others in hypersonic cone wakes. 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 study, hot-wire fluctuation measurements were made for a range of Reynolds numbers. These measurements indicated a completely stable near wake at Re_∞ = 51,600 and large amplifications of small disturbances at Re_∞ = 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 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 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. F44620-69-C-0013

104. *Goodyer, M. J.: **The Roll Control of Magnetically Suspended Wind Tunnel Models by Transverse Magnets.** University of Southampton Rep. No. AASU-291, (1969), 3 refs.

N69-39330#

A wind tunnel magnetic suspension system has been developed at University of Southampton. 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 to orientate the model properly with respect to suspension electro-magnets, and to counteract any aerodynamic rolling moment. The original roll control system used 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 built having up to five times the moment capacity that previously could be incorporated.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

105. *Vlajinac, M.: **A Pneumatic Calibration Rig for Use With a Magnetic Suspension and Balance System.** Tech. Rep., November 1967-August 1969. Wright-Patterson AFB Rep. ARL-70-0016, MIT-TR-159, January 1970, 41 pp.

AD-707858 N70-40056#

This paper describes the preliminary study and design of a prototype pneumatic calibration rig for use with a magnetic suspension system. Results and performance of the pneumatic calibration rig are shown. Previous calibration techniques and advantages of this new technique are discussed.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

106. *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, February 1970, 25 pp., 4 refs., (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 Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

107. *Vlajinac, M.; and *Gilliam, G. D.: **Aerodynamic Testing on Conical Configurations Using a Magnetic Suspension System.** Final Rep. June 1-October 30, 1969. Wright-Patterson AFB Rep. ARL-70-0067, MIT-TR-162, April 1970, 81 pp., 8 refs.

AD-709197 N70-41721#

Tests were made 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 made 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 made 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF 33(615)-1470

108. *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.** AFOSR-70-1588TR, AEEP-3435-115-70U, April 1970, 70 pp., 42 refs.

AD-712741 N71-14891#

This paper reports on drag measurements on spheres in high speed transition regime flow. 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 used 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Contract No. AF-AFOSR-1046-67.

109. *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, September 1967-January 1970.** AEDC TR-70-80, May 1970, 50 pp., 14 refs. (U.S. Gov't Agencies and their Contractors Only). Unclassified report.

AD-869,634 X70-17092#

The von Kármán Gas Dynamics Facility at AEDC has recently completed development of a new wind tunnel testing facility. A magnetic model suspension system has been incorporated with a 13.25-inch-diameter, axisymmetric, contoured nozzle which produces uniform Mach 8 flow in a 50-inch-long test section. In addition to magnetic suspension, the tunnel is unique in the size of models which can be tested and in its X-ray model position detection system which allows the nozzle and test section to be smooth and free of window ports. Detailed surveys of laminar, transitional, and turbulent near wakes can be obtained with the probing mechanism provided at the downstream end of the test section. Preliminary results of initial wake tests on a 4-inch-diameter, 10-degree cone are presented. Schlieren photographs and pitot pressure surveys were obtained at free-stream Reynolds numbers of 0.05×10^6 and 0.2×10^6 per inch and at distances downstream of the model base from 8 to 28 inch ($2 \leq x/D \leq 7$). These preliminary results demonstrate some of the unique testing capabilities of this new hypersonic, magnetic model suspension facility.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389 U.S.A.
Contract No. F40600-69-C-0001

110. *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 University 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, January 1971.

A71-20152#

An isolated, isochoric Dewar and superconducting ring, operable up to 130 000 ampere turns, has been installed in the Princeton Spherator. Plasma physics experiments have been made with the ring levitated and stabilized using 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, Princeton, NJ 08540 U.S.A.
AEC supported research

111. *Gilliam, G. D.: **Data Reduction Techniques for Use With a Wind Tunnel Magnetic Suspension and Balance System. Interim Technical Rep., November 1968-June 1970.** MIT-TR-167; NASA CR-111844, June 1970, 70 pp., 5 refs.

N71-23122#

This paper gives the equations relating the forces and moments exerted on a body by the magnetic fields produced by the M.I.T.-NASA prototype magnetic balance. 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. NAS1-8658

112. *Zarin, N. A.: **Measurement of Non-Continuum and Turbulence Effects on Subsonic Sphere Drag.** NASA CR-1585, June 1970, 137 pp., 81 refs.

N70-31869#

The drag of spheres, at Mach numbers from 0.10 to 0.57, Reynolds numbers ranging from 40 to 5,000, Knudsen numbers as high as 0.060, and turbulence intensities up to 13% were measured in a continuous wind tunnel using a magnetic suspension system. Stainless steel ball bearings having diameters of from 1 to 6.3 mm were used as models. The effects of free-stream turbulence, compressibility, and gas rarefaction were observed and compared with existing data wherever possible.

*University of Michigan, Ann Arbor, MI 48109 U.S.A.
Grant No. NGR-23-005-003

113. *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, January 1971, pp. 3-5, 4 refs., (A71-20151#). Also published as NASA TM-X-72184.

N75-70783
A71-20151#

This paper reports on the design of an electromagnetic balance using superconducting coils. 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-inch 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
NSF supported Grant No. NGR-47-005-029

114. *Vlajinac, M.: **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, 11 pp., 3 refs.

N80-71558

A summary of the construction and initial operation of a transonic wind tunnel for use with a 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" × 4" and is located at the M.I.T. Aerophysics Laboratory.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. N00123-67-C-1598

115. *Vlajinac, M.; *Stephens, T.; *Gilliam, G. D.; *Pertsas, N. V.; and *Covert, E. E.: **Subsonic Static Characteristics of Slender Wing Configurations Using a Magnetic Suspension and Balance System.** MIT-TR-168, July 1970, 25 pp., 7 refs. NASA CR-1796, July 1971.

N71-29775#

Wind tunnel studies of the static aerodynamic characteristics of three sharp-edged, slender wings were made 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° to 30° at a Reynolds number of the order of 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. NAS1-8658

116. *Bogdonoff, S. M.: **Hypersonic Wake Studies. Final Report, 15 January 1962-15 January 1970.** July 1970, 18 pp., 16 refs.

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. 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. The tunnel uses pure helium as the test fluid and can generate Mach numbers from 8-20. 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 of approximately 120,000/inch.

*Princeton University, Princeton, NJ 08540 U.S.A.
Contract No. Nonr.-1858(37)

117. *Vlajinac, M.; *Stephens, T.; *Gilliam, G. D.; and *Pertsas, N. V.: **Subsonic and Supersonic Static Aerodynamic Characteristics of a Family of Bulbous Base Cones Measured With a Magnetic Suspension and Balance System.** MIT-TR-166, November 1970. NASA CR-1932, January 1972, 63 pp., 5 refs.

N72-14984#

This paper presents the results of subsonic and supersonic wind-tunnel tests with a magnetic balance and suspension system on a family of bulbous based cone configurations. 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.

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Contract No. NAS1-8658

118. *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, January 25-27, 1971, 11 pp., 19 refs.

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 made 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

119. *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, February 1971, 17 pp., 4 refs. (Supersedes RAE-TR-70022 and ARC-32346.)

N72-11014#

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

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120. *McLaughlin, D. K.; **Carter, J. E.; ***Finston, M.; and ****Forney, J. A.: **Experimental Investigation of the Mean Flow of the Laminar Supersonic Cone Wake.** AIAA Journal, vol. 9, no. 3, March 1971, pp. 479-484, 25 refs.

A71-22091#

This paper presents results of an experimental study of the mean flow of the near wake of a sharp, 7° 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.

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**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
***Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
****NASA Marshall Space Flight Center, Huntsville, AL 35812 U.S.A.
Contract No. AF 44(620)-69-C-0013

121. *Willard, J. W.; *File, J.; and *Martin, G. D.: **Levitated Ring in FM-1.** Rep. No. MATT-842, CONF-710418-19, presented at the 4th Symposium on Engineering Problems of Fusion Research, Washington, D.C., April 20, 1971, 9 pp., 5 refs.

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 as a function of 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, Princeton, NJ 08540 U.S.A.
Contract AT(30-1)-1238

122. *McLaughlin, D. K.: **Experimental Investigation of the Stability of the Laminar Supersonic Cone Wake.** AIAA Journal, vol. 9, no. 4, April 1971, pp. 696-702, 18 refs.

A71-25475#

This paper presents the results of a study of the instability occurring in the wake of a 7° 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF (620)-C-0013

123. *Raghunath, B. S.: **Error Analysis in the Evaluation of Aerodynamic Derivatives from University of Virginia Wind-Tunnel Cold Magnetic Balance System.** University of Virginia, Ph.D. Thesis, June 1971, 126+ pp.

NASA Langley Library No. CN-156,708

The dynamic testing of a model in the University of Virginia cold magnetic balance wind-tunnel facility is expected to consist of measurement of the balance forces and moments and observation of the motion of the model. The aerodynamic derivatives of the model will be evaluated from these observations. The proper design of a data acquisition system needs information concerning the dependence of the accuracy of the evaluated aerodynamic derivatives on the noise level in the observations. For this purpose, the motion of the projected first model, a cone, is calculated with "known" aerodynamic derivatives. This data is corrupted by various amounts of noise. The aerodynamic derivatives are then evaluated from the noisy motion by two methods: 1) the "Brute-force" method, and 2) the method of parametric differentiation. The Brute-force method treats the differential equations of motion as algebraic equations in the unknown aerodynamic derivatives and uses the method of least squares to average a large number of data points. In the method of parametric differentiation, the equations of motion are considered in "aerodynamic derivative" space and the method of least squares is applied. The relationships between noise level and the accuracy of the evaluated aerodynamic derivatives are presented in the dissertation. The Brute-force method determines the hitherto inseparable aerodynamic derivatives C_{m_q} and $C_{m_{\dot{\alpha}}}$ separately with reasonable accuracy at reasonable noise levels. The method of parametric differentiation determines the force derivatives with surprising accuracy at all reasonable noise levels. Thus, the two methods complement one another in the evaluation of aerodynamic derivatives from the dynamic tests of models in this facility.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

124. *Goodyer, M. J. (editor): **2nd International Symposium on Electro-Magnetic Suspension.** University of Southampton, Southampton, England, Proceedings, July 12-14, 1971, 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, electromagnetic model position sensing systems 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, and the simulation of gravity in wind tunnels with the aid of magnetic fields.

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125. *Beams, J. W.: **Some Remarks on Servo-Controlled Magnetic Suspension 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 Prof. Beams was read at the Symposium by Prof. H. M. Parker. The paper discusses the part researchers at the University of Virginia had in the early development of magnetic suspension.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

126. *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, 9 refs.

N73-24272#
or A72-24757#

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

This paper describes a prototype facility consisting of a superconducting magnetic suspension and balance and a supersonic wind tunnel. This facility was developed with the objectives of establishing the feasibility of using the three-component magnetic balance concept for dynamic stability studies, and studying 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 used 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant Nos. NGR-47-005-029; No. NGR-47-005-110; and No. NGR-47-005-112.

127. *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 are used 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

128. *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, 15 refs.

A72-24759#
or A73-24273#

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

This paper contains a summary of the magnetic field and field gradient requirements for magnetic suspension in a Mach 3, 6-inch 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 Nb_3Sn 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 multi-filament superconductors.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
NASA Grants NGR-47-005-029; NGR 47-005-110, and NGR 47-005-112

129. *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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

130. *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, 3 refs.

A72-24763#

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

131. *Altmann, H.: **An Optical Scanning Detection System and its Use with 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 University, Parks Road, Oxford OX1 3PJ, England

132. *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, 2 refs.

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.–NASA Prototype Magnetic Balance is presented. In addition, a procedure for determining the parameter in the equations for a particular model is outlined.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
NASA Grants 47-005-029, 149, and 112.

133. *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), 9 refs.

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

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grants NGR-47-005-029; NGR-47-005-149;
NGR-47-005-112

134. *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 minutes followed by a rest period of 30 minutes.

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

135. *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, 7 pp.

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

136. *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, 13 pp., 11 refs.

A72-24769#

This paper presents the results of subsonic and supersonic wind tunnel tests with a magnetic balance and suspension system on a family of bulbous-based cone models. 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

137. *Abdel-Kawi, S.; *Diab, T. A. G.; *Goodyer, M. J.; *Henderson, R. I.; and *Judd, M.: **Aerodynamic Data Acquisition with the University of Southampton Magnetic Balance.** 2nd Int. Symp. of Electro-Magnetic Suspension, Proceedings, July 12-14, 1971, pp. 0.1-0.17; Discussion, pp. O.18, O.19, 19 pp., 11 refs.

A72-24770#

A brief discussion 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

138. *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, 18 pp., 6 refs.

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 a study of sting effects are reported. Current and future research plans are discussed from the point of view of facility development.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. AF-AFOSR-69-1798

139. *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 made by Roos and Will (1971), Bailey and Hyatt (1971), and Covert and Vlajinac at M.I.T. (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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

140. *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.

N73-24276#
A72-24773#

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-112

141. *Zapata, R. N.: **Safety Aspects of Superconducting Magnetic Suspension Systems.** 2nd Int. Symp. on Electro-Magnetic Suspension, Proceedings, July 12-14, 1971, pp. Q.10-Q.14.

N73-24277#
or A72-24774

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

Various forms of failure are discussed that any designer or builder of a superconducting magnetic suspension system should thoroughly consider to make sure 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. 154 in this bibliography.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-112

142. *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.

N73-24275#
A72-24776#

Note: This paper is also contained in "Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies" which is citation no. 154 in this bibliography.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grants No. NGR-47-005-029; No. NGR-47-005-112

143. *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, Unclassified and unlimited as of February 27, 1990, formerly 72X76040.

AD-894178

Tests are described on the use of the magnetic suspension system in the RAE Hypersonic Tunnel as a force balance. Details are given of the calibration method employed to relate the currents in the electromagnets (using a computer program), to the forces and moment applied on the model. A possible improved calibration system is also discussed.

*Royal Aerospace Establishment, Farnborough, Hampshire GU14 6TD, England

144. *Phillips, W. 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, 6 refs.

A71-32124#

Measurements were made in hypersonic flow from a free jet 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.

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**University of Virginia, Charlottesville, VA 22901 U.S.A.
NSF Grant No. CK5559; Grant No. AF AFOSR-1046-67

145. *Zarin, N. A.; and **Nicholls, J. A.: **Sphere Drag in Solid Rockets–Non-Continuum and Turbulence Effects.** Combustion and Science Technology, vol. 3, August 1971, pp. 273-285, 27 refs.

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 using a magnetic suspension system. Drag data have been obtained at Reynolds numbers (Re) ranging from 40 to 5,000, 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 $\leq$ 100. For sphere drag data obtained at turbulence levels from 3 to 13% and Reynolds numbers from 600 to 5,000, 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 Aeronautical Laboratory, Inc., Buffalo, NY 14850 U.S.A.
**University of Michigan, Ann Arbor, MI 48109 U.S.A.
Grant Nos. NsG-86-60; No. NGR-23-005-003

146. *Stephens, T.; *Vlajinac, M.; and *Covert, E. E.: **Recent Development and Application of a Wind Tunnel Magnetic Suspension and Balance System.** Final Tech. Report, April-October 1971. NASA CR-127,390, October 1971, 6 pp., 3 refs.

N72-73800

The effort of this report period was devoted to two items: (1) Measurement of Subsonic Sphere Drag and (2) Development of a Roll Attitude Sensor. A study was made to determine the laminar flow drag coefficient of spheres of various sizes in a subsonic wind tunnel. The tests were made using the M.I.T.-NASA 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

147. *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, 12 refs.

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%.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
**Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

148. *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., January 17-19, 1972, 19 refs.

AIAA Paper 72-164 A72-16829#

A functional description of a prototype six component magnetic balance system for wind tunnel use 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
NASA-USAF-supported research

149. *Day, L. E.: **Wind Tunnel Wall Effects on Cones With Bulbous Bases.** M.I.T., Thesis for M.S. degree, January 1972, 52 pp., 9 refs.

N80-71537

In an attempt to deduce wind tunnel wall interference effects, a series of tests were performed using geometrically similar 6° 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.

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150. *Vlajinac, M.; and *Covert, E. E.: **Sting-Free Measurements of Sphere Drag in Laminar Flow.** Journal of Fluid Mechanics, vol. 54, Part 3, August 8, 1972, pp. 385-392, 11 refs.

A72-40110

An aerodynamic investigation was conducted to determine the laminar-flow drag coefficient of spheres of various sizes in a subsonic wind tunnel. These tests were conducted using the M.I.T.-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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

151. *Raghunath, B. S.; and *Parker, H. M.: **Evaluation of Aerodynamic Derivatives From a Magnetic Balance System.** NASA CR-112305 (1972), 32 pp., 7 refs.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
NASA Grant No. NGR 47-005-029

152. *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., January 10-12, 1973, 6 pp., 18 refs.

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 finite static pressure outside the free-jet Mach bottle and 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
AFOSR Grant 69-1798

153. *Coffin, J. B.; and *Haldeman, C. 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, January 1973, 25 pp., 11 refs.

AD-755108 N73-20001#

Progress is reported on an experimental program to determine the Magnus forces on the center of gravity and the rotational start-up 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 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 the 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. DAAA21-72-C-0254

154. *Zapata, R. N.: **Development of a Superconducting Electromagnetic Suspension and Balance System for Dynamic Stability Studies.** Final Tech. Report. University Va. Rep. No. ESS-4009-101-73U. NASA CR-132255, February 1973, 76 pp.

N73-24271#

A prototype facility consisting of 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) studying design concepts and parameters needed to extrapolate 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 used 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 are copies of papers contributed by the University of Virginia research group at the 2nd International Symposium on Electro-Magnetic Suspension held at the University of Southampton, July 1971. For abstracts of these papers see citation nos. 126, 128, 133, 140, 141, and 142 in this bibliography.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
NASA Grant NGR-47-005-029

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

AD-787883 N75-73717

This paper presents 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_0 half-angle, adiabatic-wall cones, at $M_\infty = 6.32$ and free-stream Reynolds numbers from 88,000/inch, to 117,000/inch. 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 ($M_\infty = 4.3$) near-wake investigation of the same model geometry at identical Reynolds numbers. Results confirm 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 $M_\infty = 6.32$ the viscous region was found to extend beyond the wake shock wake whereas at the supersonic speeds, 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. (This report contains the same information as in the author's SCD thesis.)

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. AF-F44620-69-C-0013

156. *Altmann, H.: **A Magnetic Suspension System for the Measurement of Sphere Drag in Low Density Supersonic Flow.** Oxford University, Department 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.

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157. *Fajen, J. D.; and *Smoak, R. 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, August 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 using a physical support such as 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 physical support has an effect on the airflow which will affect the accuracy of the aerodynamic data to be obtained. It is hoped the University of Virginia magnetic wind tunnel balance will solve these two problems.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

158. *Haldeman, C. W.; *Coffin, J. B.; *Birtwell, E. P.; and **Vlajinac, M.: **Improvements in the Magnetic Balance System Required for Magnus Testing.** In ICIASF '73; 5th Int. Congress on Instrumentation in Aerospace Simulation Facilities, Pasadena, CA, September 10-12, 1973, Record.

A74-26476, pp. 24-30
or A74-26478

Recent improvements 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 to obtain measurements of the aerodynamic Magnus side force on spinning bodies of revolution at angles of attack up to 10°. Improvements described include a laser position system with an angular holding capability of 0.02 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 $M = 0.27$ ($Re = 7.7 \times 10^5$) to 0.43 ($Re = 1.3 \times 10^6$). Magnetically obtained Magnus side force data is presented which exhibits a scatter of less than 0.005 in side force coefficient.

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U.S. Army supported research

159. *Hadjimichalis, K. S.: **A Study of Sphere Drag in the Transition from Continuum to Free Molecular Flow.** Oxford University, Department of Engineering Science, Rep. 1073/73, October 1973, 145 pp.

N74-18660#

An experimental study was made of the effect of wall temperature on the drag of a sphere in the transition from continuum to free molecular flow. An electromagnetic suspension system was used both to suspend the model and to measure the drag force exerted by the flow. The experiments were made 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 University, Parks Road, Oxford OX1 3PJ, England
Contract No. AT/2057-042

160. *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, pp. 27-107.

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, for example, 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.

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161. *Birtwell, E. P.: **Magnus Forces and Sting Interference on Magnetically-Suspended Ogive Cylinders.** M.I.T., Thesis for M.S. degree, May 1974, 94 pp., 36 refs.

N80-71560#

Subsonic Magnus testing was made 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.

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DAAD-05-72-C-0181

162. *Haldeman, C. W.; *Coffin, J. B.; *Birtwell, E. P.; and *Vlajinac, M.: **Magnus Measurements With the Magnetic Balance System.** Final Tech. Rep., March 6, 1972-December 30, 1973. Ballistics Research Labs. Rep. BRL-CR-153, May 1974, 47 pp., 12 refs.

AD-782753 N75-13236#

This paper describes recent wind tunnel tests in the Magnetic Balance System at the M.I.T. Aerophysics Laboratory. Improvement in the balance, which holds wind tunnel models magnetically without physical supports, was required to obtain measurements of the aerodynamic Magnus side force on spinning bodies of revolution at angles of attack up to 10° 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 0.02°, 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 $M = 0.27$ $(Re = 7.7 \times 10^5)$ to 0.43 $(Re = 1.3 \times 10^6)$. 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. DAAD05-72-C-0181

163. *Zapata, R. N.; *Humphris, R. R.; and *Henderson, K. 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, January 1975, 10 pp., 9 refs.

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

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 large systems compatible with existing and planned high Reynolds number wind tunnels have been made and show that this experimental technique should be particularly attractive when used with large cryogenic wind tunnels.
*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grants No. NGR-47-005-029; NGR-47-005-110; NGR-47-005-112; NSG-1010

164. *Beams, J. W.: **Magnetic Suspension Balance. Final Rep., (June 15, 1971-June 15, 1974).** Rep. No. AROD-9775, 1-P;

DA-ARO(01)-31-124-71-G47; July 26, 1974, 12 pp.

AD-783387 N75-77594

The servo-controlled magnetic suspension balance was improved and simplified. It now weighs the freely suspended mass to at least one part in 1,000,000. The upward force exerted by the balance on the suspended body is strictly linear with the current in the control circuit over ranges in the order of 100,000 to 1,000,000. A number of applications of the balance are outlined. The servo-controlled magnetic torsion balance has been simplified and improved until the suspended body has no observable angular restoring torque when it is given an angular displacement. Also it has no observable friction per se from zero to maximum rotor speeds. When desirable, a reliable restoring torque (over a wide range of values) can be built into the torsion balance. A few examples of the use of this device are mentioned.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. DA-ARO-D-31-124-74

165. *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., September 30-October 2, 1974. IEEE Transactions on Magnetics, vol. MAG-11, no. 2, March 1975, pp. 598-601, 8 refs.

A75-25833

Initial operational characteristics of a wind tunnel electromagnetic balance utilizing superconducting coils are reported. Both dc and ac 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 ac 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grants NGR-47-005-029; NGR-47-005-110; NGR-47-005-112; NSG-1010

166. *Bisplinghoff, R. L.; *Coffin, J. B.; *Covert, E. E.; *Finn, D. M.; and *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 March-31 December 1974.** MIT-TR-190; PA-TR-4806, December 1974, 68 pp., 6 refs.

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° as measured with the magnetic balance system at M = 0.18 and 0.37. Re_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 dc power supply was constructed using 300 ampere, 30 volt dc aircraft generators. The steady state and transient response characteristics of this power supply are reported.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. DAAA21-74-C-0304

167. *Hadjimichalis, K. S.; and *Brundin, C. L.: **The Effect of Wall Temperature on Sphere Drag in Hypersonic Transition Flow.** In: 9th International Symposium on Rarefied Gas Dynamics, Göttingen, West Germany, 1974, Paper No. D.13, 9 pp., 29 refs.

QC168.I5, 1974, Vol II A74-42235

A detailed study has been made of the drag of spheres in the transition from continuum to free molecular flow. The aim of the study was to produce a correlating parameter which predicts the influence of wall to stagnation temperature ratio. A parallel experimental study has been made in the Oxford University low density wind tunnel using an electromagnetic suspension system and drag balance in conjunction with the flow produced by a freely expanding jet of air. The measurements were taken for: $6<M<12$, $0.25\leq T_w/T_o\leq 1$, $0.915<Re_2<81.7$ ($16.4>Km_\infty>0.036$).

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168. *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 September 1969-30 September 1974.** University Va. ESS-4009-102-75, NASA CR-141284, January 1975, 59 pp. Also NASA CR-2565, July 1975, 64 pp., 10 refs.

N75-28025#

The unique design and operational characteristics of a prototype magnetic suspension and balance facility which uses 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 at high Reynolds number 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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NGR-47-005-112

169. *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, April 14-17, 1975. IEEE Transactions on Magnetics, vol. MAG-11, September 1975, pp. 1514-1516, 3 refs.

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 University of Southampton 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.

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170. *Ahmadi, A. R.; and *Finston, M.: **Wall Temperature Effects on Laminar Wakes. Final Tech. Rep. 1 November 1973-30 June 1975.** M.I.T. Rep. TR-191, AFOSR-75-1634TR, July 1975, 68 pp., 21 refs.

AD-A019530 N76-24517#

An experimental study was made of the effects of cold wall conditions on the structure of the laminar near wake of a 7° 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.

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Contract No. F44620-74-C-0025

171. *Blankson, I. M.; and *Finston, M.: **Measurements in the Laminar Near-Wake of Magnetically Suspended Cones at M = 6.3.** AIAA Journal, vol. 13, no. 12, December 1975, pp. 1562-1567, 20 refs.

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 $M_\infty = 6.32$ 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 Mach number on the structure of the axisymmetric cone near-wake when compared with the results of a previous laminar supersonic ($M_\infty = 4.3$) near-wake studies of the same model geometry at similar Reynolds numbers. The study confirmed 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 $M_\infty = 6.32$ the viscous region was found to extend beyond the wake shock wave, whereas at the supersonic speeds, 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.

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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, December 1977, pp. 891; and (2) Blankson, I. M.; and Finston, M.; **Reply of Authors to R. I. Crane.** AIAA Journal, vol. 15, no. 6, December 1977, p. 892.

*Imperial College of Science & Technology, London, England

172. *Zapata, R. N.: **Magnetic Suspension Techniques for Large Scale Aerodynamic Testing.** In: "Wind Tunnel Design and Testing Techniques," AGARD-CP-174, March 1976, pp. 39-1 through 39-14, (N76-25213#), 15 refs.

N76-25213#
Paper No. 39
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 building large 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 aerodynamic testing at high Reynolds number. 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, are discussed in some detail.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. NSG-1010

173. *Bisplinghoff, R. L.: **Advanced Calibration Techniques for the M.I.T. Magnetic Suspension and Balance System.** M.I.T., Thesis for M.S. degree, May 1976, 98 pp., 8 refs.

N80-71559#

Procedures were developed for calibrating models for spin and angle of attack effects in the Massachusetts Institute of Technology 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 made 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. A computer program for calculating the oscillatory terms in the force equations is discussed for this case.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract No. DAHC04-75-C-0001

174. *Zapata, R. N.: **Development of the Design Concept for a Medium-Scale Wind Tunnel Magnetic Suspension System.** Semiannual Status Report, 1 October 1975-31 March 1976. June 15, 1976, 3 pp., 2 refs.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
NASA Grant No. NSG1010

175. *Diab, T. A. G.: **Improved Wind Tunnel Testing and Data Reduction Methods Using a Magnetic Suspension System.** University of Southampton Ph.D. Thesis, July 1976, 369 pp., 46 refs.

N78-78588

Improved techniques and data reduction methods for aerodynamic force measurements were proposed and tested using the magnetic suspension and balance of University of Southampton 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.

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176. *Goethert, B. H.: **Technical Evaluation Report on Windtunnel Design and Testing Techniques.** AGARD-AR-97, August 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 use 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, and so forth.

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177. *Pierce, T. V., Jr.; and *Zapata, R. N.: **Superconductor Coil Geometry and AC Losses.** Journal of Applied Physics, vol. 47, August 1976, pp. 3745-3746, 5 refs.

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 losses can be reduced by using low winding densities, provided that hysteresis losses are independent of winding density. 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 U.S.A.
Grant No. NSG-1010

178. *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. September 1976, 55 pp. (Available to U.S. Government Agencies Only). Requests must be made to Director, USA Ballistic Research Labs., ATTN: DRXBR-TS, Aberdeen Proving Ground, MD 21005.

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 0.45, M = 0.22, Re = 2.6×10^5, and angles of attack from -3° to +5°. 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 = 0.7×10^5 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) = 0.35 based on wind velocity, sound frequency, and ring radial thickness.

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Contract No. DAAD05-74C-0735

179. *Bharathan, D.; *Fisher, S. S.; and *Zapata, R. N.: **Aerodynamic Stability Testing With Magnetically Suspended Models.** Final Report, March 1, 1974-August 31, 1976. September 1976, 135 pp., 46 refs. AFOSR-76-0036TR; UVA/525 603/ESS76/101.

AD-A031473 N77-22048#

Note: For this report in thesis form, see citation no. 186 in this bibliography.

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. The response of each model is measured in a frequency range near pitch resonance.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
Grant No. AFOSR 74-2705

180. *Bharathan, D.; and *Fisher, S. S.: **Stability Derivative Measurements with Magnetically Suspended Cone-Cylinder Models.** 15th Aerospace Sciences Meeting, Los Angeles, Calif., January 24-26, 1977. Also "Journal of Spacecraft and Rockets," vol. 14, no. 12, December 1977, pp. 719-723, 13 refs.

AIAA Paper 77-79 A77-19813#

In an initial feasibility study, the stability derivatives, Cm_α, $Cm_{\dot\alpha} + Cm_q\ C_\ell z_\alpha$ and $Cz_{\dot\alpha} + Cz_q$ for 5- and 7-caliber cone-cylinder models have been measured at $M = 0.071$ and $Re = 1.3 \times 10^4$ 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 used 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.

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Grant No. AFOSR-74-2705

181. *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, January 1977, 71 pp.

AD-A035861 N77-82310 or A78-23186#

Note: 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", citation no. 187 in this bibliography, AIAA Journal, February 1978, by the same authors.

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 M.I.T. Aerophysics Laboratory. Data are reported at $M = 0.27$ to 0.43 and $Re = 1 \times 10^5$ to 1.2×10^6 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° and $Re = 0.77 \times 10^6$. Above 7° 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 2° angle of attack. 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° and 9° both artificial roughness and a support sting increase the size of the classical Magnus force. Results are compared with other reported data.

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Contract No. DAADO5-74-C-0735

182. *Finn, D. M.; *Haldeman, C. W.; and *Covert, E. 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, February 1977, 77 pp., 22 refs.

AD-A037836 N77-27077#

Total pressure measurements were made 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 study 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 M.S. thesis by D. M. Finn dated February 1976.)

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Contract No. DAADO5-74-C-0735

183. *Griffin, S. A.; **Brocard, M.; and ***Bazin, M.: **Model Systems and Their Impact on the Operation of Pressurized Windtunnels.** Appendix 5 of AGARD-AR-105, "A Further Review of Current Research Related to the Design and Operation of Large Windtunnels", August 1977.

ISBN 92-835-1252-9 N77-32177#, pp. 92-106

The object of the discussion described in Appendix 5 is to determine the feasibility of designing and building wind tunnel model systems capable of withstanding the loads and environmental conditions of High Reynolds Number Tunnels such as the NTF, the LHERT planned for Europe, and other high pressure tunnels.

The five sessions were on:

1. Model Design, pp. 92-96
2. Model Deformation, pp. 96-97
3. Support Systems, pp. 97-98
4. Instrumentation and Balances, pp. 99-101
5. Techniques and Specialized Equipment, pp. 101-102

There are 77 references included in Appendix 5.

*General Dynamics, Convair, San Diego, CA 92138 U.S.A.
**AECMA, Association Européenne des Constructeurs de Materiel Aérospatial, 88 Boulevards Malherbes, 75008 Paris, France
***ONERA, B.P. 72, F-92322 Châtillon Cedex, France

184. *Covert, E. E.; *Haldeman, C. W.; and *Ziph, B.: **Increasing the Force Limits of the Magnetic Balance System. Final Report, April 15, 1976-September 30, 1977.** MIT-TR-199; ARO-13897.1-EX; November 1977, 27 pp., 4 refs.

AD-A050746 N78-22121#

This report describes the construction and testing of new motor generator power supplies and filter inductors for use with the magnetic balance system. Motor generator output is ±380 volts with a current limit of ±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 = ωL/R as a function of frequency measured for the coils. Measured Q at 20 KC was 660.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Contract No. DAAG29-76-C-0028

185. *Luh, P. B.; *Covert, E. E.; *Whitaker, H. P.; and *Haldeman, C. W.: **Application of Digital Control to a Magnetic Model Suspension and Balance System. Final Report, April 1, 1976-November 30, 1977.** MIT-TR-198, December 1977, 120 pp., 10 refs. (This report was also published as NASA CR-145316, January 1978.)

N78-14060#
N78-20145#

The feasibility of using a digital computer to control a magnetic suspension and balance system (MSBS) for use with wind tunnel models was studied. 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 made 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.)

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Contract No. NsG-1292

186. *Bharathan, D.: **Aerodynamic Stability Testing With Magnetically Suspended Models.** University of Virginia Ph. D. Thesis, 1977, 130 pp., 46 refs.

N78-32108
University Microfilms (Order No. 7812113)

Note: For another publication of this work see citation no. 179 in this bibliography.

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.

*University of Virginia, Charlottesville, VA 22901 U.S.A.
AFSOR Grant 74-2705

187. *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, February 1978, pp. 111-116, 20 refs.

N77-82310
or A78-23186#

Note: This is a condensed and corrected version of citation no. 181 in this bibliography.

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°. 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Grant Nos. DAAD05-74-C-0735; DAHC04-75-C-0001

188. *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 University, Rep. No. OUEL-1235/78, March 1978, 119 pp., 50 refs.

N79-23938#

An electromagnetic jig and balance was built for use with the Oxford University low density tunnel to carry out a comprehensive experimental survey of aerodynamic force on slender axisymmetric bodies in rarefied hypersonic flow. 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 1,200 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 University, Parks Road, Oxford OX1 3PJ, England
Min.-Def./PE-AT/2057/042

189. *Covert, E. E.; and *Haldeman, C. W.: **Initial Wind Tunnel Tests of a Magnetically-Suspended Spinning and Coning Ogive Cylinder. Final Rep., 1 September 1974-31 December 1977.** MIT-TR-201; Aero-12209.3-E, March 1978, 24 pp., 6 refs.

AD-A053758 N78-27090#

This paper reports on research extending magnetic balance techniques to produce simultaneous spinning and coning motion of a magnetically-suspended wind tunnel model. 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° and speeds 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Contract No. DAAG29-75-C-0001

190. *Britcher, C. P.: **The Magnetic Suspension and Balance System in the Cryogenic Wind Tunnel.** University of Southampton B.Sc. Honours Project Report, April 1978, 95 pp., 33 refs.

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 using a cryotunnel with a magnetic suspension and balance system are identified. Suitable modifications, including building a new test section leg, allowed the installation of the University of Southampton 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 to -181.6 °C have been achieved with a model in steady suspension. Drag coefficient measurements are presented for a 7-calibre AN spinner model over a very wide range of Reynolds Number. Operational difficulties, so far encountered, can be overcome by suitable detail modifications.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

191. *Haslam-Jones, T. F.; and *Brundin, C. L.: **Vertex Angle and Flow Uniformity Effects on Rarefied Hypersonic Cone Drag.** In "Rarefied Gas Dynamics," Proceedings of the 11th International Symposium, Cannes, France, July 3-8, 1978, Vol. I., (A80-34876), pp. 303-310, 17 refs.

QC168.I5 1978, Vol. 1 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° were tested at Mach numbers between 5.1 and 9 and base-diameter free-stream Reynolds numbers between 110 and 1,200. 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 University, Parks Road, Oxford OX1 3PJ, England
Ministry of Defense Contract AT/2057/042

192. *Kraemer, R. A.: **Low A.C. Loss Superconducting Coils for a Wind Tunnel Magnetic Suspension and Balance System,** M.I.T., Thesis for M. S. degree, NASA CR-164289, September 1978, 119 pp., 23 refs.

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 ac current is devised and shown to be accurate within 20% of measured losses.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Grant No. NSG-1356

193. *Haldeman, C. W.; **Kraemer, R. A.; and *Way, P.: **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, England, April 3-5, 1979, 15 pp., 17 refs.

A80-24087#

Magnetic model suspension and balance systems for wind tunnel use have been designed, tested, and used at Massachusetts Institute of Technology'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 built 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
**Arizona State University, Tempe, AZ 85281 U.S.A.

194. *Britcher, C. P.; and *Goodyer, M. J.: **The University of Southampton Magnetic Suspension/Cryogenic Wind Tunnel Facility.** Paper No. 10, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 7 refs.

A80-24088#

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

195. *Chan, Y. M.: **Sensitivity Adaptive Control of a Magnetic Suspension System.** Rep. No. UILU-ENG-78-2236DC-25. Illinois University at Urbana-Champaign, MS Thesis, May 1979, 97 pp., 16 refs.

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 a faster computing device or a simplified mathematical model. Its application will be most pertinent to a system with slow time constants.

*University of Illinois, Urbana-Champaign, Urbana, IL 61801 U.S.A.
Contracts DAAG29-78-C-0016; NSF ENG-74-20091; AF-AFOSR-3633-78; NSF INT-77-2069

196. *Way, P.: **A Roll Control System for a Magnetic Wind Tunnel Balance and Model Suspension System.** M.I.T., Thesis for M.S. degree, NASA CR-162640, June 1979, 80 pp., 9 refs.

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 ac 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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.

197. *Solomon, M.; *Finston, M.; and *Haldeman, C. W.: **Wake Studies Related to Reentrant Pyramids. Final Rep., 1 January 1976-30 November 1978.** MIT-TR-205, AFOSR-79-0984TR, August 1979, 82 pp., 12 refs.

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 to study the axial development of the azimuthal asymmetry of the wake. 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 wake of the pyramid and to make a comparison to the axisymmetric cone wake.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Contract No. F44620-76-C-0049

198. *Haldeman, C. W.; and *Covert, E. 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, September 24-26, 1979. Naval Postgraduate School, Monterey, Calif., pp. 194-200, 6 refs.

N80-71554#
or A80-29476, pp. 194-200

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
Research supported by U.S. Army Research Office, Durham, NC 27709 U.S.A.

199. *Goodyer, M. J.: **Cryogenic Wind Tunnel Activities at the University of Southampton.** NASA CR-159,144, September 1979, 9 pp., 5 refs.

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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
NASA Grant NSG-7523

200. *Prey, S. W.: **A. C. Losses in Interacting Superconducting Magnet Coils.** M.I.T., Thesis for M.S. degree, NASA CR-162580, September 1979, 75 pp., 15 refs.

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.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
NASA Grant 1356

201. *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, November 1979, 35 pp., 8 refs.

N80-11104#

This paper examines the technology 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. 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant No. NSG-7525

202. *Bodyov, A. B.; and *Shermanov, P. M. (Compilers): **Magnetic Suspension of Models in Wind Tunnels. Surveys, Translations, Abstracts.** (Magnitnaya podveska modeley v aerodinamicheskikh trubakh. Obzory, perevody, referaty.) Technical Information Department of the N. E. Zhukovskiy Central Aerodynamic Institute Rep. No. 557, 1979, 58 pp., 28 refs., in Russian.

NASA Langley Research Center Technical Library No. CN-157,098

*N. E. Zhukovskiy Central Aerodynamic Institute

203. *Alishahi, M. M.: **Preliminary Design of a Superconducting Coil Array for NASA Prototype Magnetic Balance.** M.S. Thesis, NASA CR-164027, May 1980, 67 pp., 14 refs.

N81-18064#

Using a computer program, a partly optimized configuration for a superconducting version of side and lift coil system of M.I.T.-NASA prototype is presented. Cable size for the above mentioned coils and also for the superconducting and magnetizing coils was determined, with consideration of the overall computed field.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Grant NsG-1356

204. *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 Rep. January 1, 1977-August 31, 1980. MIT-TR-207, NASA CR-165660, November 1980, 142 pp., 35 refs.

N81-20086#

The use of superconducting coils for a general purpose magnetic balance is studied. Under the conditions of operation with fields of 1 or 2 tesla and frequencies of 20 to 40 Hz as well as dc, 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 made and tested using such a cable of 220 strands of varnish-insulated, 0.064 mm outside diameter, 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 ac fields up to 0.5 tesla, slewing rates up to 53 tesla/sec and frequencies up to 30 Hz. The ac losses were measured from helium boil-off and were approximately 20 percent higher than those calculated. Losses were dominated by hysteresis. 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 M.I.T.-NASA prototype magnetic balance using superconductors.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Grant NSG 1356

205. *Covert, E. E.; *Eberhardt, D. S.; and *Haldeman, C. W.: **Further Studies on Magnus Phenomena on Spinning and Coning Bodies. Final Rep., 25 October 1978-24 October, 1980.** Rep. No. MIT-TR-209; ARO-15813.3-E, December 1980, 17 pp., 6 refs.

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 Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
Contract DAAG29-79-C-0002

206. *Tuttle, M. H.; and **Gloss, B. B.: **Support Interference of Wind Tunnel Models: A Selective Annotated Bibliography.** NASA-TM-81909, March 1981, 36 pp., 146 refs. (Currently (1991) being updated.)

N81-20084#

Note: For a supplement to this support interference bibliography see citation no. 226 in this bibliography.

This bibliography, with abstracts, consists of 143 citations arranged in chronological order by dates of publication in the case of documents or books, and by dates of presentation for papers. 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.

*Kentron International, Inc., Hampton, VA 23666 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

207. *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., 1 ref. (Period covered November 1, 1979-November 1, 1980)

N81-26159#

The University of Southampton 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.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

208. *Moore, R. H.: **Photodiode Array Position Sensing of a Model in a Magnetic Suspension Wind Tunnel.** NASA CR-185,871, Submitted to University of Southampton (England) for B.Sc. in Electronic Engineering, May 1981, 56 pp., 5 refs.

N89-71302

This report studies the use of a 512 element linear photodiode array to determine the position of a model in a magnetic suspension wind tunnel. A suitable optical system is developed and a circuit is designed to give a digital and analogue output of position. This is incorporated into the heave control loop of an existing magnetic suspension wind tunnel and is shown to operate satisfactorily. Studies are carried out into the immunity of the array output to smoke inserted in the wind tunnel and a number of recommendations are made for further work.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
NASA Grant NSC-7523

209. *Britcher, C. P.: **Electromagnet Configurations for Extreme Attitude Testing in Magnetic Suspension and Balance Systems.** NASA CR-163862, May 1981, 22 pp.

N81-15008#

It is desirable that a large magnetic suspension and balance system (LMSBS) be capable of supporting and restraining typical models over a wide range of test attitudes under representative test conditions. Several fundamental difficulties arise, including: (1) Identification of electromagnet array geometries capable of generating, via field and field gradient components, forces and moments on the model in the required senses and magnitudes over the full range of model attitudes, (2) Synthesis of control algorithms capable of accommodating large changes in model aerodynamic characteristics and magnetic couplings to the electromagnets, (3) Design of position, attitude, and other sensors to monitor wide ranges of model motion. This report addresses part of (1), that is, the inclusion of adequate versatility into the electromagnet array configuration. Sizing the electromagnets thus specified to satisfy particular absolute force and moment requirements must be done separately. Magnetic performance of a permanent magnet model core, air cored electromagnet MSBS may easily and reliably be computed, such as by use of the Southampton University program FORCE (point field calculation and coil interface array processing segments derived from M.I.T. program TABLE). FORCE calculates model forces and moments via representations of the model as an assembly of dipoles and the electromagnets as an assembly of line currents. A more detailed description of the program is given in Appendix 1. Some aspects of the performance of an ellipsoidal iron cored model may be inferred from the above under certain circumstances.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
NASA Grant NSG-7423

210. *Covert, E. E.; and *Haldeman, C. W.: **Research Developing Closed Loop Roll Control for Magnetic Balance Systems. Semi-annual Status Report,** (February 1-July 31, 1981), NASA CR-164989, July 1981, 50 pp., 8 refs.

N82-12084#

Computer inputs were interfaced to the magnetic balance outputs to provide computer position control and data acquisition. The use of parameter identification as a means of determining dynamic characteristics was studied. The thyraton and motor generator power supplies for the pitch and yaw degrees of freedom were repaired. Topics covered include: choice of a method for handling dynamic system data; applications to the magnetic balance; the computer interface; and wind tunnel tests, results, and error analysis.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
NASA Grant NSG-1502

211. *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, Contract Report, 1 November 1980-1 November 1981, April 1982, 60 pp., 12 refs.

N83-18747#

The 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 concerning a relatively new dc scheme, referred to as the *spanwise iron magnet scheme* are presented. Computations made using the finite element computer program 'GFUN' 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, Southampton, Hampshire SO9 5NH, England

212. *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.. In: Rarefied Gas Dynamics, Vol. 1, (A86-42501), New York, Plenum Press, 1985, pp. 435-460, 11 refs.

A86-42540

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°. 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, Parks Road, Oxford OX1 3PJ, England
Research supported by Ministry of Defense

213. *Bloom, H. L.: **Design Concepts and Cost Studies for Magnetic Suspension and Balance Systems, Final Rep. November 1980-March 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. In general, the concepts 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 Co., Energy Systems Programs Department, Schenectady, NY 12345 U.S.A.
NAS1-16000
Prepared for Kentron International, Inc., Hampton, VA 23666 U.S.A.

214. *Wu, Y. Y.: **Design of a Horizontal Liquid Helium Cryostat for Refrigerating a Flying Superconducting Magnet in a Wind Tunnel.** NASA CR-165980, Progress Rep. June 1981-April 1982, August 1982, 65 pp., 8 refs.

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.

This report presents the design of a horizontal liquid helium cryostat for refrigerating a flying superconducting magnet in a wind tunnel. 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, Southampton, Hampshire SO9 5NH, England
NSG-7523

215. *Covert, E. E.; *Haldeman, C. W.; *Ramohalli, G.; and *Way, P.: **Development of Closed Loop Roll Control for Magnetic Balance Systems. Final Rep. February 1978 to February 1982.** NASA CR-166017, October 1982, 87 pp., 22 refs.

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 M.I.T. Aerophysics Laboratory, thus, showing feasibility for a roll control system for any large magnetic balance system which might be built. 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, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
NSG-1502

216. *Baheti, R. S.: **Multivariable Frequency Domain Controller for Magnetic Suspension and Balance Systems.** Presented at the IEEE 21st Conference on Decision and Control, held at Orlando, Fla., December 8-10, 1982. In: Proceedings, Vol. 3, pp. 1020-1025, (A84-19051). Also: IEEE Transactions on Automatic Control, vol. AC-29, no. 8, August 1984, pp. 725-728, 4 refs.

TJ217-I17 1982
(pp. 1020-1025)

A84-19138

This paper considers the control system for a magnetic suspension and balance system for an airplane model in a large wind tunnel. In this system, superconducting coils generate magnetic forces and torques on the magnetized soft iron core of the airplane model. The control system is a position servo where the airplane model, with six degrees of freedom, follows the reference static or dynamic input commands. The controller design, based on the characteristic loci method, minimizes the effects of aerodynamic and inertial cross-couplings, and provides the specified dynamic response.

*General Electric Co., Corporate Research and Development, Automation & Control Laboratory, Schenectady, NY 12345 U.S.A., Supported by NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

217. *Humphris, R. R., and *Zapata, R. N.: **Development of the Design Concepts for a Medium-Scale Wind Tunnel Magnetic Suspension System.** Final Rep., February 1977 to September 1982, UVA/643078/MAE82/111; NASA CR-166042, December 1982, 38 pp., 4 refs.

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

*University of Virginia, Charlottesville, VA 22901 U.S.A.
NSG-1010

218. *Rebuffet, P.: **The Effect of Supports on the Flow Behind a Body.** Presented at La Reunion sur les Effets des Interactions en Soufflerie du Groupe de Trail, held in Rhode St. Genèse, Belgium, March 2-5, 1959, 47 pp., and translated into English by Kanner (Leo) Associates, Redwood City, Calif., NASA TM-77073, May 1983, 31 pp., 5 refs., in English.

N80-71569 (French)
N83-33909# (English)

Note: For the original paper, in French, see citation no. 10 in this bibliography.

Two cases in a supersonic flow with a turbulent boundary layer are studied to determine the effects of supports on models with a flat base. 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.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France
Contract (for translation) NASW-3541

219. *Tuttle, M. H., **Kilgore, R. A., and **Boyden, R. P.: **Magnetic Suspension and Balance Systems, A Selected, Annotated Bibliography.** NASA TM-84661, July 1983, 50 pp. (This bibliography is now updated and superseded by the present (1991) publication.)

N83-29273#

The above publication, containing 206 entries, superseded an earlier bibliography (NASA TM-80225, April 1980), but is now superseded by this present (1991) publication, which supersedes and updates all previous bibliographies in this series on Magentic Suspension and Balance Systems.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

220. *Dubois, G.: **The Drag of Magnetically Suspended Wind-Tunnel Models With Nose-Cones of Various Shapes.** Translation into English from La Recherche Aeronautique, no. 87-64, March-April 1962, pp. 47-54. Translated by Kanner (Leo) Associates, Redwood City, Calif., NASA TM-77325, August 1983, 19 pp., 6 refs., in English.

N84-16137#

Note: For the original French report see citation no. 24 in this bibliography.

This article concerns the experimental determination of optimum nose-cones (minimum drag) of a body of revolution at supersonic and hypersonic speeds using the ONERA magnetic suspension. The study concerns two groups of models, specifically: a group whose nose-cone has a profile in the shape of X^n and the AGARD B group whose nose-cone is plotted in accordance with a given law. The results obtained for the first group are comparable to those calculated with the approximations of Cole and Newton and the experiments of Kubota.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France
Contract NASW-3541 (for translation).

221. *Britcher, C. P.: **Some Aspects of Wind Tunnel Magnetic Suspension Systems With Special Application at Large Physical Scales.** Report, July 1981-July 1982. NASA CR-172154, September 1983, 333 pp., 66 refs., (Ph.D. thesis).

N83-36038#

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 studied. 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 University of Southampton 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, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

222. *Britcher, C. P.: **Performance Measurements of a Pilot Superconducting Solenoid Model Core for a Wind Tunnel Magnetic Suspension and Balance System. Contractor Report, October 1982-July 1983,** NASA CR-172243, November 1983, 31 pp., 3 refs.

N84-12192#

Persistent superconducting solenoids may offer higher model magnetic moments than conventional ferromagnetic cores in large scale wind tunnel magnetic suspension and balance system (MSBS), thereby achieving economics in suspension electromagnet and power supply size and cost. An experimental superconducting solenoid model core has been built and demonstrated with the University of Southampton MSBS. Initial performance and calibration data verifies the technical feasibility of this model core concept.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

223. *Britcher, C. P.: **Progress Toward Magnetic Suspension and Balance Systems for Large Wind Tunnels.** Presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nev., January 9-12, 1984, 9 pp., 9 refs. Also: Journal of Aircraft, vol. 22, no. 4, April 1985, pp. 264-269, 9 refs.

AIAA Paper 84-0413 A84-18075#

Recent developments and current research efforts leading toward realization of a large-scale production wind tunnel magnetic suspension and balance facility are reviewed. Progress has been made in the areas of model roll control, high-angle-of-attack testing, digital system control, calibration techniques, high magnetic moment superconducting solenoid model cores, and system failure tolerance. Formal design studies have confirmed the engineering feasibility of large-scale facilities.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Contract NSG-7523
Grants - University of Southampton, England, SERC-RS-78305574; and GR/B/3691.5

224. *Dahlen, G. A.: **Cone Drag in the Transition from Continuum to Free Molecular Flow.** Rep. No. QUEL 1538/84, March 1984, 152 pp., 80 refs.

N85-31023#

The effect of wall temperature on hypersonic zero-incidence cone drag in the near-continuum to transition flow regimes was studied in a wind tunnel at Mach numbers from 5.2 to 5.9 and at Reynolds numbers from 50 to 1,300. Cone wall-to-stagnation temperature ratios were varied between 1.0 and 0.17. Results indicate a reduction in drag of the order of 10% as the wall temperature is reduced between limits of the stagnation and free-stream temperatures. Increases in cone vertex angle of rarefaction reduce the effect of wall temperature on drag. The effect of nose bluntness ratio (r_n/r_b) on cone drag was measured for 3° and 6° semivertex angle cones for a systematic variation of r_n/r_b between 0 and 0.4. No significant changes in drag levels are noted for $r_n/r_b \leq 0.2$: however, bluntness ratios of 0.3 and 0.4 result in progressive increases in drag over the range of Reynolds number.

*Oxford University, Parks Road, Oxford OX1 3PJ, England
Contract MIN-DEF/PE-AT-2057/042
Contract MIN-DEF/PE-AT/2057/086

225. *Britcher, C. P.; *Goodyer, M. J.; *Scurlock, R. G.; and *Wu, Y. Y.: **A Flying Superconducting Magnet and Cryostat for Magnetic Suspension of Wind-Tunnel Models.** In: Cryogenics, vol. 24, April 1984, pp. 185-189, 11 refs.

ISSN 0011-2275 A85-19098

This paper examines the engineering practicality of a persistent high-field superconducting solenoid cryostat as a magnetic suspension and balance system (MSBS) for wind-tunnel testing of aircraft and missile models. The test apparatus is a simple solenoid of filamentary NbTi superconductor with a cupronickel matrix. The apparatus, with a length-to-diameter ratio of 6 to 1 and a radius of 32 mm, used a 0.25 mm wire with a critical current of 27 A in an external field of 6 T. The total heat inleak of 150 mW was achieved. Helium boiloff rates were measured over a range of operating conditions, including pitch attitudes from 10° nose down to 90° nose up; the rate was estimated as low, but the aerodynamic acceptability of venting gaseous helium has not been determined. It is shown that the effectiveness of the concept increases with increasing scale, and performance in excess of that of conventional ferromagnets is achievable with reduction in size and costs, and that the concept is suitable for use in transonic wind-tunnel testing. Detailed specifications and schematics are included.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NsG 7523

226. *Tuttle, M. H.; and **Lawing, P. L.: **Support Interference of Wind Tunnel Models - A Selective Annotated Bibliography.** NASA TM-81909, Supplement, May 1984, 13 pp., 33 refs. (Presently (1991) being updated.)

N84-26708

Note: For the original bibliography see citation no. 206 in this bibliography.

This supplement to NASA TM-81909 (N81-20084) continues the numbering used in the original bibliography, and consists of 33 citations which focus specifically upon support interference problems which are thought to be directly solvable by magnetic suspension and balance systems (MSBS). Included are some more recent publications as well as several works inadvertently omitted from the earlier, more comprehensive, compilation.

*Kentron International, Inc., Hampton, VA 23666 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

227. *Boom, R. W.; *Eyssa, Y. M.; *McIntosh, G. E.; and *Abdelsalam, M. K.: **Magnetic Suspension and Balance System Study, Final Report, June 1983-March 1984**, NASA CR-3802, July 1984, 118 pp., 6 refs.

N84-29888#

A compact design for a superconducting magnetic suspension and balance system is developed for an 8- by 8-Foot transonic wind tunnel. The main features of the design are: a compact superconducting solenoid in the suspended airplane model; permanent magnet wings; one common liquid helium dewar for all superconducting coils; efficient new race track coils for roll torques; use of established 11 kA cryostable ac conductor; acceptable ac losses during 10 Hz control even with all steel structure; and a 560 liter/hour helium liquefier. Considerable design simplicity, reduced magnet weights, and reduced heat leak results from using one common dewar which eliminates most heavy steel structure between coils and the suspended model. Operational availability is thought to approach 100% for such magnet systems. The weight and cost of the magnet system is approximately one-third that of previous, less compact, designs.

*Madison Magnetics, Inc., 216 Walnut St., Madison, WI 53705 U.S.A.
Contract NAS1-17428

228. *Voronkov, V. S.: **Synthesis of a System for the Stabilization of a Magnetic Suspension and an Experimental Study of its Dynamics (Sintez sistemy stabilizatsii magnitnogo podvesa i eksperimental noe issledovanie ee dinamiki).** *Priborostroenie* vol. 27, August 1984, pp. 32-37, 5 refs., in Russian. Translation into English is NASA TT-20617, (X90-10044#), October 1989.

ISSN 0021-3454 A85-10472

Note: Translation into English of Priborostroenie V.27, August 1984, pp. 32-37 is X90-10044# (NASA TT-20617).

A description is given of the synthesis of a magnetic suspension with allowance for constraints of control voltage on the electromagnet. It is shown that small parameters are of little significance in the stabilization, and that optimal control in the suspension can be realized with sufficient precision according to a criterion involving the maximum attraction region of the stable equilibrium state. Details of the experimental study of system dynamics are discussed.

*Gor'kovskii Gosudarstvennyi Universitet, Gorki, U.S.S.R.

229. *Boom, R. W.; *Eyssa, Y. M.; *McIntosh, G. E.; *Abdelsalam, M. K.; **Scurlock, R. G.; **Wu, Y. Y.; **Goodyer, M. J.; **Balcerek, K.; **Eskins, J.; and ***Britcher, C. P.: **Superconducting Electromagnets for Large Wind Tunnel Magnetic Suspension and Balance Systems.** Presented at the Applied Superconductivity Conference, San Diego, CA, September 9-13, 1984, 4 pp., 6 refs.

A85-21546#

This paper presents a new design study of a Magnetic Suspension and Balance System (MSBS) for airplane models in a large 8 ft × 8 ft wind tunnel. New developments in the design include: use of a superconducting solenoid as a model core instead of magnetized iron; combination of permanent magnet material in the model wings along with four race-track coils to produce the required roll torque; and mounting of all the magnets in an integral cold structure instead of in separate cryostats. Design of superconducting solenoid model cores and practical experience with a small-scale prototype are discussed.

*Madison Magnetics, Inc., 216 Walnut St., Madison, WI 53705 U.S.A.
**University of Southampton, Southampton, Hampshire SO9 5NH, England
***NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Contract NAS1-17428, Grant NsG-7523

230. *Goodyer, M. J.: **The Generation of Rolling Moments With the Superconducting Solenoid Model.** NASA CR-172520, January 1985, 24 pp., 13 refs.

N85-18068#

The superconducting solenoid model is a pilot model core for levitation in a wind tunnel magnetic suspension system. This type of core would replace the ferromagnetic core typically installed in the model fuselage. For suspension purposes, the solenoid is operated upon by a set of electromagnets surrounding the wind tunnel which are to support and restrain the model at required positions and orientations under the influence of powerful aerodynamic disturbances. The subject of providing sources of magnets rolling moment for use when spanwise magnets, which can be used for winged models, are not available is covered. Several methods have emerged for generating a rolling moment based on the use of additional superconducting loops or magnetic poles positioned around or within the solenoid. Predictions of the moment capacities of superconducting loops in models sized for a large wind tunnel are presented. An existing prototype superconducting model proved a suitable vehicle for demonstrating and calibrating, at a smaller scale, some of the other roll elements based on magnetic pole devices. Calibration data are included.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
Contract NAS1-17919

231. *Boyden, R. P.; and *Tcheng, P.: **Status of Magnetic Suspension Technology.** Presented at the Langley Symposium on Aerodynamics, held at NASA Langley Research Center, Hampton, Va. on April 25-26, 1985, In: Vol. 1, (N88-14926) December 1986, pp. 261-277, 6 refs.

N88-14939#

The reasons for the continuing interest in the Magnetic Suspension and Balance System (MSBS) are highlighted. Typical problems that can arise because of model-support interference in a transonic wind tunnel are shown to illustrate the need for MSBS. The two magnetic suspension systems in operation at Langley are the only ones active in the U.S. One of these systems is the 13-inch MSBS which was borrowed from the Air Force Arnold Engineering Development Center. The other system is the 6-inch MSBS which was developed by M.I.T. Aerophysics Laboratory with NASA and DOD funding. Each of these systems is combined with a subsonic wind tunnel. Ongoing research in both of these systems is covered. Last year, Madison Magnetics, Inc., completed a contractural design and cost study using some advance concepts for a large MSBS which would be compatible with an 8-foot transonic wind tunnel, and the highlights of the study are presented. Sverdrup Technology, Inc. recently made a study for Langley, under contract, on the potential usefulness to the aerospace industry of a proposed large MSBS combined with a suitable transonic wind tunnel. The results of that study are discussed. Langley has partially funded the MSBS work at the University of Southampton for about 6 years under a grant arrangement and the major results are also summarized.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

232. *Britcher, C. P.: **Progress Toward Magnetic Suspension and Balance Systems for Large Wind Tunnels.** Journal of Aircraft, vol. 22, April 1985, pp. 264-269, 13 refs.

ISSN 0021-8669 A85-29252#

Note: For the paper on which this article is based see citation no. 223 in this bibliography.

Recent developments and current research efforts leading towards realization of a large scale production wind tunnel Magnetic Suspension and Balance facility are reviewed. Progress has been made in the areas of model roll control, high angle-of-attack testing, digital system control, high magnetic moment superconducting solenoid model cores, and system failure tolerance. Formal design studies have confirmed the engineering feasibility of large-scale facilities.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

233. *Martindale, W. R.; *Butler, R. W.; and *Starr, R. F., Jr.: **Study on Needs for a Magnetic Suspension System Operating With a Transonic Wind Tunnel.** Final Report., May 1985, 107 pp., 6 refs.

N85-26759#

Note: For a condensed version of this report see citation no. 268 in this bibliography.

The U.S. aeronautical industry was surveyed to determine if current and future transonic testing requirements are sufficient to justify continued development work on magnetic suspension and balance systems (MSBS) by NASA. The effort involved preparation of a brief technical description of magnetic suspension and balance systems, design of a survey form asking specific questions about the role of the MSBS in satisfying future testing requirements, selecting nine major aeronautics companies to which the description and survey forms were sent, and visiting the companies and discussing the survey to obtain greater insight to their response to the survey. Evaluation and documentation of the survey responses and recommendations which evolved from the study are presented.

Appendix I, Magnetic Suspension and Balance System-A Brief Technical and Programmatic Description, pp. 35-51, 6 refs.

*Sverdrup Technology, Inc., 600 William Northern Blvd., P. O. Box 884, Tullahoma, TN 37388 U.S.A.
Contract No. NAS1-17423

234. *Goodyer, M. J.: **A Preliminary Investigation of the Dynamic Force - Calibration of a Magnetic Suspension and Balance System.** NASA CR-172580, June 1983-January 1984.

May 1985, 14 pp.

N85-23808#

The aerodynamic forces and moments acting upon a magnetically suspended wind tunnel model are derived from calibrations of suspension electro-magnet currents against known forces. As an alternative to the conventional calibration method of applying steady forces to the model, this report outlines early experiences with dynamic calibration, that is a calibration obtained by oscillating a model in suspension and deriving a force/current relationship from its inertia force and the unsteady components of currents. Advantages of dynamic calibration are speed and simplicity. The two methods of calibration applied to one force component show good agreement.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant No. NsG-7523

235. Kaznacheyev, B. A.: **Optimum Dimensions of Power Solenoids for Magnetic Suspension.** NASA TM-77864, May 1985. Translation of "Optimal'nyye Razmery Silovykh Solenoidov Magnitnogo Podvesa", Izv. Vyssh. Ucheb. Zaved.: Elektromekhan., Novocherkassk, no. 2, February 1984, pp. 94-96. In: Joint Publications Research Service JPRS-UEE-84-010. (N85-13118). Translated by The Corporate Word, Pittsburgh, PA. 8 pp., 4 refs. in English.

N85-28716#

Design optimization of power solenoids for controllable and stabilizable magnetic suspensions with force compensation in a wind tunnel is shown, assuming that the model of a levitating body is a sphere of ferromagnetic material with constant magnetic permeability. This sphere, with a radius much smaller than its distance from the solenoid above, is to be maintained in position on the solenoid axis by balance of the vertical electromagnetic force and the force of gravitation. The necessary vertical (axial) force generated by the solenoid is expressed as a function of relevant system dimensions, solenoid design parameters, and physical properties of the body. On the basis of this relation and the relation of solenoid power, three families of curves are obtained. They depict the solenoid power for a given force as a function of the solenoid length with either outside radius or inside radius as a variable parameter and as a function of the outside radius with inside radius as a variable parameter. These curves indicate the optimum solenoid length and outside radius, for minimum power, corresponding to a given outside radius and inside radius, respectively.

Contract NASW-4006 (for translation)

236. *Britcher, C. P.: **Effect of Superconducting Solenoid Model Cores on Spanwise Iron Magnet Roll Control.** NASA TM-86378, June 1985, 25 pp., 8 refs.

N85-27915#

Compared with conventional ferromagnetic fuselage cores, superconducting solenoid cores appear to offer significant reductions in the projected cost of a large wind tunnel magnetic suspension and balance system. The provision of sufficient magnetic roll torque capability has been a long-standing problem with all magnetic suspension and balance systems; and the spanwise iron magnet scheme appears to be the most powerful system available. This scheme uses iron cores installed in the wings of the model. It was anticipated that the magnetization of these cores, and hence the roll torque generated, would be affected by the powerful external magnetic field of the superconducting solenoid. A preliminary study has been made of the effect of the superconducting solenoid fuselage model core concept on the spanwise iron magnet roll torque generation scheme. Computed data for one representative configuration indicate that reductions in available roll torque occur over a range of applied magnetic field levels. These results indicate that a 30-percent increase in roll electromagnet capacity over that previously determined will be required for a representative 8-foot wind tunnel magnetic suspension and balance system design.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Grant NsG-7523

237. *LaFleur, S.: **Advanced Optical Position Sensors for Magnetically Suspended Wind Tunnel Models.** In: ICIASF '85, 11th, International Congress on Instrumentation in Aerospace Simulation Facilities, held at Stanford, Calif., August 26-28, 1985, Record (A86-38226), New York Institute of Electrical and Electronics Engineers, 1985, pp. 106-114, 13 refs.

A86-38238

A major concern to aerodynamicists has been the corruption of wind tunnel test data by model support structures, such as stings or struts. A technique for magnetically suspending wind tunnel models was used by Tournier and Laurenceau (1957) to overcome this problem. This technique is now implemented with the aid of a Large Magnetic Suspension and Balance System (LMSBS) and advanced position sensors for measuring model attitude and position within the test section. Two different optical position sensors are discussed, taking into account a device based on the use of linear CCD arrays, and a device using area CID cameras. Current techniques in image processing have been used to develop target tracking algorithms capable of subpixel resolution for the sensors. The algorithms are discussed in detail, and some preliminary test results are reported.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
Contract NAS1-17979

238. *Boyden, R. P.; *Britcher, C. P.; and *Tcheng, P.: **Status of Wind Tunnel Magnetic Suspension Research.** Presented at the SAE Aerospace Technology Conference and Exposition, Long Beach, Calif., October 14-17, 1985, 11 pp., 18 refs.

SAE Paper 851898 A86-38361#

This paper reports the status of the NASA Langley Research Center program aimed at the development of the technology required for large-scale Magnetic Suspension and Balance Systems. The use of magnetic suspension of the model in a wind tunnel is seen to be the only viable method to eliminate aerodynamic interference problems arising with mechanical model-supports. The two small-scale magnetic suspension systems in operation at Langley are the only ones now active in the U.S. The general features and capabilities of these two systems and all of the ongoing research in the use of magnetic suspension are described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

239. *Boom, R. W.; *Eyssa, Y. M.; *McIntosh, G. E.; and *Abdelsalam, M. K.: **Magnetic Suspension and Balance System Advanced Study, Final Report, December 1984-June 1985.**

NASA CR-3937, October 1985, 122 pp., 9 refs.

N86-14278#

An improved compact design for a superconducting magnetic suspension and balance system for an 8 ft. × 8 ft. transonic wind tunnel is developed. The original design of an MSBS in NASA CR-3802 used 14 external superconductive coils and a superconductive solenoid in the test model suspended in a wind tunnel. The improvements are in the following areas: test model solenoid options, dynamic force limits on the model, magnet cooling options, structure and cryogenic designs, power supply specifications, and cost and performance evaluations. The improvements are: MSBS cost reduction of 28%, weight reduction of 43%, magnet system ampere-meter reduction of 38%, helium liquefier capacity reduction by 33%, magnet system stored energy reduction by 55%, ac loss to liquid helium reduced by 76%, system power supply reduced by 68%, test coil pole strength increased by 19%, wing magnetization increased by 40%, and control frequency limit increased by 200% from 10 Hz to 30 Hz. The improvements are due to: magnetic holmium coil forms in the test model, better rare earth permanent magnets in the wings, fiberglass-epoxy structure replacing stainless steel, better coil configuration, and new saddle roll coil design.

*Madison Magnetics, Inc., 216 Walnut St., Madison, WI 53705 U.S.A.
Contract NAS1-17931

240. *Dahlen, G. A.; and *Brundin, C. L.: **Wall Temperature Effects on Rarefied Hypersonic Cone Drag.** In: Rarefied Gas Dynamics, Vol. 1 (A86-42501), New York, Plenum Press, 1985, pp. 435-460, 11 refs.

A86-42540

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 semivertex angles of 3°, 6°, 10° and 15°. The resulting data indicate a consistent reduction in drag as 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, Parks Road, Oxford OX1 3PJ, England

241. *Eskins, J.: **Further Investigation Into Calibration Techniques for a Magnetic Suspension and Balance System.** Contractor Report, January-September 1985. NASA CR-178056, February 1986, 44 pp., 5 refs.

N86-20412#

Calibrations made on three different magnetic cores for wind tunnel models suspended in the University of Southampton Magnetic Suspension and Balance System (SUMSBS) are detailed. The first core studied was the University of Southampton pilot Superconducting Solenoid model, first flown in July 1983. Static calibrations of lift force, drag force, and pitching moment, together with lift force and pitching moment calibrations determined by the dynamic method, are detailed in this report. Other types of cores studied in a similar manner were conventional permanent magnets, Alnico, and samarium-cobalt. All static calibrations gave a linear dependence of force on electromagnet current as expected. Dynamic calibrations are faster but are proving to be not as easily analyzed as static calibrations. There are still some effects to be explained, but dynamic lift calibration results were obtained agreeing to within 2 percent of the static calibration value.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

242. *Barnwell, R. W.; *Edwards, C. L. W.; *Kilgore, R. A.; and *Dress, D. A.: **Optimum Transonic Wind Tunnel.** AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In: Technical Papers (A86-24726), pp. 173-182, 18 refs.

AIAA Paper 86-0755 A86-24743#

The optimum facility to complement existing high Reynolds number transonic wind tunnels is discussed. It is proposed that the facility be cryogenic, have a total pressure of five atmospheres or less, and have a test section on the order of 4- to 5-meters square. The large size is to accommodate complicated models such as those used in propulsion testing. It is suggested that magnetic suspension and wall interference minimization and correction procedures be used. Simplicity of initial design is stressed as a means of providing for growth opportunities.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

243. *Bushnell, D. M.; and *Trimpi, R. L.: **Supersonic Wind Tunnel Optimization.** Presented at AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In: Technical Papers, (A86-24726), pp. 282-300, 90 refs.

AIAA Paper 86-0773 A86-24754#

Attention is given to major problems arising in the course of definition studies for an optimum supersonic wind tunnel that uses advanced technologies. The issues identified encompass (1) large amplitude stream disturbances due to acoustic radiation from nozzle wall boundary layers; (2) flow field and model shape distortion caused by sting supports and their installation; (3) lack of sufficient three-dimensional flow visualization and diagnostic capabilities that allow ready identification of 'Reynolds number effects'; (4) lack of aerodynamic/propulsion facilities for investigation of the requisite range of vehicle attitudes and transient propulsion behavior; and (5) inordinately large energy usage, primarily due to diffuser inefficiency. Remedies are offered for these problems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

244. *Carmichael, A. T.; *Hinchliffe, S.; *Murgatroyd, P. N.; and *Williams, I. D.: **Magnetic Suspension Systems With Digital Controllers.** Review of Scientific Instruments, vol. 57, August 1986, pp. 1611-1615, 11 refs.

ISSN 0034-6748/86

Single-axis magnetic suspensions, using optical position sensing and dc electromagnets have been developed with eight-bit-word digital controllers that replace the familiar analog phase-advance or proportional-plus-derivative circuits. Control algorithms are obtained by a simple curve-fitting approach to signals sampled at constant rates. Stable suspension has been demonstrated at sampling rates down to 75 Hz when the magnet current has series transistor regulation, and at 100 Hz in a thyristor-regulated system.

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245. *Scudiere, M. B.; **Willems, R. A.; and ***Gillies, G. T.: **Digital Controller for a Magnetic Suspension System.** Review of Scientific Instruments, vol. 57, #8, August 1986, pp. 1616-1626, 19 refs.

ISSN 0034-6748/86

An active magnetic suspension system controlled digitally by a microprocessor has been built and operated in our laboratories. The control algorithm has integral, proportional, and derivative feedback loops. The remainder of the system including the sensor, power amplifier, and suspension coils, is of standard design. This developmental system has been used successfully to suspend small steel spheres and small rotors up to 190 g, and shows promise of having wide application.

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**Oak Ridge National Laboratory, Oak Ridge, TN 37831 U.S.A.
***University of Virginia, Charlottesville, VA 22901 U.S.A.

246. *Vyshkov, Yu. D.; *Kovalnogov, S. A.; *Usachov, V. N.; and *Shapovalov, G. K.: **A System for the Electromagnetic Levitation of Models in a Subsonic Wind Tunnel. Sistema elektromagnitnogo podvesa modelei v dozvukovoi aerodinamicheskoi trube.** In: TsAGI, Uchenye Zapiski, vol. 17, no. 4, 1986, pp. 94-97, 2 refs., in Russian.

ISSN 0321-3429 A88-50066

Note: NASA TT-20447, (X89-10591), September 1989, is an English translation.

An electromagnetic system is described which is capable of levitating models up to 2 kg in a subsonic wind tunnel. Aerodynamic drag measurements are presented for models tested in the 400 × 600 mm test section of a subsonic wind tunnel in the flow velocity range 0-60 m/s. Results of measurements of the interference of a supporting device on the aerodynamic drag are also presented.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

247. *Usachov, V. N.; *Kuzin, A. V.; and *Skubachevska, T. G.: **Photoelectrical Sensor for Detection of the Geometrical Parameters of the Object** (Fotoelektricheskiy datchik dlia opredelenia geometricheskix parametrov ob 'ekta) In: Bulletin Izobreteniy, no. 4, Invention N 1208477, U.S.S.R., 1986, pp. 232, in Russian.

An optical model position sensor is presented. A light beam of special shape passes across the model. The position of the model can be calculated from the measured position of the shadow of the model on the surfaces of the detectors. The original construction of the sensor provides the detection of vertical and horizontal displacements of the model in one optical channel.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

248. *Lawing, P. L.; *Dress, D. A.; and *Kilgore, R. A.: **Potential Benefits of Magnetic Suspension and Balance Systems,** NASA TM-89079, February 1987, 43 pp., 9 refs.

N87-17718#

This paper describes the potential of Magnetic Suspension and Balance Systems (MSBS) to improve conventional wind tunnel testing techniques. Topics include: elimination of model geometry distortion and support interference to improve the measurement accuracy of aerodynamic coefficients; removal of testing restrictions due to supports; improved dynamic stability data; and stores separation testing. Substantial increases in wind tunnel productivity are anticipated due to the coalescence of these improvements. Specific improvements are also forecast in testing methods for missiles, helicopters, fighter aircraft, twin fuselage transports and bombers, stage separation, water tunnels, and automobiles. In a more speculative vein, new wind tunnel test techniques are envisioned as a result of applying MSBS. These include "free-flight" computer trajectories in the test section, pilot-in-the-loop and designer-in-the-loop testing, shipboard missile launch simulation, and optimization of hybrid hypersonic configurations. Also addressed are potential applications of MSBS to such diverse technologies as medical research and practice, industrial robotics, space weaponry, and ore processing in space.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

249. *Britcher, C. P.: **User Guide for the Digital Control System of the NASA/Langley Research Center's 13-Inch Magnetic Suspension and Balance System–Final Report, 23 October 1985-30 September 1986.** March 1987, 81 pp., 7 refs.

N87-18574#

The technical background to the development of the digital control system of the NASA Langley Research Center's 13-inch Magnetic Suspension and Balance System (MSBS) is reviewed. The implementation of traditional MSBS control algorithms in digital form is examined. Extensive details of the 13-inch MSBS digital controller and related hardware are given, together with introductory instructions for system operators. Full listings of software are included in Appendices.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
Contract NAS1-17993

250. *Britcher, C. P.: **Technical Background for a Demonstration Magnetic Levitation System,** NACA CR-178301, May 1987, 38 pp., 15 refs.

N87-25332#

This paper presents a preliminary technical assessment of the feasibility of a demonstration Magnetic Levitation system, required to support aerodynamic models with a specified clear air volume around them. Preliminary calculations of required sizes of electromagnets and power supplies are made, indicating that the system is practical. Other aspects, including model position sensing and controller design, are briefly addressed.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
NAG1-716

251. *Covert, E. E.: **Magnetic Suspension and Balance Systems for Use With Wind Tunnels.** Presented at the 12th International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '87, in Williamsburg, Va., June 22-25, 1987. In: Record

(A88-36483) New York, Institute of Electrical and Electronics Engineers, Inc., 1987, 12 pp., 63 refs.
TK7882.M415-1987, pp. 283-294 A88-36518

Note: For a journal article based on this paper see citation no. 269 in this bibliography.

Early work on MSBS is described. Some examples of particular systems are presented and their results indicate that it is practical to suspend wind tunnel models magnetically, and that these suspension schemes provide accurate aerodynamic data. It seems likely that these systems will become more common as the need for more accurate data, and the need for data simulating more complex flight conditions in the wind tunnel becomes more important. A reference list of 63 references is appended.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

252. *Boom, R. W.; *Abdelsalam, M. K.; *Eyssa, Y. M.; and *McIntosh, G. E.: **Magnetic Suspension and Balance System (MSBS) Advanced Study. Part I - System Design and Part II - Superconducting Solenoid and Magnetic Wings for Wind Tunnel Models.** Presented at the 12th International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '87, in Williamsburg, Va., June 22-25, 1987. In: Record (A88-36483) New York, Institute of Electrical and Electronics Engineers, Inc., 1987, 13 pp., 12 refs.

TK 7882.M415-1987, pp. 295-307 A88-36519

A magnetic suspension and balance system is designed to support models of aircraft or other objects in wind tunnels using magnetic forces. Major design improvements have been achieved, resulting in reductions of the system size, weight, and cost. These improvements are due to: (1) the use of holmium in the model core to increase its magnetic moment, (2) the use of a powerful new permanent magnet material in the model wings, (3) a new arrangement for the roll coils, and (4) the use of a nonmetallic structure to eliminate eddy current losses. The conceptual design of the holmium core superconductive solenoid and of the new permanent magnet wing assembly is described in detail. The discussion includes comparisons of the pole strengths for different model core magnets, the design of a superconducting solenoid and cryostat, and the analysis of model wing magnetic requirements.

*Madison Magnetics, Inc., 216 Walnut St., Madison, WI 53705 U.S.A.
Contract NAS1-17931

253. *Roberts, P. W.; and *Tcheng, P.: **Strain-Gage Balance Calibration of a Magnetic Suspension and Balance System.** Presented at the 12th International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '87, in Williamsburg, Va., June 22-25, 1987. In: Record (A88-36483) New York, Institute of Electrical and Electronics Engineers, Inc., 1987, 14 pp., 8 refs.

TK7882.M415,1987, pp. 308-321 A88-36520#

A load calibration of the NASA 13" magnetic suspension and balance system (MSBS) is described. The calibration procedure was originally intended to establish the empirical relationship between the coil currents and the external loads (forces and moments) applied to a magnetically suspended calibrator. However, it was discovered that the performance of a strain-gage balance is not affected when subjected to the magnetic environment of the MSBS. The use of a strain-gage balance greatly reduces the effort required to make a calibration of coil current as a function of load since the external loads can be directly inferred from the balance outputs while a calibrator is suspended in MSBS. It is conceivable that in the future such a calibration could become unnecessary, since an even more important use of a strain-gage balance in MSBS environment might be the acquisition of precision aerodynamic force and moment data by telemetering the balance outputs from a suspended model/core/balance during wind tunnel tests.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

254. *Tcheng, P.; and *Schott, T. D.: **A Five Component Electro-Optical Positioning System.** Presented at the 12th International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '87, in Williamsburg, Va., June 22-25, 1987. In: Record (A88-36483) New York, Institute of Electrical and Electronics Engineers, Inc., 1987, 12 pp., 5 refs.

TK7882.M415,1987, pp. 322-333 A88-36521#

The development of a five-component electro-optical positioning system for detecting the location of wind tunnel models within the test section is discussed. The system consists of three low power helium-neon lasers, five linear photodiode arrays, an assembly of optics that includes lenses and mirrors, and a signal conditioner. The system is in use with the 13-inch magnetic suspension and balance system (MSBS) at the NASA Langley Research Center. Initially, the system was developed as an auxiliary model position and attitude detecting system for that facility, but it has since been modified and interfaced with a PDP minicomputer to provide position feedback for the control loop.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

255. *Britcher, C. P.; **Goodyer, M. J.; **Eskins, J.; **Parker, D. H.; and **Halford, R. J.: **Digital Control of Wind Tunnel Magnetic Suspension and Balance Systems.** Presented at the 12th International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '87, in Williamsburg, Va., June 22-25, 1987. In: Record (A88-36483) New York, Institute of Electrical and Electronics Engineers, Inc., 1987, 9 pp., 13 refs.

TK7882.M415,1987, pp. 334-342 A88-36522

Digital controllers are being developed for wind tunnel magnetic suspension and balance systems, which, in turn, permit wind tunnel testing of aircraft models free from support interference. Hardware and software features of two existing digital control systems are reviewed. Some aspects of model position sensing and system calibration are also discussed.

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**University of Southampton, Southampton, Hampshire SO9 5NH, England
Contract No. NAS1-17993-24
Grants NAG1-716; NsG-7523

256. *Parker, D. H.: **High Angle of Attack Position Sensing for the University of Southampton Magnetic Suspension and Balance System: Progress Report, January 1986-March 1987,** AASU-87/3, NASA CR-178358, August 1987, 38 pp., 4 refs.

N87-27681#

An all digital five channel position detection system is to be installed in the University of Southampton Magnetic Suspension and

Balance System (SUMSBS). The system is intended to monitor a much larger range of model pitch attitudes than has been possible hitherto, up to a maximum of 90° angle of attack. It is based on the use of self-scanning photodiode arrays and illuminating laser light beams, together with purpose built processing electronics. The principles behind the design of the system are discussed, together with the results of testing one channel of the system which was used to control the axial position of a magnetically suspended model in SUMSBS. The removal of optically coupled heave position information from the axial position sensing channel is described.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

257. *Britcher, C. P.; and **Kilgore, R. A.: **Magnetic Suspension and Balance Systems (MSBSs).** National Defense Academy, Advanced Experimental Techniques for Transonic Wind Tunnel Meeting, Yokosuka, Japan, October 12-23, 1987, 43 pp., 25 refs.

A91-17570#

The problems of wind tunnel testing are outlined, with attention given to the problems caused by mechanical support systems, such as support interference, dynamic-testing restrictions, and low productivity. The basic principles of magnetic suspension are highlighted, along with the history of magnetic suspension and balance systems. Roll control, size limitations, high angle of attack, reliability, position sensing, and calibration are discussed among the problems and limitations of the existing magnetic suspension and balance systems. Examples of the existing systems are presented, and design studies for future systems are outlined. Problems specific to large-scale magnetic suspension and balance systems, such as high model loads, requirements for high-power electromagnets, high-capacity power supplies, highly sophisticated control systems and position sensors, and high costs are assessed.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

258. *Kuzin, A. V.; and *Vyshkov, Yu. D.: **Optimization of Control in Multicomponental System of Electromagnetic Suspension** (Optimizacia upravienia v mnogokomponentnoiv sisteme elektromagnitnoiv podveski) In: Priborostroenie (Transactions of Colleges, Instrument Engineering), November 1987, Vol. XXX, no. 11, pp. 44-49, 4 refs., in Russian.

A88-23936

The control optimization problem for a multicomponent electromagnetic suspension system is solved using the criterion of the maximum attraction domain of the equilibrium state. Control algorithms which maximize the stability domain and the range of permissible external forces are obtained for an extended body positioned vertically in the magnetic field of two electromagnets, with constraints imposed on the control voltage applied to the electromagnet windings.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

259. *Newcomb, A. W.: **The Effect of Sting Interference at Low Speeds on the Drag Coefficient of an Ellipsoidal Body Using a Magnetic Suspension and Balance System.** NASA CR-181611, February 1988, 79 pp., 7 refs.

N88-20274#

A Boltz body of revolution (fineness ratio 7.5:1) was tested in the University of Southampton Magnetic Suspension and Balance System. The effects of sting interference on the drag coefficient of the model at zero angle of attack were noted as well as the effects on drag coefficient values at boundary layer trips. The drag coefficient values were compared with other sources and seemed to show agreement. The pressure distribution over the rear of the model with no sting interference was studied including the use of boundary layer trips.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
Contract NAS1-17919

260. *Dress, D. A.: **Drag Measurements on a Laminar Flow Body of Revolution in Langley's 13 Inch Magnetic Suspension and Balance System.** NASA CR-182909; George Washington University M.S. Thesis, April 1988, 95 pp., 45 refs.

N88-25432#

Low-speed wind tunnel drag force measurements were taken on a laminar flow body of revolution free of support interference. This body was tested at zero incidence in the NASA Langley 13 inch Magnetic Suspension and Balance System (MSBS). The primary objective of these tests was to substantiate the drag force measuring capabilities of the 13 inch MSBS. A secondary objective was to obtain support interference free drag measurements on an axisymmetric body of interest. Both objectives were met. The drag force calibrations and wind-on repeatability data provide a means of assessing the drag force measuring capabilities of the 13 inch MSBS. The measured drag coefficients for this body are of interest to researchers involved in designing minimum drag fuselage shapes. Additional studies included: the effects of fixing transition; the effects of fins installed in the tail; surface flow visualizations using both liquid crystals and oil flow; and base pressure measurements using a one-channel telemetry system. Two drag prediction codes were used to assess their usefulness in estimating overall body drag. These theoretical results did not compare well with the measured values because of the following: incorrect or non-existent modeling of a laminar separation bubble on the body and incorrect or non-existent estimates of base pressure drag.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

261. *Daniels, T. S.; and *Tripp, J. S.: **Improvements to an Electromagnetic Position Sensor for a Magnetic Suspension Tunnel.** Presented at the 34th International Instrumentation Symposium held at Albuquerque, NM, May 2-6, 1988. In: Instrument Society of America, Research Triangle Park, Durham, NC, Proceedings (A89-27651), pp. 65-70, 1 ref.

ISA Paper 88-0708 A89-27656#

The original and improved designs for the Electromagnetic Position Sensor (EPS), an electronic instrument and associated multicoil sensor for the six-inch Magnetic Suspension and Balance System (MSBS) that measures aerodynamic model position, are compared. The EPS power amplifier and oscillator, input nulling stage, reference voltage generators, bandpass filter, summation and demodulation, and final stage are described. The effects of the MSBS and of model materials on the performance are addressed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

262. *Tcheng, P.; *Schott, T. D.; and *Bryant, E. L.: **A Miniature, Infrared Pressure Telemetry System.** Presented at the 34th International Instrumentation Symposium, held at Albuquerque, New Mex., May 2-6, 1988. In: Instrument Society of America, Research Triangle Park, Durham, NC, Proceedings (A89-27651), 1988, pp. 407-416, 5 refs.

ISA Paper 88-0746 A89-27673#

A miniature, single-channel, infrared telemetry system designed for making base pressure measurements on a wind tunnel model has been developed for the 13-inch magnetic suspension and balance system (MSBS) at Langley Research Center. The system consists of a transmitter installed in the wind tunnel model and a receiver station located outside of the test section. The onboard transmitter package includes a miniature pressure transducer, a signal conditioning circuit, and IR LED and a battery package. The IR LED, which is mounted flush with the model's surface, serves as the transmitter. The system is automatically activated in a magnetic field and has low power requirements. The system has been successfully used to make low speed base pressure measurements at the 13-inch MSBS. The battery powered telemetry transmitter has a demonstrated one-hour operating life and an overall precision of better than 0.5 percent full scale.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

263. *Boyden, R. P.: **A Review of Magnetic Suspension and Balance Systems.** Presented at the 15th AIAA Aerodynamic Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 94-105, 46 refs.

AIAA Paper 88-2008 A88-37917#

This paper traces the development of Magnetic Suspension and Balance Systems (MSBSs) for use in wind tunnels. The expression MSBS implies a system that can both suspend a model and also measure the forces and moments acting on the model. This avoids the need for any mechanical support of the model. An MSBS uses electromagnets located outside the test section walls to create magnetic fields inside the test section. Measurement of the electrical current in each of the electromagnets can be used to determine the forces and moments acting on the suspended model. An MSBS is capable of supporting a model with an internal magnetized core subject to gravity, aerodynamic, and inertial loads. The model must have a core made of either a permanent magnet, magnetized soft iron, or a solenoid. The position of the suspended body is inherently unstable. A closed-loop control system which includes a position sensing system, is used to control the position of the body by controlling the applied magnetic fields. This paper includes a discussion of all the known MSBSs and the outlook for larger systems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

264. *Dress, D. A.: **Drag Measurements on a Body of Revolution in Langley's 13-inch Magnetic Suspension and Balance System.** Presented at the 15th AIAA Aerodynamic Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 106-116, 37 refs.

AIAA Paper 88-2010 A88-37918#

Note: Also see AIAA Journal, vol. 27, no. 8, August 1989, pp. 1081-1082, citation no. 281 in this bibliography.

The 13-inch Magnetic Suspension and Balance System (MSBS) at NASA Langley has been used to make low-speed wind tunnel drag force measurements on a laminar-flow body-of-revolution free of support system interference to verify the drag force measurement capabilities of the MSBS. The drag force calibrations and wind-on repeatability data obtained have verified the design capabilities for this system. A drag-prediction code has been used to assess the usefulness of an MSBS in measuring body drag.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

265. *Britcher, C. P.; and *Alcorn, C. W.: **An Experimental Investigation of the Aerodynamic Characteristics of Slanted Base Ogive-Cylinders using Magnetic Suspension Technology.** Presented at the 15th AIAA Aerodynamics Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 117-127, 15 refs.

AIAA Paper 88-2011 A88-37919#

This paper reports on an experimental study of aerodynamic characteristics of slanted base ogive cylinders at zero incidence. The Mach number range is 0.05 to 0.30. In this study, magnetically suspending the wind tunnel models eliminates flow disturbances associated with mechanical supports. This paper reports on the drastic changes in lift, pitching moment, and drag for a slight change in base slant angle. Flow visualization with liquid crystals and oil is used to observe base flow patterns responsible for the sudden changes in aerodynamic characteristics. This paper also reports on hysteretic effects that are present and discusses computational results using VSAERO and SANDRAG.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
Grant NAG1-716

266. *Britcher, C. P.; and **Parker, D. H.: **Progress Towards Extreme Attitude Testing with Magnetic Suspension and Balance Systems.** Presented at the 15th AIAA Aerodynamics Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 128-135, 8 refs.

AIAA Paper 88-2012 A88-37920#

Progress is reported in a research effort aimed towards demonstration of the feasibility of suspension and aerodynamic testing of models at high angles of attack in wind tunnel Magnetic Suspension and Balance Systems. Extensive modifications, described in this paper, have been made to the University of Southampton suspension system to facilitate this work. They include revision of electromagnet configuration, installation of all-new position sensors, and expansion of control system programs. An angle of attack range of 0 to 90° is expected for axisymmetric models. To date, suspension up to 80° has been achieved.

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**University of Southampton, Southampton, Hampshire SO9 5NH, England
Grants NsG-7523, NAG1-716

267. *Lawing, P. L.; and *Johnson, W. G., Jr.: **A Forecast of New Test Capabilities Using Magnetic Suspension and Balance Systems.** Presented at the 15th AIAA Aerodynamic Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 136-144, 24 refs.

AIAA Paper 88-2013 A88-37921#

This paper outlines the potential of Magnetic Suspension and Balance System (MSBS) technology to solve existing problems related to support interference in wind tunnels. Improvement of existing test techniques and exciting new techniques are envisioned as a result of applying MSBS. These include improved data accuracy, dynamic stability testing, two-body/stores release testing, and pilot/designer-in-the-loop tests. It also discusses the use of MSBS for testing exotic configurations such as hybrid hypersonic vehicles. A new facility concept that combines features of ballistic tubes, magnetic suspension, and cryogenic tunnels is described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

268. *Martindale, W. R.; *Butler, R. W.; and *Starr, R. F., Jr.: **Study on Needs for a Magnetic Suspension System Operating With a Transonic Wind Tunnel.** Presented at the 15th Aerodynamic Testing Conference, San Diego, Calif., May 18-20, 1988. In: Technical Papers (A88-37907), 1988, pp. 145-150, 6 refs.

AIAA Paper 88-2014 A88-37922#

Note: For the full report of this survey see citation no. 233 in this bibliography.

A survey of the U.S. aeronautical industry was made to determine if current and future transonic testing requirements are sufficient to justify continued development work on magnetic suspension and balance systems (MSBS) by NASA. The effort involved preparation of a brief technical description of magnetic balance and suspension systems, design of a survey form asking specific questions about the role of the MSBS in satisfying future testing requirements, selecting nine major aeronautical companies to which the description and survey forms were sent, and visiting the companies and discussing the survey to obtain greater insight to their response to the survey. An evaluation and discussion of the survey responses is presented.

*Sverdrup Technology, Inc., 600 William Northern Blvd., P. O. Box 884, Tullahoma, TN 37388 U.S.A.

269. *Covert, E. E.: **Magnetic Suspension and Balance Systems.** In: IEEE AES Magazine, May 1988, pp. 14-22.

Note: This article is based on a paper which is citation no. 251 in this bibliography.

The following elements are needed to have a magnetic balance and suspension system: (1) A magnetized body, (2) Two classes of magnetic fields (a) uniform fields for torque generation, (b) gradient fields for force generation, (3) Independent power supplies for each degree of freedom, (4) Independent position sensing for each degree of freedom, (5) Automatic control systems for each degree of freedom, (6) A means of determining the magnetic force which balances the applied loads. The several possible ways to meet each of the needs listed are discussed. A short history is given of the important events leading up to a successful magnetic suspension. Examples of particular systems, and a discussion of a small number of results that might well be considered to be classical, concludes this article.

*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.

270. *Boyden, R. P.; *Kilgore, R. A.; *Tcheng, P.; and **Britcher, C. P.: **Super Magnets for Large Tunnels.** In: Aerospace America, vol. 26, June 1988, pp. 36-38, 40.

A88-43521#

The development and use of a large Magnetic Suspension and Balance System (MSBS) in wind tunnels is examined. NASA-sponsored research to develop a large MSBS, and the 2 MSBSs already in use is discussed. The MSBS holds the model in an arbitrary position in the wind tunnel test section and measures the forces and moments acting on the model. Technologies for building a large MSBS have been developed, and research is being done to reduce building costs. Magnetic suspension is advantageous because it completely eliminates interference from mechanical support systems such as stings or struts and it allows for easy rotation and translation of the model. Advances allowing operation at higher temperatures, probably using liquid nitrogen instead of liquid helium, may reduce the cost of MSBS operation. A large MSBS would require power controllers with capacity up to 10 MW, efficiency approaching 98 percent and the ability to reverse the sign of both voltage and current. Technologies include the electromagnetic position sensor, model positioning sensing, digital controller, and a precalibrated strain-gage balance.

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**Old Dominion University, Norfolk, VA 23529-0247 U.S.A.

271. *Smith, R. W.; and *Lord, R. G.: **Drag and Lift Measurements on Inclined Cones Using a Magnetic Suspension and Balance.** Presented at the 16th International Symposium on Rarefied Gas Dynamics: Theoretical and Computational Techniques, held at Pasadena, Calif., July 10-16, 1988. In: Technical Papers, (A90-37169), AIAA, Inc., Washington, D.C., 1989, pp. 493-499.

A90-37198#

Drag and lift forces on a sharp, 10° cone in hypersonic, rarefied flow at angles of incidence up to 10° have been measured using magnetic suspension and balance techniques. The measurements are therefore free from errors resulting from sting interference. The flow Mach number was approximately 6, and freestream Knudsen numbers, based on cone base diameter, varied between 0.008 and 0.02. Flow gradients were believed to be negligible. The results have been compared with calculated limiting values for inviscid continuum flow and with the experimental results of other workers.

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Research supported by the Ministry of Defense Procurement Executive

272. *Eskins, J.: **An Investigation Into Force/Moment Calibration Techniques Applicable to a Magnetic Suspension and Balance System.** NASA CR-181695, AASU Memo. 88/4, University of Southampton M. Phil. (M.S.) thesis, August 1988, 206 pp., 35 refs.

N89-10061#

This paper addresses the problem of determining the forces and moments acting on a wind tunnel model suspended in a Magnetic Suspension and Balance System. Two calibration methods were studied for three types of model cores, namely, Alnico, Samarium-Cobalt and a superconducting solenoid. Both methods involve calibrating the currents in the electromagnet array against known forces and moments. The first is a static calibration method using calibration weights and a system of pulleys. The other method, dynamic calibration, involves oscillating the model and using its inertia to provide calibration forces and moments. Static calibration data, found to produce the most reliable results, is presented for three degrees of freedom at 0°, 15°, and -10° angle of attack.

Theoretical calculations are hampered by the inability to represent iron-cored electromagnets. Dynamic calibrations, despite being quicker and easier to make, are not as accurate as static calibrations. Data for dynamic calibrations at 0° and 15° is compared with the relevant static data acquired. Distortion of oscillation traces is cited as a major source of error in dynamic calibrations.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Contract NSG-7523

273. *Kanda, H.; *Sawada, H.; and *Suenaga, H.: **The Calibration of a Model Position and Attitude Sensor With the One-Dimensional Array CCD Image Sensors.** Presented at the JSASS Aircraft Symposium, October 21, 1988, 4 pp., 4 refs., (in Japanese.)

A new sensor to measure 5 components of model position and attitude at a 10 cm distance from the model was developed. This sensor consists of three 1D array CCD image sensors arranged in a H-shape. A series of calibration tests of the sensor were made. It was found that the sensor has an accuracy of 0.3 percent full scale in the X and Z direction while it has much more error to the transverse movement of a model. This error arises because the image of a model (or a mark on the model) becomes out of focus in these directions. It was also found that cross-coupling effects are large in the outputs in the transverse directions.

*National Aerospace Laboratory, 1880 Jindaiji-Machi, Chofu-shi, Tokyo 182, Japan

274. *Alcorn, C. W.: **An Experimental Investigation of the Aerodynamic Characteristics of Slanted Base Ogive Cylinders Using Magnetic Suspension Technology.** NASA CR-181708, November 1988, 89 pp., 25 refs.

N90-10834

Note: This report was originally submitted to Old Dominion University in partial fulfillment of the requirements for the degree of Master of Science.

An experimental study is reported on slanted base ogive cylinders at zero incidence. The Mach number range is 0.05 to 0.30. All flow disturbances associated with wind tunnel supports are eliminated in this study by magnetically suspending the models. The sudden and drastic changes in the lift, pitching moment, and drag for a slight change in base slant angle are reported. Flow visualization with liquid crystals and oil is used to observe base flow patterns, which are responsible for the sudden changes in aerodynamic characteristics. Hysteretic effects in base flow pattern changes are present and are reported. The effect of a wire support attachment on the 0° slanted base model is studied. Computational drag and transition location results using VSAERO and SANDRAG are presented and compared with experimental results. Base pressure measurements over the slanted bases are made with an onboard pressure transducer using remote data telemetry.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
Contract NAG1-716

275. *Dress, D. A.: **Drag Measurements on a Modified Prolate Spheroid Using a Magnetic Suspension and Balance System.** Presented at the AIAA 27th Aerospace Sciences Meeting, Reno, Nev., January 9-12, 1989, 12 pp., 25 refs. Also: Journal of Aircraft, vol. 27, no. 6, June 1990, pp. 523-528, 22 refs., A90-40684#.

AIAA Paper 89-0648 A89-25512#
ISSN 0021-8669 A90-40684#

Low-speed wind tunnel drag force measurements were taken on a modified prolate spheroid free of support interference. This body was tested at zero incidence in the NASA Langley 13-inch Magnetic Suspension and Balance System. This shape was one of two bodies tested to determine the drag force measuring capabilities of the 13-inch MSBS. In addition, support interference on this shape at zero incidence was quantified by using a dummy sting. The drag force calibrations and wind-on repeatability data make it possible to assess the drag force measuring capabilities of the 13-inch MSBS. Comparisons with and without the sting showed differences in the drag coefficients with the dummy sting case resulting in lower drag coefficients.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

276. *Johnson, W. G., Jr.; and *Dress, D. A.: **The 13-Inch Magnetic Suspension and Balance System Wind Tunnel.** NASA TM-4090, January 1989, 48 pp., 12 refs.

N89-14241#

The Langley Research Center has a small, subsonic wind tunnel in use with the 13-inch Magnetic Suspension and Balance System (MSBS). The tunnel is capable of speeds up to Mach 0.5. This report presents tunnel design and construction details. It includes flow uniformity, angularity, and velocity fluctuation data. It also compares experimental Mach number distribution data with computed results from the General Electric Streamtube Curvature Program.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

277. *Lawson, M. A.; and *Gillies, G. T.: **Interrupt-Driven Digital Controller for a Magnetic Suspension System.** Review of Scientific Instruments, vol. 60, no. 3, March 1989, pp. 456-466, 22 refs.

The hardware interrupt structure of an MS-DOS™-based micro computer was used to enable real-time, keyboard manipulation of the control parameters of a stable, vertical magnetic suspension without halting its operation. The positions of objects suspended with this system were measured to be stable to within ± 15 μm of a reference position. Stable suspensions were achieved at sampling rates as low as 45 Hz, although the system was typically operated at sampling rates of 1,000-2,000 Hz. The dynamics of the suspension were explored for several different values of proportional, integral, and derivative gains, and the system's transient response and steady-state behavior were characterized. We present here the data resulting from those studies, as well as measurements of the suspension's drift, empirically determined values of its second-order transfer function parameters, a discussion of the suspension's foreground/background capabilities, a description of its algorithm, and details of its electromechanical construction.

*University of Virginia, Charlottesville, VA 22901 U.S.A.

278. *Groom, N. J.: **Analytical Model of a Five Degree of Freedom Magnetic Suspension and Positioning System.** NASA TM-100671, March 1989, 18 pp.

N89-21136#

An analytical model of a five degree of freedom magnetic suspension and positioning system is presented. The suspended element is a cylinder which is composed of permanent magnet material and the magnetic actuators are air core electromagnets mounted in a planar array. The analytical model consists of an open loop representation of the suspension and positioning system with electromagnet currents as inputs and displacements and rates in inertial coordinates as outputs. The uncontrolled degree of freedom is rotation about the long axis of the suspended cylinder.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

279. *Schott, T. D.; and *Tcheng, P.: **A High Resolution Electro-Optical Displacement Measurement System.** Presented at the Instrument Society of America Symposium held at Orlando, Fla., May 1-4, 1989, 14 pp., 3 refs. In: ISA, 1989-Paper #89-0045, pp. 441-454.

An improved electro-optical system has been developed to sense wind tunnel model position. The original system using 25.6 mm, 1024-element linear photodiode arrays (PDA) is being successfully used at a NASA wind tunnel but has a limited range. A new two-channel system using 61.44 mm, 4096-element PDAs has been developed to double the range of vertical and pitch measurement and increase the resolution by 60%. The PDAs are illuminated by expanding the beam of a single low power helium neon laser into a collimated sheet of light. An object placed in front of the two parallel PDAs produces a shadow on the array apertures which determines the object's position or size. A signal conditioner was designed to detect the light-to-dark and dark-to-light transitions occurring in the video signals and also to suppress optical noise. The circuit produces two binary outputs per channel, representing the locations of the object edges. A host computer receives the binary signals through a parallel line driver-receiver system and provides a 256 Hz scan-initiate clock. The system has an overall precision of +/-0.0005 inches (12.7 microns) and +/-0.015 degrees in linear and angular measurements.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

280. *Britcher, C. P.; **Alcorn, C. W.; and *Kilgore, W. A.: **Subsonic Sting Interference on the Drag of a Family of Slanted-Base Ogive Cylinders.** Presented at the AIAA 7th Applied Aerodynamics Conference, Seattle, Wash., July 31-August 2, 1989. In: Technical Papers, (A89-47626), pp. 389-397, 20 refs.

AIAA Paper 89-2206-CP A89-47665#

Note: For a related report see NASA-CR-4299, June 1990, citation no. 290 in this bibliography.

Support interference free drag measurements on a range of slanted-base ogive-cylinders are made using the NASA Langley 13-inch Magnetic Suspension and Balance System. Comparison is made to measurements with a dummy sting support. Significant support interferences are found at most test conditions. Further comparison is made between interference free base pressures, obtained using remote telemetry, and sting cavity pressures.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
**von Karman Institute, Rhode-Saint-Genèse, Belgium
NASA Langley Grant NAG-1-716

281. *Dress, D. A.: **Drag Measurements on a Laminar Flow Body of Revolution.** Presented at the 15th Aerodynamic Testing Conference, San Diego, Calif., May 18-20, 1989. In: AIAA Journal, vol. 27, no. 8, August 1989, pp. 1081-1082.

AIAA Paper 88-2010 A89-47365#

Note: This article is based on a paper presented in May 1988, see citation no. 264 in this bibliography.

Low-speed wind-tunnel drag force measurements were taken on a laminar flow body of revolution free of support interference. This body was tested at zero incidence in the NASA Langley 13-inch Magnetic Suspension and Balance System (MSBS). The primary objective of these tests was to determine the drag force measuring capabilities of the 13-inch MSBS. The drag force calibrations and wind-on repeatability data let us assess these capabilities. Other studies included the effects of fixing transition and surface flow visualizations using both liquid crystals and oil flow. In addition, the drag coefficient data from this study are compared with data from another source.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

282. *Goodyer, M. J.: **The Six Component Magnetic Suspension System for Wind Tunnel Testing.** Presented at the 7th University of Oregon Conference on Low Temperature Physics. (Workshop on High Reynolds Number Liquid Helium Flow Facilities), held at Eugene, Oregon, October 23-25, 1989, 18 pp.

A90-41725#

The design and operation of the six-component magnetic suspension and balance system are described. The methods for producing roll control movements are discussed. A delta-winged model for closed-loop control in six degrees of freedom and a superconducting solenoid model are presented and examined. Examples displaying the applicability of the system are provided.

*University of Southampton, Southampton, Hampshire SO9 5NH, England

283. *Britcher, C. P.: **Recent Aerodynamic Measurements with Magnetic Suspension Systems.** Presented at the 7th University of Oregon Conference on Low Temperature Physics. (Workshop on High Reynolds Number Liquid Helium Flow Facilities), held at Eugene, Oregon, October 23-25, 1989, 15 pp., 13 refs.

A90-44399#

This paper reviews recent aerodynamic tests of a family of slanted-base ogive-cylinders using the NASA Langley 13-inch Magnetic Suspension and Balance System. Results include drag, lift, pitching moment, support interference and base pressure measurements. Mach numbers were in the range 0.04 to 0.2. Drag results are shown to be in satisfactory agreement with previous measurements. Significant support interferences were found at all test conditions. Comparison is made between interference free base pressures, obtained using remote telemetry, and sting cavity pressures. Test results and procedures are briefly discussed in the context of the proposed helium flow facility.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.

284. *Lawing, P. L.: **Magnetic Suspension–Today's Marvel, Tomorrow's Tool.** Presented at the 7th University of Oregon Conference on Low Temperature Physics. (Workshop on High Reynolds Number Liquid Helium Flow Facilities), held at Eugene, Oregon, October 23-25, 1989. October 1990, 13 pp., 24 refs.

A90-23697#

Through constant advocacy of magnetic suspension systems (MSSs) for wind-tunnel model positioning, NASA Langley has obtained a technology-development status for the requisite large magnets, computers, automatic control techniques, and apparatus configurations, to contemplate the construction of MSSs for large wind tunnels. Attention is presently given to the prospects for MSSs in wind tunnels using superfluid helium to obtain very high Reynolds numbers, where the MSS can yield substantial enhancements of wind tunnel productivity.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

285. *Parker, D. H.: **Techniques for Extreme Attitude Suspension of a Wind Tunnel Model in a Magnetic Suspension and Balance System.** NASA CR-181895, October 1989, 274 pp., 53 refs. University of Southampton Ph.D. Thesis.

N90-14245#

This text reports on the modifications made to an existing small MSBS at Southampton University to permit the suspension and control of axisymmetric models over an angle of attack range from less than zero degrees to over ninety degrees. Previous work had shown that the existing arrangement of ten electromagnets was unable to generate one of the force components necessary for control at the extreme attitudes. Examination of possible solutions has resulted in a simple alteration which rectifies this deficiency. To generate the feedback signals essential to control the magnetically suspended model, an optical position sensing system using collimated beams of laser light illuminating photodiode arrays has been installed and tested. An analytical basis has been developed for distributing the demands for force and moment needed for model stabilisation amongst the electromagnets and over the full attitude range. This has been implemented by an MSBS control program able to continually adjust the distribution for the instantaneous incidence in accordance with pre-scheduled data. Results presented demonstrate rotations of models from zero to ninety degrees at rates of change up to ninety degrees per second, with pitching rates rising to several hundred degrees per second in response to step-change demands. A study of a design for a large MSBS suggests that such a system could be given the capability to control a model in six degrees of freedom over an unlimited angle of attack range.

*University of Southampton, Southampton, Hampshire SO9 5NH, England
Grant NSG-7523

286. *Bulekov, V. P.; and *Volkov, V. S.: **Dynamic Properties of a System for the Roll Control of a Model Electromagnetically Suspended in a Wind Tunnel** (Dinamicheskiye Svoystva sistemy Upravleniya Krenom modeli, elekromagnitno podveshennou v aerodinamicheskoy trube). In: Priborostroenie, vol. 32, December 1989, pp. 21-24, in Russian.

ISSN 0021-3454 A90-22762

Note: NASA TT-20754 (X90-10,400) is an English translation.

This paper describes a system for controlling the roll degree of freedom in a magnetic wind tunnel balance. The design, principles of operation, and characteristics of stability of the system is presented. An investigation of the dynamic properties of a system for the roll control of a magnetically suspended aircraft model in a wind tunnel is described. The facility employs eight electromagnets arranged in pairs at an angle of 45° to the coordinate axes. An optoelectronic sting sensor is used for position determinations.

*Moskovskii Aviatsionnyi Institut, Moscow, U.S.S.R.

287. *Kuzin, A. V.: **Photoelectrical Sensors of the Magnetic Suspension Systems.** (Fotoelektricheskie datchiki ustroistv elektrimagnitnoiv podveski). In: Priborostroenie, vol. 33, no. 4, April 1990, pp. 63-67, 4 refs., in Russian.

This paper describes the designs, principles of operation, performance characteristics, and problems of the optical position sensors for magnetically supported objects. The new optical model position sensor is presented. The original construction of the sensor provides the detection of vertical and horizontal displacements of the model in one optical channel.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

288. *Kuzin, A. V.: **Synthesis of the Magnetic Suspension Stabilization System for Models in a Wind Tunnel.** (Sintez sistemy stabilizatsii elektromagnitnoiv podveski modeleiv v aerodinamicheskoiv trube.) In: Elektromekhanika, no. 5, May 1990, pp. 227-230, 9 refs., in Russian.

This paper describes a six degrees of freedom magnetic suspension system to be used in a wind tunnel. The control system of the magnetic suspension system is analogue and uses control algorithms that provide the maximal area of stability of the suspended model when the limit of the control influences exists. The design principles of operation and characteristics of stability of the system are presented.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

289. *Dress, D. A.: **Drag Measurement on a Modified Prolate Spheroid Using a Magnetic Suspension and Balance System.** In: Journal of Aircraft, Volume 27, no. 6, June 1990, pp. 523-528, 22 refs.

ISSN 0021-8669 A90-40684#

Note: For an earlier paper on this work, see citation no. 275 in this bibliography.

Low-speed wind-tunnel drag-force measurements were taken on a modified prolate spheroid free of support interference. This body was tested at zero incidence in the NASA Langley 13-inch Magnetic Suspension and Balance System (MSBS). This shape was one of two bodies tested to determine the drag-force measuring capabilities of the 13-inch MSBS. In addition, support interference on this shape at zero incidence was quantified by using a dummy sting. The drag-force calibrations and wind-on repeatability data let us assess the drag-force measuring capabilities of the 13-inch MSBS. Comparisons with and without the sting showed differences in the drag coefficients with the dummy sting case resulting in lower drag coefficients. Other studies included the effects of fixing transition and surface-flow visualization using oil flow. In addition, the drag coefficient data from this study are compared with data from several other sources.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

290. *Britcher, C. P.; *Alcorn, C. W.; and *Kilgore, W. A.: **Subsonic Sting Interference on the Aerodynamic Characteristics of a Family of Slanted-Base Ogive-Cylinders.** NASA CR-4299, June 1990, 76 pp., 26 refs.

N90-24242#

Note: For an earlier presentation of this work, see citation no. 280 in this bibliography.

Support interference-free drag, lift, and pitching moment measurements on a range of slanted-base ogive-cylinders have been made using the NASA Langley 13-inch Magnetic Suspension and Balance System. Typical test Mach numbers were in the range 0.04 to 0.2. Drag results are shown to be in broad agreement with previous tests with this configuration. Measurements were repeated with a dummy sting support installed in the wind tunnel. Significant support interferences were found at all test conditions and are quantified. Further comparison is made between interference-free base pressure, obtained using remote telemetry, and sting cavity pressures.

*Old Dominion University, Norfolk, VA 23529-0247 U.S.A.
Grant NAG1-716

291. *Groom, N. J.; and *Schaffner, P. R.: **An LQR Controller Design Approach for a Large Gap Magnetic Suspension System, (LGMSS).** NASA TM-101606, July 1990, 65 pp., 6 refs.

N90-28751#

Two control approaches for a Large Gap Magnetic Suspension System (LGMSS) are investigated and numerical results are presented. The approaches are based on Linear Quadratic Regulator (LQR) control theory and include a nonzero set point regulator with constant disturbance input and an integral feedback regulator. The LGMSS provides five degree of freedom control of a cylindrical suspended element which is composed of permanent magnet material. The magnetic actuators are air core electromagnets mounted in a planar way.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

292. *Kuzin, A. V.: **Magnetic Suspension System for Aerodynamic Researches.** (Sistema elektromagnitnoiv podveski dla aerodinamicheskikh issledovaniv.) To be published in: Pribori i tekhnika eksperimenta, no. 4, August 1990, pp. 227-230, 5 refs., in Russian.

This paper describes the magnetic suspension and balance system that was created in Moscow Aviation Institute (MAI) in 1989 and is intended for laboratory investigations and development of magnetic suspension techniques. The MSBS has six degrees of freedom and its size is 300 × 400 mm. The system has seven electromagnets with conventional copper windings, and is equipped with an optical model position sensing system and an analogue control system.

*Moscow Aviation–Technological Institute, 103737, Moscow, K-31, Petrovka, 27, U.S.S.R.

293. **Aerospace Applications of Magnetic Suspension Technology. Workshop Digest.** A workshop held in NASA Langley Research Center, Hampton, Va., September 25-27, 1990, 18 pp.

Papers presented on the use of MSBS in wind-tunnel testing were:

Part I N91-21188#

1. *Groom, N. J.; and †Britcher, C. P.: **Aerospace Applications of Magnetic Suspension Technology, Part 1.** N91-21188#.

2. ‡Havenhill, D. G.; and ‡Wolke, P. J.: **Magnetic Suspension Systems for Space Applications.** N91-21189#.

3. §Bosley, R. W.; and §Trivedi, A. N.: **Advanced Magnetic Suspensions for Vibration Isolation and Fast-Attitude Control of Space-Based Generic Pointing Mounts.** N91-21190#.

4. £Downer, J.; £Goldie, J.; and £Torti, R.: **A Superconducting Large-Angle Magnetic Suspension.** N91-21191#.

5. ¥Knospe, C. R.; and ¥Hampton, R. D.: **Control Issues of Microgravity Vibration Isolation.** N91-21192#.

6. £Misovec, K. M.; £Flynn, F. J.; £Johnson, B. G.; and ♦Hedrick, J. K.: **Sliding Mode Control of Magnetic Suspensions for Precision Pointing and Tracking Applications.** N91-21193#.

7. ♣Brown, G. V.; and ♣Grodsinsky, C. M.: **Magnetic Bearings With Zero Bias.** N91-21194#.

8. £Hockney, R.; £Gondhalekar, V.; and £Hawkey, T.: **Magnetic Bearings For a Spaceflight Optical Disk Recorder.** N91-21195#.

9. ∞Trumper, D. L.; and **Slocum, A. H.: **Five Degree-of-Freedom Control of an Ultra-Precision Magnetically-Suspended Linear Bearing Ph.D. Thesis - MIT.** N91-21196#.

10. ††Boom, R. W.; ††Eyssa, Y. M.; ††Abdelsalam, M. K.; and ††McIntosh, G. E.: **Magnetic Suspension and Balance System Advanced Study, 1989 Design.** N91-21197#.

11. *Joshi, P. B.; *Goldey, C. L.; ‡‡Sacco, G. P.; and *Lawing, P. L.: **Propulsion Simulator for Magnetically-Suspended Wind Tunnel Models.** N21-21198#.

12. *Daniels, T. S.; and *Tripp, J. S.: **A Solid-State Controllable Power Supply for a Magnetic Suspension Wind Tunnel.** N91-21199.

13. *Groom, N. J.: **Description of the Large-Gap Magnetic Suspension System (LGMSS) Ground Based Experiment.** N91-21200#.

14. ††Abdelsalam, M. K.; and ††Eyssa, Y. M.: **Large Gap Magnetic Suspension System.** N91-21201#.

15. *Groom, N. J.; and †Britcher, C. P.: **Stability Considerations for Magnetic Suspension Systems Using Electromagnets Mounted in a Planar Array.** N91-21202#.

16. *Groom, N. J.; and †Britcher, C. P.: **Aerospace Applications of Magnetic Suspension Technology, Part 2.** N91-21203#.

17. ∞Trumper, D. L.: **Nonlinear Compensation Techniques for Magnetic Suspension Systems Ph.D. Thesis - MIT.** N91-21204#.

18. §§Youcef-Toumi, K.; and §§Reddy, S.: **A Time Delay Controller for Magnetic Bearings.** N91-21205#.

19. ♣Hampton, R. D.; ♣Grodsinsky, C. M.; ♣Allaire, P. E.; ♣Lewis, D. W.; and ¥Knospe, C. R.: **Microgravity Vibration Isolation: An Optimal Control Law for the One-Dimensional Case.** N91-21206#.

20. ££Knight, J.; ££McCaul, E.; and ££Xia, Z.: **Measurement and Calculation of Forces in a Magnetic Journal Bearing Actuator.** N91-21207#.

21. ¥¥McCallum, D. C.: **Dynamic Modelling and Analysis of a Magnetically Suspended Flexible Rotor M.S. Thesis, 1988.** N91-21208#.

22. ♦♦Keesee, J.; ♦♦Rawal, D.; and ♦♦Kirk, R. G.: **Critical Speeds and Forced Response Solutions for Active Magnetic Bearing Turbomachinery, Part 1.** N91-21209#.

23. ♦♦Rawal, D.; ♦♦Keesee, J.; and ♦♦Kirk, R. G.: **Critical Speeds and Forced Response Solutions for Active Magnetic Bearing Turbomachinery, Part 2.** N91-21210#.

24. ∞∞Rao, D. K.; ∞∞Lewis, P.; and ∞∞Dill, J. F.: **Reduction in Bearing Size Due to Superconductors in Magnetic Bearings.** N91-21211#.

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♦California University, Berkeley, CA U.S.A.
♣NASA Lewis Research Center, Cleveland, OH U.S.A.
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§§Massachusetts Institute of Technology, 77 Massachusetts Avenue, Boston, MA 02139 U.S.A.
££Duke University, Durham, NC U.S.A.
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♦♦Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 U.S.A.
∞∞∞Mechanical Technology, Inc., Latham, NY U.S.A.

294. *Joshi, P. B.; *Beerman, H. P.; *Chen, J. S.; *Kresch, R. H.; *Rosen, D.; and *Lintz, A. L.: **Propulsion Simulation for Magnetically Suspended Wind Tunnel Models.** Rep. No. PSI-2055/TR-859, NASA CR-182093, Final Report, Phase I, January-September 1988, October 1990, 73 pp., 18 refs.

N91-11027#

In the S.B.I.R. Phase I program, Physical Sciences Inc. (PSI) studied the feasibility of simulating propulsion-induced aerodynamic effects on scaled aircraft models in wind tunnels using Magnetic Suspension and Balance Systems (MSBS). The study dealt with techniques of generating exhaust jets of appropriate characteristics. The influence of jet intakes was not addressed in the preliminary study. The objectives of Phase I were to: (1) Define thrust and mass flow requirements of jets, (2) Evaluate techniques for generating propulsive gas within volume limitations imposed by magnetically-suspended models, (3) Make simple diagnostic experiments for techniques involving new concepts, (4) Recommend experiments for demonstration of propulsion simulation techniques in Phase II. PSI evaluated various techniques of generating exhaust jets of appropriate characteristics on scaled aircraft models in wind tunnels with Magnetic Suspension and Balance Systems (MSBS). Four concepts of remotely-operated propulsion simulators were examined. Three conceptual designs involving innovative adaptation of conventional technologies (compressed gas cylinders, liquid, and solid propellants) were developed. The fourth innovative concept, namely, the laser-assisted thruster, which can potentially simulate both inlet and exhaust flows, was found to require very high power levels for small thrust levels. This concept needs further research. Finally, a comparative evaluation of various propulsion simulators was made relative to a number of criteria of relevance to a Phase II demonstration.

*Physical Sciences, Inc., Research Park, Box 3100, Andover, MA 01801 U.S.A.

295. *Boom, R. W.; *Abdelsalam, M. K.; *Eyssa, Y. M.; and *McIntosh, G. E.: **Magnetic Suspension and Balance System, Advanced Study–Phase II**, Final Report. July 1986-May 1990, NASA CR-4327, November 1990, 228 pp., 12 refs.

N91-13463#

The design improvements for the system encompass 14 or 18 external superconductive coils mounted on a 8 x 8 foot wind tunnel, a superconductive model core magnet on a holmium mandrel to fit an F-16 model, model wings of permanent magnet material Nd2Fe14B, and fiber glass epoxy structure. The Magnetic Suspension and Balance System (MSBS) advanced design is confirmed by the successful construction and test of a full-size superconductive model core solenoid with holmium mandrel. The solenoid is 75 cm long and 12.6 cm in diameter and produces 6.1 tesla for a hold time of 47 minutes. An integrated coil system design of a new compact configuration without specific coils for roll or pitch shows promise of simplicity; magnet reductions of 30 percent compared to the most recent 1985 design are possible.

*Madison Magnetics, Inc., 216 Walnut St., Madison, WI 53705 U.S.A.
Contract NAS1-18279

296. *Kilgore, W. A.: **Comparison of Digital Controllers Used in Magnetic Suspension and Balance Systems.** NASA CR-182087, December 1990, 92 pp., 28 refs. Progress Report November 1, 1989-April 30, 1990.

N91-15425#

Dynamic systems that were once controlled by analog circuits are now controlled by digital computers. Presented is a comparison of the digital controllers presently used with magnetic suspension and balance systems. The overall responses of the systems are compared using a computer simulation of the magnetic suspension and balance system and the digital controllers. The comparisons include responses to both simulated force and position inputs. A preferred digital controller is determined from the simulated responses.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
Contract NAG1-716; NAG1-1056

297. *Sawada, H.; *Kanda, H.; and *Suenaga, H.: **The 10 cm. x 10 cm. Magnetic Suspension and Balance System at**

the National Aerospace Laboratory, Chofu, Japan. Presented at the 29th AIAA Aerospace Sciences Meeting in Reno, Nevada, January 7-10, 1991, 12 pp., 5 refs. Also: NAL TM-623, 18 pp., (1990), in Japanese.

AIAA Paper 91-0397 A91-19279#

The NAL 10 x 10 cm. magnetic suspension and balance system is described. This system has three special features: its coil configuration, the model-position sensing system, and the way of controlling the model position. The measured magnetic-field intensity distributions show that the magnetic field is controlled by the currents passing through the coils (as expected by the plane magnetic circuit model), but the magnitude of the intensity is about half as much as expected. The region of controllable field is limited to the center of the test section. The calibration test results for the model-position sensing system are compared with the analytical ones and show the measured x, z and theta are good but y, phi, and psi are poor in accuracy. The way of controlling the model position is to keep the relative model position constant with respect to the sensing system position. Then the model suspended can be changed in position over the wide range by changing the system position by this control method.

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298. *Britcher, C. P.; **Kilgore, W. A.; and *Haj, A.: **Comparison of Digital Controllers Used in Magnetic Suspension Systems.** Presented at ROMAG'91 Magnetic Bearings and Dry Gas Seals Conference and Exhibition, March 13-15, 1991, Washington, D.C., U.S.A., 10 pp., 13 refs.

An overview of some of the early developments of digital controllers, for application to wind tunnel model suspension systems, magnetic bearings, and other magnetic suspension devices is presented. Differing methods of implementation are compared, including performance comparisons by simulation. Details of present multi-degree-of-freedom wind tunnel suspension system controllers are given. The emphasis throughout is on the implementation of digital control and practical considerations, rather than synthesis of optimal control algorithms. Since the control systems of many magnetic suspension devices are similar in general form, the results and conclusions should have broad applicability.

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299. *Kuzin, A. V.: **Progress of Magnetic Suspension Systems and Magnetic Bearings in the U.S.S.R.** Presented at ROMAG'91 Magnetic Bearings and Dry Gas Seals Conference and Exhibition, March 13-15, 1991, Washington, D.C., U.S.A., 25 pp., 65 refs.
Note: For a paper with the same title, see citation no. 258 in this bibliography.

This paper traces the development and progress of magnetic suspension systems and magnetic bearings in the U.S.S.R. The paper describes magnetic bearings for turbomachines, magnetic suspension systems for vibration isolation, some special measuring devices, wind tunnels, and other applications. The design, principles of operation, and dynamic characteristics of the systems are presented.

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300. *Kuzin, A. V.: **Optimization of Control for Magnetic Suspension Systems.** Presented at ROMAG'91 Magnetic Bearings and Dry Gas Seals Conference and Exhibition, March 13-15, 1991, Washington, D.C., U.S.A., 25 pp., 65 refs.
This paper is concerned with the study of behavior of the magnetic suspension system with six degrees of freedom under the application of the control algorithms that provide the maximum area of stability of the suspended object when the limitation of the control influence exists. Optimization of control system is used for magnetic suspension systems when it is necessary to provide the maximum area of stability. The design and characteristics of stability of the system are presented. This paper introduces the synthesis of the multi-dimensional control system of the EMS for a wind tunnel according to the criterion of maximum stability area in the space, and taking into account the limitations of value of control voltages on windings of electromagnets.

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301. *Britcher, C. P.; and *Alcorn, C. W.: **Interference-Free Measurements of the Subsonic Aerodynamics of Slanted-Base Ogive-Cylinders.** In: AIAA Journal, April 1991, vol. 29, no. 4, pp. 520-525, 11 refs.

Drag, lift, pitching moment and base pressure measurements have been made, free of support interference, on a range of slanted-base ogive-cylinders, using the NASA Langley 13-inch Magnetic Suspension and Balance System. Test Mach numbers were in the range of 0.04 to 0.2. Two types of wake flow were observed, a quasi-symmetric turbulent closure or a longitudinal vortex flow. Aerodynamic characteristics differ dramatically between the two wake types. Drag measurements are shown to be in agreement with previous tests. A hysteretic behaviour of the wake with varying Reynold's number has been discovered for the 45° base. An interaction between forebody boundary layer state and wake flow and base pressures has been detected for higher slant angles.

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Report Documentation Page

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15. Supplementary Notes

Marie H. Tuttle and Deborah L. Moore: ViGYAN, Inc., Hampton, Virginia.
Robert A. Kilgore: Langley Research Center, Hampton, Virginia.

Supersedes NASA TM-80225 (Accession No. N80-22368#, April 1980) and NASA TM-84661 (Accession No. N83-29273#, July 1983).

16. Abstract

This bibliography contains 301 entries. It updates and supersedes earlier NASA bibliographies on Magnetic Suspension and Balance Systems (TM-80225, April 1980, and TM-84661, July 1983). 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. We have included author, source, and subject indexes in order to increase the usefulness of this compilation.

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