NASA Technical Memorandum 4105

Rotary Balances

A Selected, Annotated Bibliography

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CONTENTS

INTRODUCTION

Understanding and predicting aircraft motion requires a knowledge of the forces acting on the aircraft under dynamic as well as steady state conditions. One technique for measuring forces under dynamic conditions in a wind tunnel is to use a rotary balance. The rotary balance drives the model relative to the airstream and measures the resulting forces on the model.

In May of 1985, the Fluid Dynamics Panel (FDP) and the Flight Mechanics Panel (FMP) of the Advisory Group for Aerospace Research and Development (AGARD) held a symposium on *Unsteady Aerodynamics - Fundamentals And Applications To Aircraft Dynamics* in Göttingen. The Technical Evaluators of the symposium suggested the time was appropriate for a critical examination of the rotary-balance techniques used in the AGARD community for the analysis of high-angle-of-attack dynamic behavior of aircraft. This suggestion quickly led to the formation of a Working Group (WG 11) on Rotary Balances by the FDP.

This bibliography on rotary balances is a part of NASA's support of the FDP Working Group 11 on Rotary Balances.

This bibliography contains approximately 100 entries. It includes works that might be useful to anyone interested in building or using rotary balances. Emphasis is on the rotary balance rigs and testing techniques rather than the aerodynamic data. We also include some publications of historical interest which relate to key events in the development and use of rotary balances. The arrangement is chronological by date of publication in the case of reports and by presentation in the case of papers.

We include an author, source, and subject index to increase the usefulness of this compilation.

Often, we used abstracts from the NASA announcement bulletins "Scientific and Technical Aerospace Reports" (STAR) and "International Aerospace Abstracts" (IAA). In other cases, we've used abstracts written by the authors. We modified or shortened some abstracts, using only parts pertinent to rotary balances. The information included about the authors was correct at the time the papers were written. We have noted those entries which appear in several forms. We include accession numbers, report numbers, and other identifying information in the citations to ease the filling of requests for specific items.

When requesting material, you should include the complete citation.

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

BIBLIOGRAPHY

1 *Glauert, H.: **The Investigation of the Spin of an Aeroplane.** British ARC R&M 618, June 1919, 45 pp.

Langley Research Center library number 1104.3
35

This paper discusses the characteristics of a spin. It describes the first scientific experiments on the behavior of an airplane in a spin which were carried out in 1916. It discusses some laboratory experiments, later carried out at the National Physical Laboratory, and analyzes the results. It presents dangers involved in spinning, stresses on the wing structure, and causes of accidents during spinning. The paper discusses the mathematical theory and the need for steady-state rotational flow aerodynamics for spin analysis. The author attempts to calculate data theoretically using strip theory. Two appendices are: "Major F. W. Goodden's Report on the Spinning of an 'F' Aeroplane," and "Experiments Using a Twisted Aerofoil."

*National Physical Laboratory, Teddington, UK

2 *Relf, E. F.; and *Lavender, T.: **A Continuous Rotation Balance for the Measurement of L_p at Small Rates of Roll.** British ARC R&M 828, (Ae. 79) Aug. 1922, 4 pp. (1 folding diagram).

Langley Research Center library number 5341.2
NPL/6

This report describes an apparatus to measure the variation of rolling moment with angular velocity of roll when the latter quantity is small. It does this either for a complete model aeroplane or for wings alone. The R.A.E. has recently constructed a similar apparatus, but this was not intended for use at very low rotational speeds. It is not suitable for that purpose because the measurement of rolling moment includes the friction of the supporting bearings. The present apparatus substitutes a two-point support for the ball bearings of the R.A.E. design. Also, the gear-ratio between motor and model is much greater, to secure steady rotation at a very low speed. The paper includes drawings of the apparatus and the procedure for using it.

*National Physical Laboratory, Teddington, UK

3 *Lavender, T.: **A Continuous Rotation Balance for the Measurement of Pitching and Yawing Moments Due to Angular Velocity of Roll (M_p and N_p).** British ARC R&M 936, (Ae. 157), Feb. 1925, 3 pp. (2 figs.)

Langley Research Center library number 5341.2
NPL/10

R. & M. 828 (see entry 2) gives a description of a continuous rotation balance for the measurement of L_p at small rates of roll. We have modified this apparatus to allow a continuous rotation of the model about an axis parallel to the wind, while permitting a small angular oscillation about a second axis at right angles to the wind. We can arrange this second axis either as a *pitch* or a *yaw* axis. As in the L_p apparatus, the small electric motor through a suitable reduction gear (in this case a double spur gear, substituted for the worm) drives the hollow shaft mounted on ball bearings. We suspend the whole assembly from the roof of the wind tunnel by wires. The apparatus itself is supported on hardened steel points and cups.

*National Physical Laboratory, Teddington, UK

4 *Gates, S. B.; and **Bryant, L. W.: **The Spinning of Aeroplanes.** British ARC R&M 1001, (Ae. 242), 1926, 128 pp.

Langley Research Center library number 1104.3
18

Note: For another form of this report see Royal Aeronautical Society Journal, July 1927, pp. 619-688.

This report is a comprehensive survey of recent work in England on the subject of spinning. The problem is extraordinarily complex, and a complete solution can only follow the production of much more experimental data than is available. Nevertheless, we have made much solid progress in fundamental parts of the subject with the comparatively rudimentary material at our disposal. The geometry and the mechanics of the steady spin are now understood in general outline. It is our intent to put on record this knowledge, the evidence on which it rests, and speculations regarding the character of the accelerated motions of entry to, and recovery from, the steady spin. We have recently planned an elaborate experimental programme involving a radical change in wind-tunnel technique, but we cannot expect this to bear fruit for a long time. Now seems to be a favourable moment for taking stock of the progress already made. The paper notes we must replace the rotation balances in wind tunnels by a more effective apparatus.

*Royal Aircraft Establishment, Bedford, UK
**National Physical Laboratory, Teddington, UK

5 *Irving, H. B.; and *Batson, A. S.: **Further Experiments on a Model of the "Bantam" Aeroplane With Special Reference to the "Flat Spin."** British ARC R&M 1107, (Ae. 284), June 1927, 37 pp.

Langley Research Center library number 1104.3
BAT Bantam/2

We have extended the incidence range of previous experiments from about 40° to nearly 90° and made measurements of the three moments due to rolling about the wind axis through the center of gravity of the aeroplane. We have studied the contribution of the tail to these moments in some detail. We have measured the effect of rolling on drag for the complete model and for body with tail. The paper includes an appendix entitled "Notes on Measurement of Yawing and Pitching Moments Due to Rolling."

*National Physical Laboratory, Teddington, UK

6 *Irving, H. B.; and *Batson, A. S.: **Experiments on a Model of a Single Seater Fighter Airplane in Connection With Spinning.** British ARC R&M 1184, (Ae. 347), May 1928, 19 pp.

Langley Research Center library number 1105.62
1

This paper describes the behaviour of the tail unit in a spin at a very large angle of incidence. We measured the pitching moments on a model of a single seat fighter which had experienced difficulty in recovering from a spin. We made the measurements at the request of the Design Sub-Committee, first with the normal body and tail, then with lengthened body. We made the tests on the rolling balance in the usual manner. We confined our measurements to rolling moments in view of the considerable difficulty previously experienced in obtaining reliable measurements of yawing moments on the Bantam model. In general, the results show the moments due to fin and rudder, largely shielded as they are by the tailplane, are liable to show wide variations of uncertain sign, even though we may expect the change in flow of the air approaching the tail to be slight.

*National Physical Laboratory, Teddington, UK

7 *Harris, T. A.: **The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics.** NACA TR 412, 1931, 7 pp.

Langley Research Center library number 5341
NACA
7' x 10'/1

This report describes the 7 by 10 foot wind tunnel and associated apparatus of the National Advisory Committee for Aeronautics. Included are calibration test results and typical data from both static force tests and autorotation tests made in the tunnel. The tunnel has a 6-component indicating balance, on which we measure, directly and independently, the forces and moments. We make all tests at the same dynamic pressure on models having the same area and aspect ratio. This way we obtain the results in coefficient form and require very little time to reduce the test data. We can also use the balance for making stable autorotation tests or for measuring the rolling moment due to roll. In such cases we replace the force-test model support with one designed for rotation tests.

*Langley Memorial Aeronautical Laboratory, NACA (became NASA), Langley Field, Va., USA

8 *Knight, M.; and *Wenzinger, C. J.: **Rolling Moments Due to Rolling and Yaw for Four Wing Models in Rotation.** NACA TR 379, 1931, 24 pp.

This report presents results of autorotation and torque tests on four wing systems at various rates of roll and at several βs. The test covered an α range up to 90° and βs of 0°, 5°, 10°, and 20°. We made tests in the 5-foot, closed-throat atmospheric wind tunnel of the National Advisory Committee for Aeronautics. The object of the tests was primarily to determine the effect of β on the rolling moments of the rotating wings up to large αs. We found at αs above maximum lift the rolling moments on the wings due to yaw (or side slip) from 5° to 20° were roughly the same as those due to rolling. There was a wide variation in the rolling moment due to yaw angle with both α and with pb/2V. The rates and ranges of stable autorotation for the monoplane models were considerably increased by yaw, where, for an unstaggered biplane, they were little affected. The immediate cause of the rolling moment due to yaw is apparently the building up of large loads on the forward wing tip and the reduction of loads on the rearward wing tip. The rolling moments were measured on a small electric dynamometer designed especially for the purpose.

*Langley Memorial Aeronautical Laboratory, NACA (became NASA), Langley Field, Va., USA

9 *Bamber, M. J.; and *Zimmerman, C. H.: **The Aerodynamic Forces and Moments Exerted on a Spinning Model of the NY-1 Airplane as Measured by the Spinning Balance.** NACA TR 456, Feb. 1933, 12 pp.

NACA TR 456

The tests were made on the spinning balance developed for use in the 5-foot vertical wind tunnel of the NACA. The wind tunnel is of the open-jet type. This spinning balance has 6-components from which we obtain wind-tunnel data for any of a wide range of spinning conditions. We made the present series of tests to study the effects of changes in Reynolds Number, attitude, and elevator and rudder settings on the aerodynamic forces and moments on a model when spinning. We used a model of the NY-1 airplane to compare the tunnel data with data obtained from full-scale spins of the airplane. We conclude this spinning balance is a practical and economical method of obtaining valuable data on the aerodynamic forces and moments given by a spinning model and its component parts.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

10 *Allwork, P. H.: **A Continuous Rotation Balance for the Measurement of Yawing and Rolling Moments in a Completely Represented Spin.** British ARC R&M 1579, 1934, 6 pp. and illustrations and with an appendix on the Experience Gained in the Use of the Apparatus by H. B. Irving and A. S. Batson.

Langley Research Center library number 5341.2
NPL/11

This paper describes a balance installed in the British NPL 7-ft wind tunnel. We designed the balance to measure yawing moments about an aeroplane body axis due to continuous rotation about the axis. The radius of spin is variable from zero to 12 inches. The maximum rate of spin is three revolutions per second. We can set the model at any presentation to the wind within limits. We propose the apparatus be further developed to measure pitching and rolling moments about body axes, and also total drag.

*National Physical Laboratory, Teddington, UK

11 *Bennett, C. V.; and *Johnson, J. L., Jr.: **Experimental Determination of the Damping in Roll and Aileron Rolling Effectiveness of Three Wings Having 2°, 42°, and 62° Sweepback.** NACA TN-1278, May 1947, 19 pp.

NACA TN-1278

The damping tests and aileron-rolling-effectiveness tests were made in the Langley 15-foot free-spinning tunnel on a special stand which was free in roll about the wind axis. The paper includes a photograph of the stand as set up for rotation tests. It also includes a sketch of the stand as set up to measure rolling moments with a calibrated torque rod. We obtained the damping in roll of the wings from steady-rotation tests on the roll stand and static rolling-moment tests. We obtained the stand and wing rotation by deflecting the vane. In steady rotation, we assumed the forcing moment to be equal to the damping moment and of opposite sign.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

12 *MacLachlan, R., and *Letko, W.: **Correlation of Two Experimental Methods of Determining the Rolling Characteristics of Unswept Wings.** NACA TN-1309, May 1947, 9 pp. (diagrs, photos, curves)

Langley Research Center library number 1115.5
624

We must have accurate values of the dynamic lateral-stability derivatives of the airplane to predict either its dynamic stability or its motions resulting from movement of the lateral controls. Included in the present study are two methods by which we may measure the derivatives resulting from roll. The first of these methods, used in the past by NACA, provides for forced rotation of the model in a straight air stream. The second method provides for rotation of the air stream (rolling flow) with the model fixed. A tapered wing and two geometrically similar rectangular wings were measured both in rolling flow with the wing stationary and in straight flow with forced rotation of the wing to obtain a correlation between the two methods and to determine the rolling characteristics of the wings. For unswept wings the rolling characteristics (the rate of change of rolling-moment coefficient and the rate of change of aileron hinge-moment coefficient with rolling velocity) obtained by rotation of the air agreed with those obtained by forced rotation of the wing. Calculated values of the rolling characteristics of the three wings checked closely with the experimental values.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

13 *Ribner, H. S.: **The Stability Derivatives of Low-Aspect-Ratio Triangular Wings at Subsonic and Supersonic Speeds.** NACA TN 1423, 1947, 34 pp.

NACA TN 1423

This paper treats low-aspect-ratio wings having triangular plan forms by assuming the flow potentials in planes at right angles to the long axis of the airfoils are similar to the corresponding two-dimensional potentials. We obtain pressure distributions caused by downward acceleration, pitching, rolling, sideslipping, and yawing for wings with

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

14 *Ribner, H. S.; and *Malvestuto, F. S., Jr.: **Stability Derivatives of Triangular Wings at Supersonic Speeds.** Rep. No. 908 1948, 9 pp.

This paper extends the analysis given in NACA TN No. 1423, to apply to triangular wings having large vertex angles and traveling at supersonic speeds. The lift, rolling moment due to sideslip, and damping in roll and pitch for this case are treated elsewhere using the theory of small disturbances. We use the surface potentials for $\alpha$and rolling taken therefrom to obtain the several side-force and yawing-moment derivatives that depend on leading-edge suction, and a tentative value for the rolling moment due to yawing. We obtain the lift and moment due to downward acceleration using an unpublished unsteady-flow solution. All known stability derivatives of the triangular wing at supersonic speeds, regardless of source, are summarized and presented with respect to both body axes and stability axes. The results apply only to Mach numbers for which the triangular wing lies within the Mach cone from its vertex. The spanwise variation of Mach number in the case of yawing is regulated, although the effect must be of importance.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

15 *Polhamus, E. C.: **A Simple Method of Estimating the Subsonic Lift and Damping in Roll of Sweptback Wings.** NACA Tech. Note 1862, Apr. 1949, 20 pp.

NACA TN-1862

A method of modifying existing correction factors of lifting-surface theory to account approximately for the effects of sweep has been derived. We have applied these factors to existing lifting-line theories for the lift and damping in roll of swept wings. Despite the simplicity of the resulting formulas the agreement with experimental data for low speeds is very good. We express the equation for lift entirely in terms of the geometric characteristics of the wing and the section-lift-curve slope. This eliminates the necessity for any charts. The equation for the damping in roll, however, requires a chart to determine the effective lateral center of pressure for rolling moment due to rolling. If we use the Glauert-Prandtl transformation, we can apply the formulas obtained to swept wings at subsonic speeds below the critical speed.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Air Force Base, Va., USA

15A *Kuhn, Richard E.; and Wiggins, James W.: **Wind-Tunnel Investigation to Determine the Aerodynamic Characteristics in Steady Roll of a Model at High Subsonic Speeds.** NACA RM L52K24, Jan. 1953, 39 pp.

This paper presents data taken during steady-roll tests of a complete swept-wing model and its component parts. It also describes the forced-roll sting-support system. The model was rotated about the x-stability axis. The angle of attack was changed by using offset sting adapters. The model was driven by a constant-displacement reversible hydraulic motor, located inside the main sting body. The motor was driven by a variable-displacement hydraulic pump driven by a constant-speed electric motor. Speed of rotation was varied by controlling the fluid displacement of the pump. The direction of rotation was changed by reversing the flow through an arrangement of electrically controlled solenoid valves in the hydraulic system. The forces and moments, measured by an electrical strain-gage balance inside the model, were transmitted to the recording devices through brushes and slip rings.

16 *Billion, E.: **Elementary Model for the Study of Dynamic Stability.** Presented at the AGARD Wind Tunnel and Model Testing Panel meeting, Paris, Nov. 2-6, 1954, 19 pp., in French. (English translation attached)

Langley Research Center library number N-34313

This paper describes the model and gives a report of the experiment. It also gives a brief description of the stability balance and the calculation of the damping-in-roll coefficient C_{l_p} by electrical analogy.

*ONERA/CERT, BP 4025, 31055 Toulouse Cedex, France

17 *Johnson, J. L., Jr.: **Low-Speed Measurements of Rolling and Yawing Stability Derivatives of a 60° Delta-Wing Model.** NACA RM L54G27, Dec. 1954, 17 pp.

NACA RM L54G27

This paper contains results of a study in the Langley free-flight tunnel to determine the low-speed rolling and yawing stability derivatives of a 60° delta-wing model from 0° to 30° α. The derivatives were measured by the free-to-damp oscillation technique and by the steady-roll technique.

*Langley Memorial Aeronautical Laboratory, NACA, Langley Field, Va., USA

18 *Kolb, A. W.; and *Little, F. W.: **A Rotary Balance System for Model Spin Investigations in Wind Tunnels.** Wright Air Development Center TN 59-316, Sept. 1959, 16 pp.

Langley Research Center library number N-78446

We developed a rotary balance to advance the testing techniques used in model spin investigations. The balance is capable of measuring forces and moments on spinning or tumbling models. The force measuring system has an accuracy comparable to a static balance system. The hydraulic balance drive system has excellent speed regulation and small physical size with high torque output. This paper discusses in detail the balance, its capabilities, calibration procedures, and test performances.

*Wright Air Development Center, Wright Field, Ohio, USA

19 *DeMeritte, F. J.: **The Correlation of Range and Wind-Tunnel Dynamic Stability Measurements.** NAVORD Rep. 6765, Aerodynamics Research Rep. 78, Dec. 7, 1959, 19 pp.

Langley Research Center library number N-86322

This paper describes techniques used to measure pitch damping, roll damping, and Magnus forces and moments in wind tunnels. It compares wind-tunnel data with ballistic range results. The comparison of the measurements made in the wind tunnel and firing ranges shows the data are in good agreement.

*Naval Ordnance Lab., Silver Springs, MD, USA

20 *Heyser, A.: **Aerodynamic Measurement Technique, a report on the third meeting of subcommittee (aerodyna- mische messtechnik bericht uber die 3.sitzung des unterausschusses.)** Rep. # WGLR-8/1963, 1963, 153 pp., in German.

N64-21695#

This report contains a section by E. Klinke** which describes the measurement apparatus of multi-component installable rotary balances. A study is made of the rotating behavior of a model rotating about its center of gravity. The report also describes model rotation about the stream axis, X_a, of the wind tunnel at different rotation angular velocities, ω, and for variable stagnation pressure, q.

*Wissenschaftliche Gesellschaft fuer Luft- und Raumfahrt, Cologne, West Germany

**Entwicklungsring Sued, Munich, West Germany

21 *Judd, M.; and *Goodyer, M. J.: **Some Factors in the Design of Magnetic Suspension Systems for Dynamic Testing.** Presented at the ARL Magnetic Wind Tunnel Model Suspension and Balance Symposium, held at Wright-Patterson Air Force Base, Ohio, Apr. 13-14, 1966. In: Dayton Univ. Summary, ARL-66-0135, (N67-13593), July 1966, pp. 349-385.

N67-13593

This paper discusses some general characteristics, difficulties and limitations of dynamic testing with magnetically suspended models together with possible improvements. It draws parallels between mechanical and magnetic support test techniques. It emphasizes the problem of large acceleration loads. It suggests large reductions of power requirements are possible by making the model so its outside inflexible shape is spring connected with an inner magnetic mass. The mass-spring-mass system is tuned for a desired natural frequency. The paper discusses the effect on the overall feedback characteristics and some practical considerations.

*The University, Southampton S09 5NH, Hampshire, UK

22 *Scherer, M.; and *Aguesse, M-O.: **Etude Analytique de la Vrille. (Analytical Study of the Spin.)** Presented at the AGARD Flight Mechanics Panel Specialists' Meeting held at Churchill College, Cambridge, England, Sept. 20-23, 1966. In: AGARD CP-17, Stability and Control, Part I, (N68-17439), pp. 127-159, in French.

N68-17445#

Results from the first phase of an analytical study to find a method for calculating spin agree with measurements made on a model in free spin in a vertical wind tunnel. We consider the proposed method applicable for calculations with measurements made during the flight of actual aircraft. We present calculations for the spin of a small delta aircraft model. We eliminated the uncertainties associated with scale effect and inertia constants in these studies in a horizontal wind tunnel. Two configurations were studied; one of spin stabilization and the other of escaping spin. This paper gives details of analytical results, calculations, and applications, including analytical measurements in forced rotation.

*ONERA, BP 72, 92322 Châtillon Cedex, France

23 *Wykes, J. H.; and *Casteel, G. R.: **Comparison of Computer and Flight Test Results for a Spinning Airplane.** Presented at the AGARD Flight Mechanics Panel Specialists' Meeting held at Churchill College, Cambridge, England, Sept. 20-23, 1966. In: AGARD CP-17, Stability and Control, Part I, (N68-17439), pp. 101-125.

N68-17444#

This paper reports a study designed to analytically determine the complete spinning characteristics (spin entry, steady spin, and recovery) of an airplane. We based the study on the assumption we can describe a spinning airplane in the same manner as a rolling airplane. To determine the validity of this assumption, the following were pursued: (1) We analyzed existing flight test data obtained during spin demonstrations of the F-100D to obtain data on the mechanics of spin. (2) We made a low speed wind tunnel test of the F-100D through spin αs and sideslip to obtain static aerodynamic stability and control data. (3) We developed a technique for using static aerodynamic data to obtain the rotary derivatives. Using results from the above studies, we made a series of spin calculations using digital computer methods. We compared results of these calculations with flight test data. Results show we can calculate the spin characteristics of an airplane, from incipient spin through recovery phases, using static aerodynamic wind tunnel data and estimated rotary derivatives based on these static test data. The proposed method of calculation enables the systematic study of the effects of several important variables influencing aircraft spin response and, in doing so, serves to prevent expensive redesign in later phases.

*North American Aviation, Inc., Los Angeles, CA, USA

24 *Schueler, C. J.; *Ward, L. K.; and *Hodapp, A. E., Jr.: **Techniques for Measurement of Dynamic Stability Derivatives in Ground Test Facilities.** AGARDograph 121, Oct. 1967, 209 pp., 432 refs.

N68-23768

This paper describes some of the techniques in current use for measuring dynamic stability derivatives in wind tunnels. It emphasizes the important characteristics of balance system design, data reduction methods, instrumentation and typical balance systems. It treats the use of gas bearings for dynamic stability and roll damping. It describes a three-degree-of-freedom balance system employing a spherical gas bearing.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, USA

25 *Judd, M.: **The Magnetic Suspension System as a Wind Tunnel Dynamic Balance.** Presented at the 3rd International Congress on Instrumentation in Aerospace Simulation Facilities, Polytechnic Institute of Brooklyn, Farmingdale, New York, May 5-8, 1969. In: ICIASF '69 Record, (A69-35714), pp. 198-206.

TK 7882.M4 I5, 1969, pp. 198-206 A69-35738#

This paper outlines the principles of design and operation of a magnetic suspension system together with the features and problems associated with its use as a dynamic balance. It describes the technique developed to improve resolution of measurement. It presents results for delta wing models chosen because of the availability for comparison of other theoretical and experimental data. We did the work using equipment developed in the University of Southampton.

*Massachusetts Institute of Technology, Cambridge, MA 02139, USA

26 *Schiff, L. B.; and *Tobak, M.: **Results From a New Wind-Tunnel Apparatus for Studying Coning and Spinning Motions of Bodies of Revolution.** AIAA Journal, vol. 8, Nov. 1970, pp. 1953-1957.

A71-10930#

This paper describes a rig which gives either separate or combined coning and spinning motions to a body of revolution in a wind tunnel. It uses a six-component strain gage balance to measure the aerodynamic forces and moments. Tests with a slender cone in coning motion show at small α the side-force and side-moment coefficients normalized by the coning rate are linear functions of α. The slopes are in excellent agreement with the damping-in-pitch coefficients $C_{Nq} + C_{N\dot{\alpha}}$ and $C_{mq} + C_{m\dot{\alpha}}$. This agreement is predicted by linearized theory. It indicates at small α we can measure the dynamic damping-in-pitch coefficients of a body of revolution as the steady side force and moment coefficients of the body undergoing coning motion. For larger α, where vortices appear on the leeside of the body, the normalized side force and moment coefficients become nonlinear functions of α. Photographs of the vortices show them displaced from the α plane by coning motion. This asymmetric displacement of the vortices persists over the length of the body, making them a possible source of nonlinear side moment.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

27 *Orlik-Rückemann, K. J.: **Dynamic Stability Testing of Aircraft--Needs Versus Capabilities.** Presented at the 5th International Congress on Instrumentation in Aerospace Simulation Facilities, Pasadena, Calif., Sept. 10-12, 1973. In: ICIASF '73 Record, pp. 8-23.

A74-26477

Note: For recent forms of this paper and an abstract see nos. 29 and 32.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada
Contract: NAS2-7279

28 *Covert, E. E.; *Finston, M.; *Vlajinac, M.; and *Stephens, T.: **Magnetic Balance and Suspension Systems for Use with Wind Tunnels.** In Progress in Aerospace Sciences, vol. 14. Oxford and New York, Pergamon Press, 1973, (A74-12203), pp. 27-107.

A74-12204

This paper describes the principles of operation and the design of magnetic balance and suspension systems used to provide interference-free support of models in wind-tunnel tests. We apply the term *balance* to cases where we use the suspension for direct measurement, e.g., we balance unknown aerodynamic forces and torques by (1) known gravitational and inertial forces and torques and (2) magnetic forces and torques given in terms of electric currents. This paper discusses elementary magnetic concepts, generation of forces and torques, system analysis procedures, magnetic field configurations, materials, power supplies, cooling techniques, control systems, and scaling laws.

*Massachusetts Institute of Technology, Cambridge, MA 02139, USA

29 *Orlik-Rückemann, K. J.: **Survey of Needs and Capabilities for Wind Tunnel Testing of Dynamic Stability of Aircraft at High Angles of Attack.** NASA CR-114583, 1973, 128 pp.

N73-22201#

Note: For a later version of this report see no. 32.

This paper gives the results of a survey of future requirements for dynamic stability information for such aerospace vehicles as the Space Shuttle and advanced high performance military aircraft. High α and high-Reynolds number conditions are emphasized. The author reviews the wind-tunnel capabilities in North America for measuring dynamic stability derivatives. He reports an almost total lack of capabilities to satisfy these requirements. He makes recommendations about equipment that should be built to remedy this situation. He describes some of the more advanced existing capabilities, which we use to at least partly satisfy immediate demands.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada
Contract: NAS2-7279

30 *Marchman, J. F., III; *Lutze, F. H., Jr.; and *Cliff, E. M.: **A Facility for the Measurement of Individual Rotary Motion Aerodynamic Stability Derivatives.** Presented at the 6th International Congress on Instrumentation in Aerospace Simulation Facilities, Ottawa, Canada, Sept. 22-24, 1975. In: ICIASF '75 Record (A76-22728), N.Y., Institute of Electrical and Electronics Engineers, Inc., 1975, pp. 169-174.

TK7882.M415 A76-22745

This paper describes a unique wind tunnel, the Stability Wind Tunnel, in the Aerospace and Ocean Engineering Department at Virginia Polytechnic Institute and State University. It can generate curved or rolling flow giving a means to measure pure rotary aerodynamic derivatives. The paper describes the means for providing this capability as well as the modifications made to allow sting mounting of a model with large α and β range. It describes methods of tunnel calibration, testing and data reduction and presents some results of a recent test.

*Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

31 *Bazzocchi, E.: **Stall Behavior and Spin Estimation Method by Use of Rotary Balance Measurements.** Presented at the AGARD Flight Mechanics Panel Specialists' Meeting on Stall/Spin Problems of Military Aircraft held at the von Karman Institute, Brussels, Nov. 18-22, 1975. In: AGARD CP-199 (N76-29245#), pp. 8-1 through 8-16.

N76-29253#

This paper describes wind tunnel studies of stall behavior, evaluation of lateral control devices, measurement of the aerodynamic coefficients to determine lateral-directional stability and the analytical study of spin. This research required the development of special test equipment, measurement methods, and calibration systems. The paper describes the test equipment, its use, and some of the results obtained.

*Aeronautica Macchi S.p.A., Varese, Italy

32 *Orlik-Rückemann, K. J.: **Dynamic Stability Testing of Aircraft--Needs Versus Capabilities.** In: Progress in Aerospace Sciences, TL500.P7, 1975, vol. 16, no. 4, pp. 431-447.

AD-773160 N74-19526#

Note: For an earlier form of this report see no. 29.

This paper presents highlights of a recent survey of the future needs for dynamic stability information for aerospace vehicles such as the Space Shuttle and advanced high-performance military aircraft. The author explains the importance of obtaining this information for high-α high-Reynolds-number flight conditions. A review of the wind-tunnel capabilities in North America for measuring dynamic stability derivatives reveals an almost total lack of such capabilities for Mach numbers above 0.1 at αs higher than 25°. In addition, capabilities to determine certain new cross-coupling derivatives and to obtain information on effects of the coning motion are almost completely lacking. The author makes recommendations regarding equipment needed to remedy this situation. He describes some of the more advanced existing facilities which we can use to satisfy, at least partly, the immediate needs.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

33 *Finck, H. D.; and *Sachs, G.: **Investigations of the Dynamical Behavior of an Airplane Undergoing Rolling Motion.** Untersuchung der Flugdynamik beim Rollen. Institut für Flugtechnik, Darmstadt/IFD Nr. 8/76. DCAF E002631, Apr. 5, 1976, 58 pp., in German.

N77-31177#

We studied the dynamics of a highly maneuverable subsonic aircraft during multiple roll around the length axis with a 6 degree of freedom computer program. We accounted for the nonlinear dependencies on the aerodynamic forces and moments. We show the effect of the dynamic derivation of lateral motion on the overall motion. We represent the relationship between the position of the overall rotation vector and the velocity vector.

*Technische Hochschule, Darmstadt, West Germany

34 *Malcolm, G. N.; and **Clarkson, M. H.: **Wind-tunnel Testing With a Rotary-Balance Apparatus to Simulate Aircraft Spin Motions.** Presented at the AIAA 9th Aerodynamic Testing Conference, Arlington, Tex., June 7-9, 1976. In: Technical Proceedings, pp. 143-156.

A76-38642#

Tests were made in the Ames 12-Foot Pressure Wind Tunnel on a simple airplane-like model using a rotary-balance rig to simulate a steady spin motion at high α. Tests were at Mach numbers of 0.1 and 0.25 over a wide Reynolds number range with α varying from 45 to 90 deg. During previous tests of the same research model, some difficulties were experienced with measurement accuracy in the low-to-medium range of Reynolds number because of limitations in the sensitivity of the force balances. For the present tests, we built special balances to provide accurate measurements of the nose and tail contributions to spin motions. We also made improvements to the overall test rig. This paper describes the results of this test, including some interesting hysteresis effects with spin rate. We discuss some of th

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**Florida University, Gainesville, FL 32611, USA

35 *Craig, A.: **Development of Capabilities for Stall/Spin Research. Final Rep., 1 June 1975 - 20 June 1976.** NACA CR-148, 287, June 20, 1976, 42 pp.

N76-26221#

Apparatus and techniques were developed for measuring in a low-speed wind tunnel the static and dynamic (rotary balance) aerodynamic data pertinent to spin behavior of a general aviation aircraft. The main results were: (1) collection of static force and moment data for several airplane configurations at αs from 0 to 90 degrees and βs from 0 to 40 degrees; and (2) discovery of difficulties, shortcomings, and unsuitability of some aspects of the rotary balance mount. These were identified for avoidance in a design for a new mount.

*Wichita State University, Wichita, KS 67208, USA
Contract NSG-1189

36 *Chambers, J. R.; *Bowman, J. S., Jr.; and **Malcolm, G. N.: **Stall/Spin Test Techniques Used by NASA.** June 1976.

N76-29258

This paper reports unique test techniques and facilities used to predict the stall/spin characteristics of highly maneuverable military aircraft. Three of the more important test techniques are: (1) flight tests of dynamically scaled models; (2) rotary balance tests; and (3) piloted simulator studies. Recent experience has shown extension of piloted simulation techniques to high α gives insight in to the spin susceptibility of fighter configurations during representative air combat maneuvers. In addition, use of the technique is an effective way to develop and evaluate automatic spin prevention concepts.

*NASA Langley Research Center, Hampton, VA 23665-5225, USA
**NASA Ames Research Center, Moffett Field, CA 94035, USA

37 *Burk, S. M., Jr.; and *Bowman, J. S., Jr.; and *White, W. L.: **Spin-Tunnel Investigation of the Spinning Characteristics of Typical Single-Engine General Aviation Airplane Designs. I - Low-Wing Model A: Effects of Tail Configurations.** NASA TP-1009, Sept. 1977, 92 pp.

N77-33111#

Tests were made on a 1/11-scale model of a research airplane in the Langley Spin Tunnel. The model represents a typical low-wing, single-engine, light-weight general aviation airplane. We made the test to determine the effects of tail design on spin and recovery characteristics and to evaluate a tail design criterion for satisfactory spin recovery for light airplanes. We also determined the effects of other geometric design features on the spin and recovery characteristics. The results of the test show we cannot use the existing tail design criterion for light airplanes, which uses the tail damping power factor (TDPF) as a parameter, to predict spin-recovery characteristics.

*NASA Langley Research Center, Hampton, VA 23665-5225, USA

38 *Malcolm, G. N.: **New Rotation-Balance Apparatus for Measuring Airplane Spin Aerodynamics in the Wind Tunnel.** Presented at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., Apr. 19-21, 1978. In: Technical Papers (A78-32326), pp. 495-502.

AIAA Paper 78-835 A78-32386#

Note: For a later form of this paper see no. 46.

An advanced rotary-balance rig was developed for the Ames 12-ft Pressure Wind Tunnel. Its purpose is to study the effects of spin rate, α and β, and, particularly, Reynolds number on the aerodynamics of fighter and general aviation aircraft in a steady spin. αs to 100° and βs to 30° are possible with spin rates to 42 rad/s (400 rpm) and Reynolds numbers to 30 million/ m on fighter models with wing spans typically 0.7 m. This paper gives a complete description of the new rotary-balance rig, the sting/balance/model assembly, and the operational capabilities.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

39 *Orlik-Rückemann, K. J.: **Techniques for Dynamic Stability Testing in Wind Tunnels.** Presented at the AGARD Fluid Dynamic Panel Symposium, Dynamic Stability Parameters, held in Athens, Greece, May 22-24, 1978. In: AGARD-CP-235, (N79-15061#), Nov. 1978, pp. 1-1 through 1-24, 48 refs.

N79-15062#

This paper gives a systematic review of the methods and techniques used for wind-tunnel measurements of the dynamic stability paramefers (derivatives) of an aircraft. It illustrates the review with many examples of experimental equipment available in aerospace laboratories in Canada, France, the United Kingdom, the United States, and West Germany.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

40 *Malcolm, G. N.; and *Davis, S. S.: **New NASA-Ames Wind Tunnel Techniques for Studying Airplane Spin and Two-Dimensional Unsteady Aerodynamics.** Presented at the AGARD Fluid Dynamics Panel Symposium, Dynamic Stability Parameters, held in Athens, Greece, May 22-24, 1978. In: AGARD-CP-235, (N79-15061#), Nov. 1978, pp. 3-1 through 3-12, 6 refs.

N79-15064#

Two new wind tunnel test rigs were developed at NASA-Ames Research Center. The first is a rotary-balance rig for the Ames 12-Foot Pressure Tunnel to study the effects of Reynolds number, spin rate, and α on the aerodynamics of fighter and general aviation aircraft in a steady spin motion. The second rig provides capability for oscillating a large two dimensional wing (0.5 m chord, 1.35 m span) instrumented with steady and unsteady pressure transducers in the Ames 11 x 11 ft. Transonic Wind Tunnel. This paper gives a complete description of both rigs, their capabilities, and some typical wind tunnel results.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

41 *Matthews, A. W.: **Experimental Determination of Dynamic Derivatives Due to Roll at British Aerospace, Warton Division.** Presented at the AGARD Fluid Dynamics Panel Symposium, Dynamic Stability Parameters, held in Athens, Greece, May 22-24, 1978. In: AGARD-CP-235, (N79-15061#), Nov. 1978, pp. 4-1 through 4-16, 9 refs.

N79-15065#

Two rigs for the determination of dynamic derivatives due to roll are under development at British Aerospace, Warton Division. They use the principle of continuously rolling a model in a wind-tunnel about an axis parallel to the wind. They cover a test envelope up to M = 0.95, R = 46 million/m, α = 90°, pb/2V = 0.25. We have already used one to measure derivatives on complete models at low Mach number and Reynolds number. The second, designed for operation at high subsonic Mach numbers and high Reynolds numbers, is undergoing calibration and commissioning before tunnel installation. This paper describes the general features of the rigs themselves, together with the instrumentation and control systems. It also describes the problems met during design, manufacture, calibration, commissioning and testing, together with their solutions. It

*British Aerospace (Aircraft Group) Warton Division, Warton Aerodrome, Preston, PR4 lAX, Lancashire, UK

42 *Hafer, X.: **Wind Tunnel Testing of Dynamic Derivatives in W.-Germany**. Presented at the AGARD Fluid Dynamics Panel Symposium, Dynamic Stability Parameters, held in Athens, Greece, May 22-24, 1978. In: AGARD-CP-235, (N79-15061#), Nov. 1978, pp. 5-1 through 5-12, 33 refs.

N79-15066#

This paper gives a survey of the activities of the German national working group developing dynamic wind tunnel test installations. Sponsored by the Ministry of Research and Technology, the group planned to develop four different test rigs. So far, they have completed three test rigs. The rigs are now available for routine use, which has been confirmed by many successful tests. Each rig meets very specific test requirements. The paper discusses these requirements in detail. It also gives results of a comparison of tests with the same model mounted on different test rigs in different wind tunnels. It compares the data with some flight test results of the corresponding original plane. Finally, it gives some results of linearized flight dynamic studies to demonstrate the influence of the several dynamic derivatives on the longitudinal and lateral aircraft dynamics. This paper has an excellent reference section.

*Technical University Darmstadt, Petersenstraße 30, 6100 Darmstadt, West Germany

43 *von der Decken, J.; *Schmidt, E.; and **Schulze, B.: **On the Test Procedures of the Derivative Balances Used in West Germany.** Presented at the AGARD Fluid Dynamics Panel Symposium, Dynamic Stability Parameters, held in Athens, Greece, May 22-24, 1978. In: AGARD-CP-235, (N79-15061#), Nov. 1978, pp. 6-1 through 6-17, 17 refs.

N79-15045#

The low-speed wind tunnels in West-Germany use three different rigs to measure dynamic stability derivatives on rigid models of aeroplanes and missiles: (1) a mobile oscillatory rig with rigid mechanical drive; (2) a multi-degree-of-freedom forced-oscillation rig with electrodynamic excitation; and, (3) a steady-state forced-roll rig with hydraulic motor drive. This paper gives a short description of the measuring technique and the appropriate derivative evaluation method used with each rig.

*DFVLR, Flughafen, D-3300 Braunschweig, West Germany
**Messerschmitt-Boelkow-Blohm G.m.b.H., Munich, West Germany

44 *Orlik-Rückemann, K. J., Editor: **Dynamic Stability Parameters**. Papers presented and discussions held at the Fluid Dynamics Panel Symposium held in Athens, Greece, May 22-24, 1978. AGARD-CP-235, published Nov. 1978, 636 pp.

ISBN 92-835-0223-X N79-15061#

Note: Included and placed immediately before this total compilation are five separate conference papers pertaining to rotary balances.

Discussed are the specific needs for dynamic stability information of aerospace vehicles, the form in which it should be presented, and the various means of obtaining it. Includes reports on new developments in wind-tunnel, flight test, and analytical techniques; motion analysis and non-linear formulations; and sensitivity and simulator studies. Specialists discussed a broad range of approaches to the determination of dynamic stability parameters.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

45 *Thor, W. A.: **An Investigation of the Rolling Stability Derivatives of a T-Tail Fighter Configuration at High Angles of Attack.** Society of Flight Test Engineers, Journal, vol. 1, Jan. 1979, pp. 21-25.

A79-50165

We used a wind tunnel model to study the F-104 high-load-factor stability problem. As we increase α near the stall for the model with a clean wing, roll damping drops off abruptly and yaw due to roll increases negatively (adverse yaw). This characteristics is more pronounced with the wing in the high-lift configuration of 12° leading-edge flap and 13° trailing-edge flap. This is due to the slope of the lift-curve decreasing at an earlier α for the flapped wing. Wing fences, slats, and strakes have a favorable effect on the roll damping and adverse yaw. We consider these to be the simplest and most effective aerodynamic modification to increase roll damping at high αs without degrading the longitudinal characteristics. Wing tip end plates decrease the roll damping at αs below stall.

*Wright-Patterson AFB, Dayton, OH 45433, USA

46 *Malcolm, G. N.: **New Rotation-Balance Apparatus for Measuring Airplane Spin Aerodynamics in the Wind Tunnel**. Journal of Aircraft, vol. 16, no. 4, Apr. 1979, pp. 264-268.

A78-32386

Note: For an earlier form and an abstract see no. 38.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

47 *Tischler, M. B.; and *Barlow, J. B.: **Application of the Equilibrium Spin Technique to a Typical Low-Wing General Aviation Design**. Presented at the AIAA Atmospheric Flight Mechanics Conference for Future Space Systems, Boulder, Colo., Aug. 6-8, 1979. In: Technical Papers (A79-45302), 1979, pp. 32-42.

AIAA Paper 79-1625 A79-45307#

This paper gives a graphical implementation of the equilibrium technique for obtaining spin modes from rotary balance data. Using this technique, we computed spin modes for the NASA Low-Wing General Aviation Aircraft. The computed αs are within 10° of the NASA spin tunnel results. The method also gives information on the dynamic nature of spin modes. This technique provides a great deal of information on spin modes and recovery, using data from a single experimental installation. You can use this technique in the preliminary design phase to provide basic information on aircraft spin and recovery characteristics. This paper discusses results, advantages, and limitations of using this technique.

*Maryland Univ., College Park, MD 20740, USA
Research supported by the Minta Martin Fund for Aeronautical Research

48 *Vanmansart, M.; and *Tristrant, D.: **New Directions in Spin Research**. Presented at the Association Aeronautique et Astronautique de France 16th Colloque d'Aerodynamique Appliquee, Lille, France, AAAF Paper NT 80-12, Nov. 13-15, 1979, 27 pp, in French.

A80-36843#

This paper describes studies recently undertaken or planned at IMF Lille in the field of aircraft spin research. Efforts include better use of telemetered data for comparison of flight and wind tunnel tests. They also include spin animation, and the development of spin testing methods based on free spin model instrumentation. Finally, they include spin initiation in the laboratory and studies using a rotary balance, the study of statistical correlations between aircraft configurations and spin characteristics, and analytical modeling for spin prediction. Spin research has developed considerably in the past three years. This is due to improvements in equipment, the comparison of flig

*Universite, Villeneuve-d'Ascq., Nord, France

49 *Verbrugge, R.: **The IMF Lille Rotation Balance and Associated Experimental Techniques**. Balance rotative de l' IMF, Lille et techniques experimentales associees. Lille no. 79/63, 1979. AAAF paper NT 80-13, Nov. 1979, 50 pp., in French.

A80-36844#

We have developed a rotation balance for wind tunnel simulation of aerodynamic processes at high α. In particular, the balance allows the study of control loss during flight at high α and stall/spin conditions. This paper discusses the performance of the balance in relation to geometrical and kinematic characteristics, mechanical and structural properties, aerodynamic aspects, and data acquisition and processing considerations. We developed the balance as a simulation tool in support of analytical studies of large-amplitude aerodynamic processes involving continuous spin.

*Institute de Mecanique des Fluides de Lille, 5 Blvd. Paul Painlevé, 59000 Lille, France

50 *Lutze, F. H., Jr.: **Experimental Determination of Pure Rotary Stability Derivatives Using a Curved and Rolling Flow Wind Tunnel.** Presented at the AIAA 18th Aerospace Sciences Meeting, Pasadena, Calif., Jan. 14-16, 1980, 8 pp.

AIAA Paper 80-0309 A80-18308#

This paper describes the technique of using a curved and rolling flow wind tunnel to extract pure rotary stability derivatives. It describes the curved flow and the rolling flow test sections of the Virginia Tech Stability Wind Tunnel. It includes methods for obtaining the proper velocity profiles and correcting the data acquired. It presents results from tests of current fighter configurations. It gives particular attention to comparing pure rotary derivatives with combined rotary and unsteady derivatives obtained by standard oscillation tests. It also examines the effect of curved and rolling flow on lateral static stability derivatives.

*Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA
Contract NAS1-13175-16

51 *Bihrle, W., Jr.; and **Bowman, J. S., Jr.: **Influence of Wing, Fuselage, and Tail Design on Rotational Flow Aerodynamics Beyond Maximum Lift.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colo., March 18-20, 1980. In: Technical Papers (A80-26929), 1980, pp. 237-246. Also: Journal of Aircraft, vol. 18, Nov. 1981, pp. 920-925, 16 refs.

AIAA 80-0455 A80-26955#

Note: For a later version of this paper and an abstract see no. 67.

*Bihrle Applied Research, Inc., Jericho, NY 11753, USA
**NASA Langley Research Center, Hampton, VA 23665-5225, USA

52 *Bihrle, W., Jr.; and *Barnhart, B.: **Spin Prediction Techniques.** Presented at the AIAA Atmospheric Flight Mechanics Conference, Danvers, Mass., Aug. 11-13, 1980. In: Technical Papers (A80-45855) pp. 76-82. Also: Journal of Aircraft, vol. 20, no. 2, Feb. 1983, pp. 97-101.

AIAA Paper 80-1564 N80-45863#

The NASA Langley Research Center is responsible for advancing the state-of-the-art of stall/spin technology. This includes developing and confirming experimental and analytical techniques for predicting stall/spin characteristics. As a part of this effort, two and a half years ago we developed a rotary balance rig at the Langley spin tunnel. Its purpose is to identify rapidly an airplane's aerodynamic characteristics in rotational flow. On-line rotary balance data plots and on-line predicted steady spin modes permit the designer to develop, on site, a configuration highly resistant to spins. Or, for airplanes intended for acrobatic maneuvers or training, one with good spin characteristics, that is, no spin equilibrium conditions possible with lateral-directional controls neutral. The rotary balance data are also used to compute time histories of the incipient, developed, and recovery phases of a spin. This paper discusses these spin analysis techniques and their correlation with spin-tunnel model and full-scale flight results.

*Bihrle Applied Research, Inc., Jericho, NY 11753, USA
Contracts: NAS1-14849 and NAS1-16205

53 *Orlik-Rückemann, K. J.; and *Hanff, E. S.: **Dynamic Stability Parameters at High Angles of Attack.** Presented at the 12th International Council of the Aeronautical Sciences, Congress, Munich, West Germany, Oct. 12-17, 1980. In: ICAS Proceedings, (A81-11601), AIAA, Inc., 1980, pp. 265-277.

TL 505.A24 1980 A81-11624
pp. 265-277

This paper presents a review of some of the fluid dynamics phenomena associated with oscillatory flight at high αs. It gives emphasis to asymmetric shedding of forebody vortices, asymmetric breakdown of leading edge vortices, the oscillatory motion of such vortices, and the time lag between the vortex motion and the causative motion of the aircraft. These phenomena cause a number of important effects on the dynamic stability parameters at high α. These include strong non-linearities with α, significant static and dynamic aerodynamic cross coupling, large time-dependent effects, and a strong configuration dependence. The paper briefly describes new wind tunnel testing techniques to determine all the required direct, cross, and cross-coupling moment derivatives due to oscillation in pitch, yaw, and roll as well as in vertical and lateral translation.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

54 *Otto, H.: **Roll and Spin Measurements in the Low Speed Wind Tunnel at Braunschweig.** (Roll- und Trudelmessungen im Niedergeschwindigkeits-Windkanal in Braunschweig). DFVLR-Nachrichten, Nov. 1980, pp. 16-18, in German.

A81-15704

This paper examines the measurements of aerodynamic forces and moments on aircraft models undergoing roll and spin movements in wind tunnels. The model carries out a uniform rotary motion on an axis in the direction of the wind. It has a rolling motion when the axis of rotation serves as the reference point of the model. A spin movement occurs when the reference point lies away from the axis of rotation. The assembly has the advantage that we can change the angle of pitch between the model and the axis of rotation by remote control without bringing it to a standstill.

*DFVLR, Hauptabteilung Niedergeschwindigkeits-Windkanäle, Braunschweig, West Germany

55 *Patton, J. M., Jr.: **A Status Report on NASA General Aviation Stall/Spin Flight Testing.** In: Society of Experimental Test Pilots, Technical Review, vol. 15, no. 1, (N80-33337), 1980, pp. 36-49.

N80-33340 or A81-19471

The NASA Langley Research Center has started a comprehensive program involving spin tunnel, static and rotary balance wind tunnel, full-scale wind tunnel, free flight radio control model, flight simulation, and full-scale testing. Work includes aerodynamic definition of various configurations at high αs, testing of stall and spin prevention concepts, definition of spin and spin recovery characteristics and development of test techniques and emergency spin recovery systems. This paper presents some results for the first aircraft (low-wing, single-engine) in the program, in the areas of tail design, wing leading edge design, mass distribution, center of gravity location, and small airframe changes. It also gives associated pilot observations. The paper discusses the design philosophy of the spin recovery parachute system in addition to test techniques.

*NASA Langley Research Center, Hampton, VA 23665-5225, USA

56 *Beyers, M. E.: **A New Concept for Dynamic Stability Testing.** Presented at the AIAA 19th Aerospace Sciences Meeting, St. Louis, Mo., Jan. 12-15, 1981, pp. 5-14. NAE LTR-UA-53, Sept. 1980. Also, Journal of Aircraft, vol. 20, no. 1, Jan. 1983, pp. 5-14.

AIAA Paper 81-0158 A81-20638#

This paper introduces an approach to dynamic stability testing based on the concept of orbital fixed-plane motion. A rig is conceived which forces an aircraft model in an orbital path while constrained to the fixed-plane reference system. The paper gives an exposition of the concept and shows the potential advantages in captive model testing and applications in flight mechanics. Using a single apparatus, it is possible to 1) determine a complete set of first-order dynamic stability derivatives, 2) vary the relationships between the associated motion parameters, and 3) simulate modes of aircraft motion. A validation scheme, which exploits the considerable flexibility of the method, makes it easier to extend the dynamic data to actual flight conditions.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

57 *McCormick, B. W.: **The Prediction of Normal Force and Rolling Moment Coefficients for a Spinning Wing.** NASA CR-165680, Feb. 1981, 22 pp.

N81-20068#

We used nonlinear airfoil section data for αs from 0° to 180° in a small computer code to integrate numerically the section normal force coefficients along the span as a function of the local velocity and α resulting from the combined spinning and descending motion. We developed a correction to account for the radial pressure gradient in the separated, rotating flow region above the wing. We needed this correction to obtain agreement, both in form and magnitude, with rotary balance test data.

*Pennsylvania State Univ., University Park, PA 16802, USA
NASA Order L-13435-8

58 *Orlik-Rückemann, K. J.: **Review of Techniques for Determination of Dynamic Stability Parameters in Wind Tunnels.** Presented at the NATO/ AGARD Lecture Series on Dynamic Stability Parameters, Moffett Field, Calif., Mar. 2-5, 1981, and Rhode-Saint-Genèse, Belgium, Mar. 16-19, 1981. In: AGARD-LS-114, (N81-31105), May 1981, pp. 3-1 through 3-28, 60 refs.

N81-31108#

This paper discusses the basic principles of various methods of wind tunnel testing and the practical aspects of various techniques. It illustrates these methods by examples, descriptions, and sketches of existing apparatuses. It reviews methods of measuring dynamic derivatives. It also considers the measurement of reaction and of motion, rotary and half model techniques, derivatives due to translational acceleration and pure rotation, free model techniques, and control surface oscillation techniques.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

59 *Malcolm, G. N.: **Rotary and Magnus Balances.** Presented at the NATO/AGARD Lecture Series on Dynamic Stability Parameters, Moffett Field, Calif., Mar. 2-5, 1981. In: AGARD-LS-114, May 1981, (N81-31105), pp. 6-1 through 6-26, 43 refs.

N81-31111#

This paper describes two wind tunnel techniques for determining part of the aerodynamic information required to describe the dynamic behavior of vehicles in flight. We measure forces and moments three ways: with a rotary-balance in coning motion, a Magnus balance in coning motion, and a Magnus balance in a high-speed spinning motion. Coning motion is important to both aircraft and missiles, and spinning is important for spin stabilized missiles. This paper describes basic principles of both techniques and gives examples of each type of apparatus. This paper also discusses typical experimental results.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

60 *Chambers, J. R.; *Grafton, S. B.; and **Lutze, F. H.: **Curved-Flow, Rolling-Flow, and Oscillatory Pure-Yawing Wind-Tunnel Test Methods for Determination of Dynamic Stability Derivatives.** Presented at the NATO/AGARD Lecture Series on Dynamic Stability Parameters, Moffett Field, Calif., Mar. 2-5, 1981, and Rhode-Saint-Genèse, Belgium, Mar. 16-19, 1981. In AGARD-LS-114, May 1981, (N81-31105), pp. 7-1 through 7-14, 7 refs.

A81-26933# or N81-31112#

This paper describes the test capabilities of the Stability Wind Tunnel of the Virginia Polytechnic Institute and State University. It gives calibrations for both curved and rolling flow techniques. It describes oscillatory snaking tests to determine pure yawing derivatives. It gives typical aerodynamic data for a current fighter configuration using the curved and rolling flow techniques. It discusses the application of dynamic derivatives obtained in such tests to the analysis of airplane motions in general, and to high α flight conditions in particular.

*NASA Langley Research Center, Hampton, VA 23665-5225, USA
**Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, USA

61 *Orlik-Rückemann, K. J., Editor: **Dynamic Stability Parameters,** AGARD Lecture Series held at Moffett Field, Calif., Mar. 2-5, 1981 and Rhode-Saint-Genèse, Belgium, Mar. 16-19, 1981. AGARD-LS-114, May 1981, 389 pp.
ISBN-92-835-1385-1 N81-31105#

This Lecture Series reviews the impact of high α aerodynamics on dynamic stability characteristics of aerospace vehicles. It surveys analytical, wind tunnel, and flight test techniques. Three papers from this symposium are especially pertinent to the subject of rotary balances. They are included separately as numbers 58, 59, and 60 in this bibliography.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada
Sponsored in part by the von Karman Inst. for Fluid Dynamics

62 *McCormick, B. W.: **Equilibrium Spinning of a Typical Single-Engine Low-Wing Light Aircraft.** Journal of Aircraft, vol. 18, Mar. 1981, pp. 192-199.

A81-31598#

This paper presents a study of rotary balance data, spin tunnel model, radio-controlled model, and full-scale flight results relating to the spinning of light aircraft. It also gives a method for predicting steady spin modes using rotary balance data. It discusses differences in spin characteristics of various wing, tail, and fuselage modifications as well as scale effects. The author concludes the yawing moment coefficient primarily governs an equilibrium flat spin.

*Pennsylvania State Univ., University Park, PA 16802, USA

63 *Schulze, B.: **Development and Trial of a Rotary Balance for the 3 m Low Speed Wind Tunnels in the Federal Republic of Germany: Final Report, Dec. 1979.** DCAF E002631, Rep. no. BMFT-FB-W-81-022, July 1981, 70 pp., in German.

ISSN-0170-1339 N82-15083#

Note: For an English version see the following citation.

We developed a rotary balance to determine aerodynamic damping due to rolling using a stationary measuring procedure. Due to the uniform rotation around the wind tunnel axis, we avoid vortex relaxation effects that might result from oscillatory balances. This paper describes the layout, instrumentation, and data processing. Results obtained during different wind tunnel tests with a calibration model correlate well with existing reference data and flight data. We can measure dynamic stability derivatives due to rolling for αs up to 90° and for extreme angles of inclination.

*Messerschmitt-Boelkow-Blohm G.m.b.H., Postfach 80 11 09, D-8000 Munchen 80, West Germany

64 *Schulze, B.: **Development and Trial of a Rotary Balance for the 3m-Low Speed Wind Tunnels of West-Germany.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities, Dayton, Ohio, Sept. 30-Oct. 2, 1981, 11 pp.

A83-11082

Note: This paper is not in the ICIASF '81 Record.
For the original German report, see the previous citation.

We have developed a rotary balance for 3 meter low-speed wind tunnels. It allows us to determine dynamic stability derivatives in the wind tunnel on continuously rotating aircraft models. This paper gives principal design aspects of the mechanical set-up and describes the measuring system. Test results from a calibration model on the rotary balance show a good correlation with existing reference data.

*Messerschmitt-Boelkow-Blohm G.m.b.H., Postfach 80 11 09, D-8000, Munchen 80, West Germany

65 *Beyers, M. E.: **Aerodynamic Simulation of Multi-Degree-of-Freedom Aircraft Motion.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities, Dayton, Ohio, Sept. 30-Oct. 2, 1981, 10 pp.

Note: This paper is not in the ICIASF '81 Record.

This paper reviews the rationale underlying simulations of high α aircraft motion using constrained as well as free model motions. It discusses concepts for generating several different modes of motion in a wind tunnel, including pitching and heaving, spinning, and wing rock. The methods use the NAE Orbital Apparatus, now being developed, in addition to existing free-flight test facilities. The Orbital Apparatus provides the unique opportunity of simulating aircraft motion on the same rig used to obtain a complete set of dynamic derivatives for the aircraft. We demonstrate its principles of operation using a conceptual apparatus. The exploitation of its capabilities could significantly contribute to the rational implementation of the existing mathematical model and the accuracy of the resulting computational flight simulations.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

66 *Krag, B.: **Dynamic Simulation in Wind Tunnels.** Presented at the ICIASF '81, International Congress on Instrumentation in Aerospace Simulation Facilities, Dayton, Ohio, Sept. 30, 1981. In: ICIASF '81 Record (A83-11051), pp. 271-282.

A83-11079

The Installation for Dynamic Simulation is a new wind tunnel facility which uses remotely controlled models with a special model suspension rig. This facility allows the study of both rigid body motion and elastic deformations, thus combining flight mechanic and aeroelastic testing. The model is usually of a specific aircraft and is fully instrumented. Computerized model command and control and data processing of measurements are features of the facility. Uses of the facility include the identification of dynamic flight mechanics derivatives, basic research into active control systems technology, and the development of a general aviation aircraft ride smoothing system. This paper also describes the development and testing of four different gust generators used in the simulation of realistic flight environment.

*DFVLR, Institute for Fluid Mechanics, D-3300 Brunswick, West Germany

67 *Bihrle, W., Jr.; and **Bowman, J. S., Jr.: **Influence of Wing, Fuselage, and Tail Design on Rotational Flow Aerodynamics Beyond Maximum Lift.** Journal of Aircraft, vol. 18, Nov. 1981, pp. 920-925.

Note: For an earlier version of this paper see no. 51.

The NASA Langley Research Center has started a broad general aviation stall/spin research program. Researchers at Langley developed a rotary balance system, located in the spin tunnel, to support this effort. This system makes it possible to identify airplane aerodynamic characteristics in a rotational flow environment, and thereby permits prediction of spins. This paper presents a brief description of the experimental setup, testing technique, and five model test programs. It also gives an overview of the rotary balance results and their correlation with spin tunnel free-spinning model results. We show, for example, a pronounced configuration sensitive nonlinear dependency of the aerodynamic moments on rotational rate. We show fuselage shape, horizontal tail, and, in some instances, wing location to appreciably influence the yawing moment characteristics above $\alpha = 45°$.

*Bihrle Applied Research, Inc., Jericho, NY 11753, USA
**NASA Langley Research Center, Hampton, VA 23665-5225, USA

68 *Beyers, M. E.: **Direct Free-Flight Analysis of Aircraft Dynamics at High Angles of Attack.** In: Aeronautical Society of South Africa and South African Institute of Aeronautical Engineers, Journal, vol. 2, no. 1, 1981, pp. 17-28, 26 refs.

A82-15596

This paper examines concepts for the analysis of high-maneuverability aircraft dynamics from gross flight-dynamic effects observed in wind-tunnel free-flight experiments. It reviews experimental and analytical techniques developed to study the generic non-oscillatory free-flight motion of flight vehicles trimmed at significant α. It demonstrates the feasibility of aircraft model free-flight tests from simulations. Trajectory validation schemes are proposed for the corroboration of free-flight and captive-model dynamic data. Finally, the paper examines the rationale underlying the use of data gathered in captive- and free-model dynamic stability tests of high-performance aircraft in the context of design objectives of high maneuverability and good flying qualities.

*South African Council for Scientific and Industrial Research, National Institute for Aeronautical and Systems Technology, Pretoria, Republic of South Africa

69 *Ericsson, L. E.; and *Reding, J. P.: **Review of Support Interference in Dynamic Tests.** Presented at the AIAA 12th Aerodynamic Testing Conference, Williamsburg, Va., March 22-24, 1982. In: Technical Papers (A82-24651), 1982, pp. 166-190, 79 refs. Also: AIAA Journal, vol. 21, Dec. 1983, pp. 1652-1666.

AIAA Paper 82-0594 A82-24668#

A review of information on support interference shows support interference effects are much more severe in dynamic than in static tests. Furthermore, support interference is aggravated greatly by a boat-tail or dome shaped base, even by modest base shoulder roundness, from what it is for a flat-based model. The general conclusion is we should not use asymmetric stings or sting-strut combinations. For slender bodies at low αs a transverse rod comes close to letting us measure the true dynamically destabilizing effect of a bulbous base. However, even a very slender sting distorts the near wake effect and gives an unconservatively high measure of the dynamic stability. At intermediate and high αs the sting support is superior to other support methods: the transverse rod or the strut mounting. Often, half-model testing lets us avoid most of the support interference effects. Sometimes, as for a short blunt body such as the Viking configuration, the best approach is to allow sting plunging, using a very slender sting.

*Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94086, USA

70 *Orlik-Rückemann, K. J.: **Aerodynamic Aspects of Aircraft Dynamics at High Angles of Attack.** Presented at the AIAA 9th Atmospheric Flight Mechanics Conference, San Diego, Calif., Aug. 9-11, 1982, 15 pp. Also: Journal of Aircraft, vol. 20, no. 9, Sept. 1983, pp. 737-752, 46 refs.

AIAA Paper 82-1363 A82-39836#

Note: This paper is updated in AGARD Rep. 740, Oct. 1987. (See no. 94)

This paper reviews some of the fluid dynamics phenomena associated with the oscillatory flight at high αs. It places particular emphasis on asymmetric shedding of forebody vortices, asymmetric breakdown of leading edge vortices, the oscillatory motion of such vortices, and the time lag between the motion of the vortices and the aircraft. These phenomena cause a number of important effects on the dynamic stability parameters at high αs. These include strong nonlinearities with α, significant static and dynamic aerodynamic cross-coupling, large time-dependent and hysteresis effects, and a strong configuration dependence. The paper emphasizes the need to consider all the aerodynamic reactions in their vectorial form. It discusses the importance of the above mentioned effects on our prediction capabilities of aircraft behavior at α. The author advocates the development of adequate mathematical models and describes the requirements for advanced wind tunnel techniques for performing the necessary oscillatory experiments.
*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

71 *Kalviste, J.: **Use of Rotary Balance and Forced Oscillation Test Data in a Six Degrees of Freedom Simulation.** Presented at the AIAA 9th Atmospheric Flight Mechanics Conference, San Diego, Calif., Aug. 9-11, 1982, 11 pp.

AIAA Paper 82-1364 A82-39129#

This paper presents new analysis techniques that will blend the data from rotary balance tests, forced oscillation tests, and computed dynamic derivatives for a nonlinear 6 degree-of-freedom simulation. It uses a component of the rotation vector about the velocity vector with the rotary balance test data. It uses the other components of the rotation vector with the forced oscillation test data and computed derivatives. The technique resolves the problem of separating the pure rotational and acceleration terms of the forced oscillation test data. The author makes recommendations about the data reduction procedure for forced oscillation testing to make the results more usable for aircraft motion simulation.

*Northrop Corporation, 3901 West Broadway, Hawthorne, CA 90250, USA

72 *Bihrle, W., Jr.: **Prediction of High Alpha Flight Characteristics Utilizing Rotary Balance Data.** Presented at the 13th ICAS Congress, and the AIAA Aircraft Systems and Technology Conference, Seattle, Wash., Aug. 22-27, 1982. In: Proceedings, vol. 1, (A82-40876), AIAA, 1982, pp. 761-768.

A82-40953#

The author uses rotational flow aerodynamic data, as measured on a rotary balance at low Reynolds number, to predict steady spin modes and post-stall motions. The excellent agreement obtained between predicted and full-scale flight results show low Reynolds number rotary balance data is sufficient for calculating steady-spin modes for military and general aviation configurations not having large wing leading-edge radii. The author discusses considerations in the use of low Reynolds number data to steady-state spin analysis, as well as large angle, six degree-of-freedom high α studies. The author also illustrates the procedure for developing a configuration highly resistant to spins.

*Bihrle Applied Research, Inc., Jericho, NY 11753, USA

73 *Beyers, M. E.: **A New Concept for Aircraft Dynamic Stability Testing.** Journal of Aircraft, vol. 20, no. 1, Jan. 1983, pp. 5-14.

A83-15310

Note: For an earlier form of this report and an abstract see no. 56.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

74 *Bihrle, W., Jr.; and *Barnhart, B.: **Spin Prediction Techniques.** Journal of Aircraft, vol. 20, Feb. 1983, pp. 97-101.

A83-18401#

Note: For an earlier form of this paper see no. 52.

Researchers developed a rotary balance rig located in the Langley spin tunnel to identify rapidly an airplane's aerodynamic characteristics in a rotational flow environment. The generation of on-line rotary balance data plots and predicted steady spin modes concurrent with data acquisition permit the designer to develop, on site, a configuration highly resistant to spins, or one exhibiting desirable spin characteristics if it is to be used for aerobatics or training. The rotary balance data are also used to compute time histories of the incipient, developed, and recovery phases of a spin. This paper discusses these spin analysis techniques, i.e., evaluation of rotary balance data, predicted steady spin equilibrium, and large angle, six-degree-of-freedom time history calculations.

*Bihrle Applied Research, Inc., Jericho, NY 11753, USA
Contracts: NAS1-14849 and NAS1-16205

75 *Ericsson, L. E.; and *Reding, J. P.: **Dynamics of Forebody Flow Separation and Associated Vortices.** Presented at the AIAA Atmospheric Flight Mechanics Conference, Gatlinburg, Tenn., Aug. 15-17, 1983, 12 pp., 26 refs. Also: Journal of Aircraft, vol. 22, no. 4, Apr. 1985, pp. 329-335.

AIAA Paper 83-2118 A83-41943#

We know there is a strong coupling between body motion and boundary layer separation with attendant vortex shedding. This paper studies this coupling for the particular case of a missile or an aircraft fuselage at very high αs. We can explain the unusual results obtained in recent tests by considering the so-called "moving-wall effect" on boundary layer transition and/or separation.

*Lockheed Missiles & Space Company, Inc., Sunnyvale, CA 94086, USA

76 *Orlik-Rückemann, K. J.; *Hanff, E. S.; and *Beyers, M. E.: **Recent Developments and Future Directions in Dynamic Stability Research at NAE, Ottawa.** Presented at the Fluid Dynamics Panel Symposium, Cesme, Turkey, Sept. 26-29, 1983. In: AGARD-CP-348, (N84-23564), Wind Tunnels and Testing Techniques, Feb. 1984, pp. 17-1 through 17-6, 14 refs.

N84-23582#

This paper gives a review of recent developments in dynamic stability research in the Unsteady Aerodynamics Laboratory of the NAE. The developments include design and construction of several new oscillatory rigs, conceptual studies of some additional rigs and thoughts about the future direction of the activities in this field. It briefly describes a method to account for sting oscillation effects on direct derivatives measured in a pitch oscillation experiment. It discusses some representative oscillatory results recently obtained on the so called Standard Dynamics Model.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

77 *Marazzi, R.; *Malara, D.; *Lucchesini, M.; *Comoretto, S.; and *Pacori, F.: **Use of a Small Scale Wind Tunnel and Model Shop at Aeronautica Macchi as an Industrial Tool.** Presented at the Fluid Dynamics Panel Symposium, Cesme, Turkey, Sept. 26-29, 1983. In: AGARD-CP-348, (N84-23564), Wind Tunnels and Testing Techniques, Feb. 1984, pp. 20-1 through 20-15, 10 refs.

N84-23585#

The paper describes some facilities and capabilities available at the Aerodynamic Test Department of Aeronautica Macchi. Special testing techniques allow us to use a small scale wind tunnel to obtain useful data for the development of aircraft configurations. Model work-shop capabilities permit the manufacture of specialized wind tunnel models for detailed analysis of problem areas. The paper describes the updating of a rotary balance rig to measure dynamic derivatives due to roll in the full range of model attitudes. It includes an assessment of Reynolds number effects on high lift devices of modern design. Finally, it describes the design and manufacture of an afterbody model and the manufacture and testing of flutter models.

*Aermacchi SpA, Varese, Italy

78 *Orlik-Rückemann, K. J.: **Aerodynamic Aspects of Aircraft Dynamics at High Angles of Attack.** Journal of Aircraft, vol. 20, no. 9, Sept. 1983, pp. 737-752.

A83-43964#

Note: For an earlier form of this paper and an abstract see no. 70.
*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

79 *Ericsson, L. E.; and *Reding, J. P.: **Review of Support Interference in Dynamic Tests.** AIAA Journal, vol. 21, Dec. 1983, pp. 1652-1666, 81 refs.

ISSN 0001-1452 A84-13572

Note: For an earlier version and an abstract see no. 69.

*Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94068, USA

80 *Larson, M. S.: **The Effect of Constant Versus Oscillatory Rates on Dynamic Stability Derivatives.** Air Force Inst. of Tech., M.S. Thesis, AFIT/GAE/ENY/83D-11, Dec. 1983, 101 pp.

AD-A136913 N84-19293#

The purpose of this thesis was to determine if there are phenomenological differences between dynamic derivations calculated from F-15A rotary balance data and data from other sources. To do this, two additional sets of F-15A stability derivative data were obtained: (1) design phase, and (2) production phase. The lateral dynamic derivatives were then compared through derivatives of the lateral moments with respect to the rotation rate about the velocity vector (wind vector). The author concluded differences exist between the data sets, but the dominant characteristics were the same for all of the data sets. The differences in the data were not indicative of basic (phenomenological) differences in the data itself. Therefore, the contention that oscillatory rates affect determination of the dynamic derivations was not substantiated by this study.

*Wright-Patterson AFB, Dayton, OH 45433, USA

81 *McCormick, B. W.; **Zilliac, G. G.; and ***Ballin, M. G.: **Wind Tunnel Testing and Analysis Relating to the Spinning of Light Aircraft.** Presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nev., Jan. 9-12, 1984, 13 pp.

AIAA Paper 84-0558 A84-18163#

Included is a summary of two studies related to the spinning of light aircraft. We made the first study to demonstrate we can obtain the aerodynamic forces and moments acting on the tail of a spinning aircraft from static wind-tunnel tests. The second was an analytical study of spinning using a high α aerodynamic model derived from a static wind-tunnel data base. We show the validity of the aerodynamic model by comparisons with rotary-balance and forced-oscillation data. The results of a six-degree-of-freedom analysis show we have properly modeled the dynamics and aerodynamics of the steep- and flat-spin modes of a modified Yankee airplane.

*Pennsylvania State University, University Park, PA 16802, USA
**NASA Ames Research Center, Moffett Field, CA 94035, USA
***Rockwell International Corp., Downey, CA 90241, USA

82 *Beyers, M. E.: **Characteristic Motions for Simulation of Post-Stall Maneuvers and Flight Instabilities.** In: Aeronautical Society of South Africa and South African Institute of Aeronautical Engineers, Journal, vol. 5, no. 1, 1984, pp. 20-34.

ISSN 0250-3786 A85-21679

This paper proposes an approach to the problems of experimentally determining the aerodynamic characteristics of aircraft maneuvering in the nonlinear, post-stall flight regime. It recognizes the importance of correctly representing the motion characteristics in unsteady aerodynamic measurements under these conditions. It indicates different approaches depending on whether the flight is oscillatory or nonoscillatory (aperiodic) and nonplanar or near-planar. The paper discusses the requirements for captive-model tests designed to yield the instantaneous dynamic-load histories of ramp-shaped intermittent motions and nonplanar oscillatory motions. The paper introduces the principle or "orbital epicyclic motion" and gives an analysis of its potential for high-α nonplanar oscillatory tests. In the simulation of complex, nonplanar maneuvers, it suggests an approach based on complementing the captive-model tests with wind tunnel free-flight studies of models trimmed at high α.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

83 *Poppen, W. A., Jr.: **A Method for Estimating the Rolling Moment Due to Spin Rate for Arbitrary Planform Wings.** NASA TM-86365, Jan. 1985, 23 pp.

N85-18990#

The use of aerodynamic theory for estimating the force and moments acting on spinning airplanes is of interest. For example, researchers have used strip theory to estimate the aerodynamic characteristics as a function of spin rate for wing-dominated configurations for αs up to 90^o. This paper extends this work, previously limited to constant chord wings, to wings consisting of tapered segments. Comparison of the analytical predictions with rotary balance wind tunnel data shows large discrepancies remain, particularly for αs greater than 40^o.

*NASA Langley Research Center, Hampton, VA 23665-5225, USA

84 *Ericsson, L. E.; and *Reding, J. P.: **Dynamics of Forebody Flow Separation and Associated Vortices**. Journal of Aircraft, vol. 22, no. 4, Apr. 1985, pp. 329-335.

ISSN 0021-8669 A85-29262#

Note: For an earlier version of this paper and an abstract see no. 75.

*Lockheed Missiles & Space Company, Inc., Sunnyvale, CA 94086, USA

85 *Malcolm, G. N.; and *Schiff, L. B.: **Recent Developments in Rotary-Balance Testing of Fighter Aircraft Configurations at NASA Ames Research Center.** Presented at the symposium on Unsteady Aerodynamics--Fundamentals and Application to Aircraft Dynamics held in Göttingen, West Germany, May 6-9, 1985. In: AGARD-CP-386 (N86-27224#), Nov. 1985, pp. 18-1 through 18-25.

N86-27242#

Note: For another form of this paper and an abstract see no. 91.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

86 *O'Leary, C. O.; and *Rowthorn, E. N.: **New Rotary Rig at RAE and Experiments on HIRM.** Presented at the symposium on Unsteady Aerodynamics--Fundamentals and Applications to Aircraft Dynamics held in Göttingen, West Germany, May 6-9, 1985. In: AGARD-CP-386 (N86-27224#), Nov. 1985, pp. 19-1 through 19-14. Also: Aeronautical Journal, (ISSN 000-1-9240), vol. 90, Dec. 1986, pp. 399-409.

N86-27243#

Note: For another form of this report see no. 97.

Researchers at the Royal Aircraft Establishment, Bedford, have commissioned a rig to measure the forces and moments due to continuous rate of roll. Tests were made on a High Incidence Research Model (HIRM) in two wind tunnels at $M = 0.2, 0.4$, and 0.7. We can test models up to $\alpha = 40^o$ at rotational speeds up to 350 rpm. Tests on HIRM included a study of configuration and Reynolds number effects. We compare results with similar data from another rolling rig and from small-amplitude oscillatory tests.

*Royal Aircraft Establishment, Bedford, MK41 6AE, UK

87 *Jansson, T.; and *Torngren, L.: **New Dynamic Testing Techniques and Related Results at FFA.** Presented at the symposium on Unsteady Aerodynamics--Fundamentals and Applications to Aircraft Dynamics held in Göttingen, West Germany, May 6-9, 1985. In: AGARD-CP-386 (N86-27224#), Nov. 1985, pp. 20-1 through 20-14.

N86-27244#

In recent years we have seen an emphasis on the extraction of dynamic derivatives from wind tunnel testing. This is apparent from the number of different rigs developed and in use, both in the subsonic and transonic wind tunnels. This paper briefly describes the different rigs, testing procedures and data handling. It presents a wide survey of the different rigs used for dynamic derivative testing and the corresponding testing capability.

*The Aeronautical Institute of Sweden (FAA)
S-161 11 Bromma, Sweden

88 *Tristrant, D.; and *Renier, O.: **Recents Developements des Techniques de Simulation Dynamique Appliquees a l'Identification des Parametres de Stabilite.** Presented at the symposium on Unsteady Aerodynamics--Fundamentals and Applications to Aircraft Dynamics held in Göttingen, West Germany, May 6-9, 1985. In: AGARD-CP-386 (N86-27225#), Nov. 1985, pp. 22-1 through 22-14.

N86-27246#

In the context of aircraft dynamic behavior prediction, this paper describes experimental and analytical methods to identify mathematical linear modeling parameters using a test rig at the Institut de Mecanique des Fluides de Lille. We describe the rig characteristics, the experimental procedures, the identification methods, and results from different aircraft models. Emphasis is put on the interest of a specific λ degree of freedom angle formed by the rotational vector and velocity vector. Effectively, we show that rotational tests with a non zero value of λ offer interesting possibilities for identification and allow the estimation of linear model parameters in the case of a quasi-linear path. We obtained a different degree of freedom called *gyration radius* by fixing a special mechanism onto the test rig. By carrying out a carefully selected test program, this degree of freedom allows us to identify the whole set of stability parameters, given the structure of the linear mathematical model. Finally, dynamic measures obtained during oscillatory coning using a complete aircraft model produced in evidence the large amplitude of unsteady aerodynamic phenomena at high α, which we can not ignore if we seek prediction of post stall evolutions.

*ONERA-IMFL, 5 boulevard Paul Painlevé 5900 Lille, France

89 *Orlik-Rückemann, K. J., Editor: **Unsteady Aerodynamics - Fundamentals and Applications to Aircraft Dynamics.** Fluid Dynamics and Flight Mechanics Panel Symposium held in Göttingen, West Germany, May 6-9, 1985. AGARD-CP-386, Nov. 1985, 620 pp., in English and French.

AD-A165045 N86-27224#
ISBN-92-835-0382-1

Note: See nos. 87 and 88 for some relevant papers presented at this symposium. There is a Technical Evaluation Report on this symposium, AGARD-AR-222 (N86-27182#), Jan. 1986.

This paper examines recent advances experimental and computational methods for predicting nonlinear flow phenomena in unsteady aerodynamics and stability parameters required to describe adequately the dynamic behavior of aircraft. It gives special emphasis to high α. Topics addressed include: unsteady boundary layers; unsteady separation and stall; buffeting; unsteady airloads; wind tunnel and flight test techniques, with emphasis on the measurement of nonlinearities, aerodynamic cross-coupling, hysteresis, and time dependent effects; mathematical modeling; bifurcation theory; prediction of wing rock; and advanced control systems.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

90 *Demeis, R.: **Taming the Deadly Spin.** Aerospace America, vol. 23, June 1985, pp. 74-77.

ISSN 0740-722X A85-36148#

Research into techniques and aircraft components which avoid stall and spin and/or enhance recovery began in the 1930s. Devices which delayed stall frequently accelerated the transition when it did occur. Military aircraft received the most spin wind tunnel research from the 1940s to the 1970s, when NASA began looking at light aircraft in spin. Researchers have measured forces and moments on spinning aircraft using a rotary balance. Wind tunnel tests have examined the spin aerodynamics of fuselages, airfoils, tail surfaces, strakes, and fins. Stops and warning devices have been devised to keep the nose down. Studies are now focusing on the wing leading edge because it is the initiator and center of the stall conditions. Outboard drooping wings inhibit the spread of the stall vortices across the wing. Researchers have extended this method to a discontinuous outboard droop which is being used on the British Firecracker trainer.

*Engineering Editor of "Aerospace America", 1633 Broadway, New York, NY 10019, USA

91 *Malcolm, G. N.; and *Schiff, L. B.: **Recent Developments in Rotary-Balance Testing of Fighter Aircraft Configurations at NASA Ames Research Center.** NASA TM-86714, July 1985, 28 pp.

N85-32090#

Note: For an earlier form of this report see no. 85.

Two rotary balance rigs were developed for testing airplane models in a coning motion. A large rig was developed for use in the 12-Foot Pressure Wind Tunnel primarily to permit testing at high Reynolds numbers. This rig was recently used to study the aerodynamics of 0.05-scale model of the F-15 fighter aircraft. Effects of Reynolds number, spin rate parameter, model attitude, presence of a nose boom, and model/sting mounting angle were studied. A smaller rig, which studies the aerodynamics of bodies of revolution in a coning motion, was used in the 6-by-6 foot Supersonic Wind Tunnel to study the aerodynamic behavior of a simple representation of a modern fighter, the Standard Dynamic Model (SDM). Effects of spin rate parameter and model attitude were studied. This paper gives a description of the two rigs and discusses some of the results obtained in the respective test.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

92 *Malcolm, G. N.: **Rotary-Balance Experiments on a Modern Fighter Aircraft Configuration at High Reynolds Numbers.** Presented at the AIAA 12th Atmospheric Flight Mechanics Conference, Snowmass, Colo., Aug. 19-21, 1985. In Technical Papers (A85-43826), 1985, pp. 462-482.

AIAA Paper 85-1829 A85-43870#

NASA Ames Research Center's research program to study high-angle-of-attack aerodynamic phenomena associated with high-performance aircraft includes the development and use of rotary balance rigs for wind tunnel tests of airplane models in a coning motion. A large scale rig, developed for testing models at high Reynolds numbers in the Ames 12-Foot Pressure Wind Tunnel, was recently tested with a 0.05-scale F-15 fighter model. Measurements were made at low subsonic Mach numbers and chord Reynolds numbers of 1 to 5.5 million, with angles of attack from 0 to 90 deg and sideslip angles from -15 to +15 deg. Effects of Reynolds number, spin-rate parameter, model attitude, presence of a nose boom, and model/sting mounting angle were studied.

*NASA Ames Research Center, Moffett Field, CA 94035, USA

93 *Ericsson, L. E.: **Reflections Regarding Recent Rotary Rig Results.** Presented at the AIAA 24th Aerospace Sciences Meeting, Reno, Nev., Jan. 6-9, 1986, 8 pp., 16 refs. Also: Journal of Aircraft, vol. 24, no. 1, Jan. 1987, pp. 25-30.

AIAA Paper 86-0123 A86-19703#

This paper examines recent rotary rig experiments to evaluate how well they simulate dynamic conditions existing in full scale flight. Most rig designs are prone to cause significant interference with the vortex wake shed from an advanced aircraft at high αs. The coupling existing between vehicle motion and boundary layer transition in the critical Reynolds number range, can aggravate the support interference problem. This coupling is unlikely to have been simulated in most wind tunnel tests.

*Lockheed Missiles & Space Company, Inc., Sunnyvale, CA 94086, USA

94 *Orlik-Rückemann, K. J.: **Aircraft Dynamics: Aerodynamic Aspects and Wind Tunnel Techniques.** Presented at the Special Course on Fundamentals of Fighter Aircraft Design sponsored by AGARD Fluid Dynamics Panel and the von Karman Institute, Feb. 17-28, 1986. In: AGARD Rep. 740, Oct. 1987, (N88-13315), pp. 5-1 through 5-16.

N88-13320#

Note: For earlier forms of this paper see nos. 70 and 78.

The dynamic behavior of modern fighter aircraft depends more and more on unsteady aerodynamics. Until recently, the designer concentrated on classical problems such as aeroelasticity and flutter. Dynamic stability parameters were most often determined by low α calculation methods, without much recourse to experiment. The results obtained from the few dynamic experiments were used to confirm the absence of problems rather than as design parameters. New requirements for fighter aircraft performance include the ability to fly at high α in the presence of extensive regions of separated or vortical flows, relaxed static stability, greatly increased agility, and an interest in unorthodox geometries such as closely-coupled-canard or tail-first configurations. The time lags and unsteady phenomena associated with flow fields, resulting from rapid maneuvers and large amplitude motions, significantly affect the dynamic behavior of modern fighter aircraft and become as important for aircraft design as the classical static performance criteria. A review is made of the various aerodynamic aspects affecting aircraft dynamic behavior, followed by a survey of the most pertinent experimental techniques.

*Unsteady Aerodynamics Laboratory, National Research Council of Canada, Ottawa, Ontario, K1A OR6, Canada

95 *Ericsson, L. E.; and *Reding, J. P.: **Dynamic Support Interference in High Alpha Testing.** Presented at the AIAA 14th Aerodynamic Testing Conference (A86-24726), West Palm Beach, Fla., Mar. 5-7, 1986, pp. 203-214, 32 refs.

AIAA Paper 86-0760 A86-24746#

This paper analyzes support interference effects on aerodynamic test results of aircraft models at high αs. Single degree of freedom oscillatory tests in pitch or yaw are subject to the same type of support interference through the near wake recirculatory region as experienced by slender bodies of revolution. Thus, we can correct the measurements for support interference using the same methodology. The support interference associated with rotary rigs used in coning experiments is of a different type. It is stationary in nature rather than unsteady, with the coning motion inducing a displacement of the vortex wake similar to that caused by sideslip in a static test. Making static tests at varying incidence and sideslip angles with two alternate supports can provide the information needed to correct coning experiments for support interference.

*Lockheed Missiles & Space Company, Inc., Sunnyvale, CA 94086, USA

96 *O'Leary, C. O.; and *Drew, W.: **Flow Visualization on Rolling Models Using Minitufts.** RAE TM Aero 2083, Aug. 1986, 20 pp., 4 refs.

Note: For another form of this report see no. 100.

Minitufts are increasingly used for flow visualization on static wind tunnel models. This is because we can apply them in larger numbers for increased detail and with less interference compared with conventional tufts. This Memorandum describes an extension of their use to continuously rotating models where the heavier conventional tufts are inadequate. We describe tests on two combat aircraft models in the 4m x 2.7m Low Speed Wind Tunnel. We explain measured variations of rolling moment with the aid of the minituft photographs. We include drawings and description of the RAE rotating rig.

*Royal Aircraft Establishment, Bedford MK41 6AE, UK

97 *O'Leary, C. O.; and *Rowthorn, E. N.: **New Rotary Rig at RAE and Experiments on HIRM.** Aeronautical Journal, vol. 90, Dec. 1986, pp. 399-409.

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Note: For an earlier form of this paper and abstract see no. 86.

*Royal Aeronautical Establishment, Bedford MK41 6AE, UK

98 *Ericsson, L. E.: **Reflections Regarding Recent Rotary Rig Results.** Journal of Aircraft, vol. 24, no. 1, Jan. 1987, pp. 25-30, 20 refs.

ISSN 0021-8669 A87-28070#

Note: For an earlier version of this report and an abstract see no. 93.

*Lockheed Missiles & Space Company, Inc., Sunnyvale, CA 94086, USA

99 *Kausche, G.: **Dynamic Wind Tunnel Balances in the DFVLR subsonic wind tunnel in Braunschweig (Dynamische Windkanalwaagen am Niedergeschwindigkeits-Windkanal der DFVLR in Braunschweig).** In: Zeitschrift für Flugwissenschaften und Weltraumforschung, vol. 11, May-June 1987, pp. 185-187, 7 refs., in German.

ISSN 0342-068X A88-12488

This paper briefly describes two dynamic balances for measuring dynamic derivatives in wind tunnels of the DFVLR subsonic wind tunnel in Braunschweig, the Mobile Oscillatory Derivative Balance (MODB) and the Rotary Derivative Balance (RDB). Information is presented on the measurement methods used, recent improvements and operations, and the attainable results. It is shown that the MODB, due to its mobility, has a higher productivity than the RDB.

*DFVLR, Institute für Flugmechanik, Braunschweig, West Germany

100 *O'Leary, C. D.; and *Drew, W.: **Flow Visualisation on Rolling Models Using Minitufts.** Aeronautical Journal, vol. 91, June-July 1987, pp. 269-274.

ISSN 0001-9240 A87-50587

Note: For an earlier form of this paper and an abstract see no. 96.

*Royal Aeronautical Establishment, Bedford MK41 6AE, UK

101 *Beyers, M. E.; and *Huang, X. Z.: **The Orbital-Platform Concept for Nonplanar Dynamic Testing.** Aeronautical Note NAE-AN-52, NRC No. 29133, May 1988, 40 pp.

A new concept is introduced for large-amplitude testing at high incidence. The dynamic test apparatus is characterized by an annular, orbital platform on which the model support and secondary drive mechanisms are mounted. The device can be used as a rotary apparatus, while arbitrary epicyclic motions (including fixed-plane, orbital modes) and oscillatory motions superimposed on the coning mode may be generated. The system is inherently very rigid and vibration levels can be kept very low. Aerodynamic interference is also very low as there is no need for bulky support hardware and the test section is circular. Accordingly, the system may be used to assess levels of support interference in conventional rotary tests

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AUTHOR INDEX

Entry

SUBJECT INDEX

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

SOURCE INDEX

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Robert A. Kilgore and Karen L. Sych: Langley Research Center, Hampton, Virginia.

16. Abstract
This bibliography on rotary balances contains 102 entries. It is part of NASA's support of the AGARD Fluid Dynamics Panel Working Group 11 on Rotary Balances. The bibliography includes works that might be useful to anyone interested in building or using rotary balances. Emphasis is on the rotary balance rigs and testing techniques rather than the aerodynamic data. We also include some publications of historical interest which relate to key events in the development and use of rotary balances. The arrangement is chronological by date of publication in the case of reports and by presentation in the case of papers.

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